



Mesoscale Modeling for Airborne Wind Energy Forecasting

Richard Carpenter

Weather Decision Technologies, Inc.

Norman, OK, USA

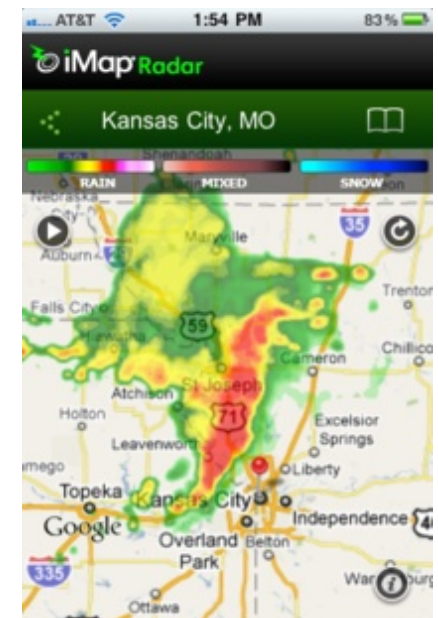
AIRBORNE 2010
WIND ENERGY
CONFERENCE

About Weather Decision Technologies

- Located on University of Oklahoma Research Campus near the National Weather Center
 - Founded in 2000 by leading scientists from world-renowned weather research organizations
 - Norman OK is growing center of weather expertise
 - 65+ employees (35 with graduate degrees)
 - Meteorological software licensed from MIT, NSSL, OU, NCAR, McGill Univ
- Unique Applications, Services and Systems
 - Radar-based tools, displays, and alerting
 - Short-term weather prediction (nowcasting of precipitation, tornadoes, hail, lightning, flooding, etc.)
 - Precise and accurate forecasts (wind, hydromet, etc.)
 - Innovative Internet and mobile display of data
 - Only private weather company invited to forecast for the Sydney, Beijing, and Vancouver Olympics

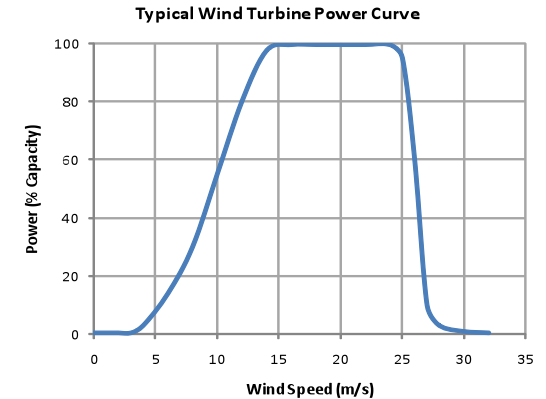


© Bob Fritchie, WDT



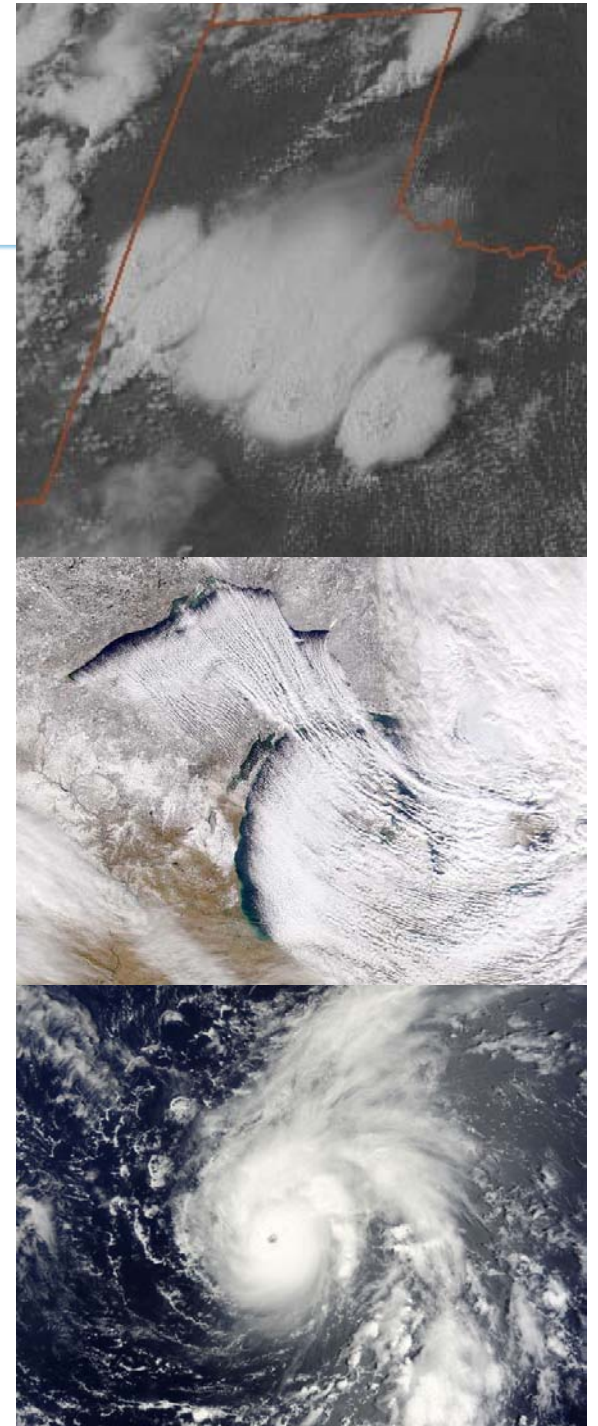
Conventional Wind Power Considerations

- Complex Power Curve
- Forecast Time Horizons
 - Hour-ahead, Day-ahead, Week-ahead
 - Peaking/Spinning Reserves
 - Regulatory requirements
 - Operations/Maintenance
- Wind Ramps
 - Abrupt changes in wind speed
- Siting/Assessment Issues
 - Measure-Correlate-Predict (MCP)
 - Vertical extrapolation from 60 m met tower – shear exponent
 - Wind shear across rotor plane typically ignored
 - Wake effects



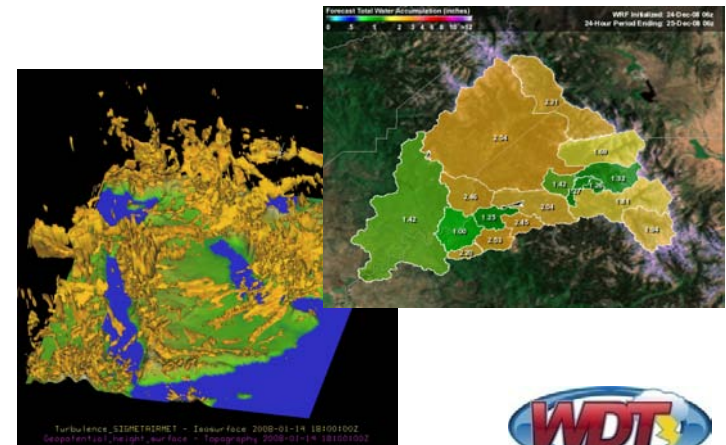
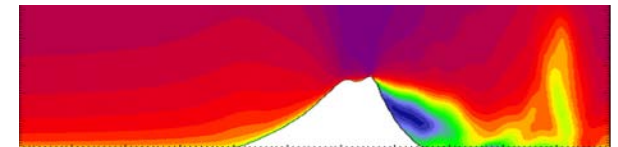
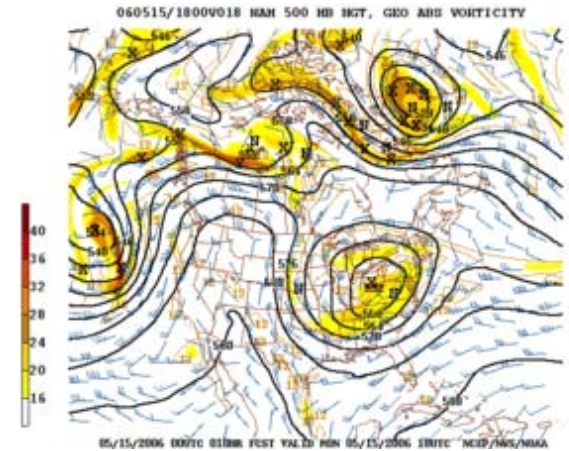
What is Mesoscale Modeling?

- **Mesoscale** refers to atmospheric phenomena on the scale of 2 to 2000 km
- Commonly subdivided into 3 ranges:
 - Meso- α (200-2000 km) – Thunderstorm complexes, Tropical cyclones
 - Meso- β (20-200 km) – Sea breezes, Lake effect snow
 - Meso- γ (2-20 km) – Thunderstorms, Complex terrain
- Compare to
 - Synoptic scale (≥ 2000 km) – High and low pressure centers, Mid-latitude cyclones, Rossby waves
 - Microscale/Storm-scale (≤ 2 km) – Tornadoes, Urban flow



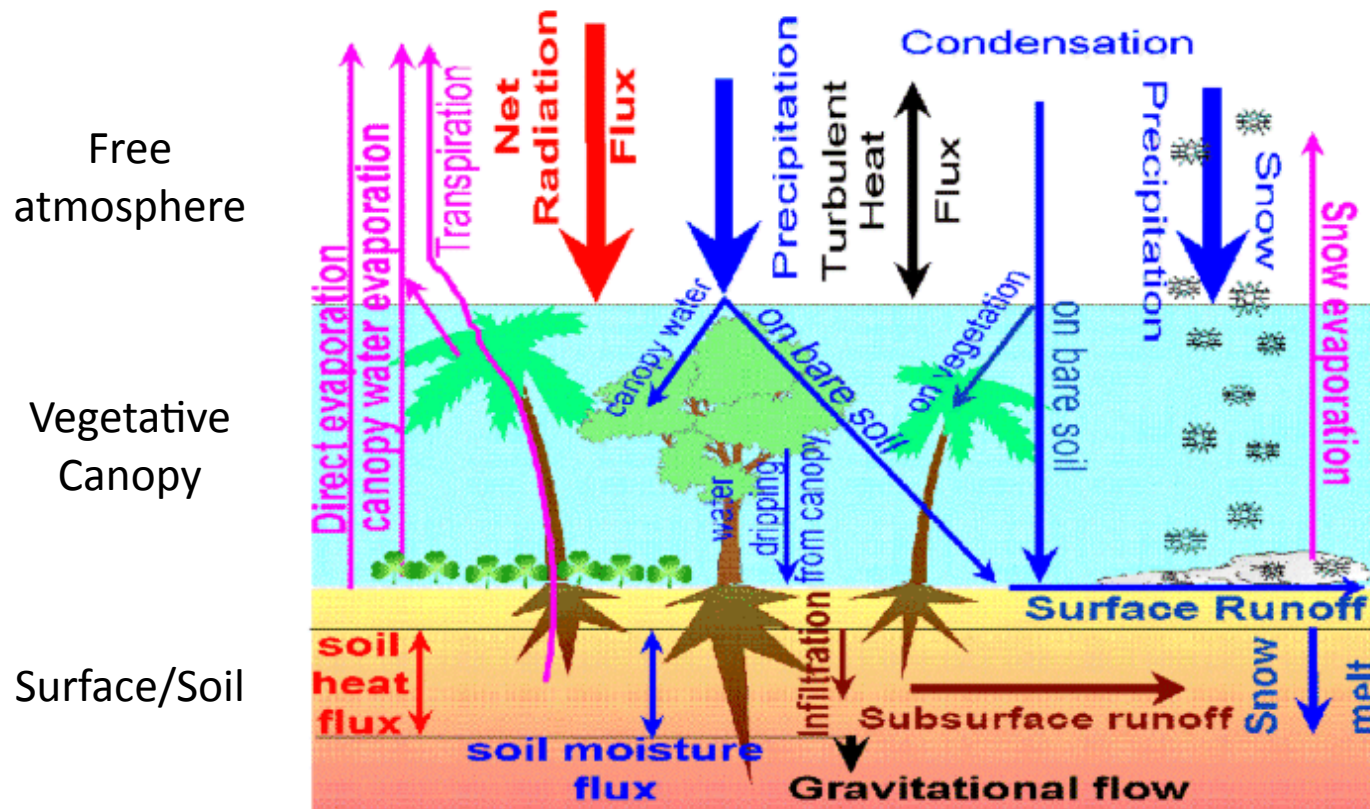
What is Mesoscale Modeling?

- Numerical Weather Prediction (NWP)
 - The application of Computational Fluid Dynamics (CFD) to solve the nonlinear partial differential equations describing the atmosphere
 - Finite differences
 - Reynolds Averaged Navier-Stokes (RANS) methods
 - *Turbulent processes are entirely parameterized*
- Variety of Mesoscale Models
 - RAMS, MM5, ARPS, WRF
- Physical Parameterizations (“Physics”)
 - Turbulence
 - Boundary layer
 - Surface Energy Balance (soil/vegetation)
 - Precipitation processes (“Microphysics”)
 - Subgridscale clouds (“Cumulus”)
 - Radiation (shortwave, longwave)



Mesoscale Modeling

- Example of a “physics” package

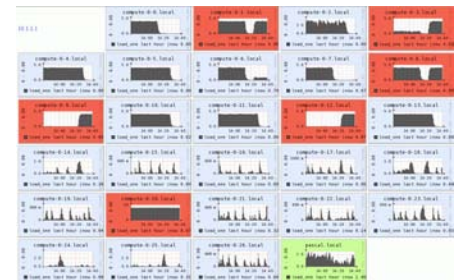


RUC-2 Land-surface model (NOAA/ESRL/GSD)



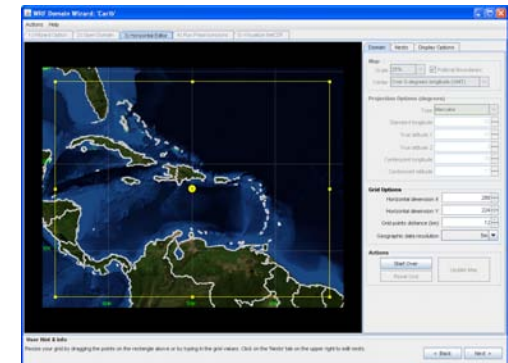
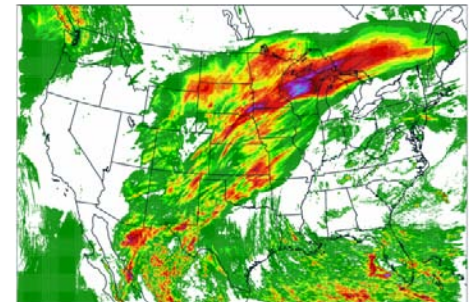
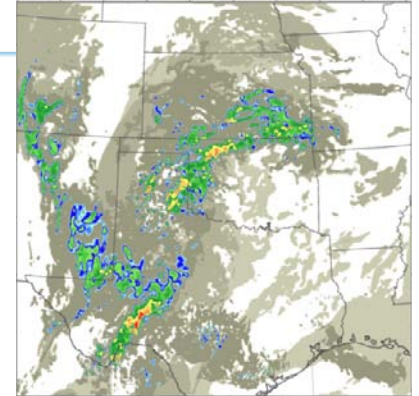
Mesoscale Modeling is Computationally Expensive

- Criteria include grid spacing, domain size, forecast duration, and run time
- Requirements generally increase with the cube of the inverse of the grid spacing
 - Refining a 12 km mesh to 3 km requires 64x resources ($x, y, time$)
- Generally requires Parallel Computing
 - Domains are “decomposed” across processing nodes/cores
 - Message Passing Interface
 - High-speed Interconnects between nodes
- Use a Colocation Facility for Operations
- Still, much can be done on a single node



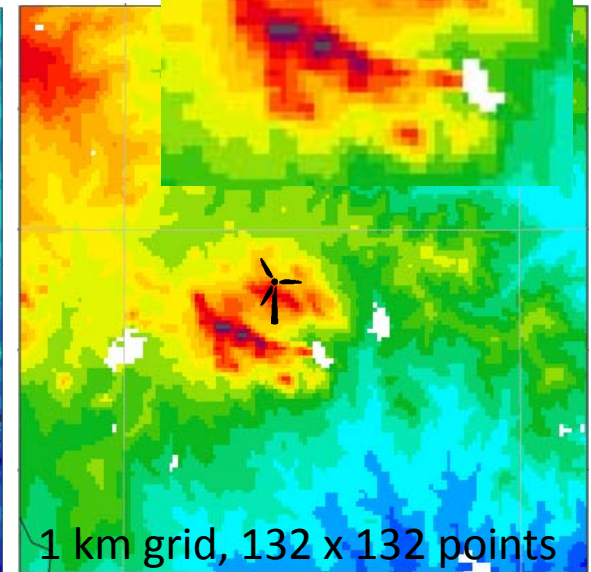
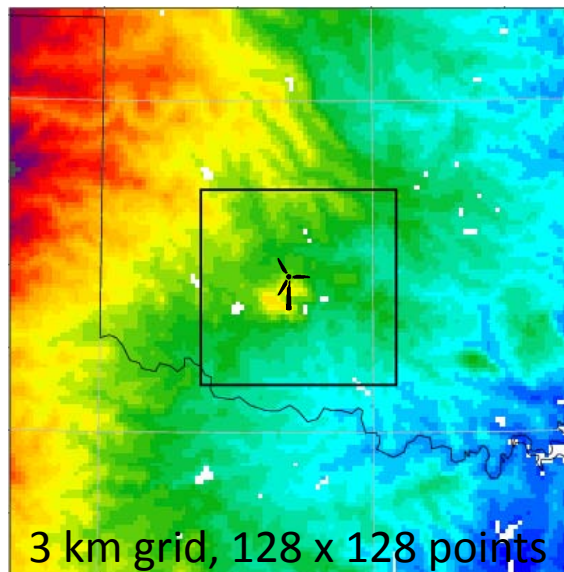
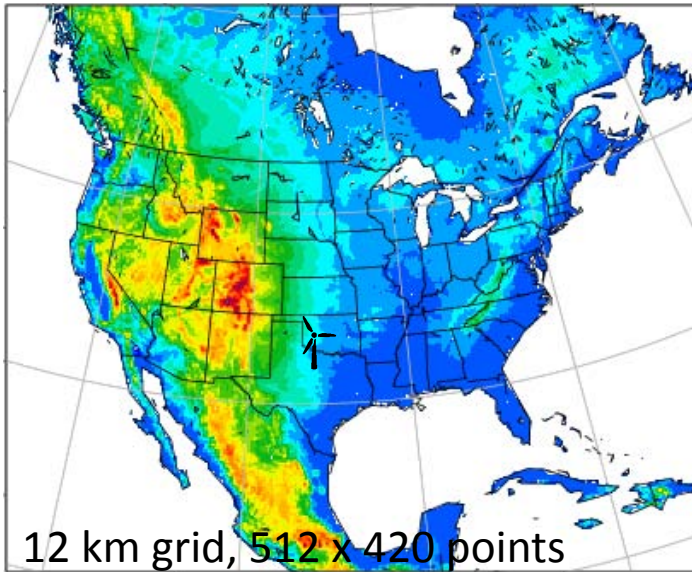
Weather Research and Forecasting (WRF) Model

- Developed and maintained over the past 10 years by NCAR, NOAA, and other U.S. agencies
 - Successor to MM5
 - Community model serving research and operations
- Many “flavors”
 - Hurricane, Chemistry, Global, Urban
 - Different dynamical solvers (“cores”)
 - Numerous “physics” options

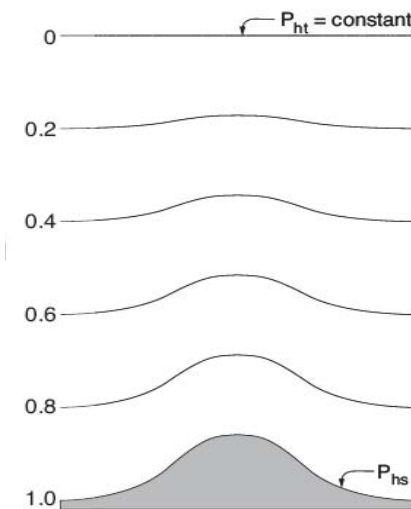


Model Grids

Flow across both mountain ranges resolved by several points

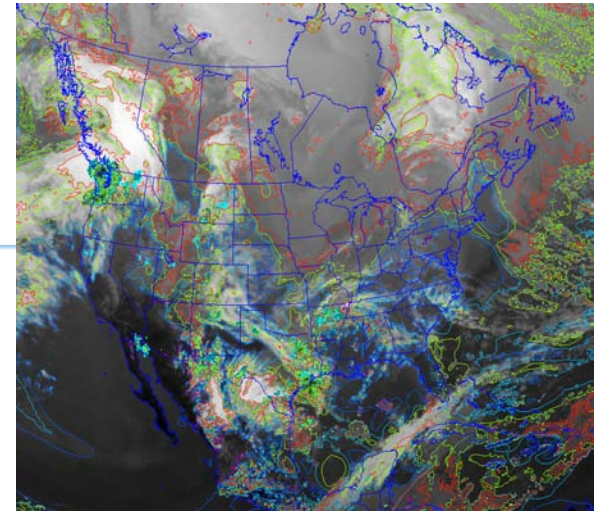


Terrain-following vertical coordinate
Height-pressure hybrid
Typically 35-50 levels



Data Assimilation

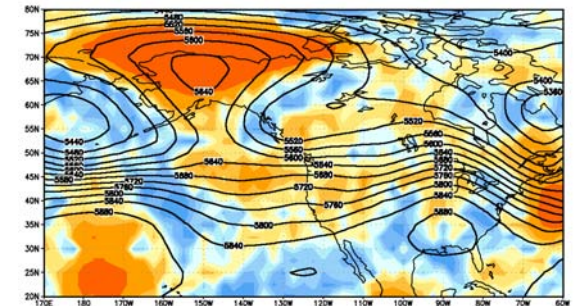
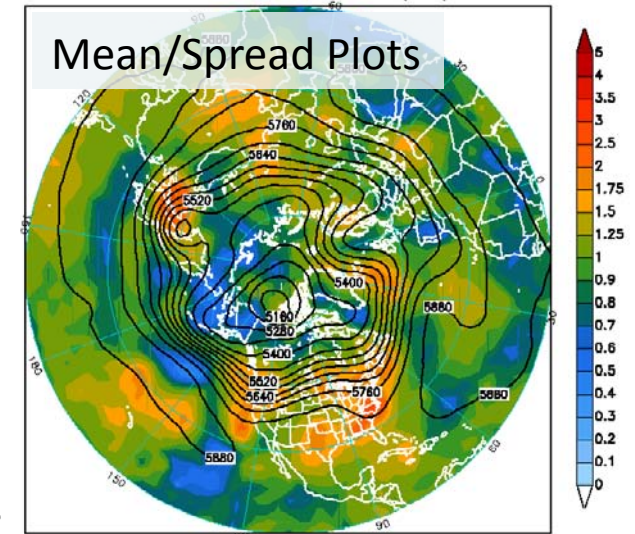
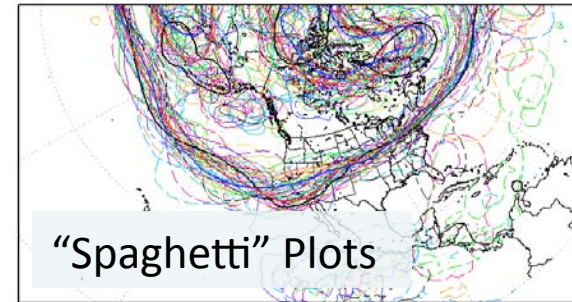
- Various Data Sources
 - Airport observations, rawinsonde, wind profiler (SODAR/LIDAR), met tower, mesonet, aircraft observations, geostationary satellite imagery, satellite-derived winds, radar, etc.
 - The atmosphere is undersampled
- Various Techniques
 - Objective Analysis
 - *Straightforward, allows widest use of available data types*
 - Four-Dimensional Data Assimilation (FDDA)
 - *“Nudges” model toward observed conditions during a pre-forecast period*
 - 3D Variational Data Assimilation (3DVAR)
 - *Complex, difficult to work with, limited in the types of data it can handle*
 - *Potential for highest accuracy*
 - 4DVAR
 - *Variational scheme allowing time-varying observations*



Forecast Ensembles

- Groups of related model forecasts
 - Improved accuracy
 - Measure of forecast confidence/uncertainty
 - A lower resolution ensemble is generally more accurate than a single higher-resolution run
- Vary models and techniques:
 - Models and physical parameterizations
 - Spatial scales (global, national, regional)
 - Run times (time-lagged ensembles)
 - Initial and boundary condition perturbations
 - Data assimilation techniques

NAEFS run for 00Z 15Sep2010 valid 00Z23SEP2010 540 and 582 height contours at 500-hPa, 1x1 degree resolution

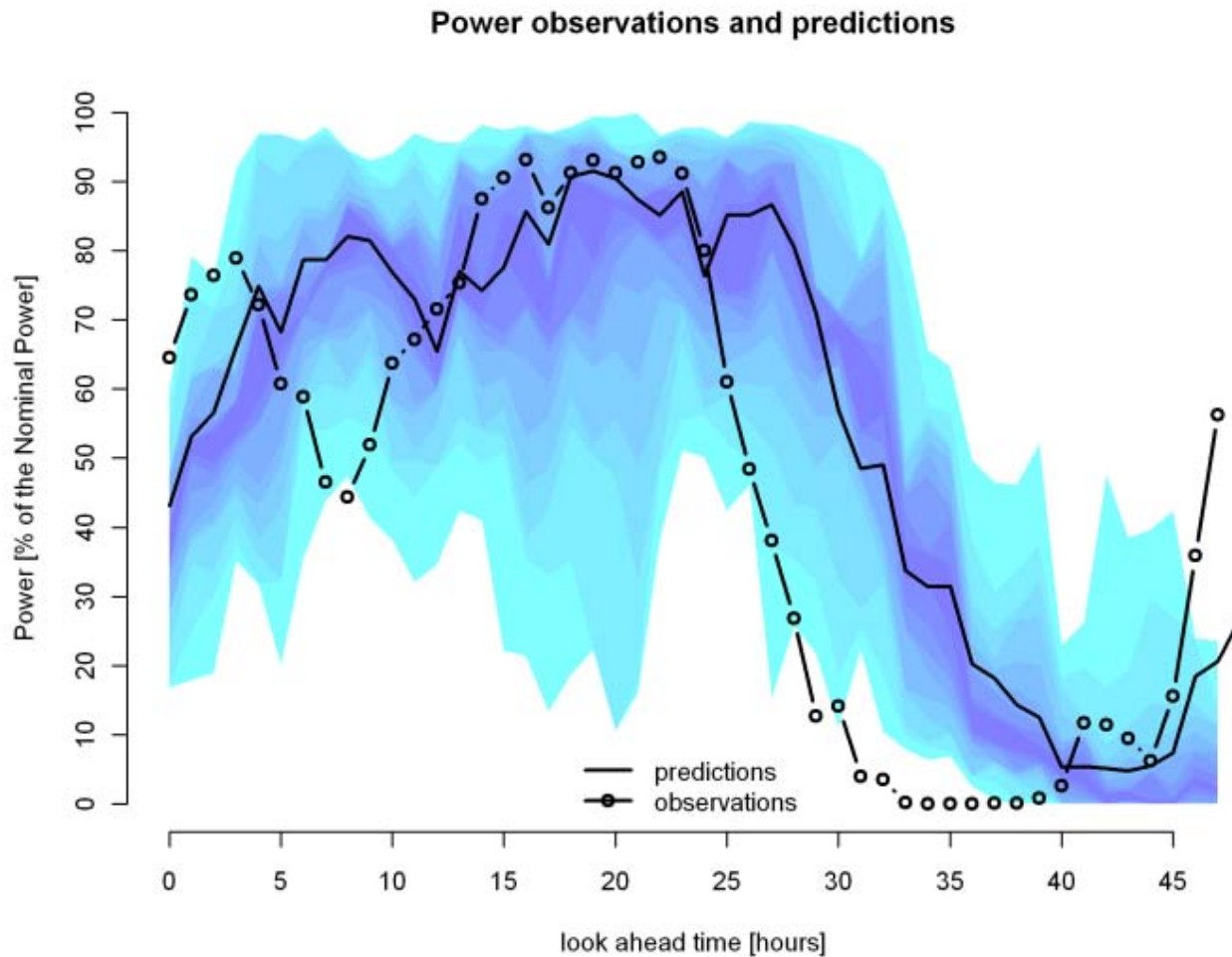


Predictability/Probability



Forecast Ensembles/Wind Ramps

- Is this a good forecast?

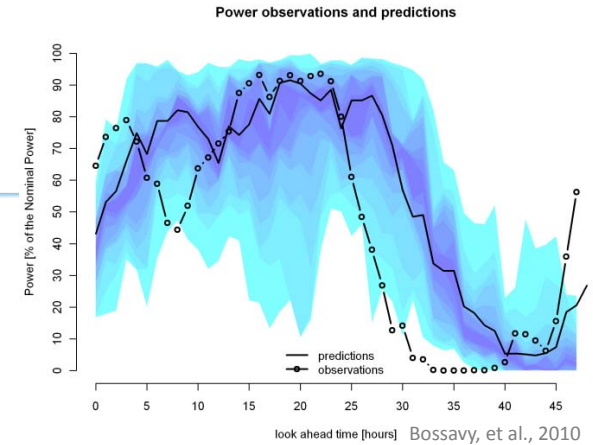


Bossavy, et al., 2010



Wind Ramps

- Associated with a number of phenomena
 - Low-level jets
 - Land-sea or mountain-valley breezes
 - Shallow cold air surges
 - Thunderstorm winds
 - Atmospheric stabilization
- Difficult to predict because of small time and space scales
 - Poorly observed on the regional scale



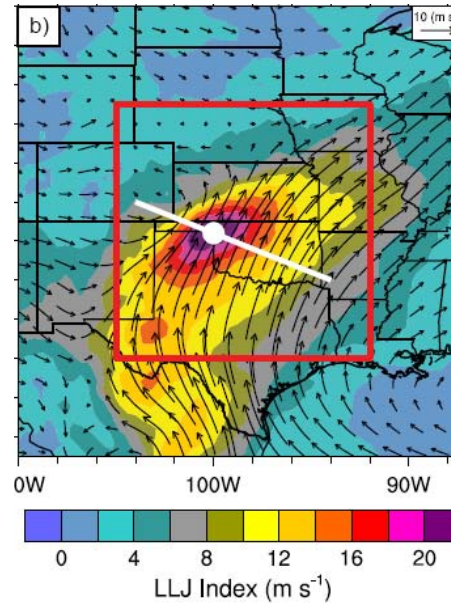
Components of a Conventional Wind Prediction System

- Mesoscale Model (WRF)
- Data Assimilation
 - Incorporate site met tower and nacelle anemometer data
 - Advanced techniques for initializing the model
- Microscale modeling
 - Forecasts are “downscaled” using a mass-consistent terrain following model to fit the precise details of complex terrain
- Statistical Processing
 - Forecasts are validated against available meteorological and power data
 - Neural Networks, Ensemble Kalman Filtering, Support Vector Machines
 - Accuracy is continually improved through training based on recent past performance
- Forecast Ensembles
 - Provide greater accuracy and a measure of forecast confidence
- Wind Ramp Prediction
 - Customized, component-based forecasts of ramp potential
- High Performance Computing Facility

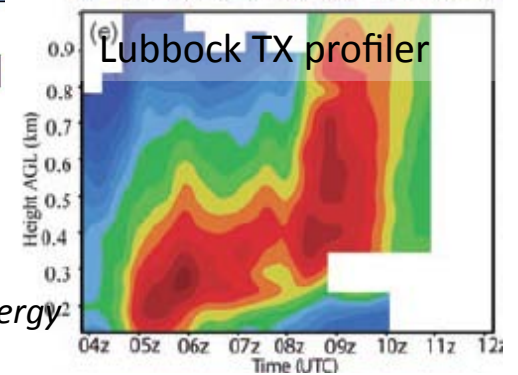
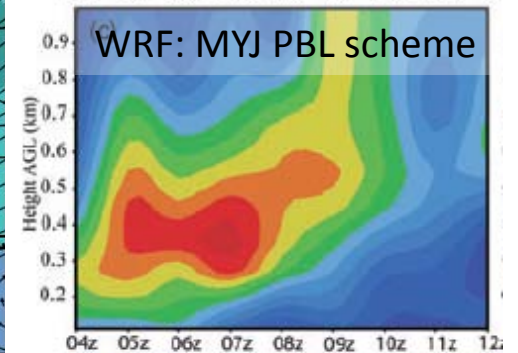
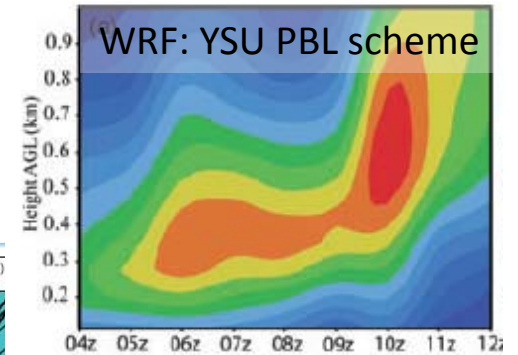


The Low-Level Jet

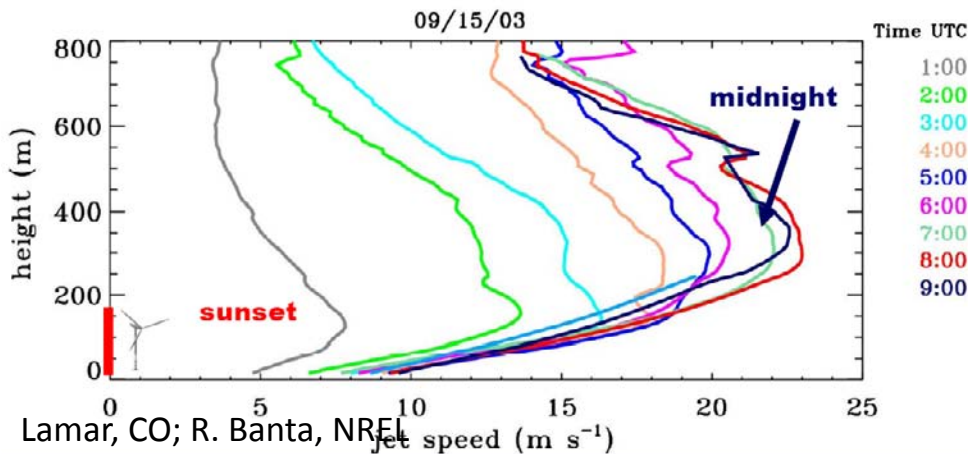
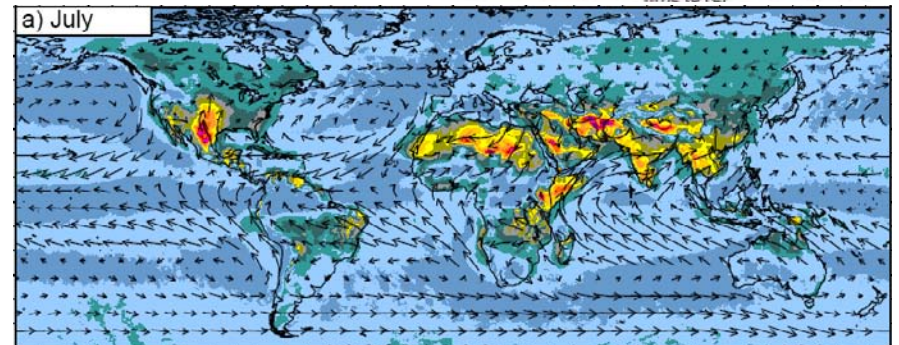
- Driven by the earth's rotation and the nighttime collapse of the boundary layer
 - Peak overnight at 300-600 m AGL
- Global distribution varies with season
 - Summertime LLJ concentrated in US Southern Plains
 - Notably, no LLJ in Europe
- Mesoscale models handle the LLJ with varying degrees of success



Rife et al., 2010, *J. Climate*



Storm et al., 2009, *Wind Energy*



Lamar, CO; R. Banta, NREL

Severe and Problematic Weather

- Thunderstorms
 - Lightning, Hail, High Winds, Heavy Rain, Tornadoes
- Icing
- Turbulence
- Wind Shifts
 - Cold front
 - Gust front

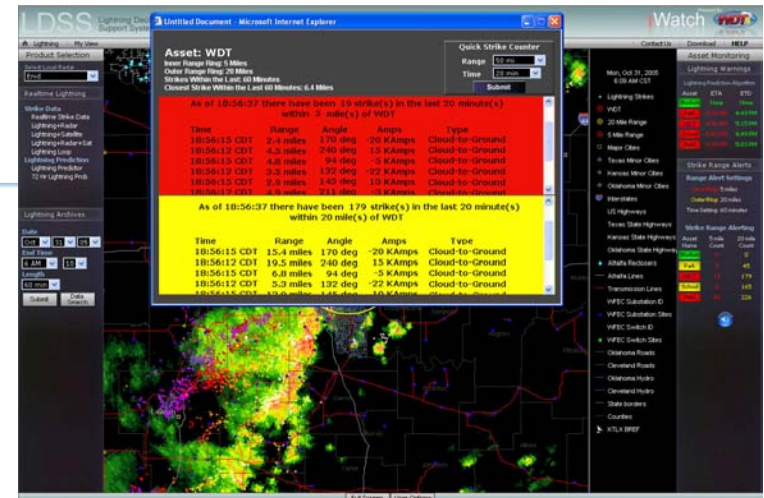


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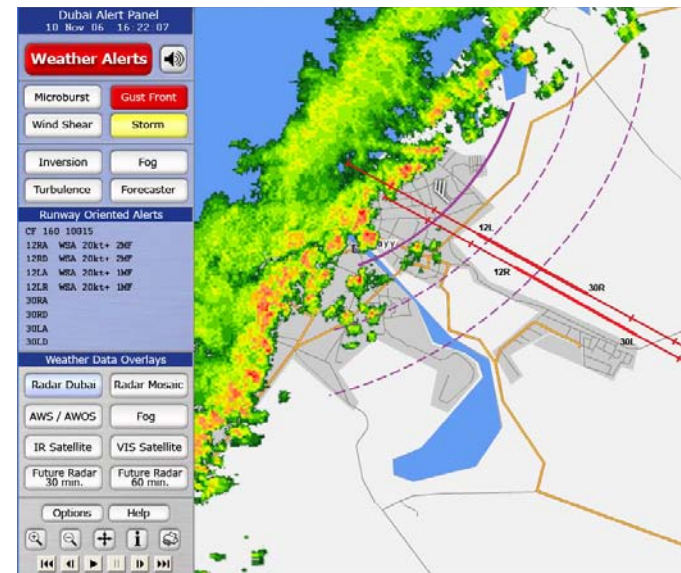


Nowcasting and Alerting

- **Nowcasting** – A short-range (1-2 hour) forecast based primarily on extrapolating current trends
 - Particularly relevant for launch/recovery
- **Thunderstorm phenomena**
 - Lightning, Winds, Hail, Heavy Rain
 - Based on storm growth and movement of radar echoes
- **Alerting based on proximity and timing (ETA/ETD)**



Lightning Alerting and Nowcasting



Gust Front Time of Arrival





Richard Carpenter
Weather Decision Technologies, Inc.
Norman, OK, USA
rcarpenter@wdtinc.com
405-503-5072

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