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Validation on MERSI/FY-3A precipitable water vapor product

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Abstract

The precipitable water vapor is one of the most active gases in the atmosphere which strongly affects the climate. China's second-generation polar orbit meteorological satellite FY-3A equipped with a Medium Resolution Spectral Imager (MERSI) is able to detect atmospheric water vapor. In this paper, water vapor data from AERONET, radiosonde and MODIS were used to validate the accuracy of the MERSI water vapor product in the different seasons and climatic regions of East Asia. The results show that the values of MERSI water vapor product are relatively lower than that of the other instruments and its accuracy is generally lower. The mean bias (MB) was −0.8 to −12.7 mm, the root mean square error (RMSE) was 2.2–17.0 mm, and the mean absolute percentage error (MAPE) varied from 31.8% to 44.1%. On the spatial variation, the accuracy of MERSI water vapor product in a descending order was from North China, West China, Japan -Korea, East China, to South China, while the seasonal variation of accuracy was the best for winter, followed by spring, then in autumn and the lowest in summer. It was found that the errors of MERSI water vapor product was mainly due to the low accuracy of radiation calibration of the MERSI absorption channel, along with the inaccurate look-up table of apparent reflectance and water vapor within the water vapor retrieved algorithm. In addition, the surface reflectance, the mixed pixels of image cloud, the humidity and temperature of atmospheric vertical profile and the haze were also found to have affected the accuracy of MERSI water vapor product.

Keywords: MERSI/FY-3A; MERSI water vapor product; East Asia; Validation; Accuracy

1. Introduction

The precipitable water vapor (PWV) is one of the most active components in the atmosphere. Although its proportion in the atmosphere is very small, that is about 0.1–3% (Liu and Liu, 2009), water vapor shows a large spatial and temporal variability (Zhang et al., 2013). It is a necessary condition to produce clouds and precipitation, and also plays a very important role in the evolution of the weather and climate (Wang et al., 2007). Water vapor is also a main greenhouse gas, with atmospheric advection, vertical transport, evaporation and condensation, it impacts atmospheric and solar radiation, thereby affects the water cycle and energy balance between the land and the atmosphere (Chou and Arking, 1981; Lin et al., 2012). Therefore, water vapor is a very essential factor for the predictions of weather and climate change.

At present, there are many observed methods for precipitable water vapor. These include ground based measurements such as radiosonde (Zhai and Eskridge, 1997), Sunphotometer (Halthore et al., 1997), GNSS (Li et al., 2015a, 2015b; Lu et al., 2015), microwave radiometer (Liu et al., 2009) and lidar (Wang et al., 2015). Currently, the satellite remote sensing methods in use include microwave retrieval of water vapor over the sea surface (Bobylev et al., 2010), the split window algorithm based

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on thermal infrared remote sensing (Kleespies and Mcmillin, 1990) and the near-infrared water vapor differential absorption method (Kaufman and Gao, 1992). The radiosonde is simple operation and low cost, with available data only at 00:00 and 12:00 UTC every day. With very limited observation stations, it becomes difficult to be applied to analyze comprehensively the spatial and temporal distribution of precipitable water vapor. Though other ground based measurements provide time-continuous water vapor data, they cann't be used to analyze the spatial distribution of water vapor. Satellite remote sensing is a high efficient and rapid observing technology, which is able to give periodic spatial data to facilitate the analysis of the temporal and spatial characteristics of water vapor, such as microwave remote sensing, thermal infrared remote sensing, visible and near-infrared remote sensing. Although the water vapor retrieved from microwave radiometer has a high accuracy, its spatial resolution is rather low. The split window algorithm based on thermal infrared remote sensing has a relatively mature and long history, but it mostly tends to detect the upper-tropospheric water vapor (Soden and Lanzante, 1996). Because the absorption of water vapor within the near infrared channel is stronger than that of the thermal infrared channel, and the total signal received from the sensor within the near-infrared channel can reflect the property of water vapor in the whole atmosphere vertical profile, the water vapor retrieved from the near-infrared channels are more accurate than that from the thermal infrared channels. The water vapor obtained from the near-infrared remote sensing, therefore, has served as a more promising method in the recent years (Gao and Goetz, 1990; Kaufman and Gao, 1992; Gao and Kaufman, 2003).

The FengYun-3 (FY-3) series is the second generation of Chinese polar-orbiting meteorological satellites. FY-3A was the first spacecraft among the series, launched on May 27th, 2008, in a near-sun synchronous polar orbit with a nominal altitude of 836 km and an equatorial crossing time of 10:30 A.M. (descending southward). The Medium-Resolution Spectral Imager (MERSI) is a keystone payload onboard FY-3A, containing 20 channels covering the spectral range from visible (VIS) to longwave infrared. The nadir spatial resolution values are 0.25 km for channels 1–5 and 1 km for channels 6–20. FY-3A MERSI is capable of providing daily global observations for a broad range of scientific studies over the atmosphere, ocean and land (Sun et al., 2012a). The National Satellite Meteorological Center, China developed a series of satellite products available about atmosphere, ocean and land using the MERSI L1B data, including the atmospheric water vapor product generated by the 15–17th near-infrared channel images (Yang and Dong, 2011). In view of the importance of water vapor and the lack of reports on the accuracy of MERSI /FY3A water vapor product, the accuracy of MERSI water vapor product is validated by using water vapor data of radiosonde and AERONET and similar MODIS water vapor product to know its effectiveness.

2. Materials and methods

2.1. Research area

Taking East Asian continent as research area, the accuracy of MERSI water vapor product will be validated in this paper. East Asia covers a total area of 12 million square kilometers, including Mongolia, China, Korea, South Korea and Japan. It faces the Pacific Ocean eastward, and is adjacent to the South China Sea southward. The precipitable water vapor over the East Asian continent mainly comes from the western Pacific, the South China Sea, the Arabian Sea and the Bay of Bengal. The seasonal variation of water vapor distribution in different regions is influenced by the Asian monsoon climate. In order to carry out the validation of the MERSI water vapor product, considering the distribution of the radiosonde and AERONET stations and the regional climatic characteristics in East Asia, the whole area is divided into five typical sub-regions. These are the West China (included Tibet Plateau), North China, East China, South China and Japan-Korea, which represent alpine plateau climate, the temperate continental climate, the temperate monsoon climate, subtropical monsoon climate, and the temperate maritime climate respectively. Due to the difference of water vapor content in each sub-region, the MERSI water vapor product in each sub-region will be compared with corresponding water vapor data of radiosonde, AERONET and MODIS/TERRA water vapor product respectively.

2.2. Material and methods

2.2.1. Radiosonde data

The global radiosonde stations take readings at 00:00 and 12:00UTC daily, while an equatorial crossing time of the FY3A satellite is 2:30UTC, which is closer to the radiosonde observation at 00:00UTC. There are 113 radiosonde stations distributed over the five sub-regions of the East Asian continent (Fig. 1). The water vapor calculated from the radiosonde data is used to evaluate the accuracy of the MERSI water vapor product. The radiosonde data contain the information on air temperature, dew point and pressure of the atmospheric vertical profile. The integrated precipitable water vapor content in the atmospheric vertical profile can be obtained by the integral of average specific humidity from the ground to the upper atmosphere at 200 hpa. It is given as (Wang and Liu, 1993):

$$PWV = \frac{1}{g\rho}\int_{p_0}^{p} q dp = \frac{1}{g\rho}\sum_{i=1}^{n}\bar{q}_i \Delta p \tag{1}$$

where p_0 and p are the atmospheric pressures over the ground and top of atmosphere respectively; n is the layer number from the ground to the upper atmosphere, and g