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Wind & Solar Energy Prediction: Challenges of Opportunities

Source: AMEC

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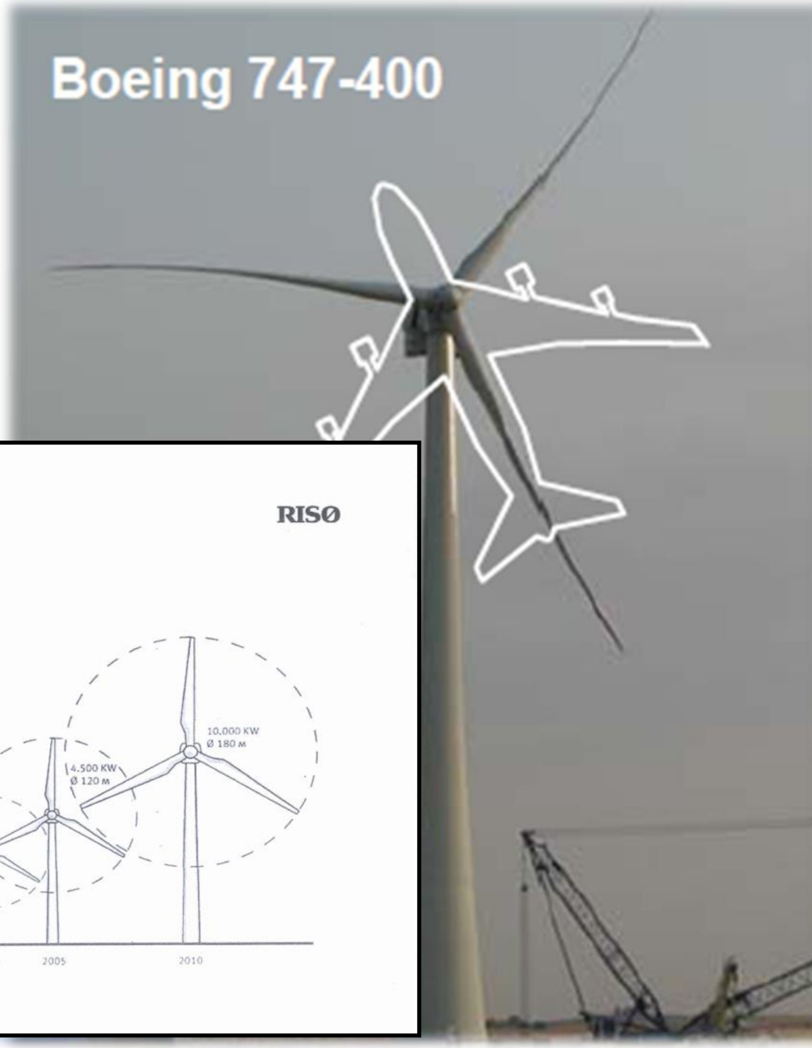
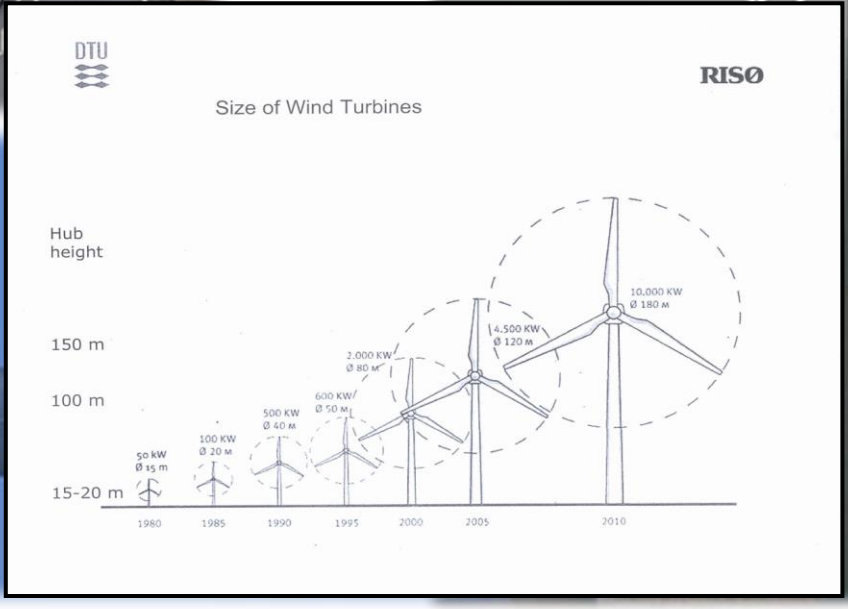
Mother Nature Is Not Always Kind

Setting the Context - Scale

Source: Terra Magnetica





Weather & Solar Energy Related Industry Issues

- **Financing** — Wind energy resource estimates at wind farm sites are over-estimated on average
- **Maintenance Costs** — Wind turbines are failing faster than predicted (up to 40% earlier)
- **Variability is Costly** — Wind & solar power variability complicate power integration and load balancing across the grid – requires reserves
- **Prediction Errors Costly** — Wind energy prediction has typical errors of 10-15% (flat terrain) to 15-25% (complex terrain)
- **Extreme Weather Impacts** — Wind turbines are not designed to handle extreme weather conditions (shear, ice, snow, high wind, etc.). More representative weather datasets are needed for turbine design

Overarching Wind Energy Science Challenges

- Boundary layer meteorology (0 to 200 m above ground) is not well understood nor is this layer well measured
- The wind energy industry greatly under appreciates the complexity of the airflow in this layer
- The wind industry has historically assumed less turbulence and more wind with height above the ground

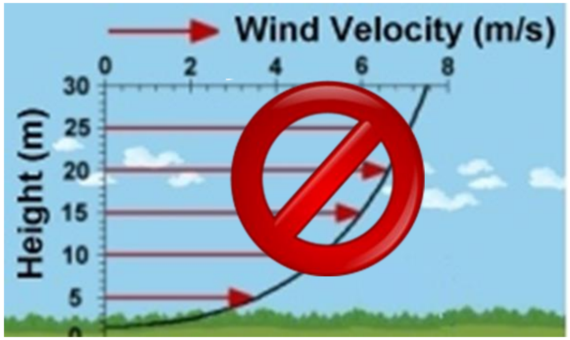


Image source: Wind Measure International

Overarching Solar Energy Science Challenge

Improve prediction needed of:

- Cloud lifecycle
- Aerosols
- Jet Contrails
- Surface conditions (snow/ice melt on solar devices)

- **Cloud and precipitation processes are highly complex and operate on very small scales (10s to 100s of meters)**
- **Weather models greatly over simplify cloud physics properties and precipitation processes.**
- **Jet contrails can spread into a cirrus deck and are not predicted by any models**

Current Meteorological Shortfalls for <u>Wind</u> Energy

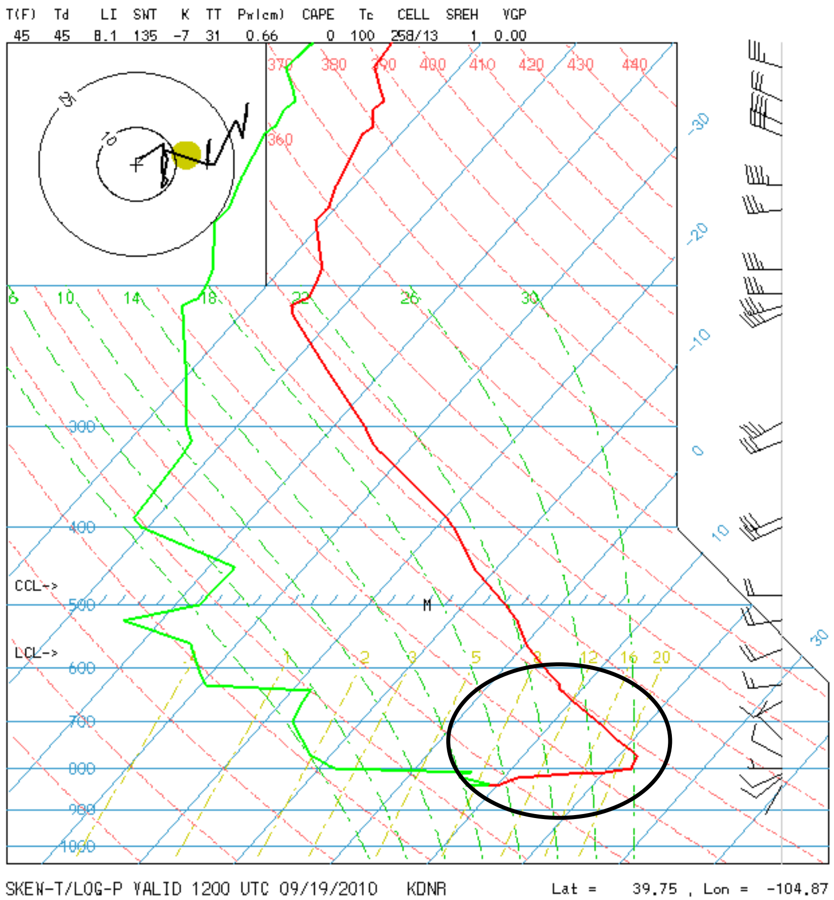
- **Lack of wind, temperature, and stability measurements between 10 and 200 m above ground**
- **Weather models not optimized for wind energy prediction and modeling across scales**
- **Need improved data assimilation techniques to take advantage of wind farm and other local observations**
- **Dearth of vertical observations offshore**
- **Lack of understanding of complex flows near the Earth's surface**
- **Ice and snow accretion and deposition prediction**

Current Meteorological Shortfalls for Solar Energy

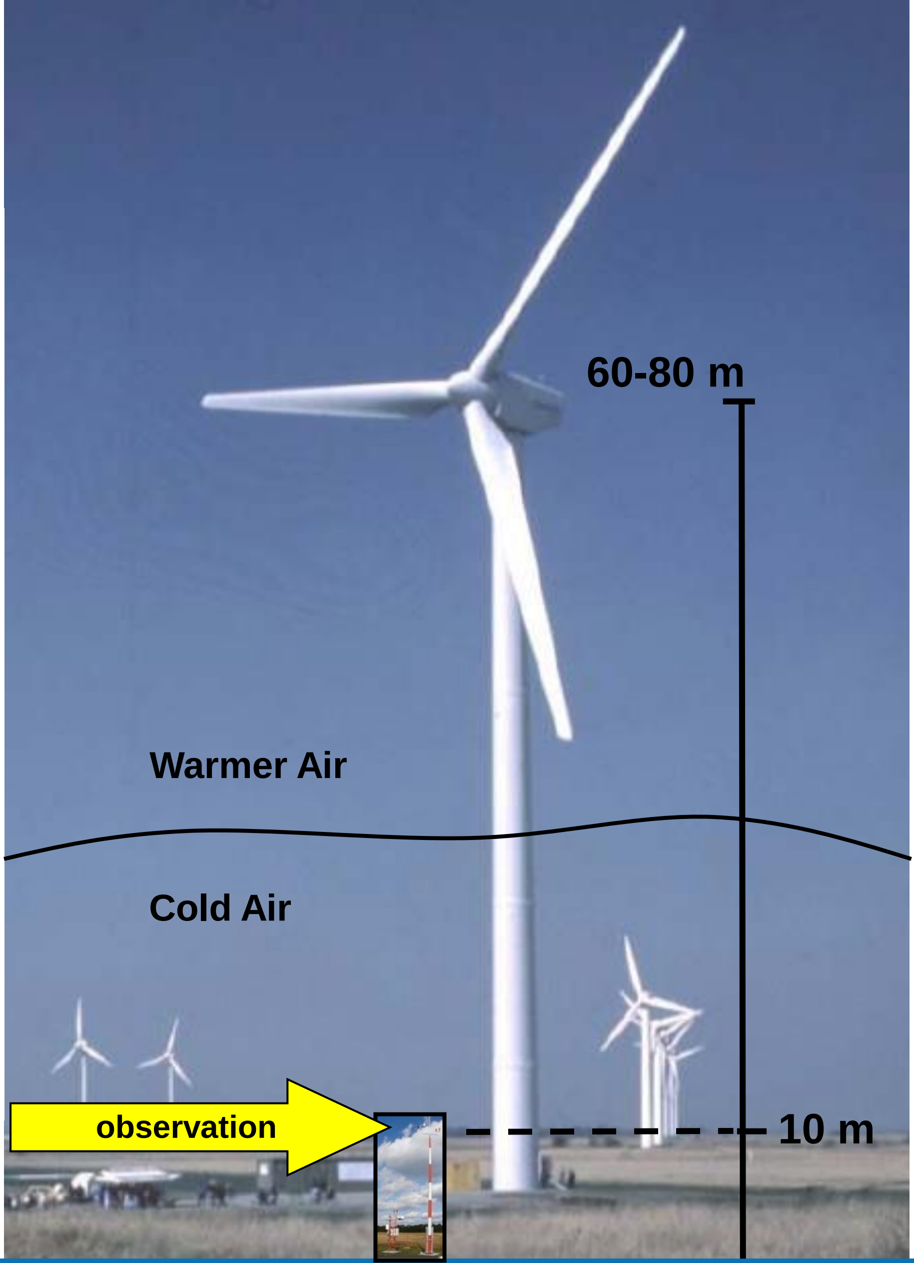
- **Lack of surface irradiance measurement covering a wide range of climates**
- **Lack of global water vapor measurements at high resolution (horizontal and vertical)**
- **Weather models not optimized for solar energy prediction; modeling across scales (synoptic to cloud scale)**
- **Inadequate data assimilation techniques to take advantage of solar farm solar and other local cloud observations**
- **Lack of full understanding of cloud physics and precipitation processes**

Examples of Complexity

Predicting Inversions – Wind Decoupling

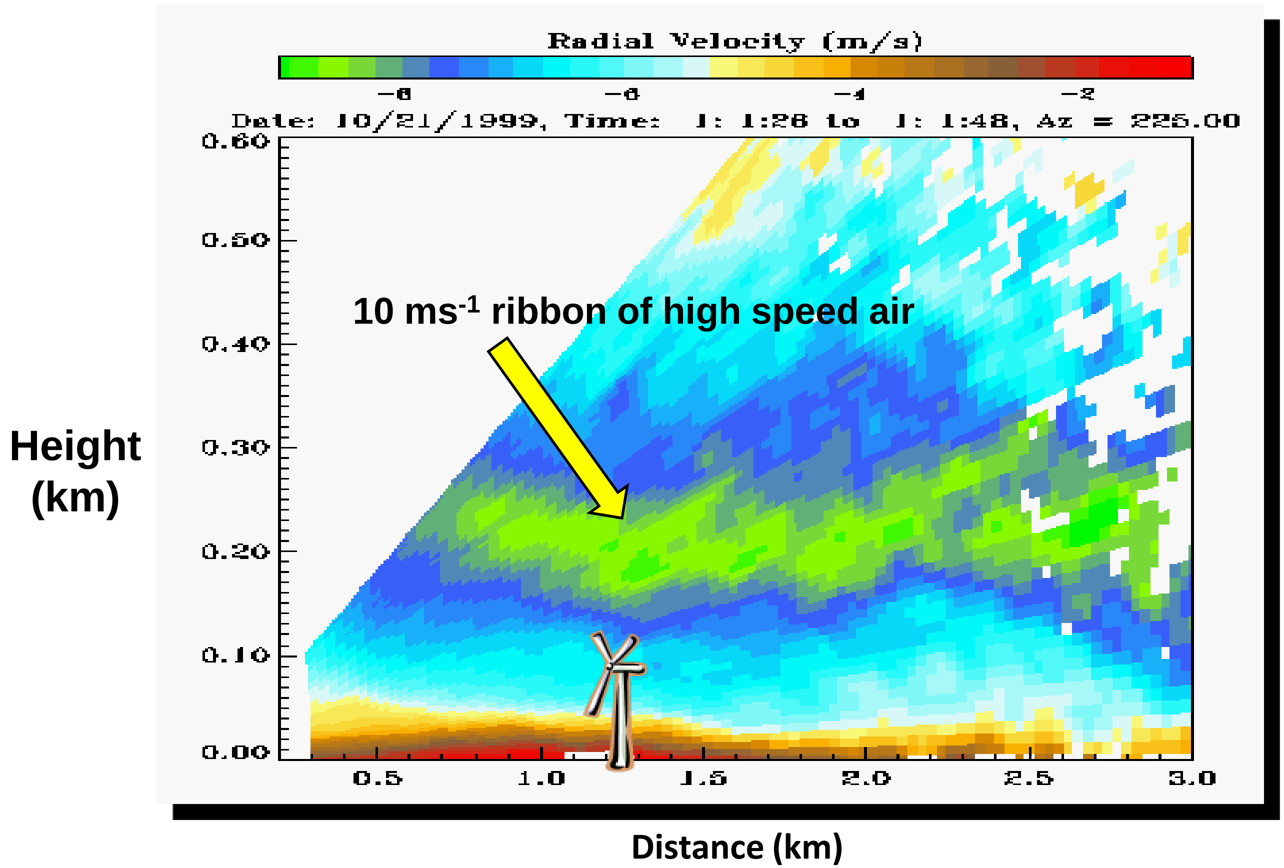


Nocturnal inversion – Denver 19 September 2010
15 degree C difference over ~1500 ft



Low-Level Jets of High Wind (U.S. Midwest)

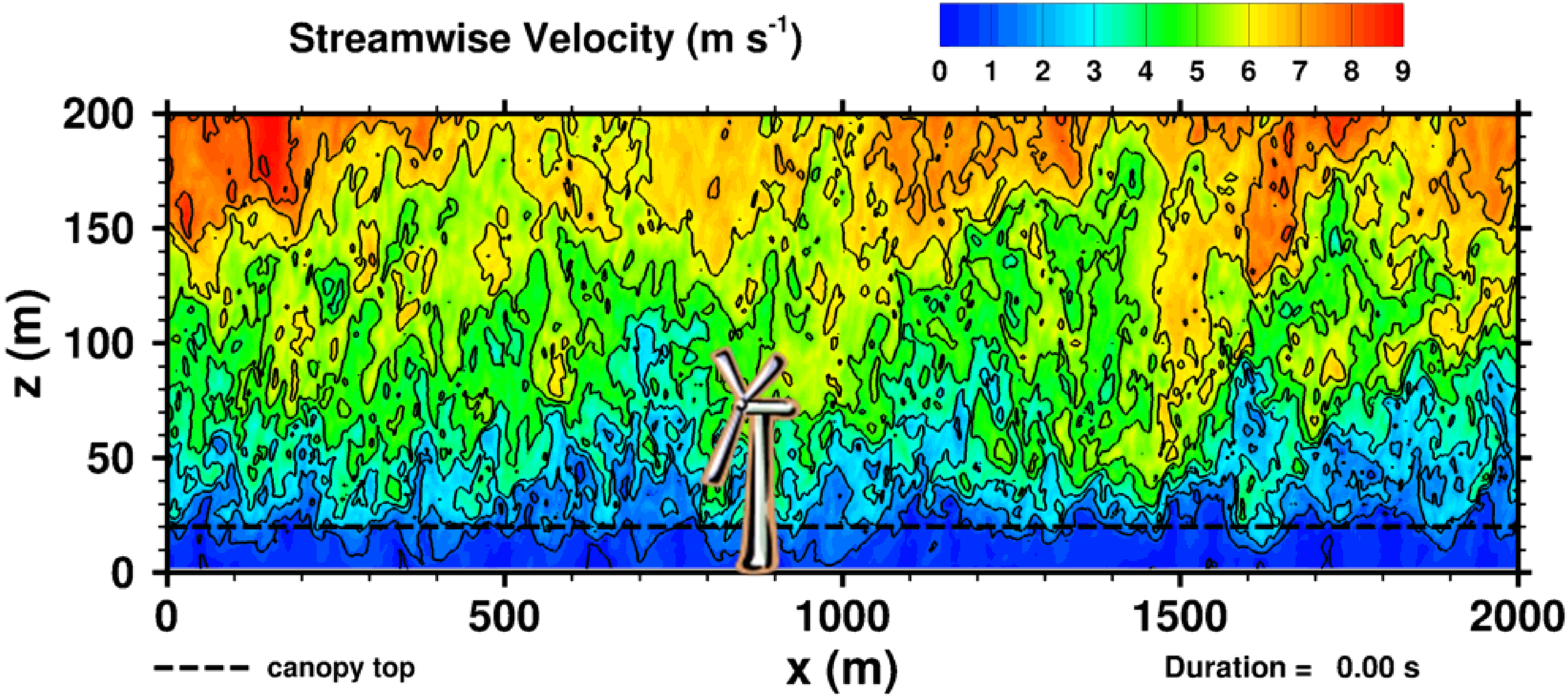
Lidar (laser radar) measured wind velocity toward lidar



Courtesy, Robert Banta, NOAA

Low-level jet streams can damage wind generators

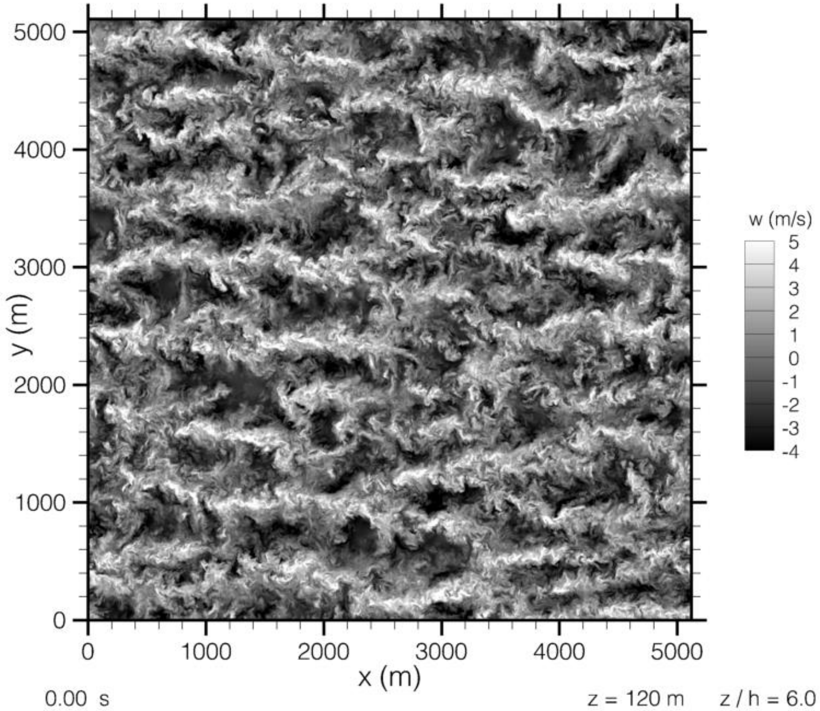
Wind Variability at Turbine Height Can be Substantial



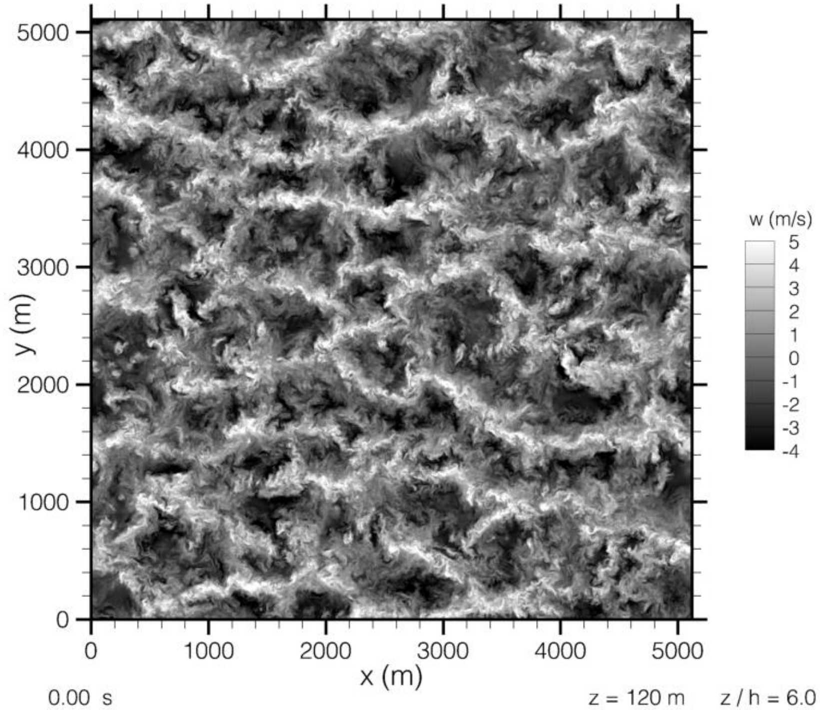
Courtesy Ned Patton, NCAR

Influence of Stability on Low-Level Flow

Horizontal slices of vertical velocity



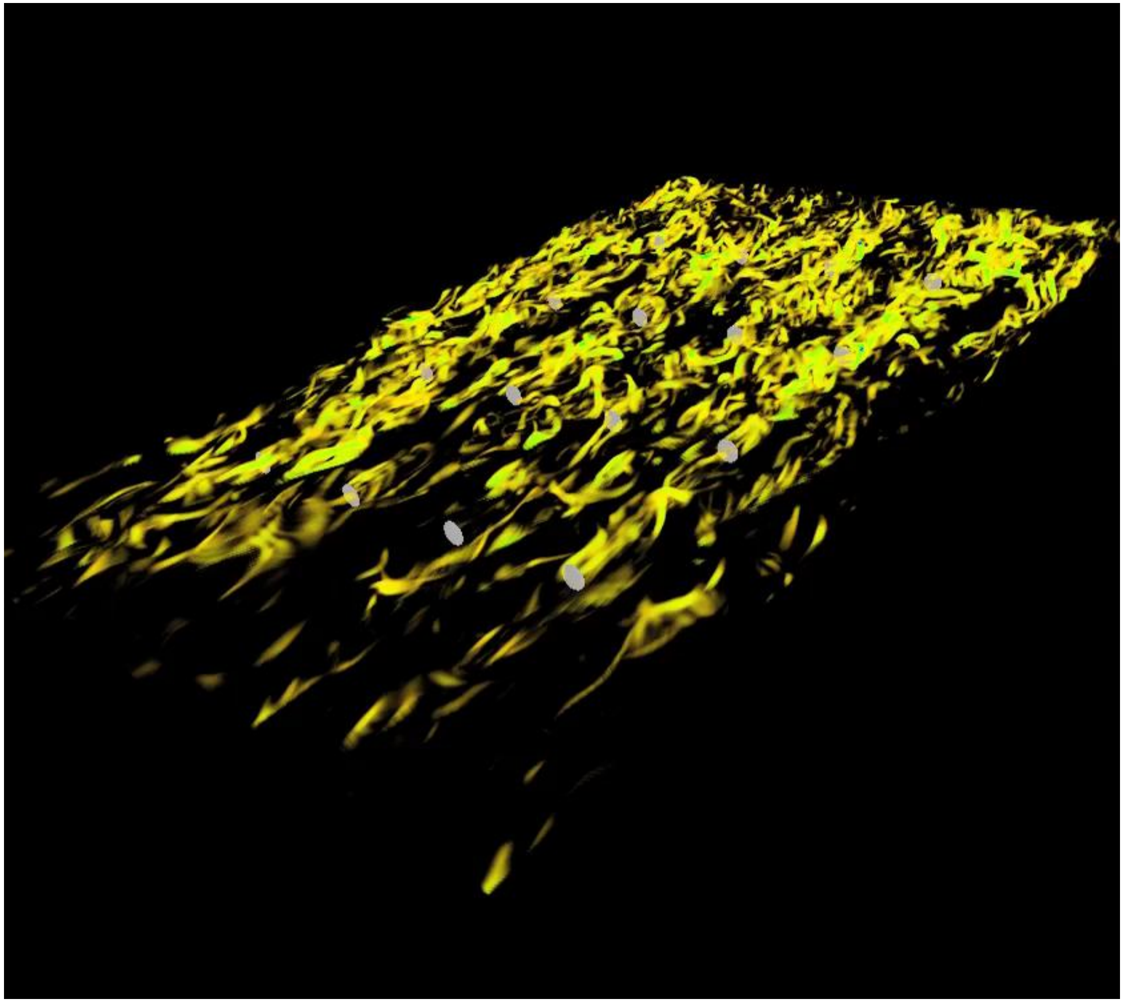
Near neutral



Strongly unstable

Courtesy Ned Patton, NCAR

Wake Effects of Turbine Arrays



Turbine wakes result in power loss, turbulence, wind shear and overall wear and tear on the turbines drive trains

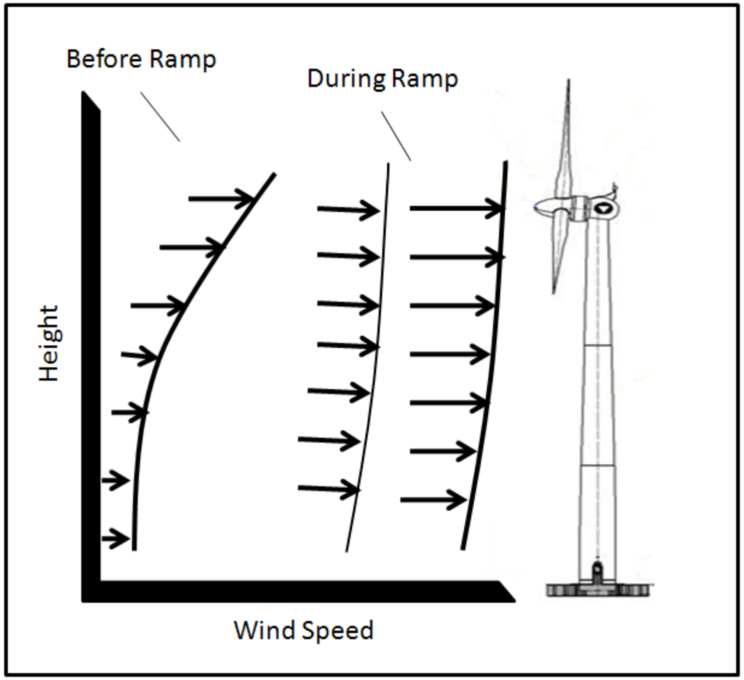
Courtesy Branko Kosovic, NCAR

Wind Shear vs. Turbine Efficiency

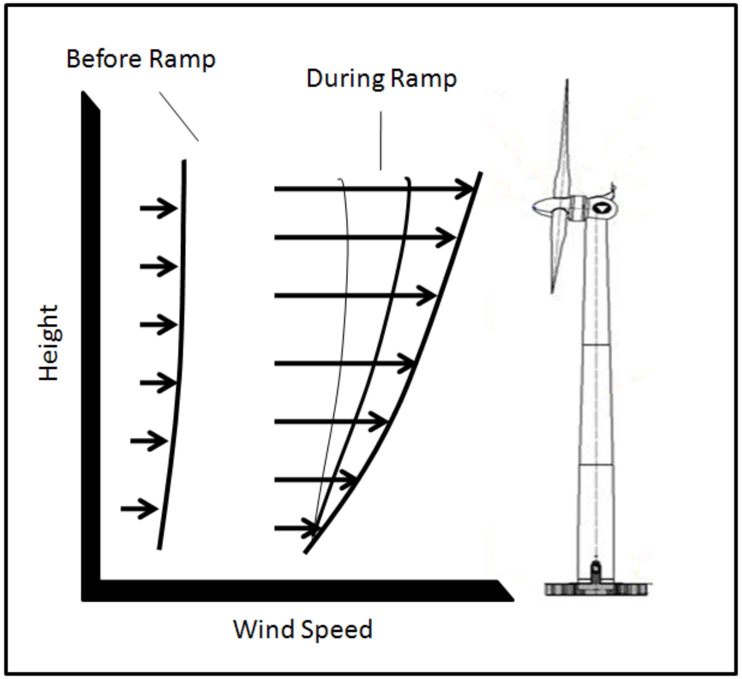
Knowledge of the wind profile is important for wind to power conversion – Shear across blades can reduce efficiency by up to 20%!

(Lundquist and Wharton, 2009)

Cold Front Wind Ramp



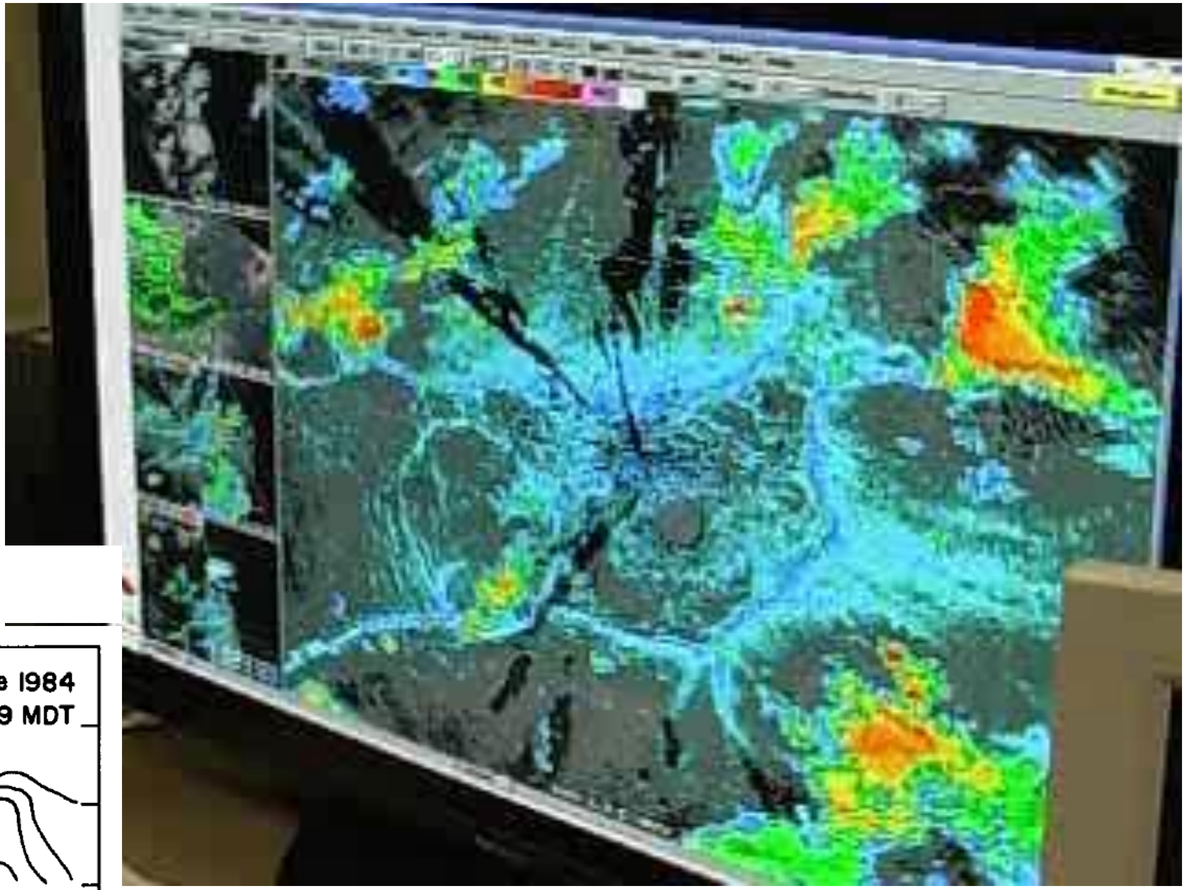
Low-level Jet Wind Ramp

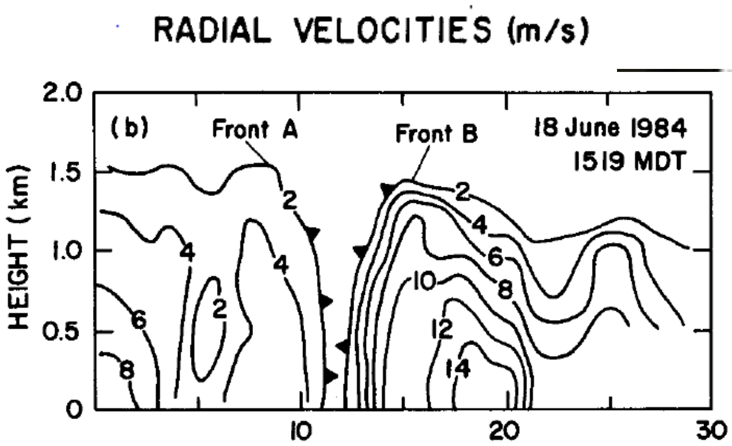


(T. Aguilar, 2010)

Wind Energy Ramps – Colliding Gust Fronts

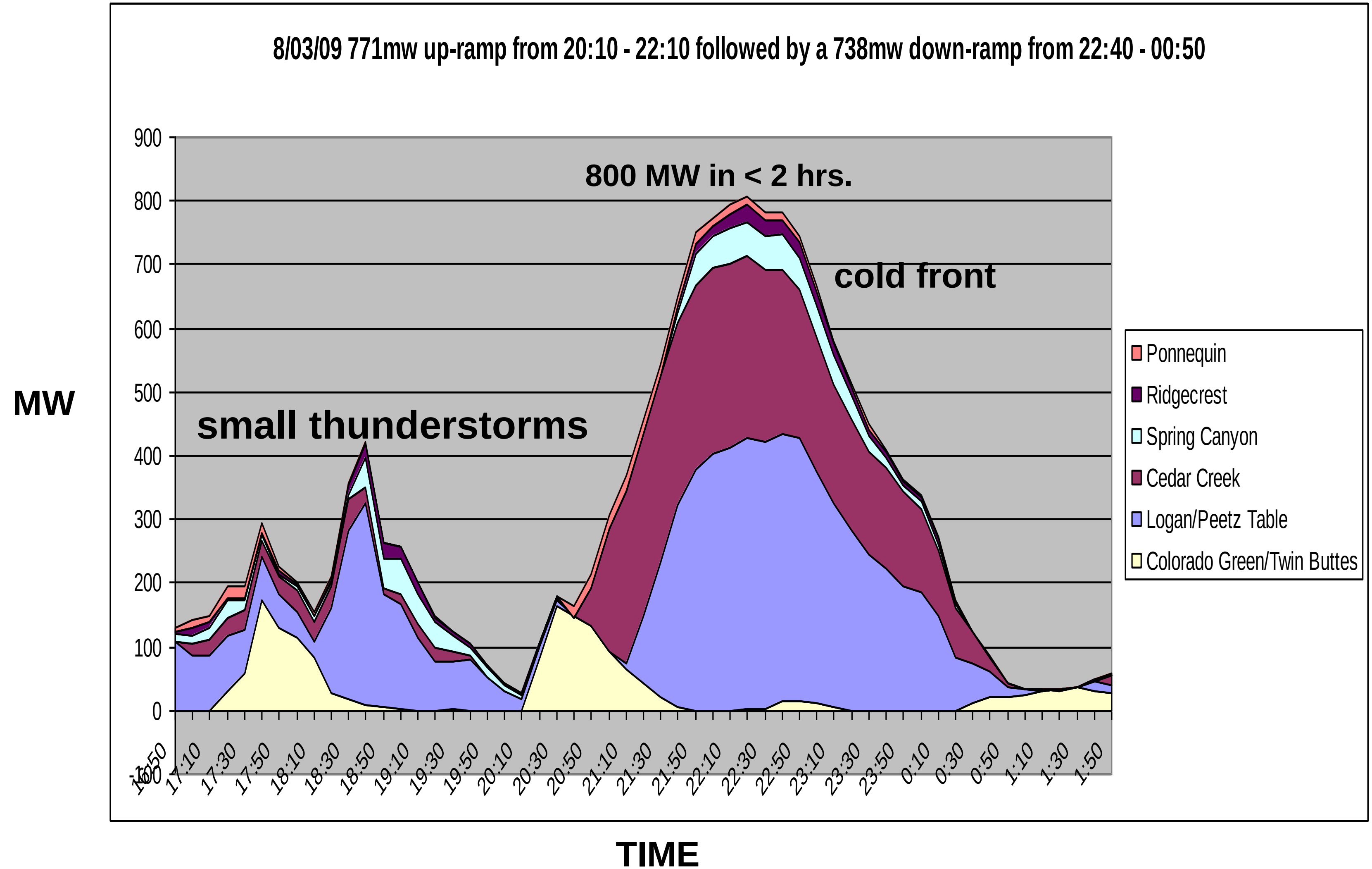
Colliding thunderstorm gust fronts in Texas





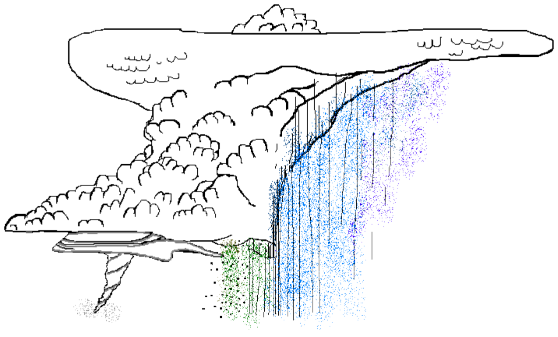
Mahoney 1988

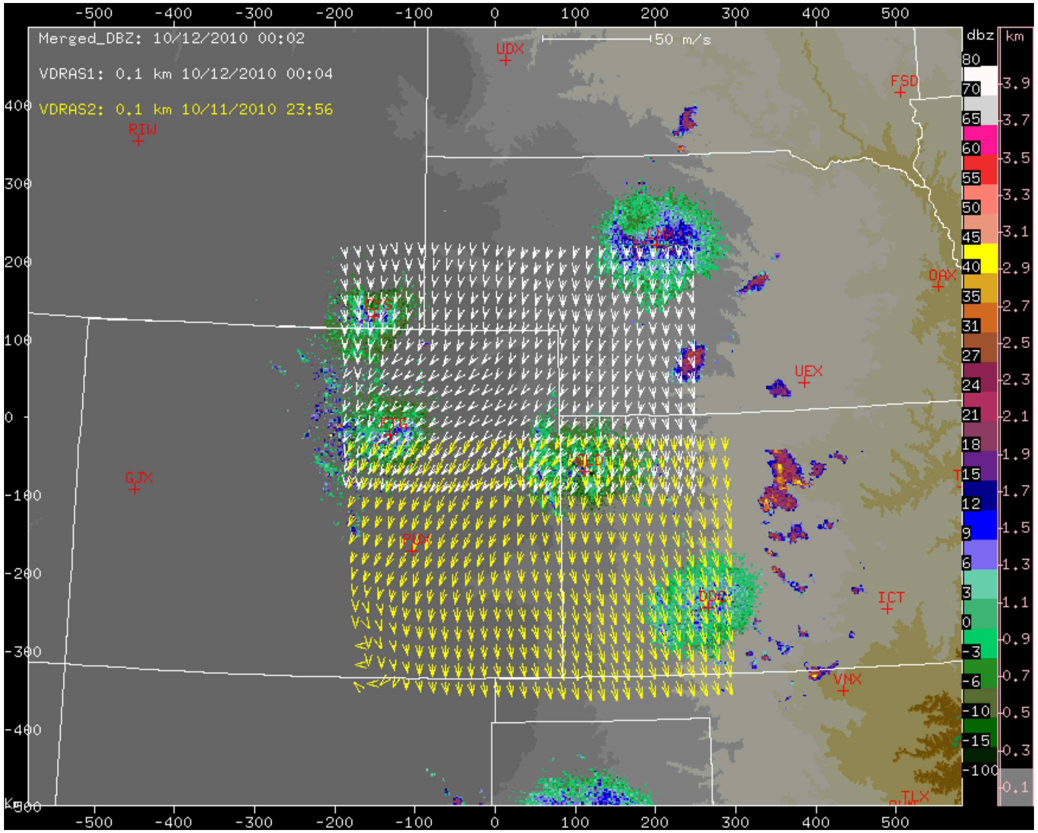
Wind Energy Ramp Events



Wind Energy Ramp Nowcasting

Predicting wind energy ramp events using a rapid cycle, high-resolution weather model and Doppler radar data.

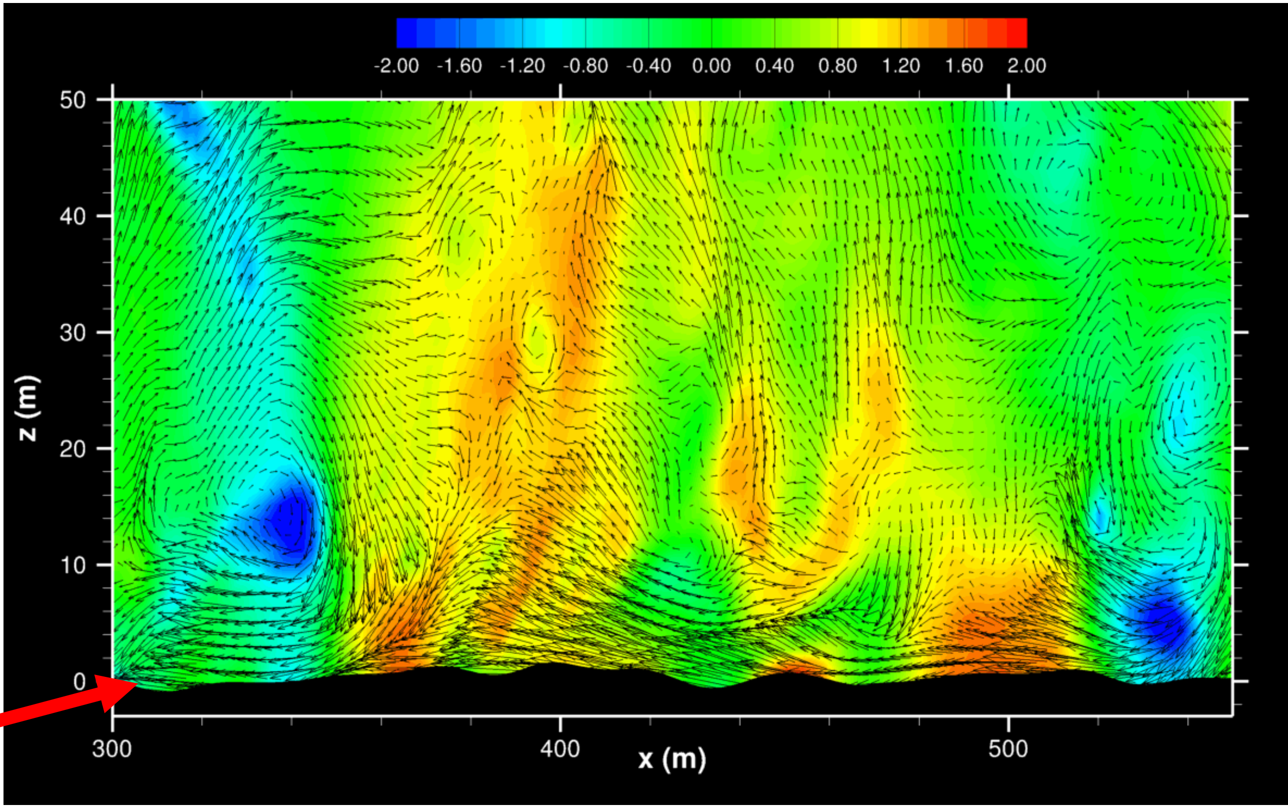




Animation of the Variational Doppler Radar Analysis System (VDRAS) covering eastern Colorado wind farms. Wind vectors and Doppler radar reflectivity are shown.

Complex Flows – Offshore Wind

For offshore applications it is important to capture wind and wave interactions



Moving waves

Peter Sullivan, NCAR

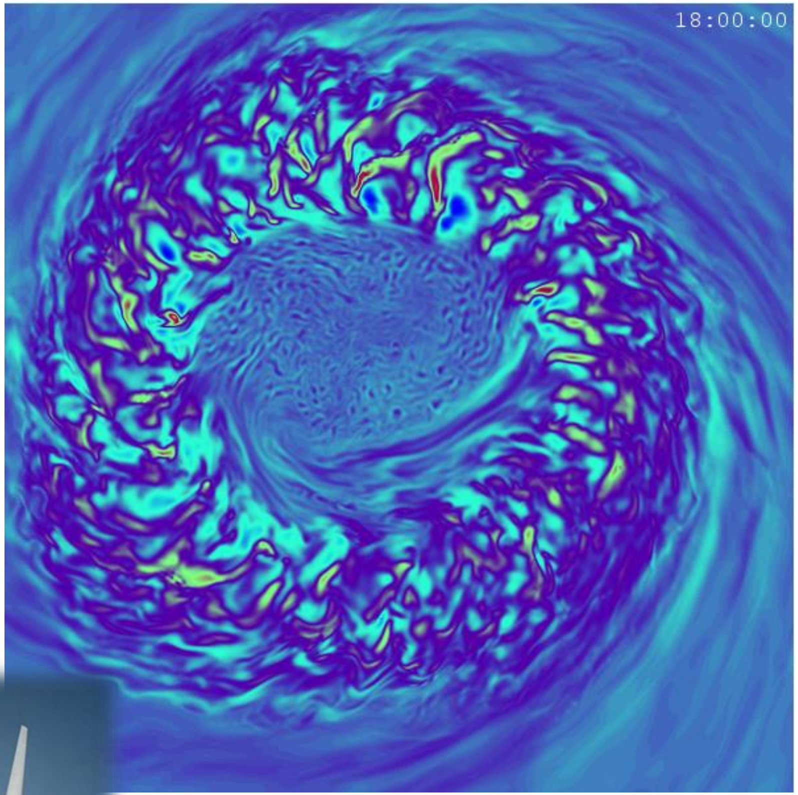
Waves generate their own wind field that persists to hub height

Hurricane Flow Characterization Complexities

WRF Hurricane Simulation
Large-Eddy Simulation (LES)
190 ft (62 m) resolution

Resolving turbulence scales

How do wind turbines respond to hurricanes, typhoons and USA Nor'easters?

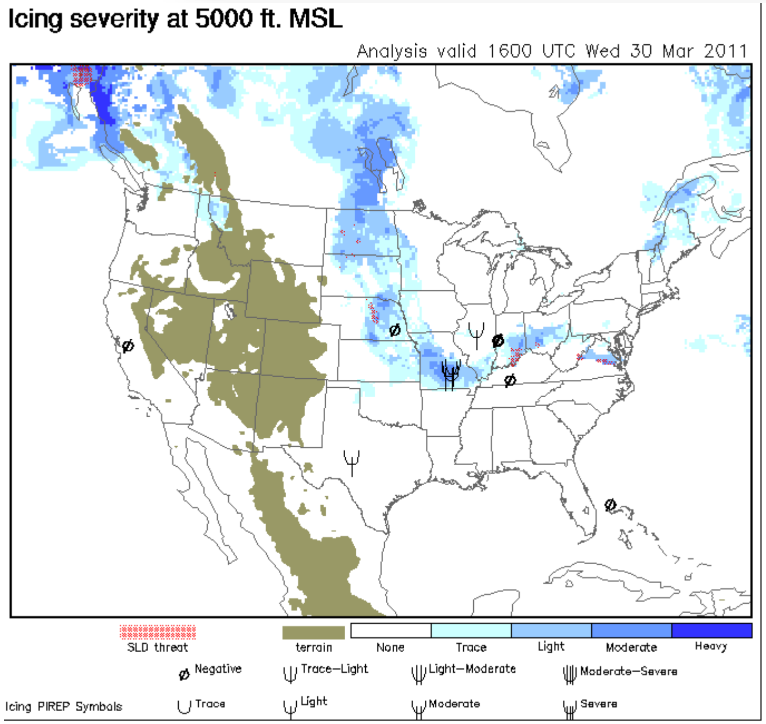


Rich Rotunno, NCAR

Icing Accretion and Snow Deposition

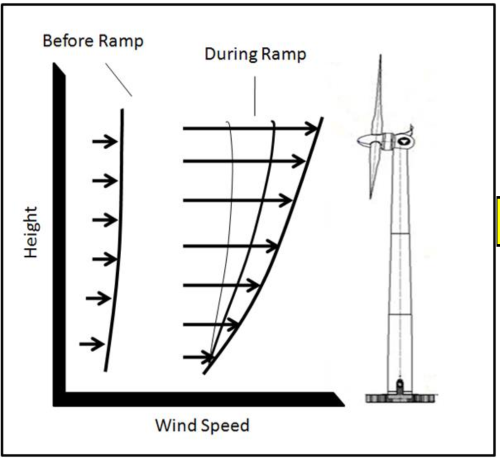
Source unknown

Icing prediction and its impact on turbine performance is a critical research topic.

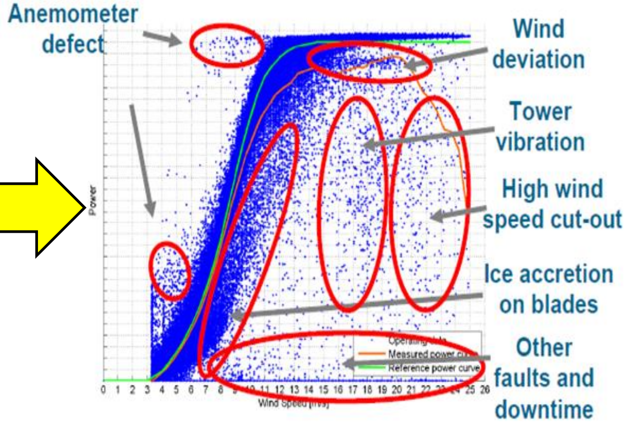


4D aviation icing product, NCAR

Wind Energy Prediction – Data Flow



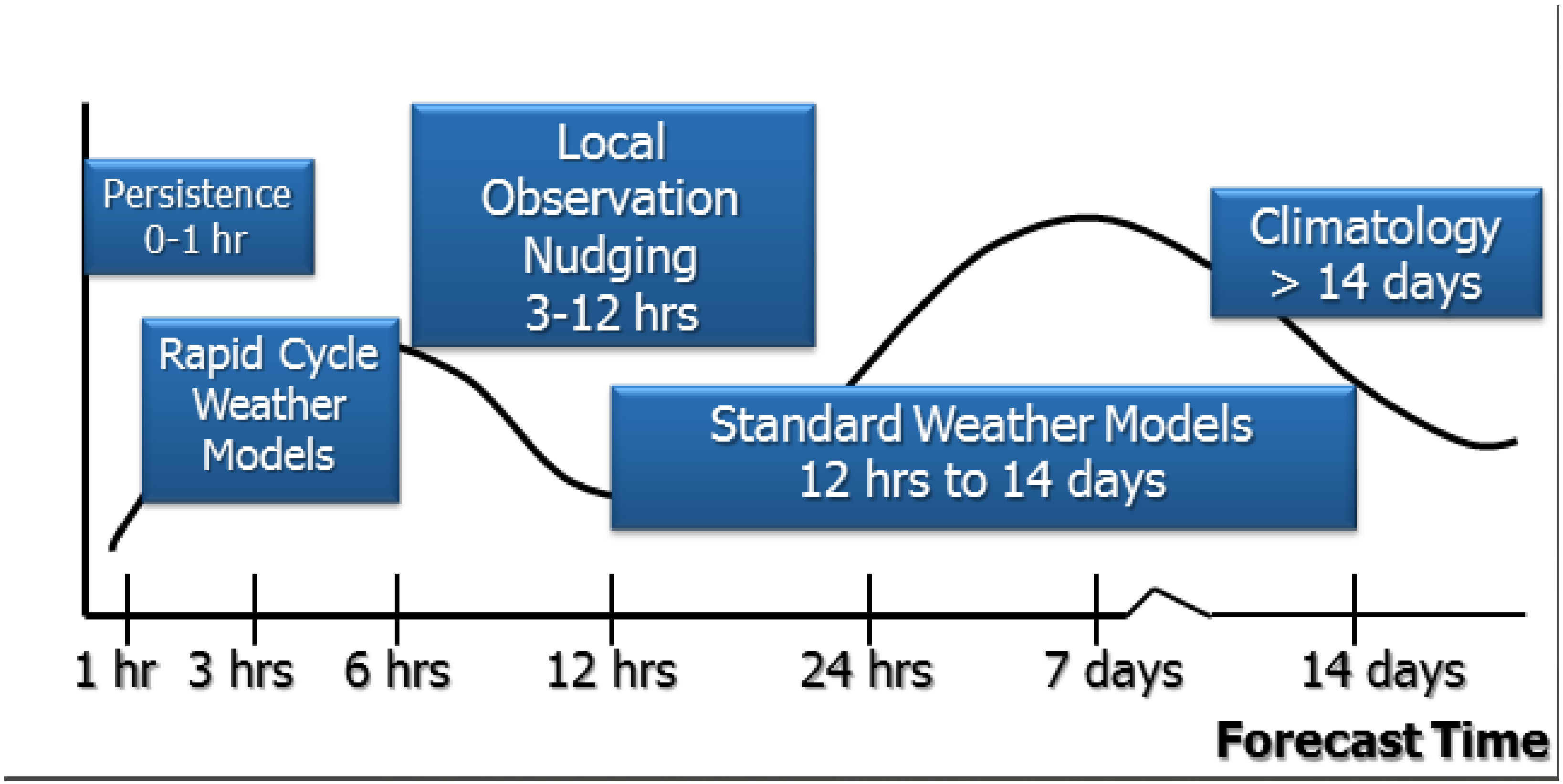
Predict wind speed at turbine height



Predict wind energy of each turbine using manufacturer or empirical power curve algorithms

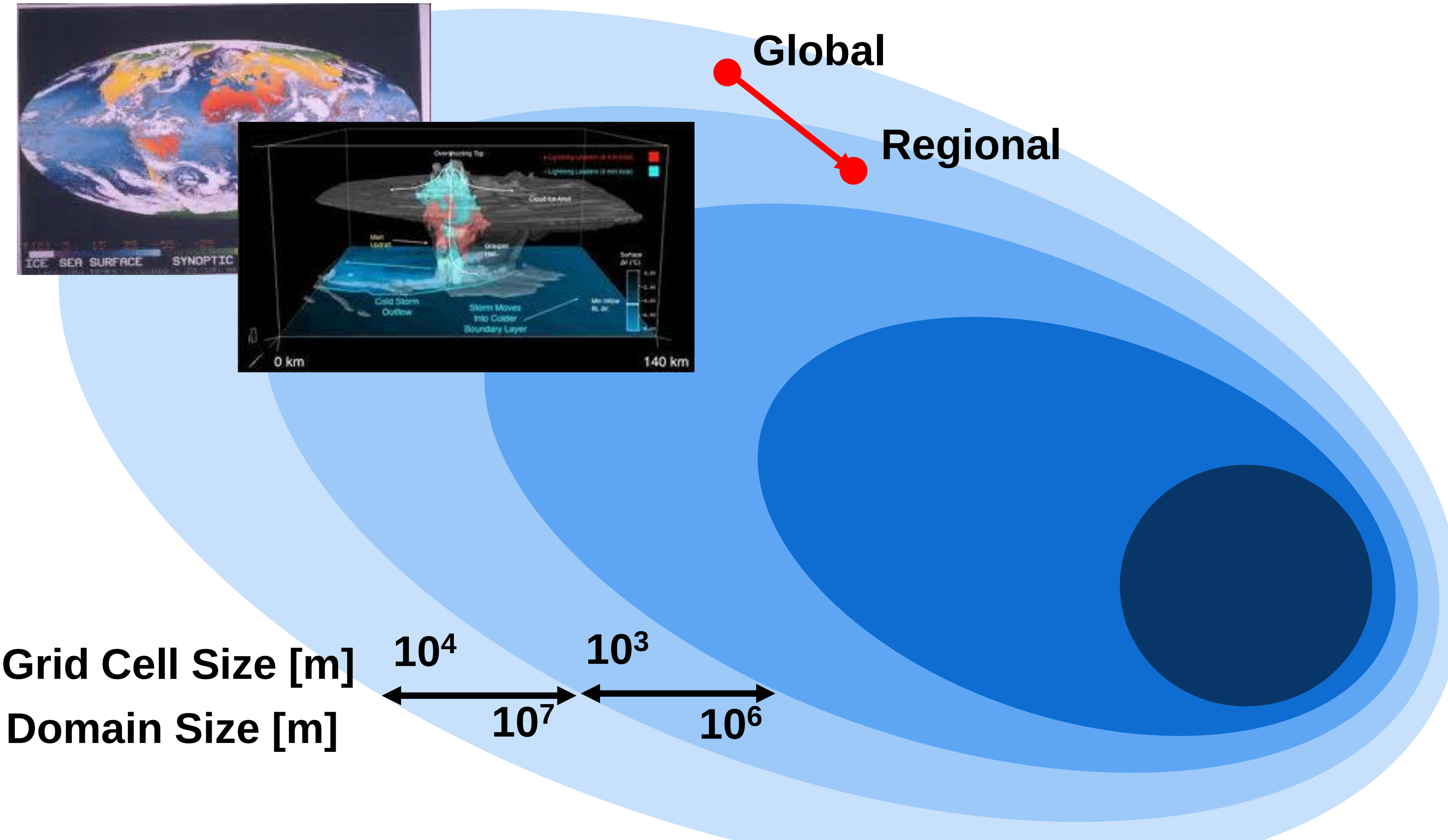
Predict electrical connection node power by adding up generation capacity of each turbine using power curve data

Optimizing Prediction by Blending Technologies



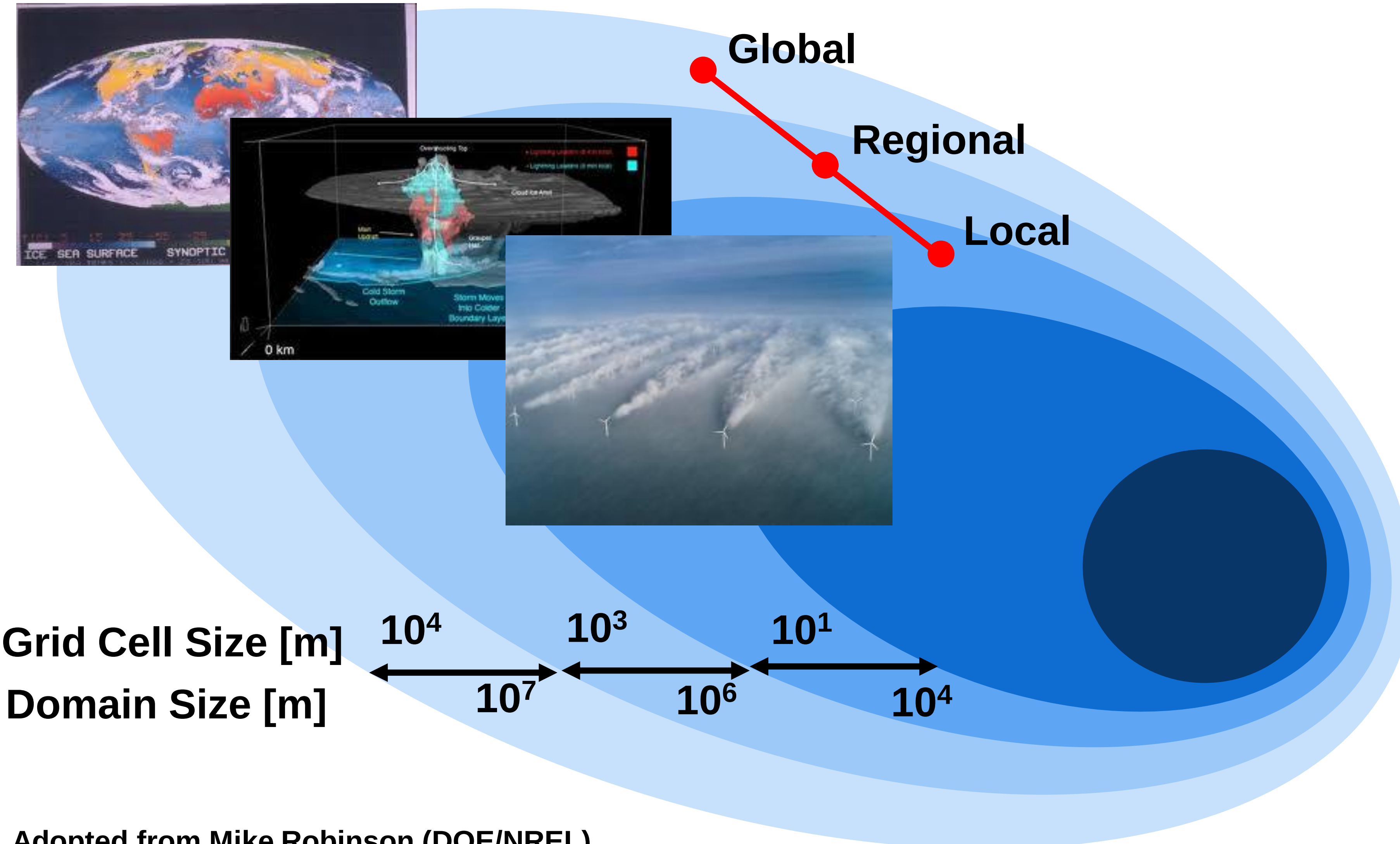
Each technology has its own 'sweet spot' with respect to prediction skill.

Research in Complex Flows



Adopted from Mike Robinson (DOE/NREL)

Research in Complex Flows



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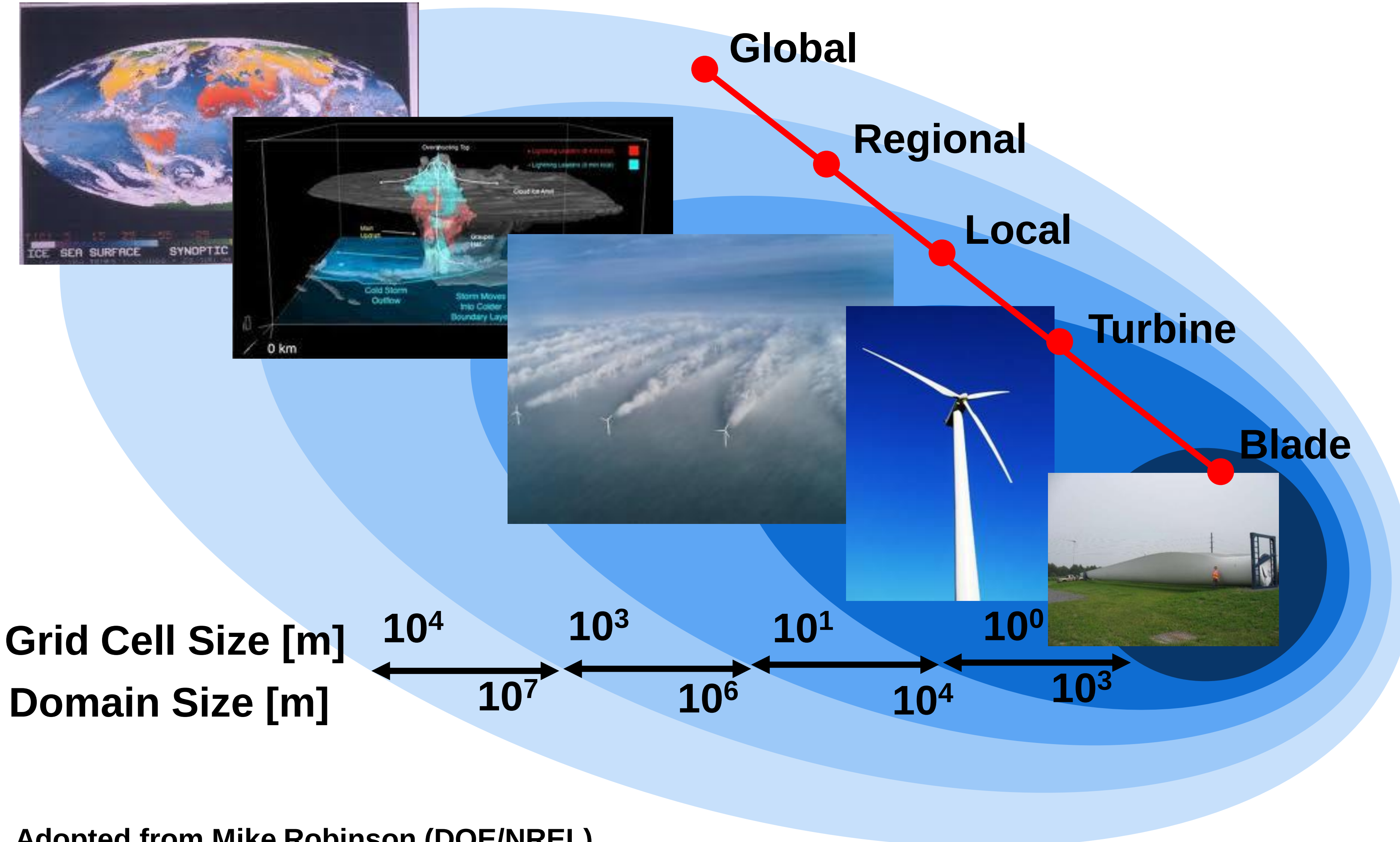
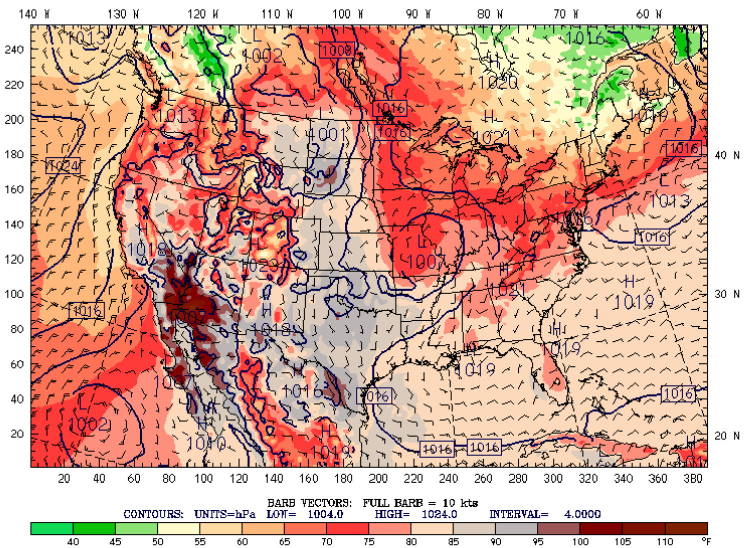
Research in Complex Flows



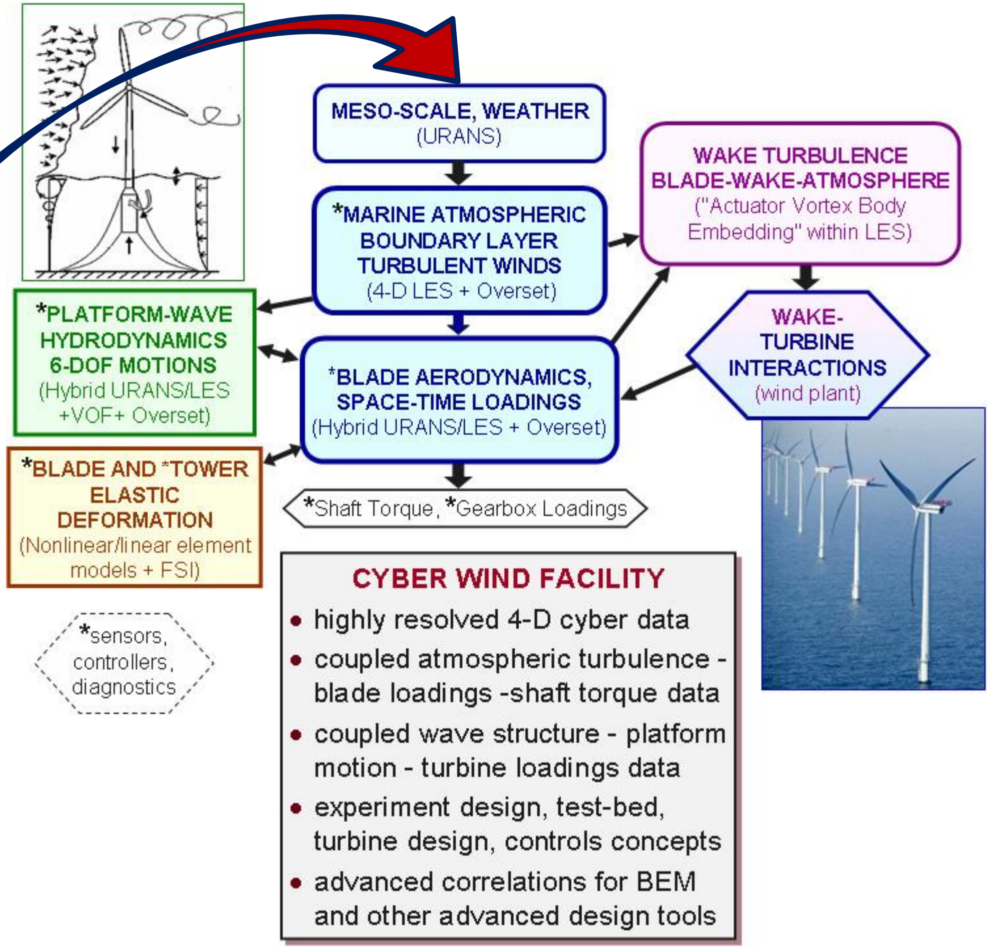
Adopted from Mike Robinson (DOE/NREL)

Fully-Coupled CFD/CSD for Turbine/Platform Interaction with the Atmosphere and Ocean

Objective: To create a state-of-the-art High- Performance Computing "Cyber Wind Facility" for the renewable energy industry and researchers.



Mesoscale Weather Data



Courtesy Jim Brasseur, Penn State

Atmospheric Science Research to Support Wind and Solar Energy

- Multi-year field experiments (on and off-shore)
- Boundary layer meteorology (complex flow)
- Cloud physics & precipitation processes (icing, snow, etc.)
- Turbulence characteristics and prediction
- Computational science (improve efficiency)
- Land surface condition prediction
- Ocean dynamics (waves, currents)
- Aerodynamic studies related to turbine design
- Multi-scale modeling (global to millimeter scales)
- Future climate modeling (effects on wind/solar resources)

Thank You

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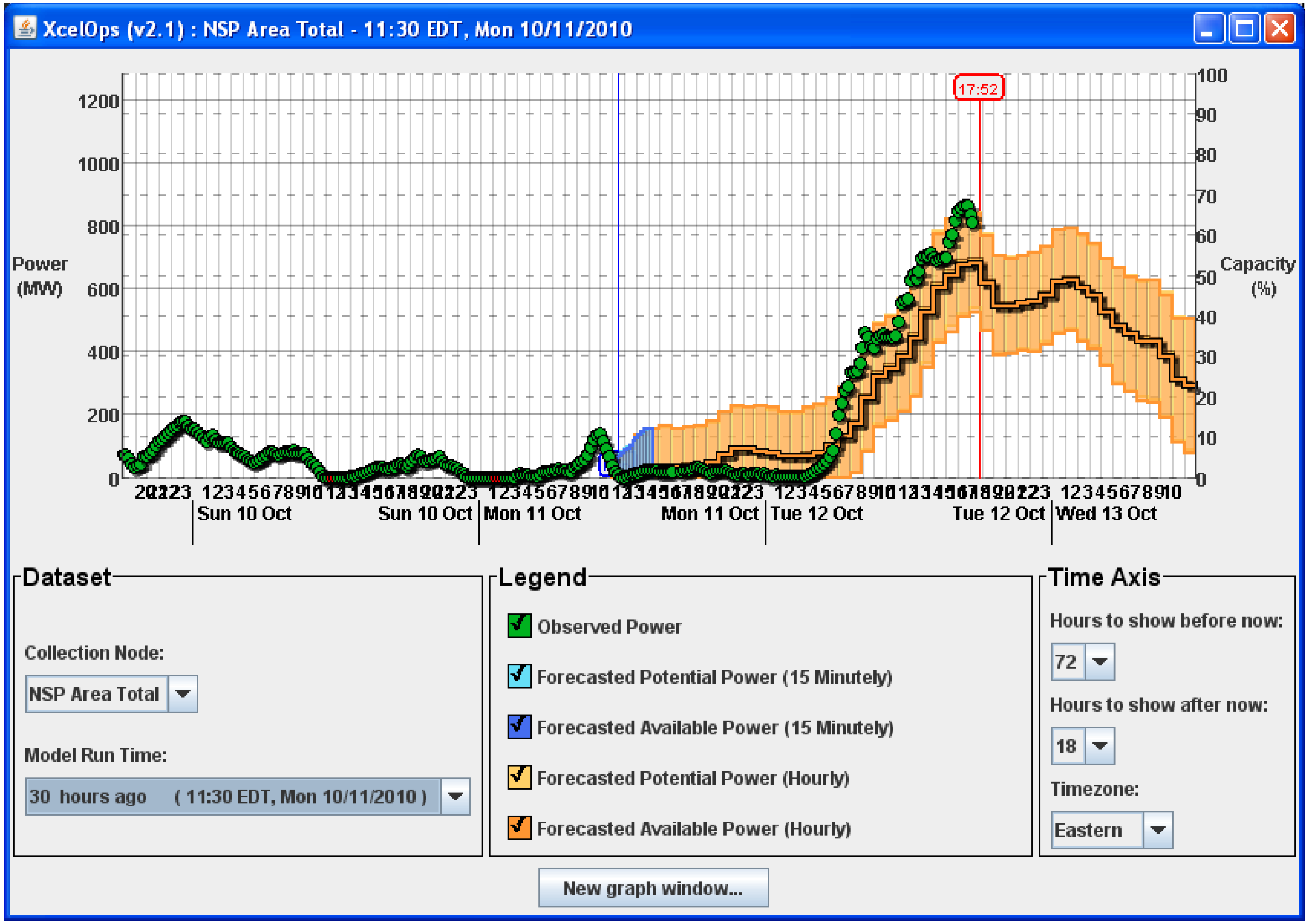
Wind Energy Prediction – User Interface



Xcel Energy Wind Energy Prediction System Hardware – Deterministic Modeling System

• Four Dell 2950 servers: 2 CPUs (8 cores) at 2.66GHz, 8-16GB RAM, 2-4TB RAID5

• Sixty-one Dell 1950 servers: 2 CPUs (8 cores) at 2.66GHz, 4or8GB RAM, 250GB, Myrinet card

• One 64 port gigabit switch for network access to storage and user access to cluster

• One 64 port Myrinet switch for high speed MPI

• Network attached, 8-10TB of storage for model processing and output.

• Installed within 2 or 3 new Dell full height (42U) racks, with peripherals such as:

  8 port KVM switch, Dell 15" LCD console panel, power distribution units, UPS 3000, all associated cabling.

Xcel Energy Wind Energy Prediction System Hardware – Ensemble Modeling System

Three Dell 2950 servers: 2 CPUs (8 cores) at 2.66GHz, 16GB RAM, 2-4TB RAID5

• Forty-two Dell 1950 servers: 2 CPUs (8 cores) at 2.66GHz, 4or8GB RAM, 250GB

• One 64 port gigabit switch for network access to storage and user access to cluster

• Network attached, 12-16TB of storage, with potential ability to scale to 40TB

• Installed within 2 new Dell full height (42U) racks, with peripherals such as:

8 port KVM switch, Dell 15” LCD console panel, power distribution units, UPS 3000, all associated cabling.