WATER VAPOUR FROM TOVS/ATOVS –
VALUE ADDED PRODUCTS AND APPLICATIONS

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1. INTRODUCTION

The German Remote Sensing Data Center (DFD) is a service provider dedicated to the task of remote sensing within the organisational structure of the German Aerospace Center DLR. DFD operates a complete ground segment for the acquisition, processing and distribution of remotely sensed parameters of the oceans, the land surfaces, and the atmosphere. Most important in its activities is the investigation of the utilization potential of Earth observation data by developing methods and strictly user-oriented, value-added products to promote both the scientific and public application of Earth observation data.

DFD is currently setting up an automatic atmospheric correction system ‚ClearView‘ for medium resolution earth observation sensors. It shall replace existing atmospheric correction modules which usually require interactive steps or which are designed especially for and therefore bound to one sensor. ClearView combines three major modules:

- A preprocessor which applies an evidence-based classification of raw data to detect clouds, shadow, dust and preliminary land cover classes.
- A radiative transfer code which accounts for absorption and scattering by aerosols, molecules and gases and anisotropic surface reflection
- An operational interface to assimilated auxiliary data as O_3 maps, total water vapour column maps, and a digital elevation model.

ClearView is demonstrated for Landsat7 – ETM, NOAA14-AVHRR and Terra1-MODIS datasets, but the atmospheric correction of ERS-2-ATSR-2, ENVISAT-AATSR, Landsat-TM/MSS, MSG, LISS, ATM, or ENVISAT-MERIS data will be possible as well. This system will be implemented and operated at DFD in cooperation with industrial partners.

User requirements for water vapour maps used in ClearView are:

- data availability for any European area at any time
- cloudfree areas only
- accuracy in total water vapour column 10 mm
- fast processing scheme

2. PROCESSING OF TOVS/ATOVS DATA AT DFD

DFD's archiving facilities contain HRPT raw data from its direct readout station back to 1990 which will be processed according to user requirements. Nowadays, DFD processes NOAA14-TOVS and NOAA15-ATOVS temperature and water vapour profiles on a routinely basis for all NOAA passes received by its facilities in Oberpfaffenhofen, Germany.

NOAA14-TOVS profiles are retrieved with the International TOVS Processing Package (ITPP5.20; *Smith et al.* 1983 and 1985). NOAA15-ATOVS profiles are processed with a combination of a slightly adapted ATOVS and AVHRR Processing Package (AAPP2.0; *EUMETSAT)* and the International ATOVS Processing Package (IAPP1.0; *Li et al.* 2000). AVHRR is included in the ITPP5.20 processing but there are no further meteorological fields used.

Comparisons of NOAA14-TOVS derived total water vapour colums with ECMWF analysis data yielded a mean difference of 1.89 mm of total water vapour column and a standard deviation of differences of 3.16 mm. These are results from a study with 12 NOAA-14 passes in a ± 15 min intervall around 6 and 12 UTC from 13.-24. November 1999 compared to ECMWF analysis fields. They are typical for similar studies performed during routinely quality control.

Comparisons of NOAA15-ATOVS derived total water vapour columns with ECWMF analysis data revealed problems in the regression method for total water vapour columns as used in the IAPP1.0. Fig. 1 gives as an example the comparison results for a pass from 21. February 2000, 18:06 UTC for total water vapour column derived as vertical integral from the IAPP water vapour profile on the left and the corresponding comparison results for the regression method on the right.

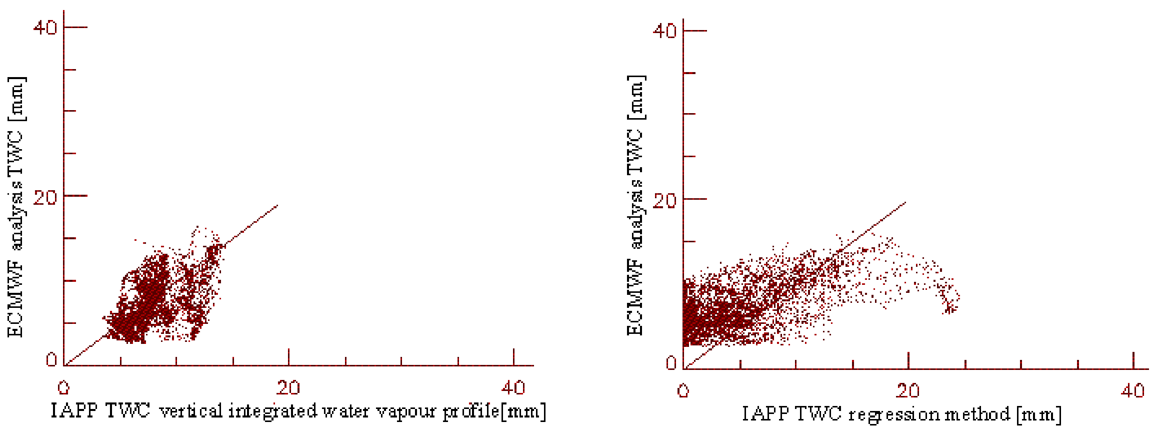

Fig. 1 Comparison of ECMWF analysis versus IAPP total water vapour column (TWC) for 21. February 2000 18 UTC (ECMWF) and 18:06 UTC (NOAA15) over the European area

a) Comparison of ECMWF with vertically integrated IAPP5.20 water vapour profiles as TWC

b) Comparison of ECMWF with TWC from IAPP5.20 regression method

This example is typical for 19 analysed NOAA15 passes over Europe from 21. February – 5. May 2000. Overall these passes the water vapour column derived as vertical integral from ATOVS profiles has a mean difference of 0.9 mm versus ECMWF analysis fields and a standard deviation of 3.9 mm. The results from the IAPP1.0 regression method yield a mean difference of 1.95 and a standard deviation of 7.01 mm.

3. THE USE OF ATMOSPHERIC WATER VAPOUR INFORMATION FOR ATMOSPHERIC CORRECTION

Solar AVHRR channels are remarkably affected by atmospheric water vapour absorption, especially channel 2 (885 nm) shows a variability of 7.7 to 22 % in reflectance values if the water vapour column is varied between 0.5 and 4.0 g/cm2. Even channel 1 (620 nm) is affected with 0.7 to 4.4 % in reflectance values, respectively (*Erbertseder et al.* 2000). Fig. 2 shows a mosaic of 3 NOAA-AVHRR scenes from the 24. April 2000. On the left the Normalized Difference Vegetation Index (NDVI) calculated from raw data is shown, on the right the NDVI calculated from atmospherically corrected AVHRR channels is given. Water vapour column, ozone column and Rayleigh scattering have been taken into account for the atmospheric correction. Aerosol and BRDF effects are neglected in this study. Both images show how atmospheric correction results in higher NDVI values and a more dynamic NDVI distribution. Secondly, a borderline between two passes situated inside the blue box over Poland gives an impression on atmospheric influence on the NDVI. In the uncorrected NDVI image the differences in atmospheric conditions results in a line structure at this border, in the corrected NDVI images this line disappears.

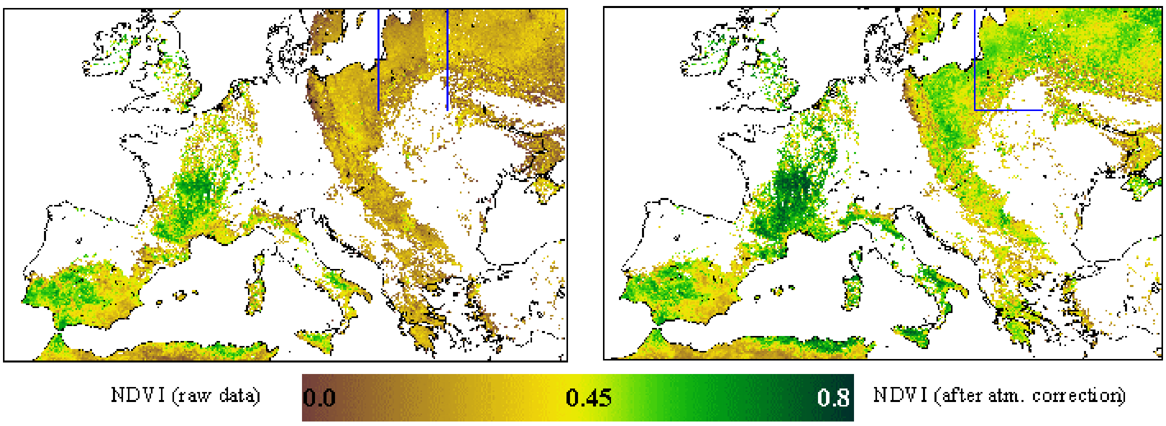

Fig.2 NOAA14-AVHRR derived Normalized Difference Vegetation Index (NDVI)
mosaic of 3 scenes (13:12, 14:52 and 16:36 UTC) from 24.April 2000
left: NDVI calculated from raw AVHRR channels 1 and 2
right: NDVI calculated from atmospherically corrected AVHRR channels 1 and 2

These images are a result of DFD's efforts to include an atmospheric correction into its operational NOAA-AVHRR processing chain and to prepare for the ClearView project mentioned above. A thorough evaluation of this atmospheric correction scheme is underway at the moment.

4. GENERATION OF WATER VAPOUR MAPS

Most suitable for atmospheric correction purposes is a water vapour sounding capability on the same platform as the instrument to be corrected or a water vapour sounding capability of the instrument itself. ENVISAT and the NOAA satellites are examples for the first possibility, TERRA–MODIS and MSG-SEVIRI are examples for the latter one. For these satellites water vapour can be derived and used straight-forward for the atmospheric correction of the solar land surface channels after remapping and spatial interpolation.

Much more difficulties are to overcome, if there is no sounding capability with spatial and temporal coincidence to the land surface oriented instrument available. For these instruments water vapour maps have to be generated from a different data source as NOAA-TOVS instruments or numerical weather forecasting analyses. An example are the widely used Landsat satellites which have typically a time difference to the nearest NOAA overpass or the nearest synoptical analysis time of 3 – 6 hours. As water vapour is the most varying parameter in atmospheric correction this time difference can cause large errors and artefacts. Especially for older Landsat images - very often used for time series and change studies - only the NOAA satellites can be used to derive the water vapour from space.

In the following sections details of the generation of water vapour maps are given.

4.1 Spatial Interpolation

An effective distance weighting method (Shepard, 1986) is used for spatial interpolation. The weighting w as function of distance r

$$w(r) = \begin{cases} \frac{1}{r} & 0 < r \le \frac{R}{3} \\ \frac{27}{4R}\left(\frac{r}{R} - 1\right)^2 & \frac{R}{3} < r \le R \\ 0 & r > R \end{cases} \qquad (1)$$

provides an effective local interpolation method with a radius R that defines a local area. All water vapour measurements inside this local area are used for spatial interpolation. This weighting function especially provides a smooth transition of its value to zero if the radius R is reached and it therefore avoids artefacts.

R can be chosen dynamically and is typically set to a value that a minimum of 5 water vapour measurements are actually used.

4.2 Temporal Interpolation with Trajectory Modelling

Strictly speaking, both, the behaviour of water vapour as a tracer to be transported and also its phase transitions have to be taken into account for temporal interpolation. Especially the water vapour's phase transitions require a complex modelling approach. On the other hand the user's requirements in the ClearView project and for atmospheric correction in general are that water vapour maps are necessary for cloudfree areas only. Cloudy areas are not of interest for users dealing with land surface issues. Therefore, phase transitions of water vapour are neglected as they normally do not occur in cloudfree areas. This reduces the problem to a pure transport problem and allows trajectory modelling as a method.

4.2.1 Use of Trajectory Model FLEXTRA

To derive water vapour maps, trajectories are started at all retrieval locations where cloudfree TOVS measurements are available inside the NOAA passes close in time to the data set that shall be corrected.

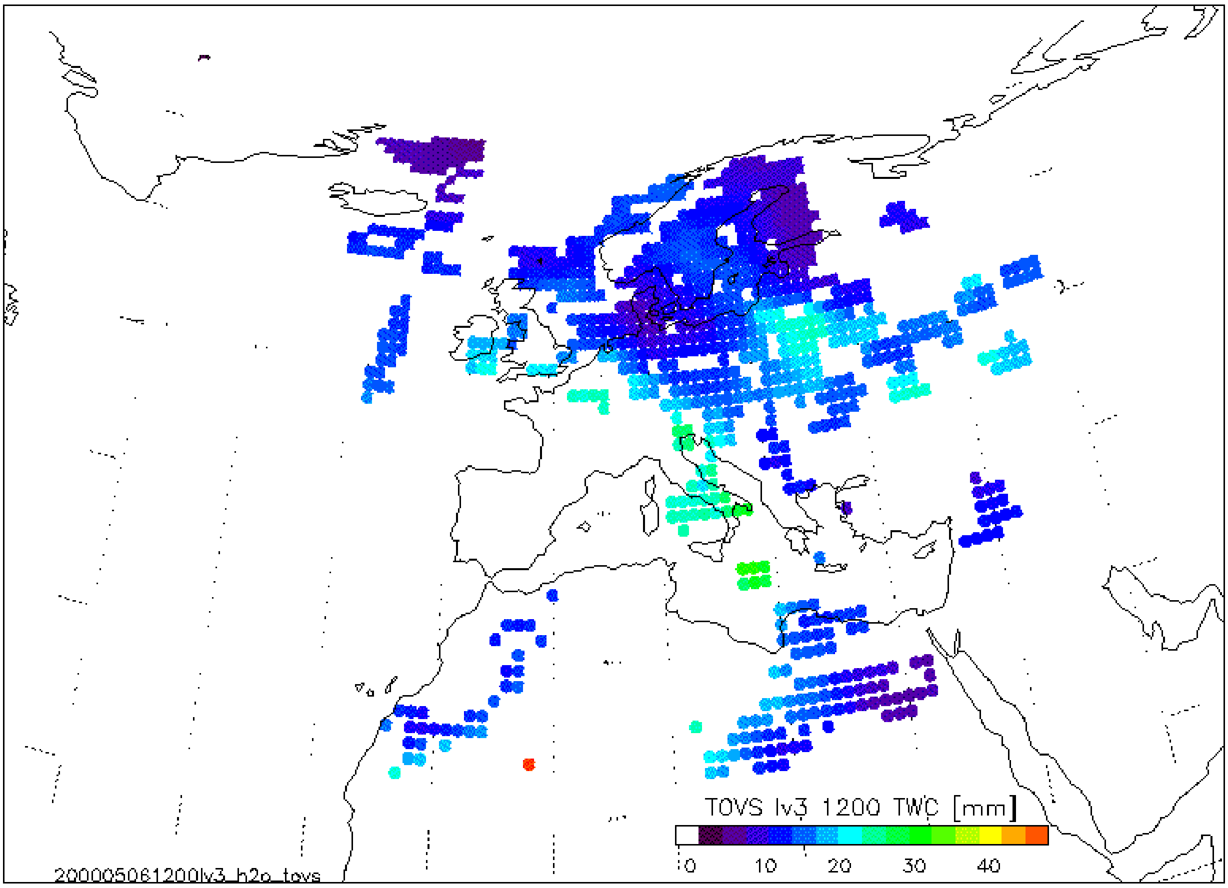

Fig.3 total water vapour column for 6. May 2000, 12 UTC
cloudfree retrievals assimilated with trajectory modelling towards 12 UTC

This is done for all tropospheric pressure levels 1000, 850, 700, 500, 400 and 300 hPa. The retrieved water vapour mixing ratio is then placed at the trajectory end at the final time step. A spatial interpolation is afterwards performed on each level and vertical integration finally delivers water vapour column.

FLEXTRA is a trajectory model developed at the University of Munich by *Stohl et al.* (e.g. 1998). It allows the calculation of forward and backward trajectories driven by ECMWF analysis wind fields. It is specificially designed to efficiently compute trajectories for many starting point. This is necessary as we use the potentially large amount of retrieval locations at 6 pressure levels as starting points for trajectories.

Figure 3 gives an example result of total water vapour column as derived with the trajectory modelling approach. NOAA14-TOVS retrieved cloudfree humidity profiles of passes at 12:35, 14:13, and 15:56 UTC on the 6. May 2000 were transported on each level with FLEXTRA, interpolated on each level and vertically integrated to calculate the total water vapour column (TWC) for cloudfree regions.

There is one unreasonable data point over the Saharan area. As result of the profile retrieval all profiles in that area are flagged as cloudy with one exception - one single retrieval in that cloudy area is flagged as cloudfree and it also has an unreasonable water vapour column value for a cloudfree retrieval. This seems to reveal a cloud detection problem in this area, which results in a cloudy water vapour column taken as a cloudfree measurement into the assimilation scheme. As the trajectory modelling approach is not valid in cloudy areas this datapoint therefore seems to be unreliable.

4.2.2 Comparison with ECMWF analysis model

To assess the quality of the trajectory modelling approach a comparison with ECMWF analysis model data was performed. TOVS derived water vapour profiles were assimilated towards the synoptical ECMWF analysis time 12 UTC and compared to the analysis field. Fig. 4 shows an example of such a comparison with data from the 6. May 2000. It reveals differences of $\pm$ 5 mm in most areas. Higher differences occur in areas next to clouds. Problems are expected here because of trajectories which reach into cloudy regions. There is no information available, where exactly the cloud fields are at 12 UTC. It is only known which retrievals are the cloudy ones. Therefore, it is not surprising that some trajectories starting at cloudfree locations reach also cloudy areas. And for these cases the assumption of water vapour as a tracer without phase transitions is not valid anymore. Therefore, these areas result in larger errors in comparison with ECMWF data.

There is one single data point over the Saharan area with an extremely high difference of –15 mm. As mentioned before this seems to be the result of a retrieval that was falsely classified as cloudfree.

As result of a comparison of 9 passes from different years a mean difference of –1.48 mm between the ECMWF analysis model and the assimilated (A)TOVS water vapour columns and a standard deviation of 4.26 mm was found.

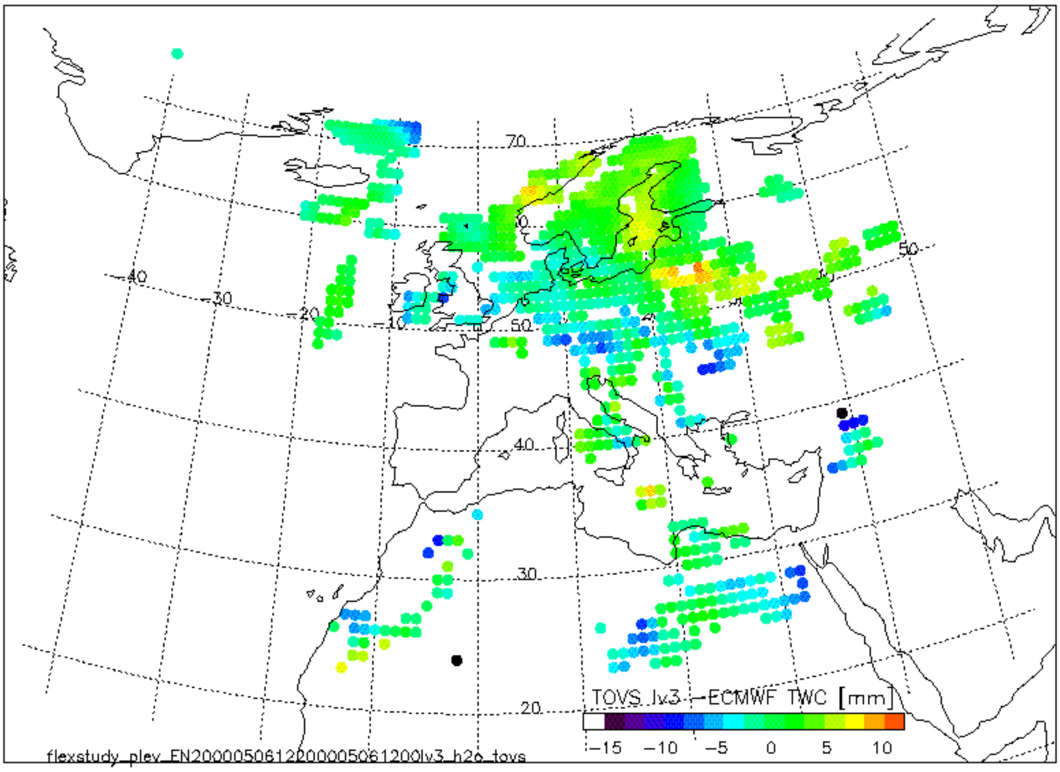

Fig.4 TOVS total water vapour column for 6. May 2000, assimilated towards 12 UTC versus ECMWF total water vapour column at 12 UTC

5. CONLUSIONS

The operational processing of NOAA14-TOVS and NOAA15-ATOVS data was sucessfully implemented at DLR-DFD. The pre-processing and retrieval packages ITPP, AAPP and IAPP have been very helpful.

The derived water vapour profiles are used as an external data set for atmospheric correction purposes inside the project ClearView. This project aims to create a prototype processor which includes these water vapour profiles together with cloud, aerosol and ozone information within an automatic atmospheric correction scheme for solar channels. Additionally, the water vapour profiles are used to operationally derive an atmospherically corrected NDVI.

An assimilation scheme using a trajectory modelling approach was tested to overcome the time interpolation problem that occurs if sensors shall be corrected that are not capable to derive water vapour information on their own.

The assimilated water vapour maps – compared with ECMWF analysis fields - show an accuracy which is highly acceptable with respect to the users requirements for atmospheric correction of ± 10 mm.

It has been shown, that the trajectory modelling approach gets to his accuracy limits if cloudy areas are reached. On the other hand, the usefulness of such data for atmospheric correction is not affected at all by that as most of these sensors are capable to detect cloudy areas on their own. This cloud information can be used as well as a mask to exclude unreasonable areas inside the water vapour maps.

Further studies of the usefulness of the trajectory modelling approach have to be performed. Especially it has to be clarified whether the advantages of the assimilated TOVS data overlay possible disadvantages that may be caused by the cloudy area handling. And it has to be examined how much improvement the assimilation scheme offers in comparison with the use of the ECMWF humidity field close in time or a pure spatial interpolation approach with neglecting the temporal variability over some hours.

6. ACKNOWLEDGEMENTS

Padsuren Tungalasaikhan has kindly provided the atmospherically corrected NDVI images as an example for water vapour influence on the NDVI.

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