WIND PROFILERS TO AID WITH MONITORING AND FORECASTING OF HIGH-IMPACT WEATHER IN THE SOUTHEASTERN AND WESTERN UNITED STATES

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With funding provided by the 2012 Disaster Relief Act (Sandy Supplemental), NOAA's Earth System Research Laboratory Physical Sciences Division (NOAA/ESRL/PSD) has installed three Doppler wind profiling radars (wind profilers) and surface meteorology towers along the U.S. Gulf and southeast coasts to help detect and monitor landfalling tropical storms and other high-impact weather events. For example, the continuous hourly data provided by the wind profilers can be used to identify tropical storm embedded convection, including tornadoes. The wind profiler data also supplement the direct tropical cyclone wind observations from aircraft dropsondes that are not available over land. The detailed vertical wind structure provided by the coastal wind profilers can help determine how much wind is translating to the surface in landfalling tropical storms. The wind profilers provide valuable data for other potentially high-impact weather, including thunderstorms, low-level jets, straight-line winds, wind shear, fronts, fire weather, and the freezing level.

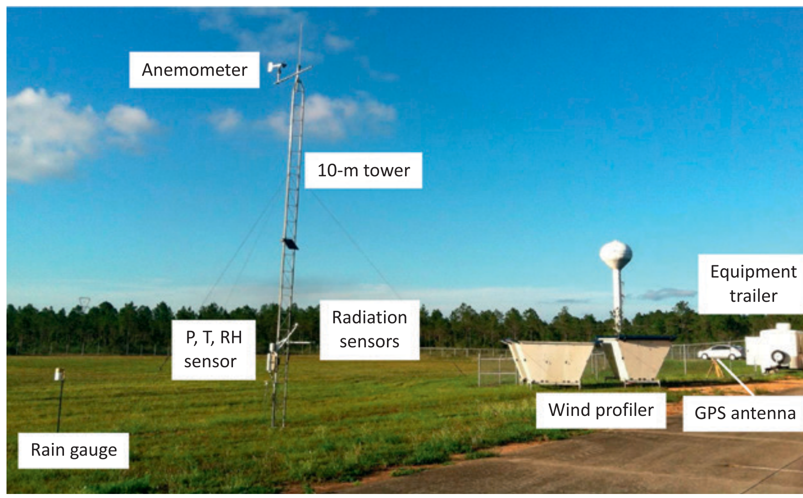

FIG. 1. A typical ARO deployment with a 915-MHz wind profiler. This ARO is installed in Moss Pt., Mississippi, as part of the Sandy Supplemental project.

Forecasters can use the observations provided by the wind profilers for situational awareness and to judge how accurately numerical models are portraying the atmosphere. The profiler data can also be assimilated into numerical models to help constrain the initial conditions.

This same combination of instruments has been used to monitor landfalling atmospheric rivers on the U.S. West Coast. For this reason, we refer to the whole collection of instruments at each site as an Atmospheric River Observatory (ARO). Figure 1 shows a typical ARO deployment. These three new AROs supported by the Sandy Supplemental complement a fourth ARO deployed in coastal North Carolina as part of NOAA's Hydrometeorology Testbed Southeast Pilot Study (HMT-SEPS; see Fig. 2, Table 1). These four AROs were installed in time to capture the 2014 hurricane season and were operated through the 2015 hurricane season and possibly beyond depending on the availability of funding to support operations and maintenance. The Sandy Supplemental also supported research at the Co-

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Table 1. Locations of the ARO installations in the southeast United States supported by the HMT-SEPS and the Sandy Supplemental projects.

Location	Station ID	Lat (°)	Lon (°)	Elev (m)	Installation date	Project
New Bern, NC	EWN	35.078	−77.046	3	6/26/2013	HMT-SEPS
Johns Island, SC	JZI	32.701	−80.006	15	6/19/2014	Sandy Supp.
Moss Point, MS	PQL	30.465	−88.527	6	6/4/2014	Sandy Supp.
Sydney, FL	SNY	27.966	−82.231	27	5/21/2014	Sandy Supp.

operative Institute for Research in Environmental Sciences at the University of Colorado to study whether the West Coast definition of atmospheric rivers is applicable in the Southeast and to determine the contribution of atmospheric rivers to extreme precipitation events in the Southeast.

With the decommissioning of the NOAA Profiler Network (NPN), a gap remains in tropospheric wind observations, especially along our nation's heavily populated coastal regions, that cannot be fully addressed by operational satellite observing systems. Satellites currently provide surface winds over the oceans and feature-track (e.g., coherent cloud or moisture fields) derived winds over the globe, but not vertical profiles of winds through the troposphere. Wind profilers provide wind measurements in the planetary boundary layer (PBL), the layer of the atmosphere influenced by the Earth's surface and where we live. The PBL is undersampled with respect to a variety of atmospheric parameters, including wind, as discussed in "Observing Weather and Climate From the Ground Up," a report produced by the National Research Council that highlighted the need for improved mesoscale weather-observing networks in the United States.

NOAA/ESRL/PSD has the capacity to deploy and operate more than a dozen wind profilers and other types of profiling radars for research field programs devoted to tropical and extratropical storms, air quality, and Arctic research, among other disciplines. The type of wind profiler deployed for the Sandy Supplemental project is the 915-MHz boundary layer wind profiler, which is designed to measure wind speed and direction profiles from 0.12 to 4 km above ground, depending on atmospheric conditions. The relatively humid background environment generally present in the southeast United States actually helps to produce stronger return signals, and thus height coverage often exceeds 6 km. A collocated 10-m tower provides near-surface wind speed and direction using a prop-vane anemometer. Other meteorology parameters [pressure, temperature, relative humidity, integrated water vapor

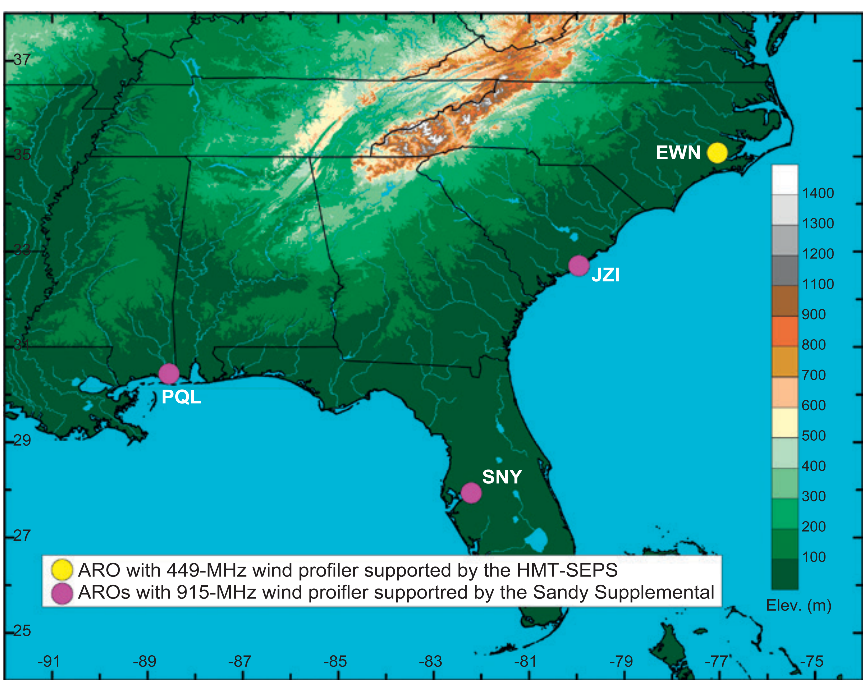

Fig. 2. Map of the southeast United States showing the locations and Station IDs (see Table 1) for the ARO deployments supported by the HMT-SEPS and Sandy Supplemental projects.

(IWV), solar and net radiation, and precipitation accumulation] are also measured on or near the 10-m tower. The combination of IWV and wind provides an estimate of the integrated vapor transport, often an important ingredient for generating precipitation.

The operating frequency (915-MHz) allows for a smaller radar antenna compared to the (full-scale 449-MHz) profilers used in the NPN, which makes this profiler highly transportable and well-suited to episodic deployment for field studies. Until 2013, this profiler was commercially available under the instrument name of LAP-3000 from Vaisala, Inc., a Finish-based weather sensor provider. In 2013, Vaisala, Inc. sold their wind profiler business to Scintec AG, a German-based remote sensor manufacturer. Scintec AG is currently manufacturing and selling a redesigned LAP-3000 boundary layer system. NOAA/ESRL/PSD had a longstanding Cooperative Research and Development Agreement with Vaisala, Inc. for the 915-MHz wind profiler. Scintec AG has agreed to continue this collaborative relationship in order to improve the current technology and to develop other new remote sensors.

In addition, NOAA/ESRL/PSD has built wind profilers for other agencies that have had a specific need for wind measurements at a particular location. For example, the U.S. Air Force required accurate wind measurements for their Tethered Aerostat Radar Systems (TARS) that carry expensive radars to detect low-flying aircraft and marine traffic as part of the U.S. drug interdiction program (the TARS program is now administered by Exelis, Inc.). In windy and high wind shear cases, the aerostats could become aerodynamically unstable, resulting in rapid loss of altitude, which ultimately could lead to damaging or destroying the radar, as well as risking injury to people and damage to property. As a result, the U.S. Air Force contracted with NOAA/ESRL/PSD to build and deploy eight "¼-scale" 449-MHz wind profilers for eight of their TARS sites across the southern U.S. border. Scintec AG is currently working with NOAA to build, deploy, operate, and maintain three of these legacy ¼-scale systems for the Pacific Northwest National Laboratory. This Pacific Northwest wind profiler network will complement a similar network of four ¼-scale 449-MHz wind profilers being installed along the California coast through a cooperative agreement between the California Department of Water Resources and NOAA/ESRL/PSD (see Fig. 3). These western U.S. agencies realize the importance of the observations provided by wind profilers for weather monitoring and wind energy partly due to the lack of available wind profile observations in the troposphere over the Pacific. The data collected by the AROs are telemetered to a data hub in Boulder,

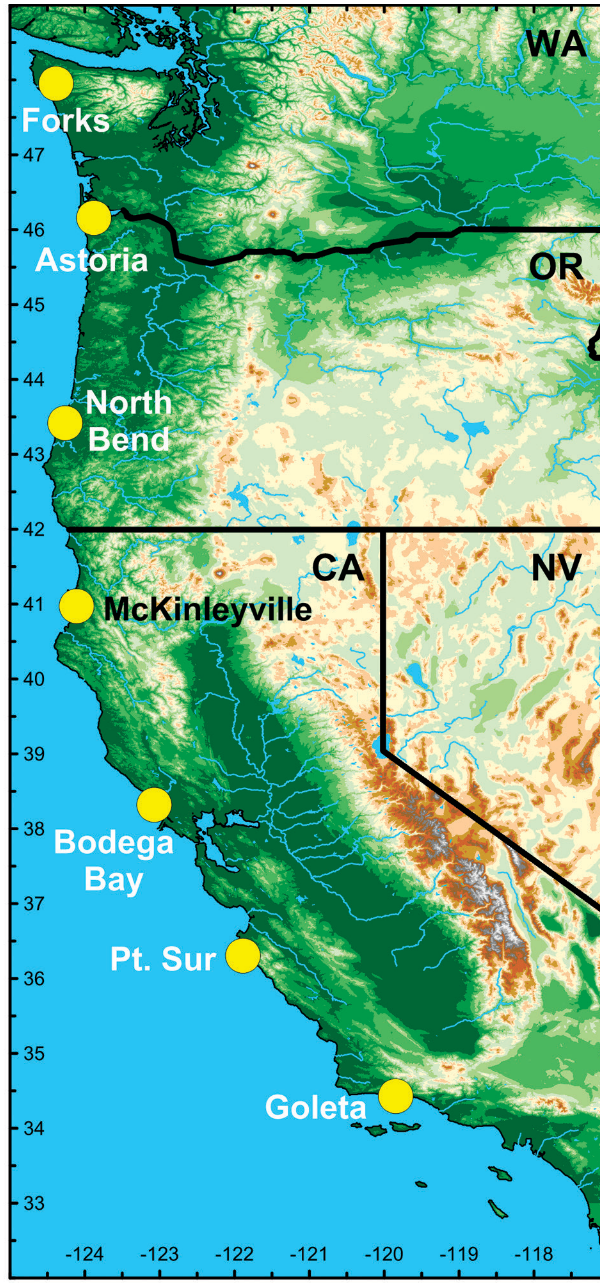

Fig. 3. Map of the U.S. West Coast showing the locations of seven semipermanent ARO deployments with 449-MHz wind profilers. This network is supported by the California Department of Water Resources and the Pacific Northwest National Laboratory.

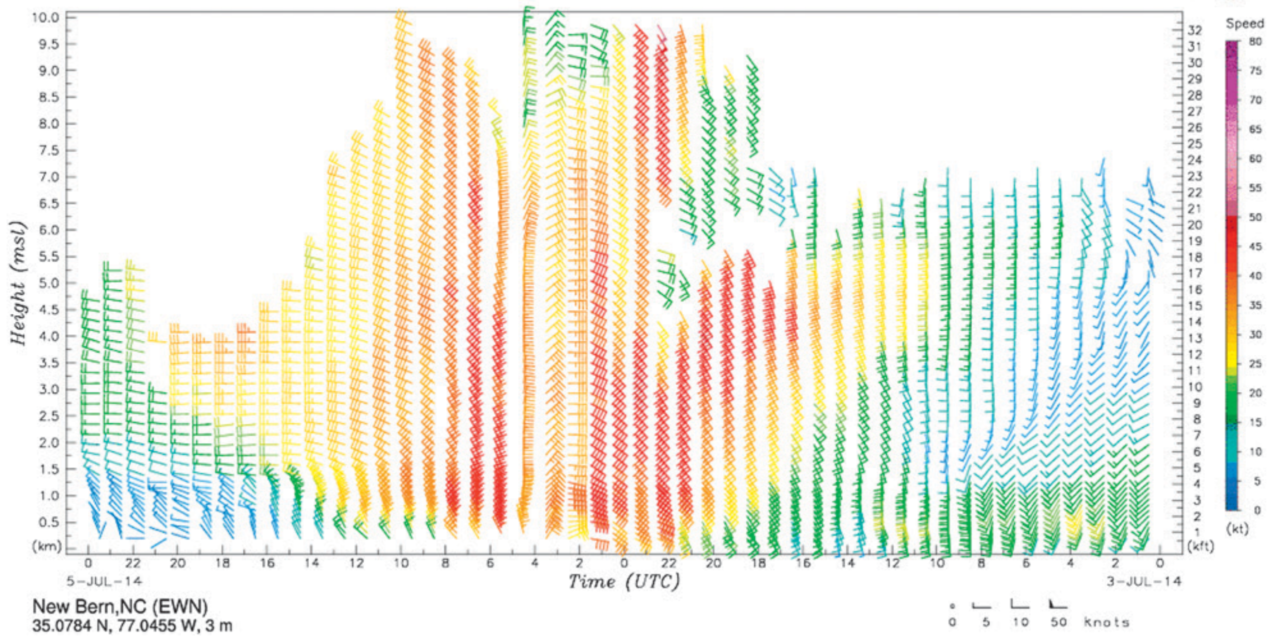

Fig. 4. 48-h time-height display of hourly-averaged wind profile observations collected at New Bern, North Carolina, during the passage of Hurricane Arthur. The wind speed at each level and time is denoted by the barb convention shown in the lower right-hand corner and is also color-coded to the speed scale on the right-hand side of the display. Wind direction is indicated by the direction from which the bottom of each flagpole is pointing. Time proceeds from right to left along the horizontal axis.

Colorado, using mostly cellular Internet communications technology. Data and images of the data are then made publicly available on the Internet through NOAA/ESRL/PSD (www.esrl.noaa.gov/psd/data/obs/datadisplay/) and are also part of the Cooperative Agency Profiler (CAP) web page on the Meteorological Data Assimilation and Ingest System (MADIS) hosted by the NOAA/ESRL/Global Systems Division (https://madis-data.noaa.gov/cap/profiler.jsp). However, to make these observations most accessible to weather forecasters, it will be important to develop display capability for wind profiler observations in AWIPS2, the next-generation weather processing system currently being transitioned to the NWS.

During the passage of Hurricane Arthur in early July 2014, the Southeast ARO network provided real-time observations of the storm structure. Figure 4 is a time-height cross section of wind profile observations collected at New Bern, North Carolina, from 0000 UTC 3 July to 0000 UTC 4 July 2014. The data document the hurricane passage with great detail. Strong winds descend with time until passage of the storm center, after which strong winds ascend with time on the backside of the storm. The shift in hourly wind directions puts the hurricane's eye passage at about 0400 UTC 4 July. Figure 5 is a time series of 2-min average surface meteorology parameters collected on the 10-m tower collocated with the wind profiler for the same period. The passage of the hurricane's eye is associated with local minima in surface pressure and wind speed along with the wind direction shift at approximately 0400 UTC 4 July 2014, consistent with the timing based on the wind profiles. A GPS receiver is used to measure the IWV via the satellite occultation technique. The IWV peaks at about 6.5 cm just on either side of the eye. Rainbands are evident in the precipitation time series. One might expect this greatly enhanced water vapor to produce even heavier rain rates given the increased supply of moisture available to produce condensate and precipitation if the necessary dynamic forcing exists. However, at this juncture of the storm, drier continental air had already started to be entrained, which helped to inhibit convective development (not shown). In addition, the storm was beginning to increase its northeasterly track speed.

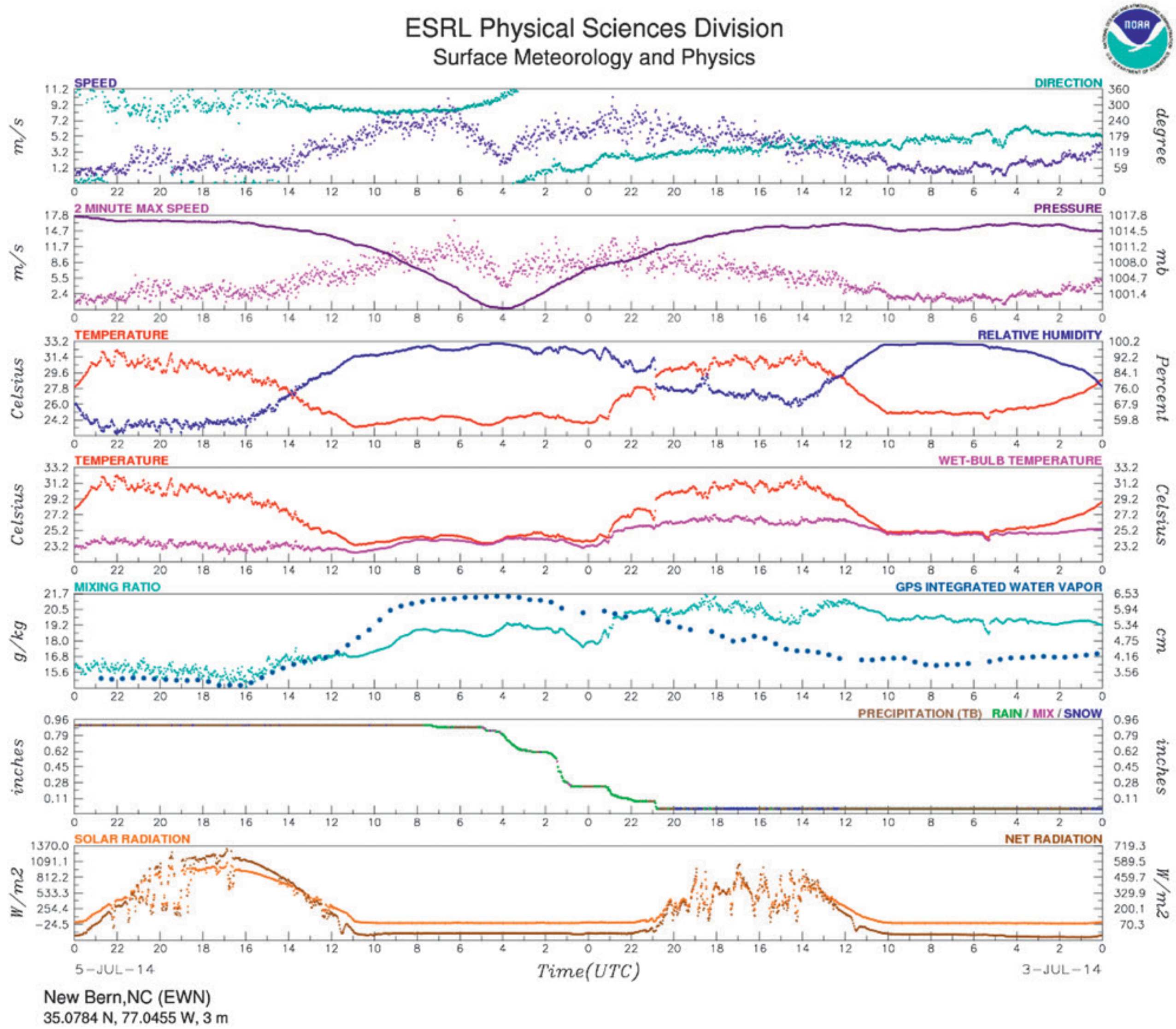

Fig. 5. Time series of surface meteorology parameters, integrated water vapor, solar radiation, and net radiation collected on a 10-m tower collocated with the Doppler wind profiler at New Bern, North Carolina, during the passage of Hurricane Arthur. Time proceeds from right to left along the horizontal axis.

While the coastal observations of Arthur from the New Bern site revealed useful data on in situ storm structure, the addition of more wind profilers located farther inland would provide a better picture of the environment into which a landfalling storm is moving. It is well known that inland boundaries resulting from extratropical transition processes largely determine rainfall maximization and surface wind gust potential. It will be beneficial to pursue future investigation of how additional wind profiling observing systems may be deployed to improve predictability of landfalling tropical system impacts in this region.