GPS Precipitable Water Mapping Using RUC Station Pressures

Poster 4.1

Jim Means (jmeans@ucsd.edu) **and** ***Daniel Cayan (dcayan@ucsd.edu)***

Scripps Institution of Oceanography, UC San Diego

Abstract:

GPS tropospheric travel-time delays can be used to determine precipitable water (integrated water vapor) at the GPS site, if the station pressure is known. A large number of GPS receivers have been deployed by geophysicists in order to track lithospheric plate motion and movement along faults; unfortunately, barometers are not routinely deployed at these sites, so they are not directly available for precipitable water measurements. To get around this problem, we will use RUC model output to compute station pressures. When combined with hourly GPS delay data, this gives us the ability to calculate precipitable water on an hourly basis and map it to a grid. The timeliness of this data and its high resolution make it a unique tool in operational forecasting.

Background:

Travel-time delays between satellites and fixed GPS sites on the ground vary due to a number of different factors, but most importantly due to the amount of dry air and water vapor between the GPS receiver and the satellite. The delay due to the dry air can be calculated if the atmospheric pressure is known at the site (station pressure) and then the delay due to the integrated atmospheric water vapor (precipitable water) can be simply related to the total delay. If one knows the total delay and station pressure then the precipitable water at the GPS site can easily be calculated.

In order to track plate motions and continuously monitor local crust deformation in California, geophysicists are deploying large numbers of fixed GPS receivers that transmit data in real-time. Although these real-time GPS stations primary purpose is studies of the solid earth, there is an opportunity to use them to generate near real-time high resolution maps of precipitable water. This should be useful not just for studies of climate, but should also assist in the forecasting of significant hydrometeorological events.

The key obstacle to be overcome is the lack of meteorological data at the GPS sites. In previous studies we have shown that it is possible to determine accurate station pressures by interpolating North American Regional Reanalysis geopotential height data to the GPS sites. While such an approach can be effective in climatological studies, it obviously is impractical for forecasting. However, we believe that using the hourly analyses output from the 13 kilometer resolution Rapid Update Cycle model we can obtain similar results in real-time that we obtained with reanalysis.

To this end we have received a Blasker Environmental grant from the San Diego Foundation to demonstrate the ability to generate near real-time high resolution precipitable water maps of Southern California and make them available to the forecasting community. Since this work is just begun, in this paper we don't have results to show yet, but will demonstrate the technique and show the results obtained using reanalysis rather than the RUC analyses.

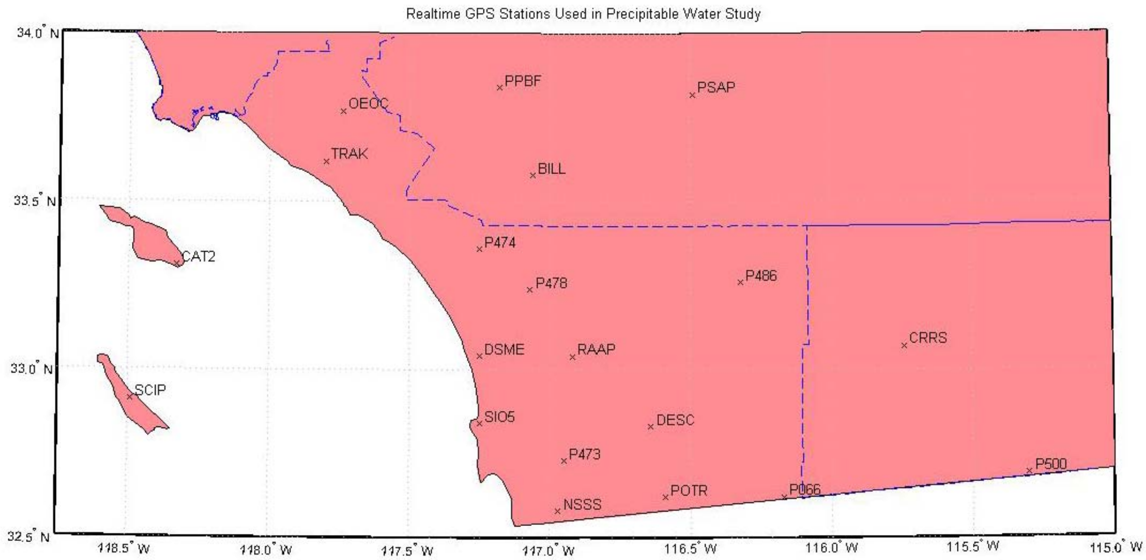

Figure 1. GPS Stations of the California Real-time Network to be used in this study

Station Pressure from Analyses

The key obstacle to be overcome is the lack of co-located meteorological stations at the GPS sites, but we have demonstrated previously that this handicap can be overcome with reanalysis data. While this technique is not possible with real-time data, we expect that a similar approach can be used by using hourly analyses from the Rapid Update Cycle model to generate interpolated pressure and temperature data at the GPS sites.

The Regional Update Cycle provides hourly analyses at 13 kilometer resolution over the continental United States (CONUS). Horizontal and vertical interpolation of the geopotential surfaces will allow us to calculate accurate station pressures for the real-time GPS sites used in the study, just as interpolation of the.North American Regional Reanalysis (NARR) has been shown to be effect in climatological studies.. As a demonstration of how well this technique has worked with reanalysis data, the following graph shows a scatterplot comparison of precipitable water data at a particular GPS site where NOAA continuously monitors pressure and temperature data, with precipitable water generated from reanalysis data. The correlation is obvious. There is a low bias to the reanalysis PW data that would probably go away temperature in the calculation—this is something we plan on implementing with the real-time data.

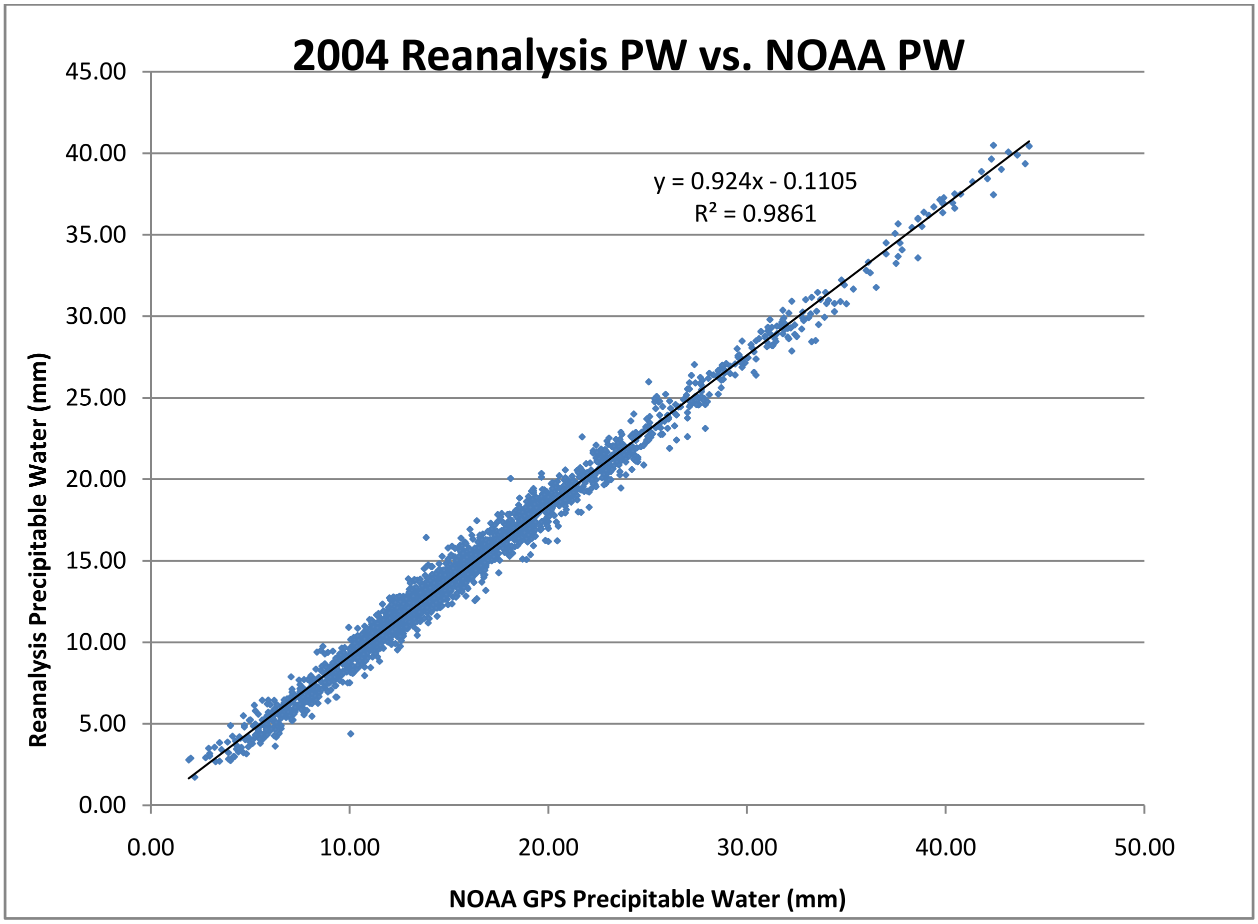

Figure 2. Scatterplot comparing GPS precipitable water calculated from reanalysis interpolated station pressures with that calculated from directly measured station pressure.

Application to Hydrometeorological Events: Southwestern Monsoon

The Southwestern Monsoon is one of the most dominant and regular weather patterns in North America. While previous studies have concentrated on the effects in Arizona, its influence extends farther west into California and Nevada also, with effects as obvious as mountain and desert thunderstorms and as subtle as increased nighttime temperatures and disruption of the coastal marine layer. There is a relative scarcity of direct observations over the sparsely populated regions of the Colorado River Valley and Mojave deserts, but since this region is seismically active there is no shortage of fixed GPS receivers, so relatively high-resolution images of precipitable water can be obtained.

Strong monsoon events are associated with high values of precipitable water and can be significant hydrometeorological events, including flash flooding and severe thunderstorms. Since data is sparse in the region, GPS precipitable water provides an opportunity to greatly improve forecasting of flooding events in the region.

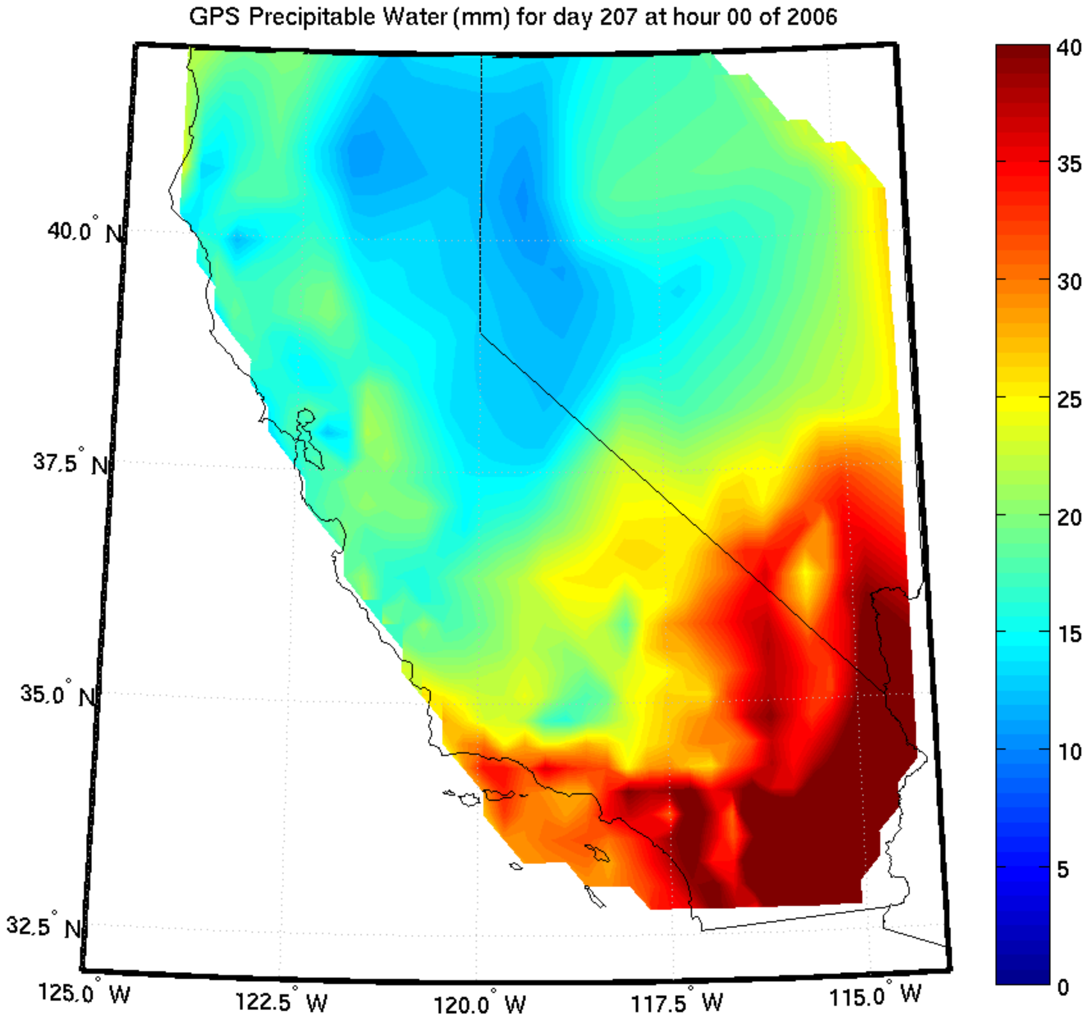

Figure 3. GPS Precipitable water image from reanalysis, showing well-developed monsoon with deep moisture of Southern California and Nevada

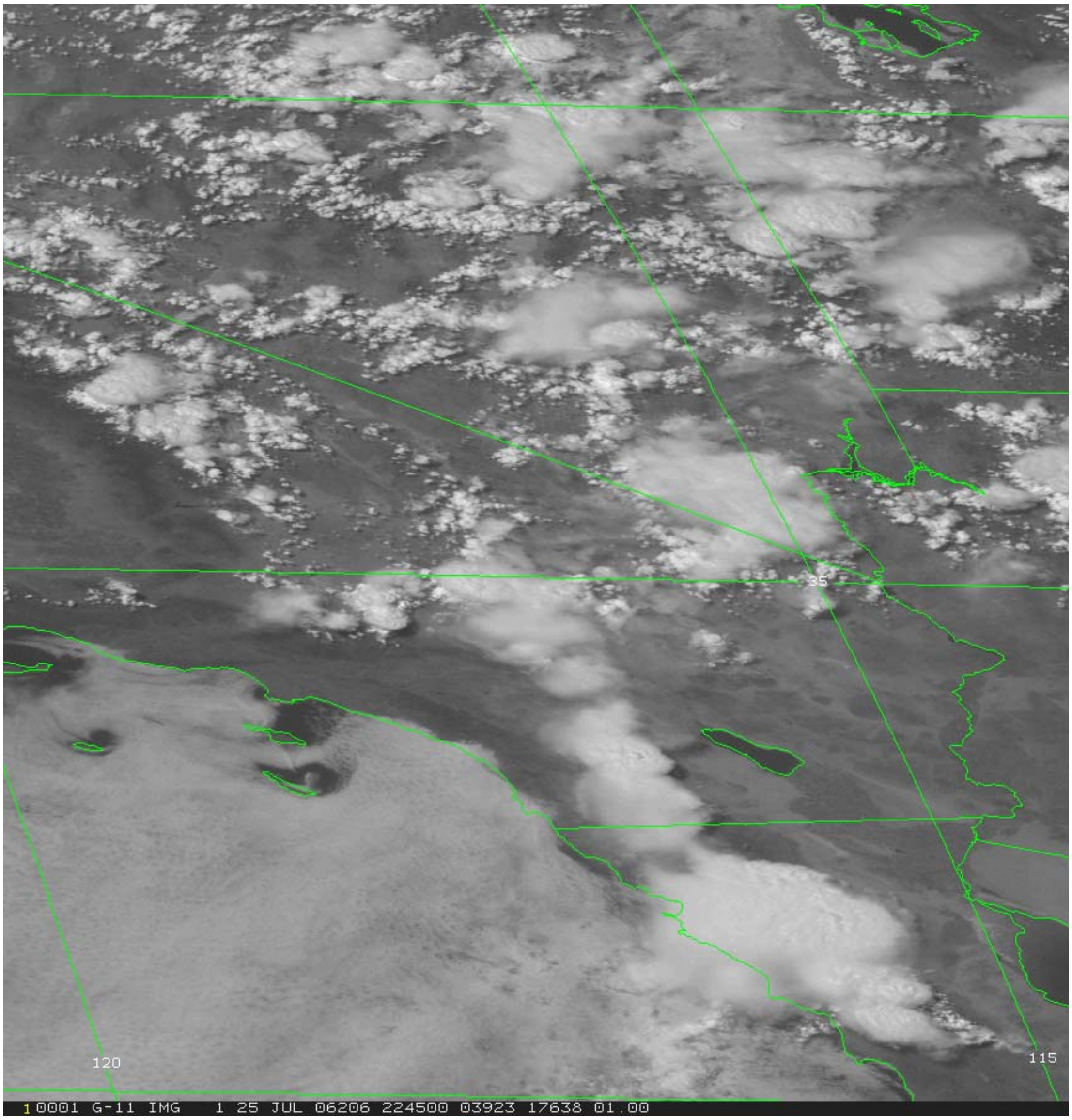

Figure 4. Visible satellite image from approximately the same time as Figure 3, showing numerous large thunderstorms complexes over Southern California and Nevada

Application to Hydrometeorological Events: Atmospheric Rivers

In recent years there has been recognition that many of the mid-latitude cyclonic storms that cause serious flooding along the North American west coast are associated with long linear features of high precipitable water, that apparently connect the mid-latitude storms to source of water vapor in the deep tropics. These “atmospheric rivers” are obvious on SSM/I imagery of integrated water vapor. Once these atmospheric rivers impinge on the coastline the SSM/I satellites are no longer able to provide images, so the behavior of the atmospheric rivers over the land is not clear. In this application the GPS water vapor imagery (which is currently only available over land surfaces) provides complementary information to the satellite images.

Figures 5 through 9 show a sequence of GPS precipitable water images of an atmospheric river type storm that caused widespread flooding in Southern California. The total sequence covers approximate six days time, with the time measured from the atmospheric river peak. The sequence clearly shows an initial state where the atmosphere over California is relatively dry, then a moistening from the west as the atmospheric river begins to affect the region, at the peak there is a well-defined zone of increased precipitable water over Southern California, then the last two figures show the high precipitable water exiting to the southeast and a return to dry conditions.

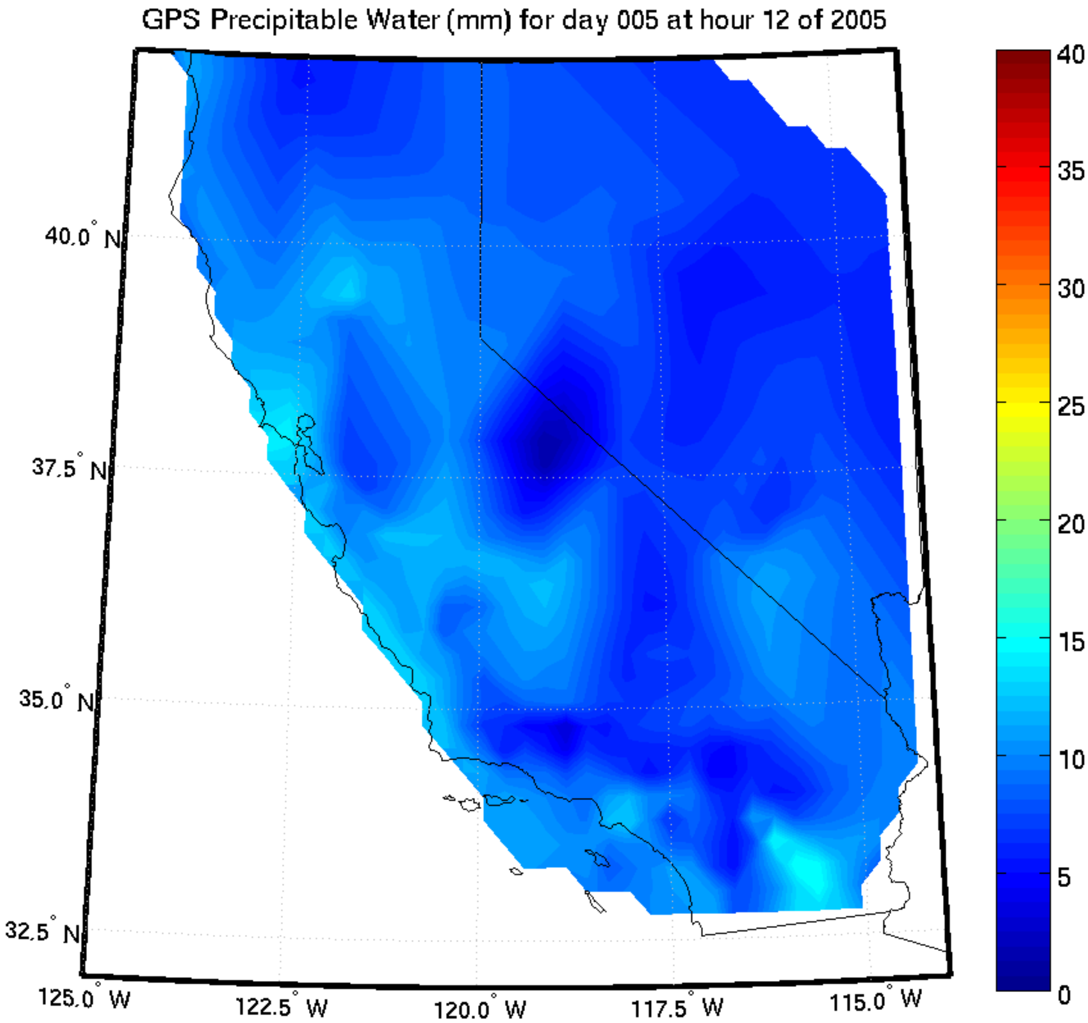

Figure 5. Day -3.5. Initial state, prior to onset of atmospheric river event over Southern California, showing low precipitable water values over entire state.

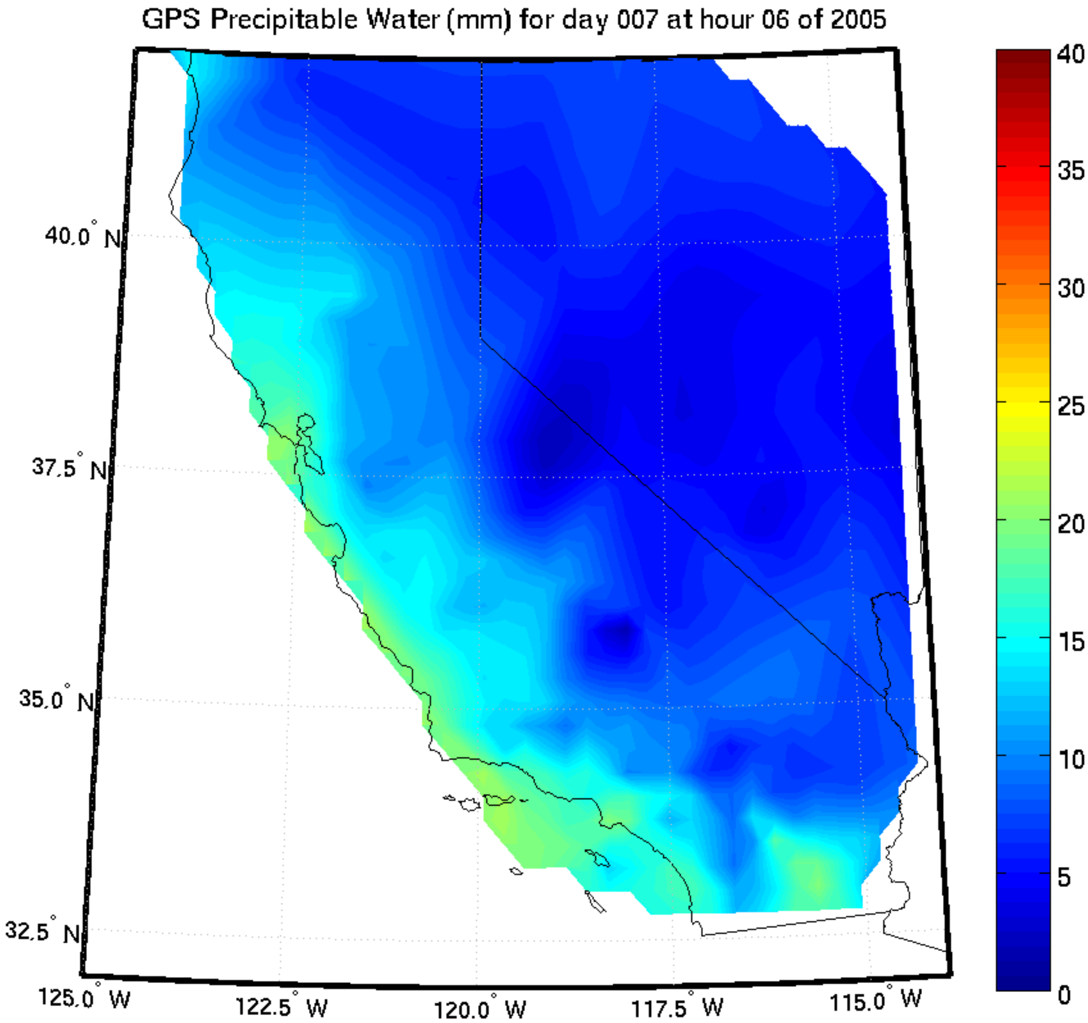

Figure 6. Day -1.7. As atmospheric river impinges on California, air mass moistens from west to east

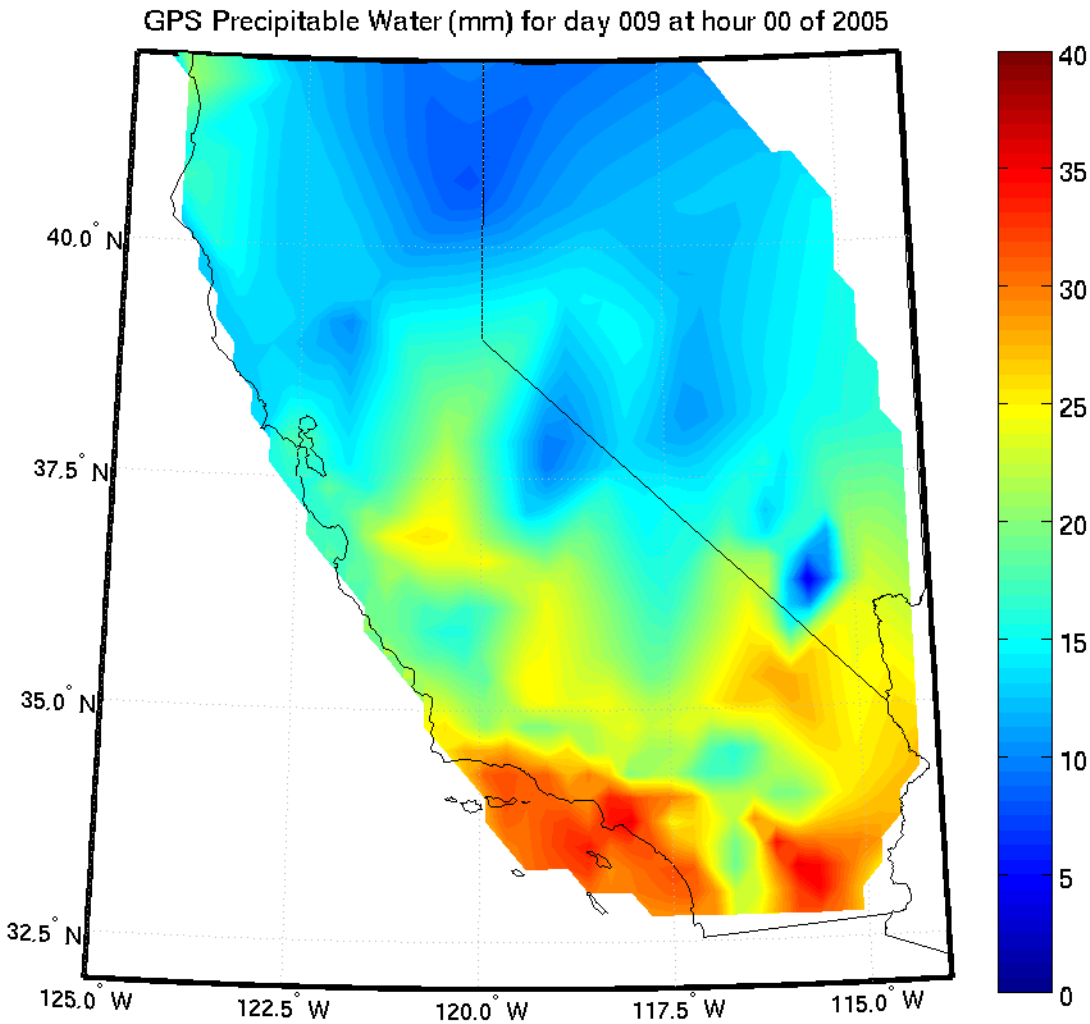

Figure 7. Day 0. At peak of atmospheric river event, precipitable water totals of greater than 25 mm occur across Southern California. Note lower values over peninsular and transverse mountain ranges, where depth of atmospheric column is decreased

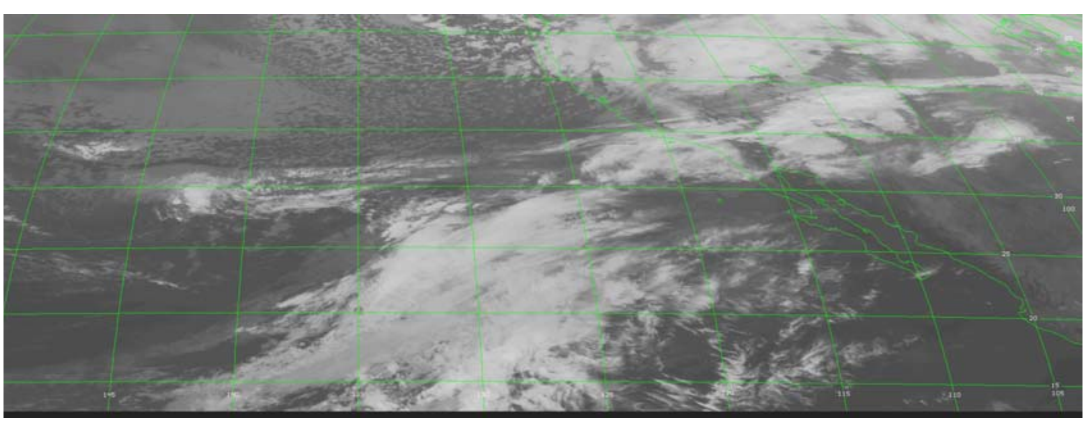

Figure 8. Day 0. IR GOES image taken at approximately the same time as Figure 7, showing moisture streaming from the tropics across Southern California and the West.

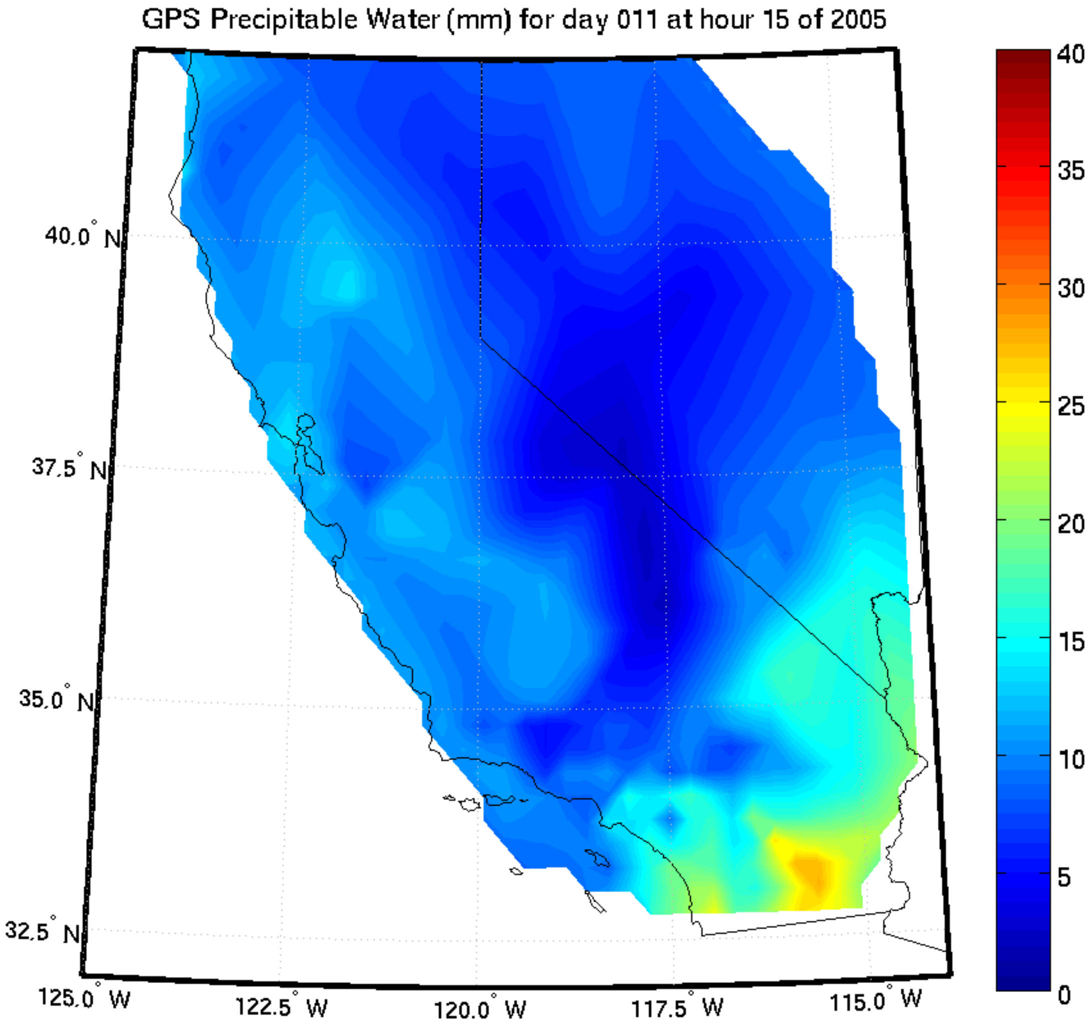

Figure 9. Day +2.6. Atmospheric river exits the region from northwest to southeast, as evidenced by sharp dividing line between moist and drier air

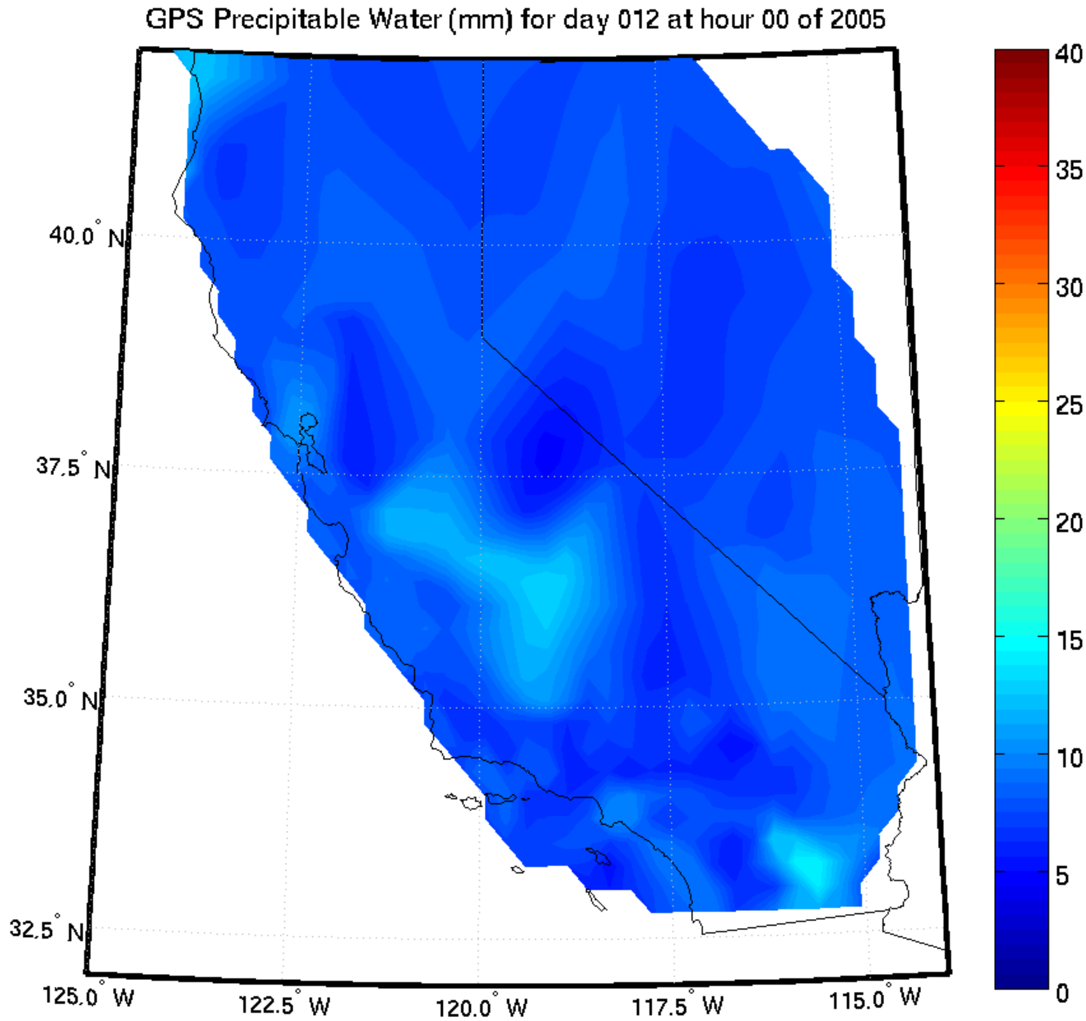

Figure 10. Day +3. Air mass returns to drier state following passage of atmospheric river out of the region

Conclusion and Future Directions

We have previously demonstrated that station pressures interpolated from reanalysis can be used with archived GPS data to generate high-resolution images of precipitable water over California. Under a grant from the San Diego Foundation we are extending this technique to use real-time GPS data and analyses from the 13-kilometer RUC model. We expect to have results from this project within the next six months, and if, as expected, we can generate near real-time precipitable water images we will upload them to a public website and make them available to forecasters, researchers, and emergency planners to determine whether this data enables more accurate forecasts of incipient flooding situations.