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Evaluating radon-derived mixing depth as a potential length scale for nocturnal mixing processes over land

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To evaluate, and ultimately improve, numerical schemes for vertical mixing and exchange within the atmospheric boundary layer, and in particular the nocturnal boundary layer, it is necessary to quantify mixing processes within the lower atmosphere at a temporal resolution sufficient to resolve the diurnal cycle. One way to quantitatively characterize near-surface mixing on diurnal time scales is to make continuous, high temporal resolution vertical gradient measurements of a suitable atmospheric tracer. Radon-222 (radon) is a naturally occurring, radioactive, noble gas that is poorly soluble in water. It has a relatively uniform terrestrial source function and its only significant atmospheric sink is radioactive decay. Radon's 3.8-day half-life is also ideal for atmospheric boundary layer mixing studies, being much larger than turbulent timescales ($<$1 hour) but short enough to ensure typical concentrations in the free troposphere are orders of magnitude lower than near surface concentrations. Under strongly stable conditions, when the nocturnal mixing depth can become too shallow to be resolved by SODAR or LIDAR, near-surface radon concentrations remain intimately linked to the local mixing depth.

Radon gradient measurements between 2 and 50 m have been collected for more than a year from a 50 m tower near Sydney, Australia, using a pair of 1500 L dual flow loop, two filter radon detectors, with a lower limit of detection of approximately 40 mBq m^{-3}. The site is topographically complex and, being less than 20 km from the coast, is also subjected to marine influences. While the magnitude of the diurnal radon signal at Lucas Heights is suppressed compared to that of flat, inland sites, a clear correlation is observed between the measured radon gradients and the strength of mechanical and/or convective turbulence. On windy nights (wind speeds in excess of 2 ms^{-1}, or Bulk Richardson number less 0.25), the 2 – 50 m radon gradient rarely exceeds 1 Bq m^{-3}. However, on strongly stable nights (clear skies with wind speeds < 2 ms^{-1}), when the mixing depth is small and sometimes even below 50 m (so that the upper tower level is above the stable boundary layer), large radon gradients are observed that can exceed 5 Bq m^{-3}.

On stable nights it is possible to estimate the nocturnal mixing depth using a simple depth-integrated radon budget equation. The present investigation focuses on whether these mixing depth estimates could be useful as a length scale for investigations of nocturnal mixing processes. Initial comparisons with nocturnal mixing depths derived from simulations using the regional LAPS model provided by the Australian Bureau of Meteorology have been encouraging, considering the local terrain variability.