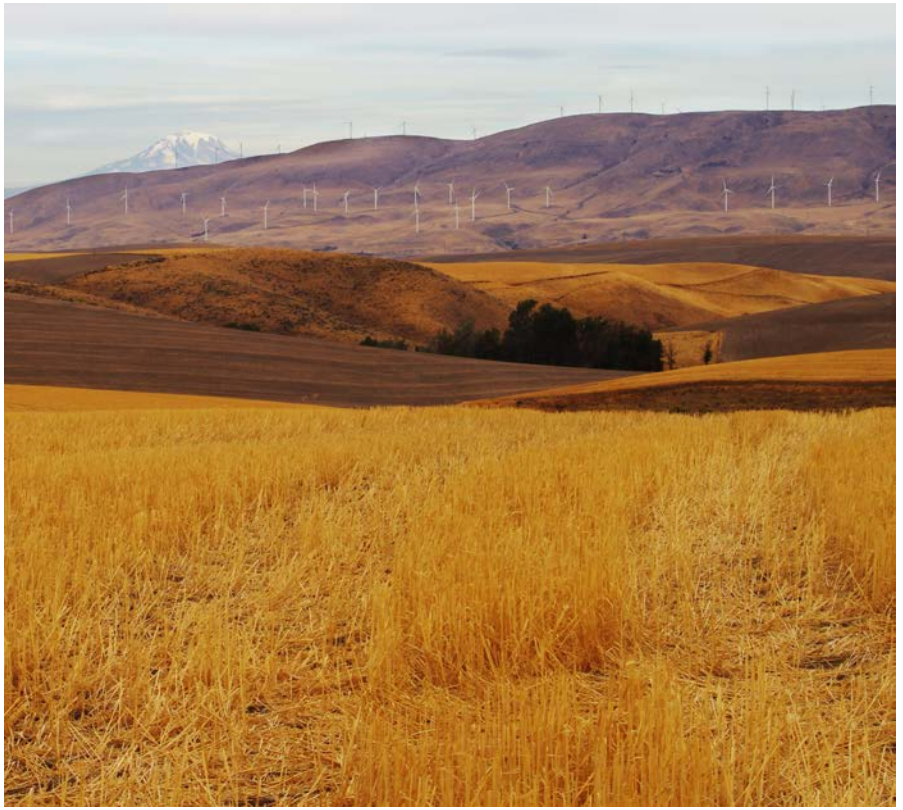
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Second Wind Forecast Improvement Project (WFIP 2) T4



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FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

T4: A2e: Mesoscale Physics and Inflow: WFIP 2

Project Summary

- WFIP2 was a four-year multi-institutional field and modeling study integrating industry, academia, NOAA, and DOE national laboratories in an effort to improve wind forecasts in the 0–45 hour ahead time frame. The focus area for the project was the Columbia Basin of the northwest United States, a wind energy region in complex terrain, which poses severe challenges to forecast models.

Project Objective & Impact

- The overall objective of WFIP2 was to improve short-term wind forecasts by improving model treatment of atmospheric processes in complex terrain. Improvements have already been transferred to NOAA's High Resolution Rapid Refresh Model, a foundational weather forecast model run operationally by the National Weather Service, which provides hourly forecasts to drive power forecasts for the wind industry.

Project Attributes

Project Principal Investigator(s)

Jim McCaa (Vaisala), Dave Turner (NOAA), Rao Kotamarthi (ANL), Katherine Lundquist (LLNL), Caroline Draxl (NREL), Will Shaw (PNNL)

DOE Lead

Joel Cline (Michael Derby)

Project Partners/Subs

NOAA Earth Science Research Laboratory; NOAA Air Resources Laboratory; NOAA National Weather Service; Iberdrola Renewables; Sothern California Edison; Eurus Energy; Siemens; Portland General Electric; University of Colorado; Texas Tech University; University of Notre Dame; National Center for Atmospheric Research; Lockheed Martin; Sharply Focused; Bonneville Power Administration

Project Duration

October 2015–September 2018

Technical Merit and Relevance

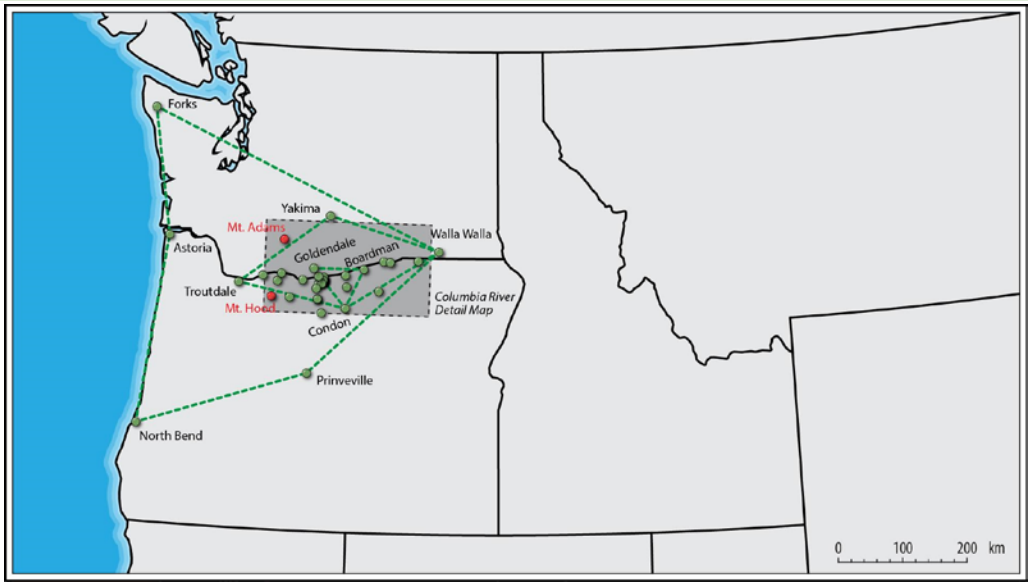
- **Forecast errors expensive for wind industry**
  - Errors occur due to: lack of knowledge of atmospheric physics; inadequate representation of temporal and spatial scales
  - Extreme storms cannot be covered by pure statistics; present a big risk
- **Two ways to improve short-term (0-45 hr) wind forecasts**
  - Improvement of Model Initialization
    - Hypothesis: More accurate model initialization will provide a more accurate forecast
    - Current initialization data are sparse in the turbine swept area and some observations of unknown data quality
    - First field study (WFIP 1): 2011-2012
      - Supplemented two areas with extensive observations, including profilers
      - Demonstrated clear improvement in forecast accuracy
  - Improvement of Model Physics
    - Current parameterizations do not effectively account for complex terrain, where horizontal gradients are often important
    - Better numerical techniques needed
    - Second field study (WFIP 2): 2015-2017 with model analysis in 2017-2018
      - Focus is to collect observations to evaluate and improve model physics, particularly for complex terrain, where much wind power is deployed

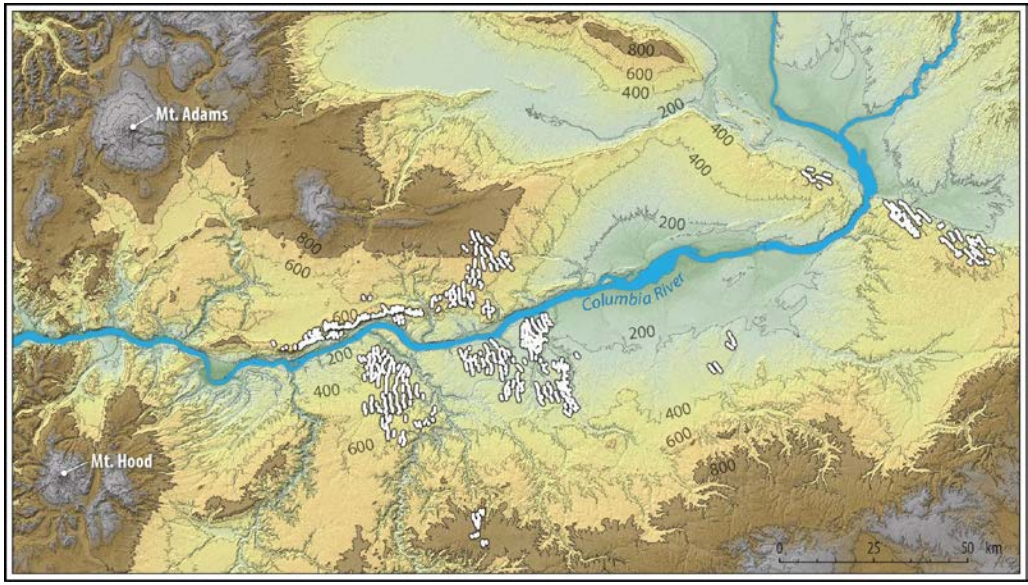
Approach and Methodology

- **Goal**
  - **Improve our understanding of atmospheric flows and processes** that occur **in complex terrain** and affect wind forecasts at hub heights
- **Approach**
  - Engage industry, academia, national laboratories
  - **Carry out an 18 month field campaign**
  - **Develop improved physical parameterizations in WRF-ARW** (with a focus on RAP & HRRR)
  - **Develop decision support tools** based on probabilistic forecast information for system operations
  - **Transfer model improvements** to NOAA (to be run operationally) and NCAR as open source

Approach and Methodology

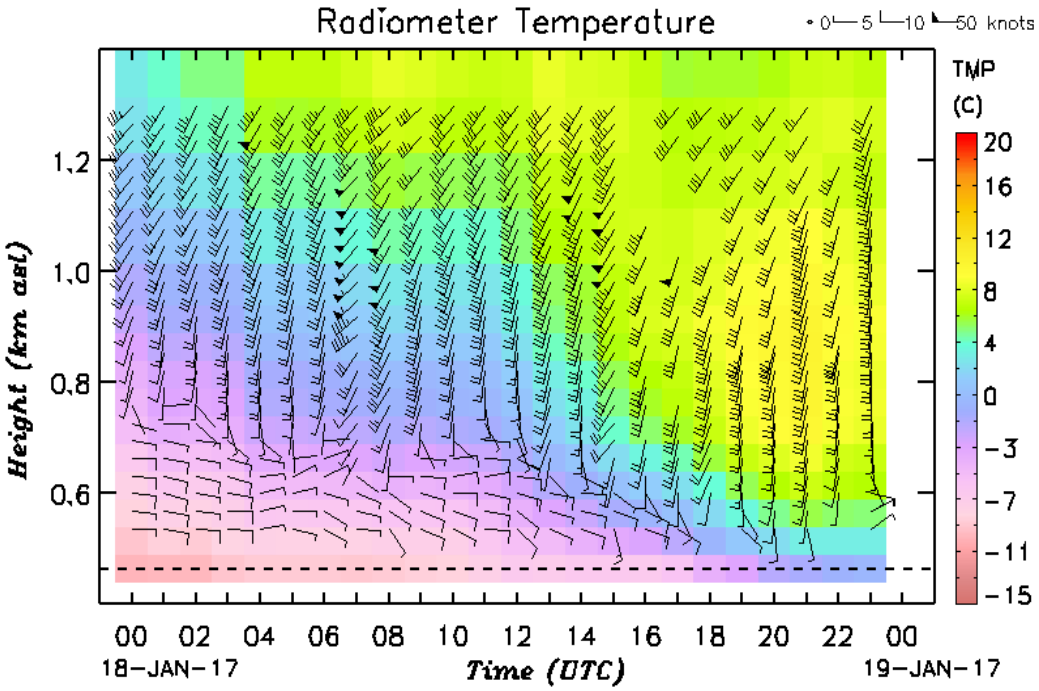
- Observe boundary layer on multiple scales over a full annual cycle.
- Use data to evaluate baseline NWP model performance, parameterizations, and numerical techniques and their improvements over annual spectrum of atmospheric conditions
- Use observations to establish uncertainties in models and develop decision support tools for power forecasts incorporating uncertainty
- Archive observations and benchmark model output in a publicly accessible data archive to engage the broader community in advancing complex terrain meteorology





Approach and Methodology

- **Key phenomena in WFIP 2 region relevant to wind energy applications:**
  - ➢ Timing and intensity of frontal passages
  - ➢ Orographic lee waves, wakes
  - ➢ Convective outflows
  - ➢ Marine layer
  - ➢ Regional thermal contrast
  - ➢ Gap flows



- **Ever-present challenge: Build up and erosion of stable layers with associated strong wind shears**

- **Many of these phenomena identified as forecasting challenges for the wind industry during various meetings and workshops**

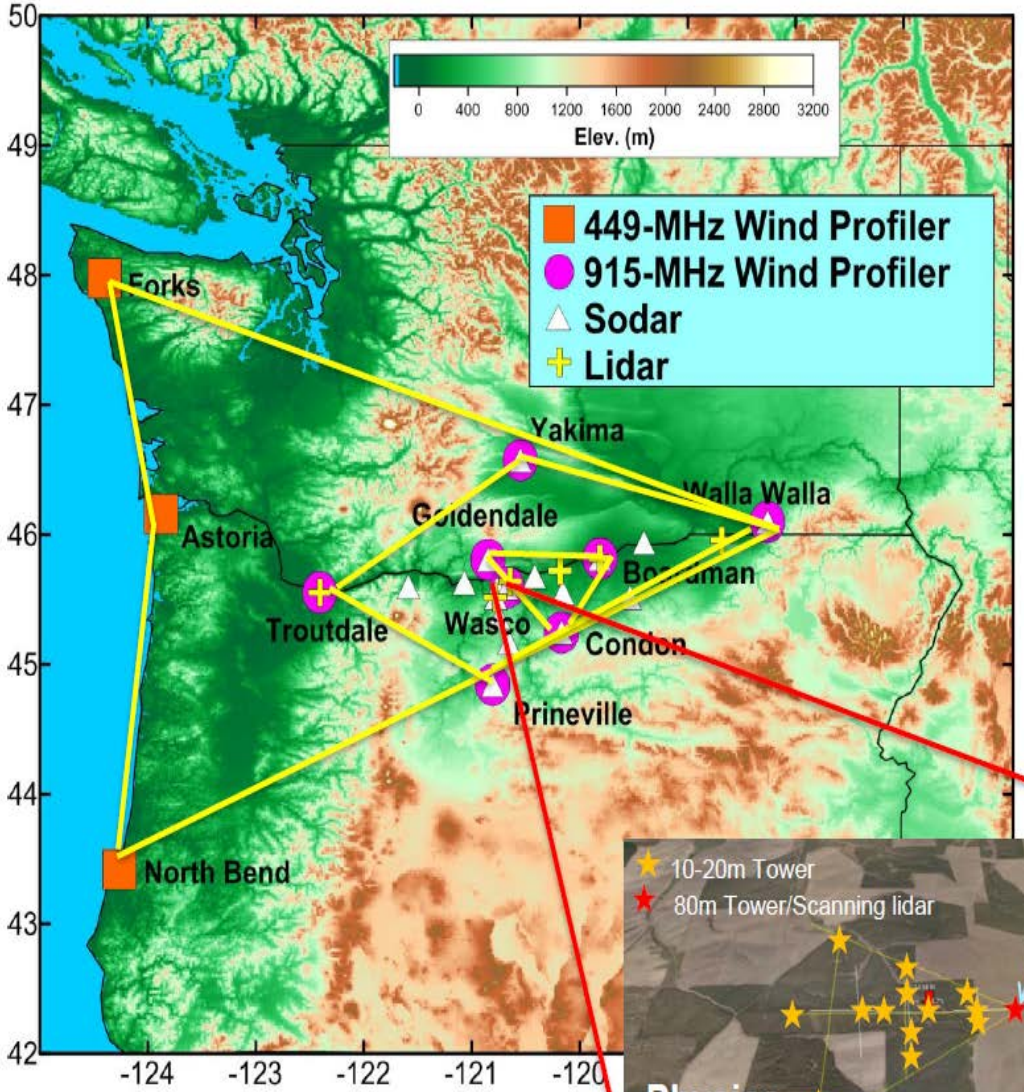
Accomplishments and Progress

- Concluded successful field study
- Improved model physics transferred to NWS operational models
- Decision Support Tool demonstrated
- Data and benchmark model output provided to Data Archive and Portal
- Journal articles submitted to Bulletin of the American Meteorological Society

Vansycle Ridge, NE Oregon

	FY 2017				FY 2018			
Key Milestone	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Q1: Draft report on HRRR verification and validation metrics								
Q2: Land surface model sensitivity study configured								
Q3: Completed of boundary layer depth estimates								
Q4: Completed surface flux calculation from PNNL sensors								
Q1: Report to DOE on alternative finite difference methods								
Q2: Complete WFIP2 simulation case with new numerical methods								
Q3: Produce integrated data set for model validation								
Q4: Draft manuscript on WFIP2 completed for journal								

Accomplishments and Progress

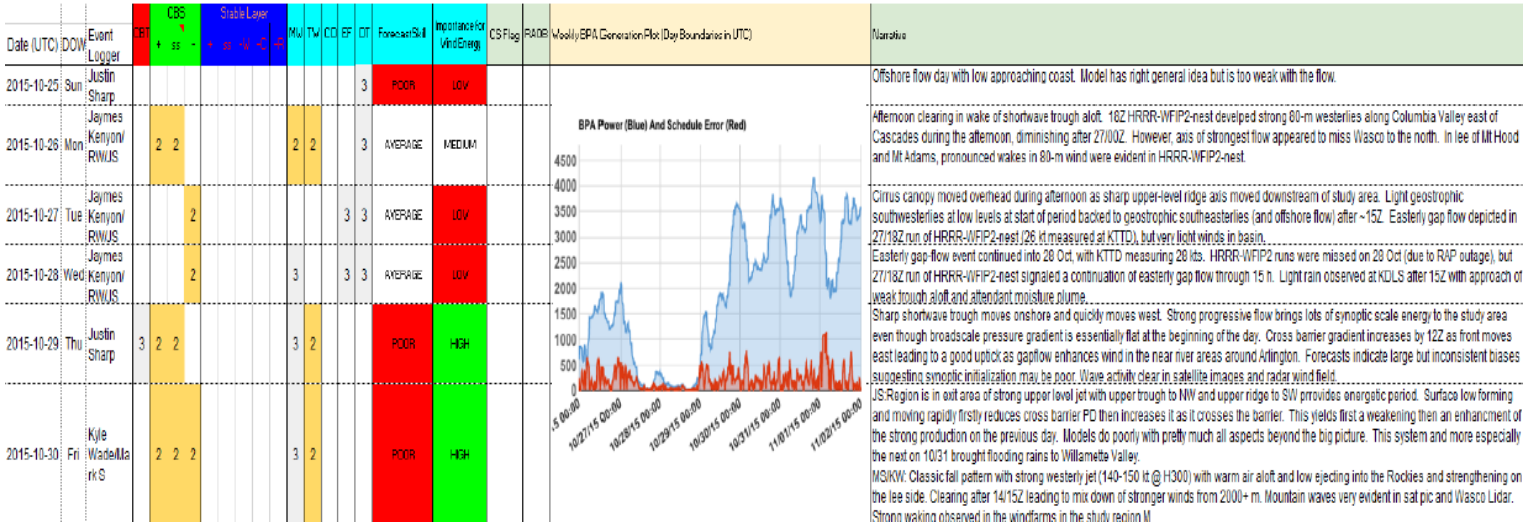


- 11 wind profiling radars
- 17 sodars
- 5 wind profiling lidars
- 5 scanning lidars
- 4 mw radiometers
- 10 microbarographs
- 1 Ceilometer
- 28 sonic anemometers
- 5 radiative flux systems
- 4 soil moisture sites
- ~200 radiosonde launches
- Wind plant data from 14 wind plants (1,569 turbines)

Field Campaign:
All 4 seasons
Oct 2015 - March 2017
(18 months)

Accomplishments and Progress

- Daily log captures the occurrence of phenomena important to the project
  - Standardized and as objective as possible
  - Assigns importance to events
  - Places them in the context of the regional wind power generation, forecast skill, and importance to wind energy
- Real-time evaluation in HRRR forecasts helped prioritize parameterizations to work on first
- Narrative provides useful context for future users



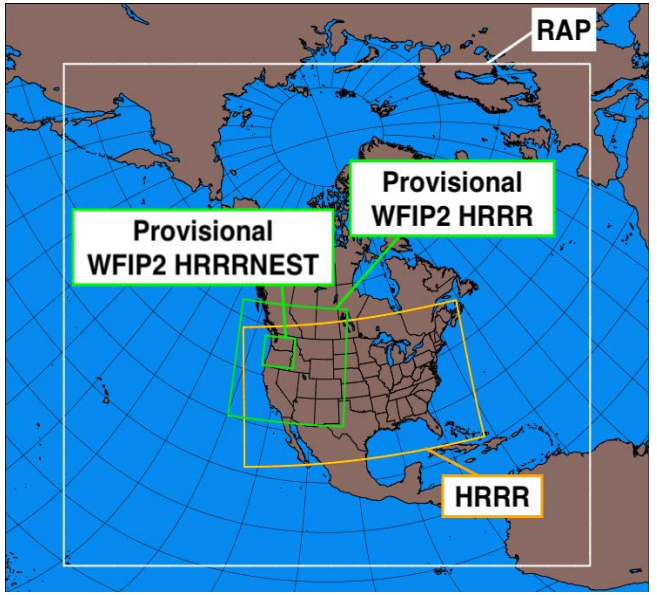
Date (UTC)	DOW	Event Logger	FBT	CBS +	CBS ss	CBS -	Stable Layer +	Stable Layer ss	Stable Layer -	MW	TW	CDI	EF	DT	Forecast Skill	Importance for Wind Energy	CS Flag	RADB	Modified BPA Generation Plot (Day Boundaries in UTC)	Narrative
2015-10-25	Sun	Justin Sharp												3	POOR	LOW				Offshore flow day with low approaching coast. Model has right general idea but is too weak with the flow.
2015-10-26	Mon	Jaymes Kenyon/ RWJS		2	2					2	2			3	AVERAGE	MEDIUM				Afternoon clearing in wake of shortwave trough aloft. 18Z HRRR-WFIP2-nest develped strong 80-m westerlies along Columbia Valley east of Cascades during the afternoon, diminishing after 27/00Z. However, axis of strongest flow appeared to miss Wasco to the north. In lee of Mt Hood and Mt Adams, pronounced wakes in 80-m wind were evident in HRRR-WFIP2-nest.
2015-10-27	Tue	Jaymes Kenyon/ RWJS				2							3	3	AVERAGE	LOW				Cirrus canopy moved overhead during afternoon as sharp upper-level ridge axis moved downstream of study area. Light geostrophic southwesterlies at low levels at start of period backed to geostrophic southeasterlies (and offshore flow) after ~15Z. Easterly gap flow depicted in 27/18Z run of HRRR-WFIP2-nest (26 kt measured at KTTD), but very light winds in basin.
2015-10-28	Wed	Jaymes Kenyon/ RWJS				2				3			3	3	AVERAGE	LOW				Easterly gap-flow event continued into 28 Oct, with KTTD measuring 28 kts. HRRR-WFIP2 runs were missed on 28 Oct (due to RAP outage), but 27/18Z run of HRRR-WFIP2-nest signaled a continuation of easterly gap flow through 15 h. Light rain observed at KDLS after 15Z with approach of weak trough aloft and attendant moisture plume.
2015-10-29	Thu	Justin Sharp	3	2	2					3	2				POOR	HIGH				Sharp shortwave trough moves onshore and quickly moves west. Strong progressive flow brings lots of synoptic scale energy to the study area even though broadscale pressure gradient is essentially flat at the beginning of the day. Cross barrier gradient increases by 12Z as front moves east leading to a good uptick as gapflow enhances wind in the near river areas around Arlington. Forecasts indicate large but inconsistent biases suggesting synoptic initialization may be poor. Wave activity clear in satellite images and radar wind field.
2015-10-30	Fri	Kyle Wade/Mark S		2	2	2				3	2				POOR	HIGH				JS:Region is in exit area of strong upper level jet with upper trough to NW and upper ridge to SW provides energetic period. Surface low forming and moving rapidly firstly reduces cross barrier PD then increases it as it crosses the barrier. This yields first a weakening then an enhancment of the strong production on the previous day. Models do poorly with pretty much all aspects beyond the big picture. This system and more especially the next on 10/31 brought flooding rains to Willamette Valley. MS/KW: Classic fall pattern with strong westerly jet (140-150 kt @ H300) with warm air aloft and low ejecting into the Rockies and strengthening on the lee side. Clearing after 14/15Z leading to mix down of stronger winds from 2000+ m. Mountain waves very evident in sat pic and Wasco Lidar. Strong waking observed in the windfarms in the study region M

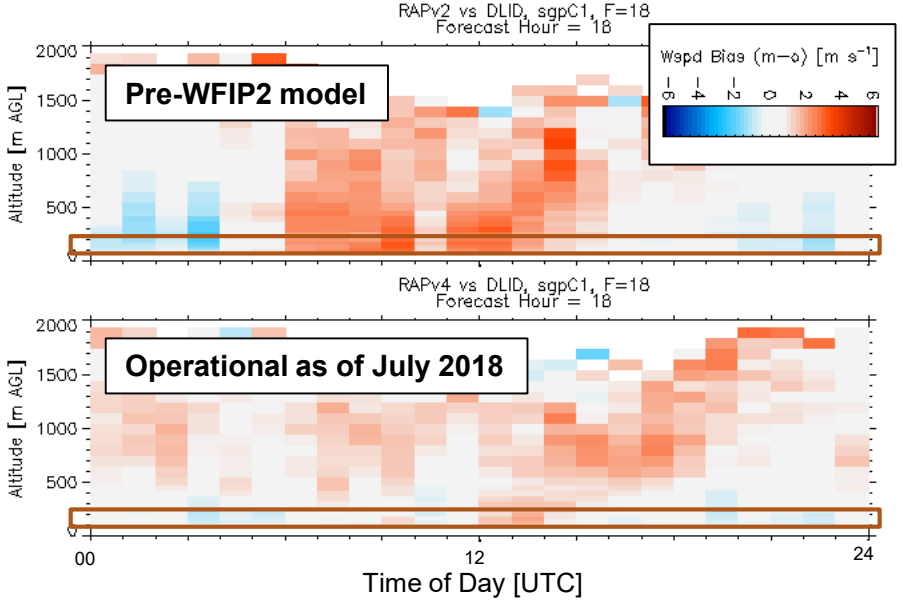
Accomplishments and Progress

- **Field Deployment Completed**
  - Field measurements officially ended on 31 March 2017
  - Instruments continued recording until retrieved
- **Remote Sensing Analyses**
  - Joint observations of ramps from sodar and lidar
  - Automated determination of PBL depth
- **HRRR Model Improvements**
- **3D PBL parameterizations developed**
  - Account for full stress tensor and stress divergence
- **Verification and Validation**
  - Formalism defined and implemented
- **Uncertainty Quantification**

Accomplishments and Progress

- **Specific improvements to RAP/HRRR**
  - Improvements in mixing parameterization in the boundary layer
  - Addition of sub-gridscale clouds and their impact with solar radiation
  - Addition of wind drag due to sub-gridscale variations in topography
  - Improvements in the coupling of the land surface with the atmosphere (esp if snow)
  - New vertical coordinate that minimizes numerical errors in terrain (more important at flight altitude than at surface)





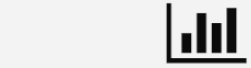
Accomplishments and Progress

Archived Model Output

Type	Framework	Grid Spacing	Initial and Boundary Conditions (NetCDF)	Forecast Output (GRIB2)
Real-time	RAP-ESRL, HRRR-ESRL, Experimental HRRR, and nest	13, 3, 3, and 0.75 km, respectively	Yes	No
Case Studies	HRRR and nest	3 and 0.75 km, respectively	Yes	15-min output to 24 h (nest start delayed 1 h)
10-day Retrospectives	RAP, HRRR, and nest	13, 3, and 0.75 km, respectively	No	1-h output to 21 h (RAP), 15-min output to 18 h (HRRR and nest; nest start delayed 1 h)
Year-long Reforecast (four 1-month periods)	Cold-start parent with nest	3 and 0.75 km, respectively	Yes	15-min output to 24 h (nest start delayed 3 h)

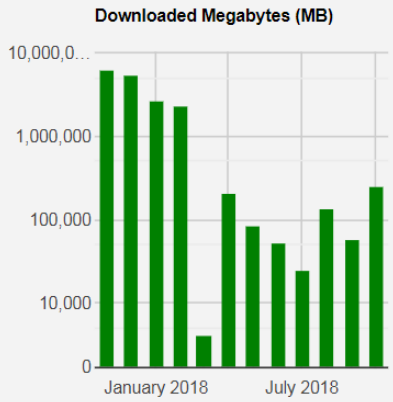
Accomplishments and Progress

- **Data sets**
  - http://a2e.energy.gov/projects/wfip2
- **Case Studies**
  - Represent key phenomena for validation
- **Year-long Reforecasts**
  - Full-year, twice daily initializations with 24-hr Fx
  - Control and experimental
- **Fully Cycled Retrospective Tests**
  - Two 10-day periods, hourly updates, to 750 m
- **Verification and Validation**
- **Improvements Passed to Operational RAP and HRRR**
  - WFIP2 influenced versions became operational at NCEP in July 2018)
- **Decision Support Tools**
  - Actionable forecasts; positive industry response



276
Datasets

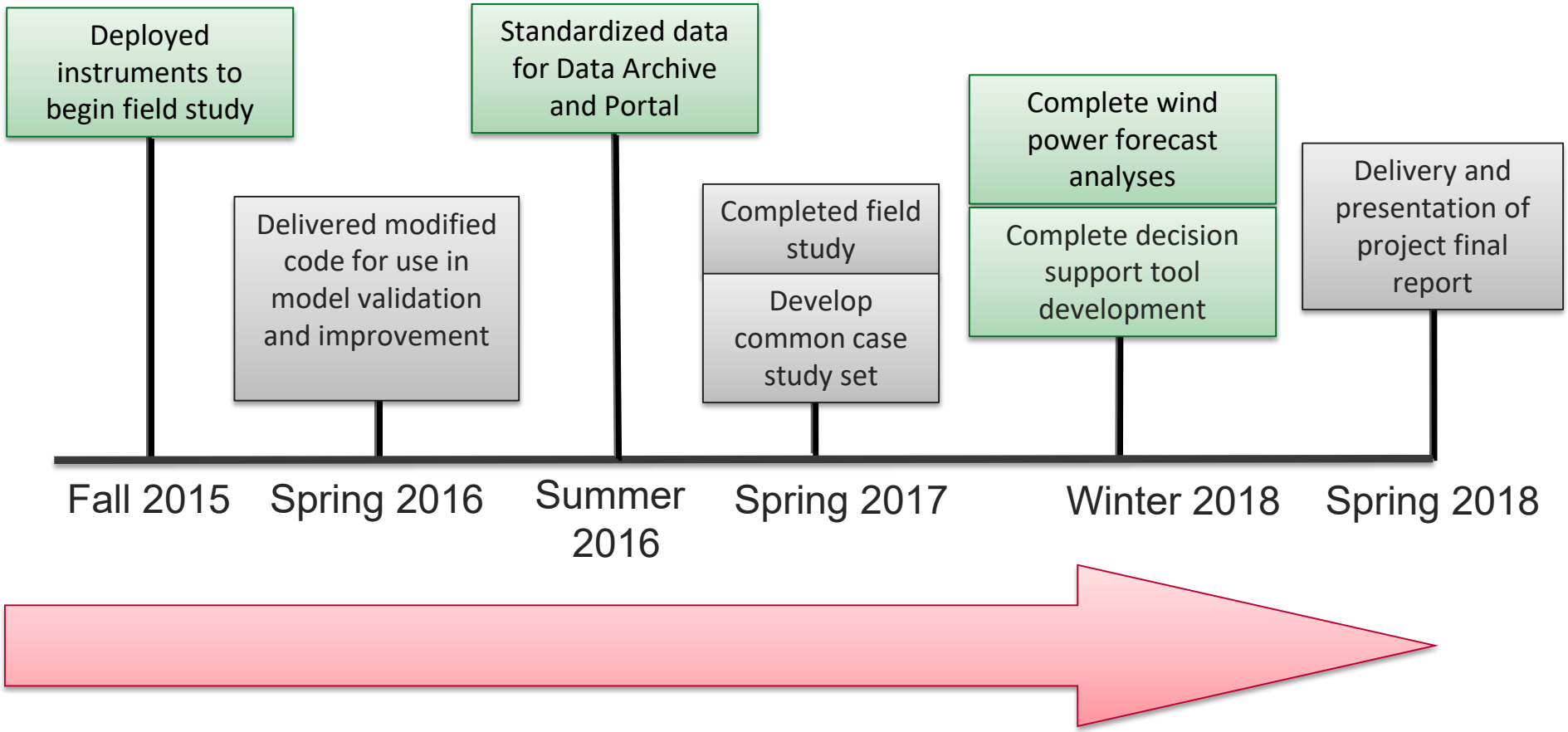
209.5 TB
Stored



DAP information for WFIP2 data as of 22 October 2018

Accomplishments and Progress

- **Primary Challenges Overcome**
  - Securing field measurement sites
  - Securing sufficient computational resources; multiple architectures



Communication, Coordination, and Commercialization

- **Numerous presentations**
  - American Meteorological Society conferences
    - Special WFIP2 sessions 2017 and 2019
    - Conferences on Boundary Layers and Turbulence
  - Energy Systems Integration Group Forecasting Workshops
  - Wind Energy Science Conference
- **IEA Wind Task 36: Forecasting for Wind Energy**
  - WFIP2 a primary U.S. contribution
- **Journal Articles**
  - Overview series to appear in Bulletin of the AMS
  - Additional articles in process