J. Ind. Geophys. Union (January 2009)
Vol.13, No.1, pp.17-23

Annual variability of water vapor from GPS and MODIS data over the Indo-Gangetic Plains

Sanjay Kumar, A.K.Singh, Anup K.Prasad[1] and R.P.Singh[1]
Atmospheric Research Lab., Department of Physics, Banaras Hindu University, Varanasi- 221 005
[1] Department of Physics, Computational Science and Engineering, Chapman University, One University Drive, Orange, CA 92866, USA
Email: abhay_s@rediffmail.com)

ABSTRACT
The knowledge of water vapor variability is important at any location in India for weather forecast, numerical weather prediction and also in the early information about the onset of monsoon. In the absence of ground observations, the satellite remote sensing and the Global Positioning System (GPS) have emerged as an important tool in estimation of water vapor. The total column atmospheric water vapor, obtained from Global Positioning System (GPS) and Moderate Resolution Imaging Spectroradiometer (MODIS), is found to be very dynamic over the Indo-Gangetic (IG) plains. In this paper, we present our preliminary analysis of GPS along with satellite (MODIS) derived water vapor and its annual variability over the IG plains of India (Varanasi - BHU station and Kanpur – IITK station) during the period January, 2007 to December, 2007. The monthly and seasonal variations of water vapor show strong variability and its relation with the monsoon. The role of GPS and satellite derived meteorological parameters in understanding the dynamics of the monsoon and climate conditions over Indian sub-continent are discussed.

INTRODUCTION

Water vapor is one of the important constituents of the atmosphere that affects thermodynamics of the atmosphere and has impact on the climatic processes (Rocken et al., 1993, Bevis et al., 1994; Duan et al., 1996; Key & Box 2000). GPS and satellite remote sensing have emerged as one of the reliable sources of water vapor estimation in the atmosphere (Bevis et al., 1994; Businger et al., 1996). GPS provides estimate of continuous (hourly averaged) total column water vapor during all weather conditions, over ground-based stations using very high frequency and ultra high frequency (VHF-UHF) microwaves (1-3 GHz) from a constellation of GPS satellites. Atmospheric water vapor is one of the dominant greenhouse gases (Raval & Ramnathan 1989). It also has a significant influence on the accuracy of the GPS measurements for space geodetic applications. The variability of atmospheric water vapor is large on a temporal as well as on a spatial scale (Jarlemark 1998). Recently, Jade et al. (2005) have shown the variability of GPS water vapor over Bangalore in southern India and Hanle in northern Himalayan region. Prasad et al. (2007) have shown the variability of GPS water vapor over Indian subcontinent and found that the total column water vapor obtained from GPS and Moderate Resolution Imaging Spectro-radiometer (MODIS) to be very dynamic over the Indian sub-continent. Water vapor is found to be highly variable over the Indo-Gangetic (IG) plain which is one of the agriculturally very productive regions in the world.

In this paper, we discuss the variability of GPS water vapor along with MODIS satellite derived water vapor over the northern plains (IIT Kanpur and BHU Varanasi) of India during the year 2007. The variability of water vapor and its relation with the temperature and rainfall is also shown. The water vapor over Varanasi and Kanpur shows a characteristic changes associated with the meteorological parameters showing a close relation with the dynamics of monsoon.

GPS DATA PROCESSING

Satellite microwave signals from space to ground GPS receiver is delayed due to atmosphere (troposphere). The delay in GPS signal, as measured by ground receiver in two frequencies induced by troposphere, consists of two parts; dry and wet delay which is obtained from the difference between total and dry delay (model using pressure data either from NCEP

(National Center for Environmental Prediction) or local barometer) (Rocken et al., 1993; Bevis et al., 1994; Duan et al., 1996). The analysis of GPS data recorded in Rinex format, for two stations lie in Indo-Gangetic plains about 350 km apart is carried out using GAMIT/GLOBK software (http:/ www.gpsg.mit.edu/simon/gtgk/) and the total water vapor is derived for these two stations. The GPS data for IIT Kanpur (IITK) and BHU Varanasi (VNS) is obtained using Trimble Survey Grade Dual frequency receiver (Trimble 5700 with zephyr geodetic antenna, 1.2 and 1.5 GHz). The accuracy of GPS water vapor measurement partially depends on the accuracy of surface pressure measurements. The NCEP estimates are found to be within acceptable limits for GPS stations without local MET (meteorological) package except high altitude stations where NCEP estimates are found to be less accurate (Quinn & Herring 1996). Daily Rinex files containing data at every 30 seconds interval were processed using inbuilt FORTRAN script to obtain water vapor at 30 seconds interval. We estimated hourly averaged precipitable water vapor, for IITK and VNS for further analysis.

WATER VAPOR USING MODIS DATA

The MODIS is a key scientific instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. MODIS Terra covers the globe every 1-2 days, provides data in moderate spatial resolution (250 m at nadir) with swath width (2330 Km), and large spectral range (36 channels between 0.412 to 14.2 µm). We have used Level-3 MODIS terra (MOD08_M3, http://modis-atmos.gsfc.nasa.gov) monthly and (MOD08_D3) daily global grid product (near infrared water vapor with clear column) available at spatial resolution of 1 degree. MODIS water vapor is derived from channels in near infrared region that are useful for remote sensing of water vapor (King et al., 1992; Gao & Kaufman 1998, 2003). MODIS water vapor estimation may have error up to 10 % especially under hazy conditions described by (Gao & Kaufman 1998). Correlation between MODIS and GPS water vapor has been found to be greater than 0.95 over Tibet and Europe (Li, Muller & Cross 2003; Liu et al., 2006) and Indian subcontinent (Prasad et al., 2007).

Here, we have taken daily rainfall and surface temperature from the local India Meteorological Department (IMD) station located on our campus (at the Department of Geophysics Banaras Hindu University, Varanasi). The monthly rainfall product from Tropical Rainfall Measuring Mission (TRMM, 3B43 Version 6) has been obtained from Goddard Earth Sciences (GES, http://disc.sci.gsfc.nasa.gov/). The monthly rainfall data obtained from TRMM (spatial resolution of 0.25^0 x 0.25^0) available since 1998.

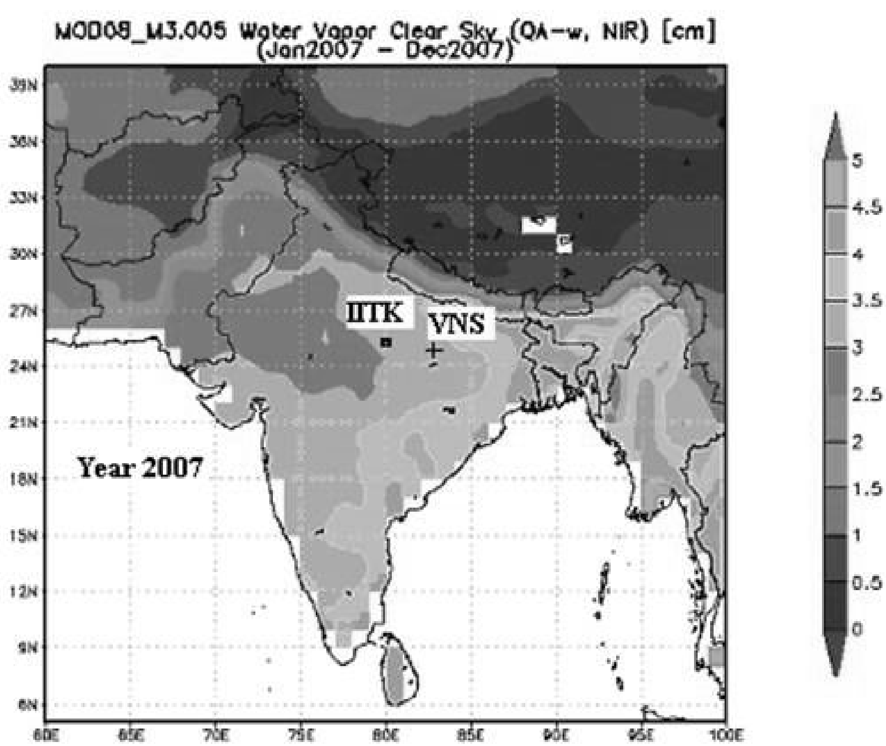


Figure 1 (a). The distribution of MODIS water vapor (cm) over Indian subcontinent during the year 2007.

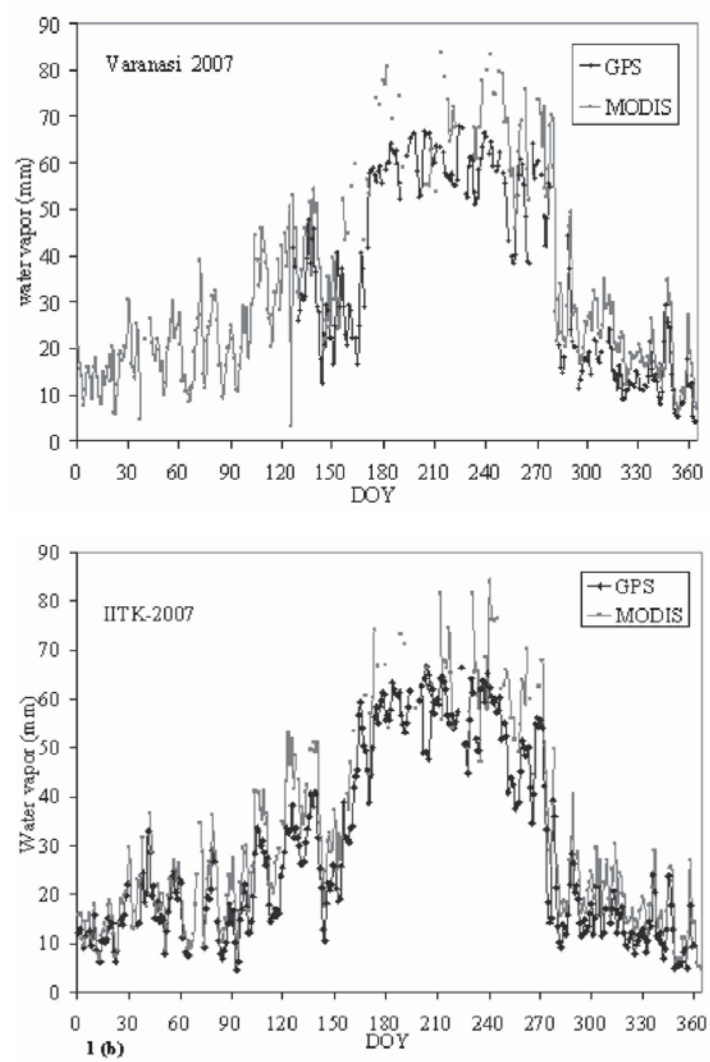


Figure 1 (b). The daily variation of GPS and MODIS water vapor over Varanasi and IIT Kanpur for year 2007.

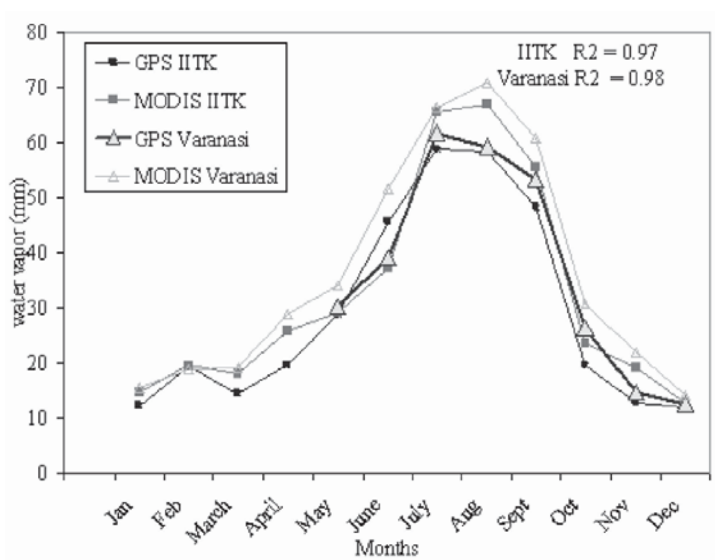


Figure 2. The variation of monthly mean GPS water vapor and monthly mean MODIS water vapor over both the stations.

RESULTS

Comparison of GPS and MODIS water vapor:

Figure 1(a) shows the distribution of MODIS water vapor (mm) over the Indian sub-continent during the year 2007. The yearly column water vapor shows a small difference (30-35 mm). Figure 1(b) shows daily variation of GPS and MODIS water vapor over IIT Kanpur and Varanasi for the year 2007. It is seen from the Fig.1(b) that the daily GPS water vapor varies over wide range (4-68 mm) for Varanasi and in the range 5-67 mm) over IIT Kanpur during the year 2007 with minimum in winter and maximum in monsoon season. The correlation (R^2) between daily GPS and MODIS water vapor for the whole year of 2007 is found to be 0.97 for IITK and 0.93 for VNS. The monthly mean water vapor estimated from GPS and derived from MODIS water vapor (Fig.2) is found to be 0.98 for VNS and 0.97 for IITK. The monthly mean GPS water vapor is found to be maximum (up to 59 mm for IITK and 62 mm for VNS) during monsoon season and minimum (up to 4.5 mm for IITK and 4 mm for VNS) during winter season. The correlation between MODIS and GPS water vapor for the summer season is found to be $R^2 = 0.97$ for IITK, $R^2 = 0.84$ for VNS, for the monsoon season is $R^2 = 0.94$ for IITK, $R^2= 0.92$ for VNS and for the winter season $R^2 = 0.87$ for IITK and $R^2= 0.86$ for VNS. The monthly water vapor fraction (in %) for both stations is found to be maximum during the monsoon season in the month of July (IITK 16.80 %; VNS 20.77 %).

Variability of GPS water vapor with meteorological parameters:

The total water vapor column is very much dependent on surface temperature and rainfall. Variation of daily GPS water vapor and surface temperature and rainfall for Varanasi, respectively is shown in figures 3a and 3b. The correlation (R^2) between daily GPS water vapor and surface temperature is found to be 0.71 for Varanasi.

The correlation (R^2) between monthly mean GPS water vapor and ground observed rainfall is found to be 0.45 and between monthly mean water vapor and monthly mean TRMM rainfall is around 0.92 for Varanasi and 0.85 for IIT Kanpur. Table 1 shows the monthly rainfall derived from TRMM over Varanasi and Kanpur. GPS water vapor shows a strong correlation ($R^2 = 0.94$ for VNS and $R^2 = 0.85$ for IITK) with TRMM rainfall compared to the ground observed rainfall ($R^2 = 0.45$ for VNS).

Table 1. Distribution of TRMM rainfall for BHU Varanasi and IIT Kanpur for year 2007.

Month of Year 2007	BHU TRMM rainfall (mm)	IITK TRMM rainfall (mm)
January	0.82	10.75
February	45.33	72.85
March	19.55	12.58
April	6.16	6.84
May	29.17	25.11
June	50.20	81.42
July	285.00	295.12
August	158.60	182.50
September	194.80	71.72
October	16.01	3.15
November	0.00	1.58
December	0.00	3.31

DISCUSSION

The column water vapor shows a large enhancement with the monsoon onset (usually 3rd week of June or 1st week of July) and with phases of monsoon (onset-break and withdrawal) (July to October) for both the stations. The water vapor estimated from the other satellites such as Special Sensor Microwave/ Imager (SSM/I) also shows an enhancement with the monsoon onset season (Singh et al., 2004). The correlation between monthly mean GPS water vapor and monthly mean MODIS water vapor is found to be 0.98 for VNS and 0.97 for IITK. Recently, Prasad et al. (2007) made a comparison of GPS and MODIS water vapor over Indian sub-continent for the period 2004 and 2005, the correlation was found to be more than 0.95. During summer season an enhancement of water vapor is found to be associated with the dust storm events (Prasad et al., 2007). The correlation (R^2) between GPS water vapor and TRMM rainfall is found to be 0.94 for VNS and 0.85 for IITK; this shows a good agreement between GPS water vapor and TRMM rainfall. The correlation between GPS water vapor and ground observed surface temperature is found to be 0.71 for VNS.

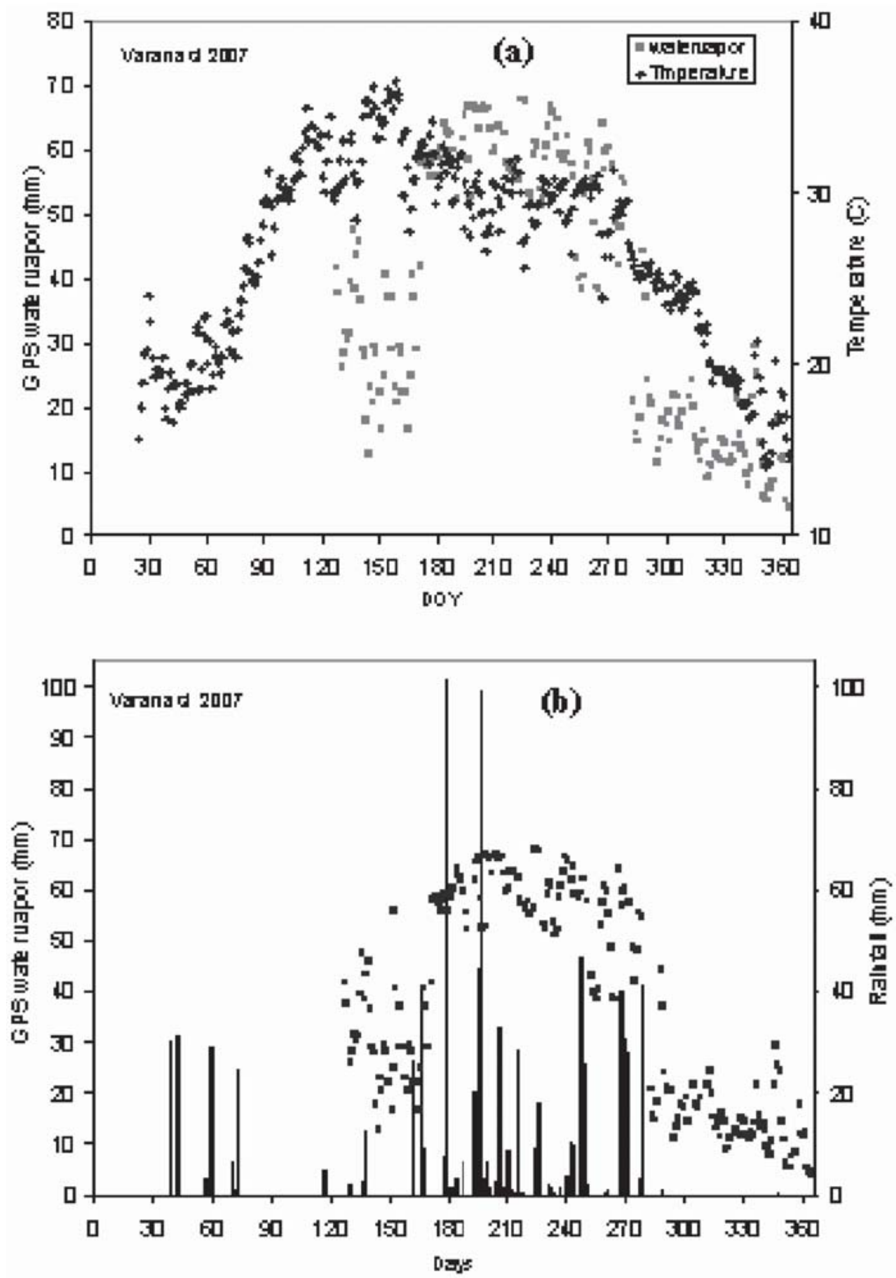


Figure 3 (a) Variation of ground observed surface temperature and GPS water vapor at Varanasi (b) Variation of ground observed Rainfall (bar) and GPS water vapor at Varanasi.

CONCLUSIONS

From the analysis of GPS and MODOS data observed at Varanasi and Kanpur, following conclusion are drawn:

- The water vapor retrieved from GPS is found to be highly correlated with satellite observation (MODIS), which has wide spatial coverage as seen over Indian subcontinent.
- A high correlation between GPS and MODIS derived water vapor (0.98 for VNS and 0.97 for IITK) shows accuracy of GPS measurements.
- The column water vapor estimated from GPS data is found to be very sensitive with surface temperature, monsoon onset and rainfall.
- GPS water vapor is more correlated with satellite rainfall (TRMM) data compared to the ground observed rainfall.

ACKNOWLEDGEMENTS

The work is partly supported by the Ministry of Earth Sciences (MoES), New Delhi and partly by the Department of Science and Technology (DST), New Delhi under a SERC Project to A.K.Singh.

REFERENCES

Bai, Z. & Feng, Y., 2003. GPS water vapor estimation using interpolated surface meteorological data from Australian automatic weather stations, J.Global Positioning Syst.,2 (2), 83-89.

Bevis M., Businger, S., Chiswell, S., Herring, T., Anthes, R., Rocken, C. & Ware, R.H., 1994. GPS Meteorology: Mapping zenith wet delays onto precipitable water, J. Appl. Metrology, 33, 379-386.

Businger, S., Chiswell, S.R., Bevis, M., Duan, J., Anthes, R.A., Rocken, C., Ware, R.H., Exner, M., Van Hove, T. & Solheim F.S., 1996. The promise of GPS in atmospheric monitoring, Bull. Amer. Meteor. Soc., 77, 5-18.

Duan, J., Bevis, M., Fang, P., Bock, Y., Chiswell, S., Businger, S., Rocken, C., Solheim F., Van Hove, T., Ware, R., McClusky, S., Herring, T.A. & King, R.W., 1996. GPS Metrology: Direct estimation of the absolute value of precipitable water, J. Appl. Metrology, 35, 830-838.

Gao, B.C. & Kaufman, Y.J., 1998. The MODIS Near-IR water vapor algorithm. Products: MOD05, MOD08. ATBD-MOD-03.

Gao, B.C. & Kaufman, Y.J., 2003. Water vapor retrieval using Moderate Resolution Imaging Spectro-radiometer (MODIS) near infrared channels, J. Geophys. Res., 108 (D13), 4389, doi: 10.1029/2002JD003023.

Jade, S., Vijayan, M.S.M., Gaur, V.K., Prabhu, T.P. & Sahu, S.C., 2005. Estimates of precipitable water vapor from GPS data over the Indian subcontinent, J. Atmos. Solar-Terr. Phys., 67(6): 623-635.

Jarlemark, Per O. J., 1997. Analysis of temporal and spatial variations in atmospheric water vapor using microwave radiometry technical report No. 308, School of electrical and computer engineering, Chalmers University of Technology, Goteberg, Sweden.

Kay, M.J., & Box, M., 2000. Radiative effects of absorbing aerosols and the impact of water vapor. J. Geophys. Res., 105 (D10), 12221-12234, 10.1029/2000JD900065.

King, M.D., Kaufman, Y.J., Menzel, W.P., & Tanre, D., 1992. Remote sensing of cloud, aerosol, and water vapor properties from the Moderate Resolution Imaging Spectro-radiometer (MODIS). IEEE Trans. Geosci. Remote Sens., 30, 1-27.

Li, Z., Muller, J. & Cross, P., 2003. Comparison of precipitable water vapor derived from radiosonde, GPS, and Moderate Resolution Imaging Spectro-radiometer (MODIS) measurements. J. Geophys. Res., 108 (D20), 4651, doi:101029/2003JD003372.

Liu, J., Liang, H., Sun, Z., & Zhou, X., 2006. Variation of the Moderate Resolution Imaging Spectro-radiometer precipitable water vapor product using measurements from GPS on the Tibetan Plateau. J. Geophys. Res., 111, D14103, doi:10.1029/2005JD007028.

Prasad, A.K., Singh, R.P., Singh, Shatrughan & Nanda, DIP S., 2007. GPS and satellite meotrology for understanding monsoon dynamics over the Indian subcontinent. (Proceeding of Symposium HS 2004 at IUGG 2007, Perugia, July 2007), IAHS Publ. 313, 33-39.

Quinn, K.J. & Herring, T.A., 1996. GPS atmospheric water vapor measurements without the use of local barometers, AGU Fall Meet 1996, Poster G12A-06.

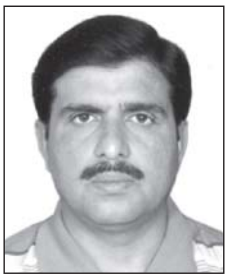
Rocken, C., Ware, R.H., Van Hove, T., Solheim, F., Alber, C., Johnson, J. & Bevis, M.G., 1993. Sensing atmospheric water vapor with the GPS, Geophys. Res. Lett., 20, 2631-2634.

Raval, A. & V, Ramnathan., 1989. Observational determination of the green house effect. Nature, 342, 758-761.

Singh, R.P., Dey, S., Sahoo, A.K. & Kafatos, M., 2004. Retrieval of water vapor using SSM/I and its relation with the onset of the monsoon, Ann. Geophys., 22, 3079-3083.

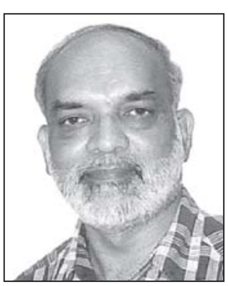
(Revised accepted 2008 December 25; Received 2008 November 10)

Mr. Sanjay Kumar is currently working as a Junior Research Fellow in the Atmospheric Research Laboratory, Department of Physics, Banaras Hindu University, Varanasi. He did his Master degree (M.Sc. 2005) from Banaras Hindu University. Currently he is doing his research in ionospheric TEC, ionospheric scintillation and water vapor studies using GPS data.



Dr. Abhay Kumar Singh is currently Reader in Dept. of Physics, Banaras Hindu University, Varanasi. He obtained Ph.D. from BHU, Varanasi in 1993. He was Lecturer in Maharaja College, Ara from 1996 to 2005 and then joined as Reader in Department of Physics, BHU, Varanasi in 2005. He was BOYSCAST Fellow at Department of Theoretical Space Physics, Umea University, Umea, Sweden from 2002 to 2003 awarded by DST, New Delhi. His research interest includes: Space Weather Studies of Upper Atmosphere, Study of Ionospheric Irregularities using VHF & GPS scintillations, GPS based Total Electron Content (TEC) & Water Vapor content measurements, Study of VLF Whistler-Mode waves, Electrodynamics of the Atmosphere-Ionosphere-Magnetosphere, Seismo-electromagnetics to study Earthquake Precursors, Atmospheric studies involving aerosols, dust storms, winter fog, and their radiative and climate effects.

Dr. Anup Krishna Prasad, Research Assistant Professor, Dept. of Physics, Computational Science and Engineering, Schmid College of Science, Hashinger #211, Chapman University, 1 University Drive, Orange, CA 92866, Phone: (Off.) 714-289-2051; (Cell) +1-571-730-9083; Email: anupiitk@gmail.com. Ph.D. 2007, Indian Institute of Technology Kanpur, India. Current research interest: Image processing of remotely sensed data for environmental studies. Atmospheric studies involving aerosols, dust storms, winter fog, and their radiative and climate effects. Climate change induced by greenhouse gases such as NOX, CO, CO2, CH4, water vapor. Anomalous changes in the global temperature, precipitation, hydrological cycle and their impacts on the vegetation. Analytical study of land, ocean and atmosphere components, processes and feedbacks using multi-sensor satellite data. Space based near real-time study of global hazards such as droughts, floods, hurricanes, earthquakes.



Prof. Ramesh P. Singh obtained Ph.D. in Geophysics from Banaras Hindu University. After spending five years (1981-1986) at the University of Alberta, Canada, he joined Indian Institute of Technology, Kanpur where he was Professor until August 2007. His research includes solid earth geophysics, early warning of natural hazards, remote sensing monitoring of land, ocean and atmosphere and understanding of coupling between lithosphere-hydrosphere-atmosphere. Presently he is Professor of Earth System Science and Remote Sensing in the Department of Physics, Computational Science and Engineering, Chapman University, California in USA.