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Studies on Columnar Water Vapor Retrieval using IRS-P3 Modular Optoelectronic Scanner (MOS)

K.Madhavi Latha and K.V.S.Badarinath
National Remote Sensing Agency, Hyderabad – 500 037

ABSTRACT
Studies on columnar water vapor are important for studies involving weather and climate modeling and the hydrologic cycle. In the present study, IRS-P3 MOS data over the heterogeneous land area covering various land use cover classes such as agricultural areas, forest areas, water bodies, etc., has been attempted, using the IRS-P3 MOS datasets of February and March (15^{th}, February, 1999 and March 11^{th}, 1999). Results of the study suggested clear differences in columnar water vapor over different land use cover classes. The contrast between the agricultural areas and forest areas and also in-between the vegetation classes, viz., dry deciduous and mixed deciduous forests has been found to be clear by using the CIBR methodology. Analysis of the results suggests that, the clouds had higher columnar water vapor (1-1.50cm) when compared to other land surface features. The columnar water vapor over the vegetation areas, during the February accounted for about 1-3.04 cm, whereas during the month of March, it accounted for about 1.0-2.90m. The columnar water vapor decreased during the dry period (summer) when compared to earlier month (February). Overall study suggested the possible use of CIBR methodology for retrieval of columnar water vapor over land areas.

INTRODUCTION

Water vapor is the key driver to global atmospheric circulation. Atmospheric water vapor has a great impact on the climate of the earth, it is the deciding factor in cloud and precipitation production and a carrier of energy exchange between the oxcean and the atmosphere and other components of the climatic system (Tahl & Schonermark 1998). Accurate water vapor measurements are required to assess atmospheric heating rates, the re-distribution of latent heat by atmosphere accompanying water vapor transport, and the effect of water vapor accumulation. Retrieval of water vapor from satellite data sets gains importance, as the watervapor strongly affects the absorbance of outgoing long wave radiation. The remotely sensed water vapor concentration can be used to obtain the information on the dynamic state of the atmosphere (Prabhakara et al. 1978). Information on the columnar water vapor can be used for the atmospheric correction of radiances measured in the infrared (IR) of region of the remotely sensed data. Detailed account on the use of water vapor column studies for atmospheric corrections has been attempted by earlier workers (Tahl & Schonermark 1998). Recognizing the importance of water vapor in the atmospheric chemistry and radiative transfer, there have been numerous attempts to retrieve columnar water vapor from satellite data. The first attempt to obtain the water-vapor profile in the atmosphere from radiometric measurements dates back to Conrath (1969). Use of NOAA AVHRR data for retrieval of columnar water vapor has been attempted by Prabhakara & Dalu 1980. SSM/I measurements of atmospheric water vapor over oceans has been attempted by Schulessel & Emery (1990). IRS-MOS data has been used to retrieve the columnar water vapor by Tahl & Schonermark 1998. In the present study, an attempt has been made to use the IRS-P3 MOS data over heterogeneous land cover having different land use classes such as agricultural areas, dry deciduous forest, mixed deciduous forest, fallow areas, water bodies etc.

STUDY AREA

The East Godavari District, Andhra Pradesh, India has been chosen for the present study (Fig.1). The study area is located at northeastern part of the Andhra Pradesh state, between 160 17' and 180 30' north latitudes and 81^{o} 30' and 82^{o} 32' East Longitude. The district ranks fourteenth in the state. The total area of the district is about 10,807 sq.kms, which is nearly 3.94 % of total area of the state. The study area comprises of different land use / cover classes, viz., forests, urban areas, water bodies, sandy areas, industrial areas, agricultural lands etc., and most of the study area is predominately covered by forests. The forest remains deciduous only for a shorter period of the entire year, particularly during the month of May season. The top canopy of the forest reaches at the maximum of 20-25 meters height with a closed canopy and is mainly occupied by deciduous species with the under wood species of evergreen to semi-evergreen. The elevation of the study area varies from 400 to 600m. The soils of the district are alluvial, red soils, sandy loams and sandy clays. pH of the soils varies from 6.5 to 7.0. Grass cover is negligible. The rainfall of the district is about 1600mm with about 85 rainy days per annum.

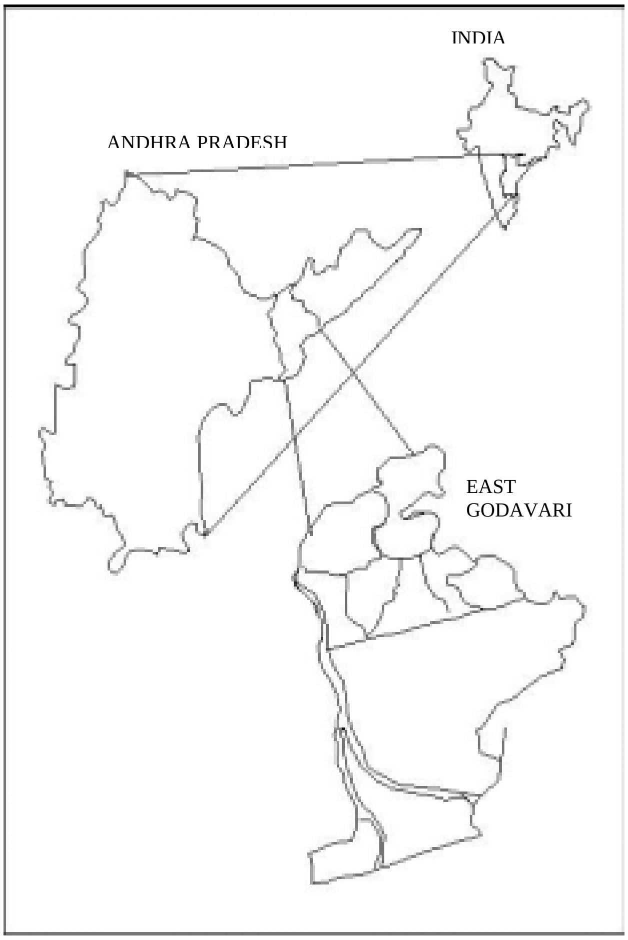


Figure.1. Study area East Godavari district

DATASETS

In the present study, IRS-P3 MOS data corresponding to 15th February, 1999 and 11th March, 1999 of East Godavari District, Andhra Pradesh, has been used for retrieval of columnar water vapor. The Modular Optoelectronic Scanner (MOS) payload is a multispectral space borne push broom spectrometer developed and built by the German Aerospace Research Establishment (DLR). IRS-P3 MOS payload was launched on 21st March 1996, using polar Satellite launch vehicle (PSLV) and comprises of two separate imaging Spectrometers (MOS-A and MOS-B) and the one channel CCD arrays Camera (MOS-C). MOS payload operates in the VIS-NIR, SWIR region of the electro magnetic spectrum and covers or wide range of atmospheric primarily related to oceans and also in the areas of atmosphere and land studies. The atmosphere spectrometer MOS-A measures the backscattered radiation in four channels (half width 1.4nm) in the absorption band of the atmospheric oxygen near 760nm and provides actual data about the atmospheric transmission, which will be used for the correction of data from surface objects. The bio-spectrometer MOS-B measures in 13 spectral bands (halfwidth about 10nm) in the spectral region from 408 to 1010nm for monitoring and investigation of the atmosphere surface system; especially oceanic bio-productivity and pollution in the shelf region (Sumnich & Schwarzer 1998), module C (MOS-C) is a single camera with an interference fitter at 1.6nm. The swath width for satellite orbitting height of 820 km is 200 km, the pixel size equal to 520 m. The MOS instrument (Zimmermann & Neumann 1996) provides remote sensing data of the spatial, spectral and radiometric radiance distribution of sun illuminated natural scenes. Radiance values range from the small levels of the ocean surface at low sun angles upto high levels of bright clouds. The emphasis concerning the instrument performance lies on spectral and radiometric measurement and less on the spatial resolution.

METHODOLOGY

The detailed methodology adopted in the present study is given by Tahl & Schonermark 1998 based on the earlier works (Green, Carrere & Conel 1989). The Continnum Interpolated Band Ratio (CIBR) is given as

$CIBR = L(\lambda_V)/c_1L(\lambda_{W1}) + c_2L(\lambda_{W2})$

where L is the radiance at the top of atmosphere The index V indicates the watervapor channel and W_1, W_2 are the neighbouring window channels. The coefficient C_1,C_2 are derived by

$C_1 = \lambda_{W2}-\lambda_v/\lambda_{W2}-\lambda_{W1}$

$C_2 = \lambda_v-\lambda_{w1}/\lambda_{W2}-\lambda_{W1}$

940nm absorption band is the most sensitive to variations in atmospheric water content (Geo & Goetz 1990) channel 12 (940nm) of the MOS-B spectrometer was selected for the water vapor channel and correspondingly 870nm and 1020nm were used as the window channels with respect to CIBR for different atmospheric and surface conditions L (λ_v), L (λ_{w1}) and L (λ_{w2}) were simulated by means of radiative transfer program MODTRAN (Kneizys et al. 1988).

The water vapor path is the amount of the gas, which is penetrated by the radiance on its sun-surface-sensor path. It can be transferred into columnar watervapor (V_c) and viceversa by means of the zenith angles of the sun and the sensor according to equation

$V_c = \lambda_p(1/\cos\theta_i + 1/\cos\theta_s)^{-1}$

where θ_I is the viewing angle of the sensor (θ_I»θ^0 for MOS-B) θs is the solar zenith angle

For the differences between the spectral reflectance curves of non-vegetation and vegetation cover, these two groups are distinguished by finding a regression function between CIBR and V_p (water vapor path values). For the vegetation and non-vegetation cover, the CIBR is given as (Tahl & Schonermark 1998),

$CIBR = e^{(-0.592 \cdot v_p^{0.568})}$ or $V_p = (In(CIBR)/0.592)^{1/0.568}$ ——(1)

$CIBR = e^{(-0.599 \cdot v_p^{0.575})}$ or $V_p = (In(CIBR)/0.599)^{1/0.575}$ ——(2)

The relative error of the watervapor content after the first regression was correlated to the logarithm of the interpolated nadir radiance of the two window channels; the second quantity being a count for the surface reflectance. Following equations gives the relationships for the cases of nonvegetation and vegetation cover respectively (Table. 1)

$V_{p.corr} = V_p/0.464 + 0.130.In(c_1L(867nm) + c_2L(1009nm)/cos\theta_S)$

and

$V_{p.corr} = V_p/0.587 + 0.092.In(c_1L(867nm) + c_2L(1009nm)/cos\theta_S)$

where L (867nm) and L(1009nm) have the unit $Wm^{-2}\ \mu m^{-1} sr^{-1}$. The errors of the watervapor values calculated with both equations (first and second regression) no longer depend on the surface reflectance. The maximum relative errors were reduced to values of +22 to –15 percent and the rms, errors to values of 5.21 and 4.57 percent (for cases of non-vegetation and vegetation cover)

Table 1. IRS-P3 MOSB Specifications

	MOS A	MOSB	MOSC
No of Spectral Band	4	13	1
Wavelength (nm)	757.0,760.6, 763.5,766.5	408,443,485,520, 570,615,650,685, 750,815,870,945, 1010.	1600
Spectral Half-Width (Nm)	1.4	10	100
GIFOV (m)	1569 x 1395	523 x 523	532 x 624
Swath (Kms)	195	200	192
Total FOV; Along x Across Track (mrad)	6.0 x 228.5	1.6 x 245.8	0.9 x 235.6
No. Of Pixels	140	384	300
Quantisation (bits)	16	16	16
Weight (Kg)	8.5	9.5	2.5

COLUMNAR WATER VAPOR MEASUREMENT FROM MICROTOPS II/OZONOMETER

In the present study, Microtops-II Ozonometer has been used for ground measurement of columnar water vapor in the study area. The instrument is equipped with 5 optical collimators, actually aligned with a full field of view of 2.5^0 and internal baffles eliminating internal reflections. It can derive the Total Columnar Ozone (the equivalent thickness of pure ozone layer at standard pressure and temperature) from measurements of 3 wavelengths in the ultra violet region. The precipitable water column is determined based on measurements at 940nm (water absorption peak) and 1020nm (no absorption by water). The calibration technique used for Microtops was developed by Reagon et al. (1987). The water vapor absorption band, viz., 1020nm filter, is affected only by aerosol scattering. For the 940nm channel located in the water vapor absorption band, the Bouguer Lambert-Beer law takes the form,

$V_1/V_{01} = exp(-\tau_{a1}\ m\text{-}K^b)$ ——(1)

where V_1 is the ground based radiation at 940nm, V_{01} is the extraterrestrial radiation, 'τ_{a1}' is the aerosol scattering coefficient at 940nm, 'u' is the vertical water vapor column thickness, 'm' is air mass K and B are constants numerically derived for the filter. For the 1020nm channel there is negligible water vapor absorption and equation takes in form:

$V_2/V_{02} = exp(-\tau_{a1}\ m)$ ——(2)

The V_{01} for the instrument is found from an extrapolation to air mass zero of the linearized.

$ln(V_1) + \tau_a m = ln(V_{01})\text{-}K^b$ ——(3)

From equations, (1), (2), (3) the vertical water vapor column in the instrument is calculated as l/b

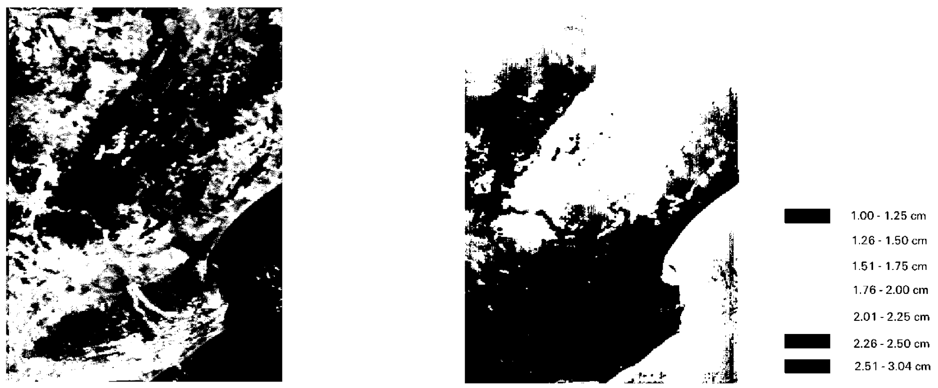
$u = [\tau_{a2}\ m(1\text{-}1.16)\text{-}l_n(V_1V_{02}/V_2V_{01})\ /\ Km^b]^{1/b} cms$

RESULTS AND DISCUSSION

Studies on columnar water vapor are important in weather and climate modeling and the hydrologic cycle. Due to its absorption and transmission properties within the visible and the longwave region respectively, it is the most important greenhouse gas, causing 53% of the greenhouse effect (Tahl & Schonermark 1998). Since the shape and depth of the atmospheric water bands are influenced not only by the water vapor present but also by surface reflectance, atmospheric scattering and instrument radiance are the important factors that affect columnar water vapor retrieval from satellite data. On the land surfaces, microwave sensors fail, due to highly varying emissivity of different land surface features. Most of the studies determine the columnar water vapor content from radiosonde measurements, IR spaceborne data or backscattered solar radiation. The former has the problem of only being point measurements whereas the latter do not reach a high accuracy (Starr & Melfi 1991). Various methods of determining the columnar water vapor from backscattered solar radiation use the highly resolved spectral data of imaging spectrometers (Tahl & Schonermark 1998). Considering the use of MOS-B data for column water vapor retrieval, in the present study, we tested the methodology given in Tahl & Schonermark (1998) for columnar water vapor retrieval using the IRS-P3 MOS data. The results of the study are shown in Figs 2 and 3. The amount of water vapor retrieved is from different land use classes. The contrast between the agricultural areas and forest areas viz., dry deciduous and mixed deciduous forests has been found to be clear by using the CIBR methodology. The columnar water vapor during the February accounted for about 1-3.04 cm, whereas during the month of March, it accounted for about 1.0-2.90cm. From the Figs 2 and 3 it is clearly evident that the columnar water vapor decreased during the dry period (summer) when compared to earlier months (February). The study area is characterized by the presence of different types of vegetation, viz., and dry deciduous and mixed dry deciduous vegetation. From the figures, it is clear that both the above types of vegetation had clear different water vapor column values. It is also interesting to note that higher water vapor values are found in the low vegetated areas and low water vapor values in the highly vegetated areas, as also observed by the previous workers (Tahl & Schonermark 1998). Monthly average columnar water vapor measured using MICROTOPS-II sunphottometer are shown in Figs 4 and 5. From ground based observations the columnar water vapor over different land use features during the February month is found to be high when compared to March. From satellite observations also it is found that during February water vapor observed to be high compared to March. When compared to February, during the March period, there was less contrast in the columnar water vapor between the agricultural areas and dry deciduous forest. Since, during the March period, most of the agriculture is in the harvesting stage and is also mostly converted to fallow, the above classes are mostly moisture limited and thus intermixing of classes with respect to columnar water vapor has been observed, when compared to moist mixed deciduous forest. The low values of columnar water vapor observed for the mixed deciduous forests when compared to forested areas in both the months is mainly attributed to elevation factor. As the water vapor density rapidly decreases with height, the integral value from the earth's surface to the top of the atmosphere decreases with the elevation of the area beneath (Tahl & Schonermark 1998). The underestimation of water vapor in the sparsely vegetated areas (dry deciduous forests) may be attributed to the reasons as envisaged by Tahl & Schonermark 1998. Taking the radiation at the top of the atmosphere, the portion of the path radiance compared to the ground-reflected radiance is larger over dark surfaces than over bright ones. As the path radiance does not reach the earth's surface, it has shorter way through the atmosphere than the surface-reflected radiance and therefore it is penetrate less water vapor leading to underestimation of water vapor content. Further, high and low values of columnar water vapor is affected by several factors. Carrere & Conel (1995) observed that, gypsum (or any hydroxyl bearing minerals), present on the surface mineralogy introduces an overestimation of the amount of water vapor retrieved up by 10% using the CIBR methodology. Further, Carrere & Conel (1995) noted that if the actual water vapor distribution in the atmosphere is uniform, but the aerosols are variable in abundance from place

COLUMN WATER VAPOUR RETRIEVAL USING MOS-B DATA

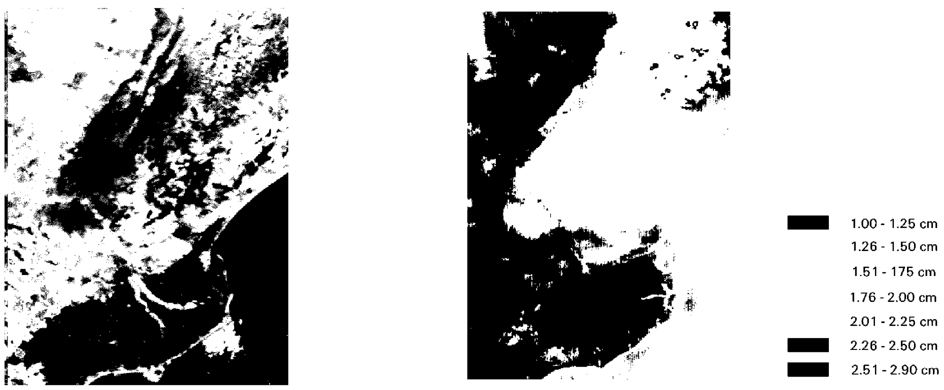
Figure 2.



FCC (11,6,4) 15th Feb,1999

Column Water Vapour, 15th Feb,1999

Figure 3.



FCC (11,6,4) 11th Mar, 1999

Column Water Vapour, 11th Mar, 1999

Figure 4.

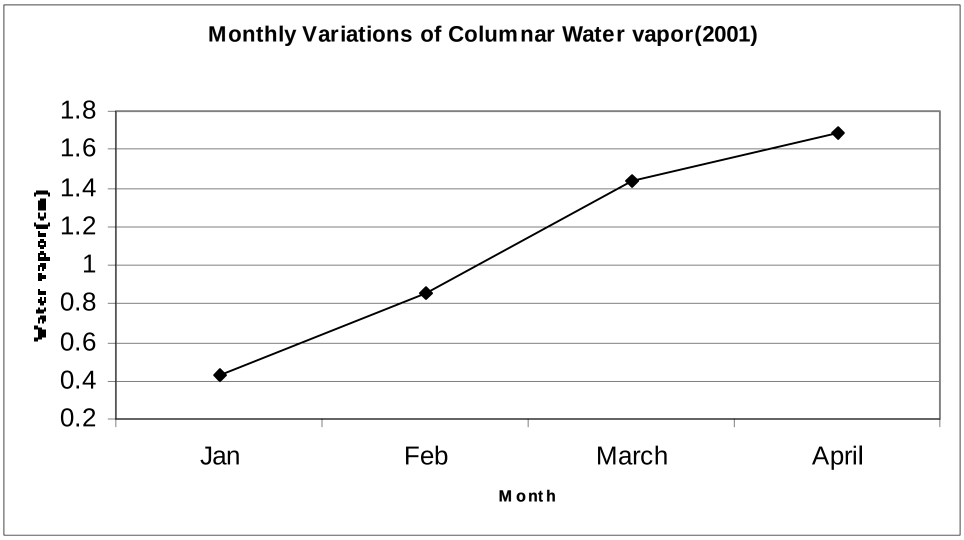
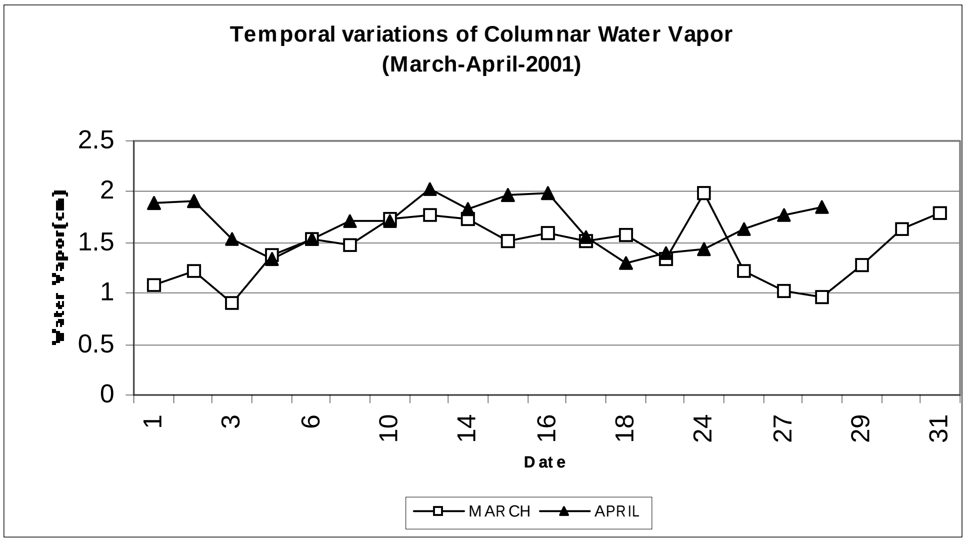


Figure 5.



to place (lateral changes) then an apparent but unreal variation in the retrieved water vapor amounts will be observed. The errors in the water vapor column are also strongly attributed to the type of aerosols modeled using the LOWTRAN in arriving at the regression relation. For example, the assumption of a rural aerosol for the reference state and its use where marine aerosol conditions prevail leads to an overestimation of water for low moisture conditions. From the study, it is inferred that, retrieval of atmospheric water vapor profile from satellite data on land is feasible using IRS-P3 MOS data and the CIBR methodology can be applied over heterogeneous areas on land successfully for retrieval of columnar water vapor. Further, it is also inferred that, vegetation types such as dry deciduous / evergreen etc., which are moisture limited and moisture excess respectively, can be clearly discriminated based on columnar water vapor image over different time periods. The methodology thus can also be used for accurate parameterization of different vegetation types, needed for vegetation modeling studies.

CONCLUSIONS

Retrieval of atmospheric water vapor profile from satellite data on land is feasible using IRS-P3 MOS data and the CIBR methodology can be applied over heterogeneous areas on land successfully for retrieval of columnar water vapor. The contrast between the agricultural areas and forest areas and also in-between the vegetation classes, viz., dry deciduous and mixed deciduous forests has been found to be clear by using the CIBR methodology.

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