EXAMINING PUBLICLY-AVAILABLE TALL-TOWER OBSERVATIONS

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1. INTRODUCTION

MesoWest (http://mesowest.utah.edu) is an ongoing collaborative project between the University of Utah, the National Weather Service (NWS), and numerous participating organizations that aims to provide access to both current and archived surface weather observations. As of June 2012, MesoWest has collected and archived data for over 34,000 unique surface stations, with 21,800 of those stations providing observations in real-time.

Of particular interest to the MesoWest project is the availability of tall-tower observations in the public domain. Recently, the Utah Office of Energy Development's Anemometer Loan Program has been transitioned over to Salt Lake Community College (SLCC) (Utah Office of Energy Development 2012). MesoWest has developed a partnership with SLCC to provide real-time access to numerous tall-tower stations across Utah. MesoWest is in the process of purchasing cell phone communications equipment that SLCC staff will outfit on up to fifteen 20-60 m tall towers. This process has already been completed for three of the expected fifteen stations.

MesoWest also received several inquiries regarding available tall-tower observations from other data providers. Two providers are the Bonneville Power Administration and the Oak Ridge National Laboratory. Both organizations display their data via web interfaces, and now provide data in real-time to MesoWest. Both networks have stations which report meteorological variables at multiple height levels.

In order to provide access to these observations, MesoWest staff needed to develop new software to retrieve, archive, and display the data. The previous methods of storing and displaying data needed to be modified from existing MesoWest infrastructure in order to handle the varying aspects of multi-level station data. This project discusses the methods used to create new storage and display products for tall-tower observations. Examples of initial "beta-test" products on the MesoWest web interface are displayed. Finally, as an application example, the new products are shown through a wind energy nowcasting concept, where they are utilized to identify and display potential wind ramp events.

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2. BACKGROUND INFORMATION

2.1. MesoWest

As mentioned in Section 1, MesoWest has been an ongoing project between the University of Utah and many contributors. These contributors include NWS Western Region Headquarters, the Salt Lake City Weather Forecast Office (WFO), and numerous other participating agencies, private firms, and universities (Horel et al. 2002). The primary goal of MesoWest is to promote storage for, access to, and use of surface weather observations across the United States (Lucke et al. 2012).

MesoWest first began as the Utah Mesonet in 1994, collecting observations from stations around Utah and distributing them to the local WFOs. In January 2000, the name was changed to MesoWest as collection of observations began to expand outwards over the western United States (Horel et al. 2002). Since then, the project has grown to cover the entire continental United States, Alaska, Hawaii, and portions of Canada and Mexico. MesoWest serves as a data aggregation location for many individual mesonets, where the data are collected, stored, displayed, and disseminated in common formats. All data in MesoWest are considered provisional and made available for public dissemination (Horel et al. 2002). Data transfer methods between MesoWest and the data provider vary between numerous pull and push approaches to access data in real-time.

Figure 1 displays the locations of over 21,800 stations that are currently providing real-time data to MesoWest. Blue stations are acquired directly from the organizations that maintain the stations, while red stations are acquired from an intermediate source (*i.e.*, not the group that maintains the stations but an entity that collects the data and serves as an access point for dissemination to others). For example, the

University of Washington disseminates Washington Department of Transportation Road weather Information System (RWIS) data to MesoWest. The green stations are those that MesoWest acquires from the Meteorological Automated Data Ingest System (MADIS), which also aggregates and disseminates data from numerous networks. As of June 2012, MesoWest acquires and disseminates data from over 120 different data providers.

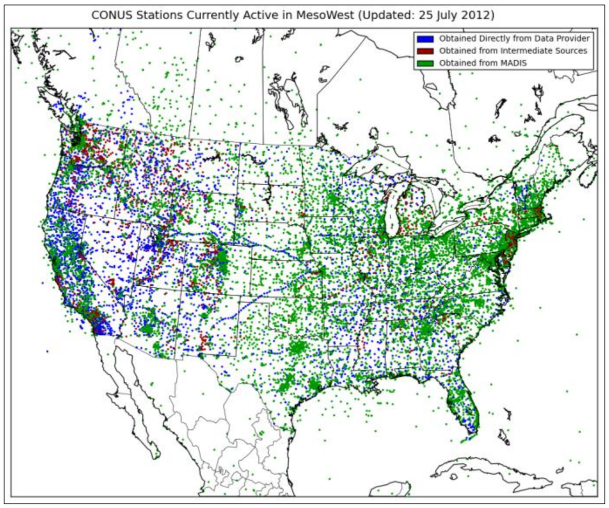

Figure 1. CONUS active MesoWest stations on 25 July 2012. Colors indicate the method of data acquisition: directly from the data provider (blue), from an intermediate source (red), or from MADIS (green).

Once data are collected, they are processed and archived in relational databases. These databases serve as the archive "backbone" for data and metadata in MesoWest. Software products are then used to access, display, and disseminate the data. Observations for stations that MesoWest aggregates (blue and red stations in Figure 1) are disseminated to MADIS every five minutes. These are subsequently included with other observational datasets for use by organizations such as the National Center for Environmental Prediction (NCEP) and local WFO offices. MesoWest data are also used extensively for research applications, such as the development of the University of Utah Two-Dimensional Variational Analysis (UU2DVAR) product and other research projects (Horel and Dong 2010; Tyndall et al. 2010; Tyndall and Horel 2012).

2.2. Tall Tower Data Providers

As mentioned in Section 1, several data providers expressed interest recently about providing tall-tower data to MesoWest. One of these providers is Bonneville Power Administration (BPA). BPA delivers power to regions within and surrounding the Columbia River Gorge in the Pacific Northwest (Bonneville Power Administration 2012a). Inclusive within BPA is a network of 20 meteorological towers, many which are placed within or adjacent to existing wind farms (Bonneville Power Administration 2012b). Four of the 20 towers are equipped with wind sensors at multiple height levels. Figure 2 displays the locations of the 20 active towers, with yellow and red markers denoting single-level and multi-level stations, respectively. These stations were added to MesoWest in December 2011 using a network name of Bonneville Power Administration Network (BPANET). Initially, data from only one wind sensor per station were acquired. Once a new storage structure for tall-tower data was completed, all observations for BPANET were acquired in real-time.

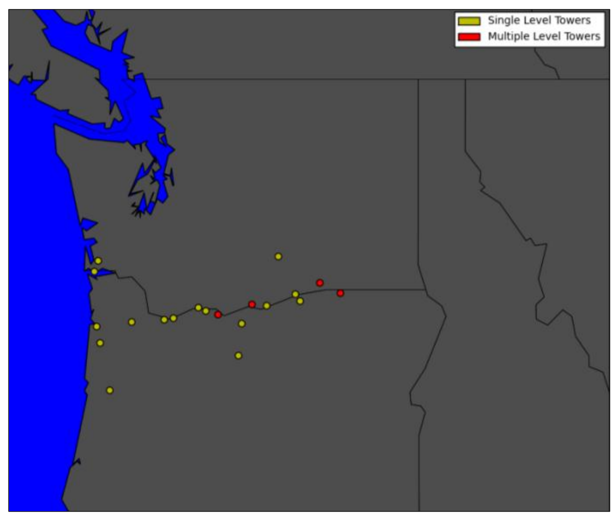

Figure 2. Tall-towers that comprise the Bonneville Power Administration (BPANET) network.

Also in late 2011, MesoWest and SLCC began a collaborative effort to establish real-time access to tall towers in Utah. The Utah Office of Energy Development was in the process of transferring management of the Anemometer Loan Program over to SLCC. MesoWest, in conjunction with SLCC, is currently purchasing communications equipment for up to fifteen of these towers. Installation of the equipment has been completed for three towers (Figure 3). The first is a 20 m tower located near the mouth of Blacksmith's Fork Canyon in Logan, UT. The second is a 50 m tower located near the southwest end of the Salt Lake Valley in Herriman, UT. Finally, the third is a 50 m tower located along Interstate 15 in the southwest corner of the state near Hurricane, UT. These towers comprise the Salt Lake Community College (SLCCNET) mesonet.

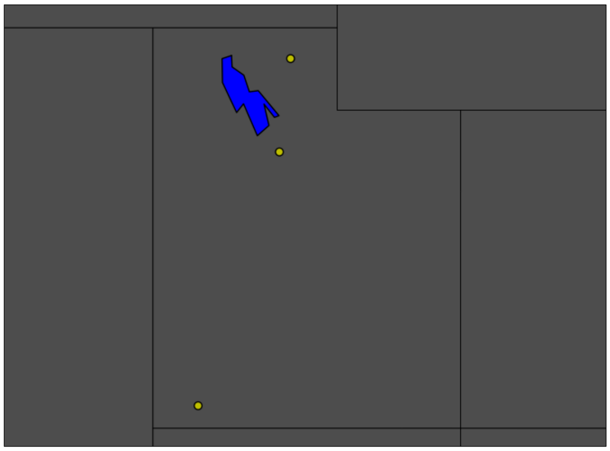

Figure 3. Tall-towers that comprise the Salt Lake Community College (SLCCNET) network.

A third provider is also transmitting tall-tower data to MesoWest. Procedures were established in April 2012 to ingest and archive data for the Oak Ridge National Laboratory Network (ORNL). The ORNL mesonet consists of 11 stations located on ORNL property in Tennessee, with many containing wind sensors at multiple height levels.

2.3. Wind Ramp Identification and Nowcasting

Providing access to tall-tower observations in MesoWest can support numerous meteorological applications. As an example, one such application is nowcasting for wind energy purposes. Wind energy continues to grow as a popular renewable energy resource across the continental United States, as evidenced by Figure 4 (U.S. Department of Energy 2012).

There are many unique challenges involved with nowcasting wind speed. In particular, nowcasting fluctuations within the critical boundaries of wind turbine operation is very challenging. Numerous studies (Zack 2007; Freedman et al. 2008; Greaves et al. 2009; Marquis et al. 2011; Deppe et al. 2012) have examined methods to better forecast these fluctuations within a turbine's power "ramp" region.

As a visual aid, two distinct wind ramp regions are shown in Figure 5 using a typical turbine power curve (Greaves et al. 2009). Note the increase in the turbine's power generation capacity (the "ramp-up" region) between wind speeds of roughly 6-12 m s^{-1}. Subsequently, note the sharp decrease above 24 m s^{-1}, where the wind becomes too strong and results in a turbine shut-down (the "ramp-down" region). Large changes in wind speed within these noted regions can have a drastic impact on energy production, and can lead to energy and profit losses if incorrectly predicted.

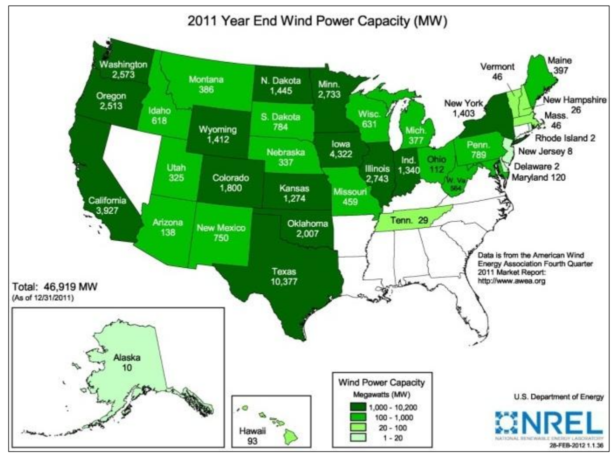

Figure 4. Year-end state wind capacity values (MW) for 2011 across the United States (U.S. Department of Energy 2012).

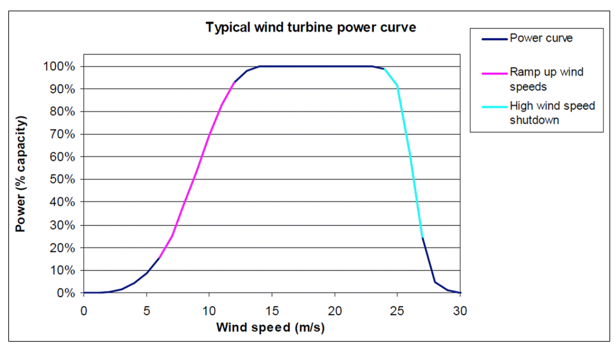

Figure 5. Graph of a typical wind speed to turbine power capacity relationship (Greaves et al. 2009).

A wind ramp event is defined as any event that results in >50% change in power capacity over a maximum period of 4 hours (Greaves et al. 2009). Using this definition, Deppe et al. (2012) translated the criteria into wind speed requirements using the power curve described in Figure 5. Wind ramp events were defined as a ±3 m s^{-1} change in wind speed while the wind speed was within 6-12 m s^{-1} during a portion of the event (Deppe et al. 2012). Events were classified as "ramp-up" or "ramp-down" based on whether power capacity was increasing or decreasing, respectively.

Wind ramp events can be produced by many physical processes. Freedman et al. (2008) highlighted several phenomena that can lead to ramp-up events including: frontal systems, dry lines, convection-induced gust fronts, and low level jets. Their study also identified ramp-down processes such as pressure gradient relaxation events. In the region operated by the BPANET network, terrain-induced flows also play a large role in wind ramp events. Thus, having a real-time source of observational data at levels closer to turbine hub height can be very useful when attempting to identify potential wind ramp periods.

3. STORING/VISUALIZING TALL-TOWER DATA

3.1. Internal Data Storage

The key to all MesoWest-related products and applications is the ability to ingest and store unique data streams in one format. To accomplish this, raw data files are acquired by the data providers, processed, and stored in relational database tables. MesoWest organizes observational data by time and by station, so quick and efficient queries can be made for display and dissemination products. Similar database tables store station metadata, such as the platform location and other important attributes.

The primary MesoWest databases were developed under the premise that a station could only report one of each data variable (*e.g.,* one wind speed or direction). For the majority of surface stations, this approach is adequate. However, this assumption fails for stations that report multiple observations of the same variable type, such as from tall towers or RWIS stations with multiple road pavement sensors. To address RWIS applications for state Department of Transportation centers, we had already hardwired some changes to the primary database structure. However, it was impractical to implement more changes in this manner.

Thus, a new database schema was formulated in order to store multiple sensors of the same variable and corresponding metadata. We implemented a concept where data could be dynamically described by varying permutations of metadata, such as sensor characteristics (*e.g.,* type, height, or orientation relative to the mast). To keep metadata current and consistent, the primary and supplemental metadata databases are synced. However, the supplemental metadata database also contains extended sensor metadata, which was an improvement over the primary metadata database. MesoWest now ingests and stores tall-tower observations in these supplemental databases for all of the data providers described in Section 2.2.

3.2. MesoWest Display Products

Tall-tower data can now be viewed via legacy MesoWest displays for typically the lowest wind sensor only or via new displays for all possible data.

A new station metadata page was developed for improved functionality and the inclusion of sensor metadata. Figures 6a and 6b display sections of the new station metadata page. The first section (Figure 6a) displays station location metadata in a simplified format. Menu items on the page allow the user to view additional station metadata if they desire. The section shown in Figure 6b depicts sensor metadata from the new dynamic database for BPANET station Butler Grade (BPBUT). This station has three separate anemometers at 30.8 m, 44.5 m, and 62.5 m AGL that record wind direction (DRCT). The station also records temperature, relative humidity, and barometric pressure, but sensor characteristics for these variables are unknown. Clicking on a data variable name will display sensor metadata, if any is available.

The second product developed was a supplemental version of the MesoWest Station Interface page. In the primary version, observational data for a station are displayed in tabular format. The user can display 24 hours of either current or archived data, with multiple options on the left-hand panel to change units, time period, and the time zone display (local time or UTC). Maximum and minimum calculations, along with other calculated variables not stored in the database, are also displayed. The supplemental version was developed using a similar structure, but also included the dynamic databases. Figures 7a and 7b display the differences between the primary and supplemental versions using SLCCNET tall tower Herriman (HERRI) as an example. Note that for this station there are two anemometers each at 30 m and 50 m AGL (Figure 7b), so extra metadata was needed to further distinguish observations (*i.e.* 'E' and 'SSW' denote the anemometer orientation from the main tower). This version allows table

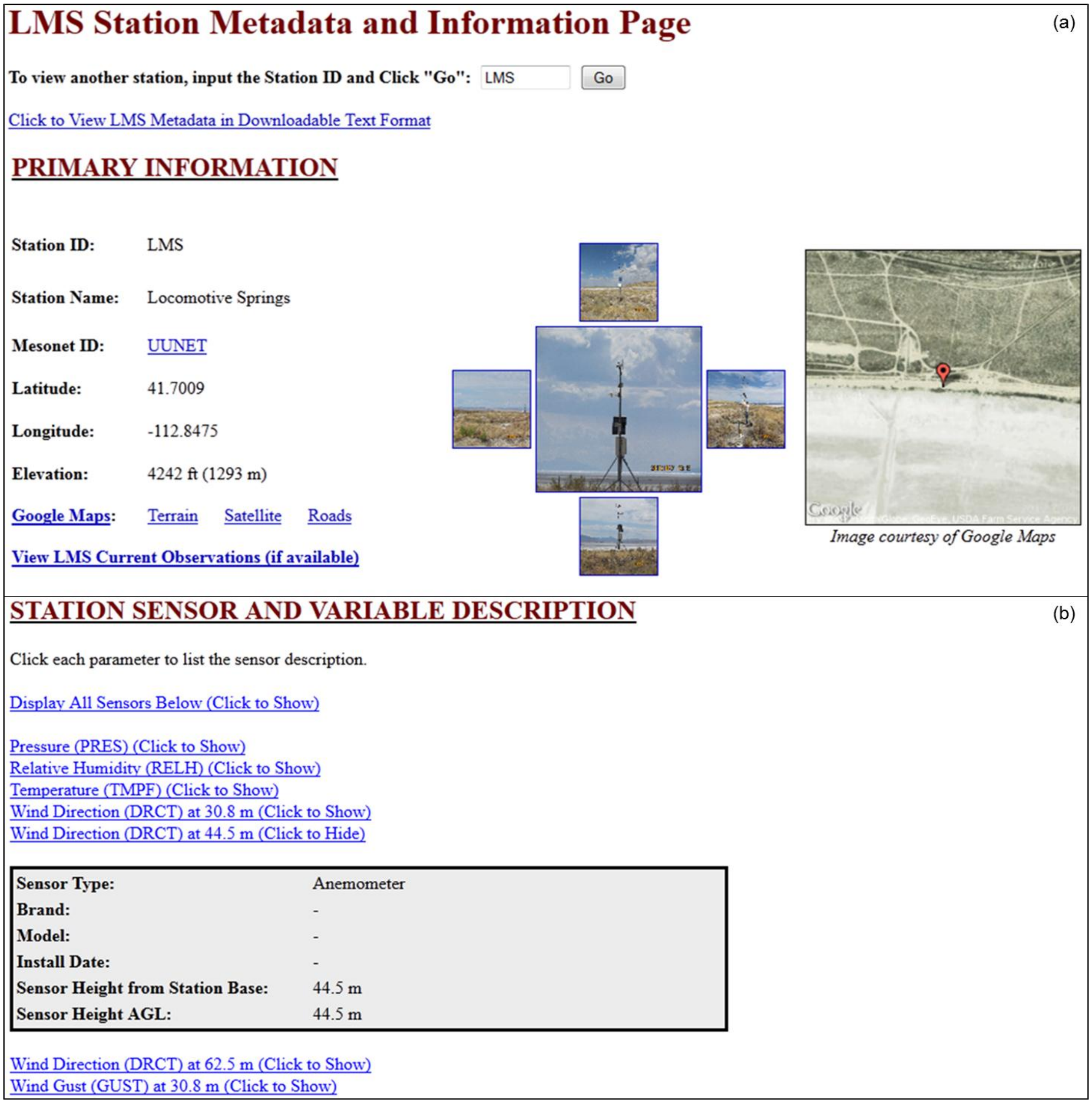

Figure 6. Examples of the new station metadata interface. Part (a) displays a new design for station metadata using station LMS as an example, while part (b) displays new capabilities to display sensor metadata using one of the BPANET tall-towers as an example.

sorting by variable type or by sensor height, and also displays the number of observations taken over a 24 hour period in the bottom table.

A comparison of the legacy graphical display (Figure 8a) and new graphical display (Figure 8b) are shown for HERRI. New options include station dependent options including checkbox options for specific sensor heights. Note how selecting temperature for HERRI (Figure 8b) displays one option at 3.0 m AGL, while selecting wind speed (Figure 9) shows five options. On the MesoWest web interface, these new tabular and graphical displays are referred to as “beta-test” products.

3.3. MesoWest Data Dissemination

While initial development of display products for tall-tower data was completed, work still needs to be done regarding data dissemination products. The existing MesoWest download interface does not have the capability to

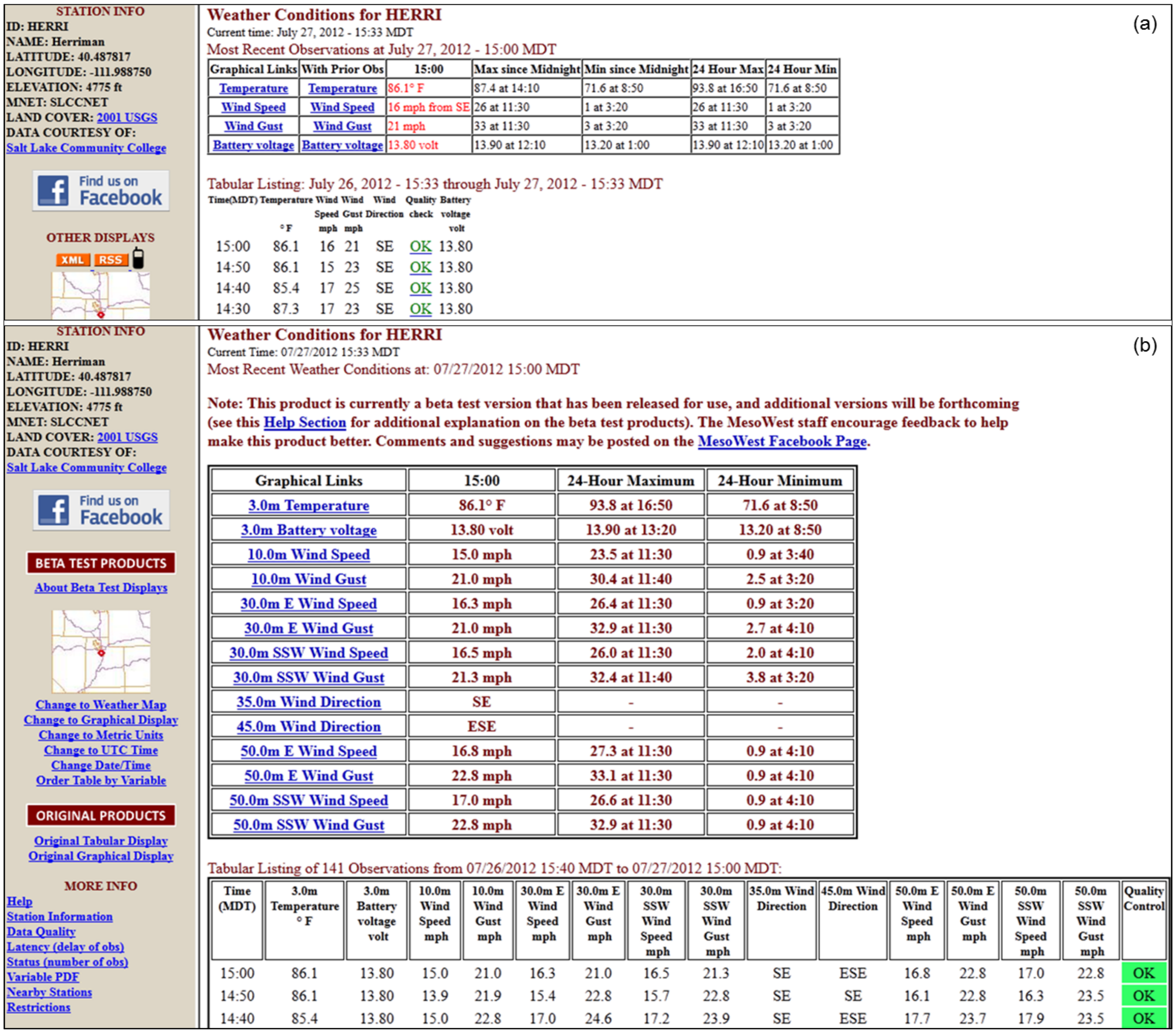

Figure 7. Examples of the differences between the a) existing and b) new versions of the tabular station interface display for SLCCNET tall-tower HERRI.

access the dynamic databases, so only limited data can be obtained for tall towers. MesoWest staff are currently working on developing a better method of accessing and downloading observations, which will include all tall-tower data.

This limitation also applies to MesoWest dissemination products for downstream recipients, such as MADIS. Current operational products disseminated to MADIS contain only limited tall-tower data. For example, MesoWest has been sending MADIS some BPANET data in real-time. This is shown in Figure 10 via the MADIS Surface Display feature (Meteorological Automated Data Ingest System 2012), where BPANET station Seven Mile (BPSML) can be identified. MesoWest has discussed with MADIS regarding a proper method for tall-tower data dissemination.

4. WIND RAMP EVENT CASE EXAMPLES

4.1. Case Identification

As an example of the use of tall-tower data, a wind ramp identification analysis was conducted for one of the available sites. Several site selection criteria were involved including: 1) location to an adjacent wind farm, 2) the presence of a wind sensor >50 m AGL to approximate winds near turbine hub height, 3) a data archive that spanned at least 90 days without significant gaps, and 4) an observation frequency reasonable enough for wind ramp identification.

Using the above criteria, the station selected was the BPANET Goodnoe Hills (BPGDH) tall tower. Station BPGDH is located

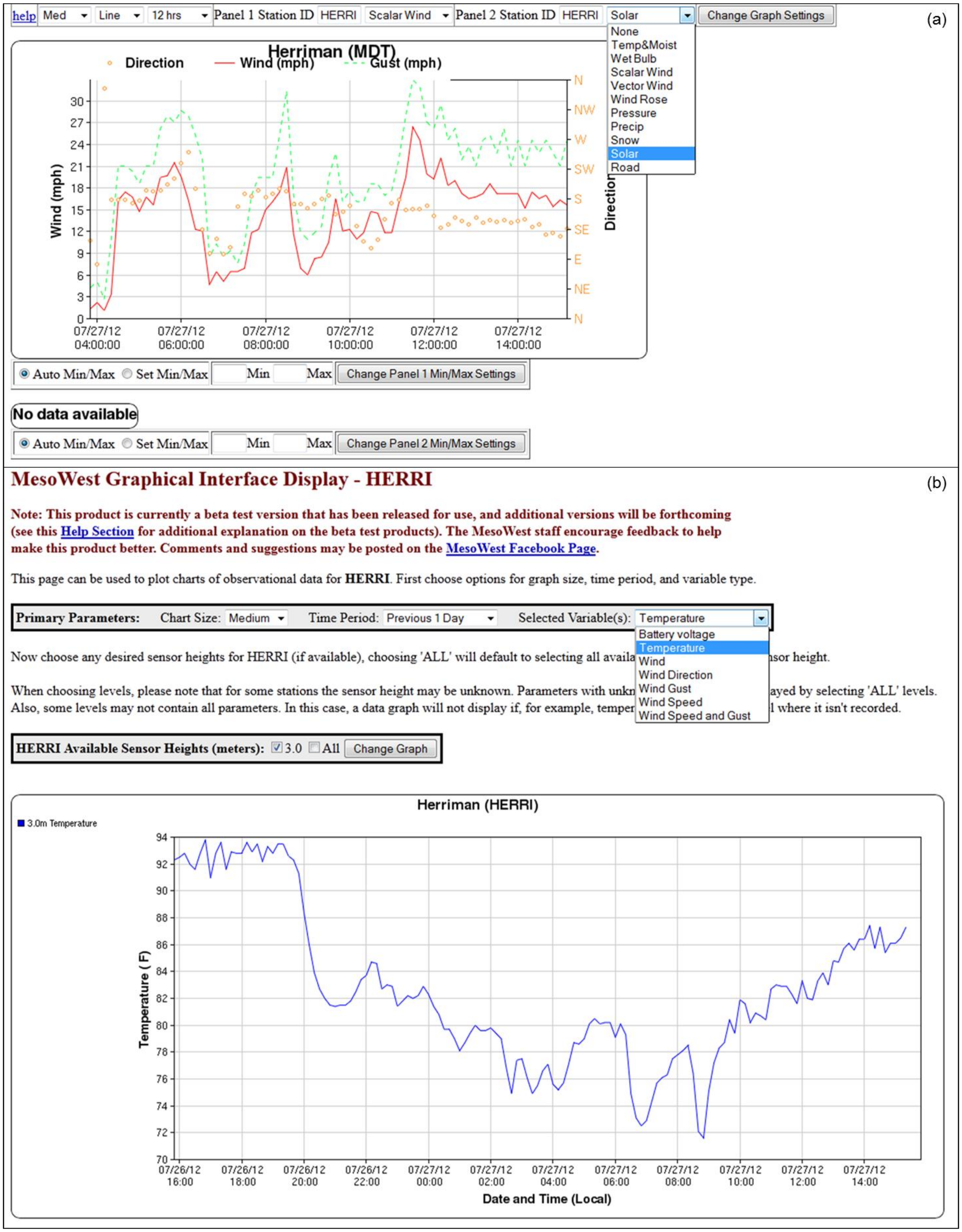

Figure 8. Examples of the differences between the a) existing and b) new versions of the tabular graphical interface display for SLCCNET tall-tower HERRI.

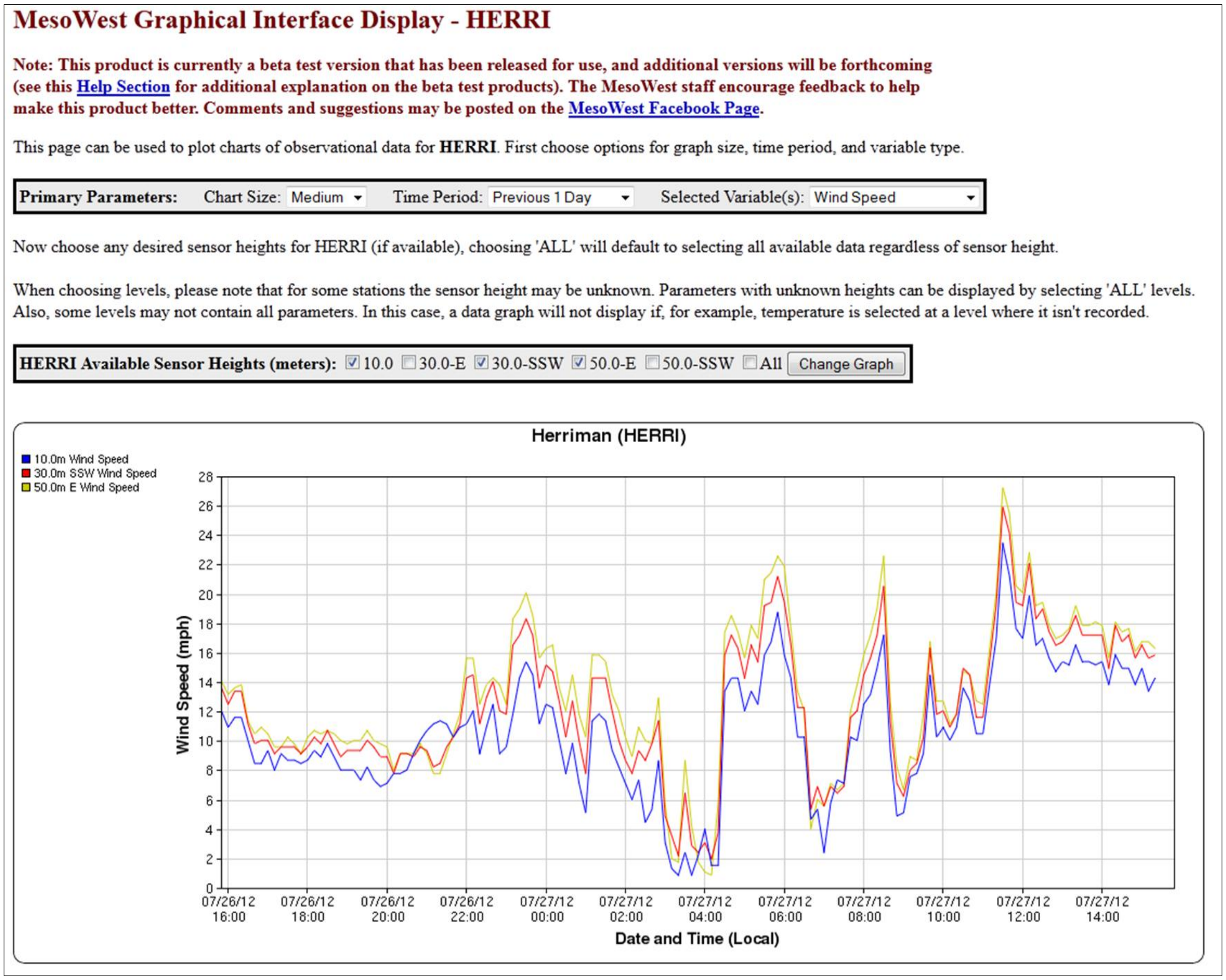

Figure 9. An additional example of the new graphical station interface for SLCCNET tall-tower HERRI. Note the additional sensor height options when selecting wind speed as a parameter.

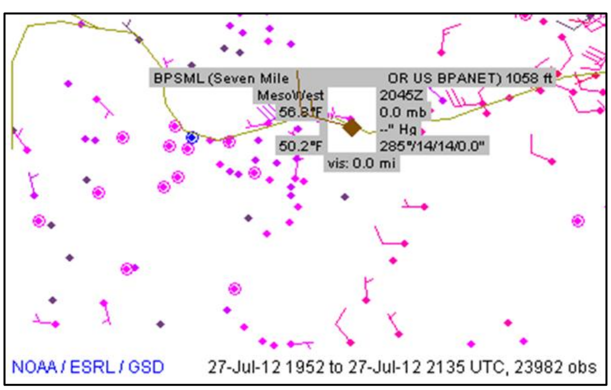

Figure 10. MADIS Surface Data Display example of BPANET station BPSML.

within the Goodnoe Hills region of southern Washington along the Columbia River Gorge. The station sits within an area populated with wind turbines, as seen on Figure 11. Since 1979, wind demonstration projects have been conducted and numerous commercial turbines have been installed within the Goodnoe Hills region (Bonneville Power Administration 2012c). The tower has two wind sensors, located at 15.2 and 59.4 m AGL, which provide 5-minute observations to MesoWest. The station also has a MesoWest data archive that began on 28 January 2012.

Using the criteria provided by Deppe et al. (2012), potential wind ramp events are examined (i.e. ±3 m s^{-1} changes in the 59.4 m AGL wind speed over 4 hour periods within the wind speed range of 6-12 m s^{-1}). After initial data filtering, events were identified using subjective analysis, which was also conducted by Deppe et al. (2012). Cases where the wind speed approached the typical turbine shutdown threshold (~ 25 m s^{-1}) were also subjectively examined as potential ramp-down events.

Figure 11. Satellite image of approximate location for BPANET station BPGDH. Imagery courtesy of Google Maps API.

4.2. Case Analysis and Results

Two examples of wind ramp events are shown using the new MesoWest graphical display. The first was a significant ramp-up event associated with a frontal passage during the latter hours of 3 May 2012. Figure 12 displays a 24-hour graph of the 59.4 m AGL wind for BPGDH ending at 1400 UTC 4 May 2012. From the figure it is clear that a large increase in wind speed (~ 14 m s^{-1}) occurred over a three-hour period from 2200-0100 UTC, with a sharp increase (~ 9 m s^{-1}) occurring just before 0000 UTC. Using Figure 5, the power capacity may have increased from roughly 10% to 100% over that period. Wind speeds greater than 12 m s^{-1} remained present at the station from 0000-0500 UTC. A less intense ramp-down period occurred from 0500-0700 UTC, where the wind speed decreased below 10 m s^{-1}.

Figure 13 depicts how large differences can be seen during the period of strongest winds (0000-0500 UTC), where the 59.4 m AGL wind speed was over 4 m s^{-1} greater than the wind speed at 15.2 m AGL. This emphasizes the usefulness of having a wind sensor closer to turbine hub height when assessing wind ramp events. The other example highlights an event that eclipsed both the ramp-up and turbine shutdown thresholds. Figure 14 displays the 59.4 m AGL wind speed for BPGDH over 24 hours ending at 0000 UTC 23 February 2012. This ramp event was caused by a strong pre-frontal pressure trough that moved in from the northwest. Wind speeds increased from roughly 6 m s^{-1} at 1000 UTC to near 25 m s^{-1} at 1400 UTC, approaching the shutdown threshold. Wind speeds then remained quite high, with wind gust values exceeding 25 m s^{-1}, for a longer period until relaxing after 2000 UTC. Figure 15 displays another large difference in the 15.2 m and 59.4 m AGL wind speeds, with differences ranging as high as 8 m s^{-1}.

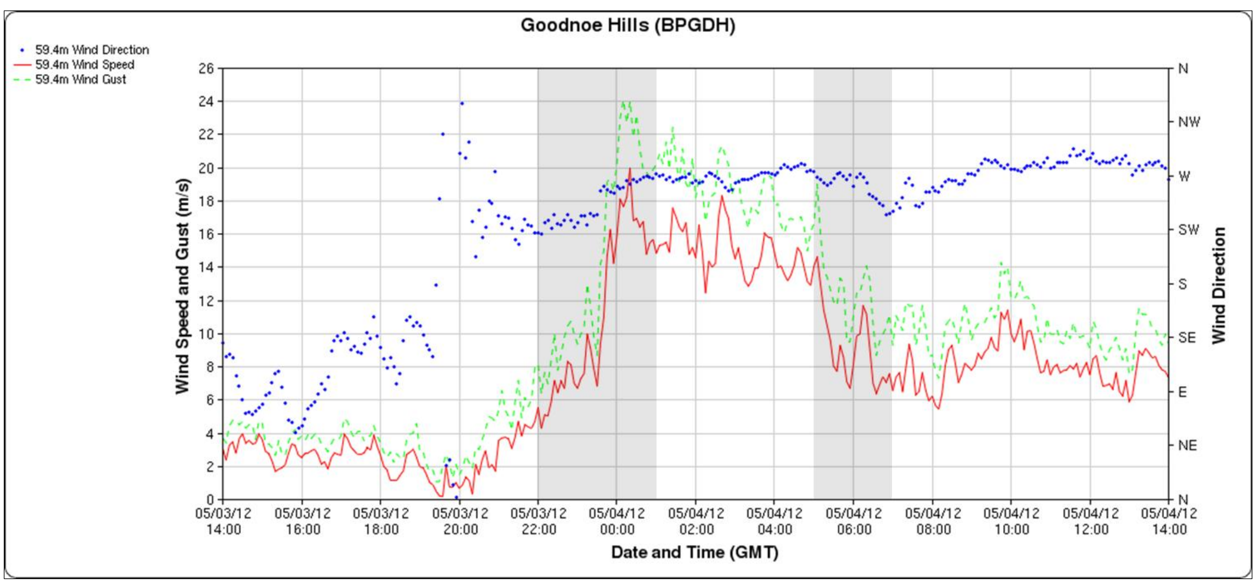

Figure 12. BPGDH 59.4 m AGL wind speed (red solid), direction (blue markers), and gust (green dashed) for 1400 UTC 3 May 2012 – 1400 UTC 4 May 2012. Shaded regions represent the prominent wind ramp periods discovered.

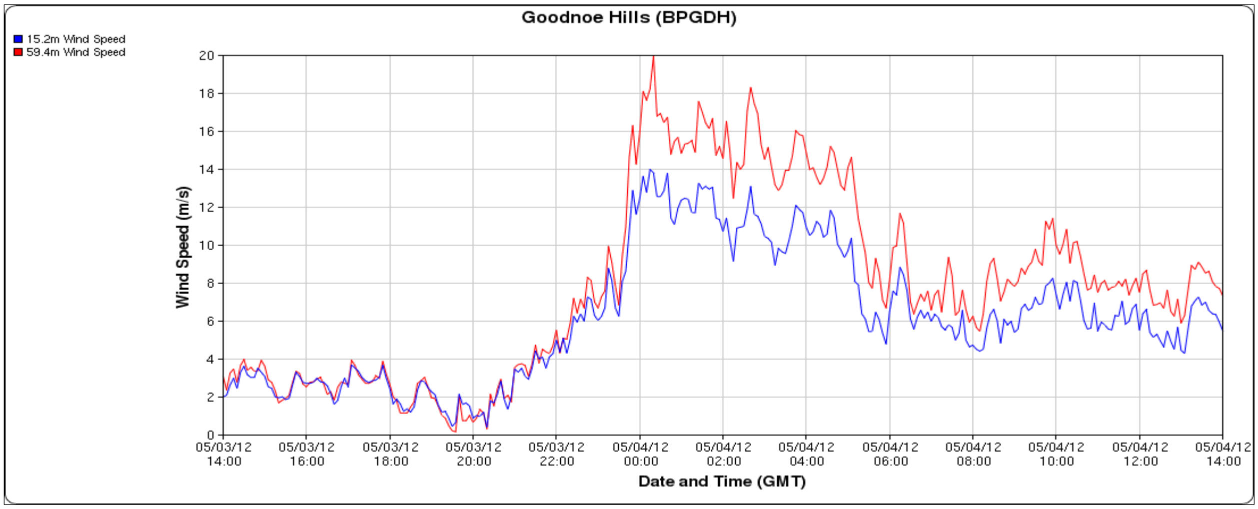

Figure 13. BPGDH 15.2 m AGL (blue) and 59.4 m AGL (red) wind speed for 1400 UTC 3 May 2012 – 1400 UTC 4 May 2012.

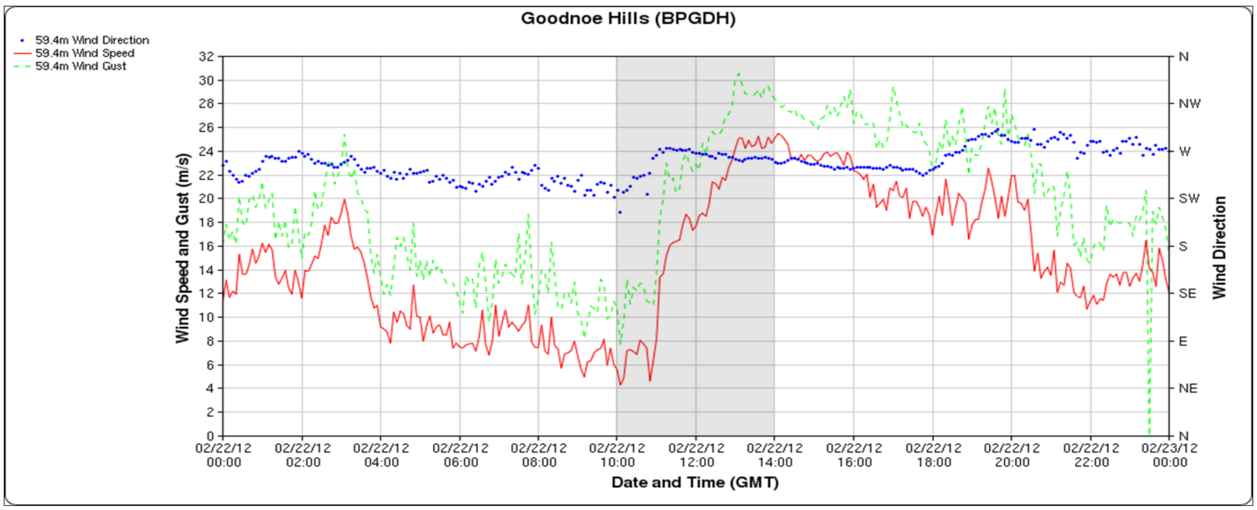

Figure 14. Same as Figure 12, except for 0000 UTC 22 Feb 2012 – 0000 UTC 23 Feb 2012.

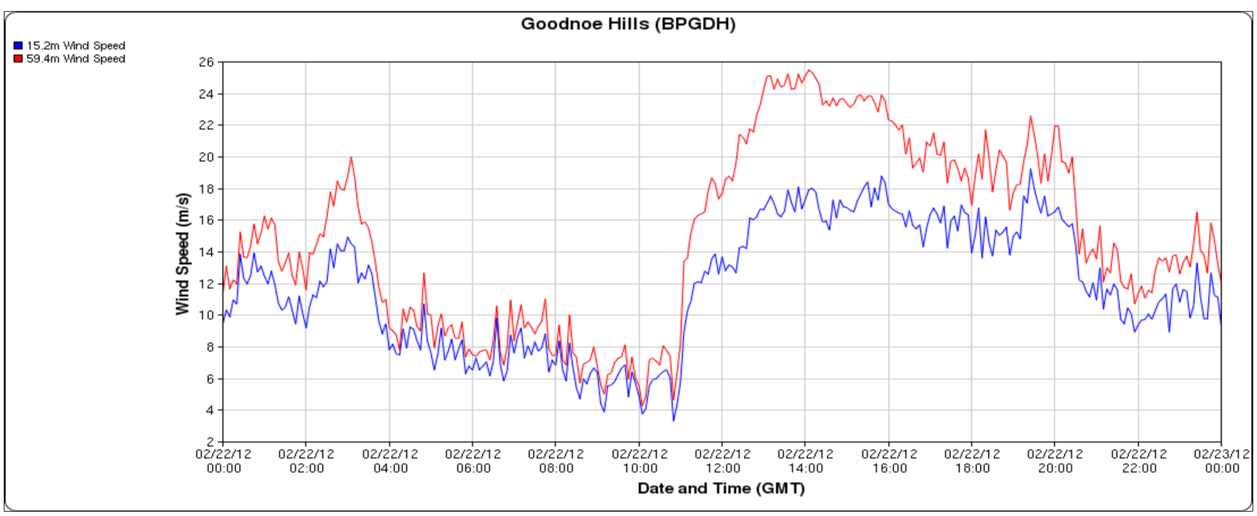

Figure 15. Same as Figure 13, except for 0000 UTC 22 Feb 2012 – 0000 UTC 23 Feb 2012.

5. SUMMARY AND FUTURE WORK

MesoWest continues to be a popular source for accessing real-time and archived surface observational data by the atmospheric science community and others. In order to fulfill the goal of promoting access to data, new procedures were implemented to ingest publicly-available tall-tower data made available to MesoWest by several data providers. This project, further motivated by a cooperative effort with Salt Lake Community College (SLCC), sought to create a method to store and display tall-tower data and metadata within the MesoWest infrastructure.

The first step of the project involved creating supplemental "dynamic" relational database schemas that could store observational data and metadata from tall towers. Once the database structure was completed, procedures were set up to acquire tall-tower data in real-time. Networks within MesoWest that have real-time tall-tower data include the BPANET, ORNL, and SLCCNET mesonets.

New display options for the MesoWest web interface were created to visualize the tall-tower data. The station metadata page was redesigned with a simplified format and more user options. Supplemental tabular and graphical displays were created and are available on MesoWest as "beta-test" products. Examples of the new graphical product were shown through a wind energy nowcasting concept. Two wind ramp events were identified for the BPANET Goodnoe Hills (BPGDH) station located along the Columbia River Gorge in Washington. The two examples highlighted the critical nature of having in-situ wind measurements closer to wind turbine hub height. The examples also showcase the new options associated with the supplemental graphical interface.

While procedures to acquire and archive tall-tower data have been completed, work remains to be completed regarding displays and dissemination products. MesoWest staff members are currently working with MADIS on developing suitable methods for disseminating all tall-tower data. We are encouraging user feedback on the new displays via email and our Facebook Page (http://www.facebook.com/mesowest). As a long-term project, interfaces utilizing more interactive tools are expected to be developed as part of an overall technical refresh effort. In addition to future software developments, MesoWest will continue to work with SLCC on providing real-time access to data for Utah tall towers. MesoWest also is willing to accept tall-tower data from any other interested networks that have their data available for public use. Interested parties can simply send a request email to the MesoWest Support Group (atmos-mesowest@lists.utah.edu).

6. ACKNOWLEDGEMENTS

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