GNSS-DERIVED PATH DELAY: A METHOD TO OBTAIN THE WET TROPOSPHERIC CORRECTION FOR COASTAL ALTIMETRY

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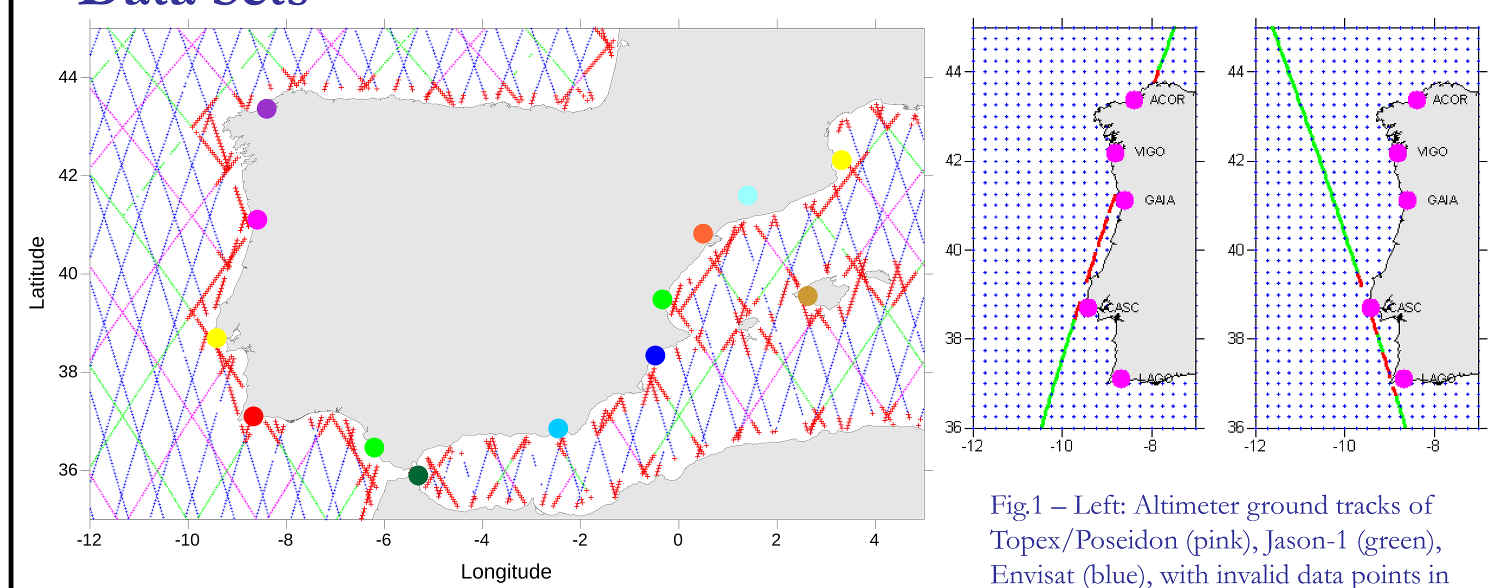
Abstract

The wet tropospheric correction is one of the major error sources in coastal altimetry. The most accurate method to derive the correction, from Microwave Radiometer (MWR) measurements, becomes unusable at distances about 50 km from the coast, due to the large MWR footprint.
This study presents an innovative method for computing the wet tropospheric correction for altimetry measurements in the coastal regions from GNSS-derived tropospheric delays, the so called GPD (GNSS-derived Path Delay) approach.
The method is based on GNSS-derived zenith wet delays (ZWD) determined at a network of coastal stations and offshore platforms or buoys equipped with dual-frequency GNSS receivers, further combined with valid MWR measurements and ZWD values from a Numerical Weather Model (NWM), such as ECMWF (European Centre for Medium Weather Forecast) Deterministic Atmospheric Model.
A methodology for computing the wet tropospheric correction at each altimeter point with invalid MWR measurement has been implemented by using a linear space-time objective analysis (OA) technique that combines all available independent ZWD values (MWR, ECMWF- and GNSS-derived) within the specified spatial and temporal scales.
The methodology has been tested for the western European coast.
Results show that the GPD estimates are highly dependent on the spatial and temporal distribution of the three data types used. A considerable number of configurations can be found, which allow the estimation of the wet delays within 1 cm error: points at distances < 50 km from a GNSS station, points for which there are valid MWR measurements within a distance < 50 km or passes with an associated measurement time very close to the time of the closest NWM grid.

Data Sets



1. Zenith wet delays (ZWD) determined at a network of GNSS stations near the coast.
2. Envisat MWR (only valid) measurements
3. ECMWF Deterministic Atmospheric Model single-level fields: surface temperature (2T) and TCWV global grids (0.25º×0.25º, 6h time interval)

Fig.1 – Left: Altimeter ground tracks of Topex/Poseidon (pink), Jason-1 (green), Envisat (blue), with invalid data points in red, and location of the regional network of 13 GNSS stations used in the study. Right: View of the West Iberian coast, with Envisat passes 160 and 1 (green for valid and red for invalid MWR measurements), GNSS stations in pink and ECMWF grid points in blue.

GNSS-derived wet tropospheric correction

At each GNSS station, the derived quantity is the zenith total delay (ZTD).
Mapping functions (MF), required to transform between the observed slant total delays and the corresponding zenith quantities, play a major role. The state-of-art MF are the VMF1 (Vienna MF 1), based on ECMWF global grids (Boehm and Schuh, 2004). To get the ZWD, the ZTD has to be corrected for the dry component (or zenith hydrostatic delay, ZHD). ZHD can be computed within a few millimetres either from *in situ* pressure data or from global VMF1 grids.
To be used for coastal altimetry, the estimated ZHD and ZWD have to be reduced to sea level, by applying a separate correction to each field (Kouba, 2008).
All GNSS processing has been performed using the GAMIT software package (ref?).
Although the region of interest is a European region, the required network must have a good global distribution, to reduce the correlation between the estimated tropospheric delays.

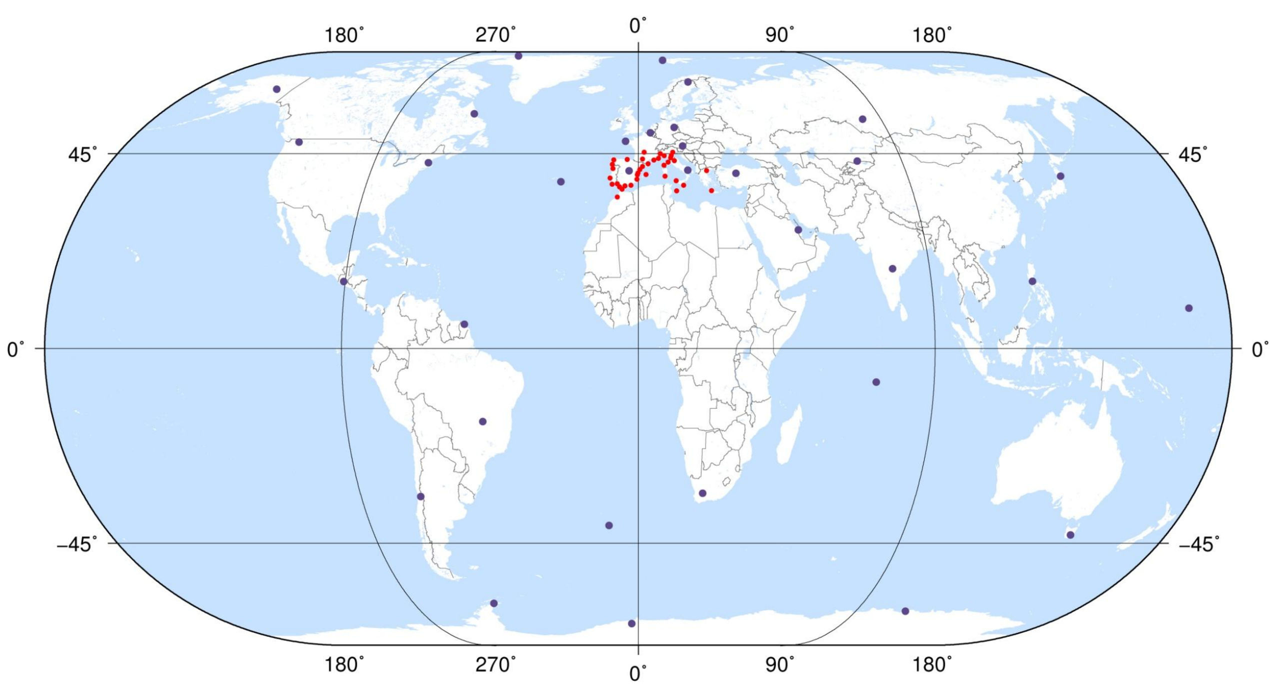


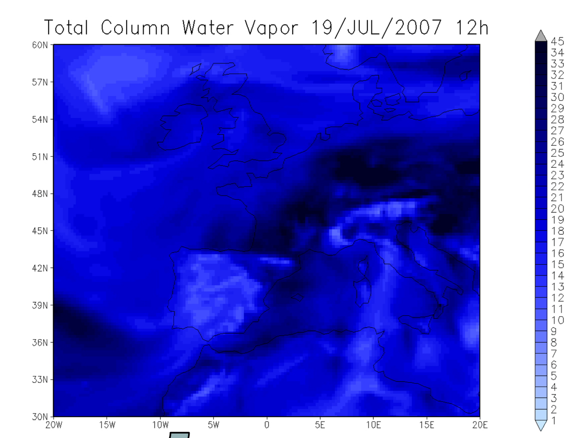
Fig.2 – Global network of GNSS stations used in the processing: IGS stations in blue and EUREF stations in red.

Fig.3 – UPorto height corrected (green) vs. non height corrected (red) ZWD (top) and ZHD (bottom) for BELL station (Spanish Northeastern Coast, height: 803m), for a 500-day period.

ECMWF-derived wet tropospheric correction

The integrated water vapour (IWV) is proportional to ZWD (e.g. Askne and Nordius 1987):

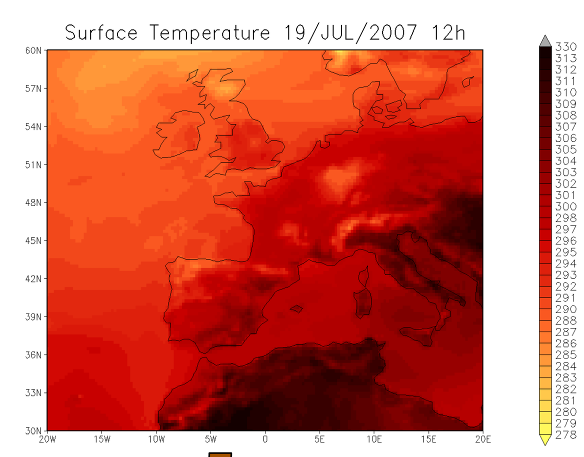
$$\frac{ZWD}{IWV} = 10^{-6} \cdot R_W \cdot \left(k_2' + \frac{k_3}{T_M}\right)$$



$$k_2' = [22.1 \pm 2.2]\,(K/hPa)$$
$$k_3 = [37100 \pm 1200]\,(K^2/hPa)$$

Mean Temperature of Troposphere (T_M) can be estimated from surface temperature (T_0) (Mendes et al. 2000):

$$T_M = 50.4 + 0.789\,T_0$$



Data Combination

The objective analysis technique (Bretherton et al. 1976) interpolates the wet tropospheric correction at each altimeter point with invalid MWR measurements from the nearby (in space and time) MWR, ECMWF- and GNSS-derived independent measurements.
Appropriate correlation functions (Schüler 2001) have been adopted, which allow the computation of the covariance matrix between each pair of measurement and the covariance vector between each measurement and the location at which an estimation is required.
Adopted spatial and temporal scales: 100 km and 100 minutes, respectively. Since ECMWF grids were given at 6h interval, for this data type the time domain has been extended to 3h.
White noise: 5 mm for MWR and GNSS-derived ZWD and 1 cm for ECMWF-derived ZWD.

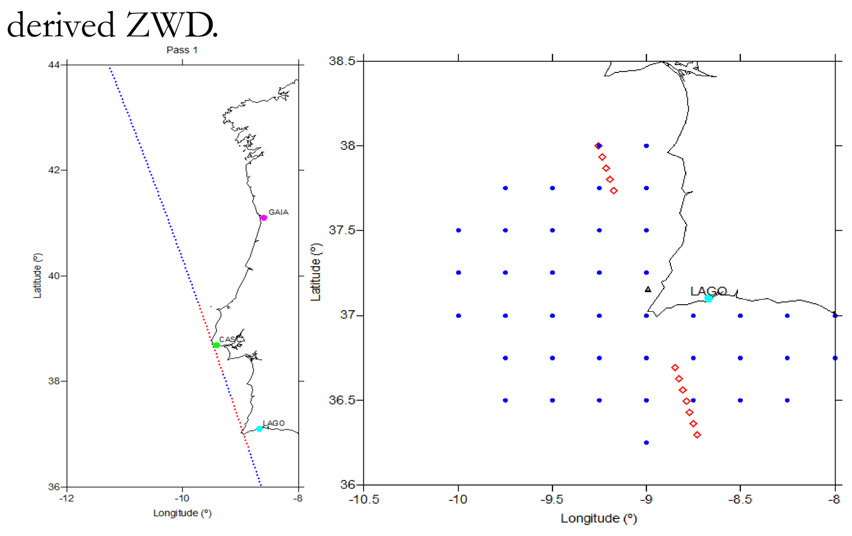


Fig. 4 - Example of data used for estimating the ZWD at a location near the Portuguese Southwestern Coast (Pt1 - black triangle): blue and red dots represent valid and invalid Envisat MWR wet delay values, model observations are represented by the blue dots and LAGO GNSS station ZWD estimates by the cyan circle – 12 GNSS observations have been used.

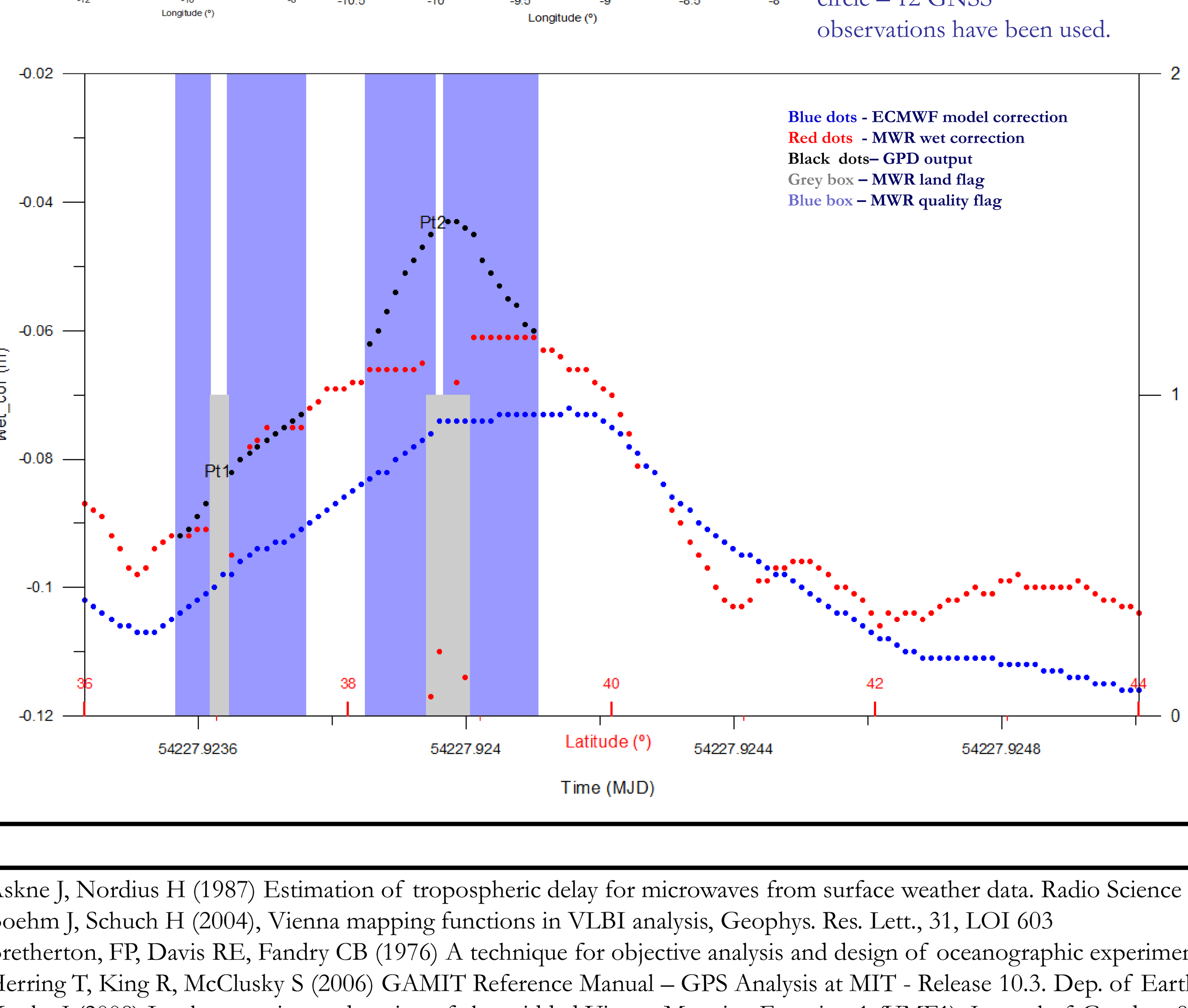


Fig. 5 – Example of algorithm application to Pt1 (see figure 4): wet delay estimates remain nearly constant in value in the light blue shaded areas (wet delay values are shown by the y-axis on the left side). The OA technique has thus output wet delay estimates (black dots) for all measurements represented by the red dots that are superimposed on the shaded areas, whichever its color, providing that these measurements have altimeter land-ocean flag equal to 0.

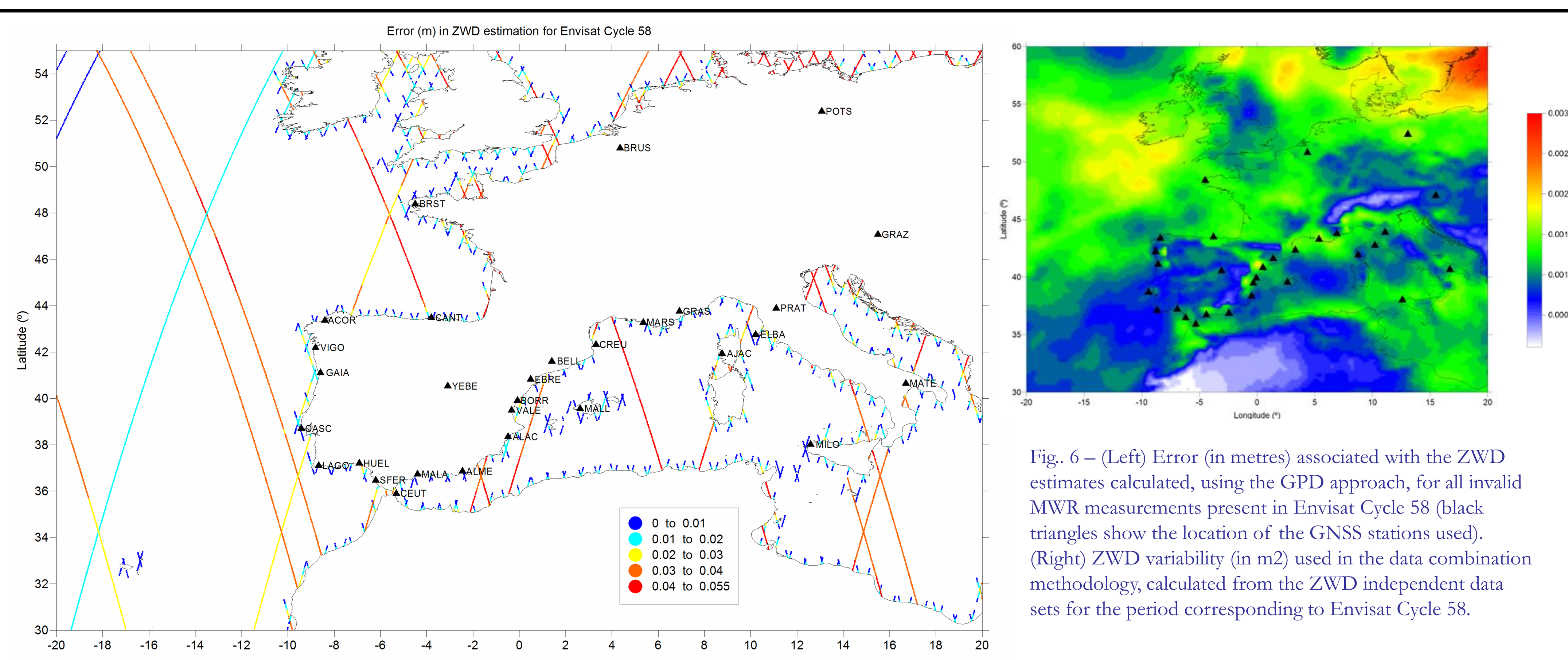


Fig. 6 – (Left) Error (in metres) associated with the ZWD estimates calculated, using the GPD approach, for all invalid MWR measurements present in Envisat Cycle 58 (black triangles show the location of the GNSS stations used). (Right) ZWD variability (in m2) used in the data combination methodology, calculated from the ZWD independent data sets for the period corresponding to Envisat Cycle 58.

SUMMARY OF RESULTS

The GPD estimates are a combined value of all available data within the specified spatial and temporal scales. Therefore the results are dependent on the spatial and temporal distribution of the three used data types.
The most critical cases occur for isolated segments containing only invalid MWR measurements (the closest valid MWR points are at distances larger than 100 km) or tracks almost parallel to the coastline, for which there are no GNSS stations within a distance of 100 km. In this case, the estimated values are solely based on NWM measurements, assumed less accurate.
A considerable number of configurations can be found, which allow the estimation of the wet delays within 1 cm error: points at distances < 50 km from a GNSS station, points for which there are valid MWR measurements within a distance < 50 km or passes with an associated measurement time very close to the time of the closest NWM grid.
To achieve this accuracy everywhere, an augmentation of the GNSS networks is advisable, ensuring a coastal station approximately every 100 km and, more importantly, in the locations where isolated segments occur containing all MWR measurements invalid.
Considering a global implementation of the method, a densification of the network of coastal GNSS stations is advisable, with a station approximately every 100 km, preferably with meteorological sensors.
Emphasis should be given to the merging of data derived from offshore GNSS stations (e.g. buoys and oil platforms). In addition, the accessibility of NWM grids at a higher temporal sampling, ideally 1 hour, is of crucial importance.

Askne J, Nordius H (1987) Estimation of tropospheric delay for microwaves from surface weather data. Radio Science 22:379-386.
Boehm J, Schuch H (2004), Vienna mapping functions in VLBI analysis, Geophys. Res. Lett., 31, LOI 603
Bretherton, FP, Davis RE, Fandry CB (1976) A technique for objective analysis and design of oceanographic experiment applied to MODE-73. Deep-Sea Research 23:559-582
Herring T, King R, McClusky S (2006) GAMIT Reference Manual – GPS Analysis at MIT - Release 10.3. Dep. of Earth, Atmospheric and Planetary Sciences, MIT
Kouba J (2008) Implementation and testing of the gridded Vienna Mapping Function 1 (VMF1). Journal of Geodesy 82:193-205 doi:10.1007/s00190-007-0170-0
Mendes VB, Prates G, Santos L, Langley RB (2000) An Evaluation of the Accuracy of Models of the Determination of the Weighted Mean Temperature of the Atmosphere. Proceedings of ION, 2000 National Technical Meeting, January 26-28, 2000, Pacific Hotel Disneyland, Anaheim, CA
Schüler T (2001) On Ground-Based GPS Tropospheric Delay Estimation. PhD Thesis, Universität der Bundeswehr München

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