

**Generating Virtual
Wind Climatologies
through the Direct
Downscaling of
MERRA Reanalysis
Data using WindSim**

WindSim Americas

User Meeting

December 4th, 2014

Orlando, FL, USA

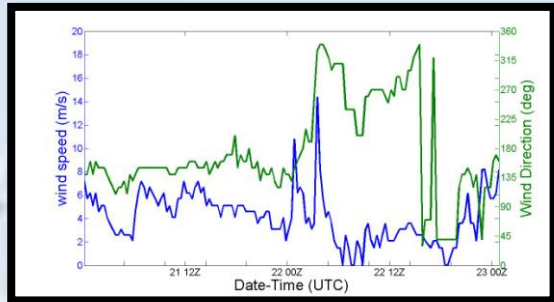
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Atmospheric Sciences
North Carolina State University**

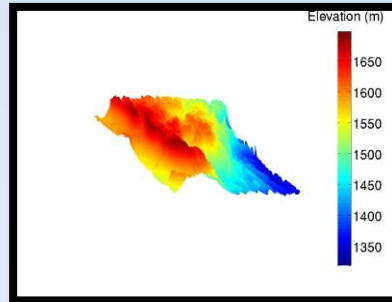
windsim

Wind Resource Assessment and Reanalysis Data

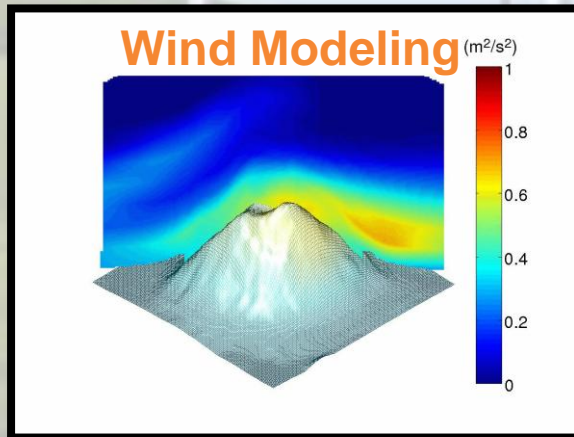
Meteorology



Geography

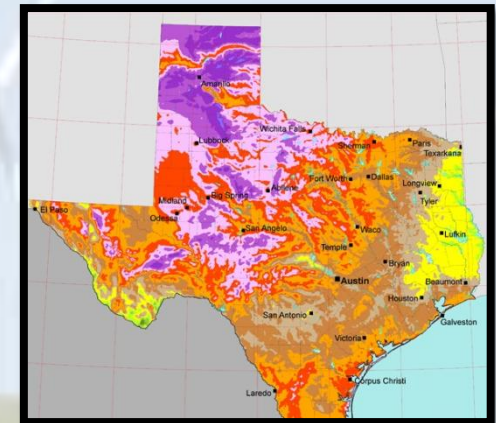


Wind Modeling (m²/s²)



Measure
Correlate
Predict

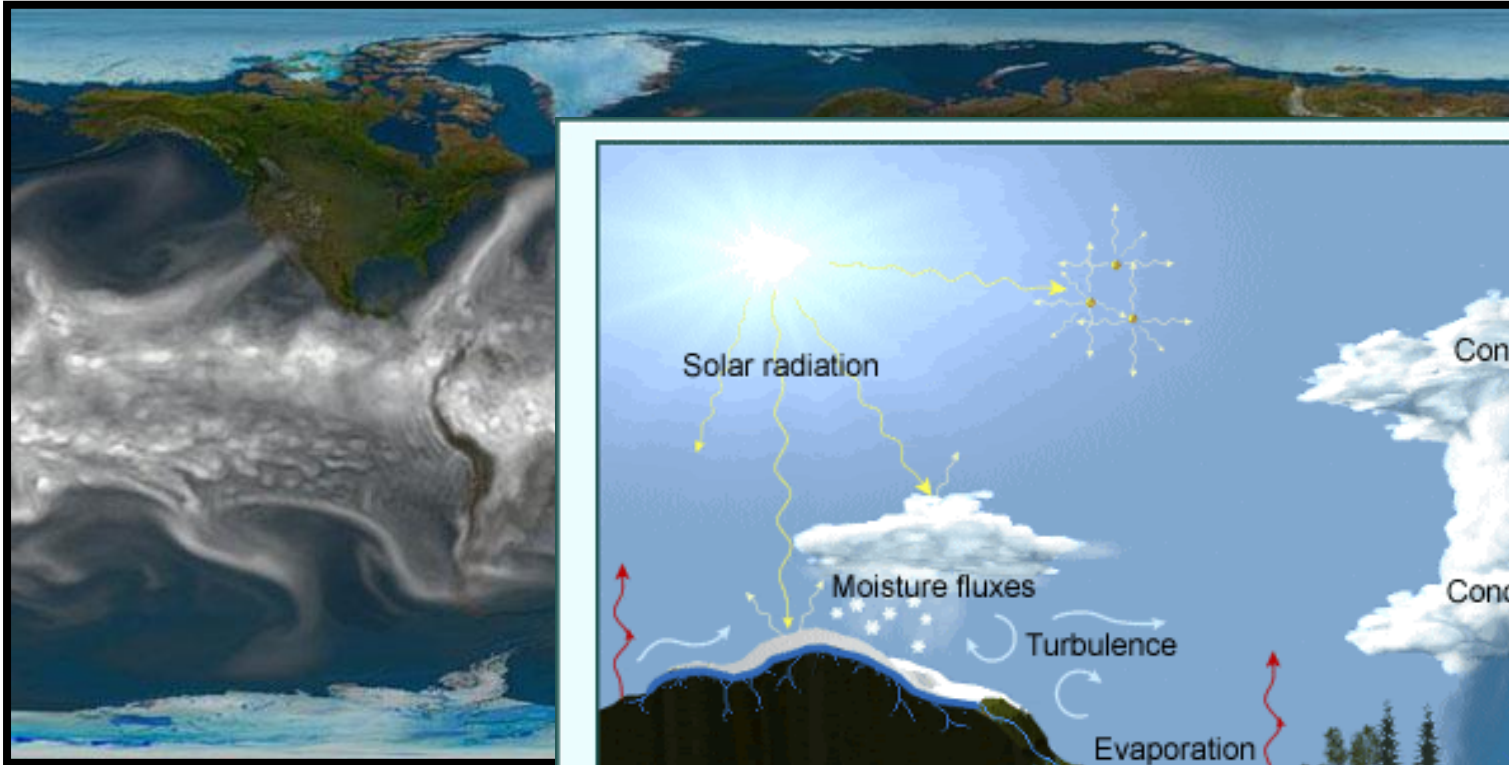
Wind Resources



Courtesy: NREL

Often times, acquiring representative and accurate wind climatology data proves most challenging...

Global Reanalysis Models

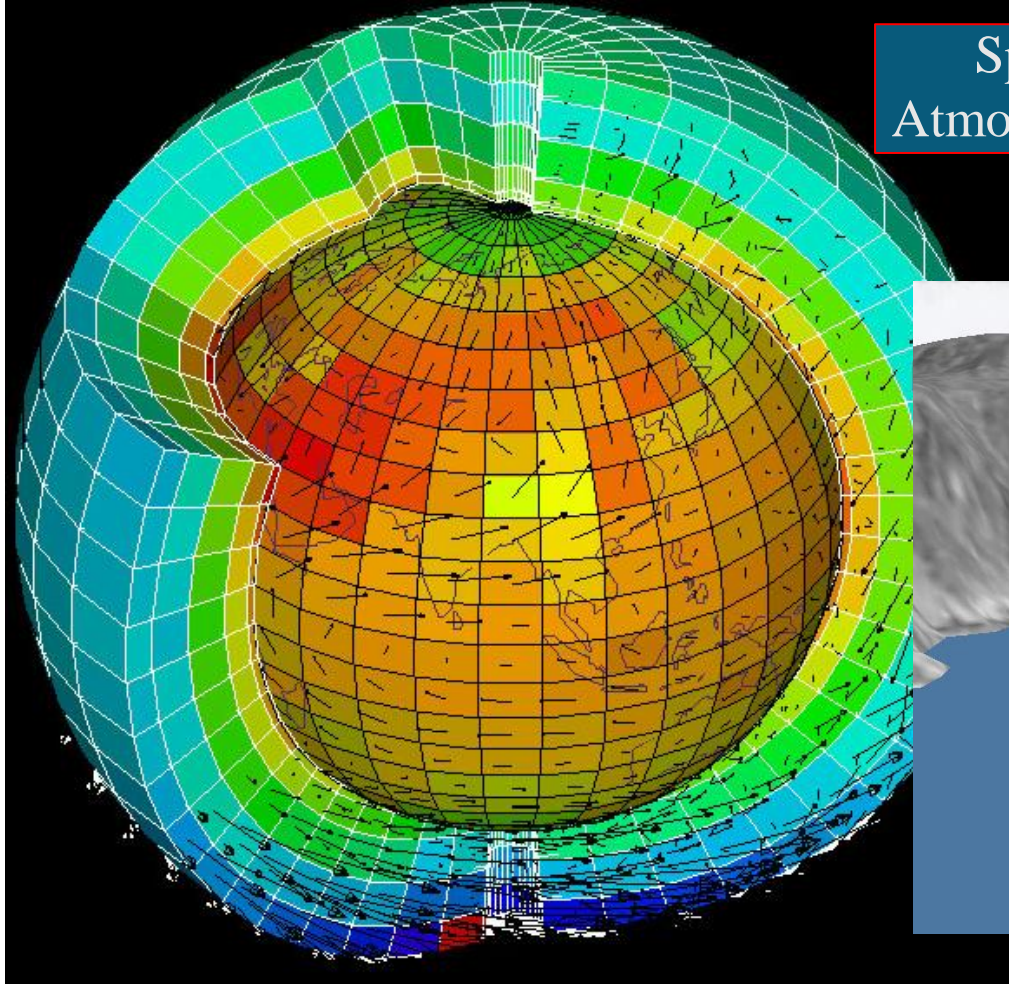


CCSM simulated instantaneous water vapor. Courtesy: University Corporation for Atmospheric Research

The COMET Program

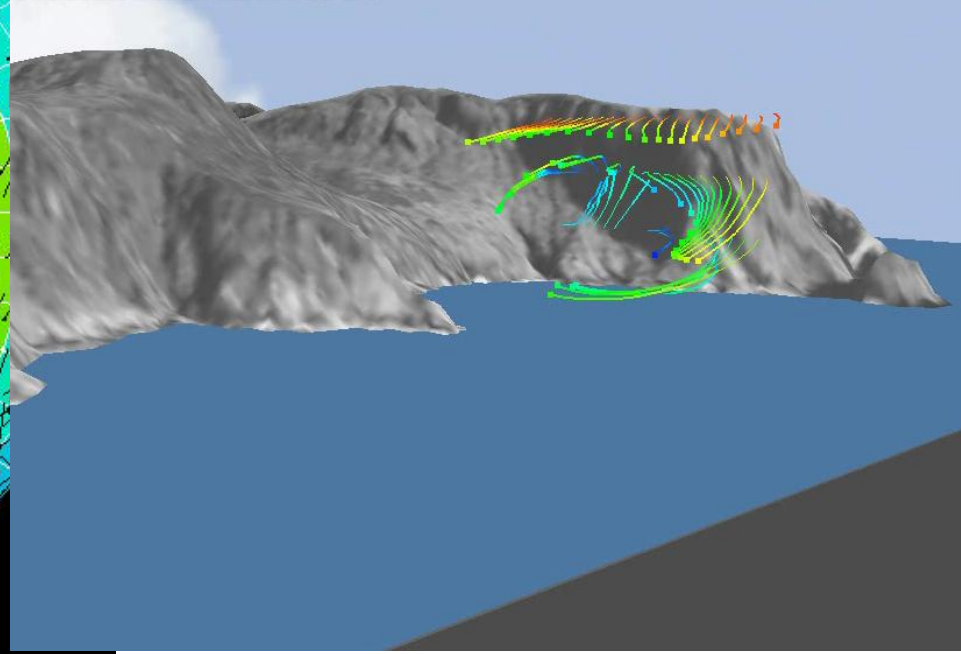
What is downscaling?

Courtesy: U. Of Toronto



Spatio-Temporal
Atmospheric Parameters

High-Resolution
Static Parameters





What are the benefits and risks associated with directly downscaling reanalysis data to the microscale?

Can we directly use mesoscale reanalysis data?



Global numerical modeling mesh. Courtesy:
UC Davis Climate and Global Change Group

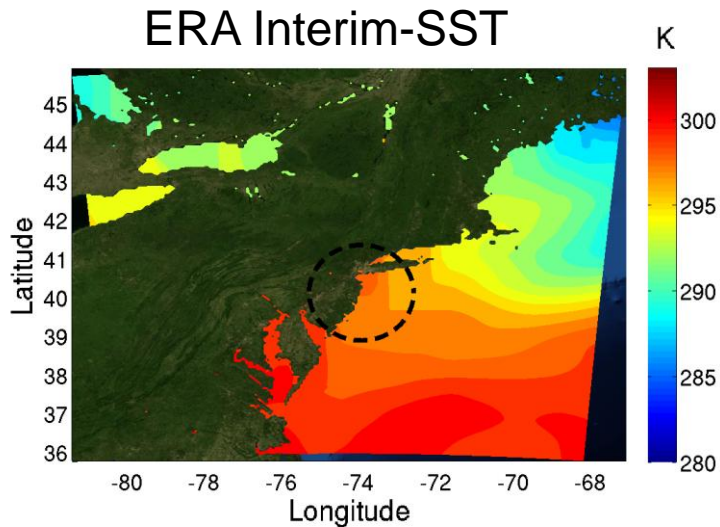
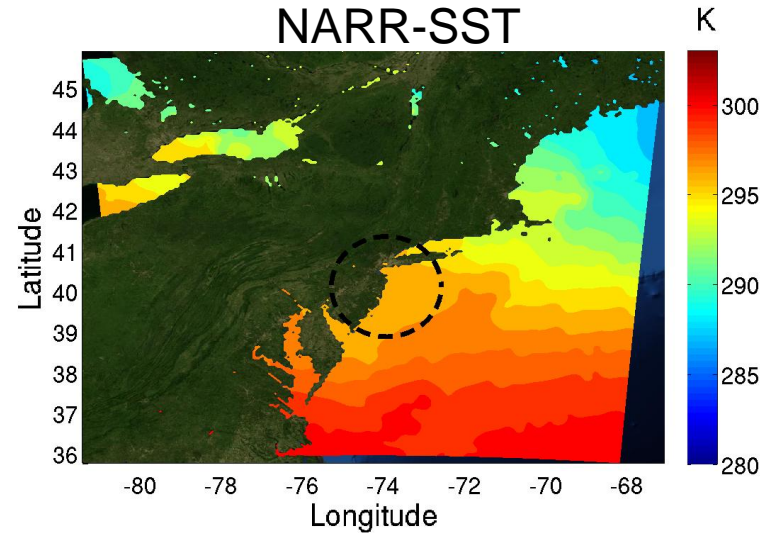
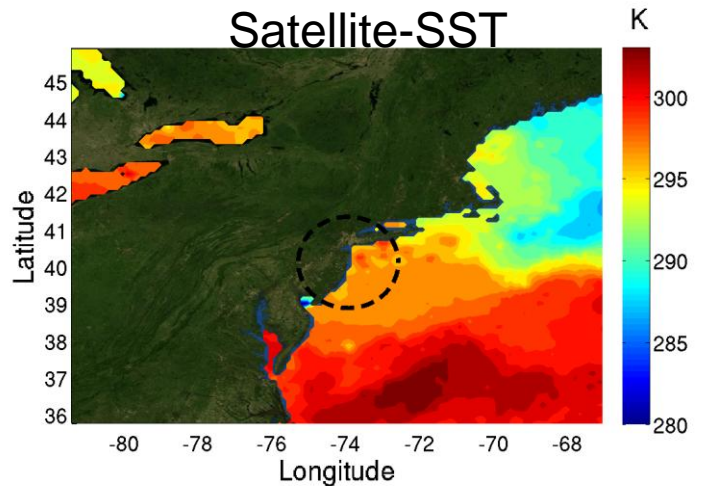
Advantages:

- Quality controlled, decades-worth of historical meteorological data
- Available for any location around the globe
- Publically available

Disadvantages:

- Course resolution (~50km or greater horizontally)
- Parameterized turbulence, surface layer, etc.
- May contain model bias or sensitivities

Variability in Reanalysis Data

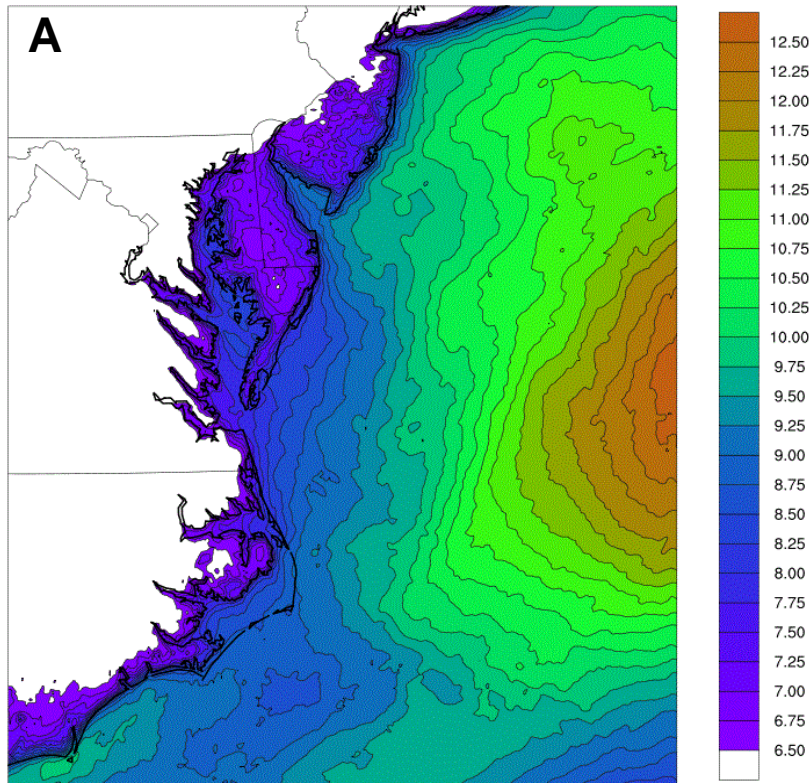


**Differences in
observational data
assimilation strategies**

Nunalee and Basu (2013), In: Wind Energy

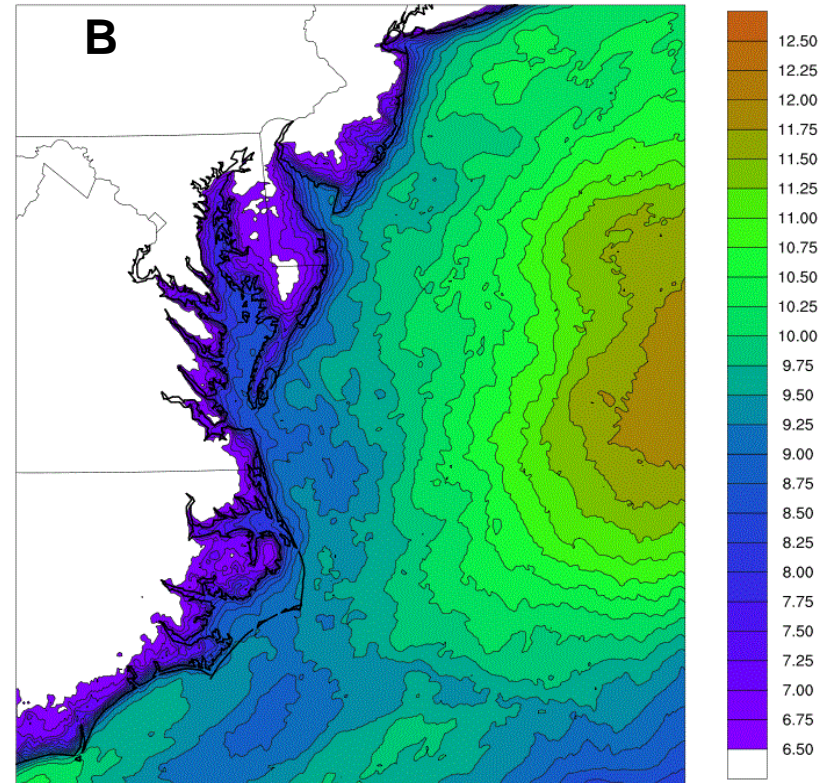
Mesoscale Models are Very Sensitive

Yonsei University Parameterization Scheme (YSU)



90-meter average wind speed (m/s)

Mellor-Yamada-Janjic Scheme (MYJ)

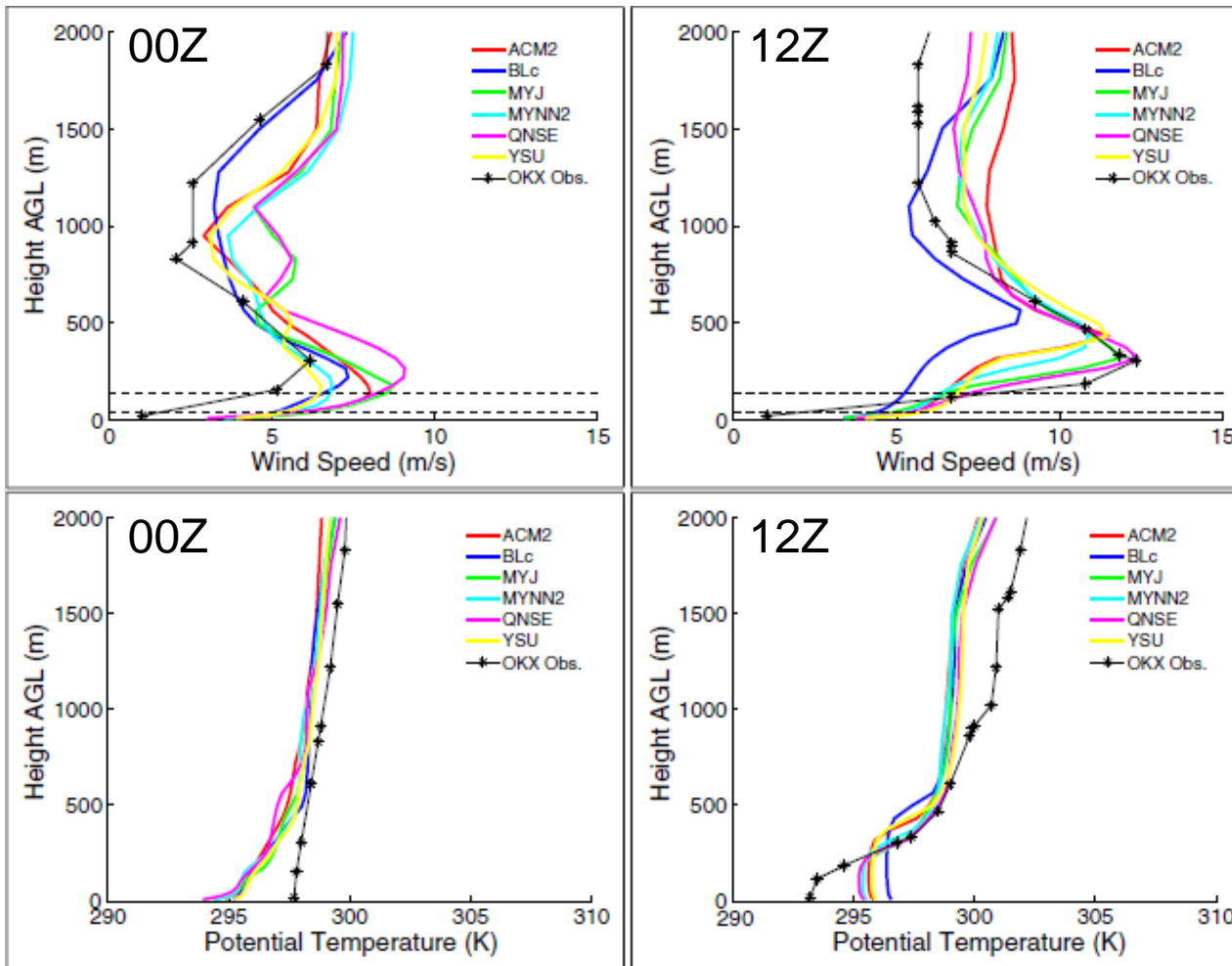


90-meter average wind speed (m/s)

Two WRF-ARW simulations run using YSU (A) and MYJ (B) turbulence parameterization schemes over a 5-day time period. All other configurations and input conditions are identical.

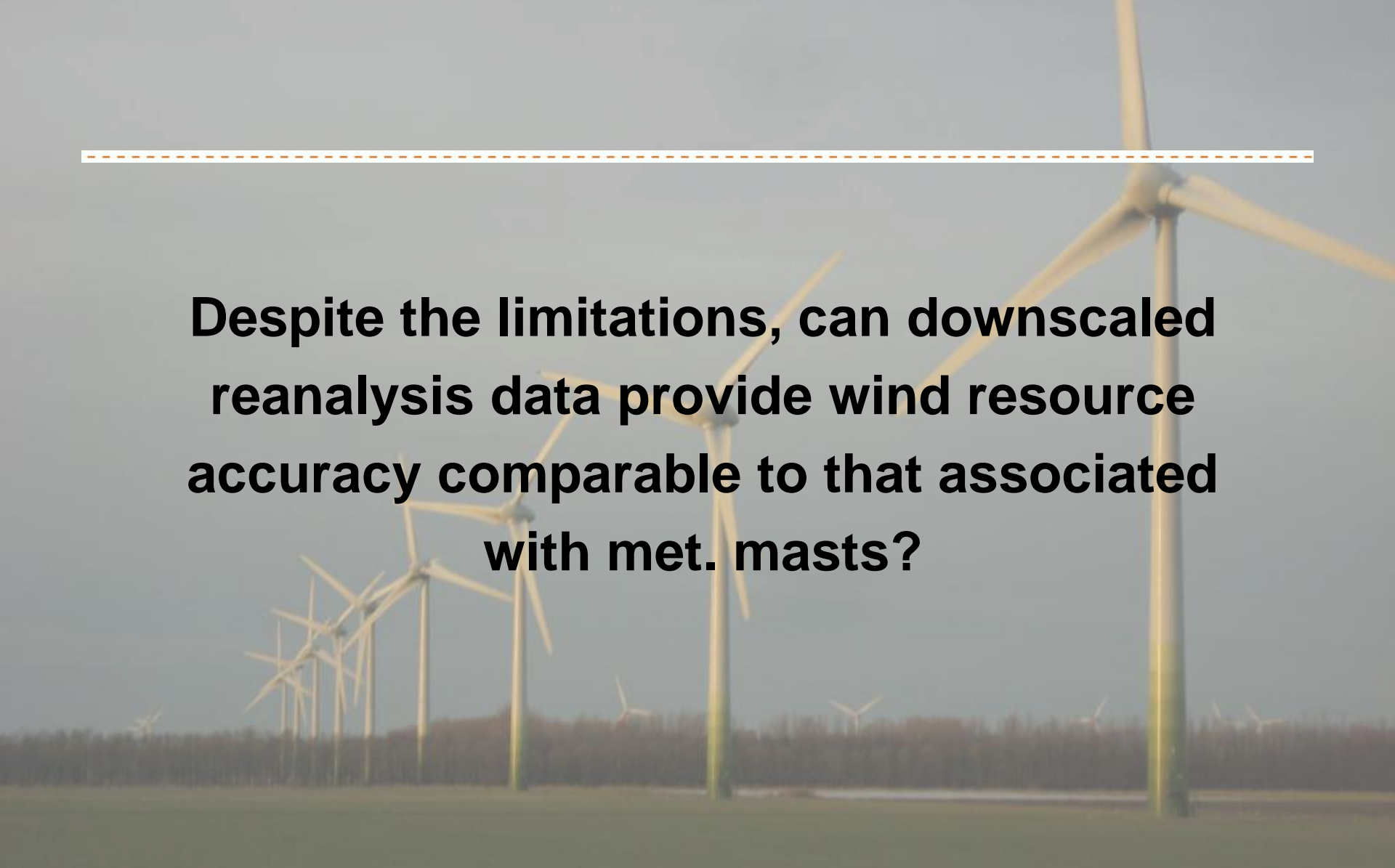
Figures: Nunalee (2011)

Model Sensitivity to Turbulence Parameterization



Nunalee and Basu (2013), In: Wind Energy

Instantaneous vertical profiles of wind speed and potential temperature during a low-level jet event along the East coast of the U.S. in 2011.



Despite the limitations, can downscaled reanalysis data provide wind resource accuracy comparable to that associated with met. masts?

NASA's MERRA Dataset

"Modern-Era Retrospective analysis for Research and Applications" (MERRA)

Extensive data assimilation system synthesizing a vast suite of observational and modeled datasets

Statistics:

Data from 1979 - current

1/2 degree latitude

2/3 degree longitude

72 vertical levels

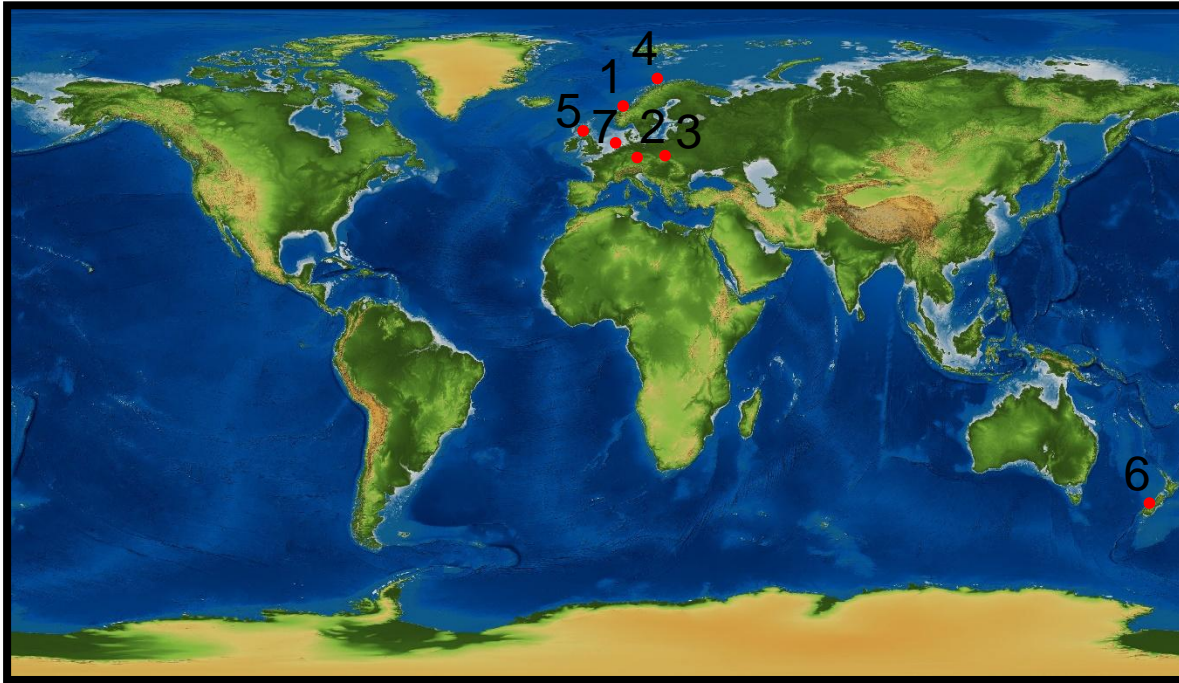
The screenshot shows the NASA Earth Data website interface. At the top, there are navigation links for Data Discovery, Data Centers, Community, Science Disciplines, and Search EOSDIS. The main header features the NASA logo and the text "GES DISC Goddard Earth Sciences Data and Information Services Center". Below this, there are tabs for "GES DISC Home", "Data Services", "Science Portals", and "Mission Portals". The "Mission Portals" tab is active, showing a list of data services including A-Train, AIRS, Aura, Modeling, MEaSUREs, SORCE, TRMM, and More... The "MDISC Modeling and Assimilation" section is highlighted, and a sidebar on the left lists "DATA HOLDINGS" (MERRA Products, MERRA Gridded Innov Obs, MERRA Data Subset, Mirador) and "DOCUMENTATION". The main content area shows the "MDISC Data Subset" page with a "Data Product" dropdown menu set to "IAU 2d atmospheric single-level diagnostics (tavg1_2d_slv_Nx)". Below this is a "Spatial Search" section with a map of the United States and a cursor at coordinates -148.00781, 27.77344. The map shows various geographical features and labels for countries like Greenland, Russia, China, India, and Australia.

<http://disc.sci.gsfc.nasa.gov/daac-bin/FTPSubset.pl>

Evaluation Method

- **Identify 7 sites with meteorological mast data and generate virtual wind climatology for each of those sites**
 - Download raw MERRA time series data for area of interest
 - Check for biases and, if needed, apply in-house bias correction
 - Generate virtual wind climatology and associated wind resource map by scaling WindSim model against unbiased MERRA data
- **Statistically compare MERRA-based and met. mast-based wind resource metrics (e.g., Weibull distribution, mean wind speed) assuming the met. masts are “the truth”**
- **If power production data is available, use MERRA-based wind resource map to estimate AEP and compare to performance data and met. mast-based estimate**

Case Studies



Locations of the seven sites used in this study.

Case	Surface Characteristics
1	Complex-Coastal/Smooth
2	Flat/Forested
3	Very Rugged/Forested + Fields
4	Small Hills/Smooth
5	Small Hills/Forest + Grassland
6	Small Trenches/Low vegetation
7	Offshore

Case Studies (1 and 2)

(1) Norwegian Wind Farm:

- Complex terrain (land-sea Interface, rugged coastline)
- 17 Wind turbines (2.3 MW Siemens 80 m hub height)
- Power production/met. mast wind data generously provided by Statkraft/Agder Energy



(2) Karlsruhe, Germany:

- Met. mast with 7 years of wind measurements (40 & 100 m AGL)
- Locally flat river basin but dense, forested areas nearby

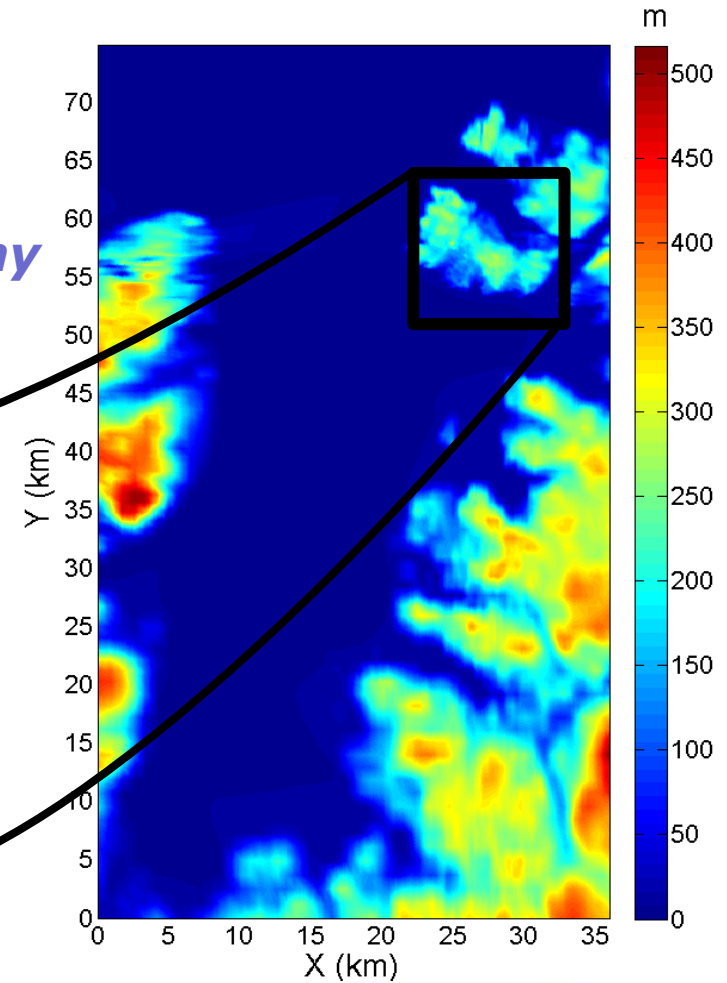
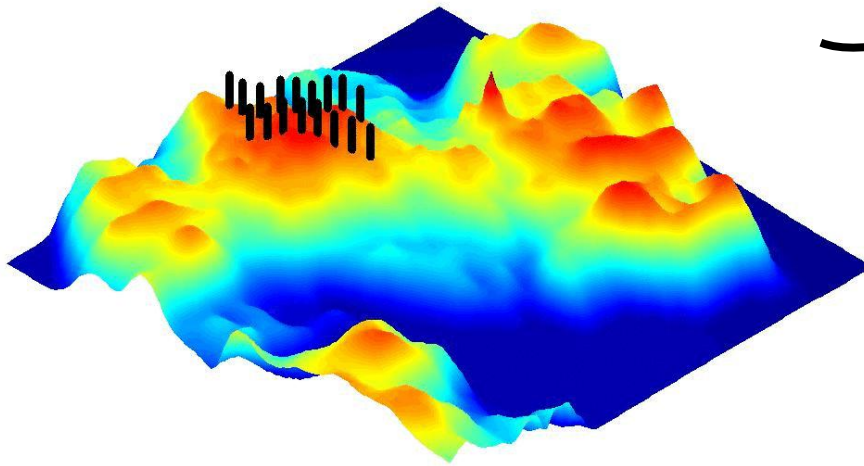
Norwegian Wind Farm (Background)

Terrain Height: Sea Level → 500 m

Roughness Lengths: $1e-4$ → 1.4

Inclination Angles: up to 49°

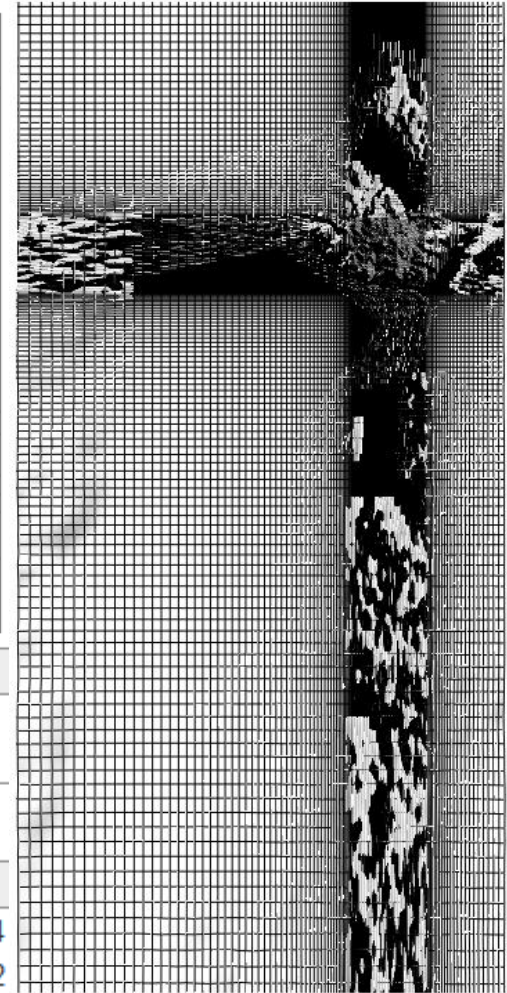
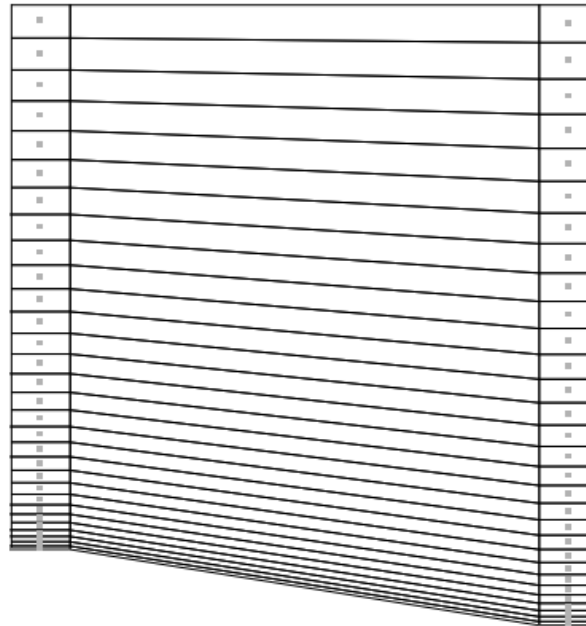
**Rugged coastal area, steep topography*



Norwegian Wind Farm (Background)

Simulation Stats:

- 2.5 Million Cells
- Standard K- ϵ Model
- Neglected Buoyancy



Horizontal Resolution

	x	y	z	total
Grid spacing, min - max (m)	29.5 - 870.7	29.2 - 1260.2	Variable	-
Number of cells	266	313	30	2497740

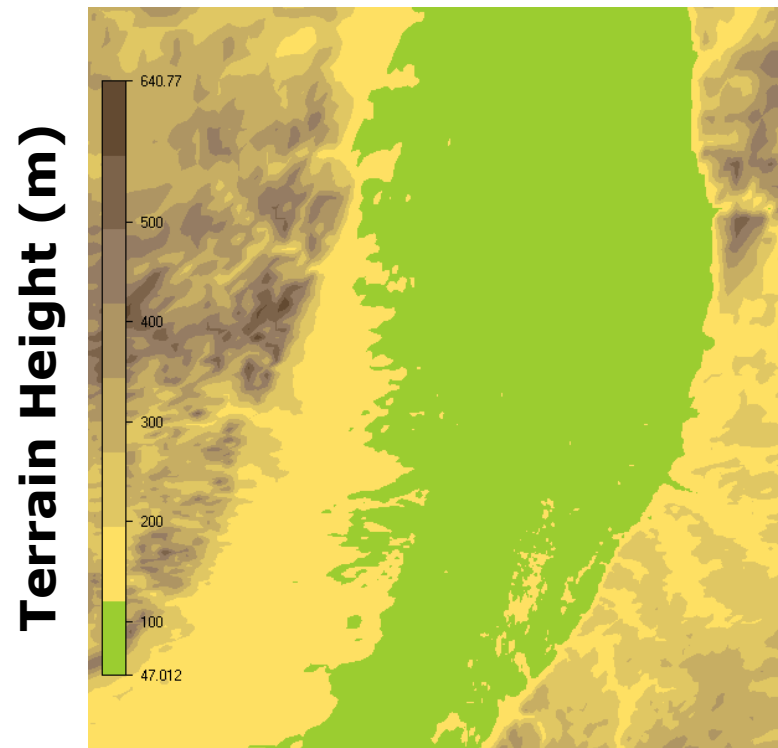
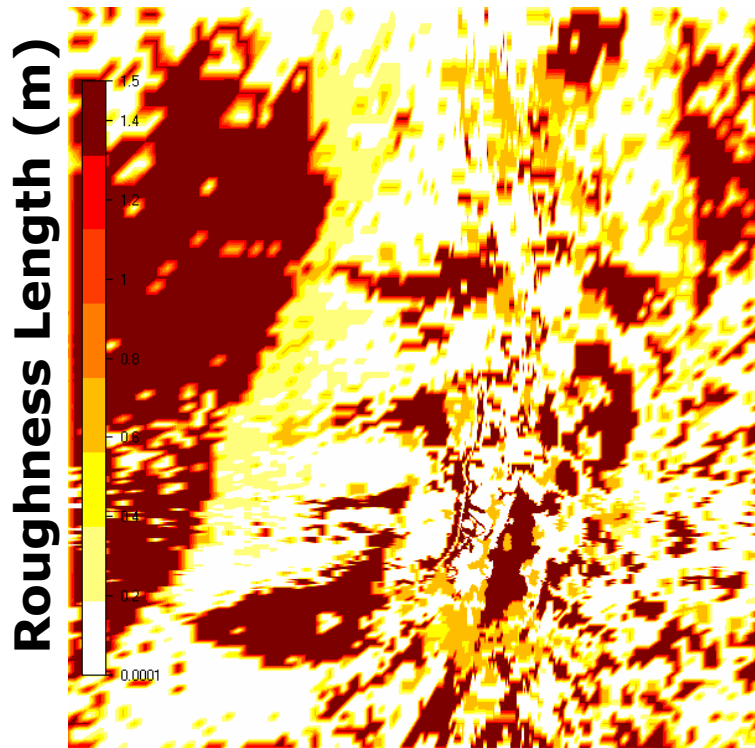
Vertical Resolution

	1	2	3	4	5	6	7	8	9	10
z-dist. max (m)	12.5	41.3	77.8	122.1	174.1	233.9	301.4	376.7	459.7	550.4
z-dist. min (m)	14.2	47.0	88.7	139.2	198.5	266.6	343.5	429.3	523.8	627.2

Karlsruhe (Background)

Terrain Height: 47 → 640 m
Roughness Lengths: 1e-4 → 1.5 m
Inclination Angles: up to 21°
**Heavily forested area*

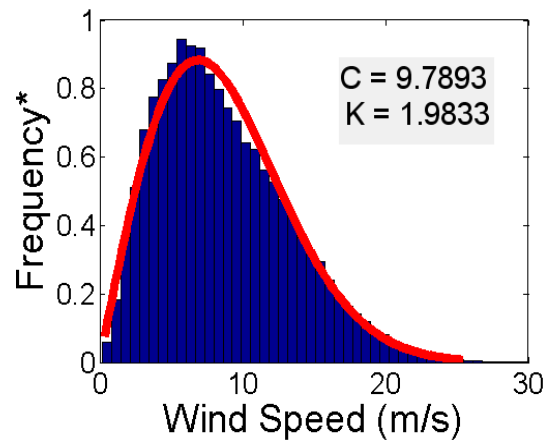
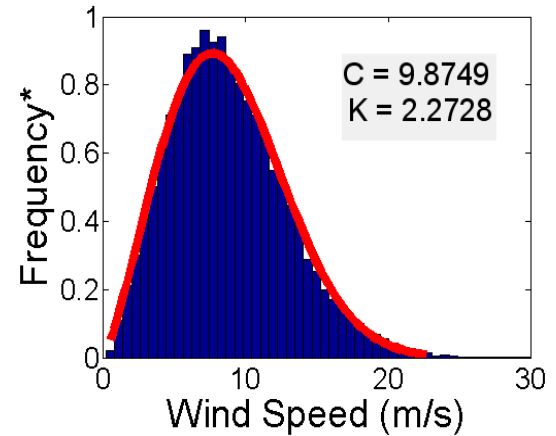
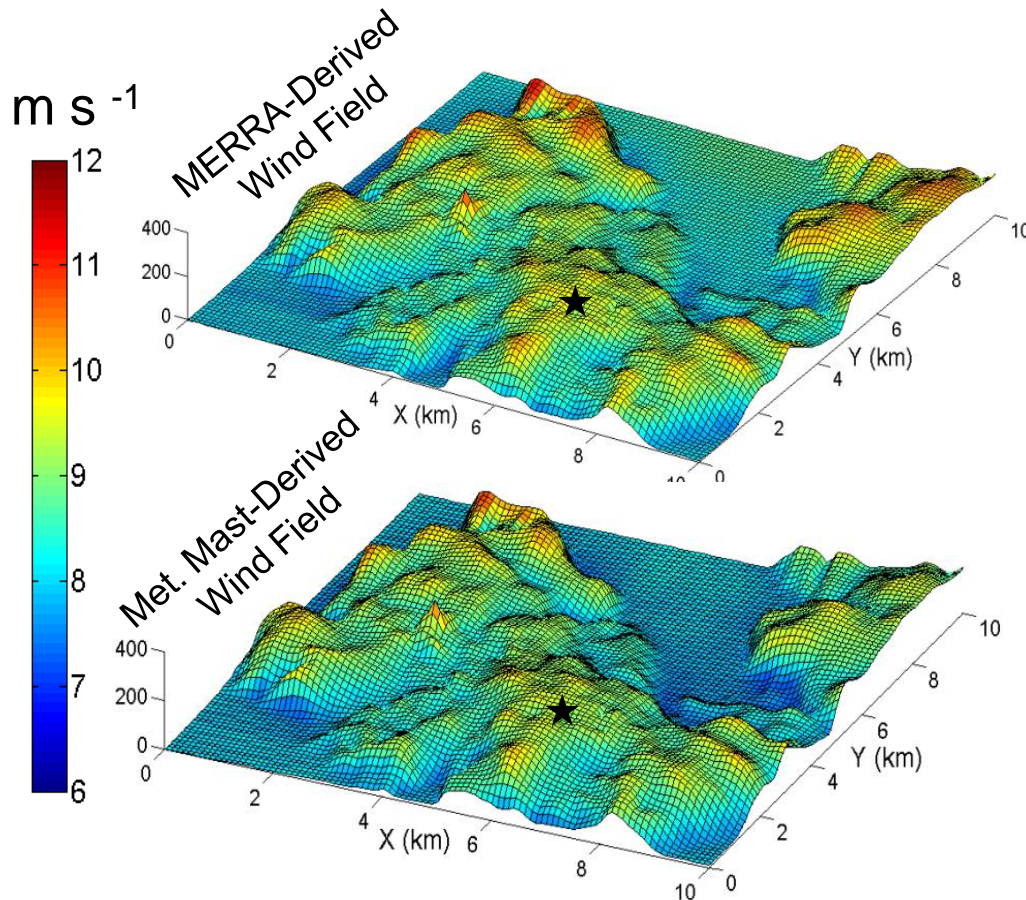
Similar simulation configuration to Norwegian Wind Farm but with Forest model activated





Results

Norwegian Wind Farm (100m Wind Resources)



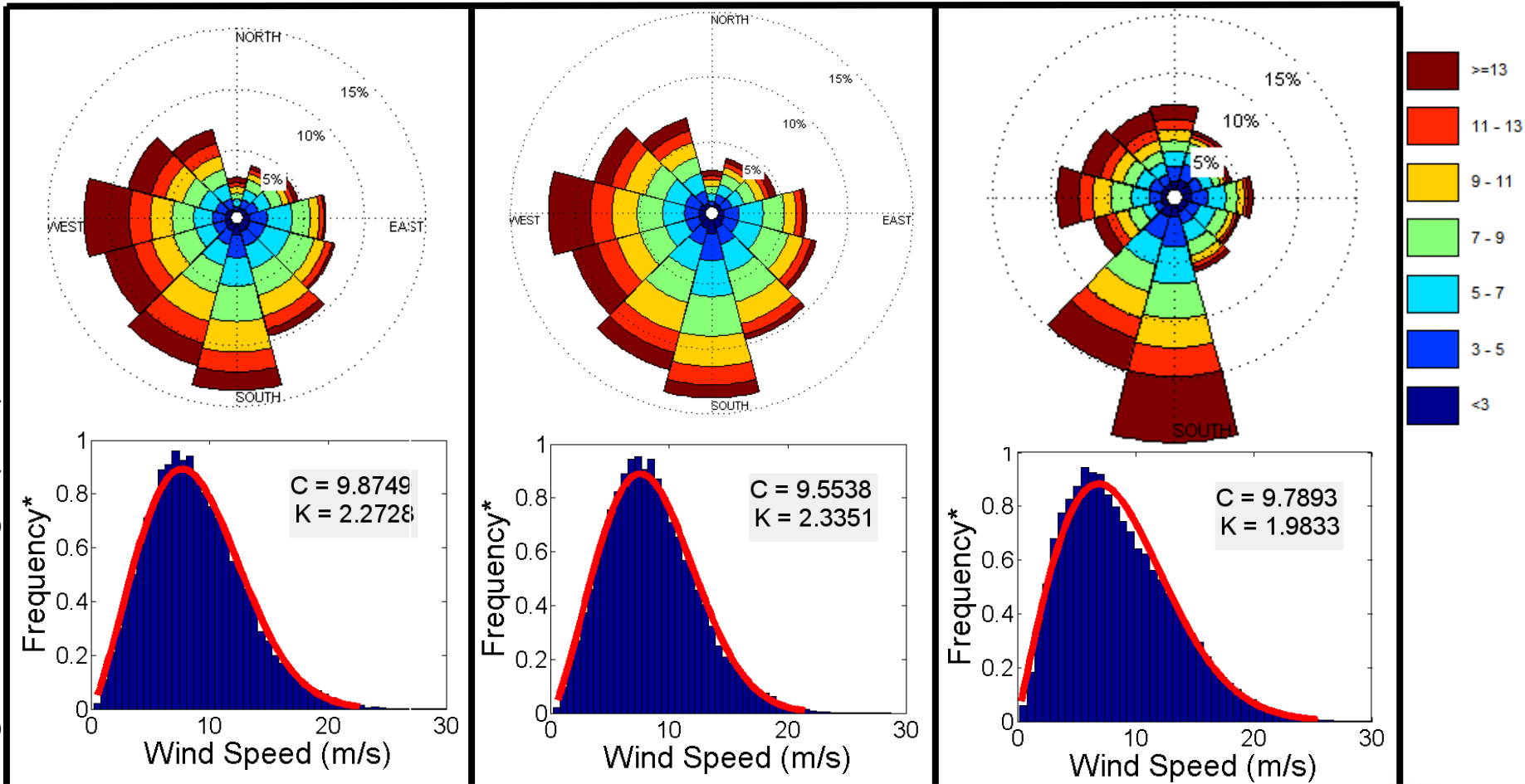
Hub Height Wind Characteristics (Norwegian Wind Farm)

RAW MERRA

Adjusted MERRA

Met. Mast

Height = Hub Height (80m)



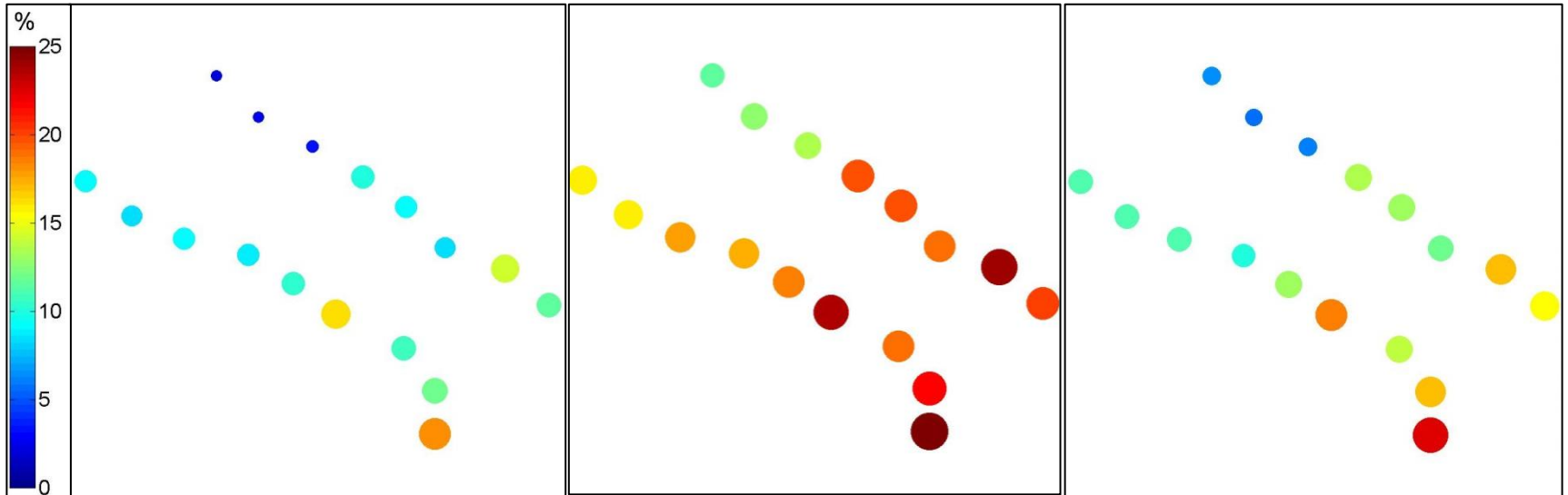
Total Facility Annual Energy Production (AEP)

- ~2.6/years of power production data
 - August 25, 2006 → October 1, 2009
- Power production data availability: **73** → **83 % per turbine**
- Assuming missing data points were not outliers, average wind farm AEP is approximately **150 GWh/y**

<i>Total Wind Farm AEP</i>	<i>Met. Mast (GWh/y)</i>	<i>RAW MERRA (GWh/y)</i>	<i>Adjusted MERRA Pts. (GWh/y)</i>
Wake Model 1	165	178	171
Wake Model 2	170	184	177
Wake Model 3	165	177	170

Turbine Specific Analysis

Percent Error With Respect to Turbine



Scaled w/ Met. Mast

Scaled w/ RAW MERRA

Scaled w/ Adjusted MERRA

Root Mean Squared Error

Met. Mast _____ 1.03

Raw MERRA _____ 2.06

Adjusted MERRA _____ 1.38

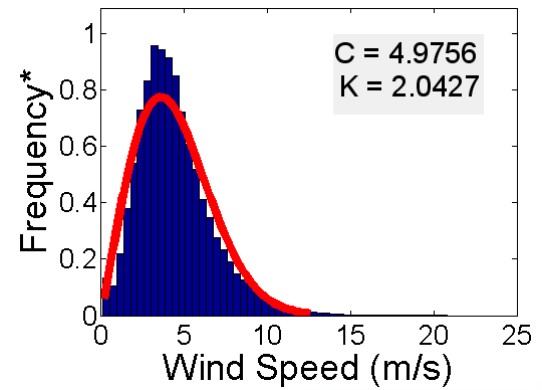
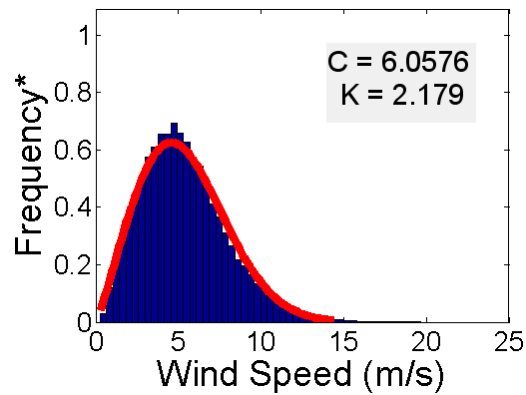
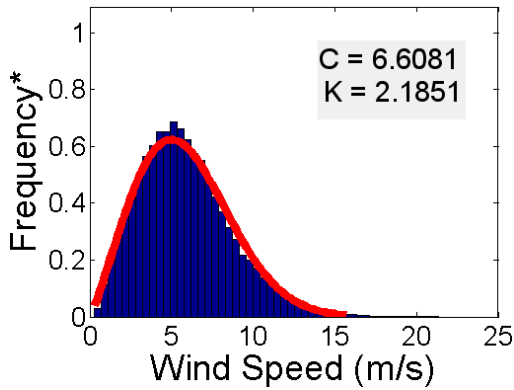
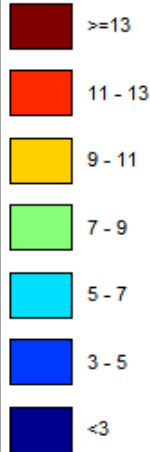
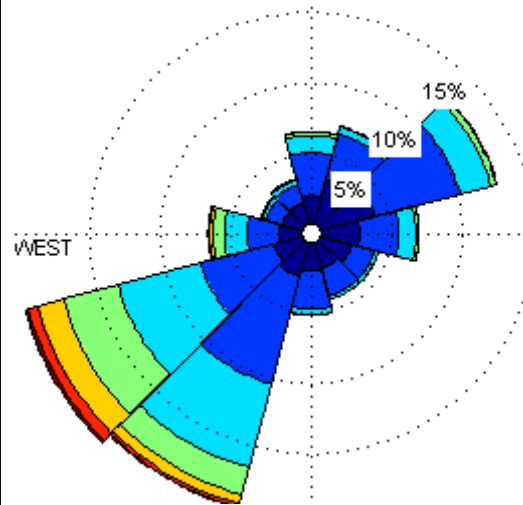
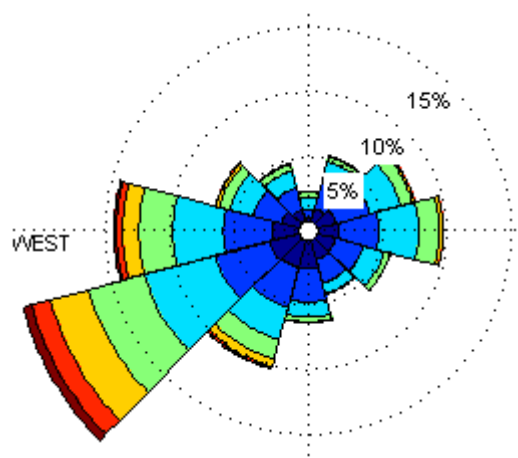
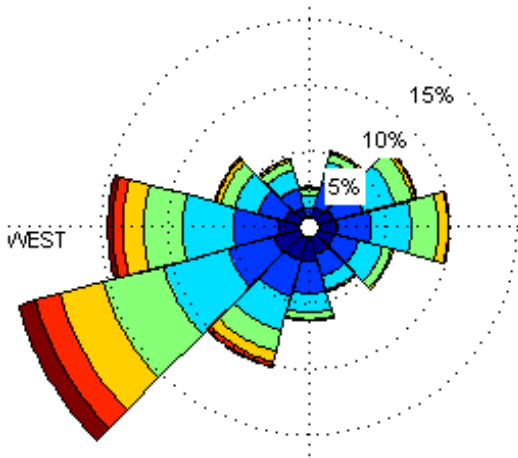
Hub Height Wind Characteristics (Karlsruhe)

RAW MERRA

Adjusted MERRA

Met. Mast

Height = Hub Height (80m)



Climatology Cross-Validation

Cross-checking MERRA data points against 50m tower measurements

Wind Farm1	<i>Simulated</i> Mean Wind Speed (m/s)	% Error (8.18 m/s mean measured wind speed)
RAW MERRA	8.67	+5.64
Adjusted MERRA	8.39	+2.51

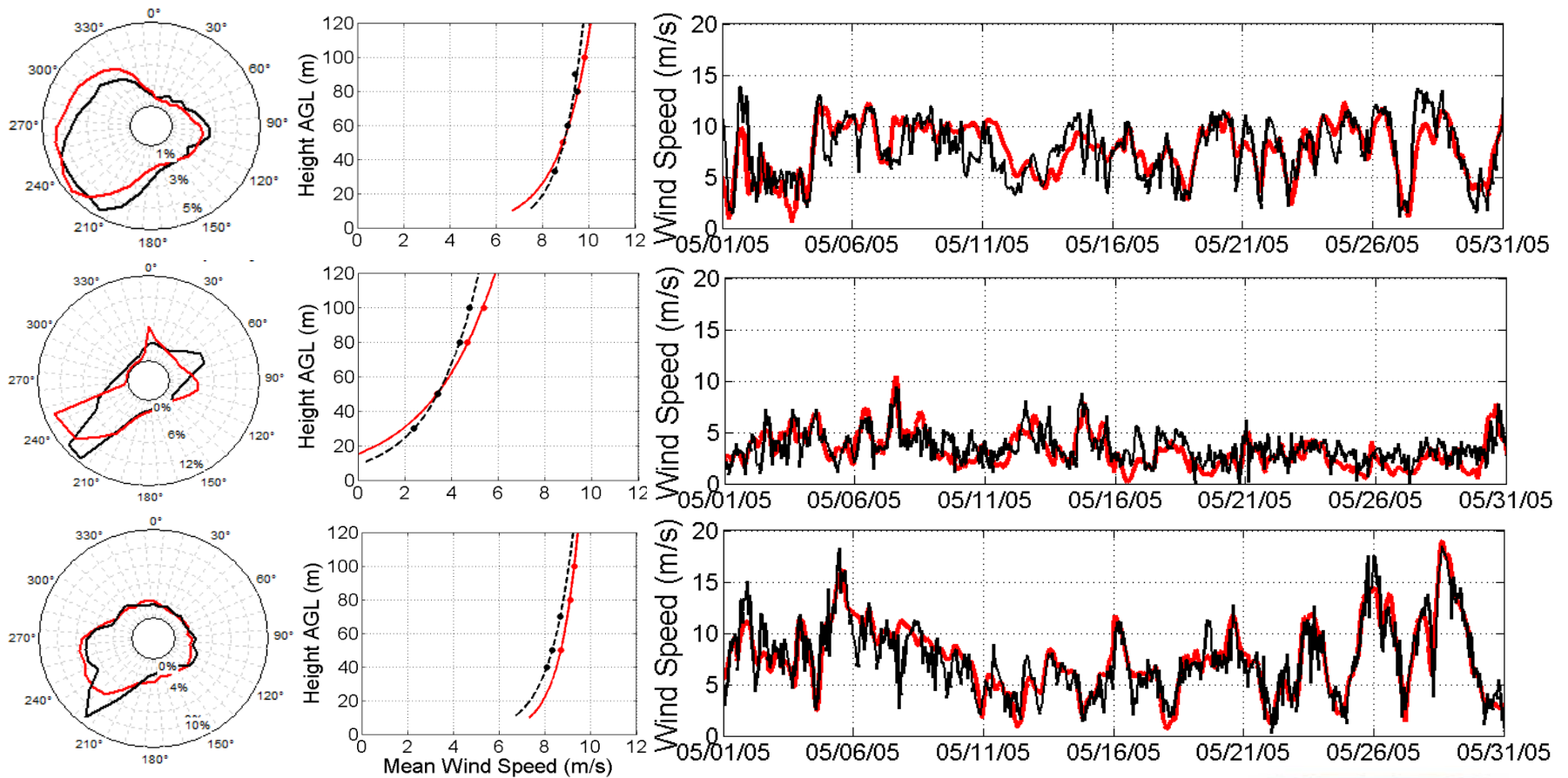
- Very rugged terrain
- High wind area

Karlsruhe	<i>Simulated</i> Mean Wind Speed (m/s)	% Error (3.45 m/s mean measured wind speed)
RAW MERRA	4.65	+25.8
Adjusted MERRA	3.62	+4.90

- Forested Terrain
- Large roughness heterogeneity

Wind Comparison

Red represents virtual climatology and black represents measurements. The three rows correspond to cases 7, 2, and 4 (in order from top to bottom).



Results

Description of cases and percent errors of virtual climatology versus met mast mean wind speed measurement.

Case	Surface Characteristics	Stability % (Neutral/Stable/Unstable)			Mean Wind Speed % Error*
1	Complex-Coastal/Smooth	16	73	11	+2.51
2	Flat/Forested	8	59	33	+4.90
3	Very Rugged/Forested + Fields	21	51	26	+15.86
4	Small Hills/Smooth	28	36	36	+6.24
5	Small Hills/Forest + Grassland	21	50	29	-10.83
6	Small Trenches/Low vegetation	12	49	39	-6.72
7	Offshore	22	54	24	-1.33

Conclusions

- **MERRA data can be used as a valuable wind climatology resource**
 - Can be used to reasonably reproduce met. mast derived wind fields
 - Power production estimates are (so far) accurate to within ~15%
- **An error correlation bias has been identified and an in-house correction algorithm is being developed**

Future Directions

- **Continue to develop MERRA bias correction algorithm**
 - Make adjustments for different surface regimes (i.e. forest, surface slope, etc.)
- **Verify technique against several other measurement sites around the world**
- **Incorporation into cloud solution...**

Virtual Wind Climatology Service

Provides time series of: *wind velocity, temperature, pressure, humidity, density, heat flux, MO length, etc.* at multiple vertical levels at 1 hour temporal resolution

Valuable for:

- Long term correction (MCP)
- Identification of potential sites for wind farm project
- Measurement campaign design
- Turbine Layout design
- Siting and energy assessment of small wind turbines
- Other applications where meteorological observation are not available (eg. pollution dispersion modeling)

Virtual Wind Climatology Service

Any length of time can be delivered; reaching back to 1979. For reference, a 10 yr dataset is approximately 15 MB and deliverable in less than 24 hours.

Location:
Easting:
Northing:
Zone:

Invalid=9999

Timestamp	Spd50m (m/s)	Dir50m (°)	Spd80m (m/s)	Dir80m (°)	Temp10m (°C)	qv10m (Kg/Kg)			
2013-05-28 00:00:00	3.73	240.60	4.07	242.23	5.45	0.0060	100982.92	90556.26	4.90
2013-05-28 01:00:00	3.64	237.68	3.95	239.13	5.12	0.0059	100920.60	90498.64	4.43
2013-05-28 02:00:00	3.48	234.18	3.76	235.44	4.83	0.0058	100866.00	90448.78	4.00
2013-05-28 03:00:00	3.37	228.99	3.62	230.10	4.80	0.0057	100819.75	90411.42	4.00
2013-05-28 04:00:00	3.10	224.68	3.32	224.79	5.78	0.0058	100777.39	90376.88	5.65
2013-05-28 05:00:00	2.74	223.55	2.91	223.33	7.33	0.0061	100747.83	90356.10	7.54
2013-05-28 06:00:00	2.61	234.37	2.83	236.05	9.98	0.0064	100728.69	90343.94	10.39
2013-05-28 07:00:00	2.65	250.06	2.92	251.64	12.17	0.0065	100689.84	90316.78	12.76
2013-05-28 08:00:00	2.76	261.04	3.04	261.98	13.53	0.0065	100625.60	90263.57	14.23
2013-05-28 09:00:00	2.60	265.38	2.87	266.04	14.28	0.0065	100570.56	90221.80	15.00
2013-05-28 10:00:00	2.46	263.30	2.71	264.11	14.77	0.0066	100534.27	90191.36	15.44
2013-05-28 11:00:00	2.37	257.36	2.60	258.50	14.81	0.0067	100498.76	90159.36	15.31 ...

<http://windsim.com/consulting-services/virtual-wind-data.aspx>

Acknowledgement

WindSim Team

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Li Di

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Thank you!