Wind Energy as a Climate Modeling Challenge

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Presentation Outline

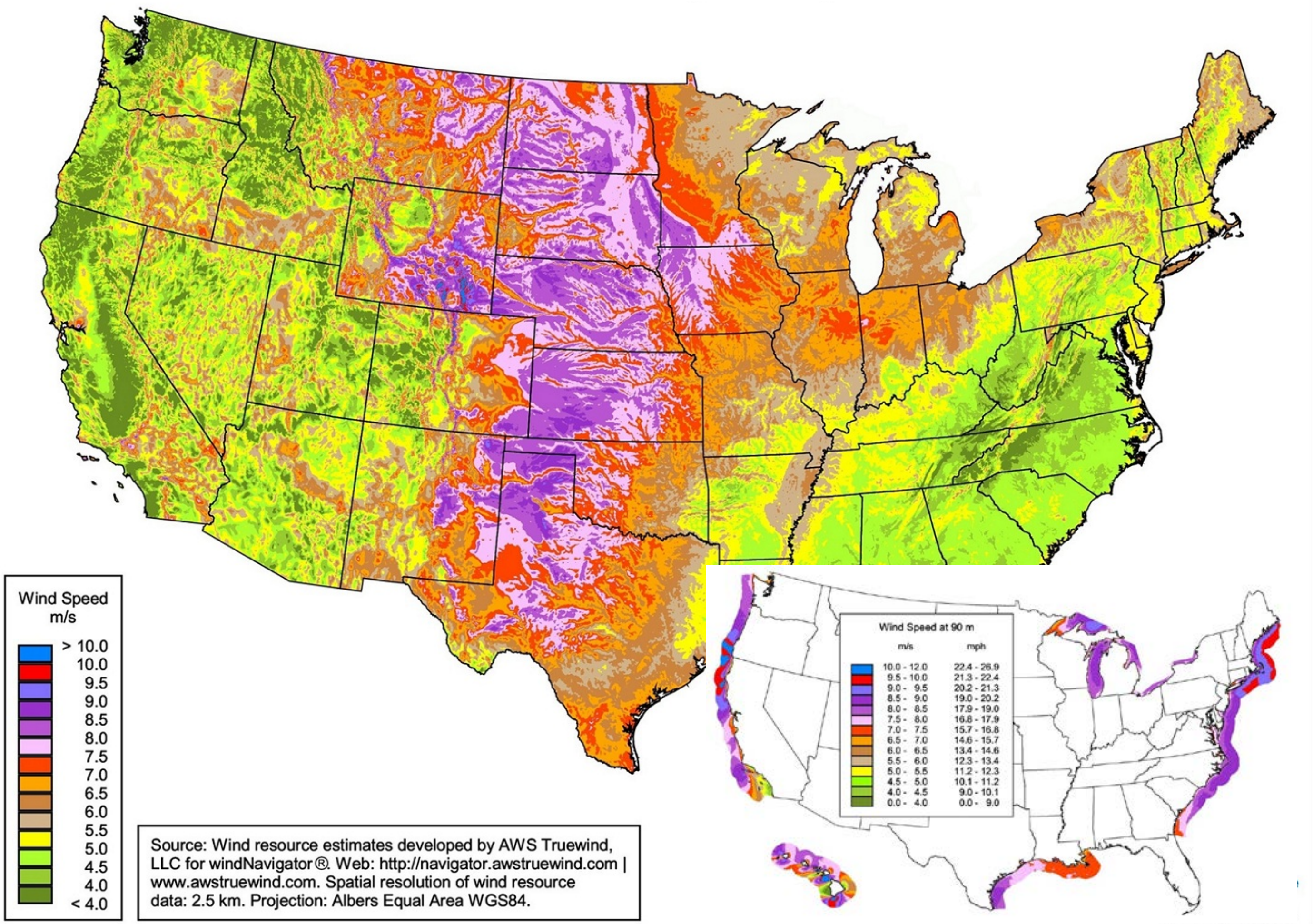
- **Relative Missions of the Offices of Science and of EERE**
- **Wind Resource & Potential Contribution to the US Energy Demand**
- **Need for Improved Predictions of Wind Climate**
- **Science Issues**

Research Emphases of SC and EERE

	Technology Readiness Level Definition
TRL 1	**Basic Research:** Initial scientific research begins. Principles are qualitatively postulated and observed. Focus is not on applications.
TRL 2	**Applied Research:** Initial practical applications are identified. Potential of material or process to satisfy a technology need is confirmed.
TRL 3	**Critical Function or Proof of Concept Established:** Applied research continues and early stage development begins. Studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology.
TRL 4	**Lab Testing/Validation of Alpha Prototype Component/Process:** Design, development and lab testing of components/processes. Results provide evidence that performance targets may be attainable based on projected or modeled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated:** System Component and/or process validation in relevant environment.

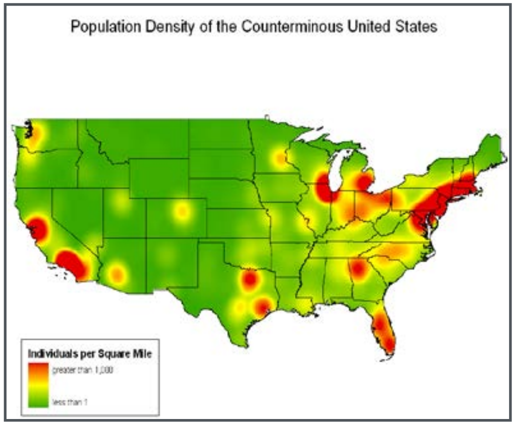
The National Wind Resource

Annual Wind Speed at 80 Meters



Source: Wind resource estimates developed by AWS Truewind, LLC for windNavigator®. Web: http://navigator.awstruewind.com | www.awstruewind.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

- **80% Domestic Load Within 150 Miles of the Coast and Great Lakes**
- **Resource Assessment Derived from Validated Mesoscale Modeling**


Population Density of the Counterminous United States

Total Wind Resource Potential

		Land Based Wind			Offshore Shallow Water (< 30 meters)			Offshore Deep Water (> 30 meters)		
Wind Class (@ 80 meters)	**Velocity Range (m/s)**	**Resource Potential (GW)**	**Capacity Factor (Weibull)**	**Quads (Quadrillion BTUs)**	**Resource Potential (GW)**	**Capacity Factor (Weibull)**	**Quads (Quadrillion BTUs)**	**Resource Potential (GW)**	**Capacity Factor (Weibull)**	**Quads (Quadrillion BTUs)**
III	6.4 - 7.0	4186	30%	37.5						
IV	7.0 - 7.5	3544	35%	37.0	249	35%	2.6	292	35%	3.1
V	7.5 - 8.0	1109	40%	13.2	365	40%	4.4	505	40%	6.0
VI	8.0 - 8.8	64	42%	0.8	294	42%	3.7	712	42%	8.9
VII	8.8 - 11.9	16	45%	0.2	164	45%	2.2	1569	45%	21.1
Total :		**8919**		**88.8**	**1072**		**12.8**	**3078**		**39.1**

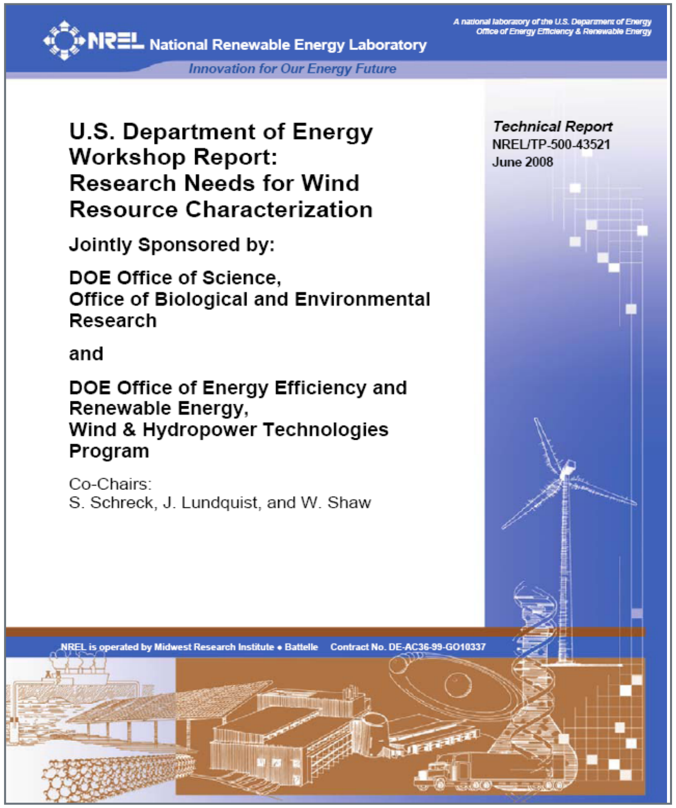
- **Total Wind Energy Potential ≈ 141 Quads**
- **Total Domestic Energy Use ≈ 98 Quads**
- **Total Electrical Energy Use ≈ 13 Quads**
- **20% by 2030 Goal (300 GW) ≈ 3 Quads**
- **Current Contribution (40 GW) ≈ 0.4 Quads**

Significant Resource Potential to Support High Wind Penetration Scenarios !!!

Research Needs for Wind Resource Characterization

- Discussions Organized by Scale
  - Turbine Dynamics
  - Micrositing and Array Effects
  - Mesoscale Processes
  - Climate Effects

- Cross-cutting Themes
  - Need for data to validate and improve models
  - Need for model improvement across the range of scales



NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Technical Report
NREL/TP-500-43521
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U.S. Department of Energy
Workshop Report:
Research Needs for Wind
Resource Characterization

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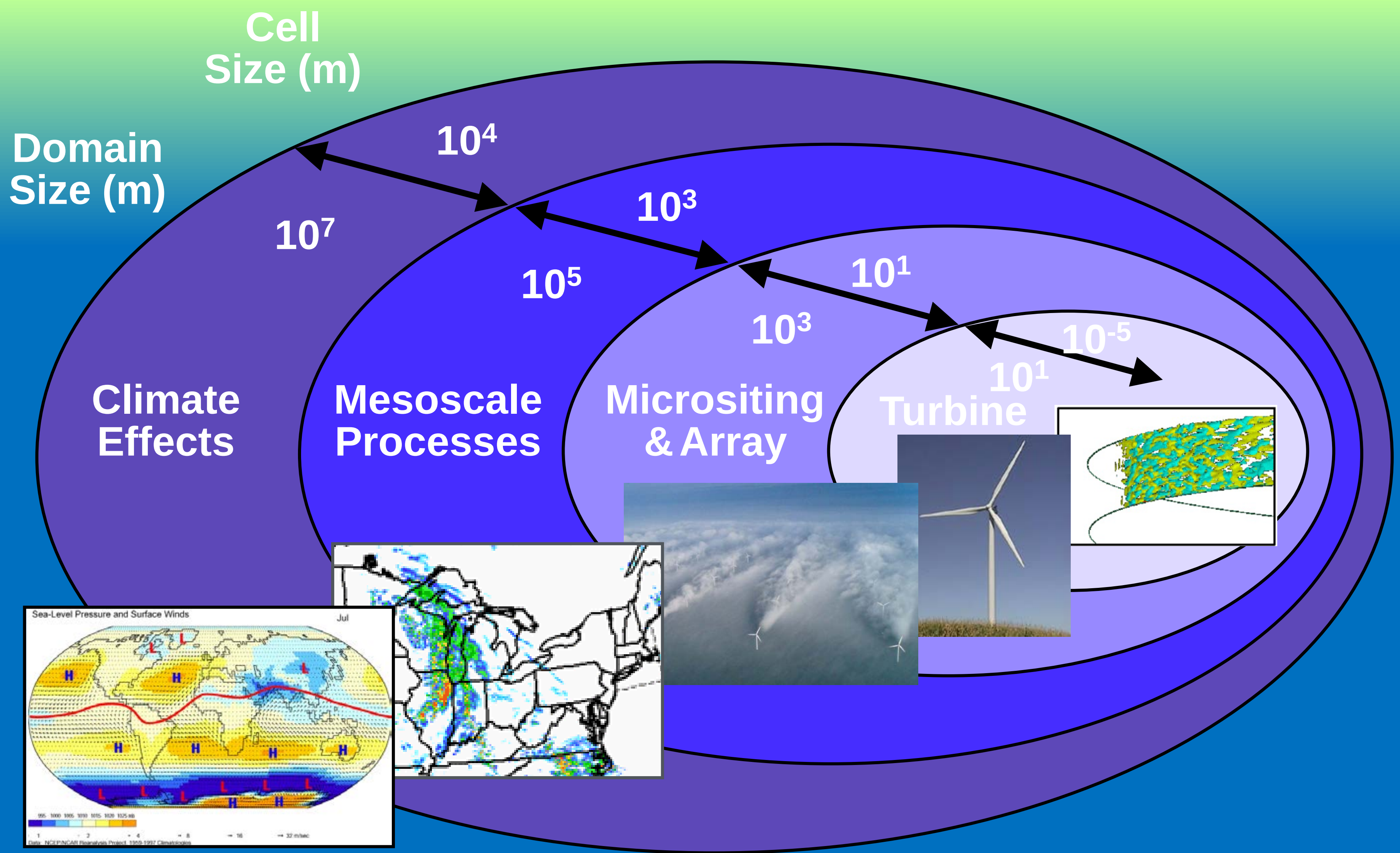
Modeling Scales



Cell Size (m)

Domain Size (m)

10^4

10^7

10^3

10^5

10^1

10^3

10^{-5}

10^1

Climate Effects

Mesoscale Processes

Micrositing & Array

Turbine

DOE Workshop on WRC 2008

Need for Wind Climate Predictions in High-penetration Wind Energy Scenarios

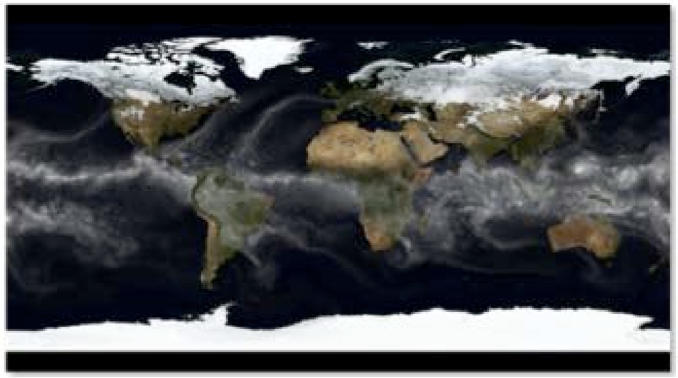
- **Wind as a Strategic National Energy Resource**
  - Development & deployment of future infrastructure – generation and transmission
- **Assessment of Potential Effects of High Penetration Scenarios**
  - Climate change Sensitivities
  - Macro & Micro Climatology Impacts
  - Insure against trading carbon alleviation for unknown consequences

Repower 5MW Demonstration at Beatrice Four-pile jacket

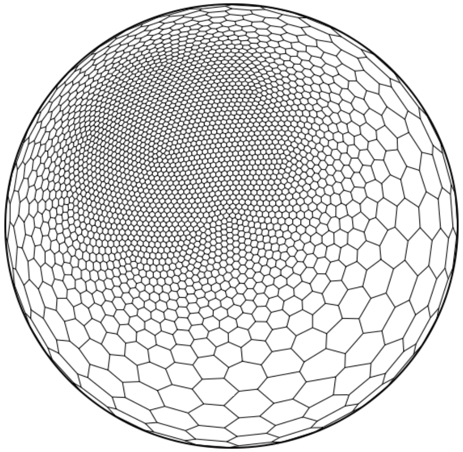
Improved Physics For Wind Prediction

- Accurately modeling wind resources requires high spatial resolution
  - To represent surface heterogeneity
  - To simulate the multi-scale processes that influence surface winds
- With high performance computing, three approaches are feasible to simulate wind climates at regional scales
  - Global high-resolution model
  - Global variable-resolution model
  - Nested regional climate model
- As spatial resolution increases, conventional subgrid-scale parameterizations become questionable, necessitating advances in treatment of physics

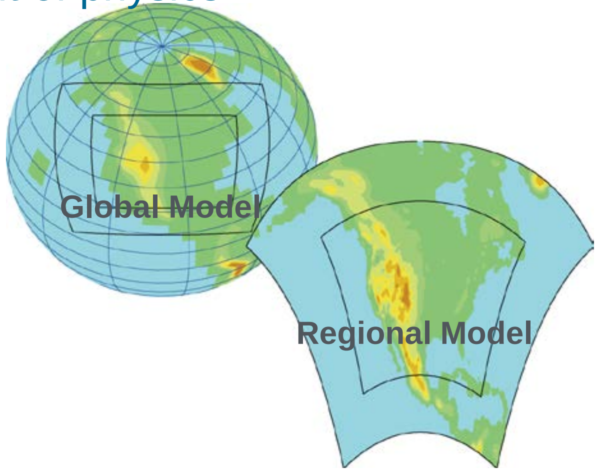
Figures provided by Ruby Leung



Global high resolution model



Global variable resolution model

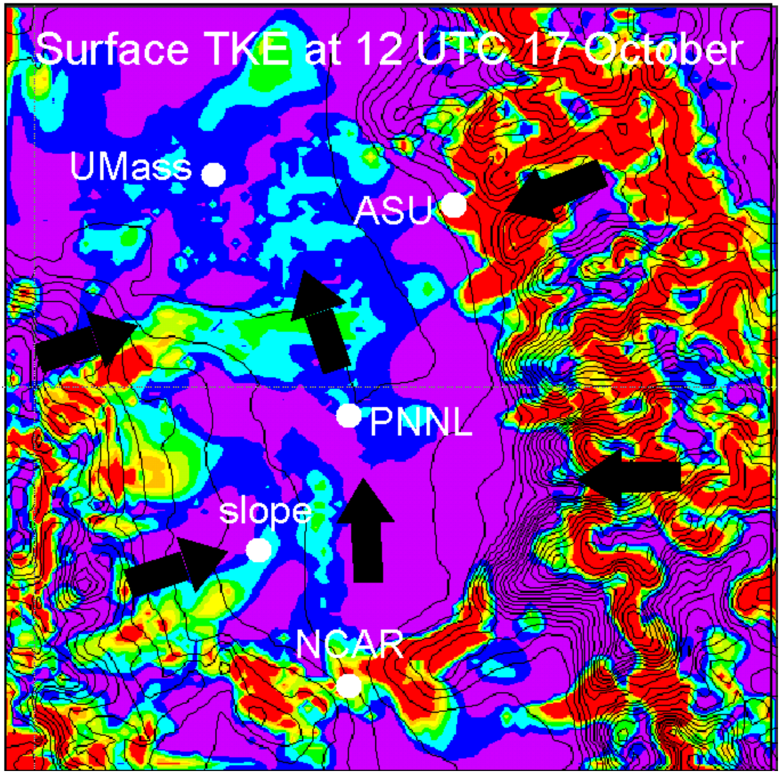


Nested regional climate model

The Real World—
Windy Point—Columbia River Gorge

Wind as a Predicted Climate Variable

- Historic Biases Too Large in Downscaling Models
  - Commonly > 1 m s^{-1}
- Fundamental Improvement in Needed in Representation of Mesoscale and Local Flows
  - Low-level jets
  - Stable boundary layers
  - Environments where effects of non-stationarity and horizontal inhomogeneity are prominent
  - Surface–atmosphere energy exchange
- Advent of High-performance Computing Making New Advances Feasible



Simulated TKE over the Salt Lake Valley
[Fast, 2002]

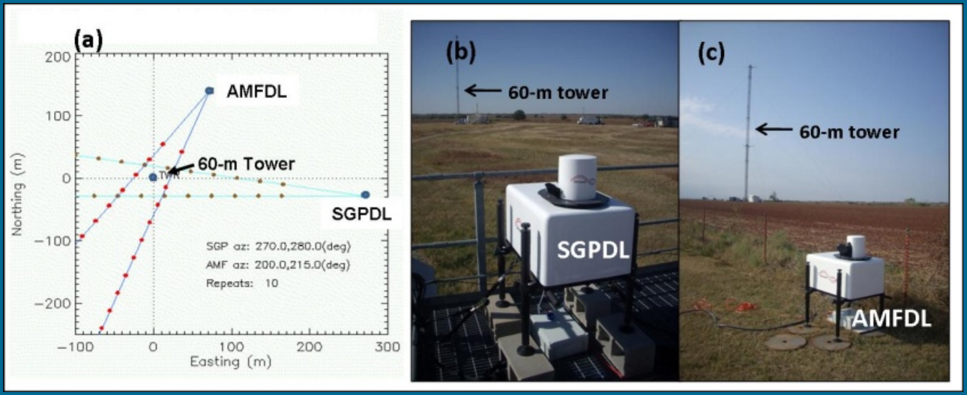
Emerging Measurement Capabilities for Evaluation of Parameterizations

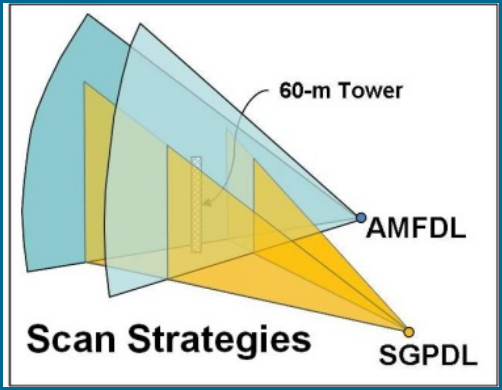
New Measurement Technologies

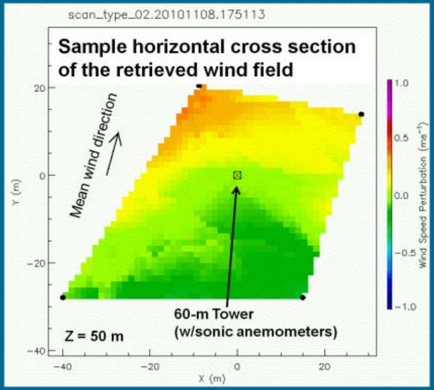
- Doppler volumetric scanning remote sensing
- Computer-controlled coordinated scanning
- Computational and storage capacity to support sophisticated wind field retrieval algorithms

New Data for Validating Modeled Fields

- Three-dimensional wind fields
  - ➢ Spatially detailed
  - ➢ Short times
  - ➢ Previously unavailable
- Data collected in real atmosphere
  - ➢ Allows more rigorous testing of models







Detailed wind field retrieval using volumetric scanning from coordinated Doppler lidars

[data from DOE's Atmospheric Radiation Measurement (ARM) site in the Southern Great Plains; algorithm development by Rob Newsom, PNNL]

Summary

- Compelling national need to accurately predict near-surface wind in climate models
- Current mesoscale models used for downscaling do not have sufficiently accurate winds at the surface.
- Increasing capabilities in high-performance computing and measurement technology offer promise of new advances.

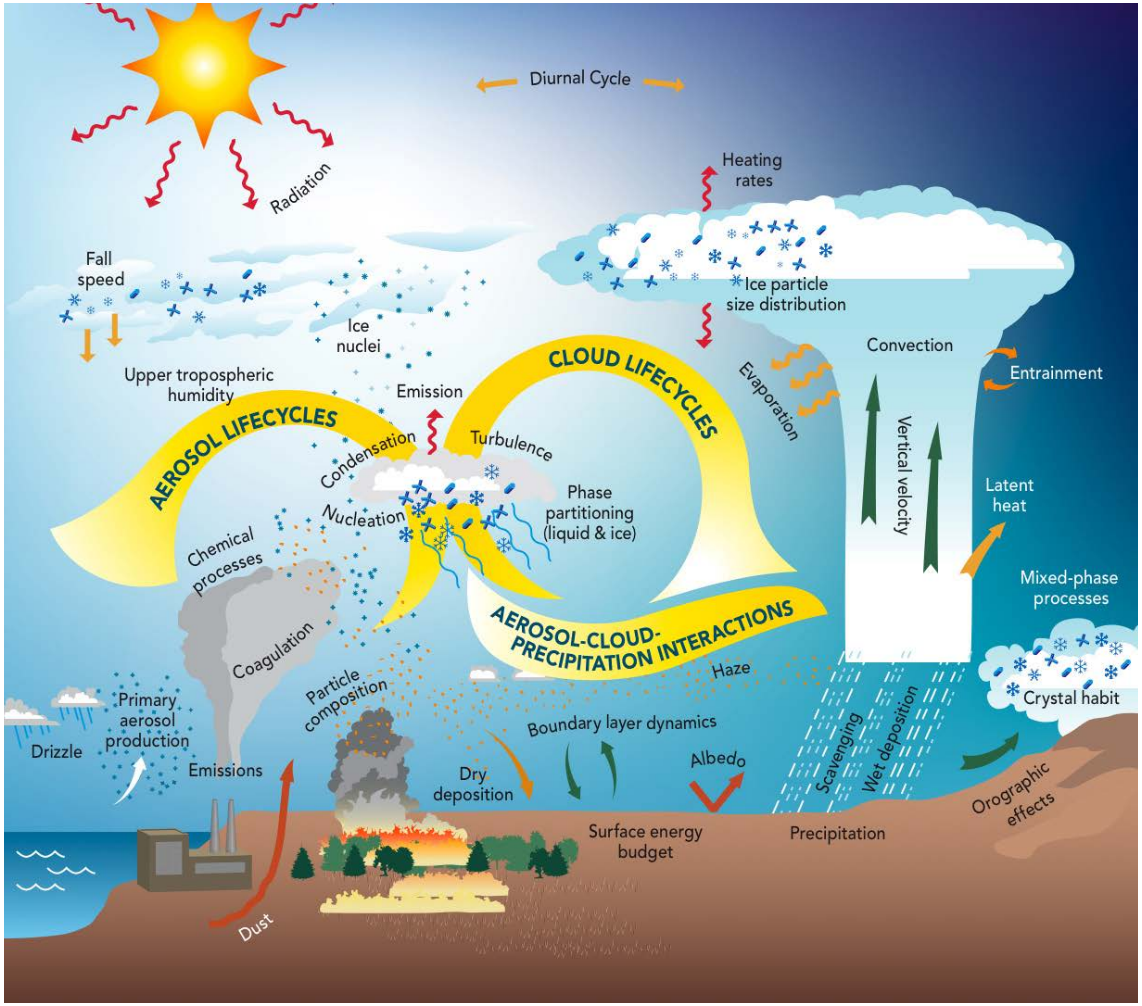


Figure provided by Wanda Ferrell