Creating the Wind Dataset for the Western Wind and Solar Integration Study (WWSIS)

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Overview

- A wind integration study quantifies the effects of wind energy on a power system.
- To be effective, an integration study must accurately model *non-existent* wind energy installations.
- This presentation describes the creation the largest dataset to be used in a wind integration study to date.

Overview

- The scope was to model an area of over four million square kilometers,

  ...at a one arc-minute spatial resolution (<2km)

  ...at a ten-minute temporal resolution

  ...for a three-year period

- A subset of points was modeled as potential wind projects (a subset of which will be used by GE to model build-out scenarios).

Introduction

- Some of the very early wind integration studies overlooked the importance of accurate wind energy modeling.
- However, recent studies have realized the additional value from accurate wind modeling…

Introduction

"*A state-of-the-art wind-integration study typically devotes a significant effort to obtaining wind data that are derived from large-scale meteorological modeling that can re-create the weather corresponding to the year(s) of load data used.*"

J.C. Smith et al., "Utility Wind Integration and Operating Impact State of the Art", IEEE Transactions on Power Systems - Special Section on Wind Energy, 2007.

The Importance of Mesoscale Modeling

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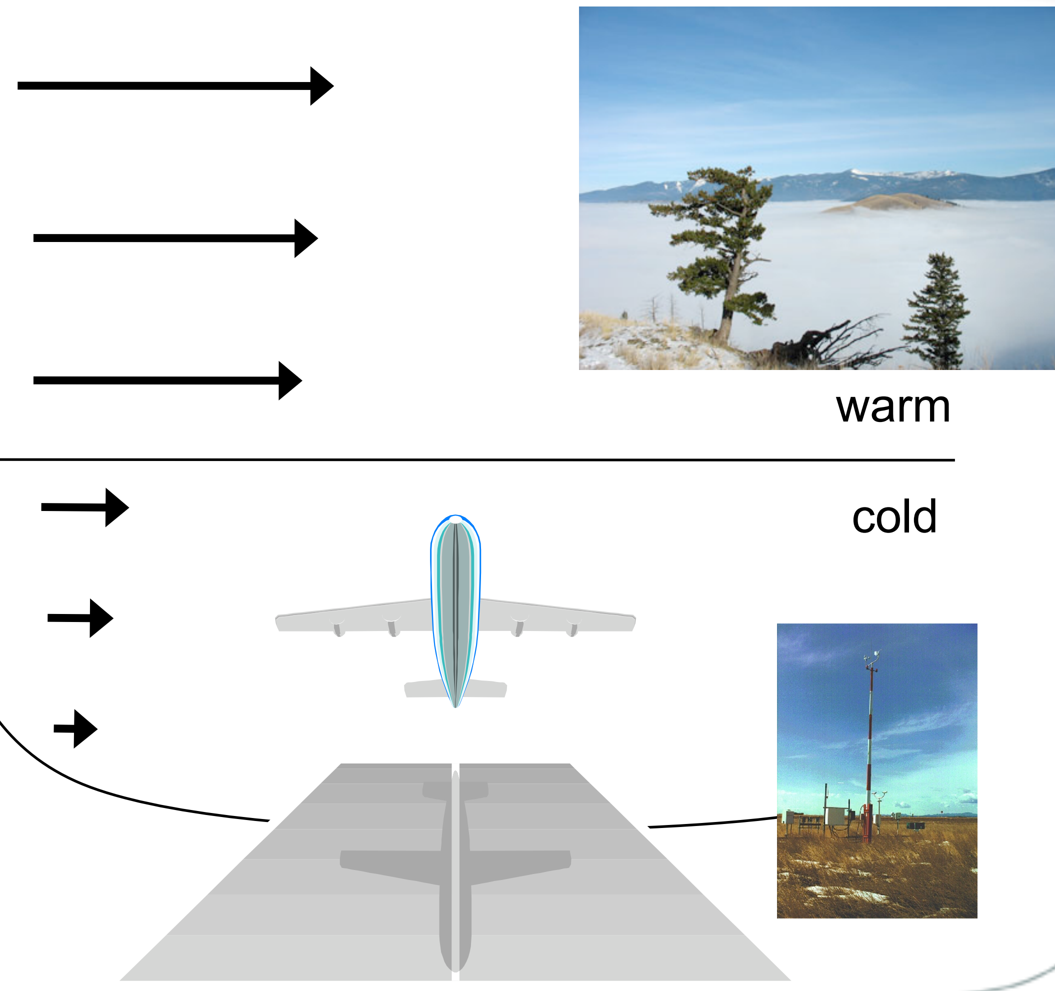
Measure-Correlate-Predict (MCP) is not a reliable way to evaluate weather at another site.

Meteorological processes causing the wind at the project site and the long-term reference location can be quite different!



Mesoscale Numerical Weather Modeling

- This technique is very well suited to providing data for an integration study:
  - Works for any year in the last few decades
  - Based on physical conservation equations (mass, energy and momentum)
  - Can provide desirable temporal and spatial resolution data (within practical limits)
  - Does not require on-site measurements, for data set creation, allowing modeling in any location (however, observations are needed at a number of locations for validation)

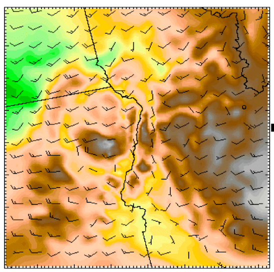
Mesoscale Numerical Weather Modeling

- The technique is not without disadvantages:
  - Models provide only an approximation of the physical world - the results are not perfect
  - Model errors can be systematic and show a characteristic pattern (such as slower ramp rates)
  - NWP models are computationally expensive
- Nevertheless, the advantages outweigh the disadvantages - and often NWP modeling is the only real option.

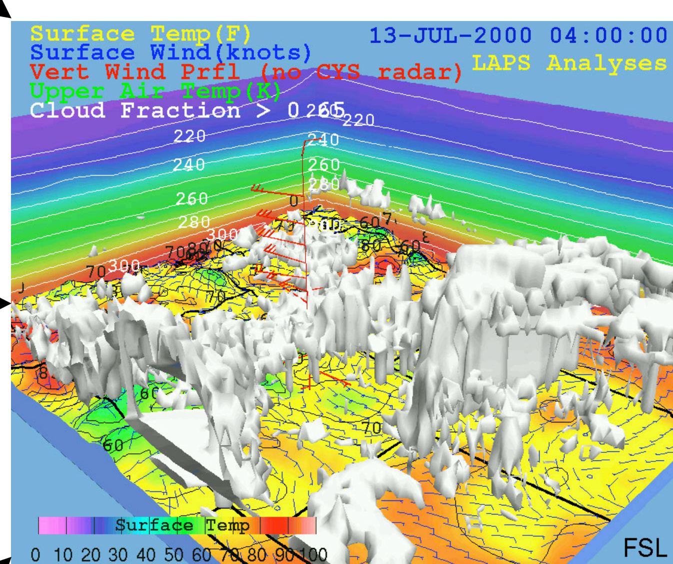
Weather Modeling Framework

Global Weather Archive 1948-present

High Resolution Terrain, Soil and Vegetation Data



Onsite Observations



Understanding of wind characteristics

Long-term variability assessments

Spatial wind maps

INPUTS

ANALYSIS

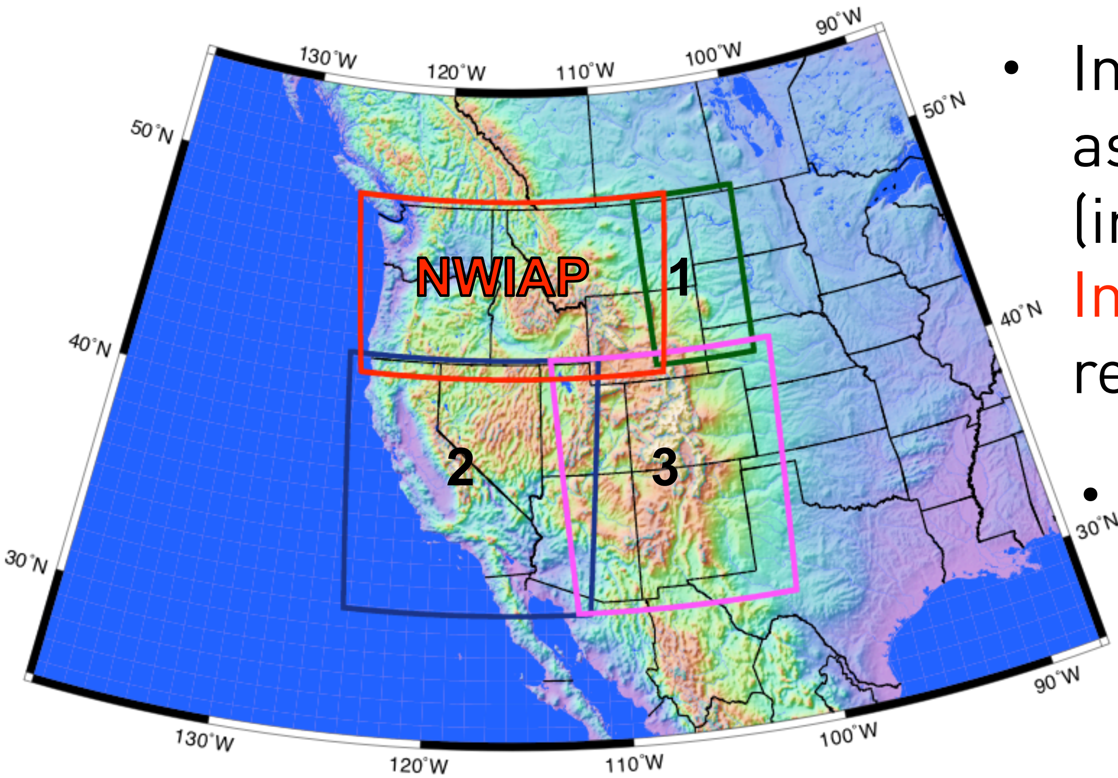
OUTPUTS

Creating the WWSIS Dataset

The Mesoscale Modeling Process

Creating the WWSIS Dataset

- The area covered by the WWSIS dataset was too large to model as a single area.



- Instead it was modeled as four separate domains (including the Northwest Integration Action Plan region – in red).
  - Later these domains were combined into a single dataset.

Creating the WWSIS Dataset

- Each of the domains were modeled individually.
- To optimize the model behavior, trial runs were made using different configurations:

NWP Configurations Using the Advanced Research WRF Core

	Vertical Levels	Planetary Boundary Layer Parameterization	Elevation Dataset	Land Surface
A	31	Yonsei University	30 arc-second USGS	5-layer soil diffusivity
B	31	Mellor-Yamada-Janjic	30 arc-second USGS	5-layer soil diffusivity
C	31	Yonsei University	30 arc-second USGS	Oregon State Uni.
D	37	Yonsei University	30 arc-second USGS	5-layer soil diffusivity

Creating the WWSIS Dataset

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Domains 1, 2, 3	D	37	Yonsei University	30 arc-second USGS	5-layer soil diffusivity

Creating the WWSIS Dataset

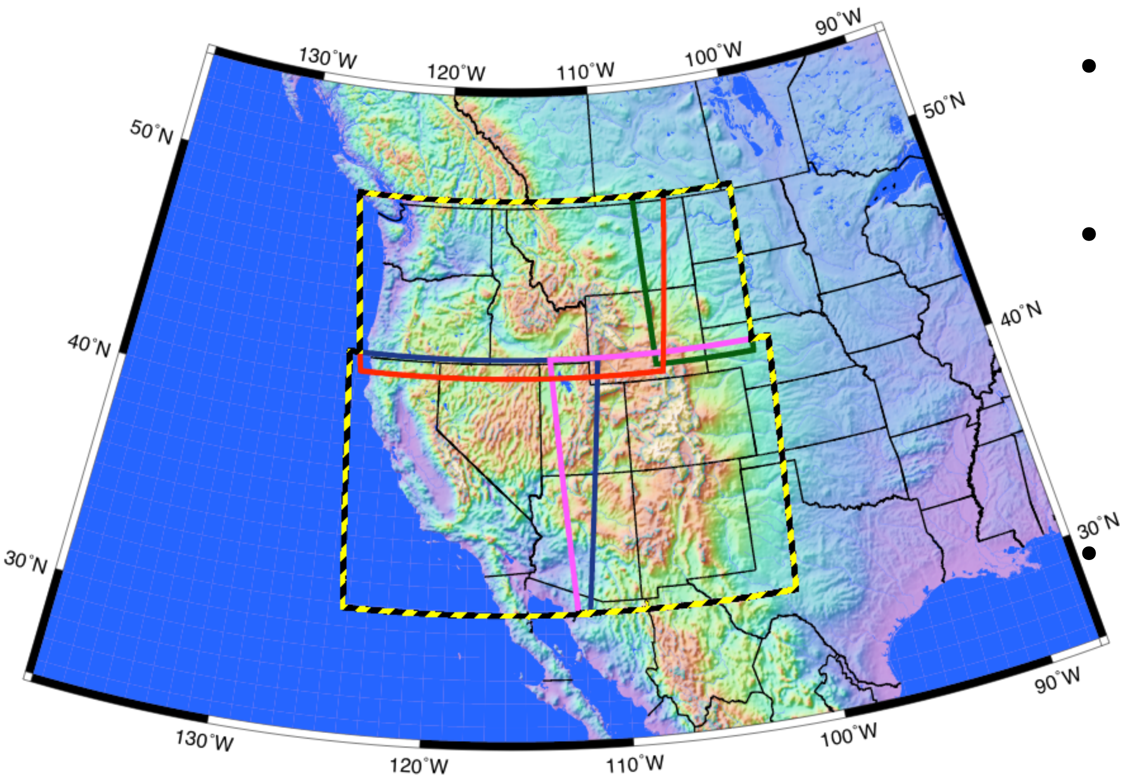
- The following data was developed for each grid point:
  - Wind speed and direction at 10 m, 20 m, 50 m, 100 m, and 200 m
  - Temperature at 0 m, 2 m, 20 m and 50 m above the surface
  - Specific humidity at 2 m above the surface
  - Pressure at the surface
  - Precipitation at the surface
  - Downwelling radiation (longwave and shortwave) at the surface

Creating a Single Consistent Dataset

- At this stage there were four separate data sets, one for each each domain, which had to be merged into a single consistent dataset
- First, the data had to be regridded from the NWP model grid to a regularly spaced latitude-longitude grid with a chosen resolution of 1 arc-minute by 1 arc-minute.
- To produce a seamless dataset, the individual model domains were blended at the overlapping boundaries.

Creating the WWSIS Dataset

- The final WWSIS wind dataset was a large dataset to create (and post-process)



- Total area was over 1.2 million grid points.
- Each grid point had a three year, ten-minute time series equal to 157,680 data points.
- Each time series was comprised of 21 modeled variables.

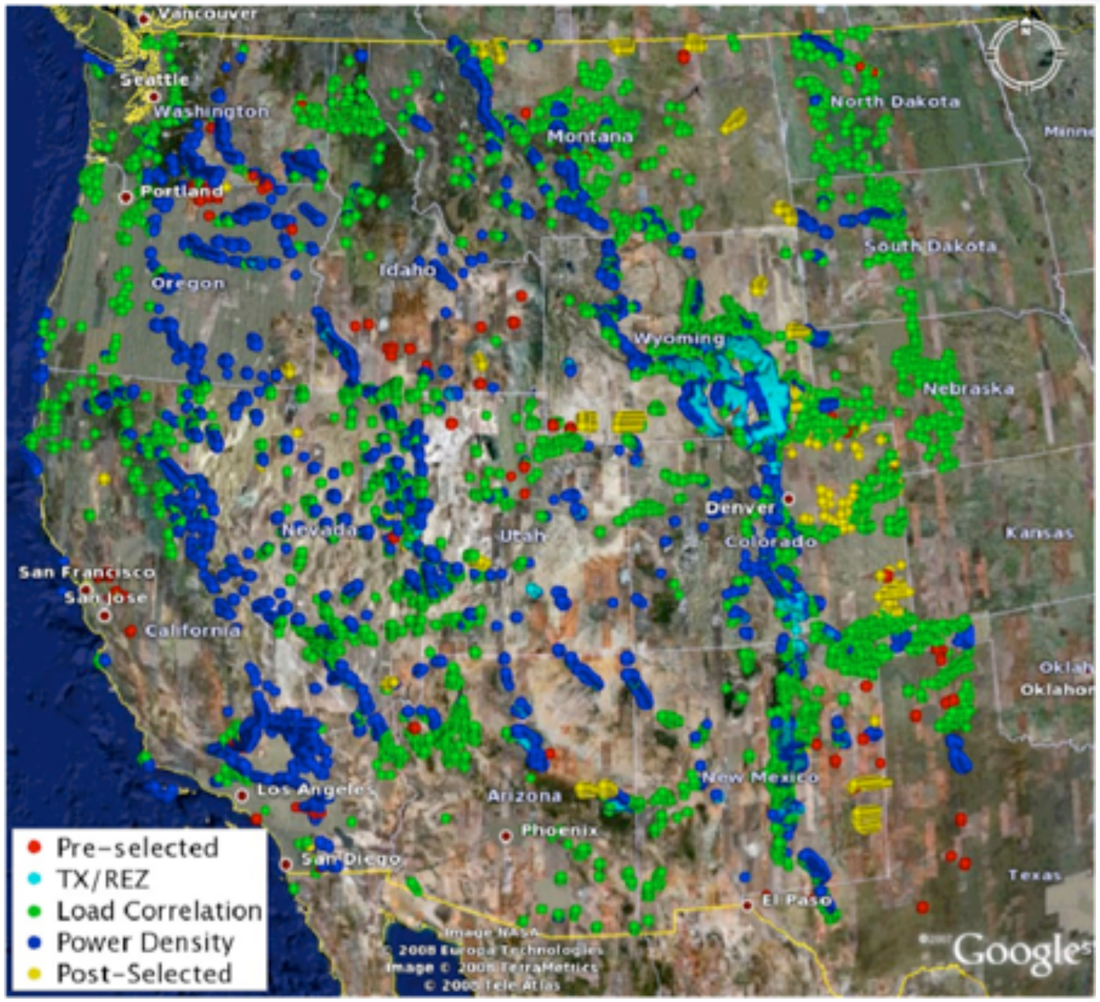
Simulating Synthetic Projects

Site Selection and Wind to Power Conversion

Simulation of Synthetic Projects

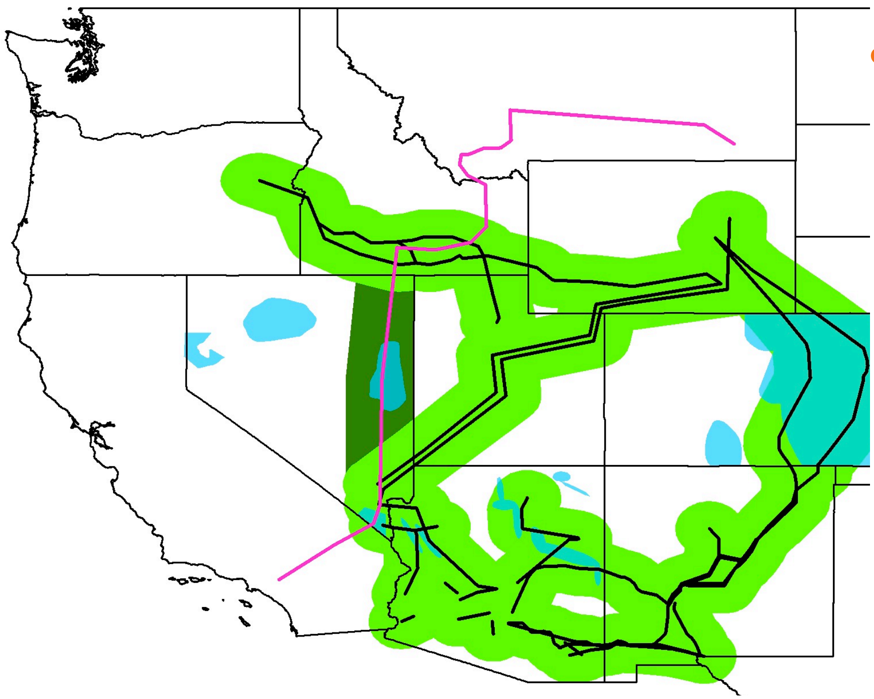
- To perform the integration study, synthetic wind projects had to be developed.
- The first task was to identify which sites were most practical; sequentially:
  - Selection of Pre-Existing/Pre-Proposed Sites
  - Proximity to Transmission (in study area)
  - Load Correlation (# sites per state from NREL)
  - Wind Power Density (# sites per state from NREL)
- Over 32,000 possible locations were selected.

Simulation of Synthetic Projects



Simulation of Synthetic Projects

- Selection of Pre-Existing/Pre-Proposed Sites
  - NREL used the Platt's database plus local knowledge to provide a list of sites



- Proximity to Transmission or Renewable Energy Zones (in study area)
  - After applying exclusion zones, the 6667 sites with the highest wind power density were selected from inside the colored regions

Simulation of Synthetic Projects

- Load Correlation / Wind Power Density

State/Offshore Region	Selected by load correlation [MWs]	Selected by power density [MWs]
Arizona*	18,000	18,000
California	8,000	74,000
Colorado*	28,000	28,500
Idaho	8,000	13,500
Montana	13,000	35,000
North Dakota	4,000	5,000
Nebraska	8,000	5,000
New Mexico*	32,000	40,500
Nevada*	33,000	48,000
Oklahoma	7,000	7,000
Oregon	4,000	36,000
South Dakota	7,000	10,000
Texas	8,000	10,000
Utah	8,000	11,000
Washington	4,000	44,000
Wyoming*	54,000	69,000
Offshore CA	1,000	4,000
Offshore WA/OR	500	1,000
TOTAL MWs	245,500	459,500

After applying the exclusion zones, the sites from within each state were selected by load correlation, then the sites with the highest wind power density were selected from the remaining sites.

Simulation of Synthetic Projects

- Each selected point covered an area of ~3.3km^2 and was modeled as its own small wind project.
- Using the following simple rules of thumb, it was calculated that each grid point could represent 10 turbines :
  - ~10 turbine diameters between strings
  - ~4 turbine diameters between adjacent turbines
- Vestas V-90 3MW turbines were used (with a view to the future), resulting in each synthetic farm being 30MW.

Simulation of Synthetic Projects

- Wind speed to power output conversion was done in two ways:
  - Rated power output (baseline)
  - SCORE-lite
- Rated power output:
  - The wind speed is "corrected" to the effective wind speed based on a standard air density (i.e. 1.225 kg/m^3)
  - The manufacturer's rating curve (for the correct air density) is used to convert the "corrected" wind speed to power output.

Simulation of Synthetic Projects

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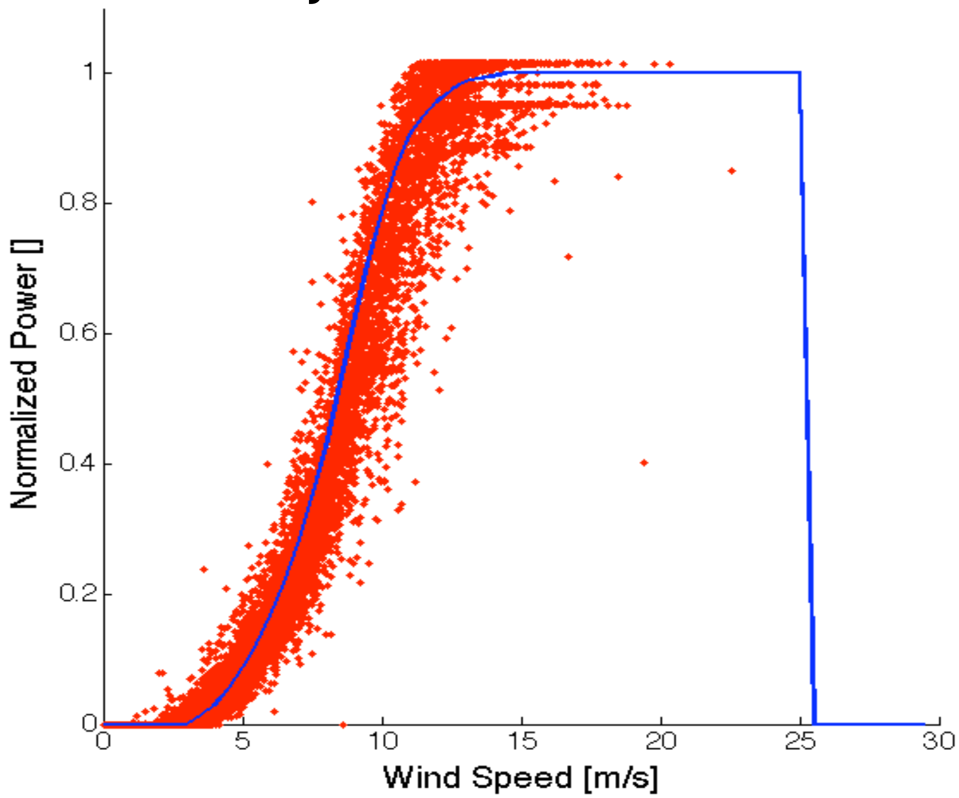
- The other process is SCORE (Statistical Correction to Output from a Record Extension).
- Why is SCORE required?
  - Modeled wind speeds are often too persistent
  - Simple upscaling of manufacturer's rating curves does not model farm-wide smoothing relationships.
  - "Farm-wide" rating curves are developed from empirical data for an entire farm and are subject to farm specifics such as project size and turbine layout.
  - Wind speed to power conversion is not deterministic.

Simulation of Synthetic Projects

- The relationship between wind speed and power output is not fully deterministic

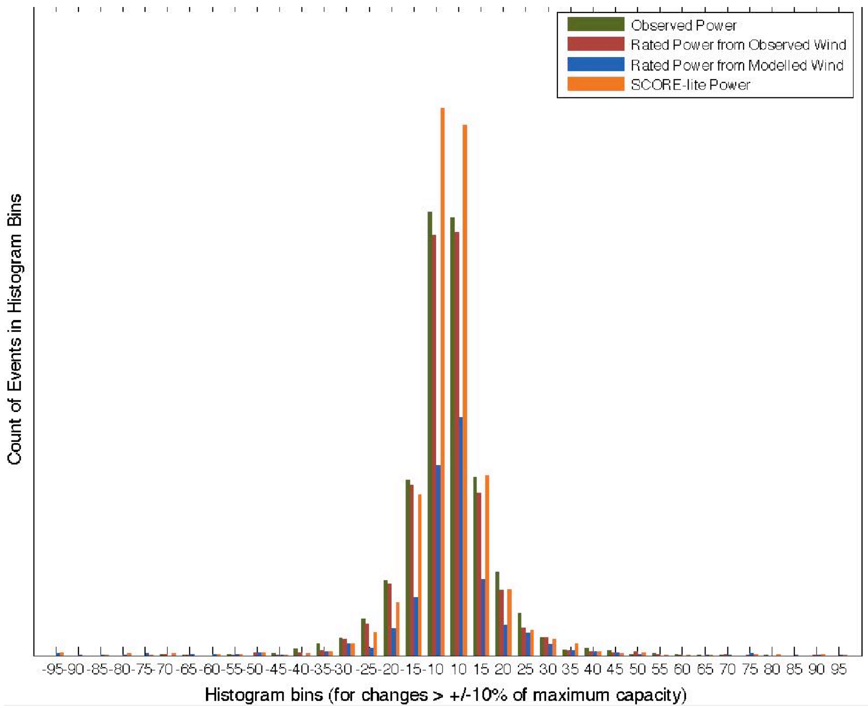


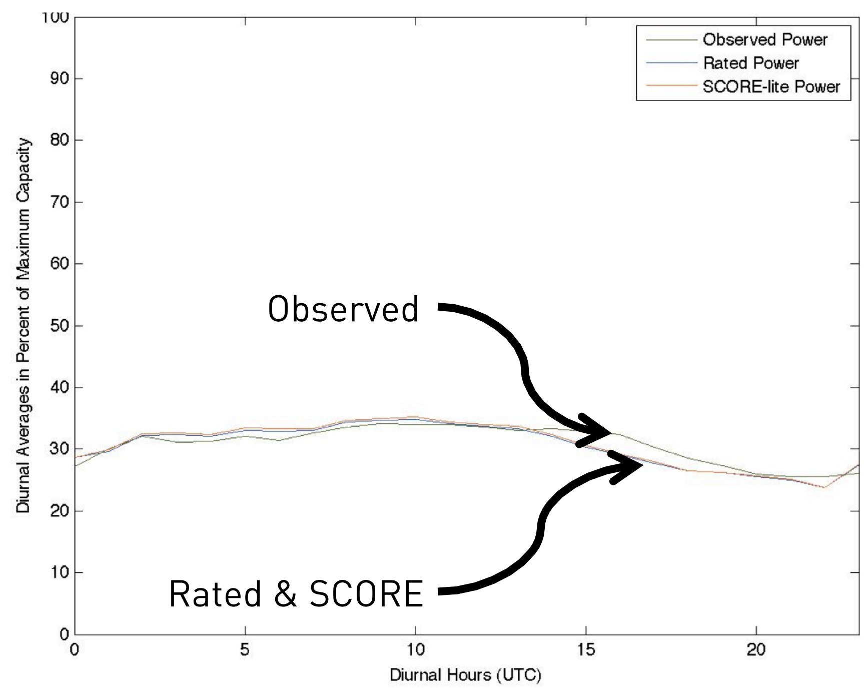
Simulation of Synthetic Projects

- How does SCORE work?
  - Accurately modeling an individual turbine (or string of turbines) will result in a more accurate representation of the entire wind farm.
  - SCORE is based on empirical experience with wind speed to power output – related directly to the size of the grid spacing used in the mesoscale model.
  - However, it is important to note that SCORE is designed to operate in a *probabilistic* manner and so it may not be right at any given moment. Instead it is designed to provide statistically correct data

Simulation of Synthetic Projects

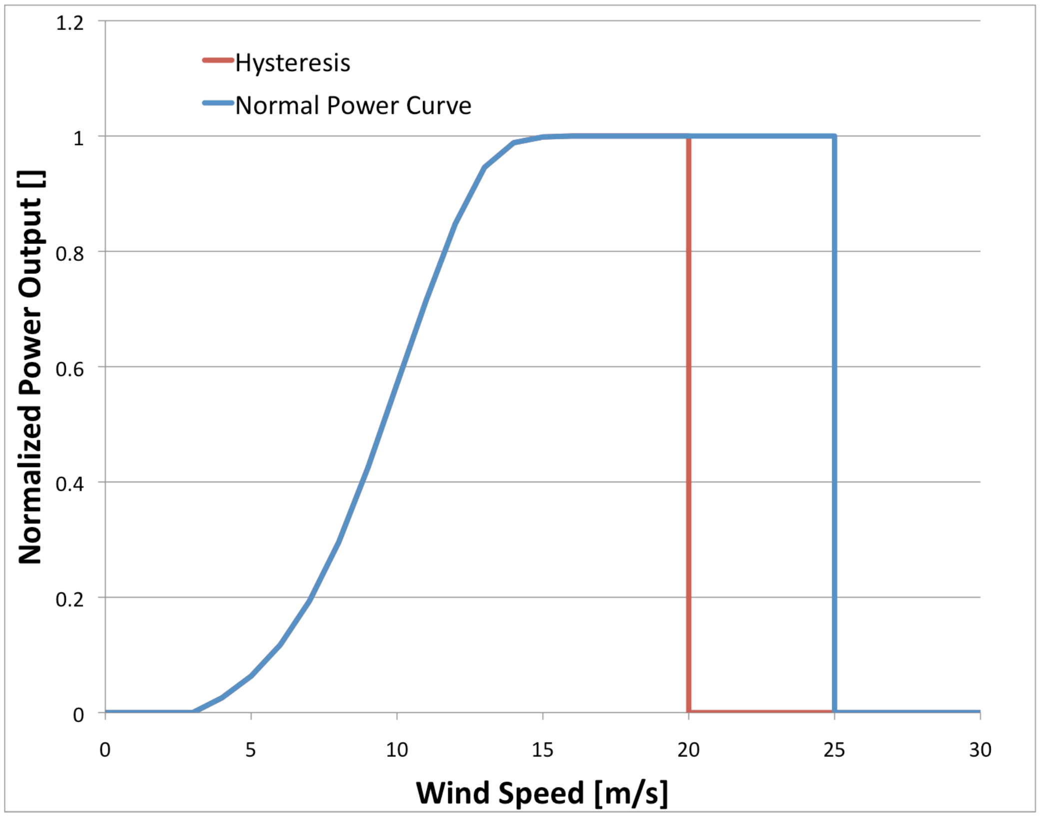
- SCORE produces more accurate ramping characteristics without changing the diurnal cycle.





Simulation of Synthetic Projects

- Finally, NREL applied a hysteresis loop to the data.



After the wind speed had reached cut-out speed (25m/s), the turbine would not produce power again until the wind speed had dropped below the cut-back-in speed (20m/s).

Forecasting for Synthetic Projects

Wind Energy and Solar Radiation Forecasting

Forecasting of Synthetic Projects

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- Neither wind nor solar power can be scheduled (in the traditional sense). As a result, forecasts of power output are required for operation.
- To simulate operation of the renewable energy projects in an integration study, simulated forecasts are also required.
- For this project 3TIER provided four wind energy forecasts for each of the 32,043 selected sites.
- 3TIER also produced a mesoscale solar forecast for the 8736 potential solar locations.

Forecasting of Synthetic Projects

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- The four wind energy forecasts were:
  - Perfect forecast (to evaluate the base cost)
  - Persistence forecast (short-term prediction)
  - Climatology forecast (baseline day-ahead)
  - Mesoscale model forecast (baseline best practice)
- The perfect forecasts and the persistence forecasts were produced for both the rated and the SCORE-lite power output, since they are both intended to be used at time scales that may be affected by the SCORE conversion process.

Forecasting of Synthetic Projects

- The mesoscale wind energy forecasts are made based on different input data than were used to develop the integration data set.
- Weather fields from the Global Forecast System (GFS) were used to produce NWP simulation at a coarser 6km resolution.
- This also allowed the entire area to be modeled as a single domain.
- However, the forecasts did not have a state-of-the-art model output statistics (MOS) correction applied and consequently represent a conservative measure of forecast accuracy.

Forecasting of Synthetic Projects

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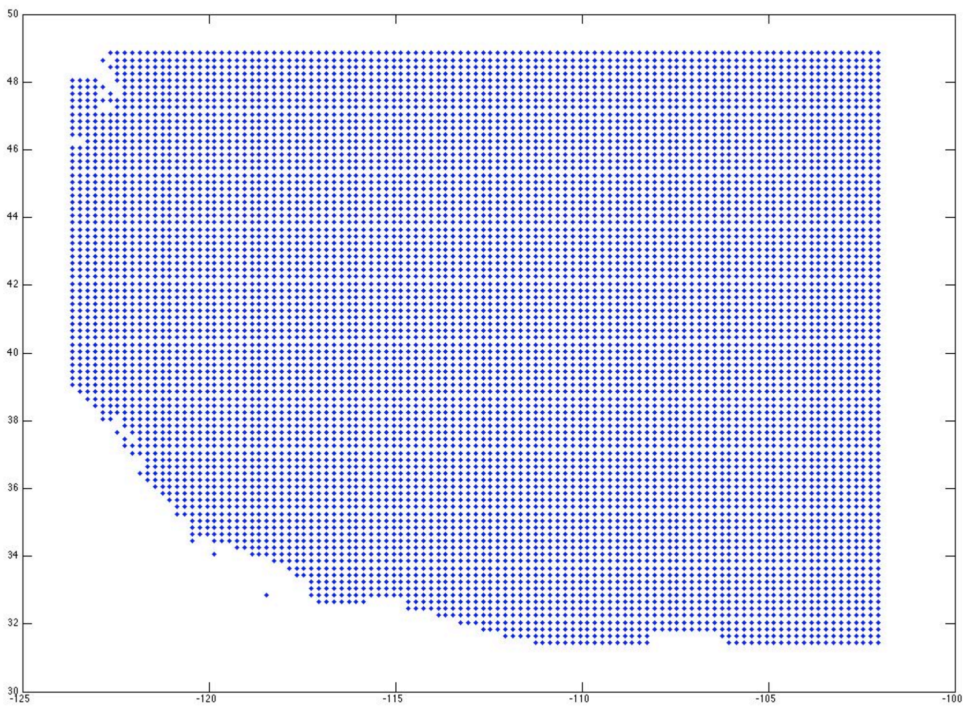
- The solar forecasts were produced for a regularly spaced latitude-longitude grid with a grid spacing of 12 arc-minutes.



- This allowed total coverage of the study area.

Forecasting of Synthetic Projects

- Solar forecasting is not as mature as wind forecasting and the process is less defined.
- To produce these forecasts 3TIER implemented a relatively simple model using NWP forecast simulations.
- The clear sky global horizontal irradiance (GHI) was calculated with the following inputs (Perez, 2002):
  - Elevation
  - Solar zenith angle
  - Linke turbidity index
  - Elevation adjusted air mass

Forecasting of Synthetic Projects

- Perez (2007), showed how to calculate the actual GHI from sky cover and the clear sky GHI.
- The mesoscale model does not produce sky cover (and the cloud parameterizations used to produce the model GHI were not necessarily trusted).
- However, the model does produce relative humidity which was converted to sky cover using the BTV SkyTool methodology from the National Oceanic and Atmospheric Administration (NOAA).

Forecasting of Synthetic Projects

- The direct normal irradiance (DNI) and diffuse irradiance were calculated from the GHI value using Perez (2002)
- However, on investigation, the solar forecast values had a high bias on clear days
  - This is suspected to have come from aerosols not represented in the NWP models, which increase turbidity
  - This high bias was corrected using a ratio of the 10-day maximum forecasted and observed value.
  - This ratio was applied to clear days in the forecast.

Displaying the Synthetic Wind Data

The Graphical Database Interface

Displaying the Synthetic Wind Data

3TIER

- The final deliverable required from 3TIER was to produce web-based time-series database interface.
- This interface provides an easy to use portal to the modeled dataset for the selected 32,043 wind sites.
- The response time is fast due to pre-rendered images.
- The interface is primarily a map interface that allows clicking and zooming much like any such interface.
- It also has a search feature based on either latitude-longitude values or a simple site ID.

Displaying the Synthetic Wind Data

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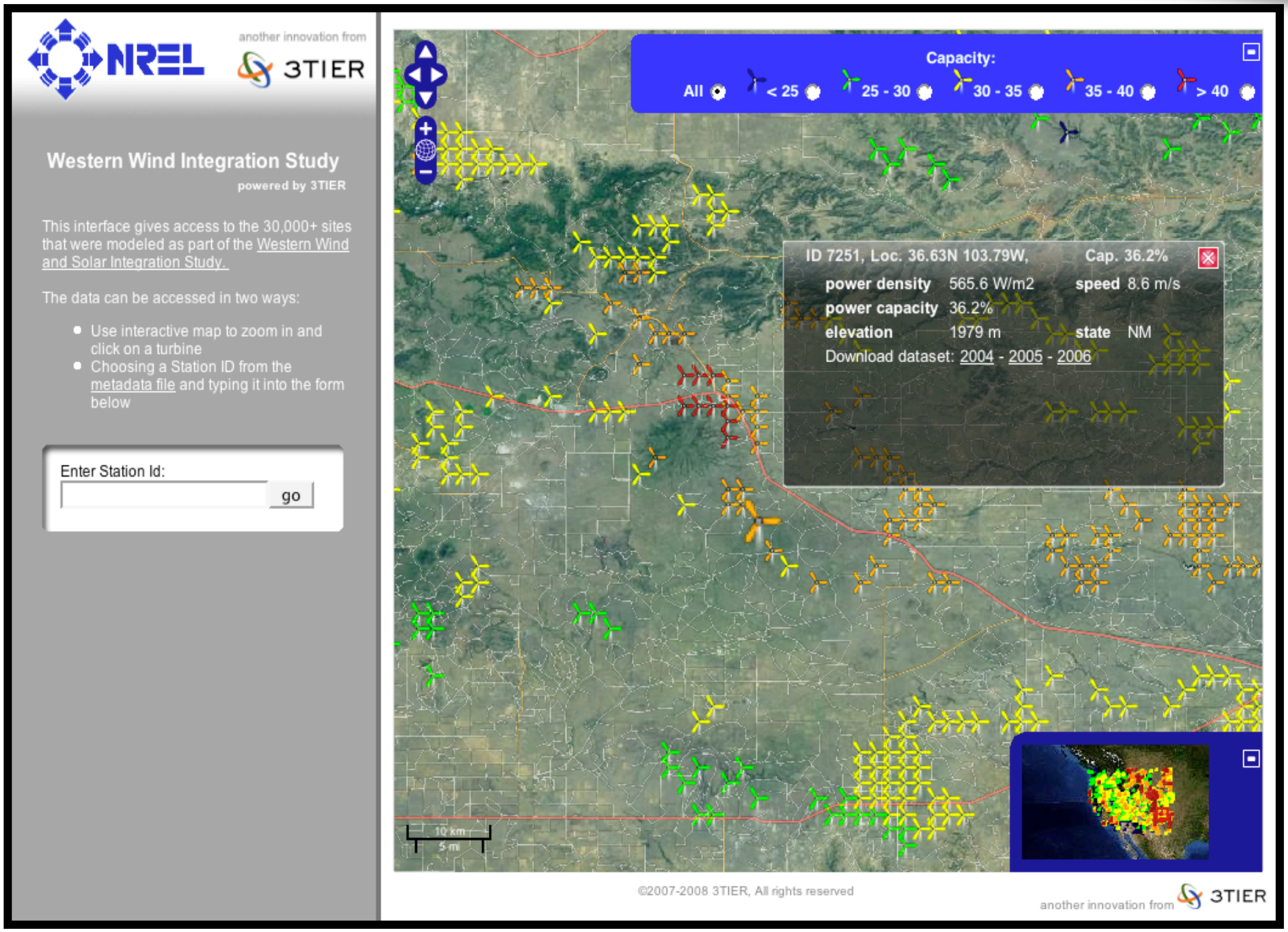
Downloadable metadata file (snapshot)

SiteID	Latitude	Longitude	Power Density [W/m2]	SCORE-lite Capacity Factor [%]	Wind Speed [m/s]	State Code	Model Elevation [m]
9269	37.742	-105.142	807.95	37.35	8.91	CO	2151.6
9270	37.742	-105.125	786.88	36.81	8.83	CO	2121.8
9271	37.742	-105.108	746.92	36.14	8.72	CO	2097.2
9272	37.742	-105.092	686.76	34.97	8.52	CO	2075.5
9273	37.742	-105.075	686.74	35.32	8.56	CO	2056.5
9274	37.742	-105.058	608.86	33.61	8.27	CO	2042.4
9275	37.742	-105.042	637.55	34.83	8.41	CO	2029.1
9276	37.742	-104.958	630.25	33.98	8.11	CO	1946.9
9277	37.742	-104.942	623.62	33.62	8.05	CO	1939.6
9278	37.742	-104.925	633.15	33.76	8.06	CO	1929.5
9279	37.742	-104.908	632	33.56	8.02	CO	1916.5
9280	37.742	-104.892	632.25	33.39	7.98	CO	1899.5
9281	37.742	-104.858	606.36	32.46	7.83	CO	1872
9282	37.742	-104.842	594.74	32	7.76	CO	1865.6
9283	37.742	-104.825	574.84	31.46	7.69	CO	1865.1
9284	37.742	-104.808	566.19	31.19	7.65	CO	1862.1
9285	37.742	-104.792	551.79	30.64	7.57	CO	1856.5
9286	37.742	-104.508	553.49	31.76	7.92	CO	1851.4
9287	37.742	-104.475	557.4	31.97	7.98	CO	1860.9
9288	37.758	-121.675	241.71	19.24	6.09	CA	281.7
9289	37.758	-118.958	509	29.31	7.57	CA	2291.9
9290	37.758	-116.408	361.5	22.27	6.38	NV	1914.9
9291	37.758	-116.358	315.31	22.26	6.78	NV	2172.3
9292	37.758	-116.342	317.72	22.98	6.96	NV	2202.6
9293	37.758	-113.258	371.08	25.02	6.64	UT	1723.7
9294	37.758	-111.792	601.58	28.34	7.39	UT	2186.8
9295	37.758	-105.392	1023.56	44.24	9.95	CO	2667.4
9296	37.758	-105.325	868.48	39.8	9.2	CO	2437.4
9297	37.758	-105.308	793.43	38.42	8.94	CO	2389.6
9298	37.758	-105.292	791.74	38.9	9	CO	2350.5
9299	37.758	-105.275	784.45	38.91	9	CO	2328.7

Displaying the Synthetic Wind Data



Conclusions

- Accurately modeling the area covered by the project was a challenge - but possible.
- The wind was modeled as four domains and combined into a single large dataset.
- The synthetic projects were modeled using a simple wind speed rating and also SCORE-lite.
- Four different wind forecasts were produced.
- A mesoscale solar forecast was also produced.
- The synthetic wind data will soon be available from an NREL hosted website.

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knowledge is power

Finally, I would like to acknowledge the 3TIER team members who were involved in this project:

Gwen Bender, Brandee Boyer, Sam Cheng, Brian Davis, Scott Eichelberger, Paul English, Eric Grimit, Bill Gustafson, Susan Hert, Chris Johnson, Mark MacIver, Stephen Johnson, Ben Martin, Jim McCaa, Lydia Mills, John Moscarillo, Dung Nguy, Bart Nijssen, Cameron Potter, Paula Royalty, Myk Sanders, Amy Sansone, Christian Sarason, Anna Schneider, Pascal Storck, Bernard Walter, Matt Wiley, Vincent Yau