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

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EMD International A/S

Vindkraftnet - 2019-05-13 @ EMD International, Aalborg

RECAS
Reduced Assessment Time

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1. Introduction to ERA5 – and comparing to other reanalysis data
2. Correlations, trends and consistency
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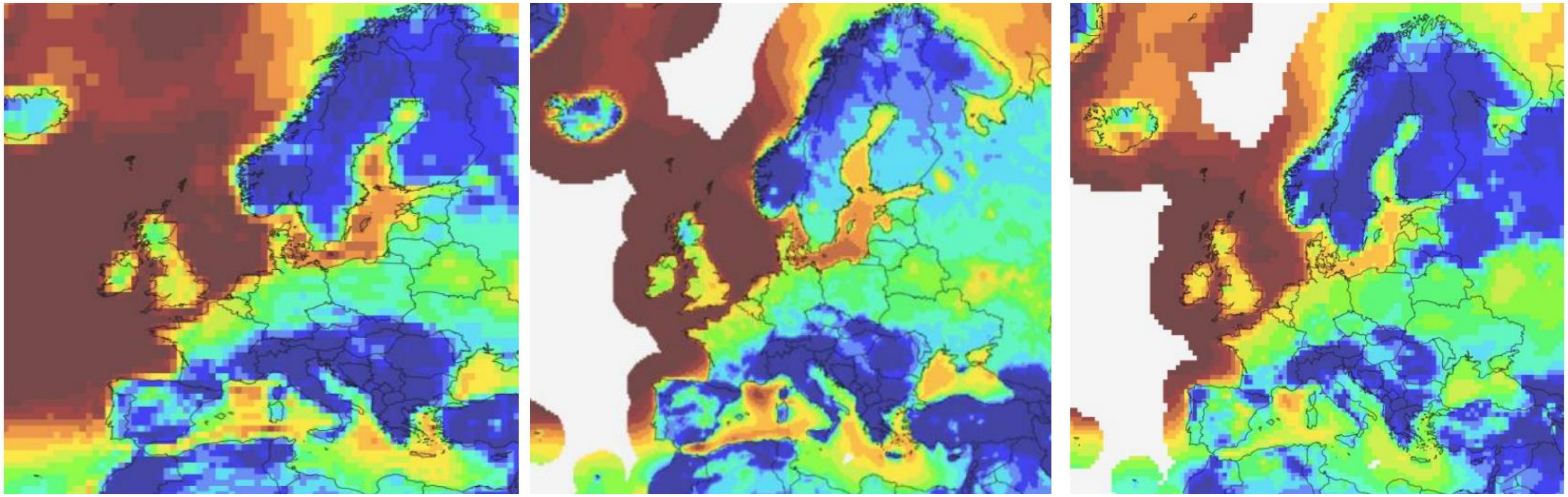
4. Summary

ERA-Interim *ERA5* *MERRA-2*



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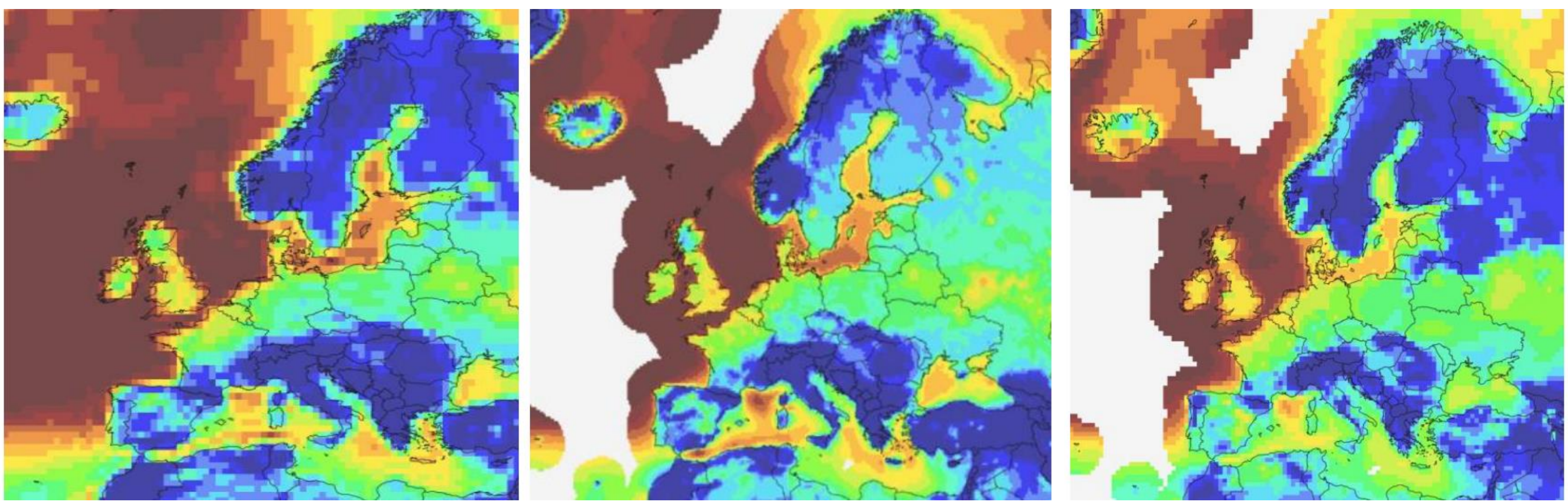


1. Introduction- Overview – ERA5

- 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

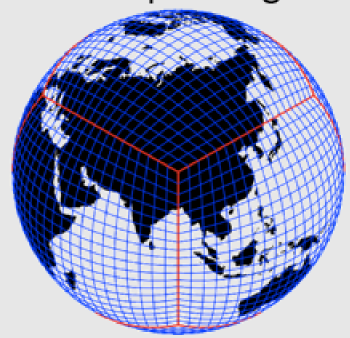
Public release plan @ http://climate.copernicus.eu/products/climate-reanalysis

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

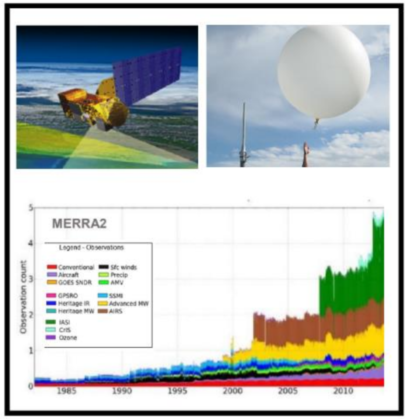
ITEM	MERRA2	MERRA
GEOS data assimilation model version	5.12.4	5.2.0
Observations per 6 hourly analysis cycle	$\sim 5 \cdot 10^6$	$\sim 2 \cdot 10^6$
Grid	Cubed sphere grid 	Regular lat-lon 
Spatial resolution (longitude)	0.625 degrees	2/3 degree
Spatial resolution (latitude)	0.5 degrees	0.5 degree
Period 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

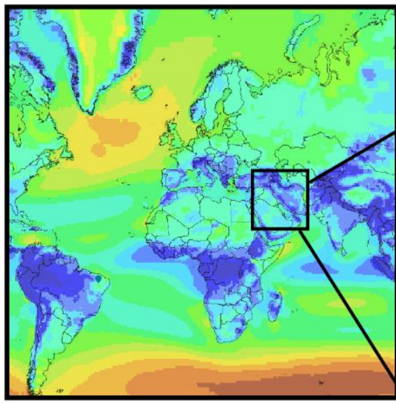
OBSERVATIONS



DATA: IN-SITU AND REMOTE OBSERVATIONS

ERA-5 RAW DATA

DATA ASSIMILATION / REANALYSIS



DATA: GLOBAL / SYNOPTIC SCALE:

Reanalysis Data: ECMWF ERA5
Spatial Resolution: ~35km

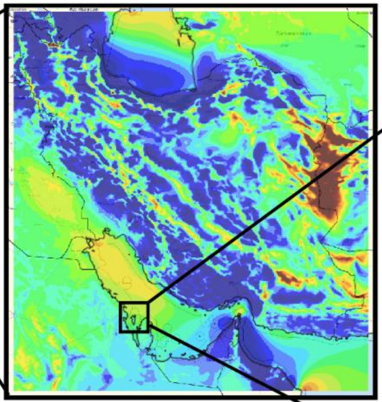
Typical model scales: ~100 km's
Time-series data, 1 hourly resolution

EMD-WRF OD

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

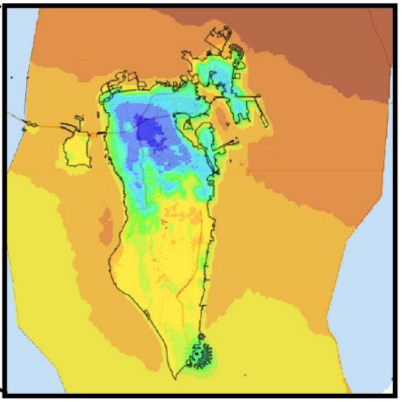
Typical model scales: ~10 km's

DOWNSCALING

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+



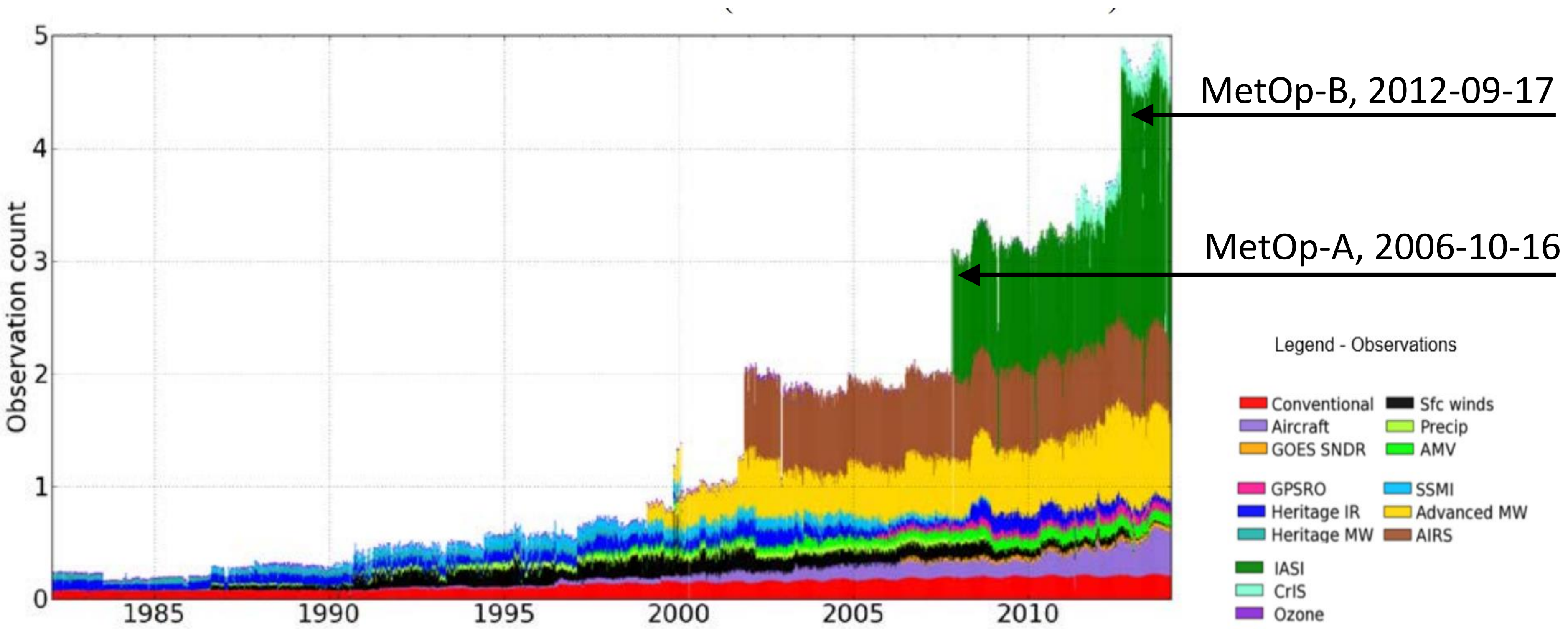
DATA: MICROSCALE:

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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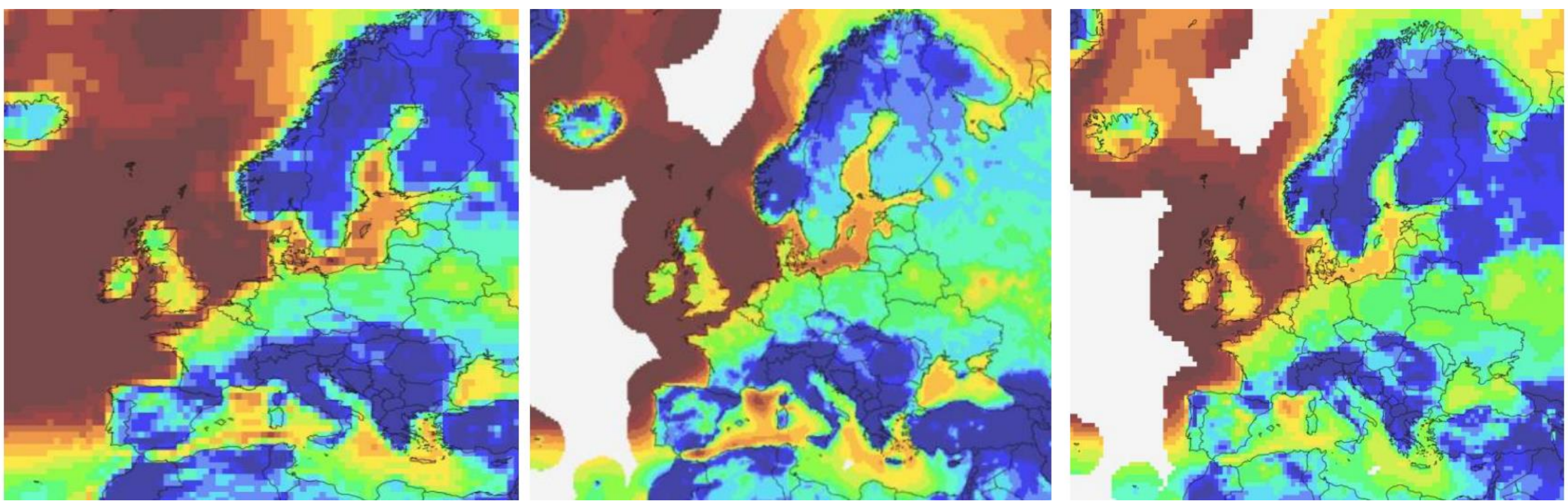

2. Correlations, Trends, Consistency

	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

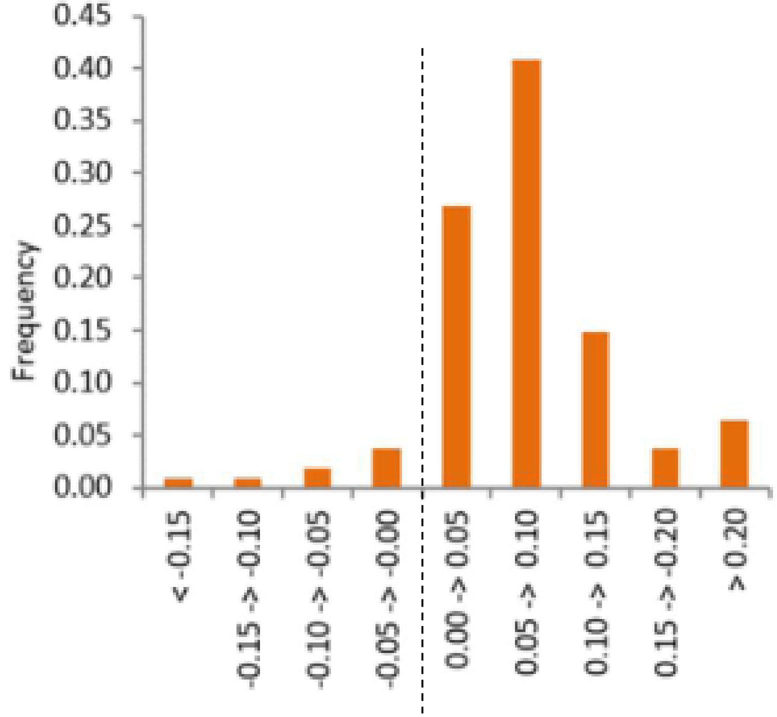

Figure 6: Improvement in correlation, ΔR, ERA5 and MERRA2 vs local masts.

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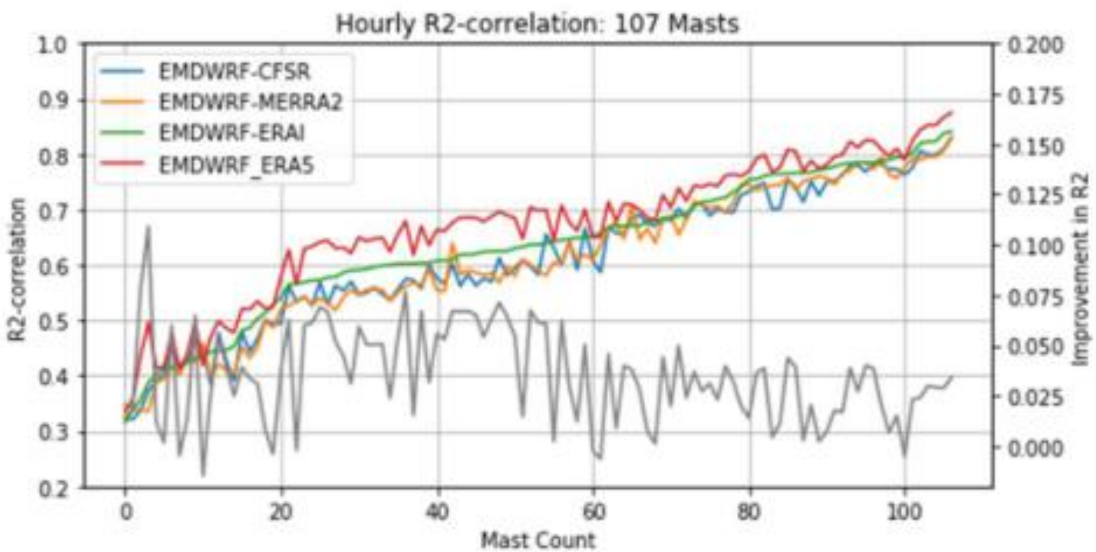
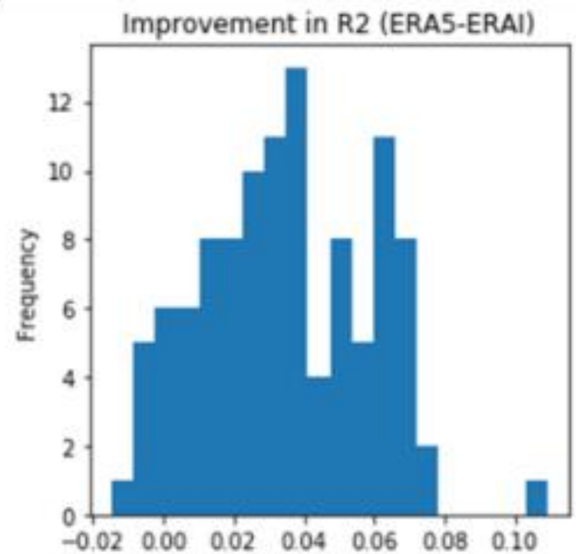
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

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

Hourly





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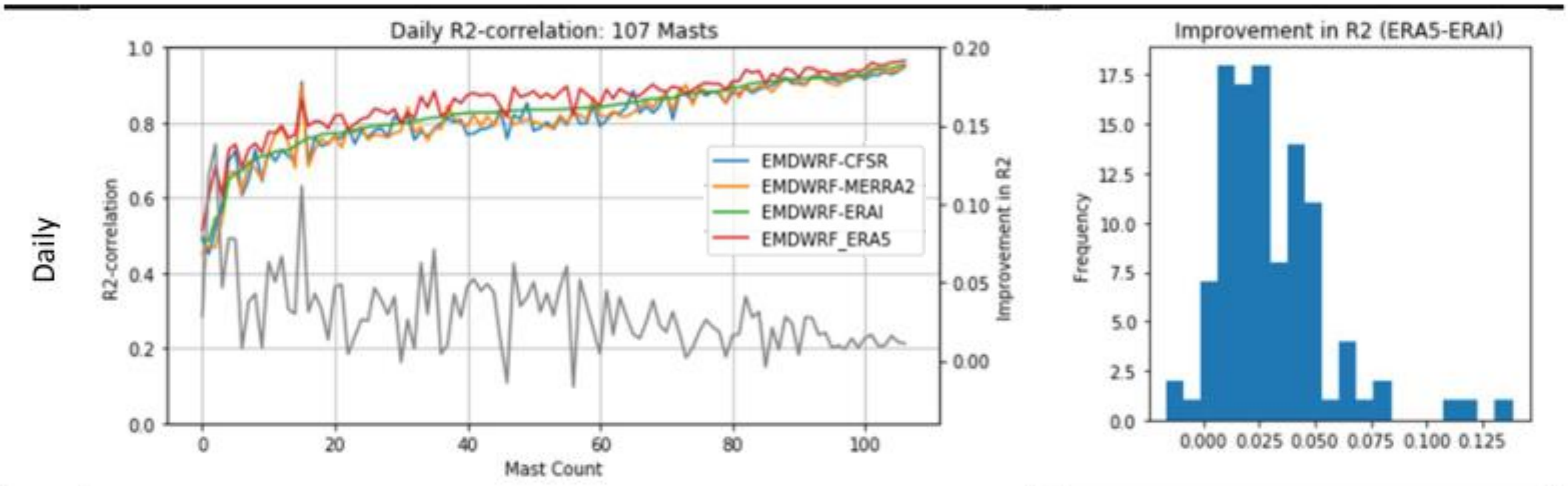
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

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



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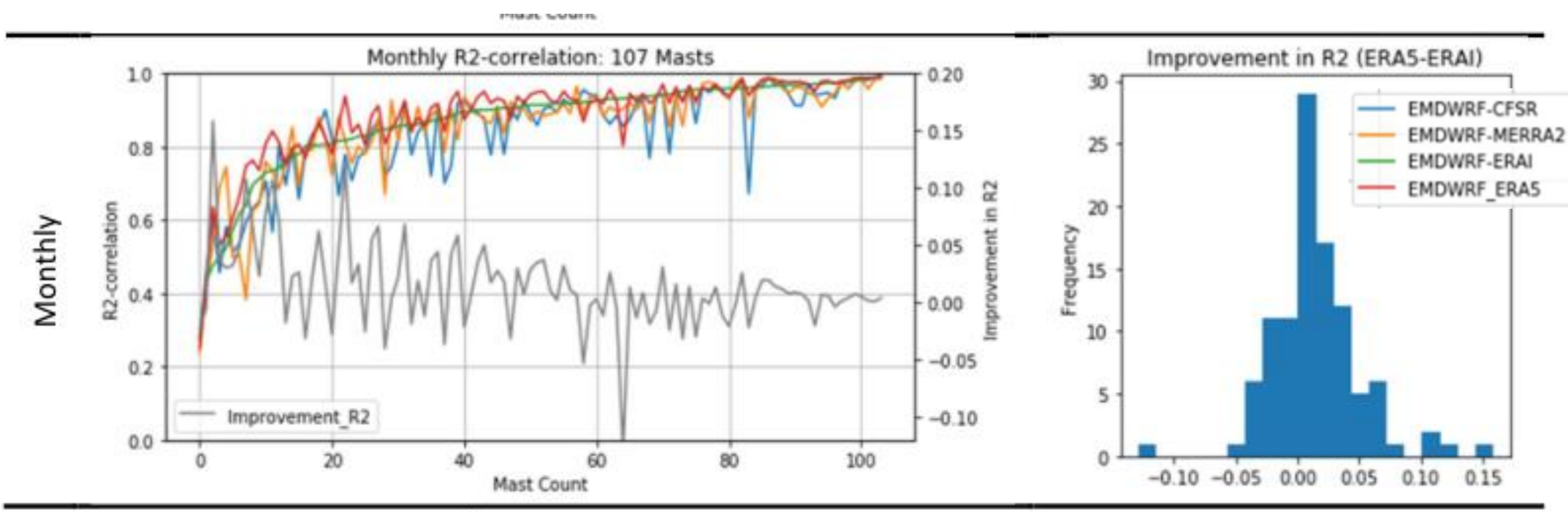
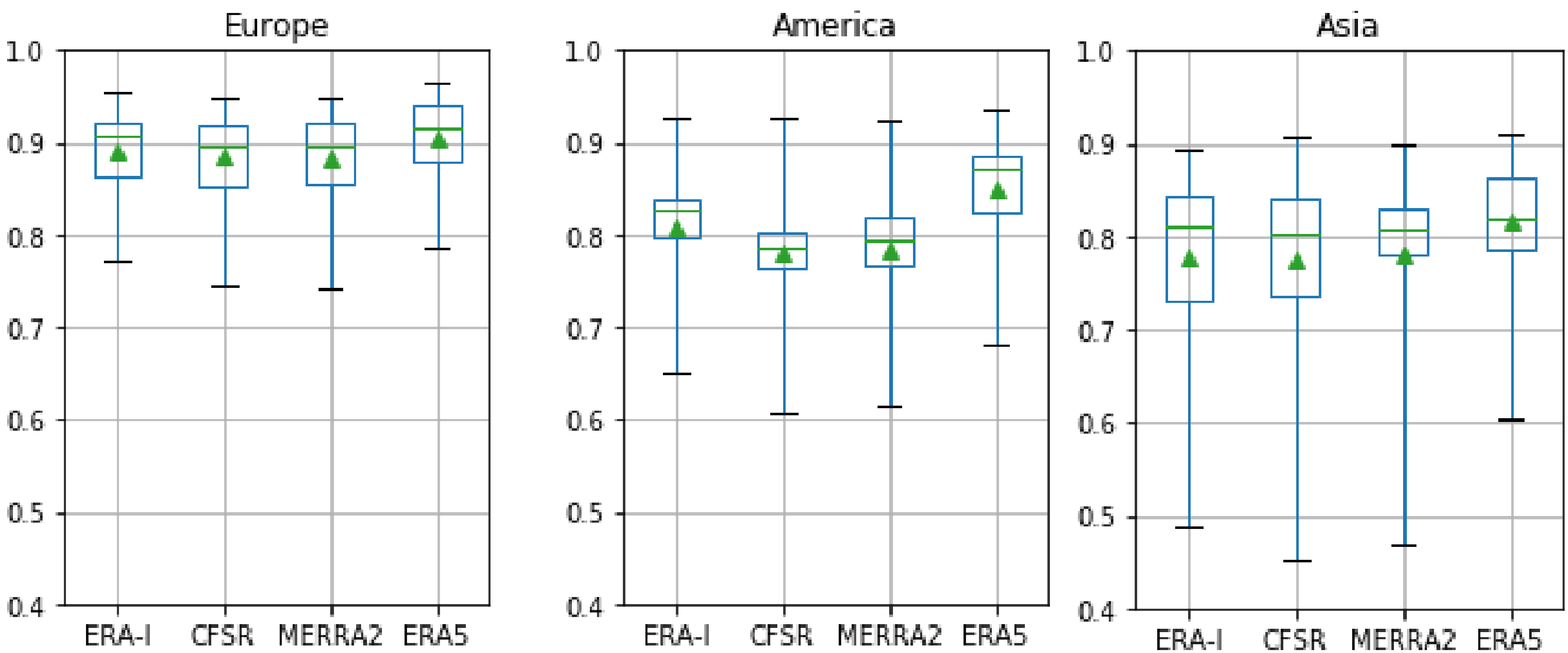
R^2 correlation – EMD-WRF OD data vs. 107 masts (wind speed)

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



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)

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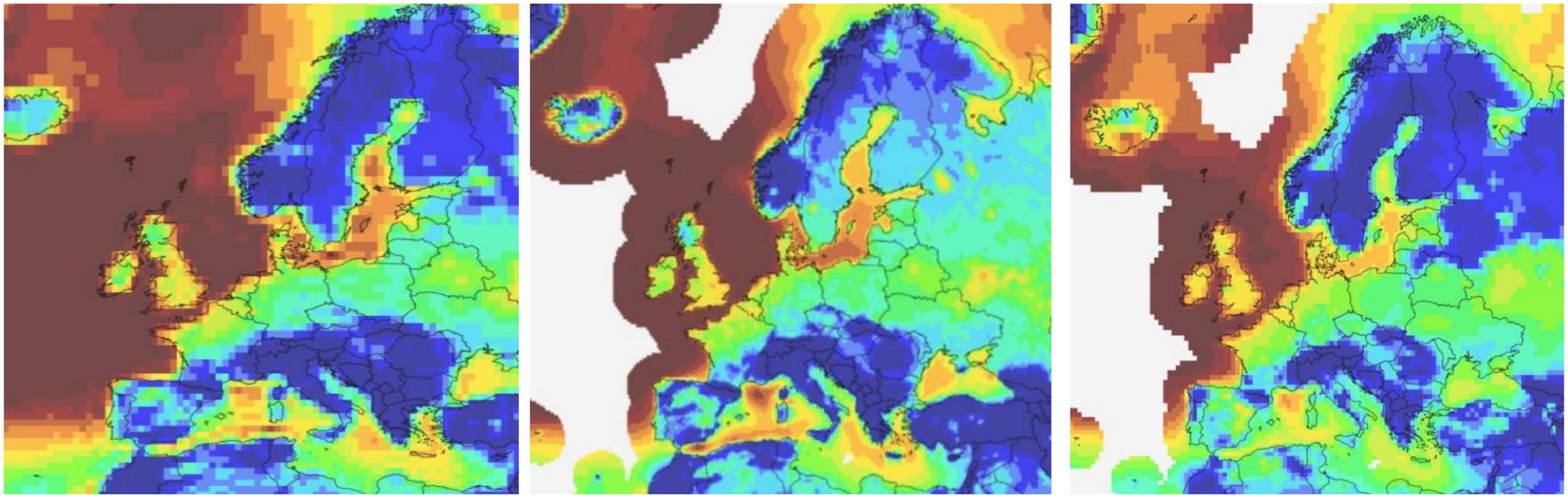

3. Short Campaigns – A Real Challenge!

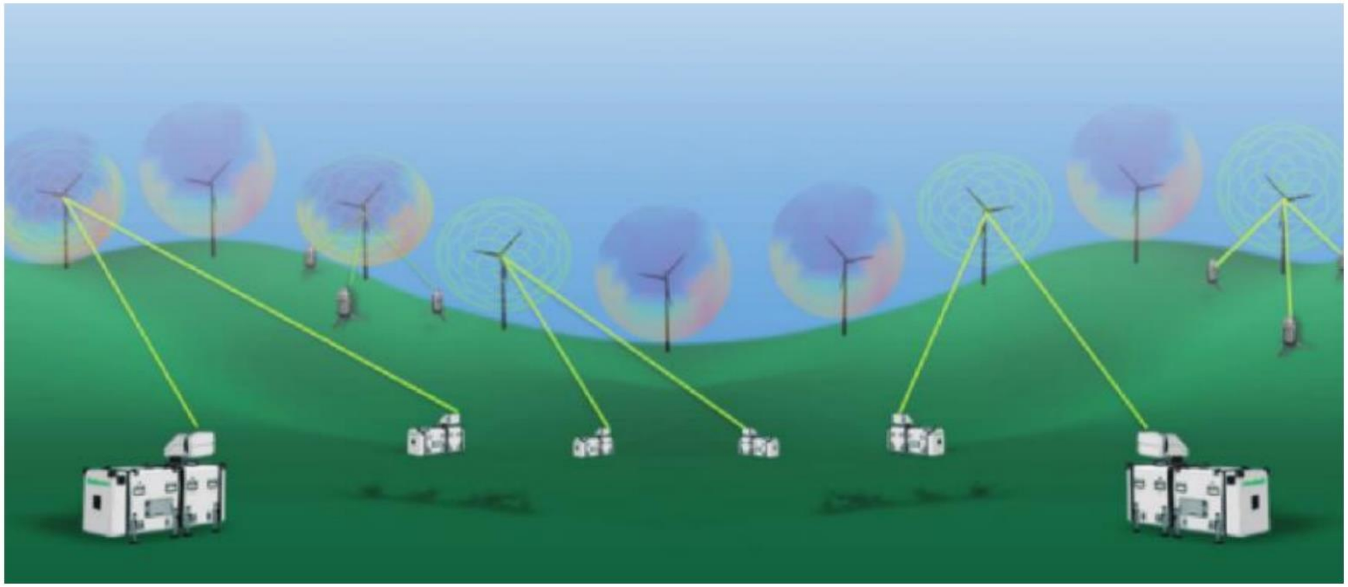

Image credit: DTU Vindenergi/Recast Project.

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Project Coordinator

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3. Short Campaigns – A Real Challenge!

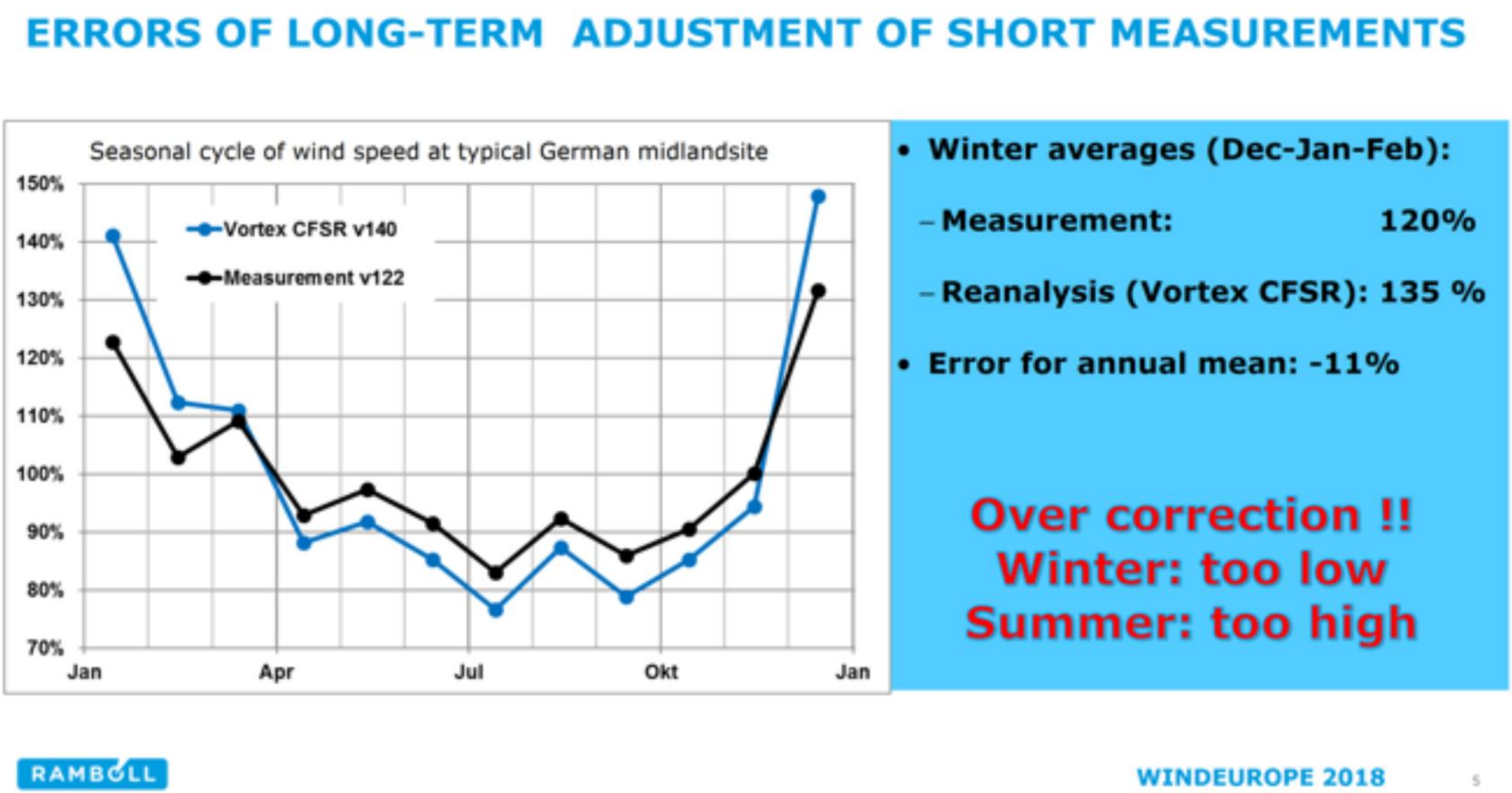


Image credit: Anselm Grötzner, Cube-Ramboll, WindEurope-2018

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)

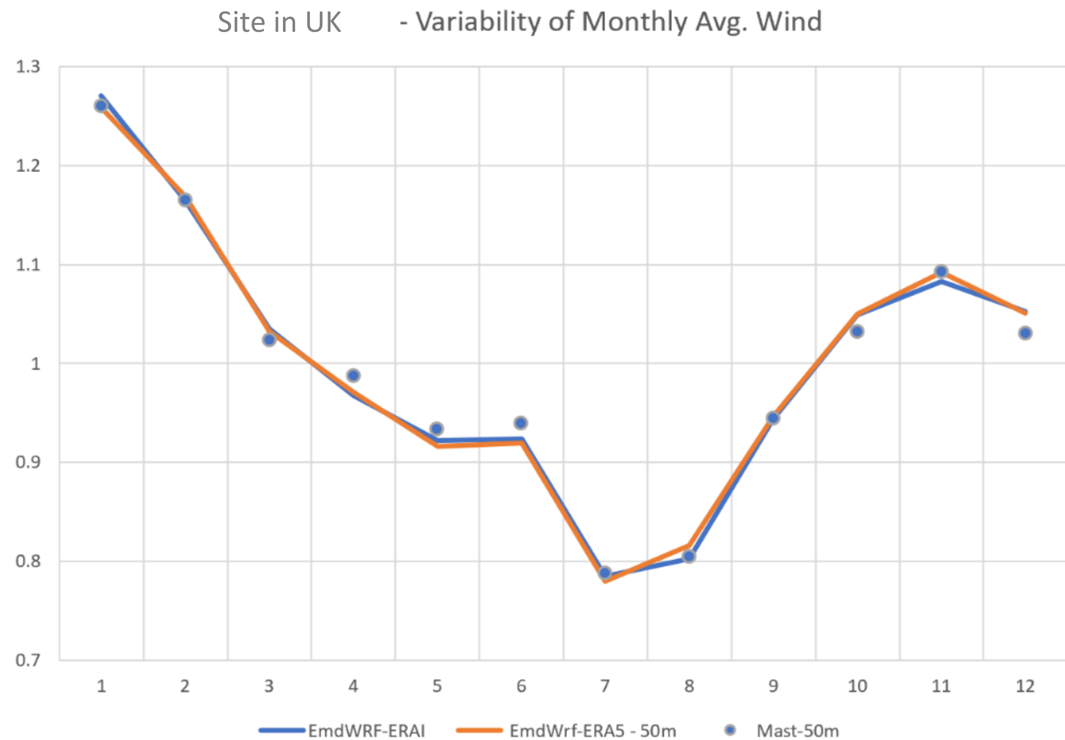
3. Short Campaigns – A Real Challenge!

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?:

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Reference data: **- Local mast**
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- 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**.

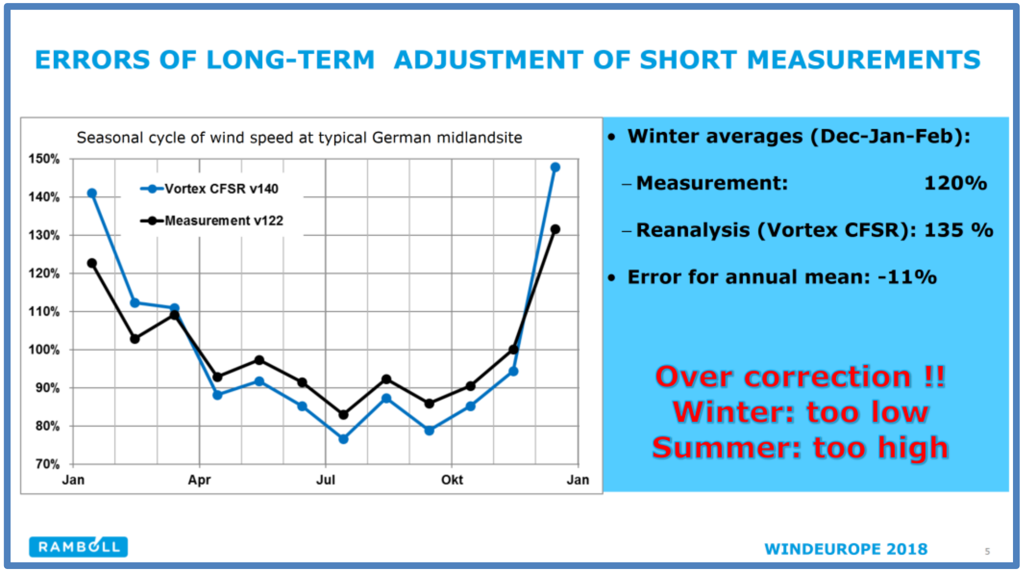
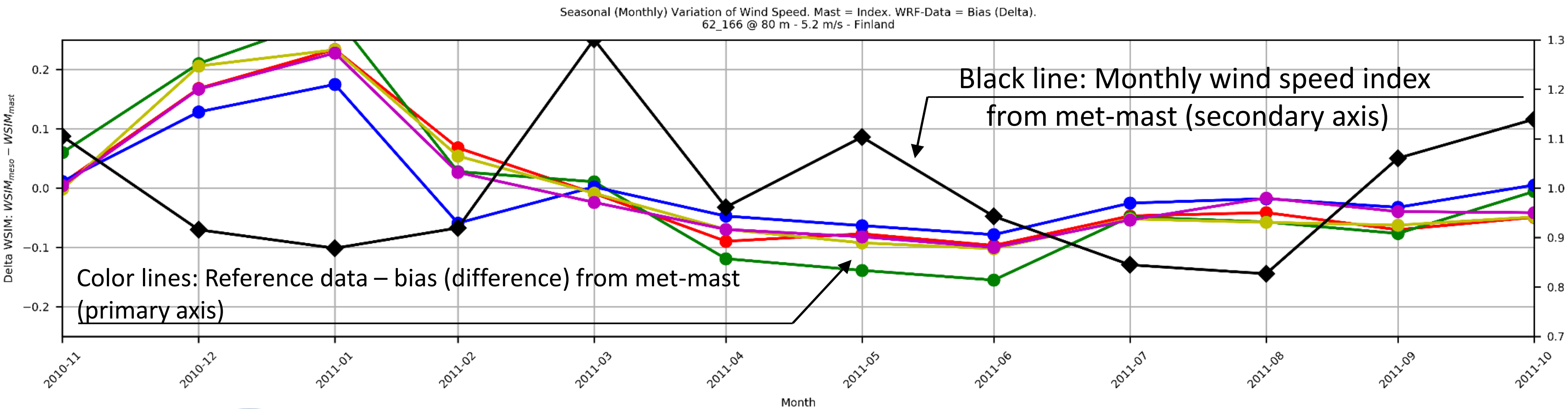
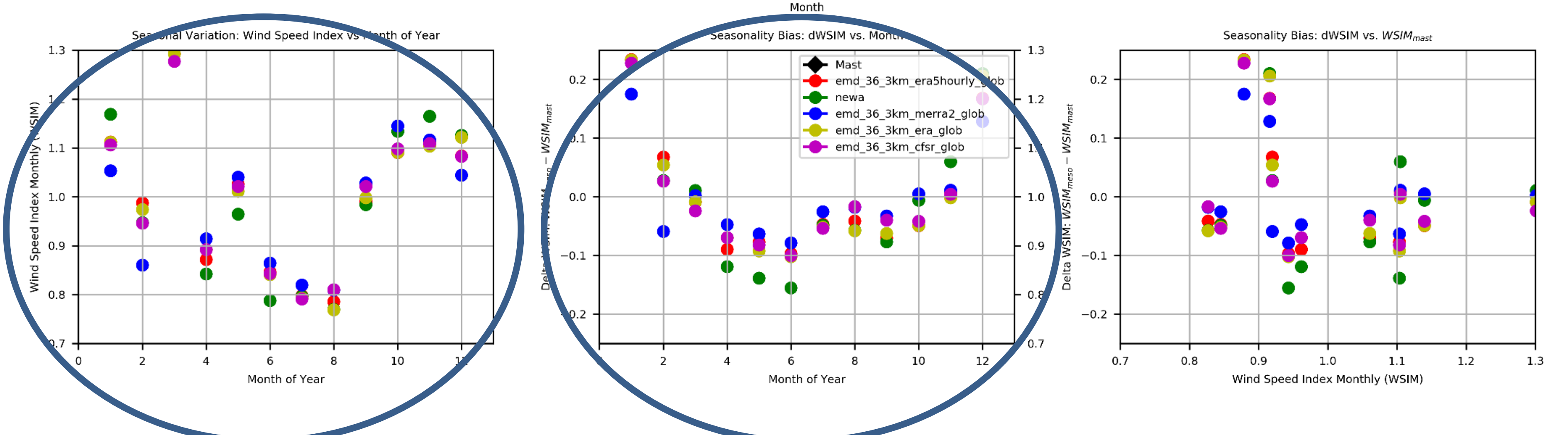


Image credit: Anselm Grötzner, Cube-Ramboll, WindEurope-2018

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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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	?

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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.

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

			EMD-WRF OD Meso Scale				
		ERA5	ERA5	MERRA2	ERA-I	CFSR	NEWA
Monthly	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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Analysis of wind-speed seasonality by visual inspection of ~10 tall masts

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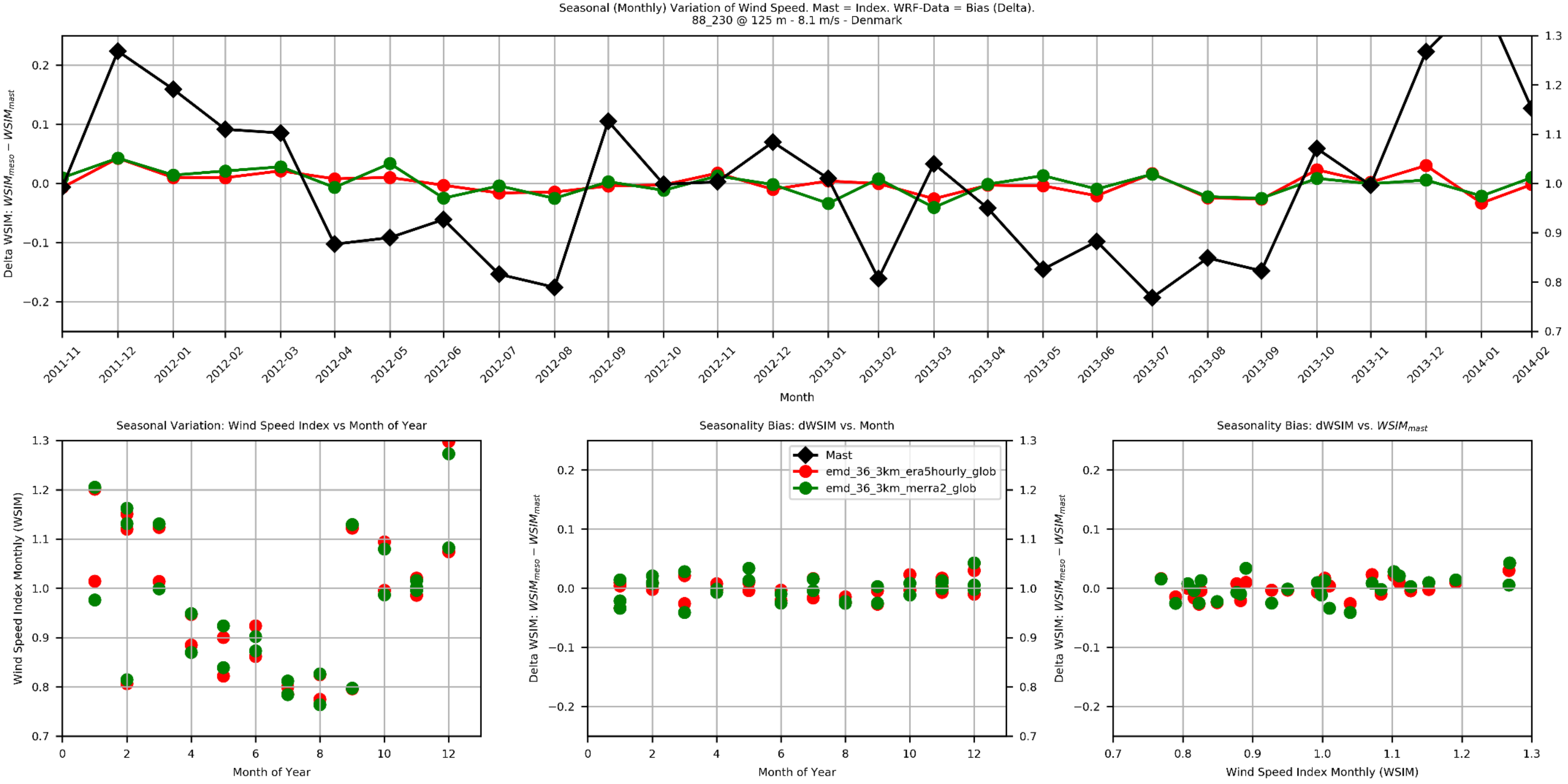

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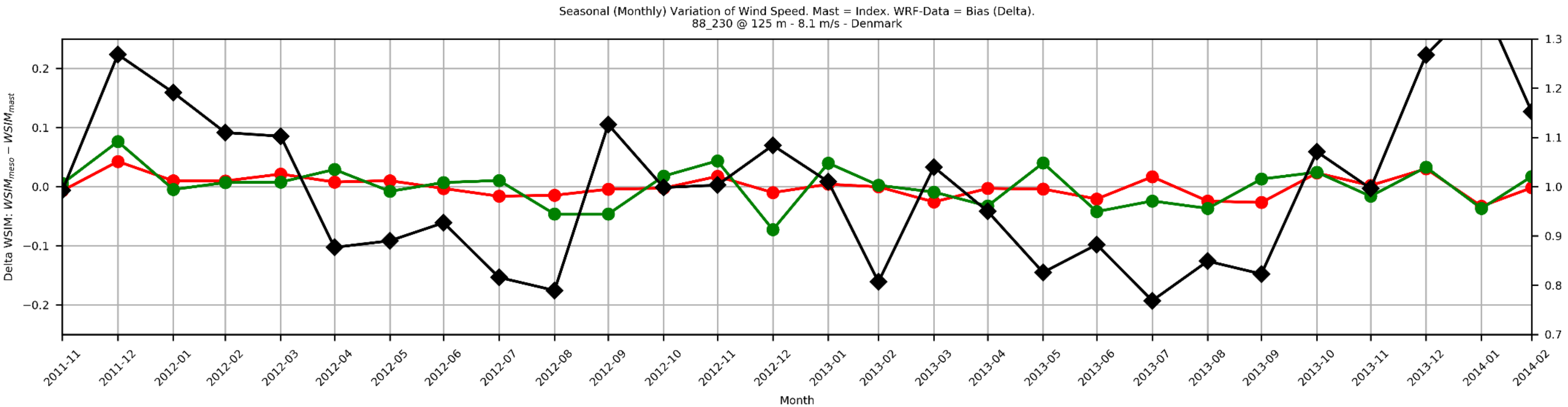

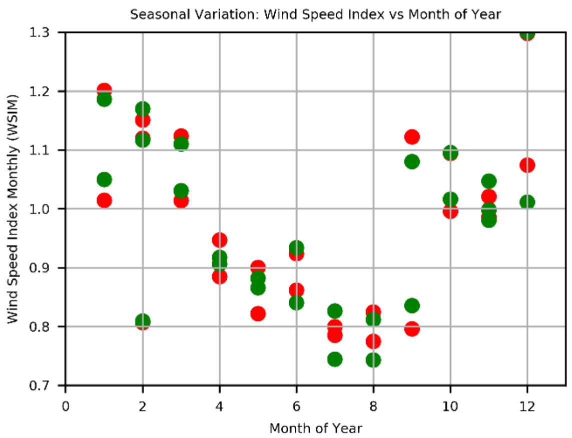

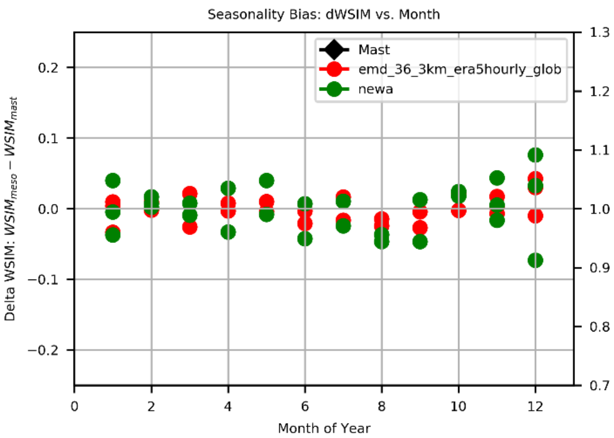

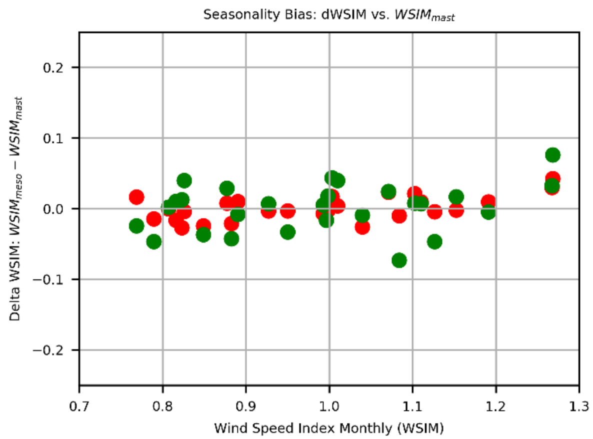

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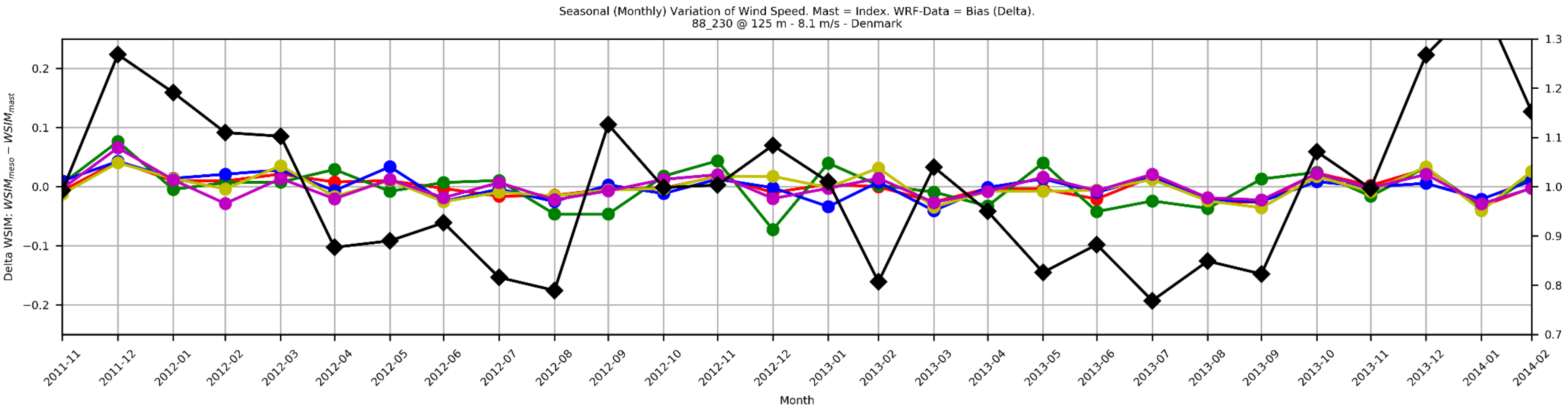

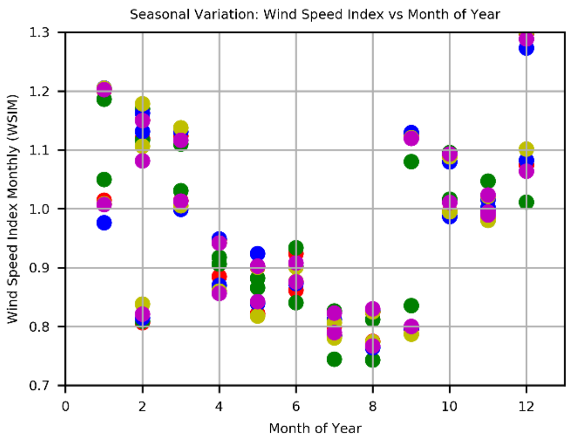

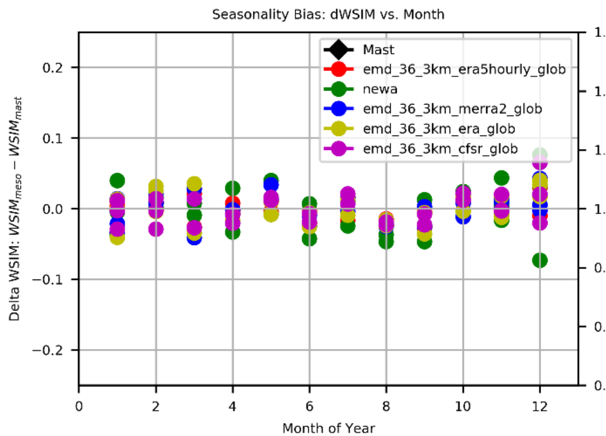

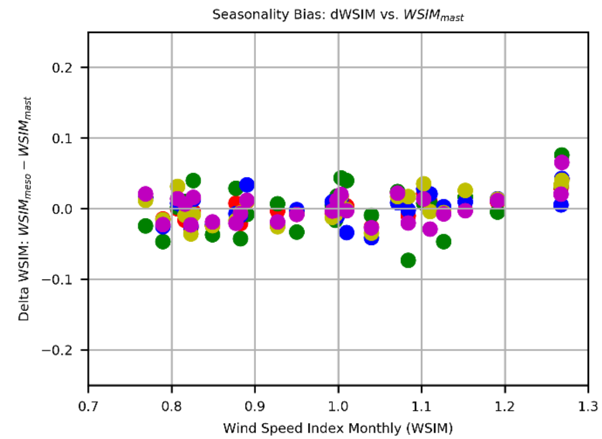

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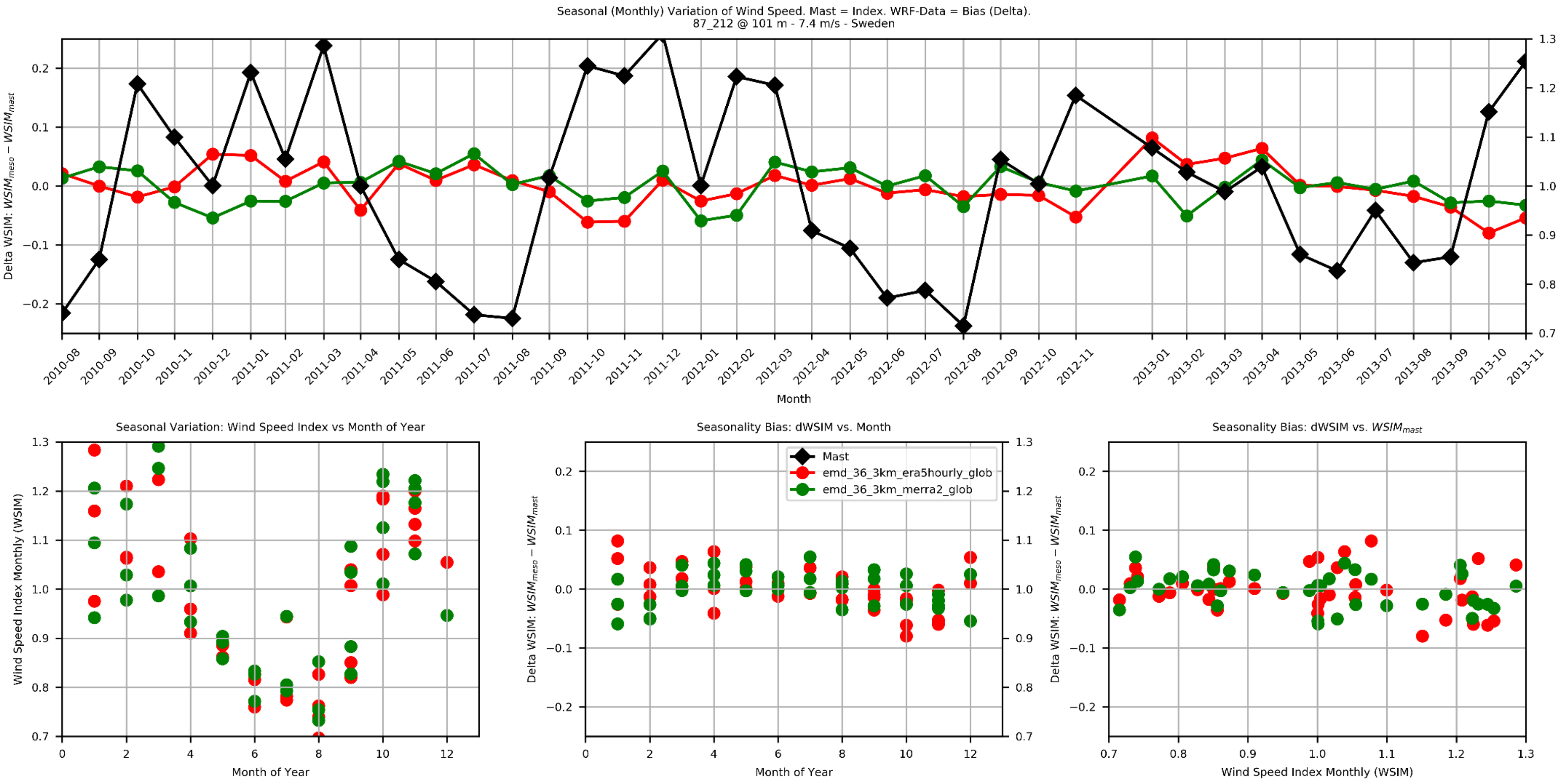
3. Short Campaigns – A Real Challenge! (SE site with some seasonal bias)



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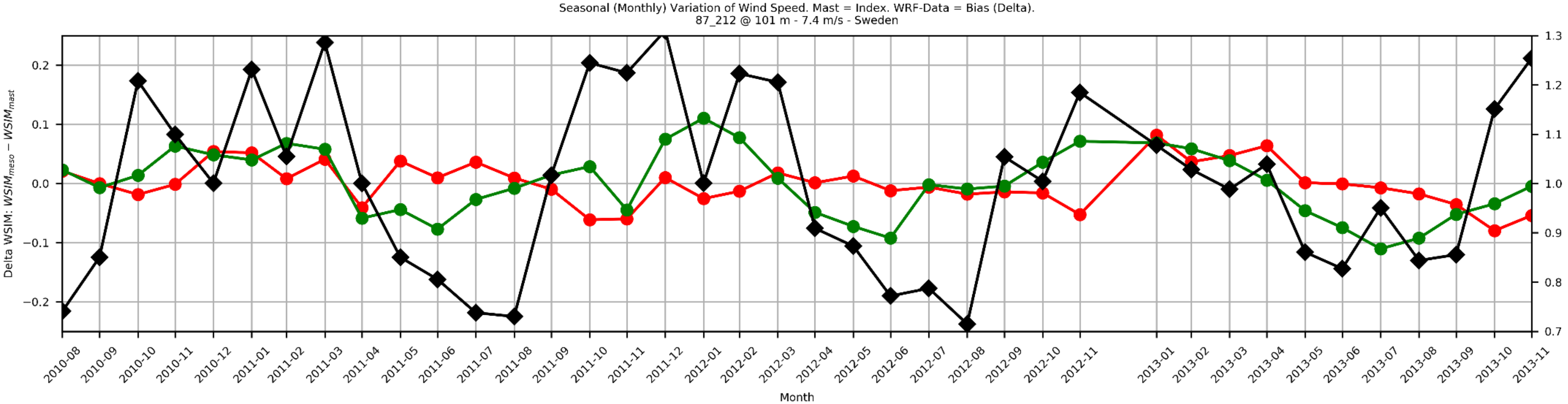

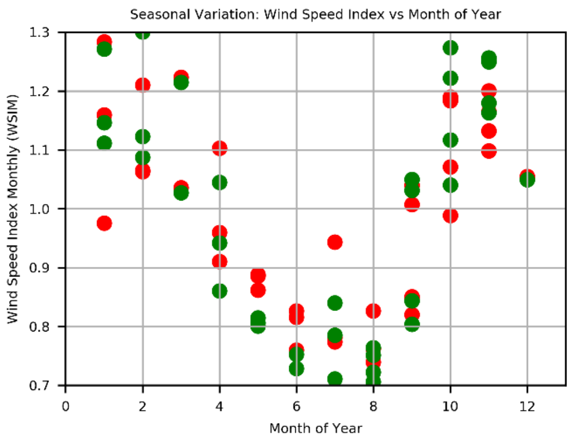

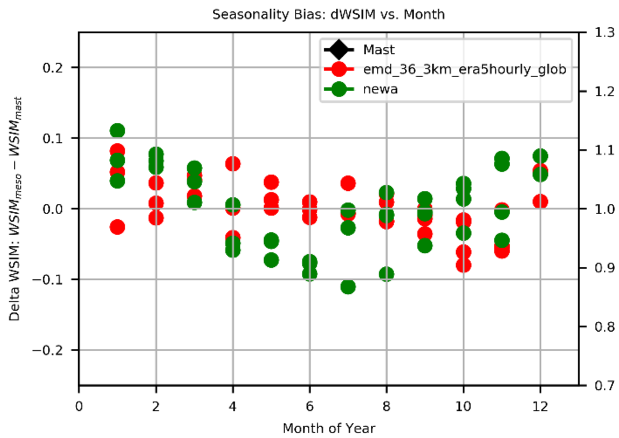

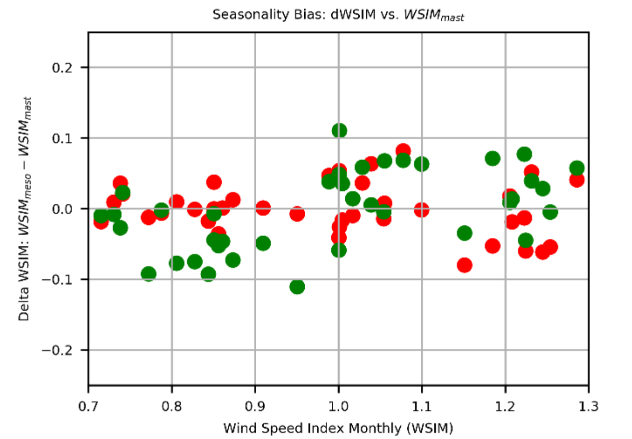

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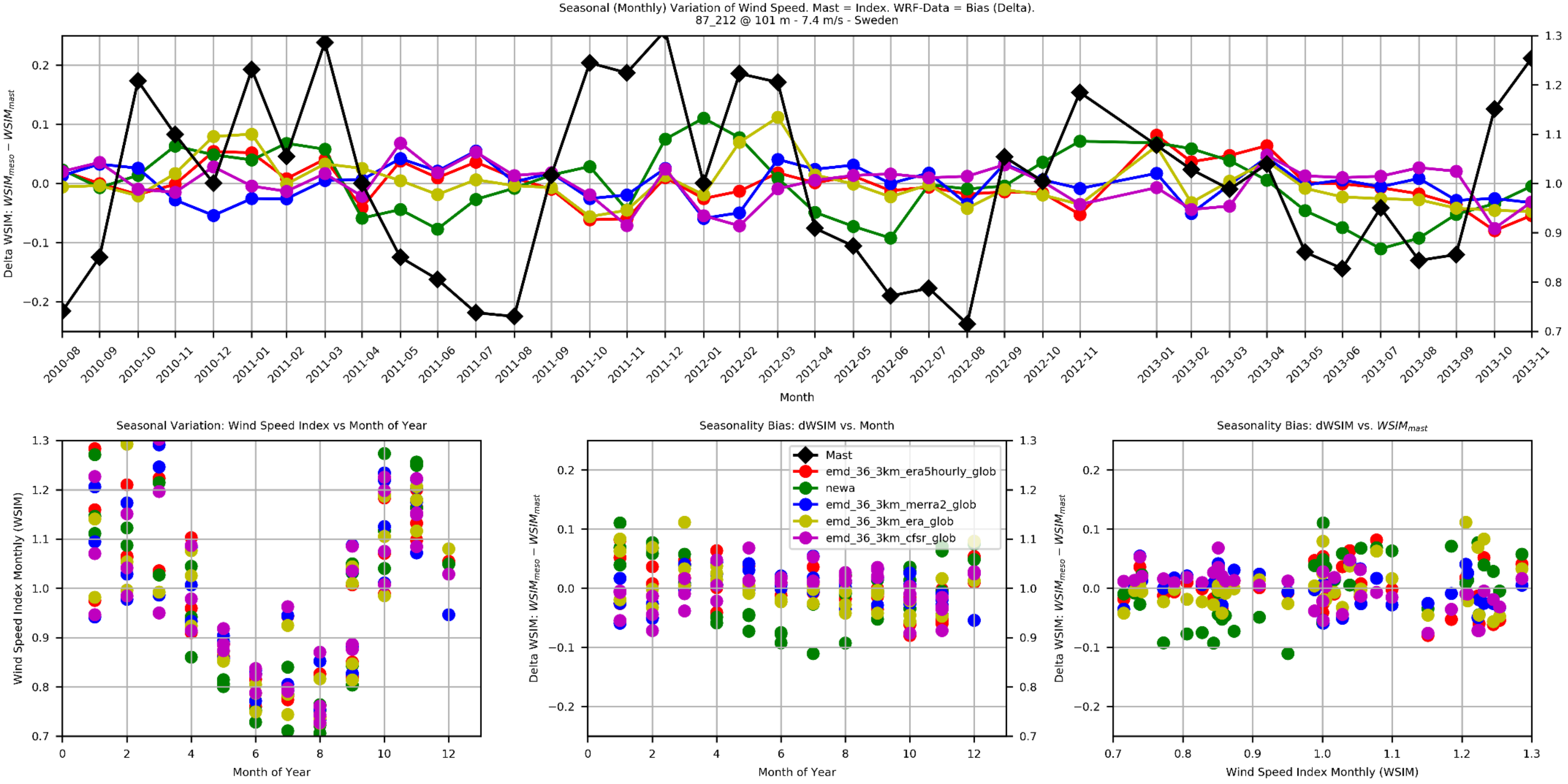

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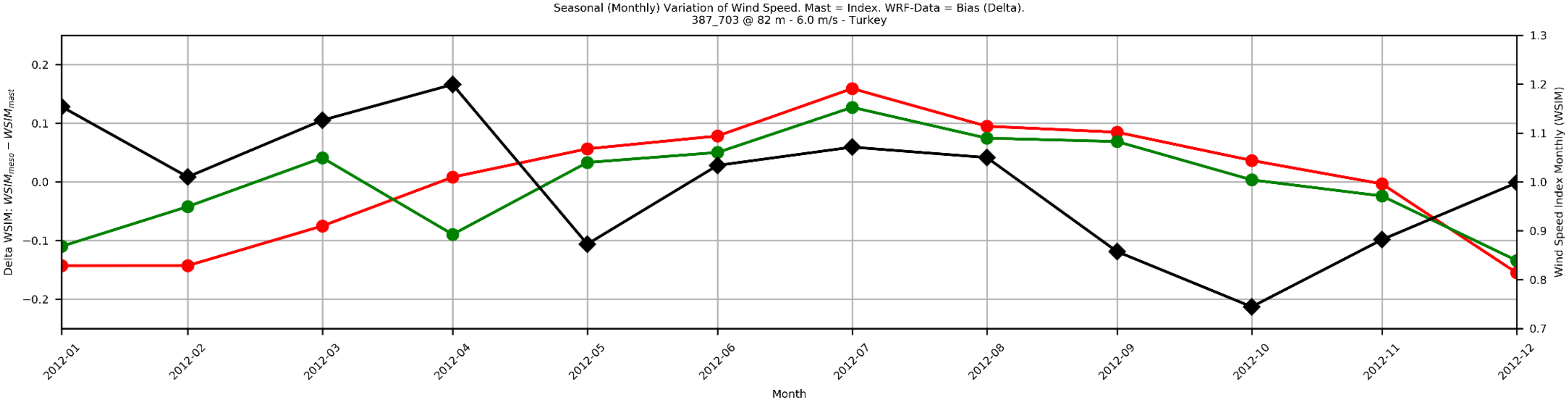
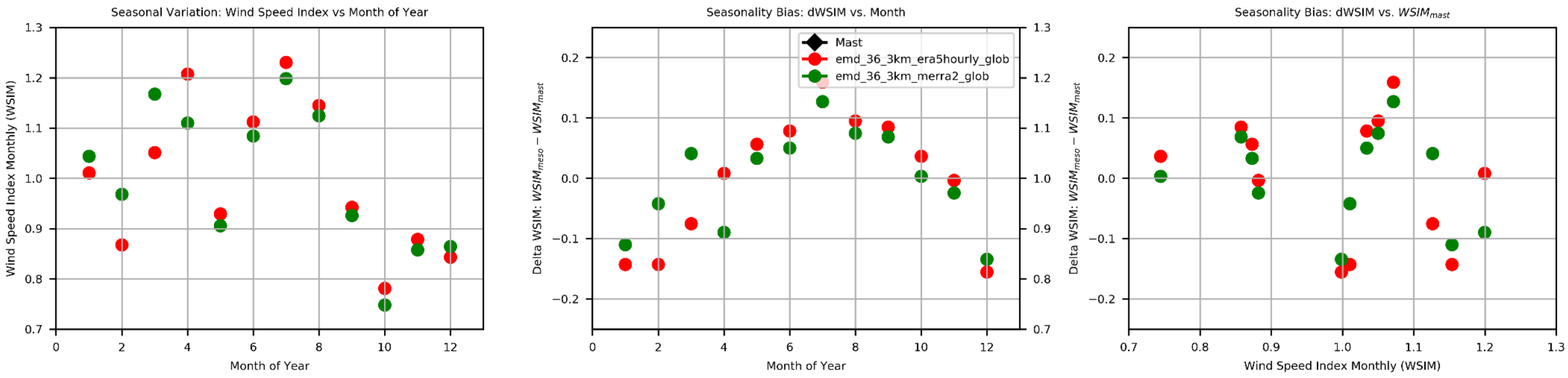
3. Short Campaigns – A Real Challenge! (TK site with some seasonal bias)





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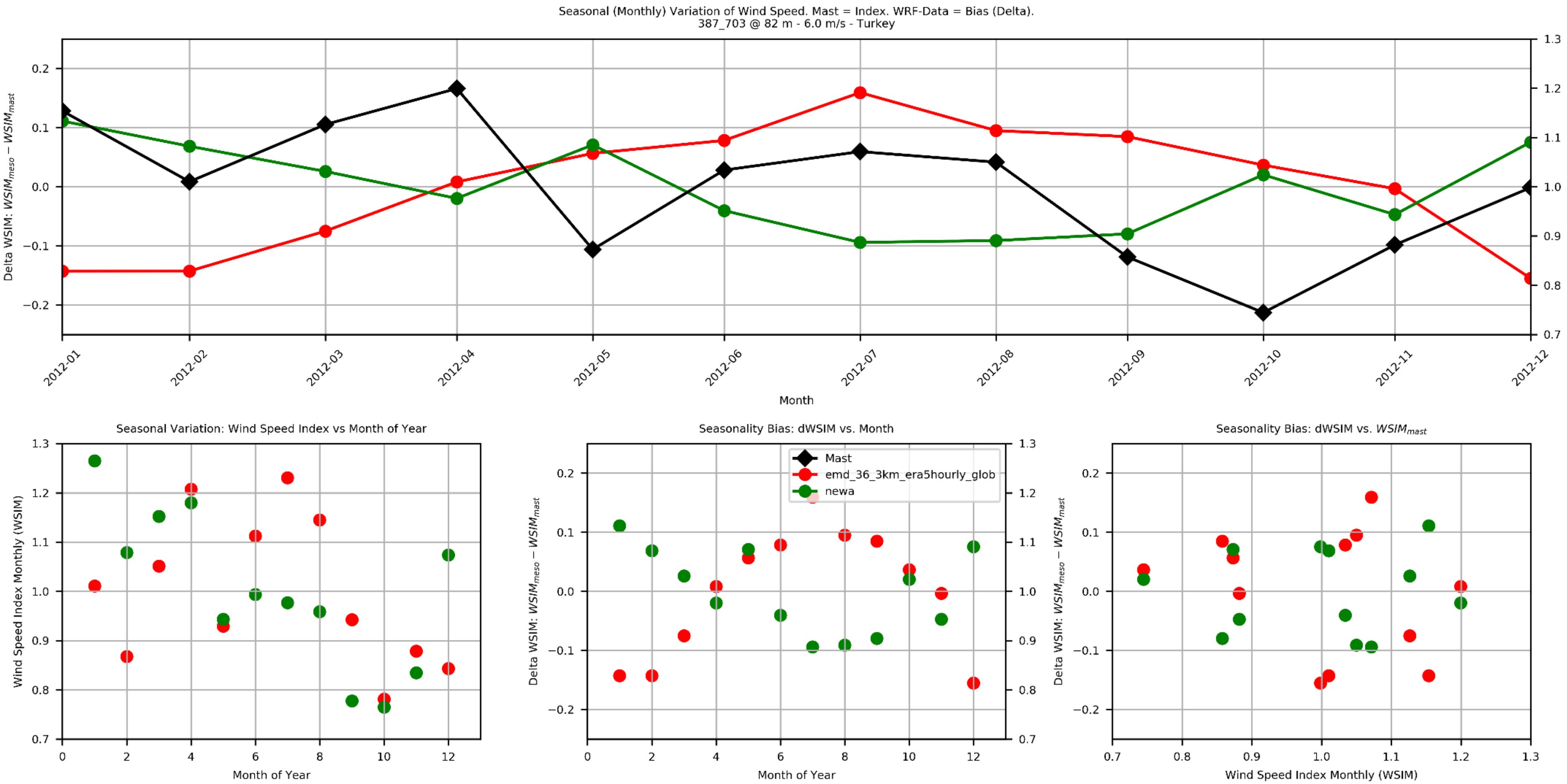

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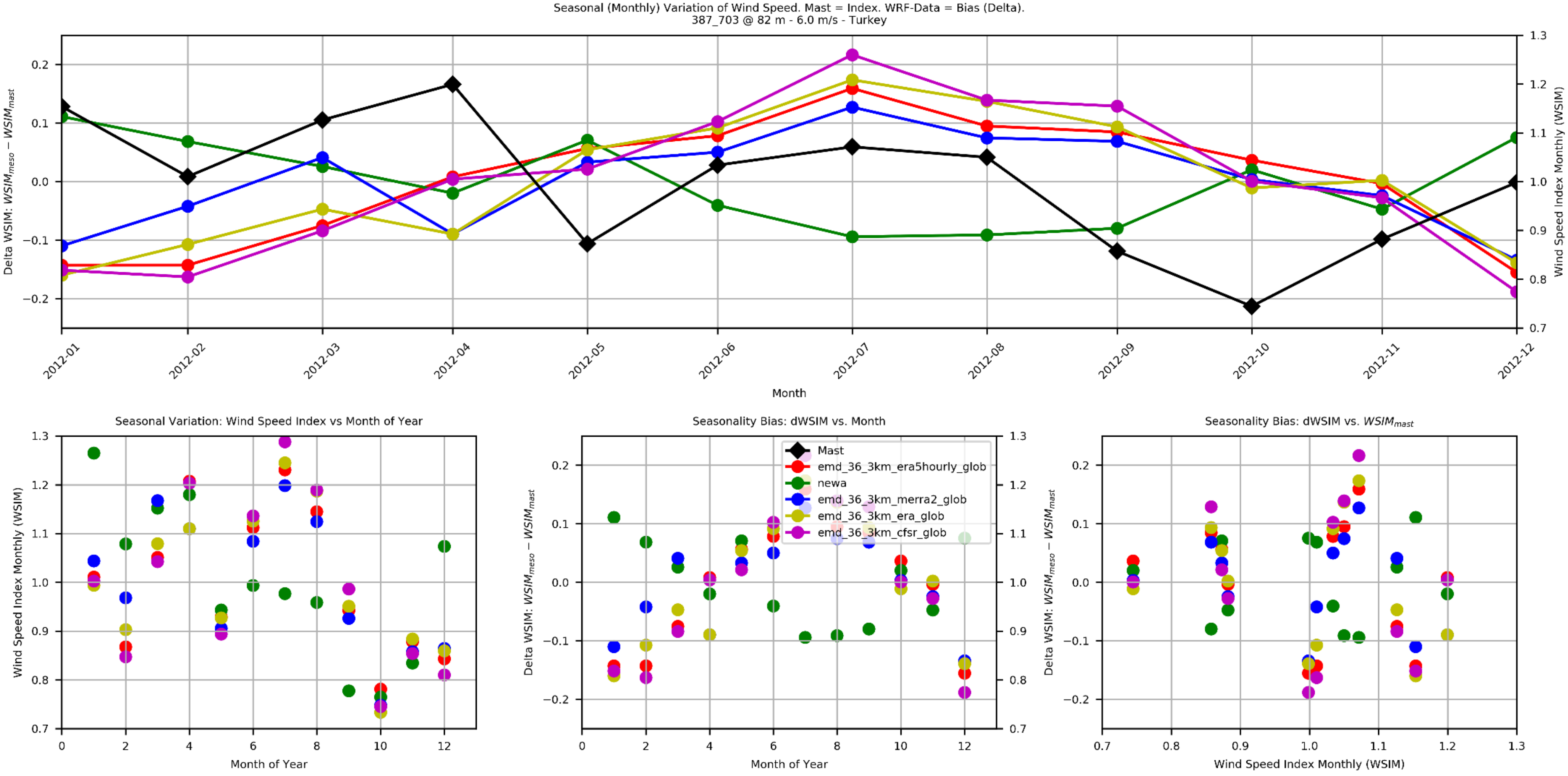

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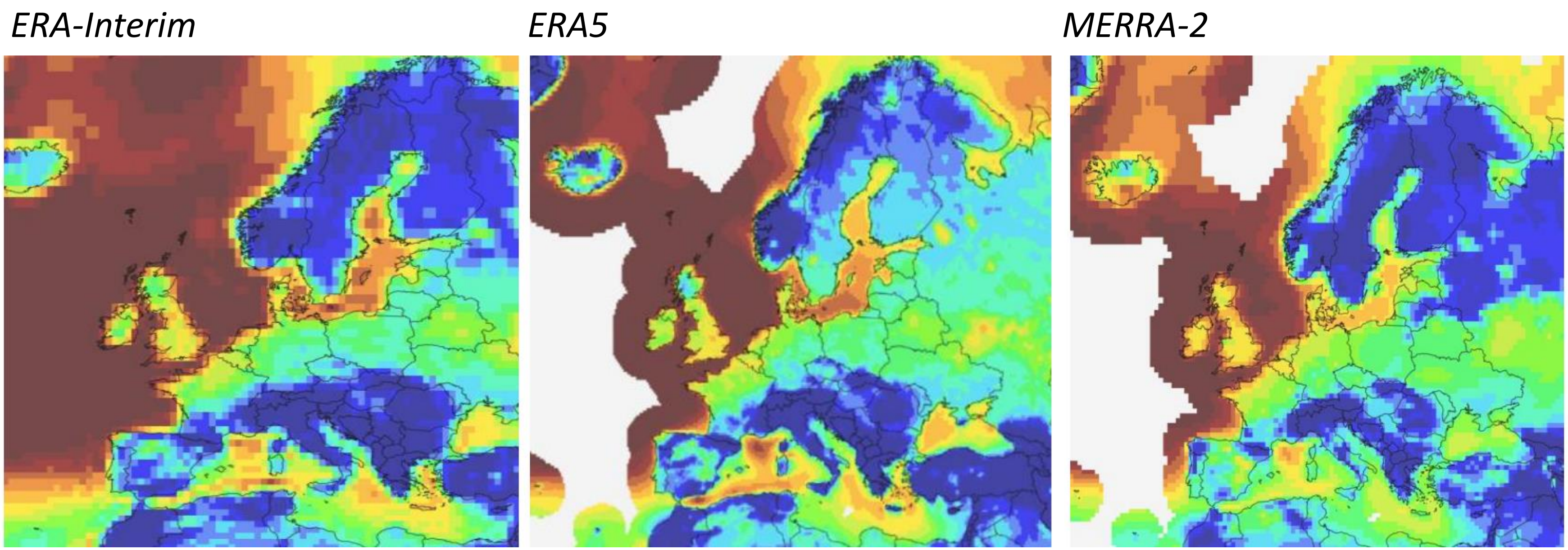

Summary

- 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