

Integrated water vapour from GPS

R. K. GIRI, L. R. MEENA, S. S. BHANDARI and R. C. BHATIA

India Meteorological Department, Lodi Road, New Delhi – 110 003, India

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e mail : rkgiri_ccs@rediffmail.com

सार – वायुमंडल में देश काल के अनुसार जलवाष्प की मात्रा में काफी अधिक परिवर्तन होता रहता है जो वायुमंडलीय प्रक्रमों में महत्वपूर्ण भूमिका निभाता है तथा सूक्ष्म मौसम विज्ञान की भूमंडलीय जलवायु में कालिक एवं स्थानिक पैमाने पर काफी विस्तृत सीमा तक कार्य करता है। इस षोष-पत्र में भूमंडलीय स्थिति प्रणाली (जी. पी. एस.) पर आधारित सुदूर संवेदी द्वारा जलवाष्प की मात्रा का पता लगाने के लिए नया दृष्टिकोण अपनाया गया है। भूमंडलीय स्थिति प्रणाली (जी. पी. एस.) उपग्रह से धरातल पर लगे रिसेवरों तक संकेतों के पहुँचने में विलंब वायुमंडलीय जलवाष्प की वजह से होता है। इस विलंब का विप्लेषण काल-विविधता के साथ शिरोबिन्दु आर्द्र विलंब (जेड. डब्ल्यू. डी.) नाम से किया गया है जिसे जी. पी. एस. आँकड़ों के प्रसंभाव्य पुद्धिकरण द्वारा सही किया जाता है। भूमंडलीय स्थिति प्रणाली के रिसेवर की मदद से प्राप्त सतह-दाब एवं तापमान पठनों और सही किए गए जेड.डब्ल्यू. डी. को रिसेवर के ऊपर पड़े समेकित जलवाष्प (आई. डब्ल्यू. वी.) में स्थानांतरित किया जा सकता है। इसमें थोड़ी सी अतिरिक्त अस्थिरता होती है। इस अध्ययन में शिरोबिन्दु कुल विलंब समय (जेड. टी. डी.) आंकड़े मौसम विज्ञान के पैकेज के बिना जी. ए. एम. आई. टी. (किंग एण्ड बोक, 1997) जी. पी. एस. आँकड़ों को संसाधित करने वाले सॉफ्टवेयर की मदद से प्राप्त किए गए हैं जिसे मैसाच्यूसेट इंस्टीट्यूट ऑफ टेकनॉलॉजी (एम. आई. टी.) द्वारा नई दिल्ली एवं बंगलोर दो स्टेशनों के जनवरी 2003 से फरवरी 2003 तक की अवधि के आँकड़ों के आधार पर विकसित किया गया है। भूमंडलीय स्थिति प्रणाली से सही किए गए समेकित जलवाष्प (आई. डब्ल्यू. वी.) तथा सीमित क्षेत्र मॉडल (एल. ए. एम.) के साथ तुलना से सही किए गए समेकित जलवाष्प (आई. डब्ल्यू. वी.) काफी हद तक सही निष्कर्ष दर्शाते हैं।

ABSTRACT. Water vapour is highly variable in space and time, and plays a large role in atmospheric processes that act over a wide range of temporal and spatial scales on global climate to micrometeorology. This paper deals with a new approach to remotely sense the water vapour based on the Global Position System (GPS). The signal propagating from GPS satellites to ground based receivers is delayed by atmospheric water vapour. The delay is parameterized in terms of time varying Zenith-Wet Delay (ZWD), which is retrieved by stochastic filtering of GPS data. With the help of surface pressure and temperature readings at the GPS receiver, the retrieved ZWD can be transformed into Integrated Water Vapour (IWV) overlying at the receiver with little additional uncertainties. In this study the Zenith Total time Delay (ZTD) data without met package is retrieved using the GAMIT (King and Bock, 1997) GPS data processing software developed by Massachusetts Institute of Technology (MIT) for the period of January 2003 to February 2003 for two stations New Delhi and Bangalore. The IWV retrieved from GPS and its comparison with Limited Area Model (LAM) retrieved IWV shows fairly good agreement.

Key words – GPS, ZWD, IWV, ZTD and LAM.

1. Introduction

Water vapor is a dominant greenhouse gas in the earth's atmosphere (Manabe and Wetherald 1967) and is one of the significant atmospheric constituents whose mixing ratio is controlled to first order by its saturation vapour pressure. Its role is not restricted to absorbing and radiating energy from the sun, but includes the effect it has on the formation of clouds and aerosols and the chemistry of the lower atmosphere. Despite its importance to atmospheric processes over a wide range of spatial and temporal scales, it is one of the least understood and poorly described components of the Earth's atmosphere. The global positioning system (GPS) consists of constellation of satellites, which transmits radio signals at two frequencies in L band (L1 = 1.2 Ghz and L2 = 1.6 Ghz). The satellite transmits two spreads spectrum

Pseudo-Random Noise (PRN) radio signals. The signal consists of a C/A (Coarse Acquisition) code at 1.023 Mhz and a P (Precision) code at 10.23 Mhz band bandwidths. Both C/A and P-codes are transmitted on the L1 frequency, whereas either C/A or P – code is transmitted on the L2 frequency depending on the ground command (Ananda, 1988). The C/A code is available to all users, however the P – code is available to only authorized users because of anti spoofing feature. The pseudo-random noise codes modulate both L1 and L2 frequencies of the GPS signal and in this way, it restricts its use in civilian and military purposes. In other words, these codes are applied on the signal for security and user specific purpose. In addition to the PRN range codes, 50 bps data, which consists of navigation message comprising both ephemeris and clock parameters are modulated on to the PRN sequence on both L1 & L2 frequencies. The GPS

satellite signals propagation speed are slowed by the Earth's atmosphere, which results in a delay in the arrival time of the transmitted signal from that expected if there were no intervening media. The delays due to the neutral atmosphere are not frequency dependent, but depend on the constituents of the atmosphere that are a mixture of dry gases and water vapor. The vertically scaled signal delays introduced by these components are called the Zenith Hydrostatic Delay (ZHD) and the Zenith Wet Delay (ZWD), respectively. In practice, the total signal delays measured by the GPS receiver from all satellites in view are mapped to the vertical using the function $1/\sin(\text{elevation angle of the satellite})$, and combined to give the Zenith Total (or Tropospheric) Delay (ZTD). At sea level, ZTD has a magnitude of about 250 cm to which the hydrostatic and wet components contribute about 97% and 3% approximately proportional to the ratio of the total mass of dry air to water vapor in the atmosphere. The ZHD is then subtracted from the ZTD to give the ZWD, which is related to the IWV directly above the GPS antenna through a factor that is proportional to the mean temperature of the atmosphere. An empirical relation estimates the mean air temperature from a surface temperature measurement. It is possible to correct for the ionospheric delay, which is frequency dependent, by using dual-frequency GPS receivers.

2. Data & methodology

The GPS Zenith Total Delay one-day mean data used in this study is obtained from Wadia Institute of Himalayan Geology, Dehradun for the months of January and February 2003. The Radiosonde data is taken from India Meteorological Department, Lodi Road, New Delhi. As an Electromagnetic wave propagates in the atmosphere, it is continuously refracted due to the varying index of refraction of the air between the top of the atmosphere and the ground. Thus the arrival time of the GPS signal at the instrument is delayed because of refractive bending and slowing of the signal. The excess path length due to curvature and bending for elevation greater than 15° is related with tropospheric path delay (Δ^{Trop}) and refractivity 'N' can be written as:

$$\Delta^{\text{Trop}} = 10^{-6} \int N^{\text{Trop}} ds \quad (1)$$

Separating Δ^{Trop} into dry and wet components (Holfman *et al.*, 2001),

$$\Delta^{\text{Trop}} = 10^{-6} \int N_d^{\text{Trop}} ds + 10^{-6} \int N_w^{\text{Trop}} ds \quad (2)$$

(I) (II)

In the Eqn. (2) above first part is the dry contribution and second part is the wet contribution of the delay. The 'dry' part contributes about 90% of Tropospheric

refraction (Smith and Weintraub, 1993). It can be accurately modeled to within the uncertainty of 2 – 5% using surface measurements such as pressure and temperature. The dry air component is assumed to obey the ideal gas law. The problem with the 'wet' contribution is that the distribution of water vapour cannot be accurately predicted. Molecules of dry air do not have a significant permanent dipole moment. However under the influence of an external electromagnetic field (radio wave) small dipole moment will induce, increasing the dielectric permittivity of the medium and hence refractive index. Similarly random distributed dipole moment for water vapour in the presence of magnetic field gets aligned with it adding to polarization of medium. Refractivity of the medium is usually described by empirical formulas related to thermo dynamical state variables of the air, which has both dry and wet term (Thayer, 1974 and Bevis *et al.*, 1994), can be written as,

$$N_d^{\text{Trop}} = K_1 * P/T \quad (3)$$

Where,

$$K_1 = 77.64 \text{ K hPa}^{-1}$$

P = dry atmosphere pressure (hPa)

$$N_w^{\text{Trop}} = K_2 * e/T + K_3 * e/T^2 \quad (4)$$

Where,

$$K_2 = -12.96 \text{ K hPa}^{-1}$$

$$K_3 = 3.718 * 10^5 \text{ K}^2 \text{ hPa}^{-1}$$

e = water vapor pressure (hPa).

T = atmospheric temperature (in degree Kelvin)

The values for K_1 , K_2 & K_3 are empirically determined and, certainly cannot fully describe the local situation.

The First and second part of Eqn. (2) are also known as Zenith Hydrostatic Delay and Zenith Wet Delay respectively. These delays in the slant direction can be written as the product of a mapping function and Zenith Total Delay (ZTD) (Davis, 1985).

$$\text{ZTD (s)} = \text{ZHD} * m_h(\epsilon) + \text{ZWD} * m_w(\epsilon) \quad (5)$$

Where,

$m_h(\epsilon)$ & $m_w(\epsilon)$ are the mapping functions for the hydrostatic and wet part respectively and ϵ is the

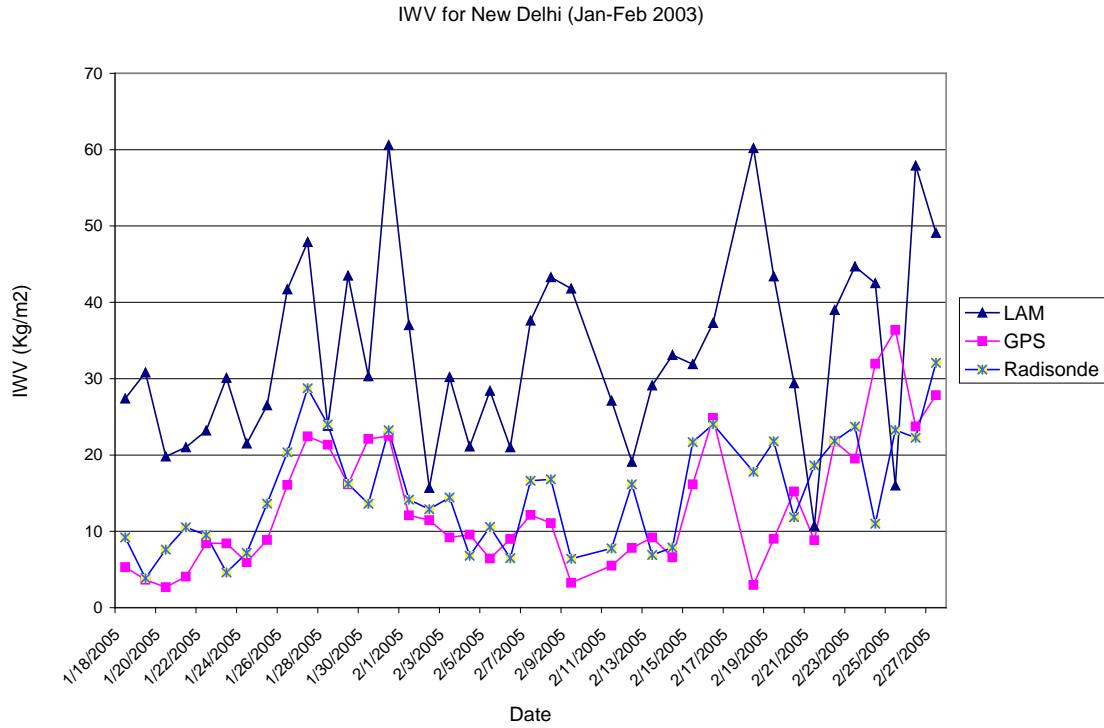


Fig. 1. IWV for NEW Delhi

elevation angle at the ground station. The Mapping function increases in delay with increasing zenith angle. The simplest model for both dry and wet components is $1/\sin\epsilon$. This model is consistent with flat earth, and is a poor approximation for low elevation satellites ($\epsilon < 15^\circ$).

Here in this paper the IWV is retrieved from the ZTD following the concept described in Bevis *et al.* (1992) and Emaradson *et al.* (1998). Firstly, the hydrostatic delay ZHD (m) is calculated using the concept in Eqn. (1) with little modification with shape factor $f(\theta, h)$, describing the height above the ellipsoid (h) in kilometers (kms) and the latitudinal (θ) variation of gravitational acceleration, as follows :

$$ZHD = (2.2768 + 0.0024) P_s / f(\theta, h) \tag{6}$$

Where,

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

Integrated water vapour (IWV in mm) is obtained by using :

$$IWV = K^* (ZTD - ZHD) \tag{7}$$

$$K = \frac{10^6}{(K_3/T_m + K_2')R_v}$$

Where,

$$K_2' = K_2 - (R_d/R_v) K_1$$

The values of K_1 , K_2 & K_3 are given above.

$$R_d = 286.9 \text{ J/kg } ^\circ\text{K} \text{ (Specific gas constant for dry air)}$$

$$R_v = 461.51 \text{ J/kg } ^\circ\text{K} \text{ (Specific gas constant for water vapour)}$$

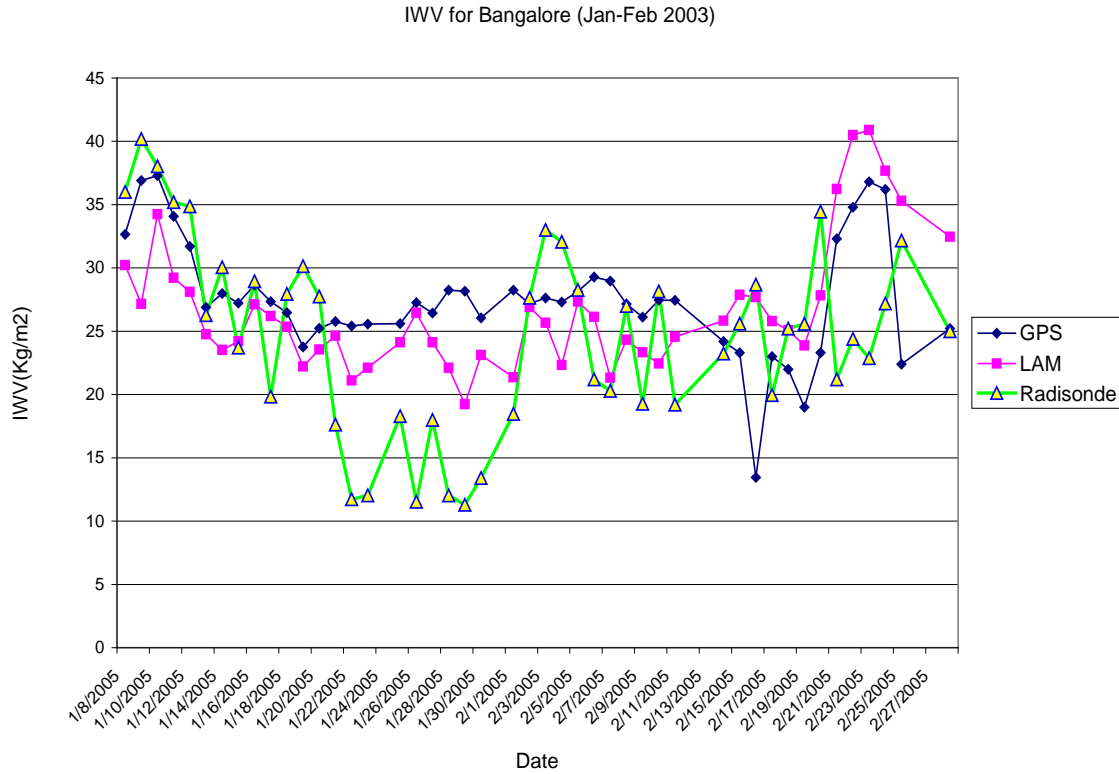


Fig. 2. IWV For Bangalore

T_m is the weighted mean atmospheric temperature estimated by:

$$T_m = 70.2 + 0.72T_s \tag{8}$$

The surface pressure P_s and surface temperature T_s are obtained from the meteorological stations (in this case New Delhi and Bangalore). The value of ZTD is obtained from GPS using the GAMIT (King and Bock, 1997) GPS data processing software. The value of ZHD is calculated from Eqn. (6) above and then using Eqn. (7) we will get the IWV in the Zenith direction from GPS data. Using Eqn. (5) we will get the IWV in slant direction also. In this paper we have used IWV only in the Zenith direction.

The value of IWV from Limited Area Model (LAM) is calculated by the vertical summation up to 300 hPa. The specific humidity is calculated by using Magnus – Tetens (Barenbrug, 1974) formula for vapour pressure and interpolated at required pressure levels to get the gridded data which is also averaged out over the two stations New

Delhi and Bangalore for the Months January and February 2003. This is shown in Eqn. (9) below:

$$IWV = \frac{1}{g} \sum_{i=1}^k q_i (p_i - p_{i-1}) \tag{9}$$

The moisture contribution above 300 hPa is neglected.

3. Results and discussions

The Integrated Water Vapour (IWV) retrieved from GPS, LAM and Radiosonde data over New Delhi and Bangalore along with Root Mean Square Error (RMSE) and bias are shown in Fig. 1 and Fig. 2 respectively. The LAM data retrieved RMSE and biases over New Delhi are higher than Bangalore. On the other hand the Radiosonde derived IWV comparison shows reasonably good agreement for both the stations. The biases over New Delhi are on positive side whereas over Bangalore on negative side for both LAM-GPS and Radiosonde - GPS.

The GPS retrieved IWV values in the case of New Delhi are closer to Radiosonde data retrieved values. LAM analysis values show the reverse effect. It shows more RMSE and bias over New Delhi in comparison to Bangalore with LAM analysis data. The results are summarized in Table 1. This variation in the values of LAM retrieved IWV and GPS is mainly because these are the gridded average values of the specific humidity (q) interpolated at each pressure levels. The procedure adopted here is linear interpolation which seems to be inaccurate as we go higher pressure levels because the moisture contents are highly variable at different layers in the atmosphere. For GPS data retrieved IWV values are also have certain degree of inaccuracies due to various reasons. The IWV 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. Actually two types of GPS instruments are available one with meteorological software and others without meteorological software. The GPS/Met software is mainly responsible for meteorological applications and other GPS instruments are mainly use for navigation purposes. Because GPS/Met instrument take the real time surface data over the station so IWV values are initialized every time (say half an hour). In this way we will get the more precise values of IWV over the station. But Zenith total delay can be determined without Met package also. In that case we give average surface pressure and temperature values of the concerned station and process the data to get Zenith Total Delay. As it is clear from Eqn. (6) that ZHD is the most sensitive for surface pressure so it will effect over IWV values. If the pressure is given with uncertainty less than 0.3 hPa or better then the hydrostatic delay can be reduced to less than 1 mm (Businger *et al.*, 1996). This is one of the main sources of error in the retrieval of IWV without met package. Because the atmospheric conditions will not remain same all the time, it may be one of the causes of more variation in the IWV values for both the stations. Apart from this, there are other sources of errors are also included like broadcast ephemeris, propagation errors in the ionosphere and troposphere, receiver and satellite clock biases multipath and receiver noise. As the Indian ionosphere is characterized by large horizontal gradients, intense irregularities, large delay to dry variations and equatorial anomaly conditions, there is a clear necessity to thoroughly understand the ionospheric time delay effects on the GPS signals (Sarma *et al.*, 2002).

Actually the water vapour distributions in the atmosphere are highly variable in space and time so its variation cannot be accurately predicted from surface measurements. Fortunately the wet contribution is only about 10% of the total tropospheric refraction. Space – borne water vapour radiometers are also commonly used

in meteorology for measuring IWV. However, space borne instruments provide only large- scale measurements of the water vapour field. Moreover, they perform better over oceans where surface emissivity is low, than over land, where surface emissivity is very changing with soil and vegetation canopy type and moisture (Mcmurdie and Katsaros, 1985). Apart from the above said sources of errors and limitations of GPS and space borne instruments, GPS is a very valuable tool for real time estimation of integrated water vapour over the station. India Meteorological Department will soon start the GPS data processing with met package for IWV and other meteorological applications at five places New Delhi, Mumbai, Chennai, Calcutta and Guwahati.

4. Concluding remarks

The integrated water vapour overlying at the ground based GPS receiver apart from various types of uncertainties shows fairly good agreement with radiosonde data for both the stations. The systematic biases and root mean square error have shown improvement with radiosonde data in comparison to Limited Area Model predicted IWV values. The real time based IWV will be very useful in understanding the moisture distribution and thermodynamics of various microphysical processes of the atmosphere. Later, this distribution will directly be communicated to the temperature and moisture fields of NWP models. This will finally improve the forecasting accuracy.

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