DTU

DTU

Wind Resource Assessment

Multi-point Measurements

Andreas Bechmann

RECAS
Reduced Assessment Time

Outline

1. **Single-point extrapolation** - *the similarity principle*

2. **Extrapolation uncertainty** - *a measure of similarity*

3. **Multi-point extrapolation** - *using ‘inverse uncertainty’*

4. **Conclusions**

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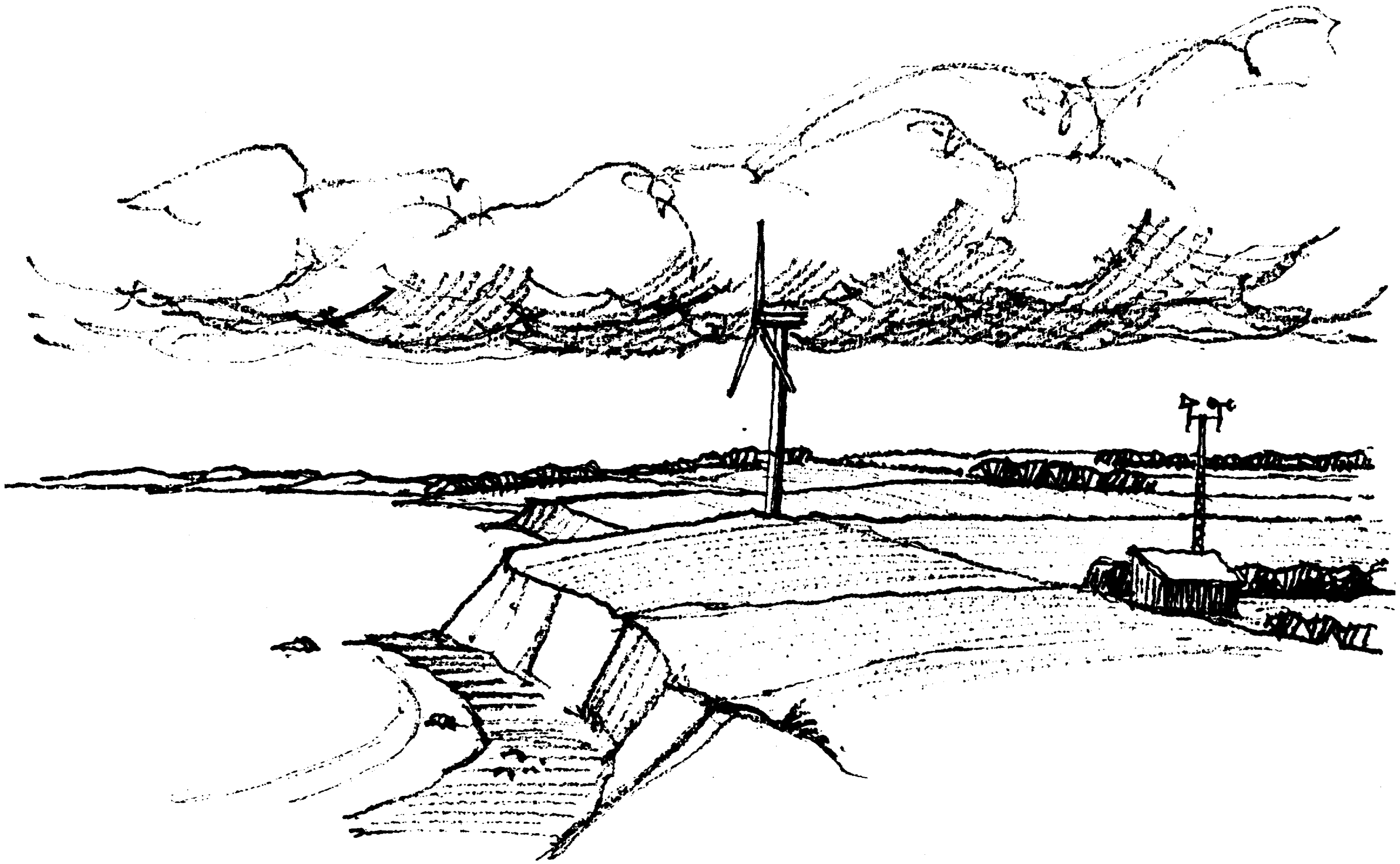
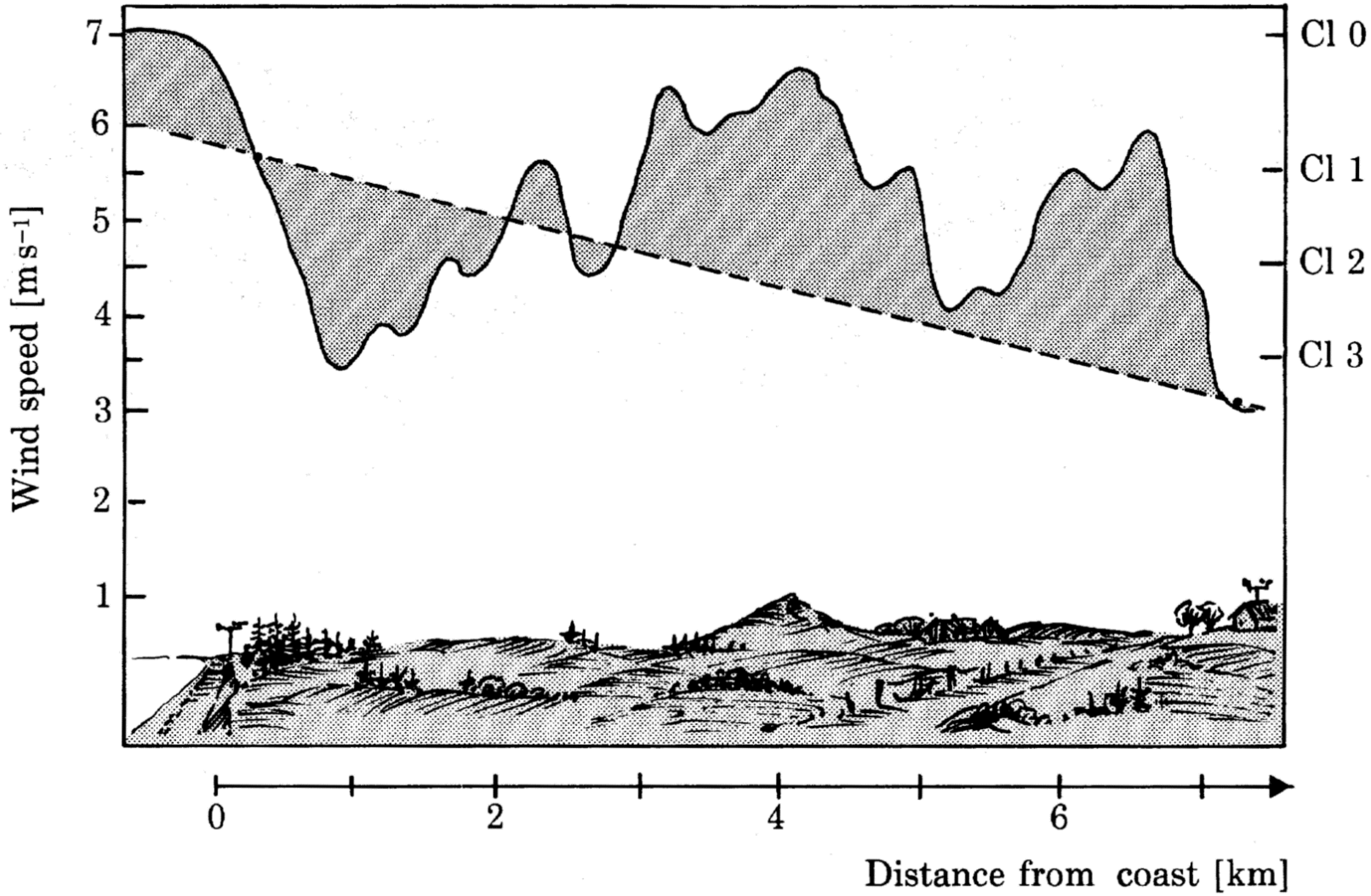
The classic problem



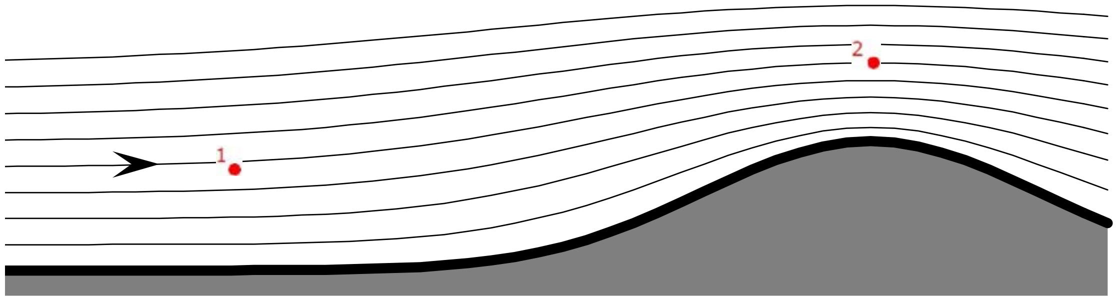
Linear interpolation…



Micro-scale flow modelling

The model calculates relative speedups:
(not wind speed)

$$\Delta S = \frac{U_2}{U_1}$$

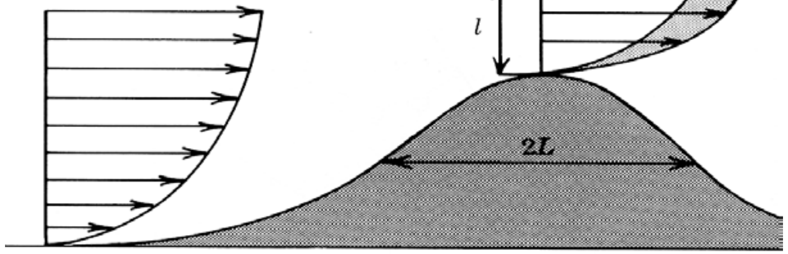


Observation:
(or LIB-file)

U_O

Prediction:

$U_P = U_O \times \Delta S$



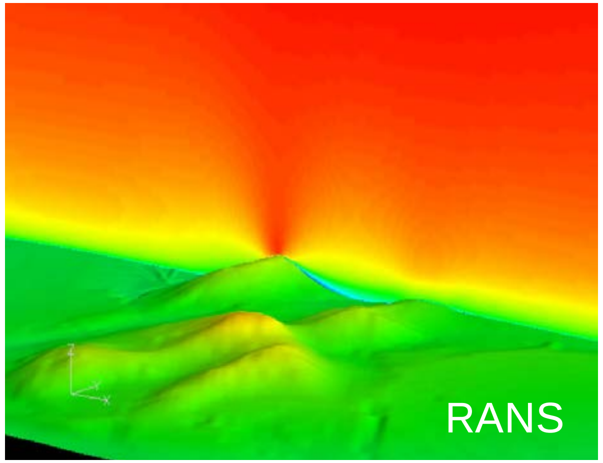
Micro-scale model: choice

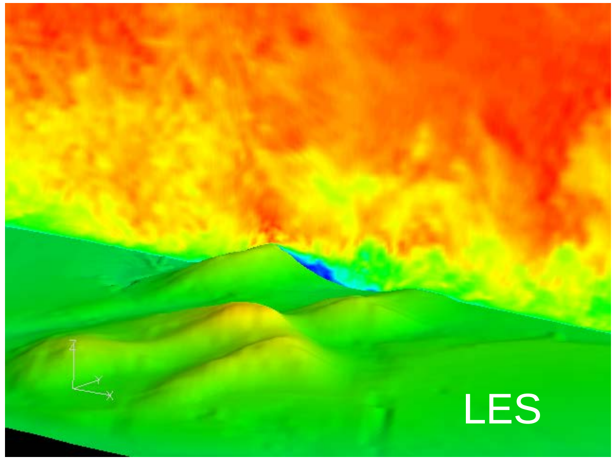
Sorted by complexity

- Linearized models (WAsP)
- RANS CFD (WAsP CFD)
- LES – partly resolves turbulence
- DNS – resolves all the turbulence

Differences among model types

- Accuracy of flow physics
- Resources required (CPU time & operator skills)
- Sensitivity and requirements to inputs / setup

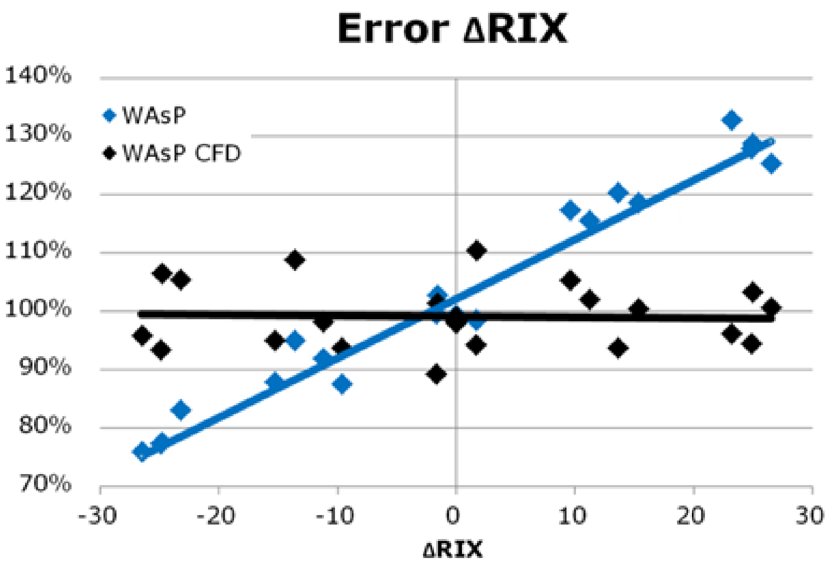




RANS and LES of the Askervein Hill. Simulations have been performed with EllipSys3D

A. Bechmann & N.N Sørensen, "Hybrid RANS/LES method for wind over complex terrain, Wind Energy 13, 36-50, 2010

Micro-scale model: spread and bias



N.G. Mortensen and E.L. Petersen. “Influence of topographical input data on the accuracy of wind flow modeling in complex terrain”. European Wind Energy Conference, Dublin, Ireland, 1997

ΔRIX = RIX(Prediction) − RIX(Observation)

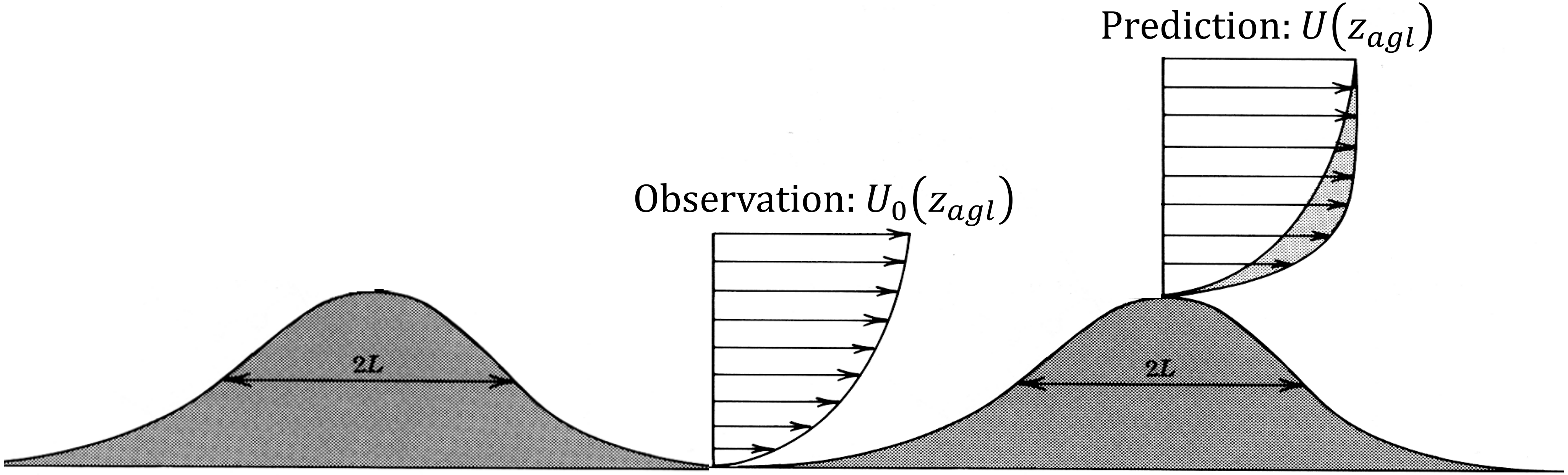
- WAsP IBZ has a ΔRIX bias
- WAsP CFD has no ΔRIX bias
- WAsP CFD has a larger spread?

-> All models have shortcomings. To reduce biases always keep the observation and prediction sites as “similar” as possible

Micro-scale model: similarity principle

To minimize errors related to the spatial extrapolation, the predictor site and the predicted site should be as "similar" as possible regarding factors like regional wind climate, roughness, orography, obstacles, etc.

Landberg et al., European Wind Energy Conference and Exhibition Proceedings, 2003



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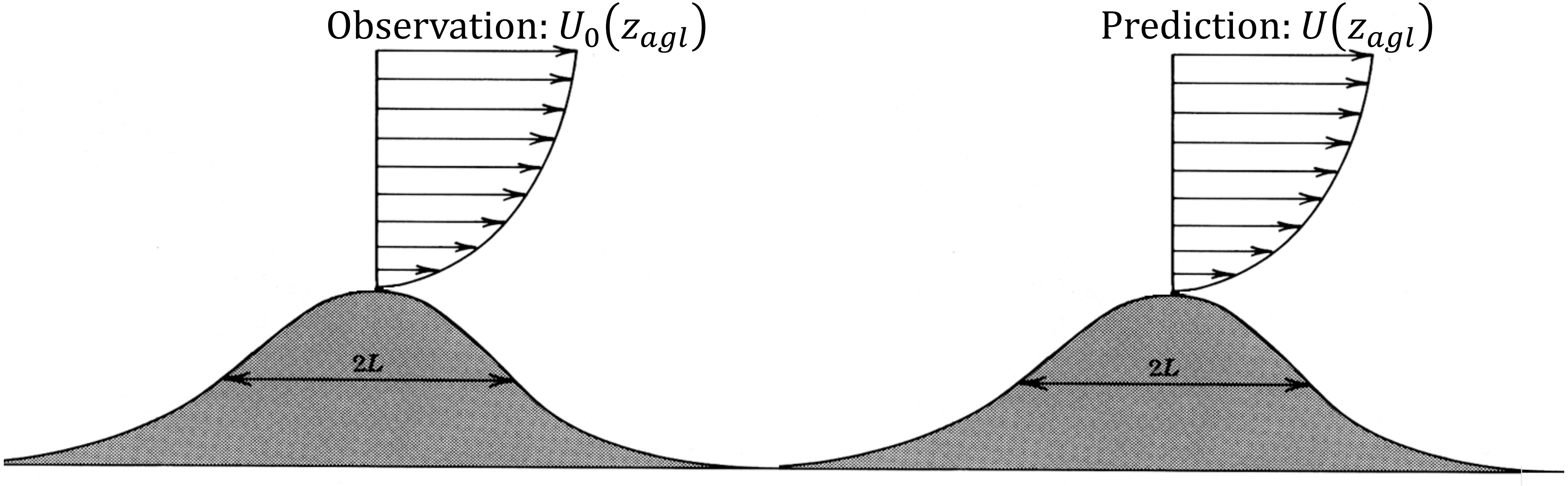

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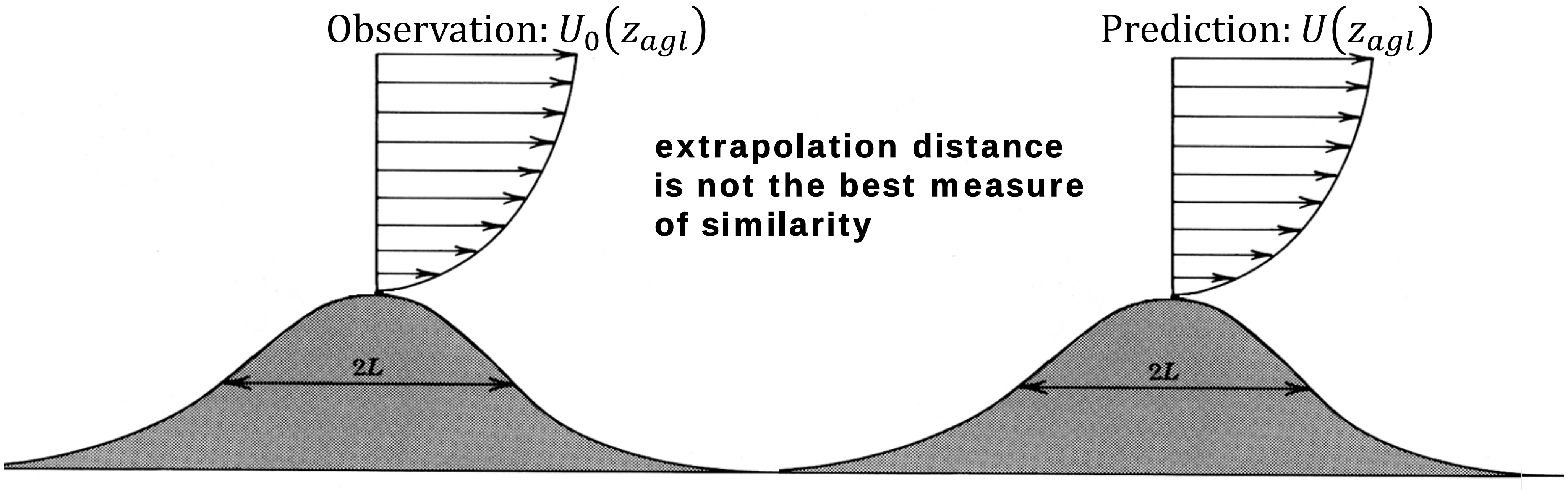

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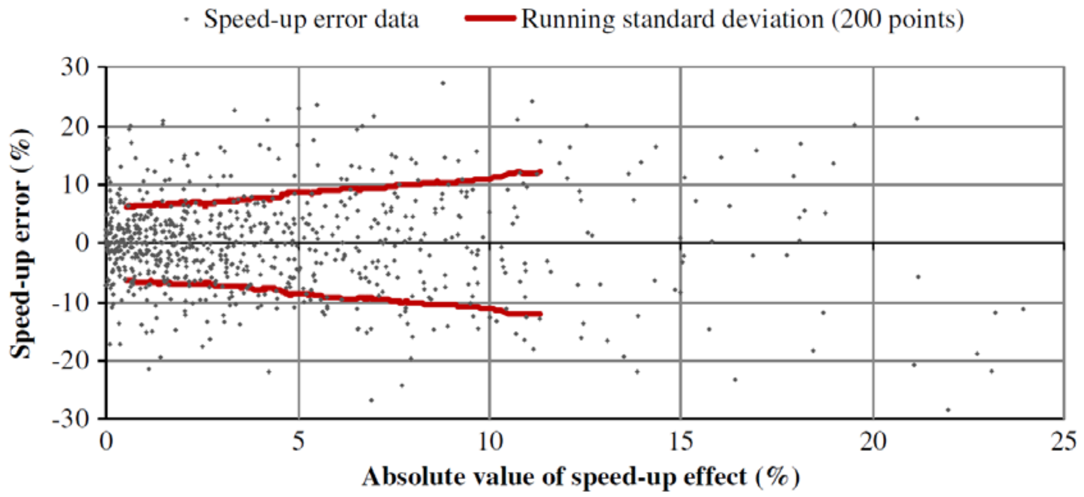
Errors due to ΔRIX

N.G. Mortensen and E.L. Petersen. "Influence of topographical input data on the accuracy of wind flow modeling in complex terrain". European Wind Energy Conference, Dublin, Ireland, 1997.

ΔRIX as "similarity" indicator:

- Indicates steep orography
- Site dependent (e.g. height above terrain)
- WAsP specific indicator

Errors due to ΔS



Clerc et al. "A Systematic Method for Quantifying Wind Flow Modelling Uncertainty in Wind Resource Assessment." Journal of Wind Engineering and Industrial Aerodynamics 111 (December): 85–94, 2012

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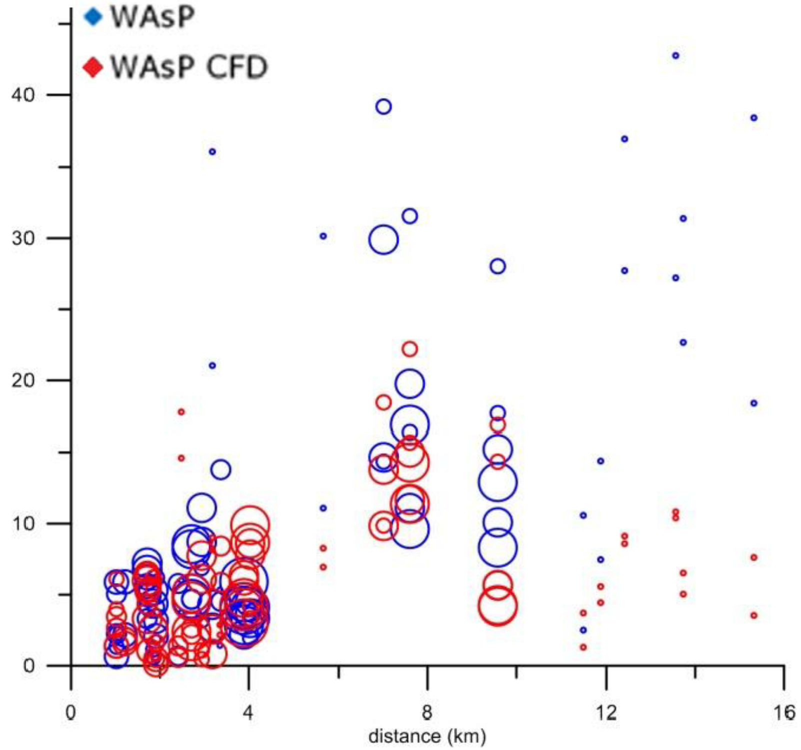
ΔS as "similarity" indicator:

- Indicates micro-scale roughness-, orography-, obstacle- & height-differences
- **Large ΔS = bias risk + high stakes**
- Every micro-scale model calculates ΔS

Errors due to distance



Bubble plot of the relative speed prediction error for WAsP (blue) and WAsP-CFD (red) for extrapolation distances in complex terrain. The bubble size is proportional to the height. Data from 27 masts allow a total of 310 data pairs (*Troen et al., Proceedings of EWEA 2014)*

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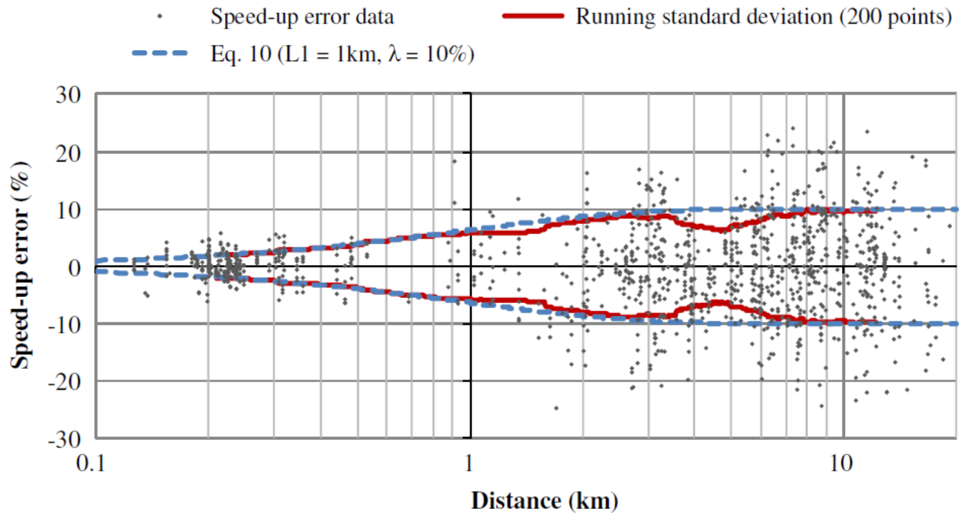
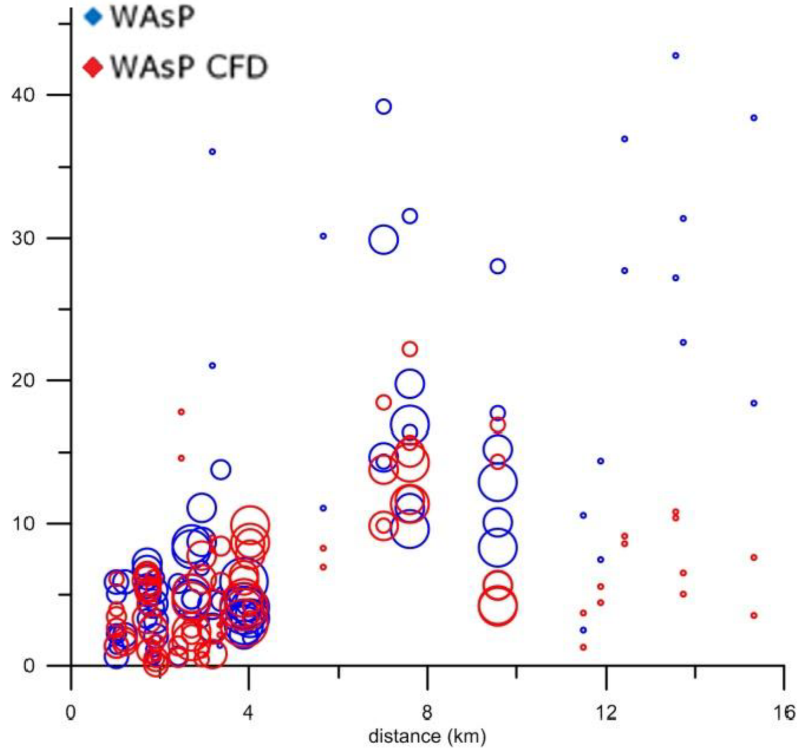


Speedup errors for horizontal extrapolation distance (gray) and running standard deviation of error (red) *(Clerc et al.)*



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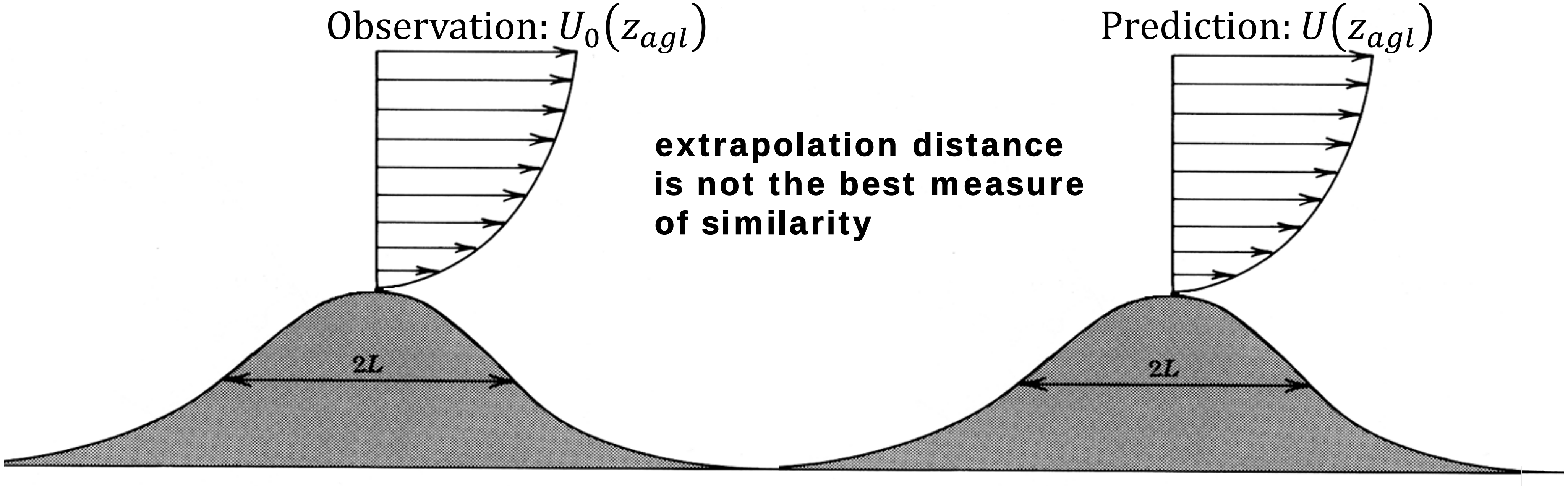
Combined measure of similarity

We want to minimize both
distance & speedup-effects



Combined measure of similarity

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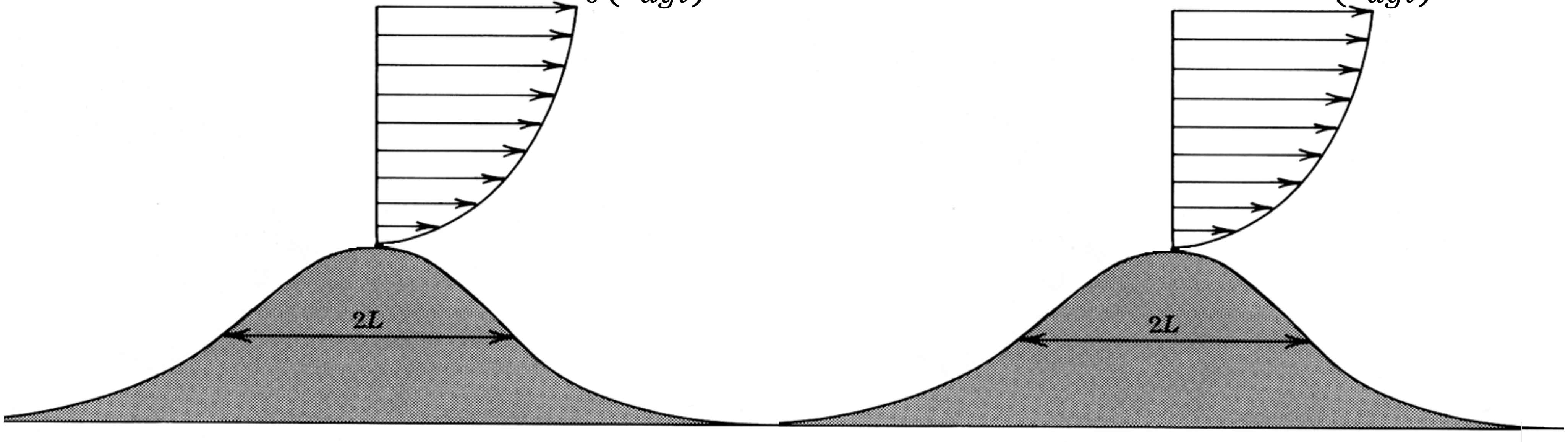
Clerc et al. combines the two:

$$u_E^2 = u_D^2 + u_S^2 = \left(\lambda\left(1 - e^{-d/L}\right)\right)^2 + (A|\Delta S|)^2$$

Observation: $U_0(z_{agl})$ Prediction: $U(z_{agl})$



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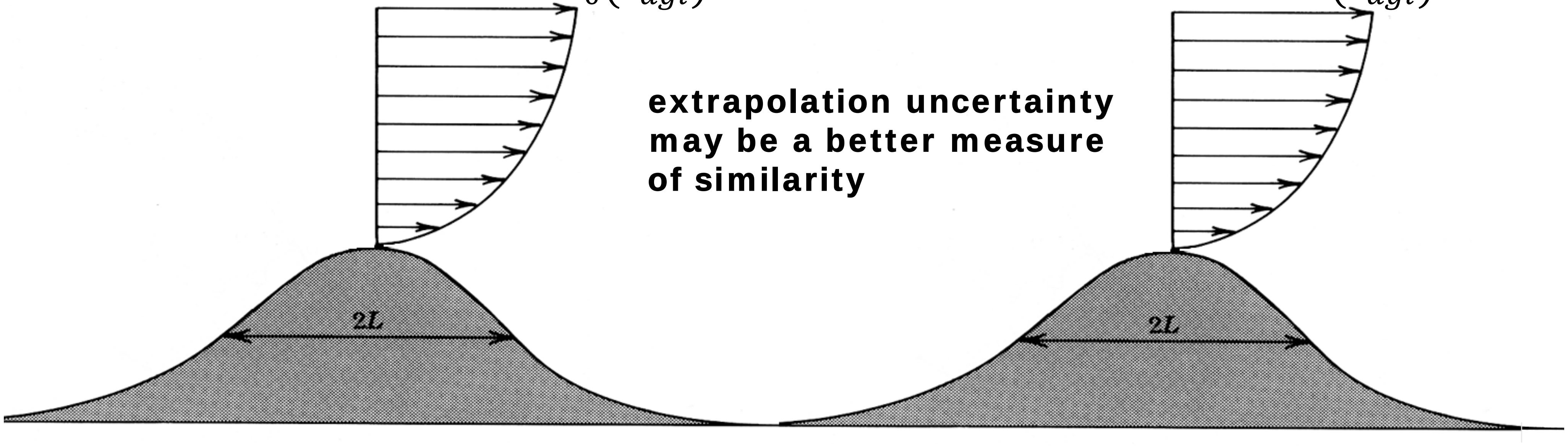

extrapolation uncertainty may be a better measure of similarity

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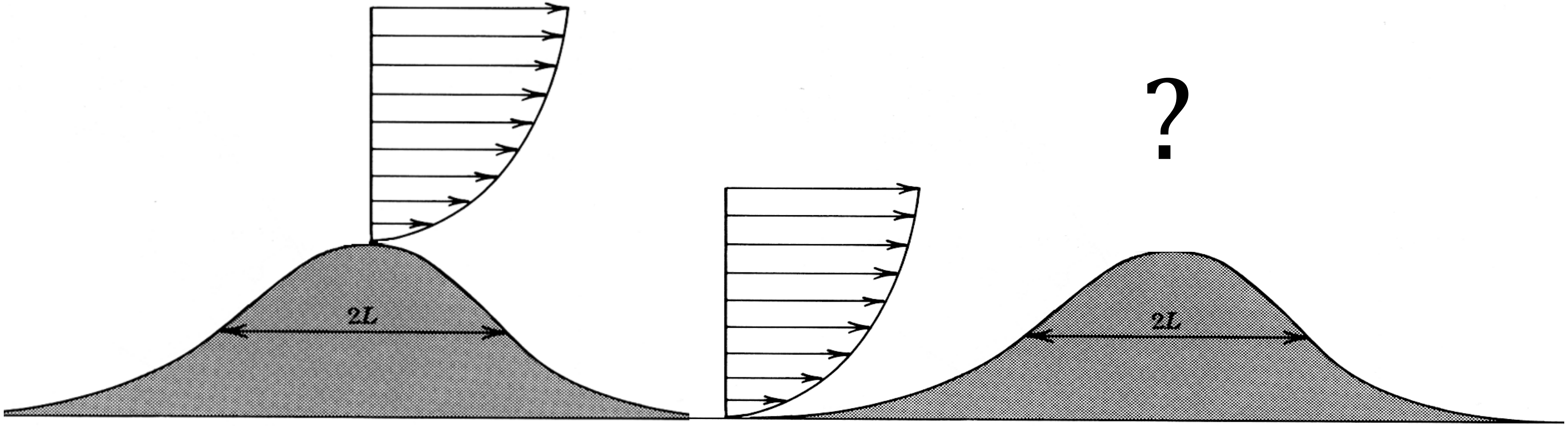
Multi-point extrapolation



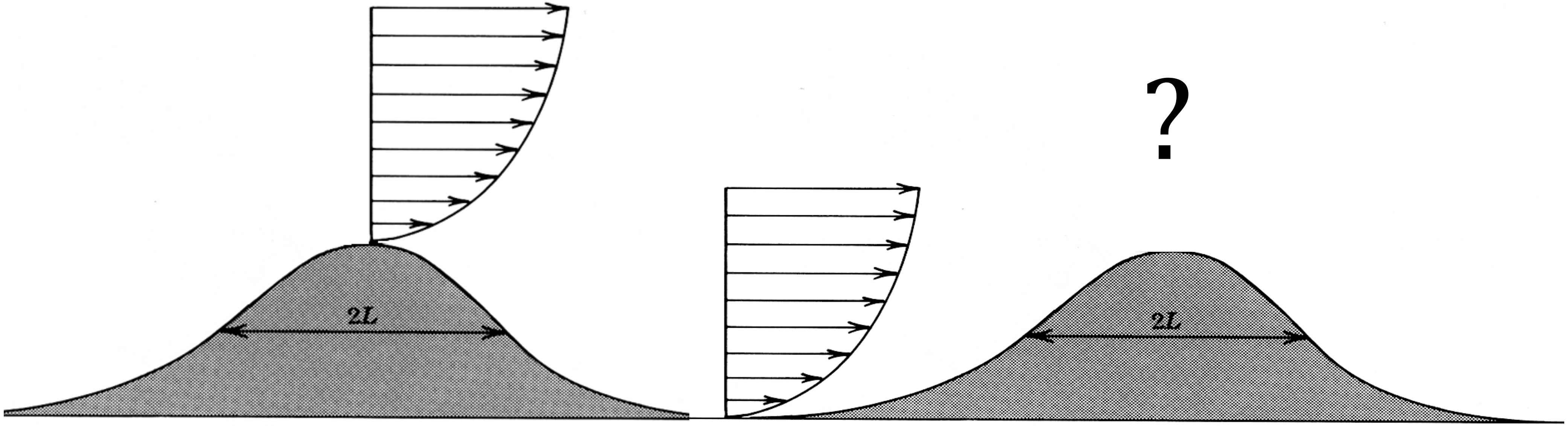
Multi-point extrapolation: closest mast

Single mast approach - WAsP

(the nearest or most "similar" mast is normally chosen)

$$U_{P,\,ij} = U_{O,j} \Delta S_{ij}$$ *WAsP uses Weibull distributions

$$E = \sum_{i=1}^{N_T} \sum_{j=1}^{N_\theta} P\left(U_{P,\,ij}\right)$$



Multi-point extrapolation: inverse distance

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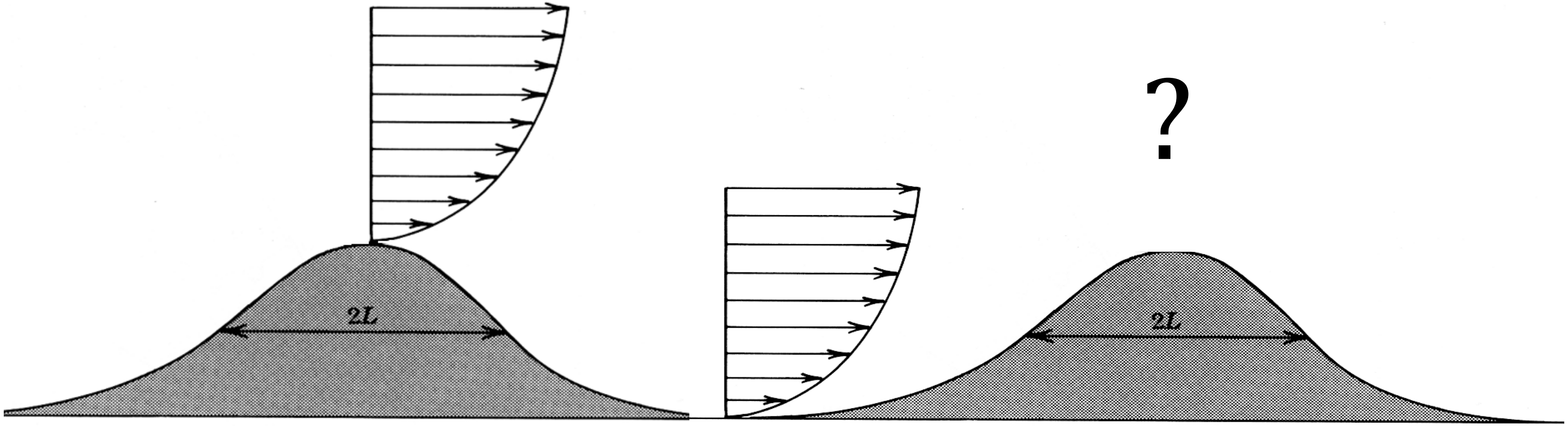
Traditional multi-mast approach

(weights are determined using the inverse distance)

$$w_{hi} = \left({}^{1}/_{d}\right)^{p}$$

$$E = \sum_{h=1}^{N_M}\sum_{i=1}^{N_T}\sum_{j=1}^{N_\theta} w_{hi}\, P\left(U_{O,hj}\Delta S_{hij}\right)$$



Multi-point extrapolation: inverse uncertainty

Multi-mast approach - WAsP

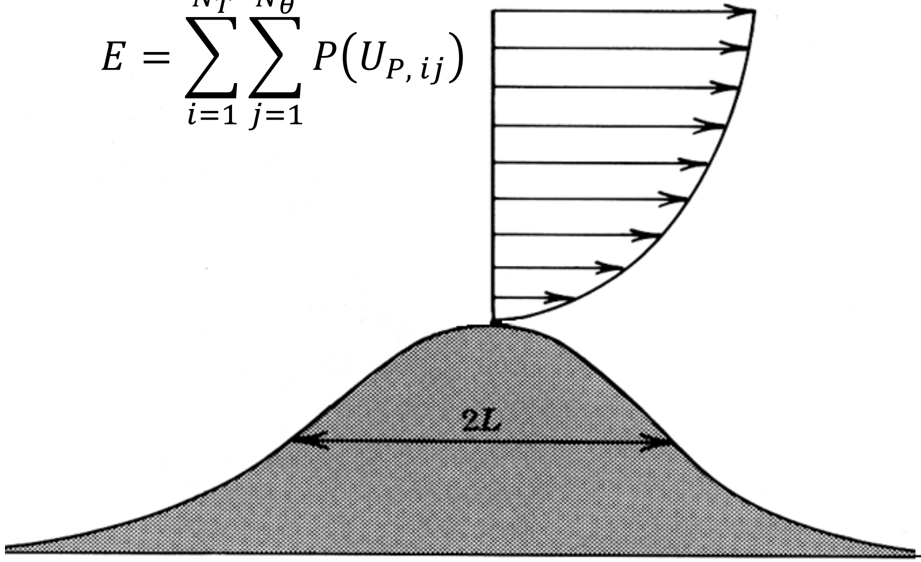
(weights are determined using inverse uncertainty)

$$w_{hi} = \left({}^{1}/_{u_E}\right)^p$$

$$U_{P,ij} = \sum_{h=1}^{N_M} w_{hi}\, U_{O,hj} \Delta S_{hij}$$

To predict mean Weibull distributions, A & k are actually found using mean 1st and 3rd order moments

$$E = \sum_{i=1}^{N_T} \sum_{j=1}^{N_\theta} P\left(U_{P,ij}\right)$$



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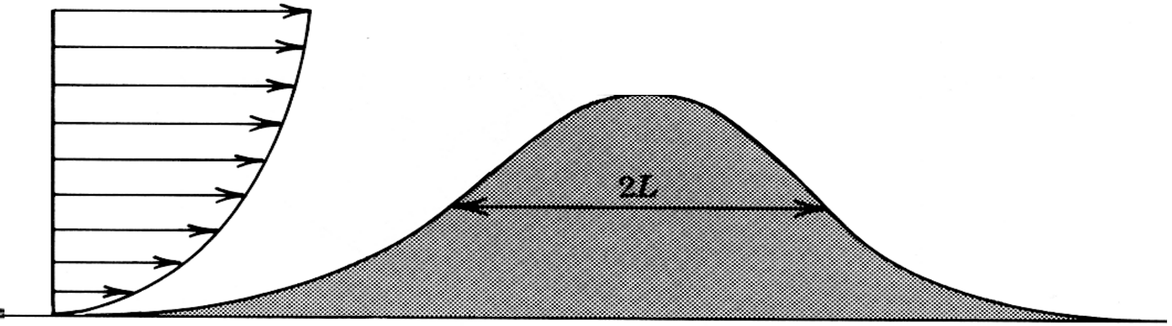
?



Multi-point validation: PyWAsP

```python
import os
import numpy as np
import pywasp as pw

## User data
site_name = "scotland"
conf = pw.wasp.Config()

# Reads all data
tabs, masts, turbines, topo, wtg, wtg_u = pw.read_data(site_name)

# Calculate mast weights
weight = pw.multimast_weights(masts, turbines, tabs)

# AEP prediction
aep_wf, ws_wt = pw.multimast_aepcalc(masts, turbines, tabs, topo, weight, wtg, wtg_u, conf)
```

Multi-point validation: extrapolation uncertainty

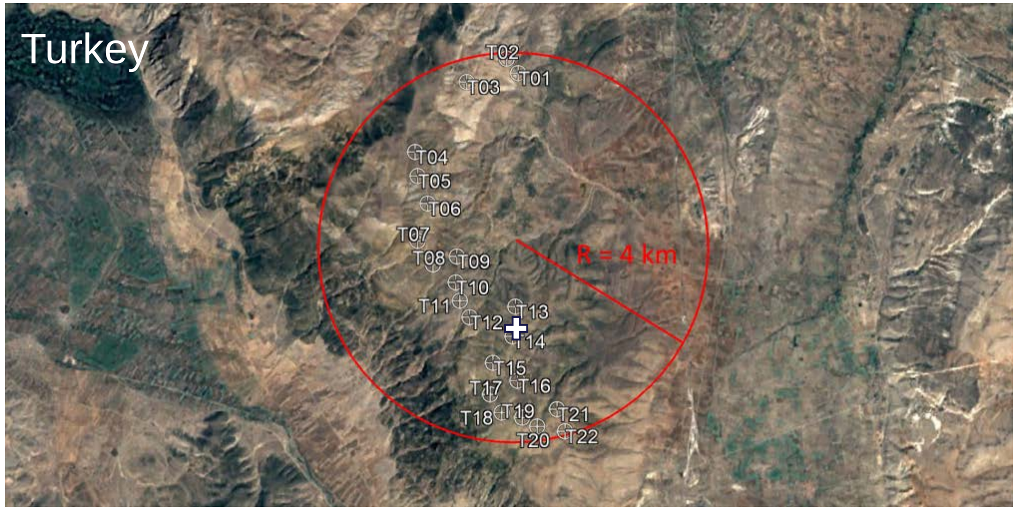
Empirical model for estimating wind flow modelling uncertainty; Clerc et. al. (2012)

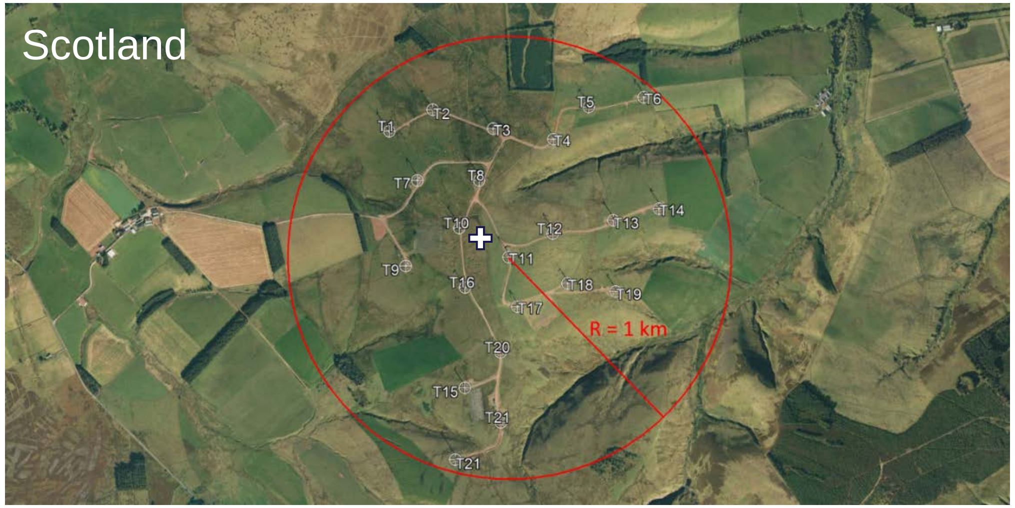
$$\left(\frac{\Delta E}{E}\right)^2 = \sum_{m=1}^{N} \sum_{n=1}^{N} \rho_{mn} u_m u_n f_m f_n$$

Correlation of speedup errors — Speedup uncertainty — AEP Sensitivity factor

Example

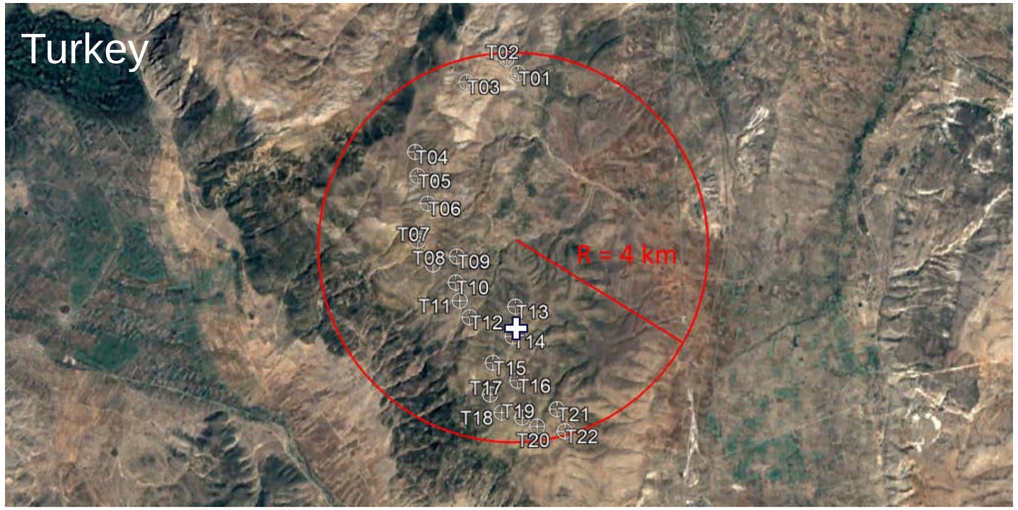
	Wind farm	Wind turbine			
	AEP	mean speed	Distance	Mast/WT height	Rated Power / Speed
Scotland (22 WT)	87.4 Gwh	7.8 m/s	623 m	47 m / 50 m	1.3 MW / 17 m/s
Turkey (22 WT)	188.0 Gwh	7.1 m/s	2455 m	80 m / 80 m	2.3 MW / 12 m/s

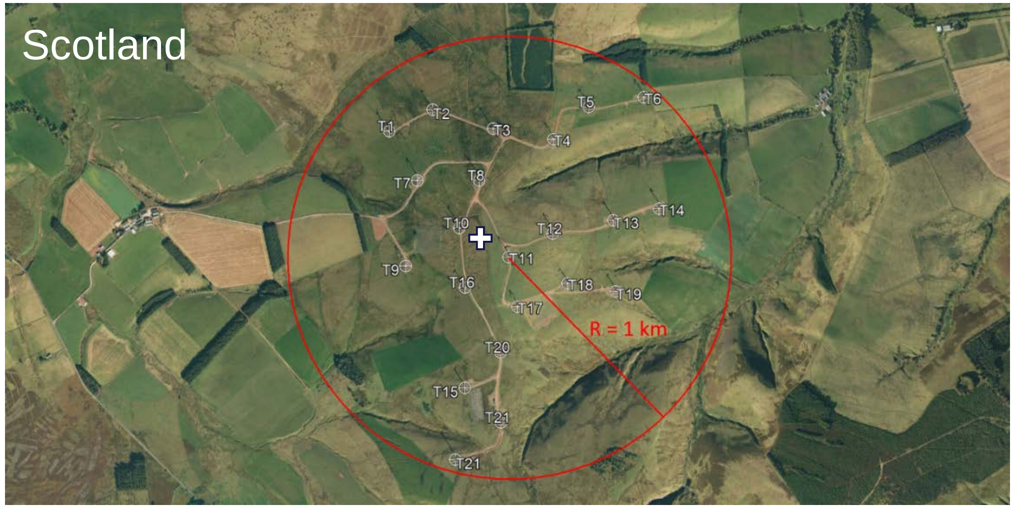




Single-point extrapolation

	Wind farm	Wind turbine	Sector
	AEP	**Speed**	**Speed**
Scotland (22 WT)	87.4 Gwh **± 7.9%**	7.8 m/s ± 5.0%	4.0%, 2.9%
Turkey (22 WT)	188.0 Gwh **± 7.3%**	7.1 m/s ± 6.6%	4.0%, 5.1%



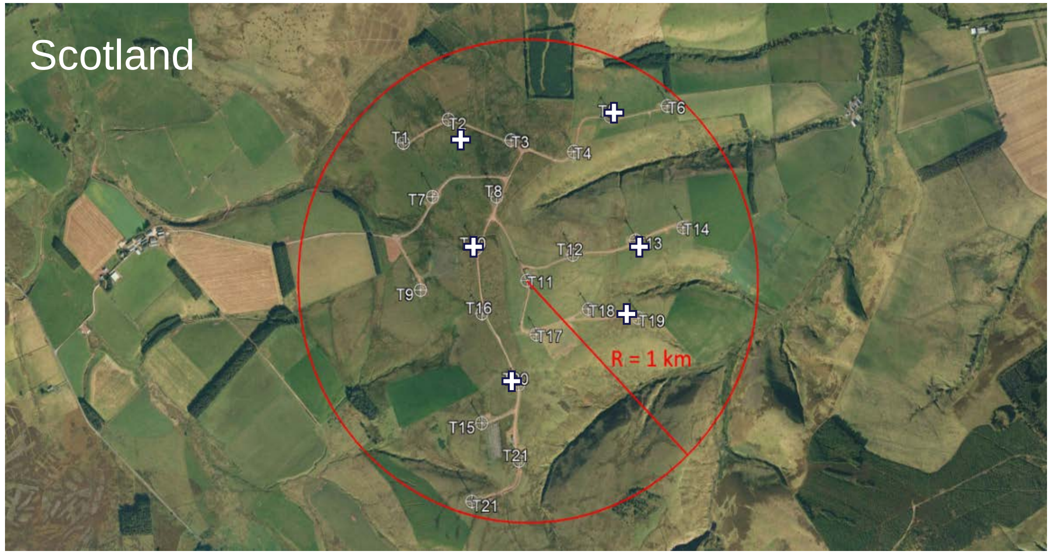


Multiple-point extrapolation: RECAST concept

RECAST
Reduced Assessment Time

	Wind farm	Wind turbine	Sector
Scotland	**UAEP**	**Uspeed**	**Uowc, Uextrs**
1 mast 4% owc (closest mast)	**± 7.9%**	**±5.0%**	4.0%, 2.9%
6 mast 4% owc (inv. uncertainty)	± 6.6% (f=1.6)	± 4.3%	4.0%, 1.4%
6 masts 5% owc (inv. uncertainty)	± 8.2% (f=1.6)	± 5.2%	5.0%, 1.4%

Increasing OWC uncertainty

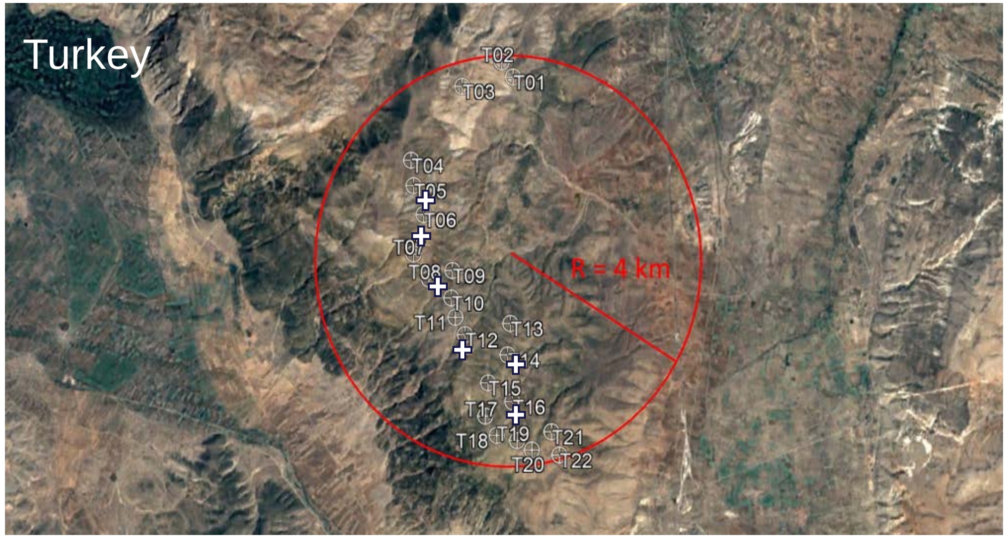


Multiple-point extrapolation – RECAST concept

	Wind farm	Wind turbine	Sector
Turkey	**UAEP**	**Uspeed**	**Uowc, Uextrs**
1 mast 4% owc (closest mast)	**± 7.3%**	**±6.6%**	4.0%, 5.1%
6 mast 4% owc (inv. uncertainty)	± 5.6% (f=1.3)	± 5.5%	4.0%, 3.7%
6 masts 5% owc (inv. uncertainty)	± 6.8% (f=1.3)	± 6.3%	5.0%, 3.7%
6 masts 5.5% owc (inv. uncertainty)	**± 7.4%** (f=1.3)	± 6.7%	5.5%, 3.7%
6 masts 6% owc (inv. uncertainty)	± 8.0% (f=1.3)	± 7.1%	6.0%, 3.7%

RECAST
Reduced Assessment Time

Increasing OWC uncertainty



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- Inverse uncertainty can be used for
  - Multipoint extrapolation incl. wind climate prediction (also for LIB-files)
  - Design of “optimal” measurement campaigns / placement of measurement point (RECAST)

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  - Design of “optimal” measurement campaigns / placement of measurement point (RECAST)

- Further work
  - Validation against ~100 multi-mast sites (Vestas)
  - Implementation in PyWAsP
  - WES conference in Cork incl. paper