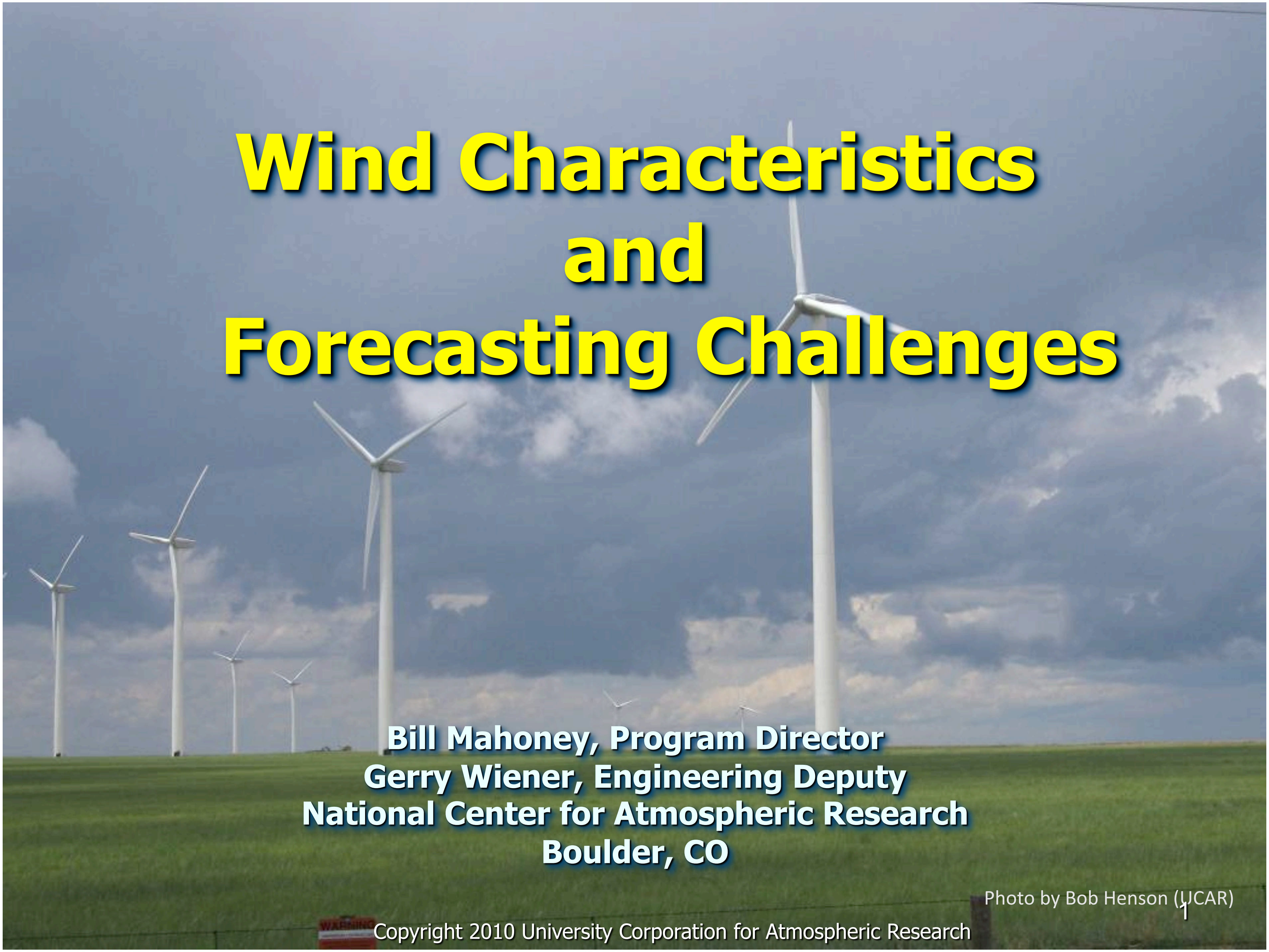


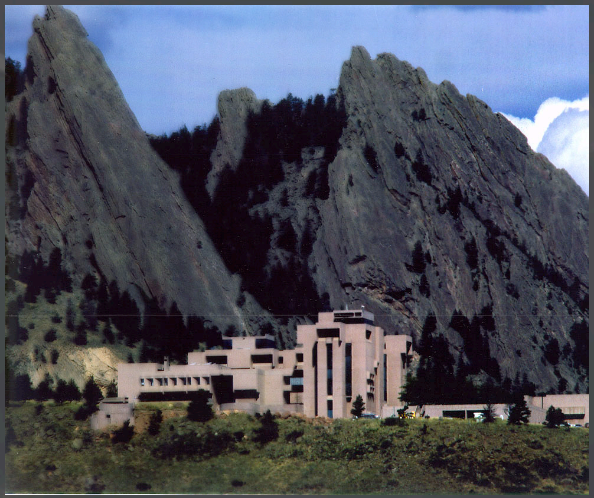
Wind Characteristics and Forecasting Challenges

Bill Mahoney, Program Director
Gerry Wiener, Engineering Deputy
National Center for Atmospheric Research
Boulder, CO

Photo by Bob Henson (UCAR)

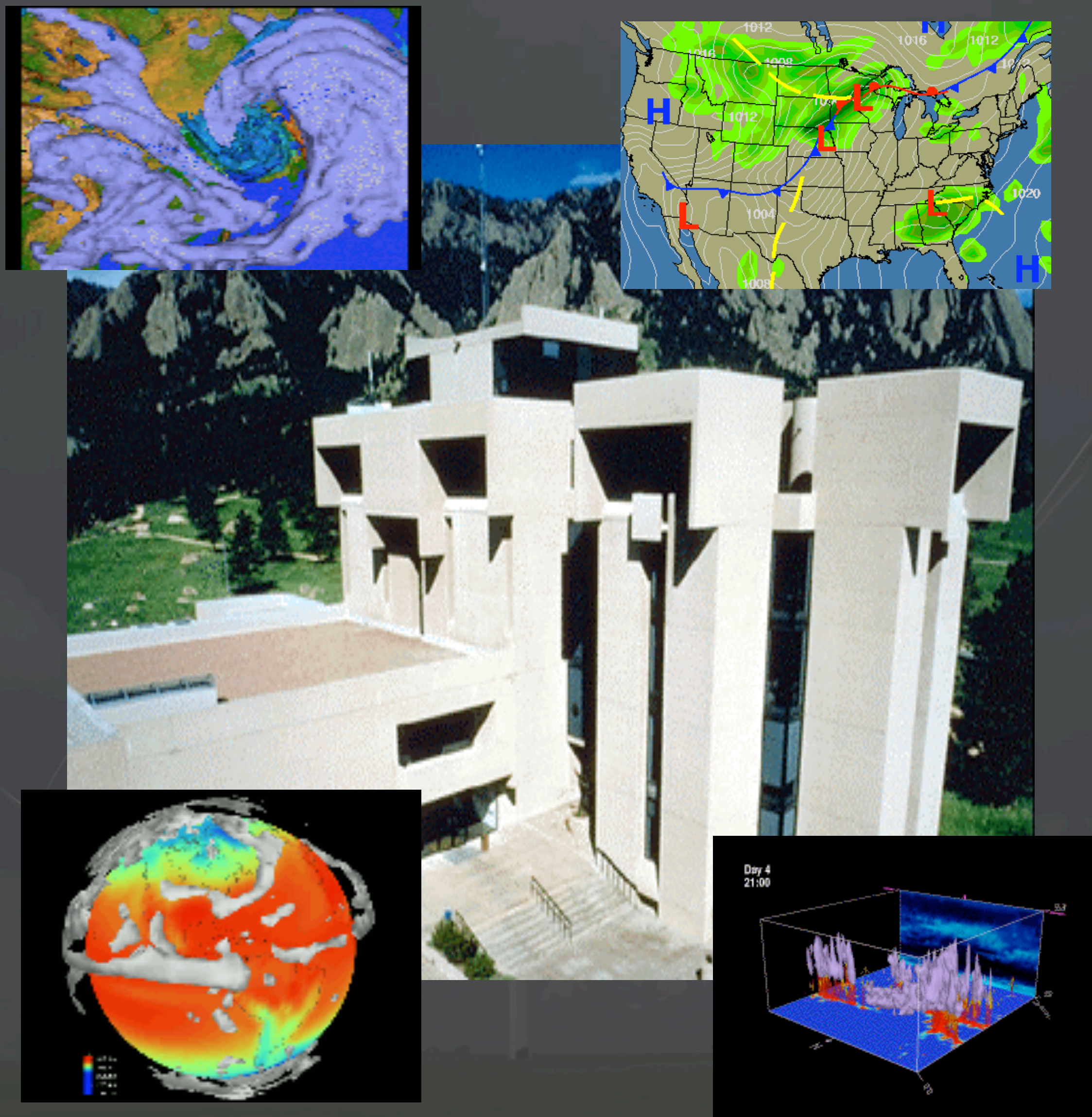
What is the National Center for Atmospheric Research (NCAR)?

- NCAR is a Federally funded research and development center sponsored by the National Science Foundation.
- NCAR is operated by the University Corporation for Atmospheric Research (UCAR), a non-profit corporation formed in 1959.
- UCAR has 1400 employees and ~$250M budget.
- Research is conducted on solar physics, climate and weather modeling, air chemistry, thunderstorms, hurricanes, icing, turbulence, societal impacts of weather, energy, etc.



NCAR, Boulder, CO

Photo by Bob Henson (UCAR)



Research Areas:

Climate Science
Air Chemistry
Solar Physics
Weather Research
- boundary layer
- thunderstorms
- weather models
- hurricanes
- land surface
- coupled models

Social Sciences
Supercomputing
Technology Transfer

National Center for Atmospheric Research (NCAR)

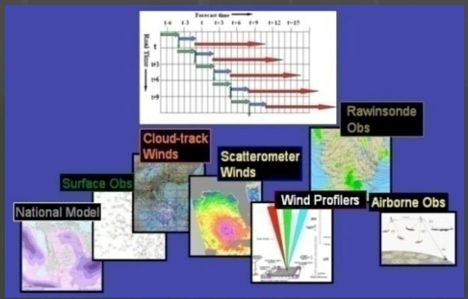
Photo by Bob Henson (UCAR)

Research Applications Laboratory

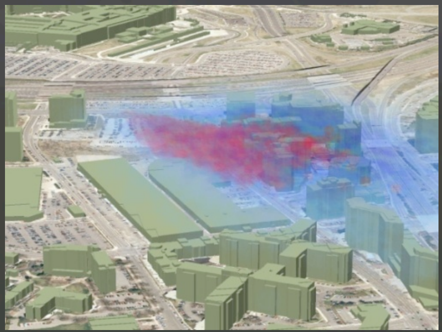
- Mission
  - Perform applied R&D geared toward weather related decision support systems
  - Transfer knowledge and technology to U.S. government agencies, the private sector, and foreign governments

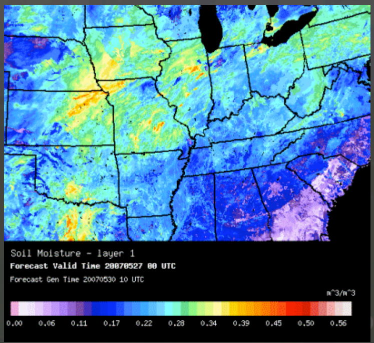
Wind Energy Related Research at NCAR

- Weather modeling (global to urban scales)
- Wind characterization (how the wind blows)
- Data assimilation (combining obs and forecast)
- Probabilistic Prediction (ensemble modeling)
- Boundary layer research and modeling
- Applied mathematics & statistics
- Land surface modeling (land climate interaction)
- Coupled models (atmosphere and ocean)



Advanced Data Assimilation


Local & Urban Scale Modeling



Soil Condition Prediction

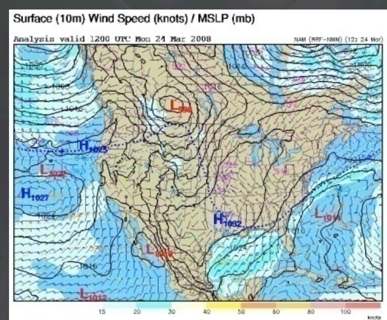

Wind Energy

to by Bob Henson (UCAR)

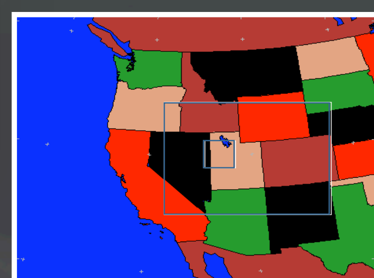
Wind Prediction Challenges

Scale Interactions are Critical

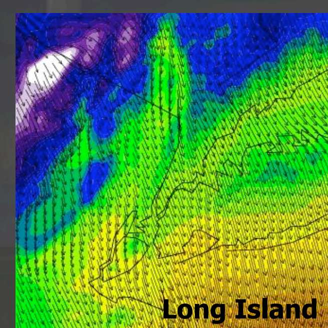
Global Scales



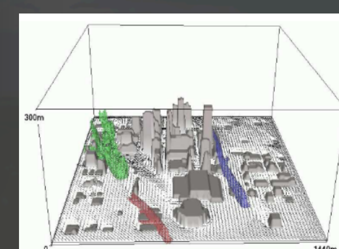
Continental Scales



Regional Scales



Local Scales



Urban Scales

Photo by Bob Henson (UCAR)

Wind Prediction Challenges

Local Effects & Phenomenon Must be Addressed

- ✓ Local Topography
- ✓ Surface Roughness
- ✓ Land Use
- ✓ Vegetation Characteristics
- ✓ Urbanization
- ✓ Atmospheric Gravity Waves
- ✓ Low-level jets
- ✓ Convection currents
- ✓ Icing

Atmospheric Boundary Waves

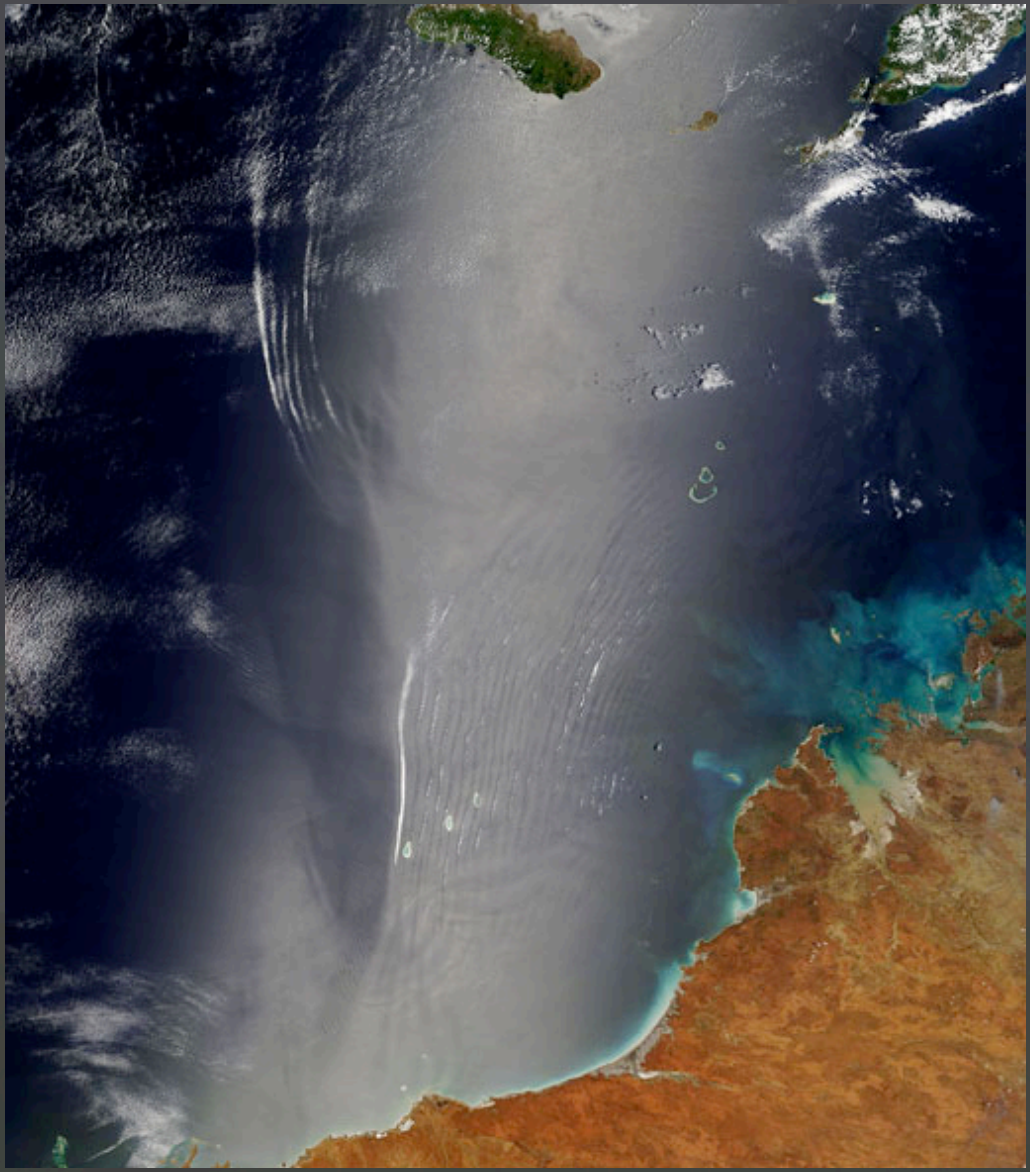


Photo Courtesy of Nasa

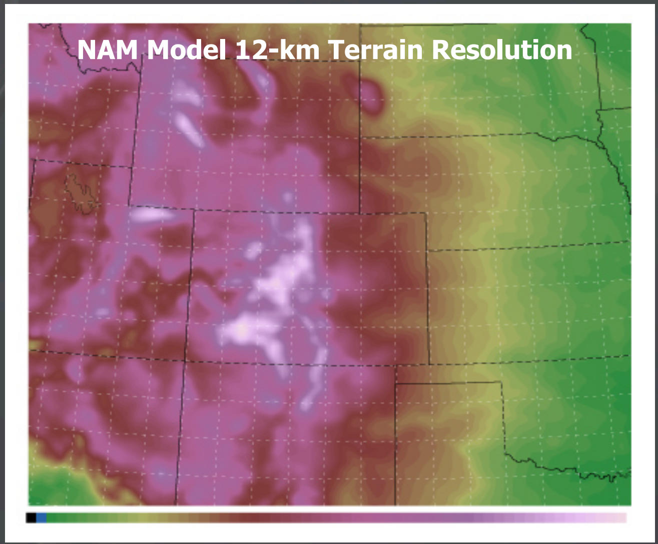
Photo by Bob Henson (UCAR)

Wind Prediction Challenges

Prediction Limitations

Weather predictions are inherently non-precise due to uncertainties in:

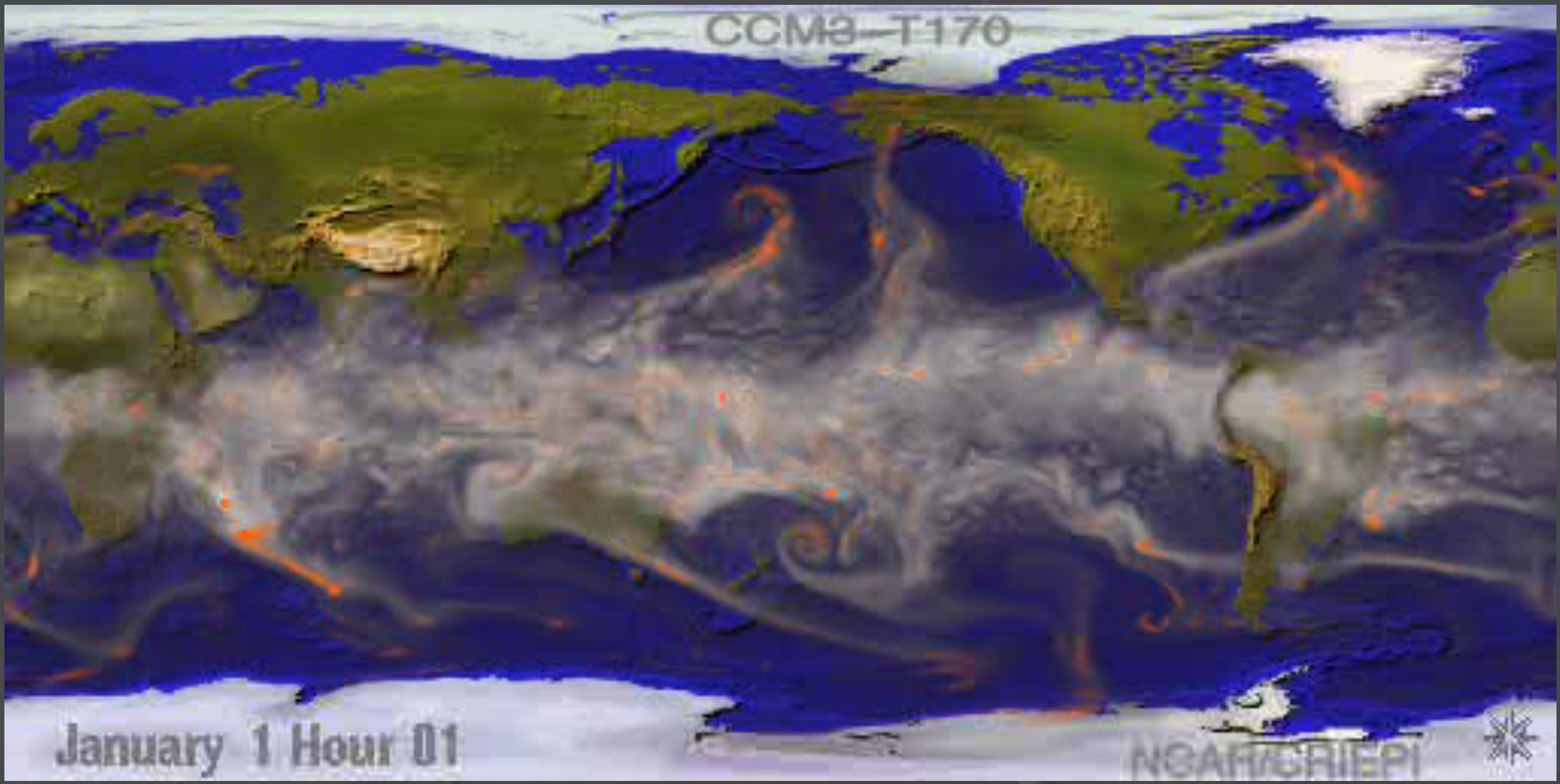
- ✓ state of the atmosphere
- ✓ analyzed initial state
- ✓ model resolution
- ✓ model physics/parameterizations
- ✓ coarse treatment of surface characteristics
- ✓ many other simplifications



Smoothed Rocky Mountains

Photo by Bob Henson (UCAR)

Atmosphere is a Fluid

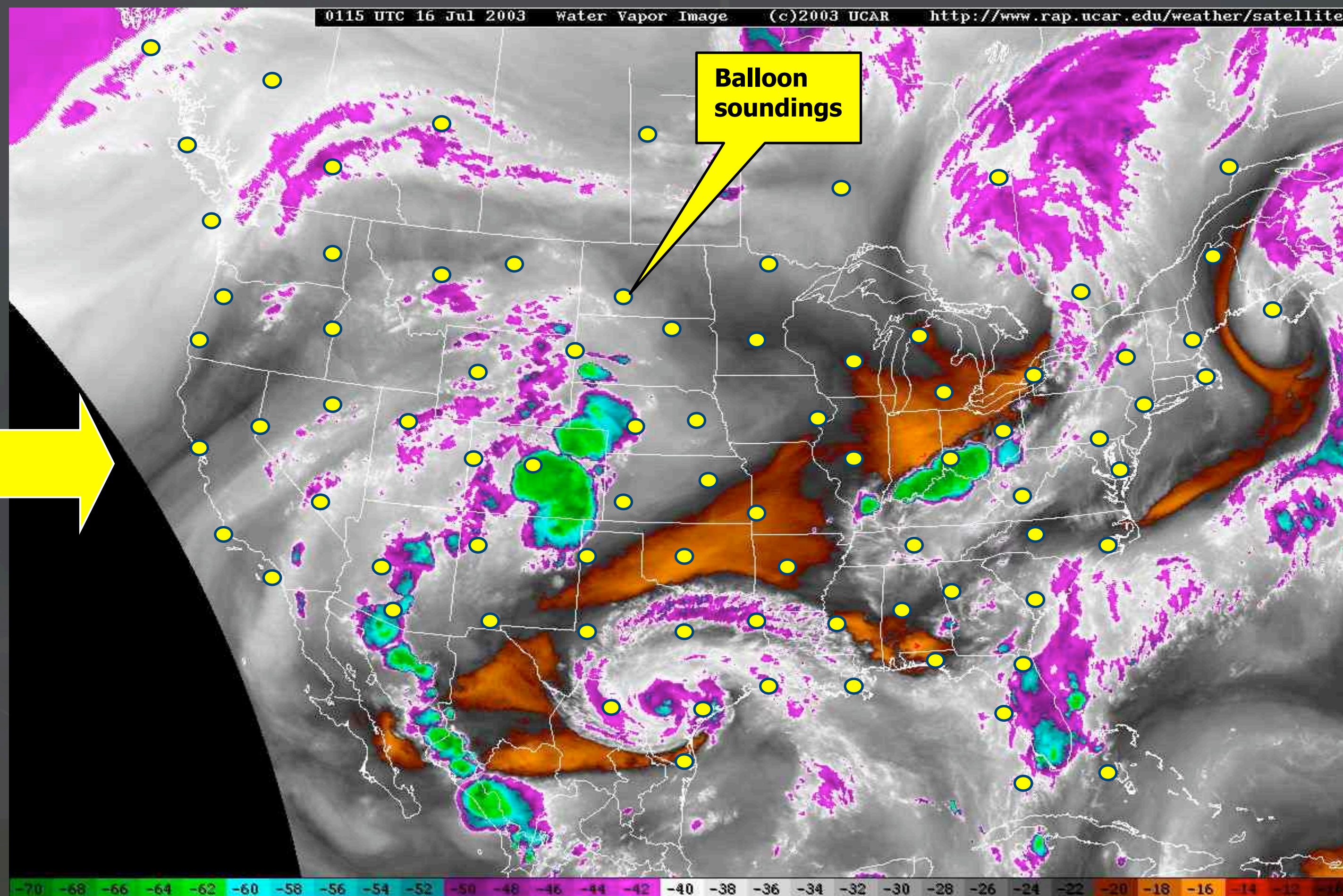


Water vapor simulation

Photo by Bob Henson (UCAR)

Wind Prediction Challenges

Complex Atmospheric Flows



A lot of details are missed between observations!

Photo by Bob Henson (UCAR)

GE 1.5 MW Wind Turbine

80 meter hub height (87 yards)
77 m blade diameter

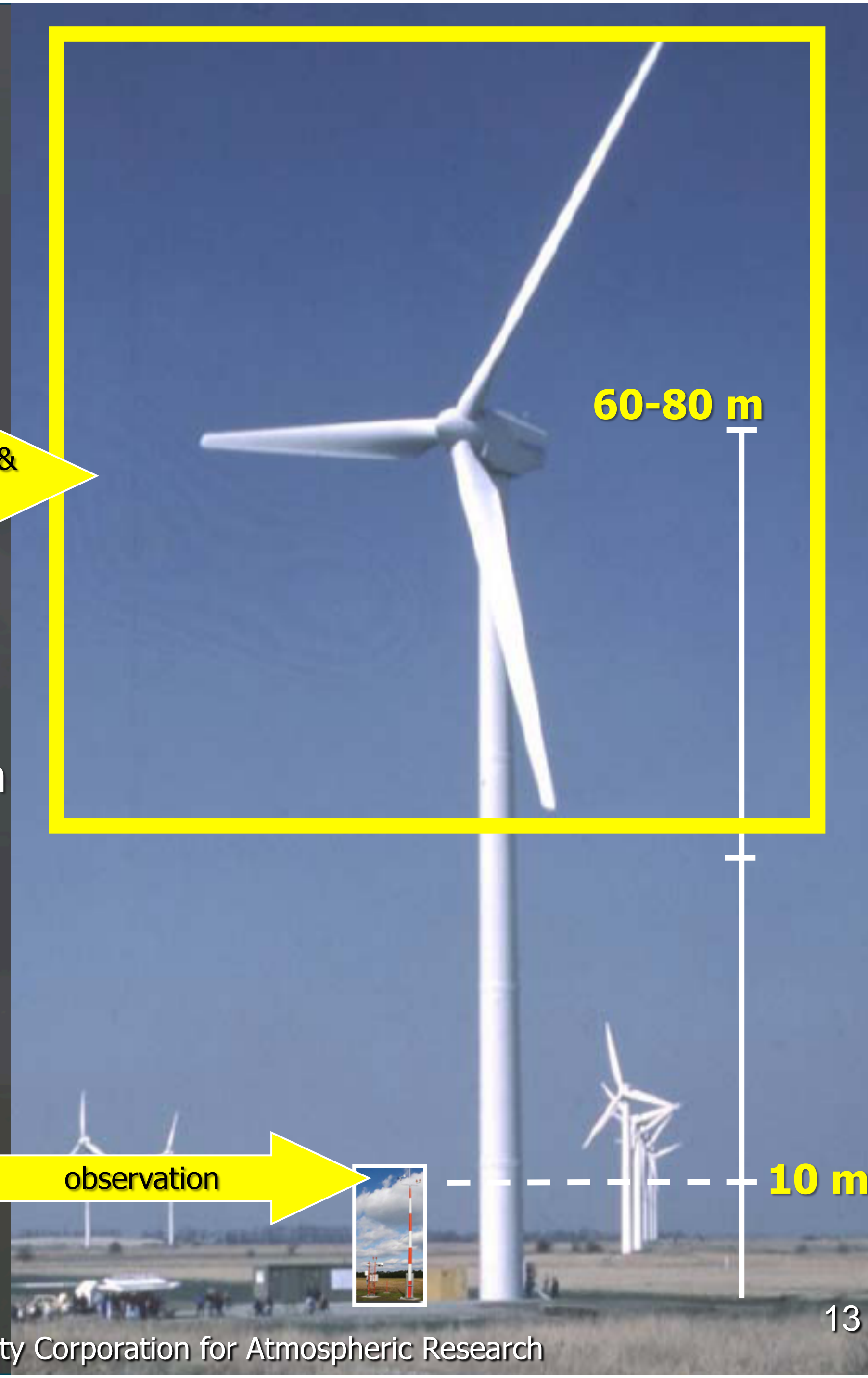
GE 1.5 MW Wind Turbine

80 meter hub height
77 m blade diameter

Assessments & Forecasts

Standard surface weather station with a 10 meter (33 ft) high wind sensor.

observation



Wind Prediction Challenges

Local Wind & Power Output Data Are Very Important

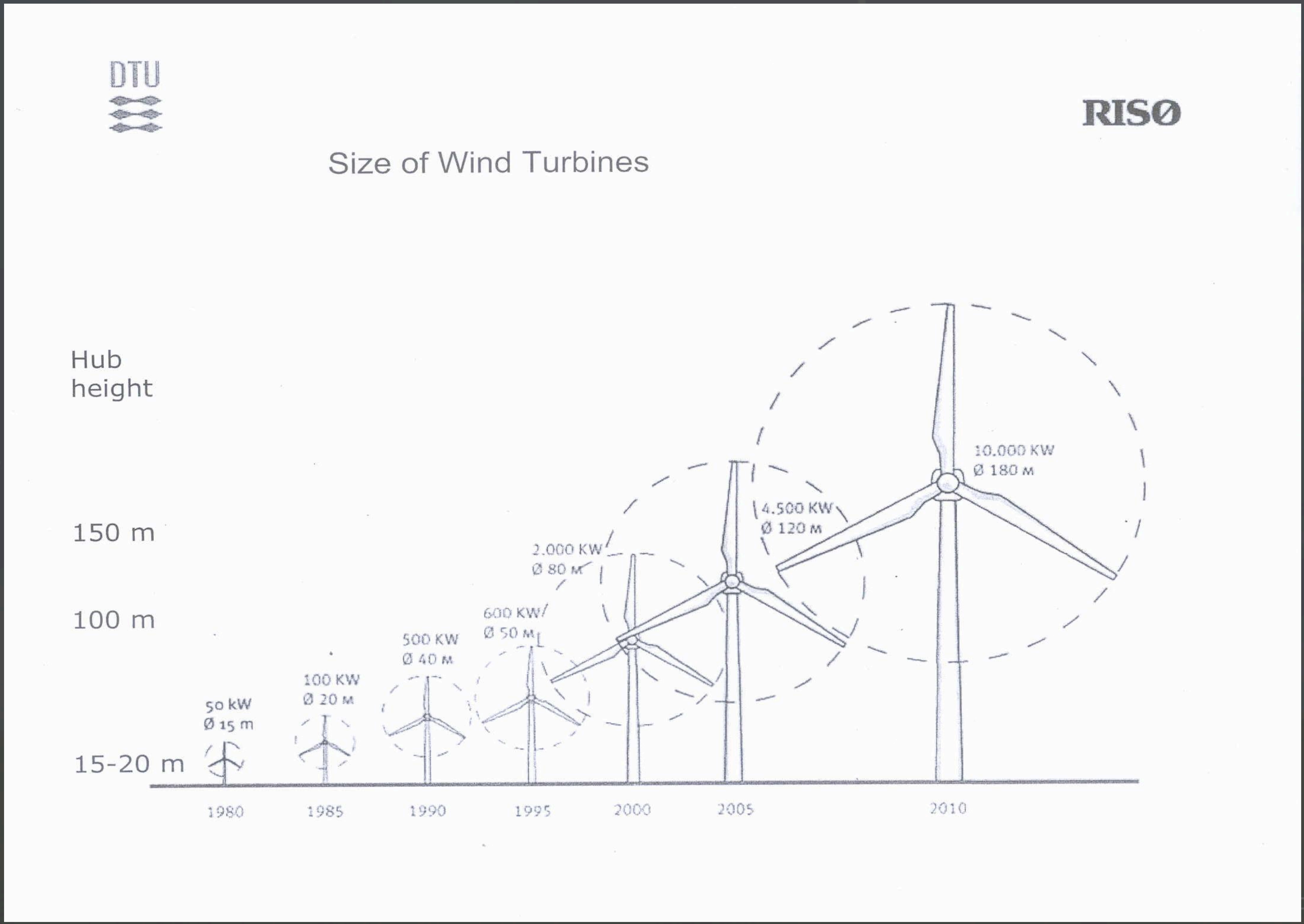
Statistical post processing will
be required to address local effects.

✓ Regression Techniques
✓ Neural Network
✓ Data Mining
✓ Etc.

Data Needs:

✓ Turbine height wind speed & direction
✓ Energy output
✓ Generator availability

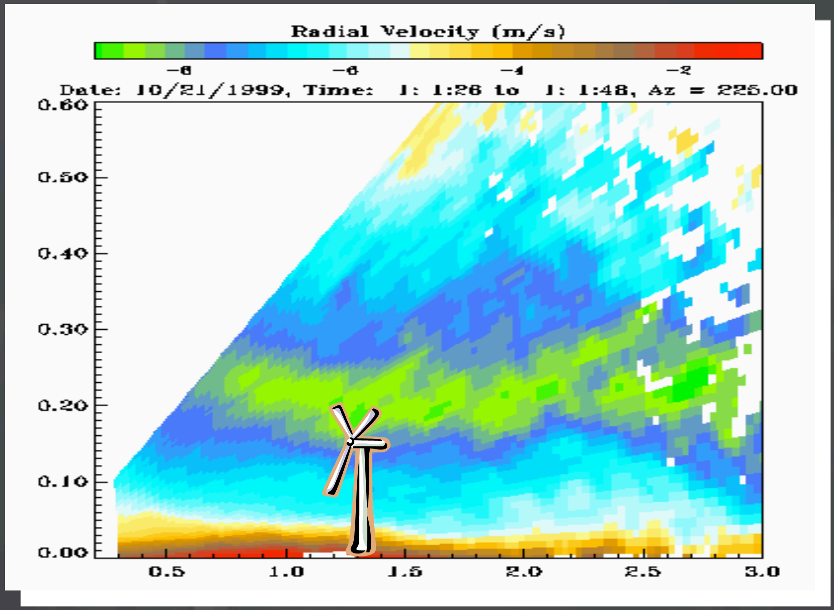
Wind Turbine Size Growth

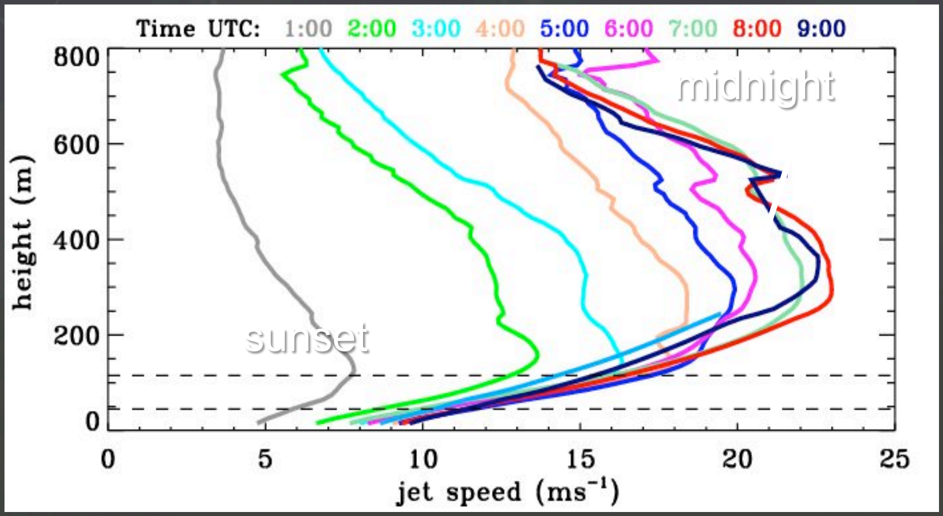


Important Atmospheric Boundary Layer Phenomenon

Low-level jets

Height (km)





Low-level jets can damage generators and reduce lifecyle

Photo by Bob Henson (UCAR)

Flows in Complex Terrain

Clark-Hall model simulation

- Five nested domains
- Inner domain 250 m horizontal resolution
- Initialized with RUC model 2200 UTC 20 Dec 2008
- Vertical cross-section through DIA
- Model showed extreme gustiness at Denver International Airport associated with lee wave amplification

21 Dec 2008 -0118 UTC
Boeing 737-500

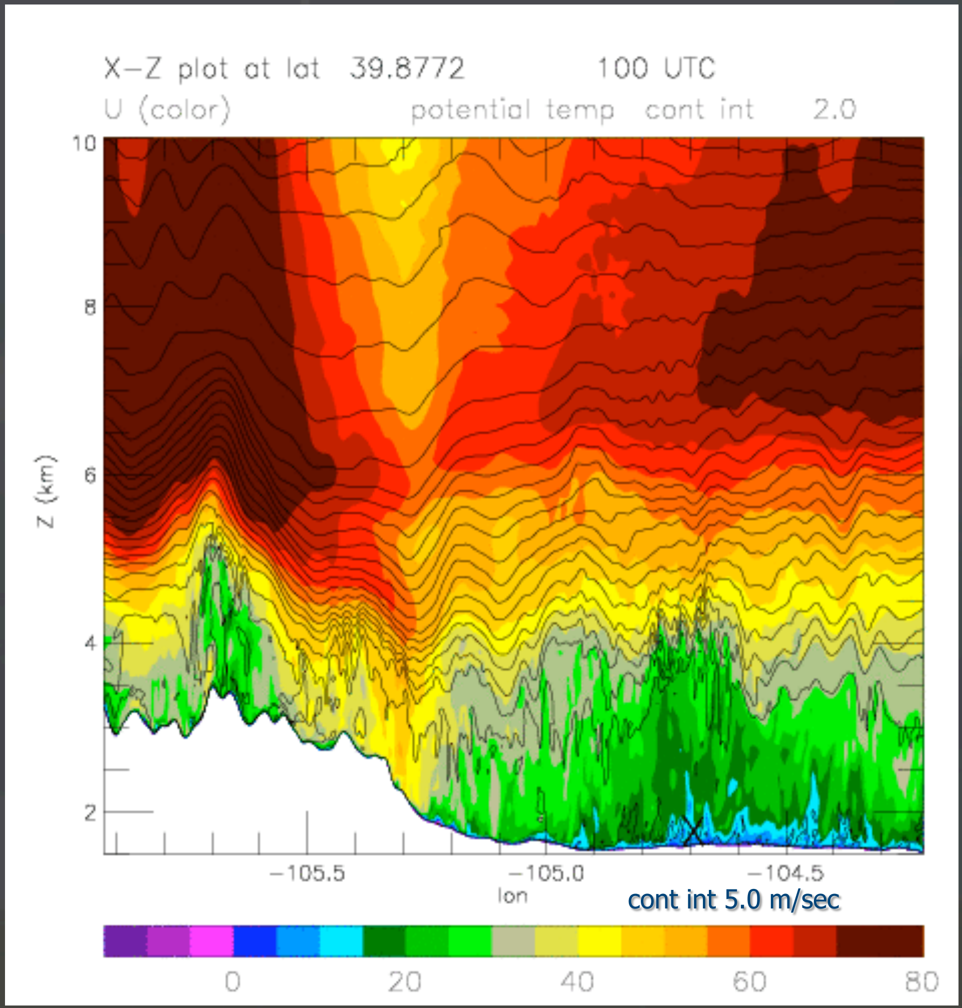
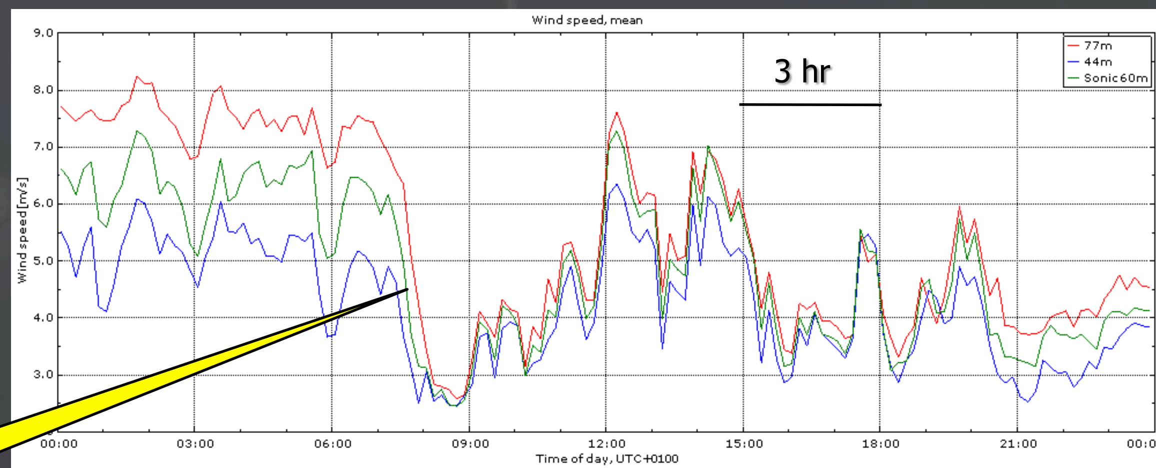


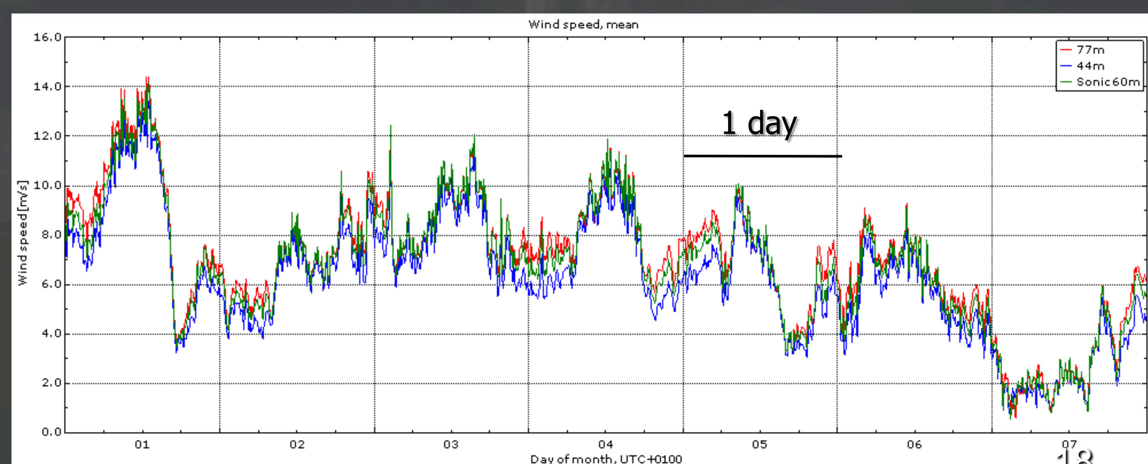
Photo by Bob Henson (UCAR)

Important Atmospheric Boundary Layer Phenomenon

Ramp-down events
Ramp-up events



Unanticipated ramp events are very costly



Example of Local Effects

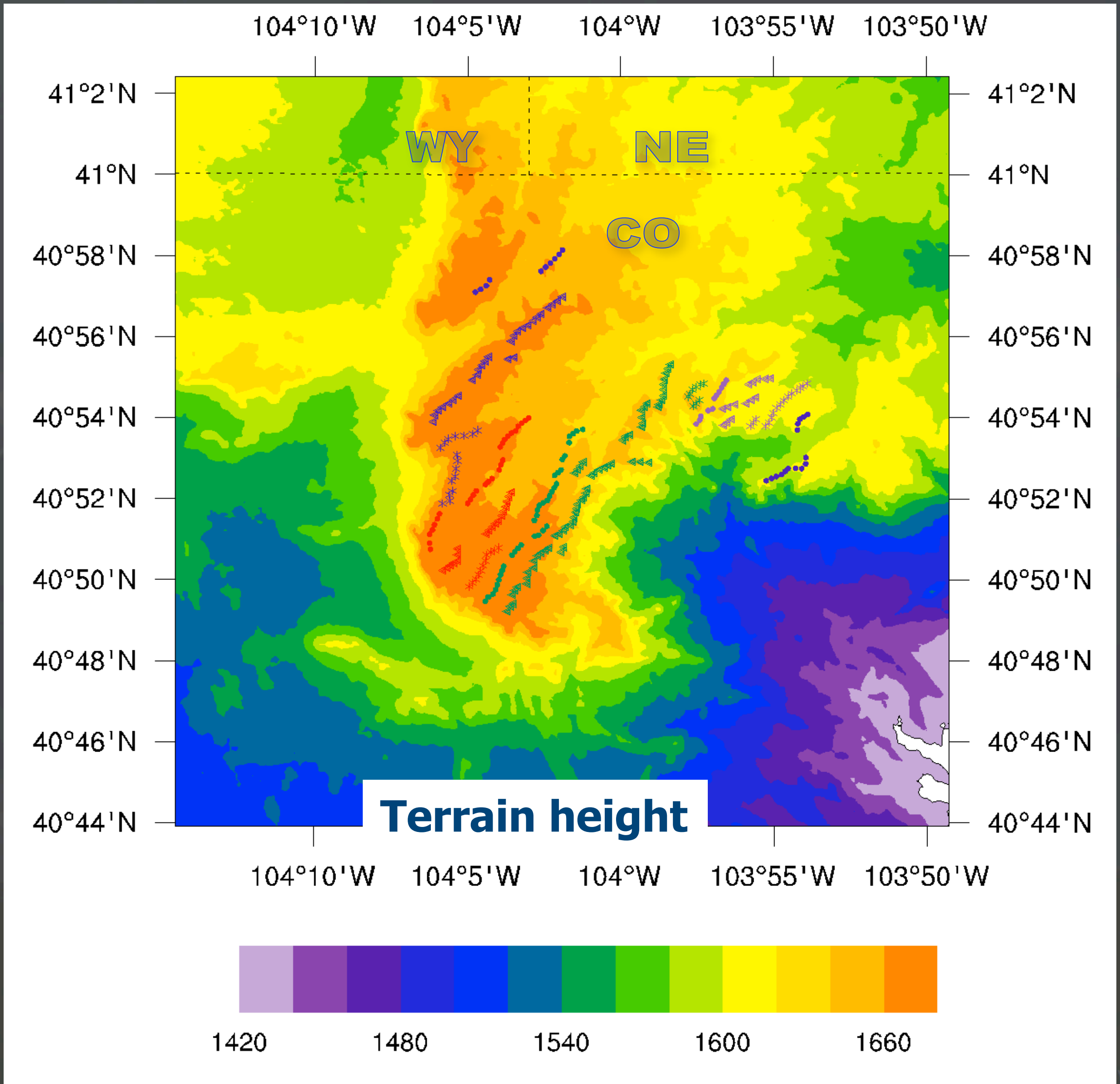
Fine-scale Modeling Study

Cedar Creek Wind Farm, Northeast Colorado
Photo by Carlye Calvin, UCAR

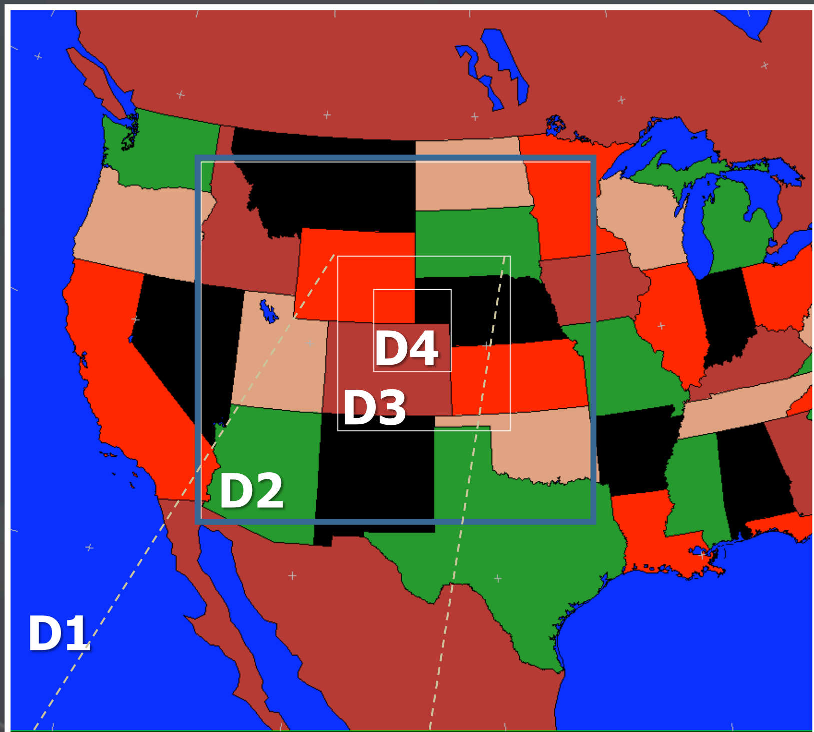
Photo by Bob Henson (UCAR)

274 Wind Turbines at Cedar Creek, Co.

Wind Speed at turbine nacelles



WRF Domains for Intra-farm Wind Studies



Ramp studies:

- D1: 30000m 128x114
- D2: 10000m 184x169
- D3: 3333m 244x247

Cedar Creek Wind Variation Study:

- D4: 1111m 331x346
- D5: 370m 505x490
- D6: 123m 262x268
- D7: 123m 280x271

RESEARCH

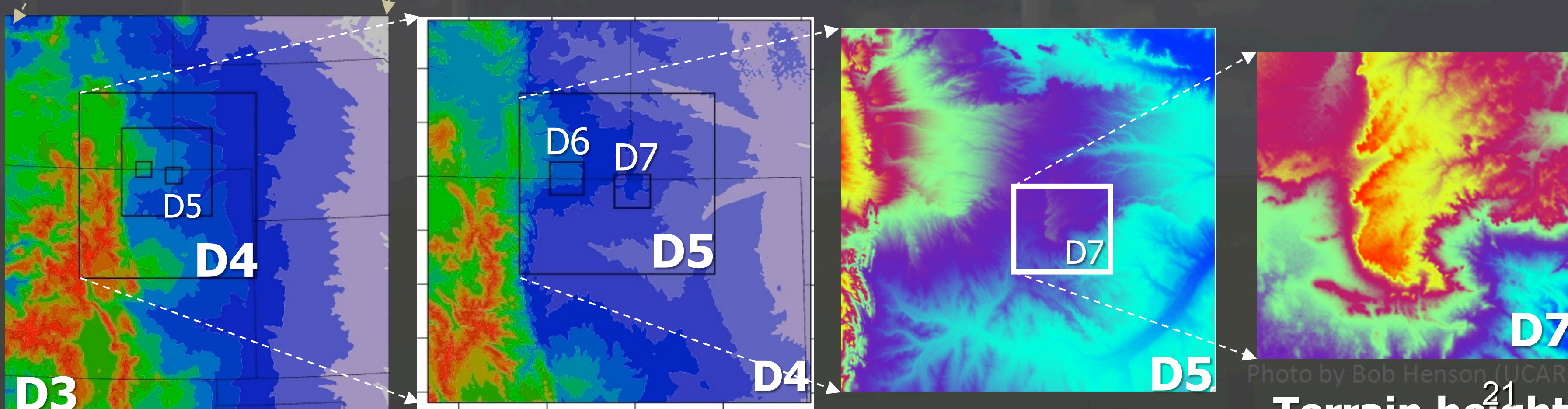
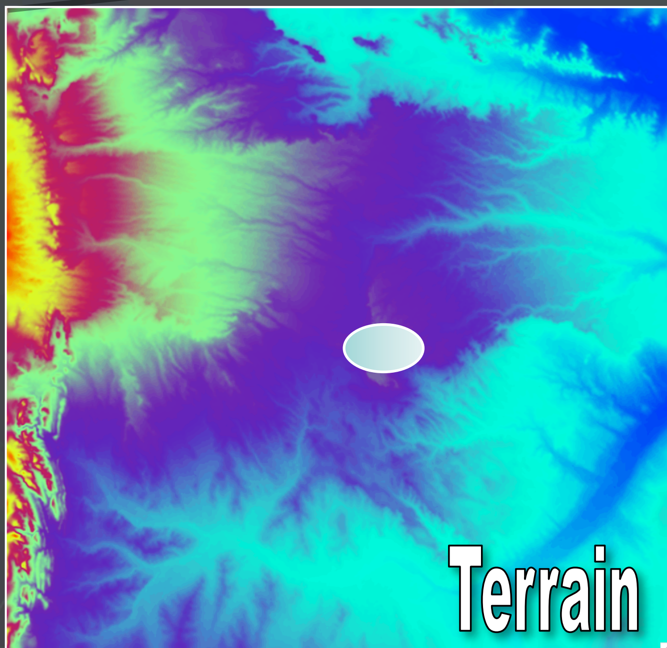
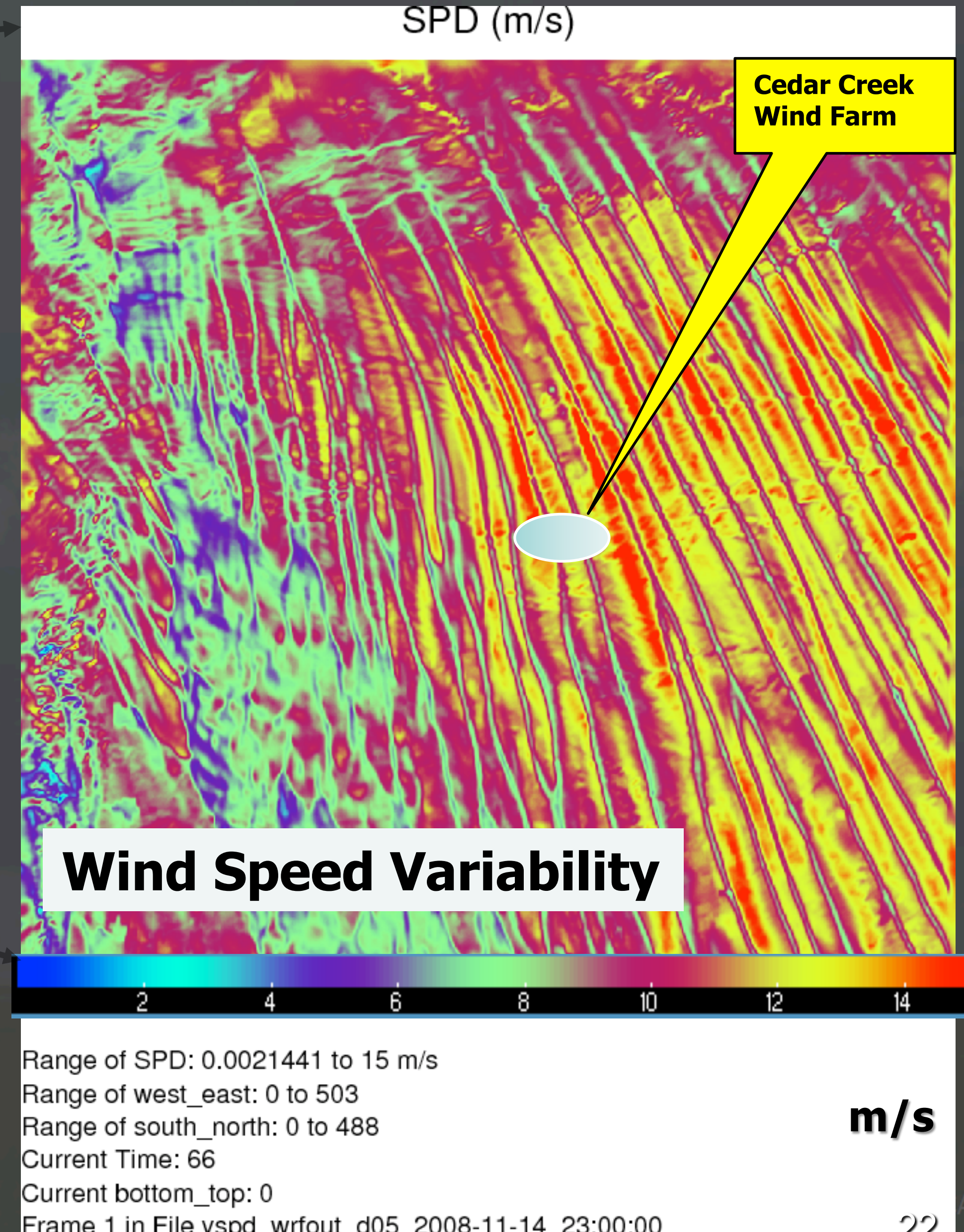


Photo by Bob Henson (UCAR)

Terrain height

Modeled Wind Speeds at 15m AGL





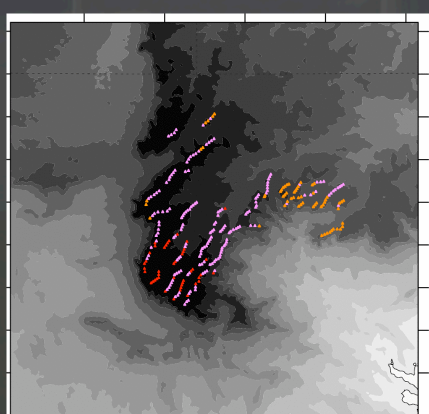
D5: DX= ~370 m

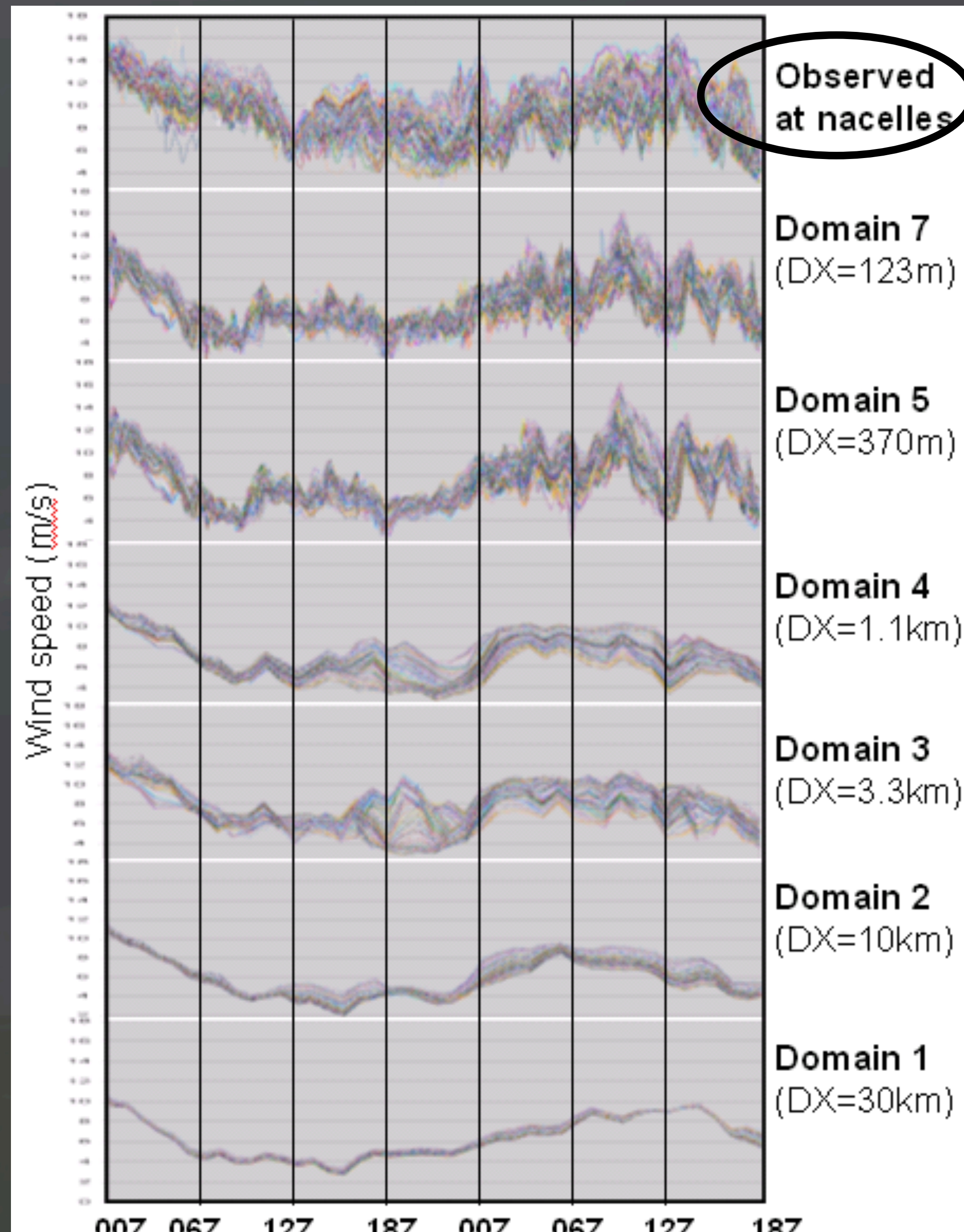
Every 10 minutes
From: Nov.14, 2008 23:00
To: Nov.15, 2008 19:00

△ Cedar Creek

Comparison of intra-farm wind variations simulated by different model grid resolutions

(By interpolating model prediction to the turbine sites)

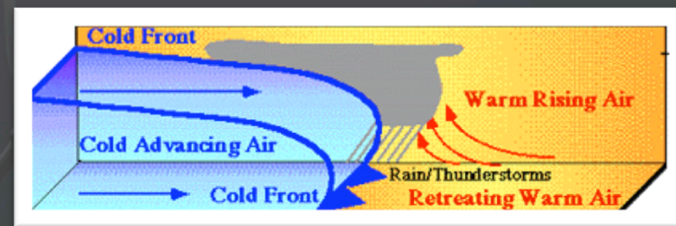




Wind Energy Nowcasting

Causes of Wind Ramp Events

- Cold Fronts
- Warm Fronts
- Thunderstorm Outflows
- Sea Breezes
- Microbursts
- Gravity Waves
- Eroding Surface Inversion
- Momentum mixing



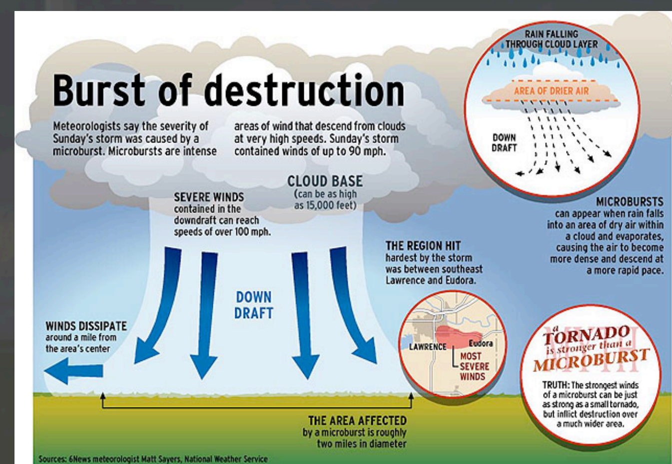


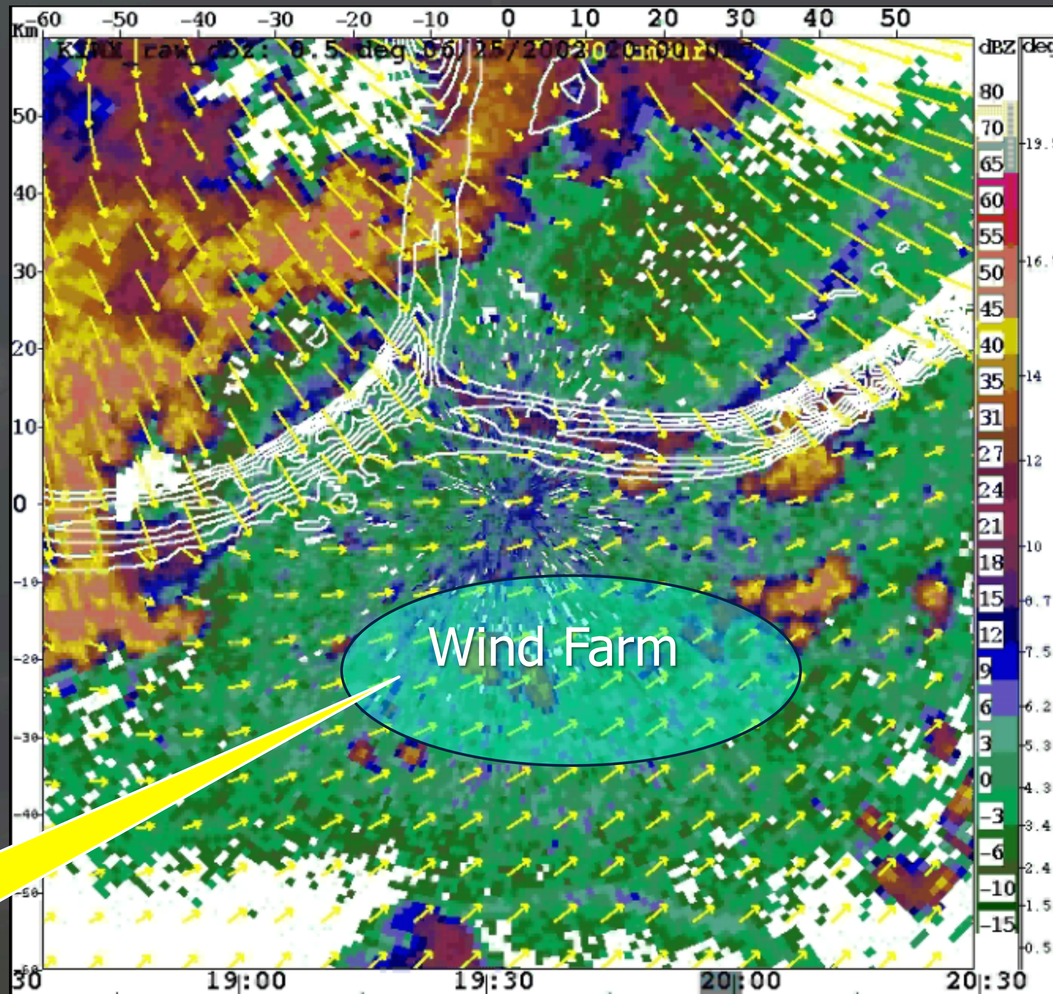
Photo by Bob Henson (UCAR)

Wind Energy Nowcasting

Gust fronts approaching 'wind farm'

Wind ramp event is imminent

Need to provide time-of-arrival and magnitude of wind energy ramp.



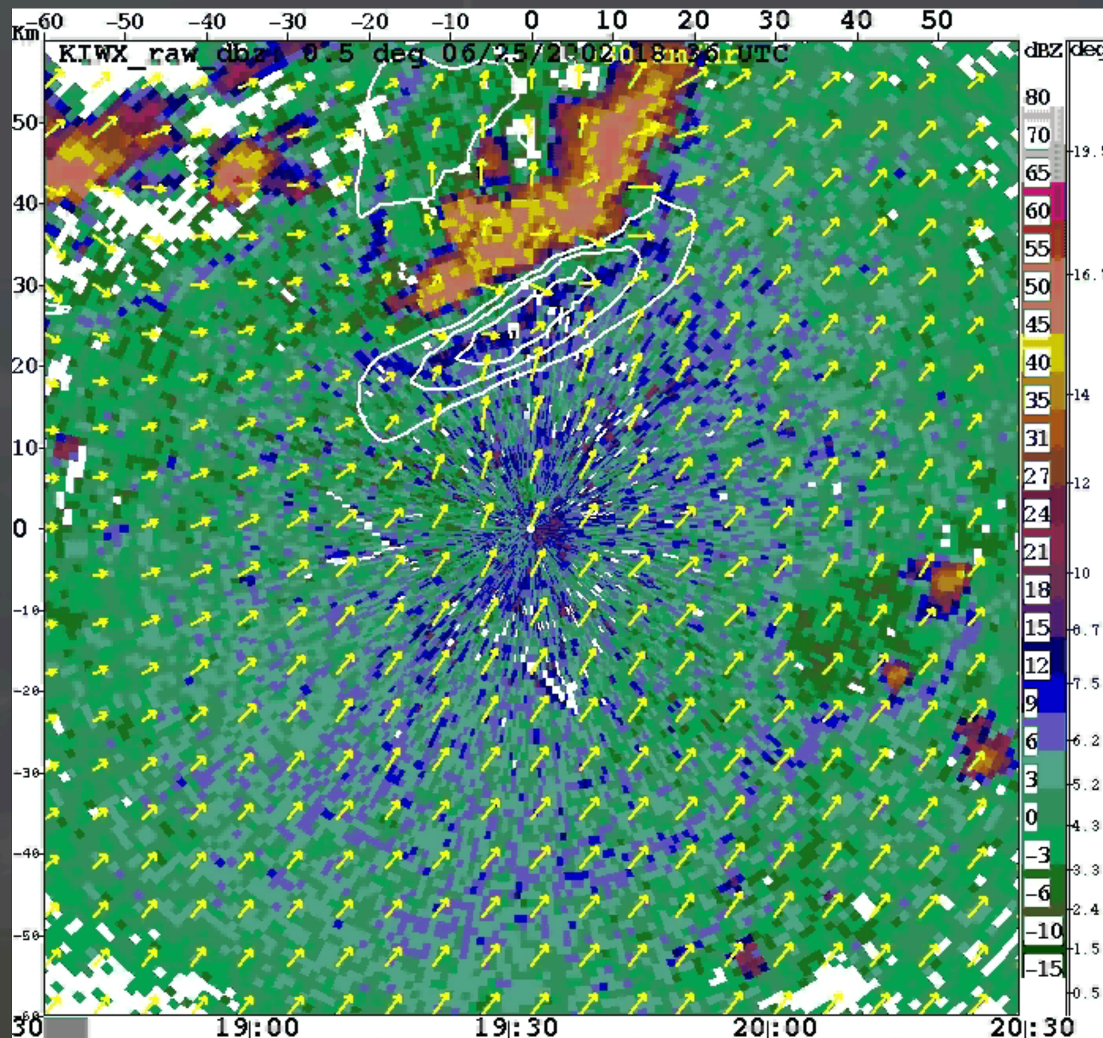
NCAR Auto-Nowcasting System

Photo by Bob Henson (UCAR)

Wind Energy Nowcasting

Gust fronts approaching 'wind farm'

Wind ramp event is imminent



NCAR Auto-Nowcasting System

Photo by Bob Henson (UCAR)

Thunderstorm-induced Wind Energy Ramp Events

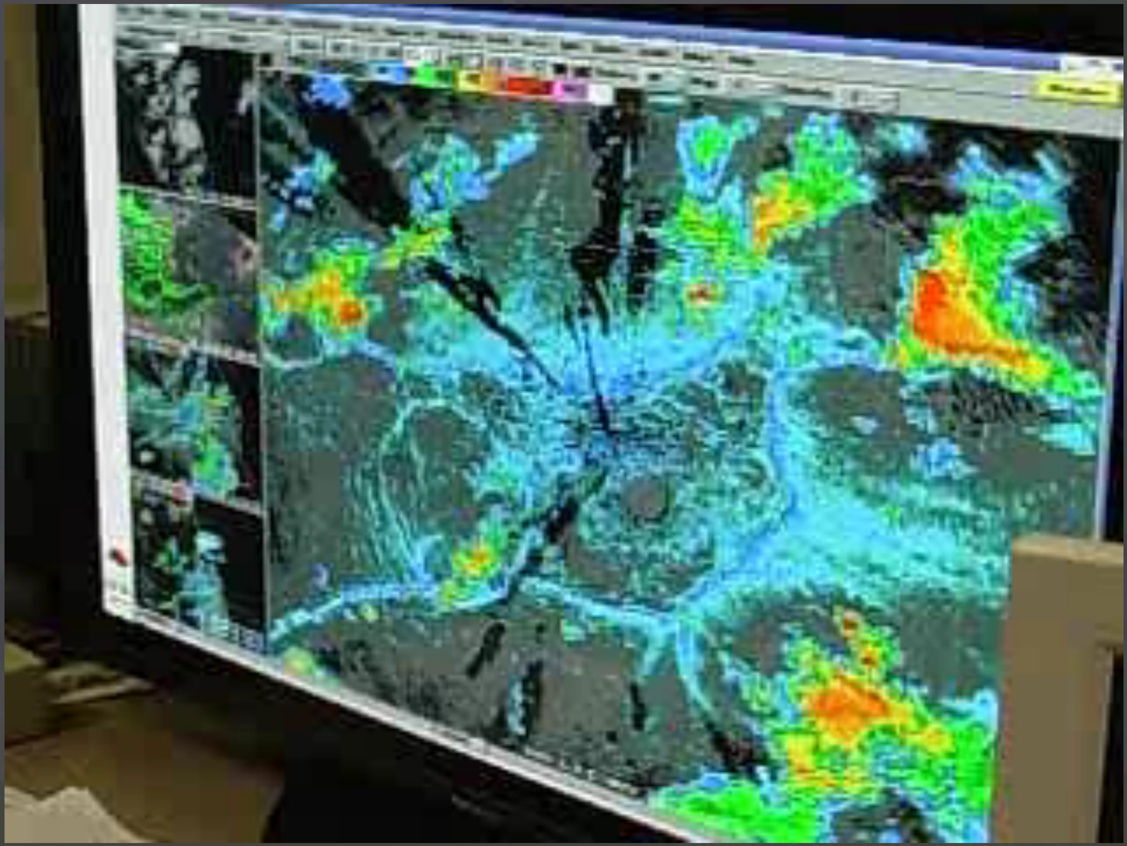
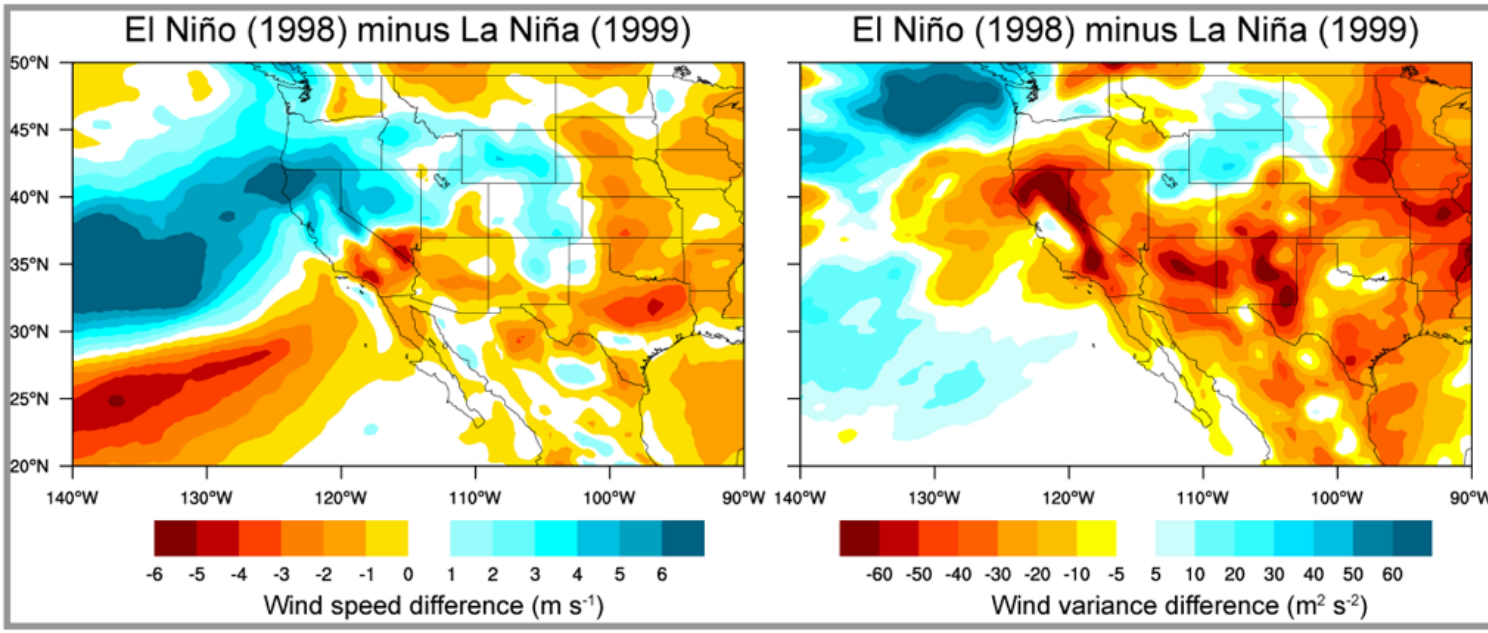


Photo by Bob Henson (UCAR)

Climate Variability & Wind Resource Assessment

Quantifying interannual variability



January winds at 0600 UTC (2300 MST)

Need to understand climate variability for wind resource assessment – (for example, La Nina vs. El Nino)

Photo by Bob Henson (UCAR)

Summary

• Wind characterization and prediction is complex as wind is influenced by global, regional, and very local conditions.

• Wind energy prediction requires complex data assimilation, physics models and statistical post processing techniques that take advantage of wind plant data.

Photo by Bob Henson (UCAR)

THANK YOU