OPERATIONAL ALTIMETRY AT GFZ - FROM ERS-2 TO ENVISAT

Matthias Rentsch, Alexander Braun, Achim Helm, Tilo Schöne

GeoForschungsZentrum Potsdam (GFZ), Division 1 "Kinematics & Dynamics of the Earth"
Telegrafenberg, D-14473 Potsdam, Germany
rentsch@gfz-potsdam.de

ABSTRACT

As part of the German Processing- and Archiving Facility for ERS (D-PAF), the Altimeter Data Processing System (ADP) at GeoForschungsZentrum Potsdam (GFZ) is responsible for the systematic acquisition and processing of ERS-2 Radar Altimeter data, the quality control, the generation of upgraded geophysical data products and its distribution. The Quick-Look Products which are based on the ERS-2 Radar Altimeter Fast Delivery Product are upgraded by merging the GFZ Preliminary Orbit, by recomputing corrections for atmospheric path delay, by applying the tides and additional altimeter range corrections, e.g. USO drift and SPTR correction. Three product types are provided and are available within 6 to 12 days, the along-track Quick-Look Ocean Product (QLOPR), the Quick-Look Ocean Crossovers (QLOPC) and the Quick-Look Sea Surface Height Model (SSHQL). The Precise Products are derived from the upgraded ERS-2 Radar Altimeter Ocean Product. Herein, the GFZ Precise Orbit is merged and the altimeter ranges are corrected in a similar way as for the Quick-Look Products. Two grid models are provided, the Short Period Sea Surface Height Model (SSH_S) which is based on the complete altimeter data sequence of one ERS-2 cycle (35 days) and the Long Period Sea Surface Height Model (SSH_L) which is produced half-yearly by accumulating all data since launch. The experience in operational altimetry with ERS-1/2 will be continued for the Envisat era. Based on Envisat Level 1b and Level 2 data products, ADP will generate various value-added ocean and ice data products. Standard geophysical data products will be provided as well as user-specific data products which will fulfill the requirements resulting from two user inquires which were initiated by GFZ in 1994 and 1995.

1. INTRODUCTION

In the framework of its operational activities, the GeoForschungsZentrum Potsdam (GFZ) is responsible on behalf of ESA for the generation and distribution of various altimeter data products for ERS-1 and ERS-2. For this purpose, GFZ has established a mission independent data processing system which also allows the processing of non-ESA missions like Geosat, Topex/Poseidon, and the future missions Envisat and Jason. The whole software system is presently updated to fulfill the requirements of the future tasks. According to ESA's data strategy, a couple of predefined altimeter data products from ERS-1 and ERS-2 are offered, which can be seperated into two main product types, the Quick-Look Products and the Precise Products. In the next two sections, these products will be presented in more detail and the latest scientific applications will be demonstrated. In 1994 and 1995, GFZ has undertaken two user polls among German and European users of altimeter data to search for their actual requirements concerning the products. A couple of new aspects result from this poll. It was emphasized that the common predefined produtcs are no longer accepted by the users and that they attach more importance on user-specific products, based on consistent, high-accurate and up-to-date geophysical correction models. These requirements will be met in the frame of the Envisat activities of GFZ as part of the German Processing- and Archiving Centre (D-PAC). The users will be able to select the final altimeter data products according to their specifications from a comprehensive and flexible structured databank system. For example, the recently launched gravity field mission CHAMP allows to access satellite orbits with unprecedented accuracy due to the improved gravity field determination. The processing system, which primarly is focussed on Envisat value-added altimeter products will be capable to handle all other present and future altimeter missions. An overview about the planned data product types for Envisat will be briefly presented in section 4, a more detailed summery is given in [1].

2. ERS-2 STANDARD ALTIMETER DATA PRODUCTS

As mentioned before, GFZ provides two types of altimeter geophysical data products for ERS-1 and ERS-2, the Quick-Look Products (QLOPR, QLOPC and SSHQL) and the Precise Products (SSH_S, SSH_L). As ERS-1 radar altimeter has already finished operating since June 1996, the following descriptions will be given only for ERS-2 Radar Altimeter which is active since April 1995, and has delivered continuous data for 5.5 years up to now. Nevertheless, GFZ has carried out a complete reprocessing of ERS-1 altimeter data in support of a 3-year mean sea level study from April 1992 to April 1995 [2].
Based on the standard ERS-2 Radar Altimeter Fast Delivery Product (ERS-2.ALT.URA), the Quick-Look Ocean Product (QLOPR), the Quick-Look Ocean Crossovers (QLOPC) and the Quick-Look Sea Surface Height Model (SSHQL) are available within 6 to 12 days after observation. QLOPR and QLOPC are produced on daily, SSHQL on a weekly basis, whereby a SSHQL contains data of one ERS-2 cycle (35 days). Based on the ERS-2 Radar Altimeter Ocean Product (ERS-2.ALT.OPR02) distributed by the French Processing and Archiving Facility for ERS (F-PAF), the Short Period Sea Surface Height Models (SSH_S) are generated cycle by cycle with a delay of around three months, depending on the processing time at the F-PAF. The Long Period Sea Surface Height Models (SSH_L) are produced half-yearly by accumulating of all data since launch.
The data upgrade process done by GFZ for ERS-2 altimeter data products consists of several steps. It implies the precise time correlation (QLOPR only), the computation and merging of tropospheric (QLOPR only) and ionospheric path delay corrections, the inclusion of solid Earth tide (QLOPR only), ocean tide and tidal loading and the application of additional altimeter range corrections (USO drift, SPTR correction). The dry and wet tropospheric correction are computed from daily meteorological files prepared by the British Processing and Archiving Facility for ERS (UK-PAF). The ionospheric correction is derived from the IRI95 ionosphere model [3]. The ocean tide and tidal loading are calculated from the Grenoble tide model FES95.2 [4]. It is also planned to implement the latest version of the Grenoble tide models, the FES98 [5]. For the Quick-Look Products the satellite position is interpolated from the GFZ Preliminary Orbit (PRL) [6]. For the Precise Products a time bias of +1.0 ms is applied and the satellite coordinates are interpolated from the GFZ Precise Orbit (PRC) [6]. Both GFZ orbit types are based on the gravity field model PGM055 [2,7]. A detailed description of the whole upgrade process is given in [8], the data flow chart for the Quick-Look Products is displayed in Fig.1.
As example of one of the standard ERS-2 altimeter products, three consecutive samples of SSHQL are illustrated in Fig.2. It should be noted that beside the interpolated sea surface height (SSH), each SSHQL contains the interpolated significant wave height (SWH), the wind speed and the SSH difference with respect to the previous SSHQL.

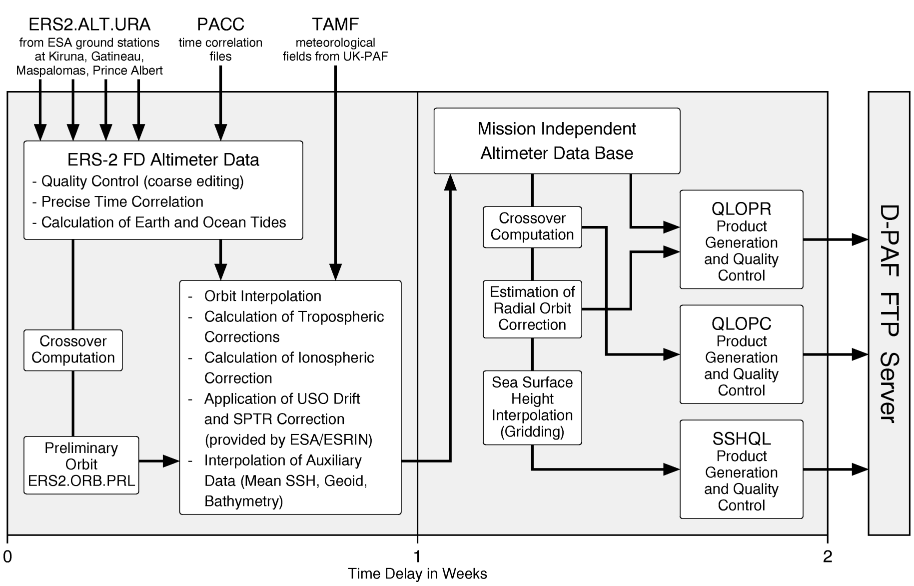

Fig. 1. ERS-2 Radar Altimeter Quick-Look Product Data Flow

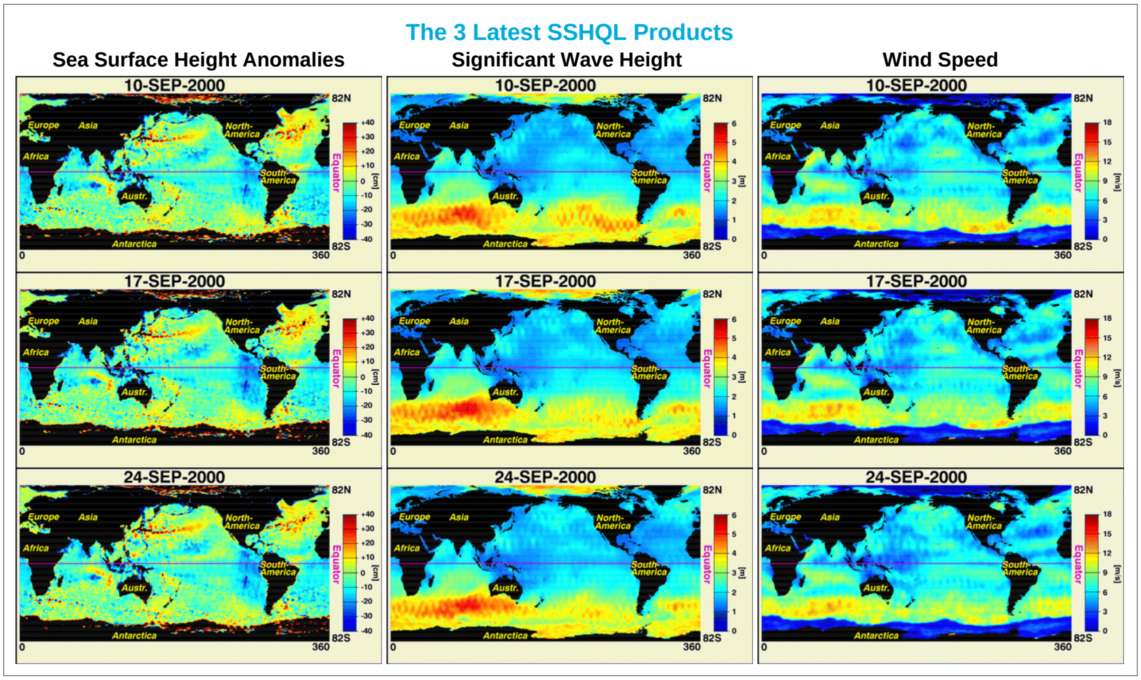

Fig. 2. SSHQL Product Samples

3. RECENT SCIENTIFIC APPLICATIONS FROM ERS-2 ALTIMETRY

Several scientific applications are obtained from the standard altimeter products, which GFZ operationally generates on behalf of ESA. In the following, two samples are presented, the monitoring of SSH anomalies in the Tropical Pacific and the illustration of time series of latitude mean values of SSH anomalies, SWH and wind speed in the North Atlantic and the North Pacific. In addition, a study was performed using a 2.5-year series of SSHQL from April 1998 to September 2000. Herein, mean and rms differences with respect to OSUMSS95 [9] were calculated, and compared by applying ionospheric corrections from different models.

Monitoring of SSH Anomalies

Fig.3 shows several plots of SSH anomalies in the Tropical Pacific (30°S to 30°N, 145°E to 70°W) derived from ERS-2 SSHQL with respect to a 1996 mean sea surface model calculated from ERS-2 QLOPR. In the two columns the events from 1997/98 and 2000 are compared. The left column clearly exhibits positive SSH anomalies up to +40 cm, which come from the 1997/98 El Niño event. The contrary situation is given in the right column, negative anomalies around -30 cm can be seen which express the changed conditions related to La Niña.

Time Series

Based on ERS-2 SSHQL, latitude mean values of SSH anomalies (with respect to OSUMSS95), SWH and wind speed are represented in Fig.4. Latitude means were computed for the North Atlantic between 90°W and 0°, and for the North Pacific between 120°E and 120°W. For SWH and wind speed latitude means, the annual variations are obvious, however, for the SSH anomalies the patterns are divergent. In the North Atlantic irregular striking positive anomalies between 20°N and 60°N are visible at the end of 1999 which could indicate an anomalous behaviour of the Gulf Stream. Alternating situations are illustrated by the SSH anomalies in the Tropical Pacific primary between 5°N and 15°N which clearly show the sea level variations connected with the El Niño Southern Oscillation (ENSO).

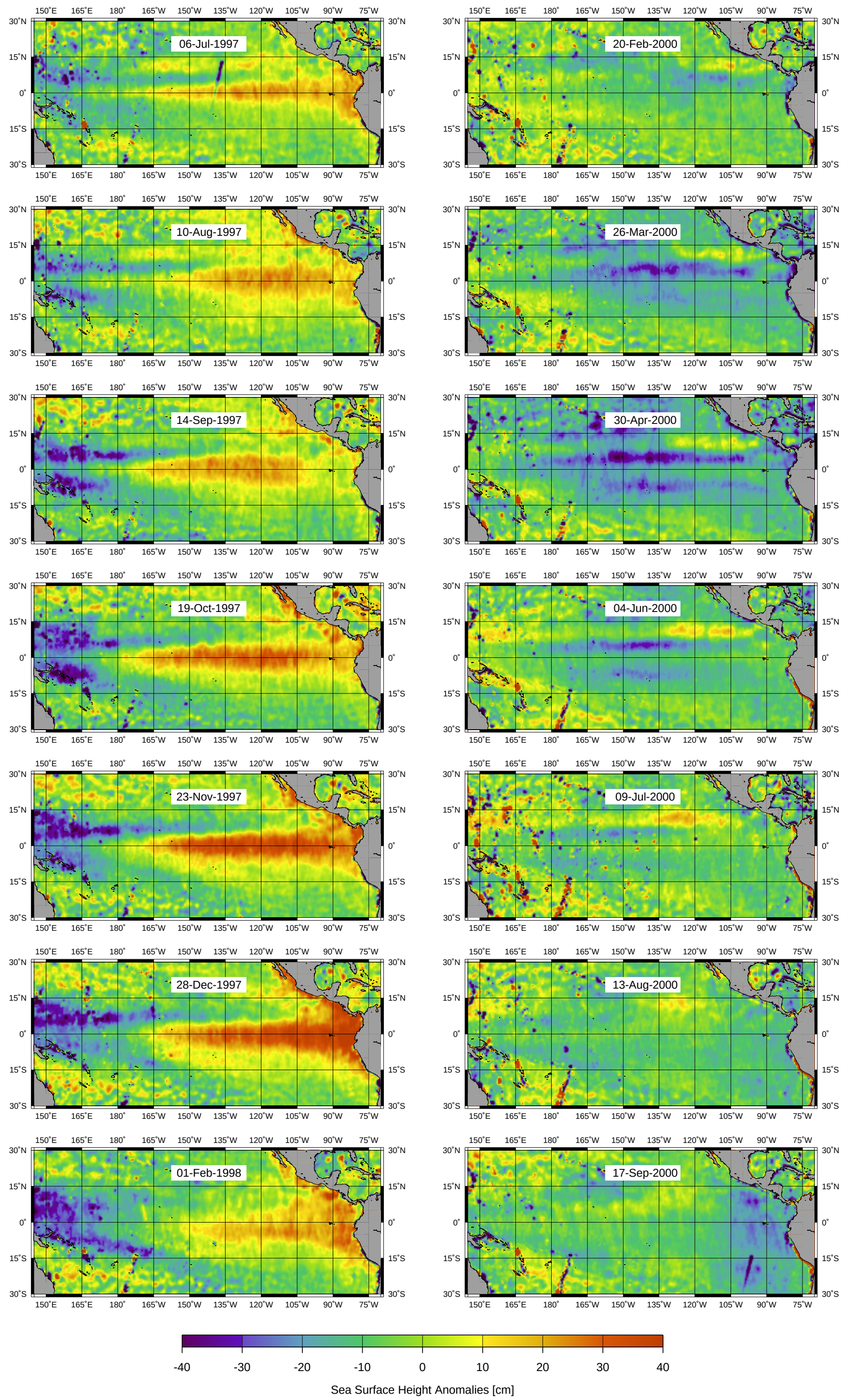

Fig. 3. SSH anomalies in 1997/98 and 2000 in the Tropical Pacific with respect to a 1996 mean sea surface. An El Niño event has developed in 1997, clearly visible in the left column as positive anomalies up to +40 cm. After nearly 3 years (see right column), these anomalies have turned into negative anomalies up to -30 cm coming from La Niña in 2000.

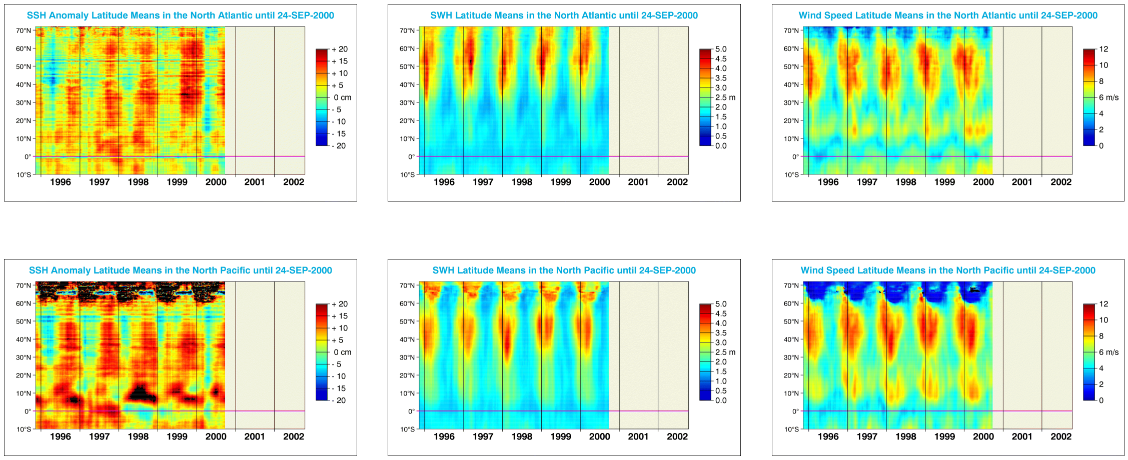

Fig. 4. Latitude means of SSH anomalies, SWH and wind speed in the North Atlantic between 90°W and 0° and in the North Pacific between 120°E and 120°W.

Case study SSHQL - IRI95 against CODG

As already mentioned, the generation of SSHQL is based on ERS-2 QLOPR (see Fig.1). According to the requirements set by ESA concerning the concistency of the standard altimeter products, the satellite orbit and the geophysical altimeter range corrections are fixed for the lifetime of ERS-2. However, just for the SSHQL, GFZ tries to improve the product quality, e.g. by refining the editing criteria and by enhancing the interpolation procedure [10]. For the case study, a 2.5-year series of SSHQL has been reprocessed. In this context it must be noted, that the software version by which the ERS-2 fast delivery data are generated at the ESA receiving stations, has been modified significantly on November 29, 1998. Hence, the wet tropospheric correction was derived from ERS-2 Microwave Radiometer (MWR) measurements, and the editing criteria for the standard deviation of the altimeter ranges had to be aligned.

31 SSHQL were generated between May 3, 1998 and November 29, 1998 and 90 SSHQL between January 3, 1999 and September 17, 2000. First, the SSHQL have been calculated by applying the ionospheric correction based on the IRI95 ionosphere model, which is the standard case. Second, the SSHQL were processed by taking the ionospheric correction derived from Global Ionospheric Maps (GIM) which the Center for Orbit Determination in Europe (CODE), located at the University of Berne, routinely generates on daily basis as one product within the automatic IGS (International GPS Service) data processing [11]. The final CODE GIM, in the following described as 'CODG', are available via anonymous ftp within about 3 days after observation. Herein, the Total Electron Content (TEC) is modeled with a spherical harmonic expansion up to degree 12 and order 8 referring to a solar-geomagnetic reference frame. The 12 2-hour sets of 149 ionosphere parameters per day are derived from GPS data of the global IGS network.

By this case study, it should be checked if the SSHQL product quality will benifit from the application of the ionospheric correction rather coming from GPS measurements than from the IRI95 model. Therefore, for each SSHQL the mean and rms differences with respect to OSUMSS95 were calculated. In the view of the high solar activity in 2000 (see http://www.aiub.unibe.ch/ionosphere/meantec.gif) better

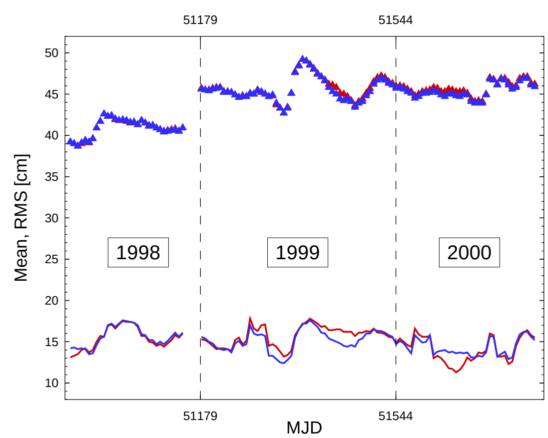

Fig. 5. SSHQL mean (below) and rms (above) differences with respect to OSUMSS95. The ionospheric correction is derived from IRI95 (red) and CODG (blue).

results could be expected from the ‘measured' CODG models than from the IRI95 model. The results are illustrated in Fig.5. Concerning the rms differences, a slight improvement can be identified by applying CODG ionospheric correction in comparison with IRI95, from the end of 1999 onwards. The jump in the rms differences at the end of 1998 is correlated with the mentioned software update and is under investigation.

4. ENVISAT VALUE-ADDED OCEAN/ICE PRODUCTS

The Envisat ESA standard products for orbit and radar altimetry (DORIS, RA-2/MWR) are provided by the French Processing and Archiving Centre (F-PAC) and are only available as Level 1b and Level 2 products. Based on these products, GFZ in cooperation with the German Processing and Archiving Centre (D-PAC), has developed a processing system for the generation and distribution of Envisat RA-2 value-added geophysical data products, which are essential for applications in geodesy, geophysics, oceanography, glaciology and environmental research. In 1994, GFZ has initiated a user poll among 22 German user groups, and in 1995, has participated in a study leaded by the Centre for Earth Observation [12], in which 90 institutes and reaserch facilities have been interviewed. The results of these inquiries have shown that the ESA standard products do not fulfill the requirements for specific applications. Thus, a generation of high-quality products was strongly desired especially by the German altimeter data users which are in many cases not well equipped with convenient processing systems. GFZ will meet the requirements primary in the frame of the Envisat mission and will provide geophysical ocean and ice data products for free access [1]. Although the user will find at least one standard product in each of the proposed 8 product groups [13], the main attention is focussed on the user-specific products which are an enormous improvement with respect to the ERS-2 altimeter products.

5. CONCLUSIONS

In a brief summery, all GFZ activities within the frame of the D-PAF were presented. The operational processing of altimeter geophysical data products on behalf of ESA based on the standard ERS-2 Radar Altimeter data was reflected. Recent scientific applications (monitoring of SSH anomalies, time series) from these products were shown, by emphasizing the efforts done by GFZ regarding the upgrade procedure of the original altimeter data. A case study on SSHQL has checked the implication of ionospheric corrections coming from different sources (IRI95, CODE GIM) on the product quality.
In the Envisat era, various new developments will be undertaken by GFZ to enhance altimeter product generation and user services. It can be expected that the reasearch activities at GFZ will also benifit from the new achivements resulting from the more demanding requirements of the altimetry user community.

6. ACKNOWLEDGEMENTS

We thank Stefan Schaer for providing the access software for CODE GIM, and Dieter Bilitza for the IRI95 ionosphere model. The FES tide models were provided by Christian Le Provost and his group. ERS-2 Ocean Product data were supplied by the F-PAF, the meteorological files were provided by the UK-PAF. Some of the color plots were generated using the Generic Mapping Tools (GMT) software package [14].

7. REFERENCES

[1] A. Braun, S. Eickschen, A. Helm, C. Reigber, M. Rentsch, and T. Schöne, “The ENVISAT RA-2 Value-Added Ocean/Ice Processor at GFZ Potsdam”, *this issue*, 2000.

[2] M. Anzenhofer and T. Gruber, “Fully reprocessed ERS-1 altimeter data from 1992 to 1995: Feasibility of the detection of long term sea level change”, *Journal of Geophysical Research*, vol. 103, pp. 8089-8112, 1997.

[3] D. Bilitza, “International reference ionosphere - status 1995/96", *Advances in Space Research*, vol. 20, pp. 1751-1754, 1997.

[4] C. Le Provost, F. Lyard, J.M. Molines, M.L. Genco, and F. Rabilloud, “A hydrodynamic ocean tide model improved by assimilating a satellite altimeter-derived data set”, *Journal of Geophysical Research,* vol. 103, pp. 5513-5530, 1998.

[5] F. Lefèvre, F.H. Lyard, and C. Le Provost, “A new global tide finite element solution independent of altimetry”, *Geophysical Research Letters,* vol. 27, pp. 2717-2720, 2000.

[6] F.-H. Massmann, C. Reigber, R. König, J.C. Raimondo, C. and Rajasenan, “ERS-1 Orbit Information provided by D-PAF”, *Proc. 2nd ERS-1 Symp. on Space at the Service of our Environment (ESA SP-361, 2 vols)*, vol. 2, pp. 765-770, 1994.

[7] T. Gruber., A. Bode, C. Reigber, and P. Schwintzer, “D-PAF Global Earth Gravity Models Based on ERS”, *Proc. 3rd ERS Symp. on Space at the Service of our Environment (ESA SP-414, 3 vols.),* vol. 3, pp. 1661-1667, 1997.

[8] T. Gruber, M. Anzenhofer, and M. Rentsch, “Improvements of D-PAF Altimeter Products”, *Proc. 3rd ERS Symp. on Space at the service of our Environment (ESA SP-414, 3 vols.),* vol. 3, pp. 1749-1752, 1997.

[9] Y. Yi, “Determination of gridded mean sea surface from TOPEX, ERS-1 and GEOSAT altimeter data”, *Report No. 434, Dept. of Geodetic Science and Surveying, The Ohio State University, Columbus, Ph.D. thesis*, 1995.

[10] M. Anzenhofer, and T. Gruber, “MSS93A: A new stationary sea surface combining one year upgraded ERS-1 fast delivery data and 1987 GEOSAT altimeter data”, *Bulletin Géodésique*, vol. 69, pp. 157-163, 1995.

[11] S. Schaer, “Mapping and Predicting the Earth's Ionosphere Using the Global Positioning System"' *Astronomical Institute University of Berne, Ph.D. thesis,* 1999.

[12] Joint Research Centre (CEO) “Collect User Requirements from Experimental User Community on Marine Altimetry - Technical Evaluation, Final Report”, CLS Toulouse, France, 1995.

[13] Product Specification Document - Value-Added Ocean/Ice Products, ENV-GFZ-PSD-VAO-3400-0001, Issue 1.0, GeoForschungsZentrum Potsdam, 1999, unpublished.

[14] P. Wessel and W.H.F. Smith, “New Version of the Generic Mapping Tools Released”, *EOS Transactions AGU,* vol. 76, p. 329, 1995.