Wind Forecast Improvement Project in Complex Terrain (WFIP-2) Field Campaign Report

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# Acronyms and Abbreviations

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<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tr>
<td>AMS</td>
<td>American Meteorological Society</td>
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<tr>
<td>ANL</td>
<td>Argonne National Laboratory</td>
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<tr>
<td>ARM</td>
<td>Atmospheric Radiation Measurement</td>
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<td>DOE</td>
<td>U.S. Department of Energy</td>
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<tr>
<td>EBBR</td>
<td>energy balance Bowen ratio</td>
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<tr>
<td>ECOR</td>
<td>eddy correlation</td>
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<td>FA</td>
<td>final amplifier</td>
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<td>GE</td>
<td>General Electric</td>
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<tr>
<td>IF</td>
<td>intermediate frequency</td>
</tr>
<tr>
<td>IOP</td>
<td>intensive operational period</td>
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<tr>
<td>km</td>
<td>kilometer</td>
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<tr>
<td>m</td>
<td>meter</td>
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<tr>
<td>MHz</td>
<td>megahertz</td>
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<tr>
<td>mi</td>
<td>mile</td>
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<tr>
<td>MII</td>
<td>modulator, IF, and interface unit</td>
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<td>ML</td>
<td>mixed layer</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>RASS</td>
<td>radio acoustic sounding system</td>
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<tr>
<td>RWP</td>
<td>radar wind profiler</td>
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<tr>
<td>SNR</td>
<td>signal-to-noise ratio</td>
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<td>WFIP-2</td>
<td>Wind Forecast Improvement Project in Complex Terrain</td>
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1.0 Summary

The Wind Forecast Improvement Project in Complex Terrain (WFIP-2) is part of a continuing effort to improve short-term wind forecasts for wind energy operations. This particular effort, nominally between September 2015 and February 2017, was dedicated to the collection of a detailed data set of atmospheric parameters associated with the development of low-level wind profiles important to wind farm applications. The region along the Columbia River Gorge in Southern Washington-Northern Oregon (Figure 1) was chosen because of its combination of mountainous terrain and a strong presence of wind farm development along with a well-defined large-scale wind regime. In the data analysis stage, ongoing efforts utilize the collected data set to improve short-term wind forecasts.

![Figure 1. May of the WFIP-2 study region.](image)

A large coterie of organizations participated in this effort, headed by Vaisala Inc., Lockheed Martin, and the National Oceanic and Atmospheric Administration (NOAA). U.S. Department of Energy (DOE) National Laboratory participation included Argonne, Pacific Northwest, and Lawrence Livermore National Laboratories, and the National Renewable Energy and Atmospheric Research Laboratory. Universities included Notre Dame, Colorado, and Texas Tech. Private organizations were represented by Eurus Energy, Iberdrola Renewables, NextEra Energy, Portland General Electric (GE), Siemens, Southern California Edison and White Creek Wind. This is not an exhaustive list.

DOE’s involvement in this intensive operational period (IOP) through its Atmospheric Radiation Measurement (ARM) Climate Research Facility consisted of a 915 MHz radar wind profiler (RWP), located in Walla Walla, Washington, as part of a triangular network of RWPs installed by Argonne National Laboratory (ANL). The RWPs operated in low- and high-power modes, providing hourly averages of wind speed and direction up to about 2.6 km (63 m vertical resolution) and 5.8 km (97 m
vertical resolution) heights, respectively. The raw spectra measurements were also provided for possible improvements in the post-processing efforts. The other two profilers were deployed in Yakima, Washington and Goldendale, Washington; these sites were separated by roughly 110 mi. Six or more additional RWPs contributed by NOAA, several Doppler lidars, and many Doppler sodars provided a comprehensive picture of the wind profile development between the surface and 6 or more km. Surface instrumentation included 10 and 3 m towers, as well as surface energy budgets using Eddy Correlation (ECOR) and Energy Balance Bowen Ratio (EBBR) approaches. See Wilzack et al. (2017) for more detail.

Although the original intent was to operate the ARM RWP with the radio acoustic sounding system (RASS), this proved impossible due to noise concerns of several nearby wineries. This particular RWP operated in conjunction with a sodar (providing high-vertical-resolution wind speed and direction measurements up to 200 m height) and a 10 m tower (providing wind speed, direction, temperature, moisture and atmospheric pressure measurements). The RWP operated between March 14, 2016 and May 15, 2017. However, the final amplifier (FA) was sent for repair between April 23, 2016 and July 9, 2016. Although the FA was successfully repaired, the RWP was not operational in Walla Walla, as its Modulator, IF, and Interface Unit (MII) was placed at Goldendale until October 27, as this location was considered more crucial to study objectives. The overall campaign period was notable in that it was considerably wetter than normal and the summer period was marked by multiple fire outbreaks, including one that destroyed a collaborating institution’s operating sodar.

2.0 Results

The data from this and other Argonne efforts have been submitted to the extensive WFIP-2 data archive and portal, as well as to the ARM external data repository. They are being used for a number of phenomenological and modeling studies (see references).

Studies of the variability and development of the atmospheric mixed layer over complex terrain are being conducted by several institutions (Muradyan et al. 2018, Bianco et al. 2018). In particular, the use of RWP data for autonomous definition of mixed-layer development is useful for long-term monitoring. It is particularly important for wind energy applications because the characteristics of atmospheric turbulence can be dramatically different within and external to the well-mixed layer (ML). ML height estimates for the complete ARM RWP data set at Walla Walla was determined based on various hourly measurements (signal-to-noise ratio [SNR], wind speed, and wind direction) as follows:

- Calculate the ratio of the SNR differences above and below each range gate in the profile. Identify the location of the maximum difference, and report the corresponding height as the ML height.
  - Find the second estimate of ML height using SNR measurements by moving the first estimate lower in height until the next maximum difference is found.
  - Define ML height as the location of the maximum of the SNR profile.
- Determine the maximum difference in the wind direction profile between the top and bottom of a sliding window. Report the corresponding height as the ML height.
- Determine when the difference in mean speed between lower and upper halves of the window is at maximum. Report the corresponding height as the ML height.
After all ML estimates are available from the above mentioned methods, they are used in conjunction with SNR and spectral width plots as well as information on the time of day, past conditions, etc. to identify and report a “best” daytime ML height estimate (Figure 2).

A second area of interest to our group is the onset, duration, and cessation of periods of strong wind shear in the wind turbine areas because of the strong effect such events can have on wind turbine performance. The combination of 3 and 10 m tower, sodar, Doppler lidar, and RWP measurements of the detailed wind profile on short time scales provides unique opportunities for useful research (Djalalova et al. 2018).

A large portion of the WFIP-2 effort in the next few years will be devoted to model development and improvement in short-term wind forecasts particularly important to the wind energy community (Wilczak et al. 2017).

3.0 Publications and References


WFIP-2 Experiment: Evaluation of Different Model Configurations at Forecasting Wind at Turbine Height. 4th International Conference on Energy and Meteorology, June 2017, I Djalalova, L Bianco, J Wilczak, J Olson, J Kenyon, R Banta, L Berg, T Bonin, M Brewer, A Choukulkar, K Clawson, A Clifton, J Cline, D Cook, R Coulter, R Eckman, E Grimit, H Fernando, L Leo, J Lundquist, M Marquis, T Martin,