Calibrating Spaceborne Microwave Radiometers with GPS

Bruce Haines (Bruce.Haines@jpl.nasa.gov), Yoaz Bar-Sever, Shailen Desai

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, U.S.A.

Abstract

Data from terrestrial GPS receivers are being used in growing numbers of applications requiring precise tropospheric sensing. One emerging application is the calibration of water vapor measurements from spaceborne microwave radiometers. An excellent candidate mission for developing this technology is TOPEX/POSEIDON (T/P). A joint U. S./France mission launched in 1992 to measure global ocean circulation and sea level, T/P carries a microwave radiometer to provide measurements of wet path delay with cm-level accuracy. The nadir-looking TOPEX microwave radiometer (TMR) was included to provide a columnar water vapor delay correction for the altimeter range measurements used in forming the sea-surface height measurements. As such, any spurious drift in the TMR measurements can map significantly into the estimated rate of change in global mean sea level from T/P.

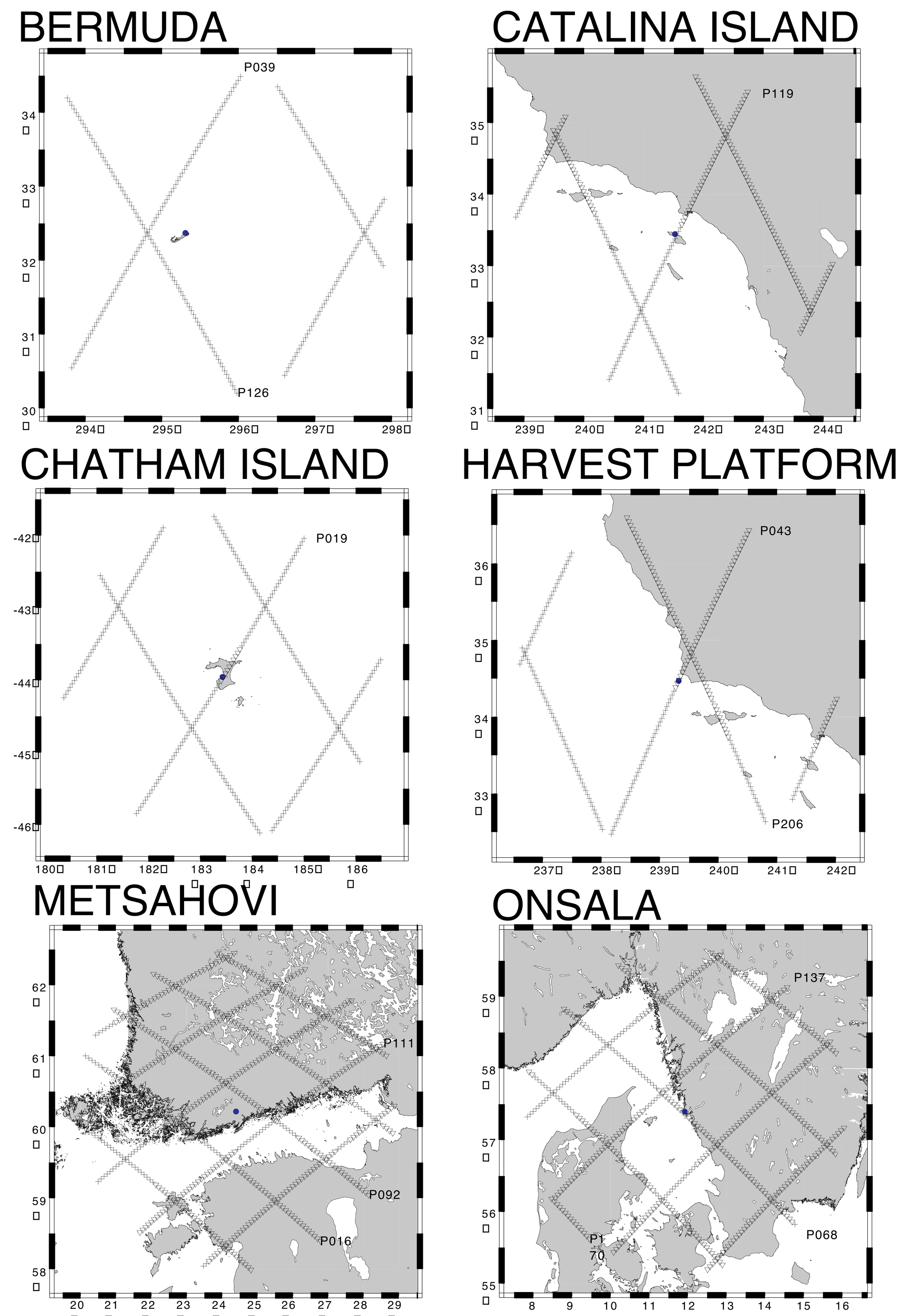
By virtue of their proximity to open-ocean T/P repeat tracks, many stations in the rapidly growing GPS global network are well suited for monitoring the TMR. For these locations, we are constructing time series based on the differences of the instantaneous vertical wet path delay derived independently from the TMR and GPS data at T/P overflight times. Using data from four GPS stations with the longest and most consistent tracking histories, we concluded that the TMR measurements of wet path delay drifted lower by 1 mm/yr from 1992-97 [*Haines and Bar-Sever*, 1998]. We discuss the challenges encountered in using these long-term GPS time series as a calibration tool. We also present new TMR drift and scale error estimates from an extended analysis incorporating additional GPS stations. Finally, we discuss plans and prospects for calibrating the radiometer on the T/P follow-on mission (Jason-1), scheduled for launch in May, 2000.

Calibration Sites

At the foundation of the calibration technique are satellite overflights of coastal and island GPS stations. In the current analysis, we use GPS data collected at six stations, four of which have occupation histories dating back to 1991–93. Maps of the GPS site locations in relation to the T/P repeat ground tracks are given at the top of the adjacent column. The repeat period of the T/P orbit is 10 days; thus, each site is visited at least 36 times per year. In fact, four of the six sites are visited much more frequently because they are located near two or three different T/P repeat ground tracks.

The footprint of the three-frequency TMR has a diameter of ~40 km. Owing to the intrusion of land in the footprint, TMR data collected at the point of closest approach (PCA) to certain GPS stations may be not be reliable. In these cases, we use TMR data from the nearest "open-water" PCA, defined to be no less than 30 km from the shore.

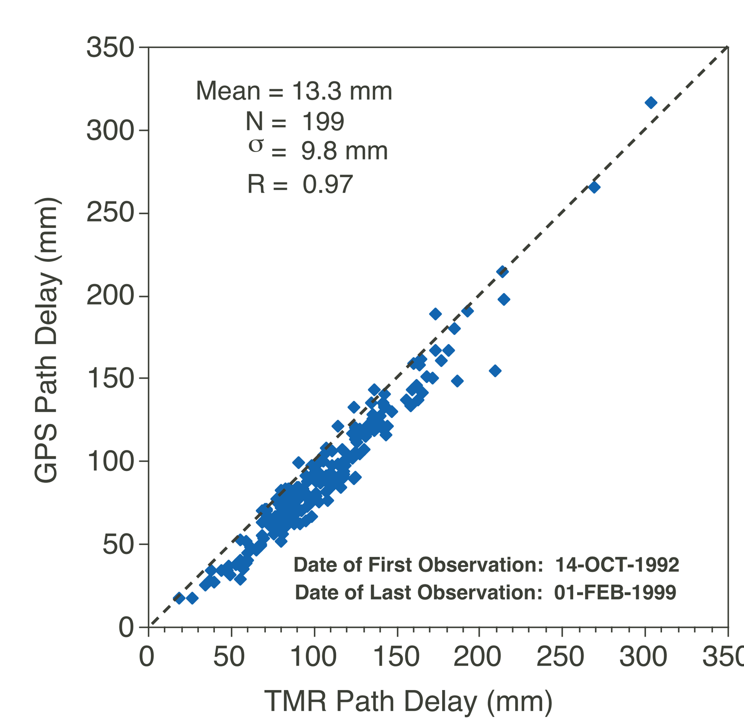
All told, 11 different ground-track approach patterns are represented in the 6-station calibration data set. The distances from the stations to the open-water PCAs are typically 20–80 km, over which zenith troposphere signal can be expected to decorrelate by 5–15 mm.



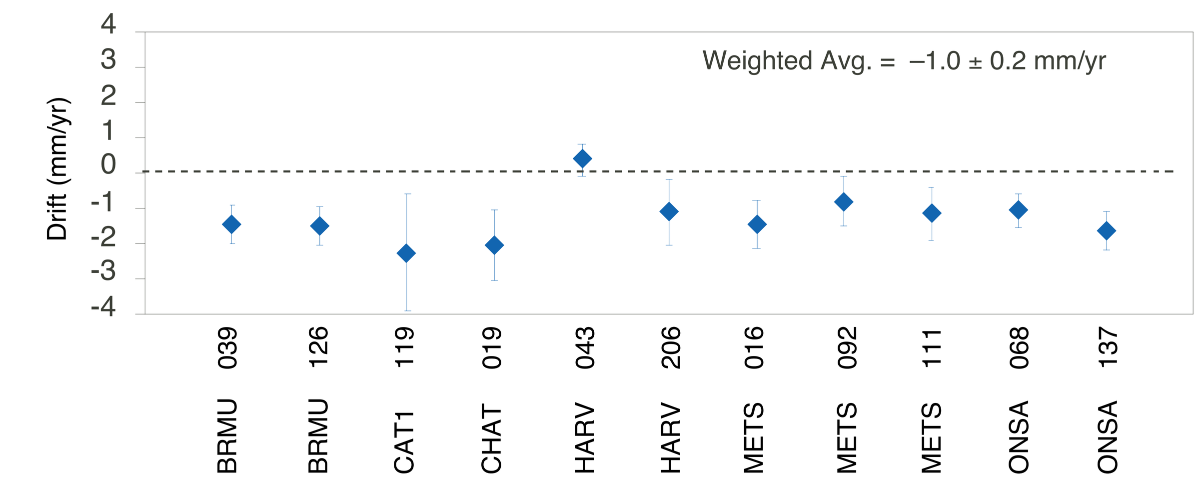
Methodology

We apply the technique of precise point positioning to process the GPS data. The wet zenith PD was estimated as a random-walk process which accumulates 9 mm^2 of variance every hour. In the nominal strategy, we also estimated delay gradients in the North and East directions. The wet zenith PD solutions were evaluated at the times of the T/P overhead passes, and the result was compared with the TMR PD extracted from the T/P geophysical data record.

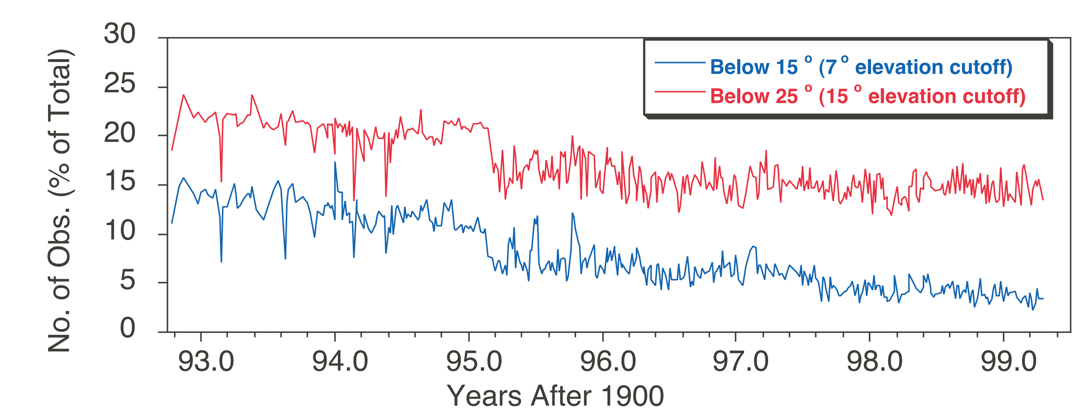
Shown in the following panel is a scatter plot of TMR vs. GPS PD (1992–99) for the overhead pass at Harvest:



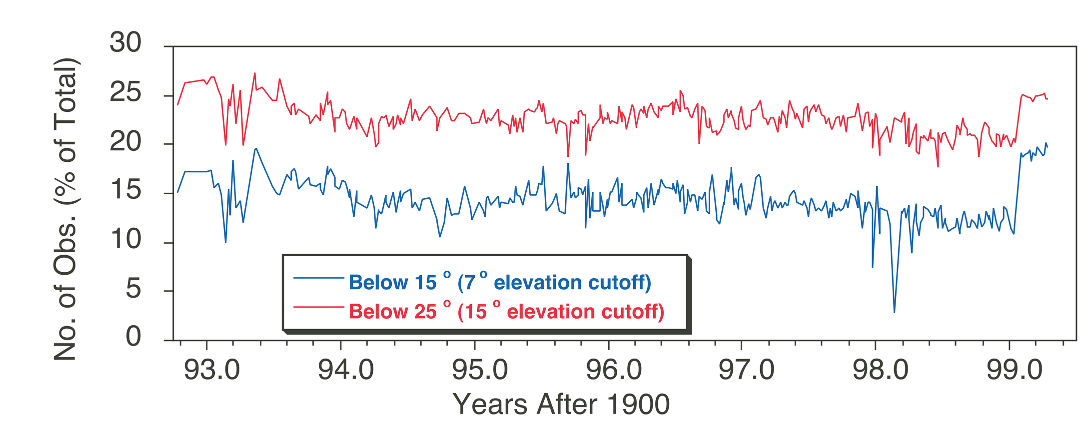
The close agreement between the TMR- and GPS-based PD estimates hints at the possibility of using time series of the differences for detecting subtle drifts in the radiometer. Provided in the following schematic are drift estimates (TMR–GPS) for the 11 station/pass pairs considered in the study:



With the exception of the direct overhead pass at Harvest, all station/pass pairs yield a negative drift. The ensemble mean is –1.0 ± 0.2 mm/yr. Concluding this is due to the TMR requires a careful consideration of systematic GPS-related errors. Of particular concern are long-term changes in the abundance of low-elevation data. The following plot shows that the Harvest GPS site has experienced a slow degradation in the numbers of satellites tracked at low elevations:



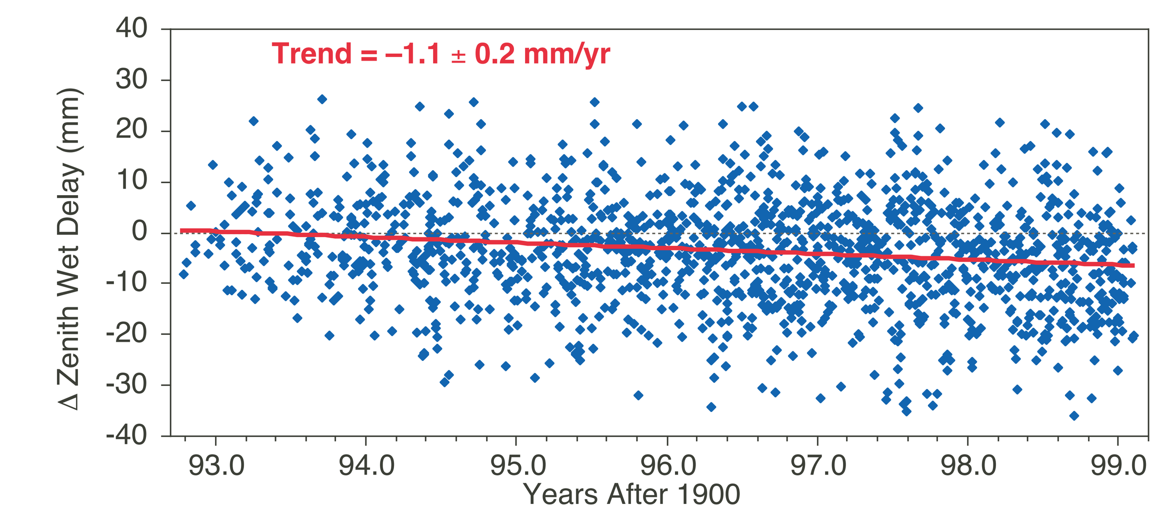
In contrast, the GPS station at Onsala has an extremely stable history of low-elevation tracking:



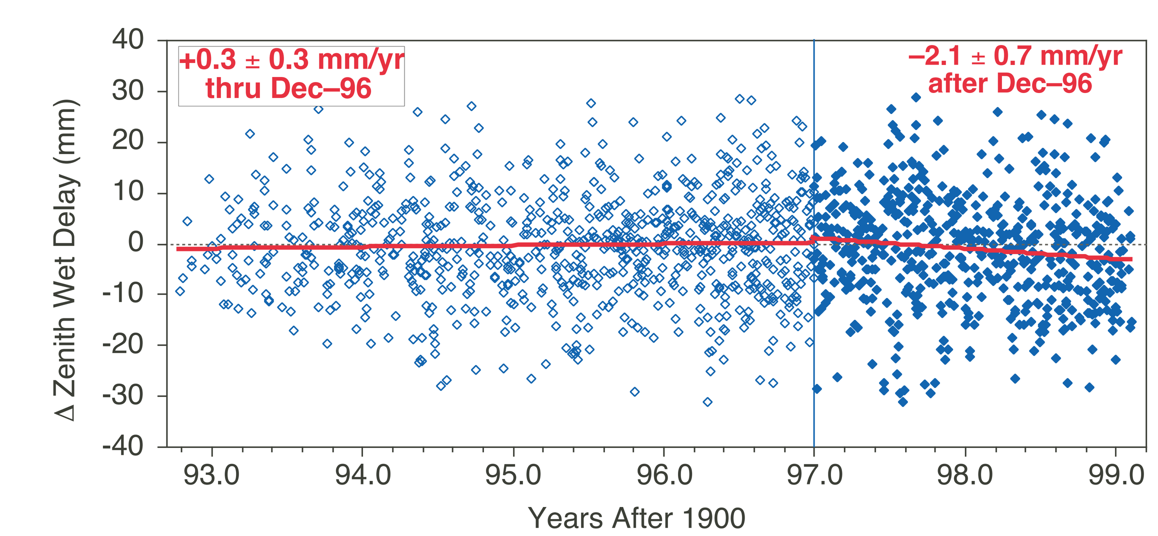
Any trend in the low-elevation tracking can have a deleterious effect on the recovery of columnar water vapor parameters. To address this, we processed GPS data from all sites using two different elevation cutoffs: 7˚ and 15˚. To further accentuate the differences in the two solution strategies, we did not estimate horizontal gradients in the 15˚ case. We found that the drift estimates for individual station/pass pairs were sensitive at the 0.5 mm/yr level to different elevation cutoffs. However, the ensemble result (–1.0 ± 0.2 mm/yr) was not affected.

Results and Conclusions

Zenith wet path delay (PD) estimates from terrestrial GPS stations strongly support that the TMR has experienced a spurious drift of –1 mm/yr. Given in the following figure is a time series (1992–99) of TMR–GPS PD differences for the entire 6-station data set. Pass-dependent biases and annual signals have been removed.



A downward trend, consistent with the TMR measuring PD shorter in time, is seen in the plot. The drift—also seen in comparisons with data from radiosondes and other radiometers—is attributed to hardware changes in the 18-GHz channel from 10/92 to 12/96 [*Keihm et al.*, 1999]. The following figure shows the TMR–GPS time series after correcting for the effects of the 18 GHz drift. To isolate the impact of the correction, the time series is divided into two segments—before and after 12/31/96.



The TMR–GPS trend through 12/96 is now indistinguishable from zero. The results suggest, however, that a trend remains after 12/96. Further analysis is needed to understand the source of this ongoing trend.

The results demonstrate that terrestrial GPS measurements can contribute significantly to the calibration of spaceborne radiometers. In addition to monitoring drift, the technique can be used to estimate scale and bias errors. At the level of accuracy for the TMR path delays, the GPS comparisons are not consistent in their determination of bias or scale. More GPS stations will be added to average down the effects of site-specific errors. Data from the expanded network will also be used to support calibration of the radiometer on Jason-1, scheduled for launch in May, 2000.

References:

Haines, B. and Y. Bar-Sever, Monitoring the TOPEX microwave radiometer with GPS: Stability of columnar water-vapor measurements, *Geophys. Res. Lett., 25*(19), 3563–3566, October 1, 1998.

Keihm, S., V. Zlotnicki and C. Ruf, TOPEX microwave radiometer performance evaluation, 1992–1998, *IEEE Trans. Geosci. Remote Sens.*, submitted, 1999.