Australian Government

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Radon-based assessment of stability affects on potential radiological releases

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H17-001 (Session 8: Modelling air dispersion and exposure to accidental releases)

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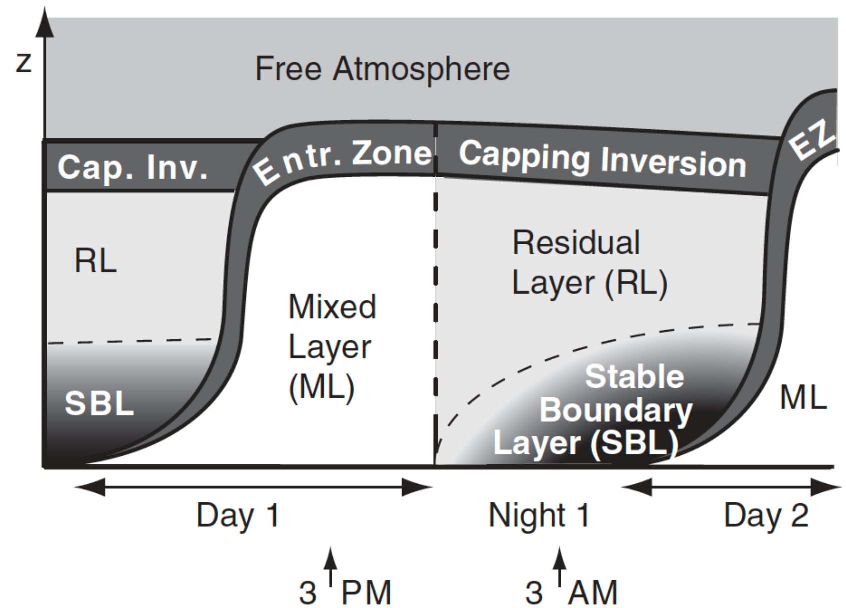
Monday 9th May 2016, Budapest, Hungary

Background and motivation

- **Personal risk and exposure directly related to concentration and time**
- **Concentration of pollutants or accidental releases related to source strength and mixing volume**
- **Atmospheric mixing volume changes diurnally, largely as a function of atmospheric stability**
- **Wide range of stability classifications**
- **More accurate techniques (e.g. L, Ri_{Bulk}) expensive, labour intensive, derived for idealised fetch conditions**



- **Common alternatives (e.g. Pasquill-Gifford) approximate / categorical**
- **Surface-emitted tracers give a direct measure of mixing intensity / extent; better than met. proxies in characterising the outcomes of vertical mixing**

Atmospheric radon (^{222}Rn)

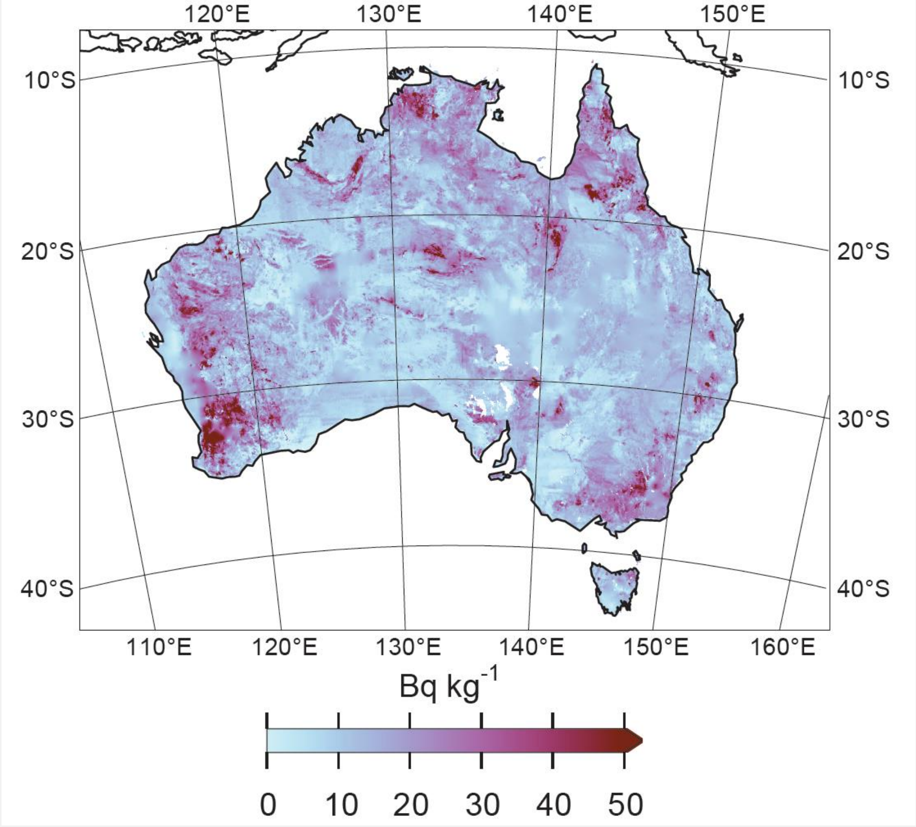
- **Radon is the only gas in the Uranium-238 decay chain**
- **Surface-only source**
- **Mostly from land (unsaturated / unfrozen) not water**
- **Source function changes relatively little in space & time**
- **Unreactive / poorly soluble: sole atmospheric sink is radioactive decay**
- **Short half-life (3.8d) → (a) doesn't accumulate in the atmosphere**

  (b) large ABL / troposphere gradient
- **Rn half-life >> mixing timescale of the ABL (1-hour)**
- **Over 1 night (10-12h) Rn is an approximately conservative (>90%) tracer**

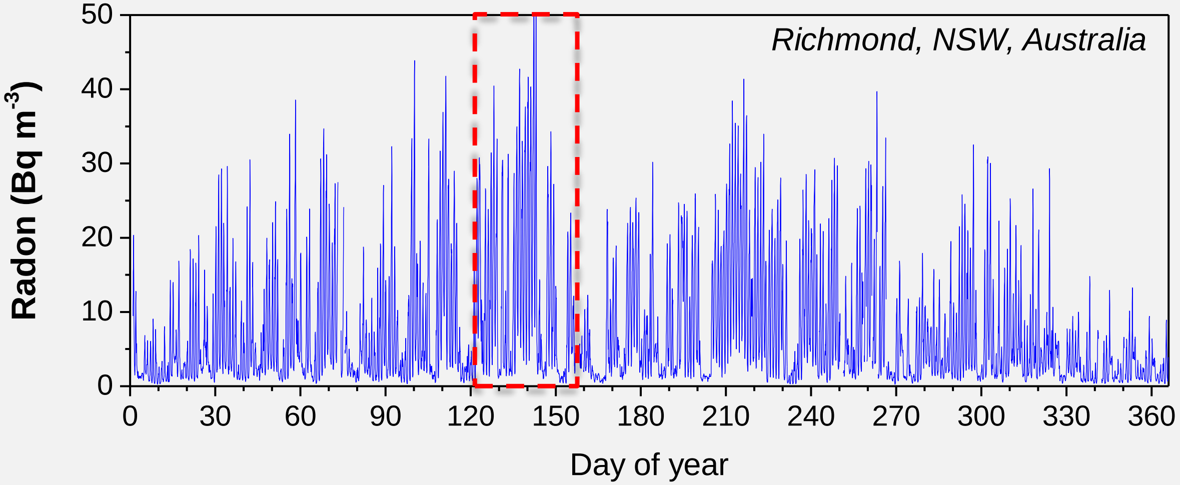
Ideal, versatile and powerful atmospheric tracer

Radon: distribution & measurement

- **Land → Ocean, huge Δ source fn.**
  (2 - 3 orders of magnitude)
- **Regional scales (10s → 1000s km)**
  factor 2 - 4 Δ source fn.
- **Local scales (≤10s km; nocturnal fetch for stable conditions) fairly uniform**
- **Parent (^{226}Ra – half life 1600 y)**
  (little temporal change except for soil moisture)



Griffiths, AD, et al., 2010: **A map of radon flux at the Australian land surface.** *Atmos. Chem. Phys.*, 10, 8969-8982.

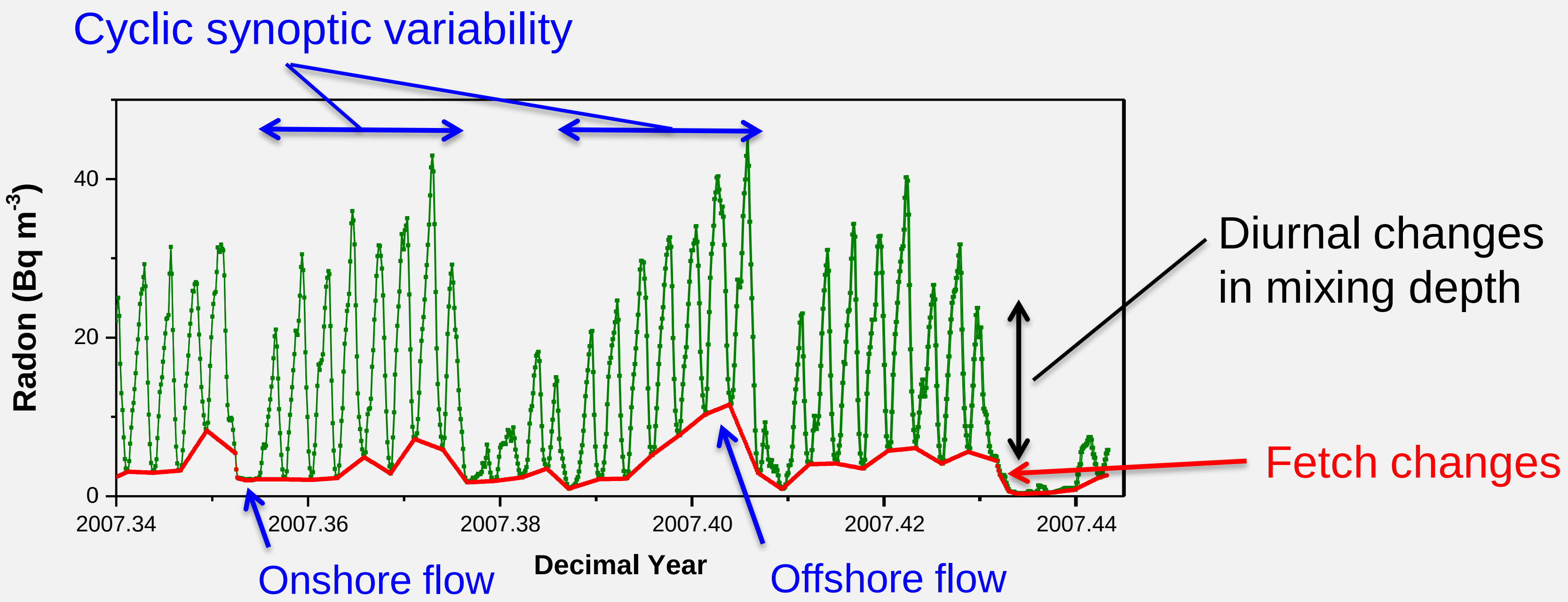


Variability on many time scales

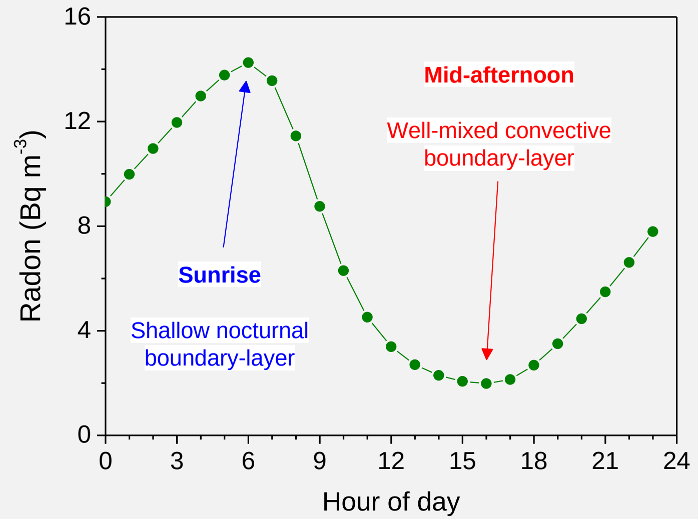
Seasonal (1-6 months)
Synoptic (2-12 days)
Diurnal (24 hours)
Sub-Diurnal

Fetch, mixing and non-local processes

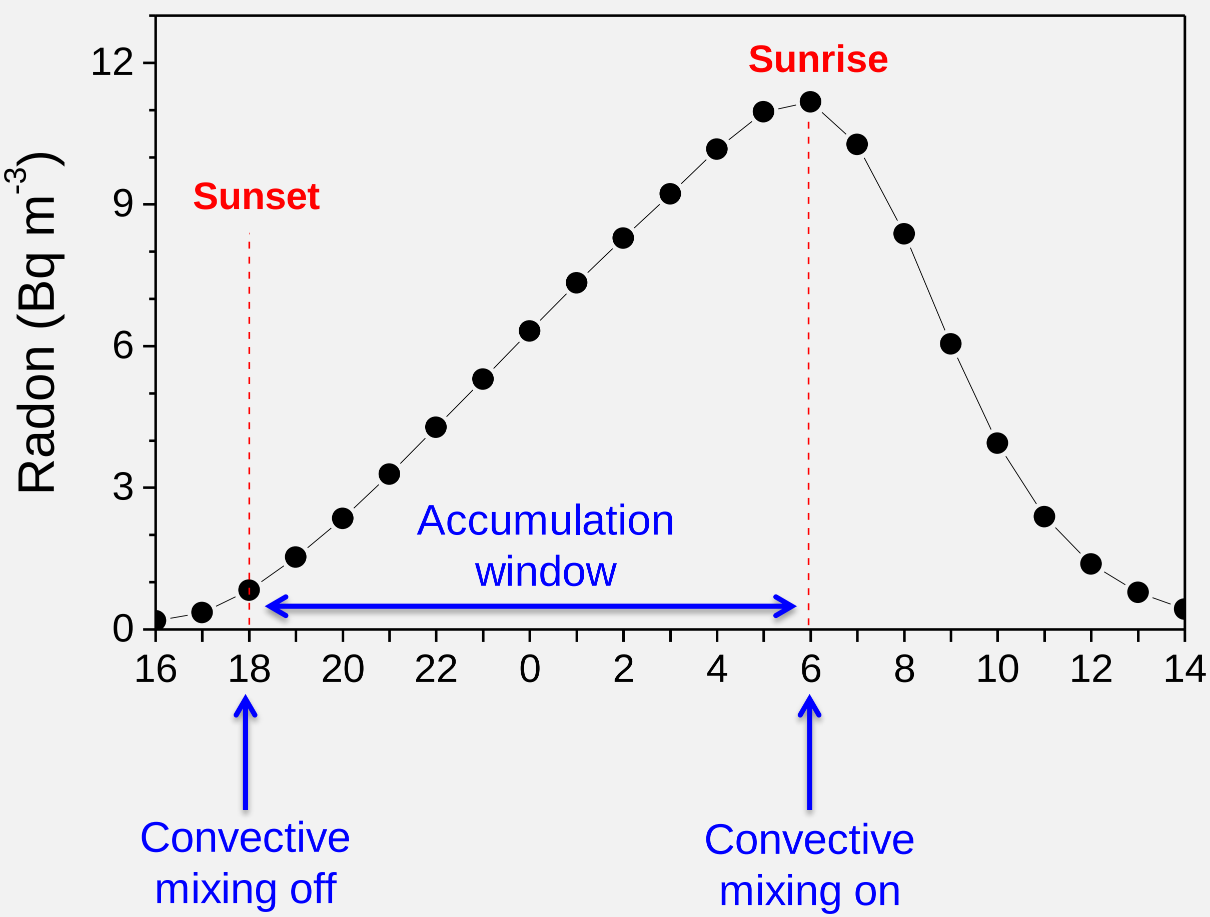
Diurnal variability - the ABL mixing indicator



- Before Rn can be used as a stability indicator, need to isolate diurnal signal
- To do this, identify the fetch signal and subtract it from the orig. time-series
- Fetch signal related to 2-week air mass history (Rn half-life 3.82 days)
- Remaining variability is driven by mixing (constant source, changing volume)



Shifted composite of *diurnal* variability



Radon: ~uniform surface source and ~conservative over 1 night

Therefore, nocturnal accumulation is **directly** related to the average **nocturnal stability** (mixing depth)

Step 1:

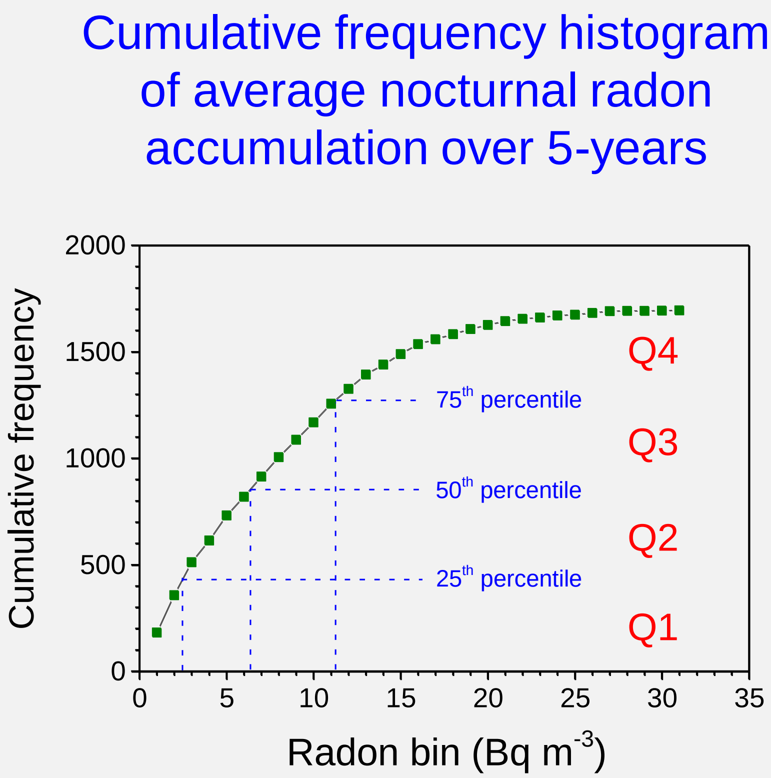
Calculate the nocturnal mean accumulation for each 24-hour period

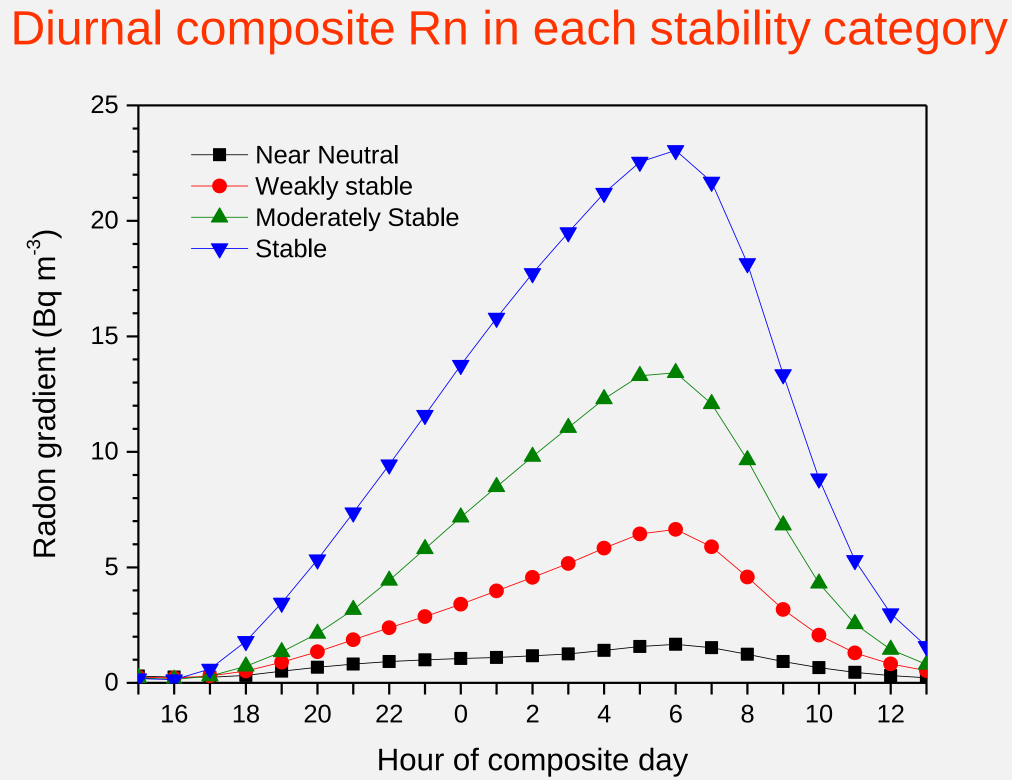
Step 2:

Group the resulting values to devise a stability classification scheme.

For more information see: Chambers, S.D., et al., 2015: **On the use of radon for quantifying the effects of atmospheric stability on urban emissions**. *Atmos. Chem. Phys.*, 15, 1175-1190.

Stability classification example





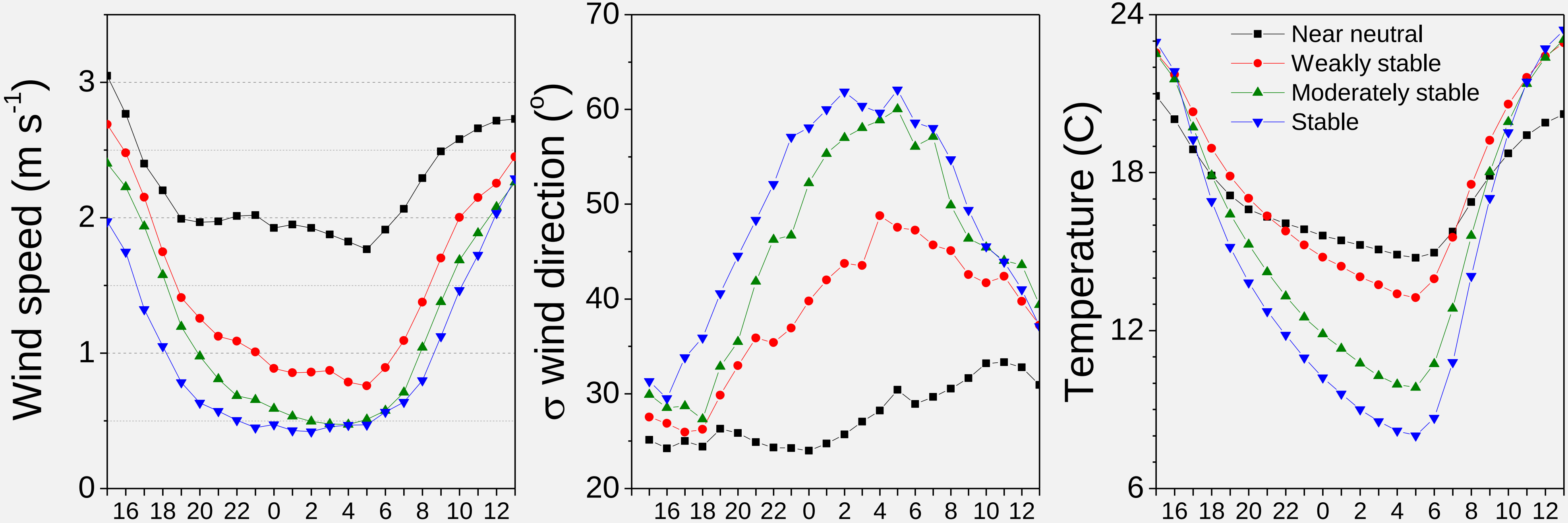
Quartile	Nocturnal mean radon gradient	Stability Category	Vertical mixing
Q1	< 2.5 Bq m^{-3}	Near neutral	strong
Q2	2.5 – 6.3 Bq m^{-3}	Weakly stable	moderate
Q3	6.3 – 11.2 Bq m^{-3}	Moderately stable	weak
Q4	>11.2 Bq m^{-3}	Stable	Very weak

About the Stability Categories

- **The number of definable nocturnal stability categories dictated by length of dataset and desired robustness of statistics**
- **1 yr, 4 seasons, 4 stab. categories: diurnal composites based on 22 days**
  5 yr, 4 seasons, 6 stab. categories: diurnal composites based on 76 days
- **Categories defined nocturnally over 10-12 hours but can generally be assigned to whole 24-hour periods (due to atmospheric persistence)**
- **The most stable nights are usually characterised by:**
  - Clear skies, calm to light winds (e.g. anticyclonic conditions)
  - Usually flanked by the most unstable (convective) days
- **The most well-mixed nights are usually characterised by:**
  - High percentage of cloud cover and moderate to strong winds
  - Usually flanked by near-neutral days
- **For regulatory dispersion modelling, radon stability categories can be used like Pasquill-Gifford categories to assign day/night wind speeds and σ_{WD} to the 16-point compass on a monthly or quarterly basis**
- **Categorisation is COMPLETELY INDEPENDENT of site meteorology**

Evaluating radon-derived stability categories: (a) Meteorology

Group met data by Rn-based stability category and form diurnal composites

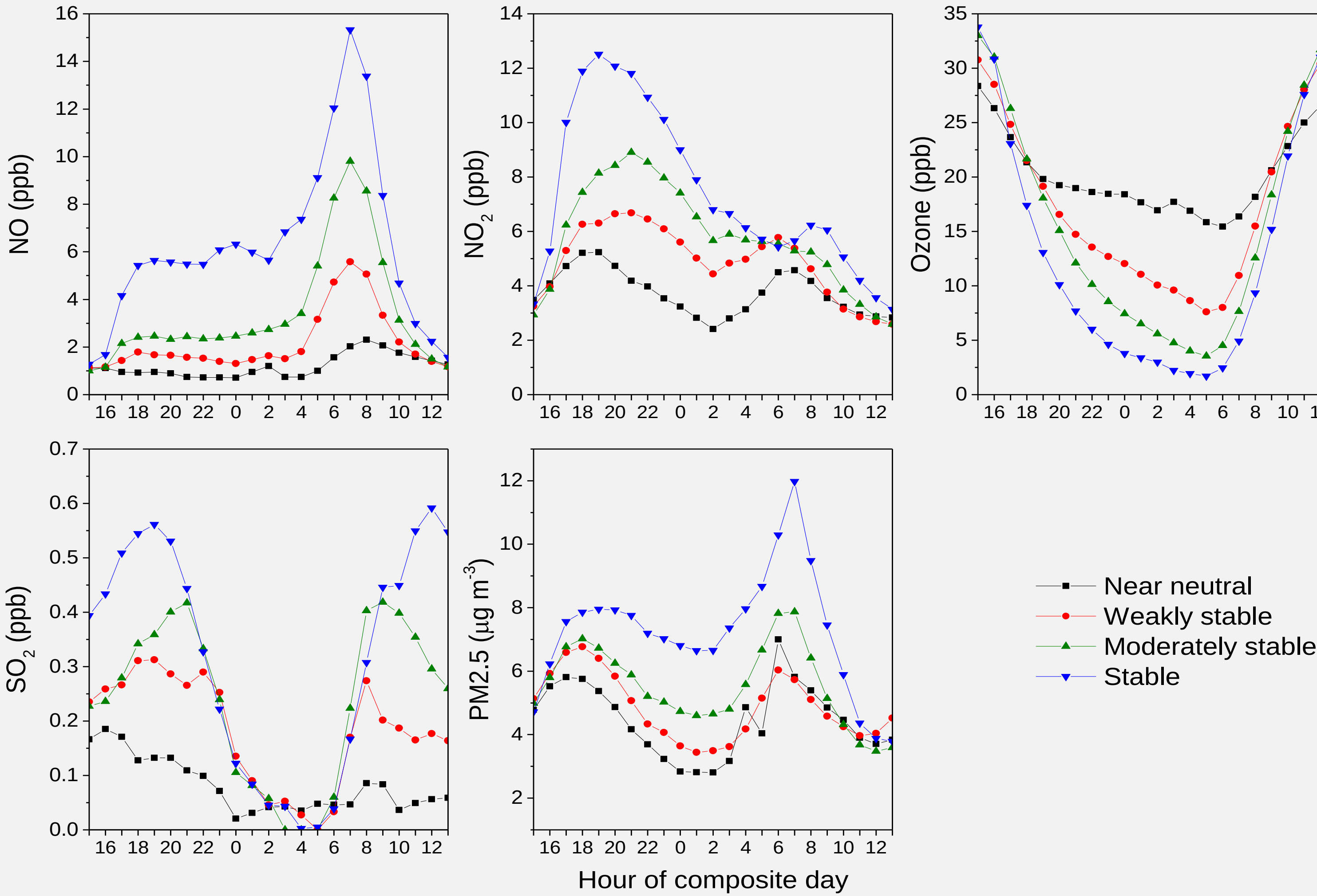


Richmond, NSW, Australia

Stable: low nocturnal wind speed, high wind direction variability, large temperature amplitude

Near-neutral: higher, more consistent, wind speed & direction, lower amplitude temp fluctuation

Evaluating radon-derived stability categories: (b) urban pollution example



Richmond, NSW, Australia

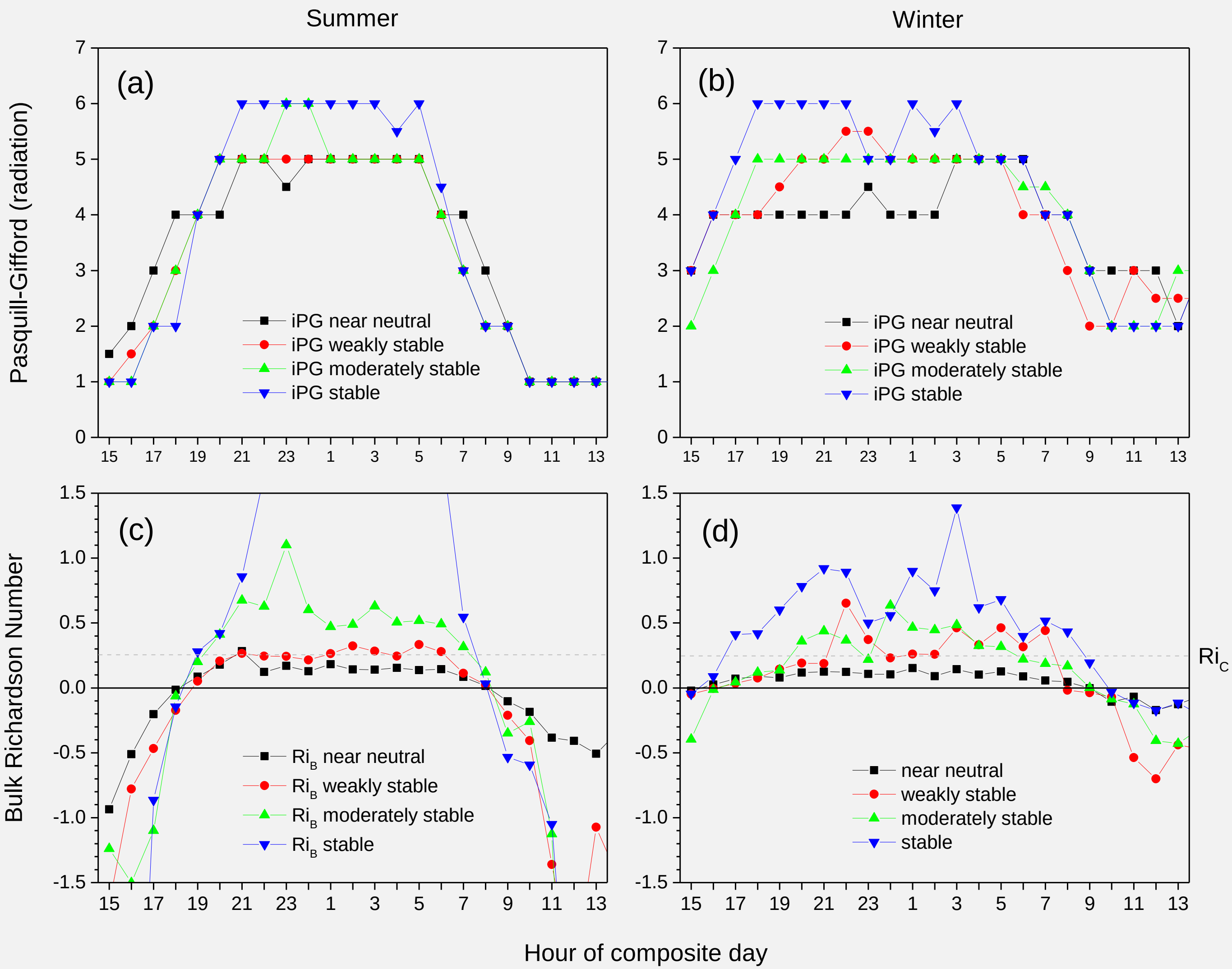
Stable: large amplitude changes

Near-neutral: small amplitude changes

NO – primary pollutant, local surface-based source (proxy for near-surface accidental emission)

Ozone behaviour supports atmospheric persistence hypothesis

Comparing radon-derived stability categories with P-G and Ri_{Bulk} categorisation



Assign hourly PG cat^s then group by Rn-based cat^s

Stable nocturnal Rn-category
PG: 6 (night), 1-2 (day)

Well-mixed Rn-category
PG: 4-5 (night), 2-4 (day)

Stable nocturnal Rn-categories Above the critical Richardson number (Ri_C=0.25)

Composite nocturnal Richardson numbers separate fairly consistently with radon-derived stability categories.

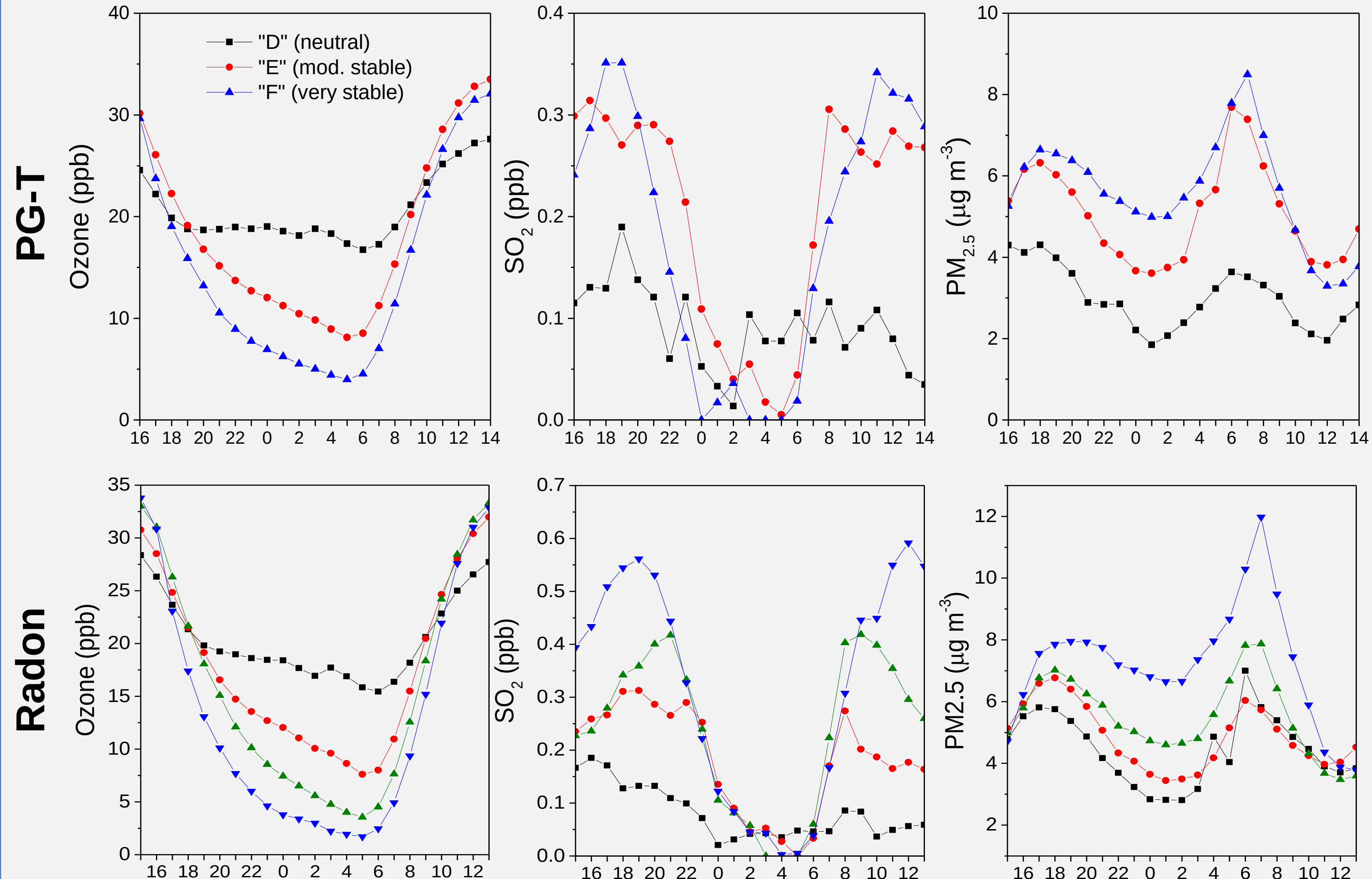
(for more info.: Williams A.G., S. Chambers and A. Griffiths. **Bulk Mixing and Decoupling of the Nocturnal Stable Boundary Layer Characterized Using a Ubiquitous Natural Tracer**. *Boundary-Layer Meteorol.*, 149, 381-402, 2013)

Chambers, S.D., et al., 2016: ***Atmospheric stability effects on potential radiological releases at a nuclear research facility in Romania: Characterising the atmospheric mixing state****. J. of Environ. Radioact., 154, 68-82.*

Characterising diurnal pollutant cycles Pasquil-Gifford vs Radon-based stability typing

PG-turbulence scheme based on σ_{WD} and mean wind speed

Nocturnal categories: **D** - neutral, **E** - moderately stable, **F** - stable



PG-T

Distinction between categories less clear.

Peak concentrations under stable conditions underestimated

Richmond, NSW, Australia

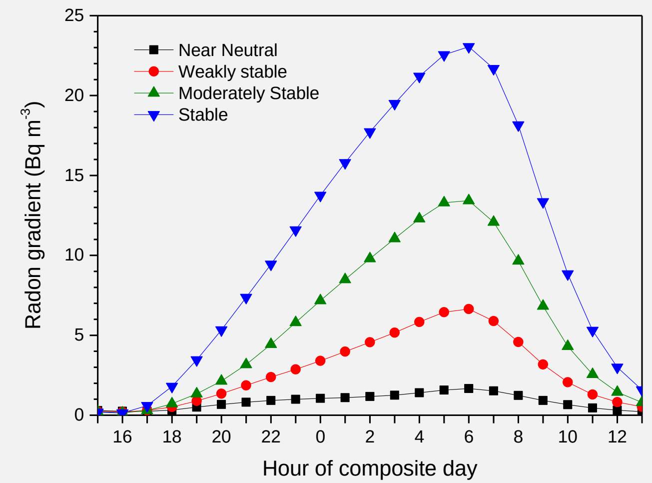
Influence of stability on nocturnal mixing depth

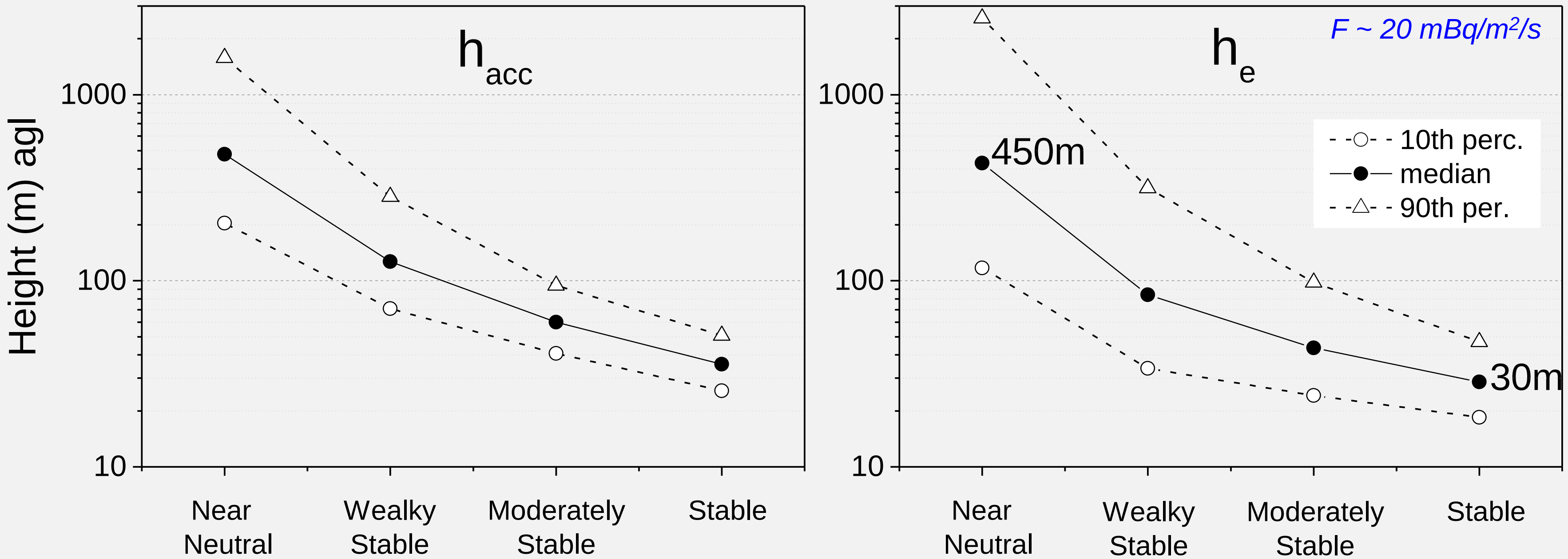
The change in radon (C) in the NBL is a balance between flux (F), decay (λ) and dilution (D).

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

Iterative solution for h: equivalent mixing depth (h_e)

Analytical solution for h: accumulated mixing height (h_{acc})

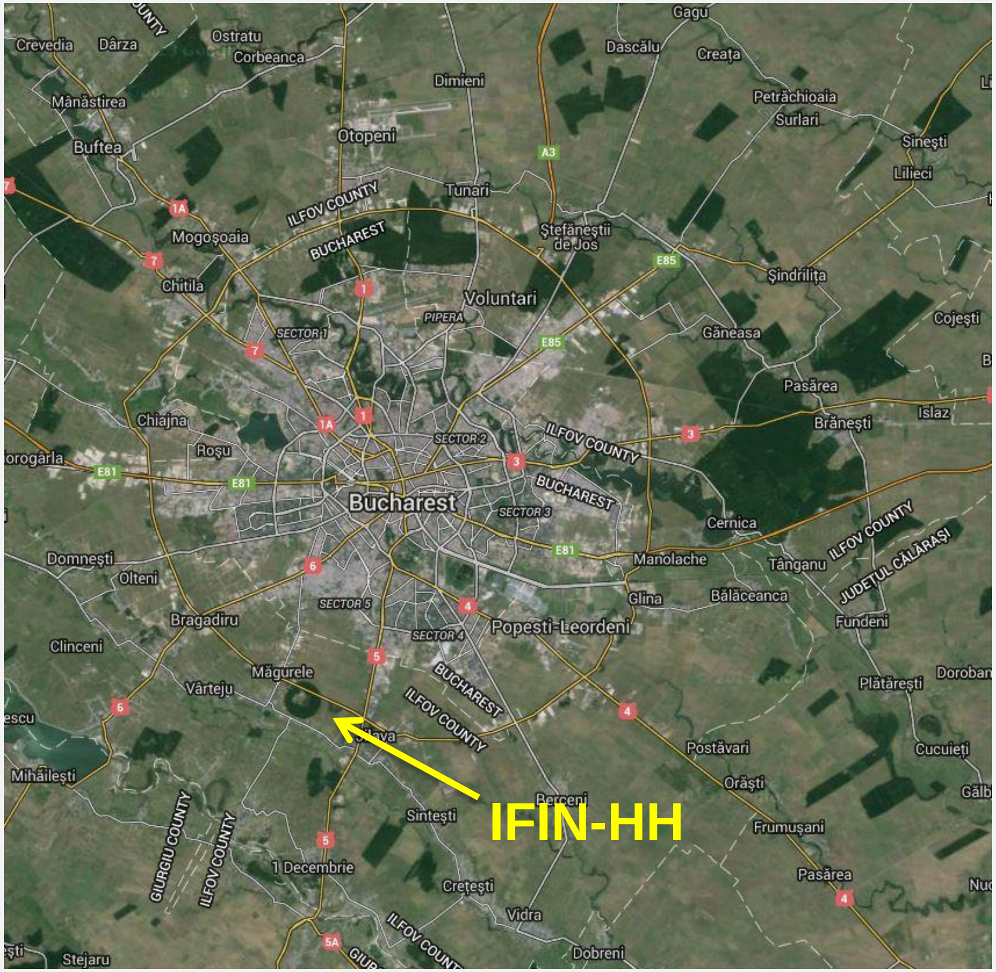


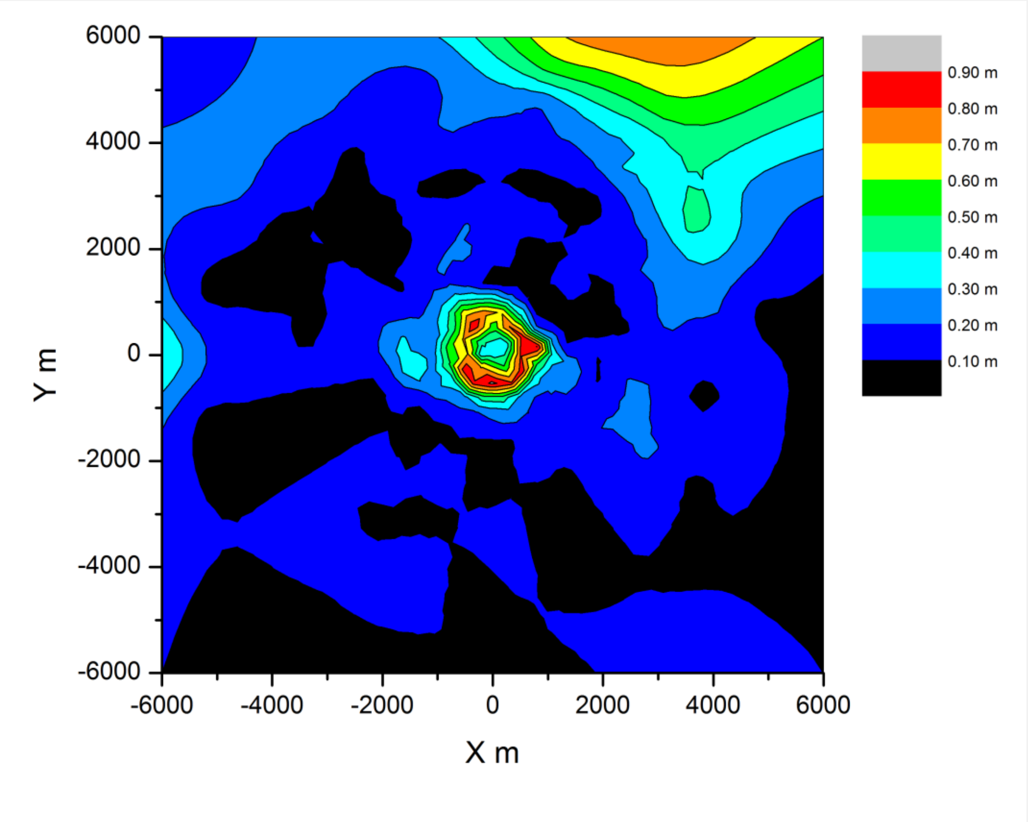


Stability / Mixing category

Richmond, NSW, Australia

National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH)



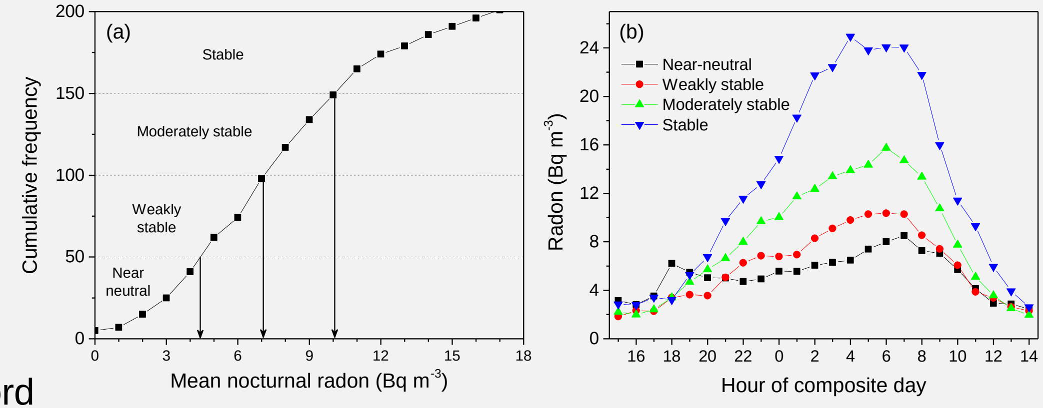


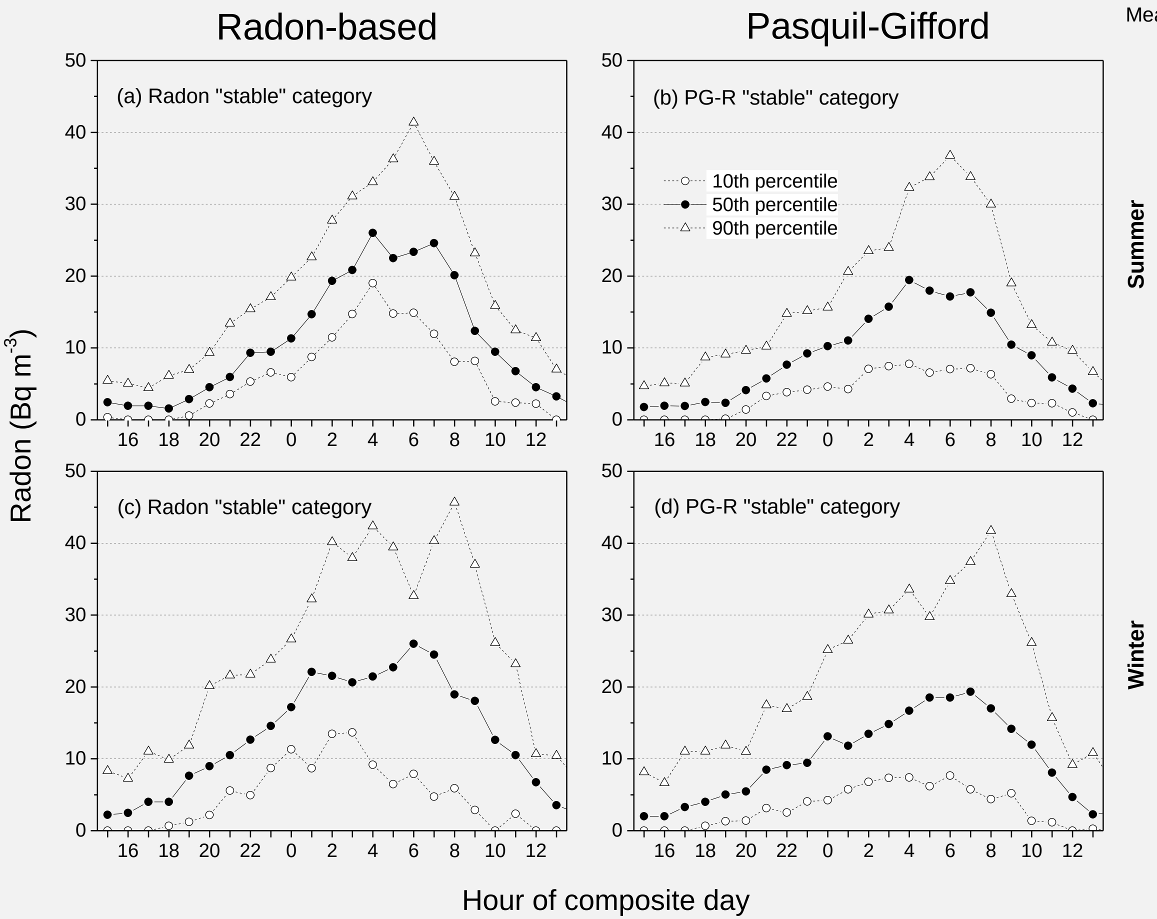
Roughness map around IFIN-HH site

IFIN-HH: 10km SW Bucharest, urban-rural landscape, observations from 60m tower, 1 km exclusion zone, roughness elements 10-15m, challenging fetch for conventional stability typing.

Seasonality of potential extreme events

Despite the non-ideal fetch conditions, radon-derived stability categories were easily assigned





Considering ONLY the most stable nocturnal atmospheric conditions:

(a) PG scheme reports 20-25% lower median concs of pollutants with near-surface sources

(b) BUT - nocturnal mixing depth under stable conditions 10-20m, and the stack release height is >40m

Chambers, S.D., et al., 2016: **Atmospheric stability effects on potential radiological releases at a nuclear research facility in Romania: Characterising the atmospheric mixing state**. *Journal of Environmental Radioactivity*, 154, 68-82.

Conclusions

- Radon is a powerful and comparatively economical tool for atmospheric stability analysis of pollution / release conc$^{s.}$
- Can be used independently of site meteorology
- Rn-based stability analysis of urban pollution superior to conventional techniques particularly in conditions of non-ideal fetch
- Day/night (12-hr) Rn-based stability categories can be provided (like PG classes) for routine dispersion modelling purposes
- Long-term characterisation of pollution by Rn-derived stability category is also ideal for:
  (1) evaluating the efficacy of emission mitigation strategies, and
  (2) providing benchmarks for evaluating CTMs

Thank you

Recent publications related to this presentation

Chambers, S.D., et al., 2011: **Separating remote fetch and local mixing influences on vertical radon measurements in the lower atmosphere.** *Tellus 63B*, 843-859.

Williams, A.G., et al., 2013. **Bulk Mixing and Decoupling of the Nocturnal Stable Boundary Layer Characterized Using a Ubiquitous Natural Tracer**. *Bound.-Lay. Meteorol*., 149, 381–402.

Chambers, S.D., et al., 2015: **On the use of radon for quantifying the effects of atmospheric stability on urban emissions**. *Atmos. Chem. Phys*., 15, 1175-1190.

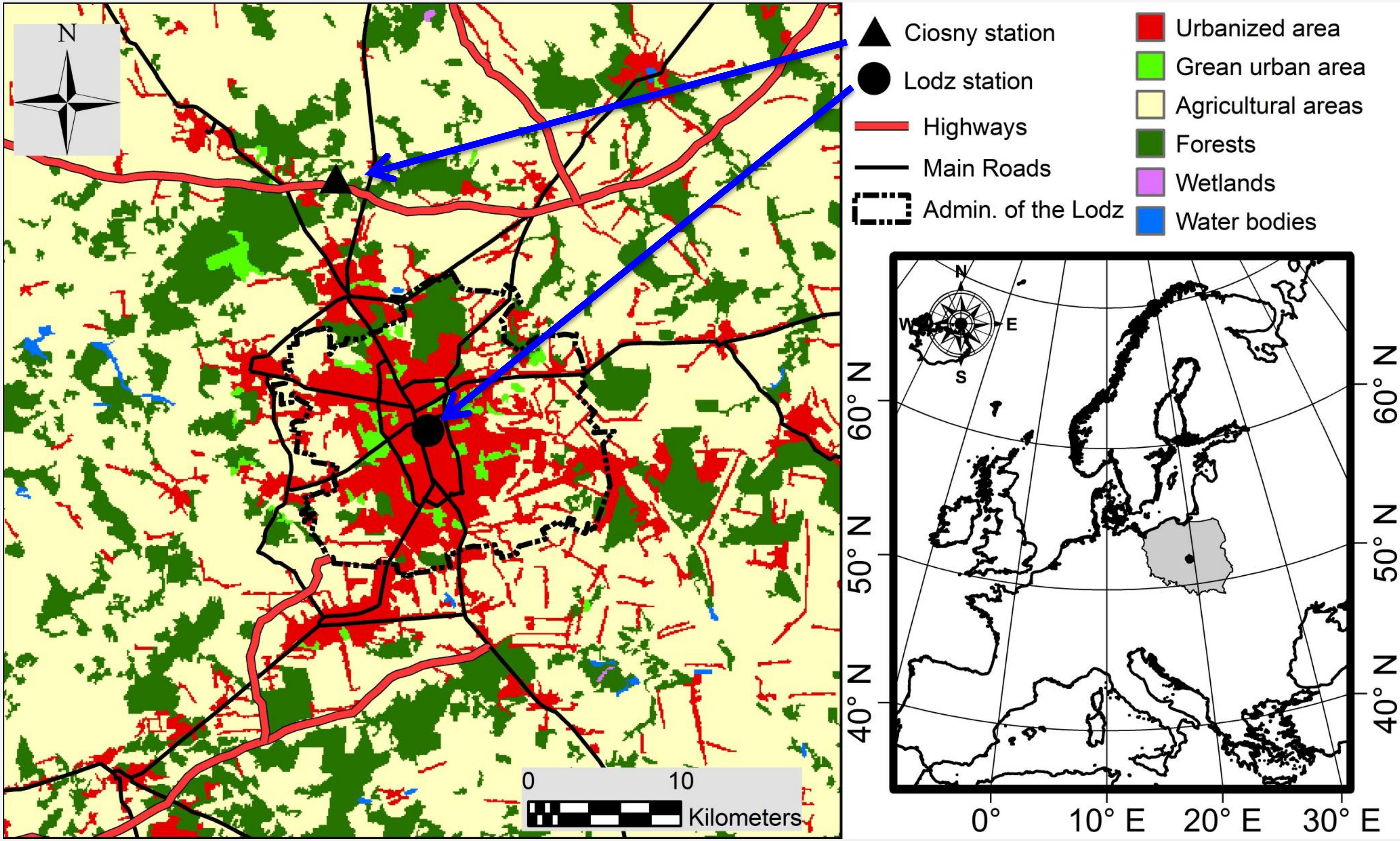
Chambers, S.D., et al., 2015: **Quantifying the influences of atmospheric stability on air pollution in Lanzhou, China, using a radon-based stability monitor**. *Atmos. Environ*., 107, 233-243.

Crawford, J., et al., 2016. **Assessing the impact of atmospheric stability on primary and secondary aerosols at Richmond, Australia, using Radon-222**. *Atmos. Environ.*, 127, 107-117.

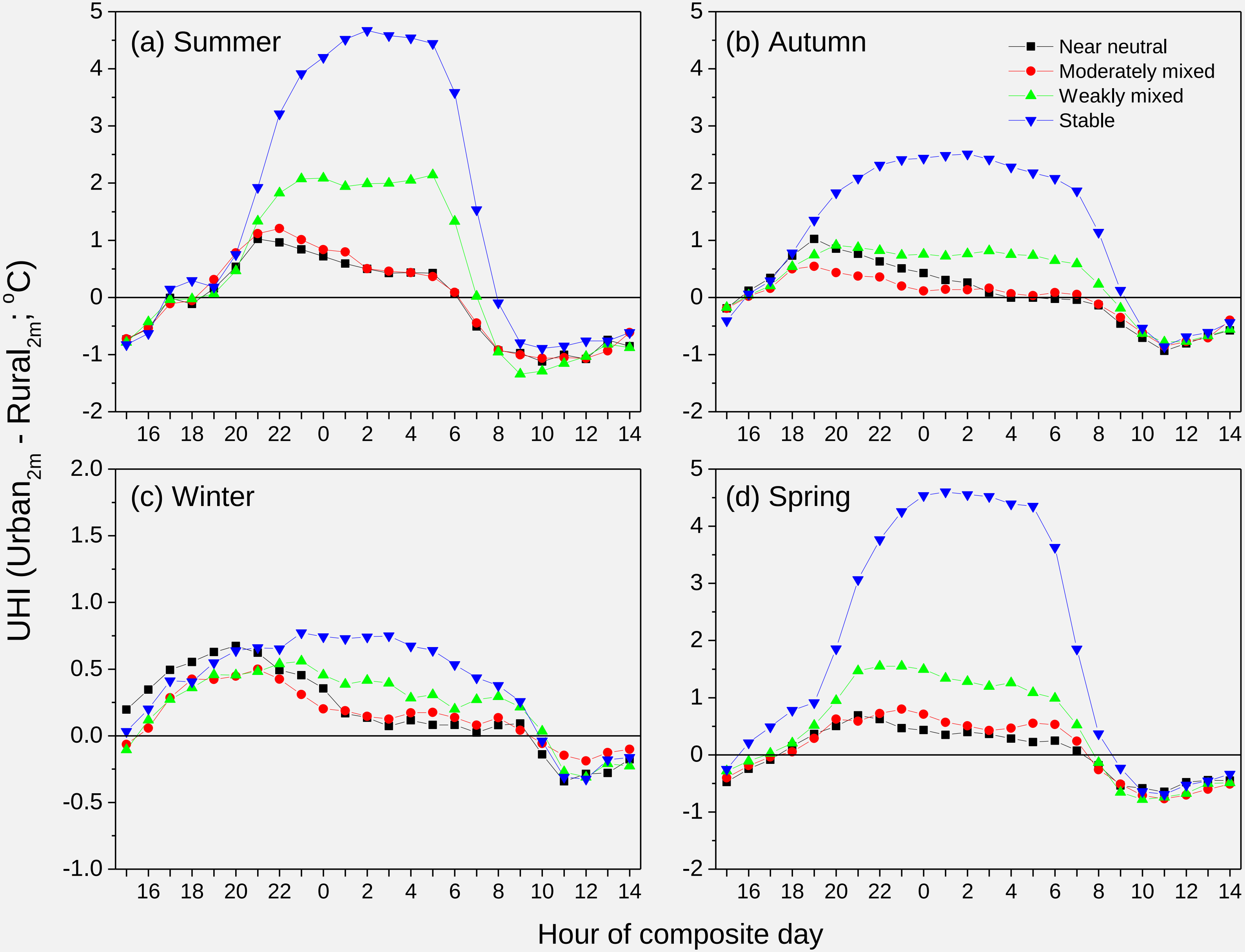
Chambers, S.D., et al., 2016: **Atmospheric stability effects on potential radiological releases at a nuclear research facility in Romania: Characterising the atmospheric mixing state.** *Journal of Environmental Radioactivity*, 154, 68-82.

Williams, A.G., et al., 2016. **Radon as a tracer of atmospheric influences on traffic-related air pollution in a small inland city**. *Tellus B*, submitted January 2016.

Poland (Łódź): urban heat island studies

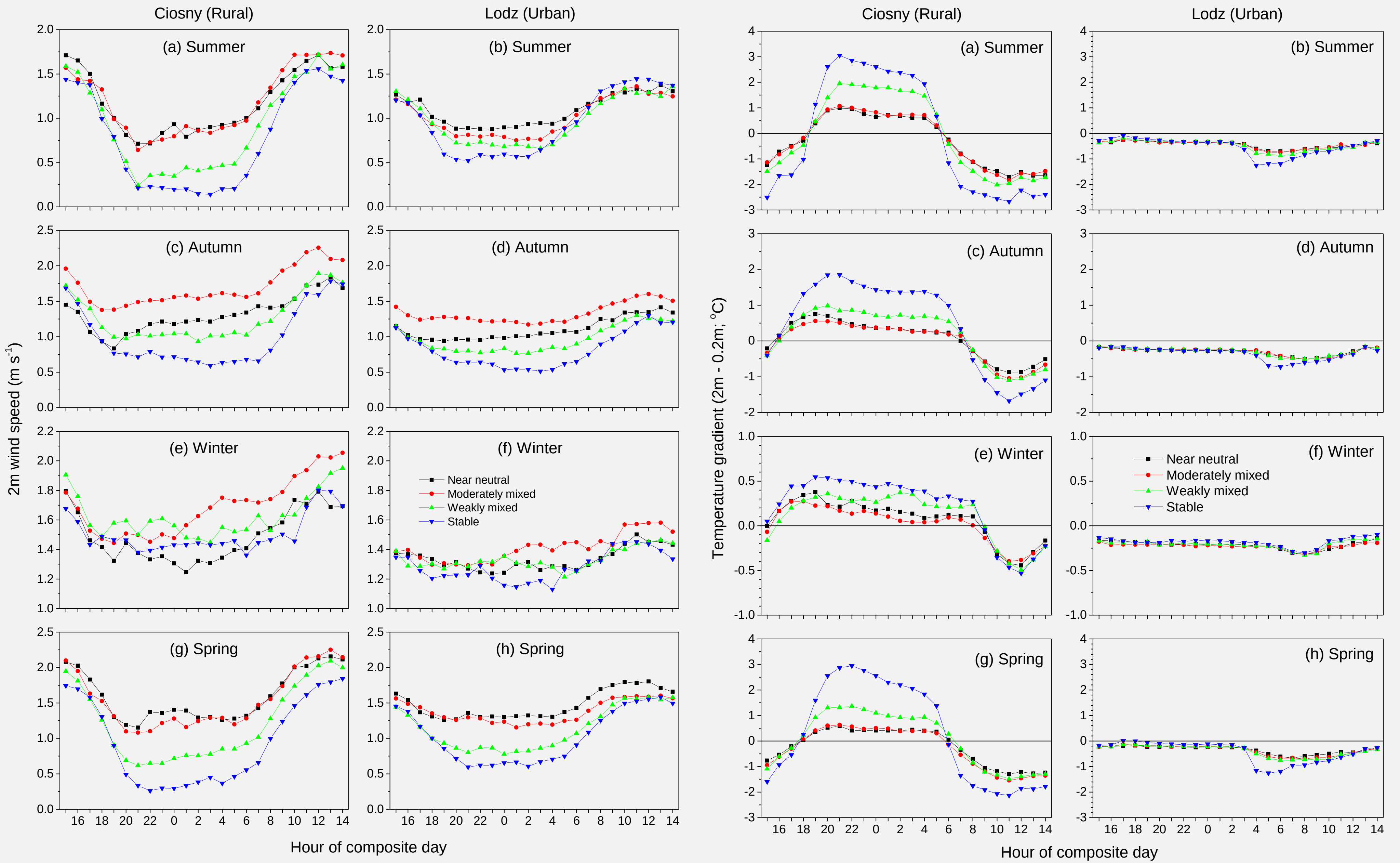


Stability affect on Urban Heat Island intensity

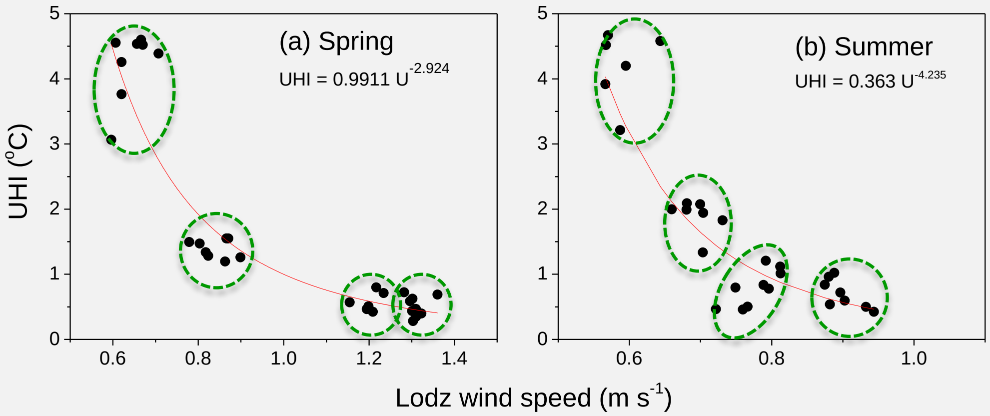


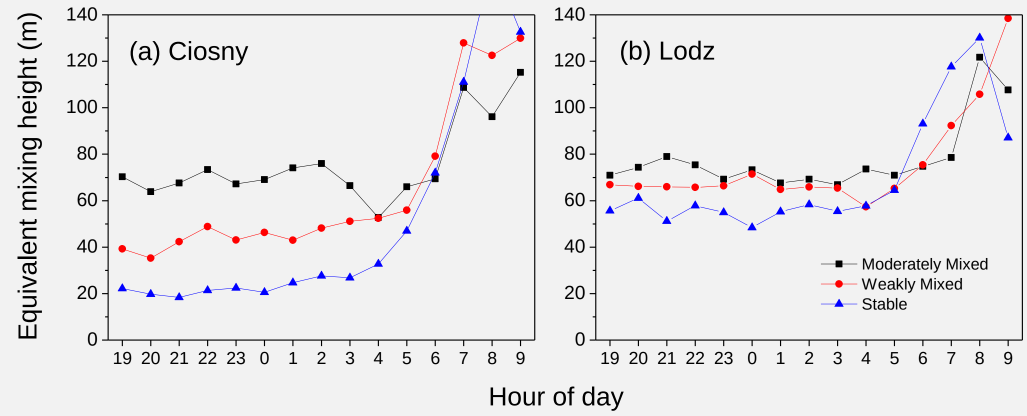
Urban Heat Island Intensity depends strongly on the regional stability (derived by radon)

Stability affects on site meteorology



Stability affects on urban meteorology





Lodz nocturnal wind direction, Spring