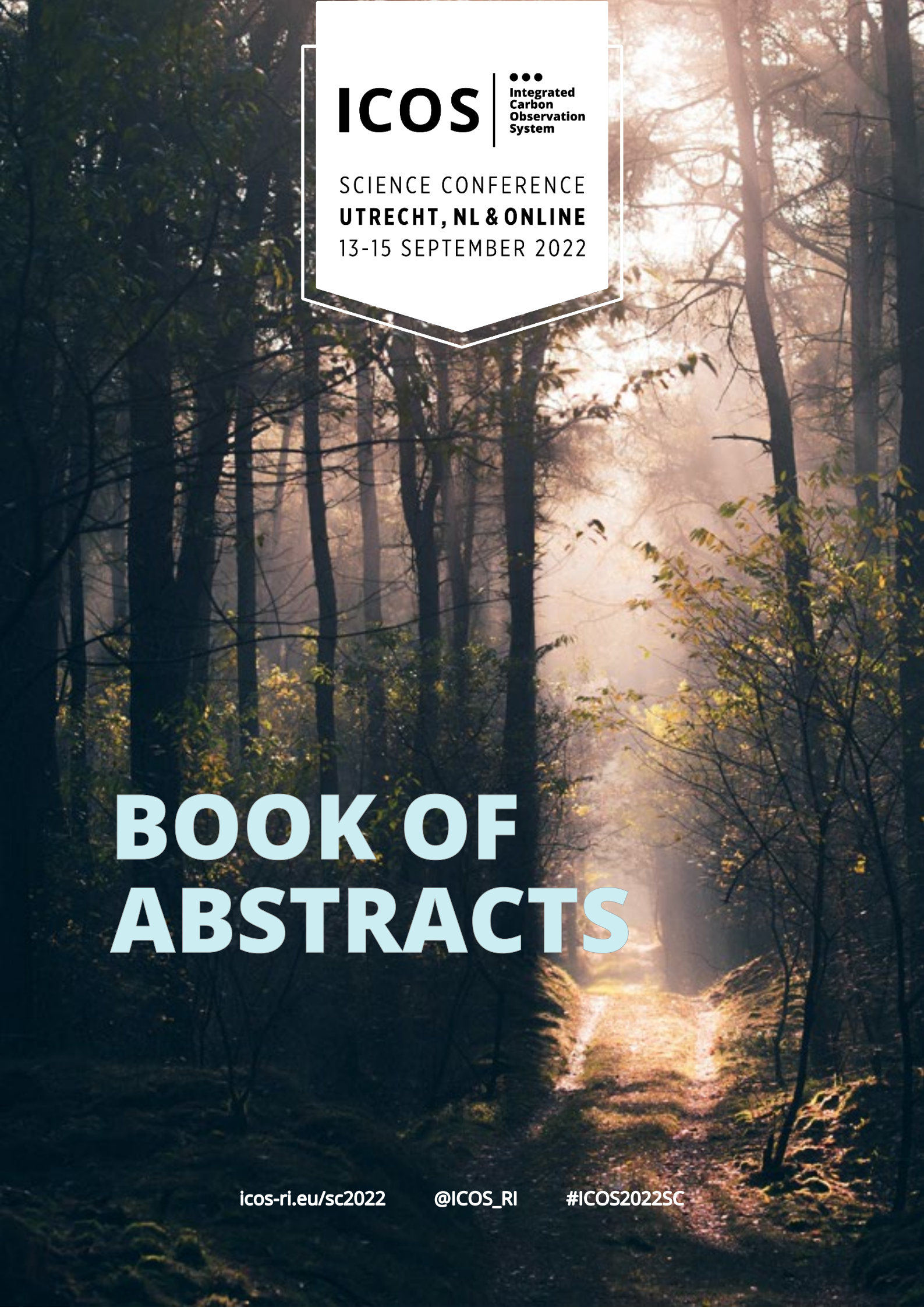

ICOS Integrated Carbon Observation System

SCIENCE CONFERENCE

UTRECHT, NL & ONLINE

13-15 SEPTEMBER 2022

BOOK OF ABSTRACTS

icos-ri.eu/sc2022 @ICOS_RI #ICOS2022SC

ICOS Integrated Carbon Observation System

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ICOS in Short

The Integrated Carbon Observation System, ICOS is a distributed European-wide research infrastructure producing high-precision data on greenhouse gas concentrations in the atmosphere and carbon fluxes between the atmosphere, land and oceans. This is important because globally the amount of greenhouse gases in the atmosphere is rising continuously, causing the climate to change. The greenhouse gases flux between the ecosystems, atmosphere and oceans, and are transported in the atmosphere for thousands of kilometres, for example, from densely populated areas to the Arctic.

ICOS provides standardised and open data from 149 measurement stations across 14 European countries. ICOS data is used by scientists who seek to understand this Earth System and by various governmental bodies and international organisations that need science-based and relevant information on greenhouse gases in their decision-making, and in efforts to mitigate the consequences of climate change. ICOS consists of more than 500 scientists, who participate in ICOS related work and operations. Together with other stakeholders, these scientists, both in the current member countries and beyond, form the ICOS community. They design, build and operate ICOS stations, but even more importantly, process and use the ICOS data while fitting complex models on it. They publish scientific papers, participate in workshops and conferences, and develop new measurement methods.

The community, as ICOS itself, has three fields; ecosystem, atmosphere, and ocean. Each of these also has strong connections to colleagues and operators outside ICOS. At the moment ICOS community includes over 80 scientific organisations, renown universities or institutes - many of which are leaders in their fields. The biennial ICOS Science Conference gathers close to 400 scientists to discuss the scientific topics around greenhouse gas measurements and climate change. The themes of the conference vary from purely scientific sessions to ones related to policy making, education and new developments in instrument manufacturing.

Plenary Speakers

Anna Agustí-Panareda

Dr. Anna Agustí-Panareda is a senior scientist at the European Centre for Medium-range weather Forecasts (ECMWF) working in the Copernicus Atmosphere Monitoring Service. She holds a PhD in meteorology from the University of Reading. Her scientific background is in the field of Numerical Weather Prediction (NWP). She has studied the impact of observations and land surface processes on the quality of weather forecasts and pollution transport. Her current research focuses on various aspects of the modelling of carbon dioxide and methane from emissions and natural fluxes at the surface to atmospheric transport, within the Integrated Forecasting System (IFS) at ECMWF. Dr. Agustí-Panareda is involved in several projects funded by the European Commission to develop a verification and support capacity for monitoring anthropogenic emissions of greenhouse gases. As part of the CoCO2 project, she is co-leading the efforts to implement a global greenhouse gas emission monitoring system within the IFS.

Dr. Agustí-Panareda is giving a plenary talk about the CoCO2 global nature run as an evaluation tool of the integrated earth system model to support the monitoring of greenhouse gas emissions on Tuesday 13 September at 9:50.

Gilles Erkens

Dr. Gilles Erkens is the chair of the National Research Program on Greenhouse Gas Emissions from Dutch Peatlands (NOBV). As a quaternary geologist he has been working on Holocene delta and river system development, peat formation and degradation, and specifically land subsidence around the world. Currently he heads the land subsidence group at Deltares Research Institute and is a senior researcher at Utrecht University. On behalf of the Netherlands he is a member of the International UNESCO working group for Land Subsidence (LASII). Within the NOBV team he works on understanding the relationship between land subsidence and CO2 emissions in peatlands and on developing a monitoring system to determine the nation-wide annual emissions with high spatial resolution. Outreach is particularly important for Dr. Erkens, as he enjoys telling the subsidence story to non-experts. He has contributed to over 300 news items, ranging from TV and radio interviews, to contributions to web-content.

Using his knowledge of the Dutch landscape Dr. Erkens also investigates historic human-induced disturbances in the carbon dynamics of the shallow subsurface, as he will show in his plenary presentation on Tuesday 13 September at 9:25.

Georg Jocher

Dr. Georg Jocher works as a scientist at the Global Change Research Institute CAS in Brno, Czech Republic. He earned a PhD in atmospheric physics with focus on micrometeorology at the Alfred Wegener Institut for Polar and Marine research in Potsdam, Germany. One of his main research foci are eddy covariance measurements at tall canopies with regards to representativeness of the eddy covariance method above the canopy. Dr. Jocher authored several publications on this topic, dealing with different measurement sites in Sweden and Czech Republic, highlighting the specific need of decoupling investigations. Decoupling investigations mean the specific assessment of the coupling between below and above canopy air masses at tall vegetation sites with regards to above canopy derived eddy covariance results. Such investigations are not standardly applied in measurement networks yet.

In his plenary talk on Tuesday 13 September at 11:35, he will present ideas and first results of a global synthesis study on the decoupling topic. The study aims to derive global relations between decoupling on the one side and atmospheric conditions/canopy properties/tower surrounding topography on the other side to improve the accuracy of eddy covariance measurements at tall vegetation sites. A further aim is to raise awareness of the topic and to initiate discussions about the topic also within measurement networks like ICOS.

Dafina Kikaj

Dr. Dafina Kikaj is a Higher Research Scientist at the National Physical Laboratory, UK. She holds a Ph.D. in atmospheric physics with a focus on the quantification of the atmospheric mixing state over complex terrain using the radioactive noble gas radon as a tracer. Her current research focuses on developing new methods based on radon to identify errors in chemical transport models, hence aiding in evaluating uncertainties in inventories of GHG emissions.

Dr. Kikaj's plenary talk on Thursday 15 September at 9:50 will present a unique standardised radon dataset for two atmospheric GHG monitoring stations: the UK DECC network's Heathfield site and the ICOS Weybourne site. These datasets will enable optimal utilisation of radon measurements by the climate research community.

Gerbrand Koren

Dr. Gerbrand Koren is an assistant professor at the Copernicus Institute of Sustainable Development at Utrecht University (UU) in the Netherlands. His research aims to quantify and improve our understanding of the cycling of carbon and water between vegetation and the atmosphere, in particular for extreme events (e.g., droughts, floods, heat waves). Previously, Dr. Koren was affiliated with Wageningen University where he conducted his PhD research on Amazon carbon cycling using a modified version of inverse model CarbonTracker Europe and sun-induced fluorescence (SIF). Using these approaches, the impact of the 2015/16 El Niño drought on the net carbon balance and the photosynthetic uptake rate (GPP) was estimated. Also, he did exploratory work, including model development and a short sampling campaign, for the novel isotopic signature Δ17O that is proposed as a tracer for GPP.

In his plenary talk on Wednesday 14 September at 9:50, Dr. Koren will address different approaches for constraining GPP and highlight their potential synergies.

John Miller

Dr. John Miller is a scientist at NOAA's Global Monitoring Laboratory in Boulder CO, USA, where he uses both numerical simulations and measurements of atmospheric concentrations of CO2 and CH4 and their stable and radio-isotopes to better understand the relationships between changing climate, direct human activity, and the trends of these gases at local, regional, and global scales. His current research includes combining measurements and simulations of carbon-14 (radiocarbon) in atmospheric CO2 to improve quantification of fossil CO2 emissions and terrestrial biospheric fluxes; using atmospheric measurements of greenhouse gases above Amazonia to better quantify and understand regional carbon balance; and applying measurements and modeling of carbon-13 in atmospheric CO2 and carbonyl sulfide at regional to global scales to better understand mechanisms influencing terrestrial biosphere carbon exchange. Over the past 20 years, he co-developed NOAA's atmospheric radiocarbon program and was instrumental in developing capacity for high quality greenhouse gas measurements in Amazonia. He has been an author on more than 130 peer-reviewed journal articles as well as numerous national and international reports and assessments.

Dr. Miller is giving his plenary talk about US fossil fuel-CO2 emissions based on measurements of atmospheric radiocarbon on Tuesday 13 September at 10:45.

Giacomo Nicolini

Dr. Giacomo Nicolini is a researcher at the Euro-Mediterranean Centre on Climate Change (CMCC), Division on Impacts on Agriculture, Forests and Ecosystem Services (IAFES) in Italy. He holds a PhD in forest ecology on measuring carbon dioxide (CO2) and methane (CH4) fluxes from tropical ecosystems. He is specialized in greenhouse gas fluxes data processing and analysis from both natural and anthropogenic environments. He is a member of the ICOS Ecosystem Thematic Centre focusing on developing measurement standards for the ICOS network, supporting the ICOS station's activity and producing the released ICOS ecosystem data. He also works on micrometeorological field experiments and on the elaboration of experimental data.

Dr. Nicolini's plenary talk on Wednesday 14 September at 9:00 will be on the impact of the social restrictions on urban CO2 emissions during the multiple COVID-19 pandemic waves in several European cities and on their evolution in the following months.

Tobias Steinhoff

Dr. Tobias Steinhoff works as a scientist at GEOMAR Helmholtz Center for Ocean Research in Kiel /Germany and as a Senior engineer for the ICOS OTC at NORCE Norwegian Research AS in Bergen Norway. His work at GEOMAR focuses on the marine carbon and oxygen cycle. He operates underway measurements of pCO2, alkalinity, pH and oxygen onboard the Container ship M/V Atlantic Sail that crosses the sub-polar North Atlantic between Europe and North America. The installation onboard is an ICOS class1 station. Currently his research focus is combining ICOS Ocean's surface carbon measurements with data from biogeochemical Argo floats (BGC-Argo) to improve the measurements. At ICOS OTC he organizes training opportunities for the ICOS Oceans network and supports the stations with their marine CO2 measurements. In this context he organized in 2021 the 1st ICOS OTC pCO2 inter-comparison exercise where more than 25 instruments measuring pCO2 in seawater were compared against each other over a range of different temperatures and pCO2 levels.

In his plenary presentation on Tuesday 13 September at 11:10, Dr. Steinhoff will show some results from the inter-comparison and give some future perspectives.

Tom Taborski

Tom Taborski is a PhD student at INRAe, France. His research focuses on enhancing the understanding of forest water fluxes and goes from its estimation to its modelisation. Using an ICOS site (FR-Bil) he aims to enhance characterization of water fluxes dynamic and parameters such as canopy conductance and after rain transpiration dynamic. Focusing on water fluxes brought him to modelisation and he aims to explore climate changes effects on forests and their possible trajectories over the next century.

His plenary presentation on Thursday 15 September at 9:25 is about Mediterranean forests water use efficiency perspectives and whether management limit climate change impacts.

Jocelyn Turnbull

Dr. Jocelyn Turnbull holds joint appointments at GNS Science, New Zealand the University of Colorado, USA, and co-chairs the WMO Integrated Global Greenhouse Gas Information System (IG3IS) program. Jocelyn leads the GNS Science Rafter Radiocarbon Laboratory, which maintains expertise in a wide range of radiocarbon applications including a radiocarbon in the atmosphere. Her research leverages radiocarbon to investigate the modern carbon cycle, particularly the source and fate of fossil fuel derived CO2. She uses atmospheric greenhouse gas observations as well as radiocarbon and related tracers to understand the sources and sinks of greenhouse gases at the local, urban and regional scales. Connecting emissions science to policy outcomes is a key component of Dr. Turnbull's research. Current projects include: CarbonWatch-NZ evaluating New Zealand's natural and anthropogenic carbon budget; INFLUX, the Indianapolis Flux Project evaluating urban greenhouse gas emissions; and SOAR Southern Ocean Atmospheric Radiocarbon investigating Southern Ocean carbon exchange.

Dr. Turnbull is giving her plenary talk on international standard for Urban Greenhouse Gas Monitoring and Assessment on Wednesday 14 September at 9:50.

Chualong Zhou

Dr. Chuanlong Zhou is currently working as a postdoc researcher at Le Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France, with focus on the analysis of the European energy consumption and high spatial-temporal carbon emissions in developing counties. He holds a Ph.D. degree in Environmental Science and a Master's degree in Computer Science specialized in machine learning.Dr. Zhou's research topics include persistent chemicals, air pollutants, health effects, and climate change. He wants to connect environmental science research with state-of-the-art computer science, such as deep learning, data visualization, and web technology.

Dr. Zhou's plenary talk on Thursday 15 September at 9:00 will be about the magnitude of the use of Russian natural gas in the EU27&UK and how the shortfalls can be filled by demand reductions in heating, shifts in power generation towards nuclear and coal, and intra-EU and international coordination, if Russian imports were to stop.

Tuesday, 13th September

Plenary presentations

290 Writing history: CO2 respiration due to 1,000 years of Dutch coastal peatlands cultivation
Plenary

Gilles Erkens

Deltares Research Institute, Utrecht, Netherlands.

Utrecht University, Utrecht, Netherlands

It is very fitting that the 5th ICOS Science Conference will be organised in the Netherlands, because arguably it has the longest record of human-induced greenhouse gas emission from peatlands in the world. Indeed, the Dutch started peatland cultivation already a 1000 years ago, causing 20 km3 of peat to degrade, which formed the archetypical Dutch landscape with its green meadows, windmills and cheese. In fact, all these Dutch icons are directly related to the historical peatland cultivation. In terms of greenhouse gas emissions, Dutch peatland CO2 respiration over the last 1000 years increased the global atmospheric concentration by ~0.50 ppmv, long before the industrial revolution. Astonishingly, even after 1000 years of respiration, about ~50% of the original carbon stock remains in the subsurface. It is, in the light of the Paris Climate Agreement, undesirable to convert the remaining stock of carbon into CO2. Measures, such as rewetting, are being proposed to reduce greenhouse gas emissions. For the Dutch, this would mean a break with the centuries old tradition how we manage the peatlands. Over the last 1000 years, we never chose (or were not able to) to reduce greenhouse gas emission. Now that we have to reduce emissions, a track record and best practices are lacking. By conducting research, and building a greenhouse gas emission monitoring network, we can gain experience in with measures that will enable us to comply with the aims of the climate agreements.

237 The CoCO2 global nature run as an evaluation tool of the integrated earth system model to support the monitoring of greenhouse gas emissions
Plenary

Anna Agusti-Panareda[1], Joe McNorton[1], Gianpaolo Balsamo[1], Cedric Bacour[2], Vladislav Bastrikov[3], Jean Bidlot[1], Bertrand Bonan[4], Nicolas Bousserez[5], Souhail Boussetta[1], Gregoire Broquet[2], Dominik Brunner[6], Jean-Christophe Calvet[4], Luca Cantarello[1], Philippe Ciais[2], Huilin Chen[7], Frederic Chevallier[2], Margarita Choulga[1], Cyril Crevoisier[8], Hugo Denier van der Gon[9], Michail Diamantakis[1], Emanuel Dutra[10], Richard Engelen[1], Johannes Flemming[1], Gabriele Arduini[1], Cyril Germineaud[11], Marc Guevara[12], Claire Granier[13,14], Sander Houweling[15], Greet Janssens-Maenhout[16], Vincent Huijnen[17], Martin Jung[18], Thomas Kaminski[19], Zak Kipling[1], Rigel Kivi[20], Ernest Koffi[5], Werner Kutsch[21], Bavo Langerock[22], Panagiotis Kountouris[5], Maarten Krol[23], Francisco Lopes[24], Fabienne Maignan[2], Julia Marshall[25], Sebastien Massart[1], Dario Papale[26], Mark Parrington[1], Coralie Perruche[11], Glen Peters[27], A.M.Roxana Petrescu[15], Wouter Peters[23], Philippe Peylin[2], Vincent-Henri Peuch[5], Michel Ramonet[2], Patricia de Rosnay[1], Marko Scholze[28], Arjo Segers[9], Alex Vermeulen[29], Sophia Walther[30], Thorsten Warneke[31], Peter Weston[1]

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[10]IPMA, Lisbon, United Kingdom.[11]Mercator Ocean International, Toulouse, France. [12]BSC, Barcelona, Spain. [13]Laboratoire d'Aérologie, CNRS-Université de Toulouse, Toulouse, France. [14]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, USA. [15]Vrije Universiteit Amsterdam, Amsterdam, Netherlands. [16]European Commission, Joint Research Centre (JRC), Ispra, Italy. [17]KNMI, De Bilt, Netherlands. [18]Max Planck Institute for Biogeochemistry (MPI-BGC), Jena, Germany. [19]Inversion Lab, Hamburg, Germany. [20]Finnish Meteorological Institute, Sodankylä, Finland. [21]ICOS ERIC Head Office, Helsinki, Finland. [22]Royal Belgian Institute for Space Aeronomy, Uccle, Belgium. [23]Wageningen University, Wageningen, Netherlands. [24]University of Lisbon, Lisbon, Portugal. [25]DLR, Oberpfaffenhofen, Germany. [26]Università degli Studi della Tuscia, Viterbo, Italy. [27]CICERO, Oslo, Norway. [28]Lund University, Lund, Sweden. [29]ICOS ERIC Carbon Portal, Lund, Sweden. [30]Max Planck Institute for Biogeochemistry, Jena, Germany. [31]University of Bremen, Bremen, Germany

The Prototype System for a Copernicus CO2 service (CoCO2) project is building a global CO2 Monitoring and Verification Support (CO2MVS) capacity to support the climate mitigation efforts encapsulated in the Paris climate agreement. This CO2MVS system will integrate satellite and in situ observations of CO2 and CH4 with prior information of their surface fluxes/emissions at global scale based on the Integrated Forecasting System (IFS) at ECMWF. The IFS is a numerical weather prediction system encompassing the Earth System to provide a wide range of environmental services, including the Copernicus Atmosphere Monitoring Service. The different CO2 and CH4modelling and prior information components in the IFS are presented and assessed in preparation for a 9-km nature run covering 2018. The nature run is a high-resolution simulation that will include new developments in the modelling of atmospheric tracer transport, CH4 chemical sink, biogenic fluxes, new datasets of ocean fluxes, and sub-monthly temporal profiles of anthropogenic emissions compared to the previous CHE nature run. An evaluation using the ICOS surface flux and other atmospheric observations, as well as vertical profiles from AirCore and additional in situ and satellite observations, is performed in order to assess the capability of the IFS to represent the variability of CO2 and CH4 from monthly to sub-daily time scales and from site level to inter-hemispheric scales. Ongoing and future model developments are also outlined. The output of the CoCO2 nature run will be made available to users in 2023 and various applications will be discussed.

283 US fossil fuel-CO2 emissions based on measurements of atmospheric radiocarbon

Plenary

John Miller[1], Nazrul Islam[1,2], Scott Lehman[3], Sourish Basu[4], Arlyn Andrews[1], Colm Sweeney[1], Pieter Tans[1], Samuel Hammer[5], Ingeborg Levin[5], Xaiomei Xu[6], Geoffrey Roest[7], Kevin Gurney[7]

[1]NOAA Global Monitoring Laboratory, Boulder, USA.[2]CIRES, University of Colorado, Boulder, USA. [3]INSTAAR, University of Colorado, Boulder, USA. [4]University of Maryland, College Park, USA. [5]University of Heidelberg, Heidelberg, Germany. [6]University of California, Irvine, USA. [7]Northern Arizona University, Flagstaff, USA

Despite inventory-based ("bottom-up") estimates of fossil-fuel emissions likely being accurate to within 10% for most developed countries, estimates of emissions based on atmospheric measurements ("top-down") are needed to bolster confidence in evaluating the efficacy of mitigation efforts. In the case of CO2, however, measurements of CO2 alone are not sufficient to determine fossil emissions because of the confounding influence of terrestrial ecosystem CO2 exchange which influences, and often dominates, spatio-temporal gradients of CO2. The rarest isotope of C, 14C (radiocarbon), is completely absent from fossil CO2 allowing us to use measurements of CO2 and 14C to isolate the fossil contribution to observed gradients. Within the context of an atmospheric inverse model, CO2 and 14C measurements provide constraints that yield optimized fluxes of both fossil and ecosystem

CO_2. With this approach, we are now able to estimate monthly fossil CO_2 emissions for different regions the U.S. for years between 2010 and 2019 with an estimated random error of ~ 2%. Initial published top-down estimates for 2010 show a high degree of correspondence between our top-down emissions and the high time- and space-resolution estimate from the bottom-up Vulcan data product, largely independent of the a priori fossil emissions used in the inversion. Our top-down estimate also exhibits statistical overlap with the US EPA's official national total, although the central values differ by ~ 5%. In addition to top-down/bottom-up comparisons, we will also discuss current limitations of the system and how these can be addressed by modeling enhancements and additional observations.

249 Results from the 1st ICOS OTC pCO2 instrument inter-comparison 2021
Plenary

Tobias Steinhoff[1,2], Thanos Gkritzalis[3], Ute Schuster[4], Craig Neill[5], Steve Jones[6], Vlad Macovei[7]

[1]NORCE Norwegian Research Centre AS, Bergen, Norway. [2]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. [3]Flanders Marine Institute (VLIZ), Oostende, Belgium. [4]University of Exeter, Exeter, United Kingdom. [5]CSIRO Oceans & Atmosphere, Hobart, Australia. [6]University of Bergen, Bergen, Norway. [7]Helmholtz-Zentrum Hereon, Geesthacht, Germany

In summer 2021, with one year delay, the Ocean Thematic Centre (OTC) of the European research infrastructure "Integrated Carbon Observation System" organized an inter-comparison exercise for pCO2 instrumentation. The exercise focused on surface applications and took place at the Flanders Marine Institute's (VLIZ) Marine Station Ostend in Ostend/Belgium. The goal was the rigorous assessment of instrument capabilities and documenting their measurement uncertainty. Following this exercise, we aim to improve the quality and aid the processing of ocean pCO2 data, enabling better estimates of ocean CO_2 uptake and ocean acidification. Furthermore, the ongoing interaction between manufacturers and the extensive user group that this experiment enabled facilitates continuous instrument improvement.
During the 2 week exercise, we deployed 29 instruments of 18 different types in a temperature-controlled water tank containing ca. 5 m3 seawater. The water pCO2 was manipulated by changing the temperature or by adding chemicals (acid or base). This allowed us to compare the pCO2 measurements at different temperatures (10 – 30°C) and pCO2 levels (200 – 800 µatm). Here we present the results from the inter-comparison and provide suggestions for future experiments and sensor development.

72 Addressing forest canopy decoupling on a global scale
Plenary

Georg Jocher

Global Change Research Institute CAS, Brno, Czech Republic

The eddy covariance (EC) method, nowadays the standard method for determining forest ecosystem-atmosphere turbulent exchange, faces a major threat in its application: the air masses below the canopy are regularly decoupled from the air masses above the canopy. Consequently, the EC measurements above the canopy like e.g. H_2O and particularly CO_2 fluxes can be biased due to missing signals from below-canopy processes. This decoupling is strongly site dependent and

influenced by meteorological conditions, canopy properties and tower-surrounding topography. It can be verified and addressed by subsequent EC measurements below and above the canopy. Specifically, the correlation of σw below and above the canopy gives information about the coupling state as this correlation is linear during periods of full coupling.

The current study aims to address the decoupling issue on a global scale. For this purpose, approximately 30 forest sites from around the world will be analyzed in a standardized way with regards to decoupling. The study sites cover manifold vegetation types and climate zones, all sites are equipped with concurrent below and above canopy EC measurements. Preliminary results highlight the dependence of decoupling on meteorological conditions, canopy properties and tower surrounding topography. Nevertheless, the final goal of this action is to derive global relations between these influence factors and decoupling which will be applicable in a general way on each forest site worldwide. Highest quality turbulent fluxes will be the outcome and the accuracy of EC derived forest water and carbon budgets will improve.

Poster Session 1

32 Greenhouse gas emission map 2.0 for Bavarian peatlands

Poster

Janina Klatt[1], Martina Schlaipfer[1,2], Matthias Drösler[1]

[1]Weihenstephan-Triesdorf University of Applied Sciences, Freising, Germany. [2]Technical University of Munich, Freising, Germany

Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

In addition to land-use and water table depth, biogeographical settings may also have an influence on peatland greenhouse gas (GHG) budgets. For this reason we have analysed the Bavarian subset of German GHG data, which consists of 163 annual budgets from 76 treatments in seven peatland regions. The land-use categories included in the dataset range from intensely used and deeply drained arable land to near-natural and restored sites. Within the framework of the KliMoBay project we use these data along with maps of land-use and mean annual water table depths to quantify GHG balances in Bavarian peatlands. The resulting map allows for a comparison of GHG budgets between the land-use types. Moreover, it can be used to identify emission hot spots which should be the focus areas for wet peatland management (paludiculture) and/or restoration measures in the near future in order to help fulfil the GHG emission mitigation targets set in in the Paris Climate Agreement, but also at national and regional levels. This map is an advancement of the Bavarian Tier 2 GHG emission map based on German average emission factors developed by Drösler & Kraut in 2020. The new Tier 3 Bavarian GHG emission map 2.0 is intended to serve as a policy tool to support the decision-making process of local stakeholders and thereby aid in prioritizing mitigation measures in Bavarian peatlands.
KliMoBay is funded by the Bavarian State Ministry of Environment and Consumer Protection through the European Regional Development Fund.

48 Methane and nitrous oxide eddy covariance flux measurements above an intensively managed grassland on organic soil

Poster

Pascal Wintjen, Jeremy Rüffer, Liv Offermanns, Christian Brümmer

Thünen Institute of Climate-Smart Agriculture, Braunschweig, Germany

Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Methane (CH4) and nitrous oxide (N2O) are potent greenhouse gases regarding their global warming potential. Agriculture is an important anthropogenic contributor to total CH4 and N2O emissions. In the past decade, fast-response instruments have become available for flux measurements using the eddy covariance (EC) method. However, studies about continuous long-term EC flux measurements of CH4 and N2O are still scarce.
In this work, we present CH4 and N2O EC flux measurements using a fast-response quantum-cascade-laser spectrometer in combination with a 3-D sonic anemometer. The setup was installed at an intensively managed grassland site on organic soil in northern Germany. The duration of the campaign was two years starting in April 2020. Averaged ambient concentrations of N2O and CH4 at

2.5 m above ground were 349 ppb and 2226 ppb, respectively, with a strong response to fertilization events leading to half-hourly values higher than 800 and 4000 ppb for N2O and CH4, respectively. Mostly emission fluxes were determined with half-hourly averages of 40 ng C m-2 s-1 and 36 ng N m-2 s-1 for CH4 and N2O, respectively. Cumulative N2O exchange was found to be higher in the first year than in the second year, whereas for CH4 the opposite observation was made. Soil water content measurements revealed that the topsoil was wetter in 2021 than in 2020 promoting microbial CH4 production.
This work provides insights in the dynamics of CH4 and N2O ecosystem-atmosphere exchange influenced by natural and anthropogenic factors and can particularly be used for optimizing nitrogen (N) management.

119 DRAINAGE IMPACT ON GREENHOUSE GAS FLUXES FROM DRAINED NUTRIENT-RICH ORGANIC SOILS UNDER GRASSLANDS IN THE HEMIBOREAL ZONE
Poster

Hanna Vahter[1], Muhammad Kamil Sardar Ali[1], Thomas Schindler[1], Andis Lazdiņš[2], Ain Kull[1], Ieva Līcīte[2], Ülo Mander[1], Aldis Butlers[1], Kaido Soosaar[1]

[1]University of Tartu, Tartu, Estonia. [2]Latvian State Forest Research Institute "Silava", Salaspils, Latvia

Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

The main objective of our study is to calculate a carbon and nitrogen budget and adjust GHG emission factors for GHG from organic soils in drained grasslands in the Baltic States. Drainage is known to turn nutrient-rich soils, often found in boreal and tropical wet climate zones, into a significant GHG source. Therefore, drainage impact on GHG fluxes throughout two full-year is studied in hemiboreal Estonia, Latvia and Lithuania from 2021. Results of the first full-year period from Estonia and Latvia will be presented.
Fluxes in nutrient-rich perennial peatland grasslands with different drainage statuses were determined on seven sites: (I) two on excessively drained fens soils, (II) two on moderately drained fens soil, (III) one on drained fens soil with increased groundwater levels, and for comparison (IV) two non-managed fens as reference sites. Measurements were made weekly or biweekly using the manual dark static chamber method (N2O, CH4) and the dynamic closed chamber method for heterotrophic respiration (CO2). In addition, environmental parameters were measured.

Our preliminary results show that drained grasslands were annual CH4 sinks (-4.67±4.27 µg m-2 h-1, mean±SE) while fens soils (III, IV) were a source of CH4. All studied sites were annual emitters of N2O (17.13±3.45 µg m-2 h-1); while moderately drained soils (II) were the highest emitter (38.94±7.73 µg m-2 h-1). Higher N2O emissions and temporal variability were associated with sites where the water level had high seasonal fluctuations. Soil CO2 fluxes peaked over all the study sites during the summer.

143 Several years of automatic chamber data reveal large temporal and spatial variation in peatland forest N_2O fluxes
Poster

Helena Rautakoski[1], Mika Korkiakoski[2], Jarmo Mäkelä[2], Kari Minkkinen[2], Mika Aurela[1], Paavo Ojanen[3], Annalea Lohila[1,2]

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

The urgent need to mitigate climate change has evoked a broad interest in better understanding and estimating N2O emissions of different ecosystems. However, accurate estimation of N2O emissions has remained a challenge, and estimates continue to have relatively high uncertainties. Part of the uncertainty in N2O emission estimates comes from an inadequate understanding of spatial and temporal variability of N2O emissions. By using automatic chamber data from a drained boreal peatland forest site (Lettosuo, ICOS associated ecosystem station), we investigated the temporal and small-scale spatial variation of forest floor-atmosphere N2O flux, and the link between temporal variation, seasonality and environmental conditions. The N2O flux greatly varied between different measurement chambers, but despite high spatial variation in the measured fluxes, the temporal variation was similar across chambers. High temporal variation seen in N2O flux was linked a) to seasonality with high-flux periods occurring in late spring, summer and winter, and b) to environmental conditions that greatly differed within and between seasons and years, revealing, how environmental conditions affect N2O flux through direct, indirect and interaction effects. The observed high temporal variation in N2O flux highlights the need for high-frequency flux measurements when estimating N2O budgets of drained boreal peatland forests and other ecosystems with possibility for high temporal variation of N2O flux. Capturing and understanding temporal variation is especially important as the occurrence of the key temperature and moisture conditions that trigger high N2O emissions will change and be highly variable between years and seasons as the climate change proceeds.

148 Harvest frequency affects carbon balances beyond the factor of carbon removal on a wet riparian fen, cultivated with Phalaris arundinacea
Poster

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Transparent chamber measurements were conducted from April – October 2020 on a peatland site in Vejrumbro, Denmark (56°26'15.3"N, 9°32'44.1"E), cultivated with Phalaris arundinacea. The site was divided into plots with treatments of zero (0-cut), two (2-cut), and five (5-cut) annual biomass harvests, receiving split-fertiliser applications with a total of 200 kg N and K ha-1 yr-1 for 2-cut and 5-cut. No fertiliser was applied to 0-cut. During the study period, the average water table depth was -24 cm. Our aim was to quantify the carbon balance after the establishment of flooding-tolerant perennial grasses on a temporarily flooded riparian peatland under different harvest and fertilisation options. Based on measured data, we found high variability of carbon budgets between treatments, and in-between plots. The highest in-between plot variability was observed for 2-cut for gross primary production (GPP, -19.7 to -29.2 t CO2-C ha-1) and net ecosystem exchange (NEE, -6.0 to -15.5 t CO2-C ha-1). While ecosystem respiration was similar for all treatments, GPP was highest on 2-cut, where we found a lower net ecosystem carbon balance (NECB, -5.1±4.0 t CO2-C ha-1) as compared to 5-cut (-1.5±2.5 t CO2-C ha-1), despite equal carbon export by harvest (2-cut: 4.8±1.9; 5-cut: 4.6±1.7 t C ha-1). All

partitioned C fluxes were similar for plots of 0-cut, resulting in a seasonal NECB of -1.8±0.8 t CO2-C ha-1. In conclusion, we found that harvest frequency affects carbon balances beyond the factor of carbon export by harvest, by stimulation of GPP.

187 Short-term impact of forest harvesting on CO2 fluxes at a fertile forestry-drained peatland
Poster

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Peatlands have been drained for forestry in Finland for a long time. The most intensive drainage took place in the 1960-70s, and now harvesting is expected for even a few millions of hectares of peatland forests in the near future. The hot question is how to mitigate the losses of carbon from the peat into the atmosphere and water courses. Are there other options to harvest in addition to clear-cutting? Could the continuous cover forestry help to mitigate the high C losses from peat?
We partially address these questions by presenting 12 + 6 years of eddy covariance CO2 flux data from a site located in Fennoscandia. We first measured the net ecosystem exchange for six years prior to the harvest above a pine-dominated fen drained for forestry in the 1970s. After the partial and clear-cut harvesting, done in 2016 separately for two sectors within the area, respectively, we continued the measurements and established a new flux measurement tower within the clear-cut sector. Now, six years after the harvest, we can assess the short-term impacts of these two different forest management practices on the atmosphere-ecosystem CO2 fluxes. It is evident that the peat layer continues to lose carbon, but there are clear differences between the harvest practices. While the partially harvested part switched into a CO2 sink a few years after the harvest, the clear-cut area continues emitting CO2. However, when accounting for the NEE + tree growth, it becomes evident that the peat in both areas is still losing C.

190 Feasibility of long-term EC measurements for N2O. The MIRO Multi-compound Gas Analyzer evaluated at a Dutch peatland.
Poster

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Greenhouse gas exchange measurements are commonly executed with open path systems especially for CO2 and CH4. In the Netherlands with its intensive agricultural use, N2O exchange potentially is an important part of the net greenhouse gas balance. These N2O exchange measurements frequently rely on discrete manual or automatic chamber measurements, whereas eddy covariance measurements on N2O could help to capture and explain the spatially inhomogeneous and infrequent

but important N2O emission events for the net N2O balance. As such reliable eddy covariance measurements on N2O are helpful in decisions on mitigation measures. Several of these measures like drainage options are studied at Zegveld, a Dutch peatland site. An evaluation of the greenhouse gas exchange results including N2O using the MIRO Multi-compound Gas Analyzer will be presented. The closed-path EC measurements by the MIRO are compared with open-path EC measurements for both CO2 and CH4. Apart from the evaluation on the main greenhouse gases, the N2O measurements of the MIRO are presented.

201 Carbon emission hotspots detected by a network of automated GHG flux chambers and eddy co-variance on a regional-scale
Poster

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Peatlands are globally important carbon stores, depleting fast following drainage and climate change. Peatlands provide numerous societal services including ecosystem diversity, climate regulation and water storage. In the Netherlands, efforts are made to reduce the climate impact of peatland drainage and develop low emission rewetting strategies. The spatial variability of potential measures is to be elucidated.

In 2020, a network of custom-made automated CO2 flux chambers (16 sites) and 2 eddy co-variance towers (open path CO2/CH4) were setup in the northern Dutch provinces, including a drainage gradient and fertilization intensity. Both paludiculture sites (Typha and Sphagnum) were flooded or near-saturated. The eddy co-variance remained in place. In contrast, CO2 flux chambers measured for 3 days every 2 weeks per site before moved to next site. The resulting gaps were filled using machine learning (random forest).
Preliminary results suggest substantial seasonal variation of carbon fluxes following largely soil temperature, radiation sums and crop height. Site to site variation in carbon fluxes was substantial. Flooded parcels revealed methane emission above 1 kg CH4 per ha per day. In contrast, the ditch water level was a poor indicator for CO2 fluxes among sites. High carbon content of the upper and intermediate soil moisture levels seemed to have promoted high carbon dioxide release instead.

A dense regional-scale network of GHG monitoring sites showed a substantial site-to-site variability of carbon fluxes and their interaction with driving forces. Spatially-sensitive GHG analysis seem to be more comprehensive compared to studies relying on low spatial replication.

252 Emissions of biogenic volatile organic compounds from a boreal fen and bog as impacted by vegetation and a period of drought
Poster

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

The emission of biogenic volatile organic compounds (BVOC), which have a net cooling impact on the climate, from peatland ecosystems are still poorly understood. We measured BVOC emissions from a boreal fen and bog situated in Siikaneva, southern Finland and assessed the role of vegetation on the quality and quantity of the emissions by vascular vegetation and moss removal experiments. In four campaigns during growing seasons in 2017 and 2018 we detected a total of 60 compounds from nine different chemical groups, with isoprene accounting for 81% of BVOC emissions. Total BVOC emissions were higher in the fen than in the bog due to higher isoprene and alkane emissions in the fen. Total BVOC emissions and the emissions of isoprene, monoterpenoids, sesquiterpenes, homoterpenes and green leaf volatiles were tightly connected to the presence of vascular vegetation. Isoprene and sesquiterpene emissions were associated with sedges, whereas monoterpenoids and homoterpenes were associated with shrubs. Emissions of oxygenated alkanes, organic halides and benzenoids were not impacted by vegetation removal. During an extreme drought event in 2018, emissions of (E)-4,8-dimethyl-1,3,7-nonatriene increased, while organic halide and oxygenated alkane emissions were negligible. We suggest that an increase in shrub cover and increased frequency of extreme weather events may have a negative impact on total BVOC emissions that otherwise are predicted to increase in warmer temperatures. Combined with the related change in the quality of BVOC emissions, this may alter the climate impact of peatlands by affecting atmospheric oxidants and the formation of secondary organic aerosols.

228 Substantial amounts of organic carbon stored in continental margin sediments are currently overlooked

Poster

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Session B. Marine and aquatic carbon cycling : B.1 Better constraining the European blue carbon stock

Continental margin sediments are an important sink for organic carbon globally, but Blue Carbon research has so far focussed on coastal vegetated ecosystems. Presumably, this is because vegetated ecosystems promote sedimentation and actively sequester carbon while seafloor sediments act as a passive receptor for organic carbon from different sources. Coastal vegetated ecosystems have been attributed a disproportionately large role in storing and burying organic carbon despite the minute area they occupy. Robust estimates of continental margin sedimentary organic carbon stocks are, however, still sparse. To overcome this limitation, we spatially predicted organic carbon content and dry bulk density of surface (upper 10 cm) sediments of the Norwegian continental margin based on harmonised measurements and environmental predictor variables using quantile regression forests. From these spatial predictions, we estimate that surficial sediments of the Norwegian continental margin contain approximately 1.1 Pg of organic carbon. This compares with 0.006 Pg stored in coastal vegetated ecosystems and 1.7 – 2.8 Pg in forest soils and biomass in Norway. Combining our results with spatial predictions made for the north-west European continental shelf yields an organic carbon stock of 1.7 Pg in surface sediments between the Bay of Biscay and the western Barents Sea. This

means that substantial amounts of organic carbon are potentially vulnerable to disturbances caused by human activities, even if only a small fraction of this organic carbon is labile. Our research demonstrates that more attention should be paid to the role of sedimentary organic carbon in the marine carbon cycle.

Poster Session 2

42 Estimation of carbon fluxes over crops using in situ measurements and a land surface model

Poster

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Session: C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

In terms of food security and as a lever for climate change mitigation, agriculture is at the center of our society's questions. It is therefore important to understand the key drivers of crop yields and carbon (C) budgets. For this purpose, land surface models are easier to use than crop models as they are based on process representation and they can provide realistic estimates and diagnosis of the variability of crop carbon budgets. However, in-situ observations using flux towers or automatic chambers are necessary to evaluate the models and the carbon flux partitioning, especially over several growing seasons and crop types. In this study, eddy covariance (EC) and automated-chamber (AC) methods were first compared and employed to assess the soil respiration of a cropland (Fr-Lam) in southwestern France. Soil respiration measured with both EC and AC presented a similar range of values with a fair correlation of 0.71 between both measurements. After evaluating the partitioning of the net ecosystem exchange (NEE) into gross primary production (GPP) and ecosystem respiration (RECO) by Reichstein's algorithm, the performance of a land surface model (Interaction between Soil-Biosphere-Atmosphere-Ags-Multi Energy Balance (ISBA-Ags-MEB)) was evaluated. ISBA-Ags-MEB simulates the main components of the carbon budget over 6 seasons of irrigated maize, and 4 seasons of winter wheat: all from 2006 to 2015, including 2019. The estimates of the model are in good agreement with EC measurements. The ISBA-Ags-MEB model requires few parameterizations and minimal optimization, thus making it promising for regional/global-scale application, including over diverse agrosystems.

105 2100+ CO2 and H2O Flux Measurements Across the Globe: Sitting on a Golden Egg?

Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

The goal of this presentation is to ignite, and provide a base for, a discussion regarding the locations where eddy covariance flux measurements of CO2 and H2O have been done simultaneously in the past and where they are being done now, and the barriers to, and advantages of, accessing and utilizing this wealth of data in a best possible manner.
Locations include large networks which already have done detailed inventories and budgets, compiled databases, and designed engaging interactive maps, but also smaller networks, tower clusters, and

individual sites, including all long-term stationary site locations, all short-term campaign locations, as well as all mobile transects over land and ocean.
The presented map shows locations of all past and present eddy covariance measurements available on the latest date of update, a total of 2126 stationary measurement locations, and 2 airborne campaigns with 27 flight tracks.
The exactly overlapping sites have been removed except for cases where a group indicated that several eddy covariance levels or closely positioned towers were deployed. It is likely that some of the locations with multiple systems have been removed in this process artificially reducing the count.
There is still a significant amount of missing measurement locations related to: (i) evapotranspiration measurements and related networks; (ii) urban GHG flux measurements; (iii) shipborne and airborne flux transects.
Thanks to everyone who contributed to this effort, especially the following organizations: FluxNet, Ameriflux, Asiaflux, CarboEurope, ChinaFlux, ICOS, KiwiFlux, OzFlux; and numerous individual groups and people for their past and future contributions.

112 Robust estimation of the carbon uptake period based on time series of atmospheric CO2 and analysis of its interannual variability
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Analyzing trends in the timing and duration of the carbon uptake period (time of the year when the CO2 uptake is greater than the CO2 release) derived from high-quality CO2 dry air mole fraction data from flask sampling sites can help us understand the changes in CO2 exchange between the terrestrial ecosystem and the atmosphere. In this study, we use a recently developed methodology for quantifying the uncertainty in curve fitting and propagating it to the CO2 seasonal cycle metrics. We focus on two metrics, namely the timing (onset and termination) and duration of the carbon uptake period. We introduce a method for estimating these metrics based on a threshold of the first derivative (FDT), which more closely corresponds to the “actual” onset and termination of the growing season. To better understand the link between interannual variability in the seasonality of surface fluxes and the seasonality of in-situ CO2 measurements it is crucial to account for variability in atmospheric transport. For this, we generate time series with varying interannual meteorology and with fixed meteorology. We investigate if the proposed FDT method can better capture the interannual variability in the carbon uptake period by simulating synthetic time series of atmospheric mixing ratios with a transport model, using fluxes with known interannual variability of the carbon uptake period. The reduced uncertainty achieved using the FDT method and analysis of the transport fluxes provide a better understanding of the CO2 exchange between the terrestrial ecosystem and the atmosphere.

163 Does Below-Above Canopy Air Mass Decoupling Impact Temperate Floodplain Forest CO2 Exchange?
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Environmental conditions influence forest ecosystems and consequently, its productivity. Thus, the quantification of forest CO2 and H2O exchange is a critical requirement to estimate the CO2 and H2O balance of forests on a local and regional scale. Besides interpreting the annual CO2 and H2O exchange corresponding to environmental conditions over the studied years (2015–2020) at the floodplain forest in Lanžhot, Czech Republic (48.6815483 N, 16.9463317 E), the influence of below-above canopy air mass decoupling on above canopy derived CO2 exchange is the focus of this study. For this purpose, we applied the eddy covariance (EC) method above and below the forest canopy, assessing different single- and two-level flux filtering strategies. We focused on one example year (2019) of concurrent below and above canopy EC measurements. We hypothesized that conventional single-level EC flux filtering strategies such as the friction velocity (u*) filtering approach might not be sufficient to fully capture the forest CO2 exchange at the studied ecosystem. Results suggest that decoupling occurs regularly, but the implication on the above canopy derived EC CO2 fluxes appears to be negligible on an annual scale. We attribute this to the open canopy and flat EC tower surrounding terrain which inhibits horizontal removal of below-canopy respired CO2.

193 Eddy Covariance station in flooded rice filed in Vietnam: preliminary results *Poster*

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Vietnam ranked 15th for the largest population in the world, with more than 97 million of the population in 2020 (Worldbank, 2022). Rice export is the strength of this country, with the 3rd position globally in 2016 (Kea et. al., 2019). In particular, the largest amount of rice production in the country is in the Mekong Delta area, in the South. And according to the third biennial updated report of Vietnam to The United Nations framework convention on Climate change, the total GHG emissions of Vietnam in 2016 was 316 million tons of CO2eq, rice cultivation placed the second position and contributed 11% emission of CO2eq (Ministry of Natural Resources and Environment, 2020). This report was made based on the general approach proposed by IPCC, and this might affect the accuracy. Therefore, in 2019, under the cooperation agreement between the Global Change Research Institute CAS and the University of Science, Vietnam National University – Ho Chi Minh City, an ecosystem station was established for GHG measurements (CO2 and CH4) in flooded rice paddle field area at the Mekong Delta area in Vietnam The station is fully equipped with state-of-art equipment for CO2 and CH4 gas exchange and micrometeorology measurements. These measurements are important to improve our knowledge about greenhouse gases exchange in this region and to investigate the factors influencing carbon cycling and sequestration in these types of ecosystems. Here, we present the infrastructure

set-up of this flooded rice ecosystem station and some preliminary results on CO2 and CH4 gas exchange.

205 Atmospheric CO2 flux variability over a temperate tidal flat revealed by Eddy Covariance measurements
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

In October 2020 and from March to June 2021, we measured CO2 exchanges by Eddy Covariance (EC) over a temperate mudflat on the French Atlantic coast. Our approach completed by other in situ field deployment allowed us better understand the carbon dynamic at diurnal, tidal and seasonal time scales related to environmental factors and microphythobenthic and oyster reef communities presented in the footprint of the EC measurements. The tidal flat acted as a carbon sinks during all seasons with significant variations. Indeed, the spring sink was the highest (0.97±1.83 µmol m−2 s−1) when the lowest mean sink was observed during summer (0.28±3.60 µmol m−2 s−1). In the corresponding wind sector, microphytobenthos-dominated area corresponded to carbon source during the spring night and summer day, emitting 0.58±2.05 µmol m−2 s−1 and 6.29±3.99 µmol m−2 s−1 of CO2; the oyster-dominated area is a carbon source during the winter and summer night, emitting 0.45±2.64 µmol m−2 s−1 and 1.37±2.63 µmol m−2 s−1 of CO2. Moreover, different water heights (Hw) have a significant effect on carbon fluxes. For example, a mean sink (-1.79±2.98 µmol m−2 s−1) when Hw=0 is significantly different from a mean source (1.07±3.13 µmol m−2 s−1) when 0.5<Hw<1 during summer. The estimated carbon sequestration potential of Brouage mudflats is -98.54 gC m-2 on acquired data, -66.09 gC m-2 at high tide and -32.45 gC m-2 at low tide.

209 Ecosystem Water Use Efficiency of Rainfed Sweet Cherry Trees in the Eastern Free State
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Agricultural production is negatively affected by the lack of rainfall in the semiarid regions of South Africa. Studies on the soil-plant-atmosphere continuum have mainly focused on water use and water stress at a tree scale (in-situ), with few conducted on an ecosystem scale. The objective of the study was to analyse daily and seasonal trends of carbon flux density (Fc), evaporation (E), gross primary production (GPP) and ecosystem water-use efficiency (EWUE) over two production seasons (2018/19 and 2019/20) of rainfed cherries under a warm temperate climate. E, Fc, GPP and WUE were quantified using open-path eddy covariance. The study was conducted in a 25-year-old sweet cherry orchard in

the eastern Free State Province, South Africa. The Fc ranged from -9.45 to -2.23 and from -11.92 to -4.04 µmol m-2 s-1 during the 2018 and 2019 measurement periods. The GPP and EWUE varied from 9.01 to 25.16 and 10.76 to 21.92 g CO2 m-2, from 1.20 to 10.29 and 0.70 to 9.72 g CO2 kg-1 H2O during the 2018 and 2019 measurement periods, respectively. During the 2018/19 post-harvest stage, evaporation gradually increased from flowering to the early post-harvest with 661 and 767 mm for the respective seasons. Results showed that sweet cherry trees with dry weight photosynthesis have a significant carbon (C) storage and carbon dioxide (CO2) sequestration in the agroecosystems.

269 A multisite data assimilation framework for Optimising the CH4 simulations from LPJ-GUESS
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Dynamic terrestrial ecosystem models like JPJ-GUESS can provide major insights into the rising concentration levels of methane (CH4) in the atmosphere. LPJ-GUESS allows quantification and understanding of the natural CH4 fluxes at various scales ranging from local to regional and global. The model contains detailed descriptions of CH4 production, oxidation, and transportation, but due to the complexity in the representation of underlying environmental processes that drive the ecosystem functioning for various spatial and temporal scales the model contains several uncertainties. A predominant part of the uncertainties are considered to be due to the unknown or poorly calibrated parameters in the model equations.
In this study, we developed a data assimilation framework based on the the Markov chain Monte Carlo algorithm to constrain the selected parameters in LPJ- GUESS using eddy-covariance observations collected from four different Scandinavian wetlands; Siikaneva wetlands in Southern Finland, Degerö mires in Northern Sweden, Lompolojankka wetlands in Northern Finland, and the Abisko-Stordalen wetlands in the Northern Sweden, with different time periods. Application of this method on uncertain parameters allows greater search of their posterior distribution, leading to a more complete characterisation of the posterior distribution. The data are used to constrain the processes behind the CH4 dynamics, and the posterior covariance structures are used to explain how the parameters and the processes are related. The results using data from four sites show that the framework is useful for larger-scale constraints on methane emissions from wetlands.

274 On the need to account for the eddy covariance footprint variability while integrating ecosystem fluxes with high-resolution earth observations
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

The exchange of energy and matter through the soil–vegetation–atmosphere is gaining more and more attention with climate change. The Glasgow Leaders' declaration on forest and land use has recently highlighted the need to achieve a balance between greenhouse gas emissions and removal by sinks for climate change adaptation. For this purpose, there is a need for measurements and models to deeply understand the global greenhouse gases budget dynamics and the relative uncertainties under present and future conditions. The energy and matter exchange can be measured at the ecosystem level with the eddy covariance technique (EC). Such data are valuable for model development and, by integration with earth observations (EO), can be exploited to infer fluxes on regional and global scales. In this context, the fluxes are frequently assimilated to point measurements or identified with a buffer around the EC tower. Such an assumption was acceptable with moderate resolution EO and it might hold on a monthly to yearly time scale but not in site-specific studies over a limited period utilizing high-resolution EO because of the EC footprint variability. For this purpose, we developed a framework for integrating a 2D EC footprint model and EO data from multiple satellites available on Google Earth Engine. By applying it to a few sites from the WW2020 ICOS dataset with different levels of land cover heterogeneity, we investigated in which situations the assimilation of the EC footprint to a buffer holds and if such assumption might be a significant source of uncertainties.

277 CO2 flux dynamics across a boreal peatland complex: Spatial variability matters
Poster

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Peatlands are complex ecosystems with both carbon and water fluxes controlled by scale-dependent feedbacks. It has been assumed that Eddy Covariance, widely regarded as being 'ecosystem scale', captures the complexity of the peatland carbon and water flux. Here we test that assumption at four locations across a boreal peatland complex. What we find is a highly variable CO2 flux with most variability attributed to plant primary productivity. Greater CO2 uptake was closely associated with the ability of the different peatland locales to maintain a high and stable water table. At one locale in particular the water table was found to vary to a greater degree than at the others and this site was a source for CO2 in contrast to the others. Our research stresses the role of peat physical and hydrological properties, which vary greatly both within and between peatlands, for determining the response of peatlands to external climatic drivers.

Poster Session 3

56 Improved metrology of low cost sensors CO2 measurements and their application for observing CO2 fluxes from Steady-State-Through (SS-TF) chambers.
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

Understanding the main processes that determine the CO2 emissions variability from soil is extremely important for a complete atmospheric CO2 budget. Dense spatial and temporal networks of soil CO2 fluxes could help in this task but nowadays are quite expensive.
Here we present how low-cost CO2 sensors can be calibrated and applied in Steady-State-Through-Flow (SS-TF) chambers for simultaneous measurements of soil CO2 fluxes and air CO2 concentrations at natural ecosystems.
The CO2 sensors response was corrected under different temperature, relative humidity and pressure conditions using a multi-sensor Air Enquirer kit. Soil CO2 fluxes measured by the proposed SS-TF and a standard closed Non-Steady-State-Non-Through-Flow (NSS-NTF) chamber were briefly compared to ensure the reliability of the results.

83 Carbon sink strength of Norway spruce forests in Europe: present and future
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

Forests sequester atmospheric carbon dioxide (CO2) and are important for climate mitigation. Net ecosystem production (NEP) varies significantly across forests in different regions depending on the dominant tree species, stand age and environmental factors. Therefore, it is important to evaluate forest NEP and its potential changes under climate change in different regions to inform forestry policy making. Norway spruce (Picea abies) is the most prevalent species in conifer forests throughout Europe. Here, we focused on Norway spruce forests and used eddy-covariance-based observations of CO2 fluxes and other environmental variables from eight sites to build a XGBoost (machine learning) model. NEP varied between -296 (source) and 1253 (sink) g C m-2 yr-1. Overall, air temperature is the most important factor driving NEP variations, followed by stand age, global radiation and precipitation. The model was used to investigate NEP in different regions within Europe. The NEP median was 585 g C m-2 yr-1, with higher NEP values in lower latitude regions. Under the “middle-of-the-road” SSP2-4.5 scenario, NEP tends to be greater in most regions by 2040. This trend is more pronounced along the Alps in France, Switzerland and southern Germany where the NEP increase could reach up to 50 g C m-2 yr-1. At the same time, a decreasing or no change NEP is also present in many areas. The study serves as an example of integrating observations from multiple sites using machine learning approach to estimate the flux at a larger scale.

88 Greenhouse gas balance of fen meadow landscapes using airborne flux measurements
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

In the Netherlands drainage of its organic soils, to enable more intensive usage of the land, leads to significant carbon dioxide release. The Dutch government seeks to reduce these emissions by about 25% in 2030. In support of these policies, the National Research programme on Greenhouse gas emissions from Fen meadow areas (in Dutch NOBV: https://www.nobveenweiden.nl/) aims to investigate the effects of various mitigation measures on the total greenhouse gas balance of the targeted areas.
One approach, complementing multi-site ground based measurements using various techniques, is to use repeated airborne surveys to measure in-situ turbulent CO2 exchange.
In 2020 and 2021 flights were made twice weekly, weather permitting, to cover three major fen meadow landscapes in the Netherlands. Flight patterns were designed such that crosswind, parallel flight tracks at 60m altitude, separated ~2km, made typical flux footprints overlapping, ensuring full spatial coverage of the major peat gradients in these respective areas.

We will present first analyses and scaling of airborne flux data for each of the three regions in relation to response variables from vegetation and soil characteristics, land and water management (EO and map based) and weather, using machine learning algorithms. We aim to ultimately provide a data driven regional greenhouse gas balances for the different fen meadow areas of the Netherlands.

151 Seasonal dynamics and regional distribution patterns of CO2 and CH4 in the north-eastern Baltic Sea
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

Significant research has been carried out in the last decade to describe the CO2 system dynamics in the Baltic Sea. However, there is a lack of knowledge in this field in the NE Baltic Sea, which is the main focus of the present study. We analysed the physical forcing and hydrographic background in the study year (2018) and tried to elucidate the observed patterns of surface water CO2 partial pressure (pCO2) and methane concentrations (cCH4). Surface water pCO2 and cCH4 were calculated from continuous measurements during six monitoring cruises onboard R/V Salme, covering the Northern Baltic Proper (NBP), the Gulf of Finland (GoF) and the Gulf of Riga (GoR) and all seasons in 2018.

The general seasonal pCO2 pattern showed oversaturation in autumn-winter and undersaturation in spring-summer in all three areas, but it locally reached the saturation level during the cruises in April, May and August in the GoR and in August in the GoF. cCH4 was oversaturated during the entire study period, but the seasonal course was not well exposed on the background of high variability. Surface

water pCO2 and cCH4 spatial distributions showed larger spatial variability in the GoR and GoF than in the NBP for all six cruises. We linked these local maxima to river bulges, coastal upwelling events, fronts and occasions when vertical mixing reached the seabed in shallow areas. We estimate that in 2018, all studied sub-basins were CO2 sinks and the average areal annual air-sea CO2 fluxes differed only marginally between the sub-basins.

181 Upgrade of the marine station PALOMA (North Adriatic Sea) in order to better determine air-sea CO2 regional fluxes in a coastal area.
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

An elastic beacon in the Gulf of Trieste hosts the marine fixed ICOS station (FOS) PALOMA. Here data from the decadal time series of discrete samples can be combined with more recent, near surface, continuous pCO2 measurements.
The Gulf of Trieste lies in the North Adriatic, strongly influenced by meteorological and marine forcing (river inputs, ocean warming) and anthropogenic pressures. Significant processes on sub-basin scale, as dense water formation during winter, can occur. Comparison with the coastal C1-Miramare ICOS station (presented in the C.2 session) highlights either complexity of this area and different contribution to long term changes of land-based vs basin scale carbon fluxes. In addition, extreme events as river floods or drought, heats waves, strong wind gusts need continuous authomated in situ measurements to be addressed.
The national funded project PRO-ICOS_Med, allowed to up-grade and reinforce the FOS with new instruments to increase its observational capability.
The instrumental pack at 3 m depth was expanded with authomated high quality pHT measures and fluorimeter, turbidimeter and C-DOM sensors, thus strengthening the possibility to understand the role of riverine inputs vs biological processes.
The atmospheric dataset (meteorological station 6 m above sea level) was upscaled with a prototype analyzer of air pCO2, joining established and cost effective technology of LICOR-840 with a custom made two point calibration system. Coupling meteorological and pCO2 data at sea will pone strong bases for integration with land-based anthropogenic CO2 sources, and highlights the impact of marine traffic as local anthropogenic CO2 source.

214 Impact of atmospheric transport on NEE estimates in the atmospheric tracer inversions
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

The impact of atmospheric transport models on CO2 estimates are highlighted through applying two mesoscale transport models in the CarboScope Regional (CSR) and LUMIA inversion systems. The Stochastic Time-Inverted Lagrangian Transport model (STILT) and FLEXPART models are used to

calculate the surface sensitivities “footprints” at 0.25-degree horizontal resolution. Virtual particles are released at site locations “receptors” every hour to sample CO2 concentrations that correspond to the observations collected from the Integrated Carbon Observation System (ICOS) network, and also from non-ICOS site network, across Europe. Results of NEE estimates show non-negligible spatial and temporal differences between inversion runs with STILT and FLEXPART. The annual difference in the flux estimates was found to be 0.52 PgC over the entire domain of Europe for 2018. The differences are mostly arising from model parametrizations, while meteorology data has a smaller contribution to the overall differences in comparison. In addition, the impact of boundary conditions was outlined by providing far field contributions to the regional domain of Europe from the two global transport models TM3 and TM5 resulting in an annual difference of 0.40 PgC. Unlike the impact of regional transport, the impact of boundary condition is consistent over time and space. Apart from that, we plan to make use of night time observations that would help resolve for gross fluxes (Gross Primary Production (GPP) and Ecosystem Respiration) in separate runs of inversions.

221 Retrieving the global mean surface CO2 level from the GAW in-situ network
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

A sufficiently dense CO2 observation network and comprehensive approach is critical to monitor changes in global CO2 and support the development of climate policies to mitigate climate change. The WMO WDCGG archives and analyses the measurements from the WMO GAW observation network, the derived global mean surface CO2 level includes uncertainty due to data extension. NOAA implemented a similar curve fitting and data extension method, while only represents the marine boundary layer. This study uses a method, semi-NOAA, and apply to almost all GAW stations, additionally also we apply the method to 3D CO2 output from the CTeu model. The semi-NOAA setup results in the global surface average ranges from 339.13±0.38 ppm in 1980 to 413.05±0.16 ppm in 2020, in high agreement (r=1, RMSE=0.053 ppm) with the WDCGG approach without the external data extension to the increased network. CTeu output at station grids or all global grids results in higher global CO2 mole fraction (~0.59 ppm or ~1.255 ppm) comparing to the estimates from station observations, however, all three show good agreement in their derive atmospheric growth rate. This implies that the sparsity of current CO2 network is not an obstacle to monitor global surface CO2 changes, while the restricted network likely underestimates the total global surface CO2 mole fraction. We find that the global surface CO2 mole fraction shows a clear linear relationship with atmospheric CO2 mass, which implies that the global surface CO2 GAW network can represent the signal of CO2 change in atmosphere very well.

258 Performance of mid-cost and low-cost sensors deployed in the ICOS-Cities CO2 sensor network in Zurich, Switzerland
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

As part of the ICOS-Cities project, a hybrid urban CO2 measurement network for monitoring of CO2 with high spatio-temporal resolution is being set up across the city of Zurich. The network includes CO2 instruments and sensors of different quality and cost. Two high quality and costly instruments are used at sites outside the city serving as a reference and for resolving the concentration and variability of atmospheric CO2 entering the urban area. In the city, a network of 19 mid-precision and mid-cost NDIR sensors deployed on roof-level captures the diluted signals of urban sources. Finally, 60 low-cost and least precise and accurate sensors are deployed on street-level next to roads, in parks and in residential and business areas for monitoring the strongest variations caused by nearby emission sources such as road traffic.
To ensure good and known data quality from this sensor network, it is essential that the used sensors are well characterized and calibrated. The mid-cost sensors are equipped with the necessary functionality to perform regular and automated two-point calibrations. The low-cost sensors lack this functionality and cannot be regularly calibrated during deployment, they were therefore only initially calibrated under laboratory conditions in a temperature and humidity controlled climate chamber. Both, mid-cost and low-cost sensors were tested prior to deployment in the field by colocation to a high-precision reference instrument. We present a comprehensive assessment of the performance of the used mid-cost and low-cost sensors.

262 The terrestrial prior flux estimates of CO2 and CH4 for atmospheric inversions
Poster

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

In ICOS Finland, in a task lead by University of Helsinki we produce estimates of the net exchange of carbon dioxide and methane between land ecosystems and the atmosphere. These sub-daily Europe-wide exchange rate maps provided with yearly updates are intended to be used as the prior estimates of natural land ecosystem fluxes in the ICOS based atmospheric inversion framework.
For this aim we use JSBACH-HIMMELI model that is a combination of two models: JSBACH, that is a land-surface model estimating ecosystem net CO2 exchange, and HIMMELI, that is a specific model for northern wetland emissions of CH4. Additionally, soil moisture and soil autotrophic respiration rates produced by JSBACH are used in estimating the CH4 source and sink strengths of upland mineral soil regions.
The daily climate data from Copernicus ERA5-Land product are used for driving the model in 0.1 degree spatial resolution and three hourly mean fluxes are estimated from 2005 onward until the end of 2025. The prior fluxes are evaluated against in situ measurements at the sites within the domain and other model estimates of CO2 and CH4 balances.
In this work we show the regional CO2 and CH4 balances through 2005-2021, evaluate them against regional model and observation based data products and discuss the strengths and development prospects of our prior flux data product.

Parallel Session 1

81 Two full years of continuous N2O and CO2 fluxes measured by eddy covariance technique in a shallow drained agricultural boreal peatland during a warm and traditional winter

Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Cultivated organic soils represent only ca. 13% of agricultural fields in Finland but they contribute to 43% and 82% of total N2O and net CO2 emissions from agricultural fields. It is well known that cultivated organic soils can be high sources of N2O and CO2 but only a minor source or sink of CH4. Contrary to CO2, N2O emissions do not follow a strong seasonal pattern. Instead they have high spatial and temporal variability throughout all seasons. Short-term N2O peak emissions can be observed after various meteorological or soil management events, for example after soil freezing and thawing or fertilization.
Low frequency measurements (e.g. chamber technique) may miss the short term peak events especially during winter, a season which contributes significantly to the annual N2O budget in boreal regions. To reduce the uncertainty and increase our understanding of N2O events, more continuous measurements are needed.
N2O and CO2 fluxes were measured continuously for two full years in Ruukki, a drained agricultural boreal peatland in Northern Finland with a shallow peat layer. To our knowledge, this is the first time that N2O fluxes are measured continuously from such a site with the Eddy Covariance technique (EC).

We will answer two research questions:
1. Does a warmer winter induce more N2O emissions than a traditional one?
2. How does the N2O and CO2 annual budget compare to the IPCC EFs?

In addition, we will present the short-term N2O variation observed in relation to weather and management events in Ruukki.

230 Modelling peatland vegetation, CO2 and CH4 emissions in the context of peatland restoration

Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Singular plant types have been shown to impact the net greenhouse gas (GHG) balance of peatlands. However, few (or no) studies have investigated the impact of dynamic plant composition on GHG

emissions in peatlands. To assess the impact of dynamic vegetation on subsequent GHG fluxes in peatlands, we developed a new model, Peatland-VU-NUCOM (PVN). This is the second process-based model to date, capable of simulating dynamic vegetation, CO2, and CH4 emissions in peatlands.

The new PVN model simulates CH4 and CO2 fluxes in relation to the plant community composition. The PVN model includes plant competition, CH4 diffusion, ebullition, root, shoot, litter exudate production, belowground decomposition, and aboveground moss development, under changing water table and climatic conditions. The model was compared against observational data collected at two sites in the Netherlands; the Horstermeer and the Ilperveld.

These results showed that plant communities impact net GHG emissions. This means peatland restoration efforts that rewet without restoring peat-forming vegetation may result in larger GHG emissions than restoration efforts that re-introduce peat forming vegetation. We also found that the interaction between PFTs influenced the potential for harvest events to reduce GHG emissions. These results indicated that plant community restoration is a critical component of peatland restoration.

211 FULL-CYCLE GREENHOUSE GAS BALANCE OF A SPHAGNUM FARM ON FORMER BOG GRASSLAND IN GERMANY

Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

To obtain a view of the climate effect of a full Sphagnum farming production cycle, we re-visited a 7-year old Sphagnum farm in North-West Germany for which published GHG data exists for the establishing years. The farm consists of Sphagnum productions strips, ditches and dams. On these compartments we measured GHG exchange in the 7th year of the production cycle and harvested Sphagnum biomass after 7 years of growth. The Sphagnum production strips were still strong CO2 sinks (-6.9 t ± 4.1 ha-1 a-1). Harvested Sphagnum lawn biomass was ~13.8 t ha-1 with an average C content of 45.6 %. CO2 emissions of the dam amounted to approximately ~30 t ha-1 a-1. Over the full 7-year production cycle the Sphagnum production strips were net GHG sinks (-3.2 ± 4.2 t ha-1 a-1 CO2-equivalents). In comparison, the ditches and dams represented net GHG sources emitting 13.8 ± 11.5 and 29.3 ± 9.8 t ha-1 a-1 (in CO2-eq), respectively. Corrected for the area share of the compartments, the farm is a net GHG source of 10.7 ± 4.9 t ha-1 a-1, thus reducing the climate warming effect compared to drained peat grassland by approximately 20 t ha-1 a-1. Because of their relative high share of 40 % of the total farm area the peat dams were the major contributor to the net warming effect of the farm. Therefore, suitable measures must be found to reduce the area of dams without substantially compromising the quality of the production system.

188 Modelling CO2 emissions from drained peat meadows with the PEATLAND-VU model
Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Monitoring CO2 fluxes is time intensive and costly. Thereby, to extract peat oxidation from the bulk CO2 flux, long term measurements are needed so that fluctuation in respiration from the short term carbon cycle (driven by biomass production) is not of influence. To overcome long term intensive measurements, a model could help out to evaluate CO2 emissions and the effect of water table increase on peat oxidation.
PEATLAND is a 1D process based model, consisting of four submodels for 1) soil physics (water table, soil temperature and soil moisture), 2) biomass production, 3) CH4 production, oxidation and transport, and 4) CO2 production. CO2 production is the sum of decomposition from different soil organic matter (SOM) pools, like litter, root exudates, microbial biomass and peat.
We calibrated the PEATLAND model for three intensively used drained peat meadows in the Netherlands, that are equipped with sensors for measuring continuously CO2 fluxes and all environmental variables related to that. These sites have a reference field and a field with elevated groundwater level.
In this presentation, we discuss the model performance on these sites. We will show how this model can be used to evaluate rewetting measures on CO2 emissions from peatlands, and what the limitations are.

171 How do CO2 fluxes relate to groundwater table on a yearly and seasonal scale in Dutch drained peatlands used for dairy farming?
Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Rewetting of drained peatlands is a proposed measure to reduce greenhouse gas (GHG) emissions. Worldwide, drained peatlands contribute 9–15% of total GHG emissions. Hence, reducing these emissions is imperative. In the Netherlands, almost all peatlands are drained and 85% are in agricultural use. The Dutch government aims to reduce emissions from peatlands with 1 Mton/year by 2030. Different measures are proposed to achieve this goal. However, there is insufficient data to quantify GHG emissions from Dutch peatlands and to validate the effects of mitigation measures. Therefore, a national research program on GHG emissions from peatlands (NOBV) was initiated in 2019. In this program we use transparent automated flux chambers, eddy covariance and aircraft measurements, combined with a network of groundwater, soil and meteorological sensors, to perform long-term, unattended measurements of soil-atmosphere GHG fluxes and potential drivers

on different dairy farms in the Netherlands.
We will present effects of elevating groundwater levels (using subsoil irrigation) on CO2 fluxes during summer and discuss differences between sites and years. In the wet year (2021) the mitigation effect was less than in the dry year (2020), in some cases even negative, and mitigation effects strongly varied among locations. Aggregating data from 5 sites shows that soil temperature and water table depth are important predictors for ecosystem respiration. Our preliminary data do not show a clear relationship between CO2 fluxes and water table depth for all seasons and soil temperature bins. Overall, a water table depth < -20 cm showed the highest reduction potential.

Parallel Session 2

134 Optimizing ecosystem carbon and water fluxes using COS and SIF within the adjoint-based data assimilation system (NUCAS)

Oral

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Carbon and water fluxes are tightly coupled through stomatal conductance. It is important to accurately estimate carbon and water fluxes to improve our understanding of climate change impacts on terrestrial carbon cycles at multiple scales. Simulations of carbon and water cycles by ecosystem models are subject to uncertanties. Among the main sources of such uncertainties are the values of processes parameters, initial and boundary conditions. Observations at multiple scales can be used to systematically constrain these control variables in a suitable data assimilation framework. In particular observations of solar-induced chlorophyll fluorescence (SIF) have been shown to be a powerful constraint on photochemical processes at leaf level. Furthermore, observations of carbonyl sulfide (COS) fluxes from ecosystems have recently been reported as a good indicator for stomatal processes. This is because COS shares with CO2 the diffusional pathway via stomata into the leaf, while its behaviour is different from CO2 in that COS will be hydrolyzed and not back-diffused. We present the newly developed adjoint-based data assimilation system NUCAS (Nanjing University Carbon Assimilation System) which combines the remote-sensing driven ecosystem model BEPS with its adjoint to enable highly efficient assimilation of multiple observational data streams including COS and SIF. We first demonstrate the robustness of the system in twin-experiments assimilating pseudo observations generated by the model. Next, we assimilate COS measurements and observations from various eddy covariance sites including those from the ICOS network. Finally, we jointly assimilate COS and SIF observations and assess their constraint on ecosystem water and carbon fluxes.

85 Contribution of deep soil layers to the transpiration of a temperate deciduous forest: quantication and implications for the modelling of productivity

Oral

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Climate change is imposing drier atmospheric and edaphic conditions on temperate forests. Here, we investigated how deep soil (down to 300 cm) water extraction contributed to the provision of water in the Fontainebleau-Barbeau temperate oak forest over two years, including the 2018 record drought.

Deep water provision was key to sustain canopy transpiration during drought, with layers below 150 cm contributing up to 60% of the transpired water in August 2018, despite their very low density of fine roots. We further showed that soil databases used to parameterize ecosystem models largely underestimated the amount of water extractable from the soil by trees, due to a considerable underestimation of the tree rooting depth. The database established for France gave an estimate of 207 mm for the soil water holding capacity (SWHC) at Fontainebleau-Barbeau, when our estimate based on the analysis of soil water content measurements was 390 mm. Running the CASTANEA forest model with the database-derived SWHC yielded a 350 gC m-2 y-1 average underestimation of annual gross primary productivity under current climate, reaching up to 700 gC m-2 y-1 under climate change scenario RCP8.5. It is likely that the strong underestimation of SWHC that we show at our site is not a special case, and concerns a large number of forest sites. Thus, we argue for a generalisation of deep soil water content measurements in forests, in order to improve the estimation of SWHC and the simulation of the forest carbon cycle in the current context of climate change.

37 Impact of soil water availability on the modelling of gross primary production of a winter wheat crop from sun induced fluorescence
Oral

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

At global scales, estimating carbon assimilation relies on the observations of sun induced fluorescence (SIF) from satellites coupled with empirical relationships between SIF and gross primary production (GPP). These relationships are only based on statistical correlations between the two variables established over eddy-covariance stations. There is a lack of a theoretical framework to relate any changes in this relationship with physiological and environmental factors. Recently, a process-based light response (MLR) model was developed to mechanistically determine the ecosystem photosynthetic activity from SIF measurements above the canopy based on the perspective of light reactions. We will test this SIF-GPP relationship on the ICOS station of Lonzée (BE-Lon) by using a FLOX device to quantify SIF above the canopy of a winter wheat crop between April and July 2022. The parameters of the MLR model (including the maximum yield of PSII φmax, the fraction of open PSII centers qL and the CO2 concentration at the fixation sites Cc) will be measured at the leaf level by a LICOR 6400 XT within the footprint of the FLOX device. The GPP estimated from the MLR model will be compared to the GPP measured by the EC station and the variability of the model parameters with soil water availability and other environmental variables will be discussed. The potential validity of this model represents an important step towards a better understanding and modelling of carbon uptake from satellite passive fluorescence at global scales.

279 The effects of biomass burning aerosols and clouds on the net CO2 balance in the grassland ecosystem in the Amazon
Oral

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

The intense colonization process in Amazon has deforested large areas that almost always precede the occurrence of fires. Fires release greenhouse gases and particulate matter into the atmosphere which causes affects the amount of solar radiation that reaches the surface. The diffusion of radiation caused by aerosols is mentioned as capable of increasing the absorption of CO2 by forests, but evaluations on crops show that this effect is null or even impairs the growth of plants. Due to the large area of the grassland Brachiaria brizantha in the Amazon, the knowledge about how the burning aerosols act on the absorption of CO2 in this vegetation is very important. The effects of aerosols and clouds were evaluated on the Light Use Efficiency (LUE) in the State of Rondônia, Brazil. The presence of aerosols and clouds proved to be beneficial. The maximum Gross Primary Production (GPP) of 0.7 gC m-2 s-1 occurred when the Photosynthetically Active Radiation (PARt) was around 1600 µmol m-2 s-1 (defined as the light saturation point) and the LUE was greater than 1 gC MJ-1, when there was more radiation diffusion. The mean of 0.74 gC MJ-1 of the LUE occurred in conditions free of aerosols and clouds, as well as below the saturation point of the PARt (1404 µmol m-2 s-1). The results indicate that changes in the diffuse fraction of radiation can alter the absorption of CO2 by the pasture with possible influences on phenological processes which were not directly observed here.

Parallel Session 3

114 Inter-comparison of CO2, CO and CH4 mixing ratios obtained by in-situ and remote measurements techniques in the Izaña Atmospheric Observatory

Oral

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Session E. Monitoring, validation and verification : E.3 Ground-based remote sensing measurements of greenhouse gases and their application for carbon cycle studies, satellite and model validation and building MVS capacity

The Izaña Observatory (IZO, 28.3ºN, 16.5ºW, 2367 m.a.s.l., Tenerife) is a subtropical high-mountain observatory belonging to the State Meteorological Agency of Spain (AEMET). IZO is normally above a temperature inversion layer and below the descending branch of the Hadley cell. Consequently, it offers excellent conditions for trace gas in situ measurements under free troposphere conditions and for observations by remote sensing techniques.
IZO has been a Global WMO-GAW (World Meteorological Organization-Global Atmosphere Watch) station since 1984, recording continuous in-situ concentrations of GHGs. In addition, since 1999 total column amounts and low-resolution vertical profiles of many different atmospheric trace gases, GHGs among them, are retrieved by using Fourier Transform Infrared Spectrometer (FTIR) in the framework of NDACC (Network for the Detection of Atmospheric Composition Change) and TCCON (Total Carbon Column Observing Network). Moreover, since 2018 a portable FTIR instrument operates in the framework of COCCON (COllaborative Carbon Column Observing Network). In 2021, Spain joined ICOS proposing IZO as its first atmospheric station.
The aim of this study is to compare the CO2, CO and CH4 mixing ratios series of in-situ and remote instruments with different time intervals to determine the best conditions where both series are representative of the same atmospheric conditions. FTIR spectrometers measure solar absorption spectra of the gases throughout the atmospheric column, unlike in-situ analysers that record concentrations at ground level. The comparability of both series is analysed in various scenarios: background conditions, biomass burning and volcanic events. In addition, these series are compared with satellite observations.

36 Analysis of CO2, CH4 and CO surface and column concentrations observed at Reunion Island by assessing WRF-Chem simulations

Oral

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Session E. Monitoring, validation and verification : E.3 Ground-based remote sensing measurements of greenhouse gases and their application for carbon cycle studies, satellite and model validation and building MVS capacity

Réunion is a French island in the Indian Ocean, which holds one of the very few atmospheric observatories in the tropical Southern Hemisphere. Moreover, it hosts experiments providing both ground-based in situ and column Fourier Transform InfraRed spectrometer (FTIR) observations of CO2, CH4 and CO atmospheric concentrations, contributing to the Integrated Carbon Observation System (ICOS), the Network for the Detection of Atmospheric Composition Change (NDACC) and the Total Carbon Column Observing Network (TCCON).

This work includes a comprehensive study of these observations made at two specific locations: in the capital Saint-Denis and at the high-altitude Maïdo Observatory. We used simulations of the Weather Research and Forecasting model coupled with chemistry (WRF-Chem), in its passive tracer option (WRF-GHG), to gain more insight in the factors that determine these concentrations. WRF-GHG provides the opportunity to distinguish the contributions of several model tracers corresponding with the following emission sectors: anthropogenic, biogenic, biomass burning, ocean and background.

This presentation will discuss the main findings from the comparisons between the observations at Réunion and the model simulations.

104 eLTER RI – an integrated, long-term ecosystem, critical zone and socio-ecology research infrastructure
Oral

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

The global grand challenges such as climate change and biodiversity loss are not occurring in isolation in time or space – they are closely interconnected and have potential to amplify each other, create nonlinear feedbacks and result in significant loss of ecosystem services that eventually affect societal well-being and humanity. While immediate impacts sometimes receive considerable attention, little is known about their long-term and systemic effects often resulting from cross-scale interactions. Closing these knowledge gaps requires an improved, transdisciplinary understanding of the multifaceted environmental system - a prerequisite for the development of appropriate mitigation and adaptation measures.
To tackle these challenges, eLTER RI is building a pan-European research infrastructure of long-term research sites in the fields of ecosystem, critical zone and socio-ecological research. The eLTER RI facilities (Sites and Platforms) cover the major European environmental gradients from the Atlantic to continental step-like areas and from the Mediterranean Basin to the Arctic, and offer a possibility for interdisciplinary collaboration, enhancing data availability, accessibility based on FAIR principles and allowing frontier research opportunities in key ecosystems. The interdisciplinary data and knowledge provided by eLTER RI enable to identify long-term environmental trends, map the drivers and

feedbacks between social and ecological systems, and provide scientifically solid grounds for potential policy solutions to local to continental scale environmental challenges.
eLTER RI searches for complementarities and collaboration opportunities with other in situ research infrastructures (e.g. ICOS, AnaEE, ACTRIS), as well as with the ones developing advanced services for users of in situ data (e.g. LifeWatch).

229 Monitoring deforestation and forest degradation embodied in consumption and trades of risk products and bio-commodities
Oral

Mirco Migliavacca, Paul Rougieaux, Selene Patani, Candan Eylul Kilsedar, Giovanni Bausano, Beck Pieter, Beuchle Rene, Clement Bourgoin, Alessandro Cescatti, Guido Ceccherini, Valeria De Laurentiis, Sarah Mubareka, Serenella Sala, Christelle Vancutsem, Peter Vogt, Frederic Achard

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

The proposal for a regulation on deforestation-free products released in November 2021 aims to minimize the European Union (EU) driven deforestation and forest degradation embodied in the consumption of risk products and bio-commodities. In this proposal was launched the "EU observatory for deforestation and forest degradation" (EUFO), which is constituted by two key components: 1) The "remote sensing component" that is focused on monitoring changes in forest cover and forest degradation globally; and 2) the "trade component" that is focused on monitoring consumption of commodities and products possibly associated with deforestation and forest degradation.
In this contribution, we present the preliminary results of the "trade components" of the EUFO. We developed a wall-to-wall toolset (the "biotrade" python package) to update and process production and trade data associated with the primary commodities selected in the regulation proposal (i.e., cocoa, coffee, soybean, palm oil, beef, and timber). We developed a land footprint model for calculating the land area embodied in the trades and consumption of the selected products and bio-commodities. Then, we evaluated the uncertainties associated with the land (and other) footprint models and discussed how research infrastructures could help to constrain these uncertainties. Finally, we will show the preliminary results of identifying the drivers of deforestation and discuss the role of EU trade and consumption.

253 Carbon Action – Towards regenerative agriculture in Finland
Oral

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Session D. Policy, Research Infrastructures and Society : D.4 Community Engagement, Training and Outreach

Two complex problems of our time, climate change and biodiversity loss, are highly interlinked. Soil

degradation is connected to these as well as many other environmental problems. Thus, soil health can play an important part in mitigating environmental crises. Agricultural soils have started to gain great interest during the past few years, also at the policy level in EU.

Carbon Action platform (www.carbonaction.org/en/front-page/) aims at multiple benefits through regenerative agriculture: improved yield, biodiversity and resilience, climate change mitigation, and reduction of nutrient runoffs to water bodies such as the Baltic Sea. The platform brings farmers, advisors, scientists, companies, and decision-makers together to perform the actions towards healthy soils. It was established in 2017 by the Baltic Sea Action Group (BSAG) together with the Finnish Meteorological Institute (FMI) coordinating the research.

The platform contains multiple research projects and a multi-disciplinary network of researchers. There are 100 Carbon Action Farms testing practices and providing data for research. Scientifically ambitious monitoring and verification system for soil carbon is being developed. Data from intensive test sites is currently visible at Field Observatory (www.fieldobservatory.org). Based on the scientific work, the platform provides free e-college for regenerative farming as well as produces practical guides for farmers. Currently, there are over 1000 members (of which >500 farmers) in the Carbon Action club. Moreover, 13 companies are involved, training their contract farmers, and renewing sourcing criteria.

Actions for soil health are urgently needed. We aim to upscale the best practices, and to achieve systemic change.

Parallel Session 4

156 Variability of methane emissions across Dutch peatlands measured by eddy covariance

Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

In the Netherlands, historical and ongoing drainage of peatlands causes aerobic microbial decomposition that releases high amounts of CO2 to the atmosphere. Agriculture on Dutch peat soils is responsible for more than 50% of agricultural greenhouse gas (GHG) emissions, despite only covering ~10% of the agricultural area. In comparison, intact peatlands are long-term carbon sinks that generally have a slightly-cooling to neutral effect on global warming, depending on the rate of CO2 uptake and emissions of methane (CH4). To meet climate commitments, reductions in carbon emissions from Dutch peatlands need to be made. Rewetting peatlands is often proposed and attractive measure to reduce or sequester CO2 emissions, however uncertainty remains regarding increases in CH4 emissions. CH4 emissions from peat soils are influenced by several factors, such as water table depth, vegetation, peat type and climate. To address this, the current rates of emissions across Dutch peatlands need to be quantified to understand the impacts on the climate and to choose appropriate mitigation strategies. In this presentation, we introduce and compare flux data from a network of eddy covariance systems recently installed on Dutch peatlands as part of the Dutch National Research Programme on Greenhouse Gases in Peatlands (NOBV). The sites cover a wide range of land uses on peat soils, including a lake, intact floating fen, grasslands with and without pressurised drainage, and a paludiculture site. Early results show the typical pattern of greater CH4 emissions with higher water levels.

16 Peatlands on Fire – Current State of the Art and Open Questions

Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

Wildfires are extended in many world regions (1,2), projected to occur more frequently in Europe, and release substantial amounts of greenhouse gases (GHG). Vegetation fires have received larger attention but knowledge on emissions composition and quantities of smouldering fires involving carbon-rich organic soils (peat) and their climate impacts is modest at best (3,4). While their surface area footprint is small, peatlands occupy large volumes underground and, once ignited, burn for months or even years (4) and disrupt ecosystems. Aside of tropical regions (5–7) the Arctic is increasingly challenged by (overwintering) peat fires (8,9). Recent studies report regional differences in peat properties (e.g., higher carbon content (4) in tropical compared to boreal peat) and also the

ambient fire conditions differ by region (e.g., drought/heat (Tropics) (6) vs. thawing permafrost (Arctic) (9,10)). This calls for a careful assessment of the heterogeneity in the context of emission inventories for atmospheric and climate models. We summarize the current knowledge and highlight open questions in the context of GHGs.

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SMP acknowledges SNSF P400P2_194390.

186 GHG budget of Irish grassland on drained organic soils and the impact of environmental drivers, management and water table level manipulation on their climate mitigation potential
Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

In Ireland, grassland is the predominant land-use on both mineral and organic soil, and the agriculture sector contributes over one-third of the national GHG emissions, while the LULUCF sector is also a net GHG source, primarily due to the drainage of peat soils. Reducing the carbon (C) losses from histosols has been highlighted as a key action for the country to reach its climate targets, and improved grassland management can further offset GHG emissions without compromising productivity. Despite their high relevance to the Irish National Inventory Report and Climate Action Plan, data on this agri-environmental system are surprisingly scarce. Here we present an integrated work to better assess the climate mitigation potential of grassland on drained organic soil, and the impact of management and water table (WT) level manipulation.
The GHG budget of a former peat extraction site, managed for grass-based silage, has been determined for 2 years using the eddy covariance technique to monitor the carbon dioxide (CO2) exchanges, and weekly static chamber measurements to assess methane (CH4) and nitrous oxide (N2O) fluxes. Initial findings show that the site is a net C source exacerbated by warmer temperatures. Combines with a peat core lysimeters mesocosm experiment designed to study the impact of management and WT height on the C and N dynamics, these data will improve the emission factors and emissions savings estimates for Irish grassland on peat soil, and help predict the effect of future climate change on the C sink/source strength of this agri-environmental system type.

117 Eddy covariance-measured greenhouse gas exchange in the Dutch peat meadows and fens: first results on effects of peat type and management
Oral

Bart Kruijt[1], Hanne Berghuis[1], Jan Biermann[1], Alex Buzacott[2], Tom Heuts[3], Wilma Jans[4], Wietse Franssen[1], Laurent Bataille[1], Reinder Nouta[5], Arnoud Frumau[6], Christian Fritz[3], Merit van den Berg[2], Ype van der Velde[2], Ronald Hutjes[1], Niek Bosma[5], Wiebe Borren[7], Jeroen Veraart[4], Gilles Erkens[8]

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

The well-known meadow landscape from the low countries, with its cows, ditches and wind mills, constitutes a large source of carbon emissions resulting from its intensive agricultural use. Multiple mitigation measures are being considered, and a national research programme to develop integrated monitoring of both magnitude of emissions and effectiveness of measures is now in full gear. The programme and associated projects include 14 (and counting) eddy covariance sites across organic soil type, management and ground water regime, including natural fens and restored wetlands, measuring both CO2 and CH4 fluxes. Whilst the network is still in its initial phase and it is too early to draw conclusions on effectiveness of mitigation, we will share a fits overview, presenting the sites and exploring the variability in observed fluxes, with a focus on seasonal behaviour and commonalties in environmental response.

84 Do mineral soil coverages reduce greenhouse gas emissions of drained fens?
Oral

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Session A. Terrestrial ecosystems : A.2 Drivers of GHG fluxes from productive and managed peatlands: measurements, modelling and mitigation

The agricultural use of organic soils usually requires drainage and leads to high greenhouse gas emissions and soil subsidence. In Switzerland, there is a high demand for maintaining agricultural use of organic soils while simultaneously reducing environmental impacts. One management option is to cover the organic soils with excavated mineral soil material. The aim of the project reported here is to evaluate the impact of soil coverage on the greenhouse gas balance. Our study site is a fen with several meters thickness, situated in Swiss Rhine valley. In the 1970s, the site was drained, pastures established and intensively managed since then. Over time, wet soil conditions turned agriculture more difficult. In 2006, one part of the site was covered with a 40 cm layer of silty soil material. Parallel observations on the covered part and the adjacent reference area started in 2018. They include eddy covariance measurements of CO2 and CH4 fluxes, as well as the quantification of carbon removal by harvest and carbon import by fertilizer. N2O measurements began in 2019 using automated chambers. The carbon balance of both sites was dominated by net CO2 emissions, while CH4 emissions were usually negligible. We observe high interannual variations of the net CO2 fluxes for both the covered and the reference site. Specifically, the common environmental conditions affecting both sites, namely the groundwater table in summer, had a strong control on the carbon emissions while inter-treatment differences were small. However, covering the organic soil with mineral soil significantly reduced N2O emissions.

Parallel Session 5

218 Mapping the changing marine CO2 system of the southern North Sea

Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

In terms of the marine carbon cycle, the North Sea is generally thought to be divided into a deeper, seasonally stratified northern sector that is a net sink of CO2 from the atmosphere and a shallower, permanently mixed southern sector that is a net CO2 source. However, measurements from the Dutch national ocean acidification monitoring programme indicate that in the last few years, the southern part may have acted as a net CO2 sink on annual timescales. To interpolate in space and time between the monthly observations from 18 sampling sites and thus calculate the overall air-sea CO2 flux, we trained a model to predict seawater pCO2 from gridded satellite data (e.g. chlorophyll concentration) and reanalysis model output (e.g. sea surface temperature) using a gradient-boosting regression technique. Here, we discuss the modelled flux, its spatiotemporal variablity and implications for optimising ongoing monitoring efforts. We also consider how the observed change in CO2 source/sink behaviour may be related to decadal variability in seawater pH, including a consistent increase over the last 10 years, revealed by pH measurements collected across the Dutch North Sea since the 1970s.

212 A regional pCO2 climatology of the Baltic Sea from in situ pCO2 observations and a model-based extrapolation approach

Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

Ocean surface pCO2 estimates are of great interest for the calculation of air-sea CO2 fluxes, oceanic uptake of anthropogenic CO2, and eventually the Global Carbon Budget. They are accessible from direct observations, which are discrete in space and time and thus always sparse, or from biogeochemical models, which only approximate reality.
Here, a combined method for the extrapolation of pCO2 observations is presented that uses (1) model-based patterns of variability from an EOF analysis with (2) observational data to constrain EOF pattern amplitudes in (3) an ensemble approach, which locally adjusts the spatial scale of the mapping to the density of the observations. Thus, data-constrained, gap- and discontinuity-free mapped fields including local error estimates are obtained without the need for or dependence on ancillary data (like, e.g., satellite sea surface temperature maps).
This extrapolation approach is generic in that it can be applied to any oceanic or coastal region covered by a suitable model and observations. It is used here to establish a regional pCO2 climatology of the central Baltic Sea, largely based on DE-SOOP Finnmaid surface pCO2 observations between

Lübeck-Travemünde (Germany) and Helsinki (Finland), which can serve as improved input for atmosphere-ocean CO2 flux estimation in this coastal environment.

280 Airborne eddy covariance for estimating regional CO2 and CH4 fluxes in NE Germany
Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

The northeast of Germany is characterized by a heterogeneous post-glacial landscape, which is illustrated by the moraines, rivers, lakes and peatlands that mostly fill former glacial runoff-valleys. This organic-soil rich landscape is important in the context of carbon and methane emissions but currently not covered by ICOS infrastructure. Although there is a growing network of EC sites available on differently managed re-wetted peatland sites, lakes, and croplands, large uncertainties will likely remain on the regional scale. We equipped a Schleicher ASK-16 motorized glider (operated by the FU Berlin, Germany) with sensors to measure carbon dioxide, methane and energy fluxes at a regional scale in Northeast Germany (a Picarro G2311-f gas analyzer, an 858 AJ Rosemount five-hole probe, a Novatel FlexPak G2-V2 GNSS-INS system, Vaisala temperature and humidity sensors (HMT311) and a OMEGA CHAL-003 thermocouple temperature sensor). To process the data, the software packages Eddy4R and py_wingpod were used to (1) calculate wind vectors, (2) turbulent fluxes and (3) footprints. Here, we show initial results from 3 different flight days of airborne EC measurements focussed on two regions: a peatland-rich region in Brandenburg and a lake-rich region in Mecklenburg-Vorpommern. This data is additionally linked to local EC tower data, as both regions featured have at least one continuously operating EC site.

265 Monitoring cropland carbon dioxide exchange with high resolution satellite imagery
Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

The cropland carbon (C) balance at regional scale still contains high uncertainties not the least due to the problem of up-scaling C fluxes of a temporarily and spatially highly divers ecosystem. The C-exchange between the terrestrial ecosystem and the atmosphere constitute the highest and most uncertain fluxes of the cropland C balance, apart from C import from organic (manure) and C export through harvest.
Combing satellite data with local eddy covariance CO2-flux data is commonly used to up-scale the C-exchange signal from point to regional scale across ecosystems. Low spatial resolution products like MODIS limit their applicability and accuracy to larger homogeneous areas involving a high degree of uncertainty rather than detecting and tracing highly dynamic (farm-)field scale CO2-fluxes from space.

We are using eddy-covariance CO2-flux data of an arable field in conjunction with Landsat 8 derived vegetation indices (VI) to assess the ability of the satellite data to monitor net-ecosystem exchange (NEE), gross-primary productivity (GPP) and ecosystem respiration (Reco) on a daily basis and a matched footprint. Simple linear regression models are built to test the ability of a range of VIs to monitor and predict CO2-exchange for croplands. We analyse the correlation between measured CO2-fluxes and VIs over the course of the growing seasons to understand when the VIs are a reliable predictor and when the signals diverge. We present a single site analyses to discuss short-comings and pitfalls of this approach and how it relates to biogeochemical processes.

164 A new terrestrial biosphere model for combining satellite and in-situ observations into a consistent view of the terrestrial carbon cycle in a variational assimilation system
Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

The Land surface Carbon Constellation (https://lcc.inversion-lab.com) project is designed to advance our understanding of the processes underlying terrestrial CO2 fluxes and to reduce related uncertainties in an integrated approach exploiting both observations (satellite and in situ) and modelling. The project demonstrates the synergistic exploitation of satellite observations from active and passive microwave sensors together with optical data for an improved understanding of the terrestrial carbon and water cycles. As such, the community terrestrial ecosystem model D&B based on the well-established DALEC and BETHY models building on the strengths of each component model in that it combines the dynamic simulation of the carbon pools and canopy phenology of DALEC with the dynamic simulation of water pools, and the canopy model of photosynthesis and energy balance of BETHY. The model uses an hourly time step, except for the water balance, which (currently) is simulated at a daily time step. Together with appropriate observation operators D&B is applied in a data assimilation framework at two well-instrumented sites at which field campaigns are carried out: The ICOS site Sodankylä, Finland, representing a boreal forest biome, and the Fluxnet site Majadas de Tietar, Spain, representing a temperate savanna biome). The model performance will also be assessed against a range of satellite observations for approximately 500 km x 500 km regions around each site. The model is embedded into a variational assimilation system that adjusts a combination of initial pool sizes and process parameters to match the observational data streams.

Parallel Session 6

125 State of the art autonomous CO2 system measurements onboard Boaty McBoatface: Results from an 8-day mission in the Celtic Sea.
Oral

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

In a world where the climatic response to human carbon emissions has reached a critical point in time, understanding the ocean's role in carbon cycling has become a major focus for scientific observation and intervention. The development of marine autonomous platforms provides observations of higher spatiotemporal resolution, which can be used to further measure, characterize, and model ocean carbon. As a part of the pioneering OCEANIDS programme, novel carbonate chemistry sensors were integrated on the Autosub Long Range (ALR) Autonomous Underwater Vehicle (Boaty McBoatface) and deployed in the Celtic Sea. The project utilized three autonomous Lab-On-Chip (LOC) sensors measuring pH, Total Alkalinity (TA), and Dissolved Inorganic Carbon (DIC). Together, these sensors enable characterization of the marine carbonate system based on direct in situ measurements. This unprecedented technology has the potential to improve our understanding of the inorganic carbon cycle in the ocean and enable ocean acidification monitoring at a higher spatial and temporal resolution than currently possible. Additionally, it presents a powerful tool for CO2 leak detection from sub-seafloor carbon sequestration and storage (CCS) sites, and paves the way towards decarbonization of ocean observations. Preliminary results collected in March 2022 during a multi-day ALR mission in the Celtic Sea from surface waters to 600m depth will be presented. Sensor data will be validated against discrete water samples collected along the ALR's track. The performance of the new technology and its potential as an observing tool for ocean CO2 observations will be evaluated.

273 Estimating air sea CO2 flux on the European shelf
Oral

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

The importance of natural carbon sinks for keeping climate change to a minimum gets more and more attention from policy makers. In the Glasgow climate pact, ensuring the integrity of all ecosystems, including the oceans, is explicitly mentioned as an important factor. With countries investing more and more into preserving and restoring natural carbon sinks along its coasts, the need for precise estimates of coastal CO2 fluxes is increasing. While CO2 fluxes in open ocean regions are relatively well constrained, this does not apply to continental shelves and marginal seas in the same way yet. Here, we present a new estimate of air-sea CO2 flux on the European shelf (15˚W – 35 ˚E, 33 – 84˚N, 1998-2020) using Random Forest Regressions to map sea surface pCO2. Dependent on the

region, the standard deviations of our pCO2 maps reach 10-34 matm. Based on these flux maps we can identify sink and source regions as well as determine their change over the last two decades.

215 Surface Ocean CO2 Monitoring Strategy
Oral

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

With a myriad of consequences of the oceans taking up CO2 emissions from human activity, the society's needs for ocean carbon cycle information are ever-increasing. Ocean carbon scientists collaborate under the IOCCP umbrella, to design and implement the observing and forecasting system required to deliver on these needs.
We developed a pilot Surface Ocean CO2 Reference Observing Network (SOCONET), providing high-quality CO2 measurements from multiple platforms. These measurements are being collated into the Surface Ocean CO2 Atlas (SOCAT), consisting of 33 million observations spanning over 60 years.
These data serve as a basis for quantification of ocean CO2 uptake, performed by applying statistical models of various complexity. The community came together to develop standardized procedures to systematically compare their results under the Surface Ocean pCO2 Mapping Intercomparison project (SOCOM).
Finally, the Global Carbon Project combines the ocean carbon information with the information from land and atmosphere to produce the annual Global Carbon Budget.
These community-led elements of the value chain have been operating for years mostly on a volunteer basis, supported by short-term research funding, which makes them unsustainable and hinders progress. We have initiated a program to transition these activities into an operational system. In very close partnership with G7 FSOI, ICOS-OTC, US NOAA, JPI-Oceans and individual champions, we develop an internationally-agreed strategy enabling integration of individual elements into a consolidated global system allowing for timely delivery of critical information for decision making.
We would like to present the progress of these efforts.

24 Investigation of the Suess Effect in the Southern Indian Ocean over the last two decades (1998-2021)
Oral

Coraline Leseurre[1], Gilles Reverdin[1], Claire Waelbroek[1], Claire Lo Monaco[1], Nicolas Metzl[1], Catherine Pierre[1], Virginie Racapé[2], Jérôme Demange[1], Jonathan Fin[1], Claude Mignon[1]

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Measurements of dissolved inorganic carbon (DIC) concentration and isotopic composition (δ13CDIC) are essential to study biological and chemical processes in the ocean, including photosynthesis and

respiration, as well as the evolution of the contribution of anthropogenic CO2 in the ocean. Anthropogenic CO2 emissions associated with fossil fuel combustion have caused the increase in anthropogenic DIC and the Suess effect (declines in δ13CDIC). To investigate the evolution of these two processes in the Indian sector of the Southern Ocean (45°S-57°S), we measured DIC and δ13CDIC in surface and water column samples collected during repeated summer cruises over the last two decades (1998-2021), conducted on board the Marion Dufresne within the French monitoring program OISO (Océan Indien Service d'Observation). δ13CDIC data were obtained by classical IRMS measurements until 2019, but recently we have used Cavity Ring-Down Spectroscopy (CRDS) coupled with a seawater acidification interface and produced simultaneous measurements of DIC and δ13CDIC. Since 1998, our results indicate an increase in DIC in the water-column associated with the anthropogenic signal that should be also observed from δ13CDIC. This is relatively well identified in the subtropical Indian sector whereas at higher latitudes, south of the sub-Antarctic front and in the fertilized waters near Crozet and Kerguelen Islands the detection of the Suess effect is not clearly revealed. Other processes like circulation, biological activity (i.e. production and remineralization of organic matter) must be taken into account to separate the natural and anthropogenic signals over 20 years.

235 Physical knowledge to improve and extend machine learning pCO2 reconstructions
Oral

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Session B. Marine and aquatic carbon cycling : B.3 New developments in estimates of the ocean sink for CO2

We present on two approaches for reconstruction of surface ocean pCO2 from sparse in situ data. The philosophy of both methods is to apply pre-processing that removes signals already quantifiable based on physical knowledge. Our goal is to simplify the components of the pCO2 signal that the statistics must learn from the data. In the pCO2-Residual product (Bennington et al. 2022a), pre-existing knowledge is the empirically-determined impact of temperature on pCO2, pCO2-T (Takahashi et al. 2002). We calculate pCO2-T from observations, remove this from observed pCO2, and then use an eXtreme Gradient Boosting (XGB) algorithm to reconstruct the remaining component, "pCO2-Residual". The final estimate of pCO2 is the sum of pCO2-T and pCO2-Residual. In LDEO-Hybrid Data Physics (HPD, Gloege et al. 2022), the pre-existing knowledge is pCO2 from the hindcast ocean biogeochemical models used in the Global Carbon Budget (Friedlingstein et al. 2021). An XGB algorithm identifies relationships between observed driver data and modeled errors in pCO2. Full-coverage model errors are reconstructed and added to the original model fields to estimate real-world pCO2. As most of the skill over the original hindcast models in LDEO-HPD comes from the climatological error correction, these climatological corrections can be used to extend the data-based estimate backwards in time to cover 1959-2020 (Bennington et al. 2022b). Compared to independent data, pCO2-Residual and LDEO-HPD are modestly more skillful than other currently-available products. This indicates that the additional of physical knowledge is a valuable contribution to the task of pCO2 reconstruction.

Poster Session 4

38 The quantification of national CH4 emissions from in situ measurements to compare with the inventory in Cyprus

Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The Eastern Mediterranean and the Middle East (EMME) region is an emerging regional hotspot of greenhouse gas (GHG) emissions, and recently overpassed EU GHG emissions. However, due to the absence of systematic atmospheric GHG measurements in EMME, it remains challenging to characterize, validate and quantify the spatial distributions and the strength of emissions in this region. Towards this direction, we performed year-long (Oct. 2020-Sep. 2021) mobile methane (CH4) measurements in Cyprus, an island located in the eastern Mediterranean Sea.

The measurements were conducted with a Picarro (G2401) set-up in a moving vehicle (car), with a sonic anemometer installed on the roof. The study's goal was to enhance our understanding of the distribution of methane on the island and ultimately validate the national bottom-up inventory of CH4 emissions. During the measuring period, we were able to quantify the strength of local CH4 emission hotspots at Koshi (active landfill), Kotsiatis (closed landfill) and Aradippou area (cattle farms). These areas account for about 26% of the total CH4 emission in Cyprus. The emission rates of these hotspots were estimated using the Gaussian plume model embedded in the Polyphemus air quality modeling system. The mean methane emission estimated from landfills in Koshi and Kotsiatis (25.9±6.4 Ggyr-1) and cattle farms (10.4±4.4 Ggyr-1) were about 1.6 times and 0.4 times higher, respectively than the bottom-up national inventory value. Notably, there is uncertainty (18%-22%) coupled to the mobile measurements, attributed to ambient wind speed, wind direction and meteorological stability levels.

51 Mahuika-Auckland: A spatially and temporally resolved fossil fuel CO2 emissions data product for Auckland, New Zealand

Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

We describe a detailed spatially and temporally resolved CO2 emissions data product, Mahuika-Auckland, for Auckland, New Zealand based on Auckland's greenhouse gas and air emissions inventories. Emissions are provided at 500 m spatial resolution and at a 1-hour time step, a level of

detail not previously available for any New Zealand city. We divide fossil fuel emissions into six sectors that comprise Auckland Region's CO2 emissions profile: on-road transport, industrial non-point buildings and point sources, commercial non-point buildings, residential non-point buildings, air transport, and sea transport. We also include separate layers representing biogenic CO2 emissions (primarily waste and wood burning). We distribute emissions spatially and temporally based on activity data, energy and fuel consumption patterns, and population statistics. This data product represents an advance from current inventories that are only resolved at the regional and annual scale, providing a new level of detail that can be used to inform emissions reduction policies and guide the development of zero carbon pathways.

58 Identification and quantification of sources and sinks of carbonyl sulfide
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Currently, the mismatch between models and measurements suggests that sources and sinks of COS have not been fully assessed. To understand sources and sinks of COS, the atmospheric station in Lutjewad (53°24'N,6°21'E,1m a.s.l.) performs continuous in situ mole fraction profile measurements. Nighttime COS fluxes of -3.0 ± 2.6 pmol m-2 s-1 were determined using the radon-tracer correlation approach. In three occasions between 2014 and 2018, remarkable COS enhancements were measured in Lutjewad at 7, 40 and 60 meters a.g.l. Following these events, samples were collected locally and analysed with a quantum cascade laser spectrometer (QCLS). Several COS sources were identified, including biodigesters, sugar production facilities and silicon carbide production facilities. These sources were added to the available databases, at a 0.1°x0.1° resolution. The updated databases were combined with a Stochastic Time-Inverted Lagrangian Transport (STILT) model to check the influence of these sources on Lutjewad's measurements. Current results suggest a strong influence on COS related to air parcels transported from known industrial sources. However, a mismatch still persists and local influences could explain the gap between modelled and measured COS concentrations. Possibly, COS emissions from these sources fluctuate due to specific factors or particular events. On the other hand, it is also possible that the enhancements in Lutjewad could be explained by scaling up the results to broader levels, including similar facilities to the current databases. Nonetheless, these results could provide a useful insight about new sources of COS to improve the accuracy of its global budget.

86 Atmospheric oxygen measurements support decadal trends in European fossil fuel CO2 emissions
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Atmospheric measurements of the O2/N2 ratio and the CO2 mole fraction (combined into the conceptual tracer "Atmospheric Potential Oxygen", APO) over continents have been proposed as a constraint on CO2 emissions from fossil fuel burning. Based on such time series from several European and global measurement stations together with an inversion of atmospheric transport, we estimated space and time dependent scaling factors on the GridFED fossil fuel emission inventory. Our results suggest that the multi-year APO data used here are able to constrain fossil fuel CO2 emissions in parts of Western Europe where the data density is highest. Within uncertainties, the APO data support the decadal decline in fossil fuel emissions over that region, even if not revealed to the inversion by the prior. We discuss various sources of uncertainty, and how the constraint may improve from the addition of the recent APO observations done within ICOS at more stations throughout Europe.

91 Estimating European CH4 fluxes using the CarboScope Regional atmospheric inversion system
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

With an increasing network of atmospheric stations that produce a continuous data stream, top-down inverse transport modelling of GHGs in a quasi-operational way becomes feasible.

The CarboScope regional inversion system embeds the regional inversion within a global inversion using the two-step approach. The regional CH4 inversion uses Lagrangian mesoscale transport from STILT, prior fluxes for peatlands, mineral soils, biomass burning, termites, anthropogenic emissions from EDGAR v6.0, and ocean fluxes. In addition an inversion using a combination of EDGAR v4.3 with the annually updated BP statistical report for the anthropogenic methane emissions was used.
The protocol for the inversion follows the methane regional inversion intercomparison project for Europe which is closely linked to the experiment performed in work package 4 of the VERIFY project for running inversions for the period 2006-2020. The domain covers most of Europe (33 – 73N, 15W – 35E) with a spatial resolution of 0.25 degree for fluxes and 0.5 degree for flux corrections inferred by the inversion.

Results for the posterior methane fluxes and uncertainties for the full period 2006-2020 are presented on annual and monthly temporal scale.

109 Experimental fossil fuel source sector attribution: potentials and limitations
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

To efficiently reduce fossil CO2 emissions, decision-makers need to know how much individual emission sectors contribute to the total emissions. Bottom-up emission inventories provide sector-specific emission information routinely. However, atmospheric CO2 observations alone cannot provide this information. Top-down source attribution is partially provided by inverse atmospheric models only. Here, we introduce an approach that addresses source attribution solely based on atmospheric observations. The proposed Multi-Proxy Source Attribution (MPSA) approach exploits the fact that during the combustion of fossil fuels, other gases here called proxies are emitted in addition to fossil fuel CO2 (ffCO2). The proxy/ffCO2 emission ratios depend on combustion conditions and, if appropriate, flue gas treatments and are characteristic for specific source sectors. We use atmospheric 14CO2, CO and NOx observations at single stations to investigate whether the atmospheric imprint of the sector-specific proxy/ffCO2 emission ratios can be determined sufficiently precise so that the observed atmospheric proxy/ffCO2 excess ratios can serve for sectoral source attribution. We introduce the theoretical concept of the MPSA approach, assuming a grouping of all ffCO2 emissions into the three main source sectors: industry including energy production, heating, and traffic. Realistic observation uncertainties and variations of the source emission ratios are applied to examine the potential and the limitations of the MPSA approach. Furthermore, we showcase the MPSA approach for observations at two ICOS stations in Germany, Karlsruhe (KIT) and Heidelberg (ICOS-CRL). Considering the findings from those real-world examples, we discuss the practical applicability of the MPSA approach and whether the simplifications made are justifiable.

110 Quantification of Methane Emission Rates from Biogas Plants in Southern Germany
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The number of biogas plants in Germany increased significantly, especially between 2007 and 2014, and currently exceeds 9,000 [UBA, March 2019]*. Well-managed biogas plants have a high potential to contribute to climate protection through the production of renewable energy (biogas and/or electrical power). However, without an adequate monitoring of biogas plants there is a high risk of methane loss, which is released into the atmosphere.
We conducted mobile methane measurements to detect emission plumes from different biogas plants in Southern Germany. The biogas plants studied are individual plants or belonging to dairy farms or waste water treatment plants. The measured CH4 enhancements were transferred to an emission rate using a Gaussian plume model. The determined methane emission rates range between 0.3 to 46.1 kgCH4 h-1 (2.2 to 12.7 % of loss relative to the production rate). These findings are comparable to the range of other studies that have determined emissions from biogas plants in other European

countries. A larger focus will be placed on both on repeated monitoring over a longer period of time of selected biogas plants and a systematic classification of potential locations of leakages.

*Umweltbundesamt, "Biogasanlagen Sicherheitstechnische Aspekte und Umweltauswirkungen", March 2019, https://www.umweltbundesamt.de/publikationen/biogasanlagen-sicherheitstechnische-aspekte

140 CarbonWatch-NZ: New Zealand's atmospheric greenhouse gas observation and modelling system
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The greenhouse gas observation network in New Zealand was initially developed to observe baseline air arriving off the ocean that was representative of large areas of the mid-latitude southern hemisphere. In more recent years the focus has shifted to include observations of air that has interacted across the country. Alongside this has been the development of an inverse modelling capability at a national scale.

The CarbonWatch NZ programme has been initiated to expand the observation network and to improve the inverse modelling techniques, providing state-of-the art national scale inversion for both carbon dioxide and methane. CarbonWatch NZ also focuses observations on carbon budgets within three key sectors: urban, agricultural and forest. Specific requirements for gas species, study environment and topography are identified for each site and an in situ analyser is selected that is most appropriate for the site, utilising a standardised control and data management scheme.

Supporting the in situ observations CarbonWatch NZ utilises a number of tracer species that assist in interpreting the processes involved in production and removal of greenhouse gases. Tracer techniques can provide insight into fossil fuel contributions, chemistry and the role of photosynthesis and respiration. Flask samples collected within the national network provide air for laboratory studies of isotopic composition of CO2, and related species like carbonyl sulfide that are impossible to be performed in the field.

142 Spatial variability of local carbon emissions and sinks in Helsinki
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Urban areas are a major source of carbon emissions and thus a significant proportion of cities will strive to be carbon neutral in the coming decades. However, monitoring the emission reductions is challenging because the emission sources vary spatially and over time and measurement methods, such as eddy covariance or satellites, involve additional emissions and sinks from vegetation and soil with significantly different behaviors. In addition, our knowledge is mainly based on data from natural ecosystems, although urban areas and their microclimate can vary from those. Modelling tools that take into account the urban structure and microclimate are needed to better quantify the carbon sinks of urban green areas.

The aim of this study is to estimate the magnitude of biogenic components compared to local anthropogenic emissions in the city of Helsinki, Finland. The Surface Urban Energy and Water balance Scheme (SUEWS) has a recently developed carbon dioxide (CO2) module that simulates both biogenic components and local anthropogenic emissions. The anthropogenic emission modelling is based on traffic rates, population densities, and energy usages. The CO2 module has been evaluated against eddy covariance flux and tree level measurements in Helsinki. The model will be run over two year period (2020–2021) with hourly resolution with the whole city divided into 250x250 m2 grids. As SUEWS has only a simple soil model to estimate CO2 emissions from soil, the soil decomposition model Yasso will be also used to estimate the variability of soil respiration in urban areas.

173 Oil and gas emission evaluation in Romania using methane and ethane mobile measurements with a tracer gas dispersion method
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Romania is one of the European countries with the highest reported emission of methane (CH4) from oil and gas operations. In 2019 the ROMEO (Romanian Methane Emissions from Oil and gas) measurement campaign was performed in Romania. Within this campaign, Technical University of Denmark (DTU) and TNO performed mobile measurements in combination with tracer release to quantify emissions. A total set of 200 oil and gas wells, and operation sites were evaluated and emissions were quantified. From 95 oil and gas site, also the ethane (C2H6) emissions were investigated. Furthermore, in several regions around Bucharest, site-specific C2H6:CH4 molar ratios were provide. The estimated CH4 and C2H6 emission factors (EF) were compared with EF for the oil and gas sector in the United States provided from literature.

182 Evaluation of six years of continuous δ13CH4 measurements in Heidelberg, Germany
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Recent instrumental developments in measurement techniques, such as cavity ring-down spectroscopy (CRDS), have made it possible to perform continuous in situ isotopic analyses of δ13C-CH4 with high temporal resolution over several years.
At an urban station in Heidelberg, south-western Germany, the CH4 mole fraction and its 13C/12C ratio in ambient air have been measured with a CRDS G2201-i analyser between 2014 and 2020. These six-year atmospheric δ13C-CH4 measurements are analysed for seasonal and long-term variations in regional and local CH4 sources.
Therefore, different approaches based on the Keeling/Miller-Tans method were tested to determine the composition of CH4 emissions in the catchment area of Heidelberg. The isotopic source signatures of methane vary between -77‰ and -30‰, with a mean value of (-52.5± 0.3) ‰. Within the last six years no significant trend and thus no significant change of the source composition in the catchment area of Heidelberg, has been detected. An annual cycle of the isotopic source mix is observed, with more depleted values (-56‰) in summer and more enriched values (-50‰) in winter, indicating a stronger biogenic CH4 contribution in summer and stronger thermogenic (e.g. natural gas) emissions in winter. These isotopic source signature results, determined from atmospheric measurements, were then compared to regional emission inventories.

183 How to rebuild Slovak Agriculture and Transport to a sustainable future?
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Projections of greenhouse gas emissions are an estimate of the progress of future greenhouse gas (GHG) emissions based on a set of assumptions about how activities in Slovakia, that cause those emissions, might change over time.
In the presented article, the scenarios with additional measures adopted before 2020 in Agriculture and Transport sector were established. These sectors are fundamental for the mitigation of emissions under the EU's Effort Sharing legislation. The main goal of the legislation aims to cut greenhouse gas emissions in the sectors that are not included in EU ETS.
In the Agriculture sector, two scenarios of emission projections were performed after 2019 - a scenario with existing measures (WEM) and a scenario with additional measures (WAM). The result of the modelling of emission projections in the WEM scenario includes policies valid after 2019. The effect is visible in declining emissions by 51.4% in comparison with 1990. The decrease in emissions by 2050 in the WAM scenario compared to 1990 is 60.8%. The policies and measures used in scenario for road transport come from the national strategies, action plans and international regulations and agreements. The WEM scenario has a growing trend as a result of increasing transportation demands and high survival rates of old vehicles with high CO2 emissions. The breaking year could possibly 2035

but the CO2 emissions won´t be decreasing to pre-1990 levels till 2050. In the case of WAM scenario, the reduction starts at 0.95% and ends at 74.37% compared to the WEM scenario.'

234 Comparing different data processing routines for the Picarro greenhouse gas analyser at Ridge Hill atmospheric monitoring station
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Since it became operational in 2012, data from the Picarro G2301 greenhouse gas analyser at Ridge Hill atmospheric monitoring station has been processed using the GCWerks software package (www.gcwerks.com), according to processing routines typically used throughout the Advanced Global Atmospheric Gases Experiment (AGAGE) network. This processing involves applying calibration factors to account for instrument nonlinearity, correcting for temporal drift based on regular measurements of a standard cylinder, and correcting for the presence of water vapour in the sample.

Recently, Ridge Hill has been undergoing the labelling process to join the ICOS network. Consequently, the same raw Picarro data is now processed using both GCWerks and the ICOS data processing routines. We present a comparison between data processed using these two different routines, identify the most significant sources of discrepancies, and discuss the implications for inter-network comparability.

250 Trends and patterns of Methane and othergreenhouse gases at Pallas measurement station
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Atop the Sammaltunturi fell in Northern Lapland in Finland, atmospheric composition has been measured since 1991. Greenhouse gas measurements began in 1998 with CO2, CH4 measurements started in 2004 and CO in 2011. Located in Pallas-Yll¨astunturi National park, the measurement site atop the fell is supported by collocated sites for ecosystem-atmosphere interaction measurements around the fell. The atmospheric measurement station at Sammaltunturi joined the Integrated Carbon Observation System (ICOS) network for greenhouse gas measurements in 2017 and in 2018 it was labelled as Class I atmosphere station (ICOS station Pallas, (PAL)). In addition to ICOS, the station is part of numerous other measurement infrastructures such as Global Atmosphere Watch (GAW), Aerosols, Clouds, and Trace gases Re-

search Infrastructure (ACTRIS) and Pan Eurasian Experiment (PEEX).
We investigate the trends and seasonal patterns of greenhouse gas concentrations, especially methane, observations from Sammaltunturi station. Special focus is placed on the methane concentrations since they have been rising since 2007, and more rapidly since 2014.
This can have serious implications for climate warming because methane has much stronger global warming potential than CO2. However, this increasing trend is not yet well understood. We aim to present how the greenhouse gas concentrations at Sammaltunturi have evolved over the measurement period.
270. Ars, Sebastien: Using in situ measurements of δ13C in methane to investigate methane emissions from the Western Canada Sedimentary Basin

Poster Session 5

73 Predicting forest productivity under extreme drought conditions: the added utility of daily standardized drought indices

Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Forests play an essential role in the carbon sink capacity of terrestrial ecosystems, but their response to extreme events such as droughts is one of the largest uncertainties in predicting the future development of the carbon cycle. Here we present predictions of gross primary productivity (GPP) using data from the ICOS network, focusing on sites that were affected by the extreme drought event in Central Europe in 2018 and 2019. Using statistical and machine learning models, we examine how the extreme event affects the nonlinear relationship between GPP, instantaneous meteorology, and long-lasting drought impacts. We hypothesize that there are lagged effects on productivity that cannot be estimated from instantaneous measurements at the sites themselves. We also hypothesize that incorporating standardized drought indices based on either precipitation, water balance, or soil moisture into the modeling framework can help update models with information on persistent impacts on GPP. Our work can contribute to improve future carbon cycle predictions, particularly under a global warming scenario with increased occurrence of heat and drought events.

100 Aridity mediates the biodiversity –productivity stability relationship in European forests.

Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

The insurance hypothesis state that biodiversity can increase the stability of forests function, including productivity, and is receiving political attention. Recent experimental evidences suggest that climate change can impact how plant diversity influences the stability of forest productivity. Still, most evidence of the biodiversity–stability relationship obtained to date comes from local studies or under a limited set of conditions. This presentation will show how climate mediates the relationships between plant diversity and ecosystem stability across European forests. We derived metrics of productivity stability derived from 16 years of remote sensing data. We combined the stability metrics with field surveys of plant diversity, vegetation traits, and climate reanalysis from 160 forest stands across Europe.

We explained a large portion of the forest productivity stability by using metrics of climate variability, plant diversity, and vegetation characteristics. Climate variability and plant diversity were selected as critical drivers of forest productivity stability. However, we found a strong climate dependency of the biodiversity-ecosystem stability relationship across the aridity gradient in Europe. Our findings suggest that plant diversity may also have a significant stabilizing in the more arid conditions evaluated. The results highlight that plant diversity should be promoted also under high aridity conditions to minimize variations in the temporal delivery of plant productivity.

We did not use ICOS data in this contribution, but we will present preliminary results using the whole set of ecosystem functions derived from flux observations and the perspectives offered by ICOS for studying the drivers of ecosystem functional stability.

152 Trace gases and air quality in North-Western Vietnam during seasonal biomass burning on the Indochina Peninsula since 2014 – Field Observations and Atmospheric Simulations
Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Biomass burning, including wildfires and agricultural burning, is a major source of atmospheric trace gases and aerosols that are often harmful for human and ecosystem health and may also alter the Earth's radiative balance. Here, we study the influence of biomass burning on the Indochinese Peninsula in Southeast Asia. There, the dry season from mid-December until mid-April leads to regularly recurring large-scale springtime biomass burning until the onset of the Asian summer south-west monsoon. Since 2014, trace gases (CO2, CH4, CO, O3) and aerosol optical properties are continuously monitored at the regional Global Atmosphere Watch (GAW) station Pha Din (PDI) in rural Northwestern Vietnam. PDI is located in a sparsely populated area on the top of a hill (1466 m a.s.l.). The station is well suited to study the large-scale fires on the Indochinese Peninsula, as plumes are frequently transported towards the site. Our analysis indicates that the annually recurrent large-scale biomass burning leads to CO mixing ratios at PDI of 1000 to 1500 ppb (hourly means) typically during February-May while mixing ratios well below 100 ppb are observed in particular in summer. In our conference contribution, we investigate the impact of biomass burning on the continuous trace gas observations at PDI. The observations are compared to modelled CO time series from an air mass back-trajectory analysis coupled to biomass burning emissions (Global Fire Assimilation System) and to a global reanalysis product of the Copernicus Atmospheric Monitoring Service.

Acknowledgements: SMP acknowledges funding from the Swiss National Science Foundation (P400P2_194390).

154 Legacy effects of the Central European 2018 hot drought cause Scots pine forest ecosystem to shift from carbon sink to source
Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

The Central European 2018 hot drought had severe impacts on many forest ecosystems, including a Scots pine (P. sylvestris) plantation at the DE-Har ecosystem site in the Upper Rhine Valley. The co-occurrence of unfavourable site-specific conditions with high air temperatures and dry conditions resulted in massive accelerated tree mortality at DE-Har. By 2019 about 23 %, by September 2020, about 47 % of all mature P. sylvestris trees (n = 368) were dead. Dead trees were mostly left in the tower source area with minimal forest management. The 2018 drought initiated a regime shift, where increased below-canopy light and water availability accelerated the growth of already existing understorey broadleaf trees. In this contribution, we assess how drought legacy effects, namely the massive P. sylvestris dieback and a vegetation shift to a understorey broadleaved forest ecosystem, affected carbon fluxes between 2019 and 2021. In 2019, the first year after the hot drought, the forest ecosystem was an annual net carbon source (+169 g C m–2 year–1), which is contrast to pre-drought eddy-covariance measurements that ranged between -200 and -600 g C m–2 year–1. Summer-season (JJA) uptake in 2019 was only about 40% of pre-drought years. In 2020, the forest ecosystem reached carbon neutrality and JJA uptake reached 70% of pre-drought years. The recovery is associated with a change in seasonality of carbon fluxes, due to the shift from evergreen to broadleaf trees, causing intensifying greening in the growing season, supported by NDVI from satellite and phenocam observations.

This work is supported by the Korea Agency for Infrastructure Technology Advancement(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 22UMRG-B158194-03).

203 How long can the carbon sink in old forests last?
Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

In order to assess how environmental changes affect the carbon cycle in mature and old-growth oak forests, we analysed the impacts of several climate scenarios and management alternatives (unmanaged, business-as-usual, bau, and adaptive) in 15 oak stands in France, where inventories can be traced back to 1927. The modelling experiment consisted in:

- reconstructing the historical growth trajectory of the 15 tree stands from 1927 to 2014 and analysing its climatic sensitivity;
- projecting the trajectory of the ecosystem until 2100.

Once calibrated against hourly values of flux data available in the Fluxnet and ICOS networks, the model reproduced satisfactorily the long-term growth history of the stands at all sites. The air vapour saturation deficit, shortwave diffuse fraction, incoming radiation and CO2 concentration were historically the most influential factors, with little interaction with soil fertility.

The projected trends for 2014-2100 are marked by drought events that have had only three historical equivalents in the past: 1976, 1989-90, 2003. From 2014 to 2070, several events or heat waves cause catastrophic tree mortality due to carbon starvation. Beyond 2070, such extremes occur every second year.

Our projections suggest that management can maintain old growth forests as a sink of carbon in the future. Indeed, the adaptive alternative reduced the exposition of forest trees to drought, as standing biomass and Leaf Area Index were reduced compared to the bau and unmanaged alternatives. The unmanaged and bau alternatives become a net source of CO2 beyond 2040 and 2070 respectively, while adaptive management maintain a net CO2 sink beyond 2100 (RCP 2.6).

268 The winner takes it all? Single tree growth response to explain forest CO2 uptake dynamics in the wake of drought events

Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

The resilience and adaptability of forests to extreme weather events is key in determining the extent to which these systems can maintain their function as natural net CO2 sink. Here we fuse long-term records of stand-level CO2 exchange obtained from eddy covariance measurements and single-tree growth increments from two deciduous forests located in central Germany, one being an unmanaged mixed beech stand and one a managed pure beech stand. The goal is to better understand the complex mosaic of tree mortality and recovery that underlies CO2 uptake dynamics in the years following a strong drought.
Indeed, at both study sites, the 2018 drought caused a significant decrease in net CO2 uptake of about 30% compared to the pre-drought reference period. However, the divergent development of the CO2 sink function in years after the drought suggests that different response strategies were at play: while CO2 uptake in the pure beech forest returned to pre-drought levels already in 2019, the CO2 uptake of the mixed forest continued to decline, and was 40% below reference levels in 2020. By examining a range of variables including site-characteristics, single-tree properties, and competition feedbacks, we seek to reveal factors that control growth trajectories of individual trees in the wake of droughts and orchestrate the evolving conversion processes at stand level.
With this work, we aim to advance the understanding of drought response mechanisms from the tree to the stand level and infer implications for shifts in forest composition and the CO2 uptake function under climate change.

282 Extreme events and power system resilience for U.S. states
Poster

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

In the context of climate change, quantification of the impact of frequent extreme events on power system is crucial to redesign the power system, which is also important to energy policy maker. In this study, we use ERA5 reanalysis dataset to quantify the impact of winter storm and heatwaves on U.S. carbon emissions and carbon intensity. We also quantify the impact of Covid-19 lockdown on U.S. carbon emissions and carbon intensity. We further checked the fossil fuel ratio change during extreme events. The results indicate that 1) During covid-19 lockdown, generally, the power system become clean. Carbon emissions have decreased in 39 U.S. states (-46.57%~-2.7%), carbon intensity have decreased in 38 U.S. states (-38.05%~-0.58%). 2) During winter storm and heatwaves, the power system become dirty. During heatwaves, carbon emissions and carbon intensity have increased in the affected U.S. states. 3) The impact of winter storm is more serious than heatwaves. During winter storm, carbon intensity and fossil fuel ratio have increased more than heatwaves period. 4) For different U.S. states, they have different strategy to increase natural gas or coal.

207 Methane emissions during winter period 2020 at Europe and Northern High Latitudes estimated by atmospheric inverse modeling and utilizing ICOS and satellite data
Poster

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Session G. Extreme Events : G.2 Effect of winter 2020 anthropogenic and climate anomalies on terrestrial, atmosphere, and ocean greenhouse gas exchange

Methane emissions in Europe and Northern High Latitudes were studied by applying data from Earth Observing (EO) satellites, in-situ measurements, and global atmospheric methane inversion model estimates. We examined the atmospheric observations from the northern ICOS sites and other networks to determine changes in methane concentration growth rates and performed atmospheric inverse model (CTE-CH4) simulations to quantify the emissions during the winter period 2020, as well as autumn and spring shoulder seasons. The investigations of Northern High Latitude methane (CH4) sources were extended to permafrost and non-permafrost regions, and their connections to environmental drivers such as seasonal soil freezing and thawing (F/T from SMOS satellite), inundated area (wetland extent), and climate drivers were examined. The results were interpreted using both anthropogenic and natural emissions solved by the model and studied by their possible anomalies, magnitude, seasonality, origin and distribution at Northern high latitudes.

Poster Session 6

18 Application of Machine learning techniques to simulate the evaporative fraction in corn crops

Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

The evaporative fraction (EF), represents an important biophysical parameter reflecting the distribution of surface available energy. In this study we investigated the daily and seasonal patterns of EF on a multi-year corn cultivation located in Southern Italy and evaluate the performance of different Machine Learning (ML) classes of algorithms to predict the EF at daily time step.
The adopted methodology consisted of 3 main steps that include (i) selection of the EF predictors (ii) comparison of the different classes of ML, (iii) application, cross-validation of the selected ML algorithms and comparison with the observed data.
Our results indicate that the Support Vector Machine (SVM) and the Gaussian Processes Regression were the best classes of ML at predicting the EF, with a total of 4 different algorithms: Cubic SVM, Medium Gaussian SVM, the Matern 5/2 GPR and the Rational quadratic GPR. The comparison between observed and predicted EF in all 4 algorithms, during the training phase, were within the 95% confidence interval: the r2 value between observed and predicted EF was 0.76 (RMSE 0.05) for the Medium Gaussian SVM , 0.99 (RMSE 0.01) for the Rational Quadratic GPR, 0.94 (RMSE 0.02) for the Mater 5/2 GPR, and 0.83 (RMSE 0.05) for the Cubic SVM algorithms. Similar results were obtained during the testing phase.
The results of the cross-validation analysis indicate that the r2 values obtained between all iterations for each of the 4 adopted ML algorithms were basically constant, confirming the ability of ML as a tool to predict EF.

27 A new ICOS Class 1 station at CNR-IMAA: a promising hub for the synergistic investigation of greenhouse gases and atmospheric aerosol

Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

At the Istituto di Metodologie per l'Analisi Ambientale of the Italian National Research Council (CNR-IMAA) is currently in progress the implementation of an ICOS-compliant Class 1 atmosphere station, forecasted to be operative within the end of 2022.

The station will be located in Tito Scalo (Southern Italy, 40.60° N, 15.72° E, 760 m asl), in a plain surrounded by low mountains (below 1100 m asl), less than 150 km from the West, South and East coasts. It is characterised by a typical mountain weather strongly influenced by Mediterranean

atmospheric circulation, resulting in generally dry, hot summers and cold winters. Due to its location, the site represents a novelty in the ICOS atmosphere network, being the Class 1 station at the lowest latitude and the first in the Mediterranean basin.
Moreover, the new station will be established in proximity of the operative ACTRIS site at CNR-IMAA for aerosol in-situ, and aerosol, clouds and trace gases remote sensing measurements, which will enable the remarkable opportunity of synergistic investigation of GHGs and atmospheric aerosol. In fact, the level of GHGs in the atmosphere including that of carbon dioxide isotopologue 14CO2 – used as a fossil fuel tracer – is expected to correlate with the particulate fingerprint, thus providing a comprehensive set of data to characterise both natural and anthropogenic pollution sources and to study their evolution.

ACKNOWLEDGMENTS
This work was supported by MUR (Italian Ministry of University) PON Ricerca e Innovazione 2014-2020 – ICOS PRO MED, CIR01_PRO-ICOS_MED and CIR01_00015 - PER-ACTRIS-IT.

66 Sampling system and measurements of CO2, CH4 and CO in the tall tower of El Arenosillo observatory (Southwestern Europe).
Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

At El Arenosillo observatory located in the southwestern Europe (37.1 N, 6.7 W, 42 m above ground level) is a protected and rural-background environment in the Doñana Natural Park and close to the coastline of the Atlantic Ocean (1 km), surrounded by a pines forest. Although the measurements on surface of carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), began in September 2019, in November 2021 the instrument was installed on a tall tower of 100 m height. The measurements are collecting in three levels at 10, 50 and 96 m using an instrument based on CDRS (Cavity Ring-Down Spectroscopy) technique (Picarro GC2401). The sampling system was designed according to the technical specifications of ICOS (Integrated Carbon Observation System) with three sampling lines at 100 m level and two at 10 and 50 m, pumps for each line, air cleaning using filters of 60, 7 and 2 µm (Swagelok filters), as well as drying system (Nafion). A flowmeter is used to monitor air flow in the lines and a pressure sensor is used to monitor sampling line pressures. Three standard tanks with a mix of gases (following the ICOS specifications) are used to calibrate with a frequency of ~4 weeks. In addition, the tall tower disposes of meteorological sensors. The pre-processing and the preliminary data will be shown. Currently, El Arenosillo station is in the labelling process of ICOS to be an atmospheric station of class two.

70 Carbon monoxide measurements at El Arenosillo Observatory.
Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

At El Arenosillo station, located in a protected rural-background area (37.1 N, 6.7 W, 42 m asl) of the Southwestern of Spain, the trends of the carbon monoxide (CO) for both emissions and levels were investigated. The Copernicus global emission inventory and AIRS (Atmospheric Infrared Sounder) observations in the period 2002-2020 were used. A downward trends of 12 ± 3 ppb decade-1 and 93 ± 6 g km-2 h-1 decade-1, were obtained for surface levels and emissions respectively. Moreover, CO was measured on surface using an instrument based on CDRS (Cavity Ring-Down Spectroscopy) technique (Picarro GC2401). In this work, the period since September 2019 to April 2021 was used. CO showed a monthly temporal evolution with high levels (~140 ppb) in the coldest months and lowest in the warmest (~100 ppb) as well as a daily variation with different levels according to the season. The weather scenarios play a strong role in the CO, the behavior patterns were identified and analysed in detail. The increase of CO was observed under conditions governed by the mesoscale processes and with the CO regional-range transported from polluted urban areas while lowest CO were recorded with maritime-clean air masses from the Atlantic Ocean. Finally, the CO was investigated under the arrival of a plume coming from a forest fire.

76 Smart Bay Santa Teresa (Eastern Ligurian Sea), a new observatory for carbon cycle related parameters

Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

Costal areas are heavily affected by direct and indirect anthropogenic impacts such as increase of air and sea water pollution due to urbanization, sea level rise, warming, ocean hypoxia and acidification, flooding, extreme events (i.e., heat-waves). Thus, there is the urgent need to implement data acquisition in coastal areas (i.e., big data with high resolution) to monitor the ongoing processes especially those related to carbon cycle where coastal calcifying ecosystems play an important role. In this framework SMART BAY Santa Teresa, cooperation platform among research institutes, SMEs and municipalities, developed an observatory in the Gulf of La Spezia (Eastern Ligurian Sea, Italy) aiming to acquire high resolution oceanographic data. To fully understand the relationships between on-going physico-chemical processes and the functioning of these ecosystems SMART BAY extensive marine observation system is carried out in three sites in the Gulf: (i) Santa Teresa bay, (ii) port of La Spezia, outside the dam, and (iii) Tinetto island, Marine Regional park of Porto Venere, out of the Gulf. The chemical and physical parameters (temperature, salinity, conductivity, dissolved O2, total alkalinity, carbonate, pH, fluorescence, selected metals, chlorophyll-a) are measured continuously and/or

discontinuously once time in a week (site i) or in a month (sites i and ii). Here the variations of the carbon dioxide system is presented, from March 2021 to July 2022 aiming to evaluate the influence of rain inputs and other environmental drivers, such as temperature, and biological processes, related to calcifying marine ecosystems (site i), on the carbonate system.

113 In-situ continuous CO2 measurement in an industrial Port-de-Bouc station (south-eastern France) and related anthropogenic tracers.
Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

The PACA (Provence-Alpes-Côte d'Azur) region (south-eastern France) has the objective of being carbon neutral by 2050. For this purpose, it is crucial to reduce uncertainties of CO2 emissions in this region. Despite the fact that the industrial sector represents 52% of CO2 emission in the Bouches-du-Rhone department (regional air quality agency ATMOSUD inventory, 2017), there was no measurement of CO2 in this area. To fill this lack of information, we have been continuously measuring the concentrations of CO2, CO and CH4 with a PICARRO G2401 CRDS analyser, to investigate the CO2 emissions from different wind sectors since June 3rd 2021 in the Port-de-Bouc station (43°24'7.056"N; 4°58'55.459"E) which is surrounded by petrochemical industries. A 14C and VOCs measurement campaign was also performed from July 21st to August 8th, 2021 using 28 flasks and 10 canisters respectively to separate CO2 emitted from fossil fuel and from biogenic sources. These data which will be presented, represent the first measurements in this industrial area and they will also be used to assess the accuracy of the regional emission inventories.

251 Is the Mediterranean biogeochemical functioning susceptible to climate change?
Poster

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

Ocean takes up heat and carbon, reducing the adverse effects of climate change, not without a cost: the ocean is warming, acidifying and losing oxygen vital to life, whilst circulation patterns are changing, and the rate of sea level rise is increasing. Similar to worldwide changes and trends, observations of several variables during the last decades provide evidence that Mediterranean waters have become warmer and saltier, the circulation pattern of the deep and intermediate layers have been altered, sea level has risen at a rate similar to the global trend at centennial scale, whilst Mediterranean Sea waters

have already encountered a decrease in pH since the preindustrial era. Future regional projections suggest that seawater warming will continue at a rate depending on the specific anthropogenic emissions scenario. Marine heat waves will become longer, more intense than today and their spatial extent will increase, while seawater acidification will continue, with a pH reduction that might be larger than 0.4 pH units at the end of the 21st century with deleterious effects on the Mediterranean ecosystems. There is strong evidence that atmosphere-driven variations of the marine environment are able to control carbon fixation, export, and transfer to oligotrophic Mediterranean abyssal plains, i.e., extreme atmospheric forcing may influence the strength and efficiency of the biological pump. CO2-driven climate fluctuations affect the response of marine biogeochemical cycles and impact the Mediterranean ecosystems properties, functions and services, while the risks and vulnerabilities become more threatening when coexist with other anthropogenic stressors, especially in coastal waters.

52 First results from the London Ground-based Column Network
Poster

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Session E. Monitoring, validation and verification : E.3 Ground-based remote sensing measurements of greenhouse gases and their application for carbon cycle studies, satellite and model validation and building MVS capacity

Cities are contributing most of the global carbon emissions and are the focal point of many political decisions on mitigation of carbon emissions, often setting more ambitious targets than national governments. If we want to devise informed mitigation policies, we need a better understanding of urban carbon budget and their diverse emission sources, underpinned by new approaches for verification of city emissions trends. New satellite observations from missions such as OCO-3 and TROPOMI and upcoming missions like MicroCarb and CO2M provide a powerful capability for evaluating and eventually improving city emission inventories.

To critically assess the quality of satellite observations over urban environments, we need to establish urban networks of ground-based instruments. In conjunction with satellite observations, data from such networks will also contribute towards data-driven emission estimates using a measurement-modelling framework. We have set up a new ground-based measurement network comprising three sites located across the city of London using portable greenhouse gas column sensors (Bruker EM27/SUN spectrometers). In addition, each site has a co-located UV/VIS MAX-DOAS spectrometer and an AERONET sensor for NO2 (tracer for fossil fuel combustion) and aerosols (key parameter for the accuracy of satellite retrievals). Additional background observations are available from a TCCON site at Harwell (west of London) and a EM27/SUN sensor at Rothamsted (north of London).
In this presentation we will present the London greenhouse gas column network and we will show and discuss findings from our first year of greenhouse gas column observations over London and their comparisons to satellite observations.

116 Ground-based remote sensing measurements of greenhouse gases at Sodankylä, Finland
Poster

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Session E. Monitoring, validation and verification : E.3 Ground-based remote sensing measurements of greenhouse gases and their application for carbon cycle studies, satellite and model validation and building MVS capacity

Ground based remote sensing measurements are essential for calibration and validation of satellite borne retrievals. At Sodankylä (67.4° N, 26.6° E) we have performed ground-based remote sensing measurements of greenhouse gases since early 2009, using a high-resolution Fourier Transform Spectrometer. Sodankylä site participates in the Total Carbon Column Observing Network (TCCON). At the TCCON sites column-averaged dry air mole fractions of CO2, CH4, N2O, HF, CO, H2O and HDO are derived based on measurements of spectra of the sun in the near-infrared spectral region. Here we present long term greenhouse gas measurements and comparisons with the collocated satellite borne observations. At the Sodankylä remote sensing site we have also performed frequent balloon borne AirCore measurements. AirCore method provides accurate profiles of greenhouse gases from surface up to the lower stratosphere, thus extending profile information above aircraft flight altitudes. We have complemented the balloon borne AirCore profiles by drone based and in situ tower measurements. Finally, we have used AirCore observations to study accuracy of the remote sensing retrievals.

124 Remote sensing measurements of greenhouse gases to support monitoring and verification support (MVS) capacity building

Poster

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Session E. Monitoring, validation and verification : E.3 Ground-based remote sensing measurements of greenhouse gases and their application for carbon cycle studies, satellite and model validation and building MVS capacity

The concentration of major greenhouse gases (GHGs) in the atmosphere is steadily increasing mainly due to emissions from anthropogenic activities. To prevent further increase, the signatory countries of the Paris agreement have pledged to reduce their carbon emissions and become carbon neutral. GHG emissions and their evolution over time need to be monitored, which makes a monitoring and verification support (MVS) capacity necessary. Such MVS will support policy and decision making on global, regional, and local scales. The European Commission advocates for an anthropogenic CO2 MVS capacity, requiring efforts at national levels and on a global scale. Building up a MVS capacity requires multiple data streams of satellite and in-situ measurements. The ground-based solar absorption remote sensing measurements of GHGs constitute one such in-situ measurement system contributing towards the MVS capacity. The partial and/or total column GHG data from ground-based remote

sensing monitoring networks have been extensively used for calibration and validation of satellite measurements and models, as well as in data assimilation exercises, and evaluation of the output generated by the MVS capacity.
In this presentation, we will show the status and latest advancements of the remote sensing measuring networks and some examples of how they support the MVS capacity. Furthermore, new instruments and products which are being developed as part of the ESA funded FRM4GHG (Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations) projects will be shown. An overview of the perspectives of such new systems' contribution towards building MVS capacity will be given.

Wednesday, 14th September, 2022

Plenary Presentations

167 Direct observations of CO2 emission reductions due to COVID-19 lockdown and their subsequent evolutions.
Plenary

Giacomo Nicolini[1,2], Gabriele Antoniella[3], Federico Carotenuto[4], Andreas Christen[5], Philippe Ciais[6], Christian Feigenwinter[7], Beniamino Gioli[4], Stavros Stagakis[7], Erik Velasco[8], Roland Vogt[7], Helen C. Ward[9], Janet Barlow[10], Nektarios Chrysoulakis[11], Pierpaolo Duce[12], Martin Graus[9], Carole Helfter[13], Bert Heusinkveld[14], Leena Järvi[15], Thomas Karl[9], Serena Marras[16], Valéry Masson[17], Bradley Matthews[18], Fred Meier[19], Eiko Nemitz[13], Simone Sabbatini[20], Dieter Scherer[19], Helmut Schume[18], Costantino Sirca[16], Gert-Jan Steeneveld[14], Carolina Vagnoli[4], Yilong Wang[21], Alessandro Zaldei[4], Bo Zheng[22], Dario Papale[2,1]

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The measures taken to contain the spread of COVID-19 in 2020 included restrictions of people's mobility and reductions in economic activities. These drastic changes in daily life, enforced through national lockdowns, led to abrupt reductions of anthropogenic CO2 emissions in urbanized areas all over the world. To examine the effect of social restrictions on local emissions of CO2, we analysed district level CO2 fluxes measured by the eddy-covariance technique from some European cities. The data span several years before the pandemic until September 2022. All sites showed a reduction in CO2 emissions during the national lockdowns. The magnitude of these reductions varies in time and space, from city to city as well as between different areas of the same city. We found that, during the first lockdowns, urban CO2 emissions were cut with respect to the same period in previous years by 5% to 87% across the analysed districts, mainly as a result of limitations on mobility. However, as the restrictions were lifted in the following months, emissions quickly rebounded to their pre-COVID levels in the majority of sites

50 Towards an International standard for Urban Greenhouse Gas Monitoring and Assessment
Plenary

Jocelyn Turnbull[1,2], Felix Vogel[3], Kim Mueller[4], Phil DeCola[5]

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The WMO sponsored Integrated Global Greenhouse Gas Information System (IG3IS) aims to further efforts to link activity-based emissions information with atmospheric observations and modelling of greenhouse gasses. Together these provide the best possible estimates of greenhouse gas emissions. A critical component of IG3IS is to establish two-way linkages between scientific practitioners and stakeholders in the policy realm, tailoring the research actions to meet policy needs.

Urban areas are of special interest, as the majority of human-produced greenhouse gasses are emitted from cities, and mitigation policies are often driven by city and local governments. Urban emissions are less well quantified than at the national scale, and detailed information about source sectors and temporal changes, as well as whole-city emissions, are essential to support policy actions.

IG3IS has recently developed the Urban Greenhouse Gas Emission Observation and Monitoring Best Research Practices document, publicly released in June 2022. This document is authored by more than 50 researchers from across academia, national and international research organizations representing a range of countries and cities with expertise in urban greenhouse gas emissions research. These guidelines are primarily intended to provide the current best practices to assist stakeholders as well as practitioners to evaluate the quality of planned and existing GHG mitigation projects. A secondary goal is to publish state-of-the-art methodologies, recommendations for application of these methodologies, as well as known challenges and limitations. The guidelines are intended to be updated every two years, and are the first step towards documentary standards in this emerging research field.

281 New constraints on photosynthesis from atmospheric tracers (δ18O, Δ17O, Δ47, COS, O2) and remote sensing proxies (SIF, NIRv)

Plenary

Gerbrand Koren[1], Getachew A. Adnew[2], Hugo J. de Boer[1], K. Folkert Boersma[3,4], Ara Cho[3], Stefan C. Dekker[1], Kim A. P. Faassen[3], Linda M. J. Kooijmans[3], Maarten C. Krol[3,2], Ingrid T. Luijkx[3], Wouter Peters[3,5], Karin T. Rebel[1], Thomas Röckmann[2]

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Many approaches exist to study the Net Ecosystem Exchange (NEE) of CO2. While eddy-covariance measurements inform about CO2 exchange on the field scale, inverse modeling approaches using atmospheric CO2 measurements inform about NEE on larger scales. Quantification of NEE is valuable because it expresses how much of the current fossil fuel CO2 emissions are compensated by the biosphere. However, to project current NEE estimates further in time, a better understanding of the underlying processes in vegetation is required. One of the key processes is Gross Primary Production (GPP, the photosynthetic uptake of CO2), which has considerable uncertainty, as reflected by current estimates for global GPP that range from 120 to 175 PgC/yr. To understand how GPP will respond to the changing climate, we need methods that can estimate GPP more accurately. Several methods have been proposed for this, including the remote sensing-based proxies Sun-Induced Fluorescence (SIF)

and Near-Infrared Reflectance from Vegetation (NIRv) that can provide detailed spatial information over large areas. Furthermore, tracer-based methods, such as the isotopic composition of CO_2 ($\delta^{18}O$, $\Delta^{17}O$ and Δ^{47}), carbonyl sulfide (COS) and O_2 can provide a more integrated signal over the footprint area for GPP. Here we report on progress on the use and integration of these methods, including a reflection on the remaining challenges.

Parallel Session 7

165 Novel quantification of regional fossil fuel CO2 reductions during COVID-19 lockdowns using atmospheric oxygen measurements

Oral

Penelope Pickers[1], Andrew Manning[1], Corinne Le Quere[1], Grant Forster[1,2], Ingrid Luijkx[3], Christoph Gerbig[4], Leigh Fleming[1], William Sturges[1]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

It is not currently possible to quantify regional-scale fossil fuel carbon dioxide (ffCO2) emissions with high accuracy in near real-time. Existing ground-based atmospheric methods for separating ffCO2 from large natural CO2 variations are constrained by sampling limitations, while bottom-up inventory-based methods typically lag real-time by one or two years.

We present a ground-based measurement approach for quantifying the regional ffCO2 component of the atmospheric CO2 mole fraction using atmospheric measurements of O2 and CO2 combined into the tracer 'Atmospheric Potential Oxygen' (APO). We demonstrate the potential of APO as a ffCO2 tracer by detecting and quantifying COVID-19 ffCO2 reductions in the atmosphere associated with the first two waves of the pandemic in the UK, using continuous data from the Weybourne Atmospheric Observatory (see presentation by Adcock et al.) and a machine learning algorithm.

Since our APO data are continuous and calibrated in-situ, our approach is cost-effective and provides high frequency (e.g., hourly) information, making it feasible to generate time series of ffCO2 and bioCO2 with orders of magnitude greater temporal resolution than ever before, and to quantify both ffCO2 and bioCO2 in the atmosphere in near real-time. Our APO-based assessment does not quantify absolute emissions, but, with the use of machine learning, we are able to quantify relative changes in emissions. We find good agreement between our APO-based estimate and the spread of ffCO2 reductions determined from three independent bottom-up methods for the United Kingdom. Recent developments in modelling APO in the UK are presented separately by Chawner and colleagues.

21 The impact of the COVID-19 lockdown on CO2 and NO2 concentrations over Rotterdam using observations and a machine learning model

Oral

Pieter Rijsdijk[1], Ingrid Super[1], Hugo Denier van der Gon[1], Arnoud Frumau[1], Marcel Moerman[1], Sander Houweling[2], Sef van den Elshout[3], Saskia Willers[3], Linh Nguyen[4]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

In the first months of 2020 the Dutch government implemented lockdown measures to limit the spread of the SARS-CoV-2 coronavirus. Because of this, many activities were limited or ceased entirely. As a consequence, anthropogenic emissions of air pollutants and greenhouse gasses suddenly decreased. This unwanted situation makes for an ideal opportunity to test the ability of the Ruisdael Rotterdam atmospheric measurement network to detect emissions changes. Understanding the networks ability to detect such changes is crucial for monitoring the effect of policy measures taken to improve air quality and combat climate change. We examine the effect of the lockdown on NO2, CO2 and CO concentrations in Rotterdam and surroundings, using data from the DCMR and national air quality monitoring network and Ruisdael stations Cabauw, Westmaas and Zweth. Two distinct approaches are taken. Firstly, the lockdown period is compared to measurements of previous years during the same period. Secondly, a business as usual scenario is predicted by a gradient boosting decision tree (machine learning) model, which is compared to observations during the lockdown (March 16 – May 1st). The main advantage of the latter approach is that it takes into account variations due to meteorology between years. To improve both analyses the data were pre-processed by detrending the data, calculating enhancement above background and filtering based on time of day. We will discuss the results of detrending, the presence of the lockdown effect especially in the NO2 and CO2 measurements, and importance of co-located measurements and data quality.

131 Applications of eddy covariance flux measurements in quantifying whole-city urban GHG emissions

Oral

Kenneth Davis[1], Natasha Miles[1], Scott Richardson[1], Alex Zhang[1], Samantha Murphy[1], Jason Horne[1], Claire Jin[2], Kai Wu[3], Sharon Gourdji[4], Kevin Gurney[5], Geoffrey Roest[5], Jocelyn Turnbull[6]

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E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Urban greenhouse gas emissions quantification has relied primarily upon atmospheric inversions and a variety of inventory approaches. Eddy covariance provides a valuable complement to these approaches. We present three applications of eddy covariance flux measurements to improving our quantification of anthropogenic GHG emissions from the city of Indianapolis, USA, as part of the Indianapolis Flux Experiment (INFLUX), the longest-running NIST urban testbed site. Turf grass is a common vegetation cover in urban environments. The phenology of turf grass differs considerably from most of the crops and forests surrounding Indianapolis. We quantify the impact of turf grass on CO2 fluxes within the city of Indianapolis and test our ability to use remote sensing of urban vegetation to separate this biological flux from the anthropogenic fluxes we are trying to isolate using atmospheric inversions. Biological fluxes from outside the city also confound our ability to isolate anthropogenic CO2 emissions by complicating the quantification of background conditions. We employ eddy covariance flux towers and multiple background mole fraction towers to evaluate the accuracy of our determination of the Indianapolis CO2 background conditions. Finally, eddy covariance presents an excellent tool for evaluation of high-resolution emissions inventories. We test the accuracy and precision of emissions inventories vs. eddy covariance measurements merged with CO/CO2ff ratios to decompose the fluxes into anthropogenic and biogenic components. We illustrate in each case how these results can be applied to improved city-scale atmospheric inversions.

138 Developing First High-resolution Anthropogenic Carbon Emission Inventory for Seoul
Oral

Yeonsoo Kim, Sujong Jeong

Seoul National University, Seoul, Korea, Republic of

Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Carbon dioxide emissions from fossil fuels, known as FFCO2, is the most significant driver of the ongoing climate change. Given that cities are responsible for more than 70% of the global carbon emissions, it has become an important issue for cities to make science-based strategies in managing urban FFCO2 emissions. To this end, it is necessary to understand spatial and temporal patterns of FFCO2 emission across urban areas. In this study, we established a high-resolution FFCO2 emission inventory which quantifies the emissions at an 1km2 and an hourly basis for 2017~2020 period for Seoul, the capital of South Korea. We used data on fossil fuel usage, traffic speed and volume, aircraft operation as activity data and applied emission estimating methods of the highest tier applicable. For some activity data that were provided at aggregated spatial(national) or temporal(annual) scales, we distributed the data to 1km2/hour scale by utilizing proxies or by applying machine learning techniques. Estimated emissions of FFCO2 emissions were greater than the ones reported by the Seoul Metropolitan Government and showed how emission patterns vary across time and space within the city. The result of this study can serve as the basis for policy makers in taking actions for effective reductions on FFCO2 emissions.

Parallel Session 8

166 Siberian 2020 heatwave increased spring CO2 uptake but not annual CO2 uptake

Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Siberia experienced an unprecedented strong and persistent heatwave in winter to spring of 2020. Using bottom–up and top–down approaches, we evaluated seasonal and annual CO2 fluxes of 2020 in the northern hemisphere (north of 30 ◦N), focusing on Siberia where the pronounced heatwave occurred. We found that, over Siberia, CO2 respiration loss in response to the pronounced positive winter temperature anomaly was greater than in previous years. However, continued warming in the spring enhanced photosynthetic CO2 uptake, resulting in the largest seasonal transition in net ecosystem CO2 exchange; that is, the largest magnitude of the switch from the net CO2 loss in winter to net CO2 uptake in spring until June. However, this exceptional transition was followed by the largest reduction in CO2 uptake in late summer due to multiple environmental constraints, including a soil moisture deficit. Despite a substantial increase of CO2 uptake by 22 ± 9 gC m−2 in the spring in response to the heatwave, the mean annual CO2 uptake over Siberia was slightly lower (3 ± 13 gC m−2 yr−1) than the average of the previous five years. These results highlight the highly dynamic response of seasonal carbon fluxes to extreme temperature anomalies at high latitudes, indicating a seasonal compensation between abnormal uptake and release of CO2 in response to extreme warmth that may limit carbon sink capacity in high northern latitudes.

129 The carbon cost of critical heat days at a subalpine coniferous forest in Switzerland

Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Over a period of seven days in June 2019, the subalpine, coniferous forest at the ICOS Class 1 Station Davos (CH-Dav) experienced record-high vapor pressure deficits (3.22 kPa) and air temperatures (28.7 °C). During such extreme conditions, the ecosystem abruptly changed from a strong carbon sink to a carbon source. We quantified the impact of these extreme conditions on net CO2 ecosystem fluxes by calculating the “carbon cost”, a measure describing the amount of potential CO2 uptake lost compared to normal conditions. Analyses of a 24-year long (1997-2020) eddy covariance dataset revealed that such extreme conditions became more frequent in recent years, carbon cost increased exponentially

with hours of critical heat, and that just a few hours per year were sufficient to impact the annual carbon budget significantly.

98 Windthrow turns a former old spruce forest into a net CO2 source for 11 years
Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

As a consequence of more frequent climate extremes (drought, windthrow, beetle infestation), an increase in badly damaged forests is expected to lead to a loss of C sinks and additional C sources in affected areas for several years. To quantify the related C budgets against the background of a typical forest C sink, direct flux measurements (EC) are an opportunity for observations at high temporal resolution.
Parallel monitoring of carbon (CO2) fluxes of a managed old spruce forest (class 1 site DE-Tha) and a young mixed oak forest after a larger windthrow in the beginning of 2007 (formerly old spruce forest, associated candidate site DE-Hzd) in East Germany (distance of 5 km) have been implemented in 2010. These flux data reveal the duration and amount of C loss at the disturbed site as well as the difference in C sinks after returning of DE-Hzd to a moderate C sink.
The mean net CO2 sink (NEP) of the old forest was 16.3 tCO2 ha-1 a-1 (2010 – 2021) whereas the young forest was a net CO2 source of 13.2 tCO2 ha-1 a-1 (2010 – 2017) switched to a net CO2 sink of 3.3 tCO2 ha-1 a-1 (2018 – 2021). The cumulative missing C sink of the disturbed site (referenced to the old spruce forest sink) for the 12-year period (2010 – 2021) amounts to 288 tCO2 ha-1 (24 tCO2 ha-1 a-1).

71 Impacts of fire severity and post-fire management practices on carbon fluxes in a Swedish boreal forest
Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Field datasets covering the impacts of wildfire on Eurasian boreal forests are rare, despite predictions of increasing fire severity and frequency. We address this gap by investigating the effects of wildfire severity and post-fire forest management practices on the carbon fluxes of Pinus sylvestris forests burnt by the Ljusdal fire (central Sweden), the largest fire during the extreme 2018 wildfire season.

Our chamber measurements showed that soil respiration was reduced after fire, with a more pronounced reduction after high severity compared to low severity fire. Fire severity and associated

tree mortality or survival also determined the effect of salvage-logging on soil respiration. Only salvage-logging of living trees after low severity fire led to a significant reduction of respiration, whereas logging of dead trees after high severity fire had no effect. Soil methane uptake was not affected by fire severity or salvage-logging.

Eddy covariance towers were also installed at two sites: a mature forest affected by low severity fire then salvage-logging and a young forest affected by high severity fire where pine seedlings were replanted. Both sites were net CO2 sources during the first three post-fire years. Rough estimates suggest that total carbon loss during the first three post-fire years at these sites is similar or greater than the carbon loss during the fire itself.

These results highlight the importance of accounting for post-fire carbon fluxes and may serve as a calibration dataset for modellers predicting the impacts of increasing fire frequency on the carbon balance in Eurasian boreal forests.

53 Partitioning photosynthesis limitations of a potato crop during drought
Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Over the past years, researchers have focused on identifying the physiological processes that restrict the net photosynthetic rate and quantifying the importance of each limiting factor. However, the constraints on photosynthesis originating from perturbations in the CO2 pathways from sub-stomatal cavities to carboxylation sites are still not fully understood, especially in crops. The aim of our study was to investigate the impact of drought on the light-limited photosynthesis rate of potato (Solanum Tubersosum) by quantifying the different photosynthesis limitations during a field-experiment. Gas-exchange and fluorescence techniques were used to measure the net assimilation rate under high irradiance (Asat), the mesophyll conductance (gm), the stomatal conductance (gs), the maximum carboxylation rate of Rubisco (Vcmax) and electron transport rate (Jmax) in response to low relative extractable water (REW) during the tuber development stage. All the variables decreased when REW passed below a threshold ranging from 0.5 to 0.7. On the opposite, the slope parameter in the stomatal optimization model (USO) increased when drought was at its maximum intensity and suggests that potato plants maintained a high transpiration rate during photosynthesis limitations induced by drought. We performed two limitation analyses identifying which factor contributed the most to the decrease of Asat: one with the USO parametrization of gs and the other with gs, gm and Vcmax. Both findings showed that the mesophyll limitation was predominant and accounted for more than 75 % of the decrease of Asat. This highlights the importance of non-stomatal limitations on potato photosynthesis during water stress.

77 Inter-annual variations in Siberian carbon release and uptake period.
Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Respiration is one of the key processes during the winter that are responsible for the variations in atmospheric CO2. Winters with higher temperatures are expected to increase microbial and plant activity, enhancing the respiratory release of CO2 and thereby weakening the annual net terrestrial carbon sink. If warm winters occur at an increasing rate as predicted by climate models, the increase in winter respiration could counterbalance the effects of an earlier start and prolonged growing season carbon uptake, thus potentially shifting northern hemisphere ecosystems from net carbon sinks to net carbon sources. Here we use the detrended 2010-2021 record of atmospheric CO2 from the Zotino Tall Tower Observatory (ZOTTO) located at 60◦48' N, 89◦21' to analyse inter-annual changes in the timing and intensity of the carbon uptake and release periods (CUP, CRP, respectively) over central Siberia. We complement our analysis with co-located eddy-covariance measurements, and the results of atmospheric inversions to disentangle the meteorological variability from ecosystem responses to climate variations. We find the CRP length and amplitude indeed increased for the last decade. This increase indicates accelerating net CO2 release. The CUP length and amplitude also showed positive trend since 2010. However, this trend is not as strong as those of the CRP, suggesting that enhanced net CO2 release during cold months cancelled out the lower trend uptake during later season. Our current results could demonstrate that a warming climate does not necessarily lead to higher CO2 uptake, even in high-latitude ecosystems considered to be temperature-limited.

Acknowledgement

This work would not have been possible without the sustained efforts of our colleague Alexey Panov (V.N. Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russian Federation).

Parallel Session 9

263 Greenhouse Gas Emission Reduction Potential through Peatland Rewetting

Oral

Aram Kalhori[1], Torsten Sachs[1], Christian Wille[1], Pia Gottschalk[1], Zhan Li[2], Joshua Hashemi[3]

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Drained peatlands are a significant source of greenhouse gas (GHG) emissions to the atmosphere. Rewetting peatlands is considered as one of the major natural climate solutions to curb these emissions and enhance terrestrial carbon sink capacity. While there is insufficient research on the effect of external pressures in temperate peatlands, drought conditions generally decrease soil moisture and lower water tables, resulting in thicker aerobic layers and thus increased potential for aerobic respiration. Here, we investigate the spatio-temporal patterns of annual carbon dioxide (CO2) and methane (CH4) fluxes in a peatland ecosystem in northeastern Germany. Rewetting occurred in winter 2004-2005 and a long-term year-round flux dataset of eddy covariance measurements is obtained (fall 2007-spring 2009 & 2013-2020 year-round). Despite the inter-annual variability, we conclude that rewetting shows a considerable contribution to CO2 emission reduction after 16 years of rewetting (-0.3 t CO2-C ha-1 yr-1). The site transitioned into a consistent growing season CO2 sink around the year 2017 (triggered by the first drought event) and reached a peak sequestration of ~800 g CO2-C m-2 during the vegetation period in summer 2020. Regardless of the drought effects, this follows post-rewetting successional vegetation dynamics, increasing gross primary productivity of these ecosystems and causing the observed source to sink transition. While this site is a large CH4 source during the initial phase, a decreased rate of emissions was observed following drought conditions (-44 kg CH4 ha-1 yr-1). The study is highlighting the need for dissemination of long-term in-situ data following rewetting at ecosystem scale.

185 Belowground Methane Turnover at a Boreal Peatland: Quantifying the Processes with in-situ Stable Isotope Methods

Oral

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Boreal peatlands emit substantial amount of CH4, a potent greenhouse gas, to the atmosphere. Despite decades of effort made on studying CH4 efflux to the atmosphere, quantifying the processes underlying CH4 emission such as the different pathways of production and oxidation remains a challenge in peatland CH 4 modeling. To this end, we conducted a first systematic study with C stable isotopes quantifying in-situ major CH4 turnover processes along a peat profile with high temporal resolution in a typical boreal peatland (Siikaneva fen) in Southern Finland.
A cavity ring-down spectrometer is utilized to capture the dynamics of belowground dissolved CH4 and CO2 concentrations and their δ13C natural abundance signatures at 10, 30 and 50cm belowground. This novel approach continuously monitors the real-time CH4 turnover processes of the

steady-state conditions along a vertical profile. Additionally, comprehensive 13C pulse labelling experiments targeting acetoclastic methanogenesis, hydrogenotrophic methanogenesis and methanotrophy were for the first time performed in-situ to trace all these processes which cannot be separated by the isotope natural abundance approach alone. Besides, we also analyzed the background microbial communities related to methanogenesis and methanotrophy both in the field and lab.
Preliminary results indicated a successful implementation of these novel methods. Unprecedented dataset for the optimization and validation of mechanistic CH4 models have been produced and that our project has potential to profoundly renew our knowledge on belowground CH4 dynamics especially in the less-studied winter and shoulder seasons.

122 Satellite CO observations for catastrophic boreal forest fires in 2021: implications for CO2 and CH4.
Oral

Leonid Yurganov

UMBC, Baltimore, USA

Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Carbon monoxide total atmospheric column retrieved from Atmospheric Infrared Sounder (AIRS) since 2002 were analyzed. Validation were provided by comparisons with TCCON accurate spectroscopic ground-based measurements. The data were corrected for a reduced sensitivity to the lower troposphere. Monthly emission rates for a reservoir between 30° N and the North Pole were calculated using a two-box model. The data were found to agree with independent bottom-up GFED4 CO monthly emissions. Both data sets register a positive long-term trend and a record high CO emission in 2021. GFED4 CO2 and CH4 also were record high. CH4 column yearly increment in 2021, measured by AIRS, corresponds to high CH4 fire emission reported by GFED4. The growing forest fires challenge a hope to counterbalance anthropogenic CO2 emission in the northern boreal area. The pyrogenic CH4 appears to be responsible for methane spike in 2021.

144 Using Soil Moisture to Improve Ecosystem Respiration Partitioning Algorithm from Eddy Covariance Flux Networks
Oral

Ngoc Nguyen

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

Nature has long played a crucial role in mitigating anthropogenic-emitted CO2 emission, with the terrestrial ecosystems sequestering roughly 30% of total anthropogenic CO2 from 1850-2020, through increased carbon storage in vegetation and soils. Vegetation fixes CO2 throughout photosynthesis, while it also releases CO2 as a by-product of metabolic respiration processes. Knowing how much CO2

that vegetation respires and how respiration is likely to change in the future is therefore necessary to understand the true potential of vegetation to sequester carbon. Nevertheless, ecosystem respiration (Reco) and its flux components from autotrophic and heterotrophic sources are challenging to measure, and the current FLUXNET Reco dataset is solely derived from modeling respiration as a function of temperature. Besides temperature and its well-studied exponential relationship to respiration, there are other constraints such as soil moisture which greatly affect ecosystem respiration activities. Previous studies have included precipitation to model ecosystem respiration; however, precipitation is considered to be sporadic and not a good predictor compared to soil moisture. Hence, with the growing volume of available data, soil water content (SWC) from remote sensing and flux towers will be used to model ecosystem respiration besides temperature. It is hypothesized that the soil moisture-respiration relationship will be positive until an excessive amount of water slows the respiration activities. For sites with no SWC data, SWC will be modeled using the water balance budget or derived from remote sensing. We hope to create a simple, yet efficient model to partition Reco from Net Ecosystem Exchange measurements of flux towers.

79 Diurnal variability of atmospheric O2 and CO2 above a boreal forest
Oral

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

The ratio between atmospheric O2:CO2, also called the Exchange Ratio (ER), can be used as a tracer on local and global scale to better understand the carbon cycle. To get a better understanding of the application of this tracer, specifically for the biosphere, we measured O2 and CO2 at two heights above the boreal forest in Hyytiälä, Finland in the summer of 2019. By measuring at two heights, we detected different ER signals from the forest and analyse their diurnal behaviour. We show that by only analysing the diurnal behaviour of the O2:CO2 concentrations themselves, the resulting exchange ratio of the atmosphere (ERatmos) is not a good indicator for the forest carbon exchange. To study the exchange ratio of the forest (ERforest), we therefore focus on the surface fluxes. We show which method to calculate the O2 and CO2 surface fluxes is most suitable, leading to improved calculations of the ERforest. We found a clear diurnal cycle for ERforest, with differences between daytime (0.92 +/- 0.17), night-time (1.04 +/- 0.04) and overall (0.83 +/- 0.24) signal. We furthermore separate these signals into an ER for respiration and assimilation processes, which can be used to get more insight in the specific carbon fluxes of this boreal forest. Overall, we show improved insights in the different ER signals of a boreal forest, why multiple measurement levels are needed to derive the forest ER signals and how our ERs deviate from the 1.1, as used in global carbon budget calculations.

22 How does drought impact water and carbon exchange in the temperate and boreal Scots pine stands?
Oral

Paulina Dukat[1,2], Marek Urbaniak[1], Klaudia Ziemblińska[1], Pasi Kolari[3], Ivan Mammarella[3], Christian Bernhofer[4], Ivan Janssens[5], Matthias Mauder[4,6], Matthias Peichl[7], Janusz Olejnik[1]

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Session C. Fluxes from local to regional scales : C.3 Utilizing eddy covariance flux networks for improved understanding of carbon-water relationships at multiple spatial and temporal scales

During last years, extended drought events have repeatedly affected Western- and Central Europe. Drought is a crucial driver altering the functioning of forests, that play a significant role in global carbon and water cycles. This research compares Scots pine-dominated forests in the temperate and boreal zones ecosystems' response to the relatively extreme meteorological drought. For this purpose, data from 5 ICOS sites and Tuczno site was used, in the latitudinal extent from 67.7° to 51° N. The used data were collected in range of years 2012-2019. The drought in 2018 has been analyzed in particular due to its severity recorded for all sites. For northern latitudes, the length of the growing season is of crucial importance for ecosystem effectivity, and the relatively extreme drought in spring has no effect on the reduction of CO2 and ET flux. More likely drought conditions – with higher temperature and radiation promote higher GPP flux in the boreal zone, where soil water is more available than in lower latitudes. For all sites the cumulative values of net ecosystem productivity (NEE) are influenced by spring conditions. Drought in 2018 contributed to the reduction of spring CO2 sink especially in temperate zone, due to reduction of both, sums of gross primary productivity (GPP) and ecosystem respiration (Reco), the NEE values remained close to the average. Highest maximum summer daily totals of GPP were recorded in the boreal zone during exceptionally dry summer months, also, there was a more rapid transition to the peak of growing season.

Poster Session 7

267 The Copernicus Cal/Val Solution (CCVS) programme and ICOS: How can they work together

Poster

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

Satellites have revolutionised our ability to Greenhouse Gas Science in many ways and it seems likely going forward that they will be key to the monitoring of the environment we need to do to understand in near real time carbon sinks and the balance of accumulation and loss with season and location. The sources of calibration data need to be as secure as those of the remote sensing information that they calibrate and there is thus a need to build partnerships between long term observing systems such as ICOS and the satellite community that rely on these data for calibration. In the CCVS project we are aiming to build the roadmap to a sustainable partnership between in situ and remote sensing communities, focusing on uncovering gaps, harmonising data formats and making reccommendations regarding how the partnership can operate and be sustained. in this contribution we will describe progress to date and present a vision for the structure of sustainable partnership between in situ and satellite communities for future implementation.

288 Introduction to and first results from RI-URBANS

Poster

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

Research Infrastructures services reinforcing air quality monitoring capacities in European URBAN & industrial areaS (RI-URBANS) bridges the gap between the expertises and capacities of air quality monitoring networks and European Research infrastructures, such as Aerosols, Clouds, and Trace gases Research InfraStructure (ACTRIS). In this presentation we will introduce the first results from RI-URBANS combining e.g., atmospheric nanoparticle concentrations, aerosol source apportionment and air quality – health indicators with a pan European perspective. We will showcase Service Tools (STs) related to near-real-time provision of atmospheric nanoparticle size distributions and on-line aerosol source apportionment, urban fine scale mapping including innovative modelling, monitoring, and crowdsourcing, development of novel health indicators of nanoparticles and Particulate Matter components and source contributions and analysis pollution hotspots. The RI-URBANS pilots in nine European cities (Athens, Barcelona, Birmingham, Bucharest, Helsinki, Milano, Paris, Rotterdam-Amsterdam, Zurich) are deployed to better address the challenges and societal needs concerning air quality (AQ) in European cities and industrial hotspots.

118 Drylands dilemma: afforestation vs. PV fields for atmospheric carbon reduction.
Poster

Rafael Stern, Jonathan Muller, Madi Amer, Lior Seguev, Eyal Rotenberg, Dan Yakir

Weizmann Institute of Science, Rehovot, Israel

Session D. Policy, Research Infrastructures and Society : D.2 Advances in nature-based negative emission technologies

Afforestation and solar energy provide useful climate-change mitigation strategies through reducing atmospheric CO2. In both cases, utilizing marginal lands in high radiation regions is often considered, which is associated with climate penalties due to their direct effects on surface albedo and temperature. Here, we quantify the climate-change mitigation potential of converting open arid area into a commercial photovoltaic (PV) field or a pines plantation, considering both atmospheric CO2 reductions (by suppressing emission or by direct uptake, respectively), and their effects on the surface energy balance. We performed campaign-based measurements covering the seasonal cycle during 2018-2019 using a unique mobile system in a photovoltaic (PV) field and its adjacent area, and data from our long-term fixed eddy-covariance station in the Yatir forest, both of which are in southern Israel. We measured key parameters associated with the surface radiative balance (including short-wave albedo and long-wave emission), and non-radiative fluxes (including sensible, H, and latent, LE, heat fluxes). In addition, we used an Unmanned Aerial Vehicle – UAV - equipped with a thermal and a multi-spectral camera for a more detailed assessment of the radiative fluxes of each element of the PV field. Estimating the “break-even time” of the radiative forcing of cumulative CO2 reduction vs. that of changes in the surface energy balance indicated ca. 1 year for the PV field, and >200 years for the plantation system in the study region. Note that this assessment does not consider other ecosystem services and societal aspects of the two “ecosystems”.

49 Two decades of cropland eddy flux measurements at Gebesee, Thuringia, Germany
Poster

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Agricultural land, almost one-third of it in the form of croplands, occupies around 40-50% of the Earth’s terrestrial surface and is a significant contributor to its greenhouse-gas balance. However, measuring the carbon budget of croplands is complicated and subject to substantial year-to-year variability, due to differences in the vegetation cover, carbon imports and exports through fertilization, harvest, and frequent disturbance by management. Long-term observations are therefore of paramount importance to gain robust insights into cropland carbon budgets.
Continuous measurements of CO2 and water vapour net ecosystem exchange, meteorological

parameters, and lateral carbon fluxes have been carried out at an agricultural site in the Thuringian plain, Germany, near the village of Gebesee since 2001, making it the longest running agricultural eddy-covariance site in Europe. Being part of CarboEurope, NitroEurope, IMECC, and eventually ICOS as a Class 1 Ecosystem station, DE-Geb has contributed to numerous studies on biosphere-atmosphere exchange in agricultural land throughout the past two decades – from experimental campaigns over remote sensing applications to long-term budgets.
In this contribution, we discuss the history of the site and insights gained from over 20 years of flux measurements under the given land management and bioclimatic conditions. We present the first estimate of a two-decade cropland net biome production based on eddy-covariance and ancillary measurements, highlighting the importance of long-term continuous observations for ICOS.

82 A widely-used eddy covariance gap-filling method creates systematic bias in C balance estimates
Poster

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Climate change mitigation requires – besides greenhouse gas emission reductions – actions to increase carbon sinks and storages in terrestrial ecosystems. However, quantification of sources and sinks of carbon depends on reliable estimates of the net ecosystem exchange of carbon dioxide (CO2). This also involves the eddy covariance technique (EC), a key method to directly measure the CO2 fluxes between ecosystems and the atmosphere. Various methods have been used to impute, or gap-fill, missing EC data and previous comparisons have shown that the accuracy of the best-performing methods, e.g. nonlinear regressions (NLR) and marginal distribution sampling (MDS), is reaching the noise limit of measurements. However, knowledge on the performance of gap-filling methods is lacking from northern ecosystems.
We have compared the performance of three gap-filling methods, MDS, NLR, and a machine learning tool called gradient boosting (XGB), and found that in high latitudes there is a potential for large C balance errors with MDS and NLR. In our study, we addressed a basic gap-filling task involving a maximum of three-day data gaps and the use of only readily available environmental drivers. We will discuss reasons for the errors and show how XGB can be used to minimize the northern site bias.

92 Continuous measurements of atmospheric carbon dioxide and oxygen at two sites in the United Kingdom
Poster

Karina Adcock[1], Andrew Manning[1], Penelope Pickers[1], Grant Forster[1,2], Leigh Fleming[1], Caroline Dylag[3], Tim Arnold[3,4]

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Measurements of atmospheric oxygen (O2) are a useful tool for understanding carbon cycle processes, in particular for identifying and attributing signals in atmospheric carbon dioxide (CO2) data to land or ocean processes. Since land biospheric fluxes of O2 and CO2 are strongly anticorrelated but ocean fluxes of O2 and CO2 are not, measurements of O2 and CO2 can be combined into a tracer that is conservative with respect to land biospheric processes, known as Atmospheric Potential Oxygen (APO). Fluxes of O2 and CO2 from fossil fuel combustion are also strongly anticorrelated, but with a different molecular exchange ratio to that for land biospheric processes; hence, short term changes in APO can be used to quantify signals in atmospheric CO2 data that originate from local to regional fossil fuel combustion.
Here, we present two atmospheric time series of O2, CO2 and APO in the UK: a 12-year record from the Weybourne Atmospheric Observatory in Norfolk and a 1-year record from the Heathfield Tall Tower in Sussex, where measurements were recently started as part of the DARE-UK (Detection and Attribution of Regional Emissions in the UK) project. We characterise seasonal variability and diurnal variability in each species at each of the two sites. These data have recently been used to assess regional fossil fuel emissions, as explained in the abstracts by Chawner et al. and Pickers et al.

233 ICOS Cities Pilot Application in Urban Landscapes (PAUL): Towards integrated city observatories for greenhouse gases
Poster

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

The time has come to develop a long-term perspective for city observatories in connection with the European research infrastructure landscape. PAUL aims to support the European Green Deal by solving specific scientific and technological problems related to the observation and verification of greenhouse gas (GHG) emissions from densely populated urban landscapes. These are fossil fuel emissions hotspots and are therefore at the heart of emission reduction efforts globally.
ICOS Cities aims to increase our understanding of specific needs of greenhouse gas emission assessment in urban environments by comparing available and novel observational approaches and implementing an integrated concept for a city observatory. The unique feature however is an innovative approach promoting the co-design principles to create services, models and observations between city administrators and scientists from multiple disciplines including social and governmental sciences.
This project will open the door for services towards cities that support evidence-based climate action-related decisions and strategic investments. The objectives are as follows:

- Bring together and evaluate different observational approaches to determine fossil fuel CO2 emissions in cities.
- Develop research infrastructures further, and provide concepts to facilitate science and services.
- Collaborate with city stakeholders and engage citizens in co-designing services that are required for GHG monitoring in order to validate the implementation of the Paris Agreement
- Increase our understanding of specific needs of GHG assessment in urban environments and create a service portfolio for setting up an urban greenhouse gas observatory.

192 The Group on the Carbon Cycle by CNR-DSSTTA: an inter-disciplinary working group to facilitate cross-collaboration on Carbon Cycle studies in Italy.

Poster

Chiara Boschi[1], Chiara Santinelli[2], Annalisa Iadanza[3], Carlo Cardellini[4], Alessio Collalti[5], Paolo Cristofanelli[6], Maurizio Ribera D'Alcalà[7], Donato Giovannelli[8], Olga Gavrichkova[9], Elena Paoletti[10], Tommaso Tesi[11], Alessandro Puntoni[12]

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Session D. Policy, Research Infrastructures and Society : D.4 Community Engagement, Training and Outreach

Here, we present the activities of the "Carbon Cycle" working group (wg) (https://dta.cnr.it/ciclo-del-carbonio/; e-mail: carbonetwork@cnr.it; social sharing #CNR_CarboNetwork), established in February 2019 by the Department of Earth System Sciences and Technologies for the Environment (DSSTTA) of the National Research Council of Italy (CNR) and composed by researchers from different CNR institutes, Italian Universities and other research bodies. The main goals of the DSSTTA "Carbon Cycle" group are:

● to engage the national scientific community involved in multiple aspects of the Carbon Cycle research, aiming at creating a transdisciplinary network;

● to contribute in defining common research themes on the Carbon Cycle, focusing on chemical, physical and biological interactions that regulate the exchanges between the Earth's "spheres";

● to identify and report possible funding opportunities and project calls over national and international landscapes;

● to support the scientific community that studies the Carbon Cycle by communicating initiatives and events, updating on novel scientific literature, informing on opportunities;

● to organize scientific meetings, dissemination and training events (workshops, summer schools, seminars).

Among the ongoing initiatives, the wg (i) releases a newsletter that highlights all the news and opportunities received from the Italian scientific community working on the Carbon Cycle every four months ("CarbonNetwork Newsletter") and (ii) it is currently organizing the International Workshop C4 "Climate Change and Carbon Cycle" (Pisa, 22-24/06/2022; https://dta.cnr.it/climate-change-and-carbon-cycle/). During this event the interactive laboratory co-organized by ICOS-Italia "Observation and Prediction: two sides of the same coin" will take place.

Poster Session 8

28 The use of continuous gamma-spectrometry monitoring to assess soil water content

Poster

Arturo Vargas[1], María Rodríguez[1], Jess Connolly[2], Roger Curcoll[1], Claudia Grossi[1], Viacheslav Morosh[3], Alessandro Rizzo[4], Annette Röttger[3]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

The use of gamma-spectrometry detectors in national radiological surveillance networks is continuously increasing because they can help to identify single radionuclide activity and their technology and data analysis have improved in the last years. It is also possible to use gamma-spectrometry for continuous monitoring of the soil water content of the surrounding area where the detector is placed. Actually, the soil density and thus the linear attenuation coefficient of gamma-rays in the soil increase when soil water content increases too.
The contribution to the measured count rates from 40K and 208Tl are mostly coming from soil activity and their variability can be used as proxy to estimate the water content in soil. This method provides an average value of the soil water content in an area of several meters, since 90% of the primary gamma fluence rate at 1 m height above the ground comes from approximately a circumference of 10 m radius and from the first 20 cm of depth. In the framework of the traceRadon1 project, measurements using a NaI(Tl) scintillator detector are being performed at different sites. Measurement campaigns at each site are carrying out for 3 months. Preliminary results of soil water content assessment using this methodology will be shown.

1This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

34 Continuous radon flux measurements: How reliable are they?

Poster

Claudia Grossi[1], Sylvester Werczynski[2], Daniel Rabago[3], Luis Quindos[3], Viacheslav Morosh[4], Stefan Röttger[4], Annette Röttger[4], Alessandro Rizzo[5], Marco Capogni[6], Marta Fuente-Lastra[7], Camille Yver[7], Arturo Vargas[1]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Radon gas is known to be the most important source of public exposure to natural environmental radioactivity. In order to apply strategies to reduce indoor radon concentration, for protecting the health of the citizens, it is important to estimate the areas with highest radon exhalation rates thus it would help to have available radon flux maps. Radon is also being used by the scientific climate and atmospheric communities as tracers for several applications such as the improvement of atmospheric transport models or the indirect estimation of GHG fluxes by the Radon Tracer Method. These previous applications will benefit from the availability of validated radon flux maps, too.

Thus, both radiation protection and climate communities will thank the existence of reliable radon flux measurements to validate and to improve present as well as future radon flux maps. The project traceRadon (reference 19ENV01) has, between its main goals, the building of a metrology chain for radon flux measurements including a transfer standard for radon flux monitors.

Here we present the steps carried out so far to create this metrology chain from the laboratory to the field together with the challenges found out in this type of measurements.

47 Measurement of the radon activity concentration at the environmental level: Calibration from lab to field
Poster

Stefan Röttger[1], Arturo Vargas[2], Roger Curcoll[2], Claudia Grossi[2], Scott Chambers[3], Annette Röttger[1], Florian Mertes[1], Monika Mazánová[4], Petr Otáhal[5]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Radon gas is the largest source of public exposure to naturally occurring radioactivity. Radon can also be used as a tracer to evaluate atmospheric transport model useful for the estimation of the origin of greenhouse gas (GHG) emissions. To increase the accuracy of both radiation protection measurements and those used for GHG modelling, traceability to SI units for radon exhalation rate from soil and its concentration in the atmosphere are needed.
Due to the previous application, it is clear than an overlapping need exists between the climate research and radiation protection communities for improved traceable low-level outdoor radon measurements, combining the challenges of collating and modelling large datasets, with setting up new radiation protection services. The EMPIR project traceRadon[1] started to provide the necessary measurement infrastructure.
Thus, measurements of radon activity concentration at the environmental level (below 100 Bq·m-3) need to be performed at national standard institutes as well as calibration laboratories and need to be transferred to the detectors operating at atmospheric measurements stations or within radiation protection networks.
With this presentation, an overview of possible national calibration techniques, as well as possible traceability chains for the transfer of the calibration to the detectors in field will be presented, first proof of principle will be shown and their applicability will be discussed.

[1] This project has received funding from the EMPIR programme co-financed by the Participating

States and from the European Union's Horizon 2020 research and innovation programme. 19ENV01 traceRadon denotes the EMPIR project reference.

67 Assessment of radon fluxes at the Hyytiälä site from campaign and model data
Poster

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Radon is an ideal passive atmospheric tracer. The use of radon as a tracer requires knowledge on the radon flux from the earth's surface into the planetary boundary layer and above, which varies on multiple scales, and depends on both meteorological and surface conditions. The soil water content seems to be a critical factor for the estimation of radon fluxes from the surface, as it influences the transport of radon gas in the porous soil medium and its subsequent exhalation to the atmosphere. It is also a crucial influence in gamma radiation dose rates, as the soil water content attenuates the propagation of gamma rays emitted by terrestrial radioisotopes (K, U, Th) in the subsurface layer. A campaign aiming to improve understanding on surface-atmosphere interactions influencing radon variability was performed at the SMEAR II station (Hyytiälä, Finland) in the framework of the transnational access project RELECT (Radioactivity and ELECTric field monitoring campaign at Hyytiälä). Detailed measurements of gamma radiation and soil radon concentration were performed from June to November 2017. These direct observations of ambient radioactivity are here analysed jointly with meteorological, surface, and flux data from the SMEARII station, and with data from radon flux models. The results focus on i) the comparison of soil water observations from the station and reanalysis data that are used in radon flux models; ii) the assessment of the influence of soil moisture (and snow) on the radon and gamma radiation temporal variability; iii) the comparison of radon flux models and observations.

68 Applications of radon as tracer for atmospheric processes and greenhouse gas flux estimations: strengths and weaknesses.
Poster

Camille Yver-Kwok[1], Marta Fuente[1], Claudia Grossi[2], Roger Curcoll[2], Ute Karstens[3], Scott Chambers[4], Tim Arnold[5], Dafina Kikaj[5], Edward Chung[5], Viacheslav Morosh[6], Stefan Röttger[6], Annette Röttger[6], Thomas Lauvaux[1]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Radon gas is chemically inert and thus its atmospheric mobility depends only on physical processes

(diffusion, adsorption, advection). These properties and its half-life time of 3.82 days make it a good tracer for regional atmospheric circulation studies. Among other methods, it can be used in the so-called Radon Tracer Method (RTM) that assumes a relation between the atmospheric concentrations of radon and the gas of interest (e.g. CO2 or CH4) under certain conditions. This calculated relationship assumes a radon exhalation rate, allowing the flux of the gas of interest to be indirectly calculated: Estimating the exhalation rate is a subject of previous and ongoing studies and this knowledge can be used to create radon exhalation maps for input to an atmospheric transport model creating radon footprints which alongside the concentration measurements allow for the flux calculation.

This presentation gives an overview on the conditions for a successful application of the RTM, the uncertainties associated to it as well as results for a selection of sites.
1This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

75 Spanish map of radium 226 as precursor of exhalation of radon gas from soils
Poster

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

A map of the Ra-226 content has been prepared from the measurements made (7000) of both soil and external gamma radiation. From these data, by applying a mathematical model, it is possible to obtain the exhalation of radon and thus a map of said magnitude for the whole of Spain. The map is compared with the one that would be derived if we take the uranium content of the soil as a reference.

80 Intercomparison of atmospheric radon monitors at Saclay (France) and Braunschweig (Germany) sites
Poster

Marta Fuente[1], Roger Curcoll[2], Camille Yver-Kwok[1], Maksym Gachkivskyi[3], Scott Chambers[4], Ingeborg Levin[3], Ileana Radulescu[5], Arturo Vargas[2], Stefan Röttger[6], Annette Röttger[6], Viacheslav Morosh[6], Claudia Grossi[2]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

The traceRadon1 project serves the purpose of establishing a metrological basis to support environmental outdoor radon measurements for use by the climate research and radiation protection

communities. One of the specific objectives of traceRadon is to develop traceable methods for the measurement of low-level outdoor radon activity concentration in the range of 1 to 100 Bq/m3, with uncertainties of 10% for k=1.

To enable traceable calibration of atmospheric radon measurement systems in the field, long-term and short-term intercomparisons of instruments used to measure environmental radon activity concentrations, including transfer instruments calibrated with low-level radon emanating sources, have to be conducted at Atmospheric Monitoring Network stations.
An overview of the intercomparison studies carried out within the framework of the traceRadon project at Saclay (France) and Braunschweig (Germany) sites will be presented and preliminary results will be discussed.

1This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

25 What is REDD+ and how to measure carbon emissions in the Amazon
Poster

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Session F. Trace Gases : F.2 Using the ICOS stations for investigating fluxes of reactive gases and aerosols in terrestrial ecosystems

It was created to develop a roadmap for enhancing forest carbon stocks and achieving sustainable management of forests through REDD+ actions. A national forest monitoring system is one of the elements to be developed by developing country Parties implementing REDD+ activities (according to paragraph 71 of decision 1/CP.16). Accordingly, the COP recognized the importance and necessity of adequate and predictable financial and technology support for developing the national forest monitoring system.

The key to any functional measurement and reporting of forest carbon is reliable data of forest area and forest area changes. Already in 2009, the COP adopted guidance on establishing robust and transparent national forest monitoring systems. Depending on national circumstances, these systems may also result from combining sub-national systems as part of national forest monitoring systems.

National forest monitoring systems should be flexible, allowing for improvement and building upon existing systems, as appropriate. They should reflect the phased approach of REDD+ implementation and enable the assessment of different forest types in the country according to national definitions, including natural forest. The data and information provided by national forest monitoring systems should be transparent, consistent over time, and suitable for measuring, reporting and verifying, taking into account national capabilities and capacities. To achieve this, the systems should also use a combination of remote sensing and ground-based forest carbon inventory approaches for estimating anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes.

257 Eddy covariance measurements of volatile organic compounds above a coniferous forest in the Netherlands

Poster

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Session F. Trace Gases : F.2 Using the ICOS stations for investigating fluxes of reactive gases and aerosols in terrestrial ecosystems

The Loobos site (52.166N, 5.744E) is a flux tower facility in a Scots pine (Pinus sylvestris) forest. In 1996 this site became part of the Euroflux project and CO2-flux and profile measurements CO2 and H2O were added. In 2000 the site became part of the Carboeurope project. Funding from the Dutch Ruisdael Infrastructure allowed the installation of a proton-transfer-reaction mass-spectrometer (PTR-TOF6000, Ionicon Analytik GmbH). Sampling occurs through a 50 m long teflon (PFA) tube (ID 6.3 mm), 12 m above the canopy, and 36 m above the ground. Data are collected at a frequency of 5 Hz and are suitable for flux calculations using the eddy covariance approach. We show first results with an emphasis on inlet characterisation.

Poster Session 9

13 Spatiotemporal variability of the pCO2 in the Pacific off Mexico

Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

The Pacific off Mexico is an extensive area in which diverse processes occur at different spatiotemporal scales, such as coastal upwelling and the confluence of different water masses, which causes great uniqueness to each region comprising the area. The study area had three regions according to their oceanographic features California Current System (CCS; 22.5-34°N), Cabo Corrientes (CC; 16.5-22.5° N), and Gulf of Tehuantepec (GT; 9-16.5° N). We used databases with information on sea surface temperature, salinity, and the partial pressure of CO2 (pCO2) from 1993 to 2018. Databases from NOAA, GLODAP, LDEO, and SOCAT. Therefore, this research aimed to describe the variation of pCO2 in this area during almost two decades. Our results showed that there is great variability in pCO2 which was higher during spring in CCS and CC; while GT had great variability in autumn-winter due to Tehuanos winds, which are inertial winds that cruise from the Gulf of Mexico to the Pacific (GT) every year in November to March. Bayesian T-test showed that there was a high probability that the regions were different, with 95% credible intervals.

55 Spatial and temporal distribution of physical and CO2 properties in the English Channel based on voluntary observing ships between 2006 and 2021.

Poster

Margaux Brandon[1], Nathalie Lefèvre[1], Dimitry Khvorostyanov[1], Denis Diverrès[2]

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Spatial and temporal evolution of SST, SSS and CO2 properties are studied in the English Channel (EnC) (48.8°N-5.2°W, 51.2°N-1.5°E) from 2006 to 2021. In situ measurements are collected using volunteer observing ships (VOS) as part of the ICOS program, during repeated transects every year, providing a good temporal coverage to study monthly to interannual variability in the area. The longitudinal distribution of the parameters highlights a strong east-west difference. SST decreases from West to East in winter and spring, while the opposite gradient is observed at the end of summer and in autumn. During the month of July, a strong SST gradient up to 3 °C is observed around 3°W. Along the transect, SSS slightly decreases from West to East, with a higher variability in the Eastern EnC. Mean SST in the EnC vary between 9 in March and 17°C in August-September and the mean

difference between seawater fCO2 and atmospheric fCO2 (ΔfCO2) ranges from -45 µatm in spring to 40 µatm in autumn. Differences in seasonality and variability are observed between the Western and Eastern EnC. A strong sink of CO2 is observed in summer in the Western EnC, while in the Eastern EnC, the strongest sink occurs in spring. These CO2 sinks are associated with a rise in biological activity as shown by the very high surface Chl-a concentrations observed from satellite images. Finally, interannual evolution of SST, SSS and CO2 properties are discussed to assess the long-term changes in this region.

62 A preliminary at-sea intercomparison between two underway pCO2 instruments shows promising results
Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

In 2021, the ICOS OTC organised an ambitious intercomparison experiment for various seawater pCO2 measuring instruments. The participants identified the need for further comparisons between pairs of instruments away from a controlled laboratory environment, and rather in a realistic field setting. Such an opportunity was found on the Ship-of-Opportunity Cap San Lorenzo, which routinely measures underway seawater pCO2 using a General Oceanics showerhead equilibrator system. For 15 weeks in spring-summer 2021, a membrane-based 4H-Jena HydroC-CO2 sensor was deployed on the vessel and measured in parallel to the GO instrument. The membrane sensor is easier to install and maintain with the trade-off of a lower reported accuracy. Nevertheless, during the deployment, the difference between the instruments was in the ±10 µatm interval for 52% of the total time, or 72% of the first half, before the membrane showed signs of biofouling due to periods of stagnate water in harbours. With the ship travelling between the Northwestern European Shelf and the south coast of Brazil, the instruments were exposed to water temperatures in the range of 9-29 °C and pCO2 levels between 170 and 650 µatm. Importantly, having both systems installed on the same ship allowed us to measure in parallel and with a large degree of confidence abrupt changes in seawater pCO2 that might have otherwise been flagged as outliers. A new generation prototype membrane sensor with higher accuracy and anti-biofouling measures is planned to be installed alongside the mentioned two instruments for a further test towards the end of 2022.

103 Seasonal variability of the air-sea CO2 flux in the Eastern Boundary Upwelling system off North West Africa
Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

The Eastern Boundary Upwelling System off northwest Africa is among the most productive regions of the ocean. In 2019, the volunteer observing ship (VOS) sailing from France to Brazil crossed this

upwelling region at different times of the year, following exactly the same track, which allows the determination of the seasonal cycle of seawater fugacity of CO2 (fCO2) and the air-sea CO2 flux. The weak permanent upwelling (26 to 33oN) is a source of CO2 in summer and autumn and a sink of CO2 in winter and spring. Thermodynamical processes mainly drive the CO2 variations in this region. The permanent upwelling (20 to 26oN) is a sink of CO2 in spring and a source of CO2 in other seasons. The supply of CO2 from subsurface waters dominate over the carbon uptake by biology, which leads to a strong outgassing, especially in winter and autumn. In spring, the region is a weak sink of CO2. South of 18oN, the ship sailed further offshore and did not sample the coastal seasonal upwelling. A sink of CO2 is observed in winter only.

213 High spatio-temporal resolution evaluation of oceanic CO2 variability based on underway data collected by a VOS line within the CARBOCAN network in the Canary Islands
Poster

Melchor González-Dávila, David Curbelo-Hernández, David González-Santana, Adrián Castro-Álamo, J. Magdalena Santana-Casiano, Aridane G. González

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

The CO2 system and ocean acidification of the Canary Islands is studied by the CARBOCAN monitoring and observation network that includes three oceanographic buoys and two VOS lines. The longest one (VOS-RENATE P), included in the ICOS program, monitors the eastern part of the archipelago between Gran Canaria-Tenerife-Lanzarote, the African coastal transition area to the North of the Canary Islands, the Strait of Gibraltar and the eastern coast of the Iberian Peninsula up to Barcelona.
The seasonal and spatial variability of the CO2 system parameters and air-sea CO2 exchange was studied in the Northeast Atlantic and the Strait of Gibraltar based data collected by the VOS-RENATE P between February 2019 and March 2021. The variability of the CO2 fugacity in seawater (fCO2,sw) was strongly driven by the seasonality of the sea surface temperature (SST). The surface waters of the entire region acted as a strong CO2 sink during the cold months and as a weak CO2 source during the warm months. A net annual CO2 sink behaviour was observed in the Canary basin (-0.26 ± 0.04 molCm-2yr-1), the northwest African continental shelf (-0.48 ± 0.09 molCm-2yr-1) and the Strait of Gibraltar (-0.82 and -1.01 molCm-2yr-1 in its northern and southern sections, respectively). The calculated CO2 flux was -2.65 TgCO2yr-1 for the Northeast Atlantic and -7.12 GgCO2yr-1 for the Strait of Gibraltar.
The CARBOCAN network is providing a high-resolution database with great relevance on improving the knowledge about the surface ocean CO2 system and acidification in oceanic and coastal areas.

219 A surface to the deep ocean carbon time-series
Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

The Porcupine Abyssal Plain Sustained Observatory (PAP–SO) is a multidisciplinary open-ocean time series site in the NE Atlantic (48°50'N 16°30'W, 4850 water depth). It is focused on the study of connections between the surface and deep ocean, following the seasonal pulses of primary production-derived particulate organic carbon into the ocean interior and to the seafloor. In situ measurements of climatically and environmentally relevant variables have been made at the site for more than 30 years. This includes autonomous year-round surface pCO2 measurements, which were first introduced in 2003. The surface waters are in direct contact with the atmosphere so are of primary concern in studies of CO2 flux and ocean acidification. Recent studies show that the annual mean surface seawater pCO2 has not increased in the last decade, however the winter-summer seasonality has increased over time. Likewise, surface pH has decreased by 0.002 units a year in this region. The effects of ocean acidification may be seen deeper in the water column. The strength of this ICOS and EMSO site is the range of year-round measurements throughout the water column and it supports the aims of projects like CLASS and iFADO. This is also a test site for new technology, including novel sensors such as lab on a chip and new platforms such as gliders.

220 A comparison of underway carbon observations in the South Atlantic
Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Accurate and reliable surface CO2 measurements can be obtained on both research vessels and ships of opportunity (SOO), through referencing of the data to gas standards or surface samples. Some of the long-distance repeat SOO routes (eg: UK-Falklands) are in remote, under-sampled regions (in this case the South Atlantic). This adds much-needed data to help constrain global flux maps and add seasonality to research vessel campaigns such as Atlantic Meridional Transect of the Atlantic (AMT). Spatial impacts of biological activity or circulation can be assessed across differing biogeochemical regimes and between years using such routes. Low cost instruments are available which will increase the frequency of measurements and therefore improve CO2 flux estimates. We describe an inter-comparison between different methods (Picarro, membrane sensors and carbonate samples) on an AMT cruise and make comparisons between the AMT and SOO transatlantic routes.

291 Results from continous greenhouse gases measurements onboard the Marion Dufresne in the souther Ocean
Poster

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Over the last decades, important efforts have been done to develop environmental monitoring networks as for example the ICOS network. Despite these improvement, there is still a lack of data in the southern hemisphere, and in particular above the oceanic areas. The MAP-IO project (Marion Dufresne Atmospheric Program Indian Ocean) launched in Autumn 2020, with the aim of studying the atmospheric composition and the ocean-atmosphere processes, represents a unique opportunity for greenhouse gases monitoring over the Indian Ocean. The French oceanographic vessel Marion Dufresne has been equipped with a set of instruments dedicated to long term atmospheric monitoring.
As part of this full instrumental package, a complete greenhouse gases (GHG) equipment set has been installed in November 2020, including a continuous high precision analyzer (providing CO2, CH4, CO measurements), a calibration and quality control setup and intake line and a GPS positioning system. The measurement system is running continuously, and provides continuous series of data, in particular over the French Austral islands area which are visited four time a year at different seasons. We will briefly present the experimental set up, measurement protocol and data quality control and we will then focus on the results obtained over the last 18 months during the oceanographic scientific campaigns as well as during the logistical operations of the vessel.
We will show and analyze the spatial distribution of GHG concentration, look at the seasonal amplitude and variability, compare the results with local monitoring stations, and also present first comparison with the CAMS model.

B.3

204 Evaluation of the drivers of FCO2 variations in the Pacific Northwest Ocean
Poster

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Session B. Marine and aquatic carbon cycling : B.3 New developments in estimates of the ocean sink for CO2

Carbon dioxide is a greenhouse gas that has increased its concentration in the atmosphere and, therefore, in the ocean due to sea-air interaction. The Pacific Northwest is an area whose physical dynamics influence the ocean-atmosphere CO2 exchange (FCO2). Therefore, the flux of this gas was estimated during the period 1983-2017, and it was found that there are different forcing agents that cause variation in its estimation, such as wind magnitude and sea temperature, among others. It was also found that there is an alternation between CO2 source and sink depending on the time of year.

286 An agile development approach to simultaneously improve models and data-based pCO2 products

Poster

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Session B. Marine and aquatic carbon cycling : B.3 New developments in estimates of the ocean sink for CO2

Models are integral to project future changes in the carbon cycle while data-based products provide insights into the historical period. We present an approach, based on the agile software development framework, where models and data-based pCO2 products can simultaneously be improved. We first construct a relationship between the model error and a suite of inputs using an eXtreme Gradient Boosting (XGBoost) algorithm. We then feed this information into SHapley Additive exPlanations (SHAP), which is an explainable AI method, to identify how specific variables contribute to model error. This information can be leveraged to address model deficiencies and improve future simulations. Finally, the physics embedded in hindcast models can be blended with machine learning to create a hybrid physics data (HPD) product. We will apply these techniques using the Global Carbon Budget hindcast models as well as the GISS ModelE earth system model. This approach presents an opportunity for agile development where in each sprint the sources of model deficiencies are addressed and the accuracy of data-based products will improve. Thus, future projections and historical reconstructions of the ocean carbon cycle should improve together.

Parallel Session 10

128 Comparison of atmospheric observations to high-resolution fossil fuel and biogenic CO2 flux models for Auckland, New Zealand

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The largest city in New Zealand, Auckland is home to roughly 1.5 million people -- one third of New Zealand's population. Despite a large urban population, the city contains a significant amount of green space that can act as a carbon sink to offset anthropogenic fossil fuel emissions. We use a high resolution (street segments and buildings, hourly) bottom-up inventory of Auckland's fossil fuel carbon dioxide emissions from a variety of data sources. We use these emissions estimates in combination with the UrbanVPRM land surface model to estimate the net carbon balance of the Auckland region. We compare this carbon balance estimate with atmospheric observations of CO2, CH4, CO, and 14CO2 collected from in-situ sensors and flasks across the city as part of the CarbonWatch NZ project. CarbonWatch NZ uses atmospheric observations and modelling to assess New Zealand's progress toward its obligations under the Paris Agreement and New Zealand's Zero Carbon Act.

145 Carbon sequestration potential of different urban green areas in Helsinki, Finland

Oral

Leena Järvi[1], Joyson Ahongshangbam[1], Minttu Havu[1], Jesse Soininen[1], Yasmin Frühauf[1], Esko Karvinen[2], Olivia Kuuri-Riutta[3,2], Anni Karvonen[1], Liisa Kulmala[2]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Cities are major contributors of carbon dioxide (CO2) emissions to the atmosphere. As a result, several cities seek solutions to reduce their CO2 emissions and maximize carbon sinks to urban vegetation and soil. Most of our current knowledge on carbon sinks is however based on data from non-urban environments even though in cities, the environmental controls of carbon flows can be different compared to their surroundings due to e.g. elevated temperatures, altered water cycle, management of green areas, limited growing space and less competition at the canopy-level.

As part of CO-CARBON and CarboCity projects aiming to increase our understanding on urban biogenic fluxes, intensive eco-physiological observations have been carried out in Helsinki, Finland between 2020-2021. The measurements are complemented by extensive soil carbon and urban ecosystem modelling. The observations over different vegetation types (park, urban forest, street

trees and apple orchard) are conducted at the vicinity of the ICOS Associated Ecosystem Station in Kumpula (FI-Kmp). The measurements include photosynthesis and chlorophyll fluorescence, sap flow, soil respiration, phenology, fine root growth, meteorology and soil properties. At FI-Kmp eddy covariance measurements presenting the ecosystem level are conducted. In this study we will demonstrate the sensitivity of the different vegetation types to heat and drought enabled by observations made on two contrasting summers (cold and rainy 2020, record warm and dry 2021). In addition, we will show how different tree species can affect carbon sequestration and storage potential of street trees using our modelling approaches in the two projects.

57 Five years of urban eddy covariance CO2 emissions correlated with dynamic shifts in urban structure and traffic regulations in the city center of Heraklion, Greece
Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Quantifying the contribution to CO2 emissions by the diverse sinks and sources that exist in the urban environment is still a work in progress, despite several studies attempting to estimate them. The majority of emissions come from anthropogenic sources, associated with e.g. fossil fuel combustion from vehicular traffic activity, space heating/cooling, household combustion or human breathing. An eddy covariance flux tower has been established in the center of Heraklion, monitoring urban CO2 fluxes since November 2016. CO2 fluxes are averaged over 30-min periods, filtered and gap filled using a moving look-up table technique mLUT. Since January 2018, the municipality of Heraklion is introducing significant traffic regulation and rebuilding initiatives. Some of these have the potential to change the urban form, and when they occur within the flux footprint area, the estimation of the local CO2 budget becomes more complicated. The investigation of the extent to which CO2 emissions are affected by these dynamic shifts is the subject of the present almost 5-year long study. New indicators are used to describe changes in traffic flow patterns of the major roads in the city center, and their effect on the observed CO2 fluxes. Results show that pedestrianization and road closures have a significant impact on daily patterns and the annual budget. Finally, government actions to prevent the spread of COVID-19 in 2020, resulted in a temporary reduction of CO2 emissions due to reduced vehicular traffic during lockdown periods.

197 Integrated Measurements and Modeling Approach for Greenhouse Gas Emission Monitoring
Oral

Jia Chen[1], Adrian Wenzel[1], Florian Dietrich[1], Patrick Aigner[1], Xinxu Zhao[1], Johannes Gensheimer[1,2], Andreas Luther[1], Moritz Makowski[1], Andreas Forstmaier[1], Friedrich Klappenbach[1], Taylor Jones[3]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Urban areas represent hotspots for anthropogenic greenhouse gas (GHG) emissions and therefore reducing urban GHG emissions plays a crucial role in achieving the emission reduction goals. Since measuring GHG emissions is a challenging and costly task, current city emission inventories rely mainly on bottom-up calculations rather than on measurements. Thus, carbon emission numbers at the scale of individual cities are subject to great uncertainty, for both carbon dioxide (CO2) and methane (CH4), as unknown or misquantified emitters cause large errors.

Here we present MUCCnet (Munich Urban Carbon Column network), the world's unique urban GHG monitoring sensor network that is based on differential column measurements. It consists of five ground-based remote sensing systems and serves to monitor urban GHG emissions over the long-term and validate satellite measurements. By using MUCCnet data as well as satellite measurements of solar-induced chlorophyll fluorescence, combined with our newly developed modeling methods based on computational fluid dynamics, machine learning, and Bayesian inversion, we started to monitor the GHG emissions and sinks, and to reveal unknown emission sources. Within the ICOS Cities project (PAUL), we are setting up 100 street-level low-cost CO2 sensors as well as 20 roof-level mid-cost CO2 sensors based on the NDIR principle, which complement the existing MUCCnet for a comprehensive emission assessment based on atmospheric concentration measurements. By additionally setting up a network of 50 low-cost sensor nodes for measuring air pollution, we can further assess co-emitted species of CO2 emitters.

90 Comparison of a downscaled emission inventory from national-scale data and a newly developed city-scale bottom-up inventory for Munich towards a better understanding of local characteristics
Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The European Union has set itself the progressive goal of achieving climate neutrality by severely reducing CO2 emissions until 2050. To do so informed decisions have to be made to introduce meaningful climate policies to impact hotspots such as urban areas and single point sources. The ICOS-cities, Pilot Application in Urban Landscapes (PAUL) project aims to support and facilitate this development by setting up integrated city observatories for greenhouse gases in three cities (Paris, Zurich, and Munich). An important starting point to evaluate CO2 emissions from cities with measurements is reliable prior data in the form of spatially explicit, state-of-the-art emission inventories.
Here we present a comparison of a downscaled inventory from national-scale data and a newly developed city-scale bottom-up inventory for Munich for the selected key sectors of transportation, energy, and heating. We update an existing 1x1km2 Europe-wide emission inventory (Super et al., 2020) and downscale it to a higher resolution of 100x100m2. In parallel, we develop the bottom-up

inventory (100x100m2) using local daily gas consumption data provided by the municipal utility company (SWM) and combine it with a geo-referenced actual usage map provided by the City of Munich. For the transportation sector, we use a macroscopic traffic model and emission factors from the Handbook Emission Factors for Road Transport (HBEFA). In Addition, we use data from hundreds of traffic-counting stations to enhance the spatial and temporal resolution. We present a comparison of the results to understand discrepancies and provide guidance for other cities aiming to develop local inventories.

Parallel Session 11

271 Two novel open-path instruments to measure ammonia fluxes successfully compared at the Cabauw grassland site (The Netherlands)

Oral

Jun Zhang[1], Daan Swart[2], Shelley van der Graaf[2], Susanna Rutledge-Jonker[2], Arjan Hensen[1], Stijn Berkhout[2], Pascal Wintjen[1,3], René van der Hoff[2], Marty Haaima[2], Arnoud Frumau[1], Pim van den Bulk[1], Ruben Schulte[2,4], Thomas van Goethem[2]

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Session F. Trace Gases : F.2 Using the ICOS stations for investigating fluxes of reactive gases and aerosols in terrestrial ecosystems

Although greenhouse gases and air quality components have been monitored at the Cabauw ICOS site (The Netherlands) for decades, observations on ammonia – despite its importance to aerosol formation, nitrogen deposition and eutrophication – have been lacking. Therefore, two novel open-path instruments for measuring NH3 concentrations and fluxes – the broadband UV-based miniDOAS 2.2D system (RIVM, Netherlands) and the QCL infrared-based HT-8700E (Healthy Photon Ltd., China) – were operated simultaneously for five weeks in August–October 2021 using the aerodynamic gradient and eddy covariance (EC) method, respectively. Despite being very different, the two techniques produced highly similar results for fluxes (correlation r = 0.87) and temporal patterns (emissions of up to ~140 ng NH3 m-2 s-1 during the day, depositions of up to ~ 80 ng NH3 m-2 s-1 at night), while differences in cumulative fluxes were small (~2%) as long as the upwind terrain was homogeneous and free of nearby obstacles.
Uptime performance of the miniDOAS reached 100% once operational, but regular intercalibration of the two miniDOAS systems was needed for optimal results (taking 35% of total time during the campaign). Nevertheless, the miniDOAS is considered robust for long-term operation. Conversely, the coating of the HT-8700E's mirror tended to degrade because of rain (21% data loss during the campaign), hence its use for long-term flux monitoring under highly variable weather conditions still presents a challenge. However, given the right circumstances the technique does provide sound quantification of NH3 fluxes.

261 Direct measurements of carbon monoxide flux over different terrestrial ecosystems

Oral

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Session F. Trace Gases : F.2 Using the ICOS stations for investigating fluxes of reactive gases and aerosols in terrestrial ecosystems

In the troposphere carbon monoxide (CO) plays a major role in atmospheric chemistry, being the largest sink of hydroxyl radical OH, which is the major oxidant of the atmosphere, and which determines the distributions of many other chemical species, including greenhouse gases like methane and ozone. For this reason CO is often considered an indirect greenhouse gas, having a

cumulative indirect radiative forcing even larger than that of nitrous oxide.
Anthropogenic activities related to the burning of fossil fuel and biomass (e.g. forest fires) as well as photochemical oxidation of methane and non-methane hydrocarbons are the main sources of CO, while the reaction with OH and soil consumption are the major sink of CO in the atmosphere. However, due to the lack of empirical data, large uncertainty exists related to the magnitude and controlling factors of biogenic sources and sinks of CO.
Here we present data on continuous eddy covariance measurements of CO fluxes, conducted during the vegetation periods above different biomes (forest, wetland, grassland, savannah, cropland) covering boreal, temperate and Mediterranean climatic regions. The measurements lasted between one month and multiple years.
All ecosystems acted as net sources of CO during the measurement periods, typically showing strong diurnal patterns characterized by small nighttime uptake and large daytime emissions. The CO fluxes were tightly correlated with solar radiation and (to a lesser degree) temperature. We partitioned the net fluxes in a light-dependent and light-independent components, and provide new estimates of biogenic direct emission of CO at global scale.

54 Ecophysiological responses of Mediterranean forests to oxidative stress: the case study of the IT-Cp2 flux site
Oral

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Session F. Trace Gases : F.2 Using the ICOS stations for investigating fluxes of reactive gases and aerosols in terrestrial ecosystems

The Mediterranean region is vulnerable to climate changes. Temperatures and the frequency of extreme events are expected to increase in the next future. Mediterranean summer is characterised by a dry-hot weather with high insulation and, under these climatic conditions, the formation of tropospheric ozone is limited only by the abundance of its precursors. This is the case of the Estate of Castelporziano, a 60 km2 natural reserve that receives plumes of polluted air from the city of Rome. We measured high concentrations and fluxes of ozone during the growing season. When it penetrates stomata, ozone damages the photosynthetic apparatus, reducing carbon sequestration. The use of satellite-derived vegetation indicators indeed, revealed a reduction in canopy cover up to 8% between 2014 and 2020 for the Estate. To better understand the ecophysiological mechanisms behind these observations, we used multi-level approach that integrates leaf-level ecophysiological measurements and satellite-level vegetation indicators to parametrize the multi-layer canopy model AIRTEE. Ozone damage functions for both photosynthesis and stomatal conductance were derived from manipulative experiments in ozone FACE facilities and implemented into the model, this led to an 8.5% increase of accuracy by comparison with Eddy Covariance fluxes of carbon, water, and ozone collected at the IT-Cp2 Holm oak flux site. By comparing different formulations for ozone damage, we estimated that tropospheric ozone alone can reduce GPP up to 213 g C m^{-2} y^{-1}. Such results highlight the need of more species-specific manipulative experiments to develop new and reliable metrics for ozone risk assessment.

256 In situ data needs for operational monitoring of greenhouse gas emissions: building a solid foundation

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The prototype CO2 Monitoring & Verification Support (MVS) capacity being developed within the CoCO2 project will extract information about anthropogenic greenhouse gas emissions from signals in the atmosphere, focusing on measurements from the planned Sentinel CO2M constellation. Such an integrated modelling system will require extensive in situ and ancillary observations in order to achieve its proposed objectives. Multiple streams of in situ measurements as well as ancillary and auxiliary data are needed for a variety of applications, including: calibrating and validating the space component, direct assimilation in models used in the core MVS capacity, validating and improving physical models, and evaluating the output generated by the MVS capacity for its end users. Each of these applications comes with a different set of requirements in terms of the timeliness, coverage, and precision of the data stream.
To ensure that the current scientific efforts can be developed into an operational service, we have documented the data flow throughout the MVS prototype and identified current channels of data provision. This lets us identify dependencies and potential weak links that could impact the provision of emissions estimate, and informs the development of an operational data pipeline that will deliver the necessary in situ and ancillary/auxiliary data to the future MVS service. This presentation maps the flow of data within the project from provider to end product(s), highlighting critical pathways and identifying potential gaps in the currently available data. This overview may inform programmatic decisions regarding future developments in in situ measurement networks.

255 Towards a Copernicus Monitoring Service for Anthropogenic Greenhouse Gas Emissions: Methodology and First Results from the IFS Global Inversion System
Oral

Nicolas Bousserez[1], Joe McNorton[2], Anna Agusti-Panareda[2], Melanie Ades[2], Luca Cantarello[1], Roberto Ribas[2], Massimo Bonavita[2], Margarita Choulga[2], Gianpaolo Balsamo[2], Richard Engelen[2]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The European Commission has entrusted the European Centre for Medium-range Weather Forecasts (ECMWF) with implementing an operational Monitoring and Verification System (MVS) for anthropogenic CO2 emissions as part of the Copernicus Atmosphere Monitoring Service. Research activities to develop this capacity have been carried out by a large consortium of partners funded under the EU-funded CHE and CoCO2 projects. The consortium will deliver the prototype systems at the required spatial and temporal scales, covering local hotspots to regional and global emission budgets. In this presentation we will describe data assimilation developments at ECMWF to build the global component of the prototype MVS, which is based on the Integrated Forecasting System (IFS). A key aspect of the methodology is the extension of the current short-window operational 4D-Var analysis to accommodate the optimisation of emission of long-lived greenhouse gases (i.e., CO2 and CH4). Efforts to implement a hybrid approach combining ensemble and adjoint-based information to

build a long-window 4D-Var will be outlined. Preliminary results from the current short-window 4D-Var inversion prototype will be presented using both cases studies and country-scale budget estimates, based on assimilation of space-based observations of XCO2 columns (OCO-2 and GOSAT) and XCH4 columns (GOSAT, TROPOMI and IASI). Comparisons with independent in situ data (e.g., TCCON) as well as previous inversion studies demonstrate the potential of the global IFS inversion prototype to provide meaningful posterior emission estimates across different spatial scales. The limitations of the system as well as possible improvements will also be discussed.

Parallel Session 12

231 Effects of extreme weather events on stem CO2 efflux
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

In the Mediterranean region, the incidents and severity of extreme weather events are projected to increase as a result of climate change.
Under short-term extreme events, the interaction between wood formation and stem CO2 efflux are still rather elusive. Among European tree species, beech is one of the most sensitive to late frost and water shortage. In this context, we monitored wood formation and stem CO2 efflux, in order to evaluate the effluxes derived by maintenance (ESm) and growth (ESg) respiration. The activities were performed in a Mediterranean beech forest for 3 years (2015–2017), including a late frost (2016) and a summer drought (2017).
ESg contributed to annual stem effluxes from 7 to 19%. The late frost reduced radial growth and, consequently, the amount of carbon fixed in the stem biomass by 80%. Stem carbon dioxide efflux in 2016 was reduced by 25%, which can be attributed to the reduction of ESg. In this year, the strong reduction of fixed C, and the contemporary lower reduction of stem CO2 efflux, strongly affected the overall stem carbon balance. Results suggest that maintenance metabolism and respiration is mandatory for tree survival, even tapping on different C source. Counter to our expectations, we found no effects of the 2017 summer drought on radial growth and stem carbon efflux. Even though late spring frost had a strong impact on beech radial growth in the current year, trees fully recovered in the following growing season, indicating high resilience of beech to this stressful event.

102 Linking UAV-LiDAR derived C-stocks and C uptake at the ecosystem level
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Understanding sequestration of living carbon (C) in agroecosystems is a question of primary importance for C-cycle modeling and land use management. Yet, aside well-studied ecosystems, many still bear significant margins of uncertainty. In this study, we aim at qualifying a new method for estimating accumulated C-stocks in agriculture sites, by predicting the above ground biomass (AGB) of vegetation throughout the growing season using mobile platforms and machine learning (ML) regression methods, and benchmarking the results with CO2 fluxes derived by the Eddy Covariance method from the ICOS DK-VNG site in Denmark. We utilised a light detection and ranging (LiDAR) sensor onboard an Unmanned Aerial Vehicle (UAV) for deriving the geometrical characteristics of crops data collection, and we conducted in parallel field-based measurements of AGB. Then, a ML pipeline was designed to provide estimates of AGB as a supervised regression problem, using the LiDAR-derived point cloud data as predicting features and the AGB labels as ground-truth target

values. The ML model attained predictions of R2 = 0.89, and mean absolute error = 73.2 g/m2 , at 0.35 m2 spatial resolution. The C-content in the AGB was assessed via laboratory analyses (46.5 +- 3% of C to AGB), and the belowground component was estimated based on allometry to AGB. The cumulative value of C uptake along the growing season was compared with the aggregate difference of predictions of C between every two consecutive UAV-LiDAR survey dates, allowing for assessment of overall prediction accuracy and quantification of uncertainty.

29 Assessing the spatial variability in methane emissions across a northern peatland complex with multiple eddy covariance towers
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Peatlands are important ecosystems in the global carbon cycle, since they store about one third of the soil carbon and are the main natural source of atmospheric methane. Methane flux measurement networks are expanding across the world with the set-up of new eddy covariance (EC) towers providing ecosystem-scale measurements of methane emissions. This expansion contributes to improving the global carbon budget calculations by incorporating more accurately the warming potential resulting from methane emissions. Northern peatlands, however, are often characterized by a heterogeneous spatial structure qualifying many of them as peatland complexes. Thus, a single EC tower might systematically fail to capture the spatial variability in methane emissions across a peatland complex. Instead, a network of multiple EC towers is required for quantifying methane emissions with an acceptable precision in northern peatland complexes, and for upscaling these to regional scales. The Kulbäcksliden peatland research infrastructure located near the municipality of Vindeln in northern Sweden includes four EC towers at different sites in a ca. 7 km² large peatland complex, hence enabling the investigation of the variability in methane emissions at the peatland complex scale. Preliminary results suggest that although methane emissions generally follow closely plant development, significant differences in the timing and amplitude of fluxes exist across the peatland complex. This implies a source of uncertainty when upscaling single tower estimates. Therefore, identifying the drivers of the within-peatland complex spatial variability in methane emissions is paramount for evaluating more accurately the contribution of peatland methane emission to the global methane budget.

19 Dynamic responses of nitrous oxide emission from a typical subtropical vegetable cropland
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

The current challenge to estimate anthropogenic nitrous oxide (N2O) emissions from the agricultural sector is an incomplete understanding of environmental impact on microbial communities; particularly, N2O is subjected to be the third-largest contributor to the global warming potential. Our findings indicate that the clear trigger temperature and water-filled pore (WFPS) for N2O response were within 28 °C and 40%–60%, respectively. Fertilization and WFPS can significantly affect the microbial communities throughout the cropping periods leading to an increased abundance of denitrifiers. It is noteworthy that Bradyrhizobium sp., and Luteimonas sp. were among the most abundant denitrifiers, which could be responsible for the unexpected high production of N2O because of their incomplete denitrification pathways. In terms of nitrogen budget, the total N2O-N efflux from a typical vegetable field accounts for 2.5±0.53 % of the nitrogen in the urea fertilizers applied during the cultivation periods, which is significantly higher than the IPCC default parameter of 1%. The results imply that in-field N2O emissions from fertilized soils are underestimated in the current national emission inventories of greenhouse gases. Clarifying mechanisms controlling impacts of environmental factors on microbial process enable greater leverage in succeeding climate sustainability.

226 Automated chamber measurements of CO2, N2O and CH4 fluxes from semi-deciduous tropical forest soil of the Congo Basin

Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Tropical rainforest soils are considered an import source of nitrous oxide (N2O) and carbon dioxide (CO2) and a sink for methane (CH4). Although the Congo Basin is the second largest tropical rainforest, data of continuous in situ flux measurements are scarce. The few completed data sets are often the result of measurements using the static manual chamber method at varying temporal resolution: long term periods of weekly or monthly sampling in combination with short periods of daily sampling. Seasonality of the fluxes can be captured with these sampling frequencies, but daily variations as well as short term responses to weather events are lacking. Moreover, due to the logistical efforts that are needed for manual sampling and analyses of gas concentrations in laboratories outside Africa, restricted daytime fluxes are available. To address these data gaps, automated, dynamic soil chambers to continuously measure N2O, CO2 and CH4 soil fluxes, have been installed in the Yangambi UNESCO biosphere reserve since May 2022. The resulting data will provide insight into the seasonality as well as daily variations of the full soil greenhouse gas balance. The data can be used to quantify the source and sink capacity of these forest soil more robustly and will increase the mechanistic understanding of what drives the greenhouse gas balance of these tropical forest soil. The resulting data will, to the best of our knowledge, be the first of its kind for the Congo Basin.

Parallel Session 13

191 Simulation of urban CO2 at building resolving scale with GRAMM/GRAL

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Cities worldwide are recognizing their important contribution to global CO2 emissions and are designing ambitious climate mitigation and adaptation plans. In order to support these activities, the project ICOS-Cities/PAUL develops unique tools to observe and verify greenhouse gas emissions from densely populated urban areas in Europe. It compares available and novel observational strategies in three pilot cities and applies atmospheric modelling tools over a wide range of scales. One of these cities is Zurich, Switzerland, where dense networks of low- and mid-cost CO2 sensors will be combined with Eddy covariance measurements and meteorological in-situ and remote sensing observations. In order to take advantage of the CO2 measurements from more than 60 sensors at street and roof-top level, we have set up the atmospheric dispersion model GRAMM/GRAL to simulate CO2 concentrations at building resolving resolution over the whole city. Inputs to the model are a detailed inventory of anthropogenic CO2 emissions and biospheric CO2 fluxes computed from high-resolution urban vegetation maps using the vegetation photosynthesis and respiration model (VPRM). Here, we present first results of the simulations focusing on annual mean contributions from different emission sectors to CO2 at street and roof-top level, diurnal and seasonal cycles of anthropogenic CO2 concentrations, comparisons between anthropogenic and biospheric CO2 in different seasons, and first comparisons against observations providing insights into the capabilities of the model system.

127 Analysis of the seasonal and interannual variations of CO2 emission over Paris based on 6-year atmospheric inversion from 2016 to 2021

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

In this study, we focus on the Paris metropolitan area, the largest urban region in the European Union and the city with the densest atmospheric CO2 network in Europe. The Parisian monitoring network is composed of 7 high-precision in situ stations, distributed over a distance of 36 km along the axis of the prevailing winds. We analyze the observed CO2 concentrations along the urban-rural gradients across Paris and quantify the citywide CO2 emissions over six years (2016-2021) using a city-scale

Bayesian inverse modeling system. Our inversion framework benefits from the use of a novel gridded hourly fossil fuel CO2 emission inventory (Origins.earth) at 1 km spatial resolution, which uses near-real-time activity data to describe temporal variations. In addition to the mid-afternoon observations, we attempt to assimilate morning CO2 concentrations based on the ability of the WRF-Chem model to simulate atmospheric boundary layer dynamics constrained by observed layer heights. The daily and seasonal variations of the inverted CO2 emissions quantify errors both in the residential and traffic sectors from the Origins inventory and of the biogenic fluxes simulated by the VPRM model. Our inversion results show a long-term decreasing trend in the annual CO2 emissions over the Paris region, which is consistent with independent estimates from other socioeconomic and inventory datasets. Finally, our results have been integrated into an operational web interface to visualize the carbon emission data in continuous time and to place them in the context of emission reduction targets and climate policies.

95 Uncertainty estimation of a CO-based continuous ffCO2 record and its potential benefit in ffCO2 inversions

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Atmospheric 14CO2 measurements are a direct and well approved method for separating the fossil fraction from a measured total CO2 signal. However, these measurements are typically only available on a low temporal resolution, which limits their potential in deducing temporally high-resolution fossil fuel CO2 (ffCO2) emissions and constraining highly variable biogenic CO2 fluxes within inversion modelling frameworks. Therefore, surrogate tracers like CO, NOx, or APO, which are co-emitted with ffCO2 and measured continuously, have been used to reconstruct continuous ffCO2 records. It is however essential to optimally estimate the uncertainty of those ffCO2 records so that they can be used in atmospheric inversions.

Here, we want to revisit the potential of carbon monoxide (CO) as a proxy for ffCO2 in urban areas. For this, we use 2-week integrated 14CO2 samples from Heidelberg, located in a metropolitan region in South-Western Germany, to derive ΔCO/ΔffCO2 ratios in relation to a clean maritime background site. We choose a simple ansatz for calibrating the continuously measured CO enhancements in Heidelberg to get a continuous ffCO2 record. To independently determine its uncertainty, we compare our ffCO2 record with ffCO2 estimates from a representative pool of >400 hourly 14C flasks. It turns out, that the uncertainty of the continuous ffCO2 record is about 3 to 4 times larger than the uncertainty of the direct 14C-based ffCO2 estimates. Therefore, we investigate the potential benefits of this continuous ffCO2 record albeit with an increased uncertainty compared to the 14C-based ffCO2 point estimates in an inversion system.

89 Application of a 14C flasksampling strategy on ICOS tall towers

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

14CO2 is a direct tracer for fossil fuel emissions that allows to quantify the fossil fuel CO2 (ffCO2) contribution to the total measured atmospheric CO2 enhancement. In recent years, estimating anthropogenic emissions for sub-national greenhouse gas (GHG) emitters has moved into the focus of research as political action is demanded for climate action. Long term observations of 14CO2 are performed at ICOS Atmospheric Class1 stations being equipped with a specially designed automated ICOS flasksampler. Apart from the purpose of quality control for continuous GHG measurements at these stations, the flasksampler is designed to take one-hour integrated samples for 14C analysis. Focusing on a flasksampling strategy that targets anthropogenic emitters in the surrounds of the Class1 stations, provides 14C observations which could support the sub-national emissions estimates. Although ICOS tall towers are generally at remote sites, where local anthropogenic emissions tend to be small, ffCO2 pollution events can be identified when the observed 14C depletion at the tower is significant with respect to an appropriately chosen background. To ensure sampling periods with potentially high radiocarbon depletion, we used a ΔCO threshold approach derived from continuous CO measurements as indicator for high ffCO2 events.
For our 14C analysis we selected daytime flask samples based on an automated ΔCO criterion. Here first results are shown and the approach and applicability to estimate the ffCO2 enhancement caused from anthropogenic emissions are discussed.

120 Monitoring CH4 emissions from active landfill and industrial sites using different types of atmospheric measurements
Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

We participated in two controlled-release experiments at the TotalEnergies Anomaly Detection Initiatives (TADI) test site (Lacq, France) in 2018 and 2019 dedicated to evaluate the ability of different local-scale atmospheric measurement and inverse modeling systems to localize and quantify fugitive CH4 emissions. We also conducted a series of mobile campaigns to regularly quantify methane

emissions from two active landfills in France operated by SUEZ. For one of the landfills, we conducted flights of drone measurements during a two days campaign and permanently deployed an LI-COR analyzer at a fixed location outside the landfill to continuously measure atmospheric CH4 mole fractions for the time evolution of landfill methane emissions. We developed and applied different inversion approaches to process mobile, fixed-point, or drone measurements, which, in all cases, rely on a Gaussian dispersion model to simulate the atmospheric plumes. Two sets of inversions in TADI based on mobile and fixed-point measurements provide estimates with a ~20-30% average error for the CH4 and CO2 release rates. The use of fixed-point measurements allows for more precise localization of sources with an average location error of ~8m. The analysis of mobile measurements at the landfills reveals difficulties in exploiting measurements close to such sites with diffuse emissions whose spatial distribution is difficult to characterize, heterogeneous, and highly variable in time. The series of estimates of the total CH4 emissions from the landfills based on atmospheric inversions using mobile plume cross-sections, drones, and a fixed-point continuous measurements show consistent orders of magnitude but high temporal variations.

Parallel Session 14

217 Projections of hydrofluorocarbon (HFC) emissions and the resulting global warming based on recent trends in observed abundances and current policies

Oral

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Emissions of hydrofluorocarbons (HFCs) have increased significantly in the past two decades, primarily as a result of the phaseout of ozone depleting substances under the Montreal Protocol and the use of HFCs as their replacements. In 2015, large increases were projected in HFC emissions in this century in the absence of regulations. Because HFCs are potent greenhouse gases they were projected to contribute significantly to global average surface warming in 2100. In several countries regulations to limit the use of HFC are already in effect. In addition, in the 2016 Kigali Amendment to the Montreal Protocol it was agreed to phasedown the consumption of HFCs globally.
We here analyze trends in observations of the atmospheric abundances of HFCs up to 2020 and emissions inferred from these observations. Total CO2-eq inferred HFC emissions continue to increase through 2019 but are 20% lower than previously projected for 2017-2019. This indicates that HFCs are used much less in certain refrigeration applications than previously projected.
Two new HFC scenarios are developed based, 1) on current trends in HFC use and Kigali-Independent control policies currently existing in several countries, and 2) current HFC trends and compliance with the Kigali Amendment. Without any controls, projections suggest a HFC contribution of 0.28-0.44 °C to global surface warming by 2100, compared to a temperature contribution of 0.14-0.31 °C projected considering the national policies current in place. Warming from HFCs is additionally limited by the Kigali Amendment controls, to a contribution of about 0.04 °C by 2100.

141 Annual Kigali Index (AKI): A New Measurement-Based Policy Tool for Verifying the Global Phase-Down of HFC

Oral

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Hydrofluorocarbons (HFCs) were introduced to replace long-lived chlorinated and brominated ozone-depleting substances. As HFCs are strong greenhouse, a phase-down of the production and consumption of HFCs with high global warming potential was internationally agreed within the Kigali Amendment to the Montreal Protocol.
An independent verification of the phase-down of production and consumption is not straightforward and potential violations are difficult to detect. As a real-world check, their change in atmospheric concentrations can be used to validate global and regional compliance with the restrictions. Here, we present the newly developed Annual Kigali-Index (AKI) to report on the progress of annually averaged global concentrations and on the emissions of all 18 HFCs included in the Kigali Amendment. Apart

from HFCs with high industrial production and considerable atmospheric concentrations, other HFCs, which have not been used in large quantities so far (i.e. HFC-134, -41, -143, -236cb, -236ea, -245ca, -152), are measured in atmospheric samples by Empa and included in the AKI.

We calculate the AKI relative to 2011-2013 (baseline developed countries) for radiative forcing (AKI-RF) and CO2-equilvalents of emissions (AKI-E). In 2020, the AKI-RF was 1.82, representing the increase of the radiative forcing from HFCs from 0.022 W m-2 for the reference period 2011-2013 to 0.040 W m-2 in 2020. The corresponding AKI-E for 2020 was 1.55. This lower value of the AKI-E was due to a reduced growth of the HFC emissions in most recent years, which could be indicative of the HFC phase-down, as stipulated in the Kigali Amendment.

139 A high-resolution spatially explicit emission inventory of fossil fuel CO2 emissions from Japan
Oral

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Japan's fossil fuel carbon dioxide (CO2) emissions total has been ranked at the fifth in the world. Spatially-explicit emissions are a powerful tool to guide emission monitoring and track our progress towards the 2030 net zero goal. Existing emissions inventories often utilize downscaling approach using spatial proxy for emissions, such as population and nighttime lights. However, the performance of emission proxy varies over countries/regions and emission sectors and thus emission downscaling introduces additional uncertainties that are often not well quantified. This study developed a country-wide, monthly, spatially explicit fossil fuel CO2 emissions inventory at a 1 x 1 km grid scale for 2015 using a bottom-up approach. This study fully utilized a wide variety of official statistics that are provided by the Statistics Bureau of Japanese government in order to build an inventory with transparency and traceability. We compared our emissions estimates with official national emissions estimates provided by the National Greenhouse Gas Inventory Report of Japan (GIO) and submitted to UNFCCC. We also compared our estimates to the Open-source Data Inventory for Anthropogenic CO2 (ODIAC) for examining spatial patterns and the performance of the nightlight-based emission downscaling. Our estimates differ from the GIO emissions by more than approximately 5% in the total emissions. We also found statistically significant difference in spatial distribution of fossil fuel CO2 emissions between this study and ODIAC. We will discuss the cause of these differences from published other emissions inventories and next steps to improve our inventory.

202 The ANR COoL-AMmetropolis project (2020-2025) : towards establishing virtuous scenarios for reducing greenhouse gas emissions of the Aix-Marseille-Provence metropolis (France) at the horizon 2030.
Oral

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

With almost 1.9 millions of inhabitants, the Aix-Marseille-Provence metropolis (AMPm) is the second most populated area of France. According to ATMOSUD, the regional air quality agency, the AMPm emits about 23.8 MteqCO2/year (roughly 95% of CO2, 4% of CH4 and 1% of N20), with 96% of these emissions outcoming from the use of fossil fuels and 4% of biogenic sources. The area is strongly industrialized, with 70% of fossil CO2 emissions (FFCO2) originating from the industrial and energy sectors. Traffic sectors (including airborne and maritime ones) represent 18% of FFCO2 and residential/commercial sectors 5% of FFCO2. The ANR COoL-AMmetropolis project (2020-2025) aims at : 1/ verifying independently the ATMOSUD AMPm inventory by top-down approaches to set-up correctly the current state of AMPm greenhouse gas (GHG) emissions ; 2/ assessing the content of environmental plans for reducing CO2 emissions of the AMPm ; 3/ interacting regularly with local stakeholders for building virtuous scenarios of CO2 emission mitigation of the AMPm at the horizon 2030 ; 4/ modeling these scenarios at the metropolis to the district scale in order to take into account the high spatio-temporal variability of emissions on the AMPm territories and helping local stakeholders to take efficient actions. The methodology and an overview of the results obtained so far will be presented, especially those on the verification of the ATMOSUD inventory that are performed through the data analysis of a dedicated atmospheric CO2 metropolitan mini-network (including the OHP ICOS-Fr station), as well as radiocarbon, emission tracers and boundary layer height campaigns.

133 Assimilation of methane plume data with grid-scale emissions maps from atmospheric inversions.
Oral

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Session D. Policy, Research Infrastructures and Society : D.3 Enhancing the use of greenhouse gas observation systems to inform, enable and frame policy

Emissions maps resolved at spatial scales and sectors are needed for the effective implementation of methane monitoring and reduction strategies. While atmospheric inversions of satellite or in-situ data provide a reasonably accurate estimate of emissions aggregated over large spatio-temporal domains, they cannot resolve emissions at high spatial resolutions because of the errors in coarse resolution observations and transport models. Methane emissions from supper-emitters are regularly observed and quantified as distinct plumes in high-resolution aircraft and satellite observations (PRISMA GHGSat, Sentinel-2). Recent studies have shown that supper-emitters are often responsible for a large

fraction of the total regional emissions. This provides a golden opportunity for climate change mitigation. The precise location and sector of a plume emitter is easily determined as plumes are observed close to the source in the high-resolution satellite data. The information content of a plume dataset can be used to improve the spatial and sectoral allocation in a grid-scale emissions map. Here, we present a method for assimilating methane plume datasets with the posterior emissions of a grid-scale atmospheric inversion using a Bayesian approach. We demonstrate the method by combining the plume dataset from a 2019 aircraft campaign and a TROPOMI inversion over the Permian basin. Our method uses the additional information in the plume dataset to improve the spatial allocation and magnitude of grid-scale emissions, while keeping the total regional emissions consistent with the TROPOMI inversion.

Parallel Session 15

180 To plough or not to plough: CO2 and N2O flux measurements

Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Within a larger program from the Dutch Ministry of Nature and the Environment (LNV; Slim Landgebruik), CO2 and N2O fluxes were measured at three fields with different treatments and crops. The aim of this study was to determine the effect of ploughing on the CO2 and N2O fluxes during six months. Therefore a large grass field was divided into 3 parts. The west field was ploughed, followed by new seeding of grass took place. The east field was ploughed and seeded with summer wheat. The south field was only mowed and used a reference field. Depending on the field, mowing, manuring, harvesting and seeding with a cover crop took place during the measurement period.
An Aerodyne dual laser spectrometer was used for the trace gas measurements (CO2, N2O, H2O, CH4, C2H6 and CO at 5Hz). Sonic anemometers were placed in the middle of the fields (20Hz). Inlet lines for the trace gas measurements were attached onto the anemometers. With a valve system, the 3 field were measured alternately (30 minutes per field).
First results of the measurements showed that the cumulative N2O flux is the highest for the new seeded grassland. When adding the N2O (as CO2 equivalents) to the CO2 flux, the highest contribution is coming from the field with summer wheat followed by a cover crop.

264 FluxWIN – The role of non-growing season processes in the methane and nitrous oxide budgets in pristine northern ecosystems

Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

The importance of non-growing season greenhouse gas fluxes to annual budgets in pristine northern terrestrial ecosystems is growing in awareness. Greenhouse gas (GHG) fluxes during the non-growing season and freeze-thaw dynamics are still underrepresented and may be a reason why current process-based models underestimate annual methane (CH4) and nitrous oxide (N2O) budgets. The FluxWIN project investigates ecological and biogeochemical processes in global carbon (C) and nitrogen (N) cycles during the non-growing and shoulder seasons by combining high-frequency greenhouse gas measurements, biogeochemical monitoring and process-based modeling. A new automated chamber system was established in 2021 to obtain soil-atmosphere CO2, CH4 and N2O exchange in real time. Additional soil gases and biogeochemical and physical parameters are monitored year-round. We control for climatic variability and quantify differences in non-growing season emissions across the landscape by using a moisture gradient from well-drained upland soils to

adjacent wetland ecosystems. The use of these automated high-frequency GHG measurements in combination with biogeochemical monitoring maximizes the likelihood of capturing episodic emissions and their drivers, which are hypothesized to be particularly important during fall freeze and spring thaw periods. The gained information on cold season biogeochemical cycles will improve feedback estimates to climate change by including non-growing season processes in global-scale process-based models.

238 Diurnal variability in and above the canopy of stable istopologues integrated to ecophysiology and boundary-layer dynamics on the temperate Scots Pine forest ecosystem Loobos (NL)
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Photosynthesis and ecosystem respiration are the two largest fluxes in the carbon cycle. It is possible to estimate their difference, net ecosystem exchange (NEE), precisely but not the individual contributions. To predict biosphere-atmosphere exchange under future climate, and the atmospheric mole fraction of CO2 requires a precise estimate of the gross fluxes. In May 2022 we will carry out an integrated campaign, integrating different atmospheric tracers for GPP and respiration with ecophysiology and meteorology at the ICOS temperate Scots Pine forest ecosystem station Loobos in the Netherlands. In the campaign different atmospheric tracers that have been used to estimate the total CO2 uptake by plants such as COS, O2/N2 ratio, and δ18O, Δ'17O, Δ47, and Δ48 of CO2 will be measured from discrete air samples collected at a one-hour resolution above the canopy at 36 m height. The oxygen isotope composition of CO2 and water are strongly coupled by photosynthesis and isotope exchange, therefore δ18O and Δ'17O of soil, leaf water, and atmospheric water vapor will also be measured. We will also measure stomatal conductance at the leaf level and A-Ci and A-PAR curves. This information can be used to improve our representation of the interaction between the canopy and the atmosphere and relate it to vapor pressure deficit, temperature, boundary layer height, and other meteorological variables which affect photosynthesis. We will present the first result of the campaign.

195 Wavelet analysis as a tool to deduce temporal multi-scale influence of climatic events on a young beech forest CO2 exchanges
Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Eco-physiological behavior of terrestrial ecosystems is highly dependent on climate variations. Underlying eco-physiological processes take place on multiple temporal scales, which hinders their identification as well as the study of their effects. Although this relationship is well-documented on time frames extending from few days to few years, decades-long studies are relatively sparse. With the growing availability of continuous eddy-covariance (EC) records of greenhouse-gas fluxes, the opportunities to conduct such long-term studies are rapidly expanding. The enlargement of available temporal series widens the possibilities to investigate inter and intra-annual variability and sensitivity of ecosystem eco-physiological responses to medium to large scale events. This study aims to explore the influence of such events on a young beech forest at ICOS-candidate Hesse site, north-eastern France. To account for the variable scale of these events, a time-frequency analysis tool, the continuous wavelet transform (CWT) is applied on 20 years of CO2 fluxes exchanges. The CWT is an increasingly popular tool in environmental time series studies, owing to its compatibility with the investigation of non-stationary phenomena. This work implements both the Mexican Hat and Morlet wavelet and exploits associated wavelet tools, such as coherencies, to account for interactions between multiple variables. New approaches to detect anomalies in EC fluxes are suggested based on the frequency analysis of time series large scale components. Ultimately, this study aims to improve the characterization of the effects of large-scale events, extending from months to years, on ecosystem eco-physiological responses variations.

108 Multi-scale measurements of solar-induced fluorescence in Sodankylä, Northern Finland
Oral

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Solar-induced fluorescence (SIF) has recently received attention as a potential, novel proxy for photosynthesis across scales, and has been retrieved using tower-based, drone-based, airborne and spaceborne techniques. Satellites and proximal measurements are in routine use in SIF research, while drone- and aircraft-based measurements may extend understanding of SIF by filling the scaling gap between proximal and space measurements. In addition, drone- and tower-based measurements have potential to be used for validation and calibration of satellite measurements.
To investigate SIF in a high-latitude environment and to provide validation support for new and upcoming satellite missions, we have initiated tower- and drone-based SIF measurements at Sodankylä, in Northern Finland. SIF has been measured with a drone since summer 2020 and on tower during the growing season of 2021 and 2022. Both instruments monitor the canopy of a boreal forest passively and measure vegetation indices and SIF simultaneously.
We report first results of tower-based and drone-based measurements, which include measurements above evergreen forest (tower + drone) and deciduous forest (drone) and high profile measurements (drone). In addition, satellite measurements by TROPOMI and OCO-2 satellites over Northern Finland have been analyzed with particular interest in the seasonal variability of SIF at high latitudes. Comparing tower- and drone-based measurements to satellite measurements extends understanding of tower and drone measurements suitability for satellite validation.

Parallel Session 16

289 A review of a new to market, yet deployment proven, high accuracy and deep deployable spectrophotometric pH sensor

Oral

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H. Manufacturers Session : H. Manufacturers Session

ClearWater Sensors Ltd. is a start-up commercialising the lab on chip-based sensors developed by the National Oceanography Centre (NOC) and University of Southampton (UoS), UK. In addition to nutrient and iron sensors, we manufacture and sell a high precision pH sensor, which can be integrated into a range of autonomous vehicles to enable the collection of high-quality pH measurements. The pH sensor is based on the spectrophotometric method. This benefits from low drift and can achieve a precision better than 0.001 and accuracy similar to, and dependent on, the accuracy of the gold standard reference buffers (<0.010). The sensor is pressure tolerant, with components that are pressure rated to 6000 m. The microfluidic nature of this sensor means the reagent consumption is low, and that the sensor is small enough to mount on gliders or other platforms where space is at a premium. The low power consumption means it is also suitable for a range of deployments. The commercial device is yet to see active service, but the design by the NOC / UoS has been successfully deployed on numerous occasions including integrated into an ocean glider, on moorings, landers, ASV, USV, ROV and to depths exceeding 4800 m. Data from the sensor in the open literature will be reviewed.

97 A portable, easy-maintaining gas analyzer with a dual-ring Herriott cell for simultaneous measurements of N2O, CH4, and CO2

Oral

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Session H. Manufacturers Session : H. Manufacturers Session

Recently, laser spectrometers have shown good capability in the high sensitivity and low maintenance measurements of mixing ratios for atmospheric greenhouse gases (GHGs). Given the fact that spectral bands of CO2, CH4, and N2O covering from near to mid-infrared (NIR to MIR) wavelengths, and the limitations in the wavelength coverage of the laser and photodetector, it is very challenging to analyze CO2, CH4, and N2O simultaneously for most cavity-enhanced analyzers using NIR lasers. Although there are alternative solutions, such as combining multiple quantum cascade laser (QCL) beams and analyzing all GHGs in the MIR wavelengths, it would significantly increase the instrumental cost. More importantly, a single optical path and MIR photodetector under a lower time-division sampling frequency and signal-to-noise ratio result in higher analytical noise.
In this work, we have developed an analyzer utilizing the advantages of detecting CO2/H2O in the NIR spectral region and N2O/CH4 in the MIR region. It employs a robust, easy-maintaining dual-ring

Herriott cell with two independent optical paths. At the inner ring optical path, CO2 and H2O are analyzed at ~4995cm-1 with a NIR laser and a photodetector. At the outer ring optical path, CH4 and N2O are analyzed at ~1275cm-1 with a QCL and an MCT photodetector. This analyzer facilitates high-sensitivity, field-deployable measurements of CO2 (200 ppbv), CH4 (2 ppbv), N2O (0.3 ppbv), and H2O (100 ppmv) simultaneously in a compact, portable instrument, which can be powered by Lithium-ion rechargeable battery continuously at the observation sites usually without grid power.

17 LI-COR Trace Gas Analyzers - Applications for Measurements of Methane, Carbon Dioxide, and Nitrous Oxide

Oral

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Session: H. Manufacturers Session

Wildfires are extended in many world regions (1,2), projected to occur more frequently in Europe, and release substantial amounts of greenhouse gases (GHG). Vegetation fires have received larger attention but knowledge on emissions composition and quantities of smouldering fires involving carbon-rich organic soils (peat) and their climate impacts is modest at best (3,4). While their surface area footprint is small, peatlands occupy large volumes underground and, once ignited, burn for months or even years (4) and disrupt ecosystems. Aside of tropical regions (5–7) the Arctic is increasingly challenged by (overwintering) peat fires (8,9). Recent studies report regional differences in peat properties (e.g., higher carbon content (4) in tropical compared to boreal peat) and also the ambient fire conditions differ by region (e.g., drought/heat (Tropics) (6) vs. thawing permafrost (Arctic) (9,10)). This calls for a careful assessment of the heterogeneity in the context of emission inventories for atmospheric and climate models. We summarize the current knowledge and highlight open questions in the context of GHGs.

Since the release of the first LI-COR Trace Gas Analyzer based on Optical Feedback Cavity Enhanced Absorption Spectroscopy (OF-CEAS) in 2018, researchers have taken advantage of the platform's portability, precision, low-drift, and speed of response to apply these instruments in a variety of ways, with many applications directly relevant to groups within the ICOS community. Now with three instruments available, for methane, carbon dioxide, and most recently nitrous oxide, the platform is now well established as an option for greenhouse gas measurements in a wide range of scenarios. In this presentation we will highlight relevant specifications of the OF-CEAS technology through customer case studies. The short-term precision and long-term stability of the LI-7810 (CH4/CO2/H2O), LI-7815 (CO2/H2O) and LI-7820 (N2O/H2O) make these instruments suitable for long-term atmospheric measurements. LI-7810 and LI-7815 instruments were tested at the ICOS Atmospheric Thematic Centre, Scripps Institution of Oceanograpy, and in a six-month test at Mace Head Atmospheric Research Station. These tests show their compatibility with WMO GAW and ICOS instrument specifications and their ability to be used with varying calibration standards and protocols. Combined with LI-COR's soil chambers and multiplexer, the three instruments are widely used for survey and long-term soil flux measurements. Portability, combined with speed of response make the instruments ideal for mobile applications. We present two examples of mobile emissions monitoring, the first with Royal Holloway, University of London and National Physical Laboratory, and the second with Seoul National University. Finally we will describe other applications, including pCO2.

292 Applications of the eosAC-LT automated flux chamber to measure continuous GHG fluxes and ongoing R&D

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H. Manufacturers Session : H. Manufacturers Session

Chamber greenhouse gas flux measurements provide critical primary and ancillary data for the ICOS ETC network. Chamber data is used in many analyses including determining heterogeneity of site fluxes, allowing for improved flux partitioning providing critical data for gap filling of eddy covariance data sets. Here we present the Eosense eosAC-LT chamber, designed for continuous unattended measurement of multispecies greenhouse gas flux. We will review the performance and features of the chamber with respect to some of the ICOS network criteria set in Pavelka et al. (2018) and then demonstrate the efficacy of the system in three short case studies which take data from wetland, agricultural and peatland ecosystems. Finally we will discuss ongoing R&D to enhance chamber performance, including modification to make the system more suitable for reactive gas species like HONO and Ammonia.

293 Performance assessment of the mobile g4301 Cavity Ring-Down Spectroscopy analyzer and practical Feedback from field Measurements

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H. Manufacturers Session : H. Manufacturers Session

Carbon dioxide (CO2) and methane (CH4) are the most important greenhouse gases, and there is an increasing need to measure these greenhouse gases with mobile measurement devices. Picarro's G4301 Cavity Ring-Down Spectroscopy (CRDS) analyzer is a high-performance, light-weight, portable, battery-powered gas concentration analyzer that has enabled real-time measurements of CO2 and CH4 in challenging environments in the field of ecosystem, soil science , glaciology, limnology and indoor air quality. Here we evaluate the performance of this portable greenhouse gas analyzer in laboratory test and share practical feedback from field measurements.

The performance of the G4301 analyzer was assessed at the Metrology Laboratory (MLab) that is part of the Atmospheric Thematic Center of ICOS. The MLab regularly tests greenhouse gas analyzers that are used within the European monitoring network ICOS (Integrated Carbon Observation System). We will present CO2 and CH4 performance data on the continuous measurement repeatability (CMR), the short-term repeatability (STR), the long-term repeatability (LTR), the ambient temperature sensitivity, the inlet pressure sensitivity, and the built-in water vapor correction.

To assess the performance of the analyzer it was deployed in mobile field measurements for both atmospheric (balloon flight) and ecosystem research (ground-based).

294 FM-CW Wind Lidar “Wind Ranger” and Multi-Path Sonic “uSonic-3 MP”
Oral

Hans-Jürgen Kirtzel

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H. Manufacturers Session : H. Manufacturers Session

1) Doppler LIDARs are powerful tools for observing atmospheric wind patterns within the PBL. Contrary to pulsed LIDARs continuous wave versions (CW) allow near surface measurements at heights starting at 10m with fine range resolutions (0.08/0.32m @ 10/40m). Because of some fundamental constraints of conventional CW LIDARs a frequency modulation was developed. The FM-CW “Wind Ranger” determines wind data for selected heights from 1 rps vertical VAD scans at 80° elevation angle allowing measurements very close to obstacles, e. g. inside forest clearings. It avoids blind zones around zero winds and verifies the effective measuring height of the analysed signal. Details of the FM-CW technique and results from a field campaign including comparisons with sonic data are presented.

(2) Robustness and operational performance of sonics are highly appreciated in scientific instrumentations but flow distortion and shadowing effects induced by sensor heads and transducers are still questioned. The same holds for corrections schemes derived from directed wind tunnel flows when applied on atmospheric wind data. Contrary to conventional sonics the 6 transducers of a “Multi-Path” sonic are grouped in a lower and an upper arrays vertically aligned to each other yielding 6 tilted and 3 vertical measuring paths. Depending on the inflow angle the most advantageously (windward) positioned triple of one vertical and 2 tilted paths is used to derive the 3D wind vector. The “uSonic-3 MP” sensor technique is explained and measurements taken from a recent comparison with various other sonic sensor are discussed for various turbulent situations.

Poster Session 10

41 Estimating carbon sources and sinks from different land-cover types in Indonesia using satellite-derived atmospheric CO2 measurement

Poster

Alberth Nahas, Ayuna Santika Putri, Yasinta Devytasari, Nur Faris Prih Waryanto, Nanda Putri Kinanti, Cici Sucianingsih, Hanif Ismail Saputra

Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), Jakarta, Indonesia

Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

For a large archipelagic nation like Indonesia, one of the challenges in monitoring atmospheric CO2 is deploying standard instruments for in situ measurements. While the number of ground-based observations for atmospheric CO2 is growing in recent years, its coverage is considered inadequate to fully represent the differences in land-cover types. As a result, data from satellite observations offer an advantage in providing better spatial resolution. This study aims at utilizing satellite-derived atmospheric CO2 measurement to estimate carbon sources and sinks from three land-cover types, namely agriculture, forest, and urban. We collected daily CO2 data from the NASA OCO-2 Level 2 bias-corrected XCO2 version 10r, covering the period 2015-2018. Meanwhile, the land-cover data is retrieved from the European Space Agency Climate Change Initiative (ESA CCI) data set version 2.0.7b for 2015. Carbon source or sink is determined by subtracting CO2 background values from observed CO2, where positive values refer to as carbon sources and negative values as carbon sinks. The daily data are then aggregated to four predominant seasons (DJF, MAM, JJA, and SON) and annual averages to assess the changes in emissions. In addition, the influence of land-cover types is examined by selecting areas of source or sink based on each type. Results show that areas defined as carbon sources or sinks vary from one season to another, with MAM being the period for dominant carbon sinks and SON for carbon sources. Variations in emissions are also attributed to different land-cover types, though the pattern is not immediately discernible.

65 Operational near-term iterative forecasting of greenhouse gas emissions from Finnish agricultural fields

Poster

Istem Fer[1], Olli Nevalainen[1], Henri Kajasilta[1], Laura Heimsch[1], Henriikka Vekuri[1], Stephanie Gerin[1], Åsa Stam[1], Toni Viskari[1], Julius Vira[1], Juha-Pekka Tuovinen[1], Tuomas Laurila[1], Mari Pihlatie[2], Liisa Kulmala[1,2], Annalea Lohila[1,3], Jari Liski[1]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Agricultural soils constitute a large carbon pool whose fluctuations over time can significantly impact countries' greenhouse gas (GHG) budgets. Rates of change in GHG emissions from agricultural lands can vary drastically due to soil type, weather and management, and in return affect the overall soil

carbon stocks and sequestration rates. This calls for reliable, low cost and operational monitoring, reporting and verification (MRV) systems for accurate estimations and accounting of fluxes and emissions. However, one of the biggest sources of uncertainty in these estimations originate from the field-level differences where agricultural lands often deviate from static emission factors that are typically used in national inventories and decision-making processes.

Towards addressing these challenges, we developed an MRV approach where a network of benchmark agricultural fields in Finland is being monitored and modeled with local simulations synthesized with site-level information. We operationalized a near-term iterative forecasting system based on the Predictive Ecosystem Analyzer (pecanproject.org) model-data integration cyberinfrastructure (Fer et al., 2020). In this workflow, gap-filled fluxes are integrated to daily values and assimilated into agro-ecosystem models jointly with remote-sensing derived observations, as well as in-situ measurements. The product of this data fusion provides the most reliable quantification of the GHG budgets from a field and disseminated via an online web service called Field Observatory (fieldobservatory.org, Nevalainen et al., 2022). The next steps in this approach are to i) provide decision support on agricultural soil carbon sequestration for atmospheric greenhouse gas removal and ii) scale up field specific estimations to the national level.

78 Operationalizing the Landscape-DNDC model through the Predictive Ecosystem Analyzer model-data integration cyberinfrastructure at SMEAR-Agri sites
Poster

Henri Kajasilta[1], Istem Fer[1], Olli Nevalainen[1], Laura Heimsch[1], Henriikka Vekuri[1], Stephanie Gerin[1], Åsa Stam[1], Toni Viskari[1], Julius Vira[1], Juha-Pekka Tuovinen[1], Tuomas Laurila[1], Mari Pihlatie[2], Liisa Kulmala[1,2], Annalea Lohila[1,3], Jari Liski[1]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The emissions from the agricultural lands contribute significantly to the national greenhouse gas (GHG) inventories. These emissions show high spatiotemporal variability due to large heterogeneity and variability in the ecosystems, weather and management practices. In order to closely monitor emissions and fluxes from agricultural sites, Helsinki University INAR RI Agriculture established two state-of-the-art measurement stations in Finland named SMEAR-Agri sites. Several measurements are taken from these fields, including eddy-covariance systems. Process-based modeling can be used to synthesize these different measurements, and re-scale process understanding from these intensively studied sites.
In this study, we couple the process-based Landscape-DNDC (Haas et al., 2013) model to the Predictive Ecosystem Analyzer (PEcAn, pecanproject.org, Fer et al., 2020) model-data integration cyberinfrastructure and simulate GHG dynamics at these sites. Coupling a model to PEcAn entails writing interfacing scripts that standardizes the execution of these models. In return, model-data synthesis workflows can leverage existing analytical modules in PEcAn such as for uncertainty analysis, calibration and forecasting. Here we report the progress of this coupling where we assess model performance before and after calibration, and its operational use in a simplified forecasting cycle. The model predictions are disseminated via an online web service called Field Observatory

(fieldobservatory.org, Nevalainen et al., 2022) and compared with observations and other model predictions at these sites.

93 Towards a Copernicus monitoring service for anthropogenic GHG emissions: an Ensemble of Data Assimilation for carbon dioxide and methane at ECMWF
Poster

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

In view of a new Copernicus anthropogenic CO2 emissions monitoring and verification support capacity developed within the CoCO2 project, the European Centre for Medium-range Weather Forecasts (ECMWF) is extending its data assimilation (DA) capabilities to estimate CO2 and methane (CH4) anthropogenic emissions.
Until now, the version of the Integrated Forecasting System used for atmospheric composition (IFS-COMPO) has exploited a short-window 4D-Var algorithm, which is not entirely suitable for the assimilation of long-lived gases such as CO2. In addition, the IFS-COMPO DA configuration is still based on a single, deterministic 4D-Var minimisation, while an Ensemble of Data Assimilation (EDA) has been utilised operationally in the IFS for Numerical Weather Prediction (NWP) since 2010.
This presentation focuses on the progress made on setting up an EDA for greenhouse gases (CO2, CH4). This approach consists of perturbing the observations, the model physical tendencies, sea surface temperatures and CO2/CH4 surface emissions, from which independent 4D-Var analyses are performed. A hybrid background error covariance matrix is used, with spatial correlations obtained from a combination of ensemble and climatological information. Furthermore, flow- and spatial-dependent background error standard deviations replace global and static vertical standard deviation profiles.
Currently, only retrievals of column-averaged dry-air mole fractions of CO2 and CH4 coming from GOSAT/TANSO and METOP-B/IASI are assimilated. The use of additional satellite instruments is anticipated in the future.
We present the results from a series of experiments to validate the system and to show its ability to approximate posterior error covariances in CO2 and CH4 emissions.

106 CO2 plume detection using deep neural networks: application to synthetic images of the XCO2 field over the Paris area
Poster

Joffrey Dumont Le Brazidec[1], Pierre Vanderbecken[1], Alban Farchi[1], Yelva Roustan[1], Marc Bocquet[1], Jinghui Lian[2,3], Grégoire Broquet[4], Thomas Lauvaux[2], Alexandre Danjou[4]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

In order to assess carbon dioxide emissions in a timely and accurate manner, the Copernicus CoCO2 project aims to build a prototype system for a CO2 emission monitoring service exploiting atmospheric CO2 measurements. As part of this project, our goal is to build an inverse system to improve the quantification of CO2 sources of large magnitude at urban scale based on the spaceborne imagery of the CO2 atmospheric plumes from these sources.
The reconstruction of such sources depends on the detection of the associated plumes in the satellite images of the CO2 average column concentrations (XCO2), which represents a significant challenge. Indeed, the signal of CO2 plumes induced by cities emissions is intrinsically difficult to detect since it rarely exceeds values of a few ppm and is perturbed by variable regional CO2 background signals.
To tackle the problem of CO2 plume detection, we investigate the potential of deep learning methods. Our models are trained on simulated XCO2 fields in the region of Paris, tracing the plume from Paris and other biogenic and anthropogenic fluxes. Convolutional neural networks are trained to predict the presence of the CO2 plume from Paris in an image. The impact of using additional input information such as meteorological conditions or temporal variations is studied and the performance of the network is evaluated. We show that full-day plumes are detected with an accuracy superior to 80%, some of them being missed due to day meteorological conditions. On the other hand, plumes at other times are always detected.

137 Changes in terrestrial carbon stock related to urbanization in Seoul metropolitan area
Poster

Joffrey Dumont Le Brazidec[1], Pierre Vanderbecken[1], Alban Farchi[1], Yelva Roustan[1], Marc Bocquet[1], Jinghui Lian[2,3], Grégoire Broquet[4], Thomas Lauvaux[2], Alexandre Danjou[4]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Urban is a major contributor to the total carbon emissions and urban forests are the only natural carbon sink. In this study, a forest carbon stock calculator is developed using high-resolution multi-remote sensing data, national forest inventory data, and machine learning algorithms that compute a real-time 2D carbon stock map reflecting multiple events, such as wildfires and long droughts. This is the first time to estimate terrestrial carbon stock changes due to urban regeneration in Gyeonggi-do, South Korea, where urban regeneration projects were actively carried out for 15 years from 2006 to 2020. Our results show that the forest area in 2020 decreased by 50% compared to 2006 and the carbon stock is reduced by 7%, from 118,269 tC to 108,989 tC. The relatively small reduction of carbon stock may be partially answered by improved carbon uptake efficiency over 15 years due to biomass growth and more efficient forest types. This study demonstrates the potential that urban is a major source of anthropogenic greenhouse gases, but can also be managed by urban planning through the reconstruction of more efficient carbon uptake forests. Our carbon stock calculator can be used to predict carbon uptake in land use, land-use change, and forestry (LULUCF) and can guide urban planning to achieve carbon-neutral goals. Our method is expected to have more advantages for countries such as East Asia that require both intensive development and carbon management in urban planning.

153 Assessing the usability of atmospheric CO2 observations for the Indian terrestrial carbon estimates

Poster

Joffrey Dumont Le Brazidec[1], Pierre Vanderbecken[1], Alban Farchi[1], Yelva Roustan[1], Marc Bocquet[1], Jinghui Lian[2,3], Grégoire Broquet[4], Thomas Lauvaux[2], Alexandre Danjou[4]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Estimation of the sources and sinks of CO2 into the atmosphere over the Indian continent has recently attained considerable attention. This is due to a possibly sizeable sub-tropical sink over the region, but the region simultaneously is a significant contributor to the emissions too. Atmospheric inversion modelling has been used to derive the geographical distribution of the CO2 sources and sinks at the global spatial scales. The development of regional surface observation networks of atmospheric CO2 and globally available satellite observations of CO2 enables these inversions to operate at a resolution close to the national scale. The goal of this study is to develop regional inversion systems that can assimilate these high-resolution observations over India. In addition to this model framework development, the present work investigates the potential of currently available observations in the inversions to deliver meaningful flux estimates at the country scale. In the conference, we will discuss the inversion approach based on CarboScope regional inversion, the choice of observations, and prior constraints, with the possibility of exploring uncertainties in each component.

161 40 years of atmospheric carbon dioxide monitoring in Hungary

Poster

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Atmospheric carbon dioxide monitoring was started in Hungary on 5 June 1981. The base of the measurements was the K-puszta background air pollution monitoring station operated by the Hungarian Meteorological Service, where the monitoring continued until July 1999. Overlapping monitoring was started at Hegyhátsál tall-tower greenhouse gas monitoring station, the present Hungarian ICOS atmospheric site (HUN), in September 1994. The 5 years of parallel measurements at the two sites 220 km away from each other allowed us to evaluate the spatial representativeness of the measurements and the limits of the combination of the two data series. Hegyhátsál is also a site for the NOAA cooperative global flask air sampling network, which provides a permanent quality control tool for the in situ measurements. Besides the presentation of the monitoring sites, the poster also presents the trend in concentration and the changes in the seasonal cycle at these mid-continental stations, as well as their similarities to and deviations from the global tendencies.

206 Estimation of greenhouse gas budgets in Finland - towards high temporal resolution atmospheric inverse model
Poster

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

It is urgent to quantify greenhouse gas (GHG) budgets on national levels in order to plan a country-specific climate change mitigation. In Finland, anthropogenic sources, such as fossil fuels and agriculture, and natural sources, such as forests and wetlands, are both equally important. Currently, there are four ICOS atmospheric stations in Finland and two non-ICOS stations continuously measuring atmospheric GHG concentrations at high precision. Those sites are located both in rural areas, measuring background air and capturing signals from natural sources, and in urban areas, where anthropogenic signals can be observed.

In this study, we use those high precision atmospheric data to estimates Finnish national CO2 and CH4 budgets using atmospheric inverse modelling systems (CTE-CH4, CIF). High resolution a priori fluxes are estimated using JSBACH-HIMMLELI for natural sources and sinks, and those for anthropogenic sources will be taken from Global Carbon Project. TM5-FLEXPART will be employed as an observation operator, and the fluxes will be optimized at 0.1x0.1 degree resolution. In addition to the surface atmospheric observations, we will assimilate satellite data, and evaluate the effect of the assimilated data. The national budgets will be estimated and update on annual bases, which will serve as an operational verification tool for national GHG reports.

222 Towards near-real-time estimates of greenhouse gas budgets
Poster

Philippe Ciais[1], Steven Davis[2], Sassan Saatchi[3], Zhu Deng[4], Benjamin Poulter[5], Frederic Chevallier[1], Giacomo Grassi[6], Zhu Liu[4], Rona Thompson[7], Galen McKinley[8], Nicholas Gruber[9], Pierre Gentine[10], A. d'Aspremont[11], Thomas Lauvaux[1], Clement Albergel[12], David Crisp[3]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

National inventories of anthropogenic greenhouse gas emissions and removals are annual at best, uncertain, and often miss components of the full national budgets. The assessment of the global CO2 budget by the Global Carbon Project is annual for the previous year and only provides national details for fossil emissions. The global CH4 budget was analyzed at a four-years interval and extends until 2017. The first N2O budget was produced last year until 2018. In the wake of the COVID pandemic, emissions dropped and are rebounding. Yet, green stimulus packages and enhanced pledges should deliver significant emissions reductions and develop projects to enhance carbon storage in some

regions. Therefore, emissions and sinks of greenhouse gases are expected to change rapidly in the coming years with contrasting trends between countries. To effectively monitor the fulfillment of emission reduction pledges in each country, more frequent observation-based assessments of national greenhouse gas budgets are needed to support national inventories. In addition to detailed coverage of managed lands surveyed by inventories, complementary knowledge of natural fluxes over unmanaged lands and the oceans is also required to unambiguously reconcile the foreseen reductions of anthropogenic emissions with the observed growth rates of greenhouse gases in the atmosphere. We show in this presentation that systematic observations in the atmosphere, and over the ocean and land surfaces can be integrated into near real time policy relevant greenhouse gas budgets to support the UN enhanced transparency framework of the Paris Agreement

227 Combined use of atmospheric and other data streams to constrain natural fluxes and anthropogenic fossil fuel emissions through Carbon Cycle Fossil Fuel Data Assimilation.
Poster

Thomas Kaminski[1], Marko Scholze[2], Peter Rayner[3], Michael Voßbeck[1], Wolfgang Knorr[1], Jeremy Silver[3], Hans Chen[2], Sander Houweling[4], Stijn Dellaert[5], Hugo Denier van der Gon[5], Ingrid Super[5]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The Paris Agreement foresees to establish a transparency framework that builds upon inventory-based national greenhouse gas emission reports, complemented by independent emission estimates derived from atmospheric measurements through inverse modelling. The atmospheric CO2 concentration reflects contributions from natural processes and from anthropogenic fossil fuel emissions. A Carbon Cycle Fossil Fuel Data Assimilation System (CCFFDAS) combines models of sectoral fossil fuel emissions, of natural fluxes and of atmospheric transport within an efficient variational assimilation framework. It can thus use atmospheric constituent measurements together with observations of the sectoral fossil emission model (such as nighttime lights and sectoral national emission totals), and observations of the terrestrial biosphere (such as remotely sensed FAPAR) as simultaneous constraints on the uncertain parameters in the fossil emission and natural flux models. We present the CCFFDAS concept including its treatment of uncertainty in observations and models and of lateral fluxes. We exemplify the operation of CCFFDASs at local and global scales and demonstrate how the system can inform the policy- and decision making process and how it can contribute to the monitoring of emission reductions at scales from local to national to continental. Finally we discuss planned applications and developments.

259 The 2019 Methane Budget And Uncertainties At 1 Degree Resolution And Each Country Through Bayesian Integration Of GOSAT Total Column Methane Data And A Priori Inventory Estimates
Poster

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

We use Optimal Estimation to quantify methane fluxes based on total column CH4 data from the Greenhouse Gases Observing Satellite (GOSAT) and the GEOS-Chem global chemistry transport model. We then project these fluxes to emissions by sector at 1 degree resolution and then to each country using a new Bayesian algorithm that accounts for prior and posterior uncertainties in the methane emissions. These estimates are intended as a pilot dataset for the Global Stock Take in support of the Paris Agreement. We find agricultural and waste emissions are 263 +/- 24 Tg CH4/yr, anthropogenic fossil emissions are 82 +/- 12 Tg CH4/yr, and natural wetland/aquatic emissions are 180 +/- 10 Tg CH4/yr. These estimates are consistent with previous inversions based on GOSAT data and the GEOS-Chem model. In addition, anthropogenic fossil estimates are consistent with those reported to the United Nations Framework Convention on Climate Change [80.4 Tg CH4/yr for 2019]. We find that total emissions for approximately 57 countries can be resolved with this observing system based on the degrees-of-freedom for signal metric (DOFS > 1.0) that can be calculated with our Bayesian flux estimation approach. Higher resolution fluxes calculated from upcoming satellite or aircraft data such as the Tropospheric Monitoring Instrument (TROPOMI) and those in formulation such as the Copernicus CO2M, MethaneSat, or Carbon Mapper can be incorporated in our Bayesian estimation framework for the purpose of reducing uncertainty and improving the spatial resolution and sectoral attribution of subsequent methane emissions estimates.

285 Quantifying and characterizing sources of CO2 and methane within the New York City metro area

Poster

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Cities contribute nearly 70% of global carbon emissions. Observations on different platforms (on-road vehicles, rooftop, aircraft) suggest different emissions for CO2 and methane in many urban areas. Satellite retrievals of CO2 and methane can be used to provide a "top down" constraint in some cities, but, for coastal cities, retrievals of CO2 and CH4 are not possible close to the land-water interface. New York City, a metro area of many islands, wetlands and rivers is the largest urban source of CO2 and methane in the USA. The current EPA methane inventory for NYC explains about one fifth of the methane emissions from the city observed from aircraft. We have developed a network of CO2 and methane observation sites around the New York City metro area. We use rooftop and mobile observations of trace gases co-emitted with various carbon source processes (e.g. ethane co-emitted with methane in Natural gas leaks, CO emitted during combustion) to identify the primary drivers of CO2 and methane emissions in the urban core. Changes during the COVID lock-downs of 2020 allowed us to test theories about the carbon source contribution from on-road transportation and economic activity in particular. Using our results, we examine the features most important for future satellites to retrieve CO2 and methane over coastal urban areas.

Poster Session 11

14 Assessing nitrous oxide emissions in time and space with minimal uncertainty using static chambers and eddy covariance from a temperate grassland

Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

We assessed the variability of N2O emissions in space and time using both static chambers (CH) and eddy covariance (EC) techniques, measured at a temperate grassland site under a fertilizer management (calcium ammonium nitrate [CAN]) in 2019. In addition to commonly used arithmetic statistics, daily mean CH emissions were also calculated using Bayesian statistics to explicitly account for the log-normal distribution of the dataset. N2O fluxes measured by CH and EC were most comparable when flux measurements were > 115 N2O -N µg m-2 hr -1, and EC and CH measurements showed spatial and temporal alignment when CH n ≥ 15. Where n ≤ 5, the Bayesian method produced large, asymmetrical uncertainties due to the difficulty of fitting an arithmetic mean from a log-normally distributed data set with few flux measurements. Annual cumulative fluxes by EC at a rate of 3.35 [± 0.5] kg N ha -1 were higher than CH using the arithmetic at a rate of 2.98 [± 0.17] kg N ha -1, and the Bayesian method at a rate of 3.13 [± 0.24] kg N h ha -1, which quantified emission factors of 1.46 %, 1.30 % and 1.36 %, respectively. This study implies that a large sample size and frequent CH flux measurements are necessary for comparison with ecosystem scale fluxes of N2O by EC, and that Bayesian statistics are an appropriate method for estimating realistic means and ranges of uncertainty for CH flux data sets.

94 A wavelet-based approach to characterise transitory CO2 flux events

Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

The need to reduce anthropogenic pressure on climate is now shared among most countries worldwide. A key challenge lies in predicting the evolution of greenhouse gases (GHG), notably CO2, by continental surfaces on a changing climate with land use and practices changes. Continuous and precise CO2 flux measurements on networks contribute to advances in this matter. Typically, CO2 fluxes are calculated over 30 minutes averaging periods using the eddy covariance method. FLUXNET and the regional carbon networks (e.g., ICOS, AsiaFlux, ...) share this standard. In sum, this method segments each period and correlates the vertical component of the wind-speed with the gas concentration, both sampled at 20Hz. Spectral approaches include Fourier transformed and wavelet spectral integrations that consist in decomposing the measured signals in frequency that are either localised in time (Wavelet) or not (Fourier). The Wavelet method is hence more adapted to non-stationary. It has been commonly used where time resolution matters the most, for instance, to assign

the flux spatially during aircraft flux measurements or capture short-term turbulent events for methane. In this study we apply a wavelet approach to help capturing transitory CO2 fluxes on two ICOS ecosystem flux towers (FR-Gri, a crop site close to a farm and FR-Fon, a mixed oak forest site). We evaluate how surface flux calculated with the wavelet and the standard eddy covariance compare, and the capacity to retrieve non-stationary fluxes, namely the release of storage flux in the morning at the forest site, and the advection flux at the farm site.

130 Quantification and partioning of pasture N2O emissions using eddy covariance and chamber measurements
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Emissions of N2O from agricultural soils are commonly described by the emission factor concept, i.e. as the product of an average emission factor (EF) and the nitrogen inputs to the grassland or cropland field. Emission factor values have been determined mostly on small experimental plots using the static chamber measurement technique. Such experiments may be problematic due to the chamber altering the environmental conditions, due to non-representative management operations, or due to strong spatial variations among chambers. The eddy covariance method, integrating emissions over a larger footprint domain, is well suited to quantify undisturbed field-scale N2O emissions, but the partioning of emissions for different nitrogen inputs and the determination of source-specific emissions and EFs is a challenge.

The study presents results of multi-annual field measurements using eddy covariance on fertilised and grazed pastures in Switzerland. A data-based partitioning method was used to attribute the observed field-scale emissions to the main source classes (synthetic and organic fertiliser applications, grazing excreta, and background). The attribution to urine and dung patches from grazing and to background was validated during one season by simultaneous chamber measurements. The partitioning allowed to calculate excreta-related and fertilizer-related N2O emissions and EFs. They were found to be lower for animal excreta and organic fertilizer than for mineral fertilizer applications. Potential problems like the gap filling of the flux time series and the definition and appropriate treatment of background emissions are discussed.

149 Assessing soil processes importance from global sensitivity analysis performed on soil-plant-atmosphere model DAISY
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue
In recent years, perturbations of precipitation regime have intensified due to climate change and has led to frequent droughts and waterlogged periods. In order to have a better understanding of the

impact of these perturbations on agro-system dynamics and their GHG exchanges, a modelling approach was combined with eddy covariance measurements. The 1D/2D open-source DAISY model was used as it has already been evaluated and compared to others frequently used models and as it simulates water, nitrogen and carbon processes for soil and plants with an hourly time resolution. Our objective is to apply this model to a 4-year crop rotation (winter wheat, potato, winter wheat, sugar beet) in Lonzée ICOS station (Level 2) that is representative of Belgian agricultural system with a silty loam soil (USDA).
As a first step in this modelling procedure, a global sensitivity analysis (GSA) was performed according to the Morris method with a focus on soil processes. To our knowledge, no GSA had been carried out on DAISY and, moreover, this step is often overlooked in modelling even though it informs on which parameter are influential and estimates the accuracy with which they must be determined. Sensitivity indices were computed, with GHG production as reference, for two whole years, providing information under specific conditions such as drought or waterlogged periods. Furthermore, GSA detected interaction effects between parameters highlighting the possible relation between soil processes.
The followed methodology and results will be presented with special focus on the analysis carried out over various edaphic conditions.

157 Quantifying understory and soil respiration fluxes in a mixed deciduous forest in Switzerland
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Understanding the biogeochemical carbon cycle is crucial to predict ecosystem responses to climate change. Therefore, it is critical to disentangle the ecosystem-atmosphere carbon dioxide (CO2) exchange of forests, i.e., CO2 uptake by photosynthesis and CO2 release by ecosystem respiration (Reco), including soil and plant respiration. Nevertheless, this is a challenging task, particularly for Reco due to the high spatial and temporal variability of respiratory fluxes within forests. One of the most efficient method to measure CO2 fluxes at high temporal resolution and integrating over large areas is the eddy covariance technique (EC). For example, below-canopy (BC) flux measurements can be used to study soil as well as understory CO2 fluxes. Yet, chamber measurements have proven useful to study soil respiration (SR), particularly in combination with BC flux measurements.
This study aimed to assess understory fluxes at the Lägeren (CH-LAE), a mixed deciduous forest in Switzerland. We used soil chamber measurements, performed during 2006-2013 as well as in summer 2021 and spring 2022, and BC flux measurements running since 2014. The objectives were (1) to test if an earlier model of SR in response to soil temperature and soil water content still applies today, (2) to partition Reco from BC flux measurements and determine its drivers, and finally (3) to compare flux magnitudes and drivers of SR from chamber and BC flux measurements. We hypothesized that the model still applied to today's measurements of SR, with a similar magnitude of SR and Reco, and main differences driven by understory vegetation.

162 Assessment of mitigation options in agricultural grassland for carbon and nitrogen emissions using the DNDC model

Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Fertilizer application and grazing are important farm management practices that impact the biogeochemical cycles of carbon and nitrogen. However, there is considerable uncertainty as to whether process-based models are able to represent greenhouse gas fluxes from alternating fertilizer and grazing events in intensively managed temperate grasslands. In the present study, the performance of the DeNitrification-DeComposition (DNDC) model was evaluated using eddy covariance measurements of nitrous oxide (N2O), ecosystem respiration (CO2-eco), and net ecosystem exchange (NEE) from a grassland site in Ireland. The DNDC model showed variable performances in simulating N2O, CO2-eco, and NEE between fertilizer application and grazing events, with the best performance observed in ecosystem CO2 with a coefficient of determination (R2) of 0.25 and 0.26, index of agreement (d): 0.63 and 0.60 and root-mean-square error (RMSE): 65.20% and 92.40% in the fertilizer and grazing periods, respectively. The DNDC model demonstrated fair performance in simulating cumulative N2O fluxes both in the fertilization and grazing events (R2= 0.28 and R2= 0.37, respectively). The model could adequately simulate the general patterns of the NEE but showed weak representations of the highly variable net ecosystem exchange. Sensitivity analysis showed that N2O emissions were sensitive to soil moisture content and temperature, bulk density, soil organic carbon, and management practices while CO2-eco and NEE were sensitive to temperature and thermal degree days. Our results suggest that, with additional improvements in biogeochemical process characterization, DNDC could become a useful tool for assessing the effects of agricultural management methods on greenhouse gas emissions.

174 Is shifting from conventional to reduced tillage worth the change in terms of greenhouse gas emissions: feedback from a long-term case study on a cultivated loamy soil in Belgium
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

The transition from conventional tillage (CT) to reduced tillage (RT) on cultivated lands to achieve carbon sequestration has shown variable impact on the greenhouse gas (GHG) balance at local sites from short to long-term studies. In this context, pseudo-replicated automated closed chambers were set up on two plots from a long-term (since 2008) differentiated tillage trial (conventional CT vs. reduced tillage RT) with four repetitions, on a loamy soil in Gembloux (Belgium). The aim was to analyse the temporal and spatial variabilities of N2O fluxes and the impacts of tillage with regards to soil physical and chemical drivers in the soil profile. Results showed no significant difference between treatments on mean CO2 and N2O emissions. Nevertheless, a visible tendency of higher N2O emissions on RT (>200%) echoes with previous experiment results over this site. The N2O emissions showed significant spatial variability within both treatments with coefficients of variation up to 400% between chamber measurements on the RT plot, especially during peak emissions, hampering

statistical comparison between treatments. These results called for further work on spatial variability at the plot scale and across the true four replicates of the trial for a finer comparison between treatments, hence further campaigns will benefit from manual chamber measurements to complement the automated closed chambers.

198 Constraints on ecosystem respiration using below- and above-canopy eddy covariance and forest-floor CO2 flux measurements in a subalpine coniferous forest
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Terrestrial ecosystems, and more specifically forests, act as an important carbon sink by sequestering about 30% of global anthropogenic CO2 emissions. Therefore, it is crucial to advance our understanding of forest CO2 fluxes in response to changes in climate. At the ecosystem scale, net ecosystem CO2 exchange (NEE) is measured above the canopy using the eddy covariance (EC) method. NEE is then partitioned into ecosystem respiration (Reco) and gross primary production, although still large uncertainties for this partitioning exist. Thus, additional constraints such as below-canopy EC and forest-floor CO2 flux measurements can improve the partitioning of ecosystem CO2 fluxes.
In this study, we used continuous measurements of above-canopy EC fluxes, below-canopy EC measurements and year-round automatic chamber measurements in a subalpine coniferous forest in Davos, Switzerland (CH-Dav; ICOS RI Class 1 station) to test the accuracy of Reco estimated from above-canopy EC measurements. Our objectives were to 1) compare Reco estimated from above- and below-canopy EC systems with automatic chamber measurements, 2) cross-validate the accuracy of Reco estimated from partitioning with below-canopy EC measurements and forest-floor CO2 exchange, 3) evaluate their respective responses to environmental drivers. We hypothesized that the forest-floor and below-canopy CO2 fluxes are dominated by soil respiration, while the above-canopy fluxes indicate a net carbon sink dominated by tree photosynthesis. Additionally, we expected that forest floor and below-canopy CO2 fluxes mainly follow changes in soil temperature and moisture, while Reco estimated from partitioning is primarily controlled by canopy photosynthesis, thus responds to light conditions and air temperature.

200 Long-term methane dynamics of a boreal fen in Northern Finland
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Boreal peatlands are a major source of global wetland methane emissions. Due to global warming, these emissions may rise strongly in future, exerting additional pressure on our climate system. Yet, long-term studies evaluating the impact of global warming on boreal peatland ecosystems are rare. In

this study, we have monitored methane emissions at a boreal fen in Northern Finland (ICOS ecosystem class I site) for 13 years (2007-2019) using the eddy covariance technique accompanied by measurements of abiotic and biotic variables such as peat temperature, water levels, and vegetation parameters. Peat temperatures strongly drove methane emissions, i.e., methane emissions were increasing markedly with peat temperature. In this presentation, we will show the long-term methane balance of the site and discuss the drivers underlying the year-to-year variation.

232 Insights from high-frequency soil carbon dioxide flux measurements in a mature oak plantation woodland: dealing with temperature inversions
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Forest soils contain a massive carbon stock, often equal to or exceeding that of the trees. Carbon is sequestered in soils due to the imbalance between large fluxes into and out of the soil. Despite its importance, however, the main flux of carbon from soils ('soil respiration'; Rs) is generally not well constrained. Better understanding of this flux and its sensitivity to environmental change is key both to improved estimates of current woodland carbon balances and for accurate prediction of carbon balances under changing climate and management scenarios.
Here, we present results from 8 automatic (closed-dynamic) chambers that were installed at the Straits Inclosure long-term carbon dioxide flux monitoring site in southern England. This is a mature oak plantation woodland which is prone to temperature inversions that result in a large build-up of carbon dioxide beneath the canopy overnight and into the morning. Both the inversion itself, and its break-up (usually by the mid-morning) can have a significant effect on the measured flux. This can be seen most clearly in the hysteresis behaviour when fluxes are plotted against soil temperature on a daily time-scale.
We show the importance of identifying these inversion events for seasonal/annual estimates of soil carbon dioxide fluxes and make recommendations as to how this could be done using a range of information typically collected at sites such as this.

266 Simultaneous CO2 and O2 flux measurements as an improved proxy for stem respiration
Poster

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Session A. Terrestrial ecosystems : A.1 GHG Fluxes at ecosystem level: Soil and Woody-tissue

Respiring cells in tree stems produce CO2 and consume O2 in a certain ratio (respiratory quotient, RQ), which typically is 1 for carbohydrate respiration. Practical measurements of "stem respiration" usually ignore the O2 uptake flux and solely measure the CO2 emissions at the stem surface assuming no alterations in CO2 while diffusing through the stem. This assumption has been criticized and suggested to measure the so-called apparent respiratory quotient (ARQ), i.e. the ratio of CO2 efflux and O2 influx at the stem surface.

Using a modified FC-2 Differential Oxygen Analyzer (Oxzilla, Sable systems Int., USA), a Li-820 Infrared gas analyzer (Li-Cor Biosciences, USA), and a fully automated gas-handling system, we measured O2 influx and CO2 efflux in custom-made steady-state stem gas exchange chambers allowing calculation of ARQ.
Between May-December 2021 we collected data from a total of more than 3500 measurement cycles (ca. 30 min each) on four mature beech trees. ARQ values ranged between ca. 0.6 to 1.5, indicating that post-respiratory processes at times significantly affected the CO2 and/or O2 fluxes. ARQ values trended towards higher values later in the year, potentially due to an increased contribution of CO2 net import to the site of measurement, but this remains speculative.
In conclusion, we found clear evidence that the common practice of measuring CO2 emissions at the stem surface can potentially result in significant bias of reported values of “stem respiration”. We highly recommend additional research into the addition of O2 measurements as a regular part of respiration measurements.

61 The impact of thinning and clear cut on the ecosystem carbon storage of Scots pine stands in Flanders, Belgium, after 15 years of management
Poster

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Forest ecosystems play a key role in the global carbon cycle. In the last decennia in many forests in Flanders a shift took place from Scots pines (Pinus sylvestris L.) to broadleaved trees to promote many forest services (e.g. climate mitigation, biodiversity, recreation). However, it could also influence the carbon stored in these forest stands. We investigated the impact of two common forest management strategies of Scots pine forests, on the carbon storage after 15 years of management. Four forest stands in Brasschaat, Antwerp (Belgium) were observed as case studies. The first forest management strategy was thinning of a Scots pine forest with group planting of seedlings of pedunculate oak (Quercus robur L.). The reference for this management strategy was an extensively managed pine stand. The second management method was the clear cut of a thinned pine stand, similar to its reference, followed by the plantation of oaks. For each stand, the carbon in all carbon pools (aboveground biomass, belowground biomass, litter and mineral soil) was measured. Results showed that for both investigated management strategies in a pine forest, no significant difference in the whole ecosystem was observed between both stands. However, some carbon was redistributed. After clear cut and a plantation of oak, the carbon in the top layer (0-30 cm) of the soil increased and in the forest floor decreased. For thinning with underplanting, little impact was observed. Though, here too, small modifications were present in the top layer of the soil.

146 10 years soil carbon sequestration in managed Sphagnum fields: The choice to harvest or perverse recently accumulated carbon in degraded peatlands
Poster

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Storing 1250-2000 Mg C/ha, peatland is the earth's most carbon-dense ecosystem. Drainage has converted more than 10% of these long-term carbon sinks to strong carbon sources. In parallel, this land-use change has led to biodiversity loss and water quality problems. A land-use alternative that allows rewetting of drained peatlands, while maintaining agricultural production is the cultivation of Sphagnum biomass as a renewable alternative for fossil peat in horticultural growing media (Sphagnum paludiculture).
We studied soil carbon and nutrient dynamics and Sphagnum productivity in a 14-ha site in Germany, where topsoil was removed and that was rewetted 10 years ago. The site was irrigated with nutrient-rich water and atmospheric nitrogen deposition was high. Our data show that 10 years after rewetting, despite high nutrient-loads, carbon sequestration was high within 2 year after initiation. The site accumulated 26 tons carbon per ha in 10 years.

Carbon sequestration by Sphagnum mosses benefited from high water tables raised by 27 mm annually. Newly stored carbon did result in only small methane release. Next to carbon, substantial amounts of nitrogen, phosphorus and potassium (561, 32 and 90 kg per ha, respectively) were sequestered. Choices in harvesting strategy of freshly formed Sphagnum fibers (complete, half or only living fibers) will determine long-term fate of the on-site carbon sequestered.
We conclude that depending on harvesting strategy wet peatland use aids in preventing soil carbon losses and downstream eutrophication. The importance of nutrients in fast-tracking carbon sequestration at low to moderate turnover warrants cross-ecosystem validation.

159 Understanding 25 years of CO2 fluxes at Loobos (NL-Loo)
Poster

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Loobos is one of the ecosystem observation sites with the longest period of record, since 1997. The forest, planted in the 1910's grew considerably and experienced climate variations. Here we analyse how well we understand the observed variations in GPP and TER by comparison with a short-term response model (A-gs, (Jacobs (1994) Arrhenius). By fitting the different parameters to the entire period of record and specific periods alone, we distinguish the effects of meteorological drivers (radiation, T, vpd, soil moisture) and the effects of gradual growth of the forest (e.g.: biomass, LAI, SOC) and disturbances (drought, heat waves). In this way, we quantify how well we understand the carbon fluxes based on external, meteorological drivers and internal ecosystem drivers. If

meteorological drivers dominate the variations, the A-gs model would be suitable for coupling to atmosphere models.

245 Spatial heterogeneity of organic carbon stock in soil profiles of a peri-urban Mediterranean forest ecosystem
Poster

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Session A. Terrestrial ecosystems : A.3 Stability of carbon pools following changes in climate and management in organic soils

Soil organic carbon (SOC) is essential for ensuring soil health and fertility, supporting key soil functions and related ecosystem services such as stabilization of soil structure and regulation of nutrient and water cycles. Moreover, SOC represents the largest terrestrial organic C reservoir but remains the largest source of uncertainty in future C cycle projections. In this context, Mediterranean areas show a high potential for C sequestration, but strictly dependent by anthropogenic pressure and changes in land use and climate. The amount, the spatial distribution, and the quality of soil organic matter, also evaluated through C and N stable isotopes, depend on transformation processes due to microbial activity. We applied a multidisciplinary approach to study C and N pools in the peri-urban Mediterranean forest of Castelporziano (Rome, Italy), a class 1 ecosystem station of the ICOS network (IT-Cp2) equipped with an eddy covariance tower measuring net ecosystem C fluxes. In the main site, several ecosystem types (e.g., holm oak, stone pine, Mediterranean scrub) and 14 soil profiles have been characterized and collected from a physical, chemical, isotopic, and spectroscopic point of view. Data will be discussed through an integrated approach to clarify the SOC dynamics in soil profile to deeper insight the processes of C stock and resilience of Mediterranean forest ecosystems. Results showing soil spatial heterogeneity may also help refining ICOS protocols for soil CO2 flux measurements which are very sensitive to the displacement of soil automatic chambers within each control point surrounding the eddy covariance tower.

Poster Session 12

30 Ground-based mobile measurements to track urban methane emissions from natural gas in twelve cities across eight countries

Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Since the 2021 United Nations Climate Change Conference in Glasgow (COP26), significant international efforts focussing on the rapid reduction of anthropogenic methane emissions have been announced. Most notably, over 100 countries have signed up for the Global Methane Pledge aiming to reduce global methane emissions by at least 30% by the end of this decade compared to the 2020 levels. In this context, the European energy sector, one of the most important mitigation targets, shows possibilities of a “no-regret” emission mitigation by eliminating losses in the natural gas distribution system. Previous studies in the USA have highlighted that the corrosion-prone natural gas distribution networks significantly contribute to the total methane emissions in urban areas.

This study highlights the value of rapidly deployable mobile surveys across different countries in providing actionable information in the quest for reducing methane emissions. We present a first synthesis combining the mobile survey data collected in twelve cities across large cities (London, Paris, etc.) as well as medium size cities (Katowice, Groningen, etc.) in eight countries.

We apply a consistent data analysis framework for all cities, which allows focus on shared characteristics and identification of generalized findings. When comparing our observation-based citywide emission estimates to inventory-based estimates of natural gas losses, we find reasonable agreement. However, we find that methane emissions from natural gas grid losses across cities are not equally distributed spatially, but dominated by a small number of strong/super-emitters, i.e. the biggest 10% of emitters are responsible 65-80% of overall emissions.

45 Inferring emissions from point sources: the use of high-resolution modelling and atmospheric chemistry

Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

A large fraction of the anthropogenic CO2 emissions is emitted by point sources. The Copernicus Carbon Dioxide Monitoring mission CO2M will cary, next to a CO2 imager, instruments to measure NO2 and aerosols. Since the lifetime of NO2 is short, satellite mapping of NO2 is well-suited to locate plumes and to estimate NOx emissions. By applying a NOx to CO2 emission ratio, estimates of the emitted CO2 can be obtained. However, there are several uncertainties that need to be addressed. These include the uncertain lifetime om NOx in plumes, the uncertainty in the NOx/CO2 emission ratio, and the fraction of NOx present as NO2. Here, we present results from high-resolution Large Eddy Simulations of plume dispersion including atmospheric chemistry to address some of these uncertainties. This work in conducted within the CoCO2 project, and aims to develop a library of plumes that will help to estimate CO2 point source emissions from satellite observations.

46 Using urban Eddy Covariance observations to inform a dynamic high-resolution urban CO2 flux model

Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

High-resolution monitoring systems of urban CO2 emissions integrating atmospheric observations are needed to assess the accuracy of the self-reported urban emission inventories and provide information useful for planning local climate change mitigation actions. This study presents a new approach for using direct urban CO2 flux observations derived by Eddy Covariance towers for optimising the estimates of a bottom-up high-resolution flux model in a dynamic data assimilation framework. The methodology is developed and applied in the city centre of Basel, Switzerland, defining a study area of 3 x 3 km which includes two long-term Eddy Covariance towers located 1.6 km apart. The results show that the applied method is most efficient when the areas covered by the Eddy Covariance flux footprints present less complexity in urban structure and CO2 source/sink mixture, such as street level sources originating from wide open areas. When strong building emissions are mixed with traffic originating by narrow urban canyon structures, then the accurate decomposition of the flux observations becomes more challenging. Additionally, the biogenic fluxes in the city green areas are a confounding factor in our results due to their extremely variable nature across the managed urban landscape. Overall, it is demonstrated that Eddy Covariance is a highly valuable tool for understanding and monitoring local scale source and sink processes within the urban environment and can be efficiently used for evaluating and optimising high-resolution models. Restrictions of the applied methodology, its scalability and complementarity to larger-scale and lower-resolution applications (e.g. atmospheric inversions) are discussed.

63 Metrics for assessing Linear Inverse Problems: a case study of a Trace Gas Inversion
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Multiple metrics have been proposed and utilized to assess the performance of linear Bayesian and geostatistical inverse problems. These metrics are mostly related to assessing reduction in prior uncertainties, comparing modeled observations to true observations, and checking distributional assumptions. These metrics though important should be augmented with sensitivity analysis to obtain a comprehensive understanding of the performance of inversions and critically improve confidence in the estimated fluxes. With this motivation, we derive analytical forms of the local sensitivities with respect to the number of inputs such as measurements, covariance parameters, covariates, and forward operator or jacobian. In addition to local sensitivity, we develop a framework for global sensitivity analysis that shows the apportionment of the uncertainty of different inputs to an inverse problem. The proposed framework is applicable to any domain that employs linear Bayesian and geostatistical inverse methods. We show the application of our methodology in the context of an atmospheric inverse problem for estimating urban GHG emissions in Los Angeles. Within its context, we also propose a mathematical framework to construct correlation functions and components of uncertainty matrices from a pre-computed jacobian that encompasses non-stationary structures.

69 Simulating atmospheric potential oxygen as a tracer for fossil fuel carbon dioxide
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

We present a novel modelling study investigating the use of atmospheric potential oxygen (APO), a tracer combining O2 and CO2 observations, for distinguishing regional fossil fuel CO2 emissions from terrestrial biospheric fluxes. Using a combination of anthropogenic and oceanic O2 and CO2 fluxes and the NAME Lagrangian particle dispersion model (LPDM), we simulate continuous APO data at the UK sites at the Weybourne Atmospheric Observatory and the Heathfield Tall Tower, in the east and south of the country, respectively (see talks by Penelope Pickers & Karina Adcock). We investigate the sensitivity of the model to each of the components used to simulate APO, including the fossil fuel and biospheric ratios of O2 to CO2 flux, and the oceanic O2 flux. Finally, we carry out an inversion technique using a hierarchical Bayesian Monte Carlo Markov chain (HBMCMC) method to obtain posterior estimates for the UK fossil fuel CO2 emissions. We find that the sensitivity to uncertainties in the fossil fuel and biospheric oxidative ratios is generally small relative to the regional APO contribution. However, the influence of ocean fluxes may be high during particular times of year.

107 On quantifying the uncertainties in simulating urban CO2 enhancements and atmospheric transport. A Lagrangian approach.
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Urban regions emit large amounts of fossil-fuel CO2 (ffCO2), and these emissions at city scales are uncertain compared to that at the global scale. Currently, the inventory-based emission estimates for ffCO2 show the uncertainty of 32.8 % and 132.4% in total and spatially disaggregated at 10 km resolution respectively for year 2017 over the Indian region. Inverse modelling that utilizes atmospheric observations has become a novel approach to improving the urban emission estimates, which can aid in monitoring each nation's progress toward their Paris Agreement climate pledges. Our study aims to implement a Lagrangian inverse modelling framework for improving the emission carbon flux estimation at a national scale over the Indian subcontinent.

We use the Stochastic Time-Inverted Lagrangian Transport (STILT) model to simulate CO2 enhancement signals due to city emissions, which will be used in the inverse modelling framework to improve the urban emission estimates. The present work assesses the potential of this Lagrangian based approach and quantifies uncertainties in simulating urban CO2 enhancements and atmospheric transport, including errors in simulating background CO2. This transport model error quantification is essential as it is a significant source of error impacting inferred surface fluxes via inverse modelling. Additionally, we use currently available observations to compare the model simulations. By incorporating sufficient observations with the adequate realization of error in the Bayesian inversion technique, we envision a more accurate carbon emission flux estimate for the Indian region. This model framework can be refined for accommodating advancements in the observations, available in the near future.

111 First results of fossil-fuel CO2 inverse modelling in European domain based on 14CO2 observations from the ICOS atmospheric station network
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

A well-established technique to estimate recently added fossil fuel CO2 (ffCO2) on the regional or continental scale is the radiocarbon (14C) method, which estimates ffCO2 from the observed 14C-CO2 depletion at a measurement site in relation to a “clean” background station. This top-down approach creates an independent, purely measurement-based source of information and, together with an atmospheric transport inversion, can be used to evaluate fossil CO2 bottom-up emission inventories.

In this study, ffCO2 is derived from two-weeks integrated 14C-CO2 samples of the Integrated Carbon Observation System (ICOS) atmospheric station network in the time period of 2016-2020. Based on these ffCO2 concentrations, we estimate European ffCO2 fluxes using the CarboScope regional inversion system including the high-resolution Stochastic Time-Inverted Lagrangian Transport model (STILT). Our results suggest that the GridFED bottom-up emission inventory of the Global Carbon Project (GCP) is consistent with the 14C-CO2 observations within the uncertainty bounds of both the inversion and the emission inventory.

160 High resolution CO2 fluxes from CarbonTracker Europe in near real-time: CTE-HR v1.0
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

We present the CarbonTracker Europe High-Resolution system (CTE-HR v1.0) that estimates CO2 exchange over Europe at high-resolution (0.1 x 0.2 degree) and in near real-time (roughly 2 months latency). It includes a novel fossil fuel emission model that uses easily available statistics on economic activity, energy-use, and weather to generate dynamic time profiles at high spatial and temporal resolution. Hourly net biosphere exchange calculated by the biosphere model SiB4 is upscaled using the high-resolution CORINNE land-cover map, and combined with GFAS fire emissions to create Net Ecosystem Exchange (NEE). An ocean flux upscaling based on wind speed and temperature for CarboScope is included in our product, to enable modeling of atmospheric CO2 mole fractions over Europe.

CTE-HR fluxes satisfactorily reproduce anomalous events for both the biosphere (i.e European drought of 2018) and fossil fuel emissions (i.e., COVID-19 lockdown) and thereby provide insight into variability of the European carbon balance. Its surface fluxes are in good agreement with ICOS tall-tower CO_2 observations, with RMSEs close to those of the (optimized) fluxes of CarbonTracker Europe. We find that CTE-HR's higher spatial resolution is especially beneficial for modelling point sources, such as power plants. Using local eddy-covariance fluxes from Amsterdam we validate the diurnal cycle on urban fossil fuel emissions.

CTE-HR fluxes will be updated monthly and are freely available from the ICOS Carbon Portal, to be used for near real-time monitoring and atmospheric modeling.

177 Effect of maintenance and construction practices on carbon sequestration of urban lawn as measured using the eddy covariance technique
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Urban areas are growing and are the highest contributors to global CO2 emissions. Urban green spaces such as urban lawn are a potential sink to offset part of the urban CO2 emissions locally. It is important to understand how the maintenance such as irrigation, mowing and constructions of a lawn as well as lawn age will affect the CO¬2 sequestration. In this study, our aim is to examine the impact of construction and maintenance practises, and environmental conditions on CO2 sequestration of an urban lawn in Espoo, Finland, using the eddy covariance (EC) technique. The EC measurements were conducted over a maintained lawn where part of the area was reconstructed using common practises to assess the impact of maintenance practices and constructions on CO2 flux. The EC measurements at 1.2 m height along with other meteorological and soil data were started in summer 2021 with the measurements still continuing in summer 2022. The total CO2 flux in summer 2021 was 66 g C m-2, indicating the urban lawn acts as source for CO2 over the period of June and September. The newly constructed lawn sequestered about 39 g C m-2 while the old lawn released about 248 g C m-2 during summer 2021 indicating a difference between the newly constructed and old lawns. As the next step, data from summer 2022 will be included to the analysis to understand carbon sequestration of the urban lawn in detail and the impact of the maintenance activities and environmental conditions on it.

194 Regional atmospheric inversions of CO2 and 14CO2 over Europe with LUMIA
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Radiocarbon (14CO2) has been widely used as a tracer to separate the natural and anthropogenic signals in CO2 atmospheric observations to quantify fossil fuel CO2 emissions and improve the estimation of natural fluxes. Due to its half-life time of ~5730 years, radiocarbon has already decayed in fossil fuels deposited millions of years ago as organic matter. Radiocarbon is naturally produced in the upper atmosphere. Still, it is a by-product of nuclear activities such as bomb tests and power generation, affecting its natural cycle and making disequilibrium fluxes. We are using LUMIA, the Lund University Modular Inversion Algorithm, for performing a series of observation system simulation experiments (OSSEs) inverting simultaneously atmospheric CO2 and 14CO2 observations from the Integrated Carbon Observation System (ICOS) station network across Europe to optimise the natural fluxes, the isotopic disequilibrium fluxes, and the anthropogenic fossil fuel emissions. In the OSSEs we apply an inverse model to simulated observations with assumed uncertainties to evaluate the impact of a potential observing system on the estimated target quantities, here, the radiocarbon observations on fossil fuel emissions. In this work, we evaluate the sensitivity of the estimated fossil fuel emissions

to constraining/prescribing 14CO2 related fluxes, to the spatial and temporal distribution of prior fluxes, and to the sampling strategy. This test setup of the inversion framework will allow us to perform regional CO2 inversions in LUMIA.

196 Comparing ICON-ART model concentrations with ICOS observations
Poster

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

High resolution modelling of greenhouse gas (GHG) concentrations is crucial for observation-based emission verification, as pursued in the integrated greenhouse gas monitoring system (ITMS) for Germany. In the ITMS, observations from ICOS towers and masts will be utilized.
Here we compare in case studies the Integrated Carbon Observation System (ICOS) observations of methane and meteorological parameters with the modelled equivalents, with special focus on the height dependency and the diurnal cycle. We employ the DWD's regional Icosahedral Nonhydrostatic (ICON) model with its ART (Aerosols and Reactive Trace gases) extension with various resolutions and model parameters. As input, we use the spatially highly resolved methane emission fields provided by TNO/Copernicus and for concentrations at the model boundary we use the ones provided by Copernicus Atmosphere Monitoring Service (CAMS). Considering the vertical profiles (temperature, wind) of the model output will allow to determine the model's capability to capture correctly the observed situation at the ICOS towers. Conclusions are drawn on the expected representativity error in different meteorological situations, as well as the required observation handling of ICOS GHG observations for the purposes of the ITMS.
This work has been funded by the German Federal Ministry for Digital and Transport programme for Development and Implementation of Copernicus services for public needs with the HoTC project.

208 Small and Lightweight Gas Measurement System for Unmanned Fixed-Wing Research Aircrafts
Poster

Hasan Mashni, Yann-Georg Buechau, Jakob Boventer, Andreas Platis, Jens Bange

Eberhard Karls University of Tübingen, Tübingen, Germany

Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

The ability to reduce CO2 and other gas emissions to meet global emission targets and air quality standards also requires measuring gas sources and sinks and gas transport mechanisms with the highest possible spatial and temporal resolution.
For a higher spatially resolution of gas distributions and concentrations in the sub-atmosphere unmanned aerial systems (UAS) can be used for in-situ measurements in conjunction with stationary ground measurements. In particular, the use of fixed-wing UAS due to their inability to flight longer

times and ranges with only a minor disturbance to the measured volume compared to widely used multicopter UASs.
This study presents a lightweight, small, cost-effective nondispersive infrared CO2 gas sensor system for universal use on board fixed wing UASs. The gas sensor is integrated into an aerodynamic 3D-printed housing, so-called "EGG-Pod". The housing is designed as a gas measurement system that acts as a passive pump which maintains a constant volumetric flow that feeds a gas measurement chamber during flight. This cost-effective approach can be transferred to other mobile platforms, due to its simple structure, and its scalability to fit other gas sensors.
To characterize this measurement system, the nocturnal CO2 stratification effect was measured. The ground-level build-up effect of CO2 is caused by ground cooling in radiant and anticyclonic weather conditions. The resulting CO2 vertical gradient was used to define the resolution of the system. For this purpose, flight measurements were compared with the measurements from the ICOS-Tower near Lindenberg Meteorological Observatory - Richard Aßmann Observatory (German Weather Service DWD).

Thursday, 15th September, 2022

Plenary Speakers

248 Supply-consumption simulations of natural gas in the European Union (EU) countries: Can Russian gas be replaced for the post Ukraine crisis period?

Plenary

Chuanlong Zhou[1], Biqing Zhu[1], Philippe Ciais[1], Simon Ben Arous[2], Hugo de Almeida rodrigues[2]

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The supply of natural gas from Russia may be cut off due to the Ukraine crisis. The objective of this research is to analyze the possibility of replacing Russian gas. Supply-storage-consumption simulations of natural gas were performed based on the physical flow balance in the daily resolution for European Union (EU) countries and the United Kingdom (UK) from 2017 to 2021. The analysis combined daily pipeline gas flow data from ENSTOG, ENTSOE power production, and monthly/annual energy statistics from Eurostat, IEA, and BP Statistical Review of World Energy. The consumption amounts and shares of Russian gas as well as other gas supply sources, including LNG import, increased EU gas production, and imports from other countries, were analyzed for different countries and seasons. Several approaches that can fill the Russian gas gap were discussed with their potential capacities: 1) reduce the public heating and house heating by shifting the temperature-consumption curves, 2) replace gas-powered electricity with biogas, coal, or nuclear supply 3) increase the LNG imports and pipeline gas imports from other countries, 4) rebalance the supply of extra non-Russian gas among EU countries through the pipeline network. The possibility of replacing Russian gas is discussed with different strategies that combine the approaches above. Also, the potential costs to the society, economy and climate were discussed for those strategies.

199 Mediteranean forests water use efficiency perspectives, can management limit climate change impacts ?

Plenary

Tom Taborski[1], Denis Loustau[1], Julien Ruffault[2], Nicolas Martin-StPaul[2], Christophe Moisy[1], Soisick Figueres[1], Hervé Cochard[2], Jean-Christophe Domec[1], Jean-Marc Limousin[3]

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Atmospheric water vapour pressure saturation deficit and soil water deficit are expected to increase dramatically in the Mediterranean region for the next decades due to the predicted rise in temperature associated with a decrease in precipitations. The objective of this study was to explore how managed forest ecosystems may respond to future climate in this particular context. We have modelled specifically the holm oak forest water use and growth in response to different climate and management scenarios.
The GO+ ecophysiological model that can implement the effect of management practices on stand water use and growth (Moreaux et al., 2020), was used to this end. Forest stands in GO+ are characterized by different canopy layers (overstorey, understorey, soil) and radiative transfer and

fluxes are modelled at an hourly time step. Here, we improved the original model soil-plant hydraulic representation by including the effect of xylem embolism on the loss of hydraulic capacity based on the SurEau-Ecos model framework (Ruffault et al., in press).

We check the model using observed data on the leaf phenology and stand growth, canopy fluxes and diurnal cycles in carbon uptake and annual water balance e.g. in the Puechabon forest (FR-Pue class 2 station).
Then, we simulated forest stands under different water regimes on different sites in the Mediterranean region as part of the SWATCH project to explore changes in water use, evapotranspiration, carbon balance and forest growth and production. In addition, we will explore how forest practices affect forest resilience in response to reduced water availability.

121 Importance of harmonizing radon datasets for reducing uncertainty in greenhouse gas emission estimates
Plenary

Dafina Kikaj[1], Edward Chung[1], Alan D Griffiths[2], Grant Foster[3], Chris Rennick[1], Jessica Connolly[1], Leigh Fleming[3], Scott Chambers[2], Tim Arnold[1]

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Current estimation of greenhouse gas (GHG) fluxes (emissions and sinks) on regional or global scales depends on the approach applied, i.e. bottom-up (based on data such as emission factors) or top-down (using measurements and atmospheric transport models). However, a significant uncertainty in top-down estimates of GHG emissions originates from atmospheric transport model error. To evaluate the contributing uncertainty from the atmospheric model, measurements of a surface-emitted atmospheric tracer with appropriate physical and chemical properties (simple and well-constrained source and sink), which responds directly to the atmospheric processes, would be highly valuable. Radon (222Rn) has been proposed as a suitable observable for this task.

Creation of standardized high-quality atmospheric 222Rn activity concentration datasets will be the most important step in the process of enabling optimal utilisation of 222Rn measurements by the climate research community studying the verification of GHG fluxes. To this end, we present a new protocol for processing measurements made by 1500L ANSTO dual-flow-loop two-filter radon detectors, including a crucial deconvolution step to correct for the instrument lag.
Measurements of 222Rn, are ongoing at 31 key European atmospheric GHG monitoring stations, 16 of which are part of the ICOS network. This study focuses on two sites: Heathfield (an inland, 100 m tall tower) and Weybourne (a coastal site) that are both used in GHG research by UK and European scientists. We present a unique 222Rn dataset for these sites and, in time, aim to expand uptake of our methods by researchers using similar measurement techniques at other sites.

Parallel Session 17

236 Global and regional carbon budget 2015–2020 inferred from OCO-2 based on an ensemble Kalman filter coupled with the GEOS-Chem model

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Understanding carbon sources and sinks across the Earth's surface is fundamental in climate science and policy. Developing new models based on state-of-the-art algorithms and data constraints can provide valuable knowledge and contribute to a final ensemble model in which various optimal carbon budget estimates are integrated. Here, we develop a new atmospheric inversion system based on the four-dimensional local ensemble transform Kalman filter (4D-LETKF) coupled with the GEOS-Chem model to infer the carbon fluxes from Orbiting Carbon Observatory-2 (OCO-2) V10r XCO2 retrievals. On average, the mean annual terrestrial and oceanic fluxes between 2015 and 2020 are estimated as −2.02 GtC yr−1 and −2.34 GtC yr−1, respectively, compensating for 21% and 24%, respectively, of global fossil CO2 emissions (9.80 GtC yr−1). Our inversion results agree with the CO2 atmospheric growth rates reported by the National Oceanic and Atmospheric Administration (NOAA) and reduce the modelled CO2 concentration biases relative to the prior fluxes against surface and aircraft measurements. Our inversion results are broadly consistent with those provided by other global atmospheric inversion models, although discrepancies still occur in the land-ocean flux partitioning schemes and seasonal flux amplitudes over boreal and tropical regions, possibly due to the sparse satellite observations and the divergent prior fluxes used in different models. Four sensitivity experiments are performed herein to vary the prior fluxes and uncertainties in our inversion system, suggesting that regions that lack OCO-2 coverage are sensitive to the priors, especially over the tropics and high latitudes.

64 Emissions Quantification of Carbon Dioxide Point Sources using OCO-3 Snapshot Area Mapping Mode.

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Nearly half of the anthropogenic carbon dioxide (CO2) emissions from fossil fuel combustion come from point sources such as power plants. Reducing emissions from these sources is essential for

mitigating climate change. Satellite instruments can detect and quantify emissions from point sources globally, providing an effective tool for monitoring. The Snapshot Area Mapping (SAM) mode of NASA's Orbiting Carbon Observatory-3 (OCO-3) provides column average CO2 concentration measurement maps over CO2 hot spots like cities and power plants. CO2 plumes from large point sources are frequently observed in SAM data, but their emissions quantification can be challenging. We employ a Bayesian inversion approach to quantify CO2 emissions from point sources using the SAM data and high-resolution WRF transport model runs. The grid-scale emissions optimization approach can disentangle multiple CO2 plumes in a single SAM map and it compensates for wind speed and direction changes. We use NO2 observations from the Sentinel-5p satellite to better assign emissions to point sources. We account for the observation time difference between Sentinel-5p and OCO-3 using WRF runs. We examine the ability of this OCO-3 observation system to account for measurement noise and data gaps, and to disentangle point sources from diffused and natural CO2 emissions.

225 The Greenhouse gas Observations of Biospheric and Local Emissions from the Upper sky (GOBLEU): Multi-species observations from passenger aircrafts in support of monitoring of anthropogenic emission

Oral

Hiroshi Suto[1], Akihiko Kuze[1], Tomohiro Oda[2,3,4], Ayako Matsumoto[5], Shigetaka Mori[6], Mayumi Shigetoh[1], Chiharu Hoshino[1], Yosuke Miyashita[5], Yasuhiro Tsubakihara[5]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

In 2021, the Japan Aerospace Exploration Agency (JAXA) and ANA HOLDINGS INC. (ANAHD) launched a new project, the Greenhouse gas Observations of Biospheric and Local Emissions from the Upper sky (GOBLEU). We introduced a “new passenger”, a carry-on luggage sized imaging spectrometer suites we newly developed, to ANA’s domestic passenger flights, and have started collected high-resolution (~100 m along track spatial resolution) spectra of nitrous dioxide (NO2), carbon dioxide (CO2) and solar induced fluorescence (SIF), with moderated spectral resolution. Our “passenger” instrument can be mounted on a passenger seat without any modification to the aircraft, and collects data routinely and frequently as regular flights go. The aim of our project is to quantify Japan’s subnational carbon emissions, especially from cities and individual sources with emission sectoral attribution in order to provide actionable information towards Japan’s 46% 2030 greenhouse gas (GHG) reduction goal. Based on the same remote sensing technique as ones used by GHG satellites, our project also prototypes the synergic use of CO2 and NO2 for enhancing the emission monitoring capability. We will show data from early GOBLEU flights and present data analyses that examine the utility of the new data we collect. We will also discuss the unique utility of our new aircraft observation and its potential contribution to GHG emission monitoring and the upcoming Global Stocktakes (GST) with an expanded observation coverage and frequency.

224 One year of aircraft vertical profile measurements of CO2, CH4 and CO in tropical east Africa

Oral

Kathryn McKain[1,2], Colm Sweeney[2], Arlyn Andrews[2], Andrew Jacobson[1,2]

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Globally, the African continent has the fastest growing population in the world and is projected to have very large increases in emissions of greenhouse gases and air pollution over the next decade, yet it is perhaps the least observed for atmospheric trace gases. Satellite measurements indicate greenhouse gas emission magnitudes and trends that are significantly different than those predicted by inventories and ecosystem models, but little ground-truth data by which to evaluate satellite retrievals for tropical Africa exist. We present one year of aircraft vertical profile measurements of CO2, CH4, and CO recently collected in Uganda in tropical east Africa. Measurements are sensitive to nearby urban emissions and regional-scale terrestrial ecosystem exchange, and reflect strong wet/dry seasonality with very large boundary layer enhancements from biomass burning and wetland emissions. This new dataset will be particularly useful for evaluating satellite retrievals of trace gases, which may be more uncertain in the tropics due to high aerosol and cloud abundances, and global models of biomass burning, which are based on satellite imagery that may be too coarse resolution to capture the numerous small fires that characterize the region. We present preliminary comparisons of the observed boundary layer enhancements and depletions to those predicted for the region by global inverse models, including those assimilating OCO-2 data and a 20-year climatological average of NOAA's CarbonTracker model optimized with in-situ data.

96 Seasonal, Inter-annual, and Inter-city Variability in Methane Emissions in the Northeastern US

Oral

Anna Karion[1], Subhomoy Ghosh[2,1], Israel Lopez-Coto[1,3], Kimberly Mueller[1], Sharon Gourdji[1], Joseph Pitt[3,4], Steve Prinzivalli[5], Elizabeth DiGangi[5], James Whetstone[1]

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Atmospheric analyses of methane (CH4) emissions in cities across the northeastern USA have consistently exceeded inventory estimates. Only one study, in Boston, examined emissions over multiple years, while others have provided snapshots at specific times. Most attributed excess emissions to natural gas leakage from the distribution sector and in-home gas use (post-meter emissions). Here we present results from two ongoing studies of urban CH4 in the Northeastern USA. First, we perform a regional analysis across five cities for one year to compare their emissions profiles using a consistent methodology across cities. The second study is an urban scale analysis using four years of CH4 observations in Washington, DC, and Baltimore, Maryland to examine seasonality and inter-annual emissions variability. In both cases, we developed a customized prior estimate of emissions in the cities of interest using available activity data and emissions factors and then compare bottom-up estimates with observed atmospheric enhancements.
In the multi-year study, we perform inversions to estimate posterior emissions for the Baltimore, Maryland and Washington DC metropolitan areas at monthly scales. We find that methane emissions

in both cities are seasonal, with generally higher emissions in winter. We also find a slight overall decline in emissions in Baltimore, but no detectable change in Washington, perhaps due to poorer observational coverage of that city in the earlier years of analysis. Posterior estimated emissions correlate negatively with temperature and positively with gas consumption, as has been found in previous studies, suggesting significant post-meter leakage of natural gas in urban areas.

223 Record high CO2 emissions from boreal fires in 2021 over the past two decades
Oral

Bo Zheng

Tsinghua Shenzhen International Graduate School, Shenzhen, China

Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Extreme fires affect the Earth's climate through their extensive direct carbon and aerosol emissions over a short period and the slow postfire recovery of ecosystems. We meet the great challenge to assess fire carbon budgets and their interaction with climate accurately due to substantial uncertainties in our current emission monitoring capability. Here, we developed a satellite-based global atmospheric inversion system for fire carbon release, integrating the latest fast-track carbon monoxide (CO) retrievals, meteorological fields, and prior information to estimate global fire carbon emissions with low latency. Based on the MOPITT (Measurements of Pollution in the Troposphere) version 9 CO product, we performed a two-decade global atmospheric inversion and reconstructed global fire carbon emission anomalies from 2000 to 2021. The inversion results suggest that the CO2 release from boreal fires during 2021 was exceptionally large, with the annual amount (0.48 Gt C) more than three standard deviations above the 2000–2020 mean. The difference in boreal fire emissions between the 2021 and 2000–2020 averages reached 0.29 Gt C, approximately equivalent to the total annual fossil emissions from Japan (0.28 Gt C) – the country with the fifth-highest emissions in 2020. The vast anomaly in carbon release during 2021 was consistent with the observed large fire occurrences in boreal forests at high latitudes that had rarely burned before. Our study urgently calls for monitoring capacity to evaluate boreal fire carbon budgets in time to help our understanding of the impact of fires on the build-up of atmospheric CO2.

Parallel Session 18

23 Development of a process-based high-resolution radon flux map for Europe: Not a straightforward exercise

Oral

Ute Karstens[1], Ingeborg Levin[2], Ida Jandl[2], Claudia Grossi[3], Jess Connolly[4], Dafina Kikaj[4], Arturo Vargas[3], Alessandro Rizzo[5], Marco Capogni[5], Marta Fuente Lastra[6], Susana Barbosa[7], Viacheslav Morosh[8]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Quantitative understanding of the processes governing radon production and transport in soils and its exhalation rate into the atmospheric boundary layer is essential, if we want to use this natural radioactive noble gas as a tracer for atmospheric transport processes. While production of radon in the soil is mainly determined by geological properties, such as soil texture and radium content, radon exhalation rate is governed by gas transport in the soil, i.e. molecular diffusion or advection driven by short-term meteorological variations. On a seasonal timescale, soil moisture content seems to be the main factor determining molecular diffusivity, and assuming steady state conditions may be sufficient to describe radon exhalation in a process-based flux model. However, a lack of high-quality, representative soil moisture observations makes it difficult to validate modelled soil moisture needed for parameterisation of diffusion in the large variety of soils in Europe, resulting in large uncertainties of seasonal exhalation rates. On shorter timescales of hours or days, the steady state assumption is no longer valid, as e.g. pressure changes can induce non-steady state advection fluxes. New high-resolution quasi-continuous radon flux measurements indeed show an unexpectedly huge variability. Simulating these non-steady state processes is, however, not straightforward, as, depending on the soil type, only less than 50% of the variability in the observations can be explained by variations of meteorological parameters, leaving us with huge uncertainties. Our current progress to simulate radon exhalation from soils will be presented, and requirements to improve this still unsatisfactory situation will be discussed.

172 Modelling of radon in application to methane emissions estimation in the UK

Oral

Edward Chung[1,2], Dafina Kikaj[1], Tim Arnold[1,2], Alistair Manning[3], Anita Ganesan[4], Chris Rennick[1], Simon O'Doherty[5], Angelina Wenger[5], Grant Forster[6], Daniel Say[5], Joseph Pitt[5]

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

To effectively tackle climate change, accurate quantification of greenhouse gas (GHG) emissions is essential. Existing top-down methods quantify fluxes by combining GHG measurements, the output of atmospheric transport models, and independent flux estimates. However, the effects of the uncertainty in the atmospheric transport models and the underlying meteorology that drives them are poorly quantified.

Typically, particle dispersion models are run assuming non-decaying, chemically inert particles for analysis of GHG concentrations in the 'regional' domain. In order to accurately model radon (222Rn) at this scale we show that consideration of radioactive decay is essential. In our analysis of atmospheric 222Rn we use the Met Office Numerical Atmospheric Modelling Environment (NAME) Lagrangian particle dispersion model and estimates of 222Rn fluxes from land to show a 222Rn model-measurement mismatch at three GHG observatories in the UK (Heathfield, Tacolneston and Weybourne).

The results of this analysis suggest times when the transport model might be over or underestimating the sensitivity of the ambient air measurements to methane (CH4) emissions, assuming that the 222Rn maps are accurate. The identified bias is used to correct the back-trajectory sensitivity maps for CH4 and show under what meteorological conditions emissions might be consistently poorly estimated. We, therefore, demonstrate how the measurement and modelling of 222Rn can assist in the quest how to improve our understanding of regional GHG emissions. Furthermore, we discuss the need for improvements to 222Rn flux maps in order to gain greater confidence in our methods to assess emissions estimate uncertainties.

126 Using radon-222 to determine 'background' concentrations of trace gases at the Weybourne Atmospheric Observatory, UK

Oral

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Atmospheric 'backgrounds' are well-mixed air masses that contain constituent gas species at concentrations considered representative of background values due to having little influence from localised sources of the species. In order to accurately assess long-term natural and anthropogenic emission influence and short-term pollution events on the atmosphere it is necessary to first identify these background atmospheric conditions; However, it is difficult to separate backgrounds from localised sources using measurements of the gas species alone.

Radon (222Rn) is a gas emitted exclusively from the earth's surface, and its only atmospheric sink is radioactive decay (t1/2 = 3.8 days). Due to this it does not accumulate significantly in the atmosphere on timescales longer than a month and is thus an ideal tracer of recent air mass contact with ice-free land surfaces. Radon can therefore be used as a tracer of any interaction with natural and anthropogenic land-based pollution sources.

In this study we have used a 3-year 222Rn timeseries (Apr2018 – Apr2021) from Weybourne Atmospheric Observatory, UK to derive monthly maritime background concentrations for CO2, O2, CH4, O3, N2O and H2. A two-step method was used to estimate the monthly background concentrations, the air masses remaining after these two steps were then investigated using NAME back-trajectories, to identify the origin of the air masses and determine the degree of land-surface

interaction. The resultant backgrounds are then compared to those calculated using a statistical method (rfbaseline), a meteorologically defined method, and for CO2 a modelled background derived using the STILT particle dispersion model.

35 Atmospheric Radon Monitor (ARMON): Overview of its applications in Spain and presentation of the new user-friendly monitor
Oral

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

The natural radioactive noble gas radon (222Rn) is widely used as atmospheric tracer for several applications such as the improvement of atmospheric transport models or the indirect estimation of GHG fluxes by the Radon Tracer Method. In order to carry on atmospheric studies with the highest possible quality, high sensitivity atmospheric radon monitors are needed.

The Atmospheric Radon MONitor (ARMON), designed and built at the Universitat Politècnica de Catalunya, is based on alpha spectrometry of 218Po electrostatically collected on a PIPs detector. This monitor allows measurements of few hundreds of mBq m-3 of radon in air. The first prototype of this instrument is already running at several Spanish stations in industrial as well as rural environments.

A new model of the ARMON was recently built and characterized in the mark of the projects MARE2EA (reference: 2019-LLAV-00035) and traceRadon (Reference: 19ENV01). The new instrument allows real time low radon concentration measurements, remote control and full spectra analysis.

An overview of the ARMON applications in Spain is presented here together with the presentation of current user-friendly monitor.

43 Use of outdoor radon activity concentration and radon flux data for radiation protection applications
Oral

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

We present the results of our research in the framework of the traceRadon1 project, regarding the use of outdoor radon activity concentration and radon flux data for two radiation protection applications.

The Basic Safety Standard Directive (2013/59/EURATOM) requires Member States to identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level, called radon priority areas (RPAs). The identification of RPAs is usually done through maps based on indoor radon measurements or on geogenic radon potential (GRP). We discuss here how GRP can be estimated using different geogenic quantities, including also outdoor radon activity concentration and radon flux data.

Moreover, we investigate how outdoor radon activity concentration and radon flux data can help to characterize radon wash out peaks in the ambient dose rate data, which are exchanged in the EURDEP early warning system for radiological/nuclear accidents (https://remon.jrc.ec.europa.eu/About/Rad-Data-Exchange). Indeed, the solid progeny of radon can be washed out from the air by rain and become deposited on the ground. This results in peaks in the ambient dose rate and a better understanding of them can prevent false alarms in the EURDEP system due to radon wash-out effects.

1This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

31 Overview on radon metrology
Oral

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Session F. Trace Gases : F.1 The role of radon gas as tracer of atmospheric processes, air mass origin and indirect retrieval of greenhouse gas emissions

Metrology provides the basis for the determination of absolute values, comparability of measurements and the use of data in models. Thus, traceability to SI units is a fundamentally necessary quality assurance for any scientifically reliable result.
The traceability chain for a new metrological challenge does not always already exist. For example, the focus of metrology for radon activity concentration was previously only in the area of radiation protection because of the need of measuring the relatively high radon activity concentrations in buildings. However, this type of traceability is not sufficient to provide traceability for high-resolution measurements of the very low radon activity concentration in the atmosphere. The traceRadon1 project aims to solve this gap in metrology, by extending the traceability chain from 100 Bq m-3 to 1 Bq m-3. This involves the development of new sources, new reference atmospheres and new transfer standards. By this, the use of radon as a tracer in climate observation is supported.

This presentation gives an overview on the basic needs for low level radon activities in regard to traceability, relevant standards and available facilities. Early results achieved by the traceRadon project will be included.

1This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

Parallel Session 19

240 The Modern Ocean Sediment Archive and Inventory of Carbon (MOSAIC 2.0): understanding the fate of terrigenous organic carbon in surface sediments

Oral

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Session C. Fluxes from local to regional scales : C.1 The fate of terrigenous organic carbon along the land-ocean aquatic continuum

Although the role of continental margins in the carbon cycle has been studied for decades, research has mostly been conducted in small spatial scales following different techniques, which hinders obtaining a clear global understanding of the distribution of the abundance, source, and age of terrigenous and marine organic carbon in continental margins. In recent years, the compliance towards data availability has led to the publication of large datasets in different repositories, but a proper harmonization of this sparsely distributed data is missing. To overcome this heterogeneous data presentation, the Modern Ocean Sediment Archive and Inventory of Carbon (MOSAIC) database [1] was recently established. This database compiles and curates data on the organic carbon content and its composition in continental margins, with emphasis on the isotopic (stable and radiocarbon) content of surficial sedimentary organic carbon to constrain the fate of terrigenous and marine organic carbon. It is continuously being developed and presently includes > 60 % more published and unpublished data and executes harmonization techniques designed to increase its richness and utility. Using more than 12000 datapoints of surficial organic carbon content, the database illustrates diverse global patterns in the distribution of high and low organic carbon in marine sediments worldwide, revealing that the role of continental margins in the global carbon cycle is highly heterogenous.
[1] Van der Voort, T.S., et al. (2021). Earth Syst. Sci. Data 13, 2135–2146. doi:10.5194/essd-13-2135-2021

254 Unaccounted methane emissions offset the carbon sink capacity of vegetated coastal ecosystems

Oral

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Session B. Marine and aquatic carbon cycling : B.1 Better constraining the European blue carbon stock

Vegetated coastal ecosystems can efficiently remove carbon dioxide (CO2) from the atmosphere and are, thus, central to nature-based climate change mitigation. However, current coastal carbon sink estimates must be questioned, as 1) rigorous evidence for the uptake of atmospheric CO2 by coastal

ecosystems through direct air-sea CO2 gas exchange remains understudied, and 2) concurrent but widely unaccounted natural methane (CH4) emissions from these environments could offset or even negate their value as atmospheric carbon sinks. We quantified hourly, daily, and seasonal air-sea CO2 and CH4 fluxes simultaneously using a fast-response automated gas equilibrator system for in situ continuous measurements across three globally prevalent coastal habitats with macroalgae, mixed-vegetation, and their surrounding unvegetated soft sediments. While unvegetated areas were predominantly a source of atmospheric CO2, the two vegetated habitats were mostly net sinks throughout the year, highlighting their potential for climate change mitigation. We also found that all habitats emitted CH4 in the order of 0.1 – 2.9 mg CH4 m-2 d-1 to the atmosphere, revealing previously unrecognised CH4 emissions from macroalgae habitats. Over an annual cycle, CO2-equivalent CH4 emissions offset 28 and 35% of the estimated carbon sink attributed to atmospheric CO2 uptake in the macroalgae and mixed-vegetated habitats, respectively, and augmented net CO2-eq. release of unvegetated sediments by 57%. Accounting for CH4 alongside CO2 sea-air fluxes becomes indispensable to correctly quantify the potential of vegetated coastal ecosystems as net atmospheric carbon sinks and develop informed climate mitigation strategies.

20 Blue Carbon and Alkalinity in contrasting coastal environments
Poster

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Session B. Marine and aquatic carbon cycling : B.1 Better constraining the European blue carbon stock

Coastal ecosystems like seagrass meadows are often considered sinks for 'blue carbon', due to their large belowground organic carbon stocks. However, fluxes of CO2 across the air-water interface vary between uptake and release, suggest that organic carbon burial is balanced by respiratory processes which generate CO2. These anaerobic respiratory pathways may also be a net source of total alkalinity (TA) which increases the CO2 uptake capacity of overlying water, due to the increase in the seawater buffer capacity when TA is produced in excess of DIC. This TA production in coastal systems can be considered another ecosystem service, due to its mitigating impact on coastal ocean acidification. To better understand the impact of benthic processes on coastal TA fluxes, we investigated two contrasting marginal systems, Florida Bay (USA) and the German Bight (southeastern North Sea).
We measured a suite of sediment-water fluxes (SO4, N2, TA, DIC, DOC, etc) in a tropical and calcifying seagrass meadow (Florida Bay), to identify the biogeochemical processes responsible for TA generation and consumption, and ultimate water-air CO2 exchange. We also investigated sediment-water exchange in the German Bight, with a focus on benthic TA fluxes. Florida Bay seagrasses were a constant source of CO2 to the atmosphere, largely driven by calcium carbonate precipitation. In contrast to the diffusive exchange in Florida Bay, advective processes dominated sediment-water TA exchange in the German Bight.

276 Measurements of the CO2 gas transfer velocity in Jade Bay
Oral

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Understanding the air-sea exchange of carbon dioxide (CO2) is important in order to predict the ocean's uptake of the gas. The speed of this exchange process is described by the gas transfer velocity. The gas transfer velocity is driven by surface ocean turbulence. However, it is difficult to measure both of these variables in the field. Existing uncertainties in the attempts to parameterise the gas transfer velocity with turbulence are based on the lack of such combined observations. To gain a combined dataset of both the CO2 gas flux and oceanic turbulence close to the air-sea interface, we use measurements onboard of the unique Sniffle buoy. The CO2 flux measurements are conducted with a floating chamber while the oceanic turbulence is measured with installed ADVs and a downward-looking 5-beam ADCP. The measurements are conducted in the coastal Jade Bay of the North Sea. Existing uncertainties in the parametrization of the gas flux and transfer velocity are particularly high in coastal regions, which feature higher dynamic variability than the open ocean. Based on the observations, we aim to reduce uncertainties in the air-sea gas exchange descriptions in coastal areas and better understand the specific processes that control the exchange.

179 The role of quality control into the value chain of ocean carbon observations
Oral

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Session B. Marine and aquatic carbon cycling : B.2 The value chain of (surface) ocean CO2 measurements

Ocean acidification, originating from the increasing release of anthropogenic CO2 in the atmosphere, is identified as one of the nine planetary boundaries. Planetary boundaries is a concept introduced in 2009 by Rockström et al., and offers a support to international governance systems in an objective of global sustainability.
Among the four parameters describing the ocean carbon system (pHT, TA, pCO2 and DIC), pH on a total scale (pHT) is the parameter enabling the direct quantification and follow-up of the changes in ocean acidification. It can also be used to derive other oceanic CO2 variables, providing key information on the study of CO2 accumulation in the ocean, acidification, and its impact.
Effecting reliable observations of pHT is thus of major importance in decision making for mitigation of, and adaptation to, ocean acidification.
Therefore, the quality control of measurement results submited in oceanographic databases is of major interest (cf. UNESCO sustainable development goal 14.3.1). It is an important component of the value chain in producing a solid basis to the observations.
To this respect, certified reference materials as well as uncertainty estimation of the measurements are necessary tools to provide meaningful observation results.
The presentation will address the implementation of the aforementioned concepts for the measurement of spectrophotometric pHT. Examples of collaborations between different communities involved in ocean observation will also be introduced (i.e. national metrology institutes, calibration laboratories, instrument manufacturers and national observation services).

123 Study of pH and CO2 variability in the Eastern Mediterranean Sea combining in situ, remote sensing and numerical modeling.

Oral

Natalia Stamataki[1,2], Constantin Frangoulis[1], Manos Pettas[1], Louisa Giannoudi[3], Kostas Tsiaras[3], Sylvia Christodoulaki[1], Andrew Luke King[4], Jukka Seppälä[5], Melilotus Thyssen[6], Giorgos Kouvarakis[7], Nikos Kalivitis[7], Nikos Mihalopoulos[7], Michel Ramonet[8], Valerie Masson Delmotte[8], Maria Kanakidou[7], George Petihakis[1]

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

In the Eastern Mediterranean Sea, the few in situ studies are insufficient for spatiotemporal consensus on where/when this area acts as a CO2 source or sink. This study presents an annual cycle of carbonate system variables measured at a fixed platform of POSEIDON system (HCB), located nearby the island of Crete. pH and pCO2 were measured at high frequency (3-6 hours) for the first time to our knowledge in the area. Continuous monitoring with sensors was complemented with laboratory measurements of pH, total alkalinity (AT) and total dissolved inorganic carbon (CT) via monthly sampling. pH from the sensor was validated against these samples. pCO2 from the sensor was validated against pairwise combinations of pH, CT and AT data, with pH and AT being the best combination. The atmospheric CO2 records at HCB were well correlated to those of Finokalia, the nearby atmospheric monitoring station. The carbonate variables measured were compared to those estimated by proposed regional algorithms which could satisfactorily estimate a) pCO2 using pH measurements along with AT and b) AT from sea-surface salinity (SSS). Furthermore, the diel to seasonal variability of pH and pCO2 was mainly driven by the sea-surface temperature. Comparison of in situ data against satellite derived ocean carbonate products (AT from SSS) showed good correlation concluding that satellite SSS could serve as a valuable tool for mapping carbonate variables. Finally, observations allowed the validation of a physical-biogeochemical model which was used to identify the spatial footprint of the carbonate variables in the Eastern Mediterranean.

Parallel Session 20

169 Estimating fire CO2 emissions using a joint CO/CO2 inversion driven by satellite data (OCO-2, TROPOMI) for the Amazon in 2019
Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The Amazon forest plays an important role in the global carbon cycle in terms of carbon storage which is jeopardised by deforestation (Davis et al. 2020). Deforestation and associated fire activity increased in recent years (e.g. INPE 2021; Pereira et al., 2020; Libonati et al., 2021). The 2019 fires in the Amazon region received much media and political attention. Fire activity in August 2019 tripled compared to August 2018 and reached a new high since 2010 (Barlow et al. 2020). Aside from fire activity data, we need information to quantify the amount of carbon released to the atmosphere. Here we report on the use of satellite observed carbon dioxide (CO2) and carbon monoxide (CO) column data from OCO-2, TROPOMI, and MOPITT to constrain the Amazon's carbon biomass burning emissions for a 6-week period in 2019. CO is used as a tracer of incomplete combustion (e.g. fires) which also releases large amounts of CO2. CO and CO2 inversions are performed using a data assimilation framework based on Carbon Tracker South America which applies an ensemble Kalman smoother with fixed-lag assimilation window (Luijkx et al., 2015). First, we separately optimise CO fire emissions and take these as fire prior emissions for a CO2 inverse run using CO/CO2 emission fractions. Subsequently, inversions are performed with coupled CO and CO2 budgets and their impact on inversion performance is evaluated. Additionally, we aim to test the use of short assimilation windows (<1 week). Here, we present preliminary results of the joint CO/CO2 inversions.

272 Possible solutions for estimation of the methane emission from coal mine ventilation shafts – source of validation data for IMEO.
Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Methane emission form both, drainage systems and ventilation shafts of coal mines, are enough efficient to be recognized from satellite platforms. Even though their location is fixed, the emission rate might fluctuate around average with spread of 75%. It is related to excavation efficiency and coal seam methane content. Amount of methane released to atmosphere from the single shaft of some hard coal mine in Poland (Silesia Coal Basin) is close to 10kt/year. However methane pledge EU

regulation is aimed to substantially reduce this emission, mines producing coke will probably remain unrestricted for a longer time. Application of contemporary optic techniques to instantly measure the methane concentration and release rate can be a base for monitoring well defined large sources which in term can serve as the calibration or validation points for methane observations carried from satellite platforms. We will present the wide range of possible instruments operating in harsh conditions occurring inside and outside of coal mine shafts and provide the accuracy calculation for some solutions. The demonstration campaign organised in Poland with the application of TDLAS open and close path instruments will be summarized.

136 MethaneSAT: Towards detecting agricultural emissions from space
Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The MethaneSAT satellite, scheduled for launch in 2023, is a joint American and Aotearoa-New Zealand (Aotearoa-NZ) initiative, involving a partnership between Environmental Defense Fund's(EDF) subsidiary MethaneSAT LLC, and the New Zealand government. The satellite's core mission is to catalyze CH4 emission reductions around the world by measuring atmospheric CH4 with unprecedented precision and mapping flux rates. While MethaneSAT was designed to detect emissions from oil and gas infrastructure, we hypothesize that it can also be used to measure more diffuse and thus harder to resolve agricultural methane emissions. We present plans for a research programme to develop and test this capability and first results from observing system simulation experiments (OSSEs) designed to assess how well we can quantify agricultural emissions from MethaneSAT data.

Aotearoa-NZ is the ideal natural laboratory for this research due to its distance from other land areas, its greenhouse gas measurement and modelling capability, and high agricultural CH4 emissions. Our project aims to develop the inverse modelling tools to quantify agricultural emissions from MethaneSAT data, and comprehensively test this capability with OSSEs and suborbital observations in Aoteaora-NZ. These observations will include-ground based information from eddy covariance and inventory data, aircraft observations, and total column measurements from two EM27 instruments and our long-running Total Column Carbon Observing Network instrument at Lauder. We are also developing a global agricultural targeting strategy for the satellite that will identify targets where the satellite is most likely to provide valuable new information.

132 Progress Towards Diagnosis of North American CO2 and CH4 Fluxes with the Expanded In-situ Measurement Network

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

North American biogenic carbon dioxide (CO2) fluxes and total methane (CH4) emissions remain poorly diagnosed at regional scales. Regional scales (areas smaller than the entire continent) are critically important because they are the scales (biomes, geopolitical units) over which management activities take place, and over which climate and ecological processes drive terrestrial fluxes. The rapid expansion in North American, tower-based greenhouse gas (GHG) measurements over the last decade, and substantial advances in atmospheric inversion methodology provide an excellent opportunity for improving our understanding of regional CO2 and CH4 fluxes. Here we discuss progress towards taking advantage of the extensive continental GHG measurement network (over 80 continuous, tower-based measurements, and over 20 flask measurement and aircraft profiling sites) and the newly operational continental-scale flux inversion system, CarbonTracker - Lagrange, to diagnose North American GHG fluxes at regional spatial and sub-seasonal temporal resolution from 2007-2018. These inverse flux estimates will eventually be cross-evaluated with comparisons of posterior mole fractions to independent atmospheric GHG mole fraction observations from the Atmospheric Carbon and Transport (ACT) - America Earth Venture Suborbital (EVS) flight campaigns, and with comparisons of posterior fluxes to regional clusters of flux towers. Also, a range of data removal experiments is planned, with the goal of illustrating the value of currently available tower and aircraft data in resolving both spatial structure and temporal patterns in GHG fluxes.

101 High-resolution methane emission estimates for Melbourne, Australia using in situ data, remote sensing and inverse methods

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Methane is a greenhouse gas and one of the most significant contributors to global warming. Methane is responsible for almost 20% of global warming caused by greenhouse gases since the pre-industrial period. Improving forecasts of the atmospheric burden of methane under different climate change mitigation pathways requires improvements in modelling systems and their inputs. Among such inputs, emissions play a significant role in methane modelling. There are different methods for producing methane emissions, including bottom-up (accounting or inventory methods) and top-down (inverse modelling using atmospheric measurements). Previous studies indicate that methane emission estimates produced by bottom-up approaches can have large disagreements with emission

estimates from atmospheric observations. This study aims to improve the urban scale methane emissions in Melbourne, Australia, using the combination of in situ atmospheric measurements, remote sensing and inverse modelling. In this study, a priori urban scale emission inventories are prepared from the Emission Database for Global Atmospheric Research (EDGAR) and locally available data. We run the offline WRF-CMAQ forward modelling system to derive the concentration of methane in the target urban area. After this step, we compare the model's outputs with the surface measurements and TROPOspheric Monitoring Instrument (TROPOMI) data product to assess the capability of the a priori emissions and atmospheric transport in estimating methane concentrations. Ultimately, a python-based four-dimensional variational (Py4DVar) data assimilation system is applied to refine methane emissions. The modelled posterior concentrations will be compared with independent observations to assess the capability of the modelling system in refining the emission data.

Parallel Session 21

158 Increased forest resistance to extreme atmospheric dryness: a case study of two characteristic Swiss forests

Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

High atmospheric dryness (or vapor pressure deficit, VPD) can drastically limit forest growth and productivity. We test the hypothesis that if VPD levels increase abruptly the negative effect on forest productivity is larger than when the increase is not abrupt. We tested our hypothesis on two characteristic forest sites in Switzerland – a sub-alpine spruce forest and a deciduous mixed forest dominated by beech. We detected abruptly occurring high VPD conditions (dry extremes) over 24 years in the spruce and 17 years in the mixed forest based on extreme deviation from mean weather conditions. Our results showed that while the frequency of abrupt dry extremes has increased only at the mixed forest site, the intensity has increased consistently at both forest sites. Secondly, using eddy covariance measurements of net ecosystem productivity (NEP), we show that the negative effect of abrupt dry extremes on NEP is significantly larger than the effect of non-abrupt dry extremes (approximately 7% more negative effect). Finally, we tested how forest resistance to abrupt dry extremes (defined as the ratio of change in NEP to increase in VPD during an extreme event) changed over time. We show that over the long-term resistance to abrupt dry extremes has increased significantly in both forests. These results suggest the possibility of a long-term biophysical acclimation of the forest, in light of increased atmospheric dryness.

40 Interpreting 2020 growth in atmospheric carbon dioxide concentrations as fossil fuel emissions declined

Oral

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Session G. Extreme Events : G.1 Abrupt changes in greenhouse gas fluxes in response to extremes: learning from observations to improve future projections

Monitoring systems designed for measuring atmospheric greenhouse-gas concentrations are under increasing pressure to provide timely and accurate information related to the drivers responsible for year-to-year growth. Over the past decade, while the rate of growth of greenhouse gas concentrations has increased, the interannual variability remains a challenge to attribute to natural and anthropogenic sources. For example, despite a temporary decline in carbon dioxide emissions in 2020, as society adapted to the coronavirus-19 pandemic, atmospheric carbon dioxide concentrations increased substantially. The 2020 increase in atmospheric carbon dioxide concentrations was instead similar to rates of growth for El Nino years. To understand this apparent discrepancy between decreased fossil fuel emissions and increasing atmospheric concentrations, we carried out an attribution study using remote sensing observations of carbon dioxide from OCO-2, vegetation

greenness from MODIS, and combined this information with land-and-ocean fluxes of carbon dioxide from process-based models. These data were integrated within NASA's GEOS atmospheric model to reconstruct atmospheric carbon dioxide anomalies and partition them to various sectors responsible. For 2020, we find that decreases in land-carbon uptake compensate for decreases in emissions, leading to sustained and increased atmospheric carbon dioxide growth. We also evaluate uncertainty in the marine boundary layer in-situ sampling network and find that compared with greenhouse gas satellites, there is good agreement, providing opportunity for low-latency satellite-based growth rate estimates. As climate extremes become more frequent, and as climate mitigation becomes more prominent, detection and attribution of greenhouse gas concentrations with lower latency can be addressed with satellite missions.

246 De-carbonization of global energy use during the COVID-19 pandemic
Oral

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Session G. Extreme Events : G.2 Effect of winter 2020 anthropogenic and climate anomalies on terrestrial, atmosphere, and ocean greenhouse gas exchange

The COVID-19 pandemic has disrupted human activities, leading to unprecedented decreases in both global energy demand and GHG emissions. Yet the mechanisms underlying have not been analyzed in detail, leaving questions about their causes and permanence. Here, using near-real-time, sub-hourly data on energy-related GHG emissions from 30countries totaling ~70% of global power generation, we show that the pandemic caused a dramatic decrease in the carbon intensity of power generation globally that reached a historical low of 414.9 tCO2eq/GWh in the first half of 2020. Moreover, the global share of energy derived from renewable and low-carbon sourcesexceeded that from coal and oil for the first time in May of 2020. Here we show that decrease in global net energy demand masks a large down-regulation of fossil-fuel-burning power plants supply (-6.1%) coincident with a surge of low-carbon sources (+6.2%). In response to changed individual behaviors, the diurnal cycle of electricity load shows strong distortions in 2020, including a flattening of the morning ramp, a lower midday peak, and delays in both the morning and midday load peaks in most countries. Overall, these changes favored solar power by moving the peak demand closer to the peak of daytime radiation. However, emission intensities in the power sector have since rebounded in many countries, and a key question for climate mitigation is thus to what extent countries can achieve and maintain lower, pandemic-level carbon intensities of electricity as part of a green recovery.

15 Leveraging Research Infrastructure Co-Location to Quantify Biogeochemical, Ecological and Social Constraints on Landscape-Scale Carbon Sequestration
Oral

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

Accurate assessments of the biogeophysical and societal controls on landscape scale carbon sequestration, storage and other relevant climate forcing agents are needed for credible climate policy. Integrated long-term site based observations, remote sensing (RS) and earth system models (ESM) all support the quantification and prediction of current and future landscape/ecosystem-scale carbon pools and fluxes. Long-term and large-scale site-based observations are of special importance as they document ongoing environmental change and “ground-truth” RS and ESM outputs.

The scientific and societal value of long-term, site-based monitoring increases with the duration of monitoring, the number of parameters measured and with timely availability of standardized, high quality data series. European-scale research infrastructure (RI) networks (e.g., eLTER, ICOS, ICP-IM) support the delivery of consistent, standardized data based on harmonized methodologies. The more RI networks are integrated through co-location of individual monitoring sites, the better ecosystem state (e.g., terrestrial carbon storage), biogeochemical constraints (e.g., macronutrient cycles), societal drivers (e.g., land use change) and tradeoffs (e.g. biodiversity) can be identified, communicated and managed.

Here, we highlight the potential for new insights into current and future landscape scale terrestrial carbon storage and sequestration that can be achieved when long-term terrestrial and aquatic monitoring sites participate in multiple RI networks.

74 Developing land-use decision-making models as inter- and transdisciplinary tools in LTSER regions
Oral

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Session D. Policy, Research Infrastructures and Society : D.1 Informing transformative change towards a sustainable future using integrated environmental research infrastructures

Effective climate change adaptation requires local contextualization of measures and integration into local long-term political agendas, as one-size-fits-all policies increasingly prove inadequate. Exploration of land users’ decision-making processes and their interdependencies across spatial and temporal scales delivers a basic understanding to inform the formulation and governance of such local adaptation strategies. This includes systematic identification and evaluation of drivers of land-use change stemming from intrinsic characteristics and cognitive processes of land users (such as attitude, lifestyle, farm structure and demography), as well as from external environmental, socio-economic and political conditions (such as climate change, market developments and subsidy regimes). We combine place-based qualitative and quantitative research to develop spatially-explicit agent-based land-use models in Long-Term Socio-Ecological Research (LTSER) platforms. The European research infrastructure eLTER and its LTSER platforms have large potential to deliver harmonized datasets from

ecological measurements, remote sensing, modelling and statistical sources as well as access to local stakeholder and support networks for transdisciplinary research. Enabling this research approach, eLTER allows for comparative cross-site analyses to identify regional differences and commonalities covering Europe's large diversity of socio-ecological systems. Supporting inter- and transdisciplinary research in such a manner, eLTER engages the scientific community not only across established research domains, but also with local stakeholders and the wider society to advance the Whole System Approach for in-situ research on Life Supporting Systems in the Anthropocene (WAILS).

Parallel Session 22

260 Operation of the ICOS-Cities urban CO2 sensor network in Zurich, Switzerland
Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

As part of the ICOS-Cities project, a hybrid urban CO2 measurement network for monitoring of CO2 with high spatio-temporal resolution is being set up across the city of Zurich. The network consists of CO2 instruments and sensors of different quality and cost, in particular two high-precision instruments, 19 mid-precision and mid-cost NDIR sensors and finally 60 low-cost devices. The sensors transmit data to a central database using a low power network (LoraWAN). All used instruments were carefully tested prior to deployment to ensure their suitability for the application.
As typical for sensor networks, the low-cost sensors used in this CO2 sensor network cannot be regularly and automatically calibrated using reference gases or instrument in the same manner as done with high quality sensors. Innovative strategies and concepts for quality assurance and quality control of the measurements are therefore necessary. However, the boundary conditions for the operation of low-cost sensors in a real sensor network inevitably lead to additional measurement uncertainties and measurement error. We present the implemented data post-processing chain and describe the concepts for identifying erroneous measured values, malfunctioning of individual sensors and for correction of sensor drift. The consequences of such additional sources of error and uncertainty for the Zurich CO2 sensor network will be discussed.

135 Mapping of regional terrestrial flux estimations over Indian region by considering the bio-physiological and environmental parameters.
Oral

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

The terrestrial biosphere is the largest natural carbon sink. Various bio-physiological processes and environmental conditions influence the terrestrial biosphere and its productivity. Due to these complex influences and feedback, the behavior and variability of the terrestrial fluxes are not sufficiently known, hindering an accurate carbon budgeting followed by the implementation of climate change policymaking and mitigation strategies. In order to better represent and quantify the atmosphere-biosphere CO2 exchange fluxes and ecosystem behavior in the inverse modeling framework, the Vegetation Photosynthesis and Respiration Model (VPRM) is employed in Indian region. VPRM is a satellite-based assimilation scheme with a simple model structure to facilitate successive parameters optimization in the inverse modeling framework. Model comparison with eddy covariance observations from distinct ecosystems showed significant model-observation bias even though the VPRM showed better performance than other existing terrestrial biosphere models over Indian domain. These results indicate the need for further refinement in model parametrization. Given

the climatology and biodiversity over Indian region, various environmental factors need to be considered in addition to what the standard model equations are composed of. The model showed improvement when environmental scalars such as soil temperature and moisture are incorporated into the model. We also utilized additional constraints from Solar-Induced Fluorescence (SIF) to improve the estimates. Since ecosystem processes are highly sensitive to a number of factors such as environmental conditions, vegetation type, phenology, etc, the modified model equation doesn't necessarily work well for all vegetation types. Our study addresses such site-specific analysis. Preliminary results will be presented.

247 First results of CO2 and H2O isotope-Flux Measurements in the Amazonia rainforest during the dry season
Oral

Robbert Moonen

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Session C. Fluxes from local to regional scales : C.4 New developments in mapping regional CO2 fluxes

To better constrain the budget of atmospheric CO2, the main inducer of climate change, we need reliable data on the biosphere-atmosphere exchange. Currently, CO2 exchange (flux) data is widely available but lacks separation into the counteracting sources and sinks as contemporary methods are unable to tell these apart. We aim to derive (climate sensitive) photosynthesis and respiration fluxes by exploiting differences within the isotopic composition of atmospheric CO2. As specific physical and chemical processes cause distinct isotopic fractionations, we can backtrack soil, plant, and atmospheric components of gross fluxes using local isotopic compositions. State of the art laser spectrometers let us derive isotopic compositions at temporal resolutions up to 10Hz, which allows for correlating isotope measurements to Scintillometer and Eddy Covariance fluxes. High-frequency H2O isotopologue measurements are also used as fluxes of CO2 and H2O are strongly linked and their isotopic fingerprints are interdependent. Together with local ecophysiology measurements giving us a ground truth, we get insight in the underlying processes at short temporal resolutions.
During August 2022, we will attempt to measure distinct isotopologue fluxes and ultimately partitioned CO2 and H2O fluxes above the Amazon Forrest at the 324-meter ATTO site in Brazil. To support the interpretation of measurements within CloudRoots we will model the isotopic exchange and underlying processes with conceptual and Large-Eddy-Simulation models. Our main goal is to further constrain the net exchanges of the largest contributor to global biosphere-atmosphere exchange, which itself is the largest source and sink of atmospheric CO2: The Amazon Rain Forrest.

Parallel Session 23

87 Controlled release experiment to verify mobile vehicle-based measurements of methane, ethane and δ13CCH4

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

Currently, numerous methods are used to determine sources and magnitudes of methane emissions, from global to local scale. In recent years, mobile, vehicle-based methane measurements have become more popular due to the relative simplicity of measurement set-up. Large scale studies of urban areas and individual facilities like landfills, wastewater treatment plants or natural gas infrastructure have been carried out. However, there have been few studies to verify or compare mobile measurement methods, especially relating to source identification.
We conducted a controlled release experiment, designed to demonstrate possibilities and limitations of using mobile, vehicle-based measurement, to determine methane emissions and fluxes from point sources, in September 2019. Controlled releases of methane and ethane were emitted for 45 minute periods from either ground level or 4 m above ground over five days under a range of wind conditions. The experiment allowed to compare a range of methodologies for calculating the methane emission rate, such as Gaussian plume modelling, Lagrangian particle dispersion modelling and algorithm based methods. The accuracy and detection limits of methods used to distinguish methane sources were verified, both for δ13CH4 isotopic signature and ethane to methane ratio. Finally, the obtained results provide an additional knowledge which leads to make recommendations on best practice for mobile vehicle-based methane measurements.
The results of controlled release experiment will be presented, focused on achieved precision and accuracy. Also, observed discrepancies between different methods will be discussed. Overall, we will show possibilities and limitations of mobile, vehicle-based methane measurements.

99 Detection and Quantification of Methane Super-Emitters by Combining Multiple Satellite Instruments

Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

With atmospheric methane concentrations increasing at record pace, identifying the “super-emitters” with the largest mitigation potential is paramount. The Tropospheric Monitoring Instrument (TROPOMI) aboard ESA’s Sentinel-5p satellite provides daily global coverage of methane concentrations at up to 7x5.5 km2 resolution. These data can be used to detect persistent methane emissions as well as large emission events such as accidents in the natural gas industry. We detect these emissions using a machine learning framework trained on methane plumes in the TROPOMI data. This automated machine learning approach allows constant global monitoring. While some plumes can be attributed to a specific source using just TROPOMI data, its kilometer-scale resolution usually does not enable that. Therefore, we use super-emitter detections made based on TROPOMI data to guide high-resolution instruments such as GHGSat, Sentinel-2, Landsat, or PRISMA to find the exact source(s) responsible. The meter-scale observations of high-resolution instruments over limited domains can then be used to identify the exact facilities responsible for the enhancements seen in TROPOMI and estimate their emissions. This information can subsequently be used to inform the operators allowing – for example – gas leaks to be fixed. We will show examples of these synergies applied to persistent emissions from coal mines and landfills and both persistent and transient emissions in the oil and gas industry. This combined use of satellite instruments gives us an important tool to enable and evaluate emission mitigation, evaluate the contribution of super-emitters to the global budget, and find targets for detailed on-ground observations.

244 Use of high temporal resolution measurements of the isotopic composition of methane to constrain emission inventories
Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

At Utrecht University, we have developed a field isotope ratio mass spectrometry instrument for high-precision dual isotope analysis (δD and δ13C) in atmospheric methane. The system has been deployed at various locations in Europe for multi-month time periods and we present an overview of the results of these long-term campaigns. The isotopic source signatures derived from two ICOS stations in the Netherlands, Cabauw and Lutjewad, show that CH4 emissions in these regions are dominated by

modern microbial CH4 formation. Measurements in Krakow, Poland, confirm that this area is dominated by fossil fuel sources.

Comparison to atmospheric models that include isotopic composition allow an isotope-based assessment of emission inventories. In Lutjewad, we concluded that both EDGAR v4.3.2 and TNO-MACC III inventories were generally in good agreement with the measurements, but fossil fuel related emissions were likely overestimated in the TNO-MACC III inventory. In Krakow, we concluded that the coal mining activities in Silesia are prominent CH4 sources . When using the EDGAR v5.0 inventory, the Upper Silesiam Coal Basin emissions in the model were in good agreement with the observations, but CH4 originating from the urban area was sometimes under-estimated in the inventory. The δ13C isotopic signature of the missing source was more enriched than from natural gas leaks, pointing towards the processing or combustion of fossil fuels. Mobile campaigns should iddentify CH4 sources from the use of fossil fuels instead of only the extraction. The categories in the inventory can then be redefined accordingly, to better represent the different sources.

275 Estimating Emissions of Methane Consistent with Atmospheric Measurements of Methane and δ13C of Methane in an Atmospheric Inverse Model
Oral

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Session E. Monitoring, validation and verification : E.1 Emission modelling and atmospheric monitoring of anthropogenic carbon emissions

We have constructed an atmospheric inversion framework to jointly assimilate measurements of methane and δ13C of methane in order to estimate source-specific methane emissions. Here we present global emission estimates from this framework for the period 1999 to 2016. We assimilate a newly constructed, multi-agency database of CH4 and δ13CH4 measurements. We find that traditional CH4-only atmospheric inversions are unlikely to estimate emissions consistent with atmospheric δ13CH4 data. Our framework attributes ca. 85% of the post-2007 methane growth to microbial sources. This contradicts the attribution of the recent growth in the methane budget of the Global Carbon Project (GCP). The GCP attribution is only consistent with our top-down estimate in the absence of δ13CH4 data. We find that δ13CH4 data can separate microbial from fossil methane emissions better than CH4 data alone can, and the largest uncertainty in using δ13CH4 data to separate different methane source types comes from our knowledge of atmospheric chemistry, specifically the distribution of tropospheric chlorine and the isotopic discrimination of the methane sinks.

Parallel Session 24

147 The Integrated Greenhouse gas Monitoring System for Germany – Modelling (ITMS-M): Opportunities for Model development

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Continuous monitoring of exchange of greenhouse gases between surface and atmosphere at policy-relevant scales based on atmospheric observations is needed in order to have independent information on changes in exchange fluxes, both from GHG emission reduction activities, but also from changes e.g. of biospheric fluxes due to a changing climate. The Integrated Greenhouse gas Monitoring System for Germany - Modelling (ITMS-M) Project starts this year, with funding from the Federal Ministry of Education and Research, with the aim to develop the capability for routine operational GHG monitoring using both in-situ as well as remote sensing data streams. Within the overall ITMS, this project covers the inverse modelling and data assimilation development, providing a demonstrator system, within the first of several (up to three) envisioned phases, with the final aim of establishing a fully operational system at the German weather service DWD. This presentation will illustrate the approaches chosen, and, if possible, very first results.

284 Low latency flux and concentration datasets in support of greenhouse gas monitoring based on NASA's GEOS modeling and data assimilation system

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

We present efforts to develop space-based greenhouse gas monitoring systems that can provide low latency information and traceability to independent observations. Through support from its Carbon Monitoring System program, NASA has developed the capability to assimilate XCO2 retrievals from the Orbiting Carbon Observatory, 2 (OCO-2) into the Goddard Earth Observing System (GEOS) Constituent Data Assimilation System (CoDAS) to create gap-filled, three-dimensional (3D) estimates of CO2 mixing ratio. When OCO-2 data are not available, concentration fields are further informed by a bottom-up flux package based on remotely sensed fire radiative power, nighttime lights, and vegetation reflectance combined with estimates of atmospheric growth rate based on surface in situ data. The 3D nature of this dataset supports evaluation with independent aircraft data, helping to ensure transparency of remotely sensed data products. These quasi-operational data are currently produced 2-3 months behind real time and are distributed via NASA and international dashboard services to a

variety of end users. In this presentation, we provide an overview of the system as well as remaining data gaps and modeling challenges. We also highlight the application of this dataset for detecting emissions anomalies associated with COVID-19 and comparing against independent emissions estimates. Finally, we highlight a new NASA initiative called the Earth Information System (EIS), which aims to support open science and applications by leveraging emerging cloud computing capabilities to increase access to NASA's greenhouse gas datasets, opportunities for co-development, and transparency in methods for analysis and flux attribution.

216 Linking regional to global greenhouse gas budgets in RECCAP2
Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Keeping global warming below 2oC by the end of the century, in line with the Paris Agreement, requires rapid reductions in greenhouse gas (GHG) emissions to reach net-zero emissions in the coming decades. This requires swift progress on GHG monitoring capabilities in order to link global growth rates of key GHGs to their specific sources/sinks at regional and, ideally, national scale, to robustly separate anthropogenic from natural fluxes and to provide low latency information about the progress towards climate change mitigation targets.

The second REgional Carbon Cycle Assessment and Processes (RECCAP2) activity of the Global Carbon Project aims to provide accurate information on regional sources and sinks of the three main greenhouse gases (CO2, CH4 and N2O) for the decade 2010-2019. Activities target: regional budgets for ten large land regions and six ocean regions that together cover the entire globe; several 'special focus' areas such as rapidly changing regions (permafrost and polar regions); the Land-Ocean Aquatic Continuum and lateral trade fluxes; the ocean's biological carbon pump; and future trends in regional GHG budgets. This effort is fueled by an ever-expanding constellation of in-situ and satellite-based GHG observations, and by increased process-based and data-driven modelling capabilities.
In RECCAP2, state-of-the-art datasets and modelling tools are being used to provide robust estimates of regional GHG budgets and constrain their uncertainties. Here, we will provide an overview of ongoing RECCAP2 activities, including progress regarding the harmonization of different approaches to estimate GHG budgets and showcase recent results for key regions.

184 Combination of XCO2 imagery and in-situ CO2 and 14CO2 measurements to monitor fossil fuel CO2 emissions at regional to local scales.

Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

The potential to quantify diffuse fossil fuel CO2 (FF) sources on large spatial scales, based on XCO2 images and atmospheric inversion techniques, may be hampered by the mix between the signal from such sources and from biogenic fluxes. The deployment of CO2 and radiocarbon (14CO2) ground-based networks could support the separation between the FF and biogenic signals. We evaluate this potential with a high resolution analytical inversion system focused on Northern France, Western Germany and a large part of the Benelux. The system hourly controls, for one day, FF emissions from the large urban areas and plants, in addition to regional budgets of more diffuse emissions and Net-Ecosystem-Exchange. The system assimilates pseudo-data from a single track of a 300-km swath XCO2 imager at 2 km resolution and from surface CO2 and/or 14CO2 networks. It represents the diversity of 14CO2 sources and sinks and not just the dilution of radiocarbon-free FF emissions. The uncertainty in the resulting FF emissions is derived to assess the potential of the different observation system combinations. The assimilation of satellite observations, over one day, yields estimates of the morning regional emissions with an uncertainty down to 10% in the satellite field of view (prior 15%). It does not provide direct information about emissions outside the satellite field of view. The co-assimilation of 14CO2 and CO2 data leads to a further reduction of the uncertainty in the FF emission estimates. However, this further reduction is significant in regions with three or more 14CO2 and CO2 sampling sites.

242 Final European synthesis of European GHG emissions and removals from the VERIFY project
Oral

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Session E. Monitoring, validation and verification : E.2 Towards operational monitoring of greenhouse gas emissions - the combination of satellite and in-situ data in an integrated system approach

Emissions and removals of greenhouse gases (GHGs) to and from the atmosphere including both anthropogenic and natural fluxes require reliable quantification, including estimates of uncertainties, to support mitigation action under the Paris Agreement. This study updates two ESSD publications and concludes a fourth scientific overview of bottom-up and top-down anthropogenic and natural GHG emissions data from all IPCC sectors in the European Union and UK. The VERIFY project establishes a pre-operational system of budgets for three different greenhouse gases which are

considered the major contributors to global warming: carbon dioxide, methane, and nitrous oxide. The data assimilates a wide range of different types of models, tightly integrating bottom-up data-driven and process-based models as well as top-down atmospheric inversions. We compare these results with official anthropogenic emissions (NGHGI) and research datasets, correcting wherever needed research data on total emissions/sinks to separate out anthropogenic emissions. We analyze differences between the different emission and sink estimates, and make recommendations towards future actions to evaluate NGHGI data.
Results are shown across the final three years of the VERIFY project. This study re-enforces the need for further advances in inverse systems: wider coverage of observational stations, more accurate accurate observation-based prior information (i.e. ecosystem model simulation) and the use of high-resolution transport models. In this direction, the VERIFY Community Inversion Framework (CIF) represents a novel approach to integrate various atmospheric transport models into a common inverse framework in order to provide quantitative estimates of different sources of uncertainty from atmospheric inversion (e.g, structural, within-model).

Parallel Session 25

241 Modelling marine carbon cycle in the Mediterranean Sea under present-day and future conditions

Oral

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

We simulated the marine carbon cycle in the Mediterranean Sea by means of the Biogeochemical Flux Model (BFM). The model was integrated in the Copernicus Marine Service reanalysis and in climate scenarios to simulate past decades and XXI century projections. The BFM, which includes 9 plankton functional types, nutrients and organic and inorganic carbon cycles and the carbonate system, was offline coupled to the ocean circulation model NEMO at the resolution of 1/24° and 1/16° for reanalysis and future projections, respectively.
Results of the Copernicus reanalysis show that the Mediterranean Sea is a weak sink of atmospheric CO2 (0.1±2.1 gC.m-2.y-1). The atmospheric and land carbon input accumulate in the basin mainly in the form of inorganic carbon which is then exported to the Atlantic Ocean. The export mechanism involves biological components and thermohaline circulation, making the Mediterranean Sea to behave as a continental shelf pump with respect to the Atlantic Ocean (net export of 12 PgC/y).
The climate projections highlight that the positive trend in atmospheric CO2 sequestration simulated by the reanalysis will steadily continue in the worst emission scenario (RCP8.5), while will tend to flatten by the end of the XXI century in the intermediate one (RCP4.5), demonstrating the effects of the implementation of reducing CO2 emission policies. Future projections show enhanced stratification, weakening of the thermohaline circulation and accumulation of inorganic carbon in the basin, with the eastern basin more impacted by changes in the circulation and carbon pump efficiency

278 Carbon and water fluxes over a urban park area in Naples

Oral

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

Knowledge of the contribution of urban forests and green spaces to the carbon fluxes in Mediterranean urban areas is extremely important for understanding the carbon mitigation potential by urban vegetation. This is even more relevant after the publication of the “European Green Deal” that supports the plantation of at least 3 billion of additional trees by 2030 in urban and peri-urban areas and the “Mediterranean strategy for sustainable development” (2016–2025) both oriented towards sustainable cities and climate neutrality.
Despite the importance, there is still little information regarding the carbon source/sink capacity of urban forests facing multiple stresses (e.g. high levels of air, water and soil pollution). To help in

addressing this gap, we take advantage of an eddy-covariance (EC) station in the "Real Bosco di Capodimonte", a large green area of 125 ha characterized by a mixed mature Mediterranean forest located within the city of Naples in Italy, to measure the CO2 and H2O fluxes. Considering the complexity of the EC tower footprint, we used a split-footprint approach to assign CO2 and H2O fluxes to the forested areas excluding the influence of the urban area.
Results showed that both CO2 and H2O fluxes are in the range of other natural evergreen Mediterranean ecosystems. In addition, the efficiency on sinking carbon is subjected to seasonal and inter annual variability, highlighting the role of physiological status of the vegetation. Finally, the vegetation of the Capodimonte Park can buffer and offset the carbon losses due to the residential area.

178 The complexity of coastal environments: unravelling the long term drivers combining data from two ICOS stations
Oral

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

PALOMA and C1-Miramare are two marine FOS ICOS stations that combine long monthly time series of the carbonate system with more recent near surface pCO2 continuous measurements. Both stations are located in the Gulf of Trieste (GoT), the northernmost part of the Mediterranean Sea, an area strongly influenced by meteorological and marine forcings, like river inputs, ocean warming and anthropogenic pressures. PALOMA site is located in the center of the gulf, whereas C1-Miramare site is close to the coast and the bottom depth is 25 and 17 m, respectively. The analysis of more than ten years of data highlighted the strong pCO2 undersaturation with higher pH during wintry months (PALOMA: 8.173±0.027 C1-Miramare: 8.175±0.037), driven by low temperatures, and a more variable situation in the other seasons. The anomaly of sea surface pCO2 showed an increase at both sites, coupled to a pH decrease of 0.002-0.004 units/yr. The high total alkalinity (TA) of N. Adriatic waters (PALOMA: 2668.8±37.6 µmol/kg; C1-Miramare: 2681.15±29.7 µmol/kg) favors CO2 absorption and changes in this parameter can modify the capacity of the GoT to act as a wintry carbon sink. While the long term trend of salinity anomaly showed an increase at both sites, TA increased at PALOMA and decreased at C1-Miramare, suggesting different weights of local riverine TA sources vs basin scale trends. These preliminary results show the benefit of combining data from more stations and the importance of both river-sea and basin scale integrated observations.

170 Greenhouse gases at the urban environment of Athens, Greece
Oral

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

Continuous greenhouse gases (CO2 and CH4) concentration measurements were performed for the first time in the city of Athens, from 21/12/2018 to date, and analyzed in relation to atmospheric levels, circulation patterns at a local, regional and long-range transport scale. In addition mapping of CO2 and CH4 and BC was performed around Athens to characterize possible “hot spots” of greenhouse gases. CO2 and CH4 present an annual cycle with maximum values during winter and minimum during summer. Clear diurnal and seasonal variations of greenhouse gases were detected, with elevated levels during night and early morning hours, associated with traffic/heating emissions and leakages of residential natural gas for CO2 and CH4, respectively. With the use of respective measurements at the regional background site at Finokalia, Crete, the contribution of local anthropogenic emissions within Athens was estimated. For CO2, maximum levels were observed during winter, suggesting an important impact of heating and especially of biomass burning on CO2 levels. On the other hand, the local CH4 levels did not seem to exhibit a seasonal trend and were similar in all seasons, suggesting that local sources of CH4 remain quite constant year-round. Backward trajectory simulations (FLEXPART) indicate industrial zones situated to the north and to the west of Athens respectively, as possible CH4 regional sources. For CO2 contributions from southern directions were also found and attributed to shipping emissions from the port of Piraeus. The present study provides knowledge needed for the determination of greenhouse gas emission mitigation strategies in Athens.

168 Assimilation of CO2 through remote sensing in a Juniper tree ecosystem at the Doñana National Park

Oral

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Session C. Fluxes from local to regional scales : C.2 Carbon cycle in the Mediterranean region: from the local to the regional scale

Doñana National Park is located in the southwest of the Iberian Peninsula, where water scarcity is recurrent together with high heterogeneity in species and ecosystems. The CO2 fixation by plants is given by the Gross Primary Production (GPP) and upscaling in situ estimates in these areas is challenging for regional and global studies, given the significant spatial variability of plant functional types and vegetation water stress in this area. The estimation of GPP is often addressed using light use efficiency models (LUE-models) which are based on the relationship between absorbed photosynthetically active radiation and its use by the plant, which establishes a maximum value per species or plant functional types that is reduced by environmental conditions. In this work, a LUE model is applied to a juniper tree (Juniperus phoenicea) ecosystem using Terra/Aqua MODIS images from 2014 to 2015. The model was tested in two ways to reduce the maximum efficiency value by: 1) forcing it with meteorological variables; 2) forcing it with both meteorological variables and a water stress index from a Two-Source Energy Balance model evapotranspiration retrievals. Both approaches were validated with in situ data from an Eddy-Covariance station. The results showed that although the application of the LUE with meteorological data had an acceptable error (~0.9 gC/m2), the use of the water stress index improved the results in situations of scarcity or abundance of water (summer and winter, respectively).