National Aeronautics and Space Administration

Densified GPS Estimates of Integrated Precipitable Water Vapor Improve Weather Forecasting during the North American Monsoon

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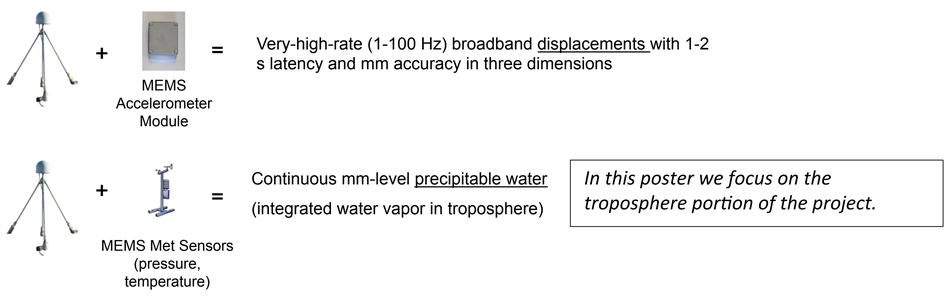
Abstract

Continuous GPS (CGPS) stations for observing crustal motion in the western U.S. now number more than 1200, with over 500 of them operating in real time. Tropospheric wet delay from real-time processing of the GPS data, along with co-located or nearby surface and temperature measurements, are being operationally converted to Precipitable Water Vapor (PWV) for evaluation as a forecasting tool (Gutman, 2011). The available density of real-time GPS in southern California now allows us to explore usage of densified GPS PWV in operational weather forecasting during weather conditions involving moisture extremes. Under a NASA Advanced Information Systems Technology (AIST) project, 37 southern California stations have been added to the NOAA GPS-Met observing network providing 30-minute estimates of PWV for ingestion into operational NOAA weather models, as well as for direct use by National Weather Service forecasters in monitoring developing weather conditions. The densified network proved advantageous in the 2013 North American Monsoon season, allowing forecasters to visualize rapid moisture increases at intervals between model runs and radiosonde observations and assisting in flood watch/warning decisions.

Project concept

In situ geodetic networks for observing crustal motion have proliferated over the last two decades, and many of the stations in California have been converted to real-time (latency <1s) high-rate (1Hz) mode. *We can now envision a prototype real-time network in southern California with approximately 40km spacing, for geodetic and meteorological use.*

Our project, funded under NASA Earth Science Technology Office's Advanced Information Systems Technology (AIST) Program, will implement onsite data fusion of real-time geodetic GPS data with low-cost accelerometer and meteorological data:

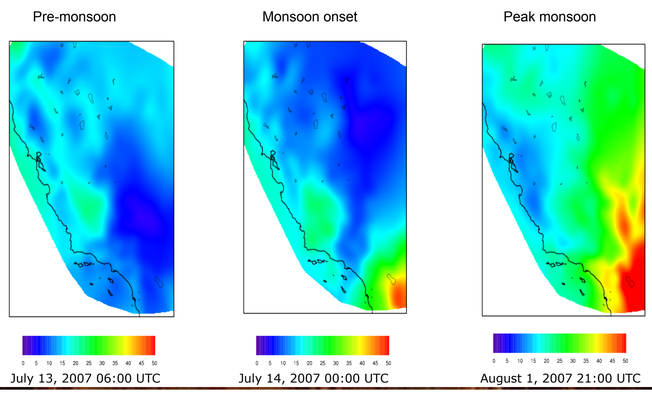


In this poster we focus on the troposphere portion of the project.

Displacements and PWV will be estimated onsite, in contrast to the current paradigm of transmitting raw data back to a central facility for processing. Advantages over the current state-of-the art include a modular design for updating existing real-time GPS stations at low cost, reduction in bandwidth required to distribute products during a natural disaster, and elimination of single points of failure.

Background

Issuing warnings for events that may threaten life and property is a critical role of weather forecasters. Often, the various weather models available to forecasters lack sufficient precision and/or disagree on the details of future weather systems; hence, most decisions to "warn" or "not to warn" are based on real-time data that give the forecaster confidence that a threatening situation has developed or is about to develop. The North American Monsoon, which occurs in summer and brings into southern California a flow of moist air that originates primarily in the Gulf of California, can produce heavy rainfall and dangerous flash flooding. Because Mexico has scarce meteorological observations, and rawinsonde sites in San Diego, Yuma, Phoenix and Las Vegas are too widely spaced to precisely locate the boundaries between moist and dry air aloft, and are launched only infrequently (6-12 hours apart), it is often difficult to forecast the details of monsoon thunderstorms. Precipitable water vapor (PWV) estimates from ground GPS visualize these weather conditions with high temporal resolution (5 to 30 min). and post-processed studies using the dense geodetic network of GPS sites in California have examined monsoon conditions in great detail (Means 2011).

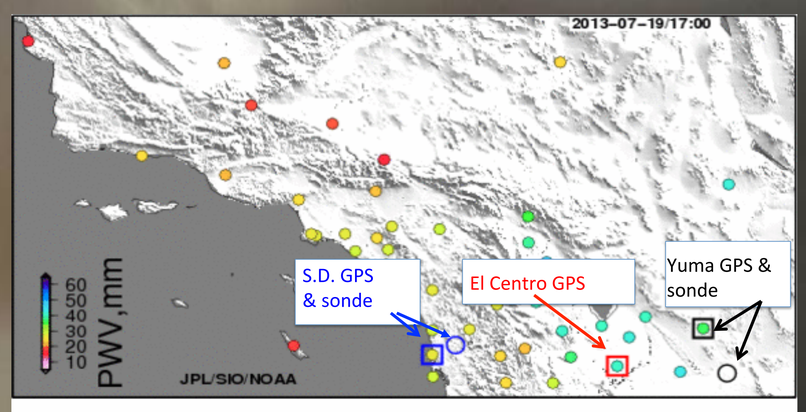


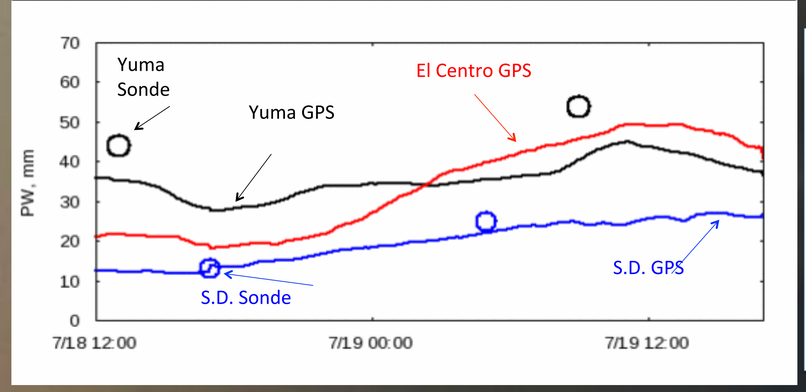
GPS estimates of PWV image the development of the North American Monsoon in southeast California.

Dense regional GPS meteorology testbed

NOAA's Earth System Research Laboratory (ESRL)'s GPS-Met program (http://gpsmet.noaa.gov) has provided 30-minute PWV estimates at about 300 locations nationwide to operational weather forecasters (Gutman et al. 2004) and numerical weather prediction models since 2005 (Smith et al. 2007). We added an additional 37 stations in Southern California to this network as a testbed for the regional use of GPS PWV in weather forecasting. A North American Monsoon event in July 2013 presented an opportunity for NOAA's National Weather Service (NWS) Weather Forecast Offices (WFOs) in San Diego and Los Angeles/Oxnard, as technology infusion partners in the project, to examine the utility of this dataset in their routine forecasting activities.

The southern "tier" of observations available to detect monsoonal moisture arriving from the Gulf of Mexico includes rawinsonde observations at Yuma, AZ and San Diego, CA, as well as about 5 GPS-Met stations in between. Soundings on the afternoon of July 18 indicated that sufficient monsoonal moisture to cause heavy rainfall (above ~35mm) had reached Yuma, but not had not spread west to San Diego. On July 19, the morning San Diego sounding indicated that PWV had increased there, but no morning sounding from Yuma was available. Forecasters were able to use the GPS PWV to characterize the moisture distribution and content in the absence of the Yuma sounding. The GPS dataset also allowed determining the moisture field at higher spatial and temporal resolutions; for example, the rate of PWV increase at El Centro, approximately midway between San Diego and Yuma, began to rise more sharply than at either San Diego or Yuma early on July 19. This information eventually led to the issuance of a Flash Flood Watch prior to many verified flash flooding events.

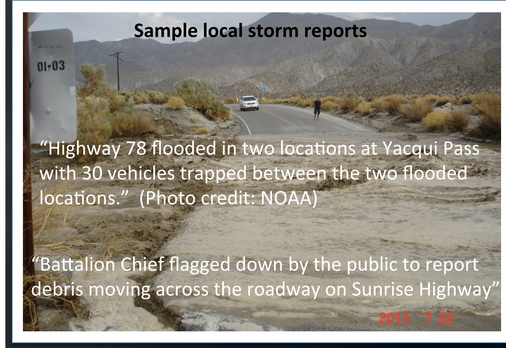


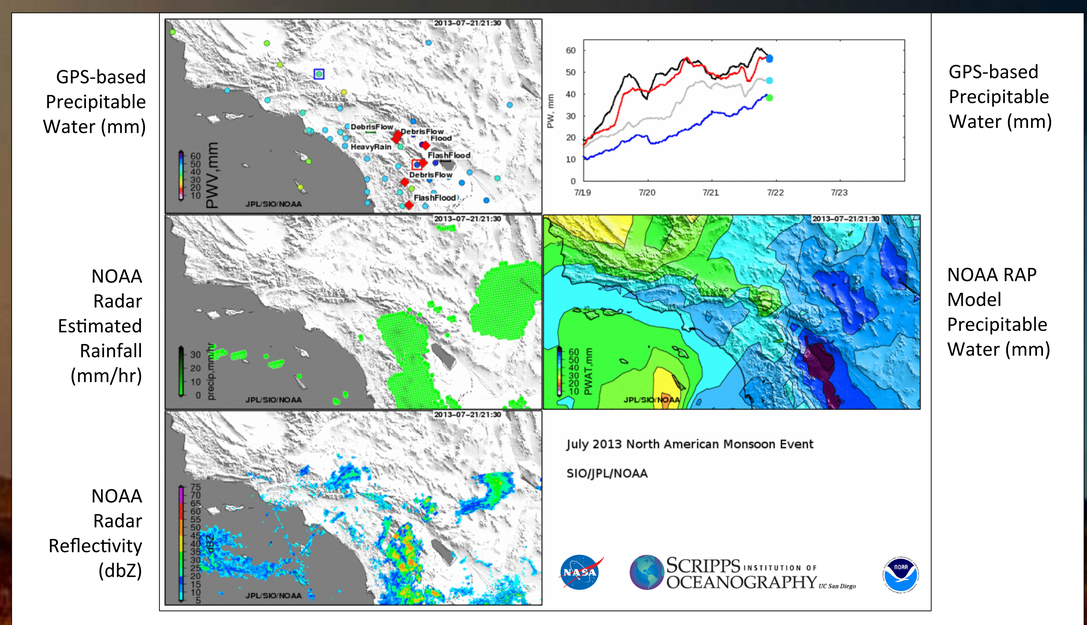


Forecaster remarks from NWS Weather Forecast Office in San Diego

"In order to see the character of the precipitable water values between Yuma and San Diego in the absence of a morning Yuma sounding, the GPS meteorology data was utilized."

"Realtime GPS precipitable water estimates were trending higher over eastern portions of the forecast area… a flash flood watch will be needed for Saturday"





* Ask to see the movie!

Conclusions

GPS PWV assisted southern California weather forecasters in monitoring water vapor and issuing flash flood warnings in a July, 2013 event. Forecasters are collaborating with project scientists to develop thresholds for precipitation onset based on the GPS PWV products, and decision support tools.

Strong thunderstorm with flash flooding near Ludlow, Calif. (Photo Credit: Will Wilkens)

References

Gutman, S.I., S.R. Sahm, S.G. Benjamin, B.E. Schwartz, K.L. Holub, J.Q. Steward, and T.L. Smith (2004), Rapid retrieval and assimilation of ground based GPS precipitable water observations at the NOAA Forecast Systems Laboratory: impact on weather forecasts, *J. Appl. Meteorol. Soc. Jpn* 82, 1B, 351-360

Gutman, S.I., 2011. The Atmospheric River Observatory: an example of a meteorological application of real-time GNSS data. Advances in GNSS Data Applications and Techniques: Real Time GPS Seismology and Beyond II, G33C. AGU Fall Meeting, San Francisco, CA.

Means, J., and D. Cayan (2012): Precipitable Water from GPS Zenith Delays Using North American Regional Reanalysis Meteorology. J. Atmos. Oceanic Technol. 30.3, 485-495. doi:10.1175/JTECH-D-12-00064.z

Neiman, P. J., White, A. B., Ralph, F. M., Gottas, D. J., & Gutman, S. I. (2009). A water vapour flux tool for precipitation forecasting. Proceedings of the ICE-Water Management, 162(2), 83-94.

Smith, T.L., S.G. Benjamin, S.I. Gutman, and S.R. Sahm (2007), Forecast impact from assimilation of GPS-IPW observations into the Rapid Update Cycle, *Mon. Wea. Rev.* 135, 8, 2914-2930.

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