Wind Forecast Improvement Project-2

Improving Model Physics in Complex Terrain

Melinda Marquis, Joe Olson, James Kenyon, Stan Benjamin, Jim Wilczak, Laura Bianco, Irina Djalalova, Katherine McCaffrey, Yelena Pichugina, Bob Banta, Aditya Choukulkar Richard Echman, Andy Clifton, Jacob Carley, Joel Cline.

Outline

- WFIP2 Goals

- Team and Sub-Team Structures

- Meteorological Challenges in the Columbia River Gorge

- Goals of Sub-Teams

Columbia River Gorge Region

Overview

Columbia River Gorge http://www.chipphillipsphotography.com

A 4-year (2014-2018), DOE-led project to improve short-term weather forecast models and increase understanding of physical phenomena such as stability, turbulence, and low-level jet that affect wind energy generation in regions of complex terrain, such as coastlines, mountains, and canyons.

WFIP2 Team members include those from a team led by Vaisala, four DOE labs (NREL, LLNL, PNNL, and ANL), and NOAA.

A field campaign in the Columbia River Gorge 2015 – 2017.

Sub-teams: experimental design, instruments, modeling, data, uncertainty quantification, verification and validation, decision support

A steering committee with representatives from DOE HQ, Vaisala, DOE labs, and NOAA.

Wind Forecast Improvement Project-2 (WFIP2): Goals

- Improve the understanding and modeling of physical phenomena in complex terrain that impact wind speeds & direction at hub heights.
  - WRF, RAP/HRRR/HRRRnest
  - 0-15 hour, and Day-ahead

- Develop decision support tools, e.g., probabilistic forecast information, uncertainty quantification and forecast reliability for system operations. Won't interfere with private sector role.

- Physical phenomena such as stability, turbulence, mountain wakes, and gap flows.

WFIP-2 Team and Sub-Teams

DOE FOA Awardee – Vaisala –
leads a team including individuals from:
- Univ. Colorado
- NCAR
- Sharply Focused
- Lockheed Martin
- Texas Tech University
- University of Notre Dame

DOE National Labs: NREL, PNNL, LLNL, ANL

NOAA (OAR: ESRL and ARL; NWS: NCEP)

Sub-Teams

- Experimental Science Design

- Instrument

- Modeling

- Data

- Uncertainty Quantification

- Verification and Validation

- Decision Support Tools

Time Line

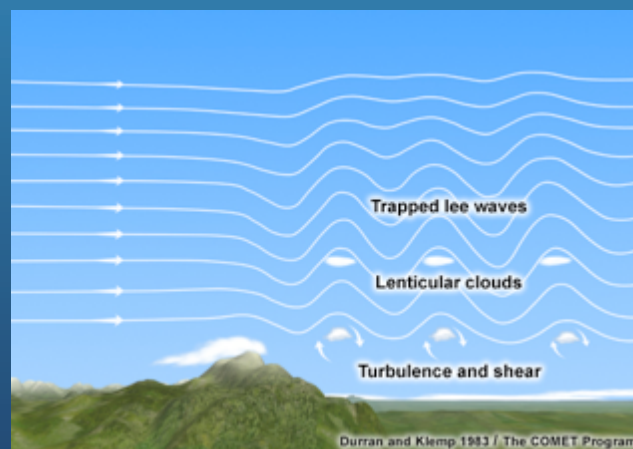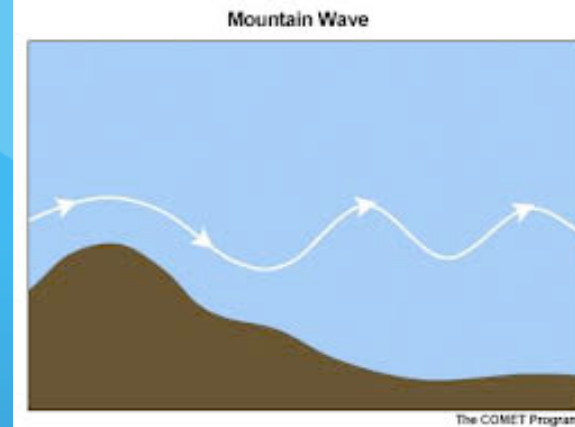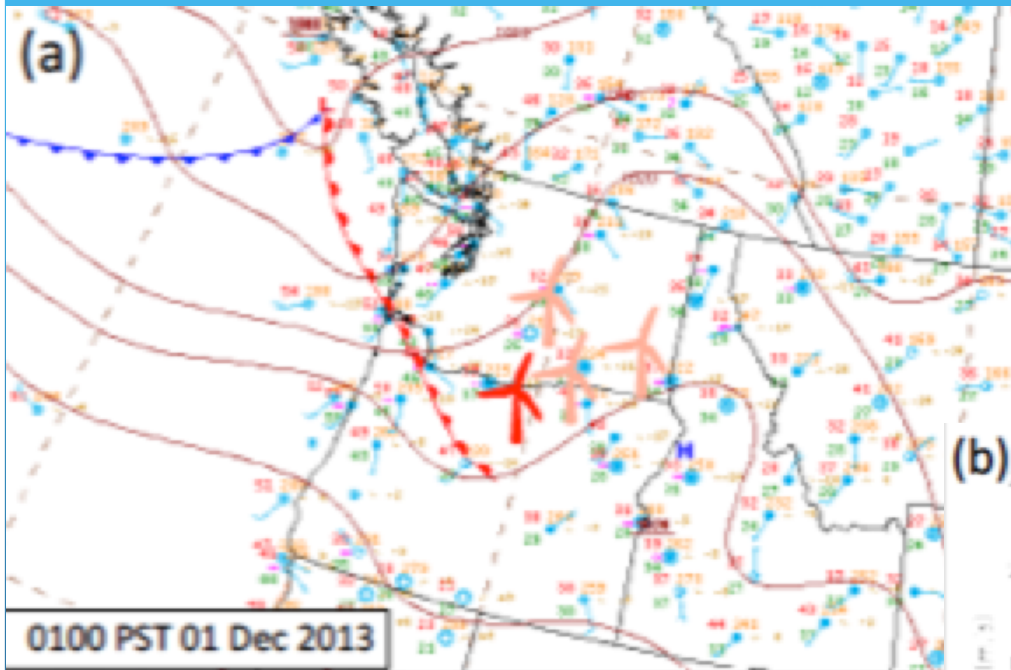| Apr 2014 – Sept. 2015	Oct 2015 – Mar 2017	April 2017 – Mar 2018
• FOA published • DOE selected awardee • Award negotiated • Early planning meetings and site visits • Land-use agreements and leases completed • Instruments deployed	• Field campaign • Up to 18 months to ensure coverage of all four seasons	• Remove campaign instruments • Data analysis • Write final report

Complex flow features in Columbia River Gorge

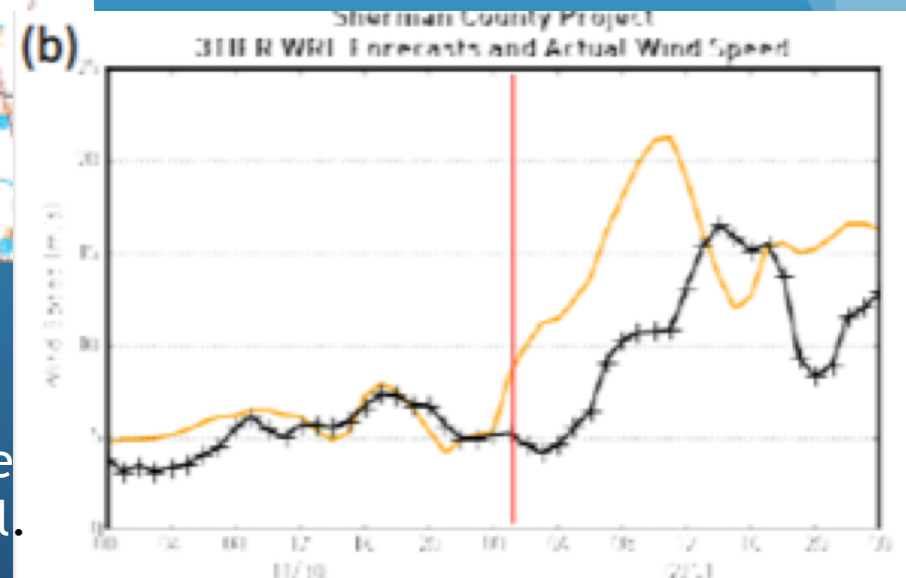Mountain Wave
The COMET Program

- Frontal passages with terrain and pre-existing air masses

- Strong cross barrier flow

- Mountain Waves
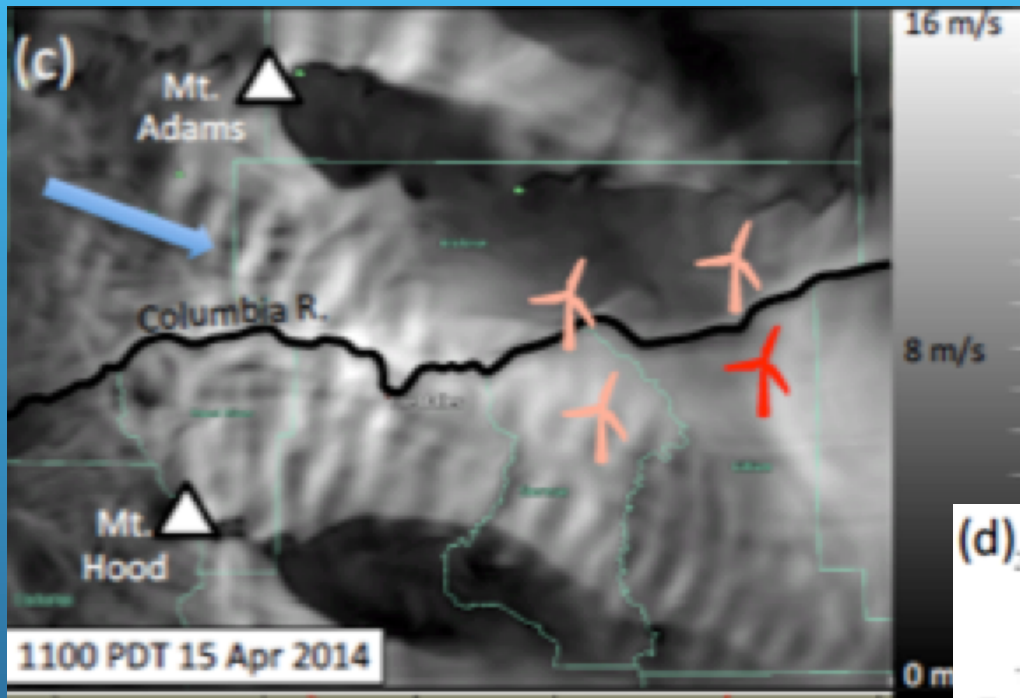
- Topographic Wakes

- Convective outflow

- Marine Pushes

Gap Types
Sloping Gap
Level Gap
The COMET Program

Trapped lee waves

Lenticular clouds

Turbulence and shear

Durran and Klemp 1983 / The COMET Program

Frontal systems with terrain and pre-existing air-masses

(a)

0100 PST 01 Dec 2013

Sherman County Project
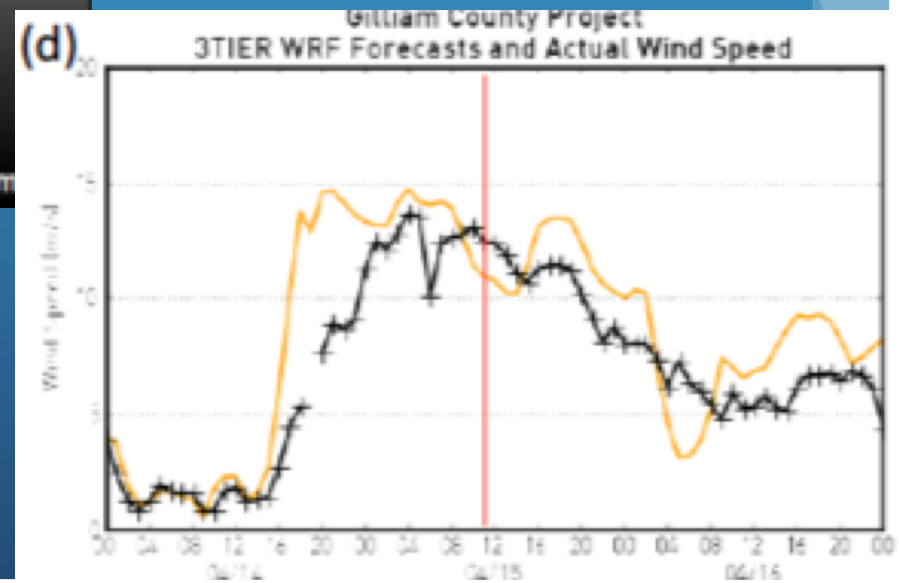31B R WRF Forecasts and Actual Wind Speed

(b)

Warm front, overrunning of cold air. NWP often over-mixes BL, leading to premature descent of windy air down to turbine level.

Strong Cross Barrier Flow

(c) 16 m/s

Mt. Adams

Columbia R.

8 m/s

Mt. Hood

1100 PDT 15 Apr 2014
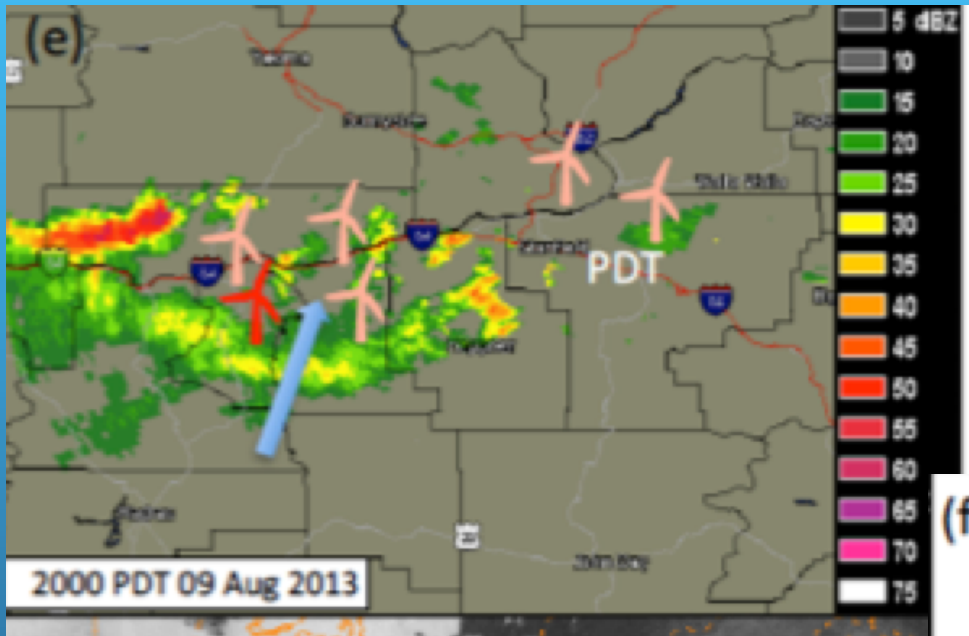
0 m

(d) Gilliam County Project
3TIER WRF Forecasts and Actual Wind Speed

Trapped lee waves and mountain wakes. NWP captured the mountain wave, but missed the amplitude and structure.

Convective Outflows

2000 PDT 09 Aug 2013
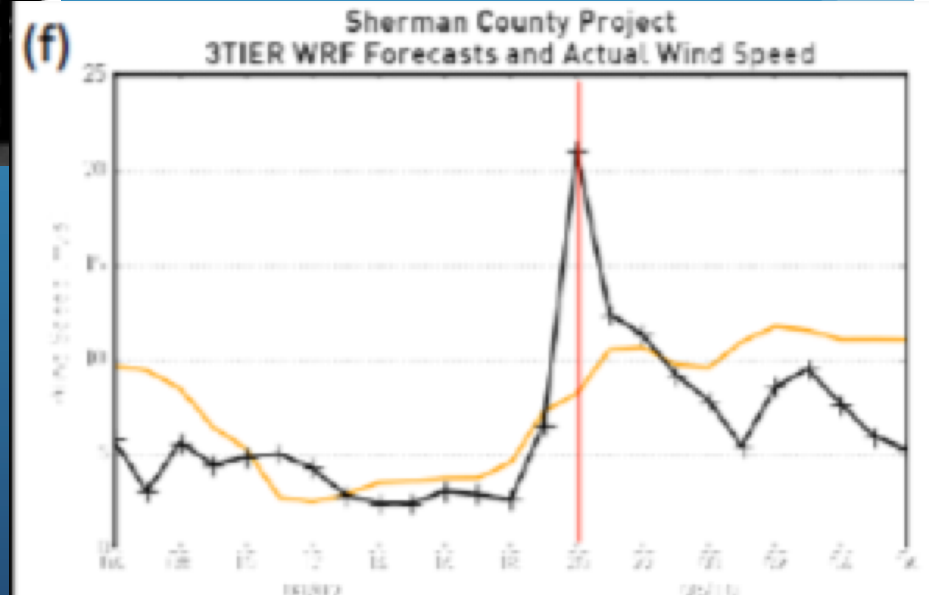
PDT

Sherman County Project
3TIER WRF Forecasts and Actual Wind Speed

NWP missed the convective outflow. NWP development has been focused on protection of life and property, not on non-severe convective outflow characteristic in PNW.

Experimental Design

1. A network of instruments to measure meso-alpha scale (200-2000 km) variability in a region with many wind plants. This will provide insight into large-scale gradients and help refine the inflow boundary conditions for the modeling portion of WFIP2.

2. A transect that is roughly perpendicular to the linear aspect of the network in #1 (above). This will allow for observation of features both perpendicular to the Cascade Mountains (e.g. topographic wakes) and parallel to the mountains (e.g. mountain waves).

3. A supersite near the intersection of the two transects. This will allow detailed observation of surface and boundary layer processes.

4. Some instruments will be located further afield to ensure the applicability of the project science to other areas of complex terrain.

Team: Jim McCaa (Vaisala) and Julie Lundquist (CU) = Co-Leads
Keith Barr (Lockheed Martin), Bronko Kosovic (NCAR),Justin Sharp (Sharply Focused), Joe Fernando (Notre Dame), Rich Coulter and Rao Kotamarthi (ANL), Jeff Mirocha and Sonia Wharton (LLNL), Andy Clifton (NREL) and Larry Berg & Will Shaw (PNNL), Joe Olson, Jim Wilczak, Bob Banta, Yelena Pichugina, Laura Bianco, Irina Djalalova, Alan Brewer (NOAA)

Instrument Team

Jim Wilczak (lead; NOAA), Joe Olson (deputy; NOAA), Larry Berg (PNNL), Mikhail Pekour (PNNL), Bob Banta (NOAA), Sonia Wharton (LLNL), Andy Clifton (NREL), Dave Jager (NREL), Dave Cook (ANL), Justin Sharp (Vaisala), Jim Bickford (Vaisala), Eric Stephan (PNNL), Leon Benjamin (NOAA), Bob Lipschutz (NOAA), Kirk Clawson (NOAA/ARL), Laura Bianco (NOAA), and Kathy Lantz (NOAA).

WFIP2 Study Area

Planned Instrument Layout

Slide courtesy of Jim Wilczak

Instrument	Number of Each	Notes
Ceilometer	1	
Profiler - Lower PBL - Wind - Sodar	8	Top out at between 200-500 m
Profiler - Lower Trop - Wind - 915 MHz	8	Winds 2-4 km ; RASS temp 0-1km; several incl sfc met (2m T,RH,p; 10m wind)
Profiler - Tropospheric - T/H - Radiometer	4	Tops out at 10 km
Scanning Doppler Lidar (Halo)	2	3 km range
Sfc Met - Hi-res micorbarograph	10	
Sfc Met - Short Met Tower	6	3m height, equipped with RM Young prop and vane anemometers, as well as instruments for temperature and humidity. Some also have broad-band radiometers and barometers.
Profiler - Lower PBL - Wind - Sodar (8/10 are Triton)	10	
Scanning Doppler Lidar (Windcube 200S)	2	3 km range
Profiler - Lower PBL - Wind - Lidar (Windcube)	4	Tops out at 200 m
Scanning Doppler Lidar (WindTracer WTX)	1	Typical range 18 km
Profiler - Lower PBL - Wind - Lidar - ZephIR 300	1	10m to 300m
SURFRad mobile units	AOD	Solar irradiance (GHI, DNI, GDI) plus full surface radiation budget: downwelling & upwelling SW and LW) radiation, SW components (total, direct and diffuse solar irradiance), AOD, spectral solar irradiance, broadband and spectral surface albedo, cloud fraction, and sky images.

Modeling Team

Joseph Olson (co-lead; NOAA-ESRL), Jim McCaa (co-lead; Vaisala), Larry Berg (DOE-PNNL), Bob Banta (NOAA-ESRL), Rick Eckman (NOAA-ARL), Mark Stoelinga (Vaisala), Branko Kosovic (NCAR), Virendra Ghate (DOE-ANL), Scott Collis (DOE-ANL), Rao Kotamarthi (DOE-ANL), Katie Lundquist (DOE-LLNL), Jeff Mirocha (DOE-LLNL), John Brown (NOAA-ESRL), Jaymes Kenyon (NOAA-ESRL), Caroline Draxl (DOE-NREL), Will Shaw (DOE-PNNL), Jerome Fast (DOE-PNNL), Julie Lundquist (CU/NREL), Wayne Angevine (NOAA-ESRL),Jian-Wen Bao (NOAA-ESRL), Sara Michelson (NOAA-ESRL), Brian Ancell (TTU)

HRRRnest (750 m)

Image courtesy of Joseph Olson.
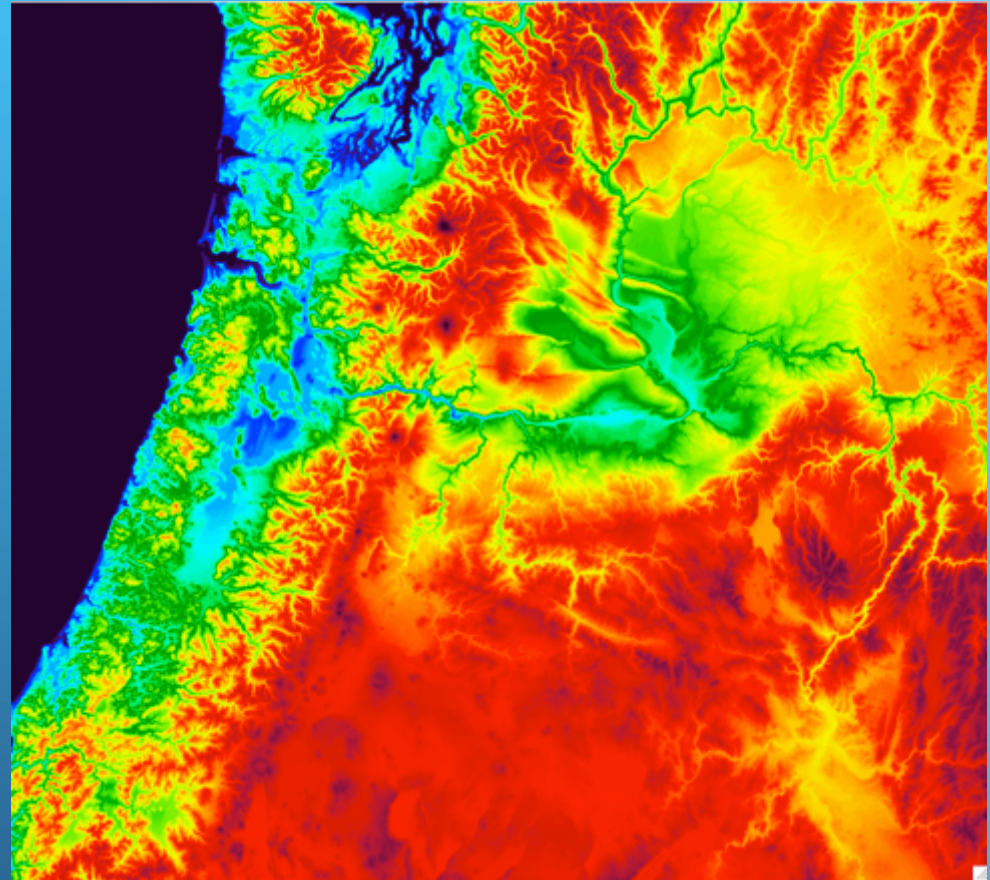
Modeling Goals

The focus is on short-term (0-15 hr) forecasts but benefits are expected to extend to next day forecasts.

Model improvements are expected at very high-resolution (≤ 3 km grid spacing to 750m) as well as coarse resolution models (>10 km grid spacing) and in between.

Therefore, the model development team needs to develop scale-aware physical parameterizations that can adaptively represent the subgrid-scale processes across all scales.

Due to the complex processes and multi-scale feedbacks, biases in boundary layer winds can originate from many different components of the model.
Therefore, the focus of the model development efforts must stretch beyond the surface layer and boundary layer parameterizations to include those related to cloud physics (fog, stratus, and shallow cumulus) and radiative processes as well.

Parameterization	Aspect	Importance	Ranking	Knowledge base
PBL	• Scale-aware • Z-less mixing length • Cloud PDFs/cloud mixing • MYNN-EDMF; coupling to ShCu • Uncertainty quantification (UQ) • Stochastic physics	Scale-aware: 2.0-0.2 km grid spacing. Z-less: stable regime Cloud PDF: moist mixing processes EDMF: convective regime UQ: diagnose sensitive parts of scheme Stochastic: may be important for dx < 1km	High (10) High (8) Low (3) High (8) High (9) Low (3)	NOAA-ESRL, PNNL, ANL, Texas Tech, NREL: general testing
Horizontal Diffusion	• 3D mixing in x-y-z coordinates (not σ-levels) • Coupling to vertical (transformation to 3D)	Important for sub-1km grid spacing and/or steep topography	Moderate (7) High (8)	NCAR, NOAA-ESRL
Surface Layer/M-O removal	• Epifanio (2007) • Ozmidov scaling • Dynamic roughness lengths	Important for sub-3km grid spacing and complex terrain Ozmidov: may improve stable regime compared to M-O Dynamic z_0: primarily forested terrain.	High (9) High (8) Moderate (4)	NOAA-ESRL, Texas A&M, LLNL, NOAA-ARL, NREL: general testing
Forest Canopy Model	• Elevated momentum sink	Very high vertical resolution (dz < 10 m), not resort to surface roughness to parameterize tall canopies.	Moderate (6)	NCAR: Ned, NOAA-ESRL
Land Surface Model	• Heat & Moisture fluxes	Provide improved LBC for PBL, error attribution	High (8)	NOAA-ARL, NOAA-ESRL
Wind Farm Parameterization	• Sub-grid turbine height variability • Scale-aware	Wind farm operations; wake impacts	Moderate (5) Moderate (4)	NOAA-ESRL, CU
Subgrid-scale clouds	• Stratus cloud fraction	Crucial for radiative processes for dx > 1 km.	High (9)	NOAA-NCAR, NCAR: Greg
Shallow-Cumulus	• Scale-aware • Trigger • Prognostic clouds • Closure(s) • Stochastic physics	Important for all dx > 1 km. Scale-aware: 4.0-0.5 km grid spacing. Improving operational models which feed higher-resolution products.	Moderate (7) High (8) Moderate (6) Moderate (6) Low (3)	NOAA-ESRL, NCAR, PNNL, ANL

| Modeling/ Numerics	Aspect	Importance	Ranking	Knowledge base
LES	• WRF-LES • WRF IBM-LES	Better quantify turbulent structures, subgrid-scale variability & model validation.	High (10) High (10)	LLNL, PNNL
Idealized flow analysis	• IBM-mesoscale parameterization interface • Noise quantification/dynamics testing in HRRR	IBM may help 3-1 km grid spacing, but no funding to interface with mesoscale parameterizations (?). Noise testing: important to quantify background error produced by numerics.	High (10) High (8)	NCAR, LLNL

Slide courtesy of Joseph Olson,

Data Team

It is the role of the data team to ensure that this data is received, quality controlled and organized in the most effective way so that it can be retrieved and analyzed by other teams and delivered to project partners with minimal friction and/or duplication of effort.

Members: Kyle Wade (lead, Vaisala), Justin Sharp (Sharply Focused)
Eric Stephan, Chitra Sivaraman, Matt MacDuff (PNNL)
Irina Djalalova, Leon Benjamin, Aditiya Choukulkar (NOAA)
Scott Collias (ANL)
Vera Bulaevskaya (LLNL)
 Andy Clifton (NREL)

FIELD OBSERVATIONS

FORECAST / VERIFICATION

Data Team

ANL

VAISALA

PNNL

NREL

NOAA

LLNL

UND

CU

Wind Farms

a2e DAP (PNNL)

NWP

DSS Tools
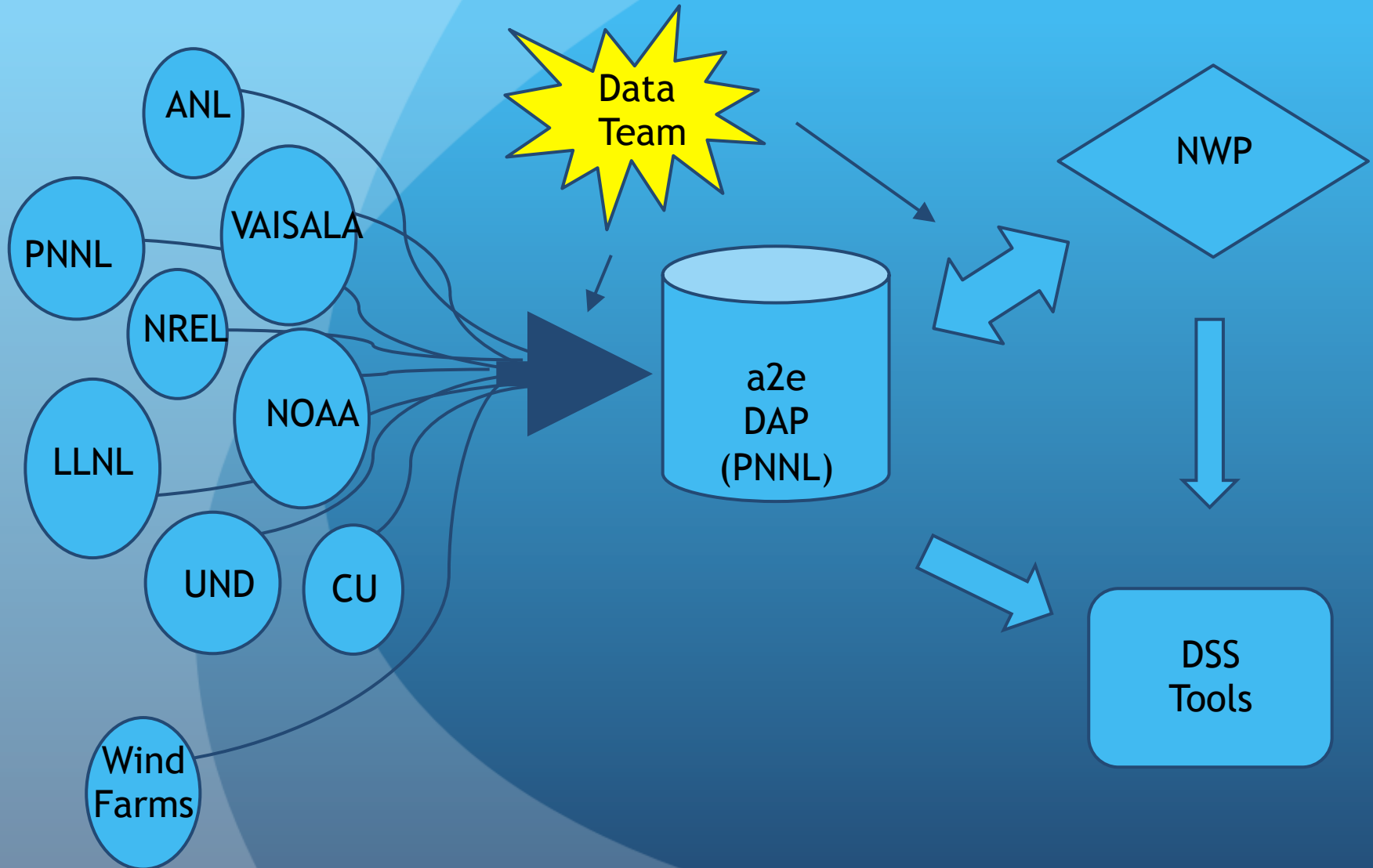
Uncertainty Quantification (UQ) in WFIP2

- UQ is the science of the quantitative characterization and reduction of uncertainties
  - Models such as WRF have a large number of tunable parameters
  - UQ techniques allow us to selectively sample the parameter space and better understand the model's sensitivity to the values of the parameters
  - UQ can also be applied to complex measurement systems

- DOE supported UQ studies are already underway for the Columbia Gorge (Berg et al. this session)
  - Informing experimental design through the identification of key parameters in WRF
  - Providing advice on the deployment of instruments to better constrain parameters, such as measurements TKE and TKE dissipation rate through the depth of the boundary layer

- Team Members: Larry Berg (lead; PNNL), Vera Bulaevskaya (alternate lead; LLNL), Brian Ancell (TTU), Bob Banta (NOAA), Emil Constantinescu (ANL), Matt Churchfield (NREL), Eric Grimit (Vaisala), Jim Wilczak (NOAA), and Yun Qian (PNNL)

Application of UQ in WFIP2

- Compare model uncertainty to long-term measurements from number of different platforms, including Doppler lidar and radar wind profiler

- Apply a wide range of different UQ techniques

- Extend UQ analysis to multiple seasons

- Use UQ analysis to help guide parameterization development
  - Highlight key parameters for further study or improved treatment

- Relate uncertainty to terrain elevation and/or slope
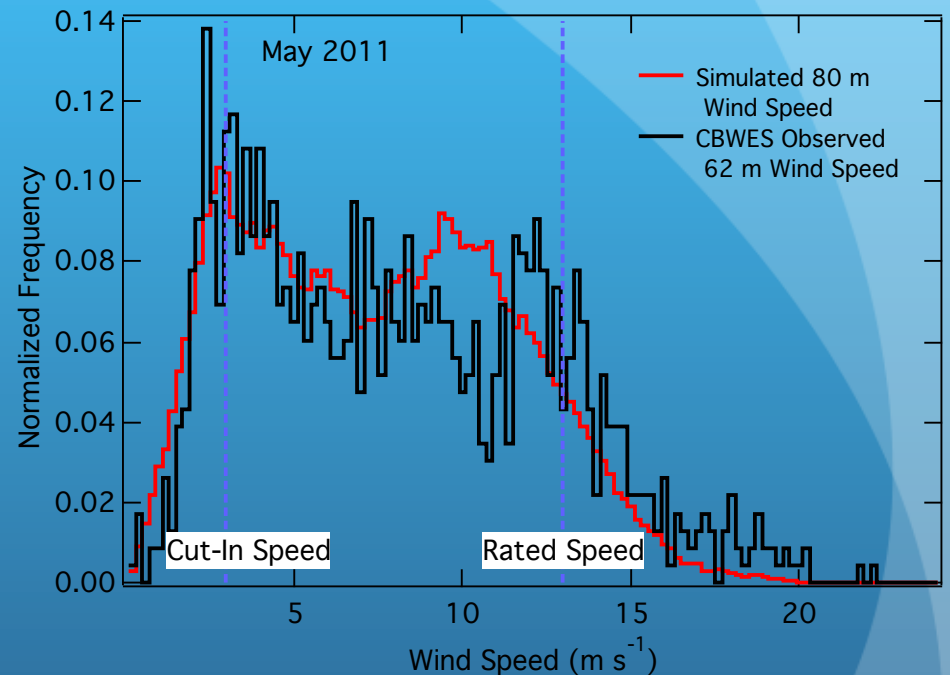
Preliminary example of simulated (256 WRF simulations with varying PBL parameters) and tower observed variability of wind speed during May 2011 at the Columbia Basin Wind Energy Study (CBWES) site, which was conducted within the WFIP2 domain.

Slide courtesy of Larry Berg

Verification & Validation Team

Goal: Define a strategy that the WFIP2 participants will follow, ensuring that effects (individually and/or in total) of the model improvements have been quantified and documented.

Team Members: Andy Clifton (Lead, NREL), Larry Berg (Deputy, PNNL), Eric Grimit (Vaisala), Rao Kotamarthi (ANL), Jeff Mirocha (LLNL), Katie Lundquist (LLNL), and Joe Olson, Aditya Choukulkar, Laura Bianco, Yelena Pichugina (NOAA).

Verification and Validation
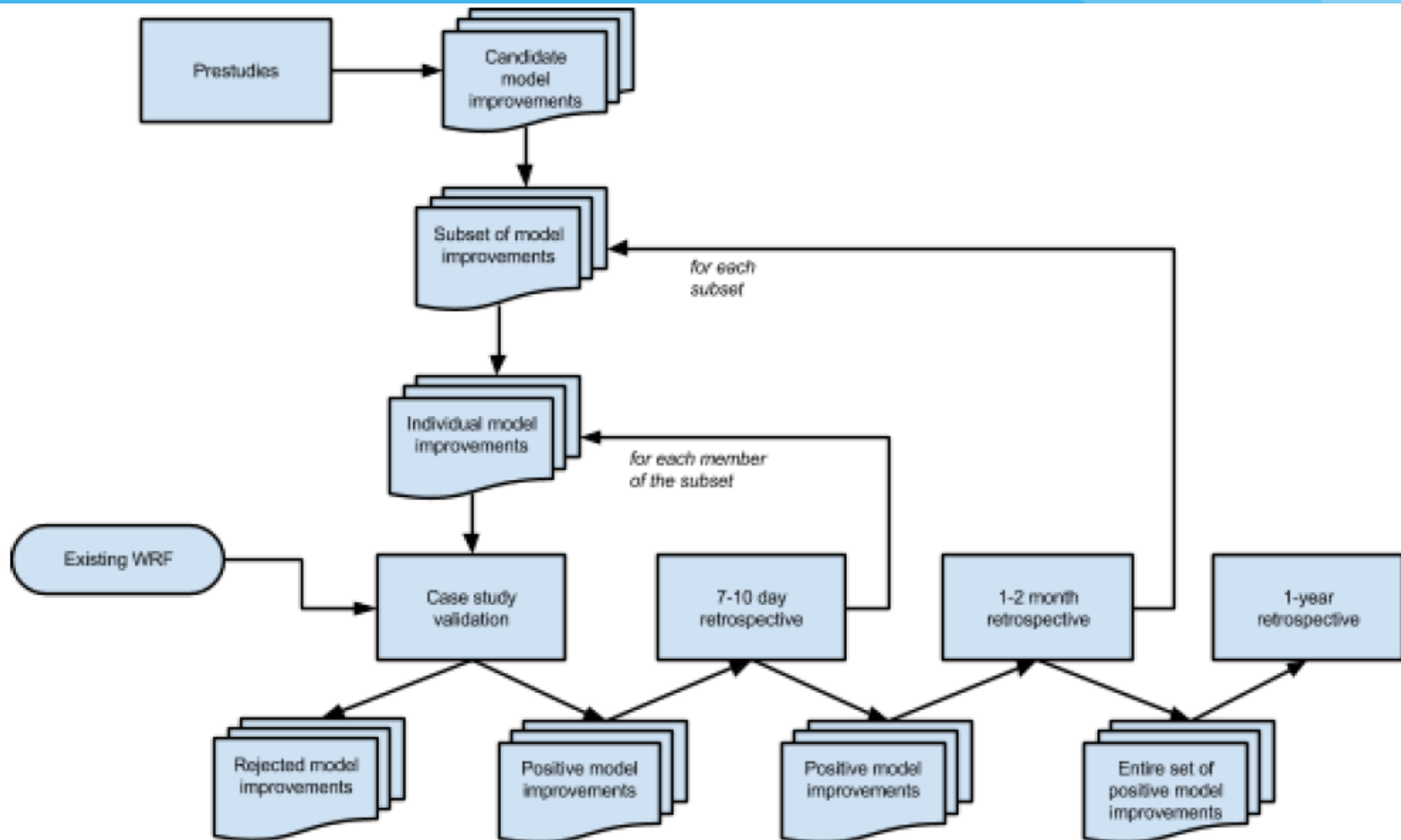
Decision Support Tools

- Lead to greater situational awareness and reduced decision-making time on the part of electric power system operators and wind power producers.

- Algorithms to detect phenomena based on enhanced HRRR forecasts and the uncertainty estimates made using the methods implemented by the Uncertainty Quantification (UQ) team.

- These tools will allow for the best use of the mesoscale models and not interfere with the private company roles of individual wind plant decision making.

- Members: Eric Grimit (Lead; Vaisala), Bri-Matthias Hodge (NREL), Yun Qian (PNNL), Jim Wilczak (NOAA).

Steering Committee

- Ensure the successful execution of the WFIP2 effort.

- Provide high-level (big picture) project management to facilitate coordination across WFIP2 teams and affiliations.

- Anticipate and mitigate risks to the project, catalyze productivity of the WFIP2 teams, and ensure the project stays on schedule, scope and on budget.

- Joel Cline(Lead, DOE), Brad Ring (DOE Contracts), DOE Labs (Will Shaw), Jim Bickford (Vaisala), and Melinda Marquis (NOAA).

Summary

4-year (2014-2018), DOE-led project to improve short-term weather forecast models and increase understanding of physical phenomena such as stability, turbulence, and low-level jet that affect wind energy generation in regions of complex terrain, such as coastlines, mountains, and canyons.

WFIP2 Team members include those from a team led by Vaisala, four DOE labs (NREL, LLNL, PNNL, and ANL), and NOAA.

A field campaign in the Columbia River Gorge will support these goals.

Sub-teams for experimental design, instruments, modeling, data, uncertainty quantification, verification and validation, decision support tools will work those WFIP2 goals.

wfip.windforecast.org

Marine Pushes

(g)

Columbia R.

0730 PDT 20 Jul 2013
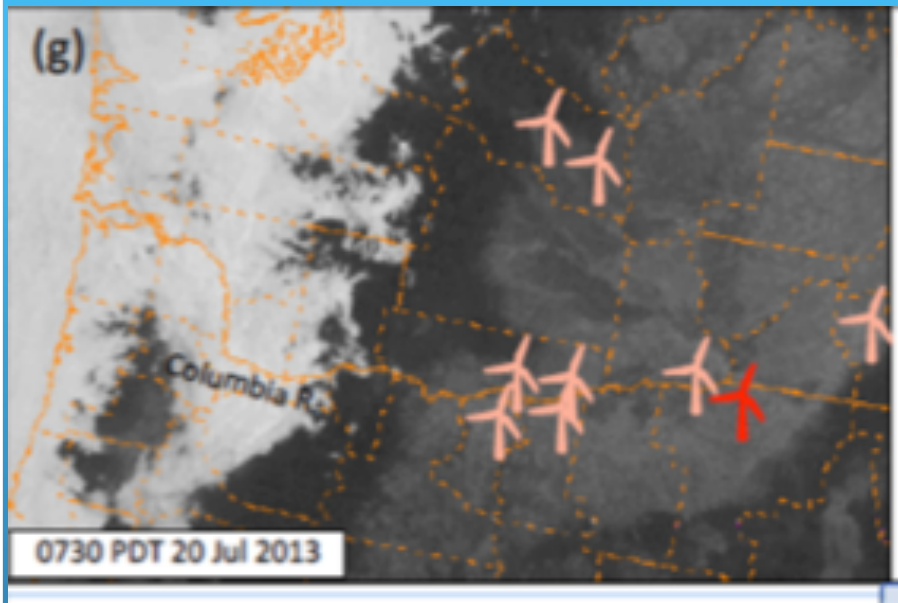
Marine push follows a period of above-average temperatures - with high pressure inland and offshore flow. The high pressure then moves inland and a weather disturbance from the west (Pacific) yields an influx of cool, cloudy air. When this air moves inland, strong winds occur on the eastern side of mountain passes and gaps.

6/11/15

(h) Vansycle Ridge Project
31HR WRF Forecasts and Actual Wind Speed