URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Atmospheric Column Water Vapor Retrieval using Atmospheric Precorrected Differential Absorption Technique from AVIRIS-NG Data

Jalpesh A. Dave*(1), Mehul R. Pandya(2), Hasmukh K. Varchand(1), Parthkumar N. Parmar(1), Himanshu J. Trivedi(1), Vishal N. Pathak(3)
(1) N. V. Patel College of Pure and Applied Sciences, Vallabh Vidyanagar, Gujarat, India
(2) Space Applications Center, Indian Space Research Organisation, Ahmedabad, Gujarat, India
(3) St. Xavier's College, Ahmedabad, Gujarat, India

Abstract

In this paper, the atmospheric column water vapor (WV) has been retrieved using atmospheric precorrected differential absorption (APDA) technique from the hyperspectral data of Next-Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG). The APDA technique is extended method of Continuum interpolation band ratio (CIBR), and it is based on Linear regression ratio (LIRR) method. In APDA the additional atmospheric precorrected term reduces atmospheric path radiance, which provides good accuracy over lower surface albedo. Moreover owing to use of more than three absorption bands, this technique gives better performance over large surface reflectance variation. Optimum absorption bands selection has been performed by derived at-sensor radiance using MODTRAN (MODerate resolution atmospheric TRANsmission) 5.3 radiative transfer model (RTM), and six WV absorption bands are selected between 1120nm to 1150nm. At-sensor radiance simulations have been carried out for varying atmospheric and surface parameters, and then a band ratio R_{APDA} is derived from absorbing and non-absorbing band, corresponding to different WV concentration. The theoretical validation of the technique has been performed using actual radiosonde WV values, which shows good agreement with a root mean square error (RMSE) of 0.0145 gm/cm^2. The technique has been first-time applied to AVIRIS-NG Indian campaign data containing heterogeneous surface of two sites of Ahmedabad and Anand. Validation of retrieved WV was carried out with the NASA's AVIRIS-NG level-2 WV products on pixel-to-pixel basis. The RMSE for Ahmedabad and Anand is 0.164 gm/cm^2 and 0.112 gm/cm^2, respectively, which demonstrates a good performance of the proposed technique for the WV retrieval.

Keywords – Column water vapor, APDA technique, MODTRAN 5.3 RTM, AVIRIS-NG.

1. Introduction

Atmospheric column WV is key parameter of climate change and green-house effect. It also used to understand surface-atmosphere interaction, infrared astronomy, hydrological cycle, biogeochemical, meteorological, and geological studies. The WV is highly dynamic molecule in the Earth's atmosphere, and have complex interaction between aerosol and clouds, which makes difficult task to evaluate it. Various differential absorption techniques have been performed by researchers to retrieve WV and other greenhouse gases using multispectral/hyperspectral data, namely: Single band ratio (SBR), Continuum interpolation band ratio (CIBR), Quadratic interpolated band ratio (QIBR), Narro/wide method, Total band ratio, Linear regression ratio (LIRR) [1] – [7]. The WV, methane (CH_4) and carbon dioxide (CO_2) gas emissions can be captured using those methods, which uses the absorption bands of particular finding parameter, a greater number of absorption bands delivers better accuracy. General concept of the differential absorption technique is taking radiance ratio of absorbing and non-absorbing bands, and finding the relation between the ratio and the particular gas concentration. However, other parameters impact, the complex interaction between other gases and band selection would have to consider in the retrieval method, which makes the method more accurate. For example, CO_2 absorption lies at near 1600nm and 2008nm bands, where WV absorption also presence in 2008nm absorption band (Figure 1), hence, WV absorption has to be considered in the development of CO_2 retrieval algorithm [7].

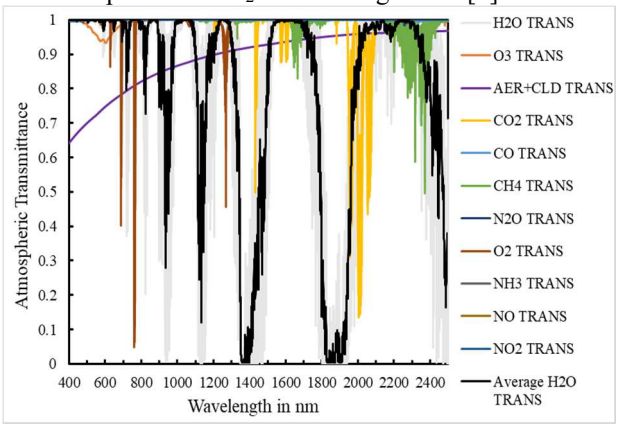


Figure 1. Atmospheric transmittance as function of wavelength for different atmospheric parameters. The data derived from MODTRAN 5.3 RTM for tropical atmosphere.

Surface reflectance is main hurdle in the retrieval of atmospheric parameter using imaging spectrometer data, because, the at-sensor radiance encompasses surface reflected radiance, which differs by surface variation. That can be solve by the above methods, however the accuracy may be differs method-by-method. All of these, cloud free atmosphere is essential.

The greenhouse gas WV absorbs 70% of incoming sunlight in infrared region and 60% in thermal region by vibrational transition [8]. Absorbed radiation is emitted in all directions as per the black body emission curve, and it will be again absorbed by surrounding WV molecules. This cycle generates greenhouse effect. The AVIRIS-NG is acquiring contiguous spectral measurements between 380nm to 2510nm with 5nm ±0.5nm spectral and up-to 4-meter spatial resolution. AVIRIS-NG Indian campaign has been carried out in two phases, and many atmospheric, surface, hydrological and vegetation parameters were retrieved [9]-[12]. In this study, column WV has been retrieved using APDA technique based on LIRR from AVIRIS-NG data over Anand and Ahmedabad. The WV molecules perturbation on at-sensor radiance have been simulated by MODTRAN 5.3 RTM, which were used to developed R_{APDA} ratio. The study describes, optimum band selection of WV absorption bands using MODTRAN 5.3 RTM derived at-sensor radiance, theory of APDA technique, methodology, retrieved WV results and conclusion.

2. Optimum Absorption band selection of atmospheric water vapor

The precision of WV retrieval method is highly dependent on absorption band, because the sensitivity of the band for certain concentration should be high, and also there should be no or less absorption of other gas in the same band. However, all criterions may not be fulfilled in practice, and therefore the method may be needs to modified. In the present study, the at-sensor radiance has been derived using MODTRAN 5.3 RTM for various WV concentration and surfaces. Figure 1 shows the atmospheric transmittance chart for WV concentration in spectral range 380 to 2500nm. The absorption curve shows the great deep at 940nm and 1140nm, which bands are higher sensitive to the WV concentration. Other absorption channels show at 730nm, 830nm, and 2180nm, which are least sensitive to the concentration of WV, and also presence of other gas absorption. Therefore, 940nm and 1140nm channels are appropriate for the WV retrieval. In this study we have been used 1140nm spectral channel for the retrieval of WV.

3. Theory of APDA technique

The APDA technique first introduced by Daniel Schlapfer et al. in 1998 [4], which was applied on AVIRIS data. This method is extended method of CIBR method, which reduces total noise of the sensor. The benefit of this method is allowed to take more than three absorption and non-absorption bands as compared to CIBR, for this reason, surface reflectance effect can be reduced and we get better accuracy. The APDA ratio equation of absorption and non-absorption bands radiance is.

$$R_{APDA} = \frac{\overline{[L_m - L_{atm,m}]_i}}{LIR\left([\lambda_r]_j, [L_r - L_{atm,r}]_j\right)|_{\overline{[\lambda_m]}}} \quad (1)$$

$$\text{Where, } L_{atm,i} = L^M_{atm,i}\left(1 + a\frac{g_i}{g_{max}}\right) \quad (2)$$

$$g_i = \frac{L^M_{atm,i,max} - L^M_{atm,i,min}}{L^M_{atm,i,min}} \quad (3)$$

Where, L_m and L_r are the at-sensor radiance for measurement channels in absorption region and reference channels in non-absorption region, respectively. $L_{atm,m}$ and $L_{atm,r}$ are atmospheric path radiance for measurement and reference channels, respectively. $LIR([x],[y])|_a$ is linear regression line point through the (x, y) at the point a. λ_r is wavelength of reference bands. $[\overline{\lambda_m}]$ is central wavelength of measurement channels. $L^M_{atm,i}$ is MODTRAN derived atmospheric path radiance for channel i. $L^M_{atm,i,max}$ and $L^M_{atm,i,min}$ are atmospheric path radiance for dry and humid atmosphere, respectively. g_i is weighing function in each channel and g_{max} is maximum weighing function of all channels. Here, i and j are absorption and non-absorption bands which used for derivations. The equation 1 represents ratio value, which is similar to LIRR method but along with atmospheric pre-corrected term. The relation between R_{APDA} and total WV concentration is exponential (Figure 2). Therefore, the relation is.

$$R_{APDA} = e^{-(\gamma + \alpha(WV)^{\beta})} \quad (4)$$

Here, α, β and γ are empirical regression coefficients.

4. Methodology

The AVIRIS-NG India campaign were carried out over 57 sites. This study has been applied over Anand and Ahmedabad sites, the data time is 25th March, 2018 and 11th February, 2016, respectively. The data have been downloaded from the JPL AVIRIS-NG data portal. Anand site contains cropland, grassland, urban and water bodies. And Ahmedabad site contains large area of urban and some cropland. These sites can help to check accuracy of the method over heterogeneous region.

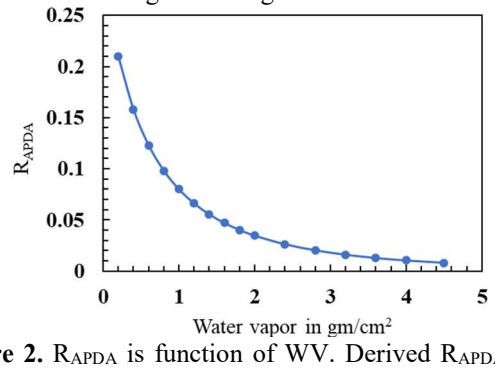


Figure 2. R_{APDA} is function of WV. Derived R_{APDA} ratio shows exponential relation with WV concentration.

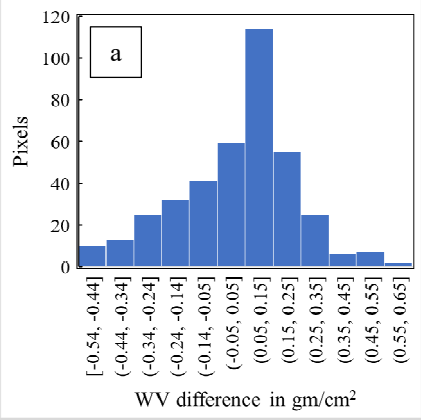
Various at-sensor radiance simulations have been carried out using MODTRAN 5.3 RTM for different land surfaces (cropland, urban, grassland, water body, crop-mosaic, dry sand) and atmospheric parameters. From the band selection analysis, six measurement bands (absorption region) and six reference bands (non-absorption region) have been selected, which are. 1123, 1128, 1133, 1138, 1143, 1148 nm; and 1043, 1048, 1053, 1243, 1248, 1253 nm, respectively. Using MODTRAN simulation, look-up table (LUT) have been developed for APDA technique. R_{APDA} ratio (Eq 1) and empirical regression coefficients (Eq 2) have been derived using LUT.

Following steps are used to retrieve column WV image.

1. Development of At-sensor radiance LUT using MODTRAN RTM simulations.
2. Computation of atmospheric path radiance using LUT.
3. Computation of R_{APDA} ratio for particular WV amount using LUT.
4. Derivation of the relation between ratio and WV amount and empirical regression coefficients using equation 4.
5. Determination of the ratio R_{APDA} using AVIRIS-NG data (Eq 1) using derived atmospheric path radiance (step 2).
6. Generation of WV image using derived empirical regression coefficients (step 4).

5. Results and discussion

The APDA method has been applied on AVIRIS-NG data over Anand and Ahmedabad region in India and the column WV have been successfully retrieved using selected bands. The selected differential absorption method has been validated theoretically using MODTRAN simulation for same atmosphere conditions and same senor passing time, which shows good correlation with original WV data with 0.01454 gm/cm^2 root means square error (RMSE) value. Pixel-to-pixel comparison shows the good correlation with NASA's AVIRIS-NG WV L2 data (Figure 3). The RMSE for Ahmedabad and Anand is and 0.164 gm/cm^2 and 0.110 gm/cm^2, respectively, which shows the good accuracy of the used method.



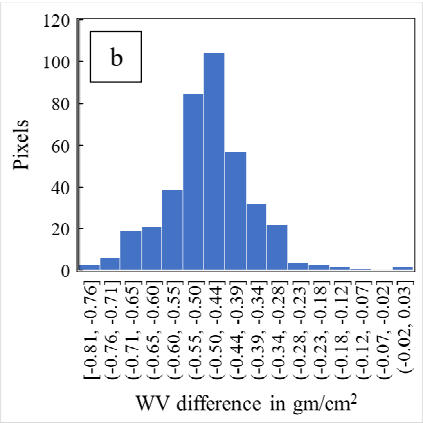


Figure 3. Pixel-to-pixel comparison of AVIRIS-NG derived WV by proposed method with NASA's WV data for Ahmedabad (a) and Anand (b).

6. Conclusions

Column water vapor has been successfully retrieved using atmospheric precorrected differential absorption technique from AVIRIS-NG Indian campaign data (Figure 4). In this study, six WV absorption bands have been selected between 1120nm to 1150nm. Retrieved WV results shows less than 0.164 gm/cm^2 RMSE over heterogeneous surfaces, which shows great achievement of the used method. A unique APDA technique is modification of radiative transfer equation, where, the atmospheric precorrected term reduces strong surface reflectance variation errors in the retrieval method. Optimum absorption bands and APDA technique allows to derive WV over flat or mountainous surfaces, however, this study performs only on flat surfaces. The APDA technique is very fast perform on AVIRIS-NG data using MODTRAN derived standard LUT. The salient features of the present methodology like, use of atmospheric precorrected term, which leads to easy applicability over heterogeneous areas even with higher elevation surfaces makes this method an inevitable tool. So, it may be used to retrieve WV and other greenhouse gases for futuristic missions like GISAT-2 which may have hyperspectral sensors on board.

7. Acknowledgement

This study has been performed under the Gujarat government Shodh scholarship. Authors would like to thank Shri Nilesh M. Desai, Director, SAC-ISRO, Ahmedabad and Dr. Basudeb Bakshi, Principal, NVPAS, Vallabh Vidyanagar for the encouragement and support to this study. Our special appreciation is to the NASA-JPL for providing the AVIRIS-NG data.

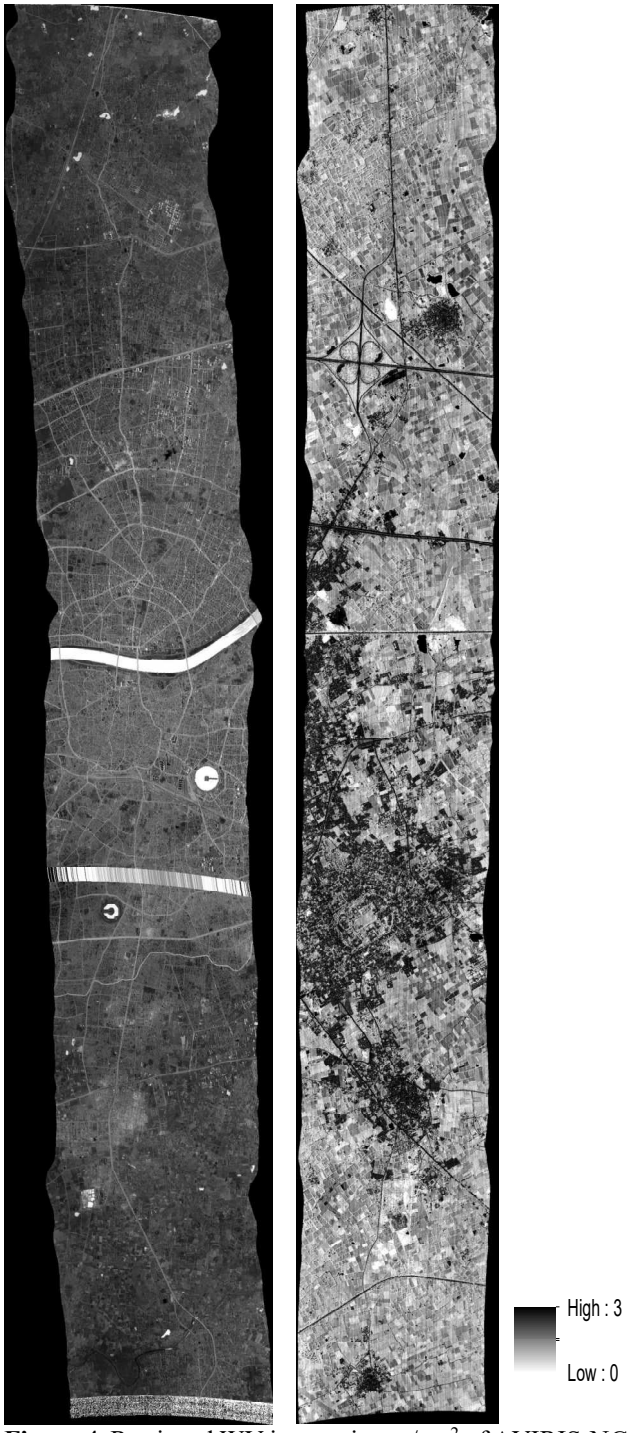


Figure 4. Retrieved WV images in gm/cm^2 of AVIRIS-NG data. Ahmedabad (left) and Anand (right).

8. References

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