A 21ST-CENTURY OBSERVING NETWORK FOR CALIFORNIA

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ABSTRACT

The NOAA Earth System Research Laboratory (ESRL) and the Scripps Institution of Oceanography (SIO) are implementing a five-year Memorandum of Agreement with the California Department of Water Resources (CA-DWR) to create a 21st-century observing, modeling, display, and decision support system to help address California's flood protection and water resource issues. This work is based on nearly a decade of scientific research into the forcings of extreme precipitation and runoff events along the U.S. West Coast conducted under NOAA's Hydrometeorology Testbed (HMT; http://hmt.noaa.gov). In order to take full advantage of the observing networks being implemented and to provide extended lead time for extreme events, a numerical modeling system focused on the U.S. West Coast is underway. This paper will describe the overall project and will demonstrate how the observing and modeling systems are providing integrated tools for improved monitoring and prediction of the extratropical storms that batter California each winter.

1. OBSERVING NETWORKS

1.1 Soil Moisture Sensors

Because antecedent soil conditions can determine whether a storm produces a flood, soil moisture sensors are being placed at 43 sites across the state (see Fig. 1). CA-DWR is partnering with SIO to install soil moisture sensors in the upper elevations of California by taking advantage of existing infrastructure at interagency Remote Automated Weather Station (RAWS) sites. ESRL is installing soil moisture sensors at lower elevation sites and primarily adjacent to California Department of Forestry fire station (CalFire) facilities. An example of an ESRL deployment is shown in Fig. 2.

1.2 GPS--Integrated Water Vapor

Water vapor fuels precipitation, and GPS technology provides a viable method of measuring the vertically integrated water vapor (IWV; [1]). Hundreds of GPS receivers exist in California for geodetic science. By installing surface meteorology sensors with the GPS receivers and by upgrading real-time communications, these GPS receiver sites can provide water vapor measurements in real time. ESRL is partnering with UNAVCO, the operators of the Plate Boundary Observatory (PBO; http://pbo.unavco.org/) where many GPS receivers already exist, to provide IWV measurements from 37 locations across the state (see Fig. 1).

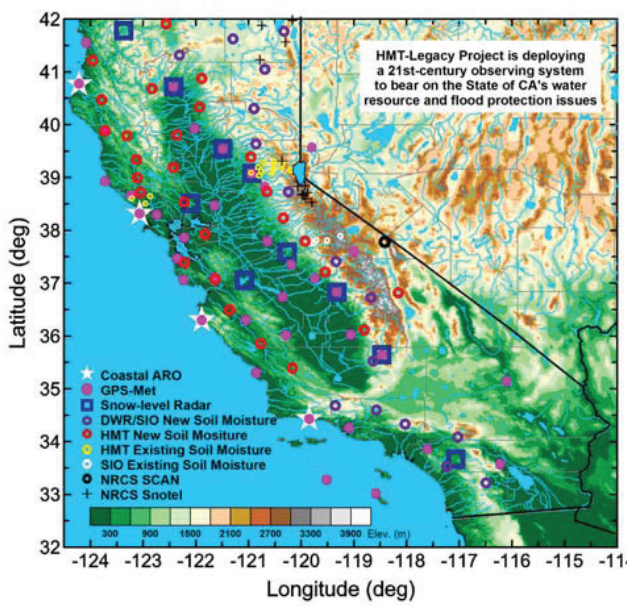

Figure 1. Map of California showing locations where instruments are being deployed as part of the observing network in the HMT Legacy Project.

1.3 Snow Level Radars

The snow level is also a significant variable with respect to flooding in mountainous watersheds because it determines the surface area throughout the watershed that is exposed to snow versus rain [2]. Engineers at ESRL have invented a new compact, frequency-modulated, continuous-wave (FM-CW) radar at S-band (Fig. 3; [3]) designed to measure the snow level at much reduced cost compared to the traditional pulsed-Doppler radars used by ESRL scientists for this purpose. These "snow-level radars" (SLRs) are being installed in ten key watersheds across the state (see Fig. 1). An example SLR deployment is shown in Fig. 3. A data display of snow-level observations from the SLR network is demonstrated in Fig. 4.

Figure 2. An example of an ESRL soil moisture monitoring site. Probes to measure the soil temperature and volumetric moisture content are buried in the ground at depths of 10 and 15 cm. The tripod mast holds a temperature/relative humidity probe and a tipping bucket rain gauge. The tripod also holds a data logger and a solar panel to provide electrical power.

Figure 3. The snow-level radar deployed at Pine Flat Dam in the central Sierra of California. The four-foot diameter radar transmit and receive antennas are at the bottom of the sloped antenna enclosures. The radar electronics and data acquisition computer reside in the environmentally controlled cabinet placed between the two antenna enclosures. Additional surface meteorological sensors (e.g, Fig. 2) are shown to the left. A GPS receiver antenna (far left) allows retrievals of integrated water vapor above the site.

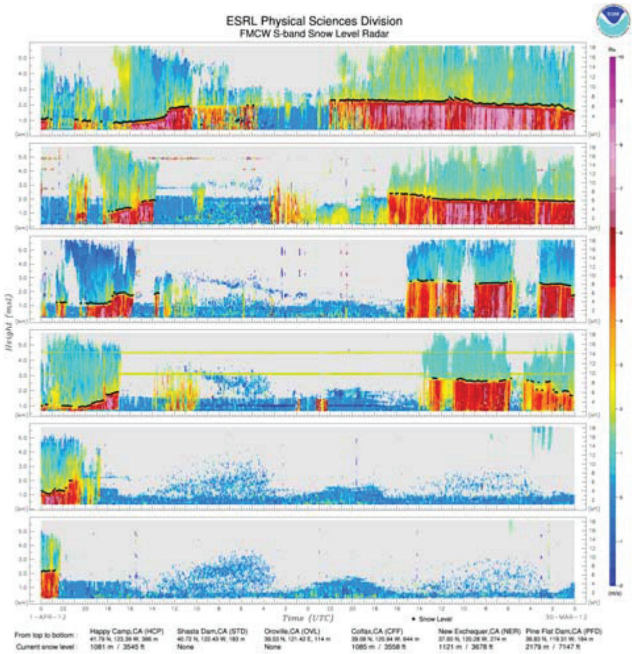

Figure 4. A time series of the snow levels (km MSL; black dots) overlaid on colored contours of Doppler vertical velocity (m s^{-1}; color scale on right) observed by six of the Snow-level Radars deployed along the California Sierra Nevada (see Fig. 1).

1.4 Coastal Atmospheric River Observatories

The winds contained in the low-level jets of landfalling winter storms contribute to the heavy orographic precipitation on the windward slopes of the coastal mountain ranges of California [4]. These jets are often accompanied by enhanced water vapor in the so-called warm conveyor belt of extratropical storms. The narrow band of enhanced water vapor is also referred to as an atmospheric river (AR).

HMT research has shown that ARs are responsible for flood-producing rains along the U.S. West Coast (e.g., [5]). ARs also have been recognized for producing floods in Western Europe (e.g., [6]) and elsewhere around the world. Microwave satellite technology, such as the Defense Meteorology Satellite Program's Special Sensor Microwave Imager (SSM/I), has allowed scientists to look more in depth into the global extent of ARs (see Fig. 5). Still, satellites measure only the water vapor in ARs, while the winds, especially in the storm's low-level jet, are not measured. In addition, the microwave technique used with satellites does not work over land, which explains why the continents are black in Fig. 5.

In response to this observing gap, HMT scientists have developed the concept of an Atmospheric River Observatory (ARO), a unique collection of instruments that monitors the atmospheric forcings associated with

ARs as they make landfall along the coast. The two key instruments in the ARO are a wind-profiling radar and a GPS receiver for IWV measurements. For this project CA-DWR has chosen to use the ¼-scale 449-MHz wind profiler technology for the four coastal AROs that are being implemented along the California coast (see Fig. 1). This choice was based on HMT experience gained in testing and evaluating wind profiling technology in the coastal environment (see http://www.esrl.noaa.gov/psd/psd2/programs/ioos/).

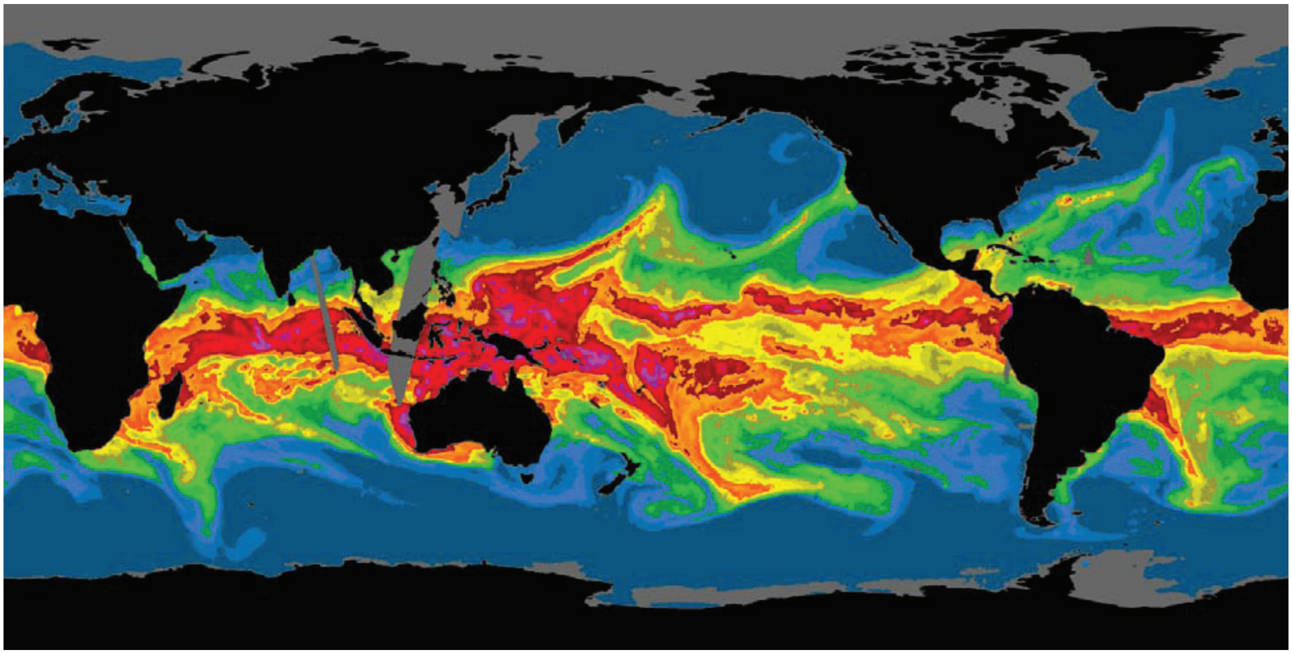

Figure 5. A global composite SSM/I satellite image of integrated water vapor (warmer colors indicate higher water vapor concentration) from 16 February 2004. Several ARs are evident, including one impacting the west coast of the U.S.

One of the real-time displays from an ARO is referred to as the water vapor flux tool and is available to weather forecasters and the public (www.esrl.noaa.gov/ psd/data/obs/). It uses thresholds for IWV, upslope wind, and bulk IWV flux that identify AR conditions. For example, [7] showed that, in order to produce orographic rain rates > 10 mm hr^{-1} in California's coastal mountains, an IWV flux exceeding 25 cm m s^{-1} is required. An example display from the prototype ARO at Bodega Bay is shown in Fig. 6.

2. OTHER PROJECT COMPONENTS

To take full advantage of the observing networks being installed and to provide advanced lead time of high impact weather, this project involves a numerical weather prediction component using the HMT WRF ensemble ([8]; HMT weather forecasts are available at http://laps.noaa.gov/forecasts/). Special display systems that can provide this value-added information in the NWS Weather Forecast Offices and River Forecast Center are also being demonstrated (e.g., the Advanced Linux Prototype System development at ESRL). Finally, decision support tools, that will allow water managers and other decision makers to make optimal use of the new observing and modeling information, are being developed. An example is the water vapor flux tool shown in Fig. 6.

3. SUMMARY

ESRL and SIO are in the midst of a five-year Memorandum of Agreement with CA-DWR to install and operate a 21st-century observing system to detect and monitor the forcings associated with landfalling winter storms and the floods they create. To advance the forecast lead time of these important storms, the project takes advantage of advances in numerical weather prediction made by ESRL and HMT. Finally, display and decision support tools are being developed that eventually may allow water managers in California to more reliably make decisions based on forecast information.

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technical teams located at the ESRL Water Cycle Branch, CA-DWR Hydrology Branch, and the SIO Department of Climate Atmospheric Science and Physical Oceanography for developing, installing, operating, and maintaining the instrumentation in this project.

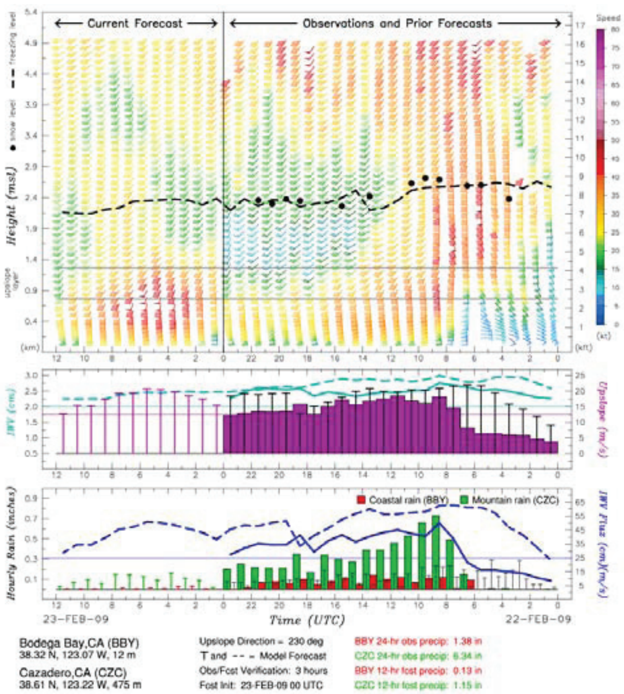

Figure 6. Example from 22-23 February 2009 of the atmospheric river water vapor flux tool displayed on the Internet (www.esrl.noaa.gov/psd/data/obs). Time moves from right to left along the horizontal axis. The current time is indicated by the vertical line in the top panel. Data plotted to the left of this line in each panel display the current HMT rapid-refresh mesoscale model forecast only (i.e., no observations), whereas data plotted to the right of the line in each panel are a combination of observations and model output (described next). (top) Wind profiler hourly averaged observations of the snow level (bold dots) and retrospective hourly HMT model forecasts of the freezing level (dashed line) at 3-hr verification time along with time-height section of hourly averaged wind profiles (flags = 25 m s^{-1}; barbs = 5 m s^{-1}; half-barbs = 2.5 m s^{-1} – wind speed color coded) observed by the ARO at Bodega Bay. (middle) Time series of hourly averaged upslope flow (m s^{-1}; from 230^{o}) observed (histogram) and predicted (T posts) in the layer between 750 and 1,250 m MSL (bounded by the dashed lines in the top panel), and IWV (cm) observed (solid line) and predicted (dashed line) by the HMT forecast model. (bottom) Time series of hourly averaged IWV flux (cm m s^{-1}) observed (solid line) and predicted (dashed line) by the HMT forecast model, and hourly rainfall histogram from Bodega Bay (mm; red) and Cazadero (mm; green), in the coastal mountains. Minimum thresholds of upslope flow, IWV, and IWV flux for the potential occurrence of heavy rain (> 10 mm h^{-1}) in atmospheric river conditions defined by [7] are indicated by the thin horizontal lines in the middle and bottom panels.

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