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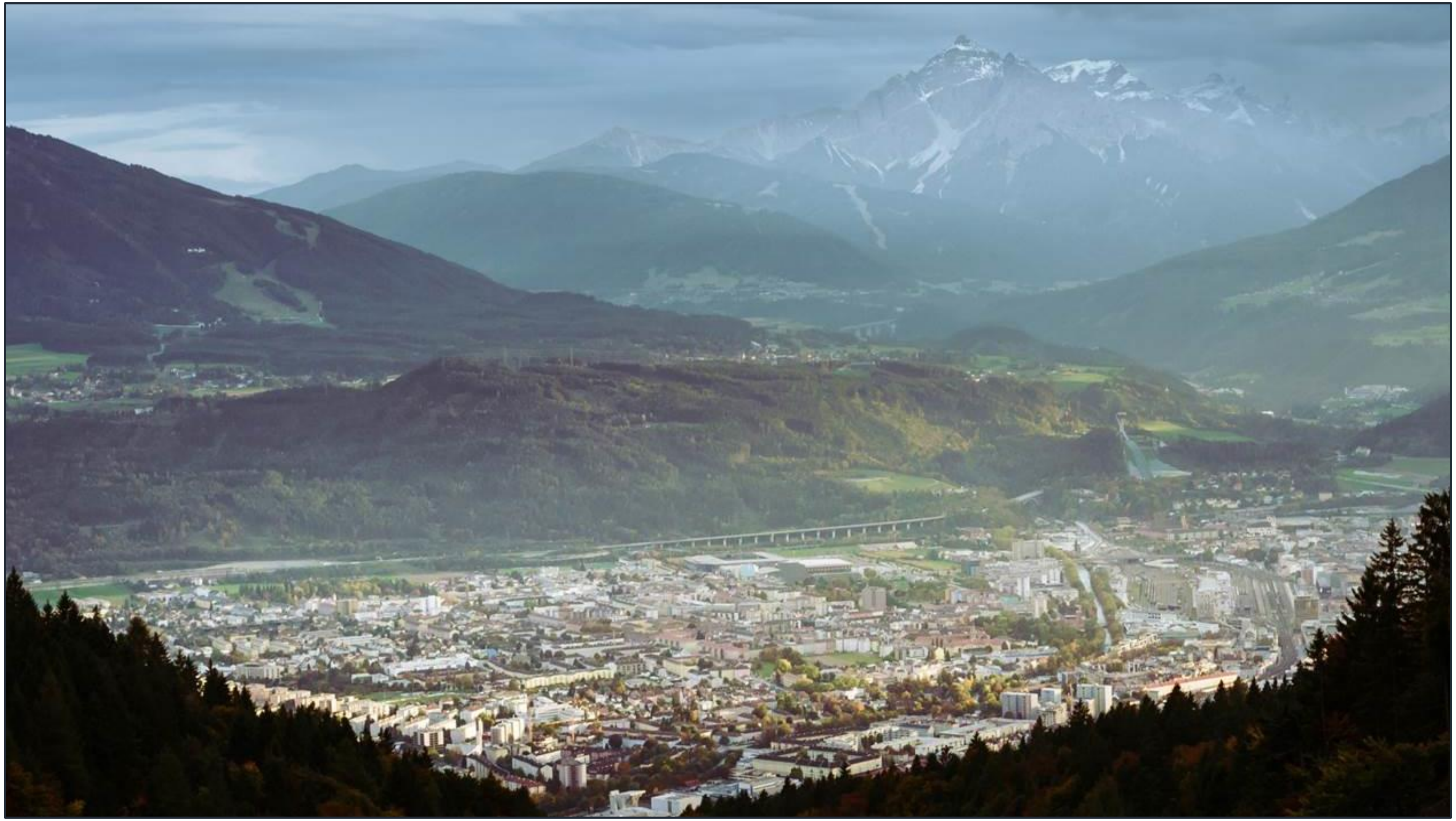

# Current challenges and future research priorities for urban areas in complex terrain

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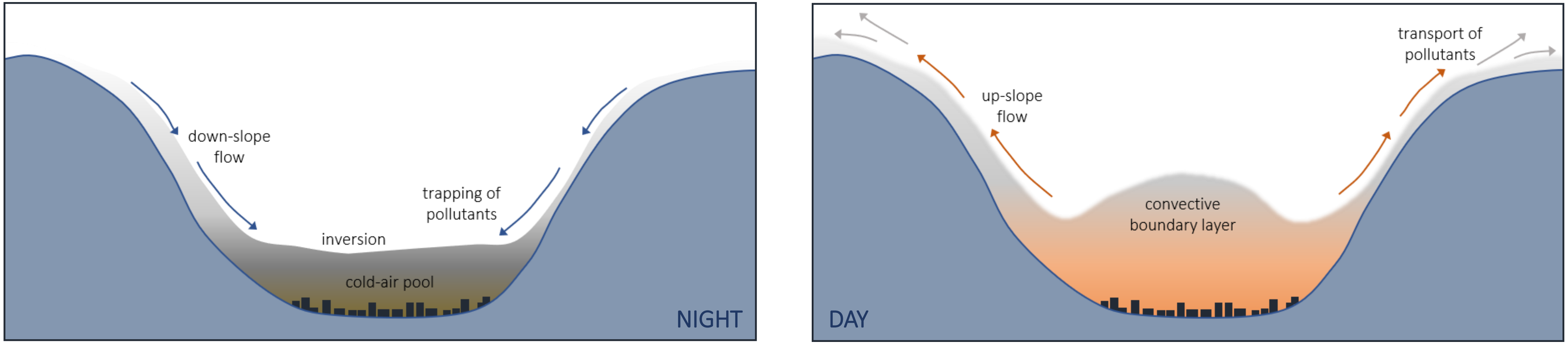
# Mountain weather poses substantial risks to infrastructure and human health

- **Air pollution**
  - orography and temperature inversions trap can pollutants close to the surface
  - in convective conditions up-slope winds can transport pollutants long distances
  - complex boundary layer structure and (re)circulation patterns are not easy to predict

- **Wind damage to infrastructure**
  - downslope windstorms, gap flows, gravity waves, rotors, enhanced turbulence

- **Extreme and/or rapidly changing conditions**
  - heatwaves (thermal stress) and freezing conditions (road safety)
  - snow (avalanches)



# Understanding and predicting these risks is a very relevant, but challenging, problem

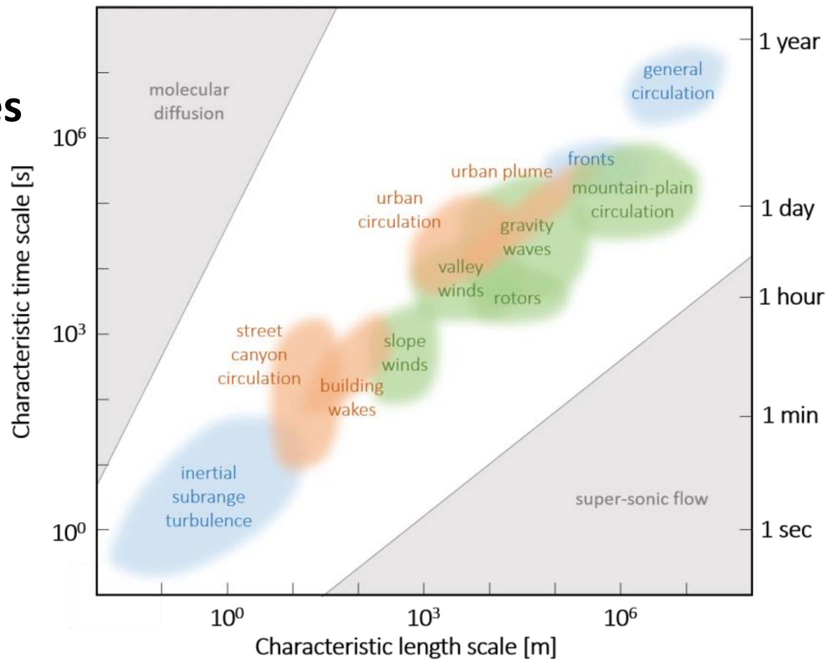
- Around 12% of the global population and over 20% of Europeans live in mountain areas…
  …with a much higher proportion living in areas of complex topography (e.g. non-flat terrain, along coastlines)

- Improving predictive capabilities in these areas is **crucial for human health**, to **minimise damage** to infrastructure and to develop more **sustainable and resilient cities**

- However, this is not an easy task!

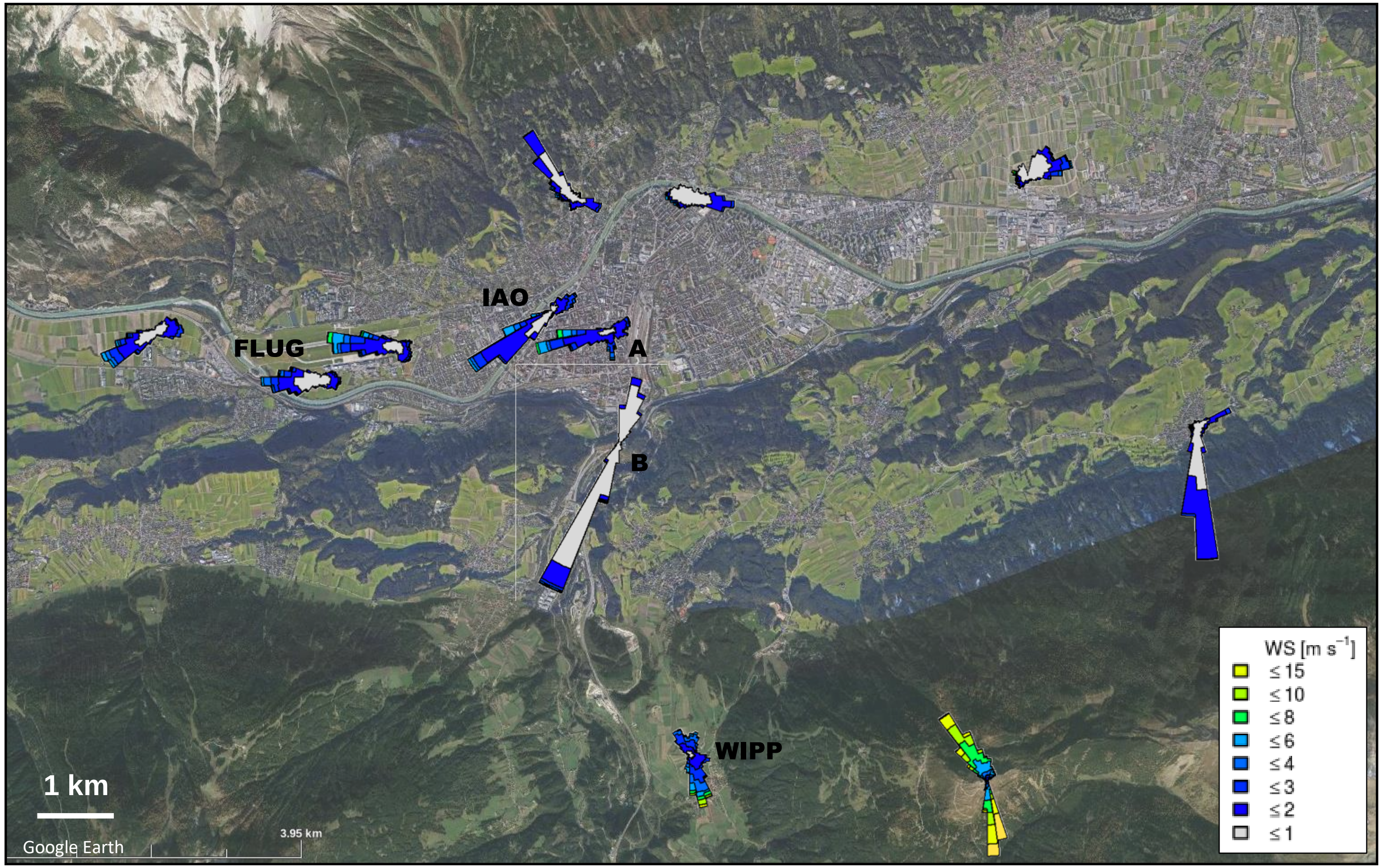
  - complex terrain is associated with a **range of processes that span multiple scales**
    - few of these processes are represented in models
    - many of these processes are ignored in observational retrievals
    - interactions between these processes are poorly understood

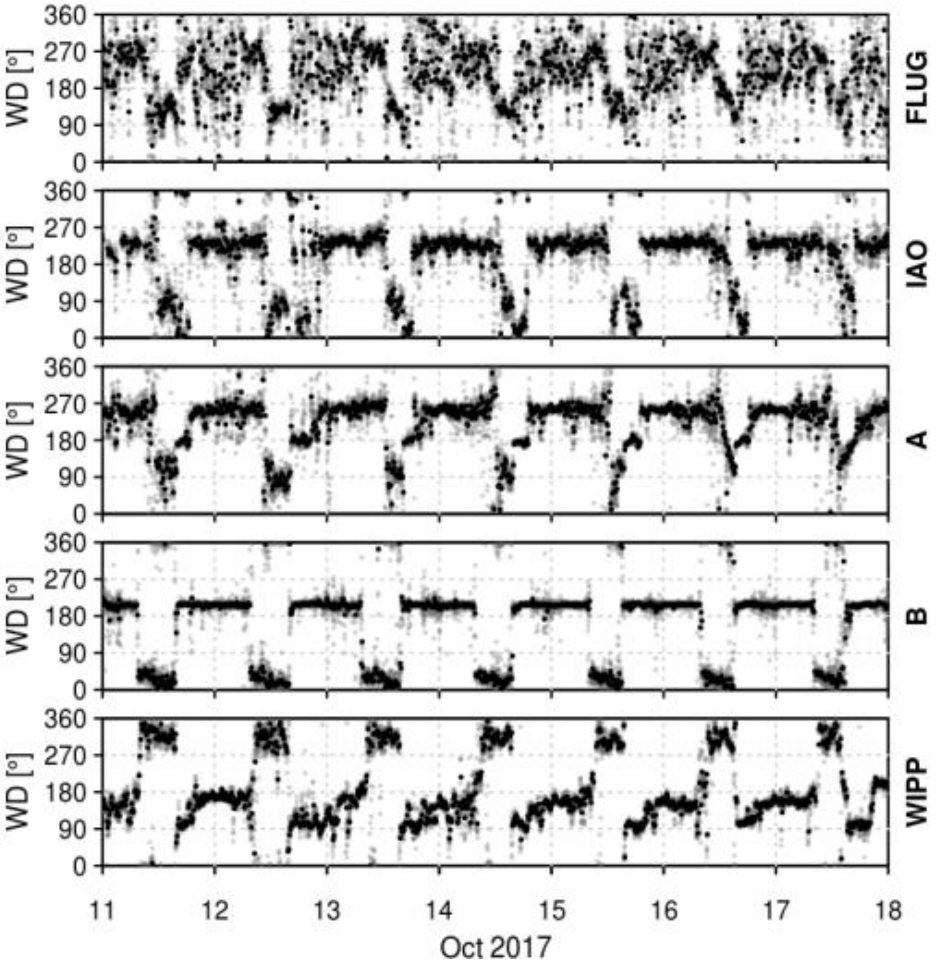
  - complex terrain leads to **extreme spatial and temporal variability**
    - obtaining representative measurements is challenging
    - simulations usually demand higher resolution
    - comparison between model and observation is non-trivial



# Considerable spatial variability in near-surface winds around Innsbruck

Data collected during the PIANO campaign Sep-Dec 2017



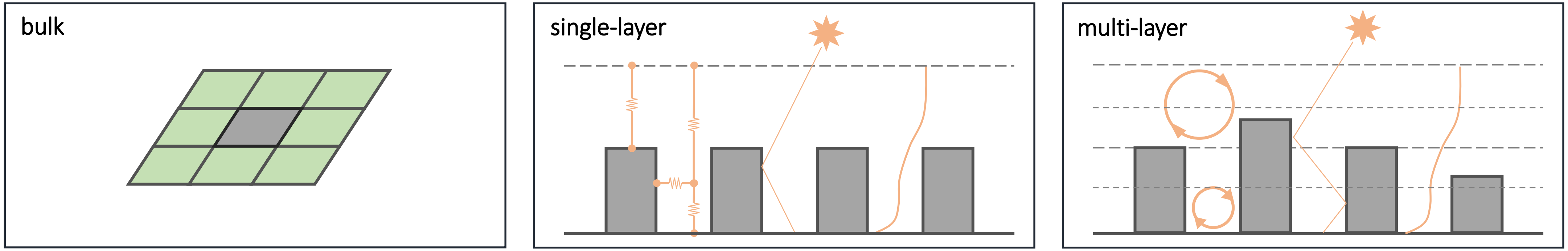




- Broad **channelling** by the valley structure with **diurnal cycles of slope- and valley-winds**
- Flow field is very sensitive to local terrain and thus **extremely spatially variable**
- Observed flow is net result of **many interacting factors at different scales**

# Current knowledge concerning urban areas

- Urban areas are now represented in numerical weather prediction models (grid spacing approx. 1 km)

- Various approaches to represent urban areas in mesoscale models:
  - **simple approach**: properties of the land-surface scheme adjusted to represent the bulk urban surface
  - **single-layer urban canopy models**: account for urban facets (roof, road, wall) [e.g. TEB, SLUCM]
  - **multi-layer urban canopy models**: account for building height variation [e.g. BEP, BEP-BEM]

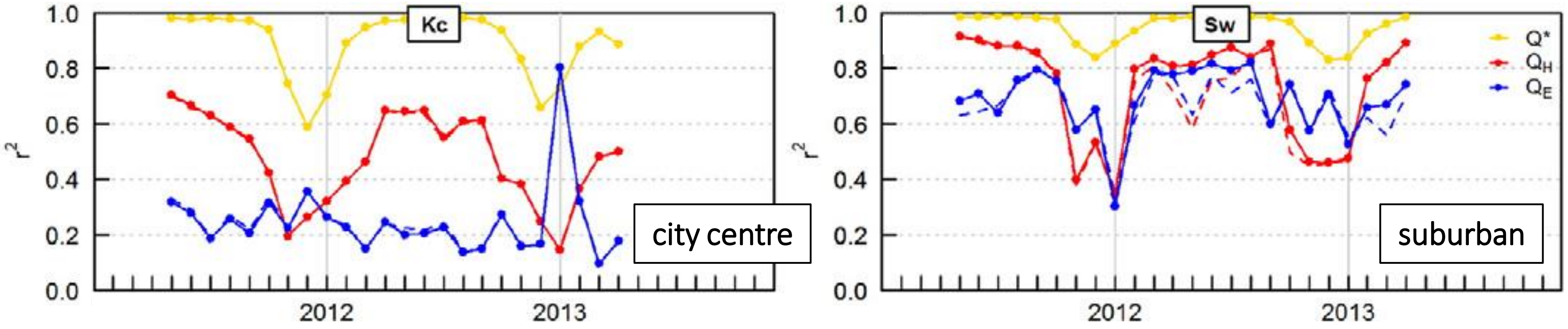



- Most models are still based on theory developed over ideal (i.e. **flat and horizontally homogeneous**) landscapes…
  …nevertheless, they are applied globally…
  …and there have been few evaluations against turbulent quantities, especially for complex terrain

# Current knowledge concerning urban areas

- Meteorologically-based models are increasingly used to inform policy, thus
    - models must be **reliable** and of **appropriate accuracy**
    - model performance **for the application** must be understood

- Findings obtained for one set of conditions may not be applicable for other conditions




Bias in model performance partly attributed to empirical parameterisations based on mid-latitude suburban summer field campaigns (Ward et al., 2016)

- Findings from one set of studies are not necessarily applicable to others
    - e.g. seasonal variability or vegetation characteristics across different climate zones
    - e.g. widely reported UHI vs. UCI for irrigated cities in arid climates
    - e.g. typical UHI mitigation measures applied to urbanised valleys could disturb pollutant transport mechanisms and impact air quality (Henao et al., 2020)

- Crucial to consider the **whole system**, not single aspects in isolation

interactions | feedbacks | inadvertent effects

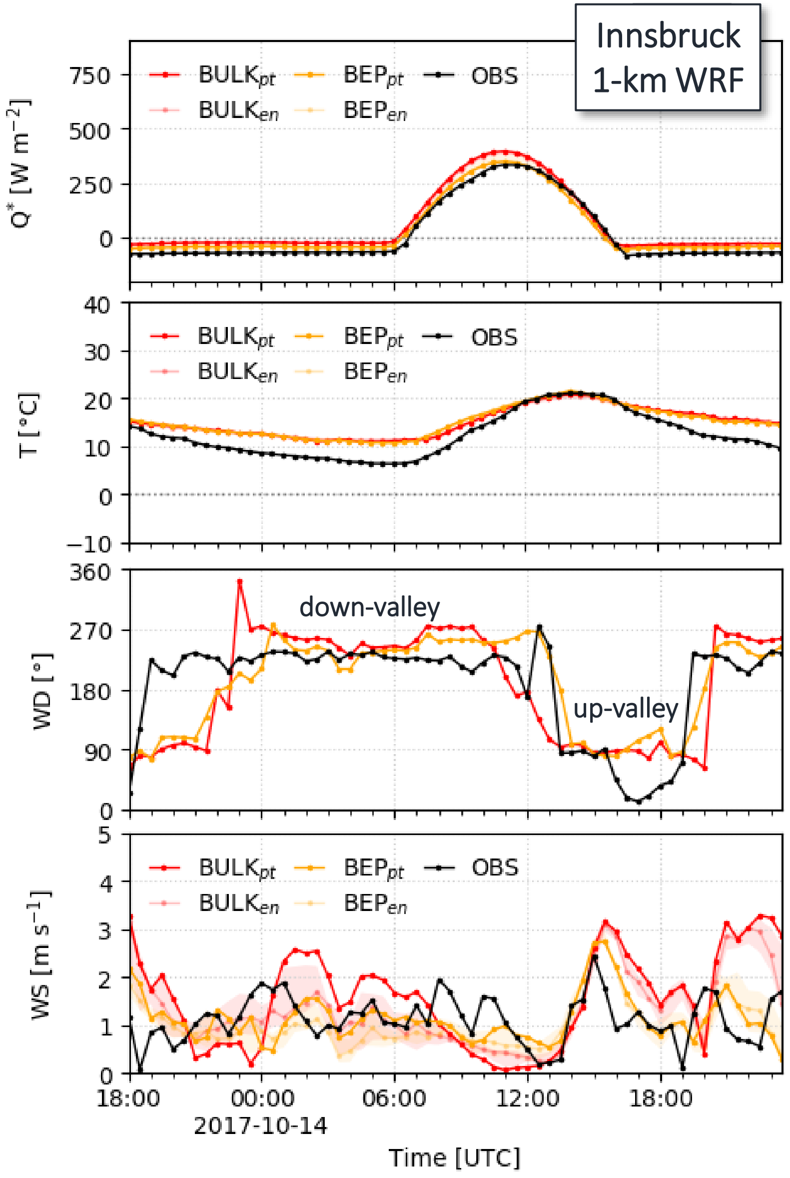
# Current knowledge concerning urban areas in complex terrain

- At **1 km grid-spacing**,
  - cities/neighbourhoods are resolved…
    …but rivers, parks, streets, buildings, etc are not
  - large-scale orography and valley-winds are reasonably well-represented (e.g. Giovannini et al., 2014; Ward et al., in prep)…
    …but smaller orographic features (e.g. side valleys) are not

- At **50-100 m grid-spacing**,
  - most relevant flow features in complex terrain are represented (e.g. Sabatier et al, 2018; Sprenger et al., 2018)
  - buildings and streets are not resolved

- For urban areas we often want to know about the **human-scale** (e.g. 1 m)
  - requires very high-resolution LES (computationally expensive)

**2016 Urban Meteorology Workshop** (Barlow et al., 2017) identified the need to
- link processes at human-scale to neighbourhood-, city- and regional-scales
- understand interactions between scales
- study the whole boundary layer, including the urban canopy layer



# How can TEAMx help?

- What (if anything) is **different in cities in complex terrain** compared to what we know from cities in flat terrain?

- Orographic effects versus urban effects
  - under what conditions are orographic effects important?
  - under what conditions do urban effects dominate?
  - which variables/processes are affected by orography?

which scales?

orographic setting?

for which applications?

weather conditions?

- How can relevant orographic effects be accounted for?
  - new/adjusted **parameterisations**
  - **pre-processors** for complex terrain (e.g. orographic shading, foehn diagnosis)
  - recommendations for **monitoring strategies/networks**
  - **data processing** considerations (e.g. QC, gap-filling)

# Important atmospheric processes and variables

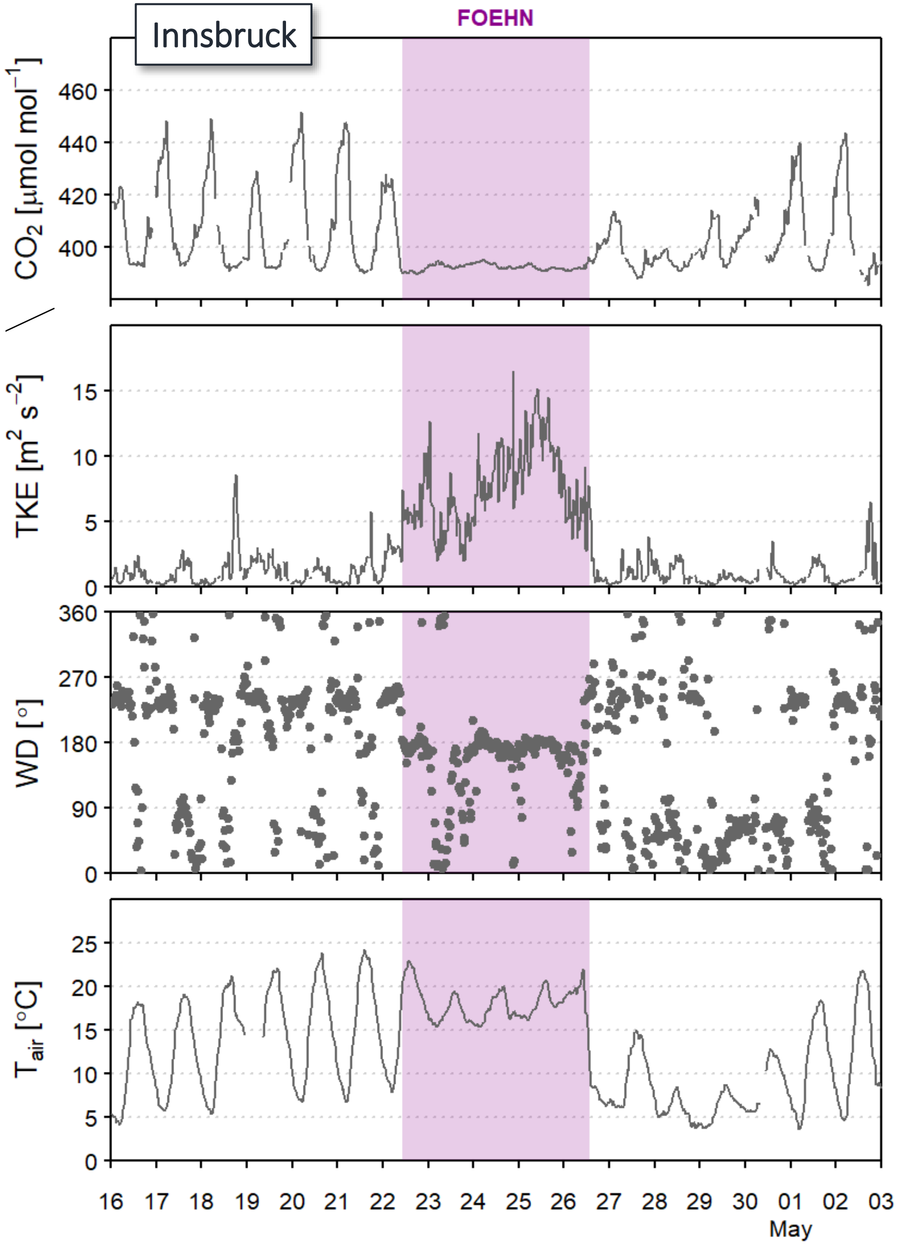
- **Drainage flows** and **cold air pools**
  - transport and trapping of pollutants close to the surface
  - cold pools can impede foehn breakthrough at the surface

- **Boundary-layer structure and development**

- **Slope- and valley-winds**
  - recirculation of pollutants by twice-daily wind reversal
  - weak flow during wind reversal can create stagnant conditions which may coincide with high anthropogenic emissions

- **Local circulations**, **gap flows**, **rotors** and their interaction with emission sources
  - informed decisions about where to locate industry

- **Interactions** between **orographically-induced flows** and **urban flows**
  - urban circulation creates convergence over city which can transport pollutants/agricultural emissions into the city




Thank you for listening

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