Improvements of D-PAF Altimeter Products

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Abstract

At D-PAF, quick-look altimeter products, based on ERS fast delivery data, and high level geophysical products, based on OPR data are operationally generated. Since launch of ERS-2, quality of all of these products has been increased significantly by incorporating reprocessed orbits and additional altimeter range corrections, which are not included in F-PAF's precise OPR altimeter data.
The paper describes in detail the upgrading procedure of ERS-1 altimeter data and demonstrates that their quality is comparable to the Topex geophysical data records. The quality of the D-PAF quick-look (QLOPR, SSHQL) and precise products (SSH, OGE, TOP) is shown in some examples, like Eddy tracing using weekly ERS-2 quick-look sea surface models, and a sea level study using 3 years reprocessed ERS-1 OPR data. Both samples indicate that with ERS altimeter data even signals in the millimeter range can be detected, if all available corrections are applied. After completion of the ERS-1 mission, a consistent 4 years time series of upgraded altimeter products is available. Because ERS-2 data run through the same upgrading chain, soon additional overlapping and new altimeter data is processed. Thus, by combination of both missions a time series over more than 5 years can be used to continue the monitoring of the ocean surface.

All D-PAF products mentioned above can be ordered via the ERS User Desk.

Keywords: Altimetry, ERS, Sea Level, D-PAF, QLOPR, SSH

Content:

1. Introduction

D-PAF operationally is generating geophysical altimeter products based on fast delivery and precise altimeter data. During the last years, quality of all of these products could be increased significantly, due to a higher quality of incoming data, a higher quality of available orbits and a reprocessing of different altimeter corrections. All actual products are based on additionally corrected altimeter ranges, which are necessary due to hardware anomalies and the oscillator drift.

D-PAF altimeter products can be separated into two classes. The first class consists of the so-called quick-look products, namely the Quick-Look Ocean Products (QLOPR), Quick-Look Ocean Crossovers (QLOPC) and Quick-Look Sea Surface Height Models (SSHQL). They are all based on ERS fast delivery altimeter data and the preliminary orbit . Further-on, all atmospheric path delay corrections, the tidal corrections and the ranges are recomputed and upgraded. The second lass consists of the precise geophysical products, as Sea Surface Height Models (SSH), Ocean Geoid Models (OGE) and Sea Surface Topography Models (TOP), which are based on F-PAF's precise ERS altimeter geophysical data records and D-PAF's precise orbits. All ERS geophysical data records from F-PAF were systematically updated with new precise orbits, new tidal models, ionospheric corrections and additional altimeter range corrections.

This reprocessed ERS-1 data currently represents the best and most consistent data set. It was used at D-PAF for different applications, i.e. a sea level study (see chapter 3.1), sea surface variability investigations and altimetric gravity anomalies computation. To provide a consistent time series of sea surface height models to all ERS users, the historic SSH models have been reprocessed with this updated data set. Such a high quality series of sea surface models can contribute to many open questions in the global change frame. From the experiences with this upgraded data set and the necessity to provide on one hand long-term consistent models for global change research, and on the other hand near real time highly precise geophysical data records for short term investigations and forecasts, the idea of new products was born.They are presented in chapter 4 and will be realized shortly after the ERS symposium in 1997.

2. Data Upgrade and Products

This chapter provides some details on the data upgrade, which is operationally done at D-PAF for the fast delivery data to quick-look ocean products (QLOPR) and for the precise altimeter data (OPR). The second part provides an overview of all D-PAF altimeter product, their current revisions and the available time periods of consistent products.This helps the users to combine only consistent data sets and products for their applications.

2.1 Data Upgrade (QLOPR, OPR)

For each parameter it is indicated in parenthesis, if it was applied for generation of QLOPR from fast delivery data and/or for OPR data upgrading.

Time Bias Correction (OPR): For ERS-1 OPR data it is known from analysis of various groups (Anzenhofer et al, 1996; Benveniste, 1996a), that a time tagging error is in the data. To estimate the time bias, the method described by Marsh and Williamson (1982) was used, which relates the crossover differences and the range derivative differences between ascending and descending arcs with the time bias. Another method to estimate the timing error is to use altimeter data (crossovers or ranges) in the orbit determination. There, the altimeter times are fixed to the very precise timing of the laser tracking data. After an extensive analysis with both methods over a 3 years analysis period, a time bias of **+1.5 msec** in the ERS-1 OPR altimeter data was identified and added to the original times. For ERS-2 a time bias of **+1 msec** was identified from an analysis of a number of cycles, and also added to the original altimeter measurement times. In order to apply the time bias correctly, all orbits had to be interpolated again, because they are timely correlated with altimeter measurements.

Precise Time Correlation (QLOPR): The UTC times in the ERS fast delivery data (URA) have millisecond errors due to the quick processing. For each Kiruna overflow, a time correlation between the satellite binary time and the correct UTC time on the station is calculated. These time correction terms are provided via ESRIN to D-PAF, where it is applied to each fast delivery altimeter record. For the other ground stations the table is extrapolated, because there is no capability to perform the time correlation there (Anzenhofer, 1995).

Orbit (QLOPR,OPR): For **QLOPR** the operational **preliminary orbit** is interpolated to fast delivery altimeter records, which do not contain any geographical information. Radial accuracy of these orbits is around 10 cm. All ERS-1 and ERS-2 **OPR version 6** data from F-PAF already contains the most recent **precise orbits (revision 2)** from D-PAF, with a radial accuracy of better than 8 cm. To take into account the time bias, all orbits were remerged into the data set (see above). F-PAF will not reprocess OPR data before the second multidisciplinary phase (21-March-1995), despite reprocessed and consistent precise orbits from D-PAF are available for the complete ERS-1 mission. For all ERS-1 **OPR version 3** products from launch to 20-March-1995, newly processed **precise orbits (revision 2)** were interpolated and included.

Altimeter Range (QLOPR,OPR): Corresponding to the OPR documentation, altimeter ranges are corrected for all instrumental effects. During the cross-calibration of the ERS-2 altimeter against the ERS-1 altimeter it was found, that two additional corrections have to be applied to the altimeter ranges (Benveniste J, 1996a, 1996b). These corrections are caused by the drift of the on-board ultrastable oscillator (USO drift), which causes an increasing range error with time, and by an internal timing error, which causes range jumps. The reason for the jumps are changes in the clock asymmetry, which are caused by low temperatures occurring during the switch-off of the instrument after instrument anomalies. The error can be quantified from the single pulse target response internal calibration data (SPTR), to correct the measured range. This so-called SPTR correction, which reaches values up to ±2 cm, is operationally computed by ESRIN. A critical element of the radar altimeter instrument is the USO drift, which causes a steady decrease of the ranges. For the ERS satellites, the USO frequency is measured on ground during all passes over the Kiruna ground station (9 or 10 of 14 passes per day). The frequency is then directly recoverable on-ground from the real-time bit-synchroniser on the ground station and comparable with an atomic frequency standard. This correction is operationally estimated by ESRIN. Both additional corrections are shown in figure 1, where the curvatures represent the SPTR and USO drift corrections for the complete ERS-1 mission. A similar table is available for the ERS-2 radar altimeter. Both terms have to be subtracted from the original ranges. For **QLOPR** processing as well as for **OPR** upgrading both **additional range corrections** are applied. This ensures compatibility of all precise products, which for example is necessary for sea level studies.

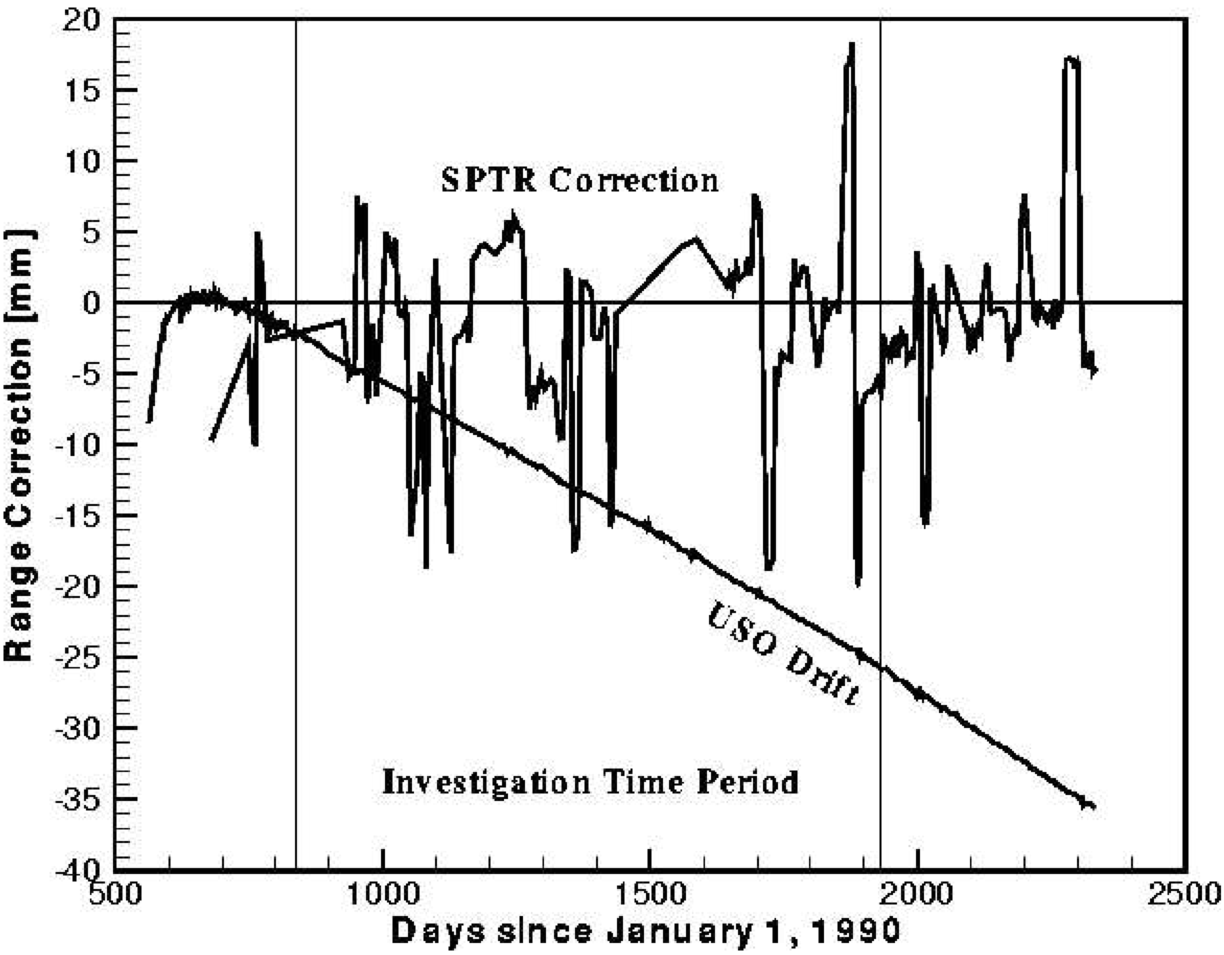

Figure 1: ERS-1 Altimeter Range Corrections Applied to QLOPR and OPR Records

Ionospheric Path Delay Correction (QLOPR,OPR): The ERS1 altimeter is a single frequency instrument and cannot measure the ionospheric path delay from dual frequency range measurements. Therefore the ionospheric correction must be computed from ionospheric models. At D-PAF, the new International Reference Ionosphere Model from 1995 (IRI95) (Bilitza, 1996) was implemented and merged into **QLOPR** and **OPR**. The International Reference Ionosphere is a project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). IRI95 is an empirical standard model of the ionosphere, based on all available data sources, which mainly are the worldwide network of ionosondes, the scatter radars, the ISIS and Alouette topside sounders, and in-situ instruments on several satellites and rockets. IRI95 describes, beside others the electron density in the altitude range from about 50 km to about 2000 km. The model inputs are the solar and ionospheric indices (IG12, Rz12) and the CCIR and URSI coefficient files for the global representation of F2 peak height and critical frequency. The ionospheric path delay correction then is calculated for each altimeter measurement from the total electron content, which is computed by integration of the electron density at different levels up to the satellite height. Using the IRI95 model instead of the 1990 solution (IRI90), better results have been be reached in terms of crossover difference statistics.

Tropospheric Path Delay Corrections (QLOPR): In the original fast delivery data the dry tropospheric correction is interpolated from look-up tables, while the wet tropospheric correction is set to a constant value of -10 cm. For recomputing both corrections, actual surface temperature, surface pressure and integrated water vapor along ERS tracks are necessary.They are generated by UK-PAF using the global weather analysis information files from the European Center for Medium Range Weather Forecast (ECMWF). UK-PAF daily receives 4 surface data sets (mean sea level pressure, 2 m air temperature, 2 m dew-point temperature, cloud cover) produced at 0, 6, 12 and 18 UTC and 2 upper-air data sets (geopotential height, temperature, relative humidity) produced at 0 and 12 UTC from ECMWF. All data sets are given on a 1.5 degree global grid. They are analyzed by UK-PAF, which produces one output file for each day containing surface pressure, surface air temperature intergrated water vapor and UTC time along the sub-satellite track for every 5 seconds. These daily files are sent to D-PAF, where they are used for tropospheric corrections computations. For each altimeter measurement time all three meteorological components are linear interpolated.

Ocean Tide and Loading Correction (QLOPR,OPR): For elastic ocean tides and loading effects the recent **FES95.2.1** model (Le Provost et al, 1996) is included in the **QLOPR** and **OPR** data sets (for version 6 OPR it is already done at F-PAF).This model is based on the purely hydrodynamic solution FES94.1, produced on the basis of the finite element model (Le Provost et al, 1994). This altimetry independent solution was generated to provide a completely independent tide model to the altimeter user community. Comparison of FES94.1 to empirical TOPEX/POSEIDON solutions showed large scale errors in the hydrodynamical model in the order of up to 6 cm in the M2 wave. Therefore, the FES94.1 model was updated by assimilating into the hydrodynamic model the earlier empirical TOPEX/POSEIDON CSR2.0 tidal solution (Shum et al, 1996) from the University of Texas in Austin. The FES95.2.1 model represents a major improvement with respect to the Schwiderski model used in version 3 OPR and older QLOPR versions.

Summary: Table 1 summarizes the current data upgrade for QLOPR and OPR. It is apparent that in version 6 OPR products, F-PAF is already including the actual tide model, the precise orbit and is performing the precise time correlation. But this data is not corrected for the additional range corrections, which are absolutely necessary for quasi all applications.

Data	Time Bias	Time Correlation	Rev. 2 Orbit	Range Corrections	IRI95 Ionosphere	Tropospheric Correction	FES95.2.1 Tide Model
ERS-2: FD to QLOPR	-	+	+	+	+	+	+
ERS-1: OPR Version 3.X	+	-	+	+	+	-	+
ERS-1/2: OPR Version 6.X	+	-	-	+	+	-	-

Table 1: Summary of D-PAF Data Upgrading (+ means upgrade by D-PAF, - means upgrade already done by F-PAF)

2.2 Products

The following table provides an overview of the current revisions of all D-PAF altimeter products. Planned products are marked in red and will be described more detailed in chapter 4. Start date means the date, when the current product revision has been started. These products are consistently processed for both missions (ERS-1 and ERS-2) and can be combined.

Product	Description	Revision	Start Date
QLOPR	upgraded fast delivery data (new orbit, tides, ionosphere and troposphere, time corrections, range corrections); for details see previous chapter; daily product; delay 2 weeks	6	28-Apr-1996
QLOPC	cross-over differences for sea surface heights, wave heights and wind speeds from QLOPR data; daily files; delay 2 weeks	6	28-Apr-1996
SSHQL	global 15'x15' grid of sea surface heights, wave heights, wind speeds from last 35 days (repeat cycle) QLOPR; weekly model; delay 2 weeks	6	28-Apr-1996
RapidOPR	upgraded fast delivery data (new orbit, tides, ionosphere and troposphere); for details see chapter 4; daily product, delay 1 day	-	1997
SSH__L	stationary sea surface height model (6'x6') based on all available OPR data since launch	3	14-Apr-1992
SSH__S	short period (cycle) sea surface height model (15'x15') based on one cycle of OPR data.	3	14-Apr-1992
SSH__M	monthly sea surface height model with reduced resolution (30'x30') designed for sea surface time series analysis (chapter 4)	3	14-Apr-1992
OGE	ocean geoid model based on stationary sea surface height model	3	14-Apr-1992
TOP	stationary sea surface topography model based on stationary sea surface height model	3	14-Apr-1992

Table 2: Current and Planned D-PAF Altimeter Products

3. Samples of Product Applications

3.1 Sea Level Analysis

Global sea level observations are necessary to answer the urgent questions about climate changes and their impact on the socio-economy. Trends in the sea level are considered as indicators of a global temperature rise caused by the increase of greenhouse gases. Between 1 and 4 degree can be expected for the next century. If this happens, the sea level will rise between 30 to 50 cm, caused by the melting of glaciers and polar ice caps and thermal expansion of the oceans. A three years time series of upgraded OPR was taken to estimate the rate of change of global mean sea level (April 1992 to March 1995). A +2 mm sea level rise per year was estimated, which is far below the assumed 30 to 50 cm in the next century. Regional characteristics, however, show extreme differences in the sea level variations (figure 2). A sea level rise in the tropics and the Indian ocean (locally up to 10 cm/year), but a sea level fall in the Eastern Pacific and higher latitudes. Investigations of sea surface temperatures, wind speeds and wave heights exhibited global positive trends, too. But, their local characteristics made an interannual period apparent .

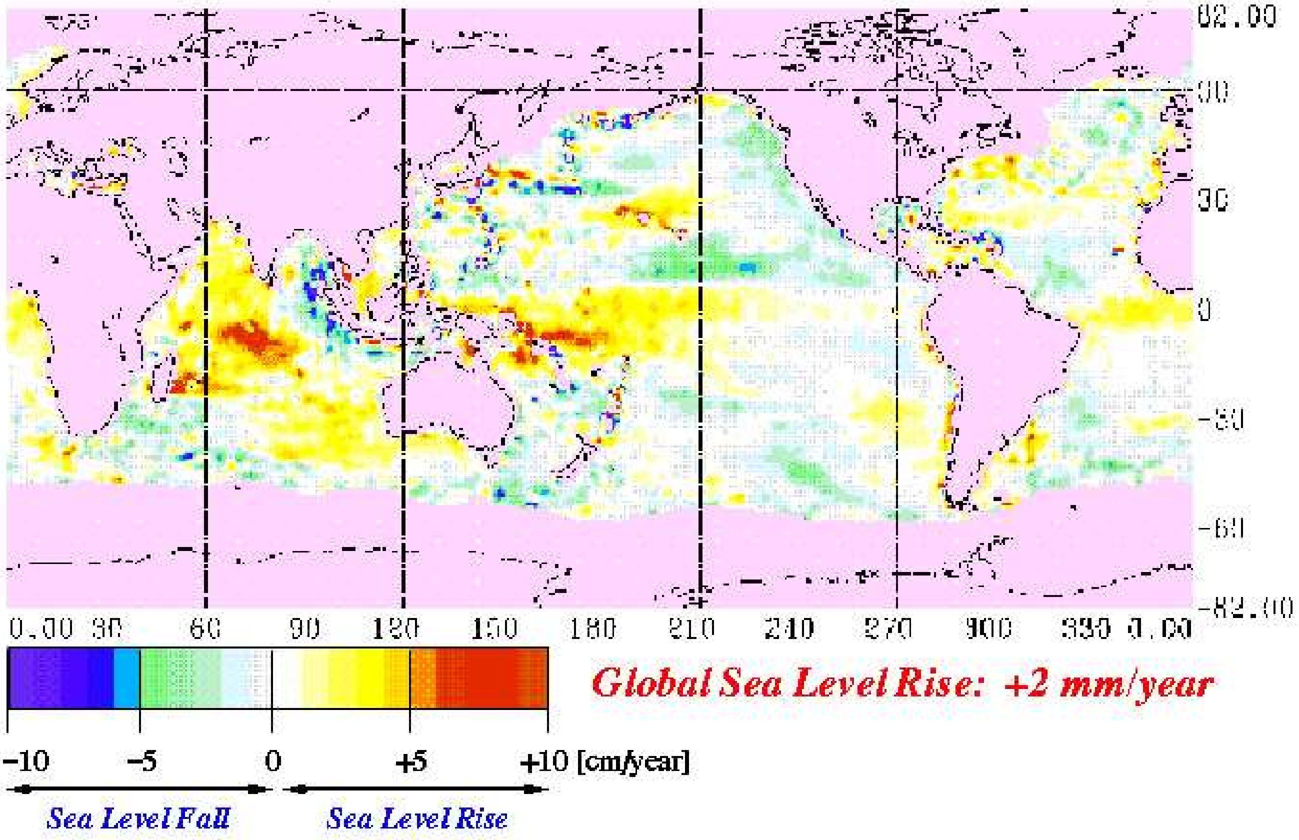

Figure 2: Regional Sea Level Trend from 3 Years Reprocessed ERS-1 Data (4-92 to 3-95)

3.2 Eddy Tracing

The Agulhas Current of the Indian Ocean flows as a western boundary current along the Southeast coast of Africa. At around 36 S it separates from the shelf and turns eastward in a great anticyclonic loop, named the Agulhas retroflection. Periodically the loop can pinch off, forming a ring which is ejected into the South Atlantic ocean. These anticyclonic rings or eddys have been tracked by altimetry between 20 - 30 S in the South Atlantic, reaching to at least 30 W, with drift rates of 5-8 cm/s (Duncombe Rae, 1991).

In order to show that these eddys can be traced with D-PAF quick look altimeter data, one year (10.02.96 - 27.01.97) of ERS-2 SSHQL's have been analyzed between 25 - 31 S and 2 E - 44 W. Figure 3 is a combination of time-latitude diagrams at different longitudes. Because anticyclonic eddys have a positive SSH-deviation compared to the background signal, the picture shows only positive anomalies, with a one year mean removed. It is apparent, that six eddys have been identified, drifting with 5.1 - 6.7 cm/s to the South American coast. The eddys have positive anomalies up to 21 cm and some are visible during the full time span. The different amplitudes of certain eddys during the observation are a result of the sampling, because the satellite track does not always hit the maximum of the eddy. As the eddys move almost only westward, they are believed to be absorbed by the southward going Brazil current at the western boundary.

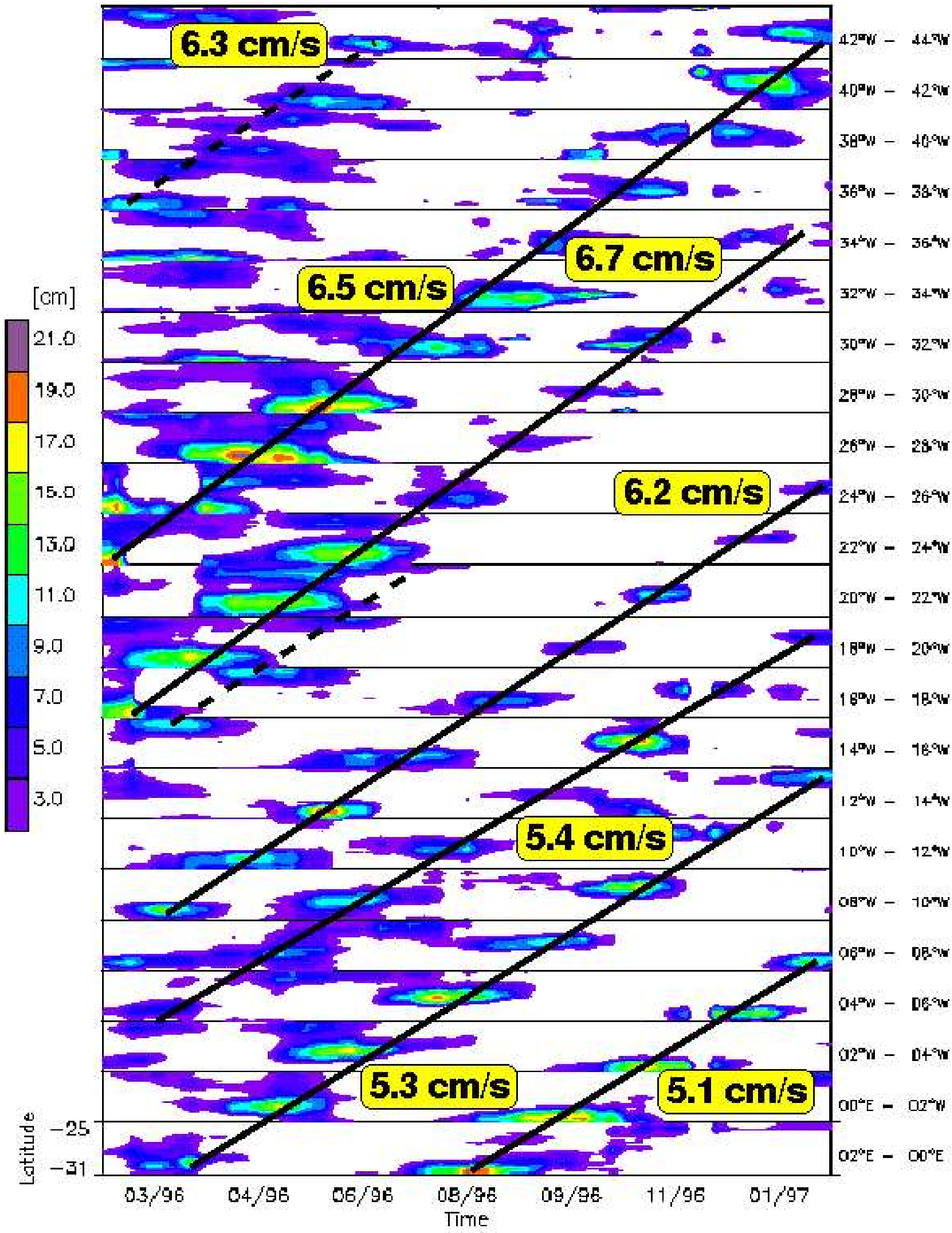

Figure 3: Agulhas Eddys in the South Atlantic as Seen by ERS-2 SSHQL's

4. Plans for New Products

In order to complement the product palette, two additional altimeter products are planned at D-PAF for the near future. Their characteristics are already described in table 2.

SSH__M: Monthly sea surface height model with 30'x30' minutes spatial resolution, consistently processed for multidisciplinary and geodetic phases of ERS-1 and ERS-2. This additional sub-product of the SSH family enables the user to analyze sea surface time series. For example, global and regional changes in the sea surface have been estimated by this product (see chapter 3.1). Especially the monthly time framing improves the correlation of the models with seasonal phenomena, which are not so easy to extract from the short period sea surface height models (SSH__S) due to their cycle base.

ROPR: Rapid Ocean Products based on upgraded fast delivery data with a delay of 1 day. This quasi real time altimeter product provides geophysical data records based on range measurements from fast delivery data (URA) with new orbit information, tides, ionospheric and tropospheric corrections. The orbit, which is, next to the range the most important parameter for using altimeter data, is generated from PRARE range and Doppler and laser tracking data (Bedrich et al, 1997). This is the first time that an orbit based on real data with an accuracy of better than 20 cm is available within less than 1 day. For example, for NOAA ERS-2 real-time altimeter products (Lilibridge et al, this issue) the Delft University JGM-3 predicted orbits with an accuracy about 1 meter are included. For tides the FES95.2.1 model (like in OPR and QLOPR) is used. Ionospheric correction is recomputed from the IRI95 model and wet troposphere is computed from monthly meteorological maps. The product completes the sequence of geophysical data record levels, starting from this near real time products, over quick-look products (QLOPR) with a delay of 2 weeks to precise products (OPR) after some months.

5. Conclusions

The paper summarizes the data upgrade for the current revision of D-PAF quick-look products (Quick-Look Ocean Products and Crossovers, Quick-Look Sea Surface Height Models). Also the final altimeter product (OPR) from F-PAF run through an additional processing chain, to take into account time and range corrections, which are not included in this product. Older ERS-1 revision 3 data were upgraded additionally by inclusion of the FES95.2.1 tide model and the completely consistent reprocessed PGM055 precise orbits. By this method a consistent time series of ERS-1 data from April 1992 to the end of the mission (June 1996) was generated. All SSH products for ERS-1 have been reprocessed from this data to generate a consistent series, which can be used for high precision altimetric applications. Two applications show the high quality of these consistently processed products. First, a sea level analysis based on 3 years monthly sea surface height models (April 1992 to March 1995) is presented. The results indicate a global sea level rise of +2 mm/year for the analysis period. Second, ERS-2 quick-look sea surface height models were used for eddy tracing in the South Atlantic. Results show that even such quick-look products (SSHQL), which are not processed with the final altimeter data set, can be used for such analysis. The weekly SSHQL products are suitable for sea surface variability analysis due to their specific characteristics.

Finally from the experiences with the other D-PAF products, two planned products are presented. First, the monthly sea surface height models with reduced spatial resolution are described. Second, the near real time ERS-2 altimeter product is presented. From the experiences of D-PAF staff with PRARE operations and the orbit and altimeter products, this new product was designed. This product is available 1 day after data acquisition with a 20 cm and better Prare and laser orbit, recomputed tides and atmospheric path delay corrections. It represents a major step to high quality real-time altimetry, which is necessary for real time ocean surface modeling (e.g. Tsunami detection).

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