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Estimation of precipitable water vapour from GPS during winter season 2003

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सार – वायुमंडल में जल वाष्प का वितरण स्थानिक रूप से और कालिक तौर पर बहुत अधिक परिवर्तनशील होता है। जल वाष्प का वितरण अनेकों वायुमंडलीय प्रक्रियाओं में प्रमुख भूमिका निभाता है। कुल समाकलित जल वाष्प अथवा समरूपी वर्षा जल वाष्प का आकलन ग्लोबल पोजिशनिंग सिस्टम (जी. पी. एस.) जेनिथ टोटल डिले (जेड. टी. डी.) के आँकड़ों की सहायता से किया जा सकता है। इसमें जेनिथ द्रवस्थैतिक डिले के मान को निदर्शित किया गया है और इसे जेड. टी. डी. से निकालने पर जेनिथ आर्द्र डिले के आँकड़े प्राप्त होंगे। अतः इस प्रकार आकलित किए गए जेड. डब्ल्यू. डी. के मान से प्रायः लगातार एम. एम. में वर्षा जल वाष्प का पता चलेगा। इस शोध–पत्र में जी. पी. एस. के आँकड़ों का उपयोग करते हुए नई दिल्ली के लिए वर्ष 2003 के शीतकालीन ऋतु और भारतीय विज्ञान संस्थान परिषद, बंगलौर के केंद्रों के लिए एम. एम. में पी. डब्ल्यू. वी. का आकलन करने का प्रयास किया गया है। इनसे प्राप्त हुए परिणामों का रेडियोसौन्दें आँकड़ों के साथ सही तालमेल पाया गया है।

ABSTRACT. The distribution of water vapour in atmosphere is highly spatial and temporal variable. It plays a key role in many atmospheric processes. The total integrated water vapour or equivalent precipitable water vapour (PWV) can be estimated with the help of Global Positioning System (GPS) Zenith Total Delay (ZTD) data. The value of Zenith Hydrostatic Delay (ZHD) is modeled and subtracting from ZTD will give Zenith wet delay (ZWD). Consequently, the estimated ZWD values will provide PWV in mm almost in a continuous manner. In this paper an attempt has been made for the estimation of PWV in mm during winter season 2003 for New Delhi and Indian Institute of Science (IISC), Bangalore stations using GPS data. The result shows fairly good agreement with the radio-sonde data.

Key words – Precipitable Water Vapour (PWV), GPS, Zenith Total Delay (ZTD), Zenith Wet Delay (ZWD).

1. Introduction

The atmospheric water vapour is very important for the vertical energy balance of the atmosphere and precipitation forecasts. Its estimation by direct or indirect method is difficult, due to its temporal and spatial variability. The direct measurement of PWV from Radiosonde and Water Vapour Radiometer is very expensive and time consuming. The retrieval in also not real time hence it cannot be used in Numerical Weather Prediction (NWP) models. Similarly the satellite based water vapour studies are more accurate for oceans than over the land area as it has emissivity problem. In the present study the GPS data is taken only in the zenith direction and without met package. Ground-based Global Positioning System (GPS) reference stations measure precise carrier-phases, which can be used to estimate integrated water vapour. GPS transmit signals, which can be received at the earth. The signal travels through the ionosphere and atmosphere both causing a delay. The ionospheric part can be eliminated using two different frequencies but to estimate the atmospheric part, processing is needed. The atmospheric part produces two types of delay one Zenith Hydrostatic Delay (ZHD) and other is Zenith Wet Delay (ZWD). The sum of ZHD and ZWD is called The Zenith Total Delay (ZTD). The ZTD data without met package is retrieved from GPS data using the GAMIT (King and Bock, 1997) GPS data processing software developed by Massachusetts Institute of Technology (MIT), U.S.A. ZHD can be modeled accurately but the ZWD is highly variable in space and time and it is very difficult to measure it precisely. Temporal variability in ZTD is highly linked to atmospheric dynamics. The study of the distribution of water vapour is very important for the genesis of meso and convective scale weather systems. Water's permanent dipole moment is also directly responsible for the unusually large latent energy associated with water's changes of phase, which in turn significantly impacts the vertical stability of the atmosphere, the structure and evolution of weather systems, and the meridional and radiational energy balance of the Earth-atmosphere system (Businger *et al.*, 1996). Thus, knowledge of the distribution of water vapor is essential for understanding

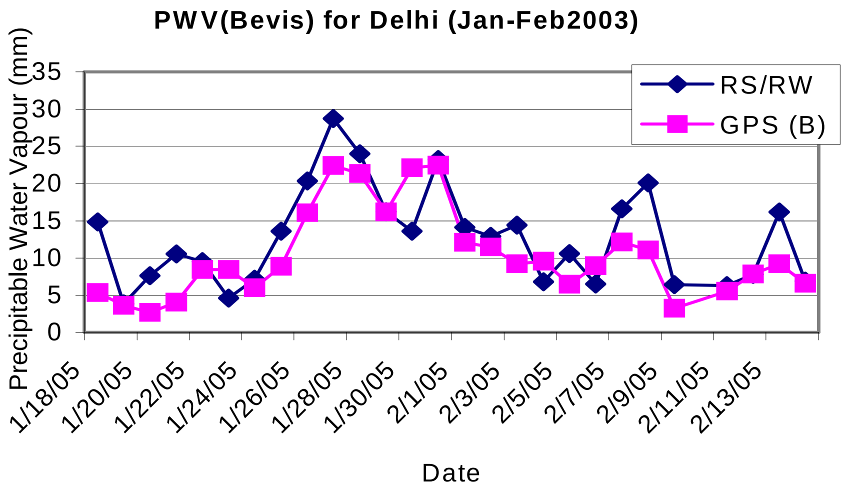

Fig. 1. Precipitable water (mm) comparison Radiosonde and GPS (Bevis) for New Delhi (Jan – Feb 2003)

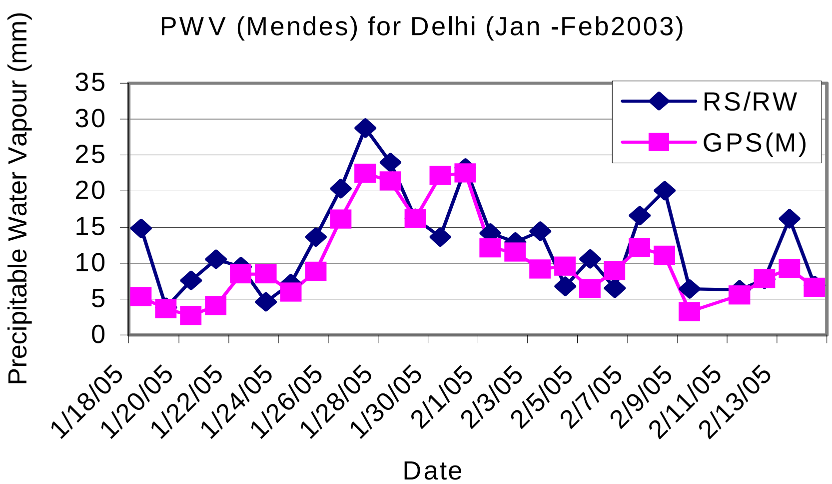

Fig. 2. Precipitable water (mm) comparison Radiosonde and GPS (Mendes) for New Delhi (Jan – Feb 2003)

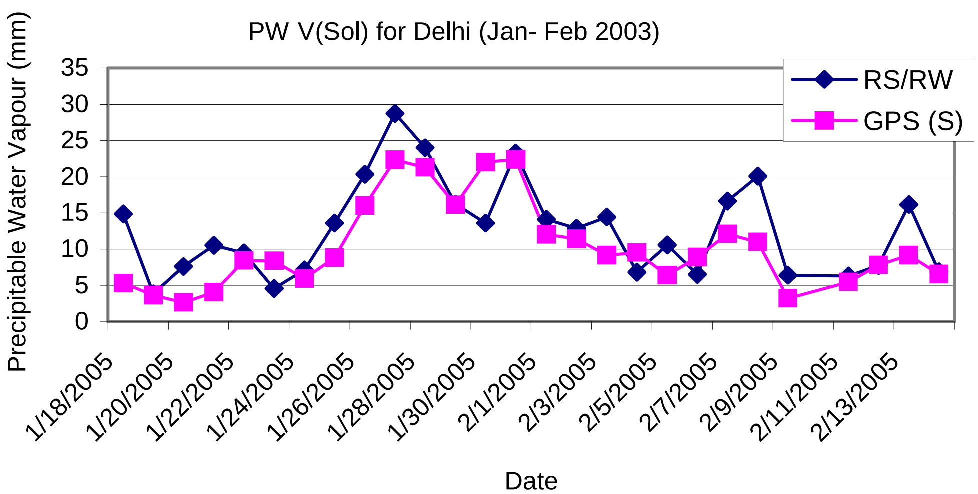

Fig. 3. Precipitable water (mm) comparison Radiosonde and GPS (Solbrig) for New Delhi (Jan – Feb 2003)

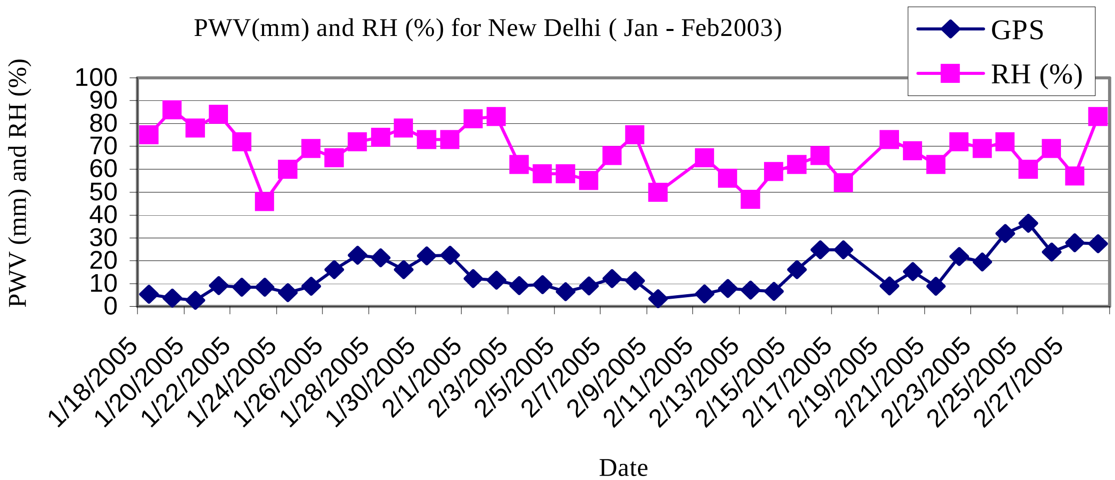

Fig. 4. Precipitable water (mm) and RH (%) for New Delhi (Jan – Feb 2003)

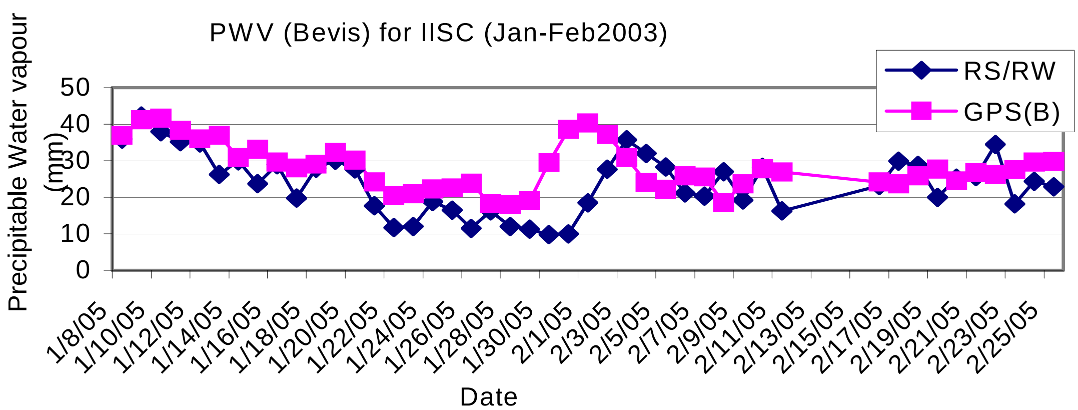

Fig. 5. Precipitable water (mm) comparison Radiosonde and GPS (Bevis) for IISC (Jan – Feb 2003)

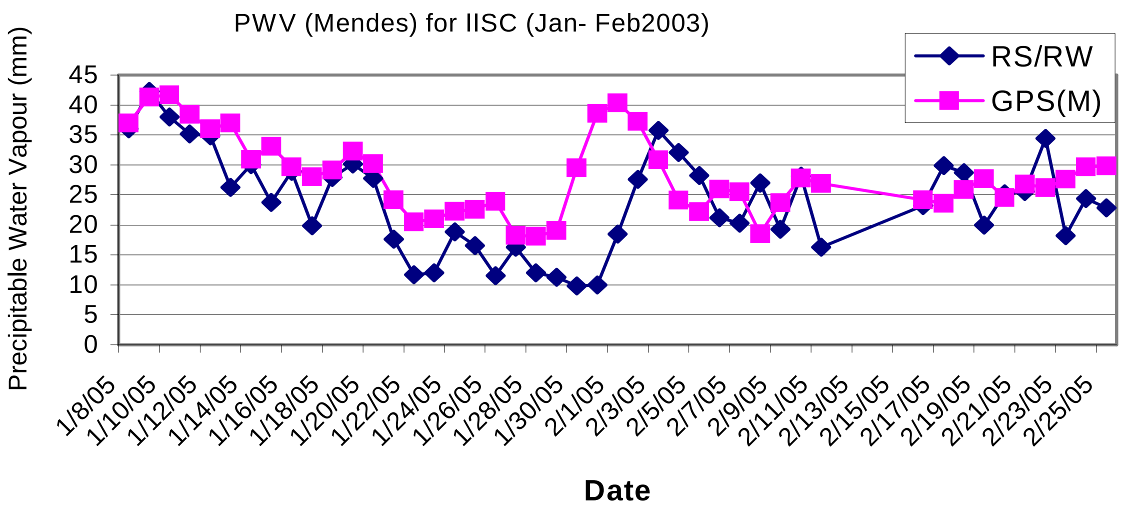

Fig. 6. Precipitable water (mm) comparison Radiosonde and GPS (Mendes) for IISC (Jan – Feb 2003)

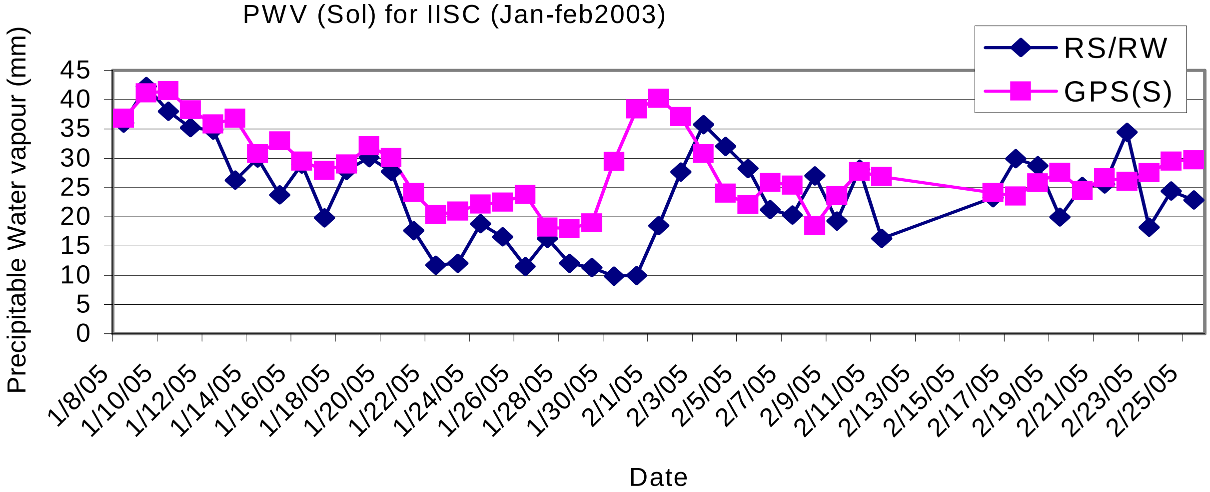

Fig. 7. Precipitable water (mm) comparison Radiosonde and GPS (Solbrig) for IISC (Jan – Feb 2003)

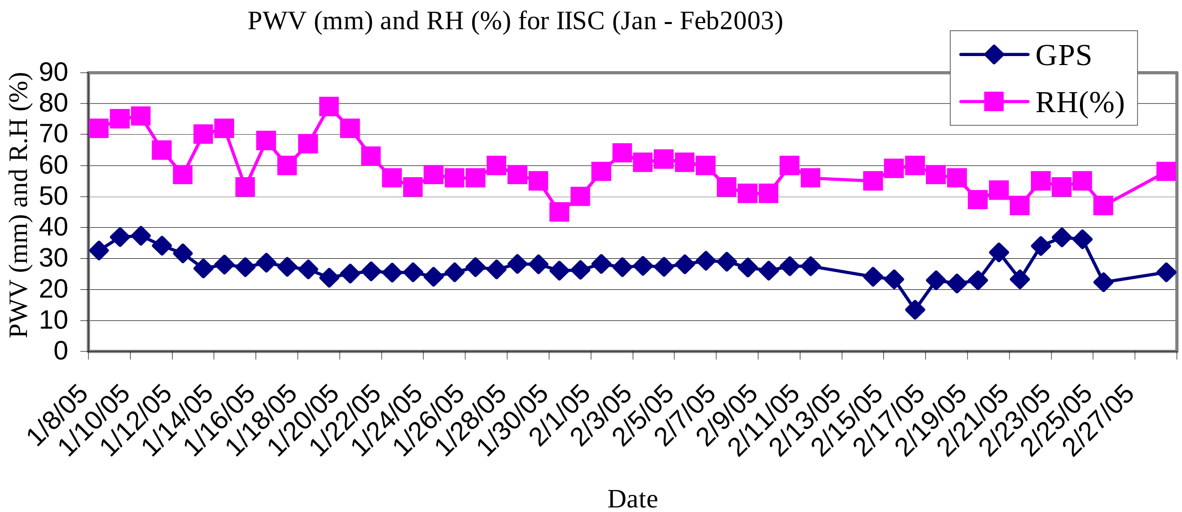

Fig. 8. Precipitable water (mm) and RH (%) for IISC (Jan – Feb 2003)

of weather and global climate. Although GPS derived water vapor is not free from errors some of them will come during GAMIT processing like biases in receiver and satellite clocks, multi-path and ionospheric correction etc.

2. Data and methodology

The GPS Zenith Total Delay Data (one day mean) used in this study is obtained from Wadia Institute of Himalayan Geology, Dehradun for the winter months of January and February 2003. The radiosonde data is taken from India Meteorological Department Lodi Road, New Delhi. Integrated Water Vapour (IWV) is retrieved from the ZTD following the concept describe in Bevis *et al.* (1992) and Emardson *et al*. (1998). Firstly, the hydrostatic delay ZHD (m) is calculated as shown below. The Zenith Hydrostatic Delay (ZHD) can be calculated from the local surface pressure

$$\text{ZHD} = (2.2768 + 0.0024)\, P_s / f(\theta, h) \quad (1)$$

Where,

$$f(\theta, h) = 1 - 0.00266\cos(2\theta) - 0.00028\, h$$

where, *Ps* is the surface pressure in millibars and $f(\theta, h)$ is a factor accounting for the variation in gravitational acceleration with latitude and height. The ZHD subtracted from ZTD yields the Zenith Wet Delay (ZWD).

Mathematically, T_m is the integrated mean temperature given by :

$$T_m \frac{\int \frac{P_r}{T} dz}{\int \frac{P_r}{T^2} dz} \quad (2)$$

Because the integrated mean temperature, T_m, is not known exactly, it can be related to the surface temperature T_s linearly by the empirically derived formula (Bevis *et al*. 1992) :

$$T_m = 70.2 + 0.72\, T_s \quad (3)$$

using this relation yields an average error in PWV of less than 4% (which is still a conservative error estimate) [Yuan *et al*., 1993].

Mean atmospheric temperature suggested by other models is given below :

$$T_m = 50.4 + 0.789 T_s\ (^\circ K) \text{ (Mendes et al., 2000)} \quad (4)$$

$$T_m = 54.7 + 0.770 T_s\ (^\circ K) \text{ (Solbrig, 2000)} \quad (5)$$

Mendes *et al*., 2000 evaluated the accuracy of models for the determination of the weighted mean temperature of the atmosphere. Over the Indian subcontinent an estimation of precipitable water from GPS data for Bangalore, Kodaikanal, Hanle and Shillong over the 3-year period has been done at CSIR Centre for Mathematical Modeling and Computer Simulation (CMMACS) Bangalore (Jade *et al*., 2004).

The PWV and IWV are expressed as follows :

$$PWV = K\, ZWD \quad (6)$$

Where,

$$K = \frac{10^6}{\left(k_3 / T_m + k_2'\right) R_v}$$

Where,

$$k_2' = k_2 - (R_d/R_v)\, k_1$$

The values of k_1, k_2 & k_3 are given above.

R_d = 286.9 J/kg.K (Specific gas constant for water vapour)

R_v = 461.51 J/kg.K (Specific gas constant for dry air)

$$IWV = \rho\, PWV \quad (7)$$

Where ρ is the density of water in kg/m^3.

3. Results and discussion

The value of ZHD is modeled (Saastamoinen, 1972) and calculated from equation (1). The value of ZTD is retrieved from GPS data using GAMIT processing software of MIT, USA. The values of PWV in mm are retrieved from equation (6). The IWV or equivalently PWV in mm values retrieved in this paper are obtained without met package. So the main parameters (pressure and temperature) will not be initialized for each fresh retrieval. Because the atmospheric conditions will not remain same for every time and in tropics the variation in day-to-day weather is more so it can show more variation in the values. It is because we are not initializing the met parameters for each fresh retrieval of IWV and hence the determination of mean temperature is also affected. Apart from there are other errors are also included like broadcast ephemeris, propagation errors in the ionosphere and troposphere, receiver and satellite clock biases multi-path and receiver noise. The atmospheric mean temperature from different temperature models (Bevis *et al*., 1992, Mendes *et al.* 2000, Solbrig, 2000) given by equation (3), (4) and (5) have been utilized for the study. The results obtained from all the three models are quite encouraging with radiosonde data [(Figs. 1 to 3 and Figs. 5 to 7)]. This study is useful for monitoring the meso and convective activity over the station. The relative humidity (R.H) values [Fig. 4 and Fig. 8] obtained for IISC and New Delhi provide an indicator for moisture during winter season 2003. The R.H values for radiosonde data and PWV from GPS data is approximately double in the case of IISC Bangalore but for New Delhi this variation is quite irregular. India Meteorological Department will start soon the GPS data processing at five places.

4. Conclusions

(*i*) The results obtained for PWV from GPS data and their comparison with three temperature models are fairly good. The root mean square error of PWV for New Delhi and IISC are approximately of the order of 4 mm and 8 mm respectively.

(*ii*) The variation in the R.H values for the two stations shows an idea of moisture and instability/ stability over the area. The R.H. variation for New Delhi is more irregular than IISC Bangalore.

3. The distribution of Intergrated Precipitable Water Vapour (IPWV) is essential for understanding of weather and global climate. Further from GPS data the variation in R.H. over an area will provide an idea of availability of moisture and instability over an area which is useful for day to day forecasting of weather.

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