Validation of MERIS Near IR water vapour retrievals using MWR and GPS measurements

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[Abstract] In this paper, the reduced resolution (RR) MEdium Resolution Imaging Spectrometer (MERIS) near infrared (IR) water vapour (PWV) products above land surfaces produced at the Freie Universität Berlin (FUB) are examined through inter-comparisons with contemporaneous microwave radiometer (MWR) and GPS data sets. The inter-comparison of MWR and MERIS water vapour retrievals showed a good correlation of 0.99 with a standard deviation of 1.0 mm, and an overall slight wet bias of MERIS near IR water vapour was observed. Unfortunately, this inter-comparison was limited by the number of samples. Moreover, a spatio-temporal comparison between MERIS and GPS water vapour products was performed using data covering all of Germany for one year from October 2002 to September 2003. MERIS water vapour values appeared to be slightly greater than GPS values under either very dry (PWV<5 mm) or very wet (PWV>25 mm) conditions. However, MERIS water vapour agreed well with GPS water vapour retrievals under moderate conditions with a standard deviation of 1.3 mm and a mean difference of -0.4 mm.

1. Introduction

The MEdium Resolution Imaging Spectrometer (MERIS) is a key payload on the ESA ENVISAT satellite, an advanced polar-orbiting Earth observation satellite launched on 1 March 2002. With the primary mission to measure ocean colour, MERIS also makes a significant contribution to atmospheric and land surface related studies [1]. MERIS allows for the global retrieval of total columnar atmospheric water vapour of the Earth every 3 days. MERIS has 15 programmable spectral bands, two of which in the near infrared (IR) are referred to as the water vapour channels (885 nm and 900 nm, respectively). MERIS near infrared water vapour products are available at two spatial resolutions. In full resolution (FR) mode each pixel has an instantaneous field of view (IFOV) of 0.019°, with a nadir spatial sampling of 260 m across track by 290 m along track (referred to as a nominal resolution of 300m). In reduced resolution (RR) mode, each pixel is approximately 1.04 km across track by 1.2 km along track at nadir (referred to as a nominal resolution of 1.2km). The unprecedented high spatial resolution compared to previous polar orbit instruments makes MERIS very attractive to the meteorological community.

It is worthwhile noting that MERIS and the Advanced Synthetic Aperture Radar (ASAR) are on board the same platform and these two datasets can be acquired simultaneously during daytime. This allows the possibility of using the

MERIS WV measurements to reduce water vapour effects on interferometric SAR (InSAR) retrievals of DEMs and surface deformation. It is well known that water vapour is a major limitation on the application of the repeat-pass InSAR technique, so MERIS has also gained a lot of attention in the radar remote sensing community.

Currently, MERIS near IR water vapour can be retrieved above land surfaces, water surfaces and clouds [2,3,4]. In this paper, the RR MERIS near IR water vapour products above land surfaces produced at the Freie Universität Berlin (FUB) are investigated. The cloud mask products produced at FUB were used to detect the presence of clouds, and herein only MERIS near IR values collected under clear sky conditions were used. Section 2 introduces the CWAVE'03 (Clouds, Water Vapour Experiment) field experiment, and the results of the inter-comparisons of MERIS, GPS and Microwave radiometer (MWR) water vapour using the CWAVE'03 data sets are presented. A spatio-temporal comparison between MERIS and GPS water vapour products is demonstrated over Germany for one year from October 2002 to September 2003 in Section 3. A spatio-temporal comparison of MERIS and MWR water vapour products is presented in Section 4 over Southern England. Finally, conclusions of this study are given in Section 5.

2. CWAVE'03: Clouds, Water Vapour Experiment

The CWAVE'03 (Clouds, Water Vapour Experiment) is a joint experiment of the EU-CLOUDMAP2 and EU-CLOUDNET project involving several university and government research groups interested in atmospheric instrumentation and Cloud Resolving Models around the UK. CWAVE'03 took place in and around the CCLRC Chilbolton Radar Observatory between 14 June and 11 July 2003. The long-term objective of this experiment is to improve weather forecast models by better understanding how clouds are to be represented in Numerical Weather Prediction Models. As a secondary objective to validate water vapour products from different instruments, a small network of 4 GPS receivers were set-up for 8 days to collect GPS measurements by University College London and the University of Bath with one co-located with a microwave radiometer. Unfortunately, this GPS receiver co-located with the MWR did not operate. In Fig. 1, the spatial distribution of the measurements stations is shown with a black square representing the microwave radiometer (MWR) and red triangles representing the GPS receivers.

GPS data were analysed using the GIPSY-OASIS II software package at UCL with the same processing strategy as described in [5]. During this experiment, surface pressure and temperature data were collected at the Sparsholt GPS station as well as the MWR station. The differential Berg pressure model was used to compute surface pressure above the other GPS stations [6]. In order to check the differential Berg pressure model, the inter-comparison between the modelled pressure and the MWR pressure values was performed. A standard deviation of 0.4 hPa was observed with a mean difference of 0.5 hPa (MWR value > modelled value). This means that the uncertainties of modelled surface pressures might result in uncertainties of PWV of less than 0.2 mm [7]. A vertical adiabatic temperature gradient of –6.5 K/km was assumed to fit surface temperatures.

The Radiometrics MP3000 microwave radiometer (MWR) was operated by the Met Office, and has channels at 22-30 GHz and 50-60 GHz to provide retrievals of PWV, as well as vertical profiles of temperature, humidity and cloud [8]. The radiometer collected observations every 200 seconds. These retrievals were produced by a neural network trained on 10 years' radiosonde data from Camborne, UK, which has a more maritime climate than Chilbolton. This might introduce errors when applied to summer conditions at Chilbolton.

During the experimental period, the MERIS near IR water vapour product was found with a high percentage of cloud free conditions over the experiment area only on 10 July 2003. Table 1 shows an instantaneous inter-comparison between GPS, MWR and MERIS near IR water vapour at 10:55 UTC on 10 July 2003. The GPS Zenith Wet Delay (ZWD) was estimated at 5-minute intervals, so GPS PWV represented a 5-min average (from 10:55 to 11:00 UTC) along the paths of GPS satellites in view [5]. The MWR data was observed at 10:55:14 UTC, and the MERIS data represented the average PWV of a pixel with a nominal resolution of 1.2 km at 10:56:50 UTC. In this case, MERIS near IR water vapour values were higher than both MWR and GPS in the range from 0.5 mm to 1.7 mm, and the standard deviation was 0.5 mm. The largest difference of 1.7 mm was found over the NTL Crawley GPS station located 4.5 km away from Chilbolton. The most likely reason is that the GPS receiver was installed next to some satellite receivers on the roof of the NTL building, and those satellite receivers might have some impacts on GPS signals. In addition, undetected clouds might have introduced an uncertainty here.

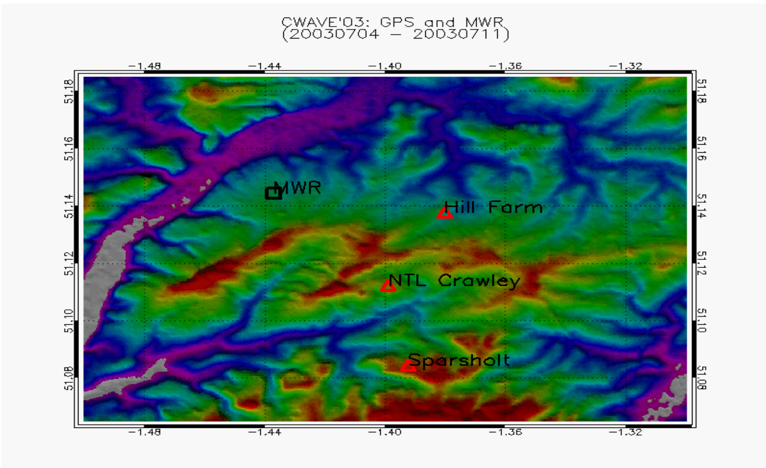

Fig. 1. GPS and MWR locations during CWAVE'03 superimposed on a hill-shaded SRTM DEM

Table 1. Comparisons of GPS, MWR and MERIS PWV in CWAVE'03 at 10:55 on 10 July 2003

Station (Instruments)	GPS/MWR PWV (mm)	MERIS PWV (mm)	Station Height (m)
Hill Farm (GPS)	31.4	31.9	134
NTL Crawley (GPS)	30.1	32.8	158
Sparsholt (GPS)	31.2	32.1	171
Chilbolton (MWR)	32.7	33.3	91

3. Spatio-temporal comparison between GPS and MERIS water vapour products over Germany

The GeoForschungsZentrum Potsdam (GFZ) is currently operating a near real time (NRT) ground-based GPS network of 182 sites with a spacing of about 50 kilometres all over Germany (Fig. 2). The NRT data analysis uses a sliding 12-hour data window based on hourly retrieved data. In order to assure the efficiency as well as the accuracy, both base cluster analysis and Precise Point Positioning (PPP) analysis are implemented as a parallel processing technique. Independent techniques (e.g. radiosondes, water vapour radiometer) and models (e.g. Local Model) were used to validate GPS water vapour, and all showed that the absolute accuracy of this

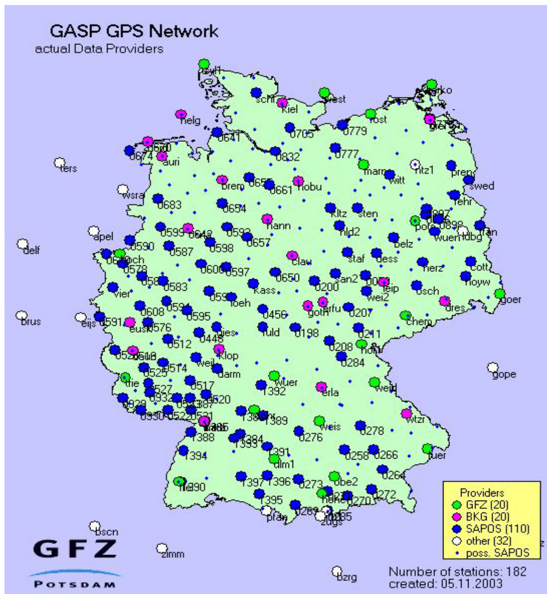

Fig. 2. GPS Network over Germany (from GFZ)

product is from 1-2 mm [9,10]. In this paper, GFZ NRT GPS water vapour products were used to compare with MERIS near IR water vapour for one year from October 2002 to September 2003. There were 157 scenes of MERIS near IR water vapour products available during this period, with some just over the border of Germany.

Fig.3a shows MERIS near IR water vapour for the period from October 2002 to September 2003 compared against PWV retrievals from GPS. The red line represents the perfect fit, and the blue line the least squares regression line. The colour gradient is used to represent the number of points: red represents the greatest number in the bin, blue means fewer numbers in the bin, and white means none. There were 2261 pairs of observation under cloud free conditions. A high correlation coefficient, 0.99, was observed between these two data sets. A linear fit of GPS and MERIS PWV yielded the relationship, MERIS PWV = 1.03(±0.003) * GPS PWV - 0.5(±0.05) mm with a standard deviation of 1.1 mm. The mean difference of (MERIS PWV - GPS PWV) was -0.2 mm with a standard deviation of 1.3 mm (not shown in Fig. 3a).

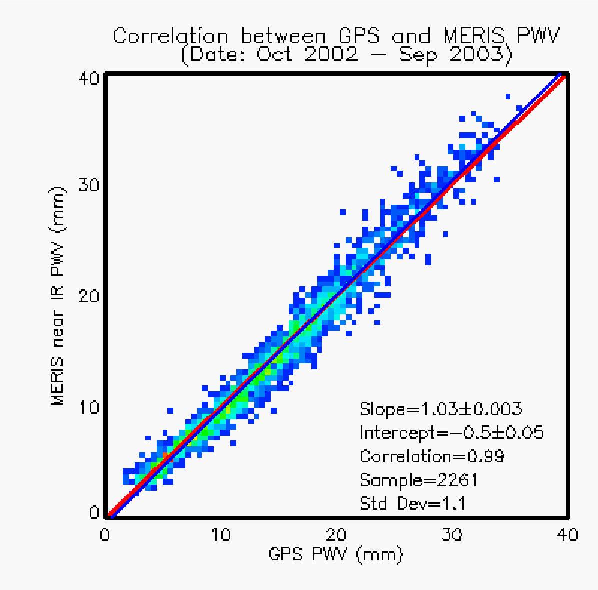

Fig. 3a. Comparison between GPS and MERIS PWV (PWV: 0 – 40 mm)

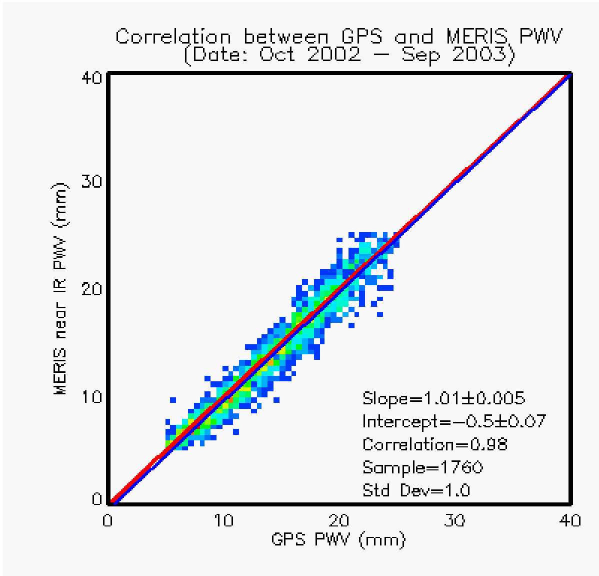

Fig. 3b. Comparison between GPS and MERIS PWV (PWV: 5 – 25 mm)

It is worth mentioning that there was no smaller value than 2.1 mm detected by MERIS in Fig 3a, whilst GPS monitored water vapour values as small as 1.4 mm under dry conditions (with a surface temperature of 3.5 Celsius degrees and a surface pressure of 982.5 hPa) in the winter. On the other hand, the largest water vapour from GPS was 35.8 mm while the largest one from MERIS was 38.1 mm as shown in Fig 3a. It appears from Fig 3a that there was an offset between MERIS and GPS water vapour when water vapour values were greater than 25.0 mm. That is, MERIS near IR water vapour were slightly greater than GPS values under wet conditions, which is consistent with the results in Section 2.

If only values from 5 to 25 mm were used in the comparison, a new linear relationship, MERIS PWV = 1.01(±0.005) * GPS PWV - 0.5(±0.07) mm, was found with a standard deviation of 1.1 mm (Fig 3b). The mean difference of (MERIS PWV - GPS PWV) was -0.4 mm with a standard deviation of 1.3 mm (not shown in Fig. 3b). The scale factor of MERIS PWV decreased from 1.03 to 1.01 relative to GPS PWV. This means that MERIS and GPS water vapour products appeared to agree well with each other under moderate conditions.

4. Spatio-temporal comparison between MWR and MERIS water vapour products over South England

Coincident observations were utilized at Chilbolton during the CWAVE'03 period. MWR data was also kindly made available during trials at Cardington and Camborne from March to September 2003. During these trials, the radiometer was configured to retrieve only from the zenith view and data was collected every 200 seconds. The radiometer antenna has a Gaussian response, with a beamwidth of ~6° at low frequencies which provide most of the humidity information. As most of the humidity is concentrated in the lowest 2 km, this corresponds to a horizontal 'footprint' similar to the Full Resolution MERIS data.

Fig 4 shows the spatio-temporal comparison of MWR and MERIS water vapour over these three sites from March to September 2003. Because only 37 scenes of MERIS data were available in South England, and cloud free observations are required in this study, only 9 valid pairs were found. Of these, 1 from Chilbolton was rejected as surface conditions were outside the envelop of the training dataset, and a further 1 rejected because it followed within 1 hour of rain, when the MWR calibration was suspect. 5 out of 7 pairs showed that MERIS near IR water vapour values were slightly greater than the retrievals of MWR with a bias of 0.4 mm and a standard deviation of 1.0 mm. There were only two pairs under wet conditions (PWV > 25 mm) in Fig 4. One pair was only 0.2 mm apart, the other pair indicated that the MERIS water vapour value was greater than the MWR value, but the difference was not significant. It is difficult to assess whether or not there was any wet bias of MERIS near IR water vapour under wet conditions from this inter-comparison, so it appears MERIS to have a wet bias on water vapour retrievals relative to MWR on the whole. The primary limitation of this inter-comparison is the lack of coincident observations.

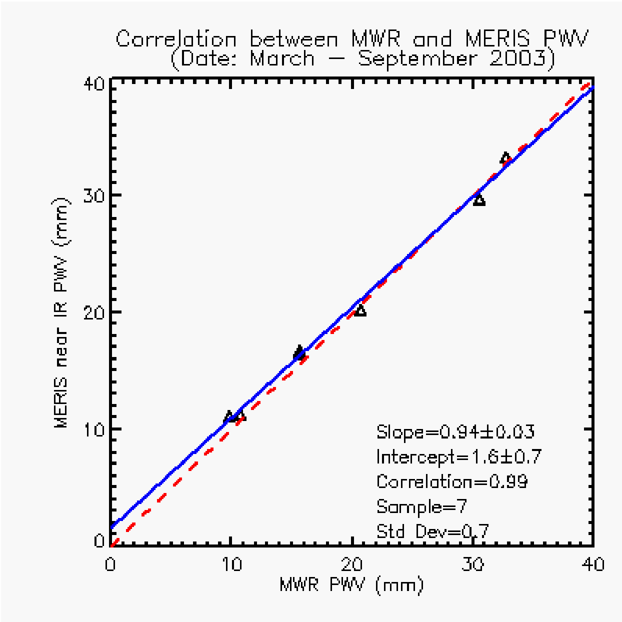

Fig. 4. Comparison between MWR and MERIS PWV

5. Conclusions

An inter-comparison of GPS, MWR and MERIS water vapour products was performed. Due to the lack of coincident observations, it is difficult to draw a convincing conclusion from the inter-comparison of MWR and MERIS water vapour products. In spite of this, the inter-comparison, to some extent, revealed that MERIS near IR water vapour products had an overall wet bias relative to MWR. The comparison between MERIS and GPS water vapour products showed that MERIS water vapour values were slightly greater than GPS values under both dry and wet conditions. However, MERIS appeared to agree well with GPS with a small standard deviation, and a slope close to unity under moderate conditions. In order to better understand MERIS near IR water vapour products, further research is required.

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