VERIFICATION OF MERIS ATMOSPHERIC LEVEL 2 PRODUCTS: INTEGRATED WATER VAPOUR ABOVE LAND, OCEAN AND CLOUDS

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ABSTRACT

Three different algorithms for the remote sensing of atmospherical water vapour above cloud free land surfaces, cloud free ocean and clouds were developed for the MERIS instrument. During the commissioning phase, two subsequent tests had to be performed: In a first verification step, the general nature of the results had to be investigated in order to detect problems in the implementation of the algorithms in the IPF. For that purpose, a comparison of the MERIS results with independent water vapour measurements from the MODIS instrument onboard the Terra platform was performed for different sites covering different geographic and climatic regions. In the second validation step, a quantitative analysis of the accuracy of the retrieved water vapour values was started by the mean of comparisons with radio soundings. For the latter, MERIS measurements taken during October 2002 above selected sites in central Europe were used.

1. MERIS ALGORITHMS

The principle of the MERIS water vapour retrieval algorithms for all three surface types (land, ocean and clouds) is based upon the use of the radiance ratio of MERIS channels 14 and 15, the first being almost free of water vapour absorption, the latter being located within the $\rho\sigma\tau$-water vapour absorption band [1]. The radiance ratio of the absorption and the window channel is used to eliminate the surface reflectance and to obtain an estimation of atmospheric transmission with regard to water vapour. The functional relationship between atmospheric water vapour content and transmission or radiance ratio, respectively is calculated by the use of radiative transfer simulations, the results of which being inverted in form of a second order polynomial whose coefficients are stored in look-up tables. Depending on the reflecting surface, the look-up tables differ significantly, e.g. in case of water vapour above clouds a non-negligible part of the absorption by water vapour takes part within the clouds and has to be corrected for. Additionally, this behaviour is a function of the cloud optical thickness, which consequently is an additional input parameter for this algorithm.

Originally, three breadboard algorithms were developed at the Freie Universität Berlin, and the knowledge for their creation was transferred to ESA / Bomem for the creation of the ESA algorithms. In the meantime, the original look-up table approach was replaced for the breadboard algorithms by the use of artificial neural networks, which significantly eases the interpolation of the simulation results onto the actual viewing geometry. However, as the physical nature of the inversion problem is relatively simple and the polynomial approach is very suitable for its analytical description, the validity of the modified breadboard algorithm for the comparison with the implementation of the ESA algorithm is not altered, i.e. no distinctive artefacts are to be expected from the use of two different regression techniques.

2. COMPARISON WITH MODIS DATA

The first test of the ESA MERIS water vapour product was performed by simple comparisons with independent water vapour measurements from the MODIS instrument flying on the Terra platform [2]. This instrument is well suited for such a test as the measurement techniques of both instruments are very similar. MODIS is also equipped with window and absorption channels around the water vapour absorption band around 900 nm whose radiance ratio is used for the estimation of atmospheric water vapour. However, one restriction applies as according to [2] in case of cloudy atmospheres the integrated water vapour derived from MODIS is based on the assumption of the cloud being located at sea level. It is not clear, whether this result is comparable to the water vapour above the actual cloud top pressure retrieved from the MERIS measurements. Consequently, this comparison was only performed for water vapour measurements above land and ocean.

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Four MERIS scenes for water above land and two scenes for water vapour above ocean ranging from sub-polar to tropical regions were chosen in order to cover a wide range of possible water vapour values. For all scenes, the appropriate MODIS overpass was chosen and the MODIS water vapour product (MOD05) was downloaded from the MODIS data distribution centre. In order to allow for a pixel-based comparison, both measurements were converted to a common, regular longitude / latitude grid using a nearest-neighbour sampling method.

The following figures show on the left panel a true colour image based on MERIS level1b data together with the outline of the corresponding MODIS measurements and the outline of the area for which the results were transformed to the common grid.

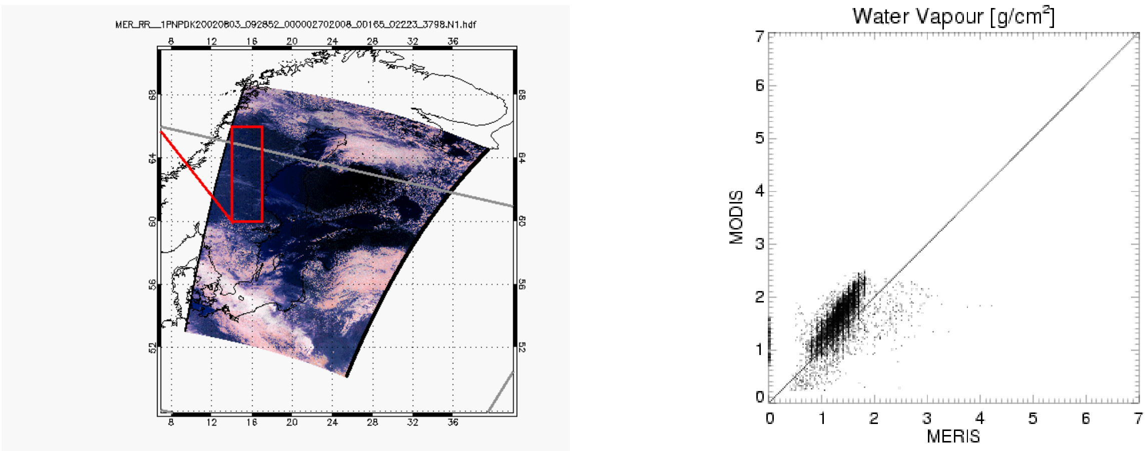

Fig. 1: MERIS true colour image (left panel) and scatter plot of MERIS and MODIS derived columnar water vapour above land (right panel) for a sub-polar region. The scatter plot only shows values within the common grid area outlined in red in the true colour image

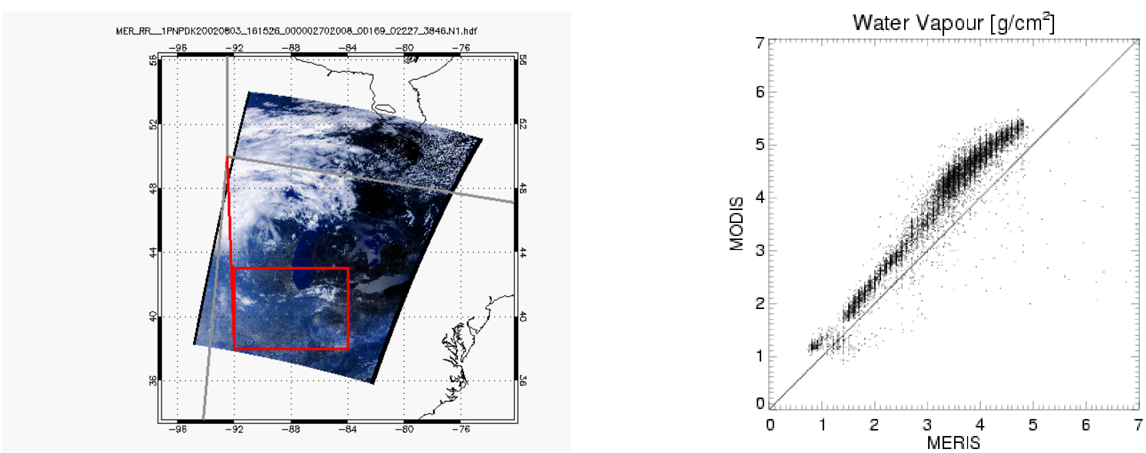

Fig. 2: As Fig. 1, but for a midlatitude region

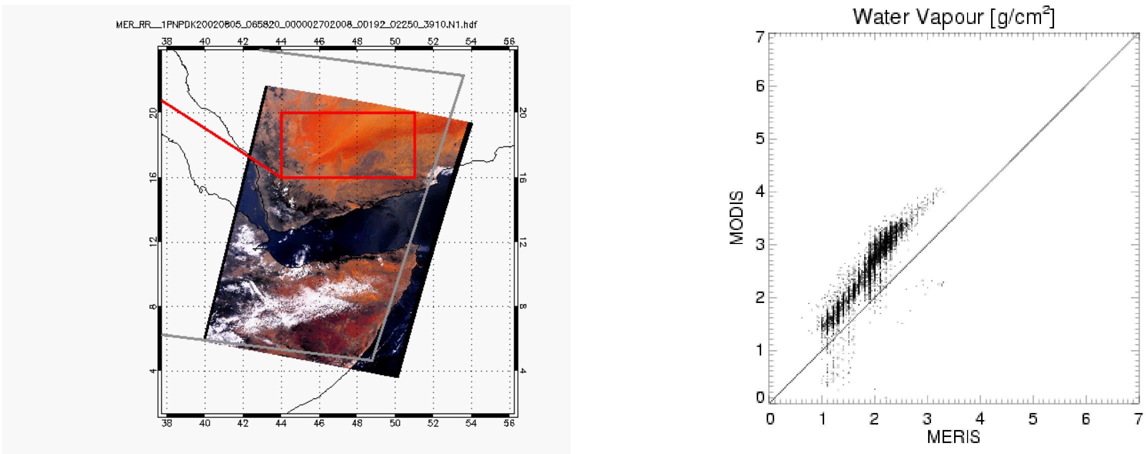

Fig. 3: As Fig. 1, but for a sub-tropical region

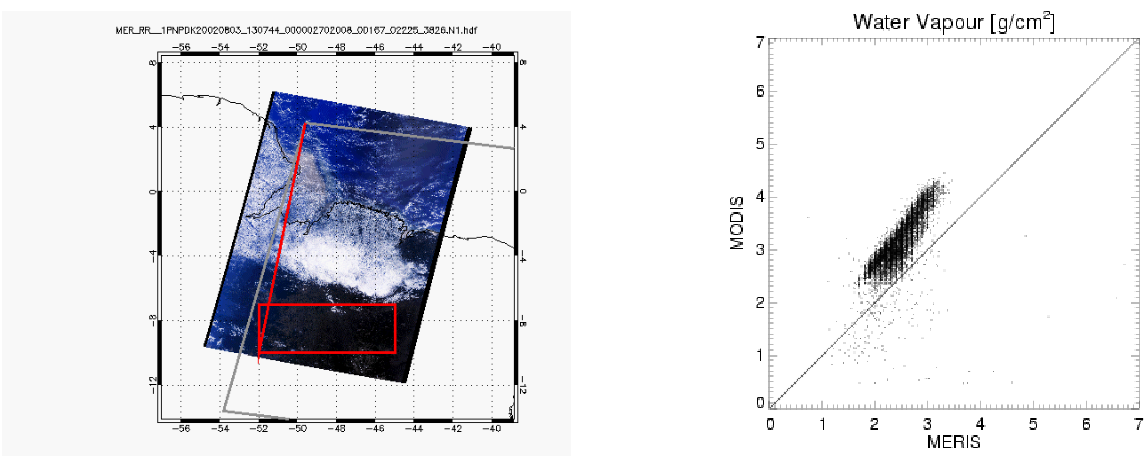

Fig. 4: As Fig. 1, but for a tropical region

All scatter plots show a very good correlation between the two methods, although a significant bias between MERIS and MODIS is also visible. However, before further quantitative validations, it is too early to qualitatively judge this result.

In the mid-latitude scene (Fig. 2), a general limitation of the algorithm is illustrated: both methods yield results up to 5 g/cm^2, which is unrealistically high for this region and season. However, the true colour image shows that a great part of the image is covered by haze or thin cirrus, which leads to an increase in photon path lengths and thus in an overestimation of the retrieved columnar water content. This example shows that correct cirrus detection is an important prerequisite for the creation of reliable datasets.

The following images exemplarily show the results for the retrieval of columnar water vapour above ocean and the comparison with MODIS data for two further MERIS scenes:

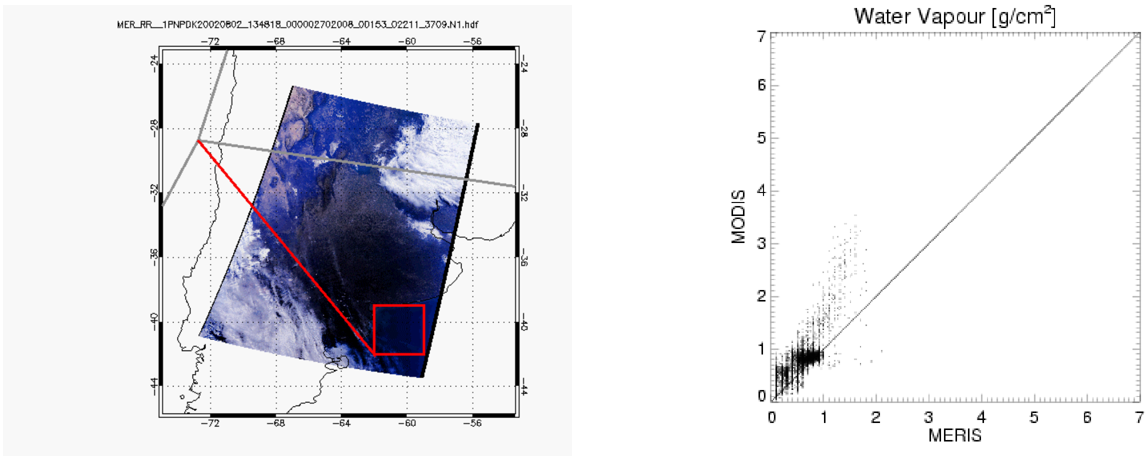

Fig. 5: As Fig. 1, but for water vapour above ocean in a midlatitude region

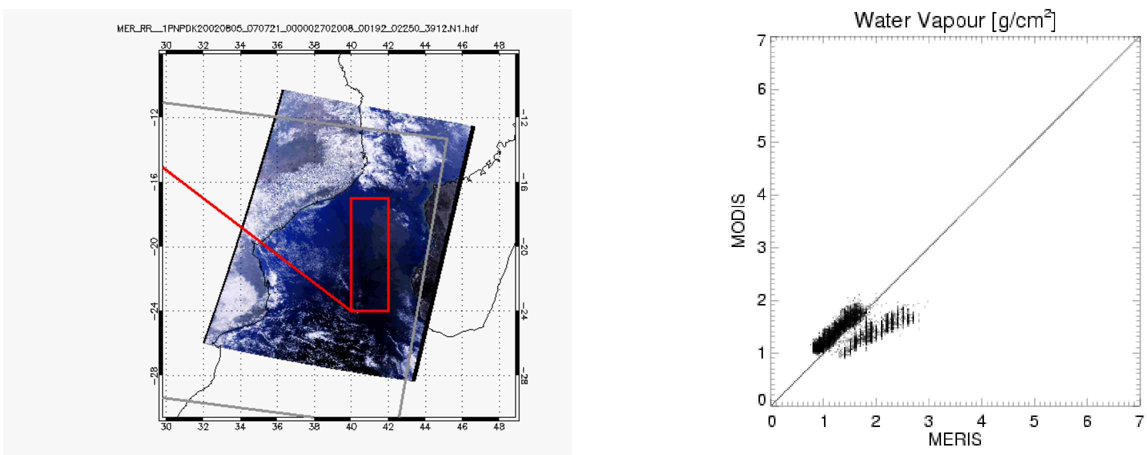

Fig. 6: As Fig. 5, but for a subtropical region

Like for water vapour above land, both comparisons give promising results and at the same time they show the need for further investigation. Especially in the second comparison, the results from MODIS and MERIS are very similar, however, a distinct feature in ocean reflectivity, hich is partly visible in the true colour image, leads to noticeable differences in the results from both algorithms.

As a first general result from these comparisons it can be stated that no severe errors are to be expected in the implementation of the algorithms for the remote sensing of columnar water vapour above land and ocean. All results are in the correct order of magnitude and the agreement between the MERIS and MODIS results is high.

3. COMPARION WITH RADIO SOUNDINGS

3.1 Water vapour above land and ocean

For this comparison, radio soundings for all stations within the MERIS scenes made available by ESA for the algorithm validation were taken for the period 13. to 24. October 2002 from the radiosonde archive of the University of Wyoming [3]. As the MERIS overpass time for central Europe is between 9:30 and 11:00 UTC and most stations perform ascents at 12 UTC, the time difference between the soundings and the MERIS measurements was mostly between 1 and 2.5 hours.

From the radio soundings the integrated water vapour content was integrated for the total column and from top of the atmosphere down to the pressure levels derived by the MERIS cloud top pressure retrieval. The biggest source of discrepancies between MERIS water vapour measurements over land and ocean and the integrated water vapour amounts from the radio soundings are expected to be clouds traversed by the radiosonde while the MERIS measurements are taken from clear sky pixel. In this case, the radiosonde water vapour content will be larger then the MERIS results as the air is saturated within the cloud. This might happen due to the time difference between radiosonde ascent and MERIS overpass and advection of clouds into the MERIS field of view or in case of clouds not properly detected by the MERIS cloud detection scheme. Therefore, strict criteria were applied to the radio soundings in order to exclude any cloud-affected measurements from the validation of the cloud free algorithms. For that purpose, a simple threshold of 80% relative humidity was chosen and all radio soundings were excluded which surpassed this threshold anywhere during their ascent.

In the end, only 18 usable radio soundings remained in the investigated dataset for the validation of the water vapour products above land, and only 5 above ocean. For the comparison with MERIS measurements, the mean integrated water vapour content was averaged from all cloud free MERIS pixel in an area covering ±0.2° around the radiosonde launch site in order to take into account the possible drift of the sonde during its ascent. The results of this comparison are summarized in table 1:

Table 1: Statistical results from the comparisons of integrated water vapour above land and ocean from MERIS measurements with radio soundings. All water vapour values in g/cm2

Surface type	Algorithm	# of RS	Mean WV RS	RMSE	BIAS	Bias corrected RMSE
Land	Breadboard	18	1.04	0.13	-0.02	0.13
Land	ESA	18	1.04	0.18	0.12	0.13
Ocean	ESA	5	0.93	0.29	-0.04	0.29

The results from this comparison reflect the first experiences gained from the comparison of MERIS with MODIS measurements. For water vapour above land, the ESA algorithm shows a significant underestimation of integrated water vapour of 0.12 g/cm^2, while the breadboard's bias is negligible. The bias corrected root mean square error for both algorithms is around 0.13 g/cm^2. For water vapour above ocean, only the results from the ESA algorithm are available. Here, the bias is also very low, while the rmse of 0.29 g/cm^2 is larger. This is in accordance to the errors expected from the inversion of the radiative transfer simulations, as for water vapour above ocean the influence of variable parameters like aerosol optical depth or ocean reflectivity on the measured radiance ratio is higher compared to measurements above land due to the fact that the ocean is almost black in this spectral region and the measured radiance is almost completely based on aerosol scattering. Although the absolute number of measurements is far too low for a final conclusion, it seems that further investigations have to be carried out in order to find the reason for the underestimation of water vapour above land by the ESA algorithm compared to MODIS measurements, to the results from the breadboard algorithm and finally to radio soundings. However, the results are very encouraging, as for water vapour above land the breadboard and for water vapour above ocean the ESA algorithm itself show a high agreement to the radiosonde measurements.

3.2 Water vapour above clouds

The results for water vapour above clouds cannot be compared to radio soundings independently, as the results are only usable in combination with a correct estimation of the cloud top height. In case of MERIS, oxygen absorption is used for the retrieval of cloud top pressure [4, 5]. Fig. 7 shows MERIS integrated water vapour and cloud top pressure measured above northern Germany the 12th of October 2002. The image is clearly separated in two regions with low clouds around 900 hPa in the northern part and high clouds with cloud tops around 500 hPa in the southern part.
However, over both cloud systems, the integrated water vapour is small with values between 0.2 and 0.6 g/cm^2 only. However, at this day a strong front was located in this region, with a temperature gradient of around 10°K between the northern and southern part of the image, thereby explaining the low water vapour values above the low clouds in the colder and thus drier northern part of the image.

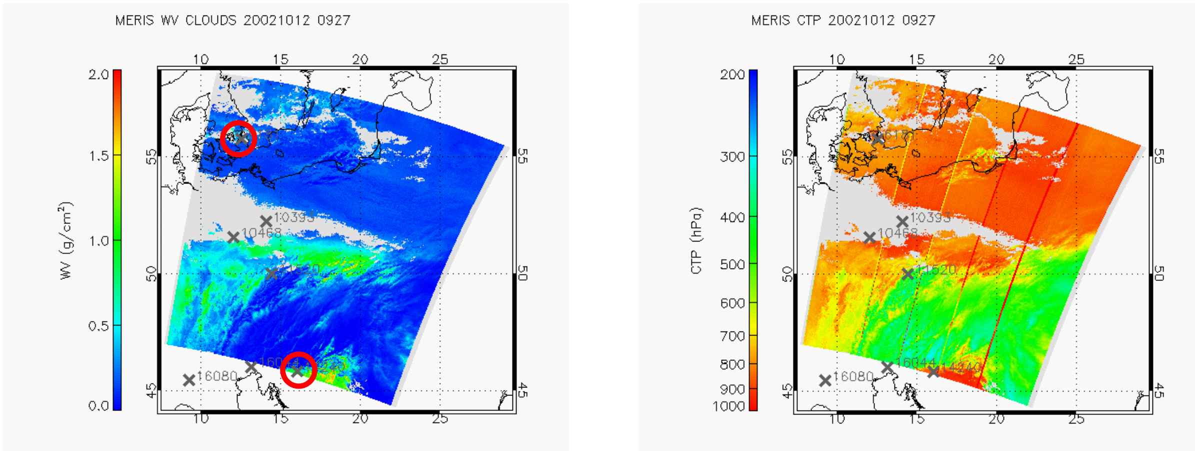

Fig. 7: Integrated water vapour above clouds (left) and cloud top pressure (right) from MERIS measurements on 12th October 2002. The red circles in the left panel indicate the radiosonde stations used for the comparisons

Two radio soundings were used for a validation of this result, both indicated by a red circle in the left panel of Fig. 7. Fig. 8 shows in black the MERIS measurements, the error bars represent 0.2 g/cm^2 uncertainty in integrated water vapour expected from the inversion of the radiative transfer simulations and 30 hPa uncertainty in cloud top pressure. The green line shows the results from the radio sounding, where for each pressure level the water vapour density was integrated from top of the atmosphere down to this level. Like in the previous comparisons, all cloudy pixel within an area of ±0.2° around the radiosonde station were used for this comparison.

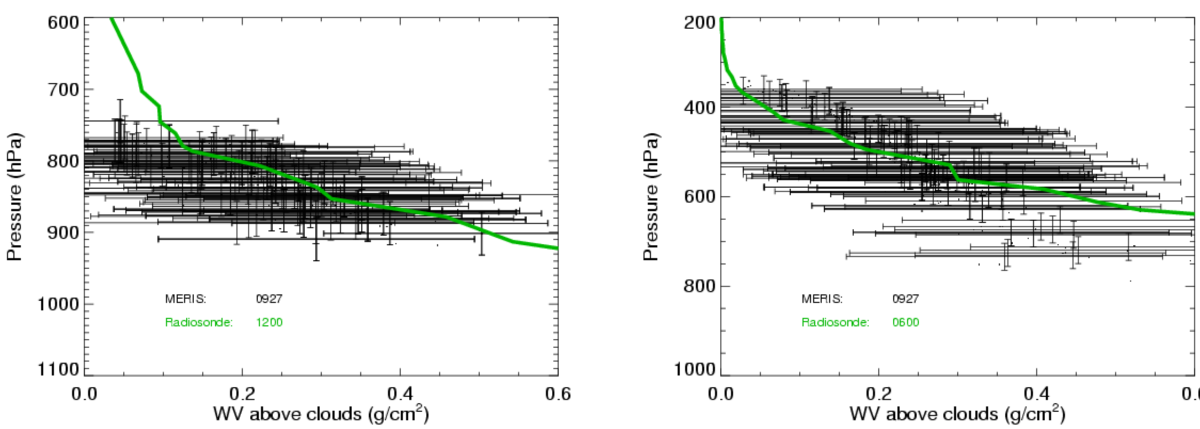

Fig. 8: Integrated water vapour and cloud top pressure from MERIS measurements (black) and from radiosonde (green). The left panel shows the results from the northern radiosonde indicated in Fig. 7, the right panel the results from the southern radiosonde

The general agreement between MERIS and radio soundings is high, although the absolute water vapour values are in the range of the estimated accuracy. Therefore a third test was performed for a radio sounding with slightly higher water vapour values. This was the case for a radiosonde measurement taken over southwestern Great Britain at the 13th of October 2002. Fig. 9 shows integrated water vapour and cloud top pressure in the area surrounding the radiosonde station, in Fig. 10 the comparison of MERIS measurements with the radiosonde data is presented:

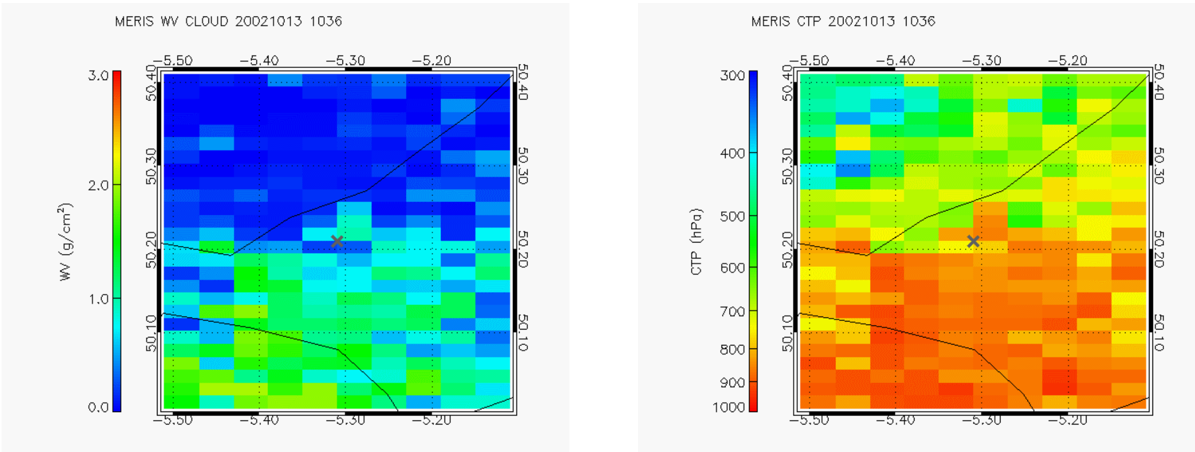

Fig. 9: Integrated water vapour above clouds (left) and cloud top pressure (right) from MERIS measurements on 13th October 2002. The cross indicates the radiosonde station used for the comparison

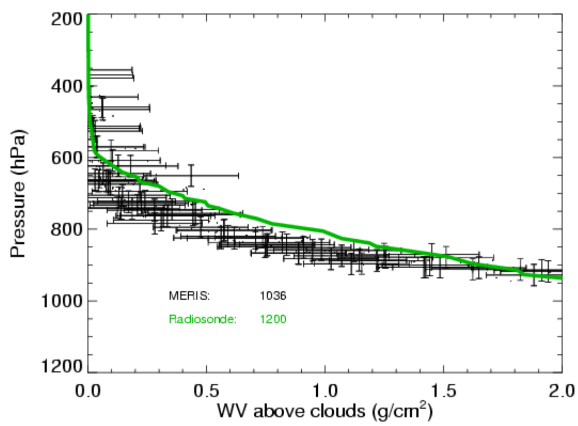

Fig. 10: Integrated water vapour and cloud top pressure from MERIS measurements (black) and from radiosonde (green)

In this example the agreement between radio sounding and MERIS measurements is very high and within the expected error ranges.

CONCLUSION

Three different algorithms for the remote sensing of columnar water vapour above land, ocean and clouds from MERIS measurements have been verified and fist validation results have been presented. For water vapour above cloud free land surfaces, the agreement of the breadboard version with radio soundings is very high, however, a bias between the breadboard and the ESA algorithm has to be subject of further investigation. For water vapour above ocean, only the ESA algorithm has been tested so far, however, the first results show high agreement between MERIS measurements and radio soundings, although the error level is higher. Here, further investigation is necessary as to how far the unknown surface reflectivity or the aerosol optical depth can be corrected for in order to increase the measurements' accuracy. Finally, for water vapour above clouds, the breadboard algorithm in combination with the MERIS algorithm for cloud top pressure retrieval shows a very high accuracy when compared with radio soundings. Due to ongoing investigation of differences between the breadboard and the ESA algorithm, the latter was not included in this study.

Generally speaking, the first verification and validation of the MERIS water vapour algorithms yielded very promising results, however, in the future some remaining open question regarding the implementation of the algorithms at ESA have to be addressed, and the validation has to be extended to far more cases.

REFERENCES

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