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Enhancing the Accuracy of Water Vapour Retrieval from Remote Sensing Observations Using Ground-based GNSS Data

Jia He

Supervisor: **Dr. Zhizhao Liu**

Graduate Date: **December 2021**

University: **Department of Land Surveying and Geo-Informatics**

Hong Kong Polytechnic University

Web-page: **https://theses.lib.polyu.edu.hk/handle/200/11218**

ABSTRACT

Water vapour, as the fundamental element and one of the most important natural greenhouse gases in the atmosphere, is vital for heat and moisture fluxes. Improved knowledge of water vapour and its variability on the different temporal-spatial scales is essential for climate and environmental research. Water vapour content can be estimated through radiosonde balloons, microwave-radiometers, sun-photometers, Global Navigation Satellite Systems (GNSS) / Global Positioning Systems (GPS), and remote sensing satellites. These observation instruments provide products with different but complementary characteristics. For instance, radiosonde and GNSS/GPS observations are usually considered as ground truth because of their high precision, but their applications are restricted by the locations of the stations. Remote sensing observation, on the other hand, is the most efficient means of water vapour observation on the global scale but with a larger retrieval error. The core research aim is to enhance the water vapour retrieval accuracy from remote sensors. Special weight was put on water vapour observation from Near Infrared (NIR) channels.

A novel retrieval method has been developed for the Moderate Resolution Imaging Spectro-radiometer (MODIS) onboard the Terra and Aqua satellite platforms in this research based on empirical regression analysis. This new approach provides an effective way to retrieve water vapour without pre-obtained atmospheric information. Water vapour data observed during 2003 ~ 2017 from 464 GPS stations located in western North America and their spatial-temporal collocated MODIS level 1 reflectance data were employed as training data for model development. The training data were resampled into 10 subsets using the bootstrap method. The regression functions trained by these independent subsets reduced the uncertainty in the model training and minimized the sensitivity of possible channel drifting. Verifications in North America show that the root mean square error (RMSE) for water vapour calculated from MODIS/Terra reduces 48.12% to 2.362 mm when using two-channel ratio transmittance and 50.74% to 2.243 mm when using three-channel ratio transmittance. The RMSE for water vapour calculated from MODIS/Aqua reduces 42.54% to 2.562 mm and 42.99% to 2.541 mm when using two-channel and three-channel ratio transmittance, respectively. Validations over five additional stations also show that the overall RMSE for MODIS/Terra data reduces 22.80% to 5.946 mm when using two-channel ratio transmittance, and 21.69% to 6.006 mm when using three-channel ratio

transmittance. For MODIS/Aqua data, the reductions are 16.42% to 6.010 mm when using two-channel ratio transmittance and 15.26% to 6.094 mm when using three-channel ratio transmittance.

The retrieval algorithm was also validated in Australia and its neighbouring area for the first time. The observation results over 2017 ~ 2019 have clearly shown that our new ensemble-based empirical regression model, which was developed using data from the North Hemisphere, is still valid in the South Hemisphere. For the data obtained from MODIS/Terra, the RMSE has reduced by 58.53% from 5.712 mm to 2.369 mm when using 2-channel ratio transmittance and has reduced by 56.14% to 2.505 mm using 3-channel ratio transmittance, respectively. For the data obtained from MODIS/Aqua, the RMSE has reduced by 49.17% from 5.170 mm to 2.628 mm using 2-channel ratio transmittance and has reduced by 46.60% to 2.761 mm using 3-channel ratio transmittance, respectively. The results further prove that the newly proposed retrieval model has very good property of having no temporal or spatial dependency over a large observation area. The coefficients can be easily applied to areas of interest without pre-calculated input parameters of atmospheric profiles. It is reasonable to conclude that this algorithm provides an effective way to retrieve water vapour globally under cloud-free condition.

On the other hand, as the surface spectral reflectance is one of the error sources for water vapour retrieval, regression functions trained for different land cover types adapted from MCD12Q1 IGBP legend are discussed. Thus, the bias for MODIS NIR channels could be further reduced. Validations in North America show that for data calculated from MODIS/Terra, the RMSE reduced 50.78% to 2.229 mm for data using two-channel ratio transmittance and 53.06% to 2.126 mm for data using three-channel ratio transmittance. For data obtained from MODIS/Aqua, the RMSE reduced 45.54% to 2.423 mm when using two-channel ratio transmittance and 45.34% to 2.432 mm when using three-channel ratio transmittance.

Last but not least, the empirical regression method was implemented for water vapour observation from MERSI/FY-3B NIR channels. The collocated MERSI L1b reflectance data in the NIR channels are used for water vapour retrieval. PWV data observed from 256 ground-based GPS stations located in the western North America in 2016 are used as reference data for model development. Then, validation is performed with data obtained during 2017 ~ 2019 from both the western North America and Australia to assess the performance of the proposed algorithm. The results indicate that the new PWV results agree very well with ground based PWV reference data. The mean absolute percentage error (MAPE) for ensemble median PWV is 16.72% ~ 36.74% in western North America and is 15.47% ~ 32.31% in Australia. The RMSE is 4.635 mm ~ 8.156 mm in western North America and is 5.383 mm ~ 8.900 mm in Australia. The weighted mean value using three-channel ratio transmittance has the best retrieval accuracy, with RMSE of 4.635 mm in western North America and 5.383 mm in Australia. Together with MERSI onboard of other FY series, more information on water vapour distribution on the global scale would be provided for climate and environmental research.