

ESTIMATION OF PRECIPITABLE WATER FROM THE THERMAL INFRARED HYPERSPECTRAL DATA

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ABSTRACT

Total precipitable water (TPW) is an important atmospheric parameter in many applications. A method was proposed to estimate TPW from thermal infrared hyperspectral data. First, 21 channel groups were selected to retrieve TPW. Then, two indices, namely, the difference- and the ratio-depth in each channel group, were used as the measurement of the water vapor absorption. By multivariate regression, the relationship between the TPW and the indices was established. Finally, this relationship was applied to the simulated thermal infrared hyperspectral data. Results showed that the root mean square error (RMSE) of the model is $0.102 \text{ g}\cdot\text{cm}^{-2}$, and the relative error is 8.1 %. The proposed method needs to be further refined in the future work, including the complete elimination of the Earth's emission in the retrieval.

Index Terms— Hyperspectral thermal infrared, total precipitable water, water vapor absorption

1. INTRODUCTION

The total column atmospheric water vapor content and its distribution are key input variables for many studies, such as the weather and climate modeling, hydrological cycles, energy budget and evapotranspiration researches.

Meanwhile, water vapor is one of the important greenhouse gases as it absorbs and emits radiative energy strongly in the atmosphere. A good knowledge of the total precipitable water (TPW) and vertical distribution of water vapor in the atmosphere will benefit the remote sensing scientists to improve the retrieval accuracy of other surface parameters, such as the land surface temperature and emissivity [1, 2], from remotely sensed data. There are several ways to obtain the TPW. The radiosonde observations can obtain the TPW with relatively high accuracy, but it is very difficult to map its global distribution because of the sparse spatial distribution of the radiosonde sites. In the past three decades, some methods have been developed to estimate the TPW from remotely sensed multi-spectral data. For example, two thermal infrared channels in the atmospheric window were used to retrieve TPW from AVHRR [3] and ATSR2 [4] data; and the near-infrared channels were used to calculate TPW from MODIS [5] data. However, due to the lack of details of gas absorption in the atmosphere for multi-spectral data, it is difficult to improve the retrieval accuracy of TPW. Infrared atmospheric sounders are also capable of retrieving water vapor profiles and then compute the TPW [6]. However, it needs a physics-based iterative procedure to get accurate results, which would be a complicated work.

Nowadays, many sensors, such as IASI and AIRS can provide hyperspectral thermal infrared (hyper-TIR) data.

The hyper-TIR data can provide detailed information of absorption characteristic of water vapor in the atmosphere, it seems to be feasible to estimate the TPW accurately from hyper-TIR data without other auxiliary data. Taking the computation time-consuming into account, this work aims to propose a fast method to estimate the TPW from hyper-TIR data. This paper is structured as follows. Section 2 is devoted to the data introduction, simulation and preparation. Section 3 describes the method of estimating TPW. Section 4 gives the results and some corresponding analysis. Conclusions are drawn in section 5.

2. DATA SIMULATION AND PREPARATION

To simulate the hyper-TIR data observed at the top of the atmosphere, the Operational Release for Automatized Atmospheric Absorption Atlas (4A/OP), a hyperspectral atmospheric radiative transfer model, is used in this study. Different atmospheric states are modeled by six standard atmosphere profiles, i.e. the US 76, tropical, mid-latitude summer, mid-latitude winter, polar summer and polar winter profiles. Thirty emissivities spectra of surface materials extracted from the Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) spectral library, including soils, vegetations, water and ice, are used to represent different land covers. Land surface temperatures are set to be -10K, -5K, 0, 5K and 10K biased from the bottom temperature of the atmospheric profiles.

In the simulation procedure, 660 ($11 \times 10 \times 6$) disturbed atmospheric profiles were generated by changing the temperature profiles and humidity profiles of the six standard atmosphere profiles. The temperatures in each layer of the profiles are varied from -10 K to 10K in step of 2K. The water vapor mixing ratios in each layer of the profiles were scaled from 0.4 to 1.3 times in step of 0.1. Furthermore, to better describe the variety of the vertical distribution of the water vapor in actual situations, the humidity profiles were then perturbed, with a standard deviation of 10% according to the original profiles. Figure 1 shows the changed and original temperature and humidity profiles of the mid-latitude summer atmosphere.

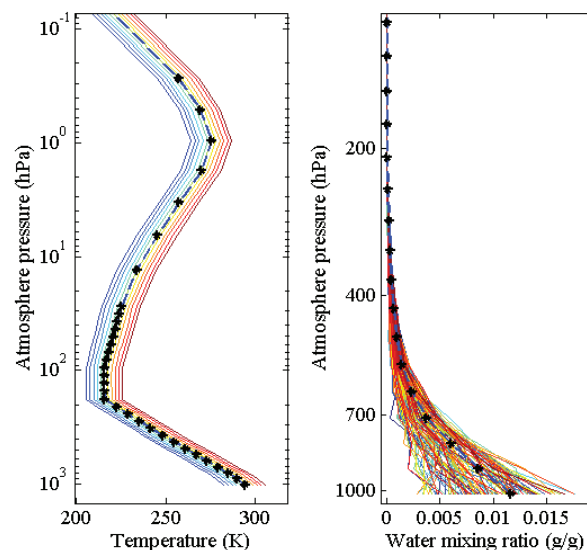


Fig.1 The changed and original temperature and humidity profiles of the mid-latitude summer atmosphere. The dashed line with star is the original profile, while other colored lines are the changed profiles.

To improve the computational efficiency, for each atmospheric profile, 4A/OP is run first to obtain the atmospheric downwelling radiance at a zenith angle of 53°, upwelling radiance and transmittance at nadir. Considering different combination of the atmospheric and land surface states, the at-sensor radiances are then simulated with the atmospheric radiative transfer equation. The hyper-TIR data are simulated for the wavelength ranging from 830 to 930 cm^{-1} with a spectral resolution of 0.5 cm^{-1} and spectral sampling interval of 0.25 cm^{-1} .

3. METHOD

3.1 Channel selection for TPW estimation

The absorption line of water vapor in the hyperspectral data contains the information of TPW. In our work, several channel groups depicting the water vapor absorption characteristics are elaborately selected first. The following issues should be considered as: 1) the line absorption characteristics in the selected channels are dominated mainly by the water vapor, while other gases, such as CO_2 ,

O₃, and CH₄, have slight influences; 2) in each channel group, three channels are adequate, where the center channel is located in the absorption line and the other two channels are transparent, and 3) there should be significant

contrast between the absorbed channel and the transparent channels. Fig. 2 shows the total 21 channel groups selected in 830~930 cm⁻¹.

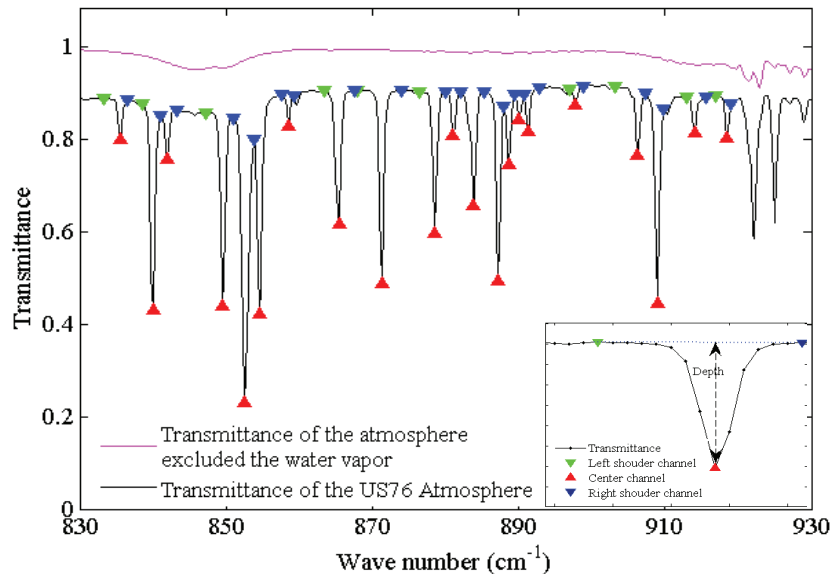


Fig.2. 21 channel groups selected for the TWP estimate.

3.2 Quantization of water absorption

The radiance observed by the sensor in each channel group forms a “valley”. The depth of the “valley” is related to the TPW. Two indices about the depths, namely, the difference-depth and the ratio-depth, are defined as:

$$D_{di} = \frac{v_{i,2} - v_{i,1}}{v_{i,3} - v_{i,1}} L(v_{i,1}) + \frac{v_{i,3} - v_{i,2}}{v_{i,3} - v_{i,1}} L(v_{i,3}) - L(v_{i,2}) \quad (1)$$

$$D_{ri} = \left(\frac{v_{i,2} - v_{i,1}}{v_{i,3} - v_{i,1}} L(v_{i,1}) + \frac{v_{i,3} - v_{i,2}}{v_{i,3} - v_{i,1}} L(v_{i,3}) \right) / L(v_{i,2}) \quad (2)$$

where D_{di} is the difference-depth of channel group i ; D_{ri} is the ratio-depth of channel group i ; $v_{i,1}$, $v_{i,2}$ and $v_{i,3}$, are the wavenumber of the left channel, the center channel and the right channel in channel group i , respectively; $L(v_{i,1})$, $L(v_{i,2})$ and $L(v_{i,3})$ are the radiances of the left, center and right channels in channel group i , respectively. The multivariate regression method is employed to determine the relationship between the TPW and the different-depth and ratio-depth for the 21 channel groups, written by

$$P_w = \sum a_i D_{di} + \sum b_i D_{ri} + c \quad (3)$$

where P_w is the TPW, a_i and b_i are the coefficients for the difference-depth and ratio-depth in channel group i respectively; c is a constant. The radiance observed by a sensor is affected by the vertical distribution of the temperature profile and the water vapor profile. To improve the retrieval accuracy, the multivariate regression is performed on each type of the atmosphere to obtain the coefficients for the specified atmospheric state.

4. RESULTS AND ANALYSIS

The proposed model was applied to the simulated hyper-TIR data. Figure 3(a) is the scatter plot of the estimated TPWs versus to actual ones. Figure 3(b) is the histogram of the difference between the estimated and the actual TPWs. The root mean square error (RMSE) of the model is 0.102 g·cm⁻², and the relative error is 8.1%. The results show that the proposed method is feasible and promising.

It should be pointed out here that the difference- and

ratio-depths used to retrieve the TPW are not only controlled by the TPW but also affected by the land surface's emission. Furthermore, the vertical distribution of the water vapor and the atmospheric temperature has some effects on the difference-depth and the ratio-depth. In another word, for a given TPW, the difference-depth and the ratio-depth may be varied with the changes of the land surface state and the shape of the temperature and water vapor profile. Therefore, more work should be done to improve the TPW estimation accuracy in the future.

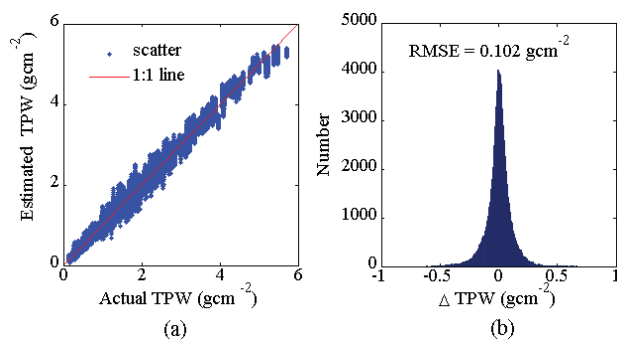


Fig.3. Results of the retrieved TPWs. (a) The scatter diagram of estimated and actual TPWs. (b) The histogram of the difference between estimated and actual TPWs.

5. CONCLUSION

In this paper, a method has been proposed to retrieve TPW from hyper-TIR data. This method uses the difference-depths and the ratio-depth of the channel groups caused by the water vapor line absorption in the observed radiance spectrum. The relationship between the two indices and TPW is regressed and applied to the simulated data. The results show that an RMSE of 0.102 g·cm⁻² can be obtained. The proposed method will be further refined in the future work, such as minimizing the effect of land surface emission and introducing information of vertical distribution of the air temperature.

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