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EVALUATION METHODS FOR OBSTACLE RESOLVED MODELLING

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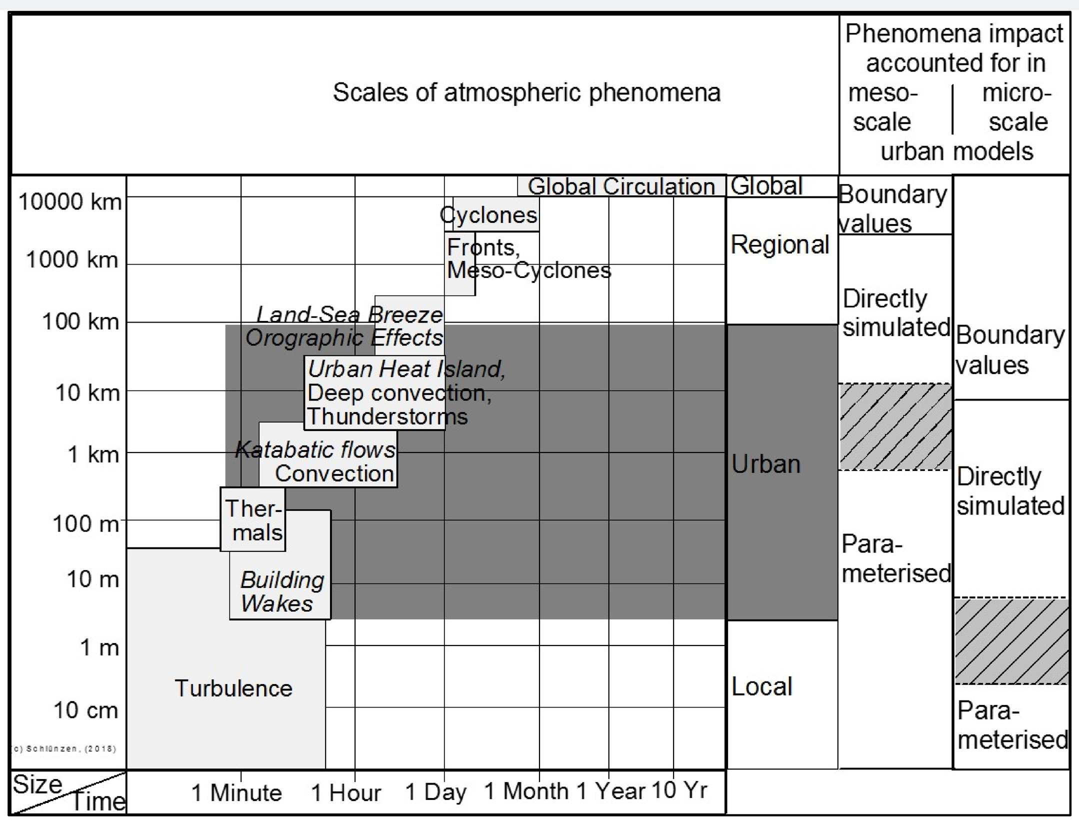
WHY DIFFERENT EVALUATIONS FOR DIFFERENT MODELS?

Obstacle resolved modelling of urban areas can be a valuable tool for urban climate research. Based on numerical model results, recommendations are given to stakeholder and relevant planning decisions are made. These might result in costly investments. Thus, researchers should not only provide results but deliver reliable results with quantified uncertainties.

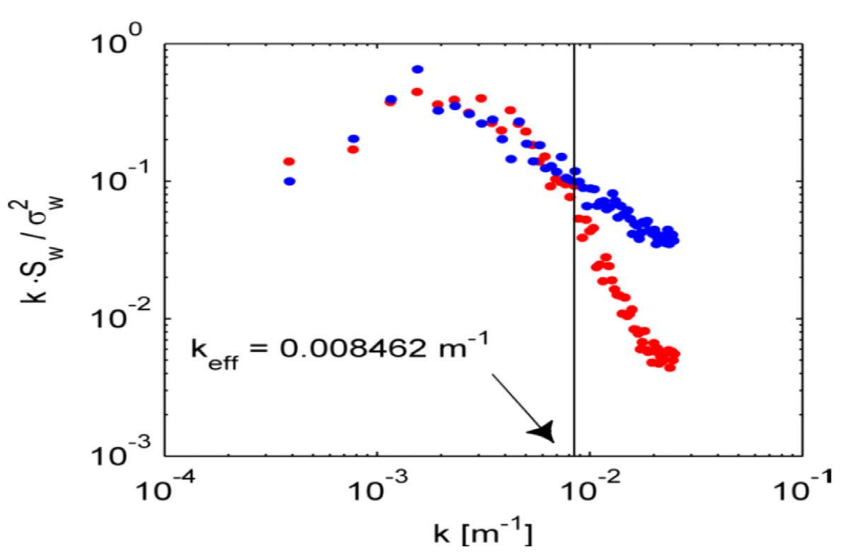
Models are tailored to specific application areas (Figure 1). Therefore, model evaluation needs to be scale and application specific.



1 Characteristic horizontal scale and time scale of atmospheric phenomena and their treatment in atmospheric models. *Italics* denote phenomena evaluated with VDI (2017b). Figure based on Schlünzen et al. (2011) and Wiesner et al. (2018).

Computational fluid dynamics models (CFD), Reynolds averaged models (RANS) or large-eddy simulation models (LES) are applied to quantify formerly only qualitatively known relations, e.g. between effects of urban green and urban climate. The model's reliability depends on several factors, including the **theoretical basics** and **simplifications made**, the **realization** as a computer code, and last not least the **model set-up** and thereby the **user applying the model**.

RANS and LES models deliver time averaged values when applied with a resolution of meters. LES models additionally resolve vortices in time. The time filtering of both depends on the sub-grid-scale turbulence scheme used, the boundary values with their turbulence characteristics, and on the numerical scheme or other filtering applied (Figure 2).



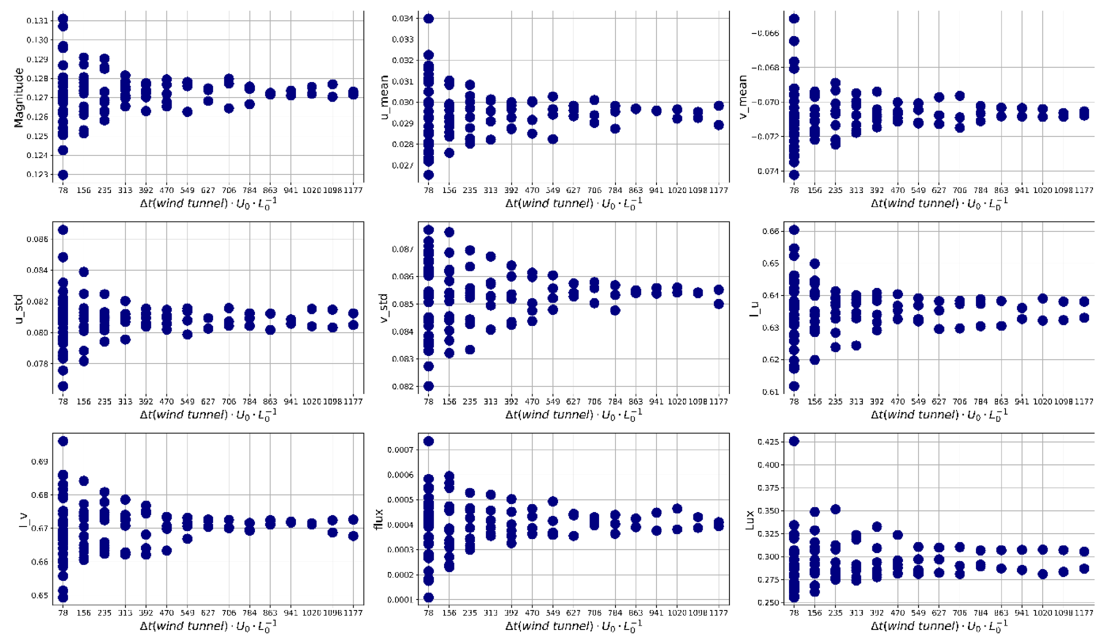
2 Spectrum of vertical wind fluctuations at 200 m for a convective situation. METRAS-LES (red) uses a damping for $2\,\Delta x$ waves, PALM (blue) introduces stochastic fluctuations at short waves. Figure form Fock (2015).

WHICH DATA FOR EVALUATION?

Evaluation of models with reference to turbulent transport is generally based on a statistical description of turbulent phenomena. It requires reference data to be of sufficient and known statistical representativeness as can be derived from complex physical modeling in dedicated boundary layer wind tunnels (Figure 3).

3 Upwind view of the wind tunnel model of Hamburg's city.

High quality wind tunnel measurements (Figure 4) enable estimating statistical uncertainty of measured data resulting from mechanically induced turbulence near the ground. Such data are difficult to derive from field measurements within the canopy layer, because turbulence driven variability can hardly be separated from other sources of temporal and spatial variability.



4 Temporal representativeness of wind data at urban measurement sites replicated in a complex wind tunnel model. The minimum expected statistical uncertainty for a given non-dimensional evaluation time period varies with the type of flow parameter chosen for the comparison.

ARE SINGLE CASE COMPARISONS SUFFICIENT FOR EVALUATION – OR DO WE NEED BROADER CONCEPTS?

Single cases help to verify a model per simulated situation. However, there are too many possible cases and solutions that a model can be verified in general, therefore only a falsification is possible (Popper, 1982). Nonetheless, to use models for scenario projections, forecasts or assessments it is important to ascertain their reliability. Since even a perfect model might deliver wrong results if wrongly used, there also needs to be quality assurances that a model user is able to calculate reliable results. These aspects are considered in evaluation concepts (Baklanov et al. 2014; Franke et al. 2011; Schlünzen 1996; 2018; VDI 2017a,b).

WHICH PARTS SHOULD BE INCLUDED IN A MODEL EVALUATION?

A model evaluation should include three parts:

A) Application area

- Target variables (e.g. heat stress, pollution load, wind comfort)
- Type of the application (e.g. single case, statistical averages, forecast, assessment)

Determines:

- What needs to be checked,
- Model type possible,
- Scales to be considered,
- Data for the evaluation.

B) Evaluation by the model developer

- General evaluation (documentation, peer reviewed publications, code traceability)
- Scientific evaluation (theoretical requirements)
- Application specific test cases (examples in e.g. Franke et al. 2011; VDI 2017a,b) ; they should
  - Cover the whole application area (stochastic selection, extremes, averages,
  - Include different evaluation types (Denis et al. 2010)
  - Describe benchmark tests in detail:
    - ✓ domain size, resolution,
    - ✓ topography / buildings,
    - ✓ input data, initialization, integration time,
    - ✓ boundary conditions,
    - ✓ how / where / when to compare,
    - ✓ reference data, model quality indicators (MQI), model quality objectives (MQO)

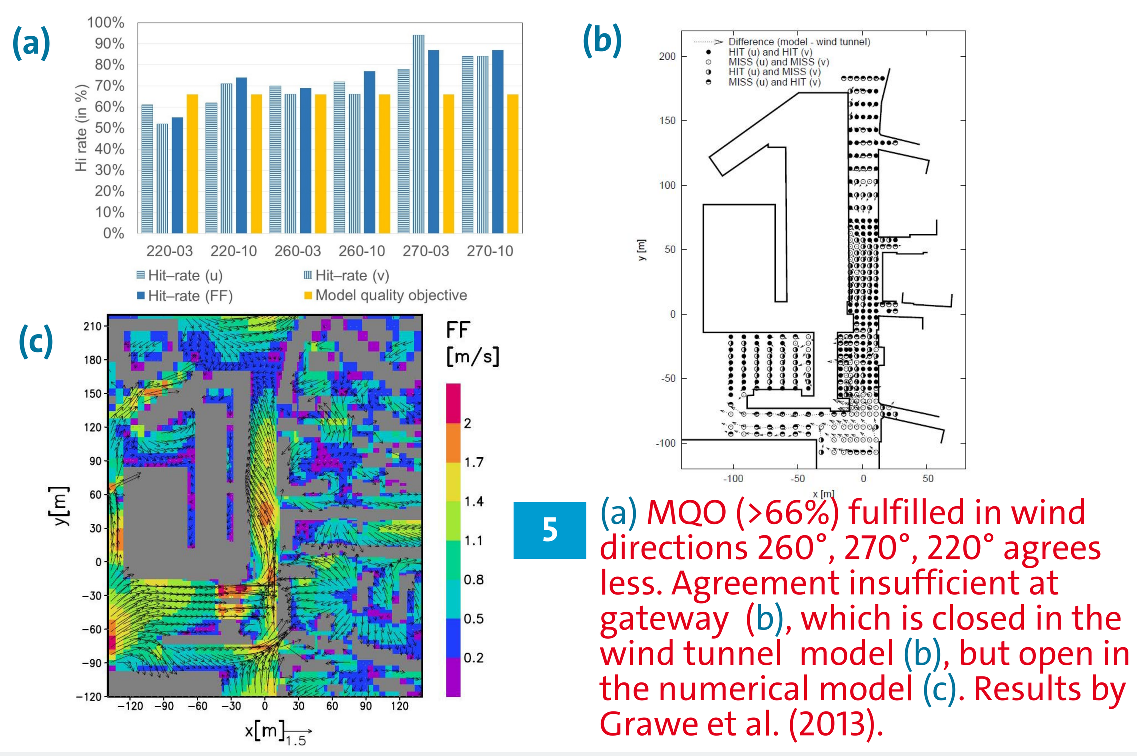
C. Evaluation by the model user

- Hints for domain size
- Selected application test as in B)

Remember: A perfect model fed with garbage will deliver physically consistent results, but they are still garbage.

EVALUATION EXAMPLE

Use of obstacle resolving model MITRAS (Salim et al. 2018), comparison to wind tunnel data, application of MQI / MQO of VDI (2017b). Performance is case dependent (Figure 5).



5 (a) MQO (>66%) fulfilled in wind directions 260°, 270°, 220° agrees less. Agreement insufficient at gateway (b), which is closed in the wind tunnel model (b), but open in the numerical model (c). Results by Grawe et al. (2013).

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