Combining lidar and radon-222 to measure mixing height

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Lidar and radon measurements both carry information about boundary-layer mixing. Is it useful to combine them?

Based on two weeks' data from an inland Australian site, we think it is.

Mixing height

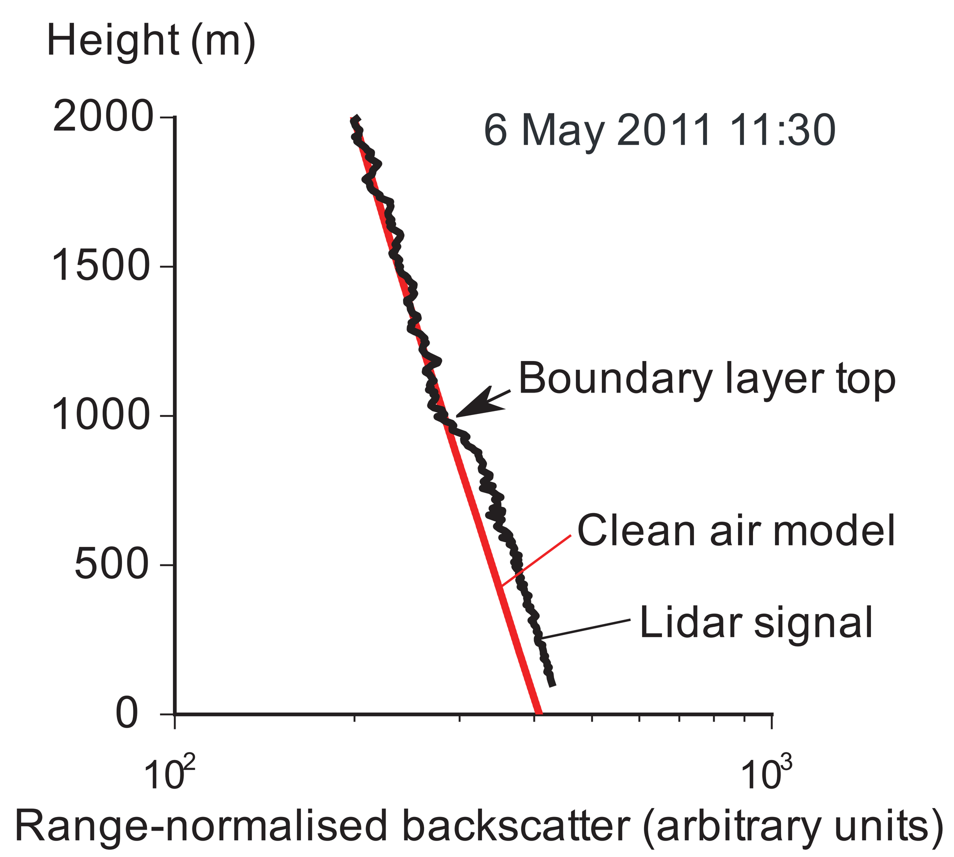
The *depth of mixing near the surface, on a time scale of one hour*, is called the mixing height. Several working definitions are used, with different benefits and limitations. Here we combine two approaches.

Measuring mixing height with lidar

Lidars measure laser light scattered back from aerosols. If local sources dominate over advection, the vertical profile of aerosol concentration establishes and maintains a structure which is a signature of vertical mixing. In a convective boundary layer, the backscatter profile has a sharp change at the mixing height, like the figure below.

When the boundary layer is stably stratified and shallow, e.g. inland at night, aerosol profiles are not much use for determining mixing height. Even during convective conditions, the success of lidar depends on the presence of aerosols in the boundary layer. In more complex situations, there can be multiple candidates for the mixing height.

Simultaneous radon measurements are one way to improve results over lidar alone.



Measuring effective mixing height with radon

Radon, meaning ^{222}Rn, is a natural passive tracer. Chemically inert, it is a product of the radioactive decay of radium in soil and decays with a half-life of 3.8 days.

A time series of radon concentration, from within the boundary layer, can be converted to a mixing length scale by assuming that changes in radon concentration, C, are proportional to the surface emissions, F, and inversely proportional to a length scale which represents mixing, h_e: the effective mixing height. Conceptually, the boundary layer is treated as a well-mixed box so that

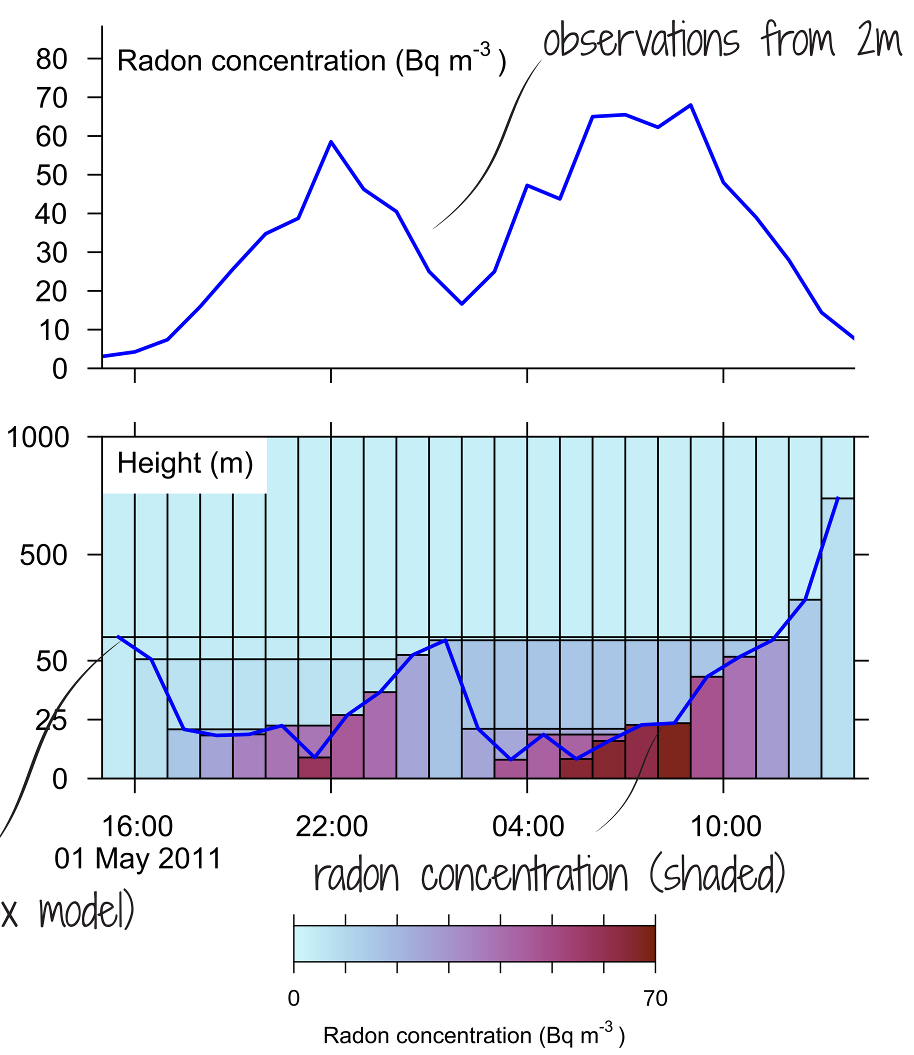
$$\frac{dC}{dt} = \frac{F}{h_e} - \lambda C - D$$

surface emissions
dilution by entrainment (zero if h_e is not growing)
effective mixing height
radioactive decay

The figure below shows the effective mixing height over a night (which also happens to show a burst of mixing beginning around 22:00).

In the absence of other measurements, the effective mixing height is not quantitative because the surface radon emissions are not known on a small enough scale. Nor is complete mixing always expected, certainly not at night.

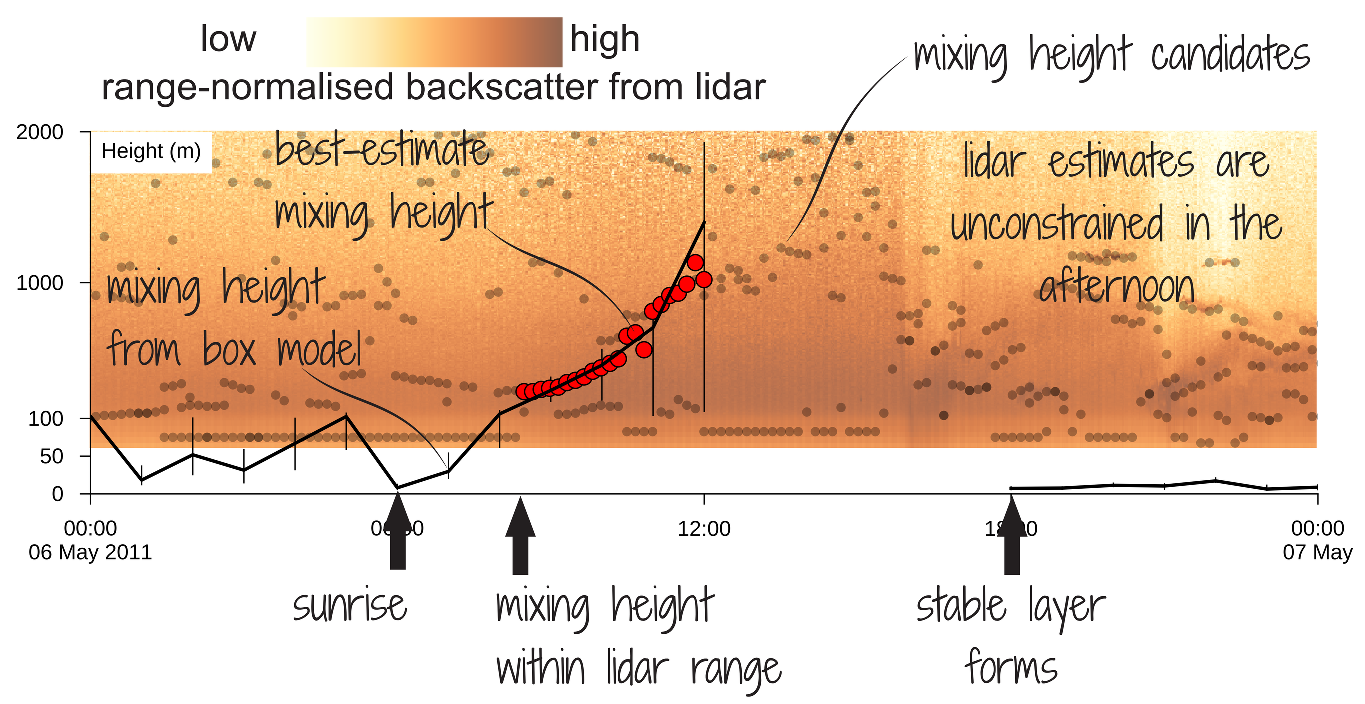
Independent information, from lidar, about the well-mixed morning boundary layer permits quantitative interpretation.



Combining both measurements

After sunrise and the establishment of vigorous convective mixing, the boundary layer becomes well mixed and the effective mixing height, from radon, corresponds with the traditionally-defined mixing height. During the morning transition, the lidar and radon-based techniques are both applicable and produce physically-comparable results.

This figure shows how we can splice together the radon-derived effective mixing height and the lidar-derived mixing heights during one morning transition (a longer period is shown at the bottom).



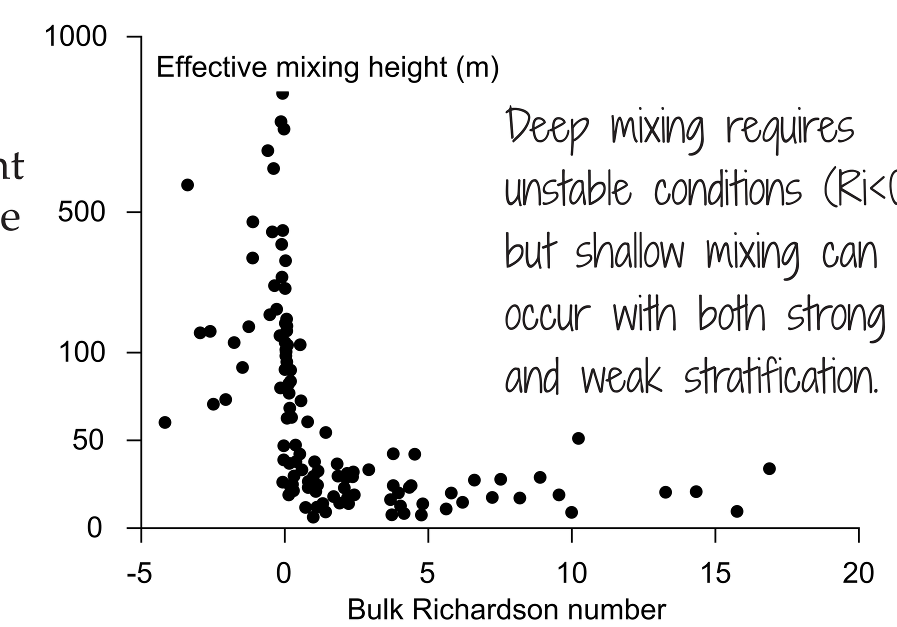
Is the effective mixing height meaningful?

This figure shows a comparison between the effective mixing height and the Bulk Richardson number (Ri).

Effective mixing height behaves like a measure of mixing.

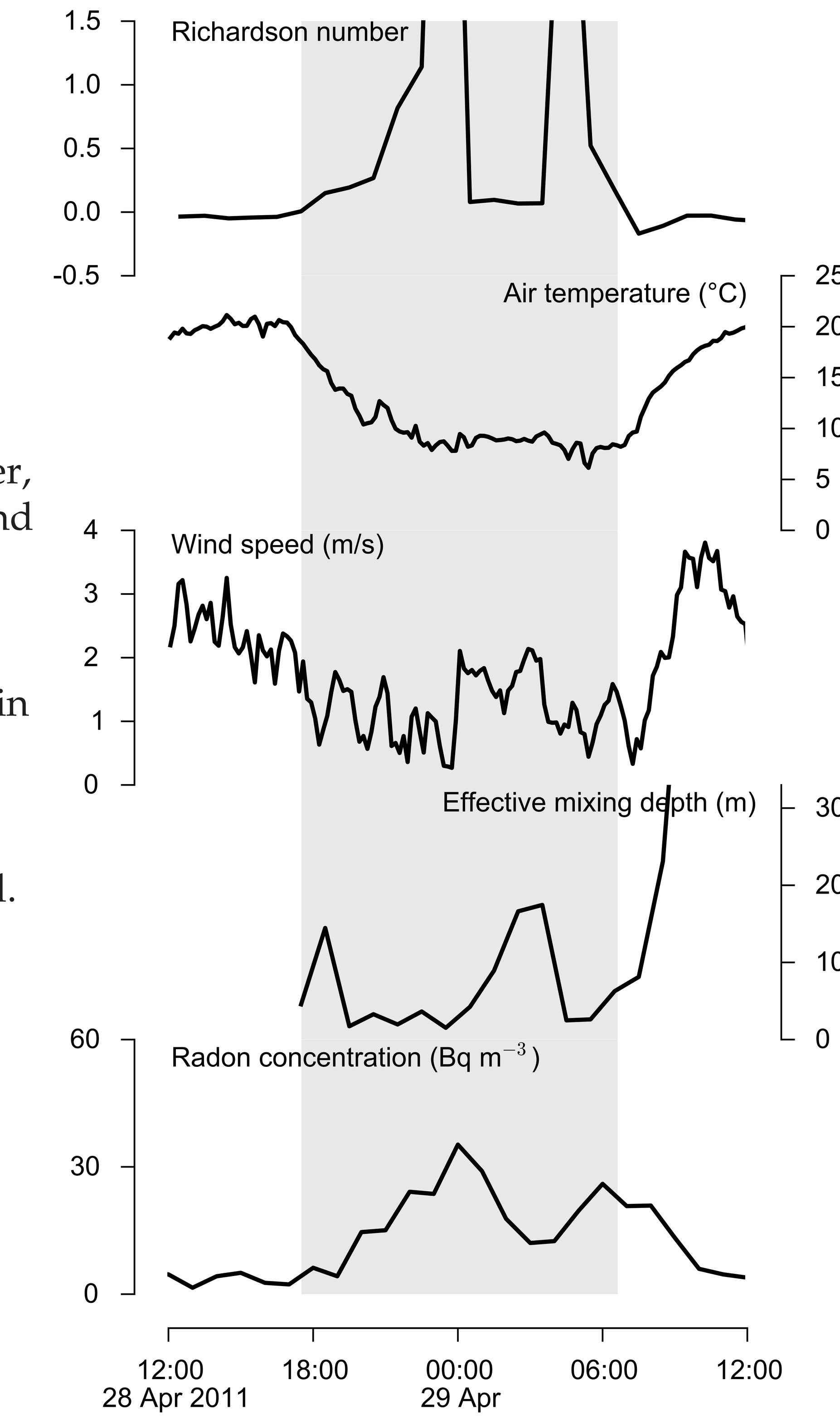
$$Ri \sim \frac{\Delta\theta}{(\Delta u)^2}$$

temperature gradient
wind speed gradient



Data from a single night shows that variations in the effective mixing height, during a night, correspond with simultaneous changes in bulk Richardson number, air temperature, and wind speed.

Interpreting intra-night fluctuations in effective mixing height as a sign of changes in mixing appears to be valid.



Conclusions

Radon measurements are an inexpensive and robust way to enhance lidar observations of boundary-layer mixing. Instrumentation costs a fraction of a commercial lidar.

By combining radon with lidar, it is possible to observe mixing over the full diurnal cycle, and lidar retrievals of mixing height are improved during the morning transition.

During the night, the relationship between radon-derived effective mixing height and conventional measures shows it to be a promising method of quantifying intermittent mixing.

Lidar combined with radon-derived effective mixing height (extended time series)