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INTEGRATED WATER VAPOUR MEASUREMENT OVER DEHRADUN USING GROUND-BASED GPS AND COMPARISON WITH VALUES OBTAINED FROM NCEP REANALYSIS AND MODIS DATA

1. Measurement of water vapour in the atmosphere can be addressed by a number of ways, from *in situ* measurements to remote sensing from satellites. Space measurements are necessary to describe the large-scale distributions for integrated water vapour content and estimates of the contents of thick layers. However, these measurements have to be improved and complemented by *in situ* measurements, especially near the surface and in the upper troposphere. Due to the assimilation procedures, forecast models capture well most features of the WV distribution, but errors remain in the data void regions such as the tropics, inducing still larger errors on the convective systems representation, for example.

The integrated water vapour over the station illustrates the importance fluctuations of the water vapour content over the station. The estimation of precipitable water vapour from GPS during winter season 2003 for Delhi and Bangalore stations when compared with radiosonde data, NCEP reanalysis and MODIS data (Giri *et al*., 2006; 2007[a]; 2007[b]) shows fairly good agreement. In this paper an attempt has been made to retrieve IWV from ground based Global Positioning System (GPS) Zenith Total Delay (ZTD) data using Bevis *et al.* (1992) approach for Dehradun (78.013° E / 30.329° N) and result has been compared with Moderate Resolution Imaging Spectroradiometer (MODIS), National Centre for Environment Prediction (NCEP) reanalysis data. As radiosonde observation is not available at Dehradun relative humidity derived from NCEP reanalysis has been utilized.

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 135 days (January to March and 8th August to 20th September 2003). From NCEP reanalysis data precipitable water vapour in kg/m^2 is available from global site (http://www.cdc.noaa.gov/cdc) at 2.5-degree latitude × 2.5 - degree longitude global grid (90° N - 90° S, 0° E - 357.5° E). The data is extracted and averaged linearly about the station position in 1° × 1° grid data. The MODIS PWV data is available from global site (http://modis.gsfc.nasa.gov/data), where in details of retrieval methodology is also given. Methodology involves ratios of water vapour absorbing channels centred near 0.905, 0.936 and 0.940 mm with atmospheric window channels at 0.865 and 1.24 mm. MODIS data processing was done at India Meteorological Department, New Delhi using IR algorithm and collection of many bins (pass files of acqua and terra satellites) which are averaged about the station position Dehradun. RH values were directly extracted from NCEP reanalysis data for Dehradun station position.

TABLE 1

Correlation coefficient (RH and IWV)

S. No.	Level (hPa)	Correlation coefficient
1	1000	0.687
2	850	0.699
3	700	0.565
4	500	0.282
5	300	0.034

TABLE 2

Root mean square error and biases

Quantity	NCEP & GPS	MODIS &GPS
RMSE (kg/m^2)	4.3	2.14
Biases (kg/m^2)	-1.53	-0.12

Integrated Water Vapour (IWV) from GPS is retrieved from the ZTD following the concept describe in Bevis *et al*., (1992) and Emardson *et al*., (1998). Brief mathematical derivation, description and procedure adopted have been discussed by Giri *et al*. (2007[a]). In a simplified way, the IWV is related with precipitable water vapour (PWV) as follows:

$$\text{IWV} = \rho\ \text{PWV} \quad \text{and}$$

$$\text{PWV} = \text{K ZWD}$$

Where, K is a constant, which depends on the *Tm* (Bevis *et al*., 1992).

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

ZWD = zenith wet delay [determined by the difference of ZTD and modelled zenith hydrostatic delay (ZHD)].

3. *Results and discussion* **-** The GPS based retrieved IWV values in kg/m^2 along with NCEP and MODIS are shown in Fig. 1 for the period of study. The

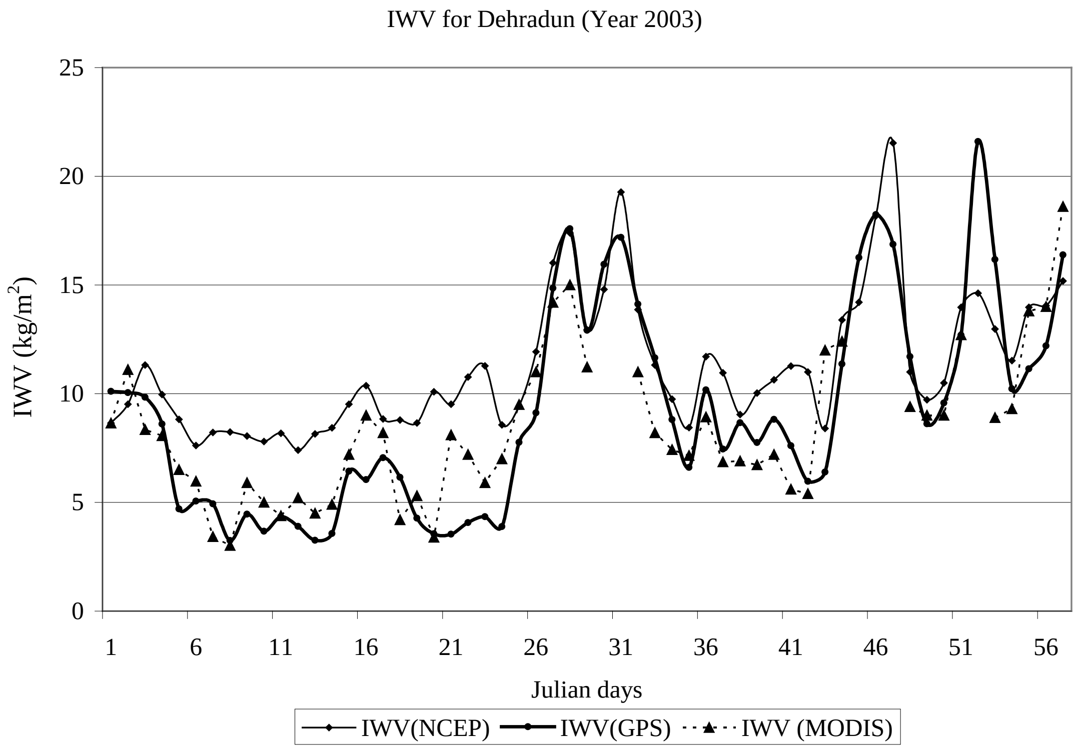

Fig. 1. Comparison of IWV (kg/m^2) derived from MODIS, NCEP & GPS for 2003 at Dehradun

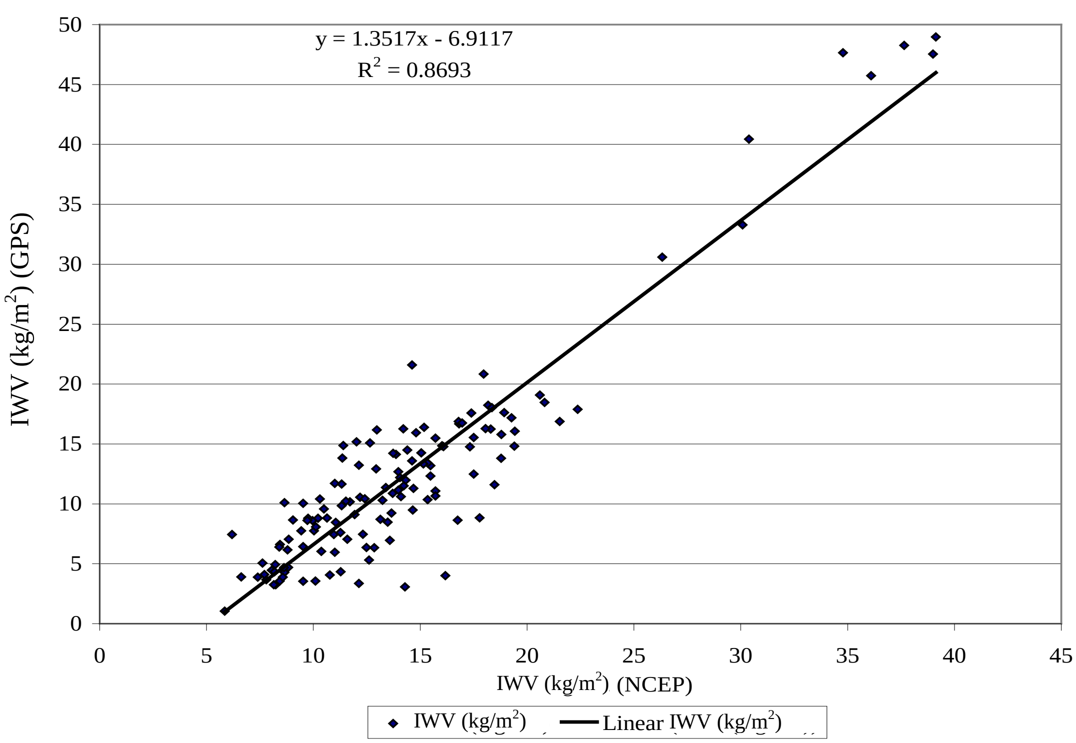

Fig. 2: Scatter diagram of IWV (kg/m^2) derived from NCEP and GPS for Dehradun

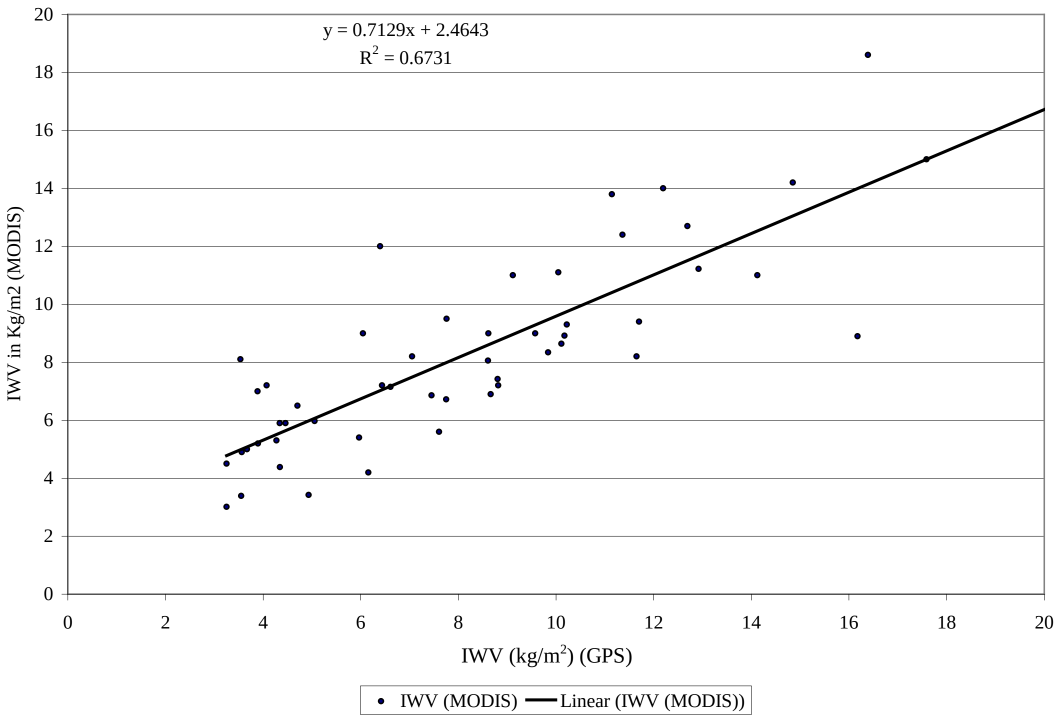

Fig. 3. Scatter diagram of IWV (kg/m^2) derived from GPS and MODIS for Dehradun

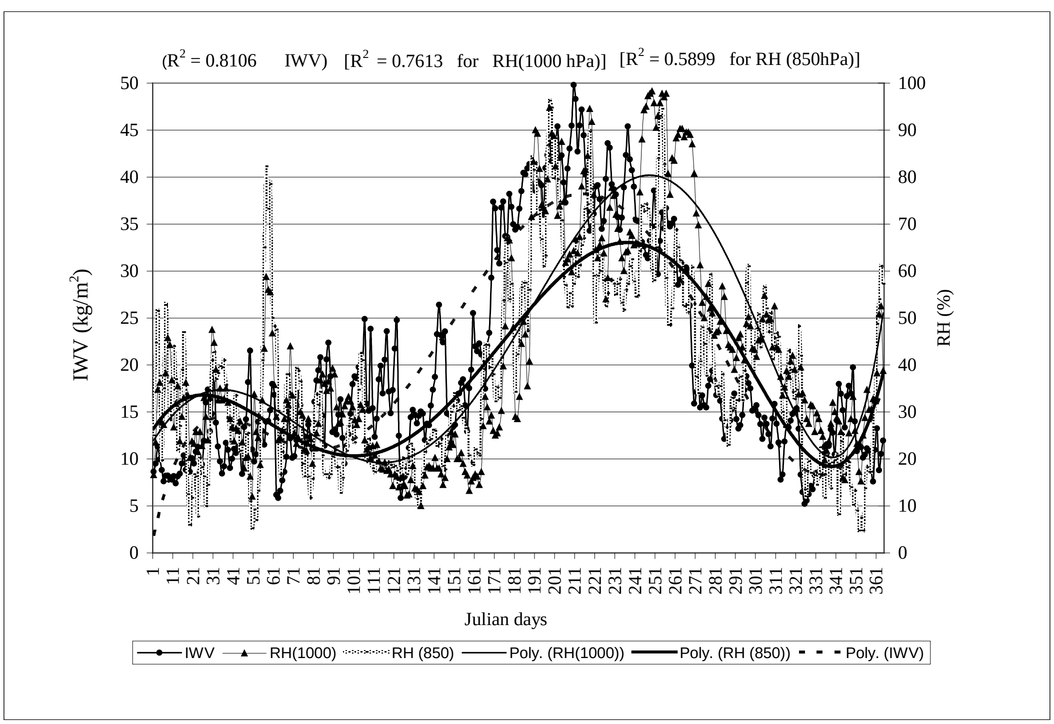

Fig. 4. R.H (1000, 850 hPa) & IWV for Dehradun (Year 2003) from NCEP reanalysis data

scatter plot analysis diagram of GPS with NCEP and MODIS derived IWV along its linear trend analysis are shown in Fig. 2 and Fig. 3 respectively which clearly shows the close association of GPS based IWV with NCEP and MODIS retrieved IWV values.

Daily averaged Relative Humidity (RH) for year 2003 derived for Dehradun from NCEP reanalysis for 1000 and 850 hPa level along with corresponding IWV has been shown in Fig. 4. It is evident from these figures that RH derived from NCEP analysis indicate similar seasonal pattern as indicated by IWV and this can be used in dynamical study of atmosphere for describing instability conditions if radiosonde derived observations are not available. Study of correlation coefficient (CC) of RH and IWV (Table 1) indicates that RH at1000 and 850 hPa levels are highly correlated with IWV**.** Results could not be validated because no radiosonde observation is available for Dehradun. The root mean square error (RMSE) and systematic bias observed in NCEP model and MODIS data analyses with GPS are given in Table 2. This indicates that GPS retrieved IWV shows reasonably good agreement with MODIS data. This bias and RMSE variation is due to temporal and spatial variation of IWV fields.

4. *Conclusion* - The IWV derived from GPS, NCEP and MODIS describe the moisture content of the area of study properly. The root mean square error (RMSE) and bias observed during the study for GPS-NCEP and GPS-MODIS are 4.3, -1.58 and 2.14, -0.12 kg/m^2 respectively. Anomaly variation is very useful to monitor the convection and seasonal fluctuation of IWV distribution over the station.

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