Continuous hourly radon gradient observations at Cabauw, the Netherlands

A review of main features of the 2007-2008 dataset

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Continuous hourly radon gradient observations at Cabauw, the Netherlands: A review of main features of the 2007-2008 dataset

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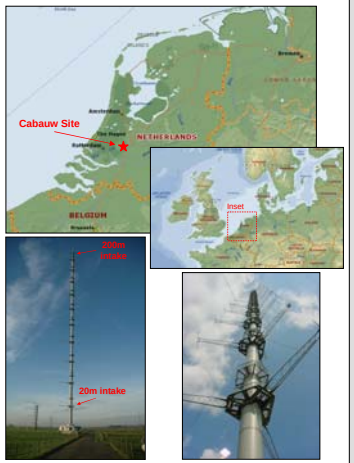
Measurement Site

Here we report preliminary results from the first two years of radon time series and radon gradient observations at Cabauw, the Netherlands (51.971ºN, 4.927ºE).



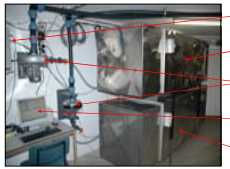
Views of the 200m meteorological research tower at the Cabauw Experimental Site for Atmospheric Research (CESAR) Observatory. The site is flat and approximately 50km from the coast.

Radon Observations

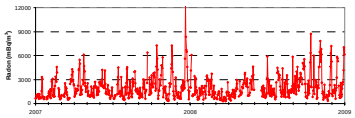
A pair of 1500 L dual flow loop, two filter radon detectors were installed within the basement of the Cabauw meteorological tower.

Sample intakes are mounted at 20 and 200m, and detectors log hourly data to a nearby PC. Each detector has a response time of ~45 minutes, a sensitivity to radon of ~0.3 counts s^{-1} (Bq m^{-3})$^{-1}$, and a lower limit of detection of <40 mBq m^{-3}.

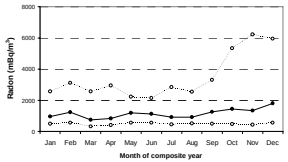
Detectors are calibrated 4 times a year using a ±4% Pylon source traceable to NIST standards. Instrumental background is also characterised 4 times a year.



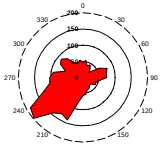
Data Overview



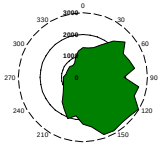
Two years of daily mean 20m radon concentration observations at the Cabauw site.



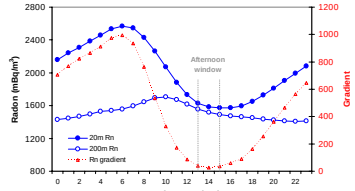
Monthly distributions (median, 10th and 90th percentiles) of daily 20m radon concentration at Cabauw. The seasonal cycle of radon at the site is characterised by Oct-Dec maxima, with lower values typical for the remainder of the year. In autumn and winter a larger proportion of air masses arriving at Cabauw travel over France and Belgium.



Angular sample frequency distribution. Most air masses approach Cabauw from the SW.



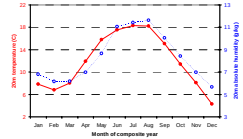
Angular distribution of 20m radon. The highest radon concentrations are associated with central European fetch.



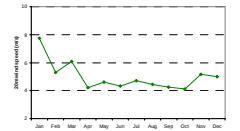
Typical diurnal variability of Cabauw radon concentrations at 20 and 200m. At 20m the signal is characterised by a maximum near sunrise and early afternoon minimum. At 200m the maximum concentration occurs mid-morning, when the nocturnal inversion is burning off and the near-surface radon gets mixed up through 200m.

Diurnal effects are minimised in the early afternoon, when the convective boundary layer is well developed and mixing is strongest. During this "afternoon window" the 20-200m gradient is minimised and radon concentrations are most closely related to airmass fetch.

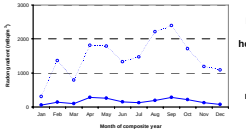
Typical Cabauw Climatology



Mean monthly temperature and absolute humidity at 20m.



Mean monthly wind speed at 20m.



Distribution (50th & 90th percentile) of hourly radon gradient.

Largest gradients correspond to months of lowest mean wind speeds.

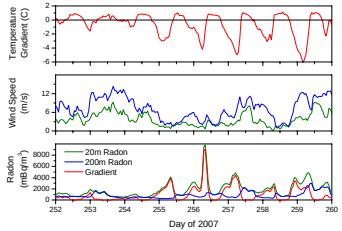
Example of hourly radon gradient observations

On hourly timescales the Cabauw radon gradient was highly variable, depending on the prevailing meteorology.

Early afternoon gradients were small (typically <100 mBq m^{-3}) due to strong convective and mechanical mixing.

Nocturnal radon gradients were largest on relatively calm nights, when near-surface temperature gradients were large and positive.

On the most strongly stable evenings the depth of the stable nocturnal boundary layer (SNBL) was less than 200m.



An 8-day example of hourly radon concentration observations at 20 and 200m (with gradient), as well as corresponding 20-200m wind speed and potential temperature gradient data.

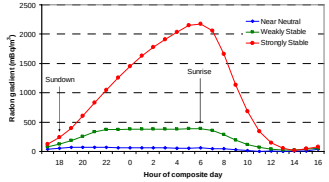
Characteristics of nocturnal radon gradient

All observations were binned (on a daily basis) according to the strength of the maximum nocturnal radon gradient (ΔRn). The following three categories were arbitrarily defined:

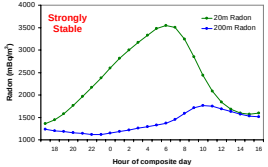
Strongly stable: $\Delta Rn \geq 1000$ mBq m^{-3}

Weakly Stable: $300 \leq \Delta Rn < 1000$ mBq m^{-3}

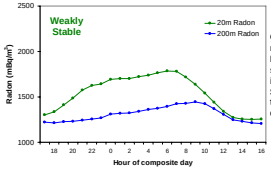
Near Neutral: $\Delta Rn < 300$ mBq m^{-3}



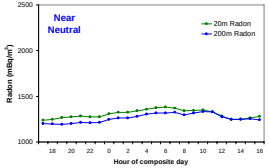
Hourly composite nocturnal radon gradient for the three arbitrarily defined stability regimes.



On strongly stable nights the SNBL is <200m and the 200m Rn concentrations reflect values in the Residual Layer above.



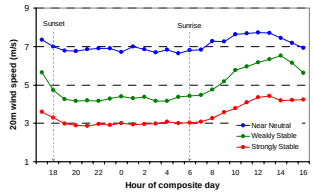
On weakly stable nights the 200m Rn concentration slowly increases, indicating that the SNBL is typically >200m deep.



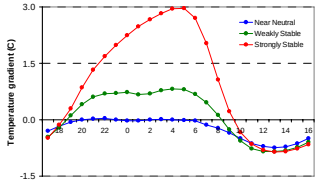
On nights with near neutral stratification the 20-200m Rn gradient is often <100 mBq m^{-3} indicative of efficient mixing processes.

To more clearly demonstrate the influence of wind speed and the near-surface temperature gradient on nocturnal mixing, composite plots of these parameters were also generated for the same stability classifications.

Meteorological influence on stability regime

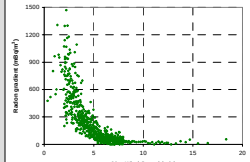


Median hourly wind speed by stability category. When U_{20} was <3 m/s conditions were usually stable. When U_{20}>6 m/s the lower 200m of the atmosphere was well mixed.



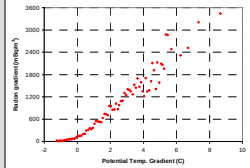
Median hourly temperature gradient by stability category. On strongly stable nights ΔT>1.5ºC. On well mixed nights there is no significant temperature gradient.

The 20-200m radon gradient as a function of wind speed and potential temperature gradient



Median hourly radon gradient in wind speed bins.

For 20m wind speeds in excess of 5 ms^{-1} the 20-200m radon gradient is small (typically < 300 mBq/m³).



Median hourly radon gradient in potential temperature gradient bins.

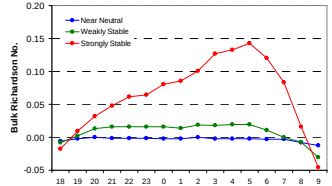
Radon gradients in excess of 300 mBq/m3 usually only developed when the 20-200m potential temperature gradient exceeded +1ºC.

Bulk Richardson Number

$$R_i = \frac{g}{\theta_v} \frac{\Delta\theta}{(\Delta U)^2}$$

The Bulk Richardson Number (Ri) is a ratio between thermodynamic and mechanical drivers of mixing in the boundary layer.

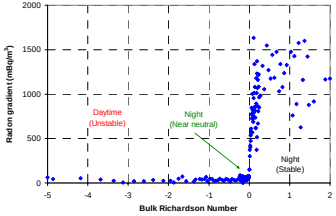
Diurnal composite plots of Ri for each of the 3 radon-defined stability regimes show distinct differences, confirming the strong dependence of near-surface radon concentration on atmospheric stability.



With increasingly negative Ri values (unstable conditions) efficient thermodynamic mixing processes maintain a small radon gradient between 20 and 200m.

For Ri values close to zero (near neutral conditions) efficient mechanical mixing processes maintain a small radon gradient between 20 and 200m.

For increasingly positive Ri values (progressively more stable conditions) the lack of mixing and, at times, complete discontinuity between 20 and 200m, leads to large radon gradients.



Median radon gradient for Richardson Number "bins" – bin size typically ranged from 20 to 200 hourly observations.

Acknowledgments

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