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traceRadon

First results from a new portable two-filter dual-flow-loop radon detector

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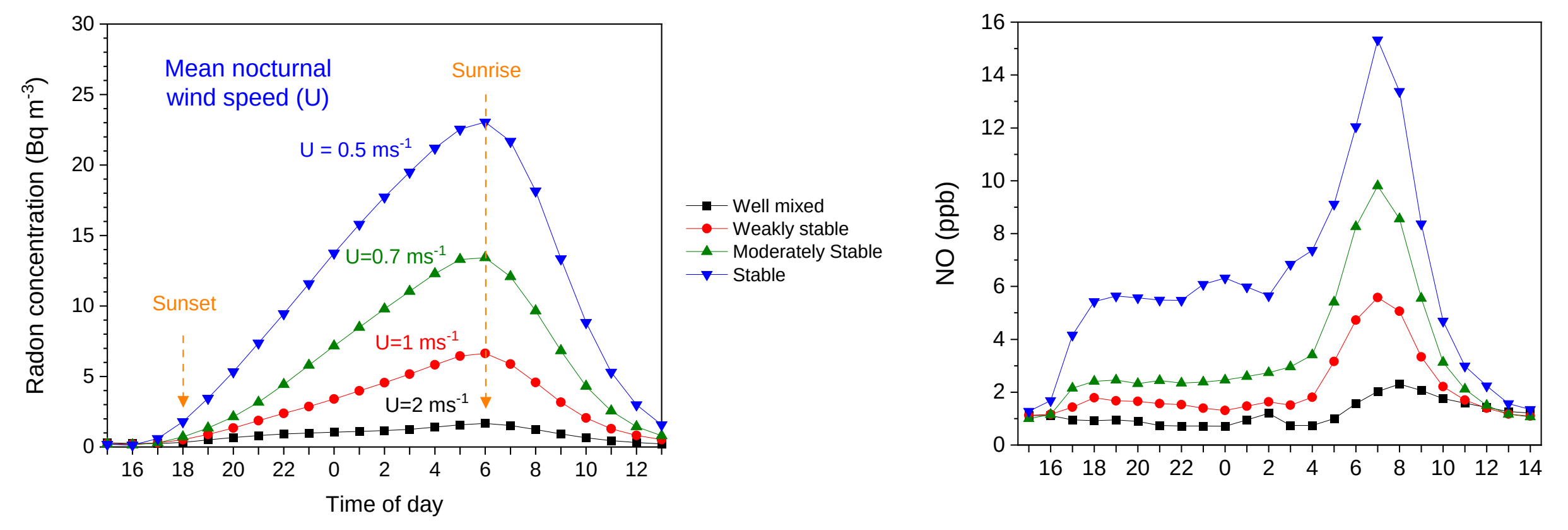
There is a growing need within the climate science, air quality and radiological protection communities, for a portable direct atmospheric radon (^{222}Rn) monitor suitable for indoor or outdoor deployment that has a low detection limit, high measurement precision, and a calibration that is traceable to the International System of Units (SI).

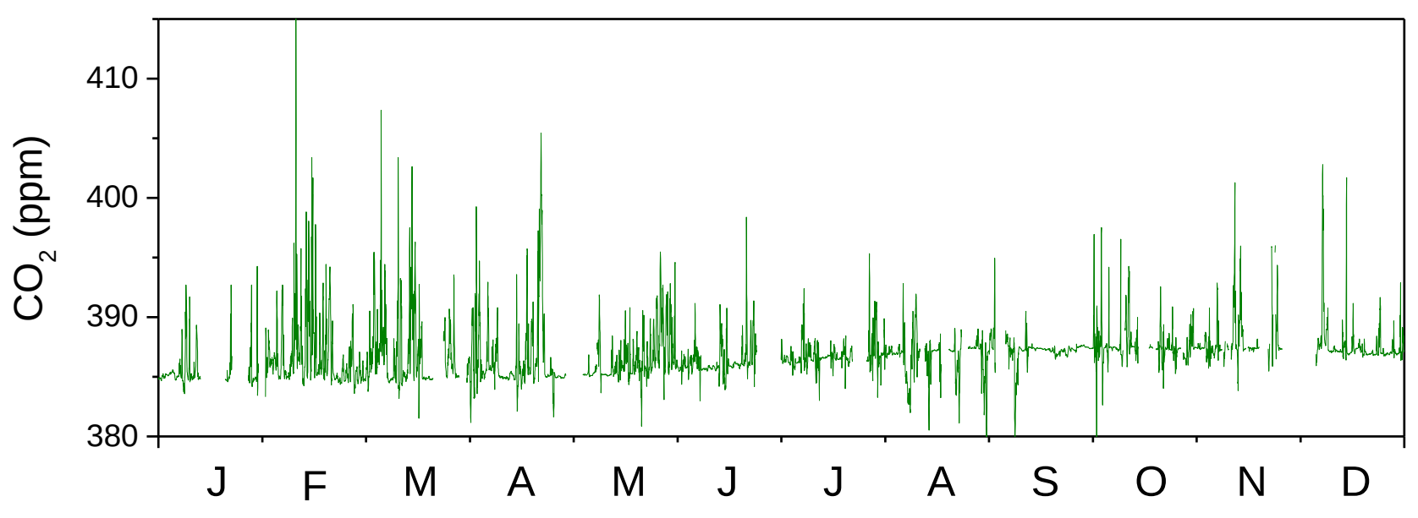
Environmental Radon Monitoring Measurement Requirements

Accurately resolving outdoor radon concentrations across the diurnal cycle at hourly temporal resolution, and reliably constraining vertical radon gradients within the surface layer (lowest ~10% of the atmospheric boundary layer, ABL), are essential for (i) developing radon-based classifications of the atmospheric mixing state, and (ii) using radon to evaluate the performance of transport and mixing schemes in urban climate or chemical transport models (Chambers et al. 2019 a,b).

In many locations ambient afternoon radon concentrations, when the ABL is deepest and most strongly mixed, can routinely drop to ≤0.5 Bq m^{-3}. Furthermore, vertical radon gradients in the lowest 100 m of the atmosphere at this time are typically of order 0.2 Bq m^{-3} (Chambers et al. 2011; Williams et al. 2011). Identifying predominantly oceanic air masses also requires a radon detection limit of ≤0.2 Bq m^{-3}. Contemporary commercial radon monitors, however, have detection limits ≥2 Bq m^{-3}, and the most accurate research-grade monitors are too large to move frequently.

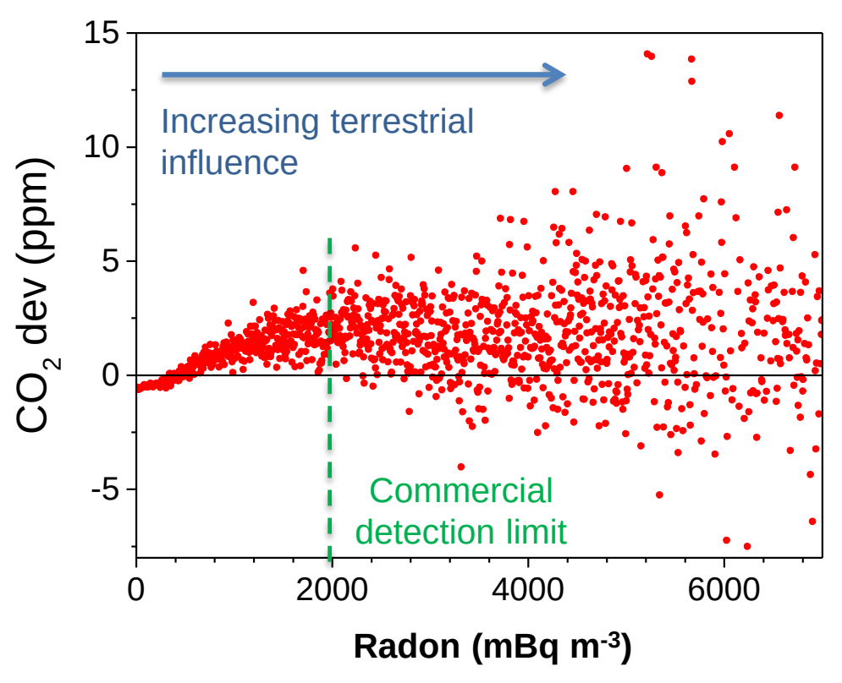


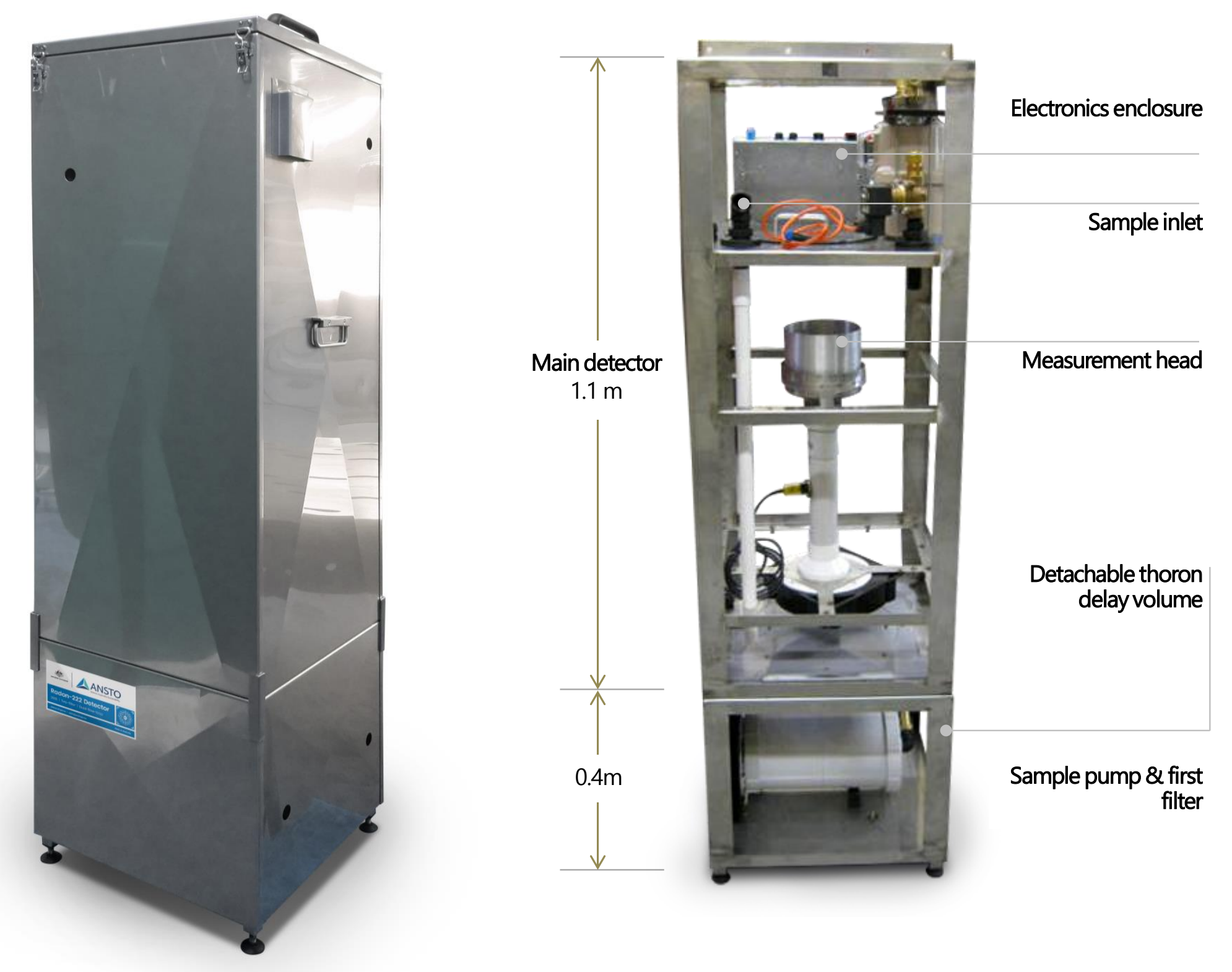
Near-surface radon observations can be used to define atmospheric mixing categories. Air quality parameters grouped accordingly exhibit typical behavior within each mixing state by averaging out spatial variability in emissions. Averaging in this way also helps to bridge the scale gap between measurements and simulations.



1-year of hourly CO_2 concentrations recorded at the Cape Grim Baseline Atmospheric Pollution Station, 250 km south of the Australian Mainland.

Deviations of CO_2 from the monthly mean value resulting from land-based sources and sinks show decreasing variability with decreasing degree of recent terrestrial influence as determined using radon as a proxy for land contact. The detection limit of commercial instruments is not sufficient to resolve oceanic values.

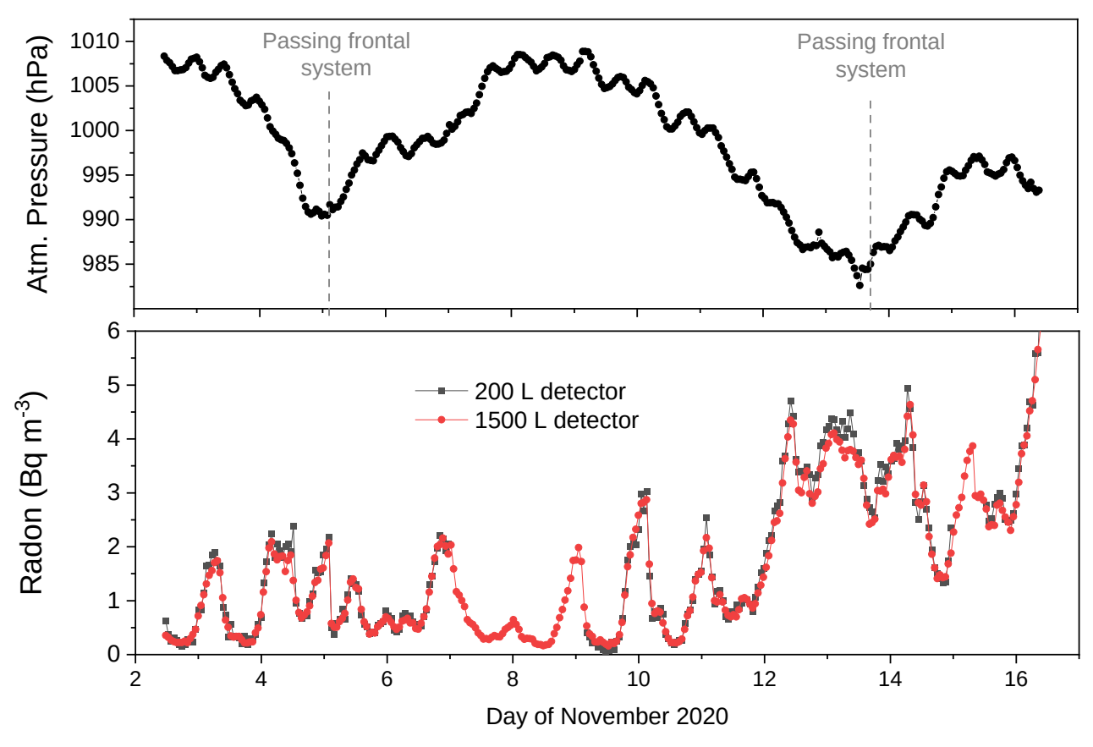




200 L two-filter dual-flow-loop ^{222}Rn detector

The new 200 L detector stands 1.5m tall and is 48cm wide. It separates into 2 pieces for transport in a standard vehicle. It is weather resistant (constructed of marine grade stainless steel), has low maintenance requirements for up to 5 years, and has a low power consumption (~100W at 240V).

The detector has a sampling flow rate of 12-15 L min-1, a <45-minute response time (correctable in post processing; Griffiths et al.. 2016), and has a 30-minute temporal resolution. It's sensitivity to radon is estimated to be 2.5 – 3 counts per minute / Bq m^{-3}, yielding a lower limit of detection around 0.15 – 0.2 Bq m^{-3}. Calibrations are automatic, and are conducted *in situ*.



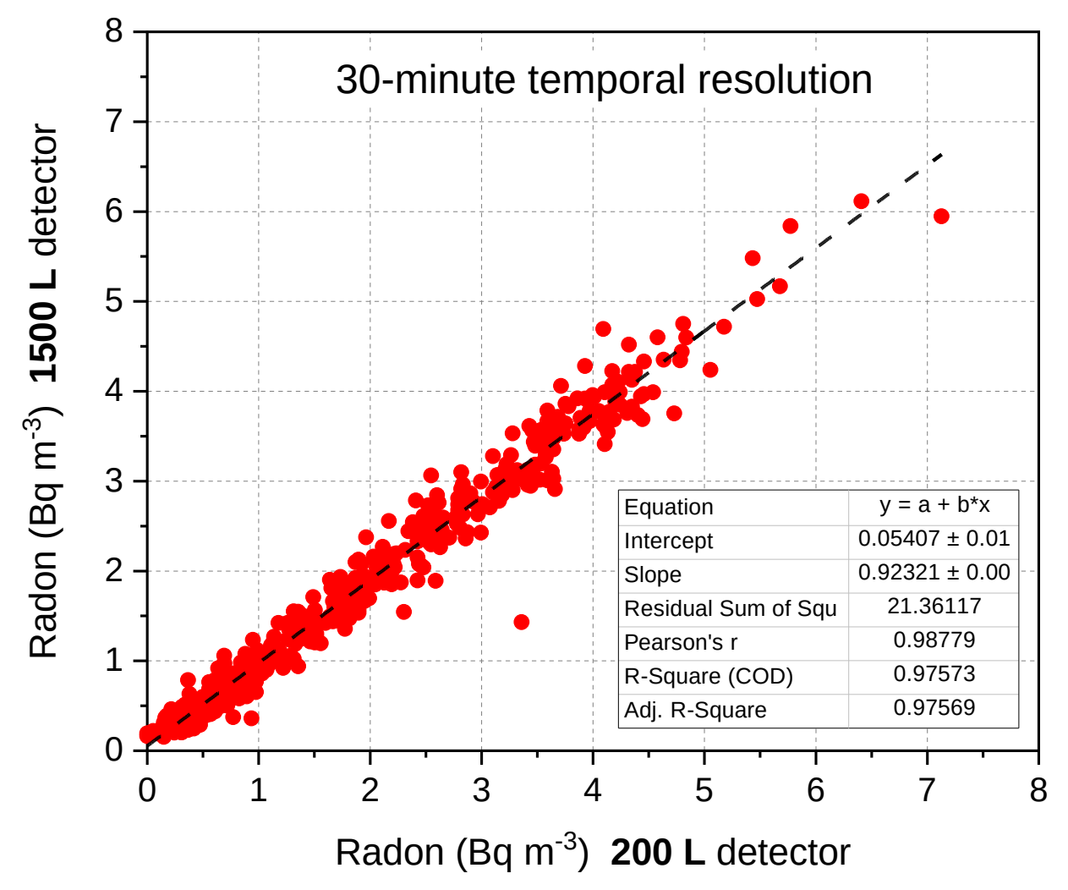
2-week comparison of hourly outdoor radon concentrations measured using a 200 L and a 1500 L radon detector, from 3 m above ground level, 15 km from the coast, south of Sydney, Australia.

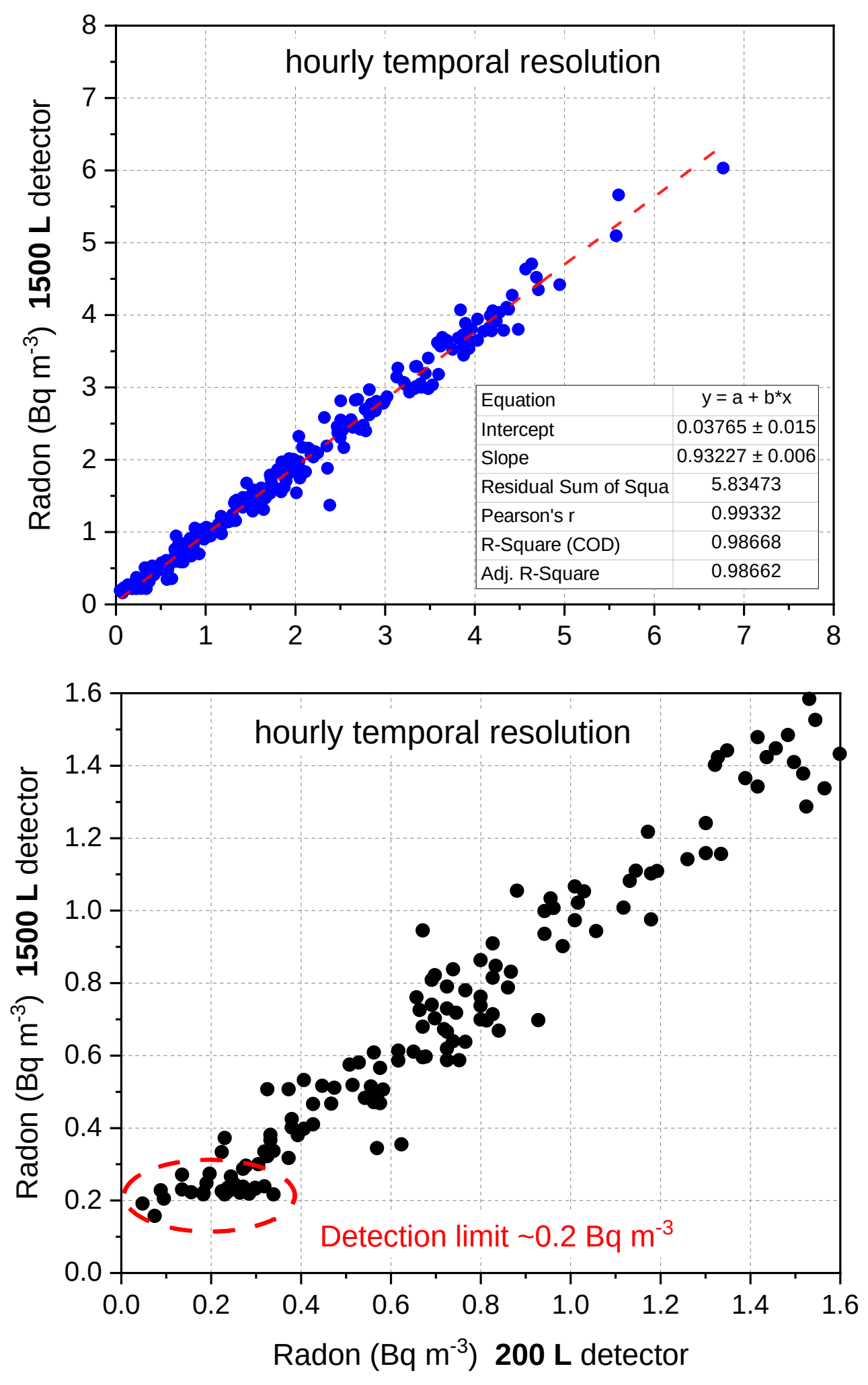
Example of a 1500 L radon detector (3.0 x 0.8 x 0.8 m in size), with separate 400 L thoron delay volume. By comparison, the 200 L detector can fit inside a 19" instrument rack (including thoron delay volume). A spatial footprint of 0.48 x 0.48 m.

Comparative performance: 200 L vs 1500 L detectors

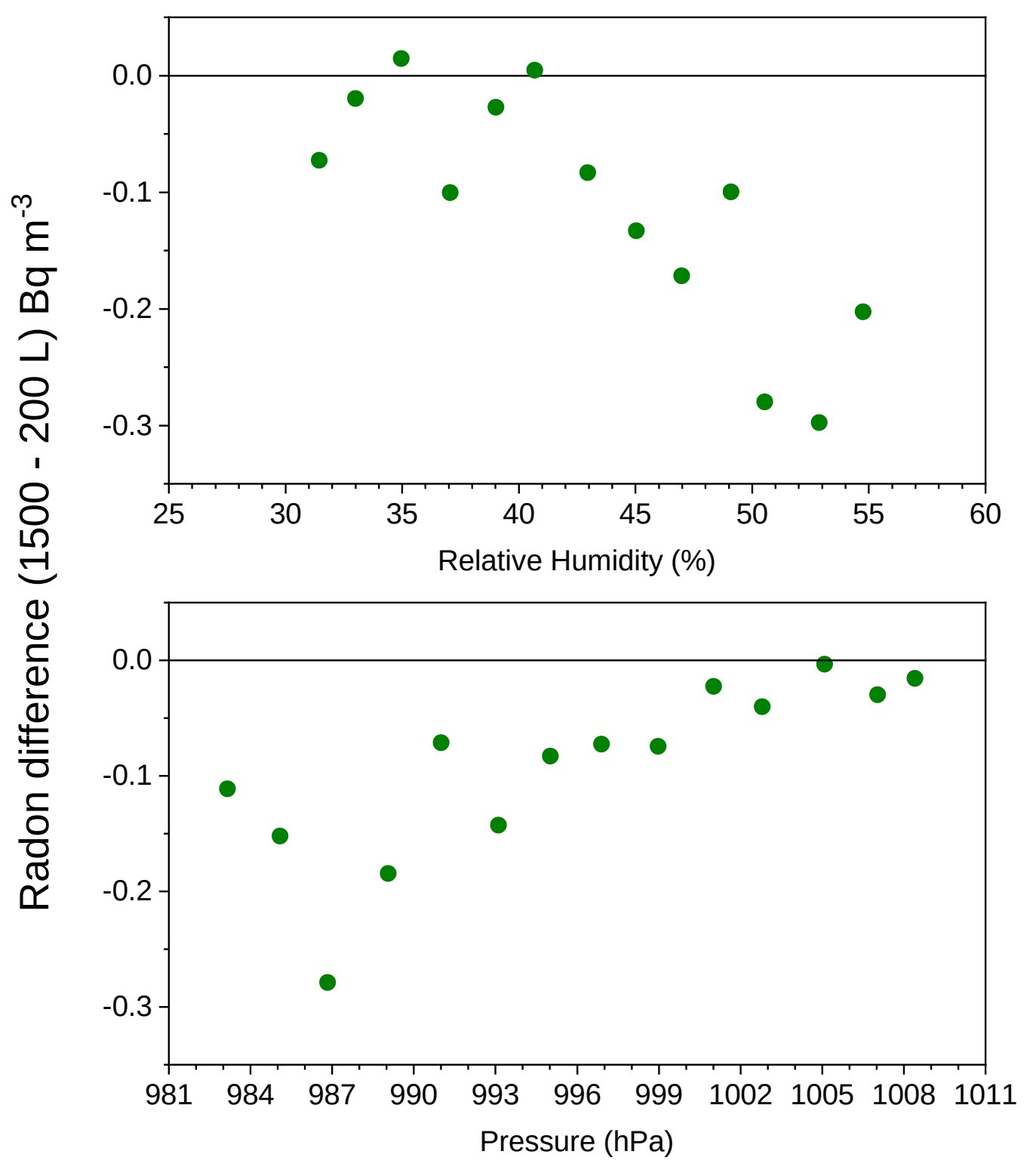
Based on hourly estimated radon concentrations over the first 2 weeks of intercomparison, a regression between the output of the 200 and 1500 L radon detectors yielded the relationship **$[Rn]_{1500}$ = 0.932$[Rn]_{200}$ + 0.038**. Uncertainty in instrumental background estimates is likely responsible for the non-zero offset ($\sigma_{Background}$ for the 1500 and 200 L detectors was 0.016 and 0.070 Bq m^{-3}, respectively).

Detectors were calibrated by injecting radon from a well-characterised Pylon ^{226}Ra source for 5 hours. Since calibration gas was injected on top of the ambient sampling air stream, necessary assumptions result in a coefficient of variability (CoV) for individual calibration events between 2-6%. The regression slope of ~0.93 is thought to be primarily attributable to this uncertainty. Objectives of the *traceRadon* project include reducing the calibration CoV, and making the calibrations traceable to the SI. Response times of the two detectors will be slightly different (see below; on account of differing volumes and flow rates), and have yet to be taken into account. Doing so will likely improve the R^2 values.





Regressions of [Rn] observed using 1500 and 200 L radon detectors, sampling from the same inlet, at 30- and 60-minute temporal resolution. Based on the local radon flux and distance from the coast, the lowest radon concentrations expected at this site are of order 0.2 Bq m^{-3}. At these concentrations the 200 L detector output fluctuates between 0.03 and 0.37 Bq m^{-3}. Initial tests indicated a lower limit of detection of 0.23 Bq m^{-3}; higher than the theoretically-predicted value of 0.13 Bq m^{-3}. Improvements to the sensitivity and detection limit may be possible by optimizing the detector's operational parameters (see below).

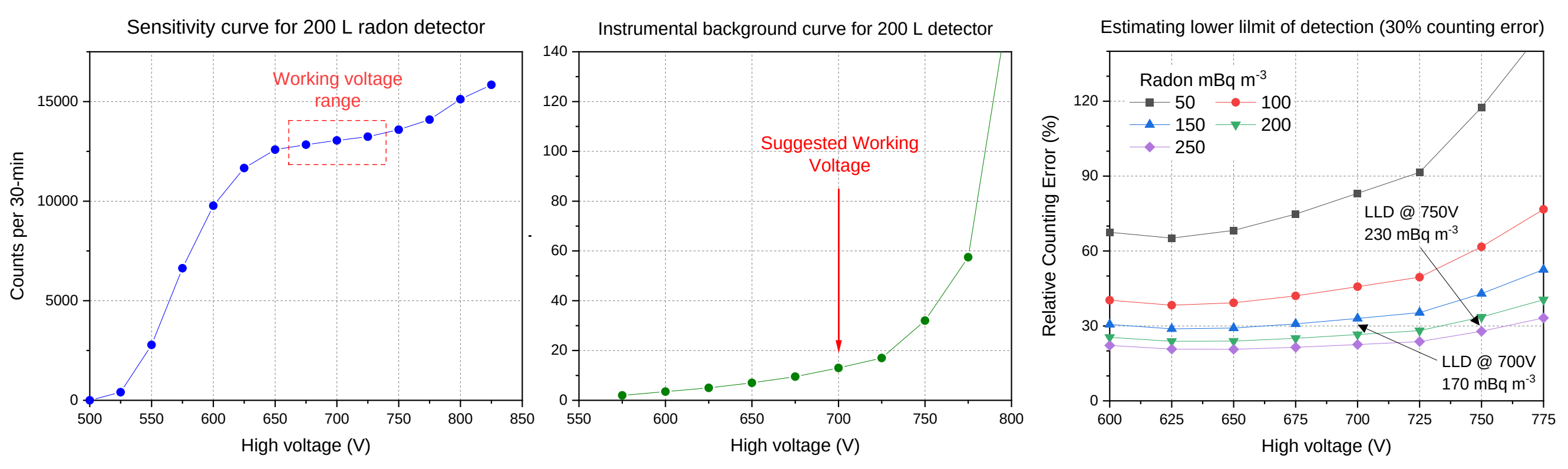


Apparent correlations of observed differences with humidity and pressure stem from calibration uncertainty. Radon concentrations are higher at night (when it is also more humid). Near Sydney, air mass fetch is more often from the west (over land) under low pressure conditions, resulting in higher radon concentrations.

Optimizing detector performance

The detectors working voltage was set at 750 V for the initial tests. Subsequent checks of the sensitivity and background characteristics have indicated that a working voltage of between 675 - 700 V would be more appropriate. Reducing the working voltage to within this range is expected to reduce the detection limit to between 0.15 - 0.17 mBq m^{-3}.

Future testing will focus on optimizing the flow rate within the detectors second flow loop to see whether the theoretically-predicted LLD of 0.13 can be reached prior to beginning tests of the new detector measurement head (Griffiths et al. *this meeting*).



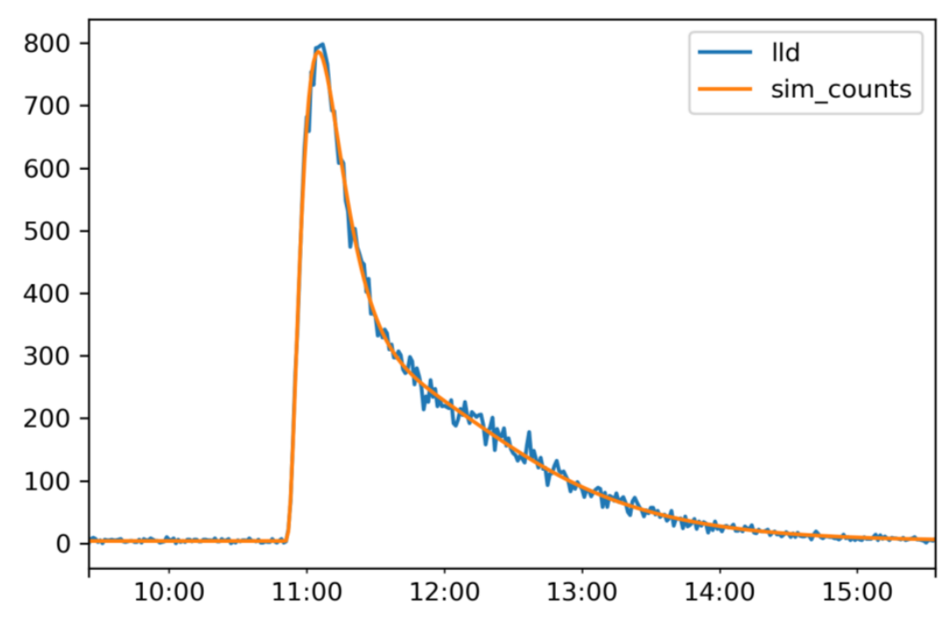
Response Time

The deconvolution model of Griffiths et al. (2016) for response time correction of two-filter radon detectors was able to reproduce results of a spike test on the 200 L detector using a 21 kBq Ra-226 source.

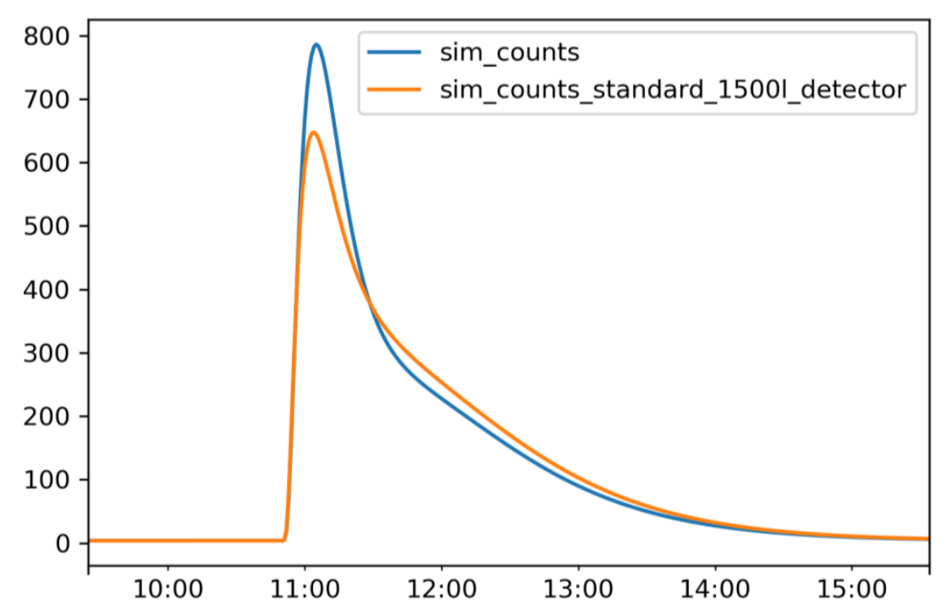
Comparison of response characteristics between the 200 L and 1500 L detectors indicates a faster response by the 200 L detector.

Overall, results from preliminary tests of the prototype 200 L two-filter dual-flow-loop radon detector indicate that it will be a valuable tool for air quality and radiological protection studies in a range of urban and remote environments.

Observed vs simulated counts per minute for a 1-min ^{222}Rn source spike test on the 200 L detector.



Comparison of simulated response of 200 & 1500 L detectors to a 1-min ^{222}Rn source spike test.



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