The Use of Airborne GNSS RO Profiles in Mesoscale Forecasts of an Atmospheric River Event

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ABSTRACT

The objective of this research program is to test the hypothesis that dense polarimetric GNSS radio occultation (RO) observations can be used to improve numerical simulations of microphysical processes in storms where it can be critical in forecasting heavy precipitation. Atmospheric rivers (ARs) are one such phenomena that are particularly relevant to the western US, where they pose a significant flood hazard and contribute to the Sierran snowpack which is the foundation of the region's water resources. We collected polarimetric GPS measurements, as well as GLONASS occultation observations, from a heavy precipitation atmospheric river event in February 2015 from the National Oceanic and Atmospheric Administration (NOAA) G-IV aircraft during the CALWATER 2015 field Campaign. Quantifying the onshore moisture transport is a crucial factor in determining the amount of precipitation, and dense airborne radio occultation observations are particularly useful for this purpose because of their high vertical resolution over the ocean.

We use the Advanced Research Weather Research Forecasting model (ARW-WRF; see Skamarock et al. 2008) to simulate the event using the best available reanalyses products and assess the results using available in-situ and remotely sensed observations. In the future this model will provide hydrometeor fields that can be used to estimate the range of expected values of polarimetric delay in the GNSS signals. Simulations will assess the capability of the GNSS observations to distinguish between competing microphysics parameterizations commonly used in mesoscale modeling. Finally, the potential impact of the observations on the forecast will be assessed using an Observation System Simulation Experiment (OSSE). This poster describes the first phase of this work.

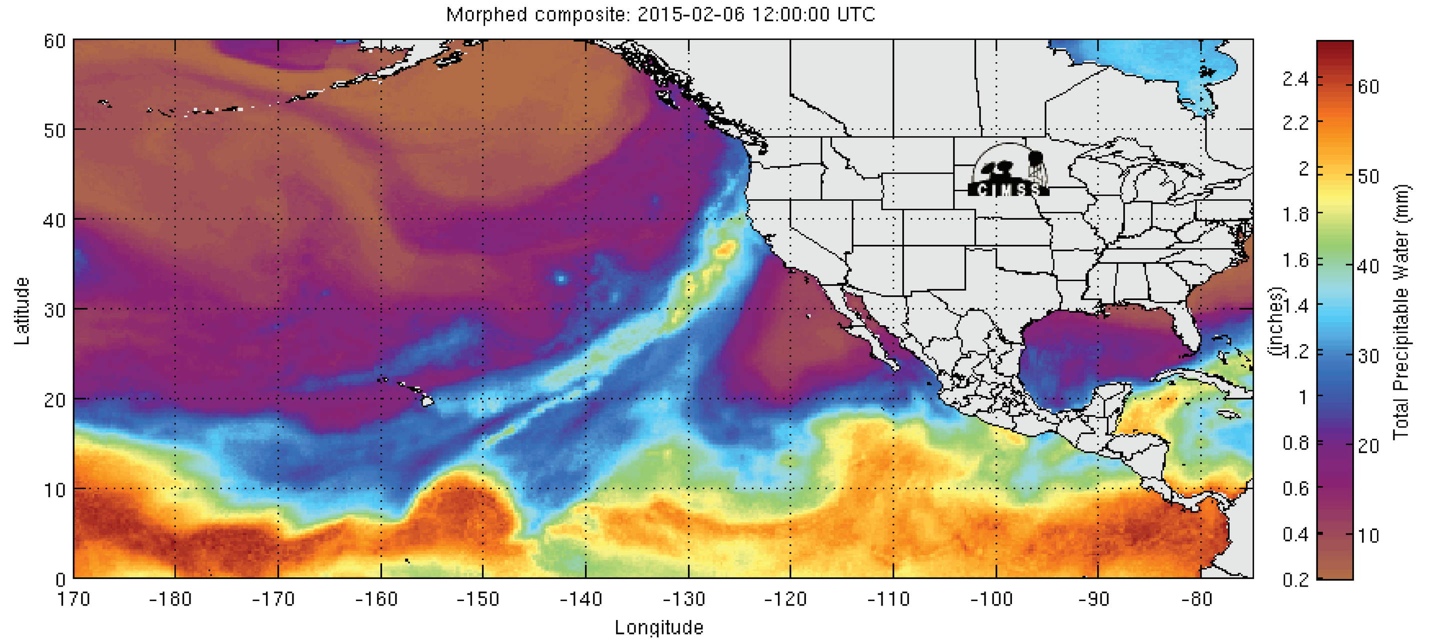
OBJECTIVES

- Investigate advantages of high resolution simulations to account for orographic precipitation, and investigate discrepancies between observed and modeled moisture and precipitation.
- Simulate the 5-7 Feb 2015 atmospheric river event using ECMWF operational analysis as initial and boundary conditions, which assimilates the broadest range of satellite observations.
- Investigate the spatial sampling of radio occultation observations from aircraft flights in relationship to moisture field errors.
- Use these results to plan forecasting experiments to address advantages of improving initial moisture fields and testing microphysics parameterizations.

CALWATER 2015 Campaign

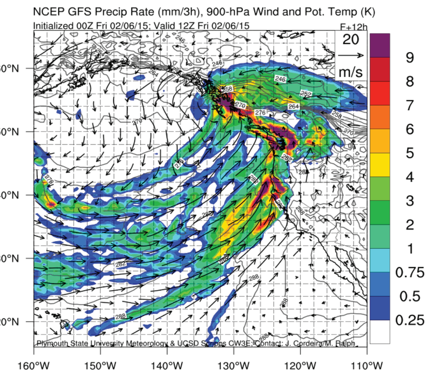
CALWATER 2015 was a multi-agency campaign with participation from NOAA, NASA, DWR, NSF, and the DOE . It is part of a 5 year program to study atmospheric river precipitation and its link with orography and aerosol effects led by PIs Marty Ralph (SIO), Kim Prather (UCSD), Allen White (NOAA), Ruby Leung (DOE-PNNL), Ryan Spackman (NOAA).

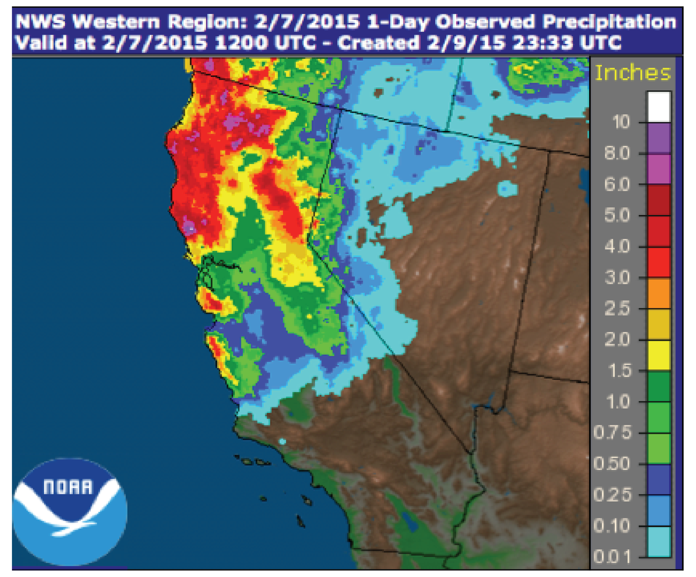
5-8 FEB 2015 ATMOSPHERIC RIVER CASE STUDY



- Accumulated precipitation for 6-7 Feb 2015 was > 8 cm for extensive regions of northern California.
- Precipitation was > 20 cm at select locations in the coastal mountains.

GFS Analysis





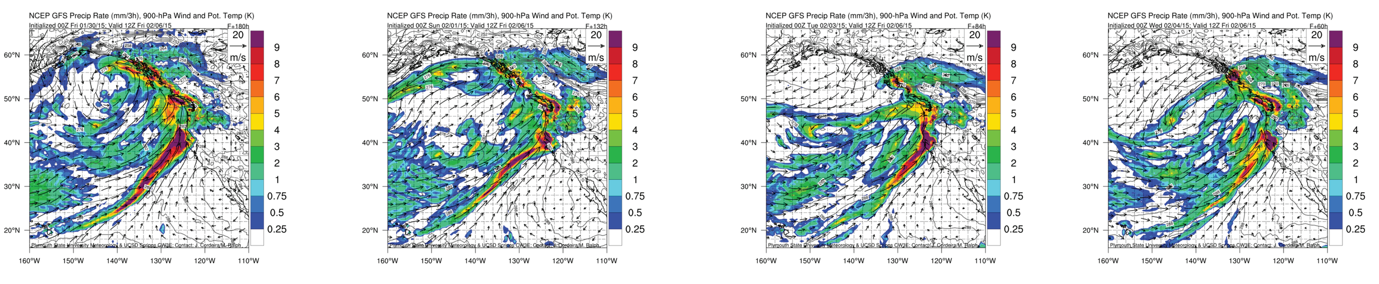
- Global Forecast ensembles did not pick up on probable AR event until 30 Jan 2015.
- Precipitation was overestimated in forecasts until the 60 hour forecast.
- Considerable uncertainty was due to multiple poorly defined low pressure centers and uncertainty in trough position 3.5 days out.

180 Hr Forecast init. 30 Jan 2014 Precip overestimated

132 Hr Forecast init. 1 Feb 2014

84 Hr Forecast init. 3 Feb 2014 Precip overestimated

60 Hr Forecast init. 4 Feb 2014 Precip more accurate



REFERENCES

Haase, J. S., et al. (2014), First results from an airborne GPS radio occultation system for atmospheric profiling, Geophys. Res. Lett., 2014, 40, 1759–1765.

Healy, S. B., et al. (2002), Abel transform inversion of radio occultation measurements made with a receiver inside the Earth's atmosphere, AnGeo, 20, 1253-1256.

Morrison, H., Thompson, G., & Tatarskii, V. (2009), Impact of cloud microphysics on the development of trailing stratiform precipitation in a simulated squall line: Comparison of one-and two-moment schemes. Monthly Weather Review, 137(3), 991-1007.

Skamarock, W.C., et al. (2008), A description of the Advanced Research WRF Version 3 NCAR Tech. Note 475 STR, 113 pp.

Xie, F., et al. (2008), Profiling the Atmosphere Using the Airborne GPS Radio Occultation Technique: A Sensitivity Study, Trans. IEEE Geosci. and Remote Sens., 46, 3424-3435.

OBSERVATIONS FROM RADIO OCCULTATION

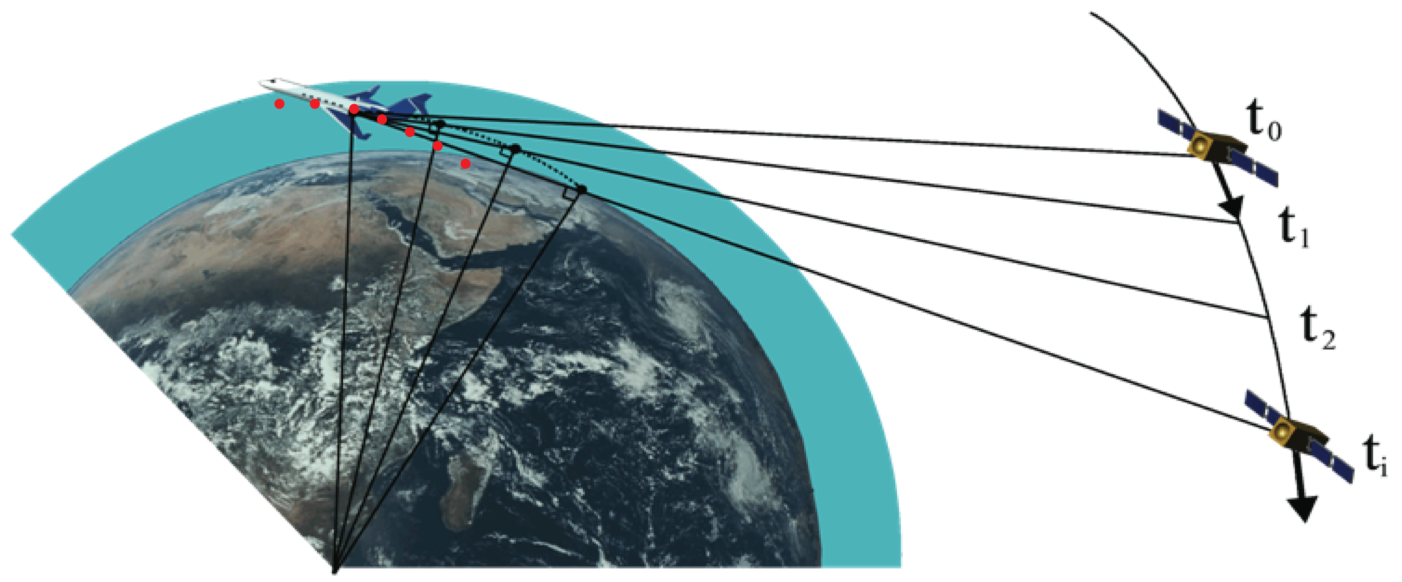
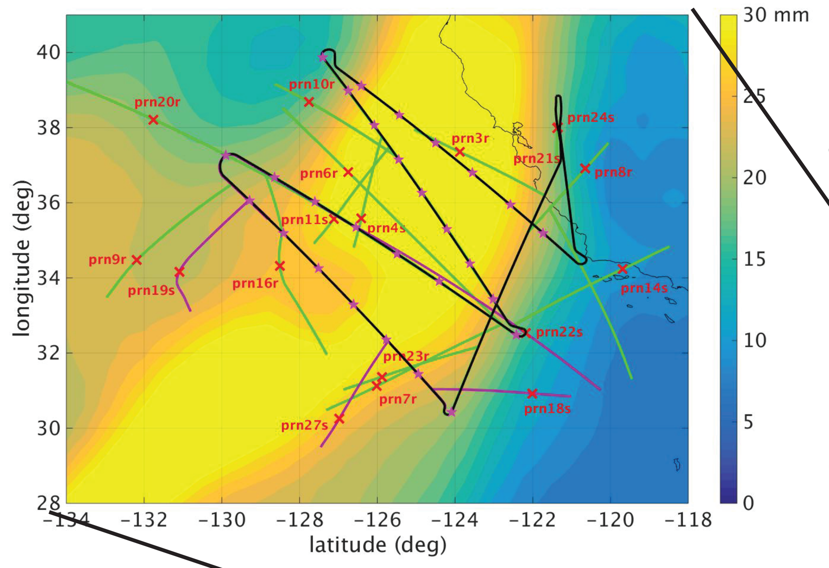
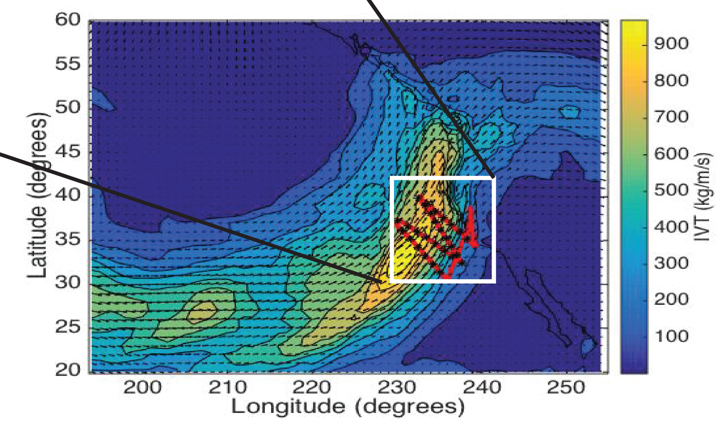


Illustration of GPS signal ray paths through the atmosphere from an occulting satellite setting below the horizon, and the tangent points of the ray paths (red), for the airborne GNSS Instrument System for Multistatic and Occultation Sensing (GISMOS) (Haase et al., 2014). The line of sight to the GPS satellite initially has a positive elevation with respect to the horizon, then a negative elevation angle below the horizon, until it sets. When the ray is refracted in the atmosphere, under the approximation of spherical symmetry, the path can be defined by a bending angle, and is observed through the excess Doppler shift of the GPS signal carrier phase. The bending angle can be related to refractivity using geometric optics (Kursinski et al., 2000; Healy et al., 2002; Xie et al., 2008; Haase et al., 2014).



Left: NOAA GIV flight trajectory (brown line) and dropsonde locations (pink stars) over TPW from model reanalysis. The occultation tangent points drift along the green curves away from the aircraft trajectory as the occulting GPS satellite sets. Pink curves are rising satellite occultations. 500 hPa tangent point location (red x) is labeled with the occulting satellite prn number. Below: 1800 UTC 06 Feb 2015 GFS analysis Integrated Vapor Transport (IVT).



ARO METHOD

- The Doppler shift is used to calculate bending angle *(α)* as a function of impact parameter *(a)*, a constant that describes the ray path, assuming a spherically symmetric atmosphere where refractive index (*n*) varies with radius *(r)* (Vorobe'ev and Krasilnikkova 1994).

$$a = n_t r_t = n_R r_R \sin(90 - el_R) = n_T r_T \sin(90 - el_T)$$

- The bending angle is converted to refractive index *(n)* using a modified inverse Abel transform (Fjeldbo, 1971) where the bending accumulated below the receiver height (r_R) is given by $\alpha_N(a)$-$\alpha_P(a)$ (Xie et al. 2008).

$$n(a) = n_r \exp\left[\frac{1}{\pi}\int_{x=a}^{n_R r_R} \frac{\alpha_N(x) - \alpha_P(x)}{\sqrt{x^2 - a^2}}dx\right]$$

- Refractivity *(N)* is a function of pressure *(P)*, temperature *(T)*, and water vapor pressure *(e)* data (Rueddiger 2002) and this equation can be used to compare model and dropsonde data or model fields to ARO observations.

Atmospheric Refractivity

$$N = (n-1)\times 10^6 = \frac{77.6439P}{T} - \frac{6.938e}{T} + \frac{3.75463\times 10^5 e}{T^2}$$

ACKNOWLEDGEMENTS

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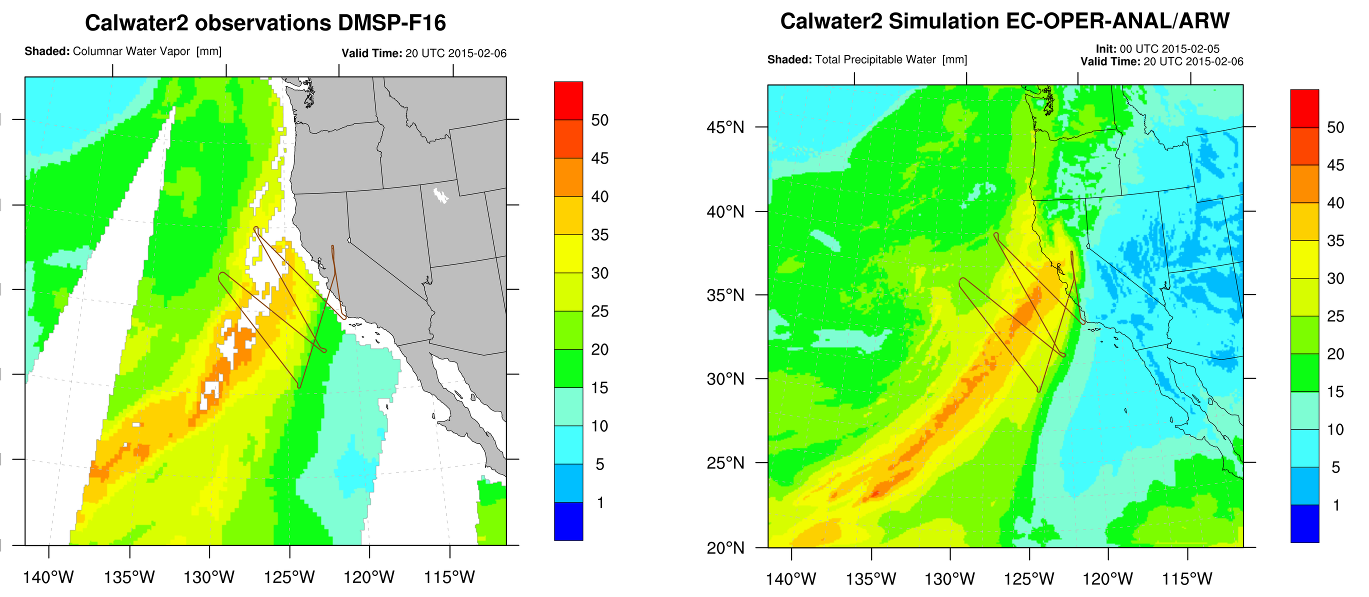
MESOCALE SIMULATIONS

Configuration of the ARW-WRF model

- system of nested grids with horizontal resolutions of 9 and 3 km.
- WRF Single-Moment 6-class microphysical scheme (Morrison et al., 2009).
- initial and boundary conditions from the ECMWF operational analysis.
- period of simulation from 0000 UTC 05 February to 1800 UTC 08 February 2015.

Simulation of Water Vapor

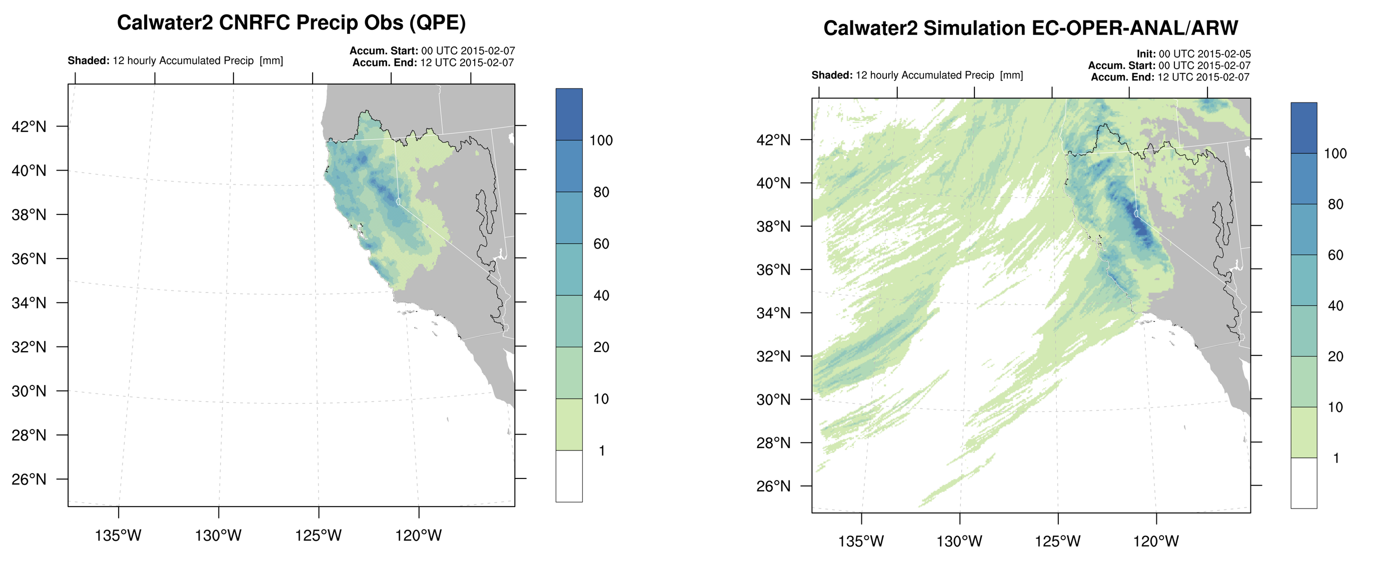
The figures below highlight deficiencies in the WRF models simulation of both the pattern and magnitude of the precipitable water (PW) field. Assimilation of the airborne GPSRO observations into the model have the potential to correct these deficiencies.



Above Left: Observations of total precipitable water (PW) using the SSMIS sensor aboard the DMSP-F16 satellite at approximately 2000 UTC 06 Feb 2015. White areas include areas within the atmospheric river where high rain rates made water vapor retrieval unreliable. *Above Right:* Forecast of PW from the WRF model also at 20 UTC 2015-02-06. The flight trajectory is overlain in brown in both plots.

Simulation of Precipitation

The figures below show that the spatial distribution of precipitation from the WRF simulation (right) is very similar to the observed precipitation (left). However, precipitation is overpredicted in the Sierra Nevada and underpredicted in the coastal ranges and northern Central Valley.



CONCLUSIONS AND FUTURE WORK

- The ECMWF operational analysis was used for initial conditions for a WRF simulation of the 5-7 Feb 2015 event because of its higher resolution.
- The high resolution WRF mesoscale simulations of the event captured the AR responsible for the moisture transport, but inadequately represented the pattern and magnitude of the precipitable water (PW) field, as shown by the SSMIS observations.
- The spatial distribution of precipitation was forecast well, however rainfall amounts were overpredicted in the Sierra Nevada and underpredicted in the coast ranges and the Central Valley.
- The sampling of the airborne GNSS observations suggests that the data collected during the event may improve the moisture distribution and forecast precipitation in mesoscale simulations.