Validation of MOD05 (Precipitable Water Vapour) using Radiosonde and GPS Measurements

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1. Introduction

Atmospheric water vapour is highly variable in both space and time across the Earth, and knowledge of the distribution of water vapour is essential in understanding weather and global climate. Space-based monitoring is the only effective way to monitor water vapour levels on a global basis, and various missions have been implemented to monitor water vapour amount. Recently, atmospheric water vapour amount has been continuously measured with the two NASA MODIS (Moderate Resolution Imaging Spectroradiometer) instruments which are onboard Terra and Aqua platforms respectively. The MODIS Precipitable Water Vapour Products (MOD05_L2, containing data from the Terra platform; MYD05_L2, containing data from the Aqua platform) consist of daytime only total column atmospheric water vapour.

The current resolution of the MODIS-PWV product is 1 x 1 km (at nadir), and the output grid of a single Level-2 MODIS granule is 1350 1-km pixels in width and 2030 1-km pixels in length. The accuracy is claimed to be 5-10% [Gao et al., 2003]. In this study, the MODIS near IR water vapour products from Terra were examined through an inter-comparisons with radiosonde (RS) and GPS data.

As MODIS-PWV is sensitive to the presence of clouds in the field of view, only MODIS-PWV values collected under clear sky conditions were used in this study. The cloud mask product used had to indicate at least 95% confidence clear.

Note that all statistics are given after 2σ elimination, i.e. all differences more than twice the standard deviation were considered to be outliers and were removed. This elimination was mainly needed where poor collocations between the data in either time or space were found, or where cloudy pixels were falsely identified as cloud free.

2. Time series Comparisons between MODIS and RS PWV

Figure 1 shows a comparison of MODIS and RS PWV above the HERS site. The Herstmonceux (HERS) site is located at (50.90˚N, 0.32˚E, 50.9 m AMSL) in East Sussex, UK. Vaisala RS80-H radiosondes were launched twice daily at 23:15 and 11:15 UT since the beginning of December of 2001, and extra launches sometimes occur at 05:15 and 17:15 UT when greater detail of the atmospheric conditions overhead was needed.

The amount of MODIS-PWV was 14%±3% larger than RS-PWV with a zero-point offset of -0.8±0.5 mm. Taking into account the scale factors of GPS-PWV relative to RS-PWV, MODIS-PWV values had a similar linear relationship to RS as to GPS within a 1σ uncertainty. Figure 1(b) shows clearly that the differences were dependent on the amount of PWV. In other words, the differences (MODIS-PWV – RS-PWV) increased with the amount of PWV.

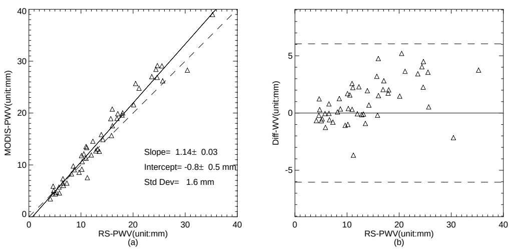

Figure 1. Scatter plots of MODIS-PWV and RS-PWV for cloud free observations at the HERS site from 02 December 2001 to 31 October 2002. (a) The number of valid samples was 50 and 2 samples were omitted due to the 2-sigma exclusion; (b) Diff-WV(difference in PWV) = MODIS-PWV – RS-PWV.

3. Time series Comparisons between MODIS and GPS PWV

Figure 2(a) shows the correlation between GPS-PWV and MODIS-PWV at the HERS station during the period from 02 December 2001 to 31 October 2002. It indicates that MODIS-PWV was larger than GPS-PWV with a scale factor of 1.09±0.02. Figure 2(b) shows that the differences (MODIS-PWV – GPS-PWV) increased slightly with the amount of PWV.

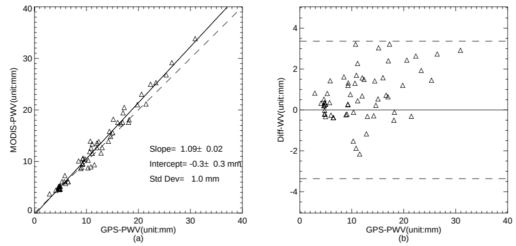

Figure 2. Scatter plots of MODIS-PWV and GPS-PWV for cloud free observations at the HERS site from 02 December 2001 to 31 October 2002. (a) The number of valid samples was 66 and 4 samples were omitted due to the 2-sigma exclusion; (b) Diff-WV(difference in PWV) = MODIS-PWV – GPS-PWV.

4. Spatial Comparisons between MODIS and GPS PWV

For the first time, a spatial inter-comparison of PWV from GPS and MODIS was performed using data collected over Germany (47-55˚N, 6-15˚E) during the period from 01 May 2002 to 30 June 2002. Figure 3 shows the distribution of GPS stations over Germany. There were 115 Terra overpasses in total in the daytime for this experimental period, with some just over the German border. For each Terra overpass, the number of GPS stations with cloud free conditions varied from 2 to 64 out of 124. A comparison was performed only when at least 10 GPS stations were cloud free. 59 out of 115 overpasses fulfilled this condition. The correlation coefficients between GPS and MODIS PWV for each overpass varied from 0.42 to 0.98 with an average of 0.82. 36 out of 59 scale factors (61%) for MODIS-PWV relative to GPS-PWV were greater than 1. More importantly, we derived an average linear fit model between MODIS and GPS PWV in this area: MODIS-PWV = 1.03(±0.12) × (GPS-PWV) – 0.1(±2.3) mm. The average scale factor for this spatial-temporal inter-comparison was smaller than that in time series (1.09±0.02, c.f. section 3), but the difference was not significant.

Bearing in mind the good agreement between GPS-PWV and MODIS-PWV in time series, particularly the small standard deviations of the linear least square solutions, we used the average linear fit as a model to calibrate MODIS-PWV, and then compared the calibrated MODIS-PWV with GPS-PWV. After such a correction and 2σ elimination, 58 overpasses fulfilled the requirement that at least 10 GPS stations were cloud free. The average correlation coefficients were almost the same, 0.83 after the correction. However, the average scale factor decreased to 1.01, the average bias from 0.6 mm to 0.2 mm, and the average standard deviation of the differences from 1.7 mm to 1.5 mm.

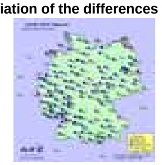

Figure 3. GASP GPS Network (Germany)

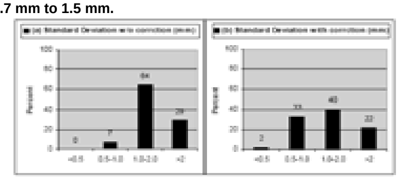

Figure 4. Statistics of spatial comparison between MODIS-PWV and GPS-PWV over Germany. (a) Standard deviations of the differences (MODIS-PWV – GPS-PWV) in millimetres without any correction; (b) Standard deviations of the differences (MODIS-PWV(calibrated) – GPS-PWV) in millimetres after correction: MODIS-PWV(calibrated) = 0.97×(MODIS-PWV) + 0.10 mm.

Figure 4 shows the distributions of the standard deviations before and after the correction. It indicates that the correction was encouraging, with more standard deviations less than 1 mm and fewer larger than 2 mm after the correction.

5. Statistics of Cloud Free Conditions

The frequency and percentage of cloud free conditions were evaluated in this study. The frequency of cloud free conditions refers to the probability of cloud free occurrence, and the percentage of cloud free conditions is inferred from the density of cloud free pixels. The cloud mask of the Moderate Resolution Imaging Spectroradiometer (MODIS) water vapour products were utilized to produce the statistics of cloud free conditions. An area of 4º×4º in Germany (49–53º N, 8-12º E) was chosen to estimate the frequency and the percentage, and a uniformly spaced grid of 1 km×1 km was applied. There were 481×481 grid-cells in total.

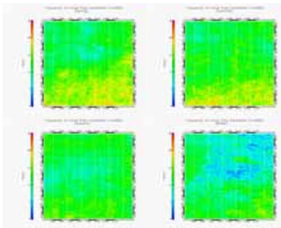

Figure 5. The frequency of cloud free conditions over Germany during the period from March 2002 to February 2003. The summer includes the months of June–August, and the winter includes the months of December–February.

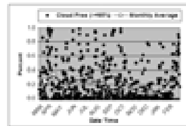

Figure 6. Statistics of percentage of cloud free conditions over Germany from March 2002 to February 2003.

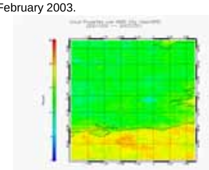

Figure 7. The frequency of cloud free conditions around London during the period from December 2001 to December 2002. Note the constant cloud cover over London!!

The seasonal frequencies of cloud free conditions in the test area were evaluated for one year starting on March 1st, 2002 and a seasonal variation was found (Figure 5). The highest and the average frequencies were 32% and 18% respectively in the summer, and by contrast 27% and 13% in the winter. The frequencies also varied from place to place. For example, the frequency in the south of the test area was higher than that in the centre. The average frequency was found to be 17% with a maximum of 25% in the area during this period from 1 March 2002 to 28 February 2003.

Figure 6 shows the percentage of cloud free conditions. It is obvious that the percentages varied widely, even from 0% to 100% on a day-to-day basis. A seasonal variation can also be observed, e.g., there are far fewer cloud free conditions in the late autumn and the early winter. The average percentage was 22% during the experimental period.

Similar analysis was also applied to the area around London in the UK (Figure 7) and the Three Gorges area in China (Figure 8), and frequencies and percentages were also found to vary mainly between 15% and 30%.

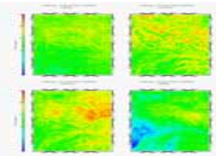

Figure 8. The frequency of cloud free conditions over the Three Gorges in China for three years from 2001 to 2003.

6. Conclusions

In this study, the Terra MODIS Near Infrared water vapour products (Collection 3) were examined. MODIS-PWV appeared to overestimate PWV against RS with scale factors from 1.14 to1.20 and standard deviations from 1.6 to 2.2 mm. MODIS-PWV appeared to overestimate PWV against GPS with scale factors from 1.07 to 1.14 and standard deviations varying from 0.8 to 1.4 mm in time series.

It is also shown that the frequencies of cloud free conditions varied from place to place and the percentages from day to day. A seasonal variation was also observed, and more cloud free observations were found in the summer than in the winter. There appears to be a problem with cloud cover estimation over large urban areas.

Reference:

Li, Z., J.-P. Muller, and P. Cross, Comparison of precipitable water vapor derived from radiosonde, GPS, and Moderate-Resolution Imaging Spectroradiometer measurements, *JGR*, *108* (D20), 4651, doi:10.1029/2003JD003372, 2003.

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