WRF Time Series Validation

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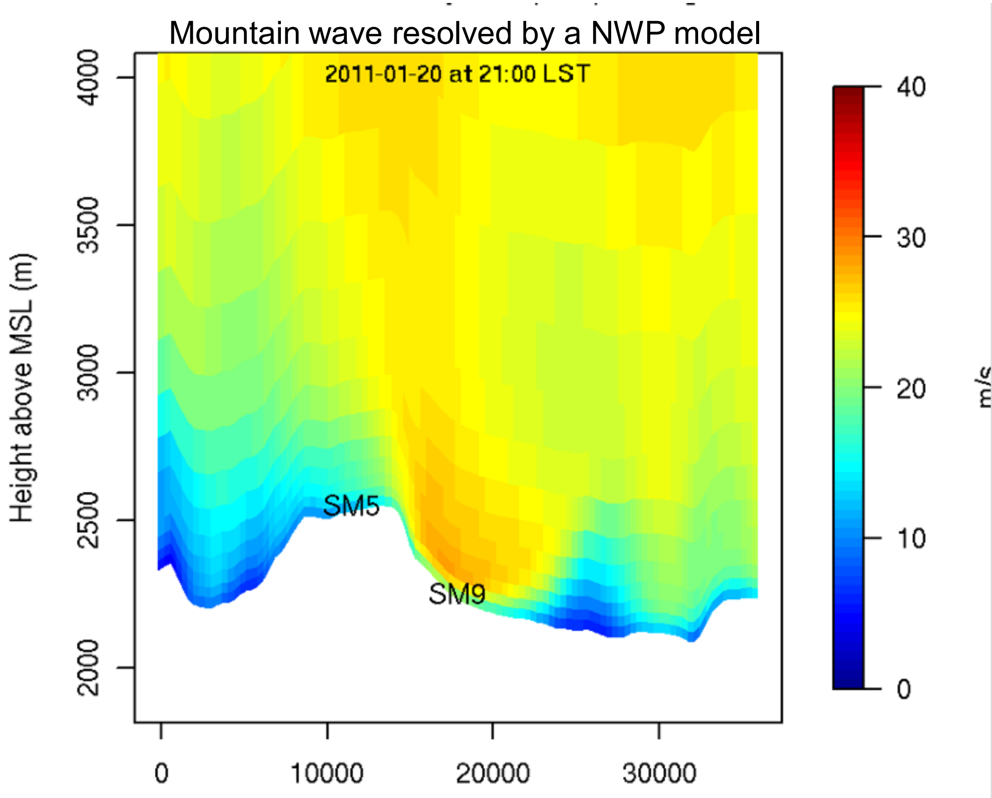
Dr. Philippe Beaucage, *Lead Research Scientist*
Dr. Akila Gothandaraman, *Research Scientist*

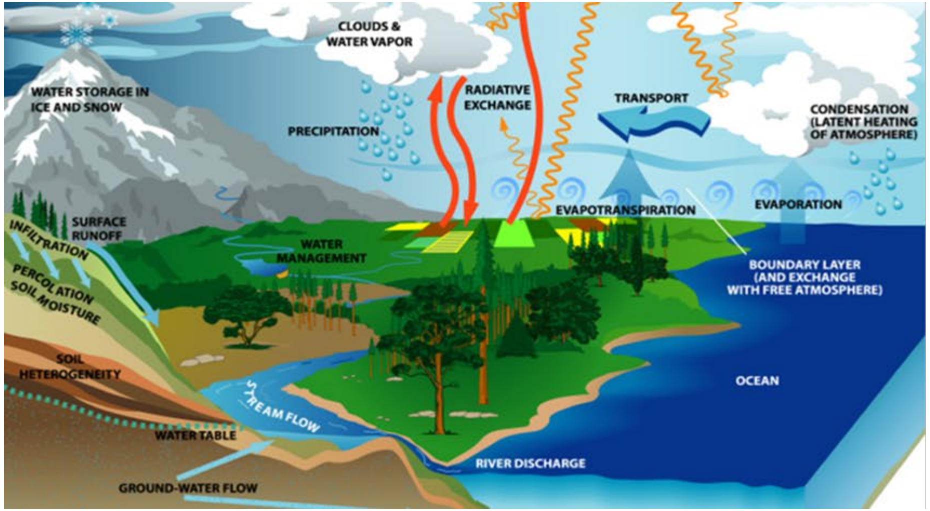
Outline

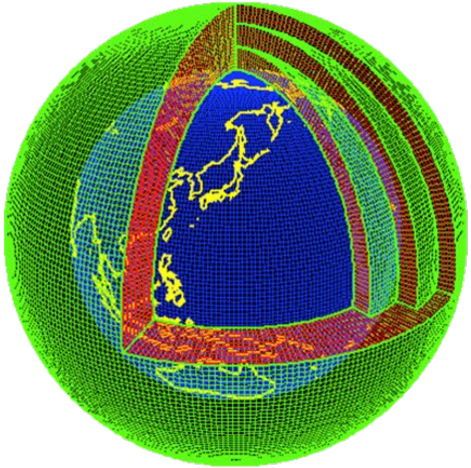
I. Introduction to mesoscale Numerical Weather Prediction models (NWP)
II. Description of Weather Research Forecasting model (WRF)
III. Sites for validation
IV. WRF validation
   - Part 1: Error statistics
   - Part 2: Diurnal and Monthly Patterns, Wind Roses



Challenges in Wind Flow Modeling

- Wind is part of a complex weather system
- Must simulate a wide range of atmospheric conditions
  - » Difficult to capture all
  - » With limited onsite observations, which conditions are most relevant is a matter of judgment
- Advanced models require much more computer time and expertise than simpler models

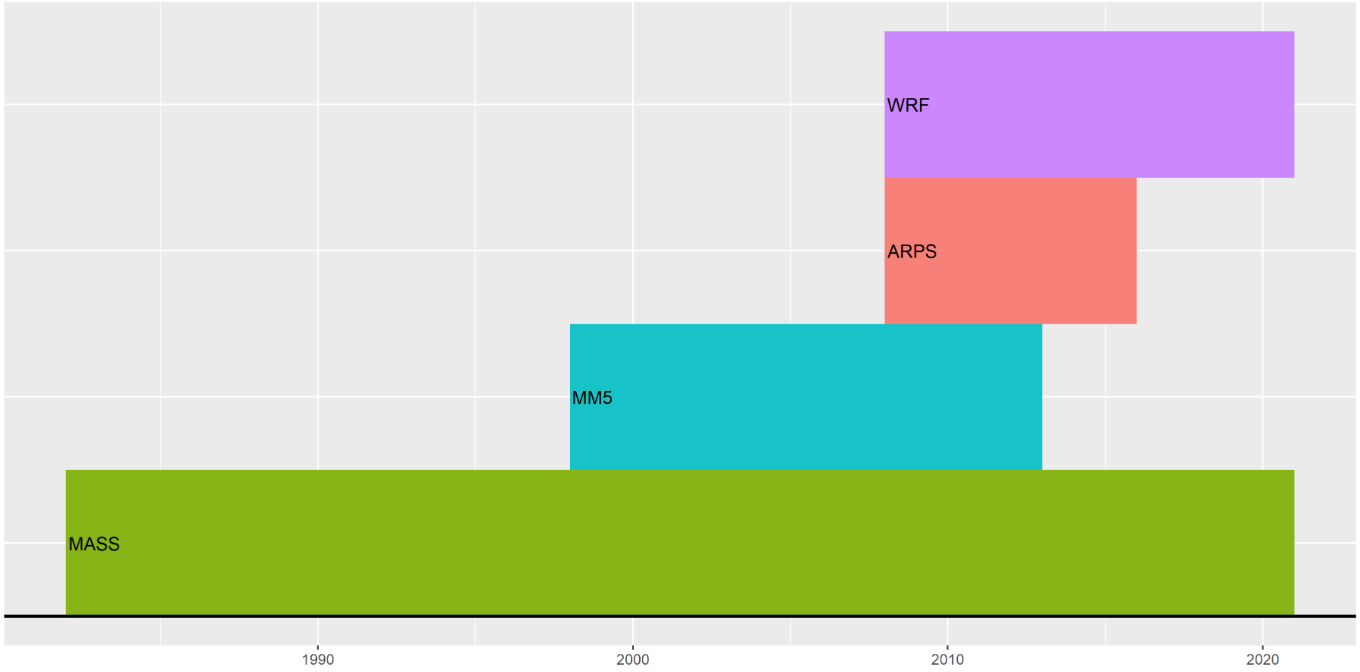




http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm

Brief History of Mesoscale NWP Modeling at UL

- For Forecasting and Resource Assessment



WRF → Weather Research and Forecasting from NCAR and others (Skamarock 2004)

ARPS → Advanced Regional Prediction System from Oklahoma University and others (Xue et al. 2000, 2001)

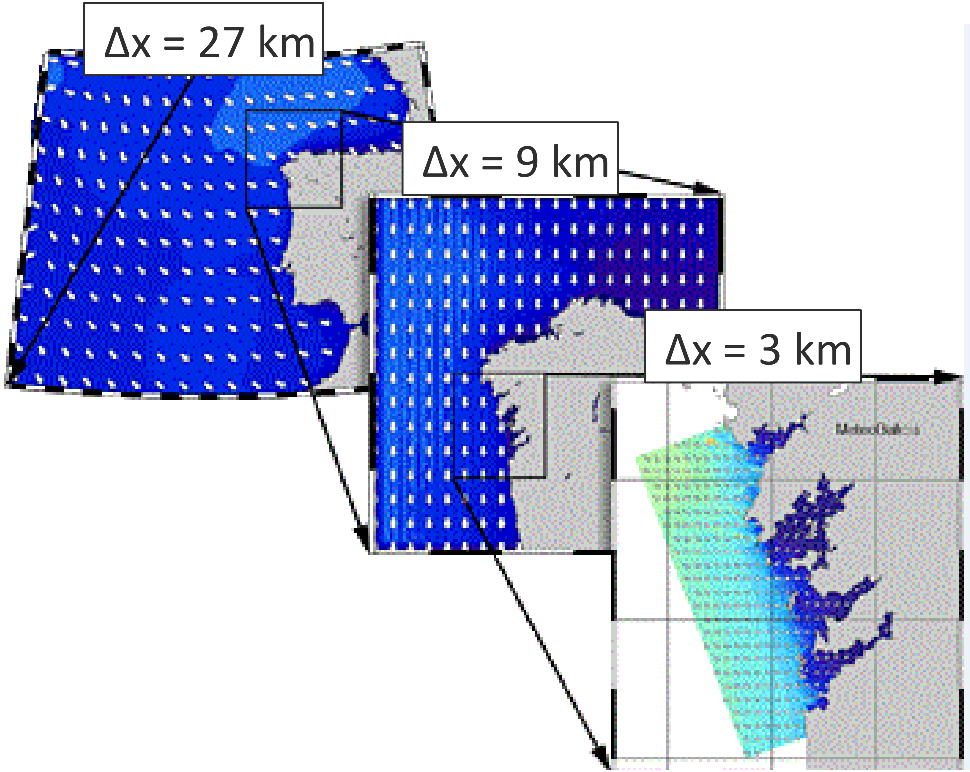
MM5 → Mesoscale Model version 5 from Penn State University and NCAR (Anthes et al. 1987)

MASS → Mesoscale Atmospheric Simulation System from MESO Inc., now UL (Kaplan et al. 1982)

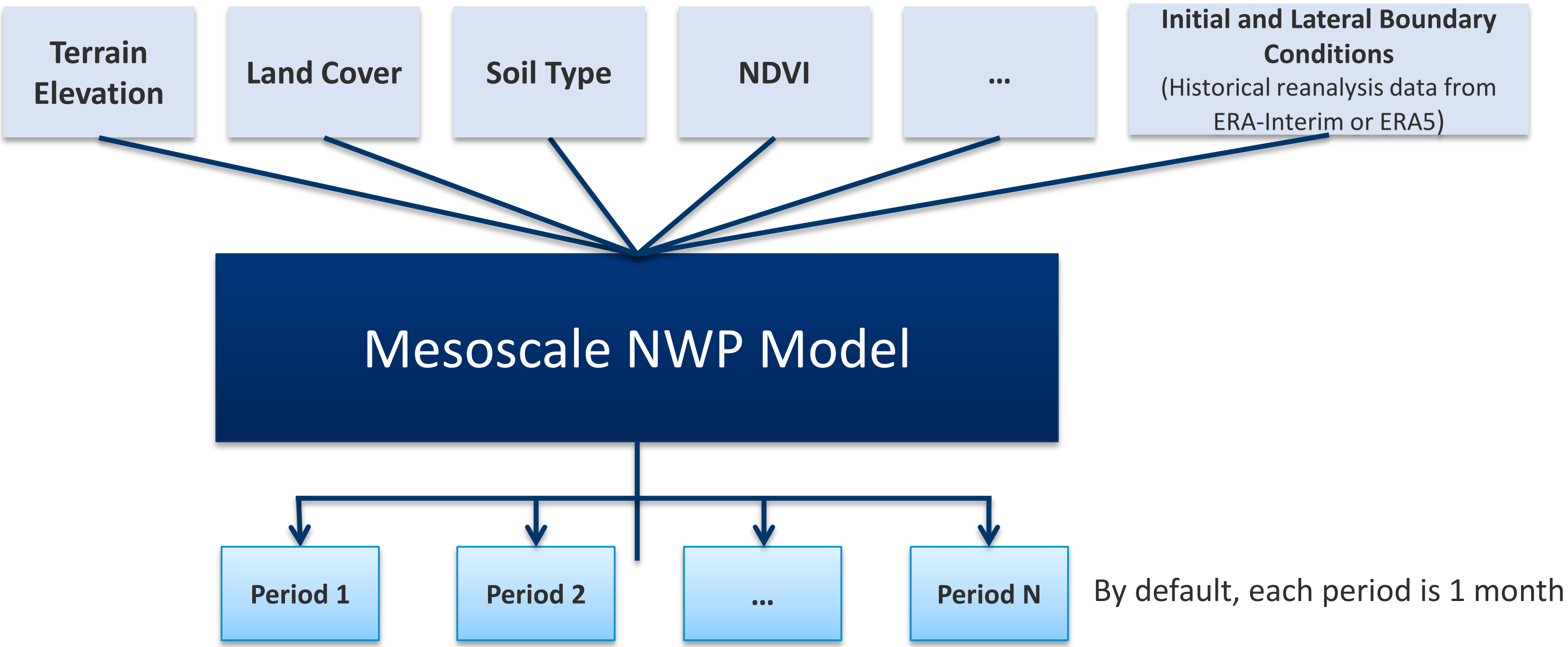
Mesoscale NWP Modeling for Resource Assessment

Weather Research and Forecasting (WRF)

- WRF is built with state-of-the-art data assimilation, dynamic and physics schemes
- WRF is open-source
  - » large community of developers
  - » updated twice a year
- WRF is fast



NWP Modeling Flowchart for Resource Assessment



WRF Time Series

Characteristics	WRF w/ ERA-Interim	WRF w/ ERA5
Model Version	WRF 3.5.1	WRF 4.1.3
Reanalysis Data	ERA-Interim	ERA5
Terrain Elevation Data	~ 90-m resolution SRTM	~ 90-m resolution SRTM
Land Cover Data	~ 90-m resolution in-house dataset [1]	~ 90-m resolution in-house dataset [1]
Sea Surface Temperature Data	From reanalysis	From reanalysis
Physics Parameterization	(confidential)	(confidential)
Dynamical Downscaling	27-9-3 km	27-9-3 km
Simulation Period	10 or 20 years typically but can go back to 1979	10 or 20 years typically but can go back to 1979

[1] NLCD 2001 in the US, Corine in Europe, GeocoverLC otherwise

Reanalysis Data: ERA-Interim vs. ERA5

	ERA-Interim	ERA5
Period	1979 – present	**1950 – present**, produced in 2 phases
Availability behind real time	2 - 3 months	2 – 3 months (final product) **2 – 5 days** (ERA5T)
Assimilation system	2006 (31r2), 4D-Var	**2016** (41r2), **4D-Var, hybrid EDA providing B**
Model input (radiation and surface)	As in operations, (inconsistent SST and sea ice)	**Appropriate for climate**, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice
Spatial resolution	79 km globally 60 levels to 10 Pa	**31 km globally** 137 levels to 1 Pa
Uncertainty estimate		**From** 10-member **EDA at 62 km**
Output frequency	6-hourly analysis fields	**Hourly** (three-hourly for the ensemble), Extended list of parameters 9 petabytes (1950 – timely updates)
Extra observations	Mostly ERA-40, GTS	Various **reprocessed CDRs, latest instruments**
Variational bias control radiosondes	Satellite radiances, RAOBCORE	Also ozone, aircraft, surface pressure, RISE

Table taken from Hersbach, H. and co-authors (2019). “Goodbye ERA-Interim, hello ERA5”. ECMWF Newsletter, No. 159, p. 17-24

Methodology for Validation

- Identify sites of varying terrain complexity :
  - 15 validation sites
- Perform WRF runs:
  - WRF with ERA-Interim
  - WRF with ERA5
- Compute error statistics of WRF time series against met tower data

Validation Sites

ID	Country	State	Terrain	Land Cover
1	USA	Maine	Moderate	Forested
2	USA	Oklahoma	Simple	Plains
3	USA	Wyoming	Moderate	grassland with shrub
4	USA	Washington	Moderate	Bare ground
5	USA	Massachusetts	Offshore (near coast)	Water
6	India	Andhra Pradesh	Moderate	Bare ground and shrub
7	India	Tamil Nadu	Moderate	Agriculture
8	India	Tamil Nadu	Complex	Agriculture and forest
9	India	Rajasthan	Simple	Sand
10	Romania	Ialomita	Simple	Agriculture
11	Spain	Catalonia	Complex	Bare ground and forest
12	Netherlands	Utrecht	Simple	Agriculture
13	Poland	Lower Silesian	Simple	Agriculture and forest
14	Netherlands	North Holland	Offshore (far from coast)	Water
15	Denmark	Syddanmark	Offshore (far from coast)	Water

WRF Time Series Validation: Part 1 – Mean Bias

ID	Country	WRF w/ ERA-Interim	WRF w/ ERA5
1	USA	-0.425	-0.48
2	USA	-0.912	-1.226
3	USA	-0.978	-0.332
4	USA	-1.755	-1.617
5	USA	-0.705	-0.384
6	India	-0.445	-0.316
7	India	1.154	1.654
8	India	0.296	-0.317
9	India	-0.977	-0.349
10	Romania	-1.651	-1.342
11	Spain	-1.259	-0.974
12	Netherlands	-0.185	-0.244
13	Poland	0.388	0.399
14	Netherlands	-0.339	-0.278
15	Denmark	-0.357	-0.293
	AVERAGE	**-0.543**	**-0.407**

- On average, WRF with ERA5 performs better than WRF with ERA-Interim in terms of mean bias error
- WRF with ERA5 yields a mean bias closer to 0 m/s at 9 out of 15 sites

WRF Time Series Validation: Part 1 – Hourly RMSE

ID	Country	WRF w/ ERA-Interim	WRF w/ ERA5
1	USA	1.648	1.617
2	USA	2.119	2.268
3	USA	3.26	2.995
4	USA	2.924	2.725
5	USA	2.195	2.093
6	India	2.348	2.378
7	India	2.24	2.415
8	India	2.626	2.359
9	India	2.272	1.949
10	Romania	2.994	2.671
11	Spain	2.699	2.487
12	Netherlands	1.683	1.752
13	Poland	1.86	1.888
14	Netherlands	1.649	2.01
15	Denmark	1.637	1.896
	AVERAGE	**2.277**	**2.234**

- On average, WRF with ERA5 performs better than WRF with ERA-Interim in terms of hourly RMSE
- WRF with ERA5 yields a lower hourly RMSE at 8 out of 15 sites

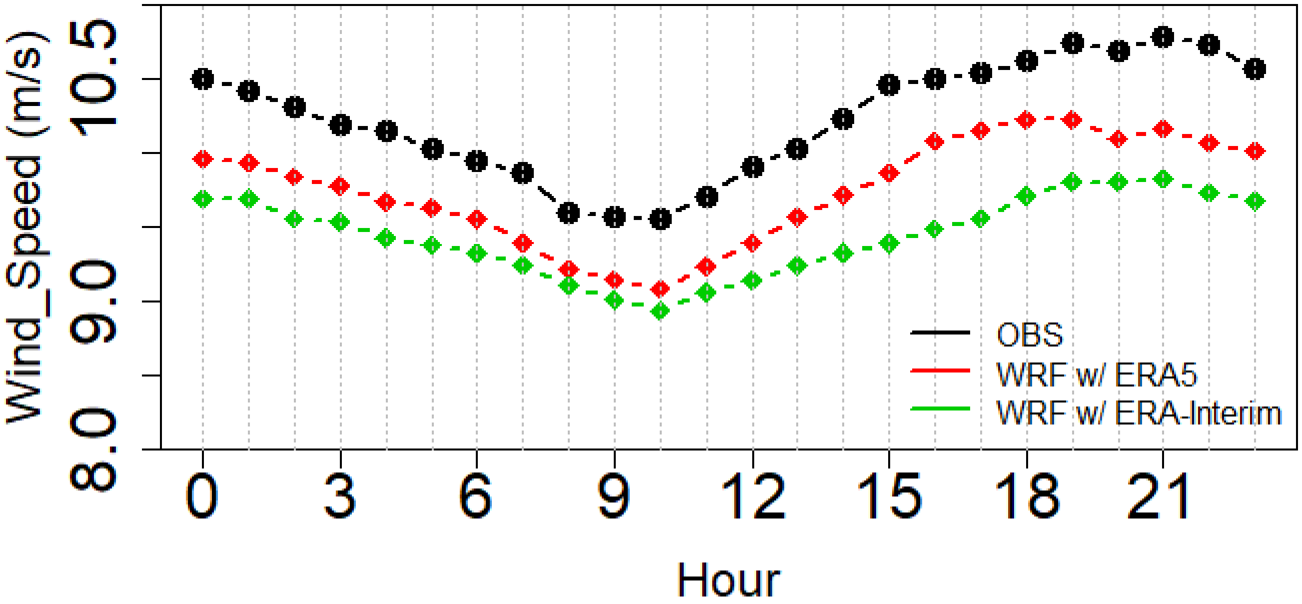
WRF Time Series Validation: Part 1 – Hourly R^2 Correlation

ID	Country	WRF w/ ERA-Interim	WRF w/ ERA5
1	USA	0.706	0.732
2	USA	0.666	0.67
3	USA	0.565	0.602
4	USA	0.626	0.674
5	USA	0.796	0.839
6	India	0.585	0.559
7	India	0.496	0.476
8	India	0.773	0.804
9	India	0.58	0.641
10	Romania	0.456	0.516
11	Spain	0.523	0.569
12	Netherlands	0.659	0.657
13	Poland	0.651	0.653
14	Netherlands	0.838	0.849
15	Denmark	0.832	0.852
	AVERAGE	**0.65**	**0.673**

- On average, WRF with ERA5 performs better than WRF with ERA-Interim in terms of hourly R^2 correlation
- WRF with ERA5 yields a higher hourly R^2 correlation at 12 out of 15 sites

WRF Time Series Validation: Part 2 – Diurnal Patterns

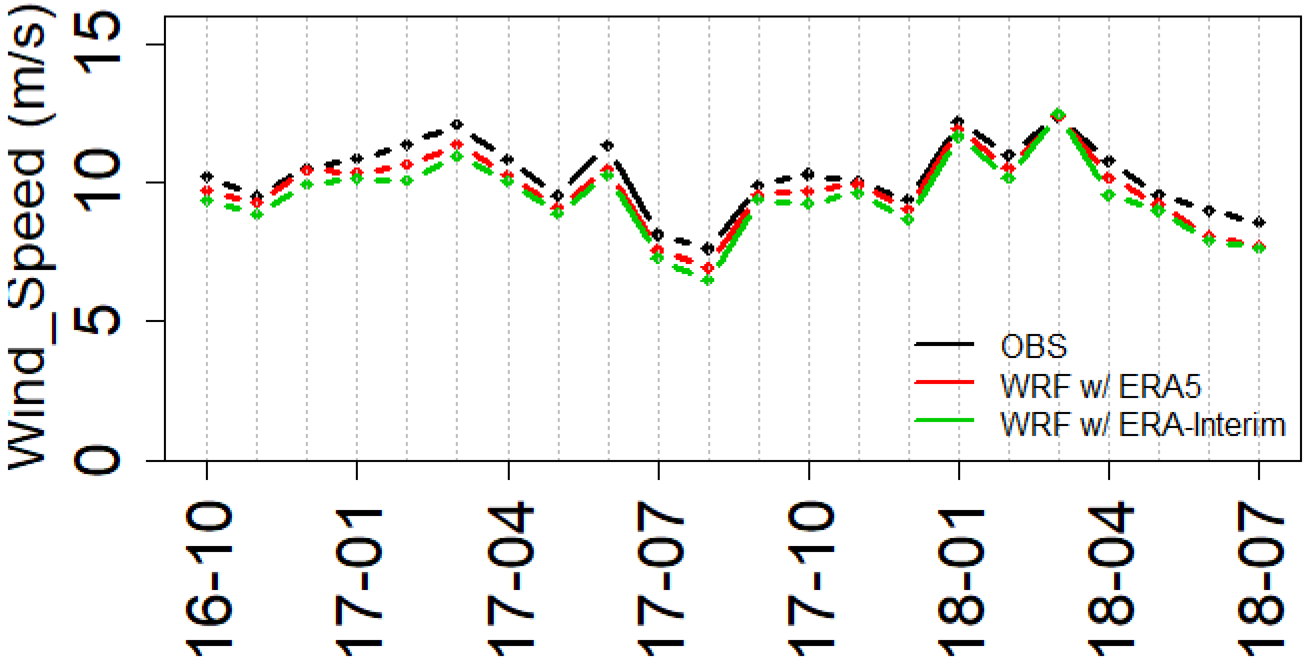
Diurnal wind patterns at Site #5



- WRF does rather well at capturing the diurnal wind patterns albeit the overall bias.
- WRF time series do not show the occasional discontinuity found in ERA5 around 9:00-10:00 UTC and 21:00-22:00 UTC

WRF Time Series Validation: Part 2 – Monthly Patterns

Monthly wind patterns at Site #5

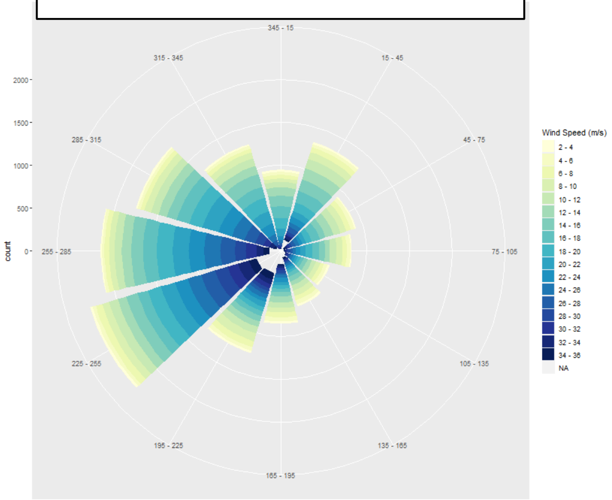


- WRF time series tend to follow the monthly wind patterns quite well.

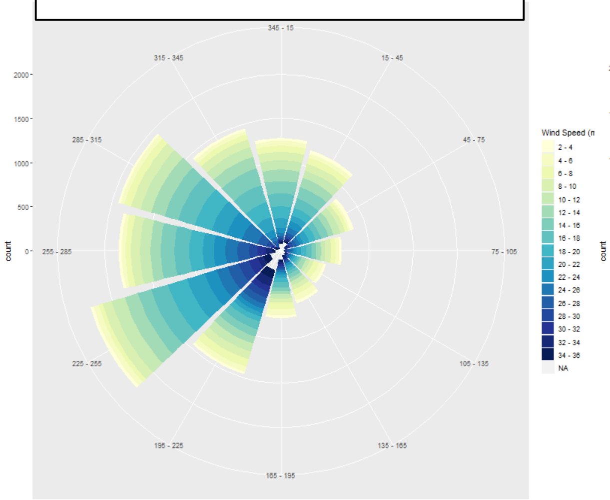
WRF Time Series Validation: Part 2 – Wind Roses

Wind roses at Site #5

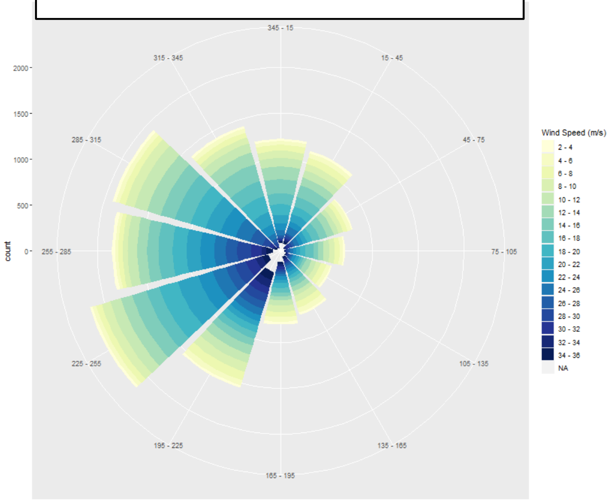
OBS



WRF w/ ERA-Interim



WRF w/ ERA5



- WRF captures reasonably well the wind roses.

Conclusion

- WRF with ERA5 performs better on average than WRF with ERA-Interim based on the error statistics shown previously although not at every single site.

- It's hard to identify a clear winner when looking at monthly and diurnal wind speed patterns or the wind roses:
  - Both WRF time series tend to match relatively well with observations albeit with a (negative) bias

Questions?
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Thank you