



Vertical Extrapolation Uncertainty in Complex Terrain

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Checking...

Did you pay attention? 😊

- Who knows windPRO?

- Who knows that EMD has a Consulting department?

Night time reading

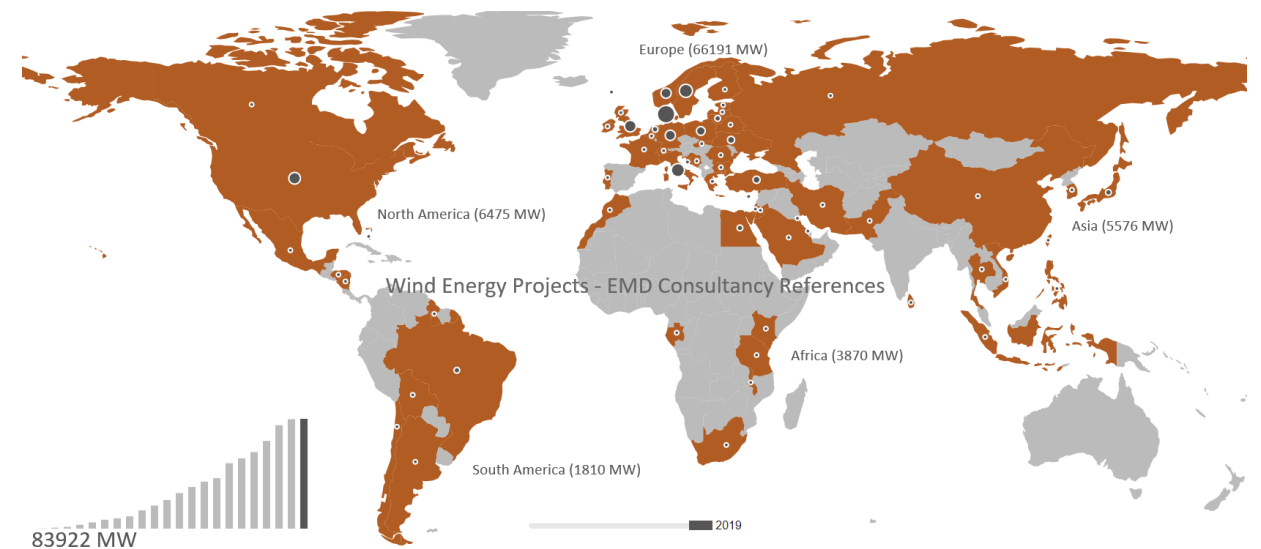
EMD Wind Consulting: Who we are

EMD's Wind Consulting is part of EMD International A/S, which was founded in 1986 and is one of the pioneers in the wind industry.

Our Wind Consulting team has conducted wind resource and environmental assessments as well as performance analysis of worldwide wind farm projects with a total planned capacity of more than **80,000 MW**, onshore and offshore.

Today, we perform consultancy jobs for global companies and banks as well as longer-term project assignments for DANIDA, World Bank and other international institutions.

EMD's long-term interaction with project developers, manufacturers, investors, utilities, banks and authorities has resulted in the world's most used and accepted software package within wind energy, **windPRO**.



Complex Terrain

- Constant nightmare for siting engineers
- Experience in complex terrain = “Medal of Bravery”
- Re-visit definition: What is “complex”?



Re-visit definition: What is “complex”?

- Minimum 3 definitions:
 - IEC 61400-1 Design Requirements – re-distribution of turbulence components
 - WAsP Quick-fix Ruggedness Index RIX
 - MEASNET: Site Assessment



Figure 2: Example of a *simple terrain* site as defined by this guideline. Such a site has only minor relief which leads to a negligible influence of orographic effects on wind conditions. The latter are therefore mainly influenced by roughness conditions.



Figure 3: Example of a *complex terrain* site as defined by this guideline. Such a site is characterised by orographic features with terrain slopes greater than 0.3 (approx. 17°), which have a significant influence on wind conditions.



Re-think!

Is “complex” really complex?

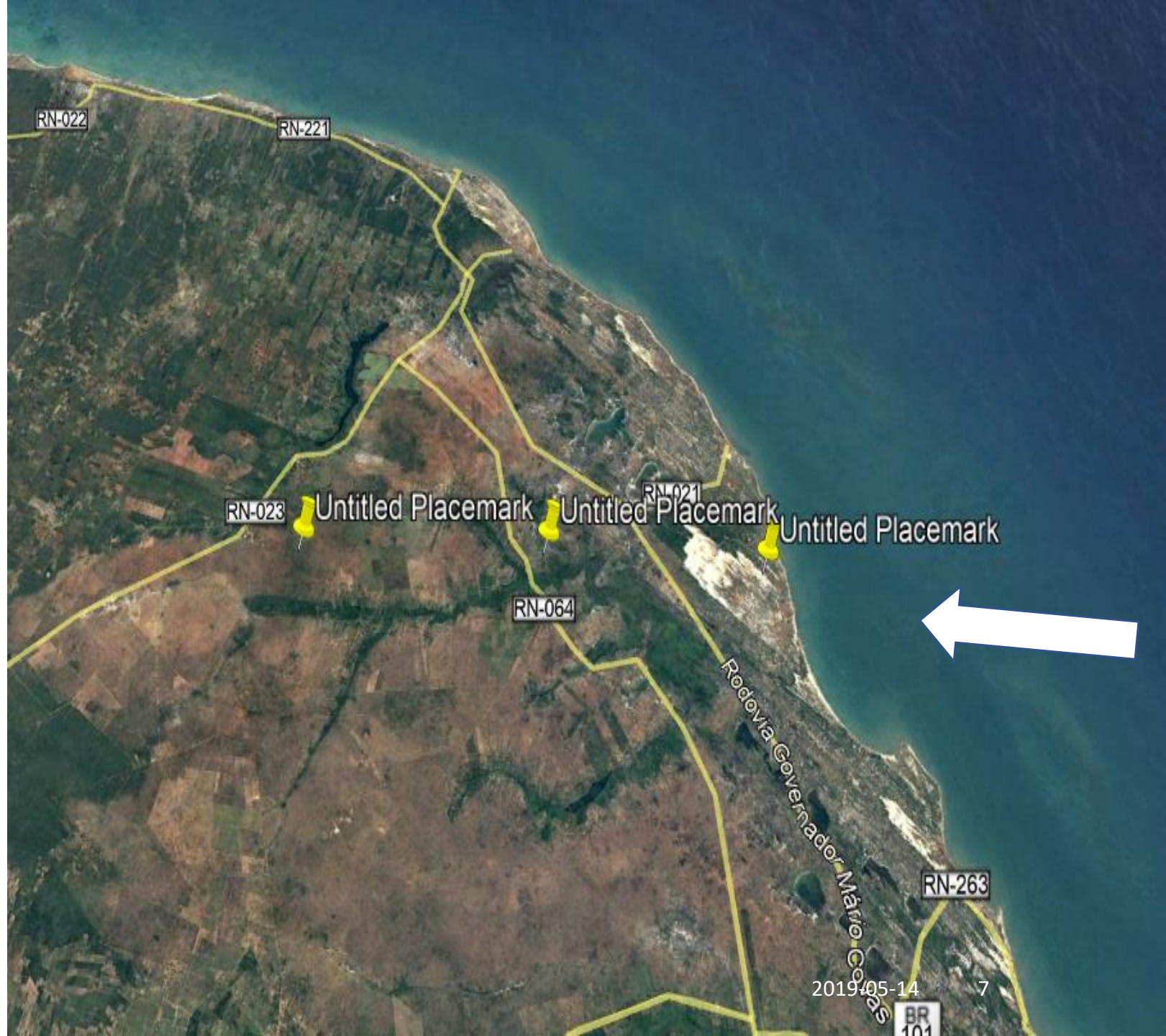
Or are there “simple” sites that are complex?



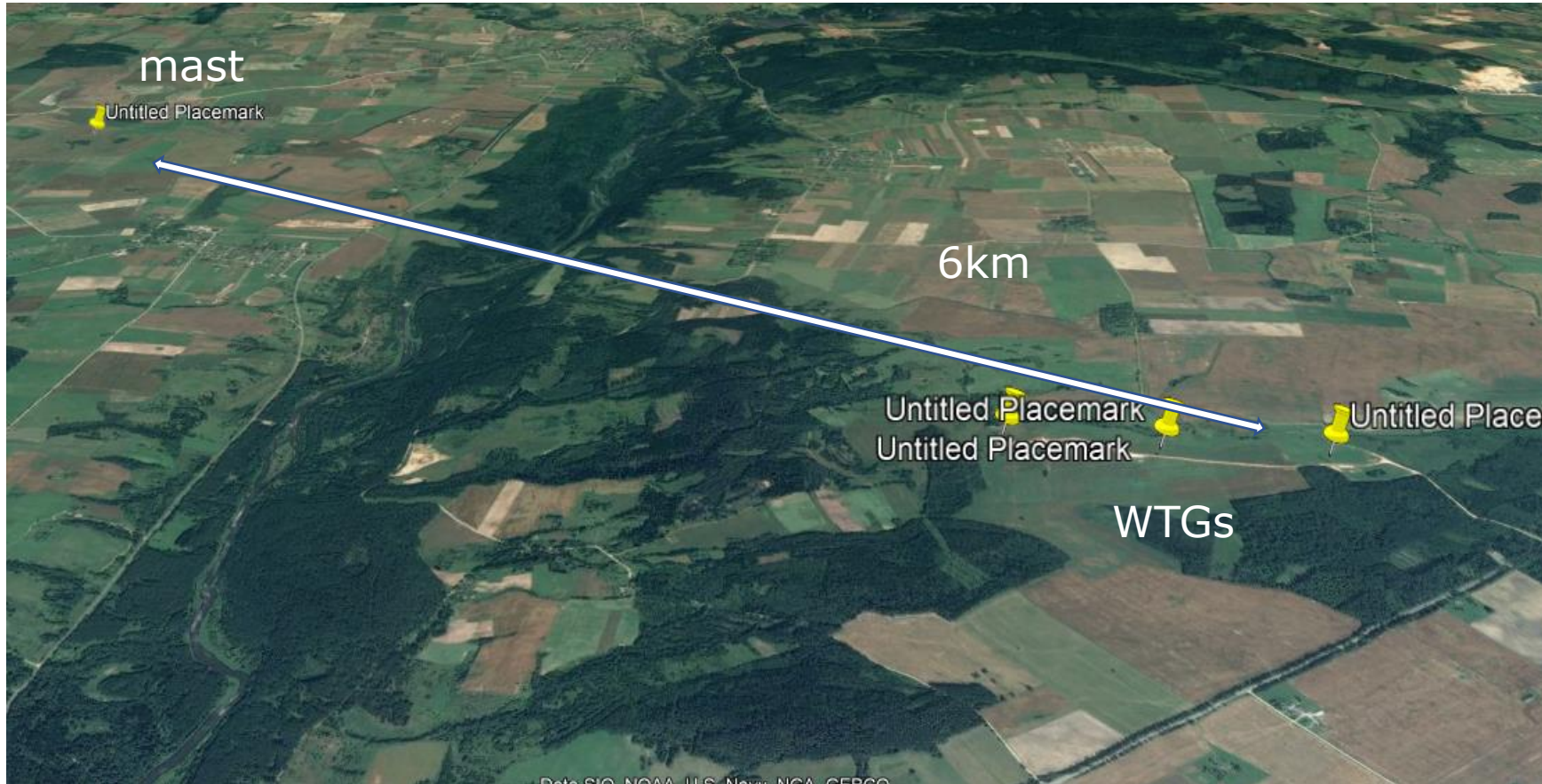
Is this complex?

Brazil

- 3 masts 5-10 km apart
- Massive decrease within short distance
- WAsP cannot do it
- We have not solved this...

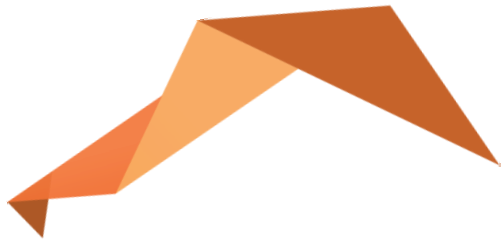


Is this complex?



Lithuania

- Terrain stretched factor 3
- Mismatch of 6% energy
- Why?



Why?

Modern times...?

- Terrain model = surface data
- Surface data translates forest as terrain
- Manual digitising of forests fixes the issue
- No more mismatch





Is this complex?

Turkey

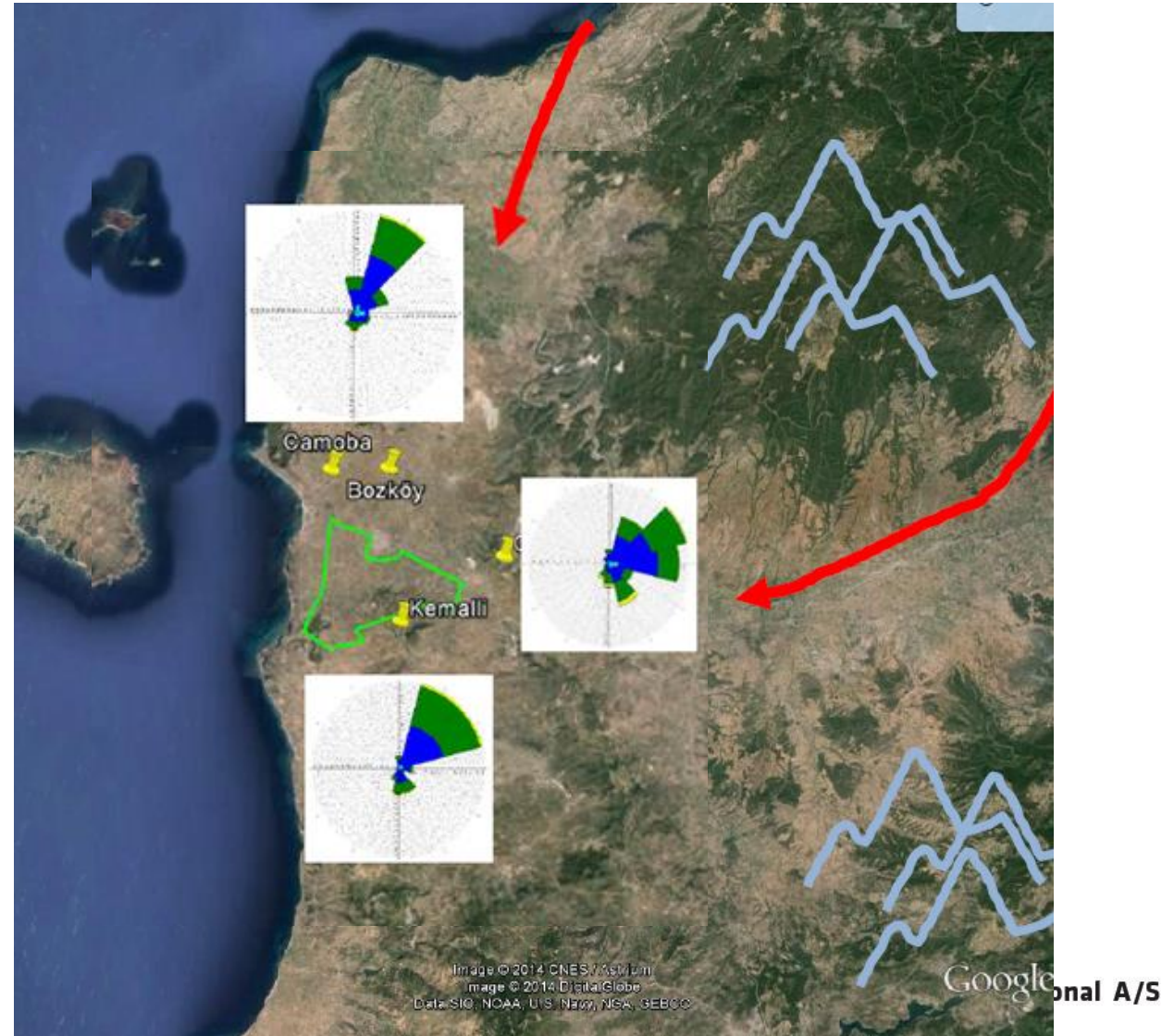
- West coast
- Flat
- 4 high quality masts in a distance of appr. 5-7km from each other
- 30° wind direction turn
- Why?

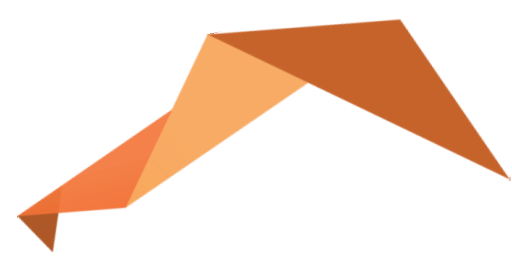
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Why 30° direction turn?

- The answer is 20km away: Mountains
- Invisible for WAsP
- But even if we know the real direction – how to deal with it?
- Park model uses ONE wind direction ONLY

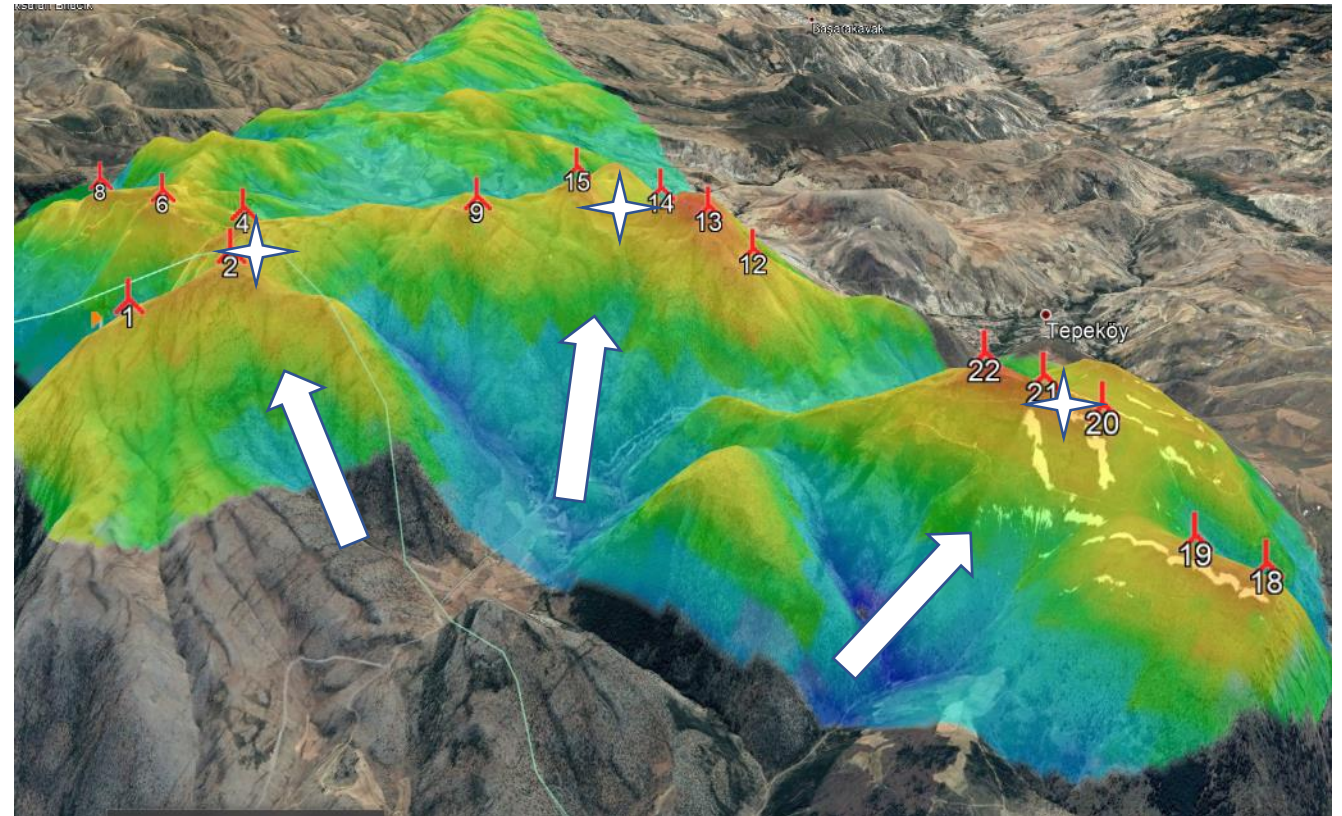


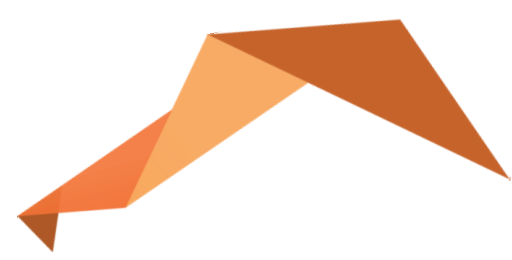


Now it is really getting complex 😊

“Banana” Issue

- Wind direction?
- Park model uses direction measured at mast
- Wake gets wrong!





Vertical Extrapolation Uncertainty

Is complex really bad?

Industry Practice: Status

- Rule of thumb: 1% uncertainty per 10m vertical extrapolation
- DTU, M. Kelly (2016):
 - Based on shear
 - **Based on logarithmic-based profile (WAsP)**

**No differentiation on
terrain/roughness**

Source: http://orbit.dtu.dk/files/126254660/VertExtrapUncert_Kelly2016_DTU_en_.pdf

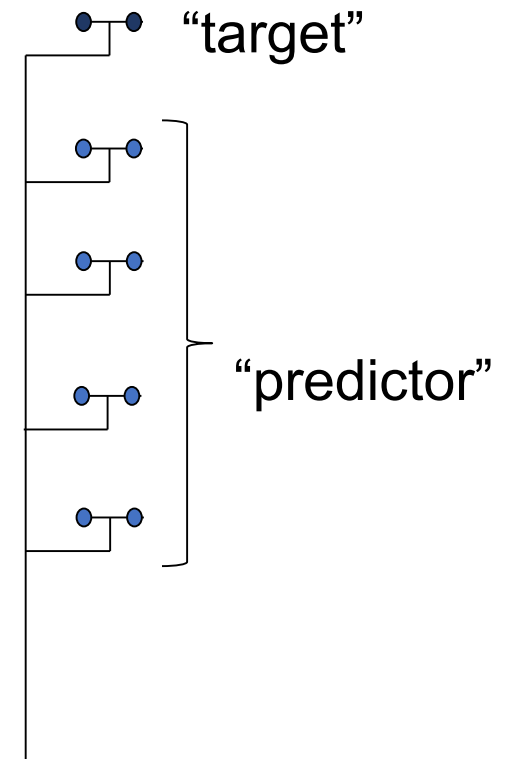
Can't we do better?

Methodology

- Use traditional tall masts (up to 200m)
- Use WAsP (incl. displacement height, stability etc. if required and available)
- Compare modelled versus measured wind speed

➔ Prediction error

- Statistical validity?
- > 1700 predictor/target couples: good basis for sound statistics!





Can't we do better?

Filter results:

Terrain: Split in 4 different scenarios:

- Flat, no forest
- Complex, no forest
- Flat, forest
- Complex, forest

Note: DTU, Kelly not applicable for forested sites

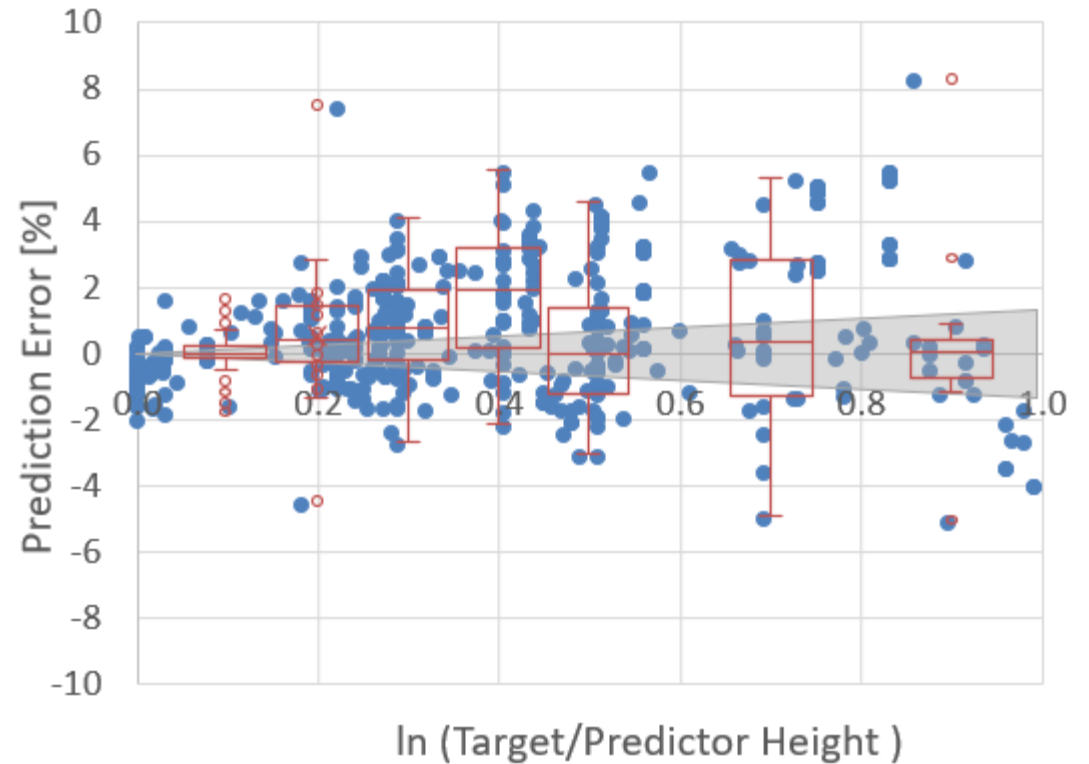
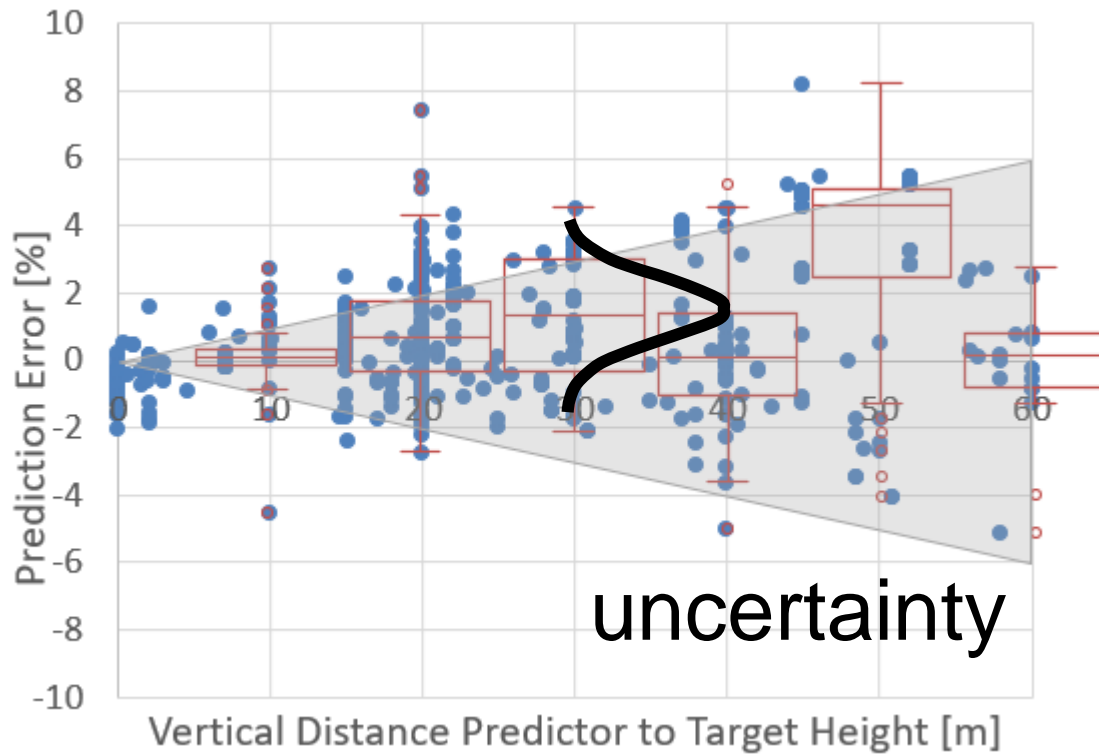
Example result

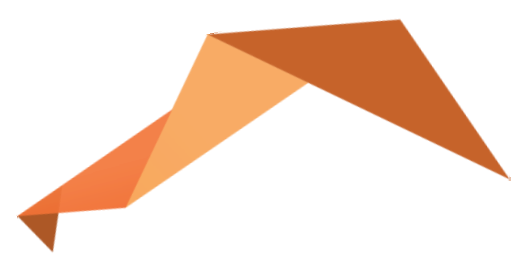
Vertical distance

Uncertainty: 1% per 10m

Expression as logarithm

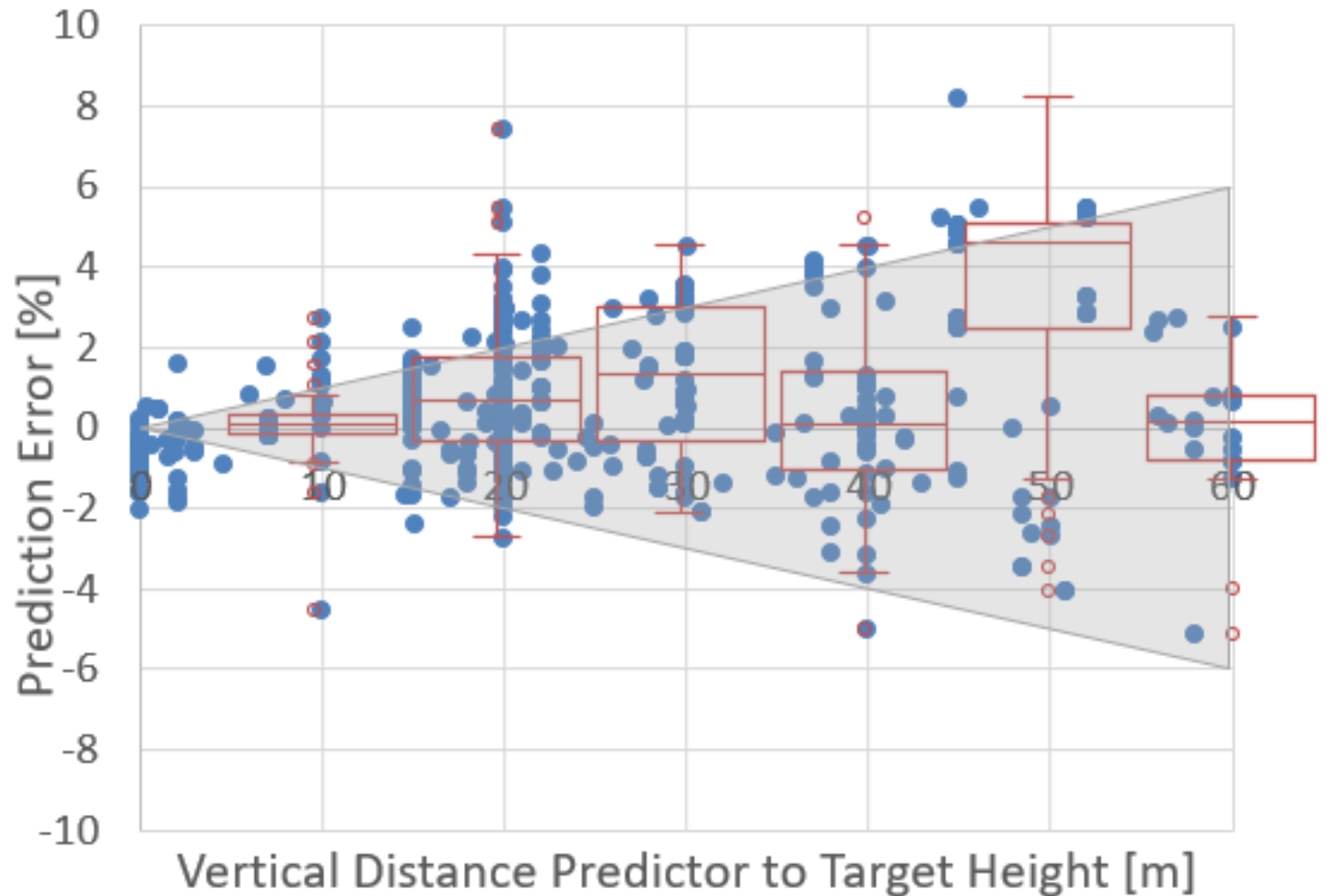
DTU uncertainty for LN



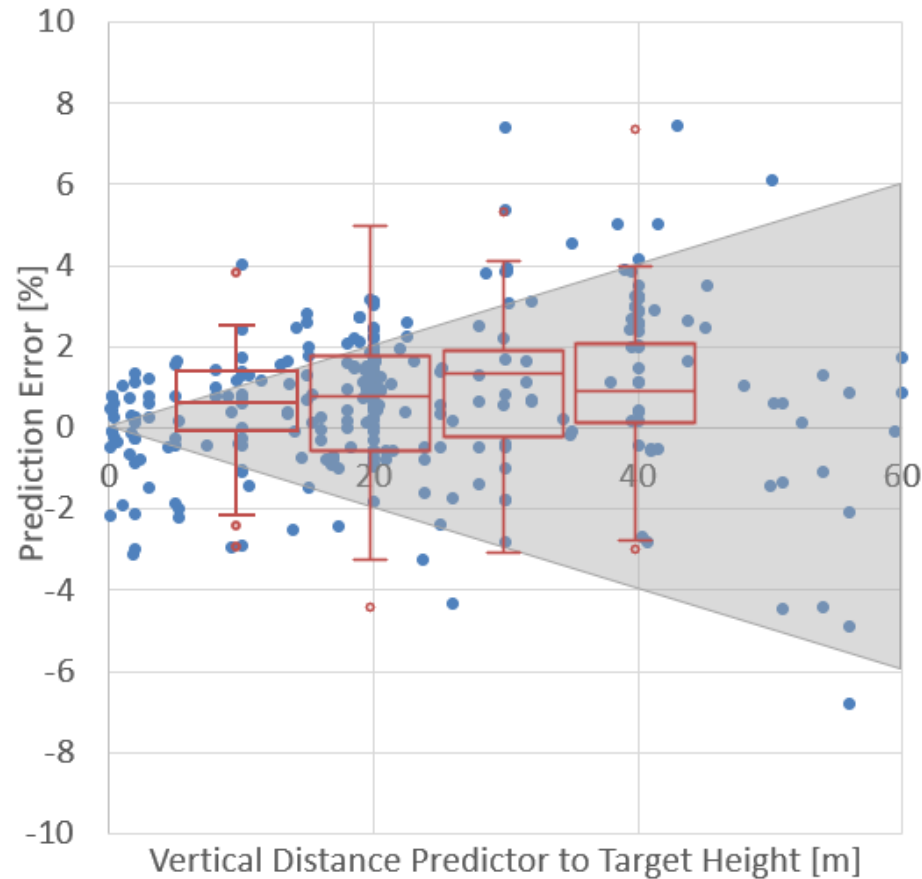
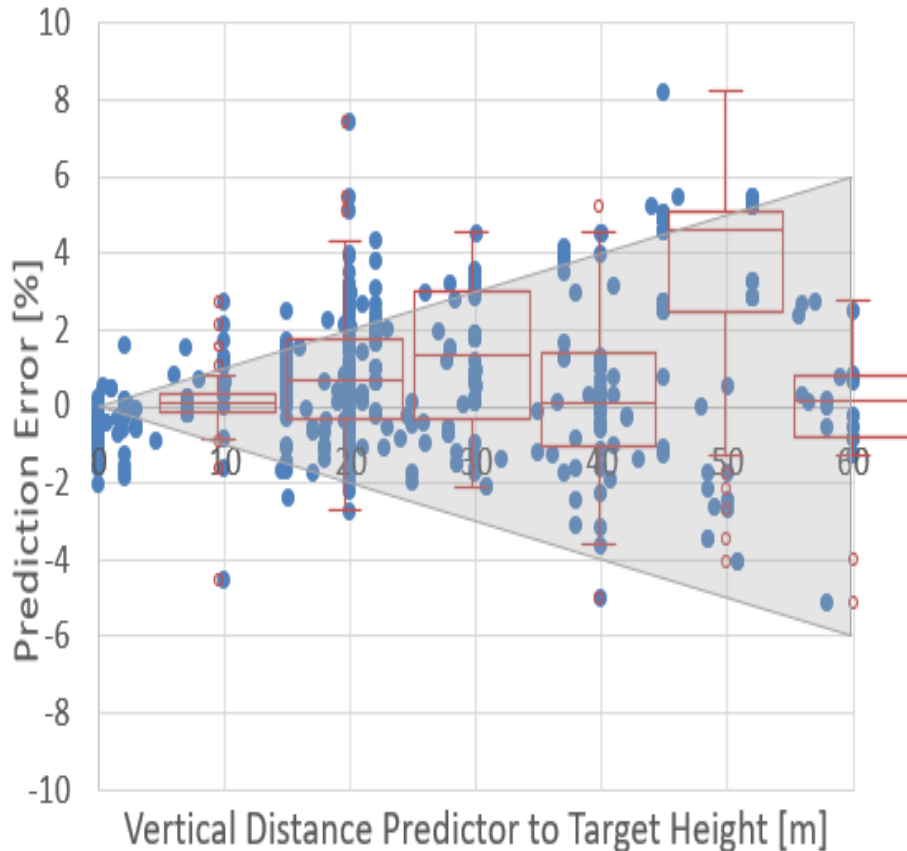


Flat, no forest

- Conclusive?
- 1% too much (box is appr. 1 std dev)
- Boxes do not “grow” with vertical distance



Flat (left) vs Complex (right)

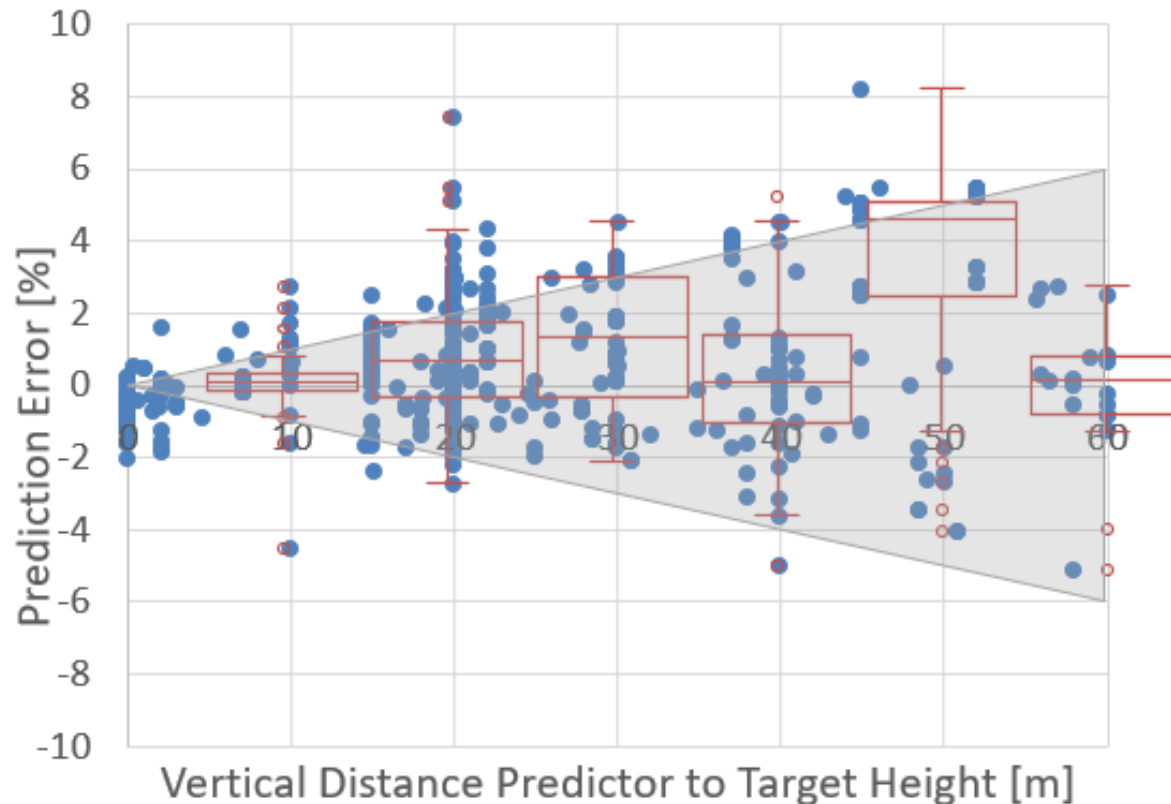


- Boxes are smaller -> Less uncertainty (as expected)
- Bias (as expected)
- Boxes do not grow

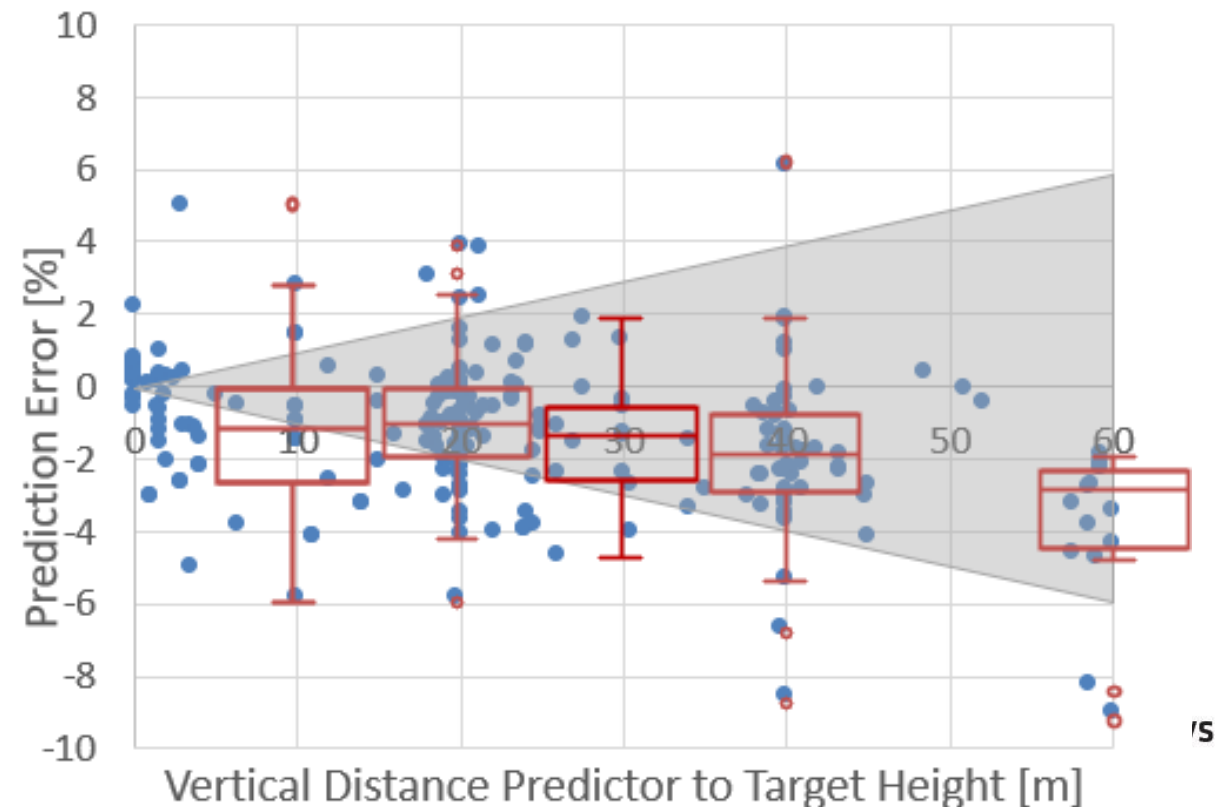
And forest? - Flat

- Under-prediction in forest (as expected)
- Boxes do not grow with vertical distance

Flat, no forest



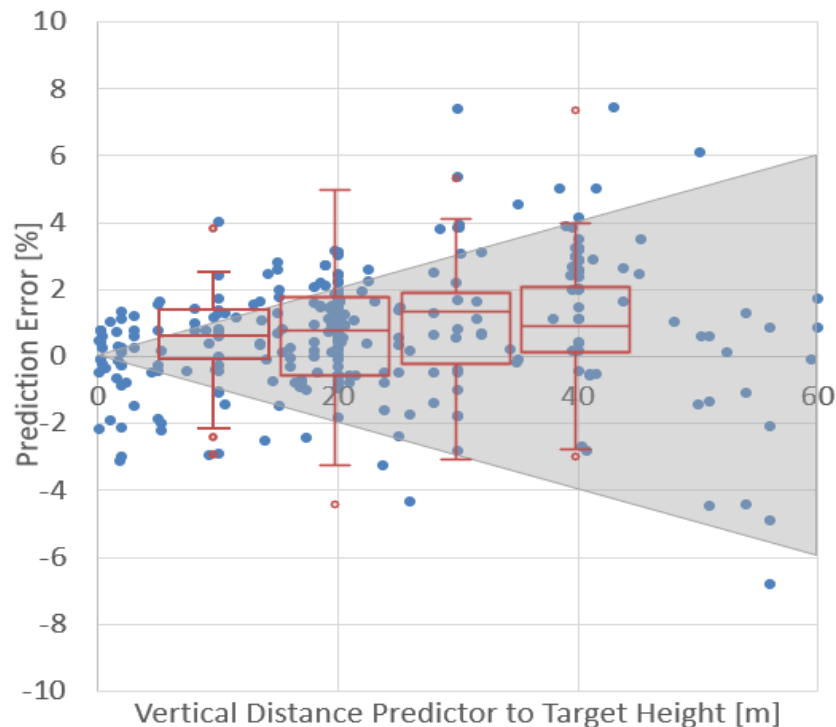
Flat, forest



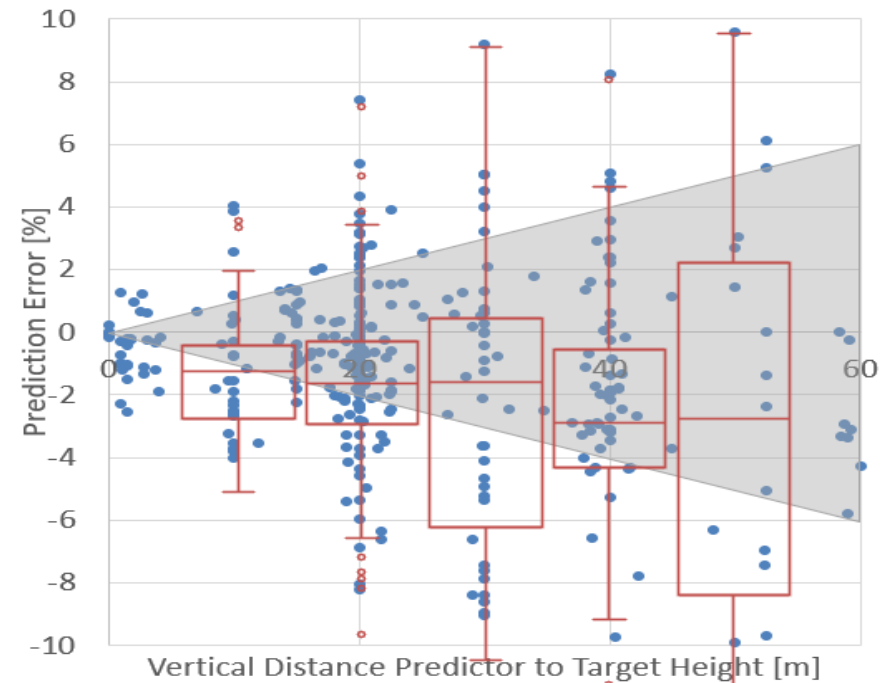
And forest? - Complex

- Under-prediction due to forest > overprediction of complex terrain
- Uncertainty around 1% per 10m

Complex, no forest



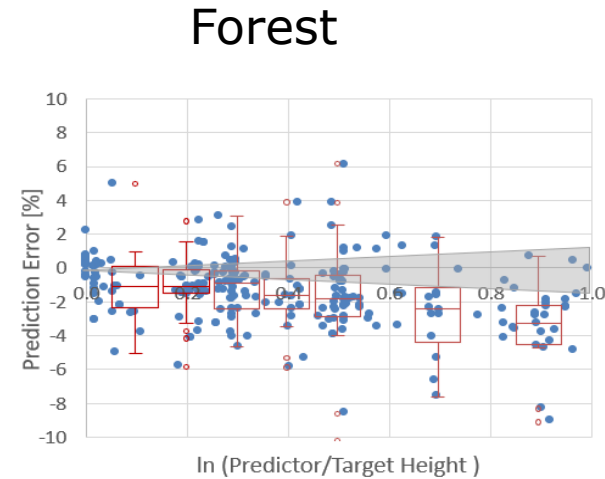
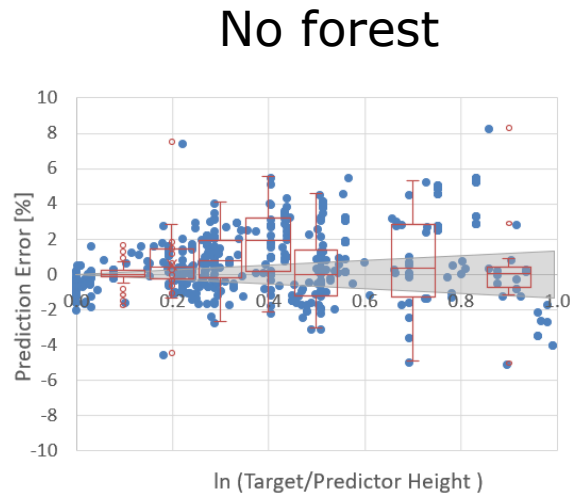
Complex, forest



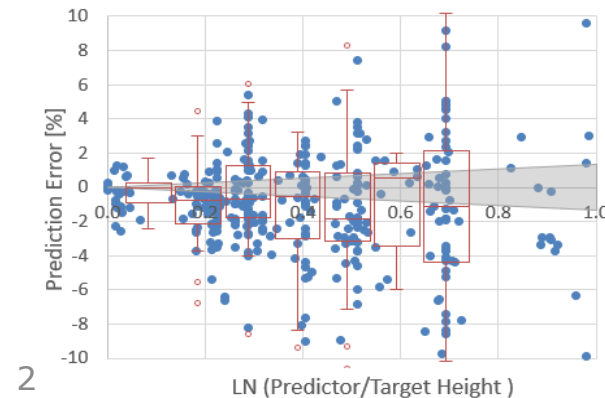
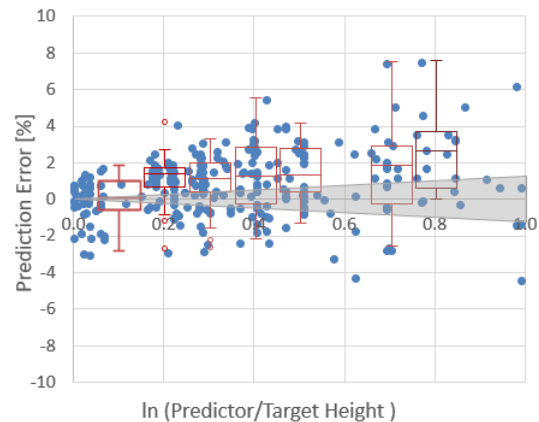
And finally IEC-15 proposal

No matter what: Under-prediction of uncertainty!

Flat



Complex





Summary

- “Complexity” not well defined
- Park model misses directional changes
- Uncertainty:
 - 1% rule only appropriate for complex forest, otherwise far too conservative
 - Uncertainty does not necessarily increase with vertical distance
 - DTU expression not suitable
- Bias:
 - Over-estimation in complex terrain as expected
 - Under-estimation in forest as expected (stability!)



A little teaser

- In most cases it does not seem to matter if you extrapolate 20 or 40m....
- So MEASNET requirements of measurement height $> 2/3$ HH might need re-visiting.

Questions?

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