EMD Presentations

Vindkraftnet 2019-05-13 @ EMD, Aalborg Denmark

Complex Terrain

1. **Models versus terrain data, what matters most.**
   Per Nielsen

2. **Vertical Wind Speed Extrapolation in Complex Terrain – As Challenging as we think?**
   Wiebke Langreder

3. **Reference wind data – challenges when doing short measurement campaigns in complex terrain**
   Morten Lybech Thøgersen

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Vindkraftnet – May 2019

El-Zayt Calibration

Per Nielsen, EMD International A/S

14-05-2019

EMD International A/S
www.emd.dk

Who is EMD?

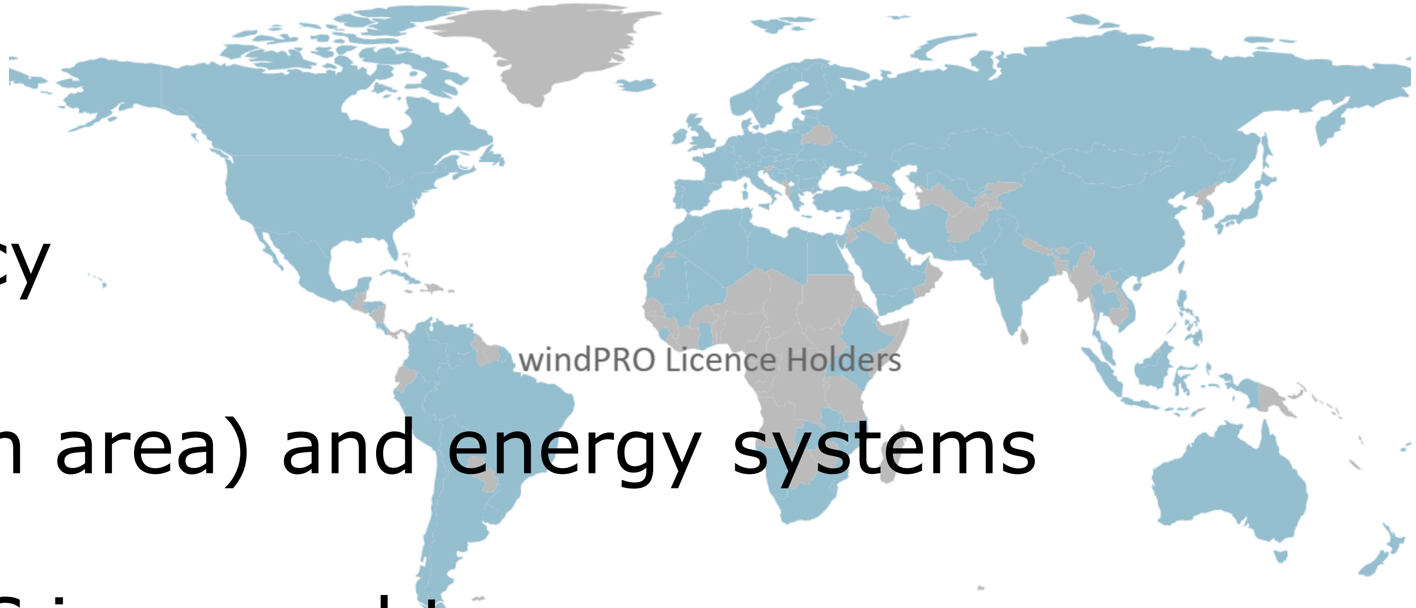
EMD = **E**nergy and **M**ilieu **D**ata (Energi- og Miljødata)

Established 1986

Software and Consultancy

Specialized in wind (main area) and energy systems

29 people 2019, 6 mio. € in annual turnover

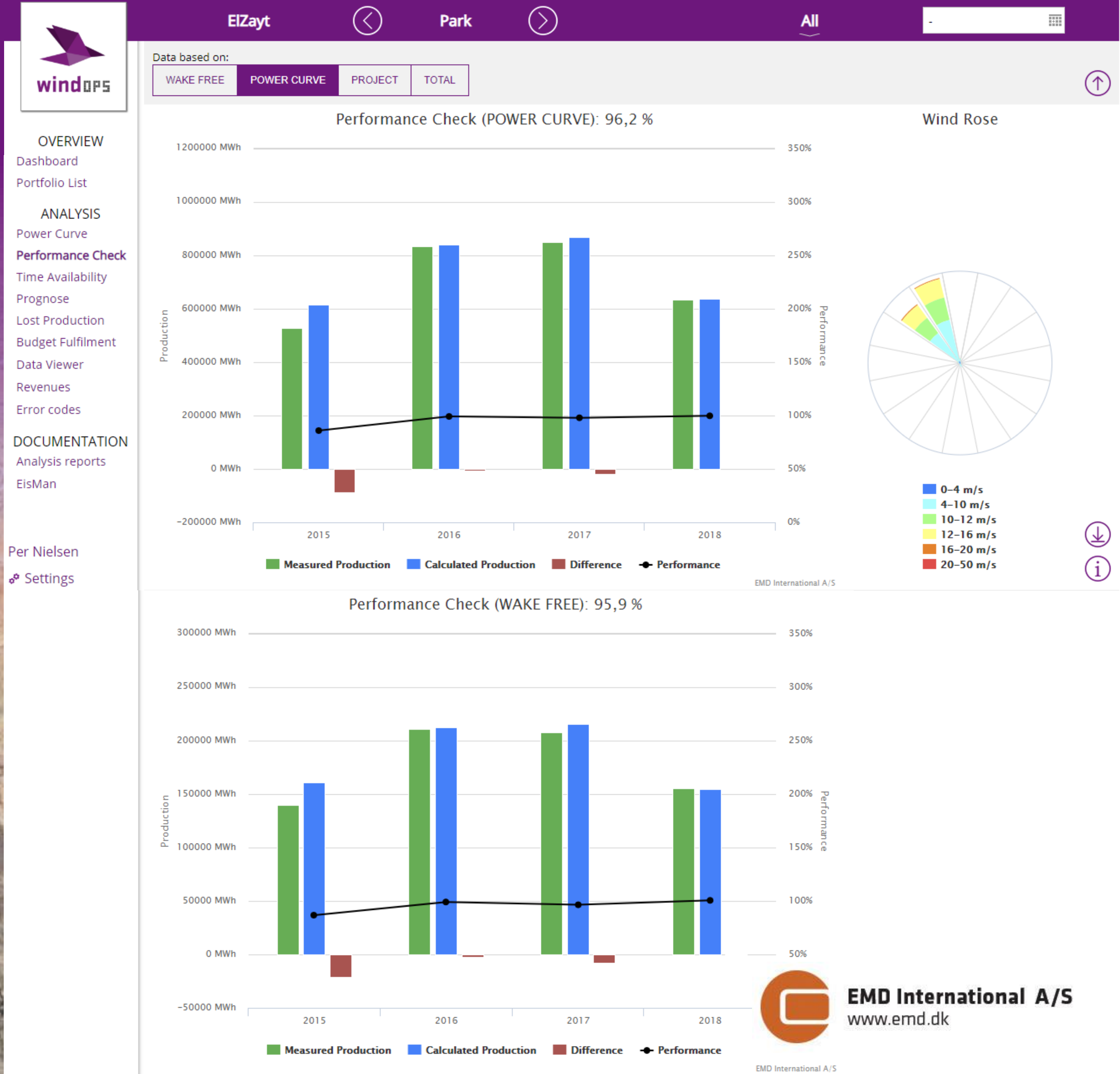


Main activities

Software	windPRO	windOPS	energyPRO	energyTRADE
Data services	windPROSPECTING	Custom data	ENFOR	
Consultancy	Wind	Energy systems	Hybrid solutions	

Example Project – Gabal El-Zayt

- 100 x 2MW Gamesa Turbines
- Performance Check every ½ year since 2015
- Monitored through windOPS, our on-line surveillance system including model calculation each 10 minutes.
- Model calibrations performed in windPRO.



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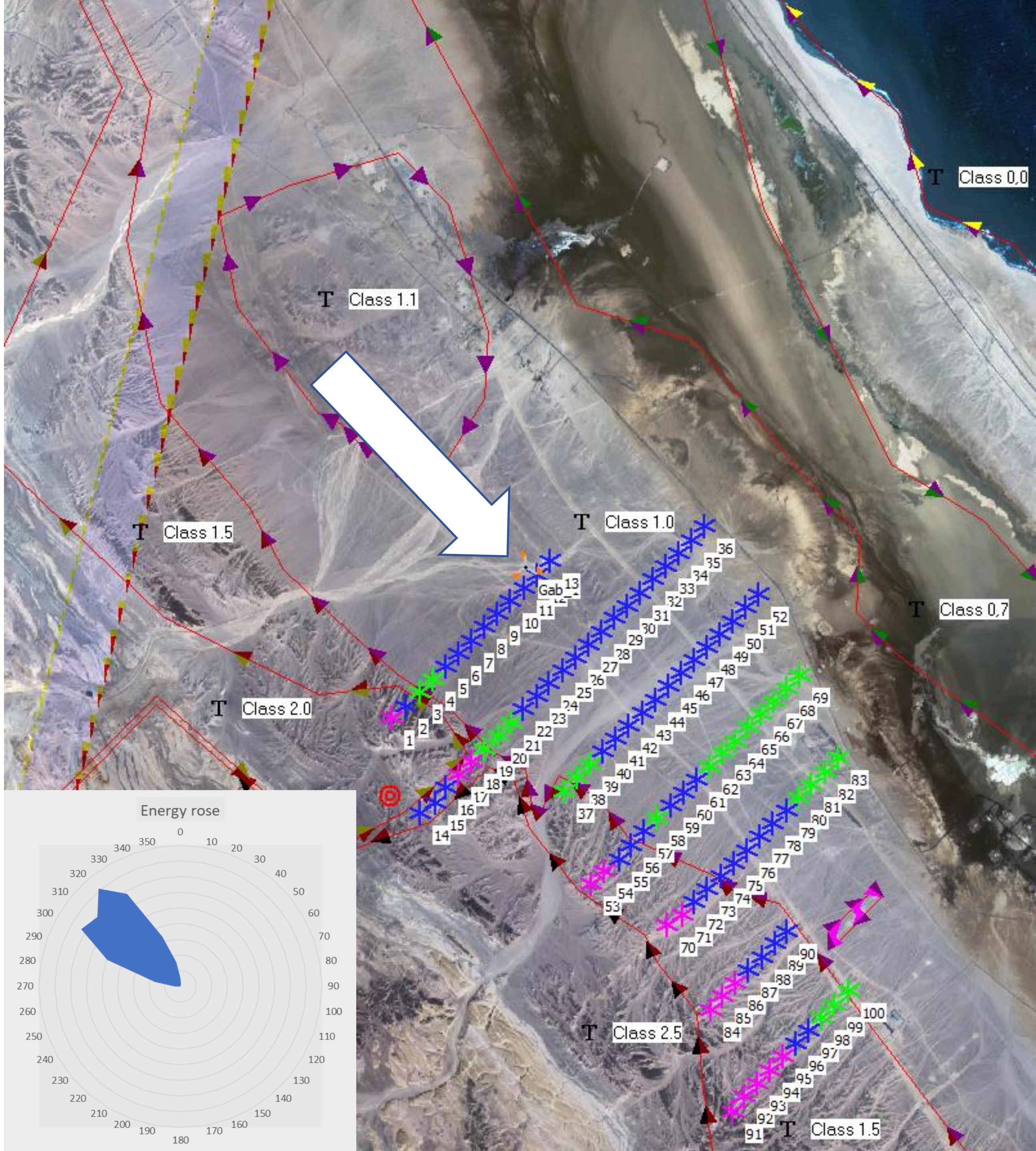
Starting with wakes; ending with complex terrain

On-site mast (Gab.1) in front of wind farm relative to main wind directions (280°-360°) used as input for time-step model calculations.

10-min production data for each WTG is loaded in windPRO Performance Check module.
Then "any" result aggregation can be performed and issues with the model or terrain can be identified.

It is surprising how important the roughness is.
The wake-loss calibration therefore highly depends on fine-tuning the roughness classification. This is currently a long iterative process.

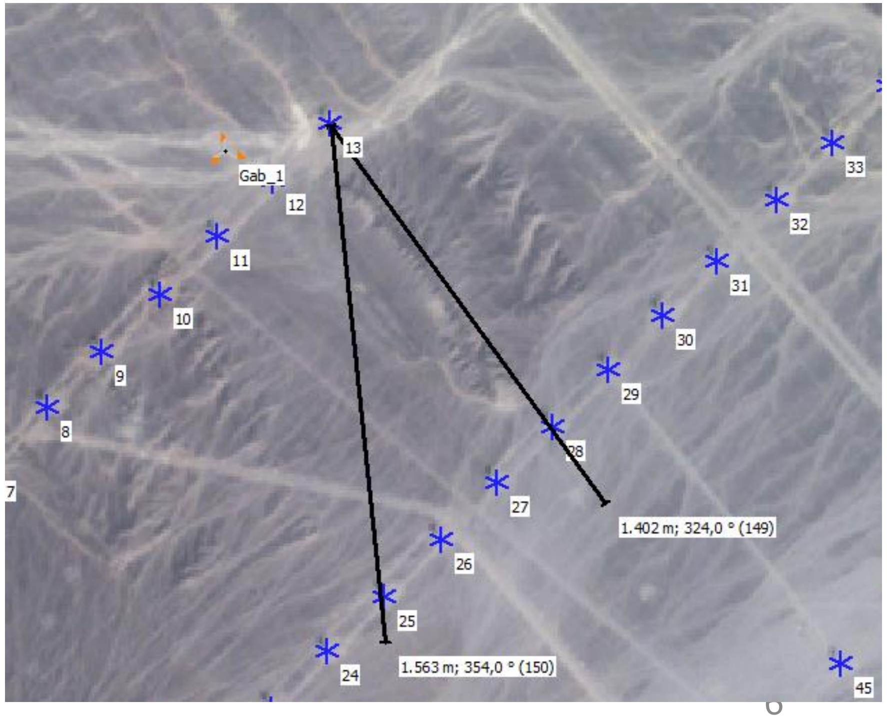
WAsP model with the new PARK2 as "main model".

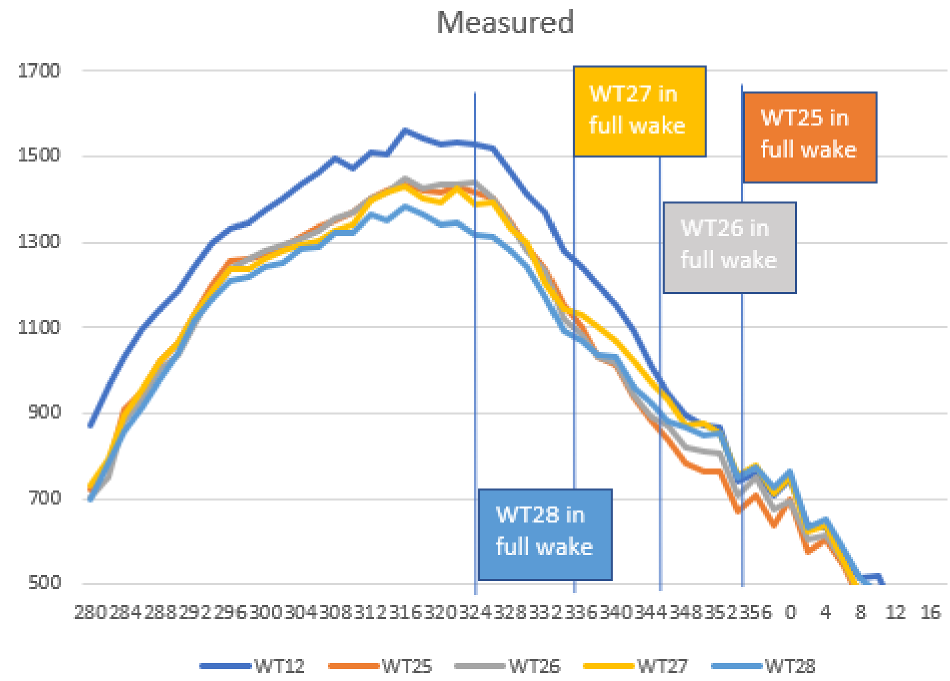


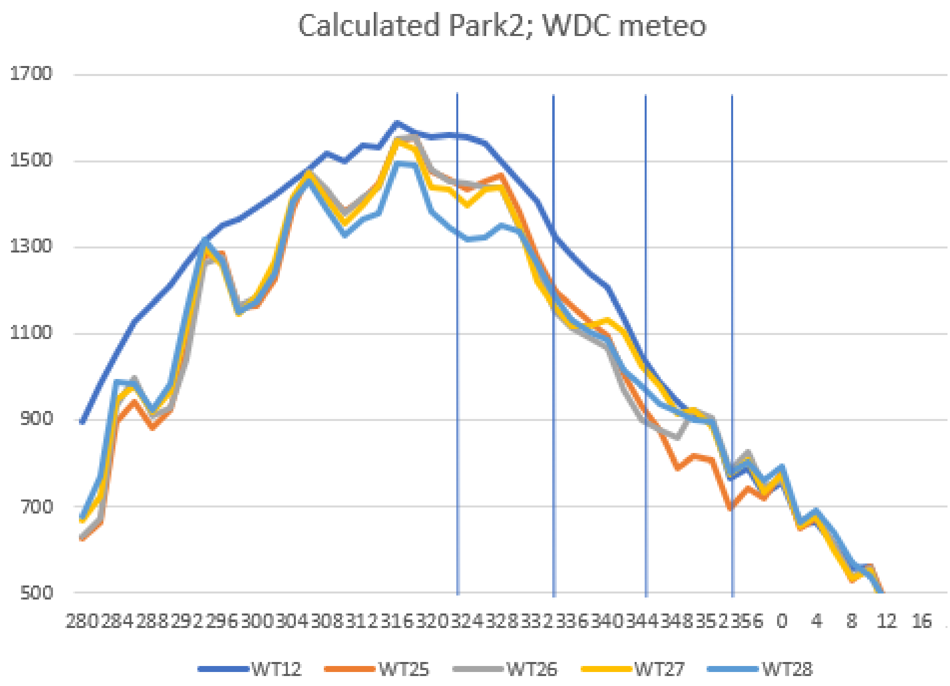
The Method – Step 1

Step 1: Checking the direction calibration.
By comparing when the wake appear in measurements and calculations to the directions measured on map (black lines), it can be validated that direction calibration is correct.

The measurements has more smoothened reductions by angle than calculations, but the patterns validates the direction calibration.





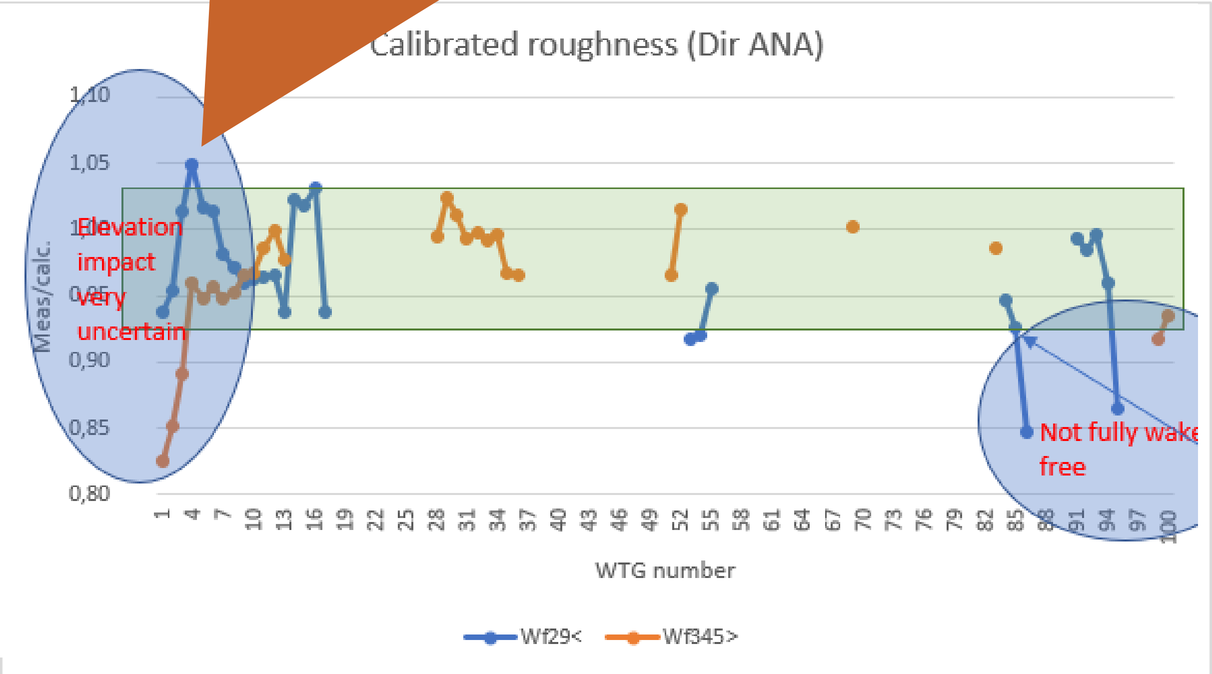


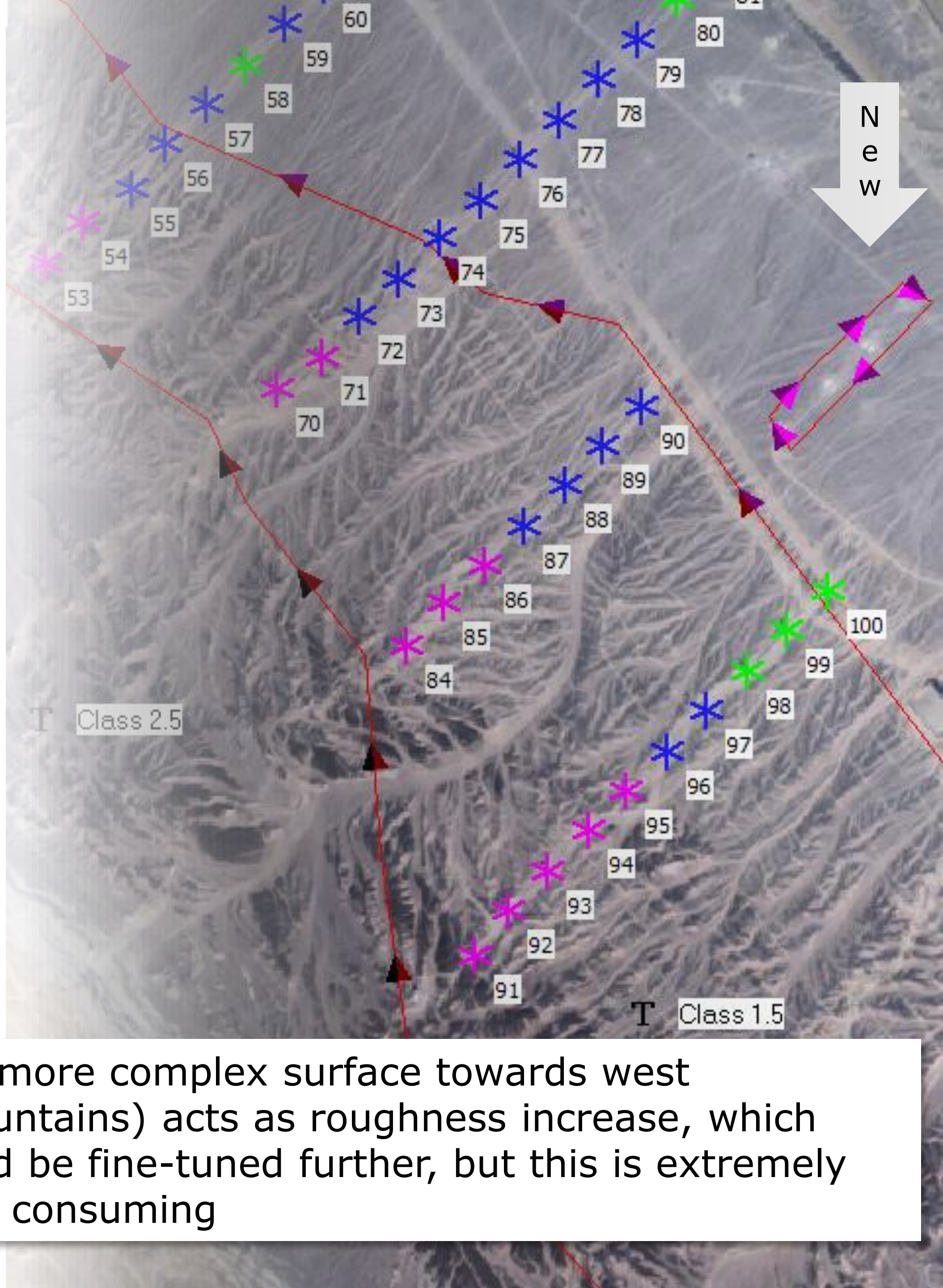
The Method – Step 2

Step 2: Calibration of the roughness model.
This is by far the most complicated. A dessert could seem simple, but desserts are not just smooth sand.

Due to relatively few data in the wake free directions (used for initial roughness calibration), the roughness calibration is later improved based on "pattern study" having all WTGs included.

This will be my focus regarding complex terrain





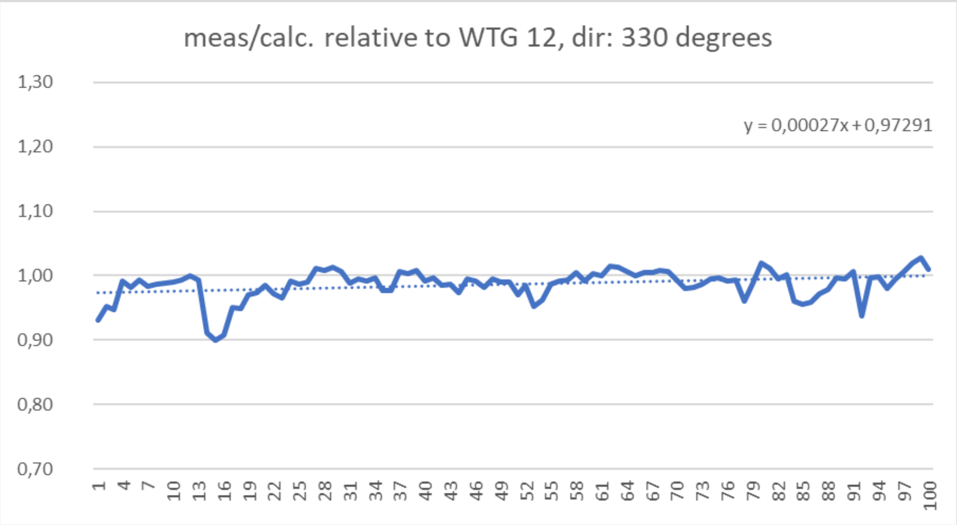
The more complex surface towards west (mountains) acts as roughness increase, which could be fine-tuned further, but this is extremely time consuming

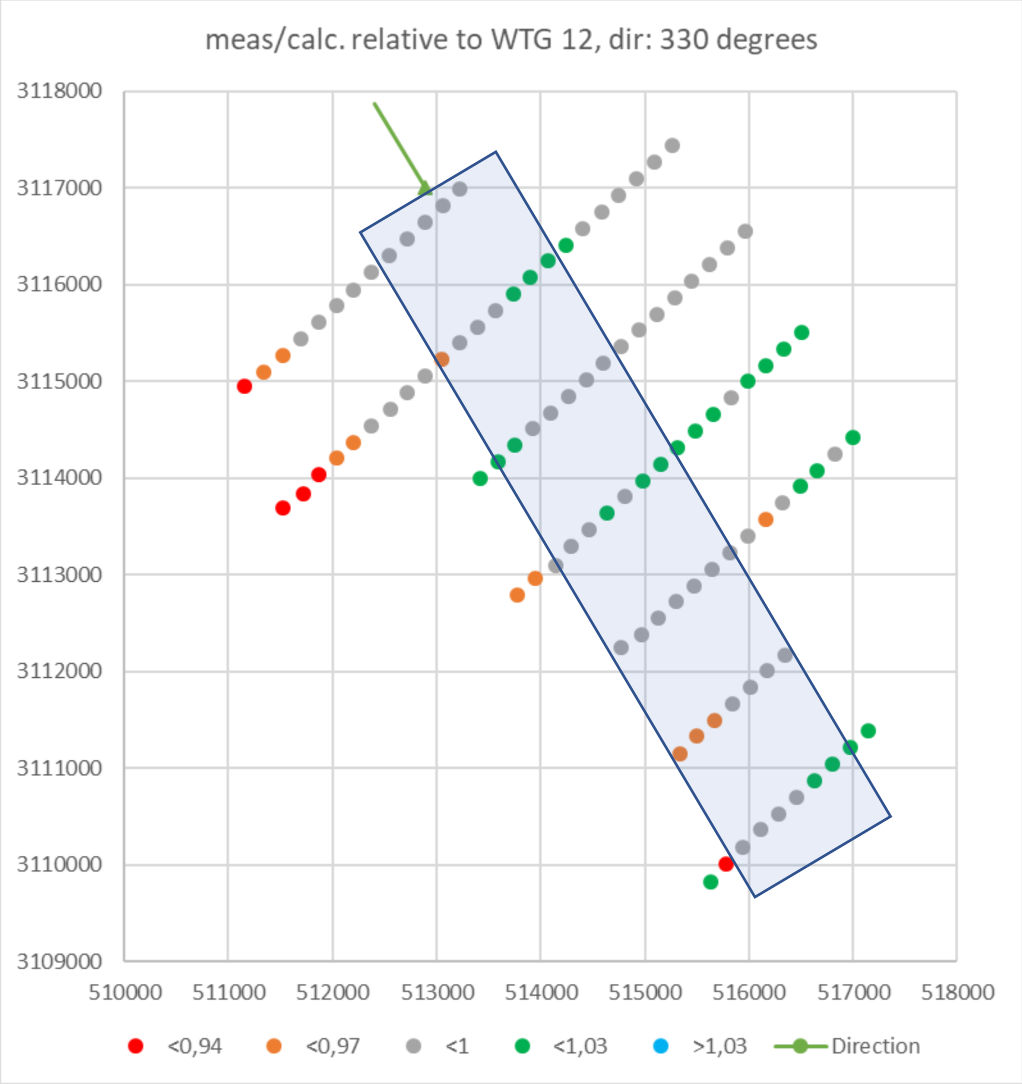
The Method – Step 3

Step 3: The wake model calibration
When the roughness was satisfying, the WDC was tuned by 10 degree sectors, looking at the performance of the turbines “most in wake” (See right example, 330°+/- 5).

Below ratio meas./calc. by WTG, in a “straight line”. Focus on the ones having most wake givers, and less on the ones with less or no wake.

Grey and Green is Very Very good, within +/-3%!





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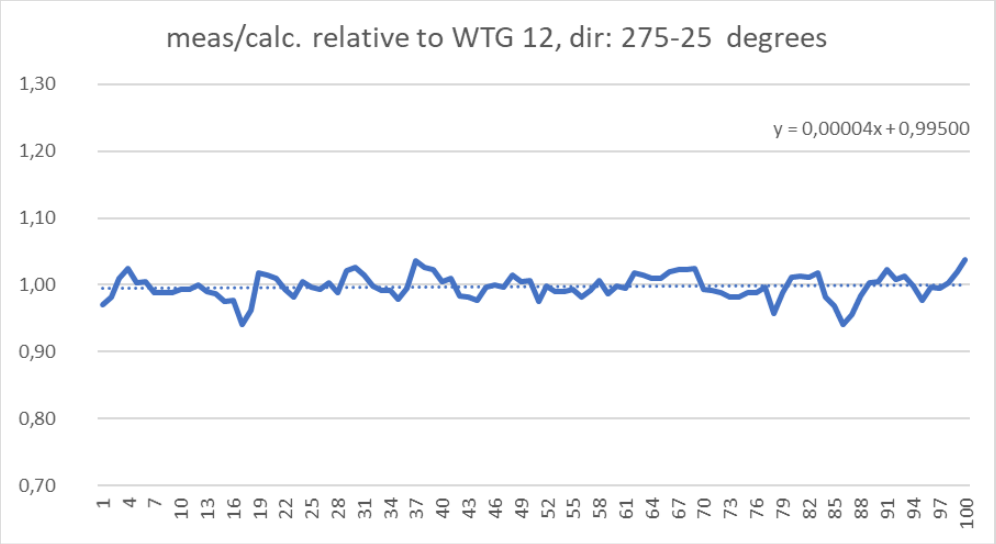
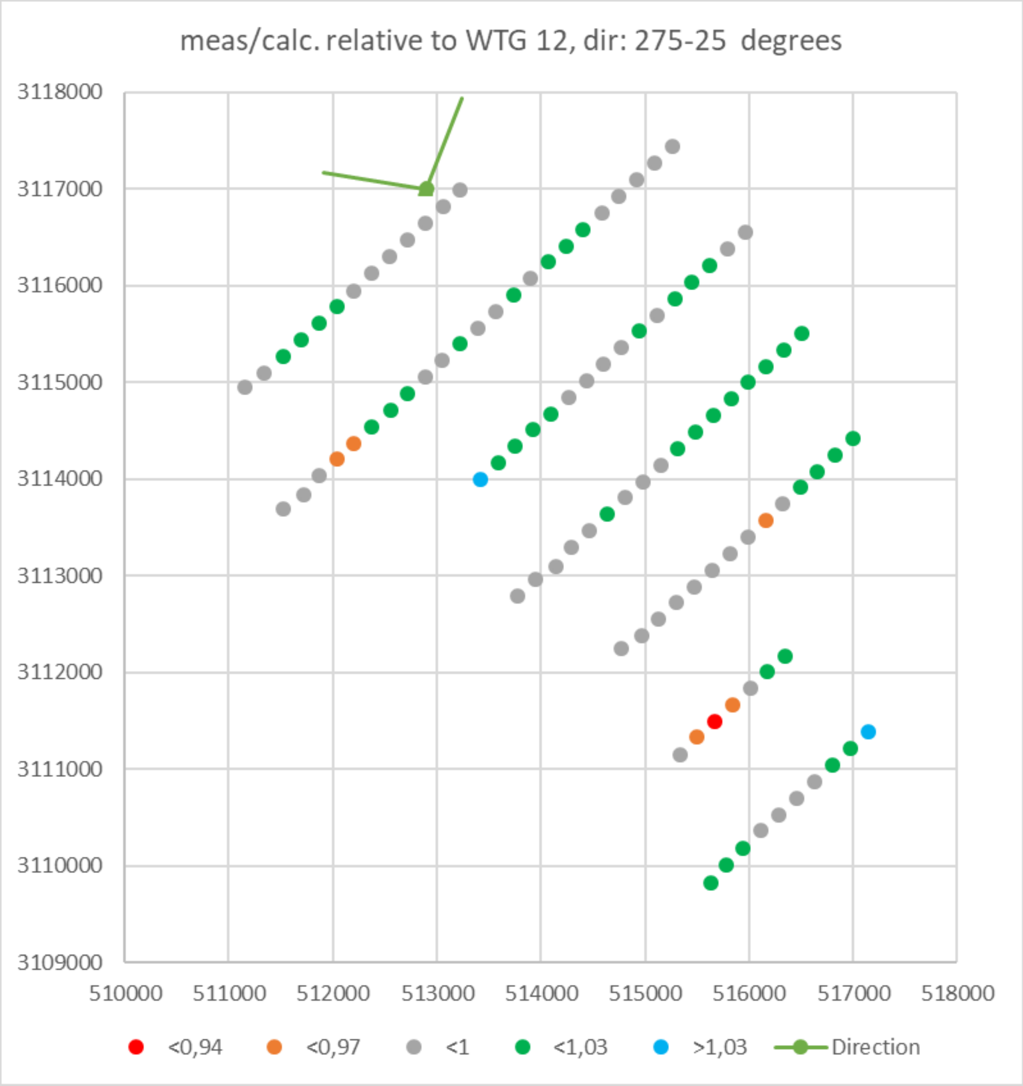
The Results – 275°-25° - 1y

Each WTG, filtered for error codes, are calculated within +/-10% of measured relative to WTG12 at the met mast for each 10 degree wind direction sectors (where mast is wake free).

92 of 100 WTGs are within +/-3% as average. This is an extremely high accuracy, and thereby the wake loss calculation also is judged very accurately.





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Wake Loss Settings

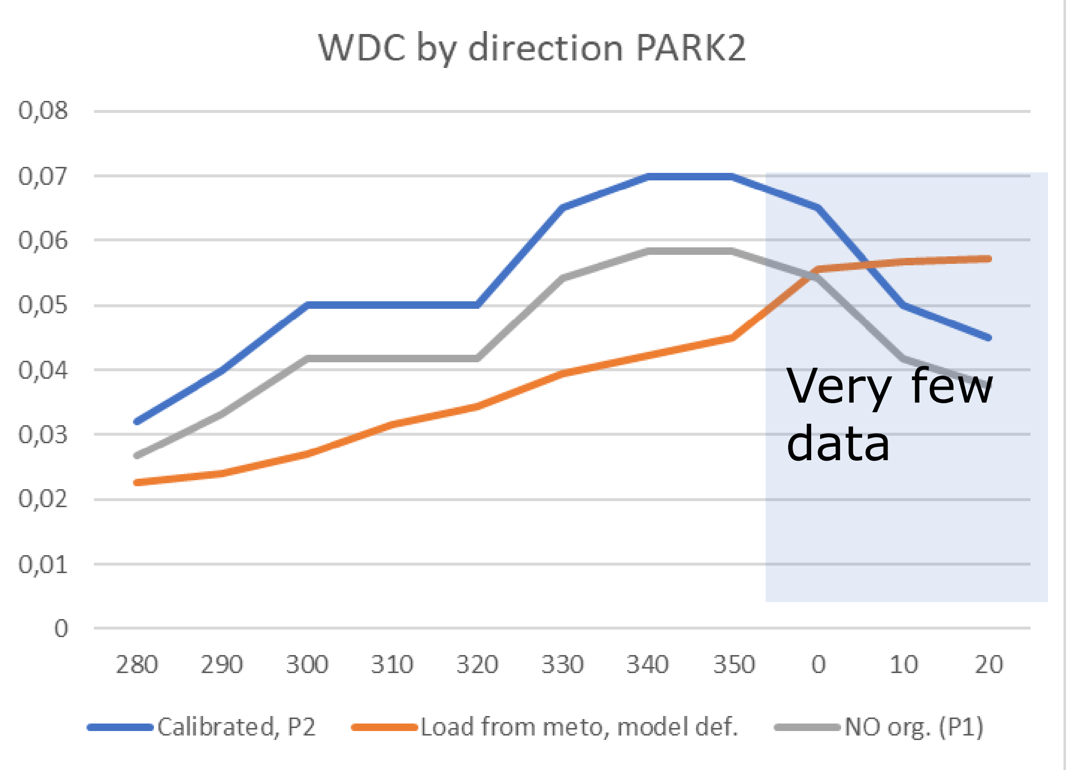
The “new“ windPRO WDC concept, letting the TI(Turbulence Intensity) control the WDC by:

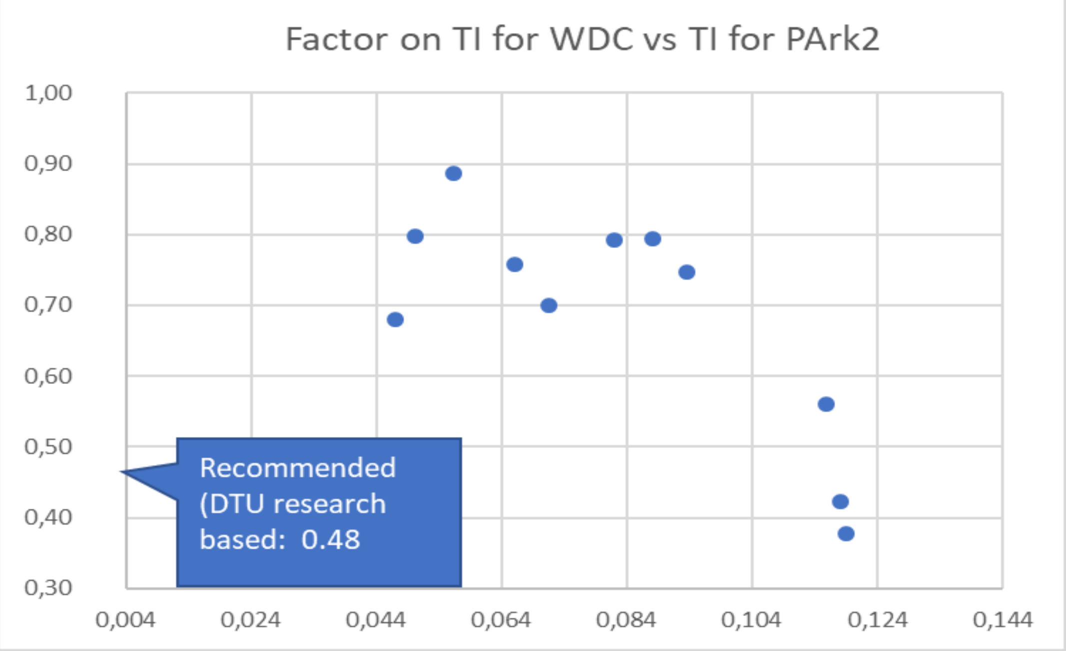
WDC = 0.48 x TI (PARK_2) and
WDC = 0.40 x TI (PARK_1)
(0.40 from DTU research project, 0.48 while PARK 2 needs 20% higher WDC due to linear combination model)

TI from measurements are loaded by 10° directions within 5-15 m/s.

A clear trend is seen with factor 0.48 being too low, whereas **0.8 seem to work here as average** (see later).

No doubt that the TI is a very important controller of the WDC.
At this site the lower TI in westerly directions (night wind from mountains) gives essentially higher wake losses.





Wake loss analyses

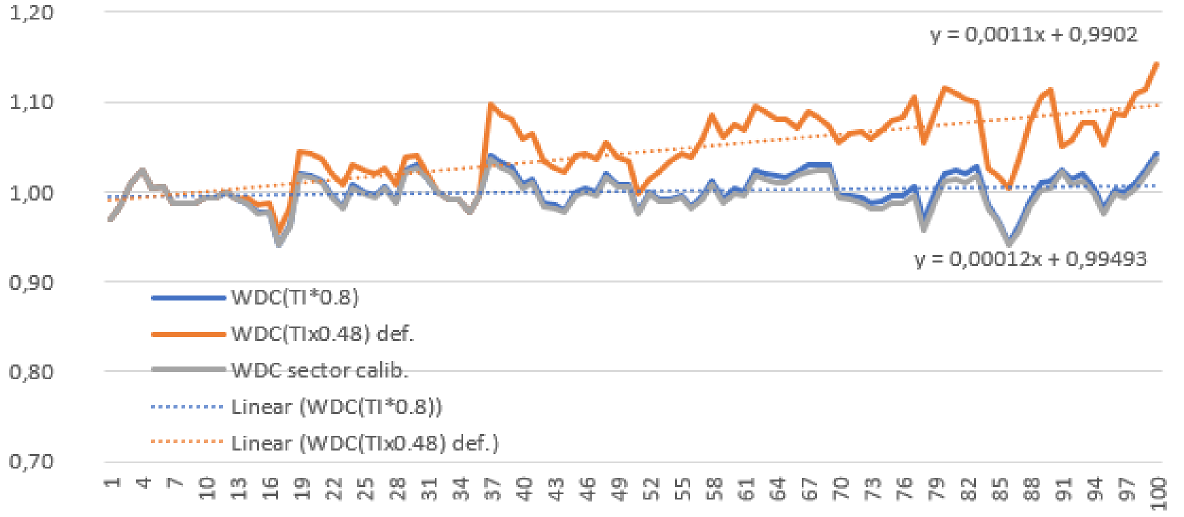
Letting TI control WDC by TIME STEP - Here shown with:
WDC = c x TI (PARK_2) with c= 0.48 (default)
and c= 0.80 (the one that works*) →

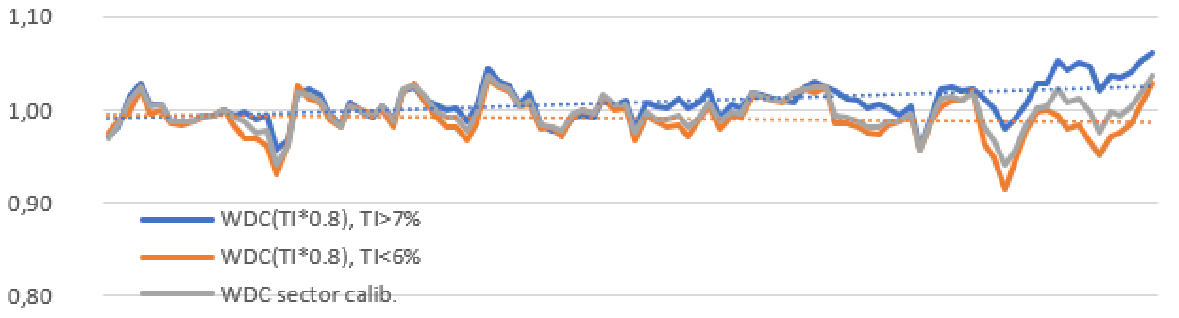
By this approach, it is possible to divide the data in low and high TI to judge how well the "simple" TI to WDC conversion works. At high TI, the calculated wake loss is slightly too high, while too low at low TI (similar seen on other windfarms) →

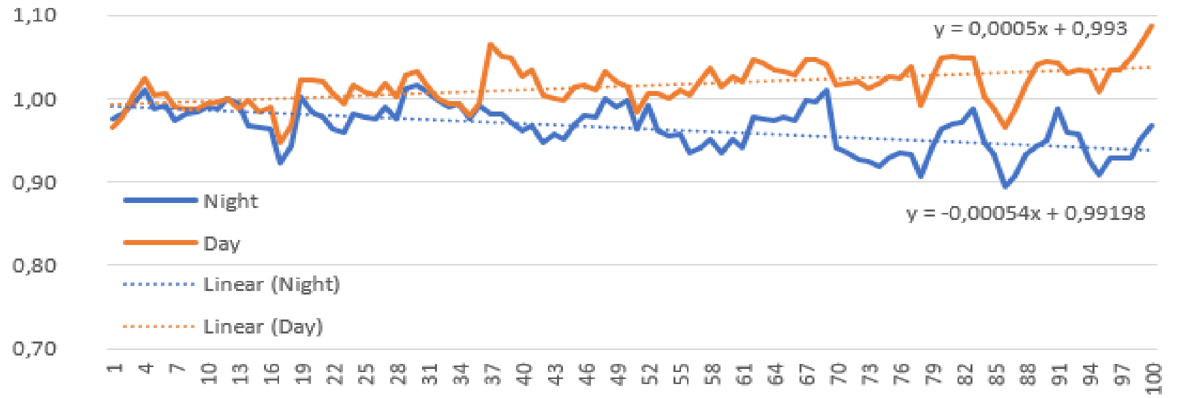
The spread day/night in Non time step TI "calculation performance" is much higher, showing a larger potential error by "just" having a sector WDC, not by time step→

… although the "basic problem" in any of the concepts is to know how to link WDC to TI. This requires test-test-test.

*) similar seen on several offshore sites



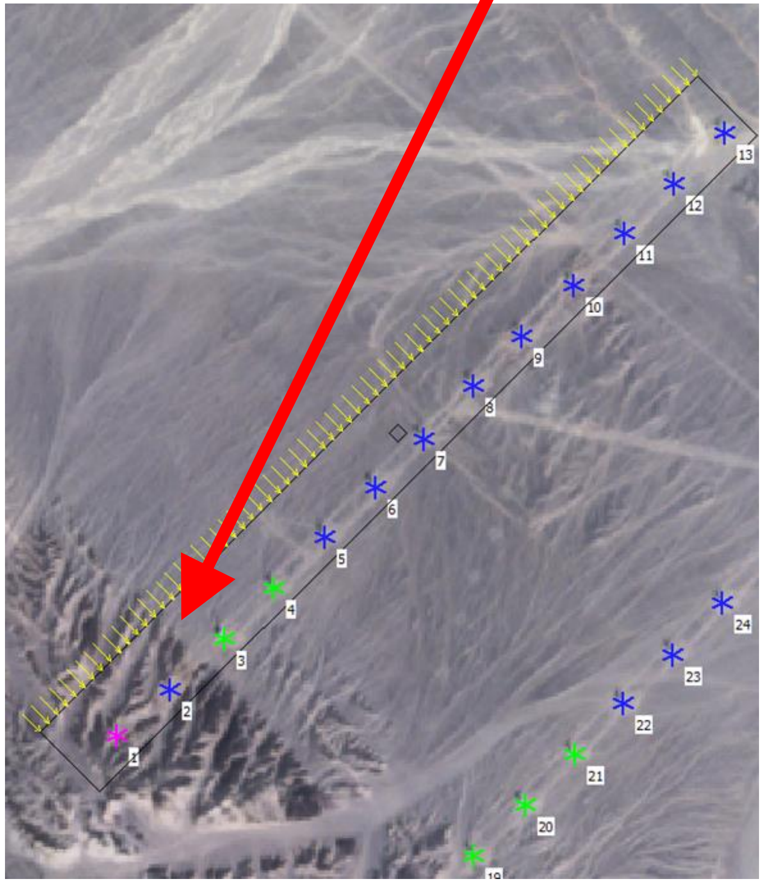


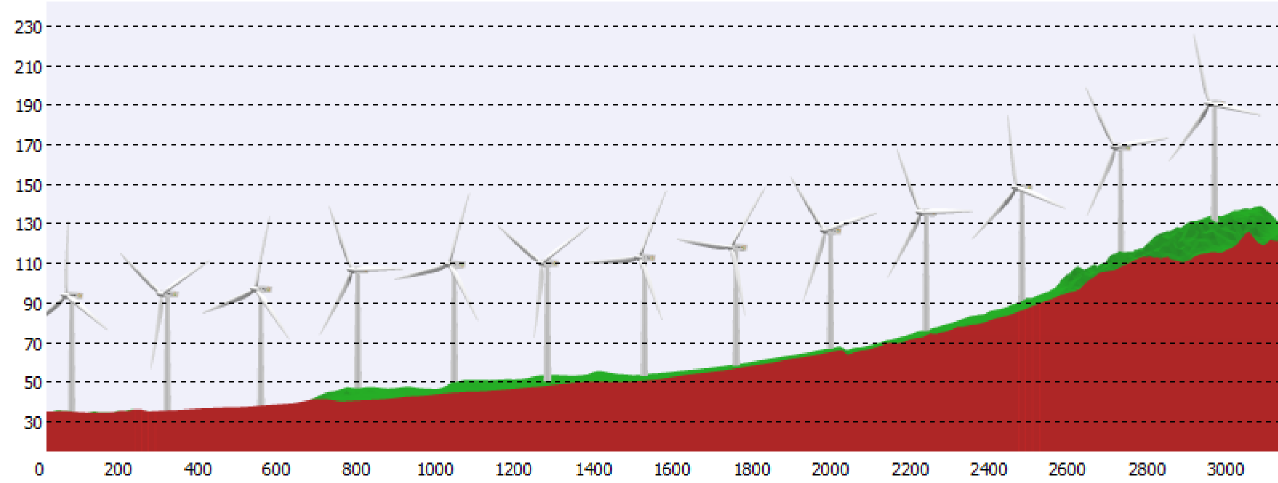


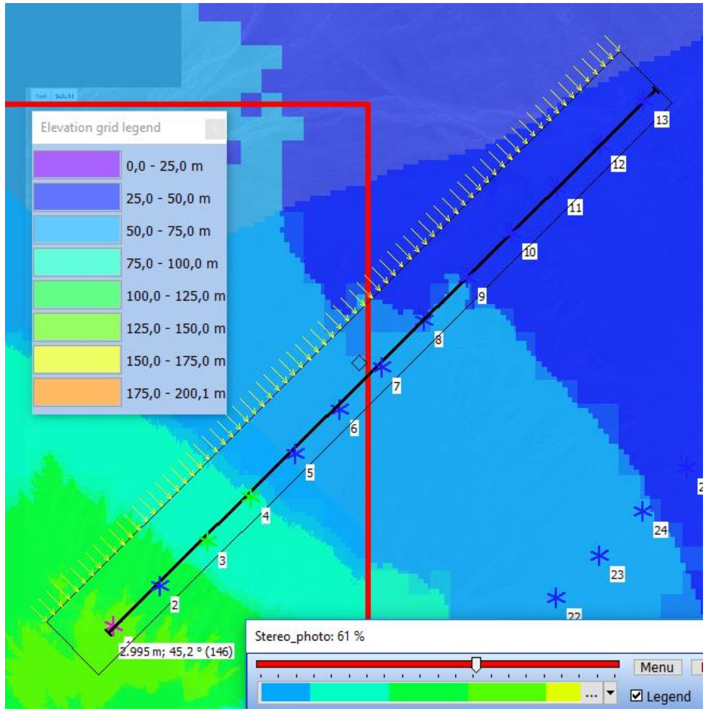
X-axis: WTG number Y-axis: meas./calc.
(>1 mean too high calculated wake loss)

Focus on Complex Terrain

The site may not look that complex.
Elevation gradually increases from 35 to 135 m at the front row (no wake issues).
But as seen below, terrain also starts to be undulated for the first turbine numbers (1-2).



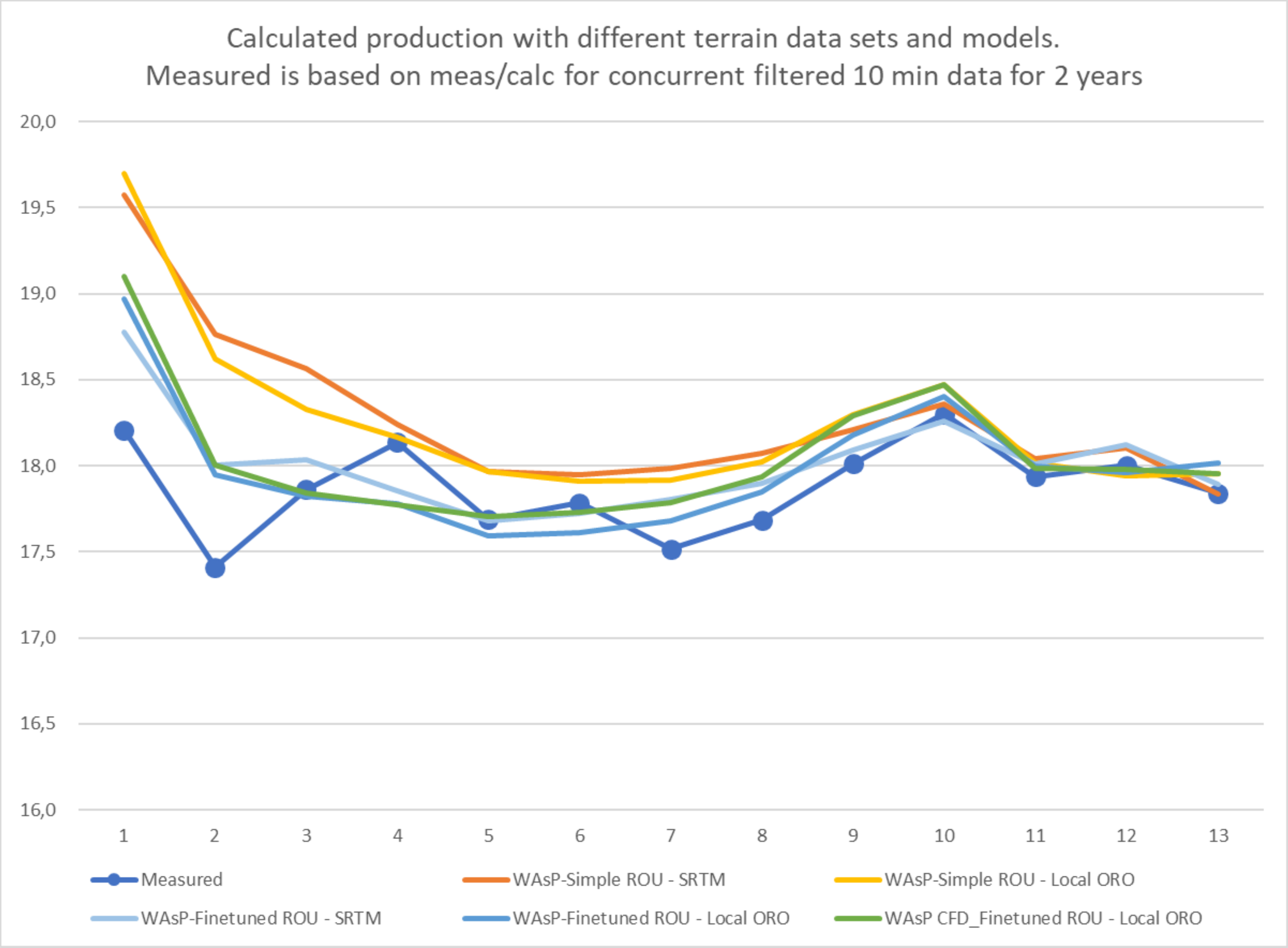




Calculations vs Measurements

4 different combinations ROUGHNESS and OROGRAPHY is tested
WAsP vs WAsP-CFD tested.

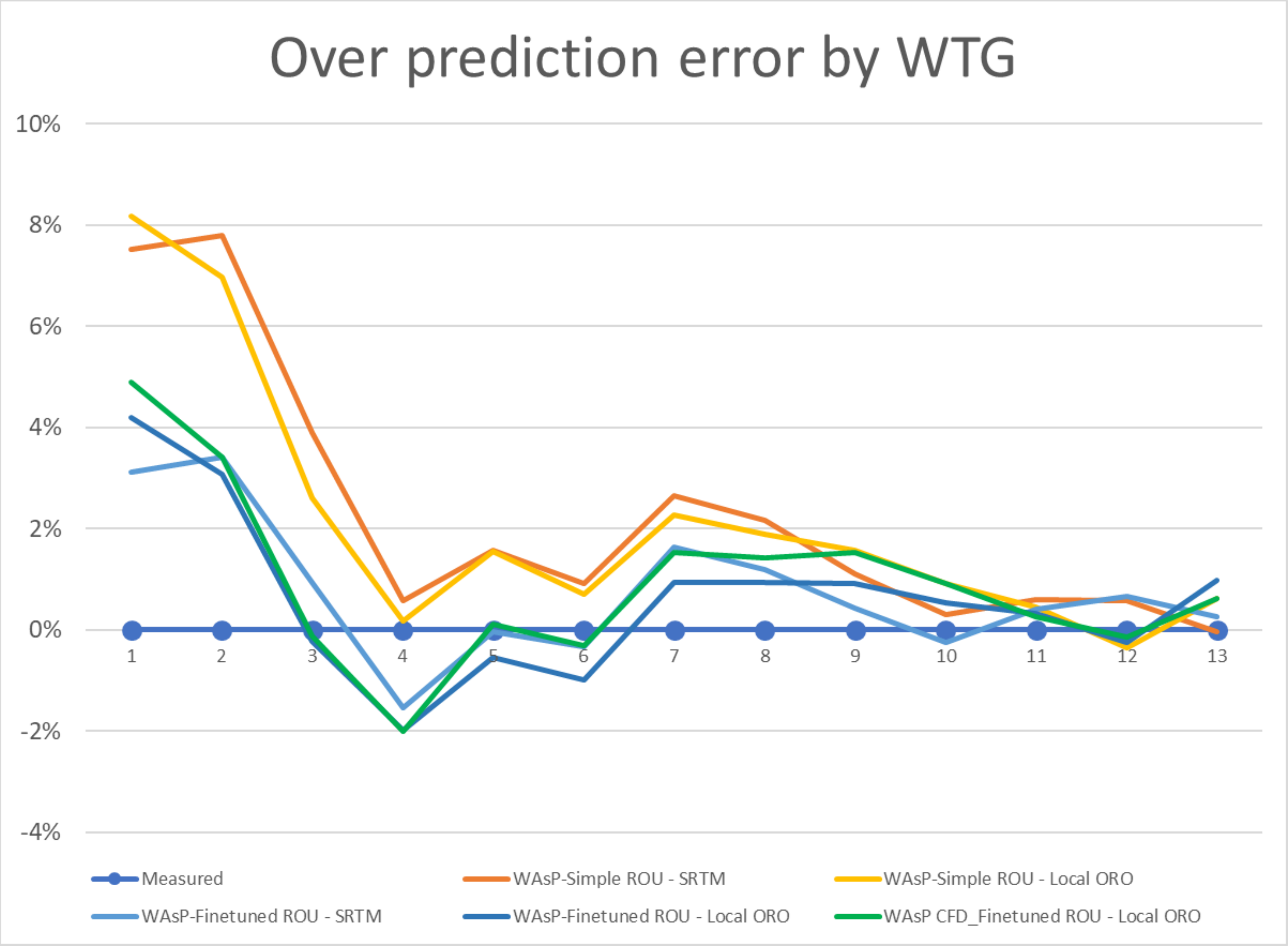
<u>Result:</u>
The roughness matters most, CFD does not improve.



Calculation error as percent

8% overprediction of WTG 1-2 reduced to 4% by roughness tuning, but at a cost of 1% underprediction of WTG 3-5.

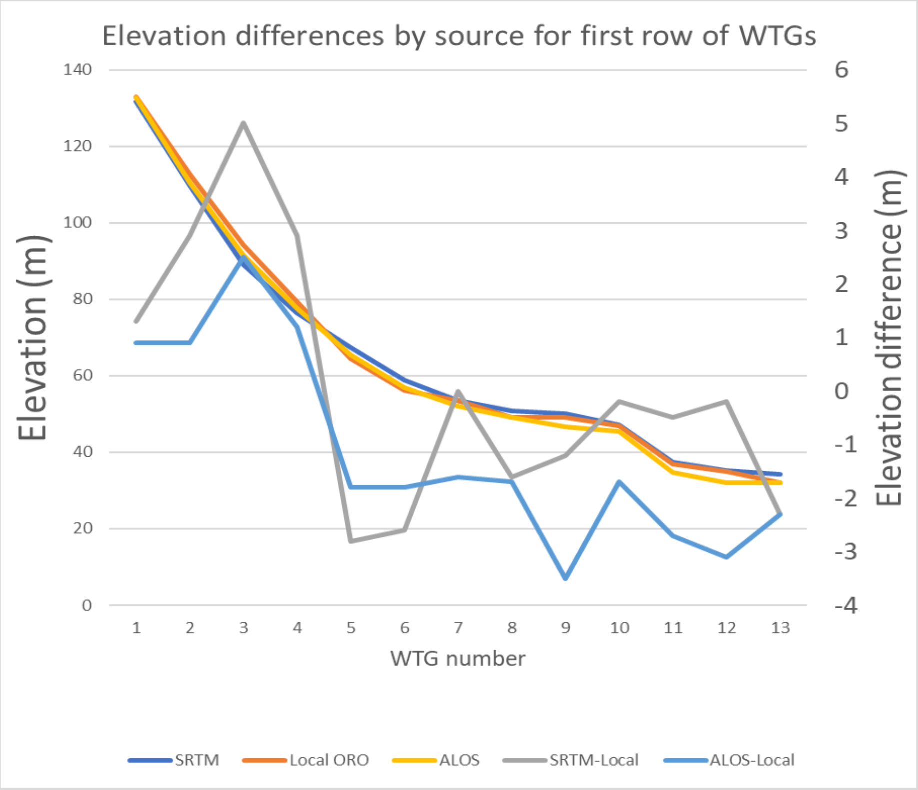
Improved elevation data do not bring real improvements, CFD likewise.

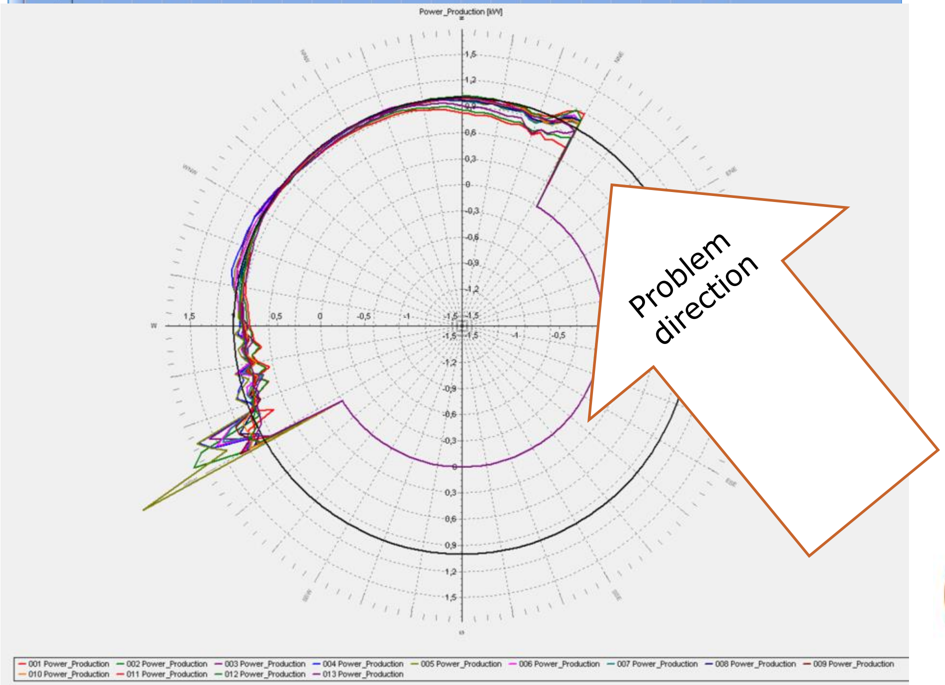


Identifying the problem area

The overprediction occurs with northernly wind direction (day hours, more turbulent).

Different elevation data sets compared below (this is *not* the problem).





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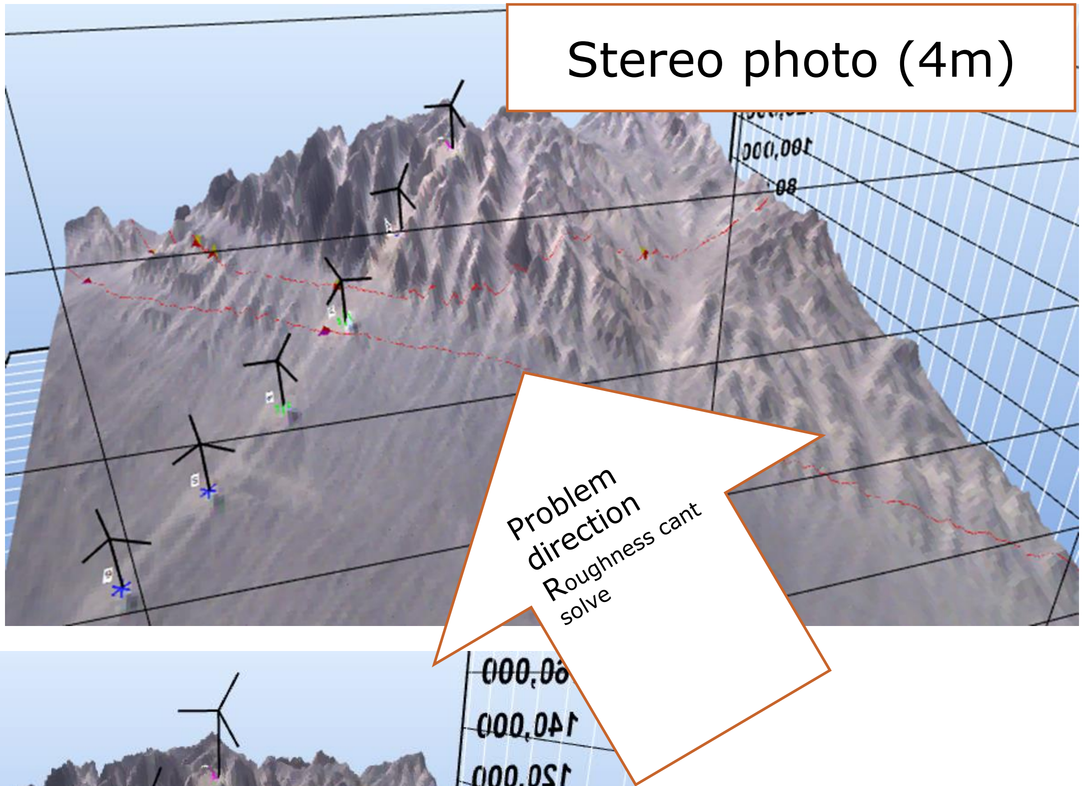
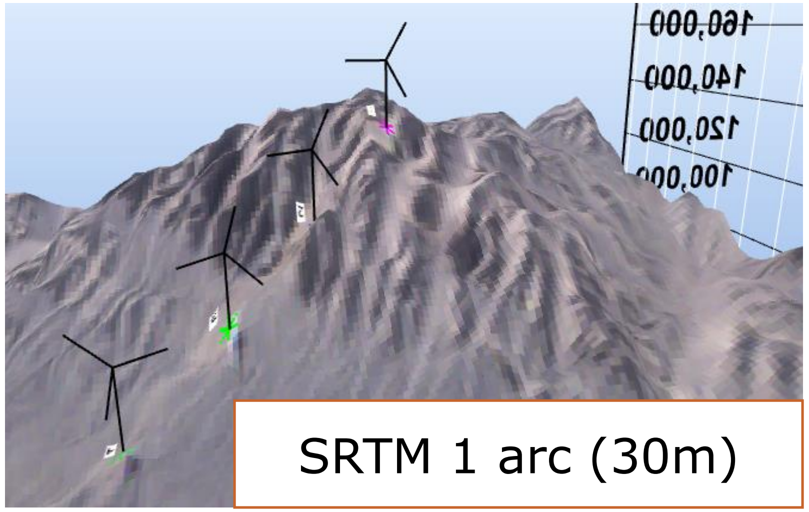
Problem area, the complex terrain

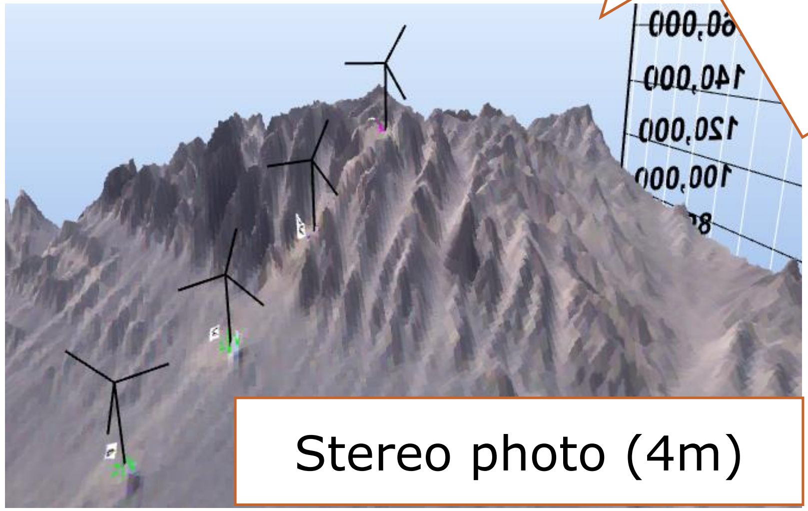
Upper the very detailed and precise satellite Stereo photo 4 m resolution data, below the coarser SRTM 1 arc second (30m) – lower right same zoom with Stereo photo data. Both shown exaggerated.

In calculations the difference is almost none.

The reason for overprediction is probably the terrain complexity with small “ripples”, not captured by the calculation models. Too coarse handling of elevation data.







Conclusion on complex terrain

Small ripples in the terrain violates the "good wind", which the models cannot capture. Partly because the terrain is smoothened before it is "feed in" to the model calculations, but also because the models don't handle smaller ripples well.

In this case *), higher detailedness in Orography data does not help.
Fine-tuning the roughness help much more, but is really difficult if not having many good calibration points (and then it is still difficult). Roughness-tuning bring the overprediction of WT 1-2 down from 8% to 4% at the cost of underpredicting WT 3-5 round 1%.

Due to short distance rippled terrain in problem direction, roughness can't solve the orography based problem, but it can in directions with longer distances with ripples.

<u>Ideas for future:</u>

- Calculate with very high resolution CFD or other more refined models
- Automatic computer-based roughness calibration
- 3D model based roughness map generator (e.g from satellite or drones)

***) For most other sites, elevation data quality is VERY important**

http://help.emd.dk/mediawiki/index.php?title=Main_Page

Digital Elevation Models (DEM)

- Austrian Elevation Model (DGM)
- Belgium Flemish Elevation Model (DTM)
- British Land-Form PANORAMA
- Danish Elevation Model (Danmarks Højdemodel)
- European Elevation Model - EU-DEM
- Finnish Elevation Model
- German Elevation Models (DGM)
- Italian-Sardinia Elevation Model
- Netherlands Elevation Models (AHN2/AHN3)
- Norwegian Digital Elevation Models (DTM/DOM)
- Northern Ireland Elevation Model - OSNI
- Shuttle Radar Topography Mission (SRTM)
- Slovenia Elevation Model
- Spanish Elevation Models (MTD)
- Swedish Elevation Model (GSD)
- US National Elevation Dataset (NED)
- Viewfinder Panoramas DEM

Digital Roughness Models (DRM)

- MODIS VCF
- European Data For Wind
- Global Land Cover Characteristics (GLCC)
- GlobCover
- Corine 2006 and Corine 2012
- National Land Cover Database 2011
- Copernicus Global Land Service, Land Cover 100

Wind Data

- NCEP/NCAR Global Reanalysis Data
- North American Regional Reanalysis Data
- QuikScat Offshore Wind Dataset
- Blended Coastal Winds
- METAR Data
- SYNOP Data
- MERRA Data
- MERRA-2 Data
- CFS- and CFSR Data
- Danish Windindex Data
- EMD-Global Wind Data (based on ERA-Interim)
- ERA5 Data
- KNMI-KNW North Sea Wind

EMD-WRF Mesoscale Wind Data

- Europe: EMD-ConWx Europe Meso Data
- Middle East: EMD-WRF Middle East Meso Data
- South Korea: EMD-WRF South Korea Meso Data
- South Africa: EMD-WRF South Africa Meso Data
- India: EMD-WRF India Meso Data
- Indonesia: EMD-WRF Indonesia Meso Data
- Global: EMD-WRF Global Meso On-Demand

Databases on Turbines

- WindPRO Wind Turbine Catalogue
- Danish Turbines (makes, positions, productions)
- Open Streep Map Turbines (positions only)
- Turbines in the United States
- Finnish Turbines (positions)

Digital Map Data

- British Ordnance Survey OpenData
- Danish Orthophoto Mosaic
- Dynamic maps
- Export of WindPRO data into Google Earth
- Finnish Orthophoto Mosaic
- Finnish Topographic Map
- Spanish Topographic Map
- GeoCover Images
- Open Street Map
- OnMaps
- Web Map Service (WMS)
- windPRO Global Satellite Imagery - 10m
- windPRO European Satellite Imagery - 2.5m

Forest Maps (Tree Heights)

- Swedish SLU Forest Map
- Finnish LUKE Forest Map

Digital Bathymetry Models (DBM), Water Depths

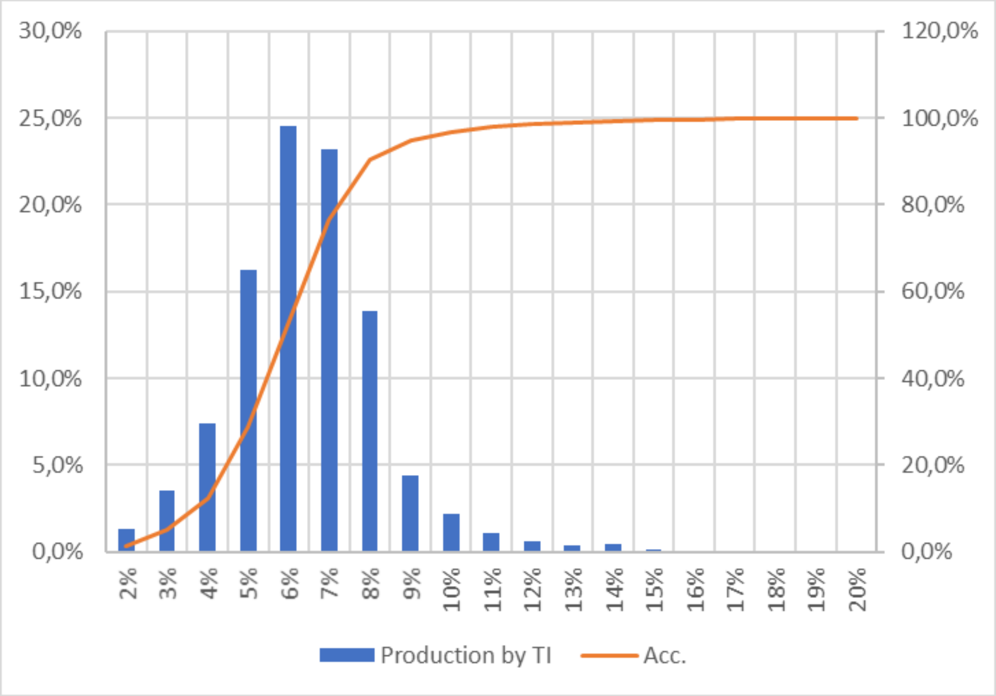
- European EMODnet Bathymetry
- Global Bathymetry GEBCO

Other Data Sources

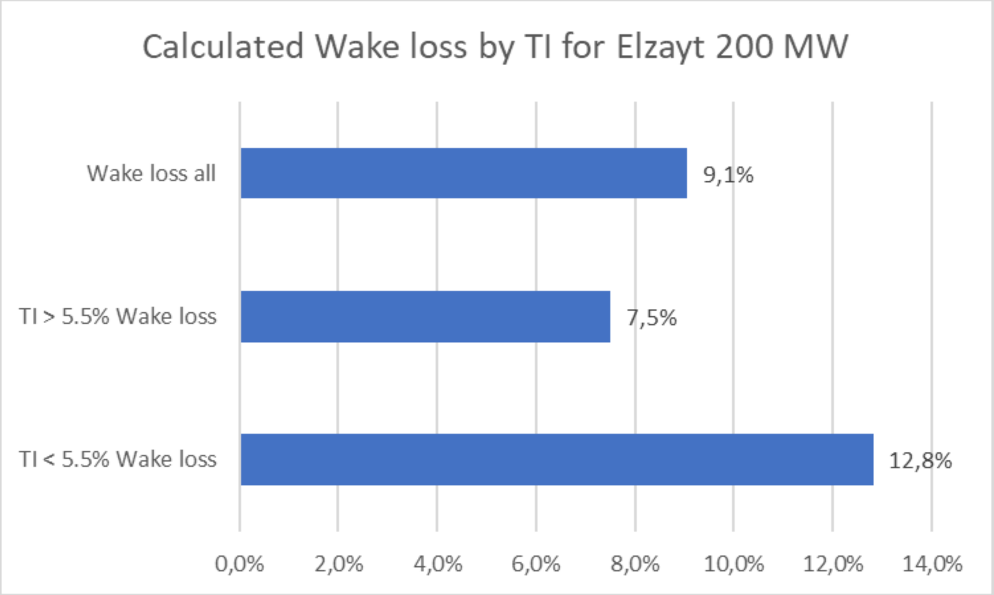
- CGIAR 90m Digital Elevation Data.
- Aster Global Elevation Model (Aster GDEM)

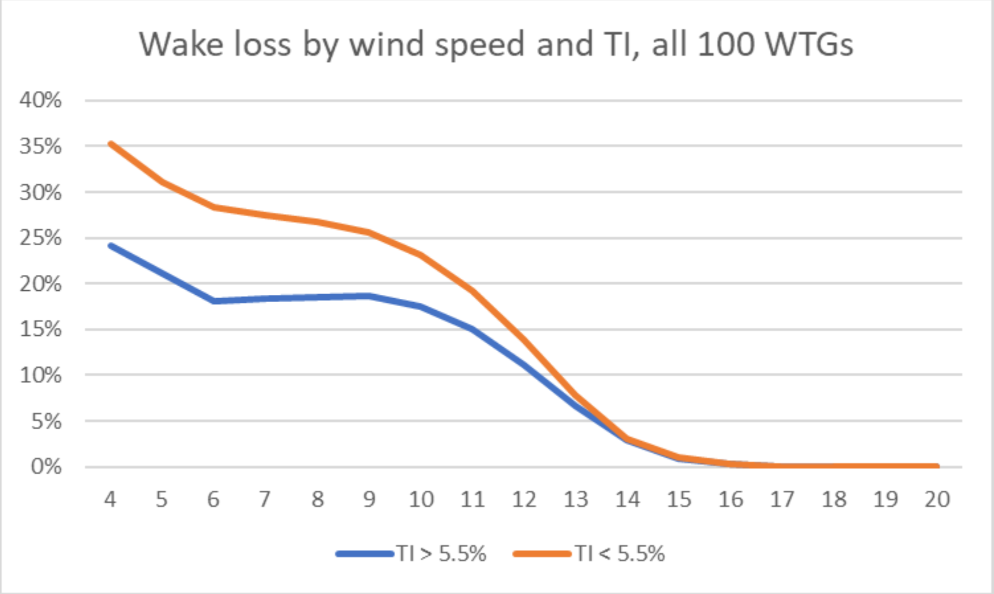
Useful information on wakes

With this very accurate calibrated wake-loss calculation, much information can be extracted from 10-minute based calculations:



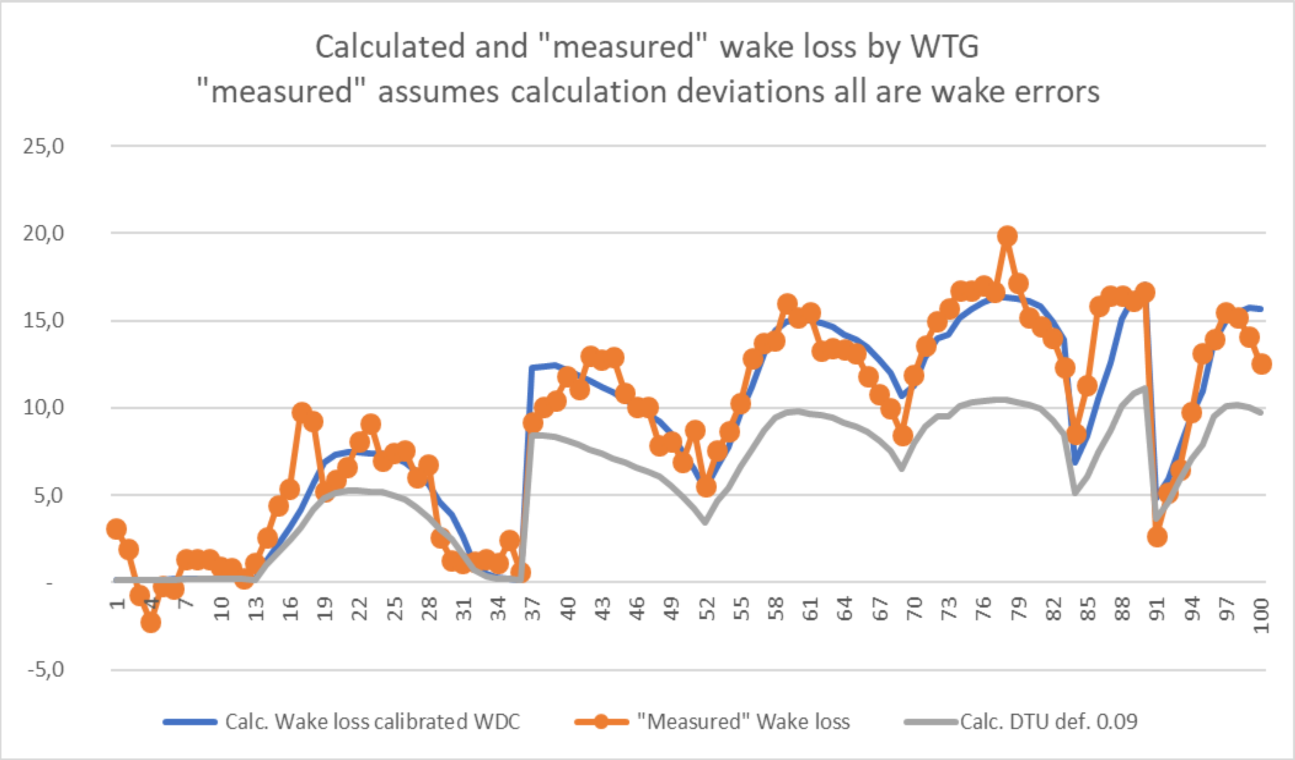
The TI really mean a lot. At this site round half the production is seen at TI < 6%, wake losses are essential higher than at other onshore sites with typical higher TI.





Conclusions on wake loss calibration

Wake loss round 9%
Up to round 18% for most waked WTG.
No ”sign” of deep array effects for this 7 row wind farm with dense spacing in row (3 RD) and row spacing of 14 RD.



Main message: WDC = TI x c
Unfortunately not as simple as WDC = TI x 0.4 (Park1) as found in ”formula” based research:

$$\mathrm{TI} \approx \left[\ln\left(\frac{z}{z_0}\right) - \psi_m(z/L) \right]^{-1}$$

$$k_w \approx 0.4\,\mathrm{TI}_h$$

http://orbit.dtu.dk/files/122284235/On_the_application_of_the_Jensen_wake_model.pdf

EMD recommendations updated for offshore in windPRO 3.3:->
In this case onshore (but offshore like), using Park2 & DTU default 0.09: calculated wake loss is 6%, with c = 0.48 12%.
The “real answer” is c = 0.8 which gives ~9% !

	DTU recommendations:		EMD recommendations 3.3 manual:	
	N.O.Jensen (PARK1)	PARK2	PARK 1	PARK 2
Offshore	0.05	0.06	WDC = TI x 0.67	WDC = TI x 0.8
Onshore	0.075	0.09	WDC = TI x 0.4	WDC = TI x 0.48

Future work

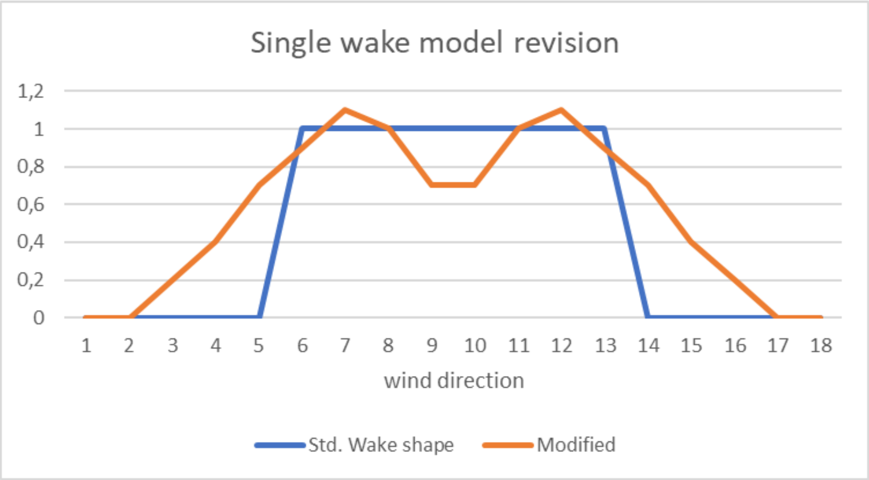
There seem to be the following major challenges regarding Wake loss calculation:

1. Finding the right conversion factor between TI and WDC
2. Solving that single row projects perform differently from multiple row projects
3. Be capable to reproduce the “wake shape” for more detailed follow-up

Ad.1.: Testing many wind farms to find out if just ONE conversion factor TI -> WDC for N.O.Jensen models will work, or there are other parameters that needs to be involved. Stability most obvious candidate.

Ad.2.: Include WDC increase by number of upwind WTGs has already shown to work very well on several single row projects and is available in windPRO (NO2005 model).

Ad.3.: The solution: Due to that wind direction not is ”fixed” within 10-min time step, less loss is seen in center angle, more at the ”shoulders”, this can be compensated – there will although be some work in finding out how and what might control the shape, e.g. Std.dev.(dir).



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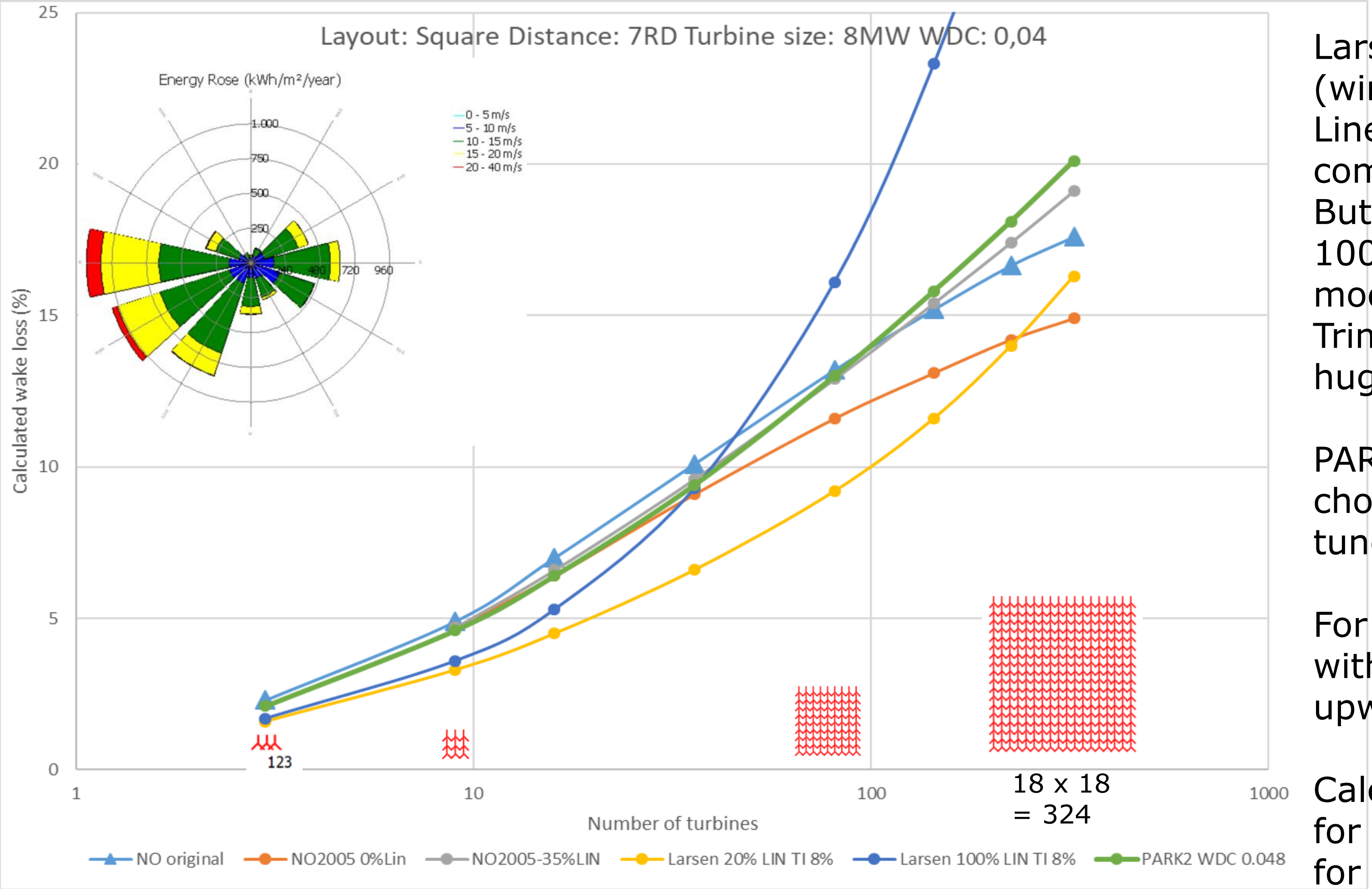
Different wake models ?

EMD is currently testing WakeBlaster – look promising, but needed?



Larsen model soon available (windPRO 3.4) with controllable Linear vs RSS deficit weight in combination model.
But definitely not a good idea with 100% linear weight and Larsen model for very large wind farms.
Trimming the combination model a huge challenge.

PARK2 probably the most "safe choice", although with TI needed to tune the WDC.

For single row wind farms, NO2005 with increased WDC by number of upwind WTGs the only precise choice.

Calc. time, 300 WTGs: 2-5 minutes for N.O.Jensen variants, 100 minutes for Larsen.

Thank you!

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Vertical Extrapolation Uncertainty in Complex Terrain

Vindkraftnet 13.5.2019 Aalborg

Wiebke Langreder, Madalina Jogararu, Thorkild G. Sørensen

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www.emd.dk

Checking…

Did you pay attention? ☺

- Who knows windPRO?
- Who knows that EMD has a Consulting department?

Night time reading

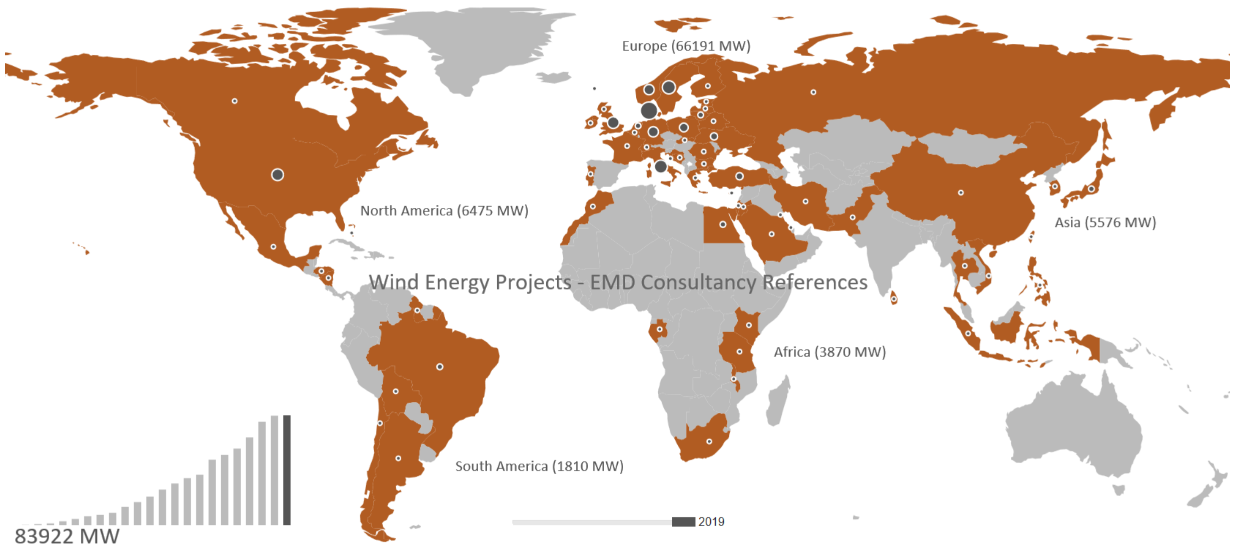
EMD Wind Consulting: Who we are

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?

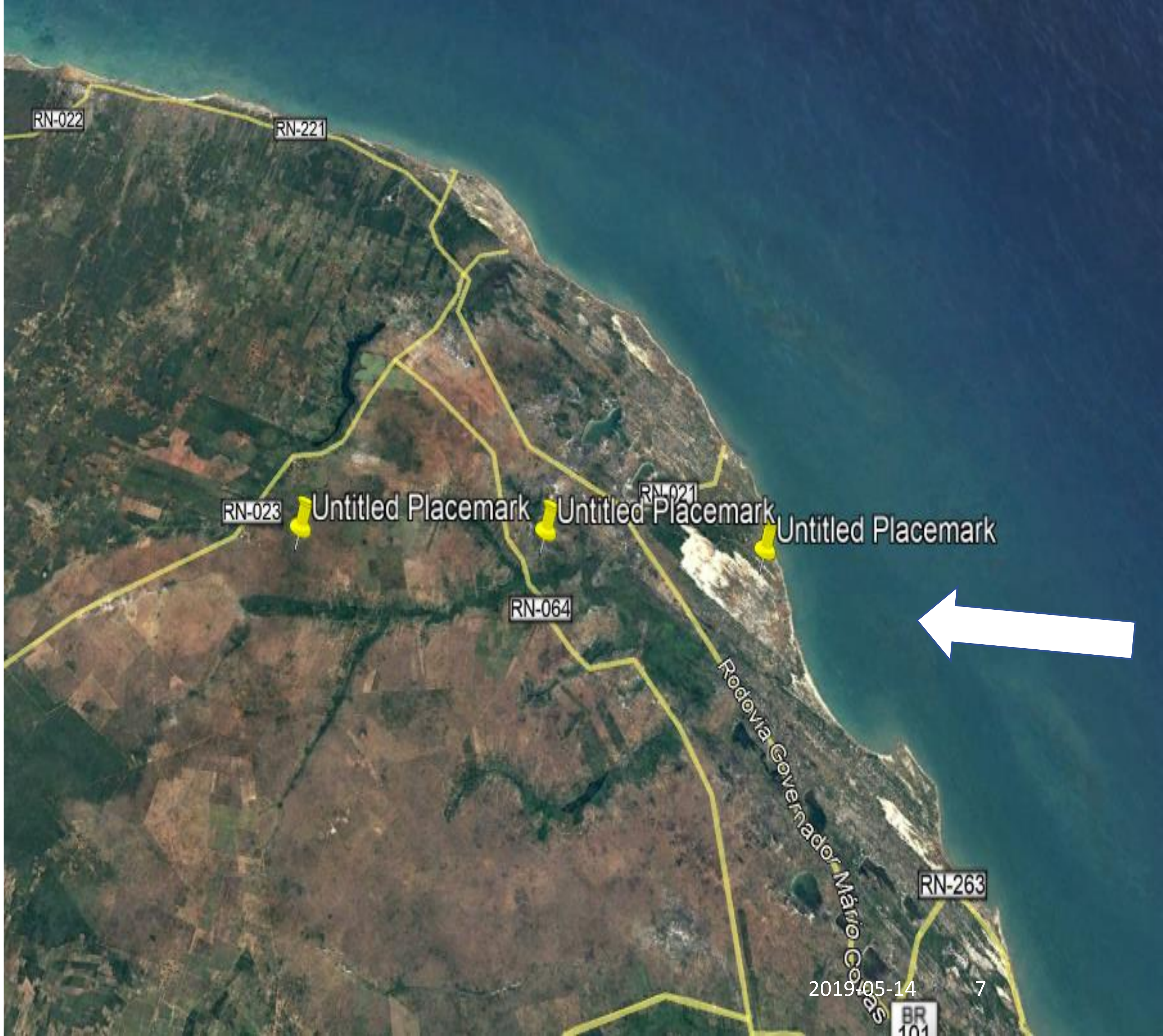
Is this complex?

Brazil

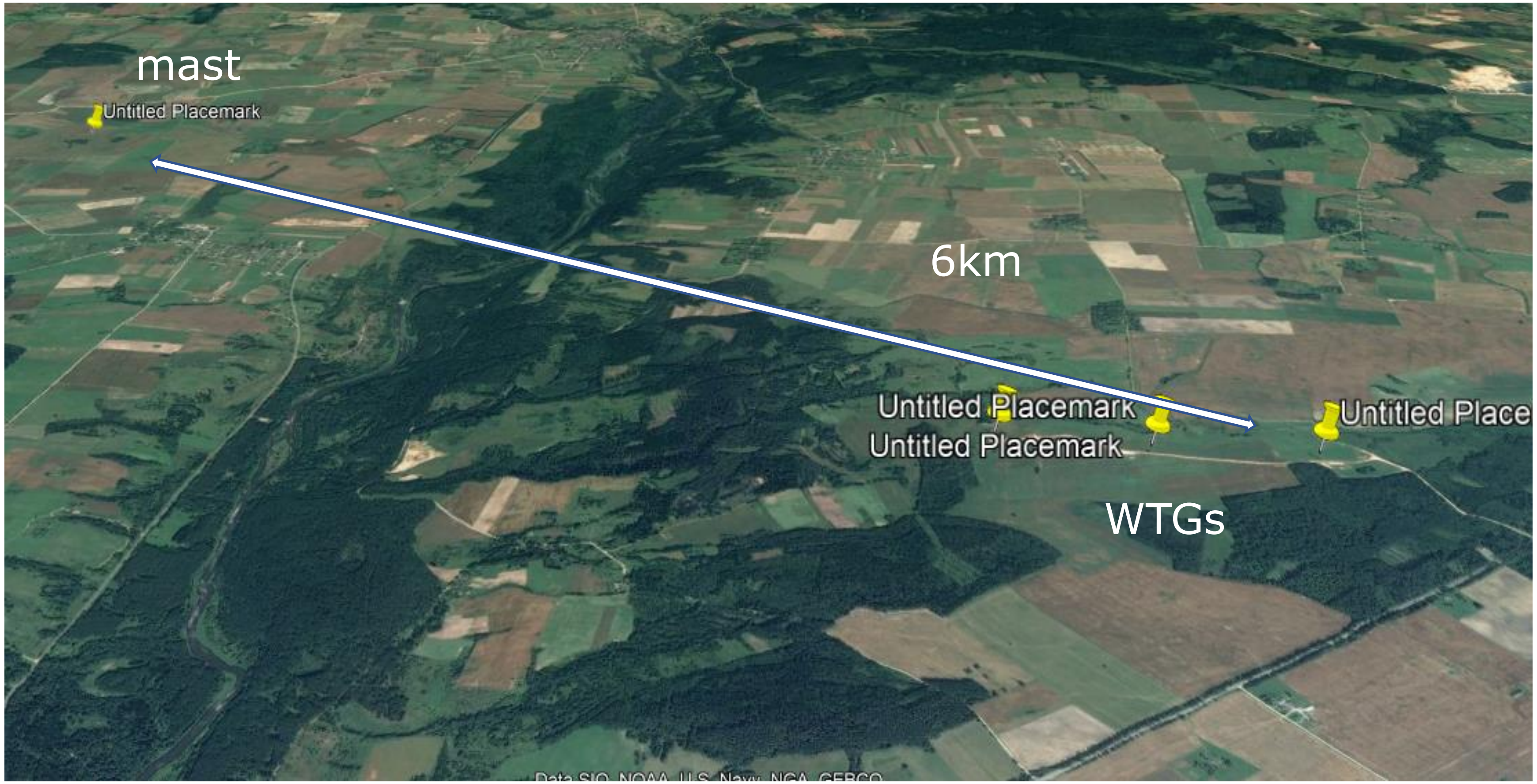
- 3 masts 5-10 km apart
- Massive decrease within short distance

- WAsP cannot do it

- We have not solved this…



Is this complex?



Lithuania

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

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Why?

Modern times…?

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

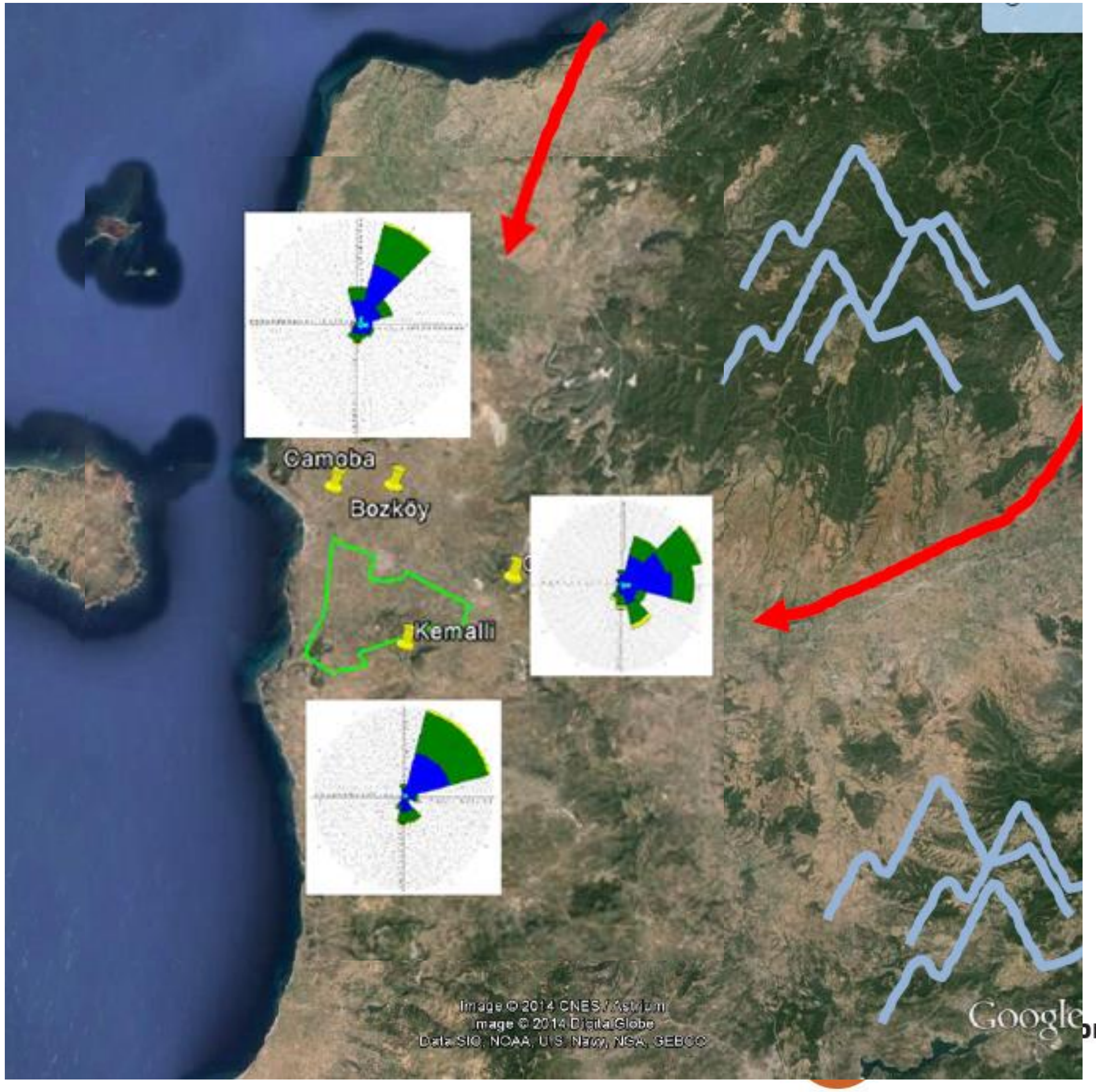
Is this complex?

Turkey

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

Why 30° direction turn?

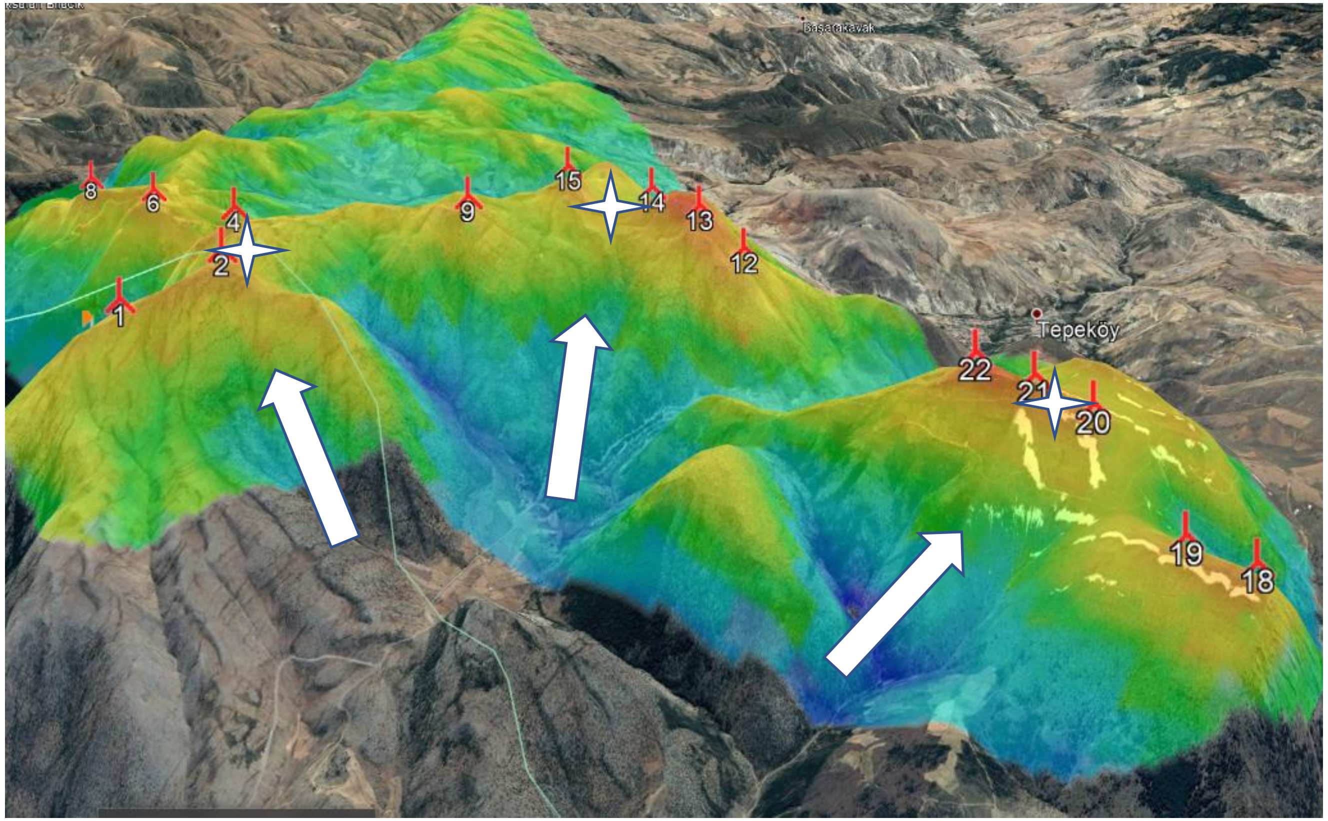
- The answer is 20km away: Mountains
- Invisible for WAsP
- But even if we know the real direction – how to deal with it?
- Park model uses ONE wind direction ONLY



Now it is really getting complex ☺

“Banana” Issue

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



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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)**

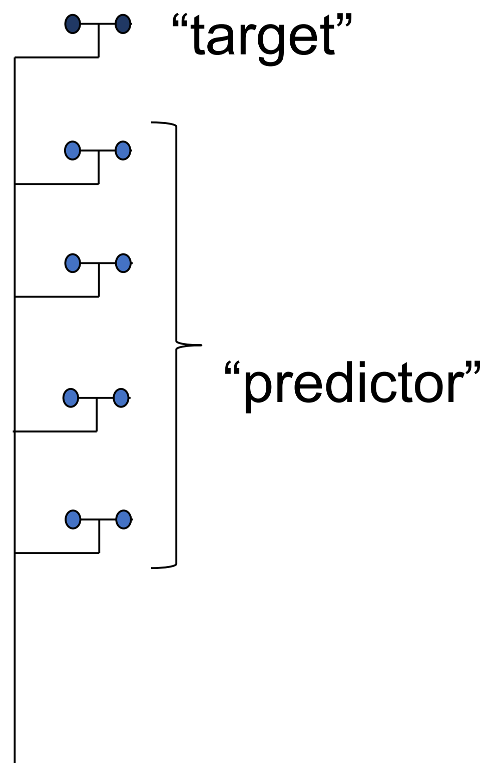
No differentiation on terrain/roughness

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

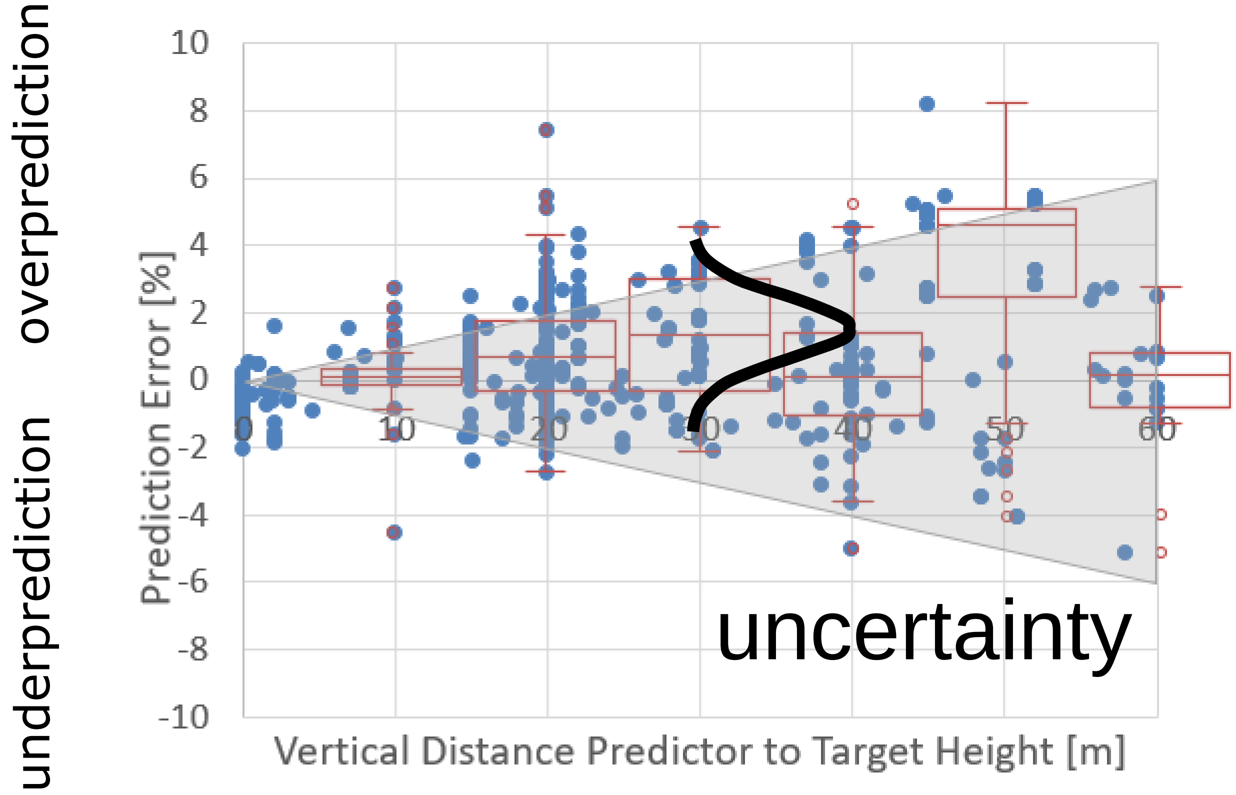
Example result

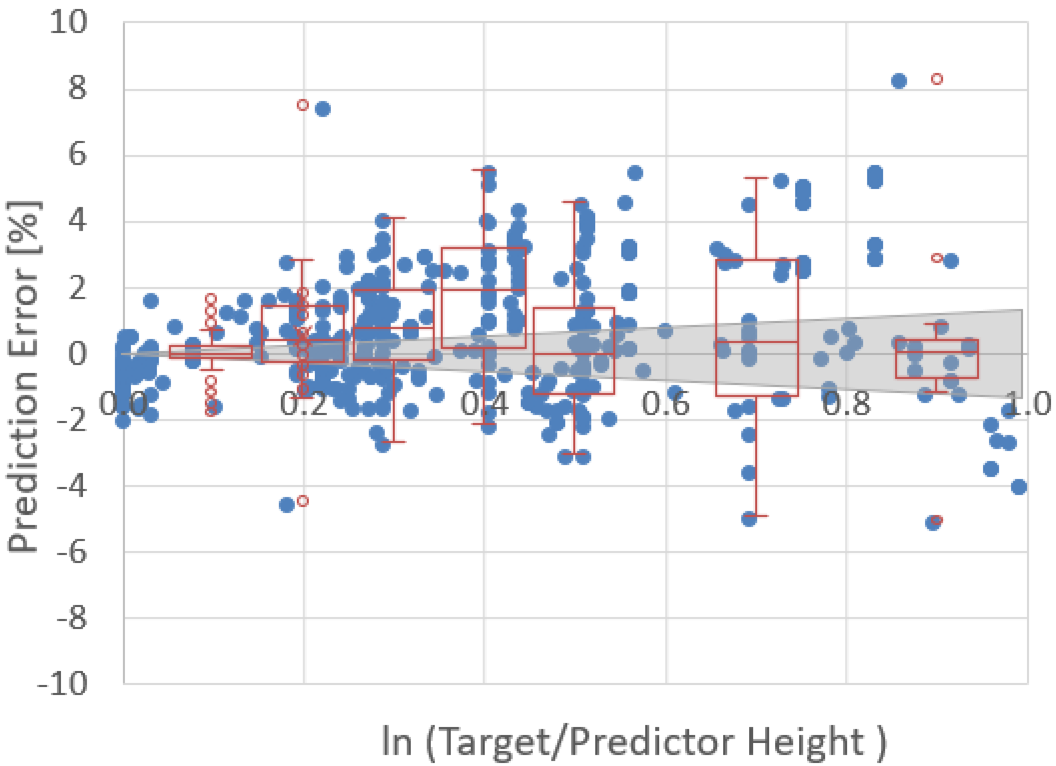
Vertical distance

Uncertainty: 1% per 10m

Expression as logarithm

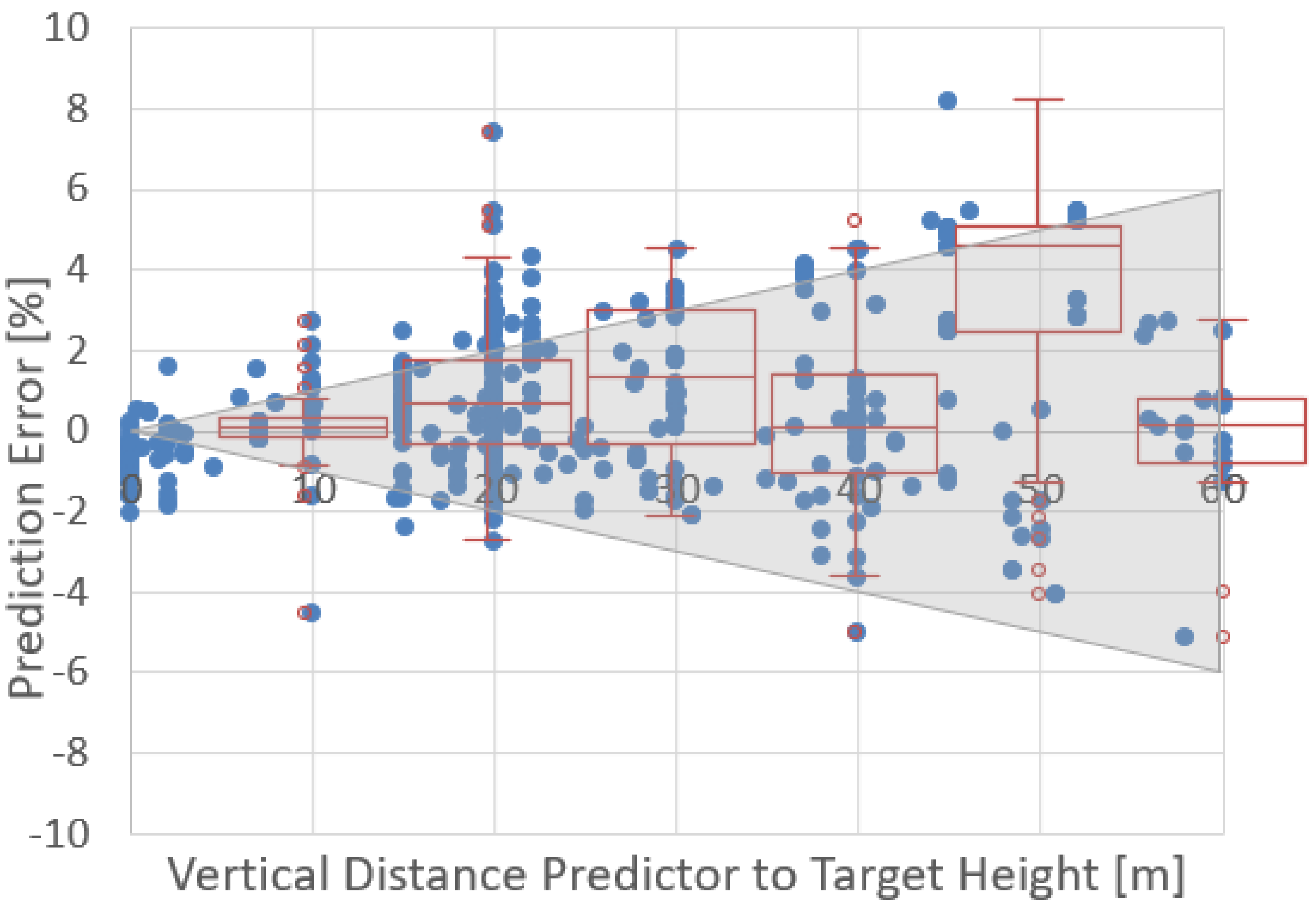
DTU uncertainty for LN



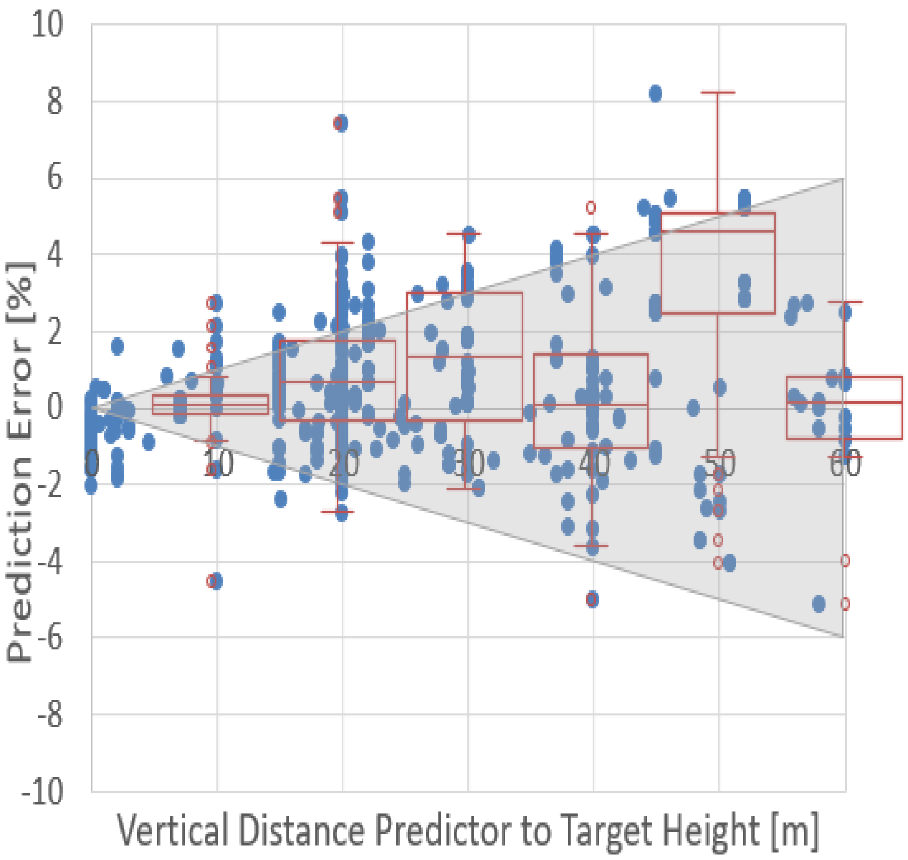


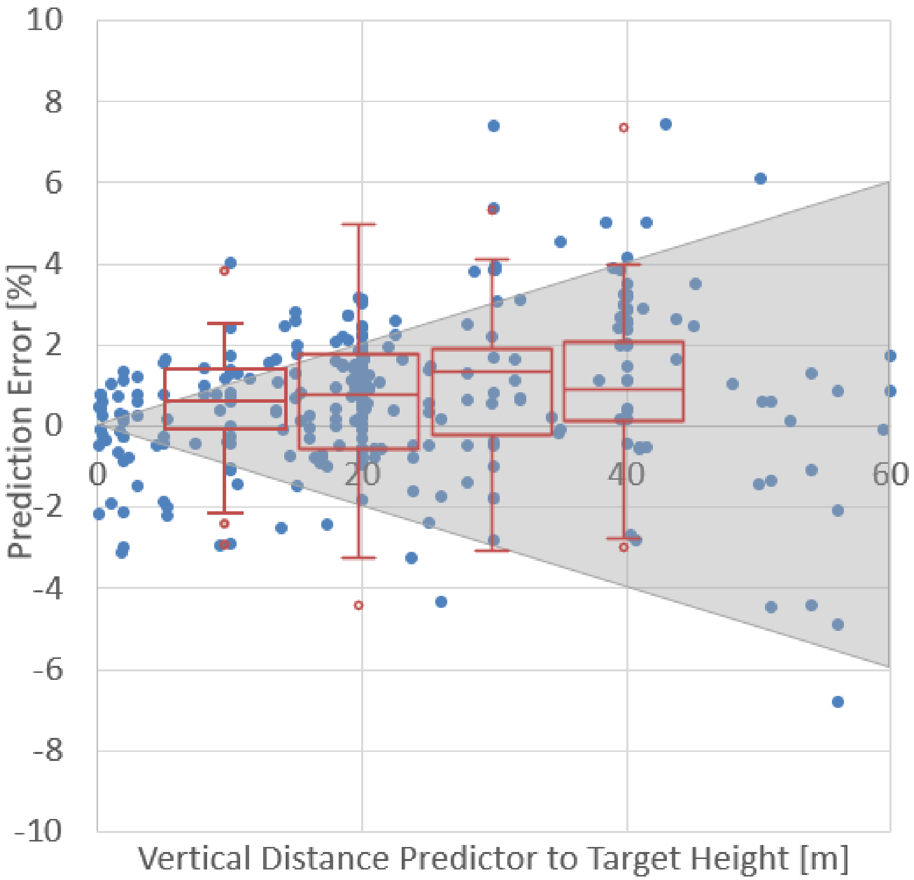
Flat, no forest

- 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

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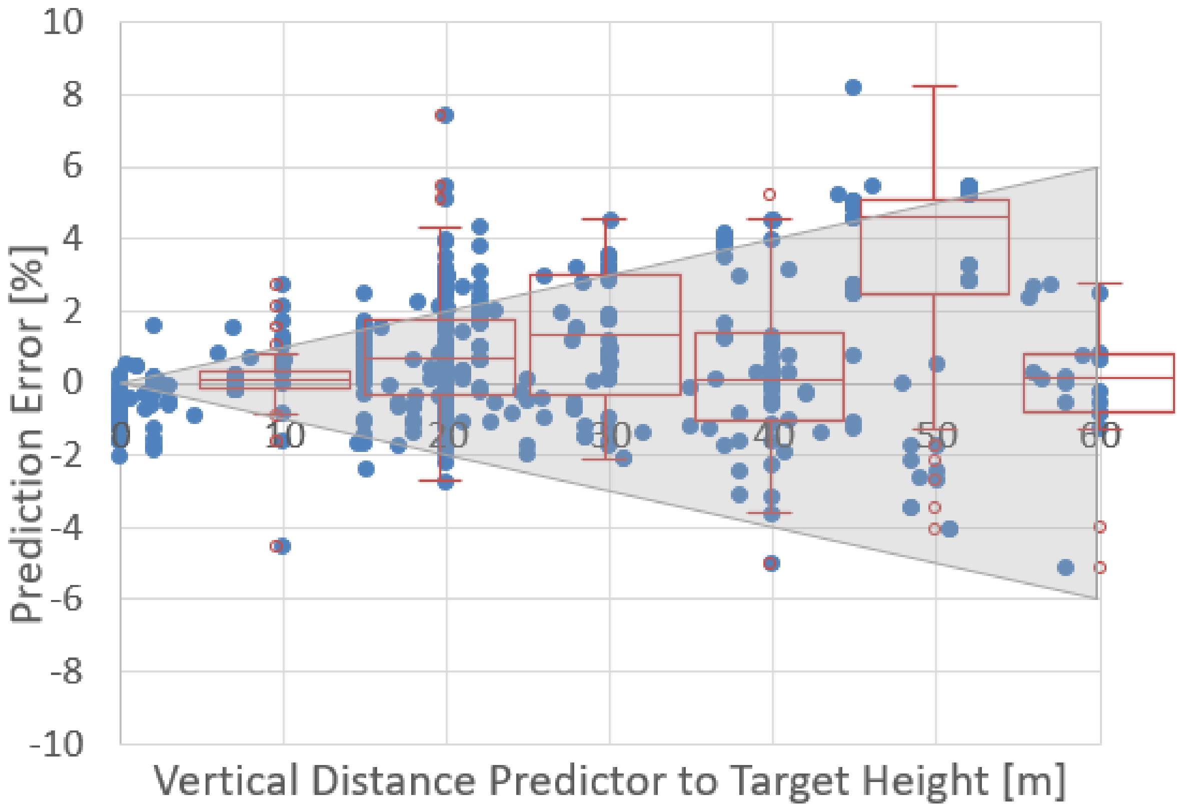
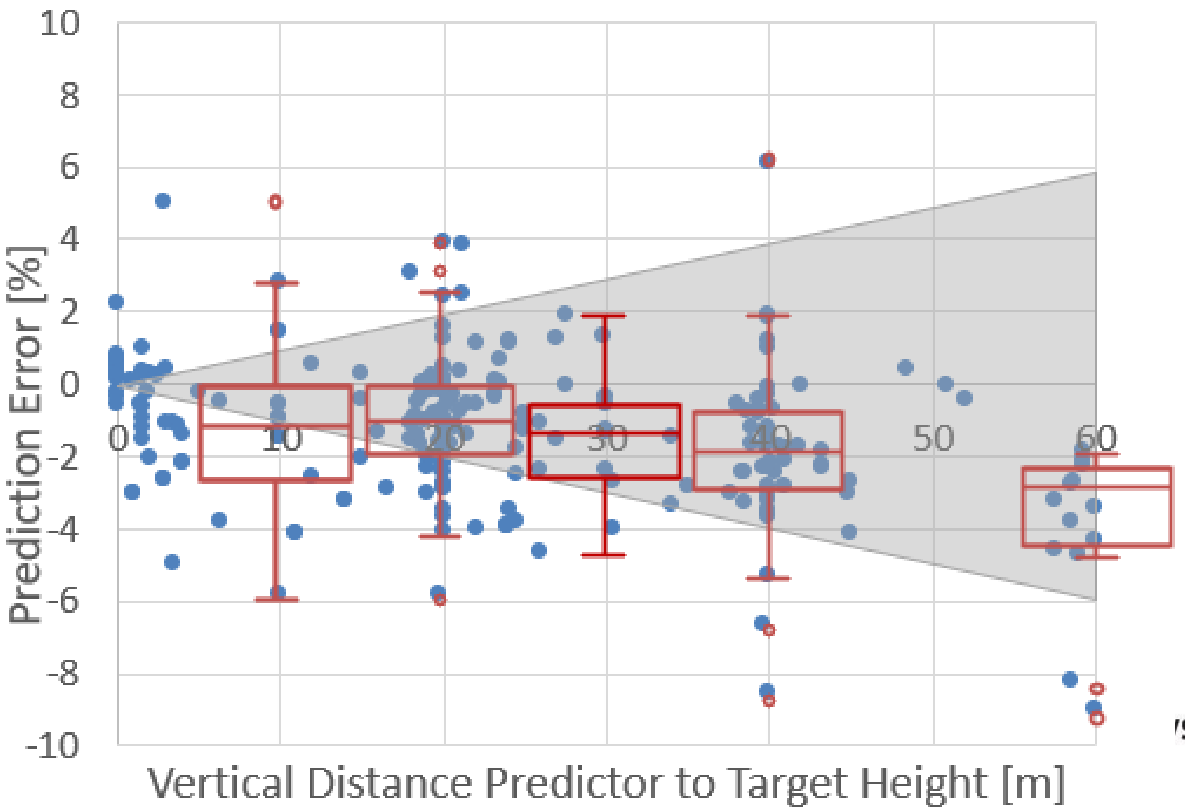
And forest? - Flat

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

Flat, no forest



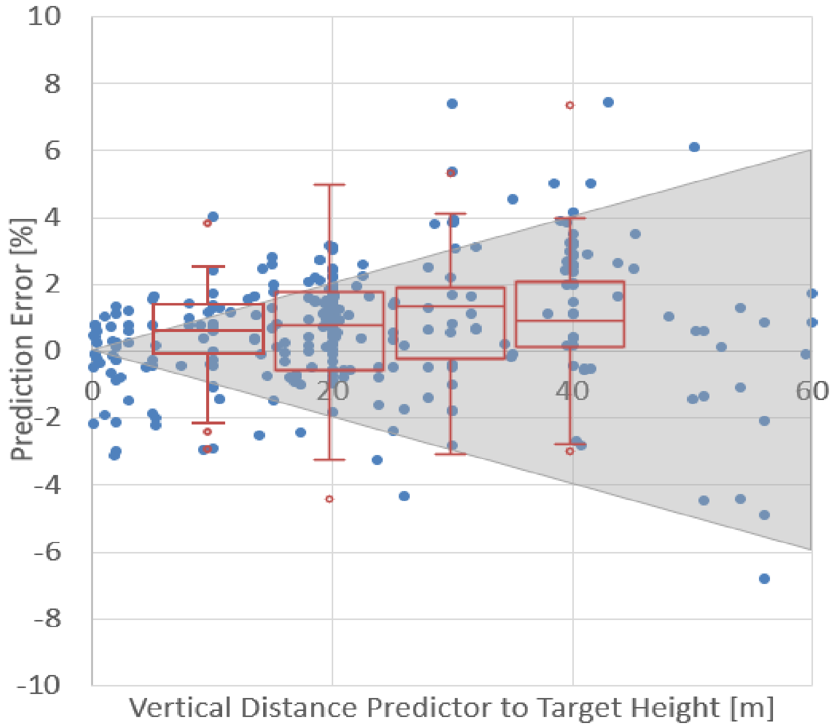
Flat, forest



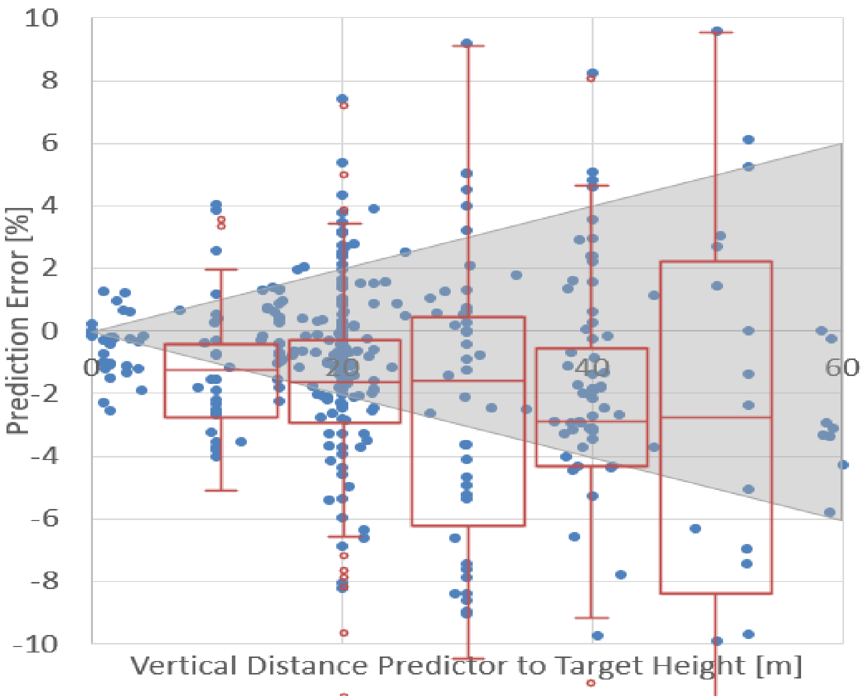
And forest? - Complex

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

Complex, no forest



Complex, forest



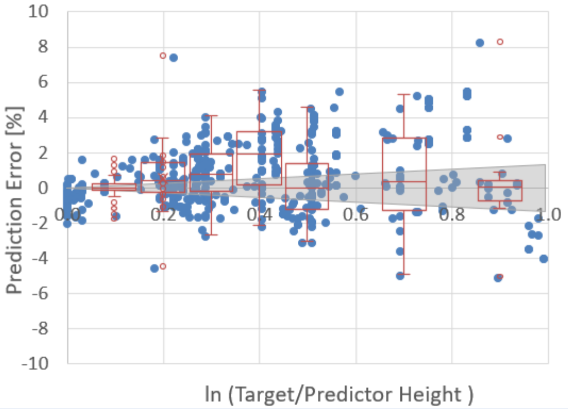
And finally IEC-15 proposal

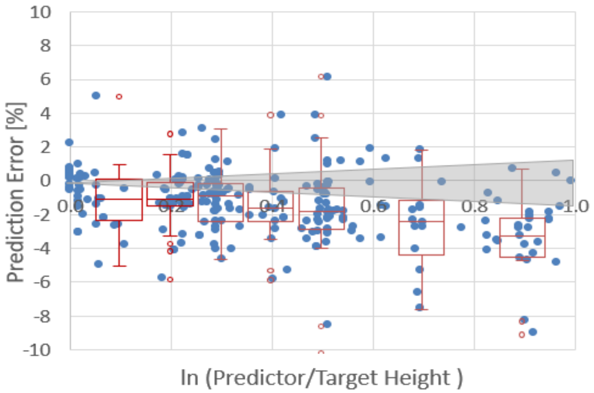
No matter what: Under-prediction of uncertainty!

No forest

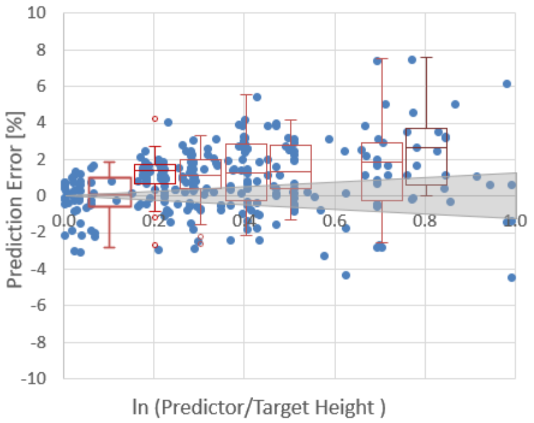
Forest

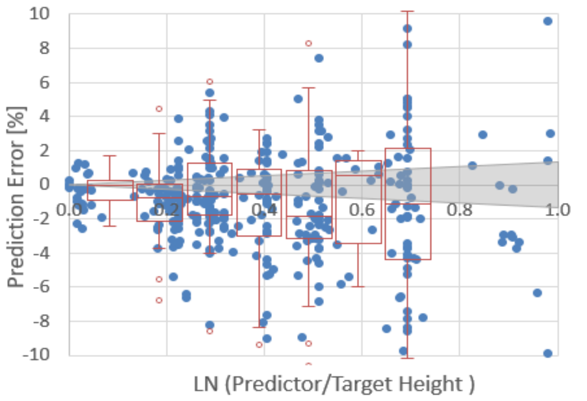
Flat





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?

Contact:

Wiebke Langreder

wl(at)emd.dk

EMD Presentations

Vindkraftnet 2019-05-13 @ EMD, Aalborg Denmark

Complex Terrain

1. **Models versus terrain data, what matters most.**
   Per Nielsen

2. **Vertical Wind Speed Extrapolation in Complex Terrain – As Challenging as we think?**
   Wiebke Langreder

3. **Reference wind data – challenges when doing short measurement campaigns in complex terrain**
   Morten Lybech Thøgersen

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- Reference Wind Data - Challenges when doing short measurement campaigns in complex terrain

Morten Lybech Thøgersen (mlt@emd.dk),
Lasse Svenningsen (ls@emd.dk) & Thorkild G. Sørensen (tgs@emd.dk)
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Vindkraftnet - 2019-05-13 @ EMD International, Aalborg

RECAS
Reduced Assessment Time

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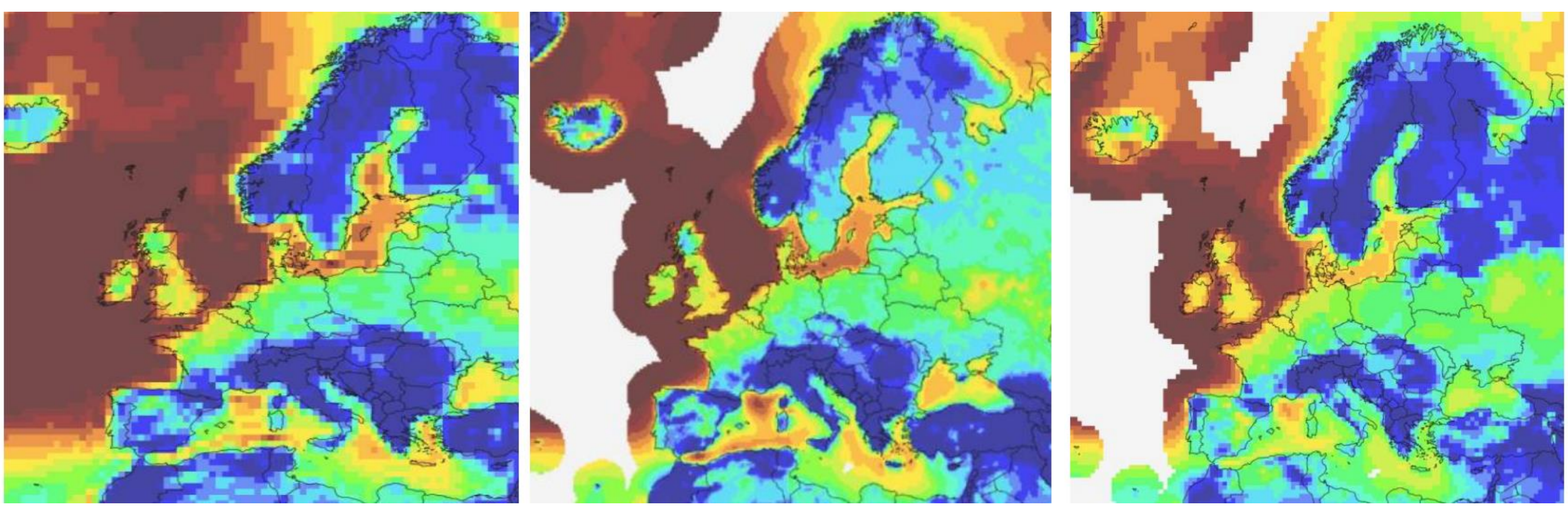
2. Correlations, trends and consistency
3. Short campaigns – a real challenge!
4. Summary

ERA-Interim *ERA5* *MERRA-2*



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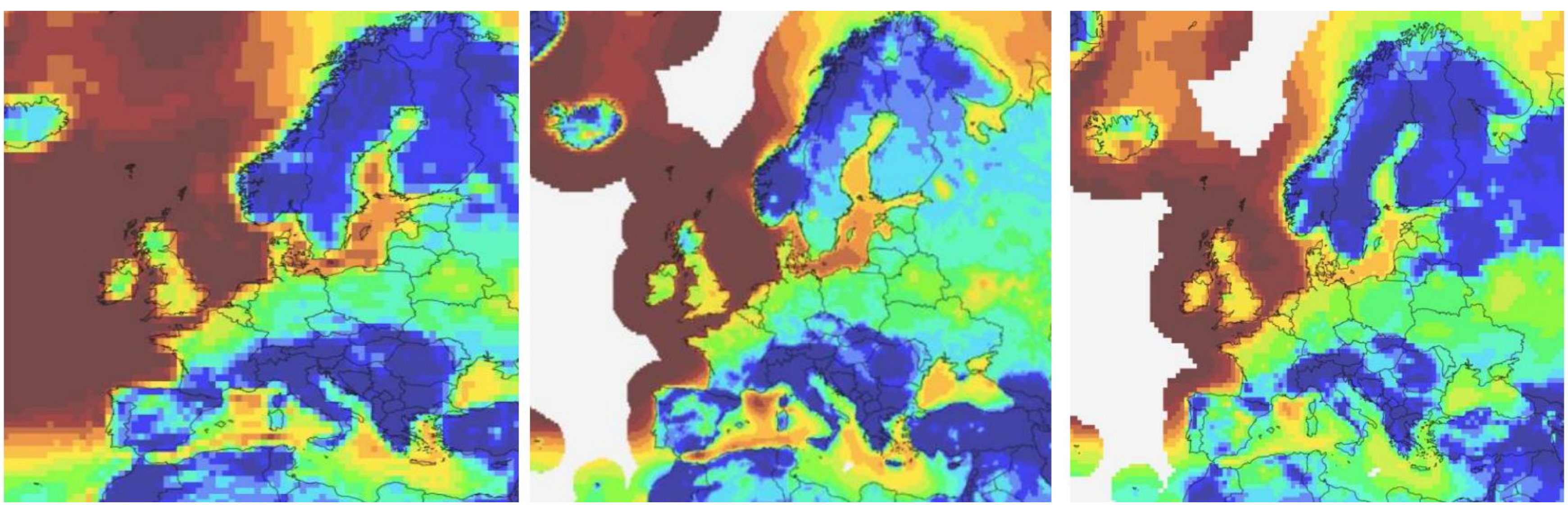


1. Introduction- Overview – ERA5

- ERA5 is ECMWF most recent reanalysis dataset (5th generation)
- Higher temporal and spatial resolution that ERA-Interim
- New parameters available – such as 100m winds

Released schedule

- 7 years was released as first segment (2010-2016)
- Continious updating (December 2017)
- Full coverage 2017 (February 2018)
- 2 extra years (2008-2009) - released primo 2018
- 1979-2007 – released early 2019

Still under development

Item	'Old' plan	'New' plan	Even newer plan
ERA5T (short delay product)	~~2017-Q4~~	~~Mid 2018~~	Mid 2019
Access to observations from 2010	~~2017-Q4~~	~~Mid 2018~~	Mid 2019
Years 1979-2007 released	~~2018-Q2~~	~~Late 2018~~	2019-Q1
Years 1950-1978 released	~~2019-Q1~~	~~2019~~	Late 2019

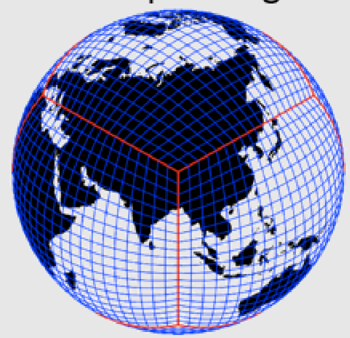
Public release plan @ http://climate.copernicus.eu/products/climate-reanalysis

1. Introduction – Comparison

Parameter \ Dataset	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
Vertical levels	137	60	72	64
Horizontal resolution	~31 km	~80 km	~50 km	~38km/~25km
Upper modelling level	0.01hPa (~80 km)	0.1hPa (~60 km)	0.01hPa (~80 km)	0.26 hPa (~55 km)
Temporal resolution	1-hourly	6-hourly	1-hourly	1-hourly
Release schedule	Monthly*	Monthly	Monthly	Daily
Assimilation model	IFS Cycle 41r2	IFS Cycle 31r2	GEOS 5.12.4	Grid-Point Statistical Interpolation, GSI
Spatial grid type	Reduced Gaussian	Reduced Gaussian	Cubed sphere	Varies
Period available (now)	2010-2016	1979-present	1980-present	CFSR: 1979-2010 CFSv2: 2011-present
Period available (at completion)	1950-present	1979-present	1980-present	CFSR: 1979-2010 CFSv2: 2011-present
Delay in data delivery	3 months *)	3 months	1-2 months	1 day

*) A preliminary version 'ERA5T' with 1 week delay will be available

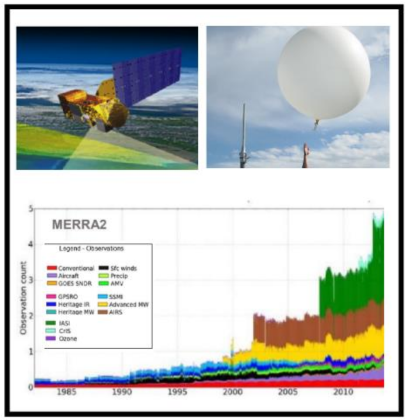
1. Introduction– Comparison

ITEM	MERRA2	MERRA
GEOS data assimilation model version	5.12.4	5.2.0
Observations per 6 hourly analysis cycle	$\sim 5 \cdot 10^6$	$\sim 2 \cdot 10^6$
Grid	Cubed sphere grid 	Regular lat-lon 
Spatial resolution (longitude)	0.625 degrees	2/3 degree
Spatial resolution (latitude)	0.5 degrees	0.5 degree
Period covered (yyyy.mm)	1980.01 - present	1979.01 – 2016.02
Best temporal resolution	1 hour	1 hour

Credits: Grid figures – P.A. Ullrich – http://amg.ucdavis.edu/research.html

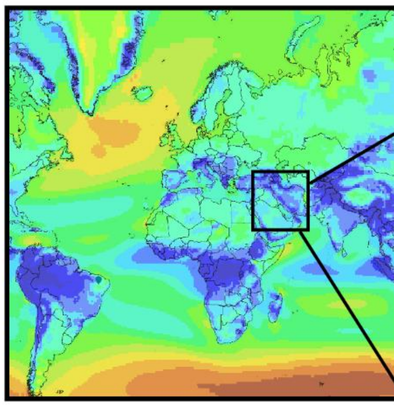
1. Introduction

OBSERVATIONS	ERA-5 RAW DATA	EMD-WRF OD	DOWNSCALING



DATA: IN-SITU AND REMOTE OBSERVATIONS

DATA ASSIMILATION / REANALYSIS



DATA: GLOBAL / SYNOPTIC SCALE:

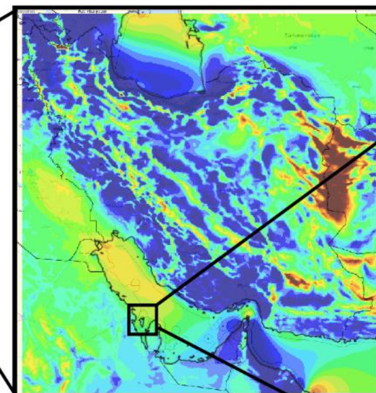
Reanalysis Data: ECMWF ERA5
Spatial Resolution: ~35km

Typical model scales: ~100 km's
Time-series data, 1 hourly resolution

EMD-WRF MESOSCALE MODELLING

Data Input:
- ERA5 Boundary Data
- Globcover Terrain

Model Execution:
- Standard EMD-WRF setup
- Spatial resolution ~ 3 km



DATA: MESOSCALE:

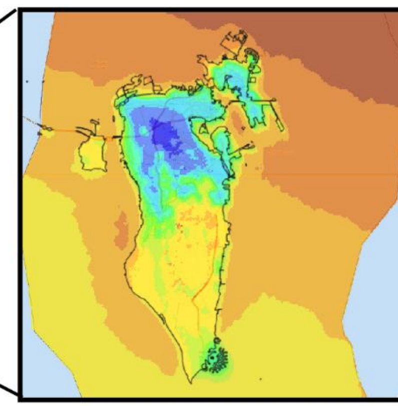
Time series, wind speed and direction
Spatial Resolution: ~3 km
Temporal resolution: 1 hour

Typical model scales: ~10 km's

EMD-MESO/MICRO DOWNSCALE MODELLING

Data Input:
- Mesoscale time series and terrain
- Detailed, high-resolution microscale terrain

Model Execution:
- WAsP version 11+
- windPRO version 3.1+



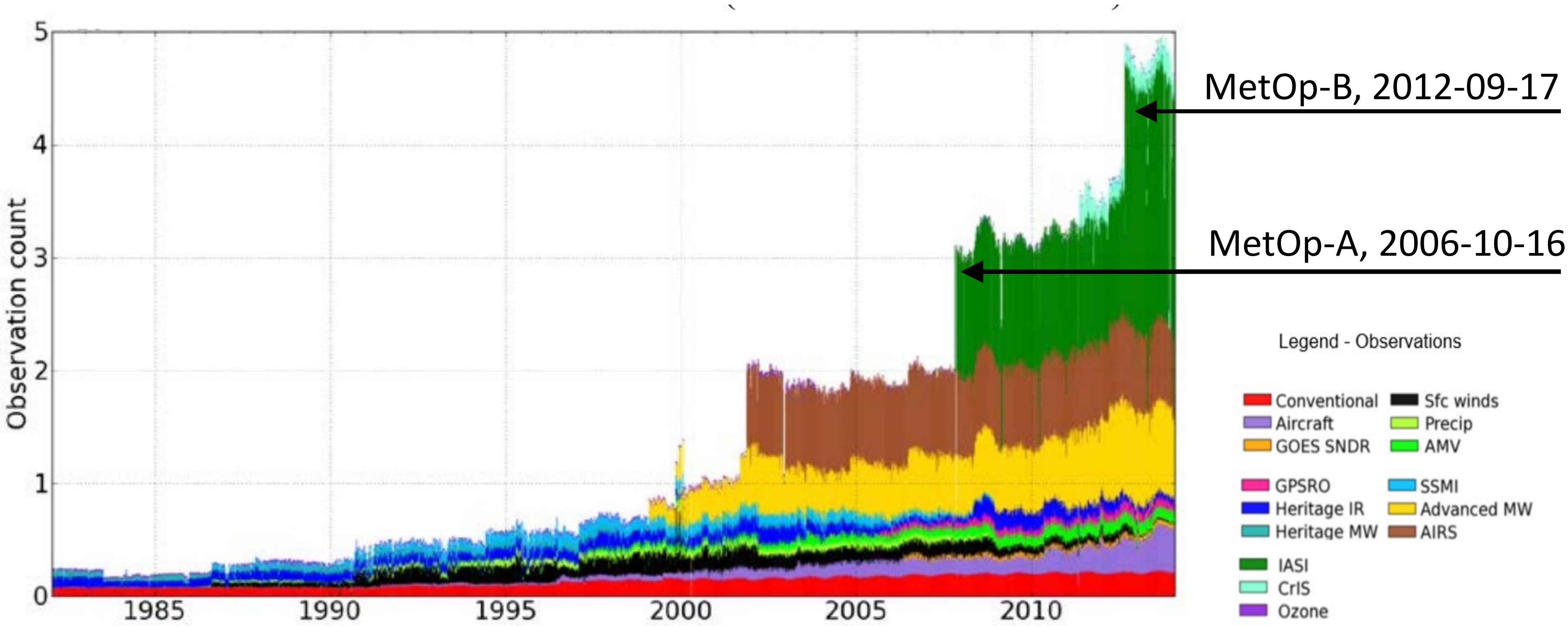
DATA: MICROSCALE:

Time series & statistical data, wind speed and direction
Spatial Resolution: ~250m
Temporal resolution: 1 hour

Typical model scales: ~10 m's

METEO/ONLINE-DATA ***METEO/ONLINE-DATA*** ***MESOSCALE-CALCULATION*** ***SCALER***

1. Introduction - Observations?



Credit:
Observations assimilated in the MERRA2 datasets for the period 01.1980 until 12.2014. Units are millions per 6 hours. From Bosilovich et al: 'MERRA-2: Initial Evaluation of the Climate - Technical Report Serieson Global Modeling and Data Assimilation – Volume 43'

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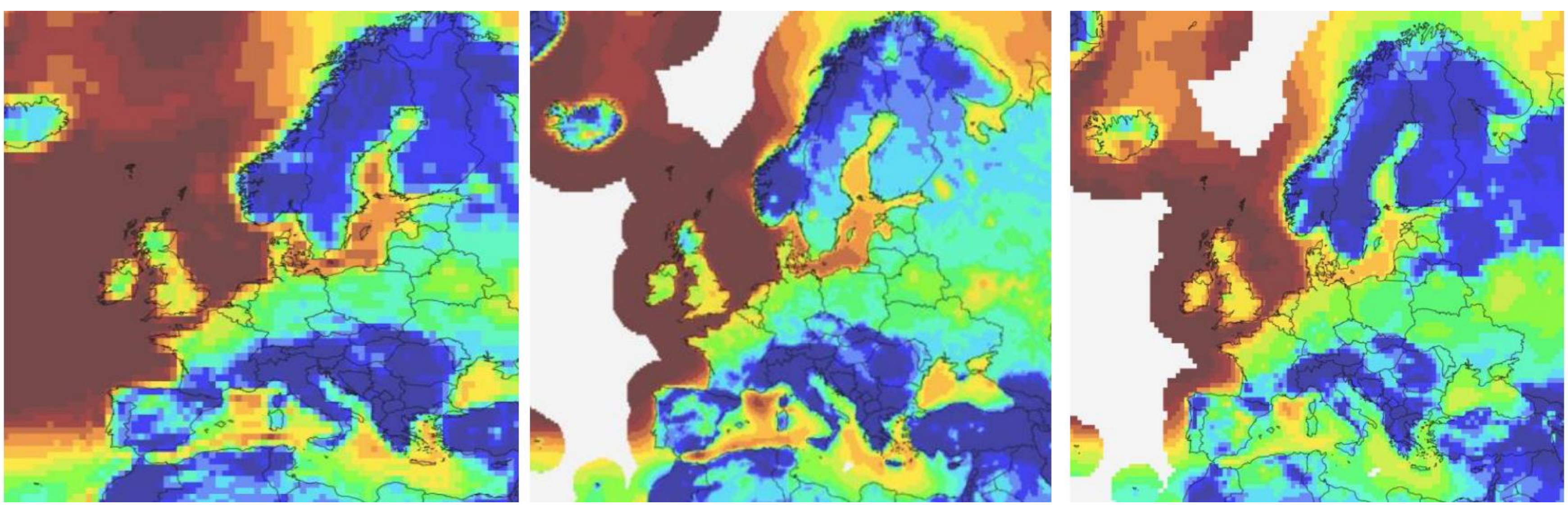

2. Correlations, Trends, Consistency

	Parameter	Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
Hourly	Mean Value		**0.65**	0.54	0.54	0.47
	Standard Deviation		**0.14**	0.17	0.15	0.16
	Minimum		**0.20**	0.10	0.17	0.08
	Maximum		**0.88**	0.81	0.84	0.80
Daily	Parameter	Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
	Mean Value		**0.83**	0.72	0.74	0.72
	Standard Deviation		**0.11**	0.18	0.15	0.14
	Minimum		**0.35**	0.17	0.27	0.18
	Maximum		**0.96**	0.93	0.96	0.93
Monthly	Parameter	Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
	Mean Value		**0.86**	0.78	0.76	0.74
	Standard Deviation		**0.12**	0.22	0.21	0.20
	Minimum		**0.34**	0.03	0.10	0.11
	Maximum		**0.99**	0.98	**0.99**	0.97

Figure 5: Wind Speed Correlation (R^2) at hourly, daily and montly averaging times. Data from 107 masts. Notes: ERA-I is interpolated to hourly values. CFSR/CFSv2 is from EMD CFSR-E dataset (0.5 deg). Green color-boldface color shows best dataset for the metric being considered.

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R^2 correlation – Global (raw) data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency

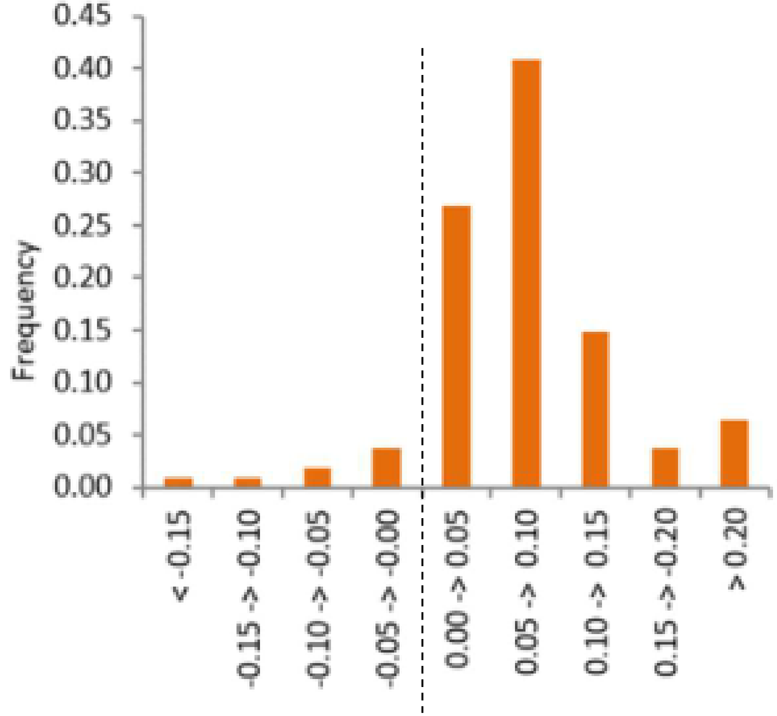

Figure 6: Improvement in correlation, ΔR, ERA5 and MERRA2 vs local masts.

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R correlation – Global (raw) data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency
R^2 – Correlation –windspeed at 107 masts

	Parameter Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
Hourly	Mean Value	**0.67**	0.64	0.61	0.61
	Standard Deviation	**0.12**	**0.12**	0.13	**0.12**
	Minimum	**0.34**	0.32	0.33	0.32
	Maximum	**0.88**	0.84	0.83	0.83
Daily	Parameter Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
	Mean Value	**0.86**	0.83	0.81	0.81
	Standard Deviation	**0.08**	0.09	0.10	0.09
	Minimum	**0.51**	0.49	0.45	0.45
	Maximum	**0.96**	0.95	0.95	0.95
Monthly	Parameter Dataset ->	ERA5	ERA-Interim	MERRA2	CFSR / CFSv2
	Mean Value	**0.89**	0.87	0.86	0.84
	Standard Deviation	**0.12**	0.13	0.14	0.14
	Minimum	0.25	0.27	0.24	**0.28**
	Maximum	**0.99**	**0.99**	**0.99**	**0.99**

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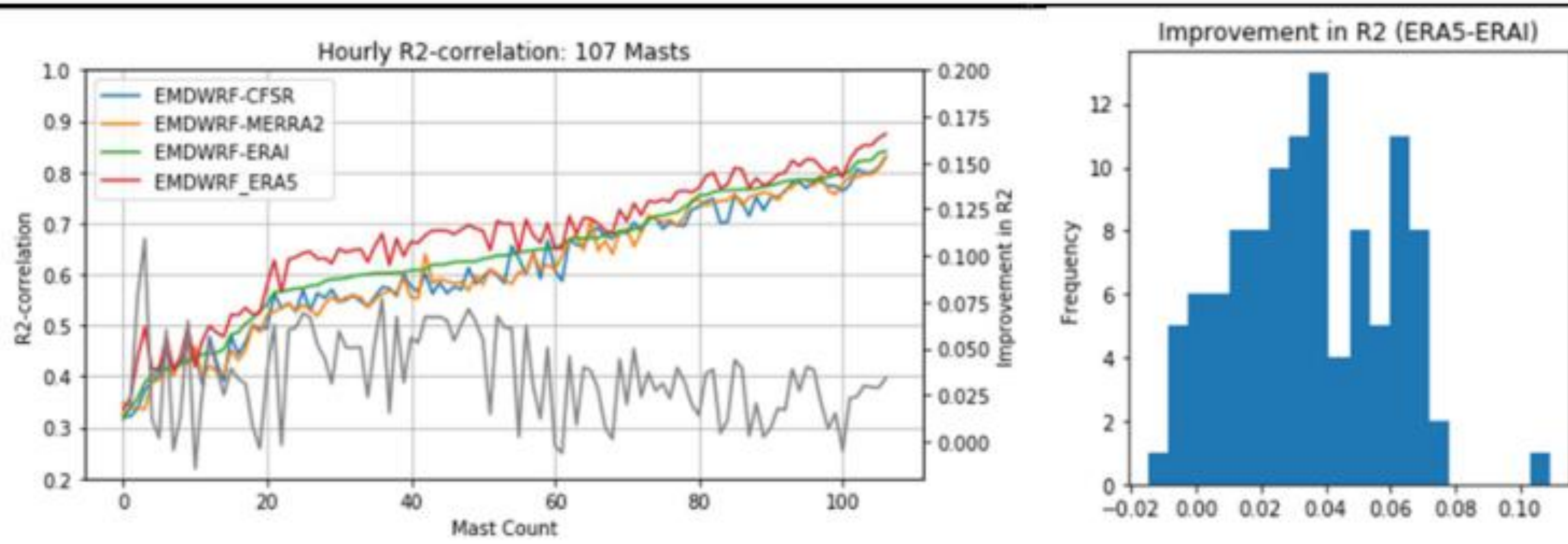
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency
Daily R^2 – Correlation – 107 masts

Hourly



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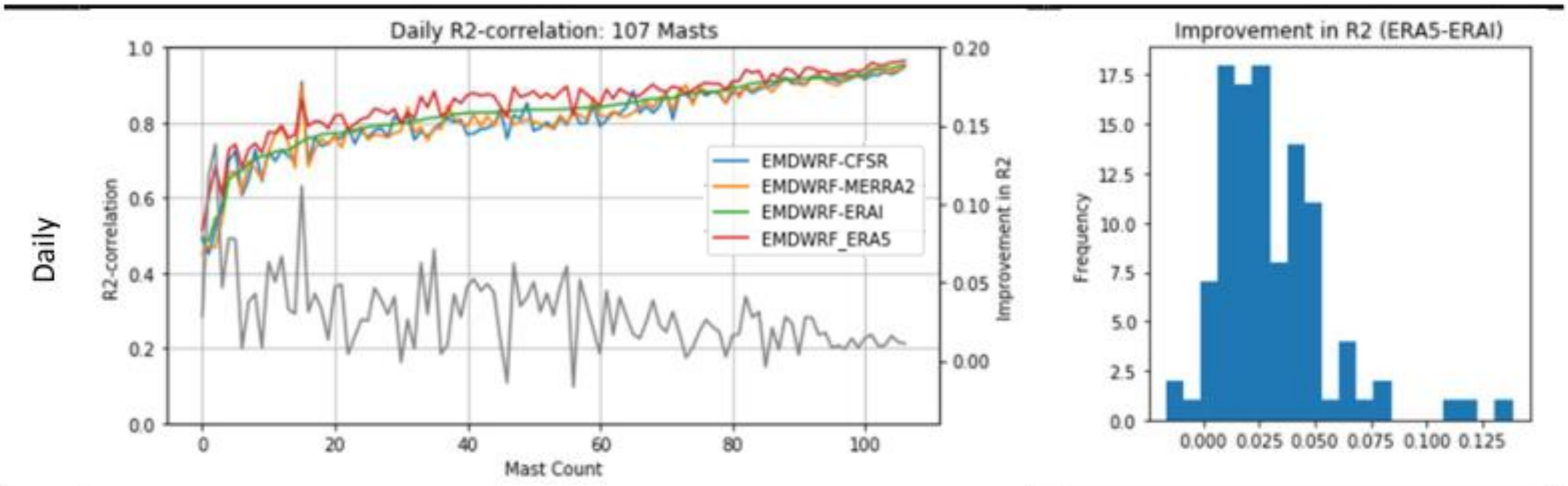
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency
Daily R^2 – Correlation – 107 masts



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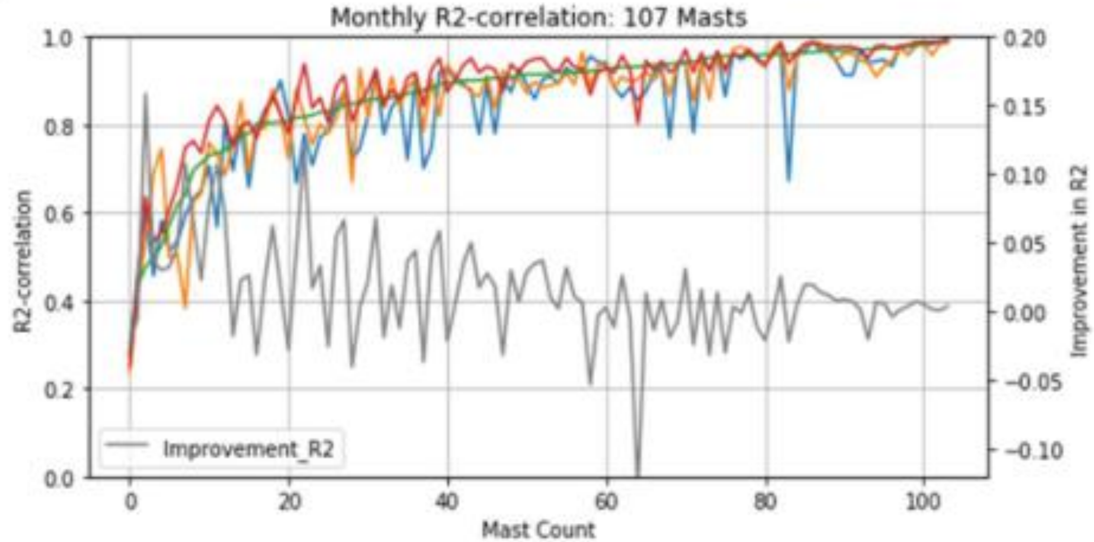
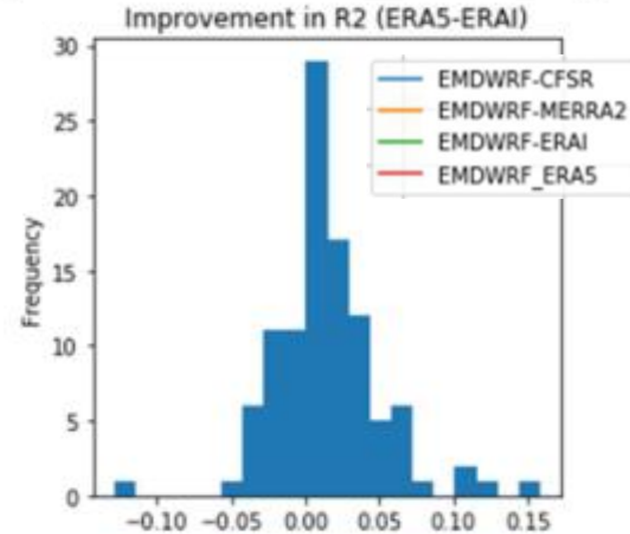
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency
Daily R^2 – Correlation – 107 masts

Monthly





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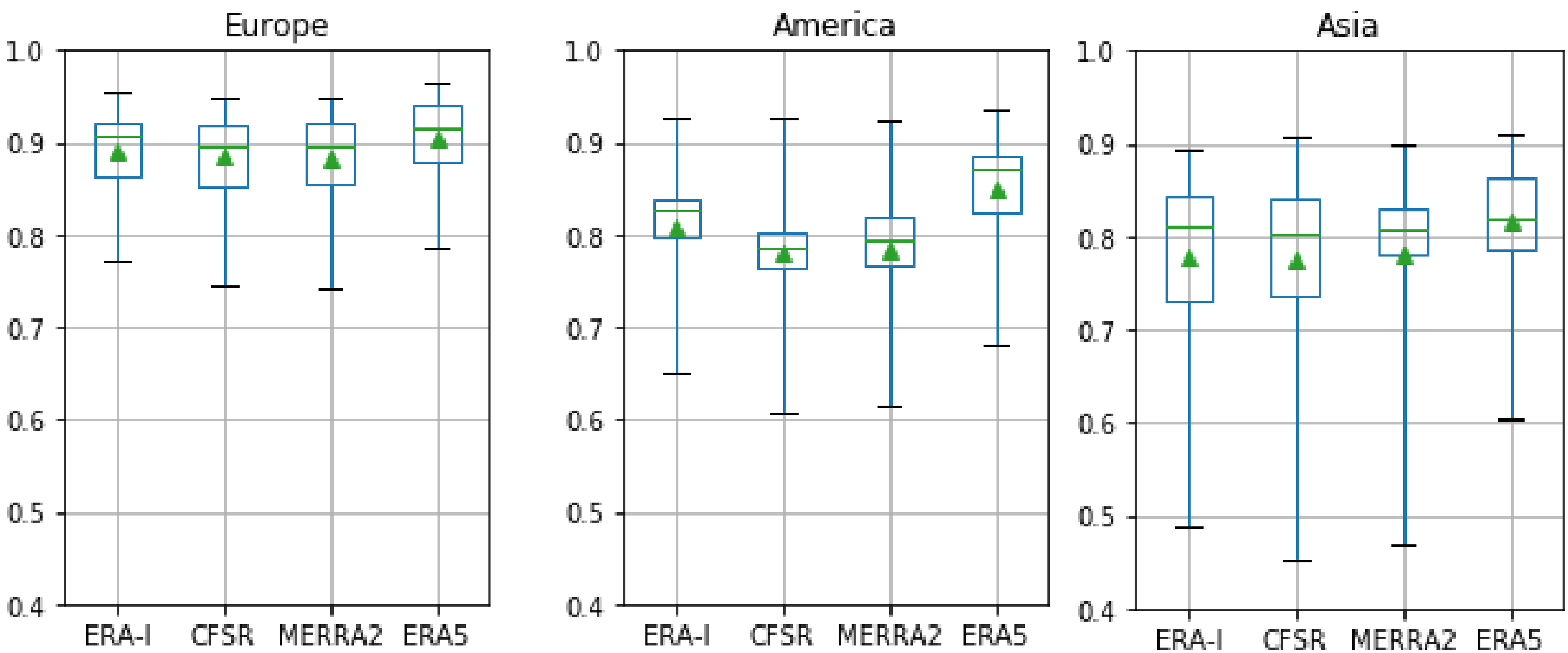
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

2. Correlations, Trends, Consistency Regional Differences



Legend for our box and whiskers plot:
Green triangle = Sample Mean
Green line = Median
Box boundaries = 25% and 75% percentiles
Outer limits = Sample minimum and maximum

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2. Main conclusions!

- **ERA5 as input to WRF - or on its own- is a significant improvement**
  - over previous reanalysis datasets

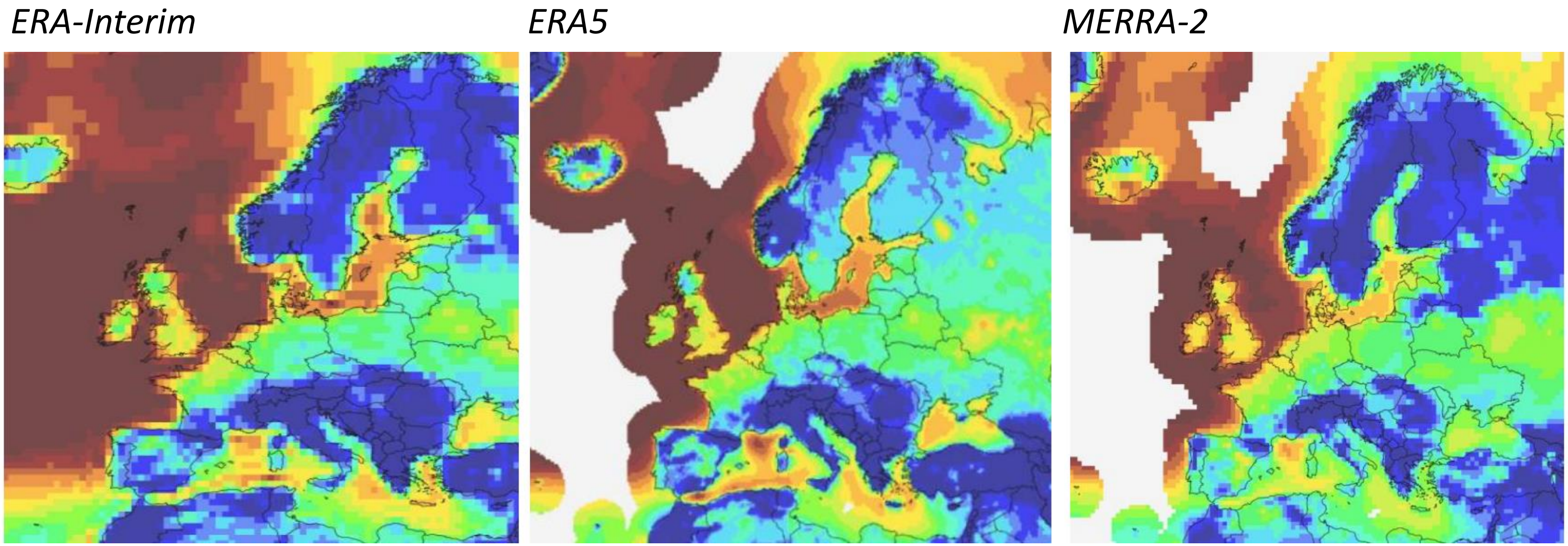
- **The standard deviation / spread is smaller**
  - so the probability of larger errors is smaller when using ERA5

- **Largest improvement found on moderate correlation sites**
  - on sites where moderate correlation is found with previous modelling; these seem to benefit the most from the improved ERA5 dataset

- ~~**ERA-Interim is still the preferred choice for long-term correlation**~~
  ~~- until a longer period of ERA5 data become available (expected Q4-2018)~~

- **ERA-5 is now the preferred choice for long-term correlation**
  - but comparisons to ERA-Interim and MERRA2 should still be done until confidence in 'older' data periods have been established.
  - through WRF or on its own (raw data)

Contents



3. Short Campaigns – A Real Challenge!

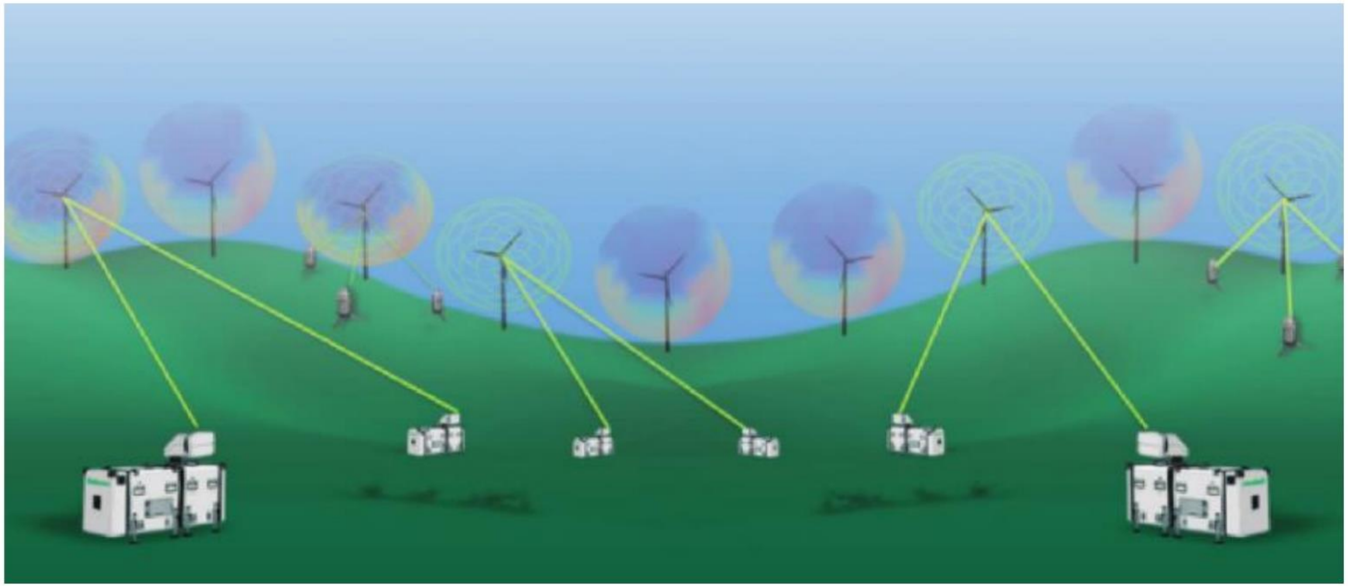


Image credit: DTU Vindenergi/Recast Project.

Funding

Innovation Fund Denmark

Project partners

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DTU Wind Energy
Department of Wind Energy

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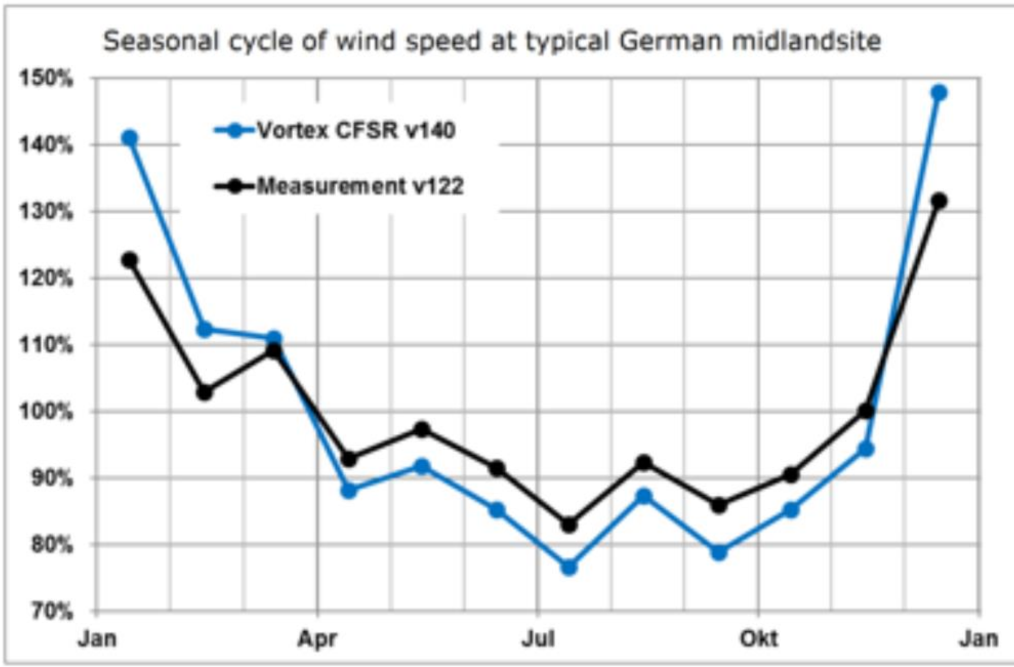
3. Short Campaigns – A Real Challenge!

ERRORS OF LONG-TERM ADJUSTMENT OF SHORT MEASUREMENTS



- **Winter averages (Dec-Jan-Feb):**
  - **Measurement: 120%**
  - **Reanalysis (Vortex CFSR): 135 %**
- **Error for annual mean: -11%**

Over correction !!
Winter: too low
Summer: too high

Image credit: Anselm Grötzner, Cube-Ramboll, WindEurope-2018

3. Short Campaigns – A Real Challenge!

Long-term adjustments leads to different results, depending on:

- **Season(s)** included
- Period analysed / length
- **Reanalysis datasets** used
- **Mesoscale dataset/vendor** used
- **MCP-method** used
  (is seasonality included in equations?)
- Model ability to predict seasonality with confidence
  (without seasonal bias)

3. Short Campaigns – A Real Challenge!

Site in UK – Existing MCP's any good for this use-case?

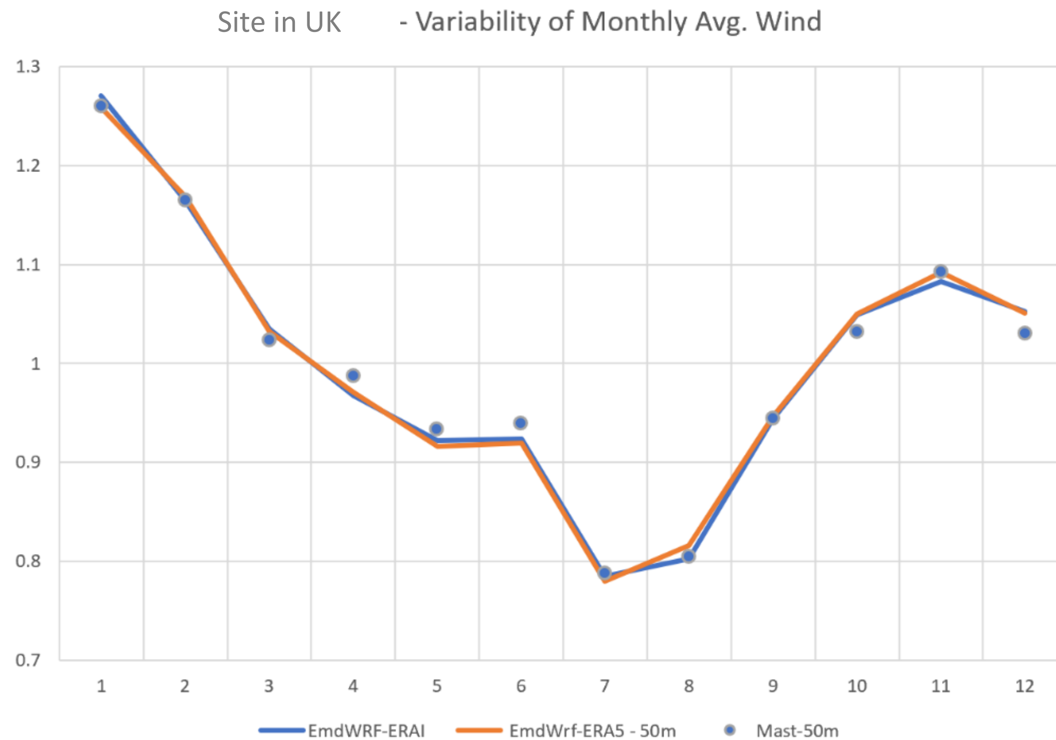
Local data: - 1 long term masts – 5 years
- 6 short term masts – months

Reference data: **- Local mast**
- EMD-WRF OD ERA5
- Merra 2 (raw)

Methods - Temporal extrapolation with 4 MCP-methods
- Horizontal extrapolation with 2 methods (WAsP + WAsP-CFD)

Reference Series: M49 - Local 50m – 5yrs of data

Mast	From	To
M49	2001.09.18	2006.09.18
M50	2001.10.10	2001.12.05
M51	2001.10.10	2001.11.24
M52	2001.12.07	2002.02.09
M53	2001.12.07	2002.02.10
M54	2002.02.10	2002.03.26
M55	2002.02.12	2002.03.26



3. Short Campaigns – A Real Challenge!

Site in UK – Existing MCP's any good?:

Local data: - 1 long term masts – 5 years
- 6 short term masts – months

Reference data: **- Local mast**
- EMD-WRF OD ERA5
- Merra 2 (raw)

Methods - Temporal extrapolation with 4 MCP-methods
- Horizontal extrapolation with 2 methods (WAsP + WAsP-CFD)

Reference Series: M49 - Local 50m – 5yrs of data

			LTC - Modelled						Calculated with M49		Delta (MCP-WAsP)	
Mast	**From**	**To**	**Regression**	**Matrix**	**Neural**	**Scaling**	**Mean**	**StdDev**	**WAsP**	**WAsP-CFD**	**WAsP**	**WAsP-CFD**
M49	2001.09.18	2006.09.18	8.33	8.33	8.33	8.33	8.33	0.00	8.26	8.25	-	-
M50	2001.10.10	2001.12.05	7.51	7.47	7.53	7.54	7.51	0.03	7.61	7.59	-1.3%	-1.0%
M51	2001.10.10	2001.11.24	7.82	7.77	7.83	7.78	7.80	0.03	7.78	7.67	0.2%	1.7%
M52	2001.12.07	2002.02.09	7.87	7.75	7.83	7.83	7.82	0.04	7.70	7.66	1.6%	2.1%
M53	2001.12.07	2002.02.10	8.05	8.02	8.06	8.03	8.04	0.02	7.99	7.95	0.6%	1.1%
M54	2002.02.10	2002.03.26	7.73	7.65	7.68	7.56	7.65	0.06	7.74	7.71	-1.1%	-0.8%
M55	2002.02.12	2002.03.26	8.03	7.97	7.97	8.05	8.00	0.04	7.86	7.85	1.8%	2.0%
										Minimum	-1.3%	-1.0%
										Maximum	1.8%	2.1%

3. Short Campaigns – A Real Challenge!

Site in UK – Existing MCP's any good?:

Local data: - 1 long term masts – 5 years
- 6 short term masts – months

Reference data: - Local mast
- **EMD-WRF OD ERA5**
- Merra 2 (raw)

Methods - Temporal extrapolation with 4 MCP-methods
- Horizontal extrapolation with 2 methods (WAsP + WAsP-CFD)

Reference Series: EMD-WRF OD – ERA5

			LTC - Modelled						Calculated with M49		Delta (MCP-WAsP)	
Mast	**From**	**To**	**Regression**	**Matrix**	**Neural**	**Scaling**	**Mean**	**StdDev**	**WAsP**	**WAsP-CFD**	**WAsP**	**WAsP-CFD**
M49	2001.09.18	2006.09.18	8.42	8.42	8.36	8.43	8.41	0.03	8.26	8.25	1.8%	1.9%
M50	2001.10.10	2001.12.05	7.46	7.53	7.42	7.57	7.50	0.06	7.61	7.59	-1.5%	-1.2%
M51	2001.10.10	2001.11.24	7.72	7.69	7.71	7.75	7.72	0.02	7.78	7.67	-0.8%	0.6%
M52	2001.12.07	2002.02.09	8.00	7.76	8.00	7.97	7.93	0.10	7.70	7.66	3.0%	3.5%
M53	2001.12.07	2002.02.10	8.16	7.97	7.98	8.16	8.06	0.09	7.99	7.95	0.9%	1.4%
M54	2002.02.10	2002.03.26	7.47	7.55	7.59	7.82	7.61	0.13	7.74	7.71	-1.7%	-1.4%
M55	2002.02.12	2002.03.26	8.20	7.97	8.12	8.38	8.17	0.15	7.86	7.85	3.9%	4.1%
										Minimum	-1.7%	-1.4%
										Maximum	3.9%	4.1%

3. Short Campaigns – A Real Challenge!

Site in UK – Existing MCP's any good?:

Local data: - 1 long term masts – 5 years
- 6 short term masts – months

Reference data: - Local mast
- EMD-WRF OD ERA5
- **Merra 2 (raw)**

Methods - Temporal extrapolation with 4 MCP-methods
- Horizontal extrapolation with 2 methods (WAsP + WAsP-CFD)

Reference Series: MERRA2 (RAW)

			LTC - Modelled						Calculated with M49		Delta (MCP-WAsP)	
Mast	**From**	**To**	**Regression**	**Matrix**	**Neural**	**Scaling**	**Mean**	**StdDev**	**WAsP**	**WAsP-CFD**	**WAsP**	**WAsP-CFD**
M49	2001.09.18	2006.09.18	8.38	8.44	8.40	8.43	8.41	0.02	8.26	8.25	1.9%	2.0%
M50	2001.10.10	2001.12.05	7.63	7.77	7.55	7.79	7.69	0.10	7.61	7.59	1.0%	1.3%
M51	2001.10.10	2001.11.24	7.90	7.93	7.93	7.98	7.94	0.03	7.78	7.67	2.0%	3.5%
M52	2001.12.07	2002.02.09	7.77	7.80	7.60	7.84	7.75	0.09	7.70	7.66	0.7%	1.2%
M53	2001.12.07	2002.02.10	7.91	8.03	7.87	8.02	7.96	0.07	7.99	7.95	-0.4%	0.1%
M54	2002.02.10	2002.03.26	7.24	7.30	7.23	7.37	7.28	0.05	7.74	7.71	-5.9%	-5.5%
M55	2002.02.12	2002.03.26	7.97	7.97	7.97	8.16	8.02	0.08	7.86	7.85	2.0%	2.1%
										Minimum	-5.9%	-5.5%
										Maximum	2.0%	3.5%

3. Short Campaigns – A Real Challenge!

Problem:
If a systematic bias/error occurs at a mast, then we will see a systematic under/over-prediction of the annual yields when doing a short windscanner/recast campaign and long-term correcting using traditional MCP-methods.

Goal:
To make a short study that evaluates the seasonal bias on several masts and using several long-term reference datasets - to see if it is a general issue.

Method:
Compare the *monthly wind speed index* from mesoscale data vs. longer mast measurement periods.
100% index period = dataset concurrent period (dataset itself is used for normalization to index 100).

- Use mast with multiple years.
- Use more mesoscale datasets.

Driven WRF with:
ERA5, ERA-I, CFSR, MERRA2, **NEWA**.

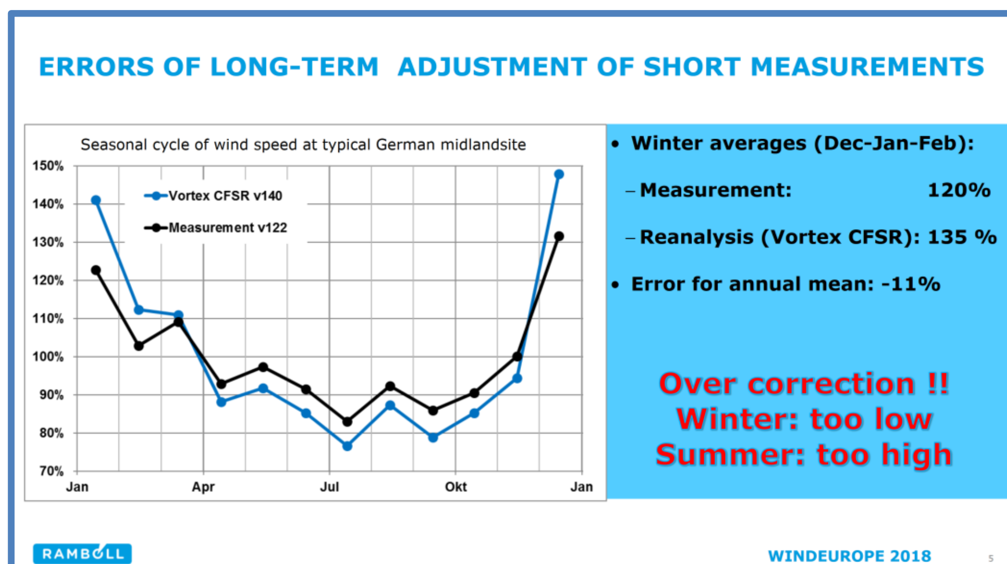
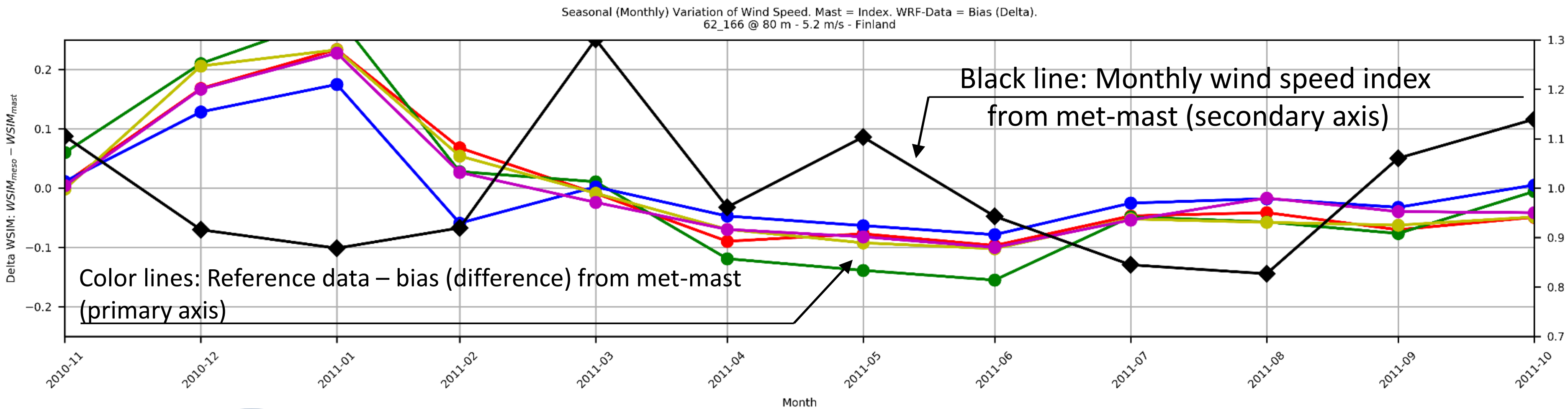
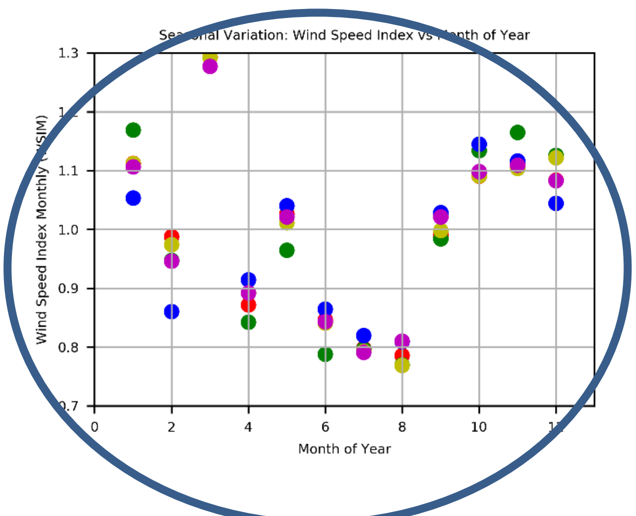


Image credit: Anselm Grötzner, Cube-Ramboll, WindEurope-2018

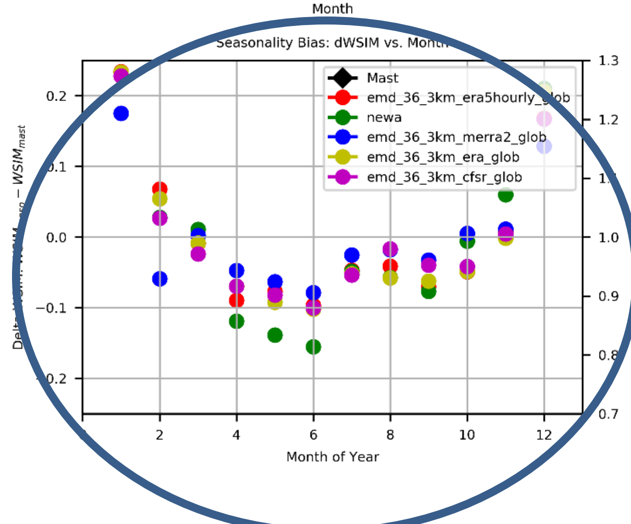
3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~100 tall masts

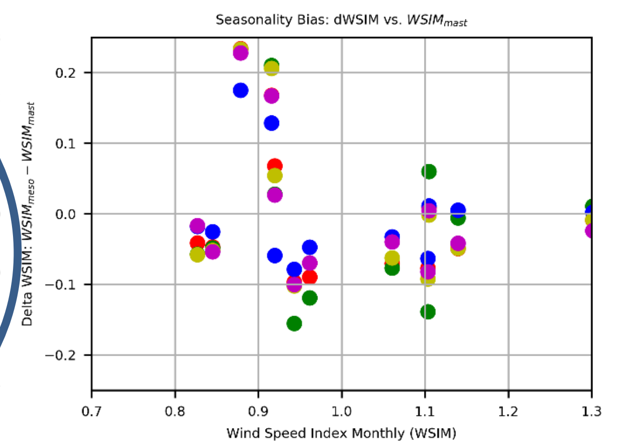




Seasonality



Seasonal bias



3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~100 tall masts

Country	# Masts	# Months	Distinct Seasonal Pattern			Seasonal Prediction Bias		
			Yes	No	%	Yes	No	%
Azerbaijan	1	17	0	1	0%	1	0	100%
Brazil	12	10-36	8	2	80%	9	3	75%
Chile	1	20	1		100%			
China	1	19						
Croatia	1	11						
Denmark	1	28	1		100%	0	1	0%
Egypt	4	11-12	4		100%	0	4	0%
Finland	4	12-24	4		100%	1	3	25%
Germany	1	12	1		100%		1	0%
Ireland	2	11	4		100%	1	3	25%
Netherlands	1	12	1		100%		1	0%
Norway	1	20	1		100%	1		100%
Poland	7	12-31	4	2	67%	1	6	14%
South-Africa	12	13-32	10	1	91%	7	4	64%
Sweden	10	10-39	9		100%		9	0%
Turkey	19	11-24	6	9	40%	8	5	62%
Uruguay	20	13-50	4	16	20%	4	16	20%
TOTAL	**98**		**58**	**31**	**65%**	**33**	**56**	**37%**

Method

1. Establish index period (100%) equal to full period of mast-measurements
2. Calculate wind speed index for mast
3. Calculate wind speed index for mesoscale datasets based on CFSR, ERA5, ERA-Interim and MERRA2
4. Classify seasonality from graphs (based on mast data and concurrent data)
5. Visually classify seasonality bias from graphs

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3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~10 tall masts

Id	Country	Seasonal Bias?
88_230	Denmark	?
90_233	Poland	Small?
397_733	Turkey	Yes
387_703	Turkey	Yes
87_212	Sweden	Small?
386_701	Turkey	Yes
255_505	Croatia	Yes
62_166	Finland	Small?
284_538	Germany	Small?
316_624	Ireland	Small?
119_289	Netherlands	Small?
100_001	Germany	?

3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~10 tall masts

	Parameter Dataset ->	ERA5-RAW	EMD-WRF OD (ERA5)	NEWA
Hourly	Mean value	0.71	**0.75**	0.65
	Coefficient of variation	0.18	0.12	**0.11**
	Minimum	0.49	**0.58**	0.54
	Maximum	**0.88**	**0.88**	0.76
Daily	**Parameter Dataset ->**	**ERA5-RAW**	**EMD-WRF OD (ERA5)**	**NEWA**
	Mean	0.86	**0.90**	0.83
	Coefficient of variation	0.12	**0.06**	0.07
	Minimum	0.64	**0.77**	0.71
	Maximum	0.96	**0.99**	0.90
Monthly	Parameter Dataset ->	ERA5-RAW	EMD-WRF OD (ERA5)	NEWA
	Mean	0.83	**0.88**	0.86
	Coefficient of variation	0.24	0.19	**0.18**
	Minimum	0.34	**0.53**	0.45
	Maximum	**0.99**	**0.99**	**0.99**

Wind Speed Correlation (R2) at hourly, daily and monthly averaging time. Data from 11 masts. Notes: Green color-boldface shows best dataset for the metric being considered. NEWA data by curtesy of the NEWA project – Thanks to Jacob Mann and Bjarke Tobias Olsen, DTU Wind Energy.

3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~10 tall masts

Monthly			EMD-WRF OD Meso Scale				
		ERA5	ERA5	MERRA2	ERA-I	CFSR	NEWA
	Mean	0.83	0.88	**0.90**	0.87	0.86	0.86
	Std.Dev	0.19	0.17	**0.11**	0.18	0.19	0.15
	Minimum	**0.34**	0.53	**0.69**	0.50	0.46	0.45
	Maximum	**0.99**	**0.99**	**0.99**	**0.99**	0.98	**0.99**

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3. Short Campaigns – A Real Challenge!

Analysis of wind-speed seasonality by visual inspection of ~10 tall masts

Id	Country	Seasonal Bias?
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397_733	Turkey	Yes
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87_212	Sweden	Small?
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284_538	Germany	Small?
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100_001	Germany	?

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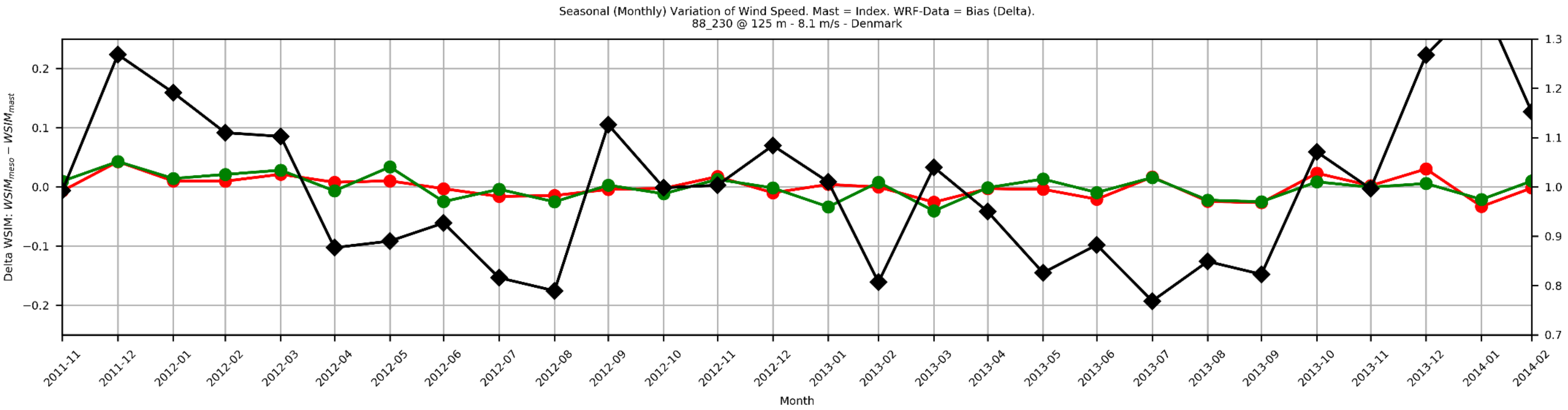
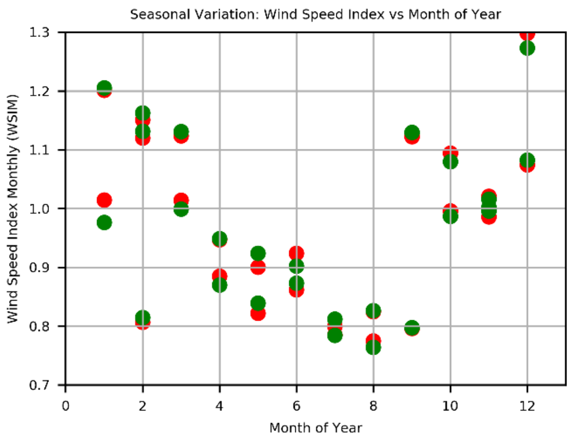
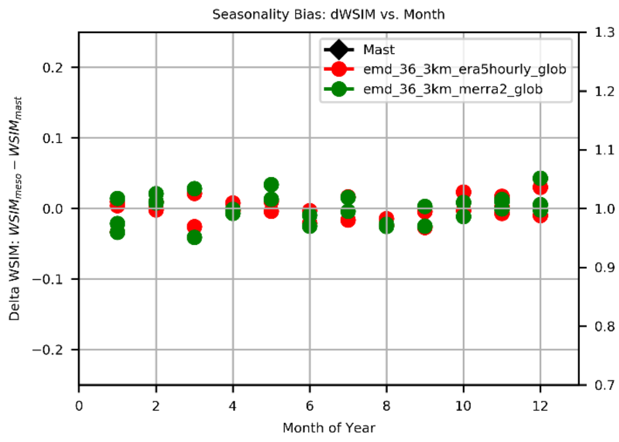
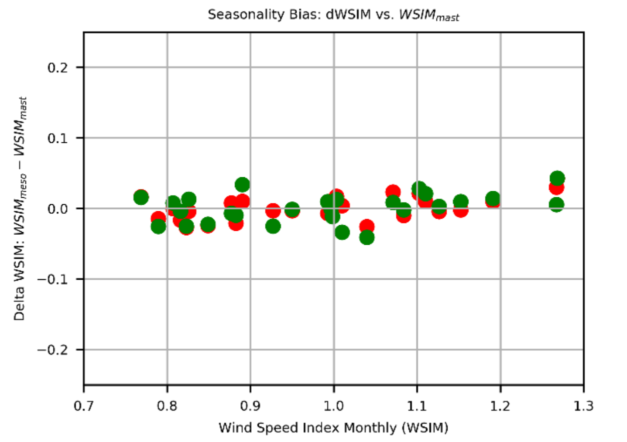
3. Short Campaigns – A Real Challenge! (DK site with no seasonal bias)









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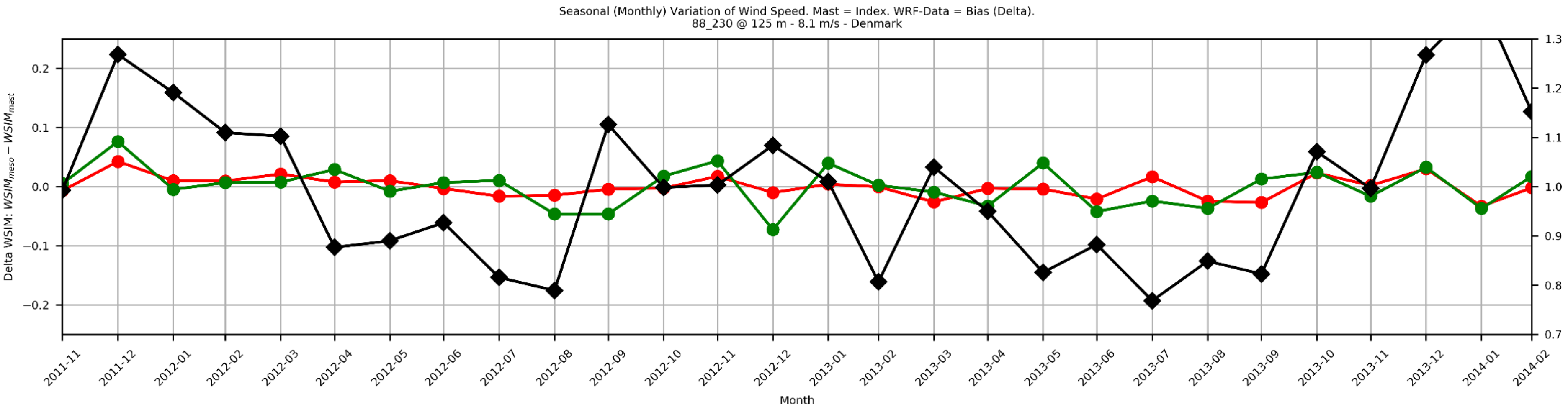
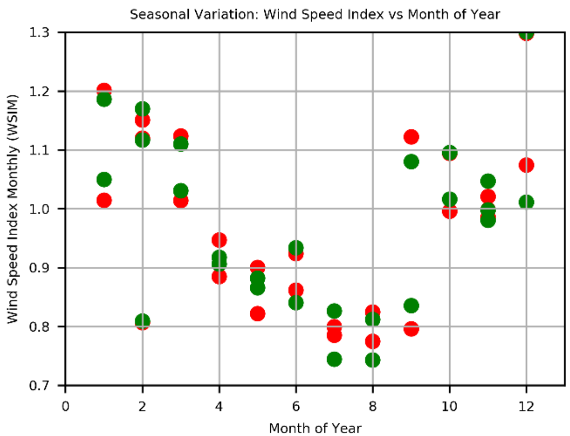
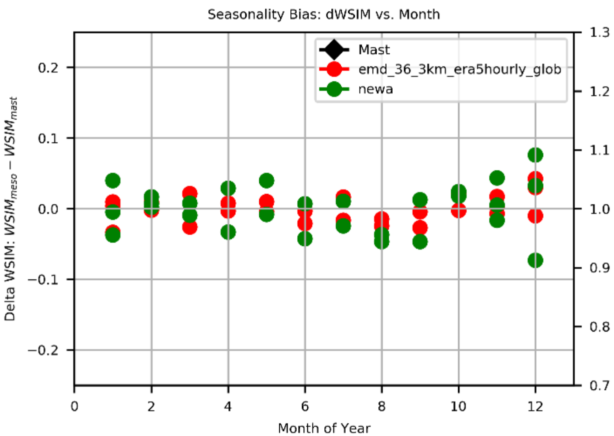
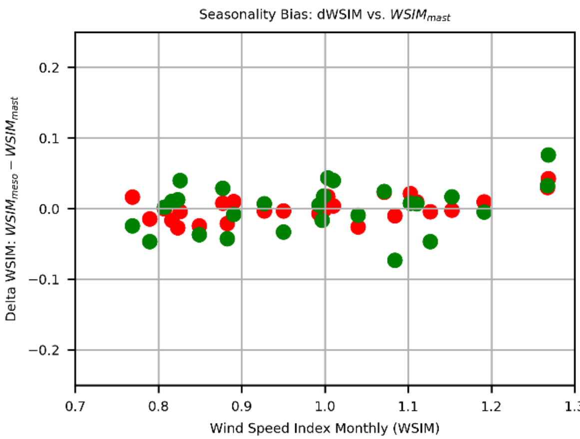
3. Short Campaigns – A Real Challenge! (DK site with no seasonal bias)









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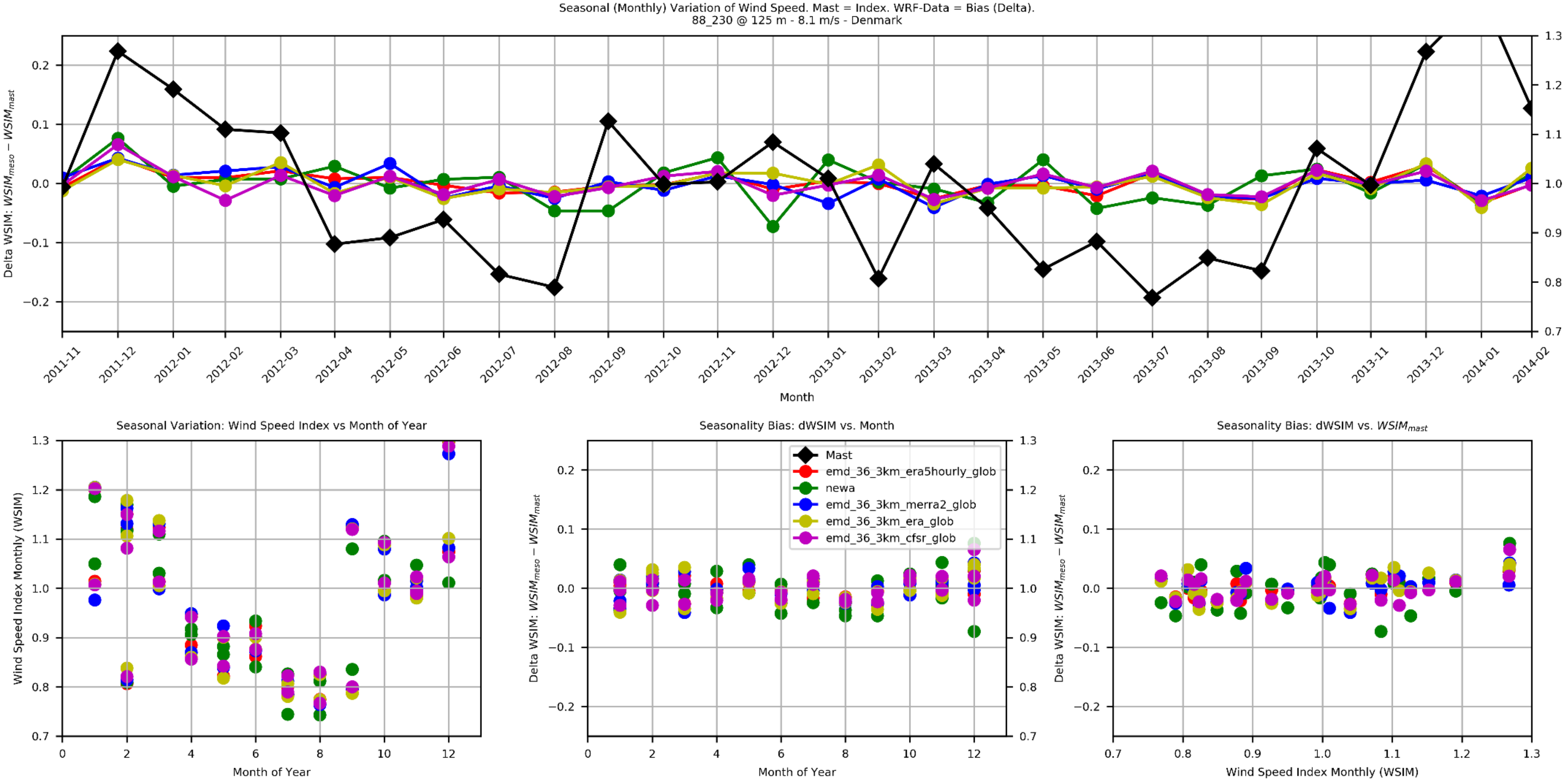
3. Short Campaigns – A Real Challenge! (DK site with no seasonal bias)



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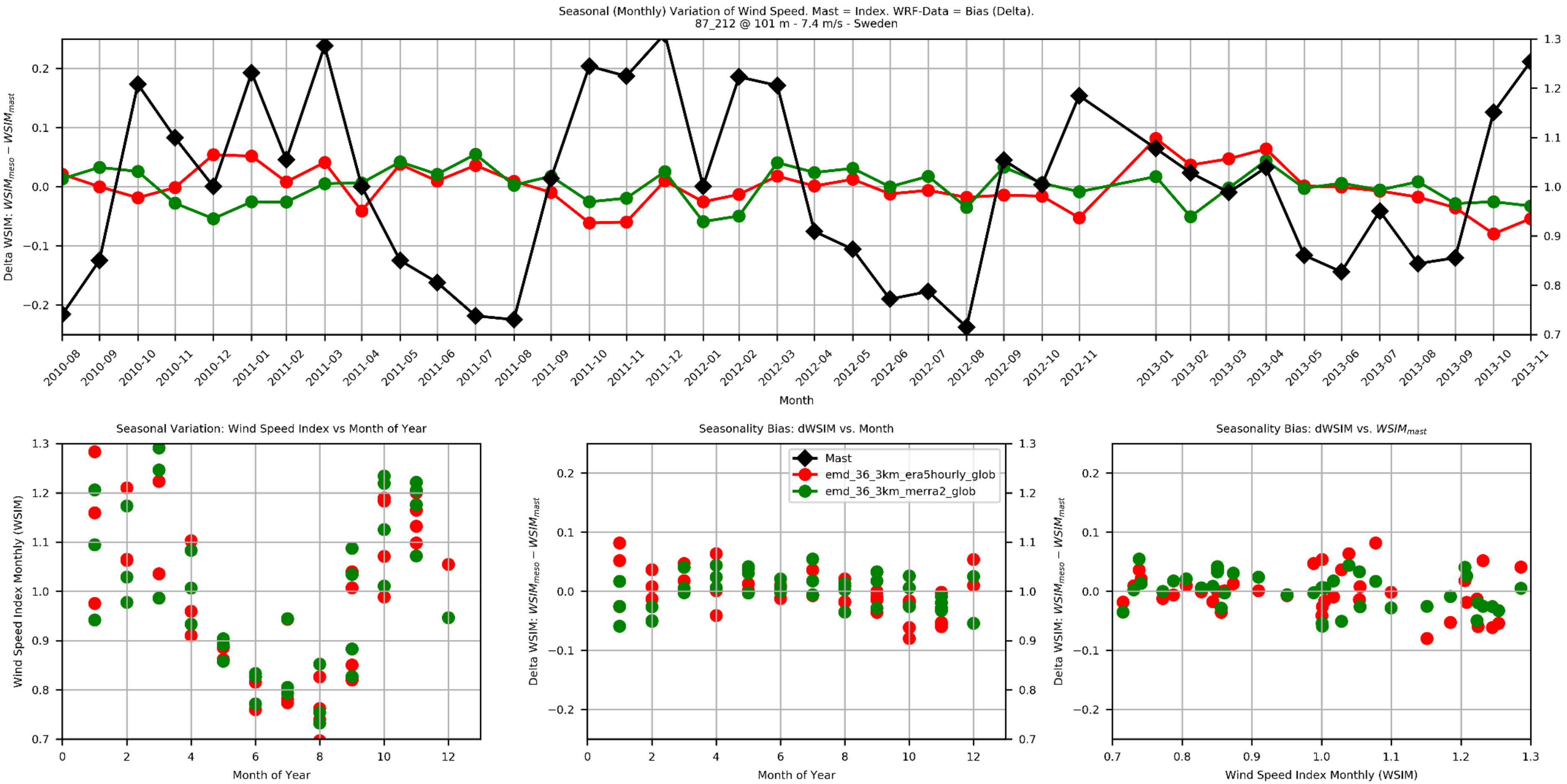
3. Short Campaigns – A Real Challenge! (SE site with some seasonal bias)



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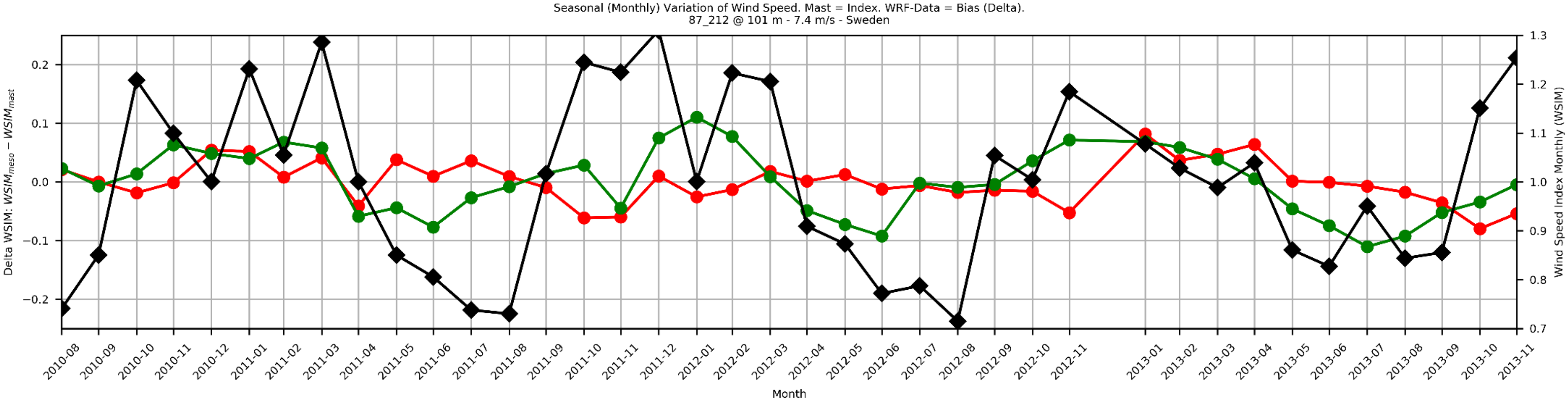

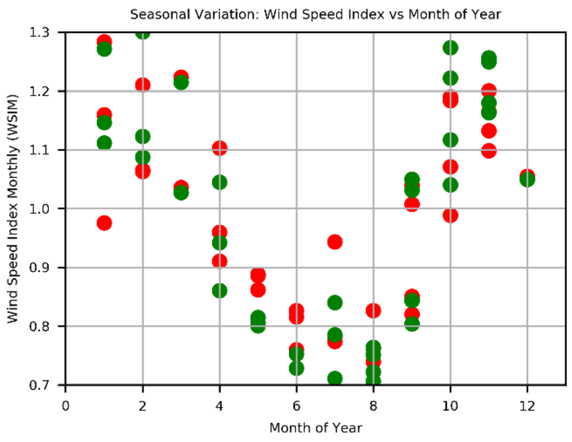

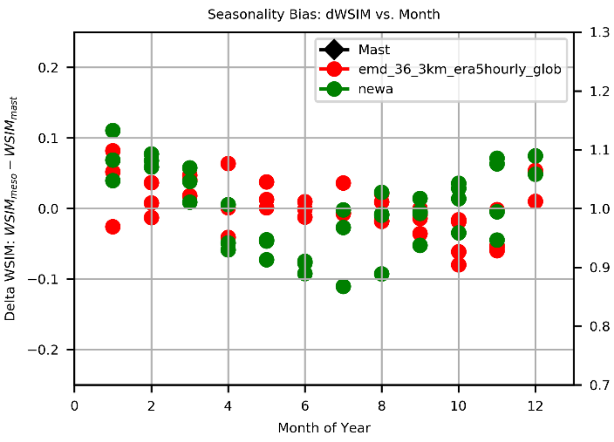

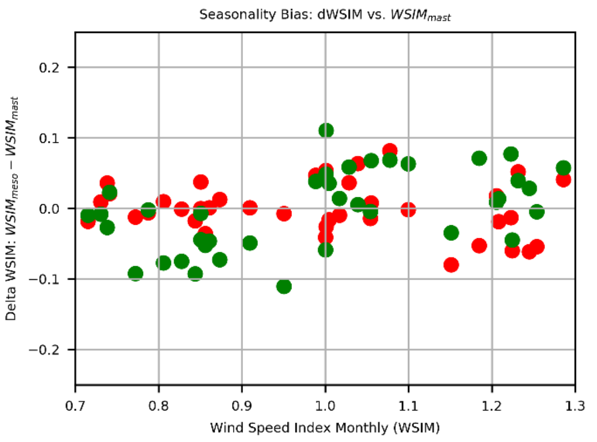

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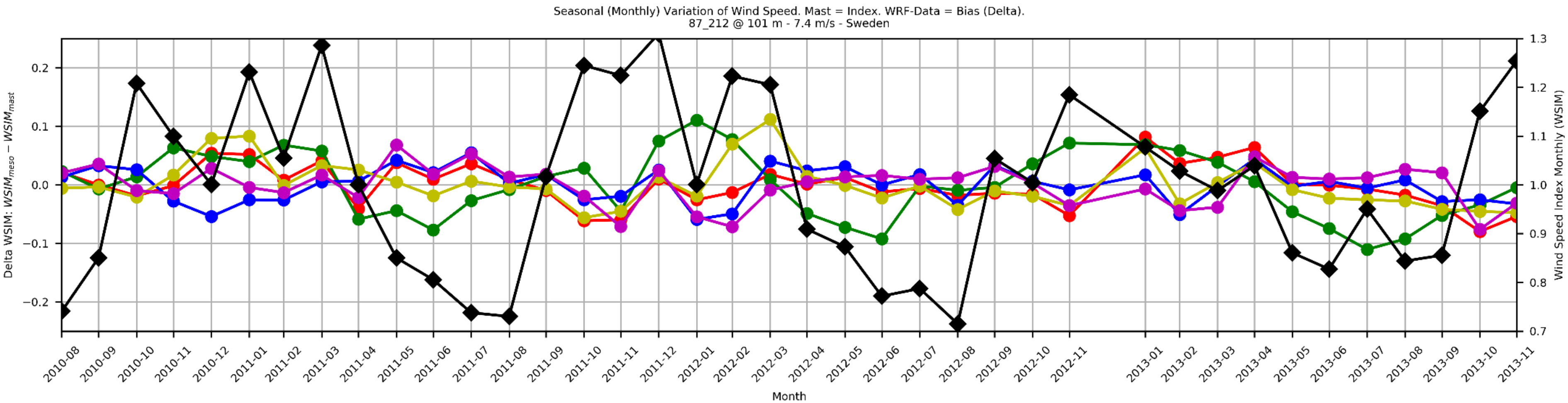
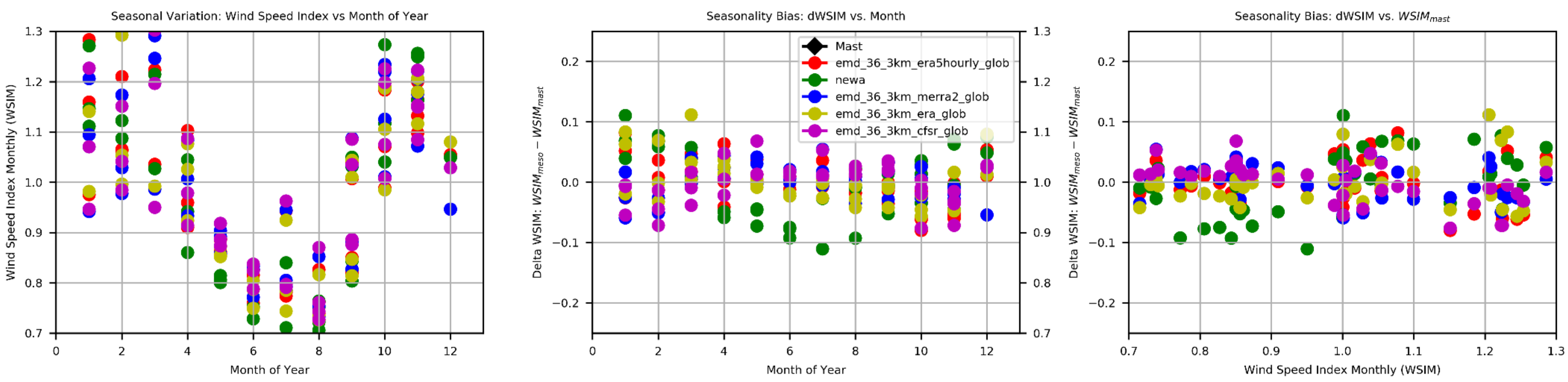
3. Short Campaigns – A Real Challenge! (SE site with some seasonal bias)





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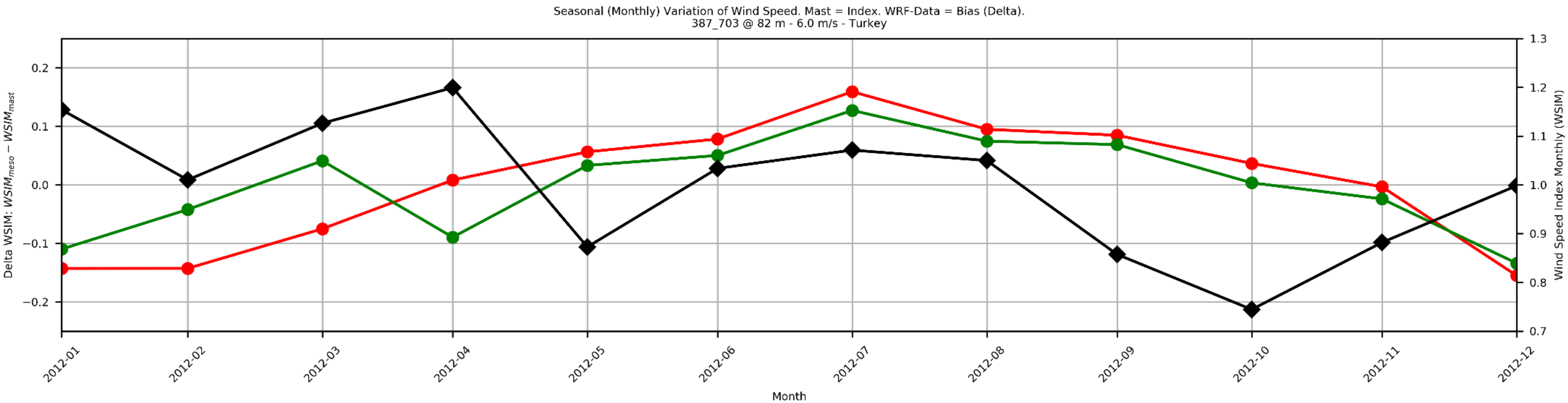
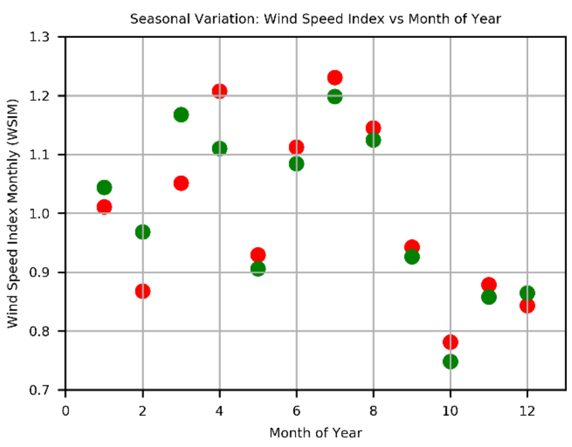
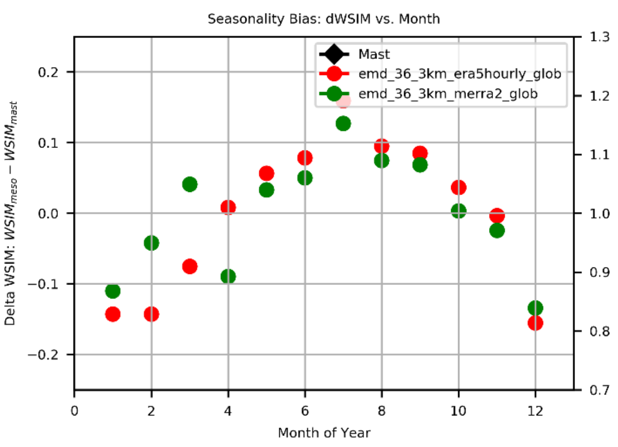
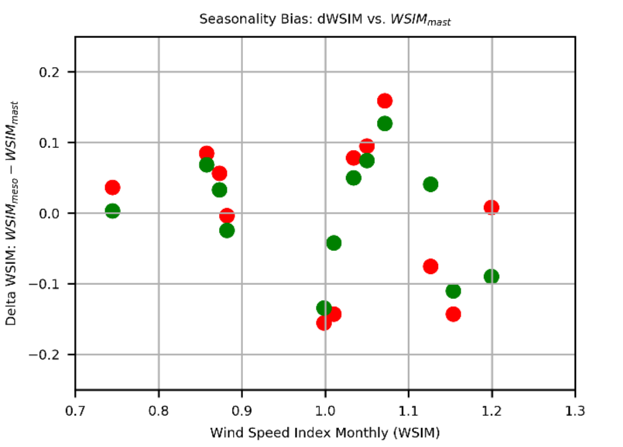
3. Short Campaigns – A Real Challenge! (TK site with some seasonal bias)









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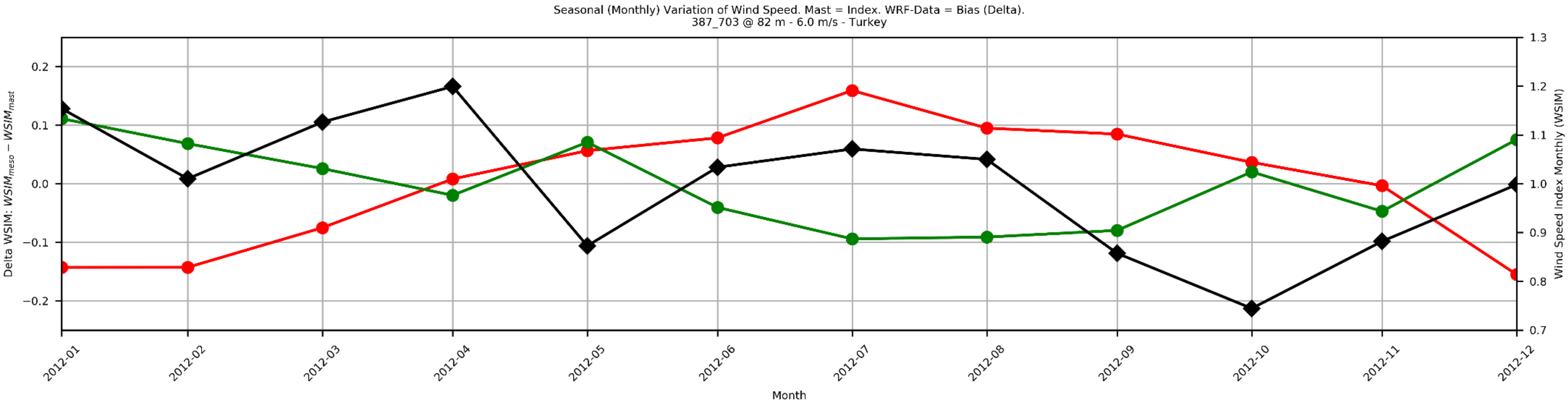
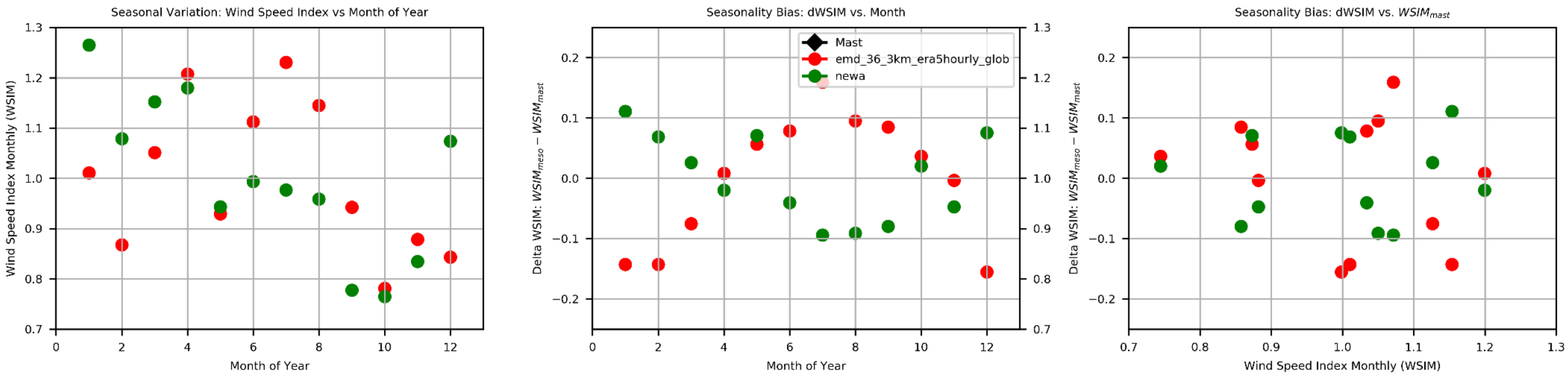
3. Short Campaigns – A Real Challenge! (TK site with some seasonal bias)





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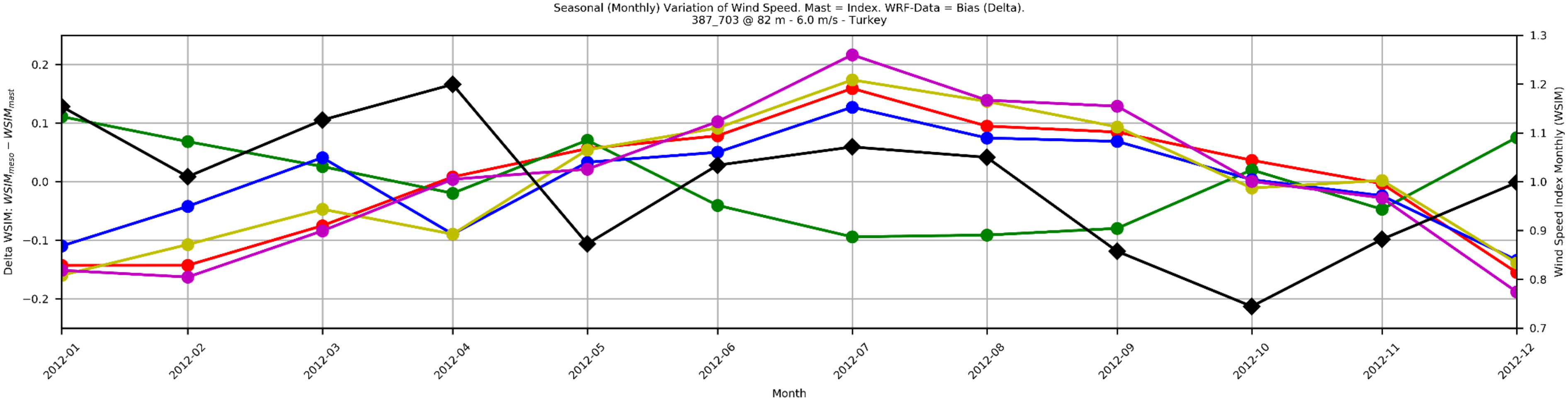

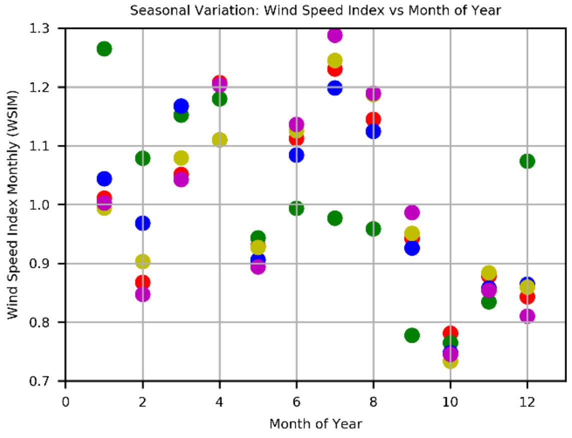

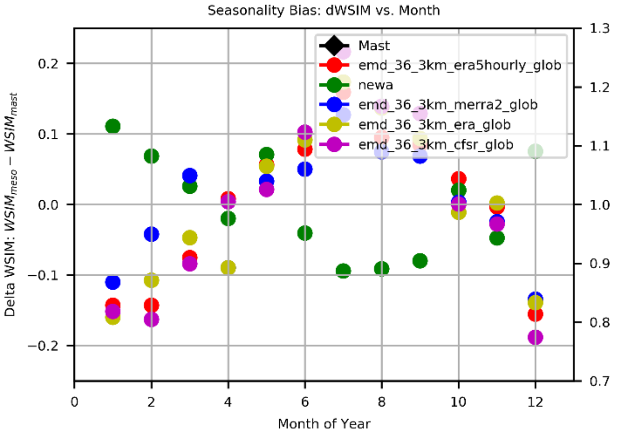

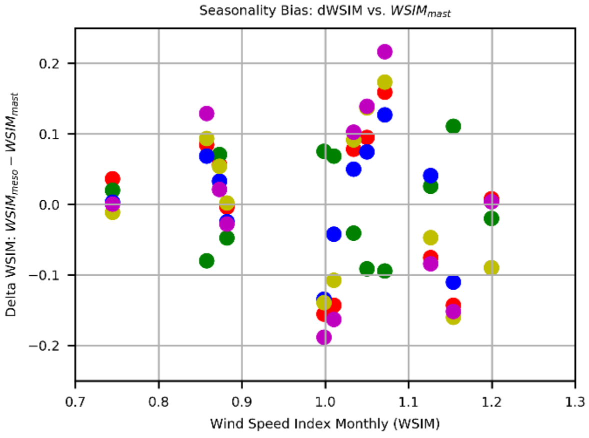

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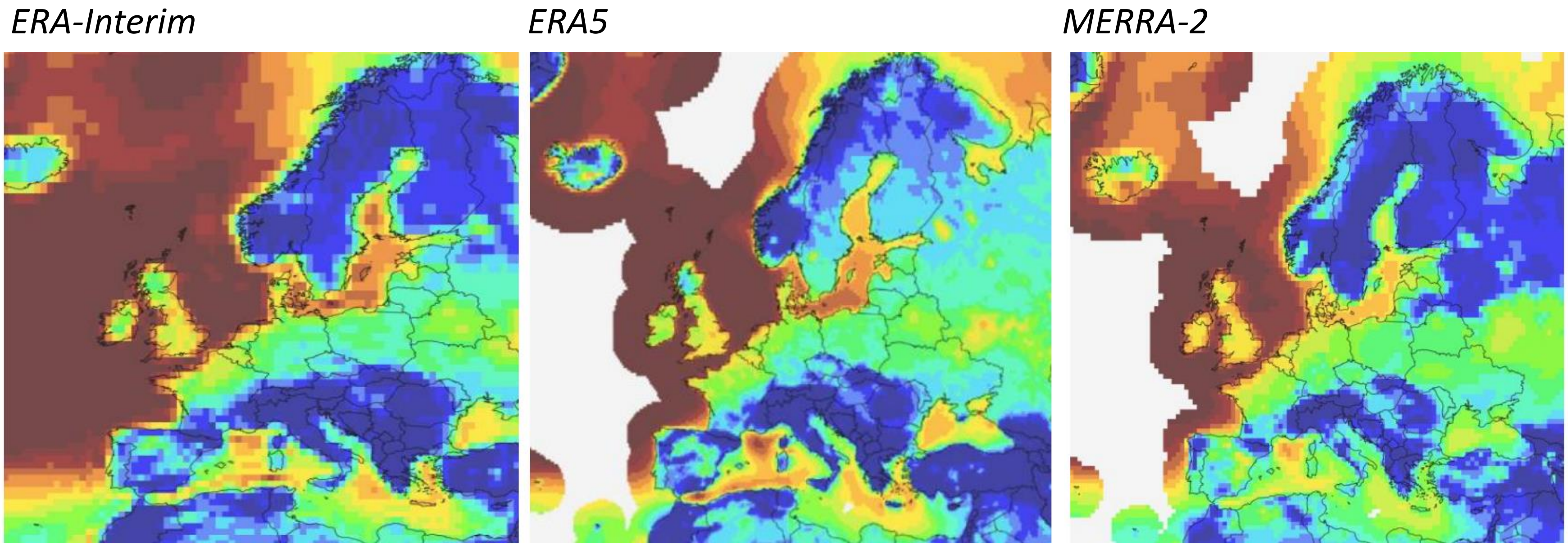

Summary

- Long-term correction using very short measurement periods (months) is a challenge for MCP-methods and long term reference data
- Seasonality should be handled in the MCP-method equations as this is an issue at ~65% of sites analyzed
- Seasonal bias is an issue at a significant number of sites (~40%) – and should be addressed by a correction algorithm
- Work is progressing in the RECAST project
  - identify seasonality and seasonal bias from existing masts
  - correct for bias
  - quantify uncertaintes
  - understand how mesoscale datasets and reanalysis data impact the results

Thank you!

Latest (release) version at:

http://help.emd.dk