

► Objectives

The Humidity Composite Product (HCP) of EUMETSAT's Satellite Application Facility on Climate Monitoring (CM-SAF) will integrate data from several existing and upcoming satellites, e.g., microwave imagers like SSM/I as well as water vapour profiling instruments on the Meteorological Operational polar platform (MetOp) and ATOVS data from NOAA platforms. CM-SAF will provide single sensor estimates as well as some merged estimates, e.g., from SSM/I and AMSU-A. The production of this thematic climate record relies on calibrated and inter-calibrated input data to be provided by the satellite operators.

Two pilot studies on the creation of daily mean fields have been undertaken. The first provided a merged result from total precipitable water (TPW) observations from AMSU-A onboard the NOAA-15 and NOAA-16 satellites and from SSM/I on DMSP-F13, F14, and F15 satellites. The second study considered the merging of ATOVS estimates from NOAA-15 and NOAA-16. In both studies the merging is performed by Kriging, an optimal interpolation technique that provides not only fully covered fields but also a corresponding map of errors. The obtained errors reflect mostly the actual sampling situation and should not be mixed up with retrieval errors that have to be determined by external comparisons to other data. The technique has been chosen because of its potential to merge data from several completely different sources if they have no bias errors. It also holds the potential to include spatiotemporal resolved information on the retrieval error itself.

Within this poster the Kriging technique is presented and an exemplary application to ATOVS data from April 2004 is shown.

► Kriging

Kriging can be regarded as a prediction of a value x_0 at a location P_0 where no measurement is available employing information from measurements at the surrounding locations P_i . A solution is not possible for one single case. However, if a time series of m measurements at each location P_i is available it is reasonable to minimise the expression:

$$\sum_{i=1}^m \left(x_0 - \sum_{i=1}^n \lambda_i (x_i + \Delta x_i) \right)^2 = \min$$

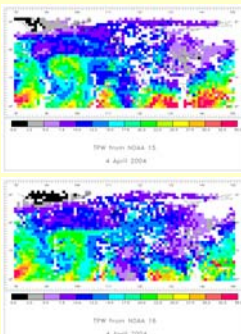
where x_i denote the available measurements, Δx_i their errors, and λ_i the weights. The minimised expression of this equation is equal to the error of the predicted value and reads:

$$[x_0, x_0] - 2 \sum_{i=1}^n \lambda_i [x_0, x_i] + \sum_{i=1}^n \sum_{j=1}^n \lambda_i \lambda_j [x_i, x_j] + \sum_{i=1}^n \lambda_i \lambda_i [\Delta x_i, \Delta x_i]$$

where $[]$ denotes temporal averaging. The first term denotes the variance at P_0 and is equal to unity if anomalies are considered. The second term contains the covariance between data points, the so called **information**. The third term contains the so called **redundance** because information from points P_i may not be independent. The last term describes the individual errors at the points P_i .

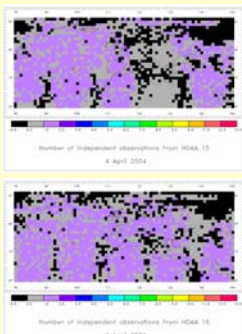
To determine the weights λ_i information on the spatial covariance and Δx_i the error of the individual observations $[\Delta x_i, \Delta x_i]$ is needed. Note that the spatial covariance is spuriously modified by error covariance between the points. Although not explicitly mentioned the average effect of the spatial error covariance is implicitly included within the information and redundance terms.

► Data

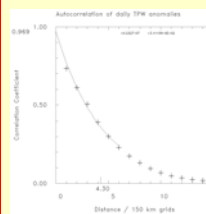


Example of the input data to be merged by the Kriging procedure. The maps to the left show the daily mean TPW derived from ATOVS on NOAA-15 and NOAA-16 on April 4, 2004. TPW is computed from NOAA's mixing ratio profile retrieval and has been brought to an equal area projection with a nominal grid cell distance of 150 km.

Maps on the right side show the number of independent observations for both platforms. Pixels of the same overpass are not considered as independent. Consequently, the maximum number of independent observations from two satellites per day is four.



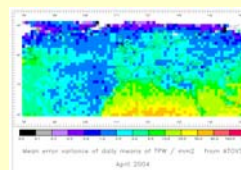
► Spatial Correlation Function



Correlation function of daily TPW anomalies for April 2004.

The correlation is calculated for daily averages, which are based on the maximal four independent observations available at each location, two from each platform and two from the morning and evening overpass, respectively. The distances are measured in units of the grid lengths of 150 km. For zero distance, no direct observation is available, but the fit of an exponential function allows a rough estimate of the average error variance, which can be read at the ordinate with the 0.969, meaning that a fraction of 0.031 of the total variance can be assigned to the error variance. The correlation length (the distance, where the correlation is decreased by a factor of 1/e compared to the correlation found for zero distance) is determined to be 4.3, corresponding to 645 km.

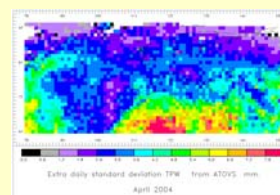
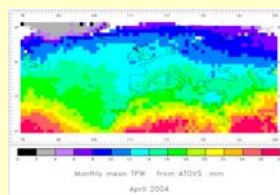
► Error Determination



Spatial distribution of the mean error variance of daily means of TPW given in mm² as derived for April 2004.

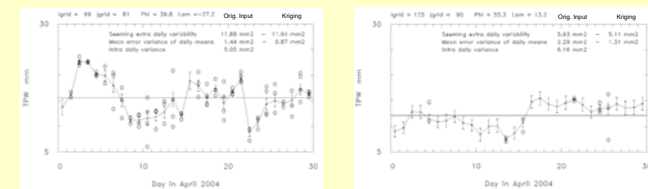
To allow the calculation of error maps the errors of each individual daily input value of the Kriging routine has to be known. To give an overview, the map shows the error variance averaged over the entire month, as calculated from the actually used daily errors. Note the extreme differences between the eastern Atlantic with errors in the order of 1 mm² and the southern Sahara with errors of 50 mm². This emphasises the need of determining the errors individually instead of using an average error estimate, which would be easily available from the correlation function.

► Products



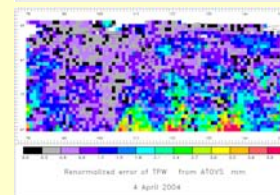
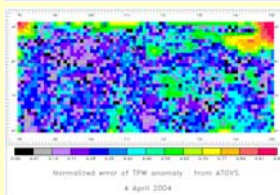
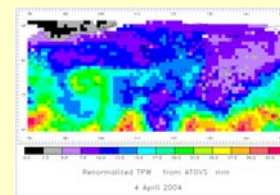
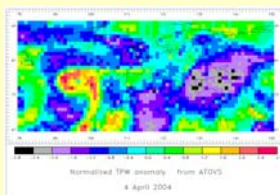
Monthly mean TPW (left) and extra daily standard deviation (right) in mm as derived from ATOVS for April 2004. These fields are used to normalise the Kriging input data. After the calculations the Kriging results have to be renormalised again to obtain TPW and corresponding errors in units of mm.

► Products



Time series showing both the independent satellite observations used as Kriging input (circles) and the obtained Kriging result, given by the solid line, for two locations (1) in the mid Atlantic (27.8°W, 39.8°N) and (2) in the Baltic Sea (13.2°E, 55.3°N). The bars show the Kriging error for each day.

The extra daily variability as it was estimated from the input observations (11.88 mm² - 1.44 mm² = 10.44 mm²) is actually somewhat lower than found by the Kriging procedure (11.94 mm²). Daily means directly derived from satellite pixels have an error variance of 1.44 mm², which is almost halved to 0.87 mm² by the Kriging procedure. On 4 April three independent satellite observations are available at location (1) (only the morning overpass of NOAA-16 is missing), with almost identical TPW observations (22.45, 22.50, 22.65 mm). Consequently, the error of this individual input value is estimated to be very small, so that the Kriging procedure provides a rather similar TPW value (22.53 mm) together with a small error estimate (0.06 mm). On 14 April, the satellite input varies considerably between 9.90 mm and 20.85 mm. However, the Kriging error remains moderate with 1.33 mm as information from neighbouring grid boxes is included. The most striking benefit from Kriging certainly is the fact that values can be attached to days with no observations at all, as e.g., for 1 April, where the error (1.55 mm) is not essentially higher than normal. The benefit of Kriging becomes more evident at locations with lower data coverage. At a grid box in the Baltic Sea between Germany and Sweden (location (2)), satellite data are available for only 6 days within April 2004. Nevertheless, a reconstruction of daily TPW time series is possible with errors of about 1 mm.



The standard Kriging output comprises of the daily mean fields and the corresponding error maps. The two upper maps show the normalised TPW anomaly (upper left) and the renormalised daily mean (upper right) from ATOVS on April 4, 2004. The values are (re)normalised by subtracting the monthly mean and dividing by the extra daily standard deviation shown above. The lower left map shows the corresponding normalised error of the TPW anomaly. Due to the normalisation the maximum error is equal to 1, corresponding to the extra daily standard deviation, which would be obtained if all daily values were set to the monthly mean. The renormalised field is shown in the lower right figure.

Acknowledgement

This research is part of contract for work and labour between the Satellite Application Facility on Climate Monitoring hosted by Deutscher Wetterdienst and the University of Bonn. The authors thank NOAA for providing level 2 ATOVS estimates operationally to DWD.