Using rapid radiosonde launches during extreme changes in water vapor transport during atmospheric river events to optimize ground-based GPS ZTD solutions

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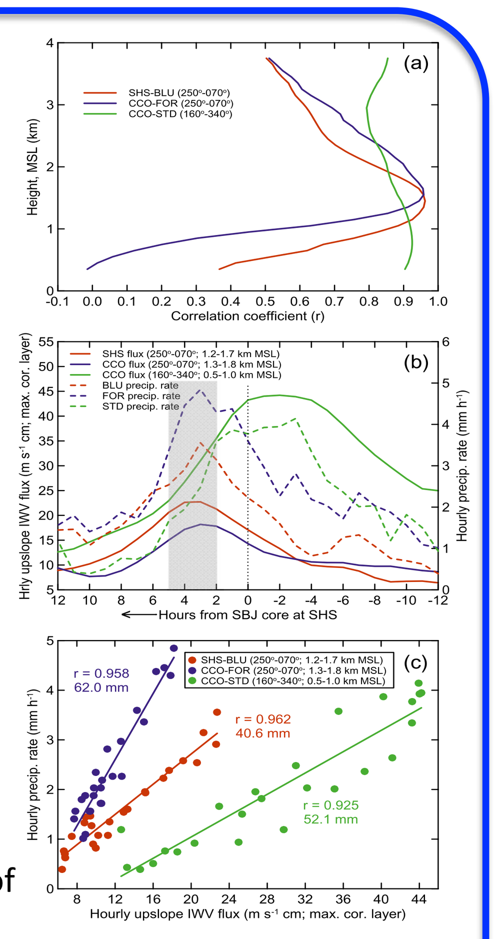
Abstract

Low level water vapor transport over the California coastal mountains has been shown to be highly correlated with the maximum precipitation in the coastal mountains in wintertime Pacific storms, where the dynamics are dominated by a low level jet ahead of the cold front associated with a mid-latitude cyclone (Neiman et al., 2013). In these cases with relatively simple dynamics driven by the orographic precipitation mechanism, water vapor transport can be quantified as the integrated water vapor multiplied by the mean wind speed in the controlling layer at approximately 1 km above the surface. Here we investigate how closely ground-based GPS measurements can track the rapid acceleration and deceleration of onshore moisture flow by comparing them to a unique dataset of rapidly launched radiosondes in several atmospheric river (AR) events in January and February 2017 carried out by the Center for Western Weather and Water Extremes (CW3E). In particular, we focus on an increase in ZTD corresponding to 16 mm of Integrated water vapor (IWV) over 21 hours on February 7 was measured the day the damage to the spillway at Oroville Dam in northern California was detected. (https://ww2.kqed.org/news/2017/02/07/engineers-assess-spillway-problem-at-oroville-dam)



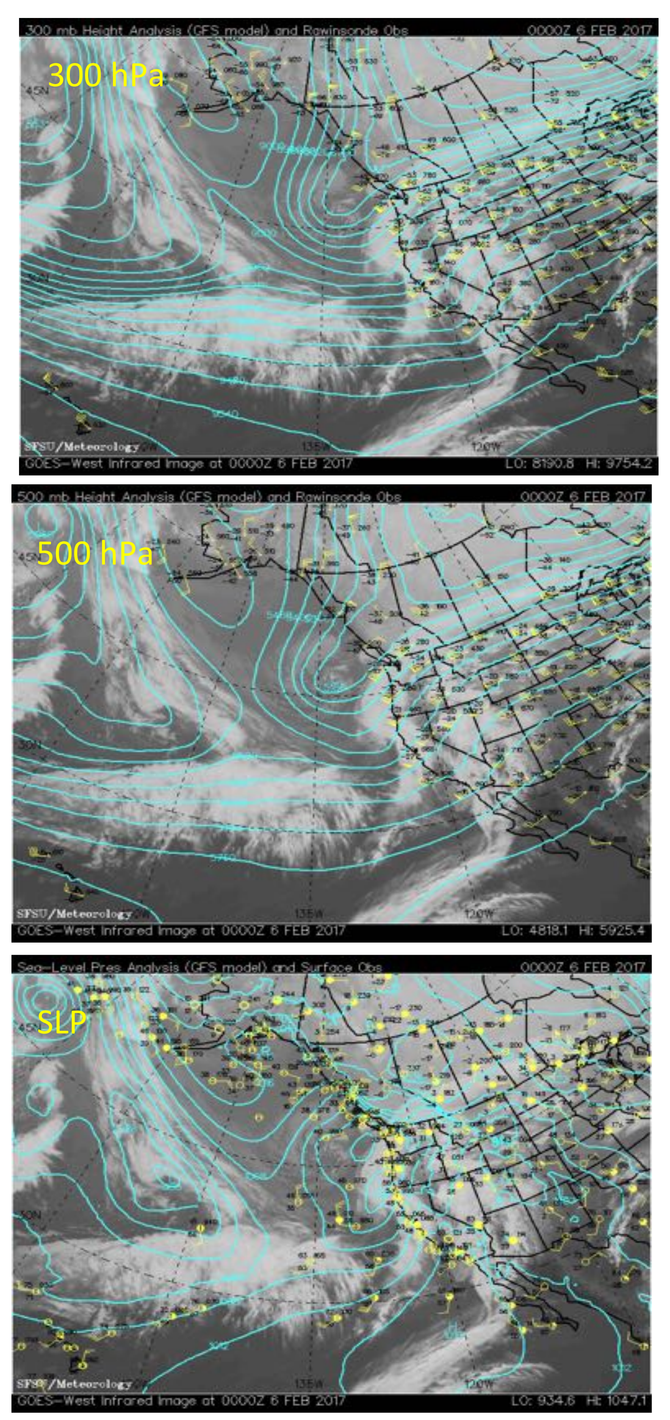
Correlation between IWV flux and precipitation rate over the time +/- 12 hours of the IWV maximum for a composite of 13 AR cases (Neiman et al., 2013).

Objectives

- Investigate the GPS data analysis options that impact rate of change of IWV
- Optimize the GPS data analysis options using 3 hourly radiosondes launches
- Review empirical relations among IWV, upslope water vapor flux, and precipitation
- Examine the sensitivity of topographic precipitation estimates to GPS IWV accuracy

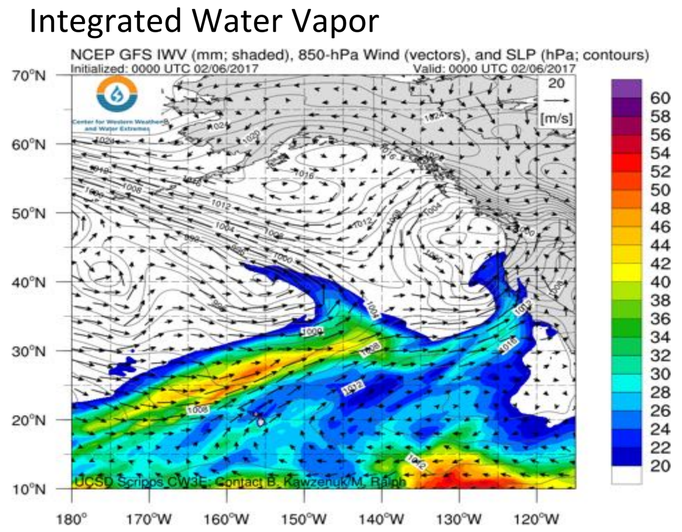
The results may be used to assess the value of dense observations of GPS ZTD available in California for real-time verification at hourly time resolution for atmospheric river events that would provide increased confidence in short term precipitation forecasting.

Synoptic situation

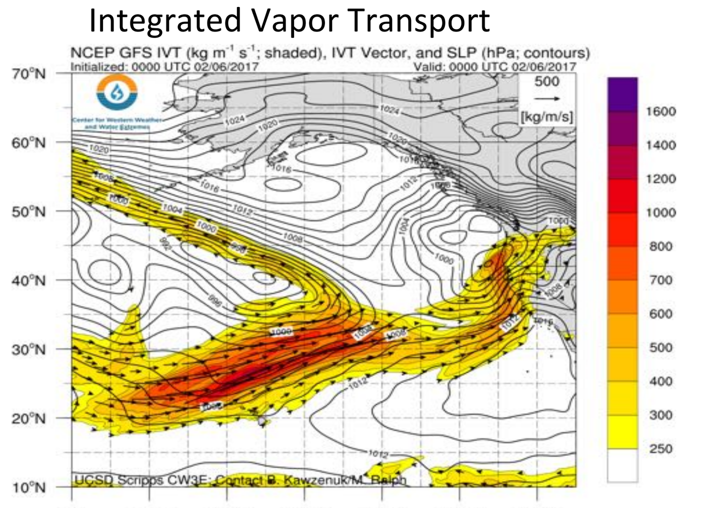


The synoptic situation on 6 February 2017 is shown below. A sequence of several consecutive low pressure centers directed moisture into northern California. This event had a typically long duration precipitation contributing to the overflow at Oroville Dam.

Integrated Water Vapor



Integrated Vapor Transport



GPS and radiosonde observation sites

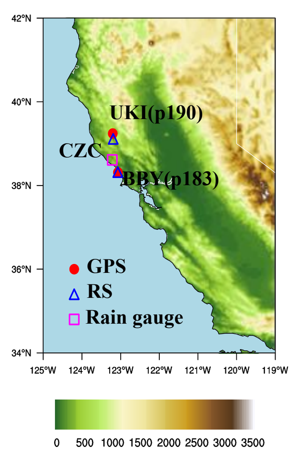


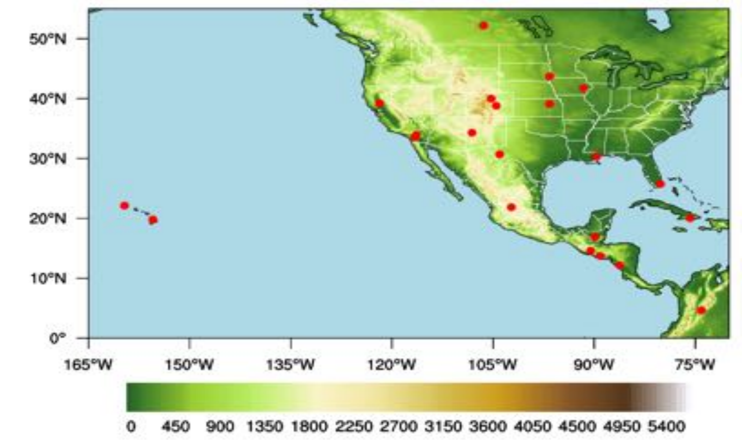
Table1 locations and equipment of RS observations

Site	Lat (°)	Lon (°)	Altitude MSL (m)	RS type	Combined Uncertainty in sounding P (hPa) >100hPa	T (°C)	RH (%)
UKI1	39.160	-123.194	182	Vaisala RS-41	1.0	0.3	4%
UKI2	39.113	-123.192	176	RS-41	1.0	0.3	4%
BBY	38.319	-123.072	13	RS-41	1.0	0.3	4%

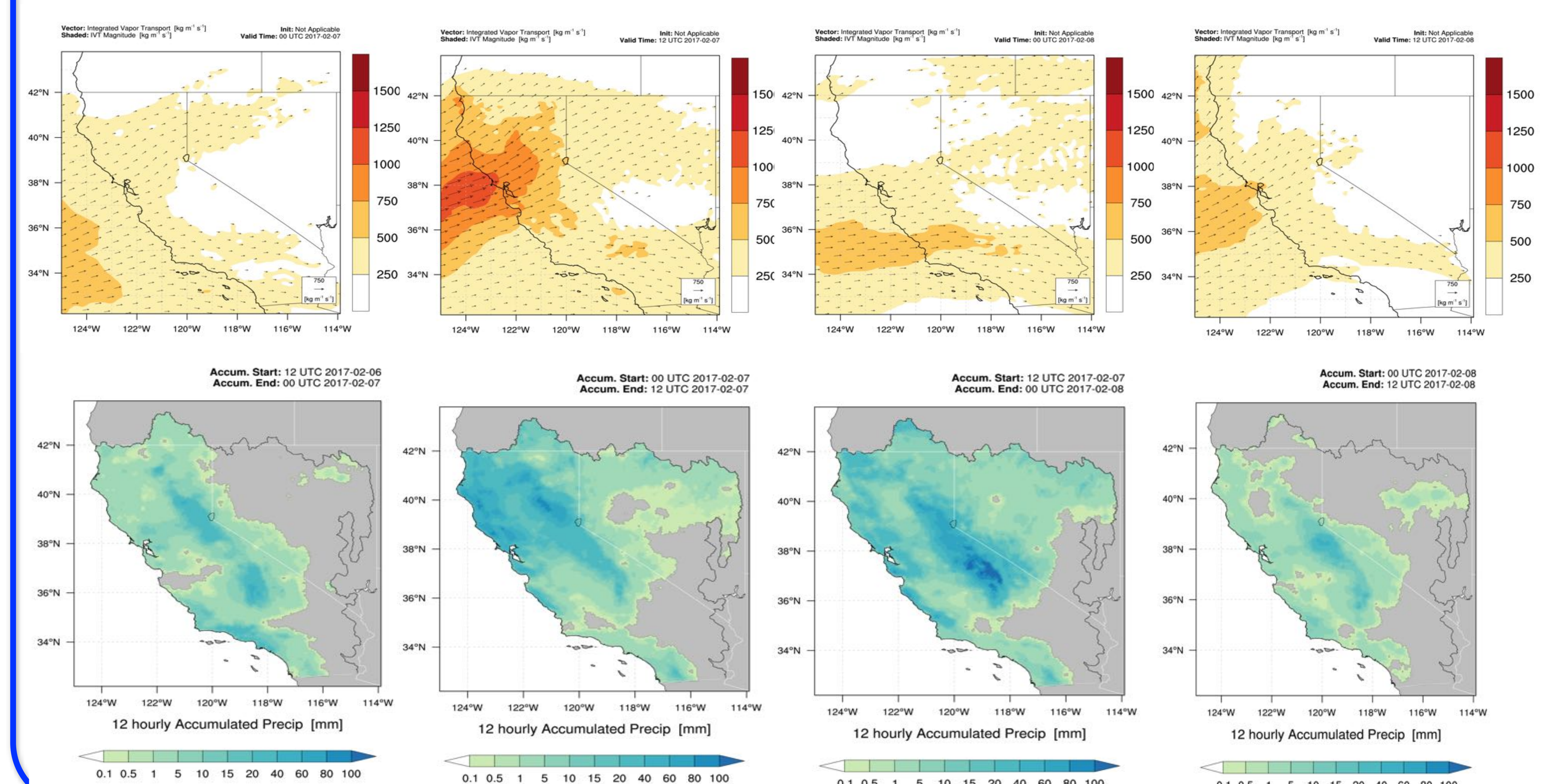
Table2 locations and equipment of GPS observations nearby RS sites

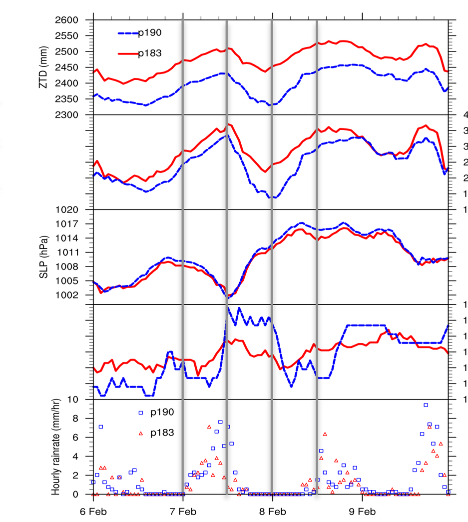
No.	Lat (deg)	Lon (deg)	AMSL (m)	REC	ANT	Dome	Corresponding RS site
P190	39.242	-123.204	232.2	TRIMBLE NETRS	TRM29659.00	SCIT	UWTP,UWWP
P183	38.314	-123.069	42.4	TRIMBLE NETR9	TRM29659.00	SCIT	BBML

GPS reference network



Rapid changes in onshore moisture transport





(1) We assume that upslope towards CZC is the same as what is observed at BBY.
(2) CZC has a rain radar which presents the possibility for further detailed work.

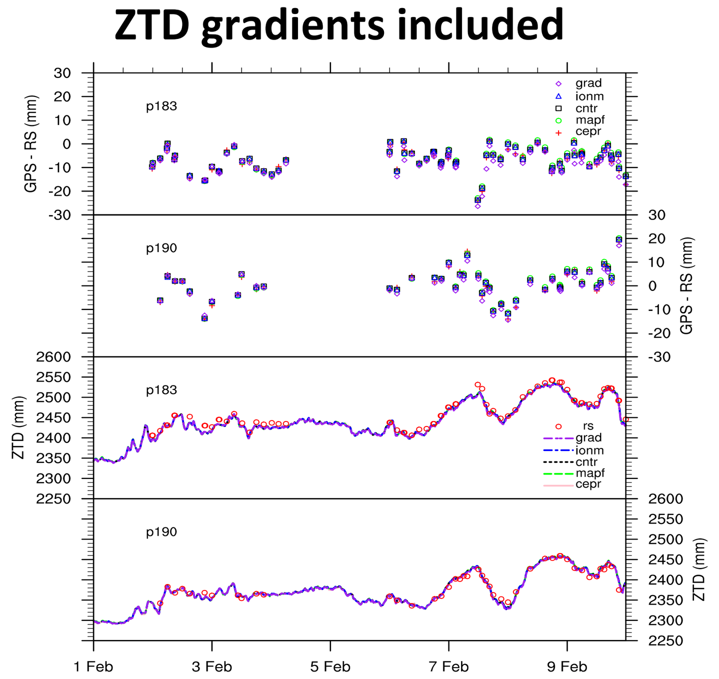
Sensitivity testing in GAMIT GPS data analysis

Parameters that must be chosen in the GPS data analysis method may have an impact on the time resolution of rapid changes in Zenith Tropospheric Delay (ZTD) solution and IWV:

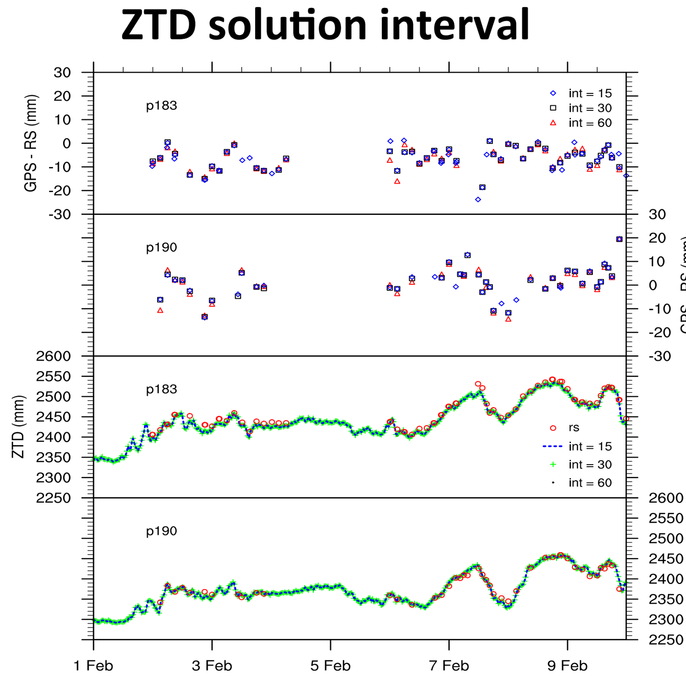
1) ZTD variance constraint balances how rapidly changes can occur against data fit.
2) ZTD solution interval (15, 30 or 60 min)
3) Solution to include ZTD gradient to account for spatial variations in moisture above a site.

Para.\name	cntr	cexp	mapf	Ionm	Grad	Zv01	Zv02	Zv03	Zv04	Zc01	Zc02
Choice of experiment	Relax	**Baseline**	Relax	Relax	Relax	Relax	Relax	Relax	Relax	Relax	Relax
Zenith delay constraints (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.25**	**0.75**
Zenith delay variation (m/sqrt(hr))	0.02	0.02	0.02	0.02	0.02	**0.005**	**0.01**	**0.05**	**0.10**	0.02	0.02
Atmospheric horizontal gradients	none	none	none	none	**yes**	none	none	none	none	none	none
Dry map function	GMF	GMF	**VMF1**	GMF	GMF	GMF	GMF	GMF	GMF	GMF	GMF
Wet map function	GMF	GMF	**VMF1**	GMF	GMF	GMF	GMF	GMF	GMF	GMF	GMF
Ion model	GMAP	GMAP	GAMP	**NONE**	GMAP	GMAP	GMAP	GMAP	GMAP	GMAP	GMAP
orbit	Final	final	final	final	final	final	final	final	final	final	final

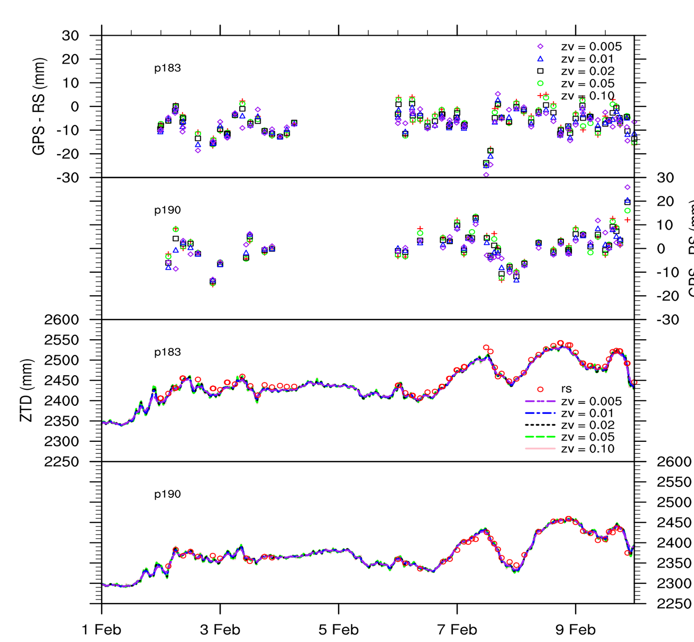
ZTD gradients included



ZTD solution interval

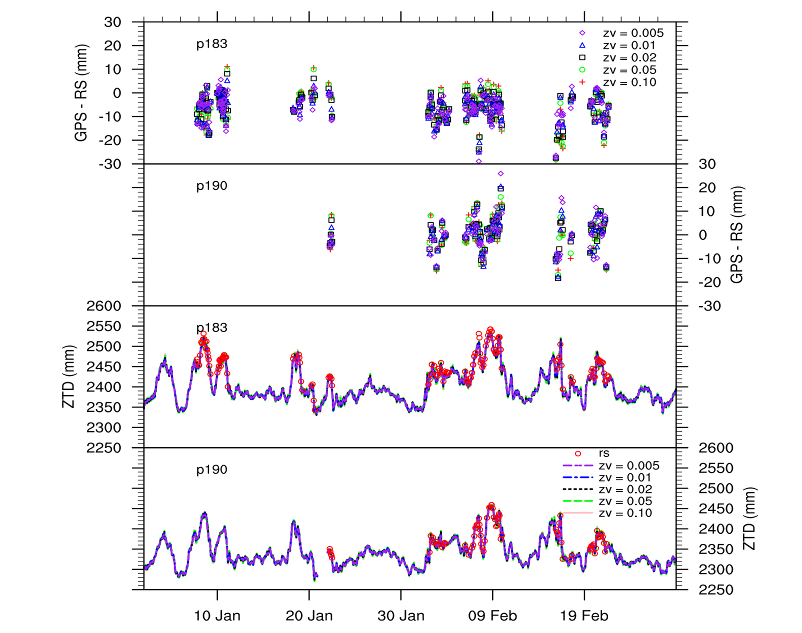


ZTD variance constraint



All tests were implemented with 15-min ZTD interval, 10-degree elevation cutoff, 24-hr sliding window, and SOPAC dynamic reference frame.

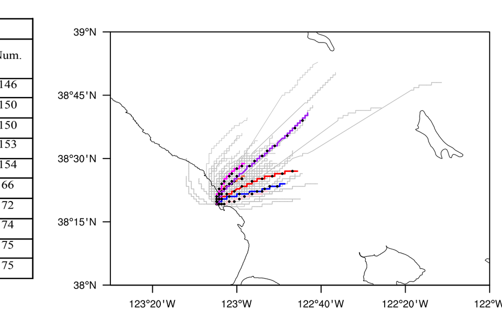
GPS ZTD comparison with radiosondes



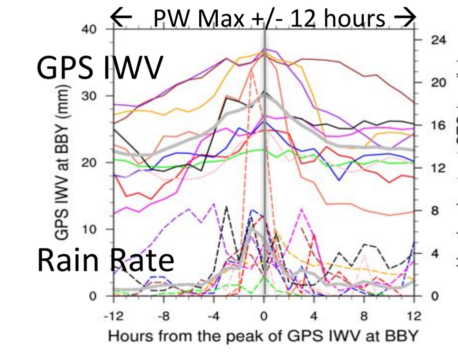
Time series of GPS ZTD (lines, lowermost two panels) and its difference compared with radiosonde (RS) (top two panels) at p183 and p190 for the time span from 2 Jan–28 Feb 2017. For GPS ZTD analysis, test of the zenith variation (ZV) with values of 0.005, 0.01, 0.02 (reference), 0.05 and 0.1 per sqrt (h) are presented. Equivalent ZTD from RS data in spring are represented by red circles.

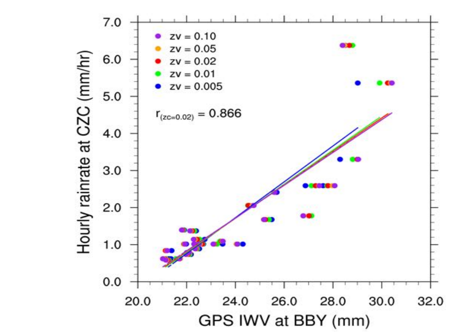
Table 3 Error of GPS ZTD with different values of zenith variation constraint (zv), i.e. different scheme minus control (Cntr) scheme and GPS minus radiosonde at sites p183 and p190 from 2 Jan to 28 Feb, 2017

Site	Schem. Zv (m)	Schem. vs. Control (mm) bias	rms	Person Corr.	Num.	GPS vs. RS (mm) bias	rms	Person Corr.	Num.
P183	0.10	0.01	1.54	1.00	5568	-5.42	5.54	0.989	146
	0.05	-0.01	1.13	1.00	5568	-5.39	5.25	0.990	150
	0.02	–	–	–	–	-5.46	4.63	0.992	150
	0.01	-0.01	1.18	1.00	5568	-5.80	4.65	0.992	153
	0.005	-0.08	2.85	1.00	5568	-6.15	4.78	0.992	154
P190	0.10	0.03	1.46	1.00	5424	0.30	6.63	0.986	66
	0.05	0.02	1.08	1.00	5424	0.40	6.70	0.985	72
	0.02	–	–	–	–	0.45	6.53	0.985	74
	0.01	-0.04	1.01	1.00	5424	0.39	6.65	0.981	75
	0.005	-0.10	2.37	1.00	5424	0.23	7.14	0.977	75



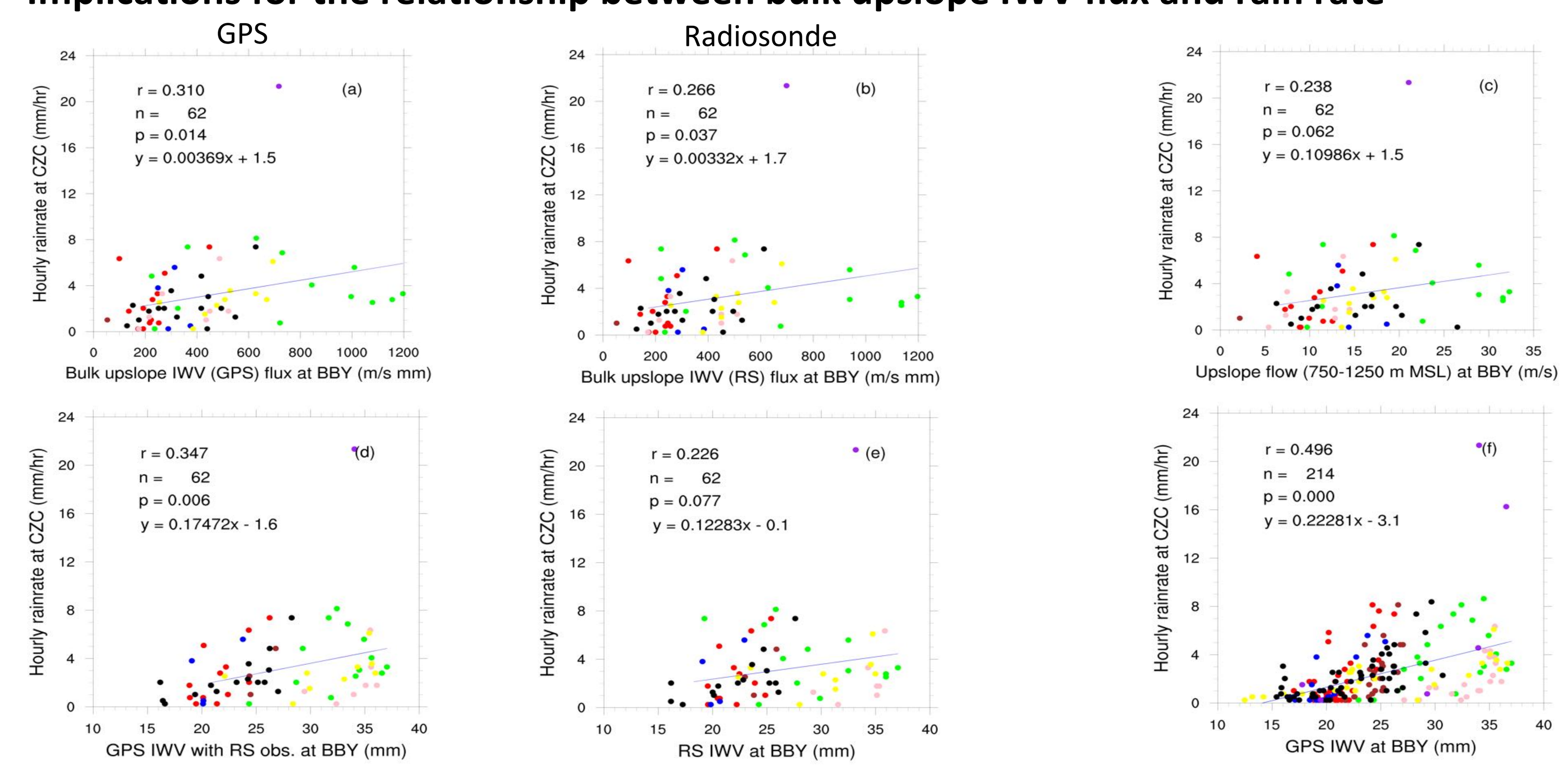
Composite of 10 rainfall events





Correlation of composite PW and precipitation as a function of time as in Neiman et al., 2013. Slope predicting precipitation is affected by ZTD constraint.

Implications for the relationship between bulk upslope IWV flux and rain rate



Correlation of GPS derived PW and upslope IWV flux with rain rate is stronger than that derived from radiosondes during rainfall events. The key is to identify that an event is underway, which limits use as a predictive tool. However, GPS IWV and expanded GPS ZTD dataset would provide added value for real-time verification and data assimilation.

Conclusions

- A ZTD variance constraint of 0.02 m/sqrt(hr) best captures the rapid ZTD changes associated with AR events without introducing spurious variations.
- Peak values are overestimated by radiosondes possibly because of strong upslope winds blowing them into higher IWV areas.
- Little difference is seen in GPS ZTD solutions that include gradients.
- A shorter solution interval of 15 min provides small improvements over larger intervals.
- Using the optimal GPS ZTD variance increases the correlation of GPS IWV with radiosonde IWV and also the correlation of bulk upslope IWV flux with hourly rain rate.

References

Neiman, P. J., Hughes, M., Moore, B. J., Ralph, F. M., & Sukovich, E. M. (2013). Sierra barrier jets, atmospheric rivers, and precipitation characteristics in Northern California: A composite perspective based on a network of wind profilers. Monthly Weather Review, 141(12), 4211-4233.

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Acknowledgements

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