Comparison of Precipitable Water Vapor Derived from GPS and Radiosonde Data for Singapore

L. S. Kumar, F. Yuan and Y. H. Lee
School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore

Abstract – **The objective of this study is to retrieve the Precipitable water vapor (PWV) by analyzing the wet tropospheric delay measurements from the NTUS receiver, and from radiosonde data at Singapore. This paper describes the procedures and results of the analysis of these concurrent measurements, meteorological data.**

Index Terms — **Precipitable Water Vapor, GPS data, GIPSY/OASIS II, Radiosonde data.**

I. Introduction

Atmospheric water vapor is highly variable in both space and time across the Earth, and knowledge of the distribution of water vapor is essential in understanding weather and global climate. GPS meteorology, an interdisciplinary scientific field, was initiated in the 1990s [1]. The integrated amount of water vapor in a column of atmosphere, i.e., the precipitable water vapor (PWV), can be determined from the geodetic positioning errors of GPS. In this paper, PWV values are retrieved by processing GPS (Global Positioning System) and radiosonde (RS) data and analysis of the observations is presented.

II. Meteorological Data

A global, 5 minutes GPS data set from the ground-based GPS measurements at the International GNSS Service (IGS) receiver, NTUS, Singapore is downloaded from the Crustal Dynamics Data Information System (CDDIS) [2]. NTUS receiver is located at 1.35^{0}N, 103.68^{0}E with ellipsoidal height 75.80 m. RS data is collected at 48698, station number at the world radiosonde system, WSSS, Singapore observation site (1.37ºN, 103.98ºE). The observation times are 0000 UTC and 1200 UTC, twice per day. RS site is located 33 km away from the NTUS GPS receiver. Weather station (WS) located very near to the GPS receiver (1.34° N, 103.68° E) provides rain rate (mm/hr) for comparison with PWV values and surface temperature.

III. Methodology

A. GPS Data Processing

Atmospheric refraction (or atmospheric delay) of GPS signals traveling from a satellite to the receiver on the earth's surface is mostly due to the earth's ionosphere and troposphere. The amount of delay in troposphere is directly related to the amount of water molecule in the troposphere. In addition to the GPS data, weighted mean temperature (T_m) values are essential to derive the PWV from the atmospheric delay, which can be obtained from the RS data or from the surface temperature values, obtained from weather station, using empirical models [2-3]. To estimate the tropospheric delay, GPS Inferred Positioning SYstem-Orbit Analysis and Simulation Software (GIPSY-OASIS II) version 6.2 software package, which was developed at the Jet Propulsion Laboratory (JPL), is used in the static mode. Satellite clock data and orbital data are obtained during processing with software via anonymous ftp server, and are routinely generated and provided by JPL [4].

GIPSY was set to run in precise point positioning (PPP) mode], using recommended script gd2p, with solid Earth tides and ocean tide loading. Antenna phase corrections and an elevation cut-off angle 15^0 were also applied. The wet delay and gradient parameters where modeled as random walk variables with 5*10^{-8} and 5*10^{-9} km/√sec, as recommended by GIPSY OASIS II manual when using data down to 7^0, respectively. Vienna Mapping Function (VMF1) is used to find ZWD. Phase ambiguities were fixed using ambiguity resolution function. The station coordinates for the NTUS receiver were first estimated and then held fix. With knowledge of the estimated ZWD from a GPS receiver at a given time and location, PWV (mm) is derived as [3]

$$PWV = \frac{\Pi \, ZWD}{\rho_v} \quad (1)$$

where

$$\Pi = \frac{10^6}{\left(\left(k_3/T_m\right) + k_2^{'}\right) \times R_v}. \quad (2)$$

Here R_v is the specific gas constant for water vapor (461.5181 J/kg K), ρ_v is density of liquid water (1000 kg/m^3) and k_3=(3.776± 0.004)*10^3 K^2/Pa, $k_2^{'}$=(17 ± 10))*10^{-2} K/Pa are refractivity constants [11]. T_m is obtained from RS data as

$$T_m = \frac{\int \frac{e}{T} dz}{\int \frac{e}{T^2} dz} \quad (3)$$

where e is the partial pressure of water vapor and T is the air temperature. T_m is also calculated using the weather station surface temperature Ts by using the empirical model [1].

$$T_m = 70.2 + 0.72 T_s \quad (4)$$

Surface temperature from weather station is available every minute whereas the RS data is available for every 12 hours.

B. Radiosonde Data Processing

Water vapor pressure [6] can be calculated using the RS temperature and relative humidity data as

$$e = RH \times \exp\left(-37.2465 + 0.213166T - 2.56908 \times 10^{-4} T^2\right) \quad (5)$$

where RH is relative humidity in percentage, T is the absolute temperature in degrees Kelvin and e is water vapor pressure in hPa. PWV can be calculated through

$$PWV = \frac{1}{\rho} \sum \left(h_{j+1} - h_j\right)\left(\rho_v^{j+1} - \rho_v^j\right) \Big/ 2 \quad (6)$$

where water vapor density $\rho_v = e/R_v T$ and h_j is the altitude at jth level.

IV. Results

PWV values are found using (1)-(4) by processing GPS data as described in Section III-A for Feb'2013. Similarly RS data is used to find PWV using (5) and (6). Fig. 1 shows the calculated PWV (mm) along with the rain rate (mm/hr) for Feb'13 using GPS and RS data. GPS,WS-T_m line shows the GPS derived PWV using the WS-T_m. Red stars, GPS,RS-T_m, represent the GPS derived PWV using the RS-T_m. Magenta circles show the RS derived PWV values. As can be seen from Fig. 1, PWVs (GPS,WS-T_m) are around 60 mm for most of the days except the drop at the first few days and between days 21 to 25 where there are no rain events and their mean is 56.93 mm. GPS derived PWV values using WS-T_m and RS-T_m (blue line and red stars) are highly correlated to each other and this shows that T_m derived from WS and RS are in good agreement. Comparisons between GPS,RS-T_m and RS derived PWV values show that the correlation between the two data sets slightly reduce and their correlation coefficient is 0.93. Fig. 2 shows the scatter plots of GPS (using RS-T_m) and RS derived PWV for Feb'13 at 8 hrs and 20 hrs (SG time).

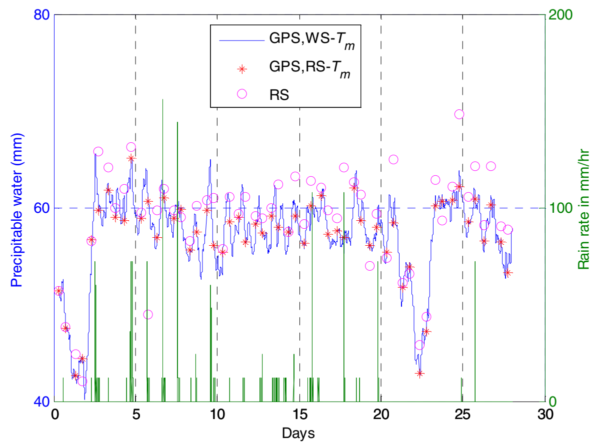

Fig. 1. Comparison of GPS derived PWV and RS derived PWV for Feb'13. Rain rate (mm/hr) is plotted in right y-axis

It is clear from Fig. 2 that the absolute difference between GPS (using RS-T_m) and RS derived PWVs is lower at 8 hrs as compared to 20 hrs data set. The correlation coefficient between the two data sets is 0.97 at 8 hrs and it reduces to 0.92 at 20 hrs. This may reflect the high temporal and spatial variability of water vapor over Singapore, causing differences between PWVs if GPS and RS launch stations are not collocated (distance between the sites are 33 km). Their difference reached as much as 3 mm at 8 hrs and 7 mm at 20 hrs respectively. It is found from Singapore's weather that it experiences frequent convective rains in the afternoons. The convective downpours are for a shorter duration and at a narrow place. So there may be the possibility of either raining at GPS or RS site while other site has no rain. This may cause the higher differences in PWVs at 20 hrs. The differences between PWVs increase for higher PWV values.

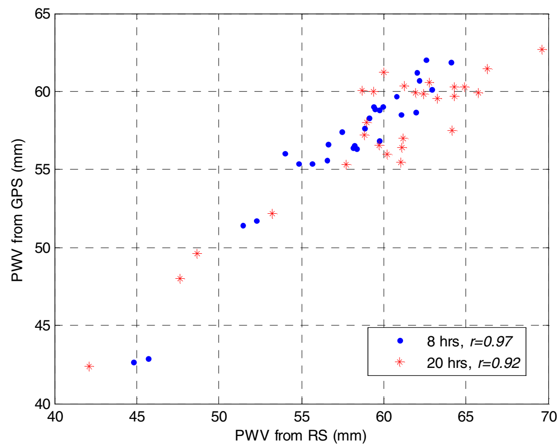

Fig. 2. Scatter plots of GPS and RS derived PWV for Feb'13

V. Conclusion

Comparisons between GPS derived PWV and RS derived PWV show that both datasets match well each other with the correlation coefficient of 0.93. The differences between the datasets may arise because GPS and RS stations are not located nearby. Comparison between the weather station rain events show that PWV has higher values during the rainy period and show its decrease in dry days.

References

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