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Installation and Initial Operation of DOE's 449 MHz Wind Profiling Radars on the U.S. West Coast

October 2015

JE Flaherty
VR Morris
AB White
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Recent work supported by the U.S. Department of Energy (DOE) has shown that adding observations to improve the initialization fields of weather forecast models results in better wind forecasts at wind turbine hub height. The work also indicated that the most effective area to add new observations is the climatologically upwind part of the forecast model domain.

To build on this work DOE, in collaboration with the National Oceanic and Atmospheric Administration (NOAA), recently completed the installation of three new wind profiling radars on the Washington and Oregon coasts. These systems operate at a frequency of 449 MHz and provide mean wind profiles to a height of roughly 8 km. The maximum measurement height depends on time-varying atmospheric conditions. This is roughly half the depth of the troposphere at these latitudes. Each system is also equipped with a radio acoustic sounding system, which provides a measure of the temperature profile to heights of approximately 2 km. Other equipment deployed alongside the radar includes a surface meteorological station and a Global Positioning System receiver for column-integrated water vapor.

This project began in fiscal year 2014 with equipment procurements and site selection. In addition, environmental reviews, equipment assembly and testing, site access agreements, and infrastructure preparations have been performed. Finally, equipment deployments with data collection and dissemination have been completed. The three new wind profiling radars have been deployed at airports in North Bend, Oregon, and Warrenton, Oregon, and at an industrial park near Forks, Washington. Data are available through the NOAA Earth Systems Research Laboratory Data Display website, and will soon be made available through the DOE's Atmosphere to electrons (A2e) Data Archive and Portal (DAP) as well.

Acknowledgments

This work was funded by the U.S. Department of Energy Office (DOE) of Energy Efficiency and Renewable Energy. We express our appreciation to Joel Cline, DOE Project Manager, for his support of this effort.

A long list of individuals were integral to the success of the work described in this report. We would like to specifically recognize administrative support from Emily Davis and Kathy Wescott of Pacific Northwest National Laboratory (PNNL) and Brian Gorton, Barbara Herrli, Holly Rosales, and Tina Schiffbauer of the National Oceanic and Atmospheric Administration (NOAA). PNNL project specialists Ginny Collier and Bev Van Zandt, and contracts specialist Susan Turner were key in setting up and tracking the project. PNNL contracts staff Ken Blaine, Kim Massie, Doug Akers, and Rick Dennis ensured that the numerous procurements and site access agreements were executed efficiently. Legal questions were managed by PNNL legal counsel Alan Rither and Steve Cook. Environmental and cultural resources concerns were expertly managed by Mike Sackschewsky and Jim Becker of PNNL and Doug McFarland of CH2MHill. Data acquisition, management, and web development was performed by Tim Coleman of the Cooperative Institute for Research in Environmental Sciences (CIRES), Dan Gottas (NOAA), Eric Stephan (PNNL), and Ken Burk (PNNL). NOAA deployment engineers Scott Abbott and Jesse Leach ensured successful testing and deployment for the instrument systems deployed for this project. Susan Ennor of PNNL provided editorial support for this report.

Finally, we express our sincere appreciation to the site owners and stakeholders that allowed these deployments to take place. With the City of Forks, Washington, Rod Fleck and Audrey Grafstrom helped to identify and facilitate the use of the Forks Industrial Park site. Mike Weston of the Port of Astoria was a valuable resource in establishing the deployment at the Astoria Regional Airport. Bob Hood and Theresa Cook of Coos County Airport District were highly supportive, particularly considering the various changes that took place at the Southwest Oregon Regional Airport. In addition, Barry Heath and Mike Jones of the Federal Aviation Administration (FAA) were especially helpful in obtaining power for the Southwest Oregon Regional Airport site.

Acronyms and Abbreviations

A2e	Atmosphere to electrons
ASOS	Automated Surface Observing System
AST	airport code for Astoria Regional Airport
AWOS	Automated Weather Observing System
CIRES	Cooperative Institute for Research in Environmental Sciences
CTCLUSI	Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians
DAP	Data Archive and Portal
DOE	Department of Energy
EMC	Environmental Modeling Center
EERE	Office of Energy Efficiency & Renewable Energy
ESRL	Earth System Research Laboratory
FAA	Federal Aviation Administration
FFT	fast Fourier transform
ft	foot(feet)
FY	fiscal year
GPS	Global Positioning System
GW	gigawatt(s)
km	kilometer(s)
m	meter(s)
MHz	megahertz
NCEP	National Centers for Environmental Prediction
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NTIA	National Telecommunications Information Administration
NWP	numerical weather prediction
NWS	National Weather Service
OTH	airport code for Southwest Oregon Regional Airport
PNNL	Pacific Northwest National Laboratory
PST	Pacific Standard Time
radar	Radio Detection and Ranging
RASS	Radio Acoustic Sounding System
sec	second(s)
U.S.	United States of America
UTC	Coordinated Universal Time
WFIP	Wind Forecast Improvement Project

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1.0 Introduction

The U.S. Department of Energy (DOE), in collaboration with the National Oceanic and Atmospheric Administration (NOAA), recently completed the installation of three new wind profiling radars on the Washington and Oregon coasts. These systems operate at a frequency of 449 MHz and provide mean wind profiles to a height of roughly 8 km, with the maximum measurement height depending on time-varying atmospheric conditions. This is roughly half the depth of the troposphere at these latitudes. Each system is also equipped with a radio acoustic sounding system (RASS), which provides a measure of the temperature profile to heights of approximately 2 km (depending on atmospheric conditions).

The motivation for establishing these systems arises from the increasing fraction of U.S. electrical energy supplied by wind. Figure 1 shows the rapid growth in installed wind energy capacity in the United States over the last decade. As of the end of 2014, the U.S. wind power capacity exceeded 65 GW, which represents approximately 5% of overall electrical energy capacity from all sources. Over the last eight years, approximately 33% of all new electrical capacity in the U.S. has been from wind (Figure 2).

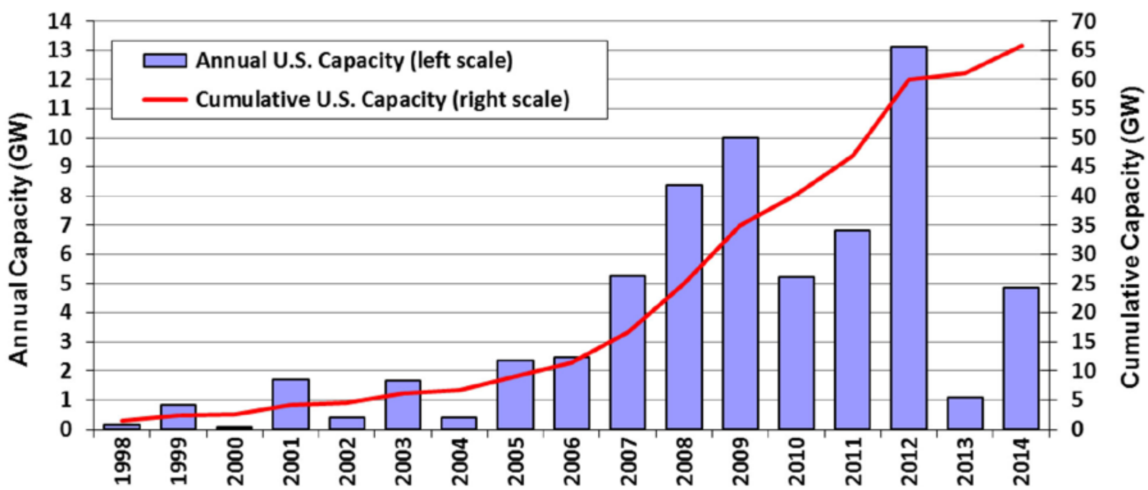

Figure 1. U.S. Wind Power Capacity Growth since 1998 (from DOE 2015)

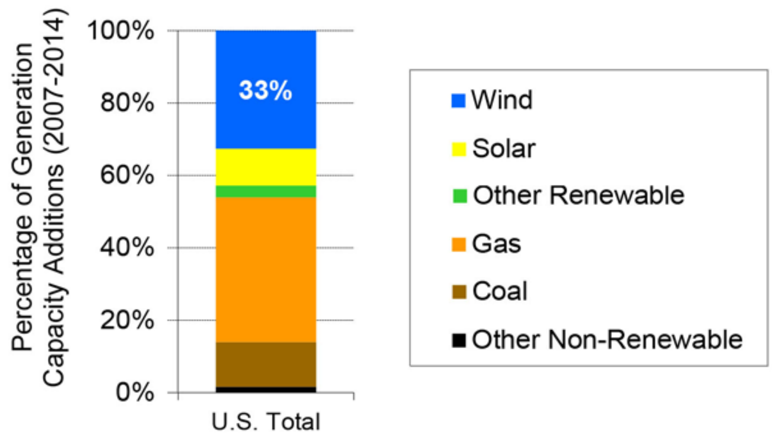

Figure 2. U.S. Power Generation Capacity Additions from 2007 to 2014 (adapted from DOE 2015)

Wind is a variable energy resource. As its proportional contribution to overall electrical power grows, it becomes increasingly important to accurately forecast wind power production in order to maintain stability in the electrical grid and keep power costs low. In turn, forecast accuracy depends substantially on data to provide accurate initialization of numerical weather forecast models. Currently, routine observations of winds and temperatures above the surface are provided primarily by sparsely distributed (in both space and time) radiosonde systems in many regions. Previous research (Benjamin et al. 2010) has demonstrated that assimilation of wind profiling radar observations into numerical weather prediction (NWP) models improves the accuracy of wind forecasts in the troposphere. DOE's recently completed Wind Forecast Improvement Project (WFIP; Wilczak et al. 2015) showed that a clear benefit to hub-height forecast accuracy is derived from providing additional model initialization data, especially above the surface. The greatest benefit is expected to be from additional data provided to the west of areas of forecast interest, because weather systems generally progress from west to east.

The three DOE profilers will complement four identical profilers that are being installed by NOAA along the California coast on behalf of the California Department of Water resources (White et al. 2013). Spaced approximately 250 km apart, the profilers together provide a "picket fence" of wind profiles that are expected to significantly improve wind forecasts from the National Weather Service's (NWS's) foundational forecast models. In addition, the data from the DOE profilers will provide valuable information to the second WFIP (WFIP 2) that will help improve the representation of physical processes in resource characterization models. The WFIP 2 field study will take place in the Columbia River Valley of Oregon and Washington during 2015–16.

This report describes the sites, equipment, and operation of the three DOE wind profilers. It also describes the data produced, its dissemination, and a summary of data collected through the end of October 2015.

2.0 Installations

The objective of the coastal radar wind profiler deployments described here is to more accurately characterize the inflow boundary conditions for numerical weather forecast models by measuring the profiles of wind speed and wind direction along the west coast of the United States. Because most large-scale systems in this area propagate from the west to the east, the expectation is that these data will not only result in wind forecast improvements in the west, but also in the next-day forecasts in the central United States.

This project began in Fiscal Year (FY) 2014, and involved several major tasks to move from concept to collecting field data. These tasks, generally, were

- equipment procurements
- equipment assembly and testing
- site selection
- site environmental reviews
- site access and infrastructure preparations
- equipment deployment
- data collection and dissemination.

The following subsections describe the equipment at each site and the three deployment sites themselves, along with some background about the site selection, environmental reviews, and site preparation.

2.1 Equipment

To characterize the atmosphere and to provide sufficient input for model boundary conditions, each wind profiler site consists of a number of pieces of equipment. The equipment deployed for this project is identical to the deployments in California, so that equipment maintenance, as well as data output and processing, are streamlined. The central instrument in the equipment suite is a quarter-scale (449 MHz) radar wind profiler with a RASS (Figure 3). Additional information concerning the selection of the coaxial-colinear, phased-array 449 MHz radar, and a comparison of its characteristics with those of the 915 MHz radar can be found in a NOAA wind profiler technology report (NOAA/ESRL 2007). The radar wind profiler measures the wind speed and direction from 180 m above the ground surface up to 8 km above the surface, depending on atmospheric conditions. Radars operate by emitting a radio signal into the atmosphere at vertical and two slightly off-vertical directions and detecting the backscatter from the atmosphere. The motion of the atmosphere results in a Doppler shift to the backscattered radio signal, and these frequency shifts from the three beams are then used to resolve the wind speed and direction. The vertical resolution for these profilers is 100 m in the lowest part of the profile (up to 5 km), and 200 m in the upper part of the profile. The radar occupies a footprint of approximately 8 m x 8 m, and the antenna elements are mounted on a back plane that is approximately 1 m above the ground surface.

NOAA engineers assembled and tested the radars at the Boulder Atmospheric Observatory in Erie, Colorado, before deploying them. Each system was operated for several weeks to ensure the components performed as expected, the data acquisition system functioned well, and any unexpected errors could be resolved. When testing was complete, each radar system was disassembled and loaded onto a flatbed trailer for transport to the deployment location. NOAA possesses an experimental license for the 449 MHz frequency from the National Telecommunications and Information Administration (NTIA). If there are no conflicting military users, the NOAA license from the NTIA allows NOAA to operate these radars at any location in the United States without a site-specific communications license.

Each radar was installed with a RASS, which emits an audible acoustic signal (similar to white noise) to obtain virtual temperature measurements in a profile up to about 2 km. The RASS operates by emitting an acoustic signal that interacts with the radio waves generated by the profiler. Bragg scattering occurs, which results in a Doppler shift in the radar signal according to the speed of the sound. By measuring the speed of sound from the return signal, and using the dependence of the speed of sound on virtual temperature (which includes some effects of humidity), the virtual temperature profile is obtained. The RASS drums are approximately 1.5 m in diameter and four drums are installed around the radar.

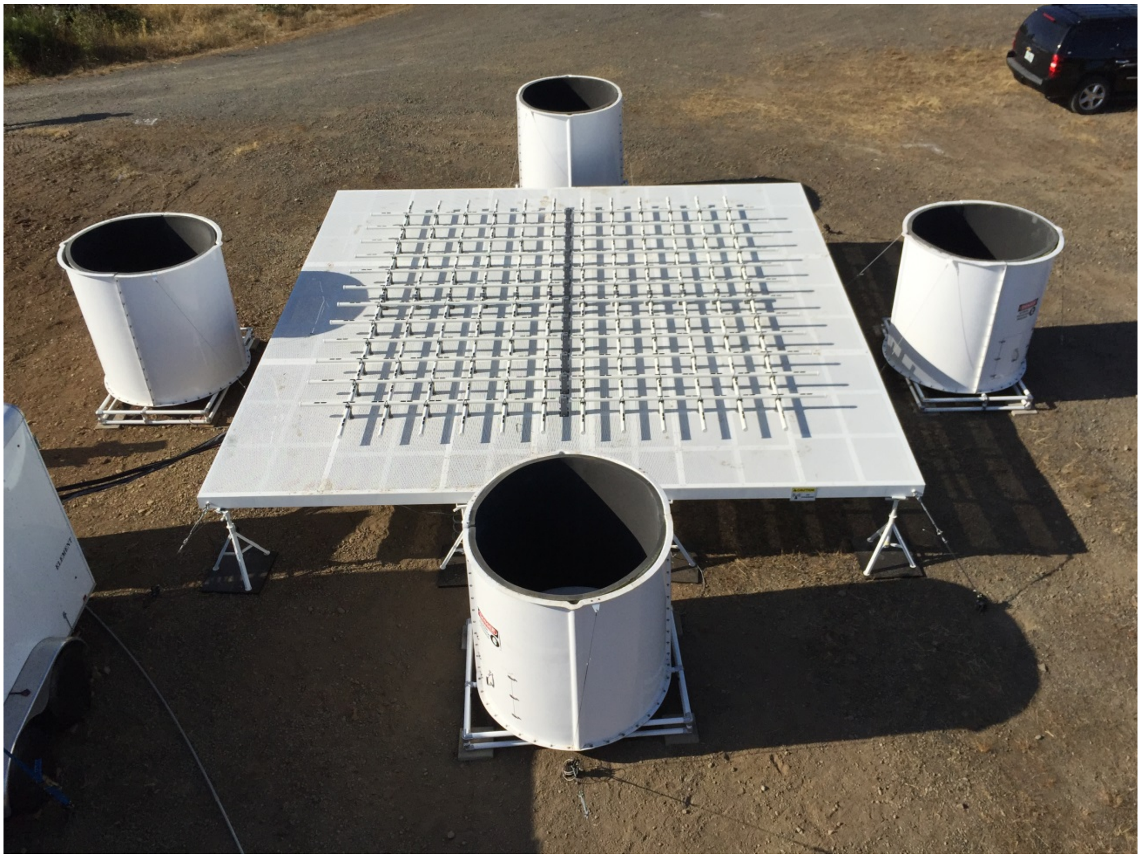

Figure 3. Radar with RASS at Forks, Washington

A 10 m tall open lattice meteorological tower, which supports a propeller-and-vane anemometer (Figure 4) for a single point wind speed and wind direction measurement, was also deployed at each site. Because the lowest range gate for the wind profiler is in excess of 100 m, the meteorological tower provides the surface meteorological conditions. In addition to measuring winds, solar radiation is measured at the top of the tower. Finally, pressure, temperature, and relative humidity sensors are mounted on the tower at 2 m.

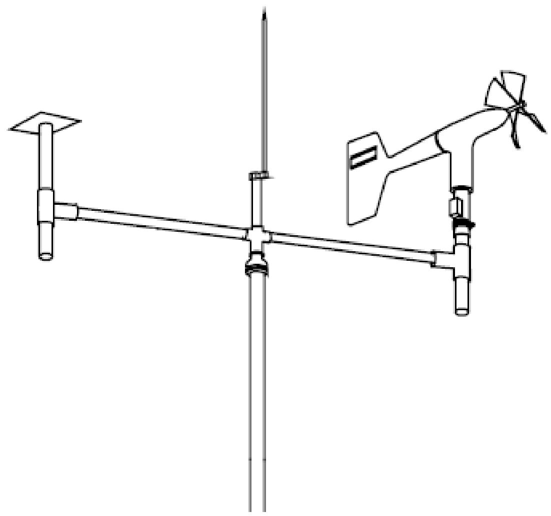

Figure 4. Radiometer Platform and Propeller-and-Vane Anemometer Mounting

Two additional stand-alone instruments are deployed alongside the radar and meteorological tower. First, a tipping-bucket precipitation sensor is mounted on a short stand near the radar. The tipping bucket rain gauge measures precipitation in increments of 0.01 in (0.25 mm) in a 6 in (15 cm) collector. Second, a Global Positioning System (GPS) antenna is mounted on a short tripod. The GPS antenna is connected to a GPS receiver in the equipment shelter, which measures the column-integrated water vapor by integrating the water delay in the microwave signal to various satellites (Bevis et al. 1992).

The final component at the radar site is an equipment shelter to contain the computer and electronics for the radar and supporting instruments. For this project, a trailer was used for this purpose. Figure 5 shows the installation at the Forks, Washington, site with the main equipment elements identified. The equipment at this site fits within a fenced area of approximately 15 m x 24 m.

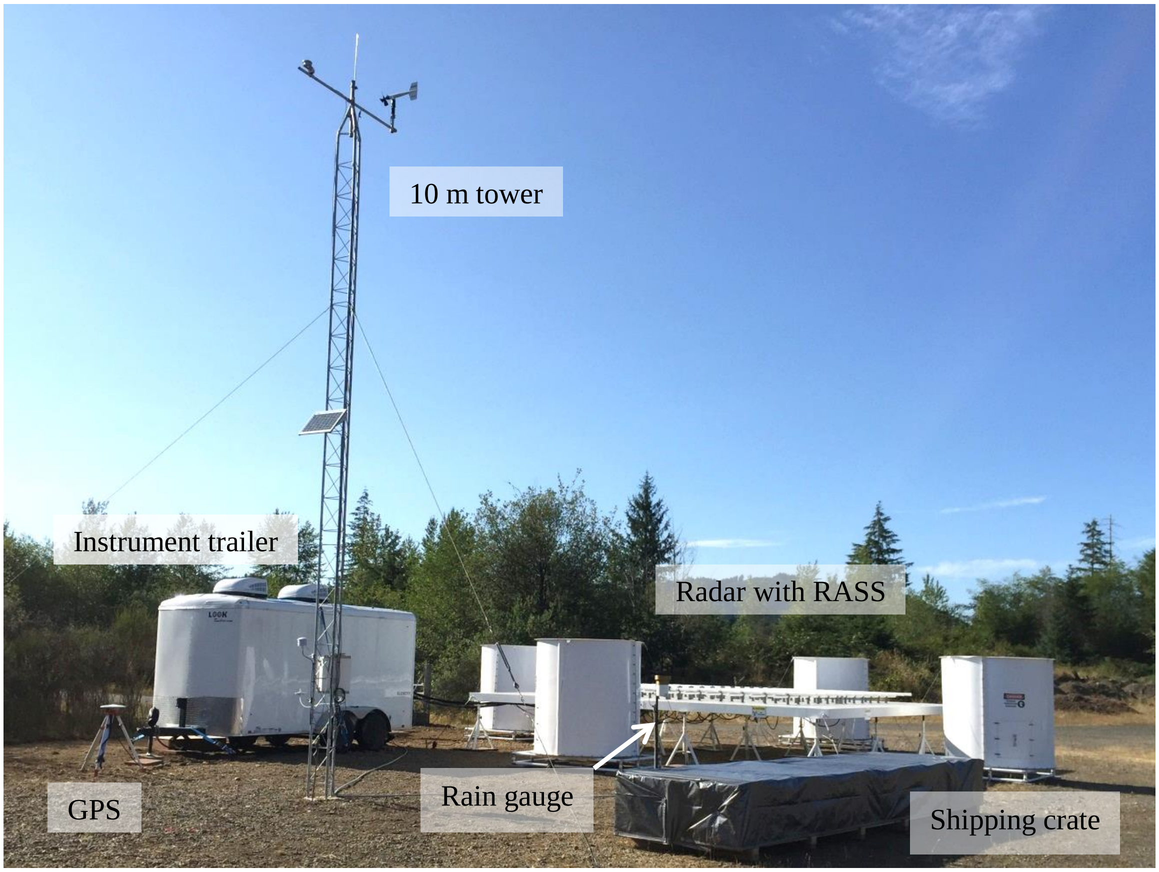

Figure 5. Radar Installation Equipment at Forks Industrial Park

2.2 Sites

As stated previously, the three coastal wind profiler sites supported under this project extend the network of identical radars deployed along the coast of California to develop a "picket fence" of wind profile measurements along the entirety of the U.S. West Coast. Each site is separated from others by approximately 250 km, from Santa Barbara, California, in the south, to Forks, Washington, in the north (Figure 6). The site selection process started by first identifying candidate areas at approximately 250 km intervals from the northernmost California site in McKinleyville. The basic criteria for the sites were that they be near the coast (within 20 km); relatively flat, open areas (trees or buildings sufficiently distant in at least two directions, for a clean radar "view"); near sea level (so the full profile starts at a reasonably low elevation, rather than starting on a mountain-top, for example); and have reasonable access to power. In addition, with the inclusion of a RASS, locations where the sound emitted from the RASS would be minimally disruptive to neighbors were considered. In general, for ease of both instrument siting and lease agreements, sites at airports or municipal sites (such as wastewater treatment plants) were explored first.

Within each area, two sites were identified for site visits. During site visits, with the assistance of representatives from the site, specific locations for radar installation were selected. The optimal radar view at each location was determined, photographs were taken, and potential sources of power were identified. The sites selected for the radar deployments were in Forks, Washington; near Astoria, Oregon; and in North Bend, Oregon. The coordinates of the radars at each site are listed in Table 1.

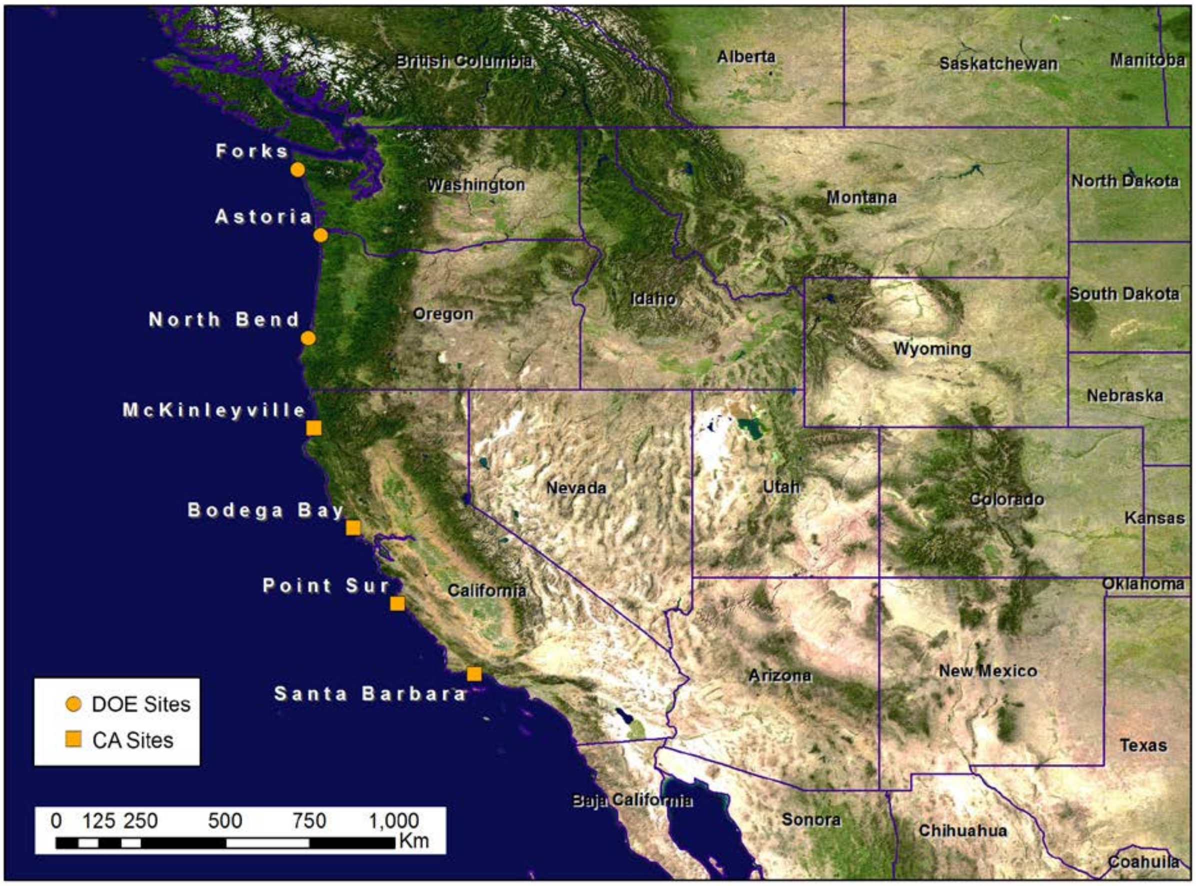

Figure 6. Radar Wind Profiler Sites Along the U.S. West Coast.

Table 1. New DOE Coastal Radar Coordinates

Site	Latitude	Longitude	Elevation Above Sea Level
Forks, WA	47° 58' 28.32" N	124° 23' 52.93" W	95 m
Astoria, OR	46° 09' 24.44" N	123° 52' 58.55" W	3 m
North Bend, OR	43° 25' 10.70" N	124° 14' 37.37" W	3 m

In southern Oregon, a site at the Southwest Oregon Regional Airport (OTH) in North Bend was selected (Figure 7). This area is dotted with several modestly sized communities, and land use in this area varies from urban to agricultural (dairy farms and cranberry bogs) and forest. A notable terrain feature in this area is the Oregon Dunes National Recreational Area, the largest coastal sand dunes in the United

States, which is indicated by the long (~60 km) strip of green, north of Coos Bay and west of Highway 101 in Figure 7.

Figure 8 shows the location of the radar site on the airport property, as well as the layout of the radar, RASS, antenna crate, and trailer at the OTH. This site is about 3 m above sea level, very flat, and covered with short grass. It is surrounded on three sides by water: Coos Bay to the west and north, and Pony Slough to the east. This airport was created by the military in the 1930s by filling in a portion of the bay.

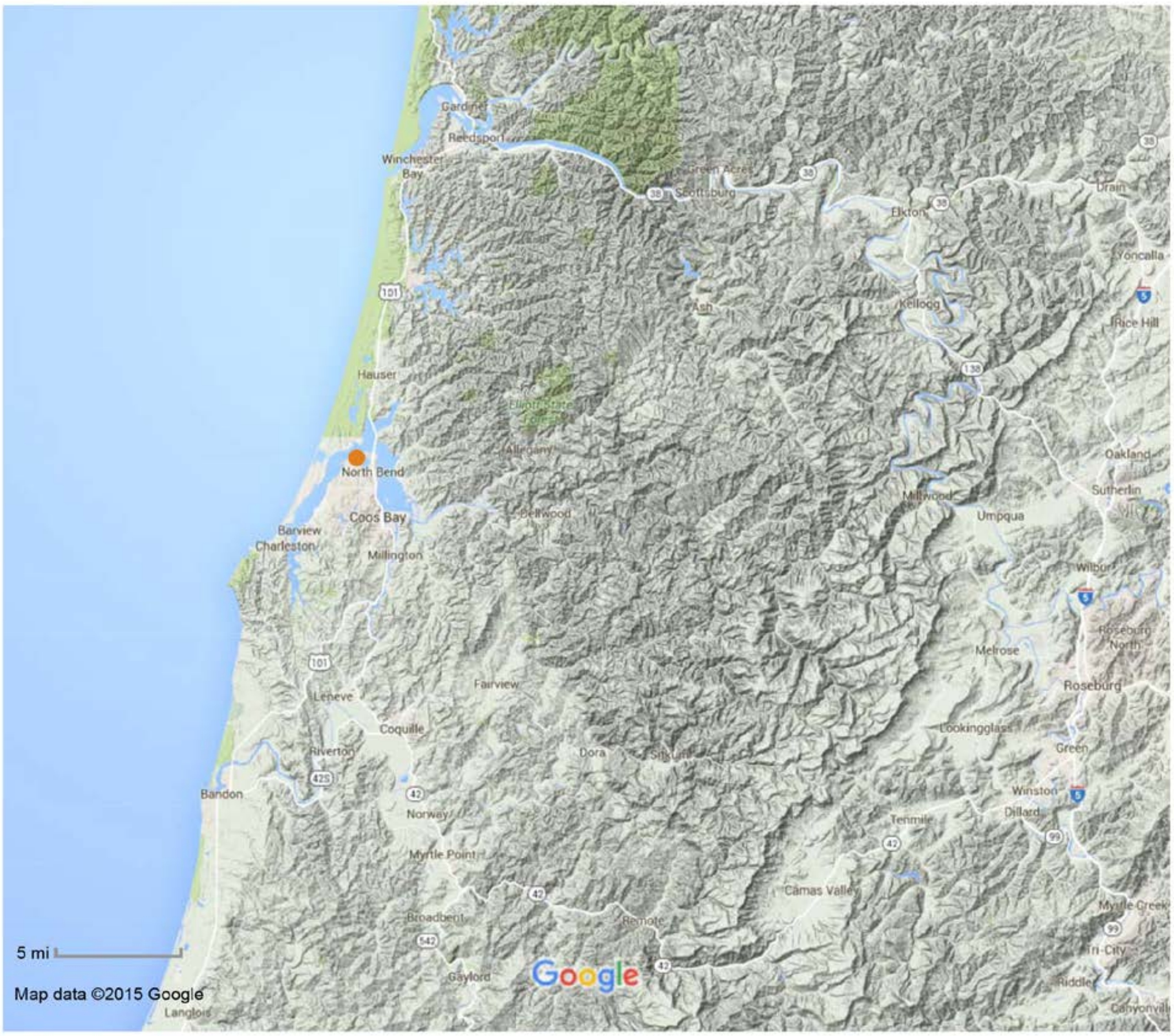

Figure 7. Overview Map of the Radar Wind Profiler Deployment at Southwest Oregon Regional Airport. The orange dot represents the location of the radar.

Figure 8. Radar Wind Profiler Deployment Location and Layout at the Southwest Oregon Regional Airport

The specific location on the airport property was initially on the northeastern tip of the airport, but that site was not approved by the Federal Aviation Administration (FAA). At airport locations, the FAA requires a 7460 Form to inform the FAA about the project and the height of any planned equipment. As a result of this 7460 Form submission, we learned that the Federal Aviation Regulation Part 77 Primary Surface extends 500 ft (150 m) from the runway centerline at this airport; no equipment of any height is permitted here. As a result, the site was re-located to the position shown in Figure 8. The power at this location is owned by the FAA, and exists there to support the Automated Surface Observing System (ASOS), which is the cluster of equipment in the greener grassy patch in Figure 8. For this radar deployment, a new power line was established upstream of the FAA transformer (the rectangular object on the west side of the ASOS cluster in Figure 8), and a new step-down transformer was installed. Permission to use the power was granted by the FAA, and the project established an agreement to compensate the FAA for the anticipated power usage.

Note that a GPS antenna/receiver is not installed at this location. A GPS antenna/receiver was installed previously at the Southwest Oregon Community College, approximately 2.8 km south of the radar site. As a result, the data from Southwest Oregon Community College will be used for column-integrated water vapor for this location.

In northern Oregon, the Astoria Regional Airport (AST), in Warrenton, Oregon, was chosen for our radar site (Figure 9). Warrenton and its neighboring city of Astoria are located in the northwestern tip of the state of Oregon. This airport is located at the mouth of the Columbia River, which separates Oregon from Washington. The northern part of the Oregon Coast Range is in this area; its tallest peak, Saddle Mountain, east of Seaside, rises to 1000 m.

Figure 10 shows the location of the radar site on the Astoria airport property as well as the equipment layout. This site is about 3 m above sea level, very flat, and covered in grass and asphalt. The grass is mowed a few times during the growing season, but can grow as tall as hip-high. The meteorological tower is located in a grassy area, between the Automated Weather Observing System (AWOS) and wind sock, while the radar, RASS, and trailer are located on a pre-existing asphalt pad. As noted above, Astoria is near the outlet of the Columbia River, and the airport itself has water bodies on two sides: Youngs Bay to the north and Lewis and Clark River to the east.

Power at the Astoria site required a new electrical line that started at the airport café, on the other side of the airport apron. A new transformer, meter, and underground routing were needed. The airport had empty conduit under the apron, which we used for this project, thereby avoiding significant trenching. An account with the local utility was established to pay for electrical consumption based on the newly installed electric meter.

The Washington site required a few iterations to identify and select the Forks Industrial Park, located 1 mile north of downtown Forks, Washington. As shown in Figure 11, the northern coast of Washington has few coastal communities, and few options for siting radar equipment on developed land. Although the Quillayute Airport is very near the community of Forks, it is a small, rural airport with little activity, and nearby residences were likely to be disturbed by the hourly sound of the RASS. This, as well an anticipated challenge in routing power for the radar equipment, prompted a search for alternative locations. After considering and visiting several other sites, the Industrial Park was identified as the site with the best radar view, access, and willing site owners. Forks is located on the Olympic Peninsula, which is bounded on the west by the Pacific Ocean, on the north by the Strait of Juan de Fuca, and on the east by Hood Canal. This is an area with temperate rain forests in the west and significant terrain features, including the Olympic Mountains centered on the peninsula. The tallest peak in the Olympic Mountains is Mount Olympus; it has an elevation of 2430 m.

Figure 12 shows the general location of the radar site on the property of the Forks Industrial Park as well as the equipment layout. The Forks Industrial Park site is located in the northeastern corner of the park in an area that is infrequently used. The ground elevation here is about 95 m above sea level. The ground surface is rocky soil and short grass, and there are blackberry bushes and scotch broom next to the site as well as taller trees in the distance. Prior to its development as an industrial park, this site was used for commercial forestry. Currently, the largest occupant in the industrial park is a non-operating lumber mill.

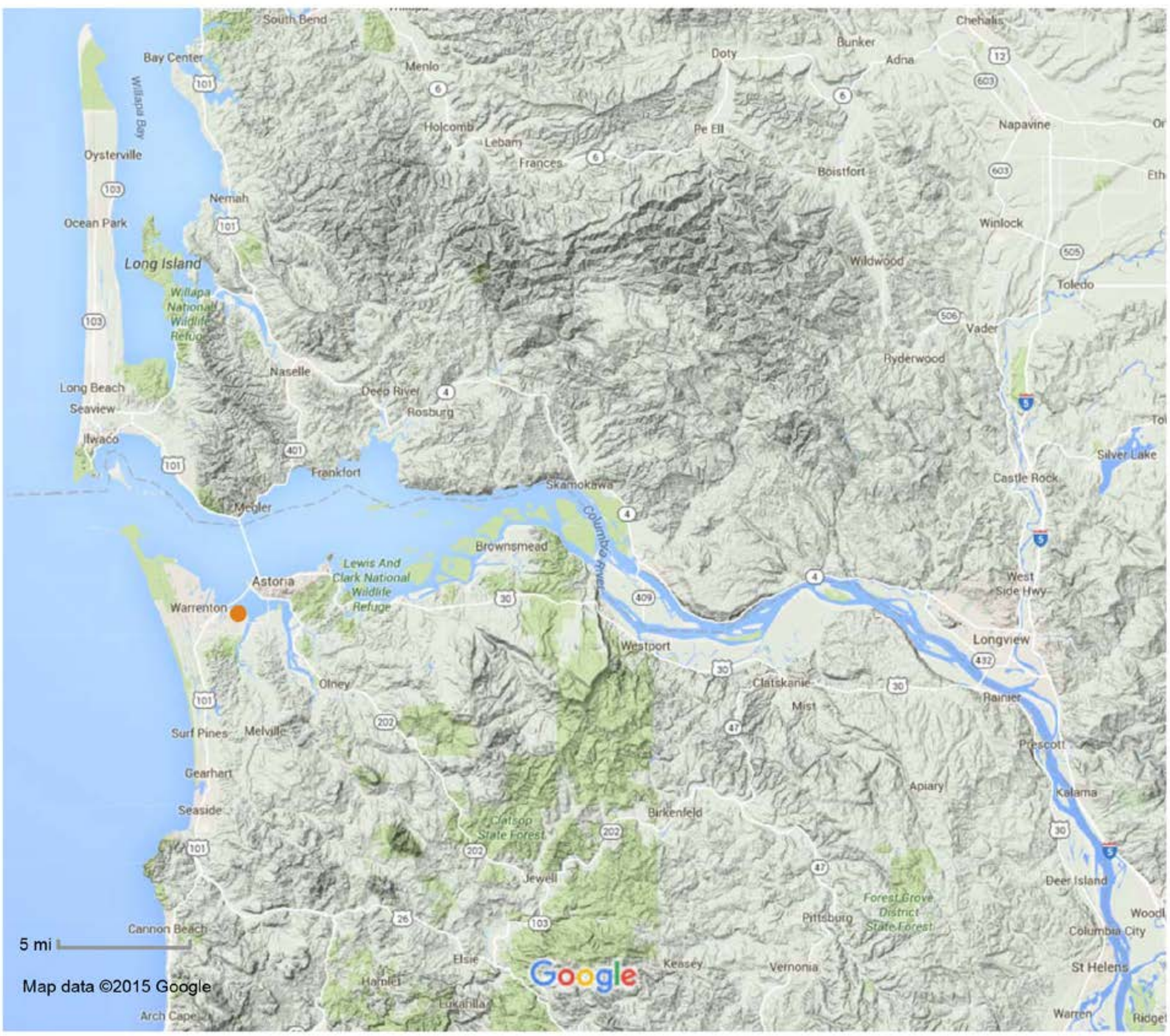

Figure 9. Overview Map of the Radar Wind Profiler Deployment at Astoria Regional Airport. The orange dot represents the location of the radar.

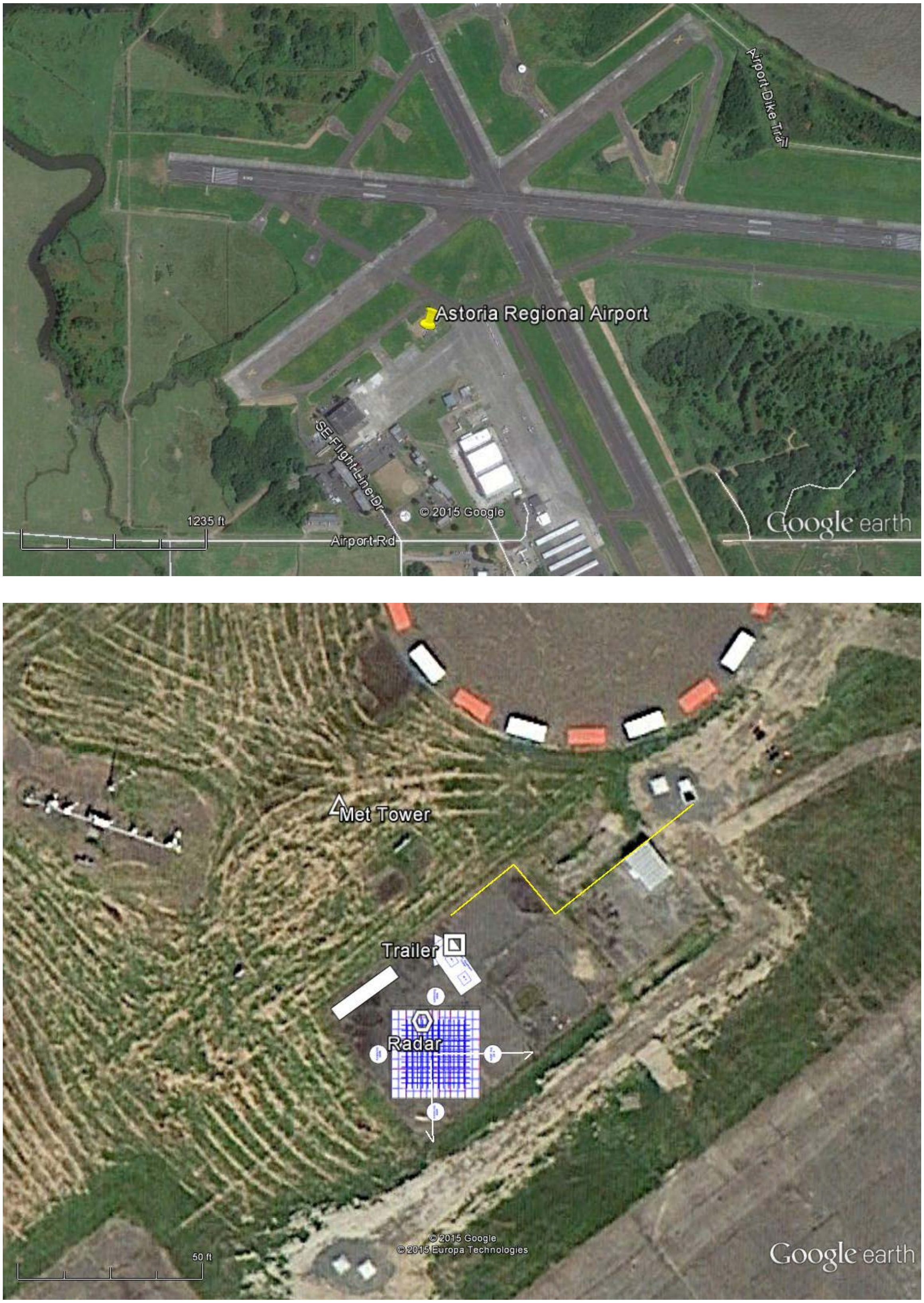

Figure 10. Radar Wind Profiler Deployment Location and Layout at Astoria Regional Airport

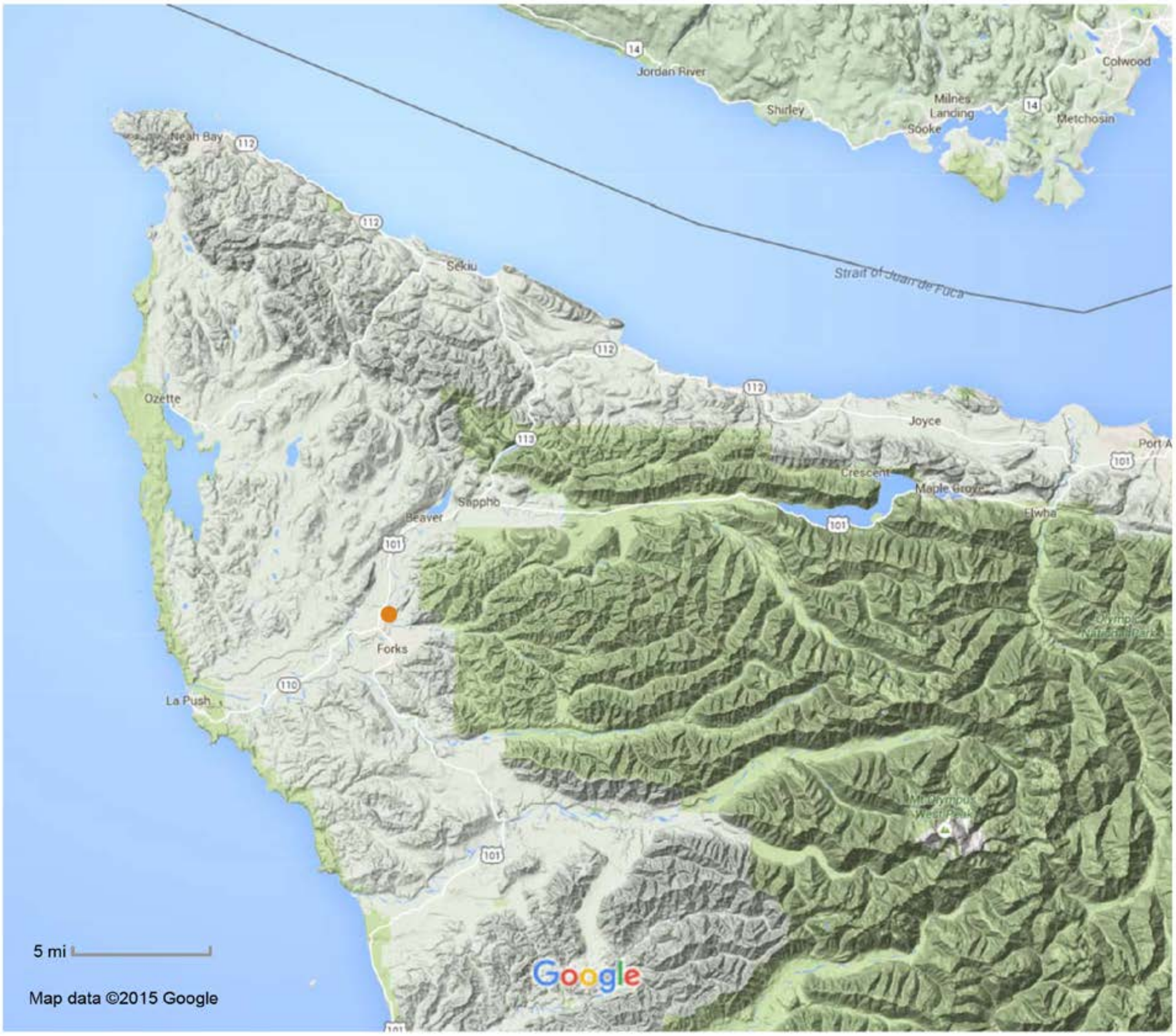

Figure 11. Overview Map of the Radar Wind Profiler Deployment at Forks Industrial Park. The orange dot represents the location of the radar.

Figure 12. Radar Wind Profiler Deployment Location and Layout at Forks Industrial Park

Since this is a federally funded project, a National Environmental Policy Act (NEPA) review was required for these sites. This involved a literature search on the history of soil disturbances at each location, a review of the migratory bird nesting tendencies for each location, as well as site visits by both a biologist and archaeologist. The biologist surveyed the site to establish whether protected species were occupying the site, while the archaeologist observed ground-disturbing activities (such as trenching or post-hole digging) to evaluate the soil contents for any cultural resources (artifacts). Although the likelihood of bird strikes on the meteorological tower guy wires is remote, bird diverters are installed at each site to further reduce the probability of bird strikes. During quarterly site maintenance visits, the area will also be surveyed for nests or bird carcasses. To minimize ground disturbances, all equipment at these sites were secured with auger-type anchors that may be removed with the equipment. A cultural resources report and biological resources report has been submitted to DOE to complete the NEPA process.

Although there is considerable fill dirt at the Southwest Oregon Regional Airport, the Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians (CTCLUSI) requested notice of ground-disturbing activities. As a result, both our archaeologist and a representative from the CTCLUSI were on-site during trenching activities. No items of cultural significance were found, but the native soil was shallower than anticipated. No threatened or endangered birds were observed at this site.

At Astoria Regional Airport, an archaeologist was on-hand during trenching activities, and no items of cultural significance were found. The streaked horned lark, a federally threatened bird species, is known to nest in maintained grassy airport areas. Although surveys in 2013 found no nesting larks, confirmation of the absence of the birds for this nesting season was required. A biologist surveyed the area three times during the nesting season and found no streaked horned larks. However, numerous savannah sparrows were found; they are not a threatened or endangered species, but are separately protected by the Federal Migratory Bird Treaty Act. For this and all sites, project staff and contractors were reminded that it is unlawful to disturb a migratory bird nest, and the radar installation activities did not encounter any nests.

At the Forks Industrial Park, an archaeologist was on-hand during trenching and fence-post–hole digging activities, and no items of cultural significance were found. No threatened or endangered birds were observed at this site.

3.0 Data

The following subsections describe the data collected at the three radar sites in Washington and Oregon, as well as the dissemination of these data for use by the community.

3.1 Operating Configuration

The radar operates in two modes: low and high. The low mode uses a 700 nanosecond pulse, 160 coherent integrations, 50 spectral averages, and 128 fast Fourier transform (FFT) points. There is a 50 microsecond interpulse period for this mode, so the dwell time for one beam is ~51.2 sec (processing time can be neglected with today's quad core processing computers). The high mode uses a 2800 nanosecond pulse, 40 coherent integrations, 50 spectral averages, and 128 FFT points. There is a 200 microsecond interpulse period for this mode, so the dwell time for one beam is also ~51.2 sec. The high mode is oversampled to provide the 200 m gate spacing. The maximum unambiguous velocity that can be determined (in the radial direction) for both modes is 20.9 m/s.

Winds are collected for approximately the first 56 minutes of the hour and RASS is collected during the last 4 minutes. Given the dwell times, 11 samples are available for each beam for wind processing during the hourly consensus averaging period. For the RASS, there is only one beam and the sampling is faster, so 16 RASS beams are available for consensus during the short amount of time for data collection by the RASS.

Clutter, or unwanted return signals from objects, rather than the clear air atmosphere, is a common interference in radar signal processing. For example, migratory birds have been observed in the radar signal at each of the three radar locations. Clutter removal algorithms are implemented to remove stationary (trees, buildings, etc.) and moving (trees, birds, etc.) forms of clutter. These algorithms are rather complex, and uses different strategies based on the type of clutter. These techniques include multiple peak picking algorithms, time-height continuity testing, and wavelet filtering, among others. Radio frequency interference (RFI) removal is also accomplished with some of the same techniques used for clutter removal.

On the 10 m towers, temperature, relative humidity, and barometric pressure are measured at 2 m above ground level, and wind speed, wind direction, and solar radiation are measured at 10 m above ground level. The raw signals from the instruments are processed into 2 min averages in the data logger before they are telemetered back to the data hub.

3.2 Data Archive and Access

Data from each site are transmitted hourly via cellular modem to an FTP server at NOAA Earth System Research Laboratory (ESRL) and are ingested into NOAA's weather forecast models. Data are currently available from the NOAA ESRL Data Display site (http://www.esrl.noaa.gov/psd/data/obs/datadisplay/, Figure 13). From this site, selecting "449 MHz Wind Profiler" from the "Instrument Categories" section and "Department of Energy" from the "Project" section allows users to filter the data to the coastal radars from the map or site list.

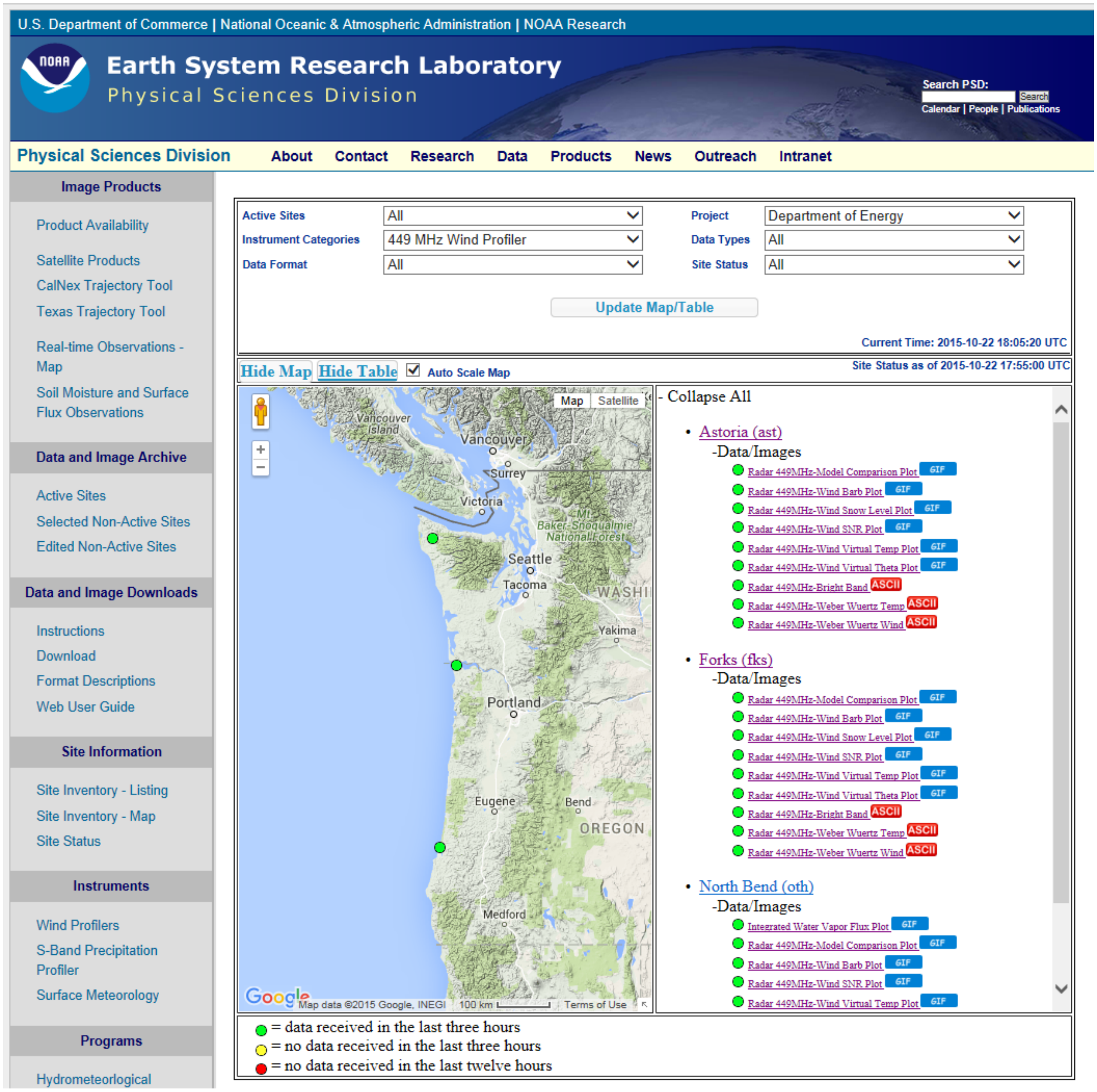

Figure 13. NOAA ESRL Data Site

The Forks, Washington, radar site was the first to be installed, and data transmission started on July 23, 2015. The second radar site installed was in Astoria, Oregon, and data transmission from this site started on September 4, 2015. At the final site in North Bend, Oregon, the radar was installed in early October, and data transmission started on October 15, 2015 (Figure 14). Data availability is typically calculated annually, so the statistics at these sites have not yet been assessed. However, as an example, the data availability from Bodega Bay this year is around 98% on a real-time basis (which included communication errors), and more data are available when considering only data outages (which included a power outage).

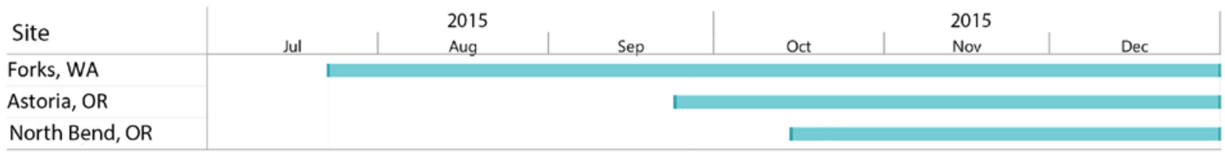

Figure 14. Chart of Operational Periods (Current and Anticipated) at Each Radar Wind Profiler Site during the Second Half of 2015.

Most of the data from these sites are transmitted in real time. The hourly winds, temperature, snow level, and radar moments from the wind profiler and RASS are available in real time. In addition, 30 min raw and processed integrated water vapor files from the GPS, and 2 min averaged surface meteorology (wind speed, wind direction, temperature, pressure, relative humidity) are available in real time. In the interest of preserving the basic radar data, and for the purposes of additional analysis, the radar spectra are saved on the local computer in the trailer at each site. During quarterly maintenance visits to the site, the spectra data will be manually downloaded to a hard drive and uploaded to the NOAA FTP server upon return to NOAA. Real-time data are also delivered to the Meteorological Assimilation Data Ingest System(MADIS). MADIS makes the profiler data available to the National Centers for Environmental Prediction (NCEP) and the Environmental Modeling Center (EMC), so that the data may be used in NOAA forecast models such as the GFS, NAM, RAP, and HRRR models.

In the very near future, these data will also be available on the A2e DAP (https://a2e.pnnl.gov/, Figure 15). This site is a repository for all data sets collected with the support of the Wind Program of DOE's Office of Energy Efficiency and Renewable Energy (EERE).

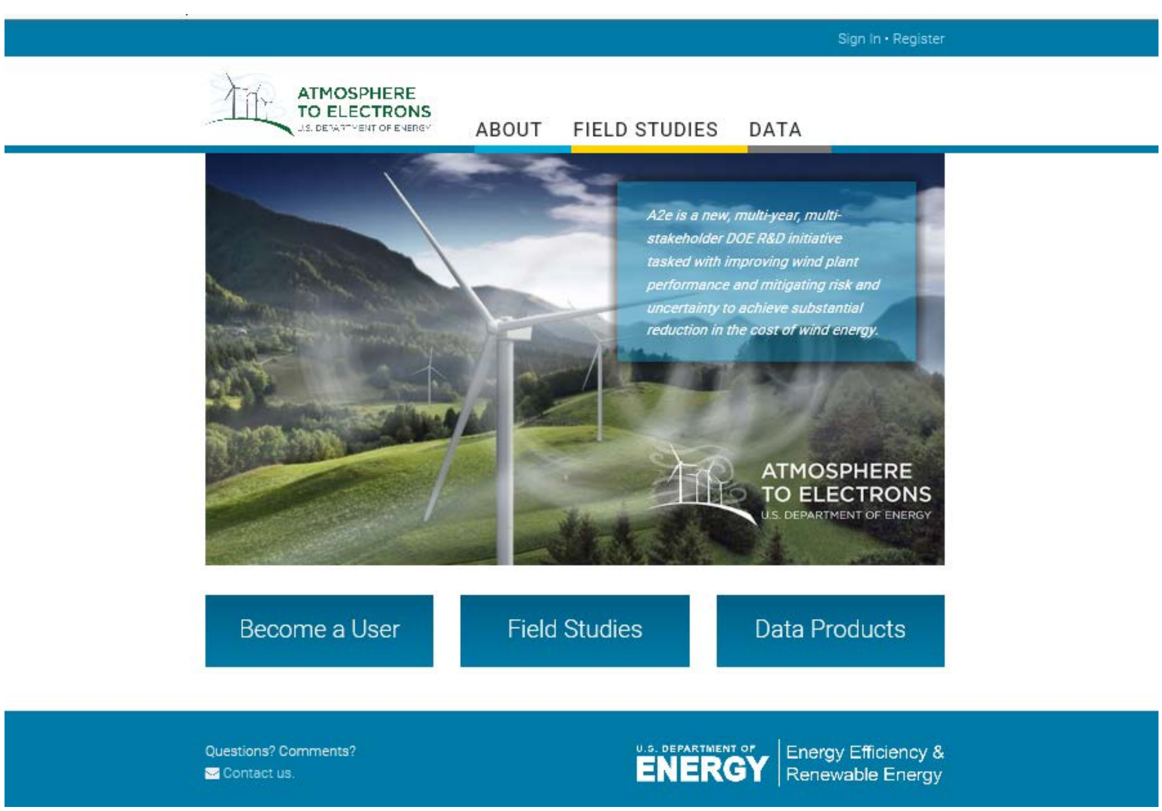

Figure 15. The DOE A2e Data Site

Figure 16 through Figure 24 are examples of data plots available from the NOAA ESRL Data Display site. These figures show data from all three sites from October 24 through 26, 2015. Note that the convention for wind profiler plots places the earliest time on the right side of the x-axes; later time is on the left side. Because meteorological features tend to come from west to east, this axis convention allows fronts to be easily identified and features to be “frozen” in time. The plots are shown in Coordinated Universal Time (UTC), which is 8 hours ahead of Pacific Standard Time (PST; e.g.,16 UTC is 08 PST). In addition, note that the ranges of the y-axes for the surface meteorological data plots are not matched across the three sites; the range is adjusted for the data in each plot.

Figure 16, Figure 19, and Figure 22 show the surface winds, which shifted direction at all three sites at around 20 UTC on October 24. An offshore low pressure system moved onshore over the time period shown in these figures, which is shown as steadily decreasing pressure at all three sites. Further, all three sites observed some precipitation starting early on the 25th.

Figure 17, Figure 20, and Figure 23 show the time-height cross section of wind speed and direction from the radar wind profilers. All three sites observed high winds at lower levels, although the Oregon sites observed particularly high winds over a most of the radar measurement depth during this period. Figure 18, Figure 21, and Figure 24 show the virtual temperature at these sites in color with an overlay of the wind barbs. These plots show the lowest 2 km of the profile, which makes it easier to distinguish some of the details of the vertical structure. For example, at Astoria, during the late hours on October 24, the winds aloft were out of the north, while near-surface winds varied from northwesterly to northeasterly. However, it appears that during the early part of October 25, mixing toward the surface occurred as virtual temperatures dropped slightly and wind shifted to a more northerly direction for several hours. At North Bend there was a fairly consistent period of northerly winds during most of October 25 near the surface (and aloft), and at 17 UTC there was a distinct wind direction shift in the lowest km of the profile.

The instrument suites deployed at these three coastal sites provide observations at high temporal and vertical spatial resolution for characterizing the inflow for the western region of the United States. The data now available at these three sites will provide improved model initialization for weather forecast models, which is, in turn, expected to result in improved hub height wind forecasts.

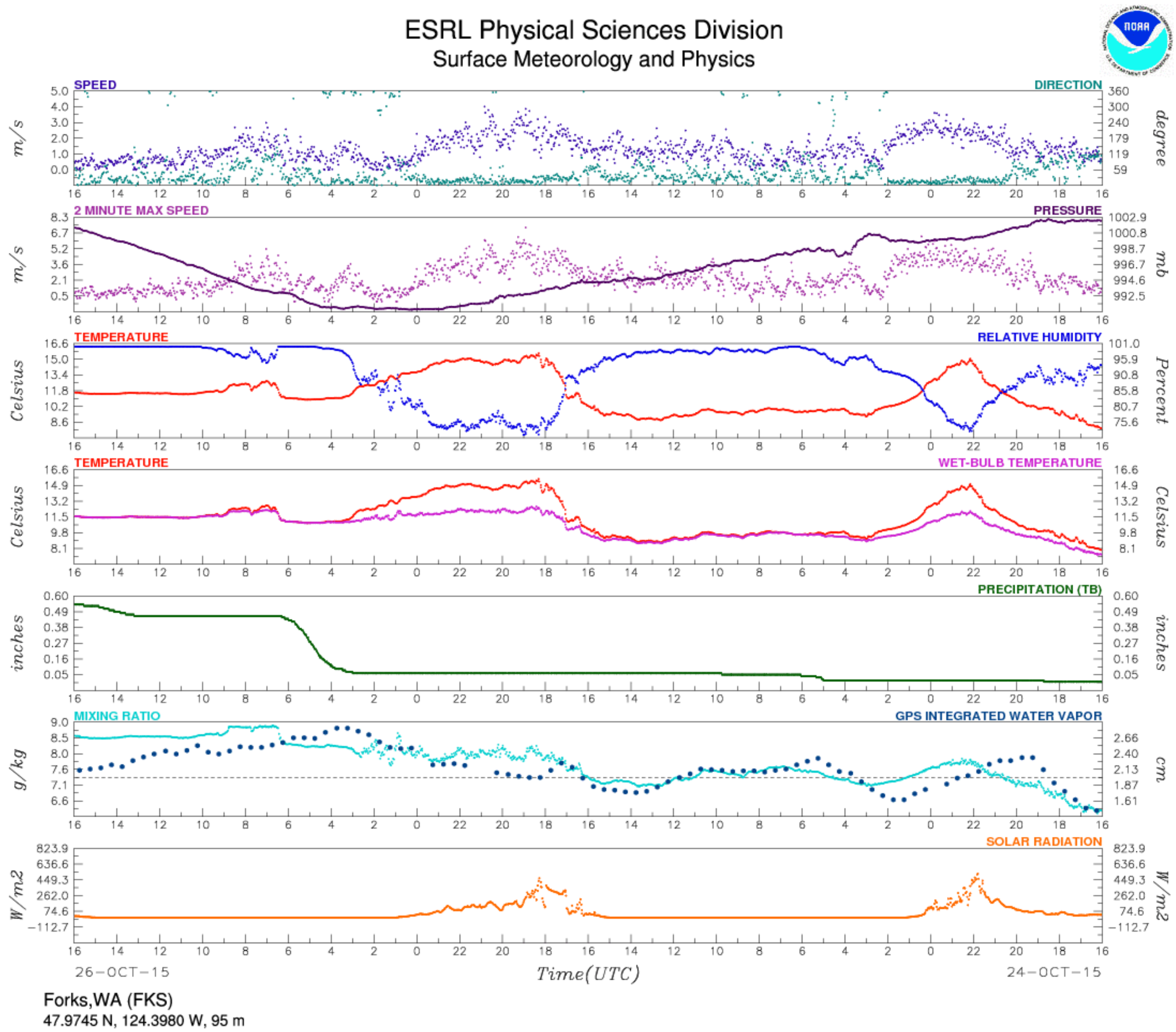

Figure 16. Sample Surface Meteorological Data from Forks, Washington.

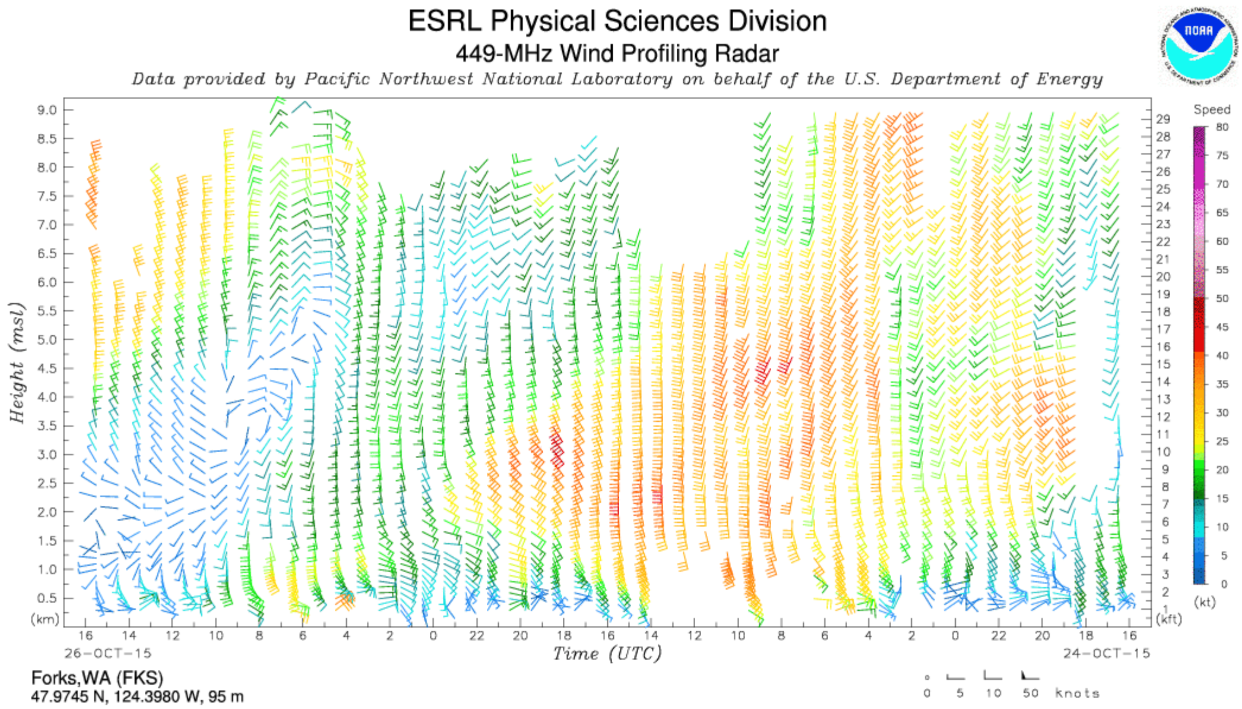

Figure 17. Sample Radar Wind Profiler Winds from Forks, Washington.

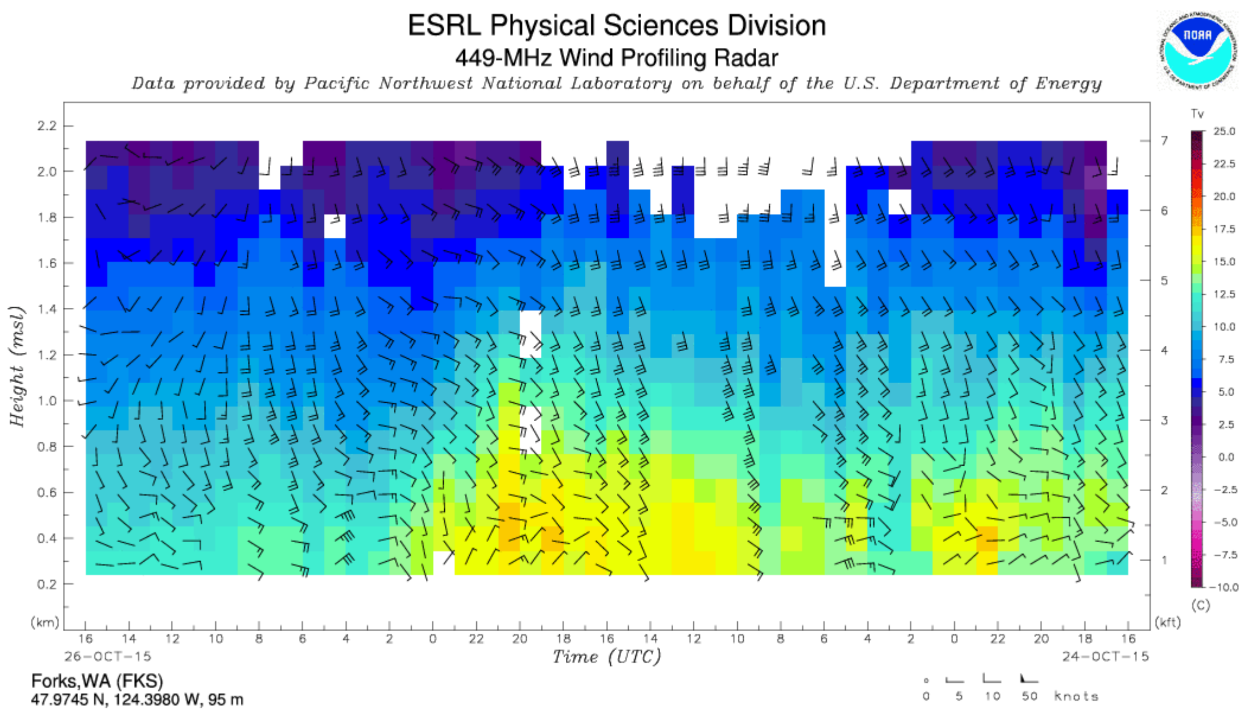

Figure 18. Sample RASS Temperatures from Forks, Washington.

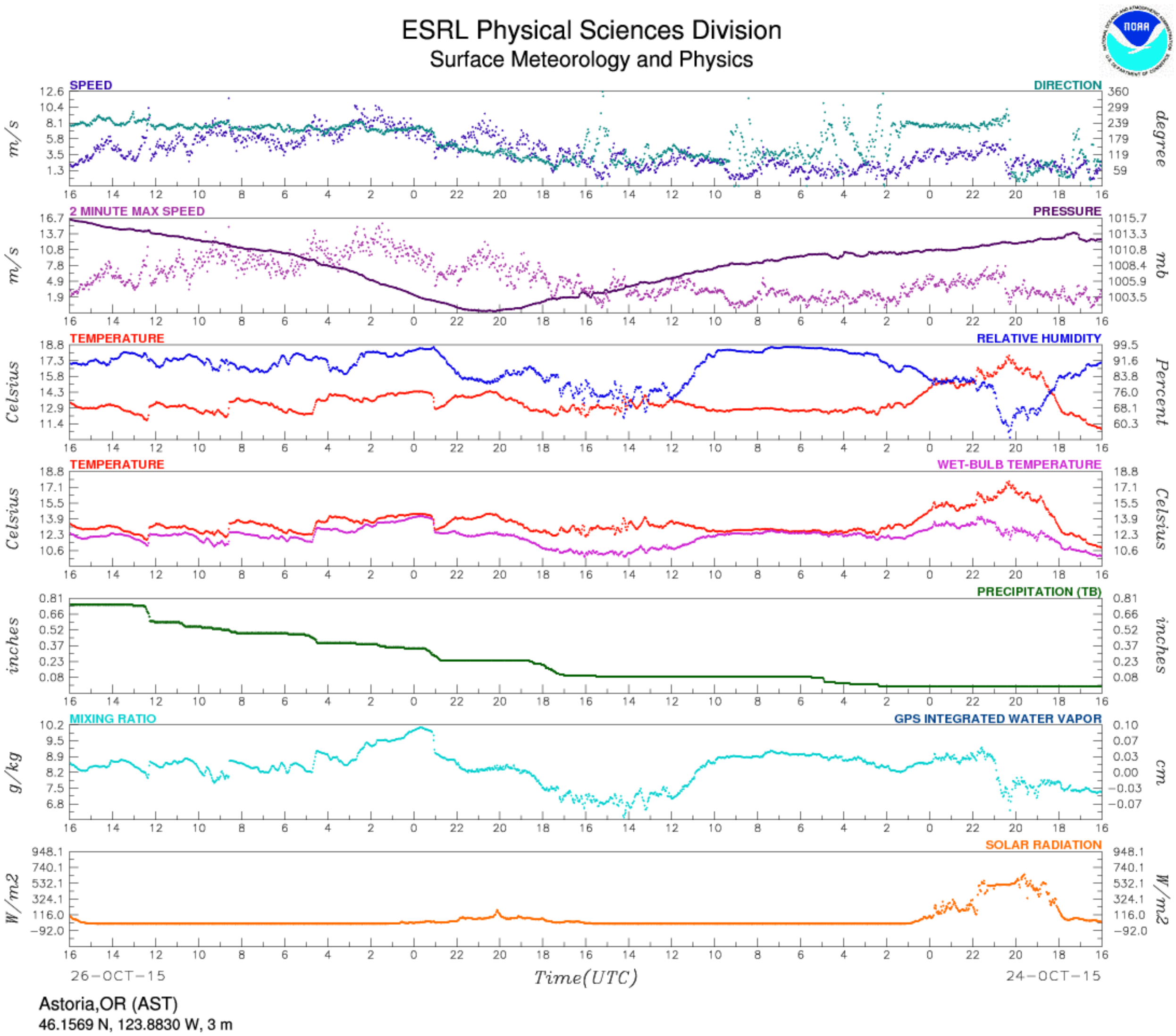

Figure 19. Sample Surface Meteorological Data from Astoria, Oregon.

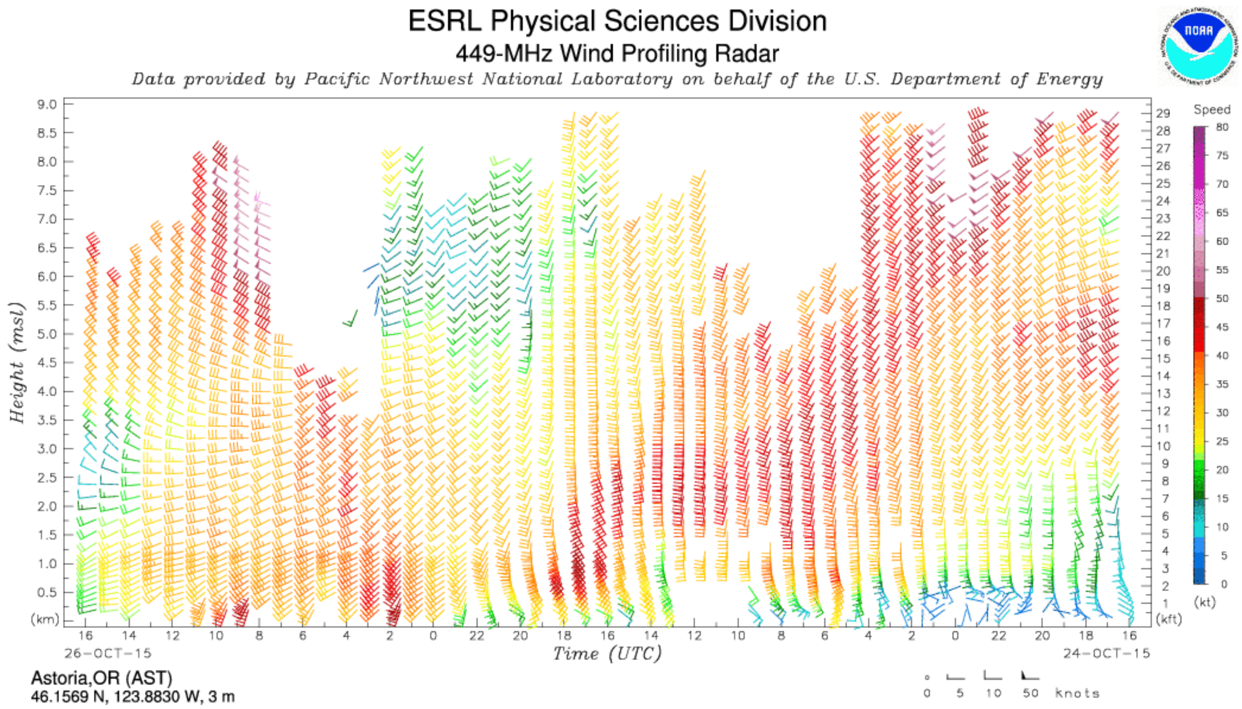

Figure 20. Sample Radar Wind Profiler Winds from Astoria, Oregon.

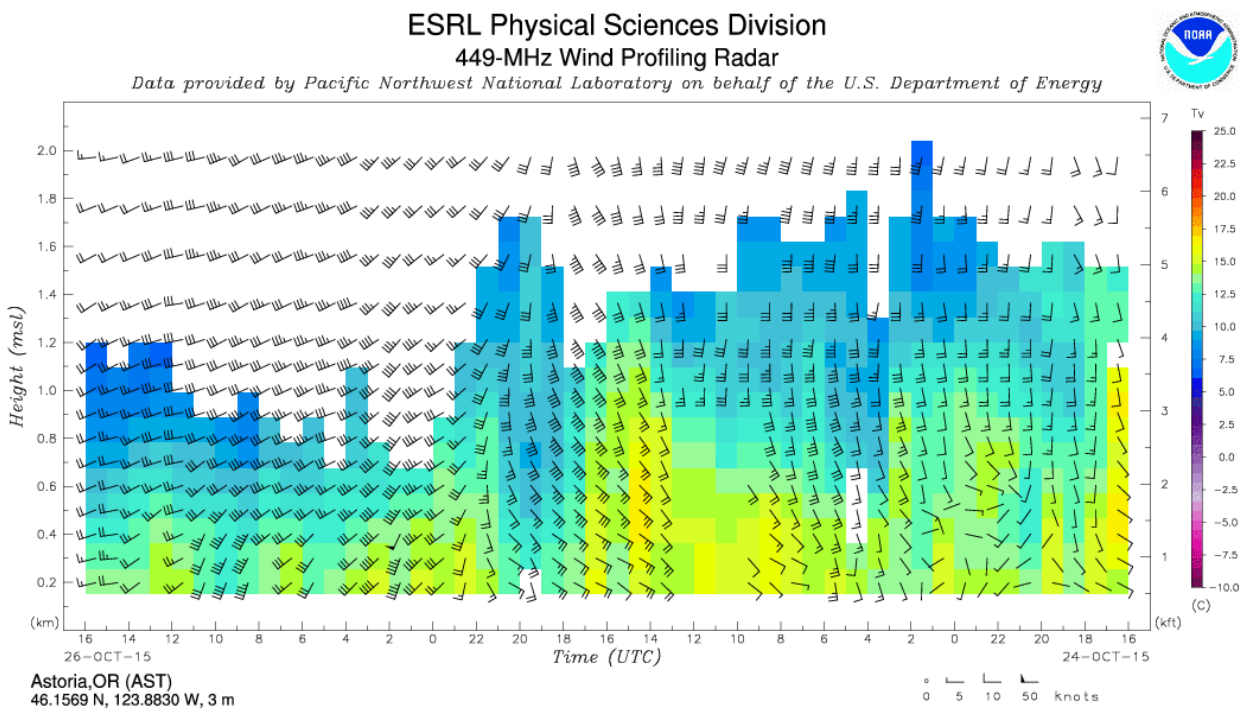

Figure 21. Sample RASS Temperatures from Astoria, Oregon.

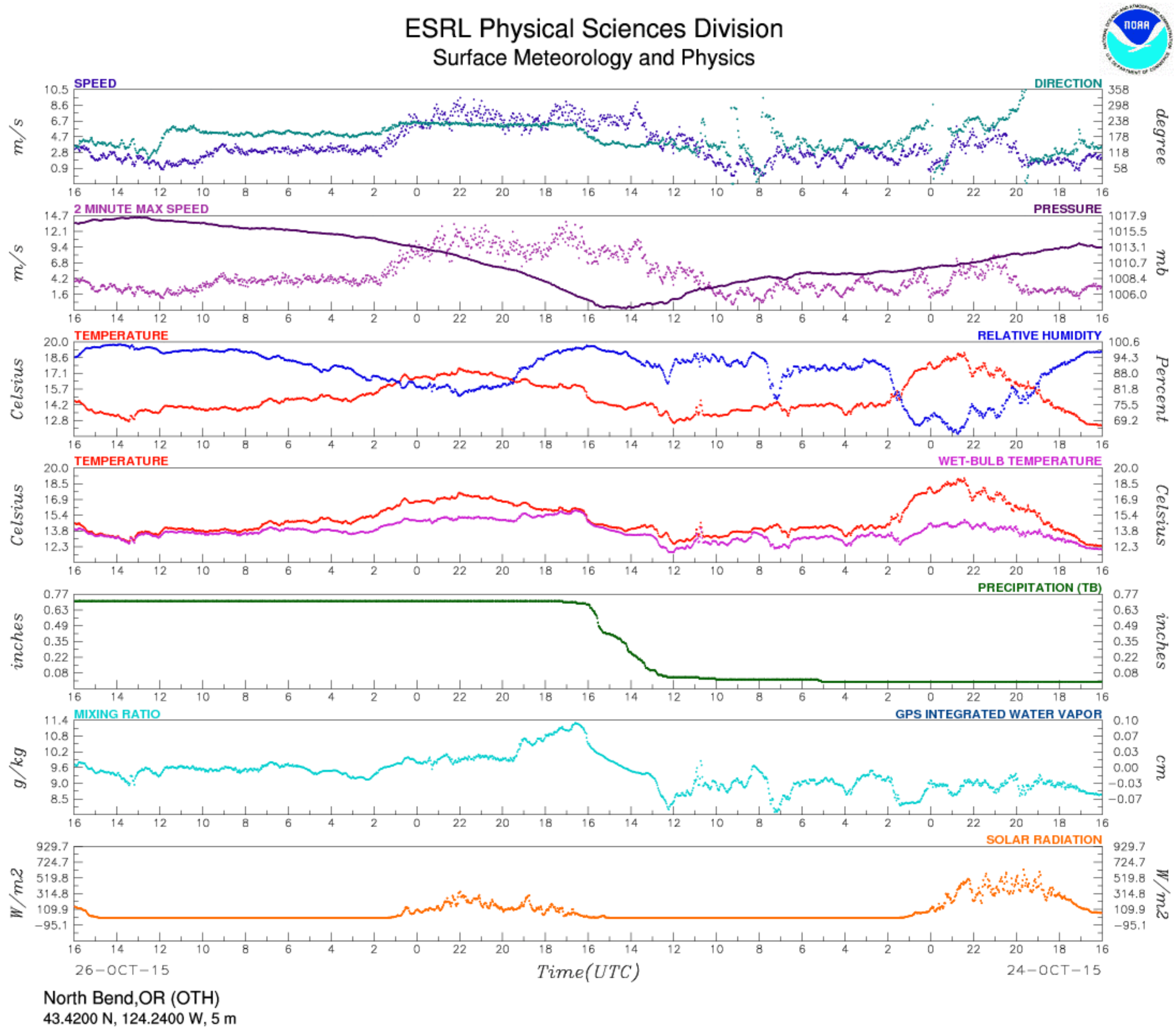

Figure 22. Sample Surface Meteorological Data from North Bend, Oregon.

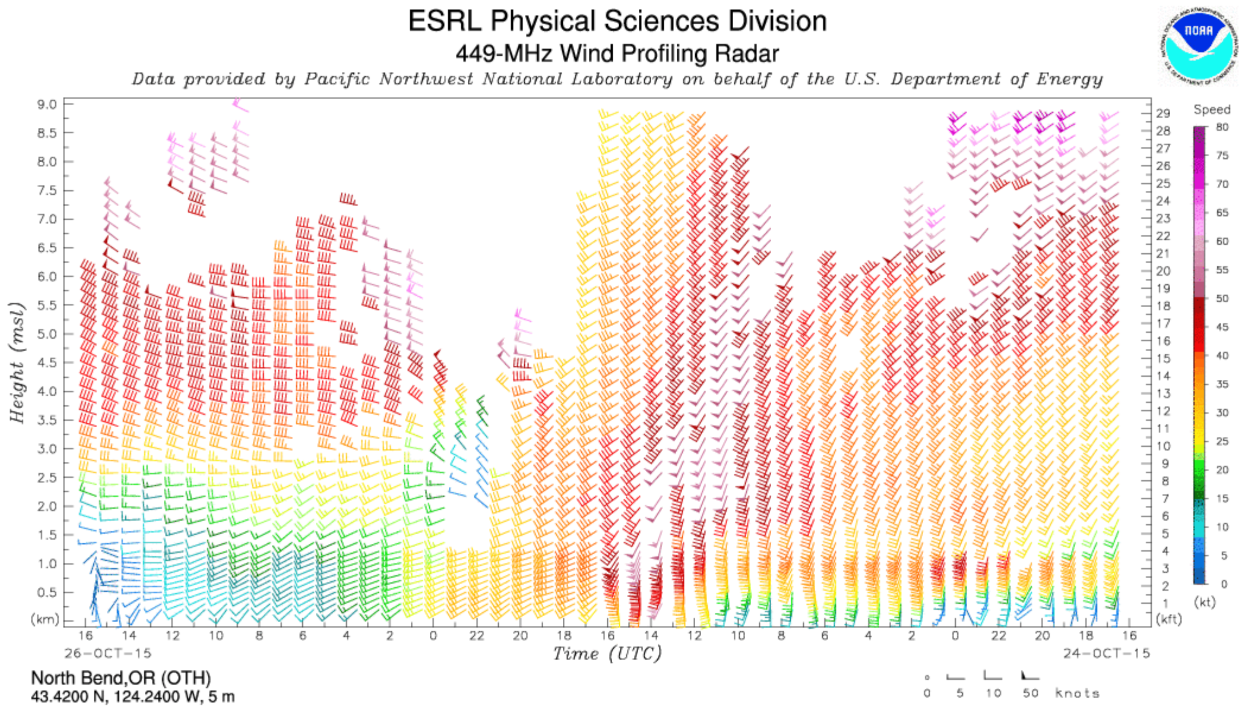

Figure 23. Sample Radar Wind Profiler Winds from North Bend, Oregon.

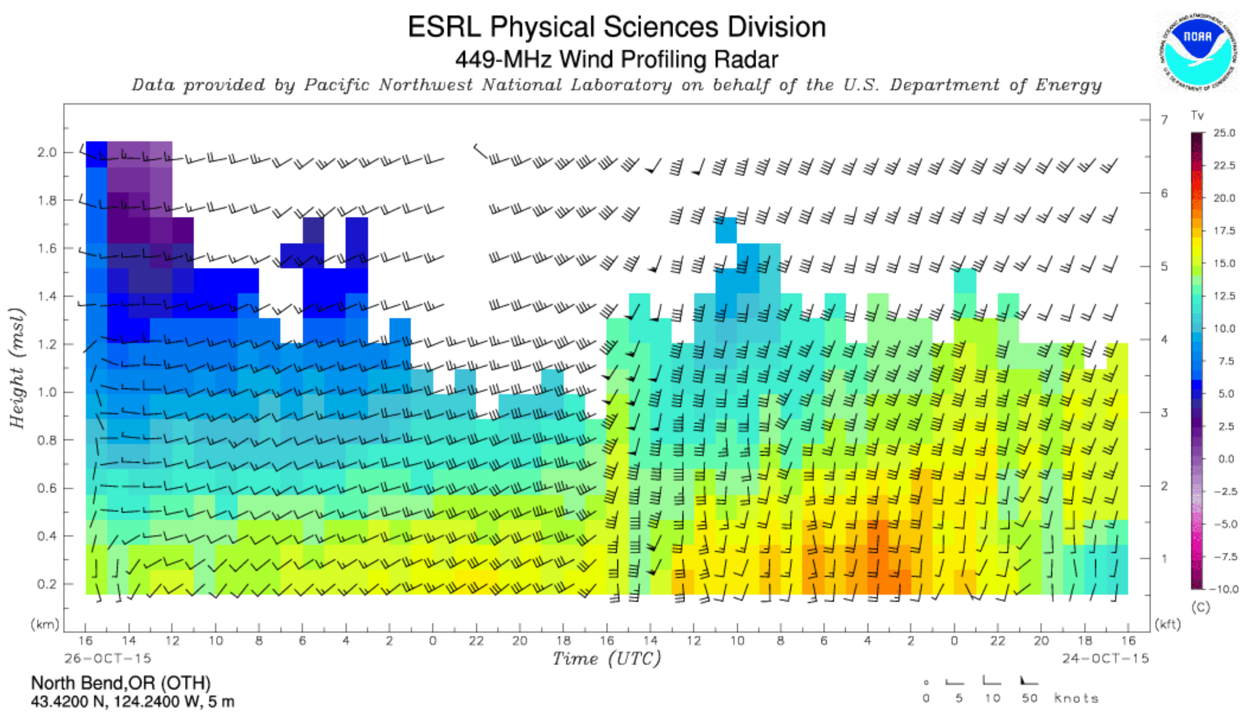

Figure 24. Sample RASS Temperatures from North Bend, Oregon.

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