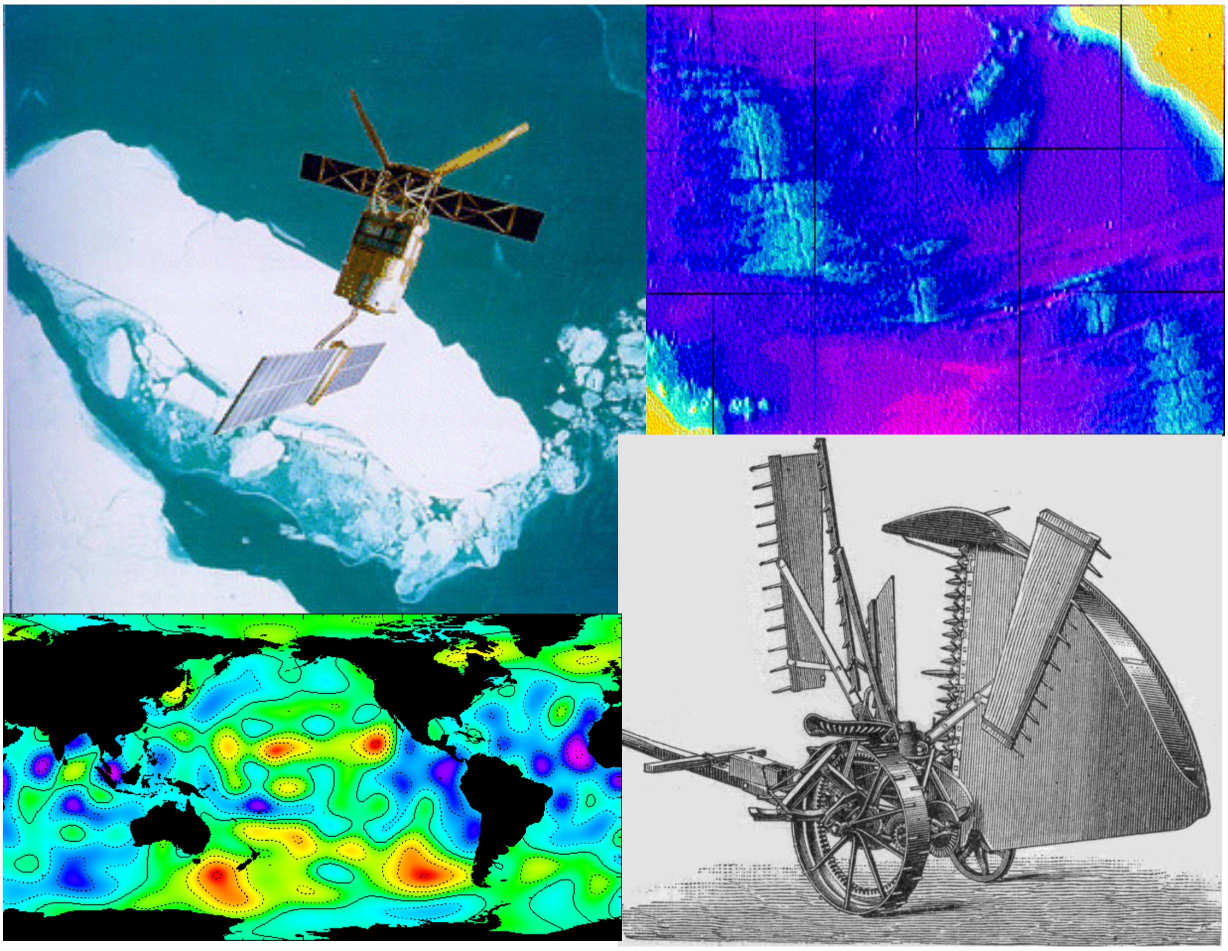
Reprocessing of Altimeter Products for ERS

REAPER



RA L2 Validation Report

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Document Change Record

Version	Date	Updated by	Reason
1.0	31/01/13	RS	Draft
1.1	22/05/13	RS	Update to REAPER v01.04
1.2	27/05/13	RS	More information of geophysical corrections
1.3	11/07/13	RS	Applied PTR and orbit fixes off-line
2.0	12/04/14	RS	Update to REAPER v01.07
2.1	14/04/14	RS	Minor updates to reflect discussions
3.0	14/07/14	RS	Update to REAPER v01.08 (final) Include orbit/range quality flagging deliverable
3.1	23/07/14	RS	Corrected false comment on non-equilibrium tides

Contents

1 Introduction

1.1 Scope

This document provides a validation of the REAPER reprocessed products for ERS-1 and ERS-2. The document has gone through several revisions as the L1b and L2 processing were updated. Please refer to Section 2 of this document for a description of the data analysed in this context.

1.2 Document Overview

Section 1 provides a brief introduction to this document.

Section 2 describes the data used for the validation.

Section 3 gives an extensive analysis of the data.

Section 4 describes the construction of the sea state bias models.

Section 5 lists issues concerning the file format and content of the REAPER RA products.

1.3 Applicable And Reference Documents

AD1 REAPER Product Specifiction. REA-IS-PSD-5001, issue 1.8, 17-Jul-2012.
R1 B. Eaton et al. (2011). NetCDF Climate and Forecast (CF) Metadata Conventions
R2 NOAA (1995). COARDS Conventions for the standardization of NetCDF files
R3 Scharroo, R., and W. H. F. Smith, A global positioning system-based climatology for the total electron content in the ionosphere, *J. Geophys. Res.,* 115(A10318), doi:10.1029/2009JA014719, 2010.
R4 Wahr, J. M., Deformation of the Earth induced by polar motion, *J. Geophys. Res.,* 90(B11), 9363–9368, doi:10.1029/JB090iB11p09363, 1985.
R5 Scharroo, R., and J. L. Lillibridge, Non-parametric sea-state bias models and their relevance to sea level change studies, in Proceedings of the 2004 Envisat & ERS Symposium, Eur. Space Agency Spec. Publ., ESA SP-572, edited by H. Lacoste and L. Ouwehand, 2005.
R6 Scharroo, R., J. L. Lillibridge, W. H. F. Smith, and E. J. O. Schrama, Cross-calibration and long-term monitoring of the microwave radiometers of ERS, TOPEX, GFO, Jason, and Envisat, Mar. Geod., 27(1- 2), 279–297, doi:10.1080/01490410490465265, 2004.

1.4 Acronyms And Abbreviations

AltiLLC	Abbreviation of 'Altimetrics LLC'
CF	Climate and Forecast
CLS	Collecte, Localisation, Satellites
CNES	Centre Nationale d'Études Spatiales
COARDS	Cooperative Ocean/Atmosphere Research Data Service
COMx	Commissioning Phase Product
DTU	Danish Technical University
EBM	Extra Backup Mode
ECMWF	European Centre for Medium-range Weather Forecasts
ERA	ECMWF Reanalysis
ERS-1/ERS-2	European Remote-sensing Satellites 1 and 2
ERS_ALT_2_	REAPER ERS L2 GDR product
ERS_ALT_2M	REAPER ERS L2 Meteo product
ERS_ALT_2S	REAPER ERS L2 SGDR product
ESOC	European Space Operations Centre
FES	Finite Element Solution
GDR	Geophysical Data Record

GIM	Global Ionophere Model
GOT	Goddard Ocean Tide model
L1/L1b/L2	Processing Levels 1, 1b, and 2
MWR	Microwave Radiometer (on ERS)
NCO	NetCDF Climate Operators
netCDF	Network Common Data Form
NIC09	NOAA Ionosphere Climatology 2009
NOAA	National Oceanic and Atmospheric Atministration
OLC	Open Loop Calibration
OPR	Ocean Product (historical ERS data)
PTR	Point Target Response
QWG	instrument Quality Working Group (on ENVISAT)
RA	Radar Altimeter (e.g. RA on ERS, RA2 on ENVISAT)
RADS	Radar Altimeter Database System
REAPER	**Re**processing **A**ltimeter **P**roducts for **ER**S
RMS	Root Mean Square
RPxx	Final Reaper Product
SDGR	Sensor Geophysical Data Record
SLA	Sea Level Anomaly
SP3	Precise orbit determination file format
SPTR	Scanning Point Target Response
SSB	Sea State Bias (correction to RA range measurement)
SWH	Significant Wave Height
TB	Brightness Temperature
TOPEX	Topography Experiment
USO	Ultra Stable Oscillator
WP	Work Package
ZGM	Zero Gyro Mode

2 Data Products

2.1 REAPER

The REAPER data used in the scope of this validation report are those produced by the "final" (post-commissioning) REAPER L2 processor **version 01.08** of May 2014. Issues that apply only to the commissioning versions are marked in **blue**.

Both ERS-1 and ERS-2 products have been analysed, in all three data flavours:

- ERS_ALT_2_: GDR product with 20-Hz and 1-Hz measurements.
- ERS_ALT_2M: Meteo product, as the GDR, but without the 20-Hz data.
- ERS_ALT_2S: Sensor data record, as the GDR, but also including waveforms, referred to as SGDR in the following.

All are provided in the binary netCDF format with CF-compliant metadata [R1]

The REAPER commissioning data were split into two periods. The first period of data covered ERS-1 Cycles 145 through 156 and ERS-2 Cycles 0 through 11, although in both cases the first and last cycle contained very little data. This period from May 1995 to April 1996 coincides with the tandem phase of the two satellites during which they were flying along the same ground track, 1 day apart.

A second period of the commissioning data covered ERS-2 Cycles 60, 61, 62, 66, 67, 68, and 75 through 85, but only cycles 75 through 85 (running from 22 July 2002 to 3 June 2003) were analysed. The first and last cycle contained very little data. The remaining cycles coincide with the Envisat mission Cycles 8 to 16, which flew 34 minutes ahead of ERS-2 on the same ground track.

The final REAPER data (version 01.08 in this report) covers all of the ERS-1 and ERS-2 missions.

The number of REAPER data files varied from release to release. It is not clear why this is the case.

Number of files	ERS-1	ERS-2 (1995/6)	ERS-2 (2002/3)
Version 01.02 (COM1)	4137		
Version 01.03 (COM2)	4925	4780	
Version 01.04 (COM3)	4885	4745	4321
Version 01.06 (COM5)	4885	4788	7340
Version 01.07 (COM6)	4930	4788	7340
Version 01.08 (RP01), coinciding with COM6	4930	4784	5953
Version 01.08 (RP01), all files	24463	43060 (all of ERS-2, 1995-2003)	

- New ERS-2 files in version 01.07 are particularly cycles 61, 67 and 68. But there were also a lot of new very small files overlapping with longer files that were already available before. For example, the second, third and forth file in the list below overlap the first:
```
E2_TEST_ERS_ALT_2M_20020722T094118_20020722T112104.NC
E2_TEST_ERS_ALT_2M_20020722T104714_20020722T105029.NC
```

E2_TEST_ERS_ALT_2M_20020722T105030_20020722T105351.NC
E2_TEST_ERS_ALT_2M_20020722T105352_20020722T105353.NC
I had to introduce new code to deal with these overlaps.

- New ERS-1 files in version 01.07 are scattered throughout the period, but particularly in period 19950927T16 through 19950928T14.
- Version 01.08 had fewer files for ERS-2 during the two periods discussed above. That is some files that existed in version 01.07 (COM6) disappeared in version 01.08 (RP01). All of these files were the type of very short files overlapping with other files discussed above, so this was a welcome change.
- .It is also recommended to produce full pass files only (with no overlaps or time reversals).

2.2 RADS

2.2.1 ERS-1 and ERS-2

For comparison ERS-1 and ERS-2 data have been retrieved from RADS. These are based on the OPR version 6 data, released from 1995 through 2010. Extensive improvements have been made to the data, including instrumental and geophysical corrections. For consistency, the REAPER/Combi orbits have been applied to these data as well.

2.2.2 Envisat

The Envisat data retrieved from RADS are based on the GDR version 2.1. Important improvements to these products include all geophysical corrections as well as:

- PTR correction tables are applied;
- S-band range bias for sides A and B: 165 mm added to range: this adjusts the dual-frequency ionospheric correction;
- CLS SSB model, although I have developed a hybrid model myself;
- CNES GDR-D orbit.

2.2.3 TOPEX

TOPEX data used for comparison is based on the Merged GDRs, enhance with several corrections, like correcting the degradation of the SWH at the end of the life of the side A altimeter. All geophysical corrections have been upgraded to current standards.

3 Validation of REAPER Data Products

This section provides analyses of the REAPER data products of version 01.08, as listed in Section 2. Unless otherwise indicated, the findings here apply to both satellites (ERS-1 and ERS-2) and to all product flavours, Meteo (ERS_ALT_2M), GDR (ERS_ALT_2_) and SGDR (ERS_ALT_2S).

3.1 Time and Location

3.1.1 Time tags

The files made currently available have overlapping ranges of time. The overlap is generally between a few seconds and half a minute. In order to avoid time reversals in the pass files created from these, I had previously decided to move to a later file as soon as it starts, thus discarding the last measurements of the earlier file. This decision is rather arbitrary and it does make a difference, as the measurement values at the end of one product and at the beginning of the next product are not entirely the same.

This procedure was no longer possible in version 01.07 since there are now tiny fractions of files, overlapping previous files. As a result I had to change to using the data the first time they are encountered. Any time that time reverses, data points are simply skipped until the time tags exceed the latest measurement found. This issue should be totally avoided. No overlapping data files should be produced in future REAPER data.

In addition, even *within* files there are regular outliers in the time tags. Several times during one cycle a file would contain a few 1-Hz records in which a time tag is off from the others by a few tens of seconds to hours. The 20-Hz time tags are likewise off. Time tags would not only *reverse* but could also *jump forward* and then back, were the one that jumped forward was the odd one out.

Particularly affected is ERS-1 cycle 150, where nearly every pass has a few time tags out of sync.

A total of **415989** ERS-1 records and **1480099** ERS-2 records were rejected based on one of the following criteria related to their time tag.

- The time tag exceeds the time range of the file: 4944 ERS-1 and 3695 ERS-2 records were rejected on this criterion.
- The time tag is greater than both the time tag that precedes it as well as the one that follows: 1011 ERS-1 and 192 ERS-2 records were rejected on this criterion.
- The time tag is earlier than the last valid time tag of the previous file: 389056 ERS-1 and 1142316 ERS-2 records were rejected on this criterion.
- The time tag is earlier than the previous valid time tag: 20978 ERS-1 and 333896 ERS-2 records were rejected on this criterion.

If either of these conditions is met, the 1-Hz records should be rejected. In some cases if was necessary first to adjust the `sensing_start` time and/or the `sensing_stop` time of the file, because the first or the last point in the file were in fact out of sync. Thus I first did not use the start and end time from the product header but instead determined the `sensing_start` time from the first date in the file name, and the `sensing_stop` time from the second date in the file name, increased by one second. Using those times appeared to be the most reliable way to determine the time range of the file. Any time outside that range was then discarded.

3.1.2 Longitude and latitude

The following issue was fixed since REAPER version 01.06:
Longitudes are in the –180º to +180º range, which would allow a higher resolution of 10^{-7} instead of 10^{-6} degrees. Increasing the resolution should be considered for a later data release.
A serious issue, though, is that in many occasions the crossing of the dateline, from negative to positive longitudes is done incorrectly, averaging both negative and positive values. As a result `longitude_1hz` has sequences like: –179949223, –179974464, –44999709, 179975212, 179950122. In this case the middle value should likely have been –179999709 instead. Note that this affects more than just the longitude. **All** geophysical corrections and the surface type flag are thus interpolated at an entirely wrong location.

For the time being, I have identified and fixed these occurrences by following the recipe:

- Select data records `j` for which
  `longitude_1hz(j-1) < -179000000` and
  `longitude_1hz(j+1) > 179000000` and
  `abs(abs(longitude_1hz(j)) - 179000000) > 1000000`.
- Determine the average of `longitude_1hz(j-1)` and `longitude_1hz(j+1)`.
- If this average is positive, set `longitude_1hz(j)` to this average minus 180000000, otherwise set `longitude_1hz(j)` to this average plus 180000000.
- Replace all geophysical corrections for record `j` by the average of those of records `j-1` and `j+1`.
- Copy the surface type flag from record `j-1` to record `j`.

This process identified 545 erroneous ERS-1 records and 526 erroneous ERS-2 records in version 01.04. The bug obvious needs to be squelched at the source: the interpolation of the 20-Hz longitudes (`longitude`) where negative and positive longitudes near the date line should be dealt with properly.

One such occurrence is at 1995-08-10T07:12:57. Otherwise longitudes generally match those determined externally within ±1 microdegree. The 20-Hz longitudes are correct.

Latitudes are generally within ±1 microdegree from those determined externally.

3.1.3 Orbital altitude

Orbital altitude (`altitude_1hz`) on the REAPER products are based on the Combined REAPER orbits computed in the framework of this project. The values on the product have been compared with those based on an orbit interpolation program used in RADS. This program has been heavily tested and shown to produce no significant differences with Jason-1 or Jason-2 products.

While the differences between the REAPER data the externally interpolated orbit are generally small (±1 mm), until version 01.06, there were also extreme excursions up to 1 meter. It was easily shown that the REAPER data were the culprit by comparing the sea level anomaly from the REAPER product with one redetermined using the external orbit.

The problem was traced back to an issue in format conversion between the original SP3-formatted files delivered by ESOC and the conversion of those files into the format used by the REAPER processor. An error of 1 meter could occur in any of the three positional components (X, Y and Z) of the satellite position.

The error was detected and fixed at ESOC. The proper files were eventually introduced in the processing of version 01.07. So no external interpolation of the orbit was performed in this iteration of the REAPER product validation, after I had established that the original issue was fixed in version 01.07.

Some periods remain in which the orbit determination has not converged to an accurate orbit. This is generally soon after or between orbital manoeuvres, see for an example. I spend significant time to identify those periods, as there is no flag on the Meteo product to identify these periods. Tables for ERS-1 and ERS-2 identifying those periods will be made available as deliverables. See Section 6.

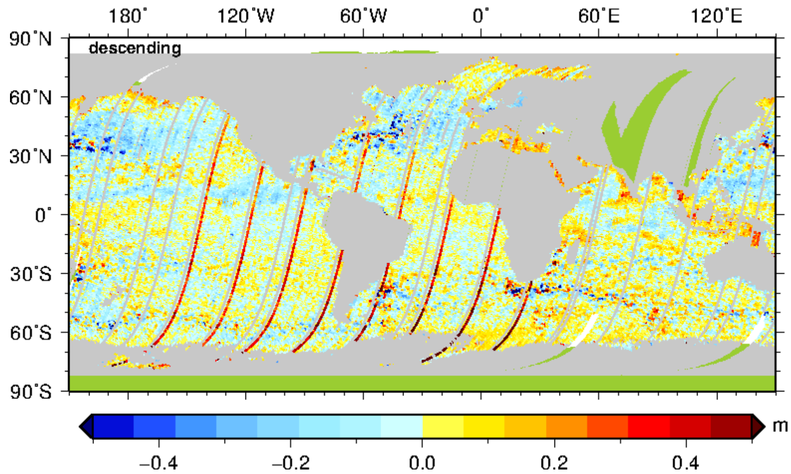

Figure 1. Map of sea level anomalies on descending tracks of ERS-1 Cycle 152.

3.2 Geophysical Corrections

3.2.1 Model dry and wet tropospheric correction

The ECMWF (ERA Interim) dry tropospheric correction (`dry_c_1hz`) and wet tropospheric correction (`wet_c_mod_1hz`) were compared to values independently produced by the RADS software. No clear errors were found. *No specific comparisons were made for inland data, which is known territory for errors in atmospheric corrections. See* Figure 5.

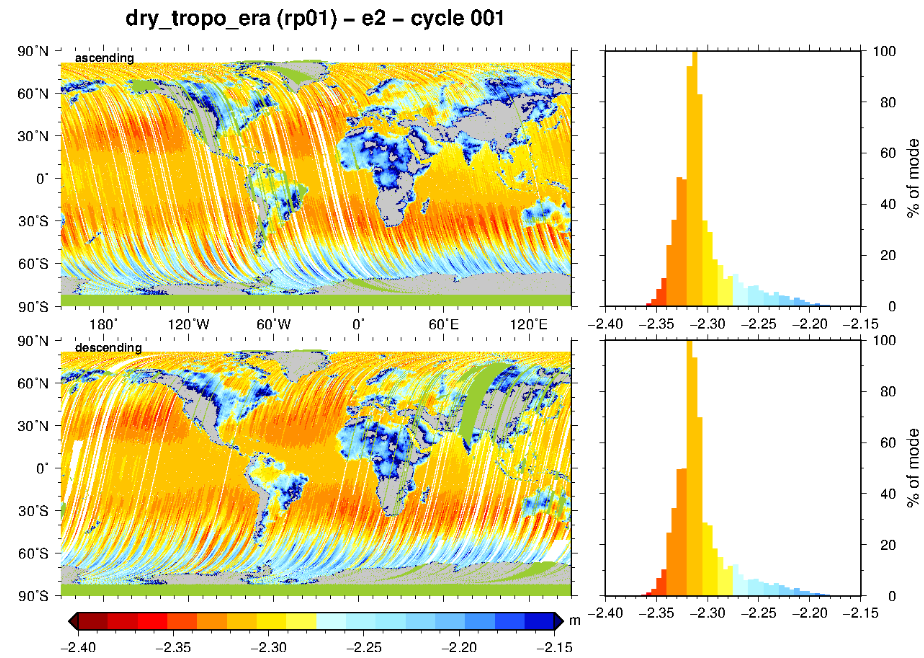

Figure 2. Dry tropospheric correction from the ERA Interim model. Values are of ERS-2 Cycle 1 from REAPER v01.07. Each of the following maps is divided between ascending tracks (top), and descending tracks (bottom). The histograms on the right are for valid over-ocean data only.

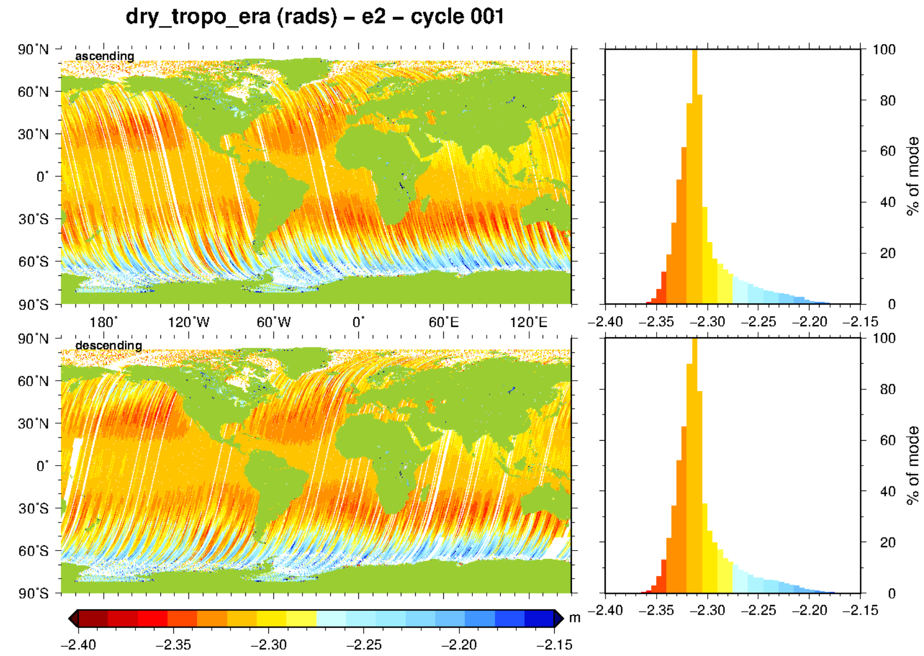

Figure 3. Dry tropospheric correction from ERA Interim model. ERS-2 Cycle 1. RADS values.

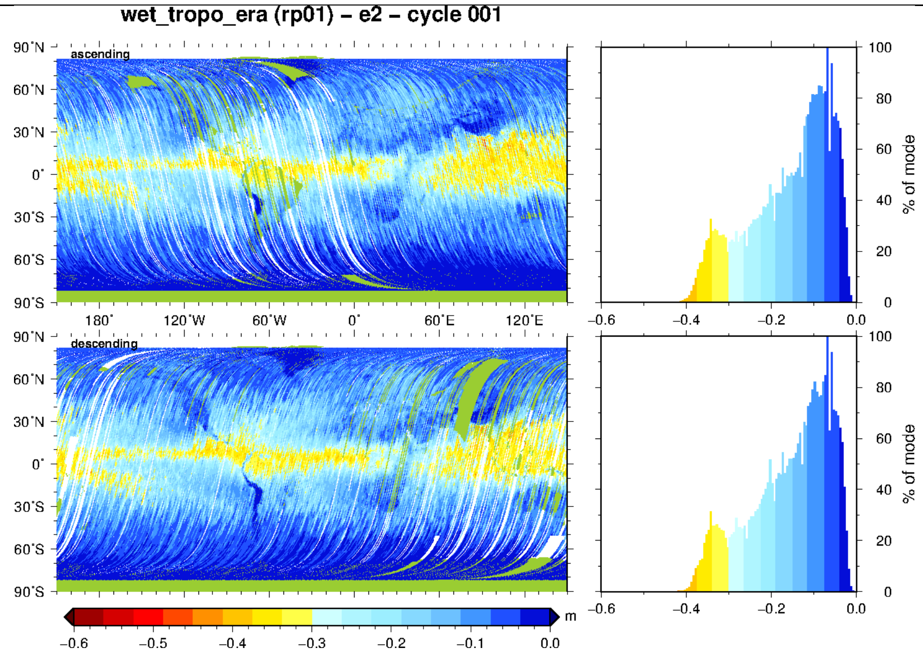

Figure 4. Wet tropospheric correction from the ERA Interim model. Values are of ERS-2 Cycle 1 from REAPER v01.07.

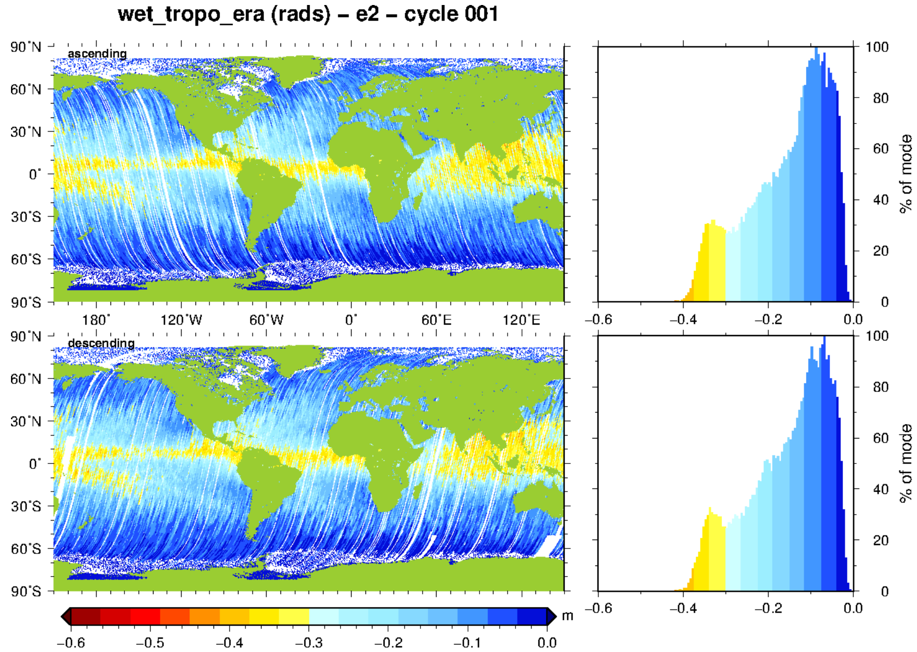

Figure 5. Wet tropospheric correction from the ERA Interim model. ERS-2 Cycle 1. RADS values.

3.2.2 GIM ionospheric correction

On all the data during the ERS-1/2 tandem mission (1995/1996), the GIM ionospheric correction (`iono_c_gps_1hz`) is invalid. This is indeed expected, as there are no GIM models available prior to 1998.

For this correction I looked at ERS-2 cycle 76 (July-August 2002). During that cycle, in version 01.04, there was a scale difference between the values on the REAPER product and those that I have determined off-line. The REAPER values are too large by a factor 1.0335. After reducing the values on the REAPER product by a factor 0.968 they agreed to within rounding error with what I determined externally.

This error must have take place in the scaling down of the TEC from GPS altitude to the altitude of ERS-1 and -2. As described in [R3] that scale factor is 0.856. Apparently in REAPER v01.04 a factor of 1.0335*0.856 = 0.885 is applied, which was incorrect.

In version 01.06, this was clearly resolved. REAPER data now agree with external correction values to within rounding errors. See Figure 6.

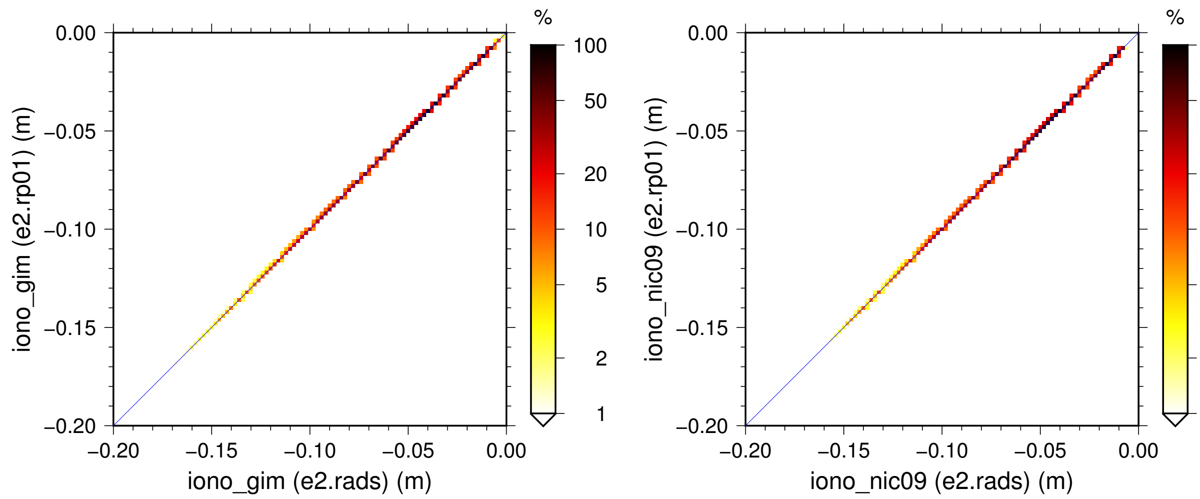

Figure 6. Scatter plots of ionospheric corrections on the REAPER RP01 data (version 01.08, vertical) against the same ionospheric corrections interpolated off-line. Left: GIM ionospheric maps; Right: NIC09 ionosphere climatology.

3.2.3 Model ionospheric correction

Until version 01.06, the NIC09 ionospheric correction suffered from exactly the same scaling error as the GIM ionospheric correction (see above). This too was fixed in version 01.07.

3.2.4 Sea state bias correction

Only a simplistic model was provided on REAPER data prior to version 01.08. Because the sea state bias depends on the retracking algorithm and its implementation, a new sea state bias model needed to be developed for the REAPER data (as discussed in Section 4). Starting with REAPER version 01.08 (RP01) this sea state bias model was incorporated on the product.

3.2.5 MOG2D dynamic atmospheric correction

The MOG2D values on REAPER are within rounding errors of what I compute externally. As mentioned in the product manual, it is indeed the total correction, and thus should *not* be combined with the inverse barometer correction. Some adjustment may be needed to the current variable name and its attributes in the netCDF data files (see Section 5.6.2).

3.2.6 GOT4.7 ocean and load tide

The GOT4.7 ocean tide values (`ocean_tide_sol1`) generally agree to within 1 mm with externally computed values, except within 50 kilometers from the coast. In the coastal areas the differences can amount to several centimeters. This may be the result of differences in interpolation strategies near the coast. This is not critical.

The GOT4.7 load tide values (`load_tide_sol1`) agree to within 1 mm everywhere.

In all versions prior to v01.06 (COM5) the load tide and the long-periodic equilibrium tide were all *included* into the ocean tide, making `ocean_tide_sol1` the geocentric ocean tide. Since v01.06 all ocean tide, load tide, equilibrium tide and non-equilibrium tide are reported separately, which is clearly identified in the `comment` attribute to the variable `ocean_tide_sol1`. That means the sea level anomaly has to be corrected for four tidal contributions: `ocean_tide_sol1`, `load_tide_sol1`, `ocean_tide_equil`, and `ocean_tide_non_equil`. The comment attributes properly reflect this.

3.2.7 FES2004 ocean and load tide

I did not validate this model (`ocean_tide_sol2` and `load_tide_sol2`). Anyhow, the model should be replaced by the more accurate and up-to-date FES2012 model.

3.2.8 Long-period equilibrium and non-equilibrium tides

Both `ocean_tide_equil` and `ocean_tide_non_equil` are correct to within rounding errors. Note the warning in the comment attribute to `ocean_tide_equil` and `ocean_tide_non_equil` that *neither* are included in the ocean tide fields (`ocean_tide_sol1` and `ocean_tide_sol2`). This is indeed the case, despite the convention of making the long-period equilibrium and non-equilibrium tides part of the ocean tide. My analysis confirms that the long-period tides *are not included* in the ocean tide. The comment attributes properly reflect this.

3.2.9 Solid earth tide

Solid earth tide values (`solid_earth_tide`) are correct to within rounding errors.

3.2.10 Pole tide

The pole tide (`pole_tide`) is based on the equilibrium pole tide, multiplied by the Love number $(1 + k_2)$ over oceans and $(1 + k_2 - h_2)$ over land and lakes, with $k_2 = 0.302$ and $h_2 = 0.609$ [R4]. However, until version 01.04, REAPER incorrectly used the factor $(1 + k_2)$ over lakes as well. This should be changed to $(1 + k_2 - h_2)$ over lakes. I can confirm that this is fixed as of version 01.07.

3.2.11 Mean sea surface

The CLS01 mean sea surface values (`mean_sea_surface_1`) differ quite significantly (around 3 mm rms difference) with externally interpolated values. This can be due to the use of different interpolants (linear, cubic spline, etc.). It is advised to replace this model with the more recent and much more accurate CNES-CLS11 mean sea surface model.

For validation purposes I added the DTU10 mean sea surface model and used that one in my analyses.

3.3 Flag Words and Counters

3.3.1 ocean_range_used_20hz

This bit map is there to indicate which ocean ranges are valid.

- When a 20-Hz measurement is **not used** the corresponding value in `ocean_range_used_20hz` is set. Hence when `ocean_range_numval` = 20, then all corresponding values of `ocean_range_used_20hz` = 0.
- From this we would expect that when `ocean_range_numval` = 0, all corresponding values of `ocean_range_used_20hz` should be set. However, in this case: all those values appear as 0.

The documentation should be adjusted to reflect this, and more practically, all values of `ocean_range_used_20hz` should be set to 1 when the corresponding `ocean_range_numval` = 0.

3.3.2 Missing flags

Some very important flags were/are missing on the Meteo data products.

- Orbit quality flag. There is no way to distinguish periods of suspected degradation of the orbit determination. Such a flag is also not available on the (S)GDR data. As a separate deliverable I have created a set of criteria to generate such a flag.
- Type of tracking. Until version 01.08 (RP01) there was no flag on the Meteo product to indicate whether the altimeter was operating the ocean or ice mode. Such a flag should be introduced, since the ERS-1 and ERS-2 altimeters were operating during significant periods in ice mode over ocean. Ice mode data *is not suitable* for ocean analyses and should be rejected. Luckily version 01.08 now has the `alt_state_flag` on the Meteo data for this purpose.

3.4 Altimeter Data and Instrumental Corrections

3.4.1 Altimeter range

The altimeter range is more difficult to compare to external information than any of the geophysical corrections or the orbital altitude. But having established above already that all of those corrections are accurate to within, any remaining considerable difference between sea level anomalies from the REAPER product and the RADS data based on OPR data must be due to differences in the altimeter ranges.

3.4.2 PTR correction

Until version 01.04, the altimeter ranges on the REAPER products suffered from incorrect PTR range corrections. IsardSAT provided tables of correct and incorrect PTR range correction for both ERS-1 and ERS-2 so that the range measurements could be adjusted. However, the adjustments due to the update of the PTR range correction were limited to a very few periods.

A second update of the PTR corrections was supplied for version 01.06 (COM5). Unfortunately numerous outliers remained in the original PTR measurements (performed roughly every 60 seconds). These outliers resulted in linear ramps in the PTR corrections with excursions of *several meters*. Although the outliers could have been detected easily, without any access to the original PTR measurements and only interpolated range corrections, it was difficult to identify where the errors started. An example of the effect on SLA is provided below.

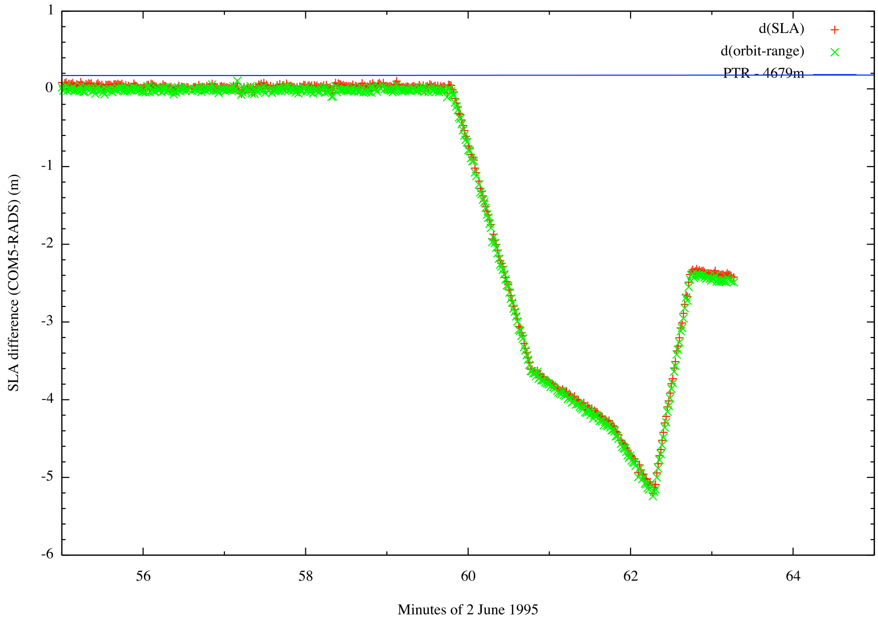

Figure 7. Variation of apparent sea level (red) anomaly as a result of outliers in the PTR measurements (at the vertices of the green linear ramps).

An outlier detection was then implemented at IsardSAT. At this point it was identified that the PTR correction may still be corrupted shortly after switch-on of the altimeter instrument. At those points the PTR range delay changes rapidly to settle on a stable value within an hour. These measurements were not removed by the outlier detection, as it was not clear whether this is actual behaviour of the instrument or only of the PTR measurements. The updated PTR correction, filtered for outliers, was implemented in version 01.07.

As mentioned above, the switch-ons of the instrument and the unusual PTR measurements at those points posed questions about their validity. Indeed, errors in the altimeter range related to switch-on remain visible in the REAPER data (See Figure 8). Consequently I devised tables for ERS-1 and ERS-2 to remove those outliers by flagging the altimeter ranges as invalid. Those will be provided as deliverables.

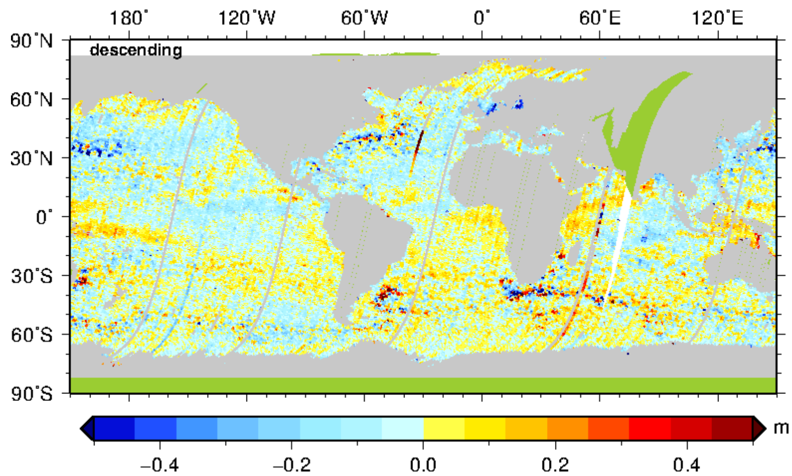

Figure 8. Sea level anomalies on descending tracks of ERS-2 Cycle 9. An anomalous stretch of data (related to switch-on) is seen south of Iceland.

3.4.3 SPTR correction

Another instrumental correction to the ERS-1 and ERS-2 data is the SPTR correction. This is, in fact, a correction to the PTR correction that results from limitations in the electronics that produce the clock-ticks that regulate the altimeter. Offsets in the cycles constant while the instrument is operating but may change when the instrument is switched off and on again. A measurement call the Scanning Point Target Response (SPTR) was introduced to determine the resulting jumps in the altimeter range. Until version 01.04 the SPTR correction was not, or was incorrectly applied to the altimeter ranges as evidenced by the characteristic jumps seen in the time series of the daily mean sea level determined from the REAPER data (red line in Figure 9).

These jumps are (mostly) absent in version 01.07, indicating that the SPTR correction was properly applied. It must be said though that there are periods during the operation of ERS-1 and -2 that no SPTR measurements were made between consecutive switch-ons of the instruments, so no knowledge of the appropriate correction is available during those periods. During discussions of the quality of the version 01.08 data, we identified that for those periods, we could still compute a reasonable SPTR correction. This the PTR drift appears smooth, the SPTR jumps are also seen the in the time series of the PTR values. Hence, any excursion from a smooth line at the moment of instrument swith-on can be used as a proxy for the missing SPTR measurements.

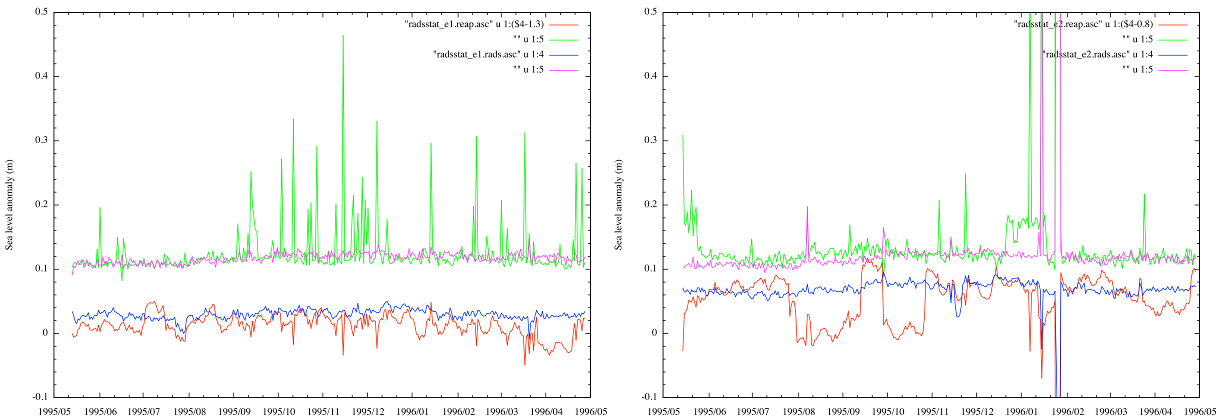

Figure 9. Statistics of sea level anomalies from ERS-1 (left) and ERS-2 (right) after fixing orbit and PTR correction, based on version 01.04 data. Daily mean and standard deviation of REAPER data are in red and green. Daily mean and standard deviation of RADS data (based on OPR) are in blue and magenta.

3.4.4 USO correction

Another issue that hampered version 01.06 was the fact that the gradual decrease in the frequency of the Ultra Stable Oscillator (USO) due to aging of the instrument was not taken into account in the determination of the altimeter range. A constant frequency was assumed instead. As a result, the ranges appeared shorter by a factor proportional to the reduction in the USO frequency. Thus, the ERS-2 sea level derived from REAPER version 01.06 data for the period 2002/2003 was biased high by several centimeters compared to the data from the beginning of the mission. The bug was confirmed by taking the USO frequency information from the header and converting that to a range correction, after which the derived sea level no longer exhibited any anomalous trend. In version 01.07, the actual USO frequency is properly used to convert any of the terms of the range measurement from number of clock ticks to values in meters.

3.4.5 Doppler correction

In version 01.02 and 01.03 the Doppler correction `dop_c` had the wrong sign (a perpetual problem in altimeter data releases). The sign of the Doppler correction should be the same as the altitude rate.

This was corrected in version 01.04 and has been correct ever since.

3.4.6 Time series

Figure 10 shows the time series of sea level anomalies derived from ERS-1 and ERS-2, along with those of TOPEX and Envisat. All appropriate geophysical corrections are applied except for a constant range bias. The DTU10 mean sea surface was used as reference. The ERA Interim model wet tropospheric correction was applied to ensure consistency between the different missions and not have a radiometer bias affect the estimation of the altimeter range biases. In this and the next sections "RP01" refers to the REAPER v01.08 data, except for an addition of the DTU10 mean sea surface, the GOT4.8 tide model, applying a timing bias of 0.68 milliseconds,. and flagging periods with large orbit errors and altimeter range errors as discussed above.

To make the results end up in a similar range, 60 cm was subtracted from the ERS-1 and ERS-2 sea level as determined from the RP01 data. Similarly, 40 cm was subtracted from the Envisat sea level as determined by the RADS data.

Figure 10 shows mean sea level anomalies, averaged over 5-day intervals. Clearly, the biases differ per mission and as well as for the different product types. Also, the time series do not always coincide after correcting for a bias.

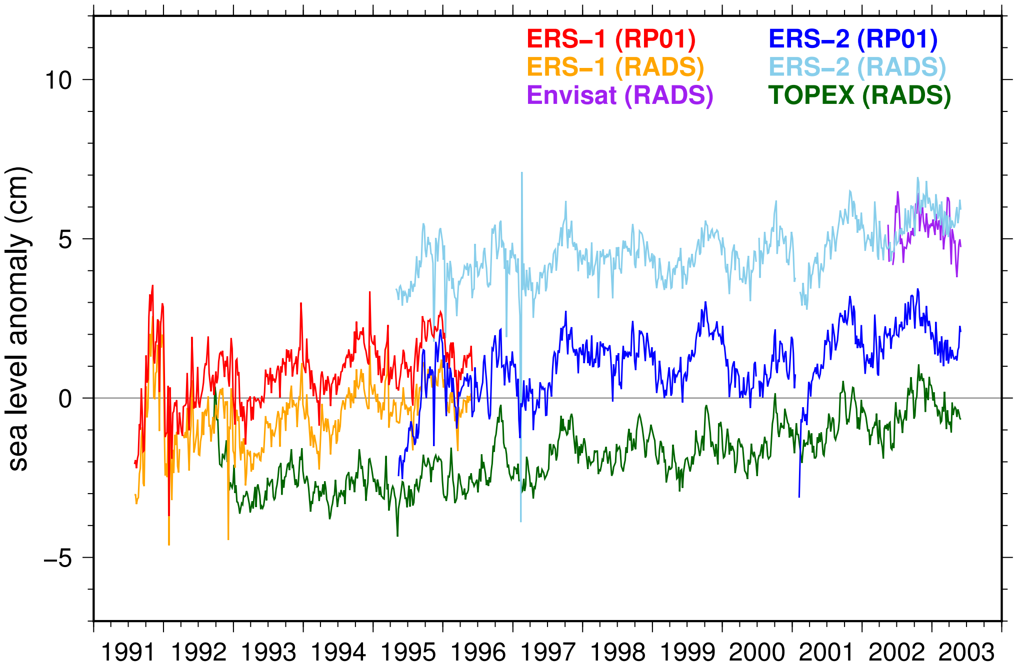

Figure 10. Time series of mean sea level anomaly, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01, reduced by 60 cm); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01, reduced by 60 cm); purple: Envisat (RADS, reduced by 40 cm), green: TOPEX (RADS).

Figure 11 shows the time series of crossover height differences with TOPEX. This shows good stability of the differences in sea level (i.e. in range). Particularly the stability of the ERS-1 range over the mission appears to have been improved compared to the RADS product. However, the height difference between ERS-2 and TOPEX seems to have become less stable. Note that the light blue line (ERS-2 RADS data) is more or less horizontal with little long-term variations, while the dark blue line (ERS-2 RP01 data) shows some significant long-term variations. Most striking variations are those during the beginning of the ERS-2 mission (second half of 1995), as well as the first half of 2001 (coinciding with transition to the "Extra Backup Mode" for attitude control), and at the very end of the mission (early 2003). Some effort may need to be directed to determine the cause of this regression.

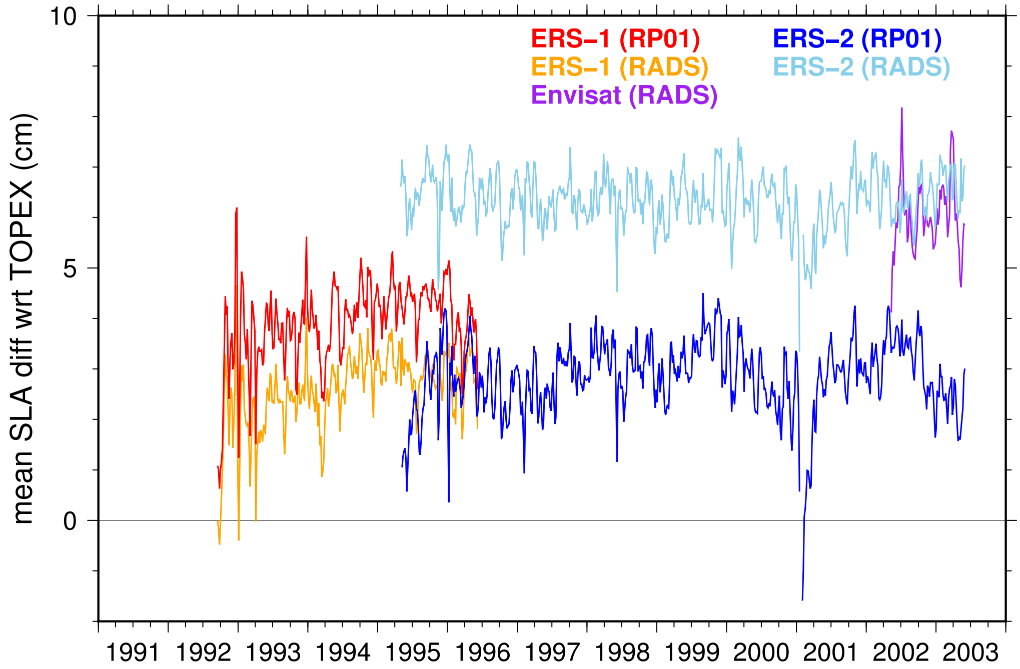

Figure 11. Time series of mean sea level anomaly differences with respect to TOPEX, as determined from dual-satellite crossovers, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01, reduced by 60 cm); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01, reduced by 60 cm); purple: Envisat (RADS, reduced by 40 cm)..

3.4.7 Bias estimation

The estimation of range bias relies on time series of mean sea level anomalies, crossover differences between the different missions, as well as comparisons between REAPER and RADS data. Those values are gathered in Table 1. The numbers at the bottom of the table are current best estimated of biases in sea level anomalies for each of the missions, assuming the TOPEX data have no bias. These are consolidated numbers from all available techniques and can be considered as the negative of range biases, i.e. positive numbers indicate that the altimeter range is too short.

Comparison	ERS-1	ERS-2
Crossover difference with TOPEX	26.0 / 639.3	63.7 / 628.4
Crossover difference with ERS-2, Envisat	–38.4 / 14.9	–397.4 / 166.4
Collinear difference with ERS-2, Envisat	–38.8 / 15.5	–396.1 / 167.2
Bias estimate (assuming TOPEX = 0)	26 / 639	64 / 628

Table 1. Comparison and bias estimates of sea level anomalies. Values are in millimeters and can be considered to be the opposite of range biases (i.e. positive values mean the range is too short). Pairs of values are for RADS/RP01 respectively.

3.4.8 Standard deviation

A good indicator of the overall performance of the sea level anomalies is to look at standard deviations of crossover height differences. The Figures below show time series of these standard deviations of all crossovers with up to 5 days of time interval between the crossing tracks. Those crossovers have then been binned by 5-day intervals and their mean and RMS has been computed. The statistics for ERS-1 and ERS-2 are compared to those of TOPEX and Envisat.

The results for ERS-1 during all of the mission (Figure 12) are very encouraging. Clearly, the REAPER data perform better than the "historical" OPR data available through RADS.

The results for ERS-2, however, are less positive, simply because the ERS-2 RADS data was already of such high quality (better than ERS-1). Nonetheless, during the entire mission the REAPER data outperform those of RADS and nears those of Envisat.

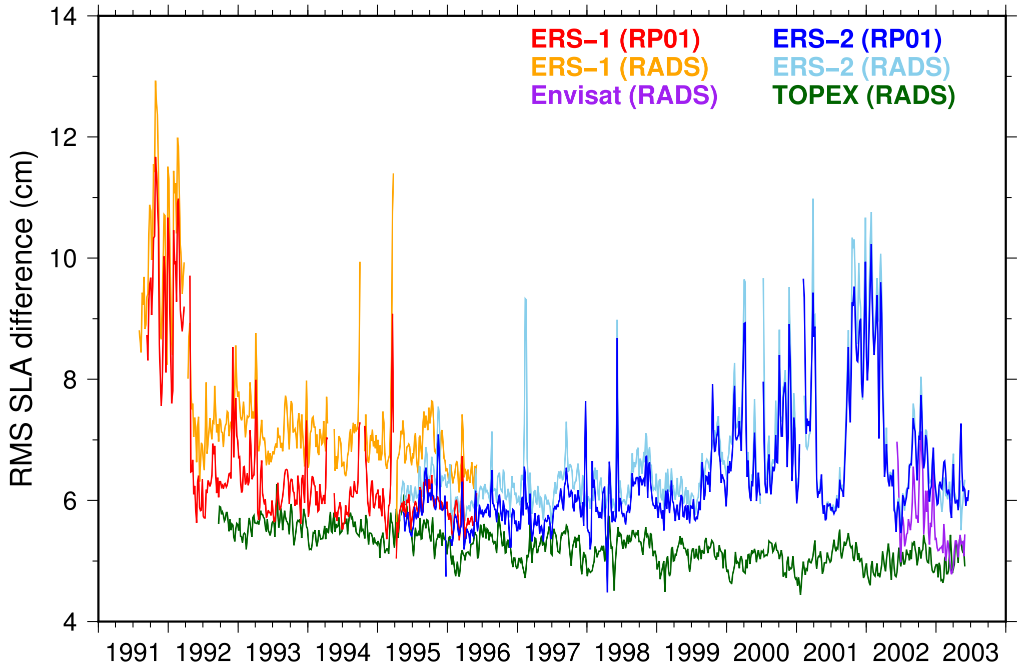

Figure 12. Time series of RMS single-satellite crossover differences of sea level anomaly. Every value spans all crossovers within a 5-day time span, having passes crossing within 5 days. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS)..

3.5 Significant wave height

3.5.1 Time series

The significant wave height (SWH) values have changed significantly between OPR (RADS) and REAPER. Figure 13 and Figure 14 show the daily means of SWH as they were on the OPR products and as they are on the REAPER products. Note that the means have increased both for ERS-1 and ERS-2 between OPR and REAPER. Also the average SWH is not the same for ERS-1 and ERS-2, neither in the OPR data nor in the REAPER data. Hence there is some system-dependent bias.

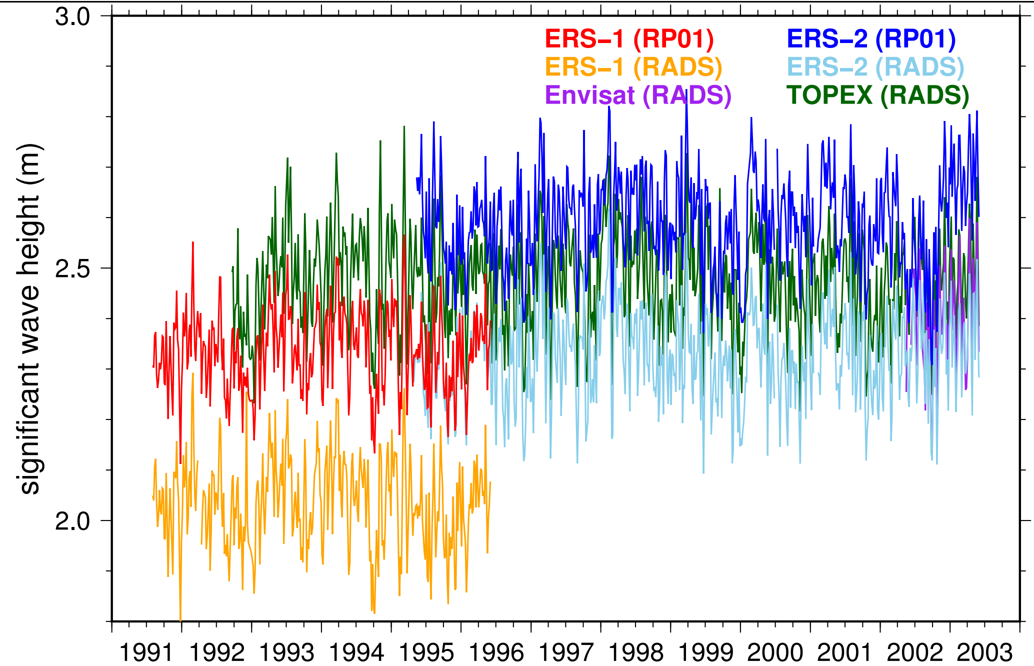

Figure 13. Time series of significant wave height, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01, reduced by 60 cm); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01, reduced by 60 cm); purple: Envisat (RADS, reduced by 40 cm), green: TOPEX (RADS).

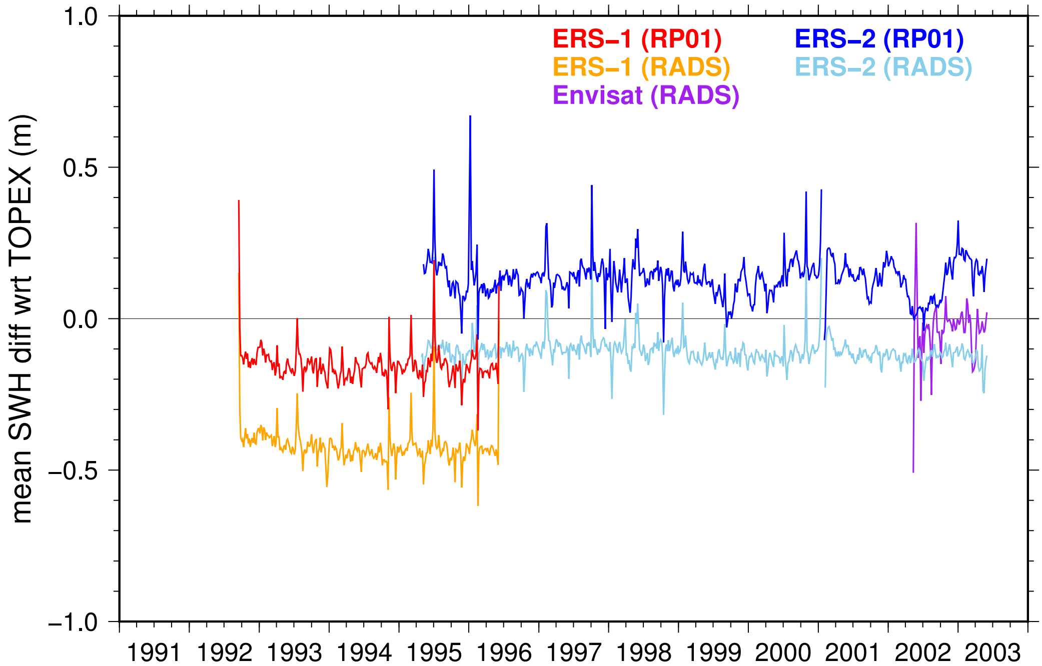

Figure 14. Time series of significant wave height differences with respect to TOPEX, as determined from dual-satellite crossovers, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

3.5.2 Bias estimation

Values for the biases in SWH are gathered in Table 2 below, based on crossover differences with TOPEX and collinear track differences between ERS-1 and ERS-2, ERS-2 and Envisat, and between the different products. The values at the bottom of the table are biases assuming TOPEX data have no bias. The pairs of values are for RADS data and REAPER (RP01) data respectively.

Comparison	ERS-1	ERS-2
Crossover difference with TOPEX	–42.83 / –15.95	–11.21 / 12.99
Crossover difference with ERS-2, Envisat	–31.88 / –27.66	–8.39 / 19.64
Collinear difference with ERS-2, Envisat	30.9 / 26.9	–8.2 / 21.6
Bias estimate (assuming TOPEX = 0)	–43 / –15	–11 / 13

Table 2. Comparison and bias estimates of Significant Wave Height. Values in centimeters. Pairs of values are for RADS/REAPER respectively.

3.5.3 Standard deviation

The crossover RMS of the single satellite crossovers of significant wave height is shown in Figure 15. Note that over the entire ERS-1 and ERS-2 missions with values for REAPER (RP01) are lower than those for the RADS products, and lower than those for TOPEX. This shows that the accuracy of the significant wave height retrieval has improved.

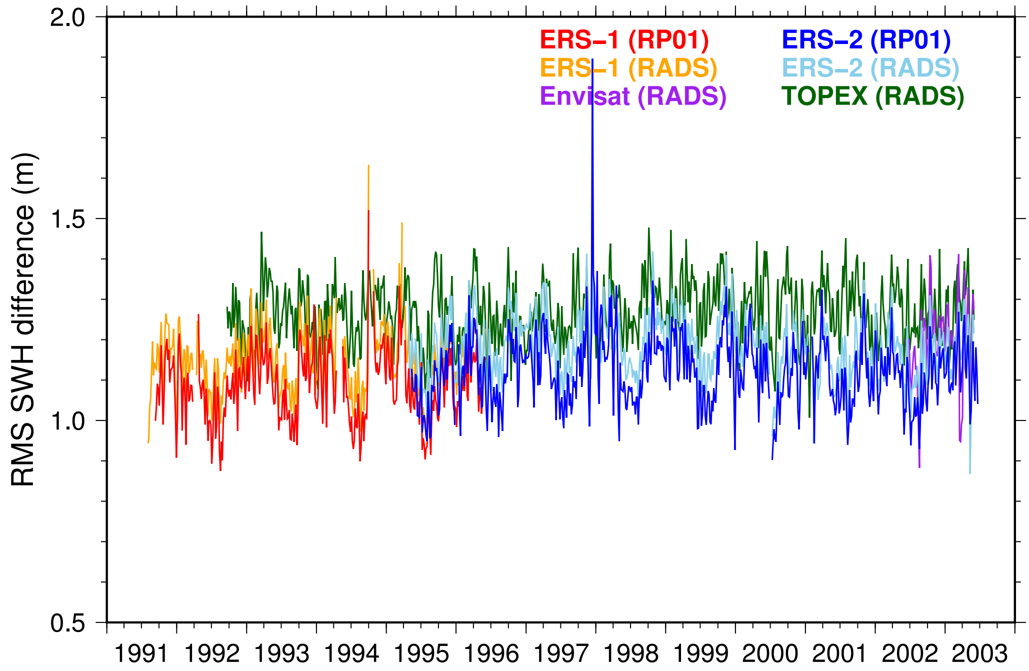

Figure 15. Time series of RMS single-satellite crossover differences of significant wave height. Every value spans all crossovers within a 5-day time span, having passes crossing within 5 days. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

3.6 Backscatter coefficient

3.6.1 Time series

The backscatter coefficient of ERS-1 and ERS-2 have decreased from OPR to REAPER data and are now even further from the TOPEX' values. Note that the ERS-2 results for the period from

2000-2003 do not match the preceding period: while the data for TOPEX and the ERS-2 data from RADS show a stable means, the REAPER (RP01) data have significantly dropped, by about 0.2 dB) in the beginning of 2000.

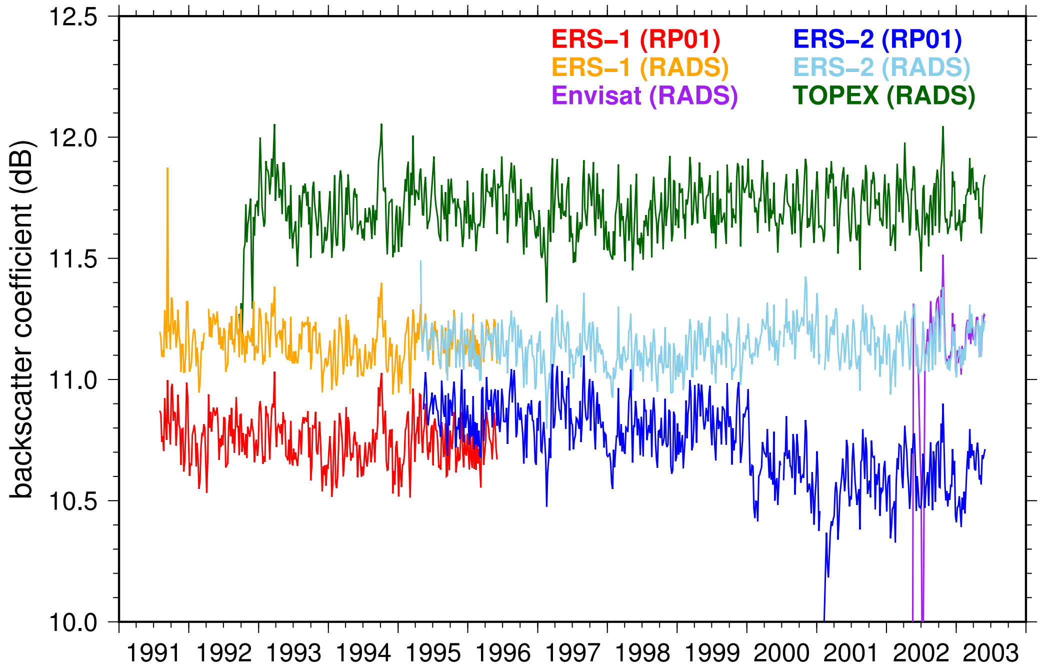

Figure 16. Time series of backscatter coefficient, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01, reduced by 60 cm); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01, reduced by 60 cm); purple: Envisat (RADS, reduced by 40 cm), green: TOPEX (RADS).

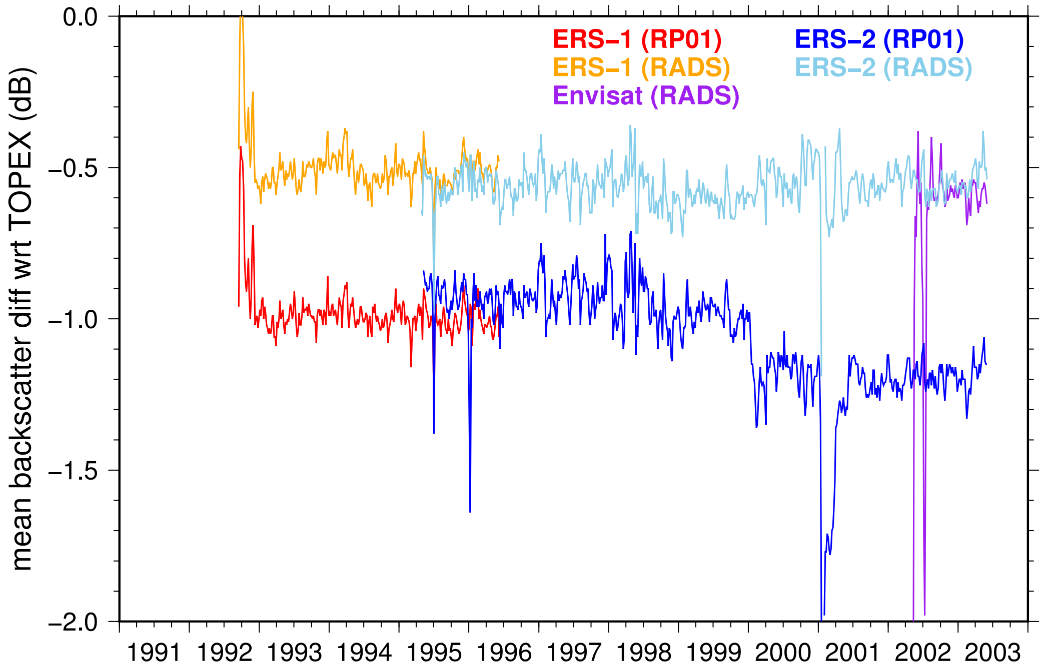

Figure 17. Time series of backscatter coefficient differences with respect to TOPEX, as determined from dual-satellite crossovers, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

The variations of the ERS-2 backscatter coincide with changes in the attitude control following the successive failures of the gyros. In RADS, a number of stepwise corrections to the backscatter are included to counterbalance the changes in backscatter observed in the data as a result of changes in the attitude control modes:

- 10 Feb 2000: Mono-gyro piloting mode started, coincides with the start of the sun-blinding period, in which earth is sensor is inoperative
- 17 Feb 2000: Gyroscope 6 fails, over to Gyroscope 5
- 3 Mar 2000: Sun-blinding period ends
- 6 Feb 2001: Extra Backup Mode (EBM) starts
- 30 Apr 2001: Zero Gyro Mode (ZGM) implemented

It would be wise to estimate corrections to the backscatter for each of these events and apply those to the REAPER data.

3.6.2 Bias estimation

Values for the biases in backscatter coefficient are gathered in the table below, based on crossover differences with TOPEX and collinear track differences between ERS-1 and ERS-2, ERS-2 and Envisat, and between the different products. The values at the bottom of the table are biases assuming that the *Envisat* data (in RADS) have no bias. This choice as reference is informed by the wind speed model, which is based on Envisat. The pairs of values are for RADS data and REAPER (RP01) data respectively.

Note that the bias estimates for the ERS-2 REAPER data will not be very accurate because of the large change in bias at the beginning of the year 2000 and the large excursion during the beginning of 2001. The bias estimate given here is intended to match the *beginning* of the ERS-2 mission.

Comparison	ERS-1	ERS-2
Crossover difference with TOPEX	–0.50 / –0.98	–0.55 / –1.07
Crossover difference with ERS-2, Envisat	0.02 / –0.10	0.08 / –0.53
Collinear difference with ERS-2, Envisat	–0.01 / 0.16	0.10 / –0.61
Bias estimate (assuming **Envisat** = 0)	0.10 / –0.40	0.05 / –0.30

Table 3. Comparison and bias estimates of backscatter coefficient. Values in decibels. Pairs of values are for RADS/REAPER respectively.

3.6.3 Standard deviation

The crossover RMS of the single satellite crossovers of significant wave height is shown in Figure 18. Note that over the values for the REAPER data are much higher than those from the RADS data. In fact, the RADS statistics are likely to be unrealistically low. It is not clear why that is the case.

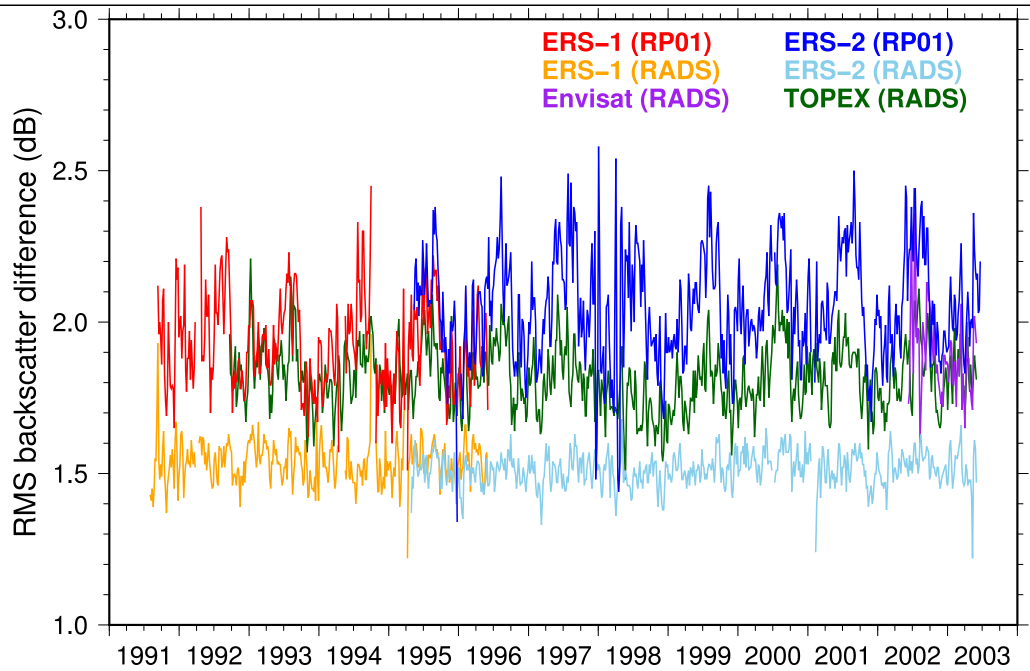

Figure 18. Time series of RMS single-satellite crossover differences of backscatter coefficient. Every value spans all crossovers within a 5-day time span, having passes crossing within 5 days. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

3.6.4 Wind speed

The wind speed model as implemented on the REAPER product is exactly the model by Saleh Abdallah, derived for Envisat. However, it is clipped at 5.0 dB on the low end and 19.6 dB on the high end. That means particularly that high wind speeds are badly represented: they are limited to 28.5 m/s. Though these winds are rare, they are very important to monitor. The clipping of the data is totally without reason and should be avoided.

Note that, because of the bias of the backscatter with respect to Envisat (low by about 0.5 to 0.8 dB) the wind speed will not be accurately calibrated.

3.7 Radiometer Data

3.7.1 MWR data missing

In version 01.07 still a significant number of the ERS-2 MWR data (radiometer wet tropospheric correction, brightness temperatures) are missing, particularly for all of the period between 30 Dec 1995 and 16 Jan 1996 and from 1 to 6 January 2003.

3.7.2 Brightness temperatures

The brightness temperatures available on the REAPER products differ significantly from those of the ERS-1/2 data in RADS as well as those for Envisat. This is born out in the Figures below.

Apart from biases, there are two significant discrepancies between the REAPER and RADS data. By the end of the ERS-1 mission (early 1996) the TB36.5 data in REAPER drops by a couple of Kelvin. Secondly, there is a spike in the TB23.8 values in the second half of 1996. This coincides with the drop of power in the 23.8 GHz channel. Likely the corrections to the brightness temperatures as suggested by Scharroo et al. [R6] were not (correctly) implemented.

First of all there is a significant discrepancy between the ERS-1 and ERS-2 during October 1995, were both channels of the ERS-1 radiometer register much larger brightness temperatures than

ERS-2 (Figure 19). Those bumps are absent in the "historical" ERS-1 data in RADS. So this must be an error in the REAPER data.

It was known that the TB23.8 for ERS-1 and ERS-2 were both slightly low compared to Envisat, by about 3 K. The TB36.5 of ERS-1 and ERS-2 was known to be slightly low. These offsets were taken into account when feeding the TB23.8 and TB36.5 into the neural network algorithm for determination of the wet tropospheric correction.

In the REAPER data there are large offsets compared to the "historical" data. The TB23.8 and TB36.5 are now about 8 resp. 7 K larger than they were before. Hence, totally different wet tropospheric corrections have been the result because those biases were not accounted for in the REAPER processing (Figure 21).

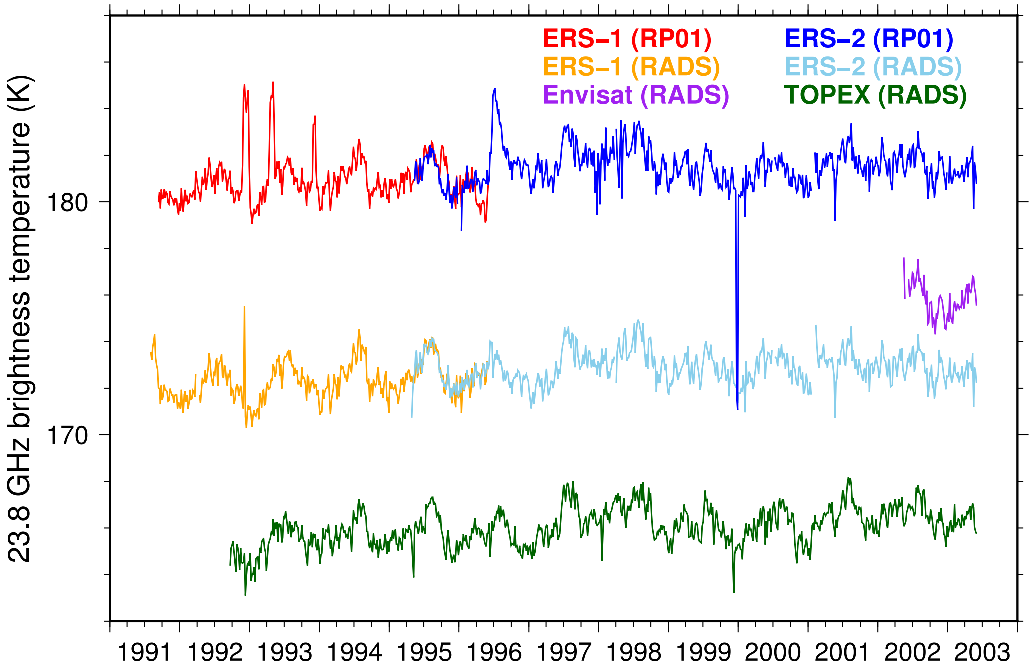

Figure 19. Time series of 23.8 GHz brightness temperature differences with respect to TOPEX' 21 GHz channel, as determined from dual-satellite crossovers, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

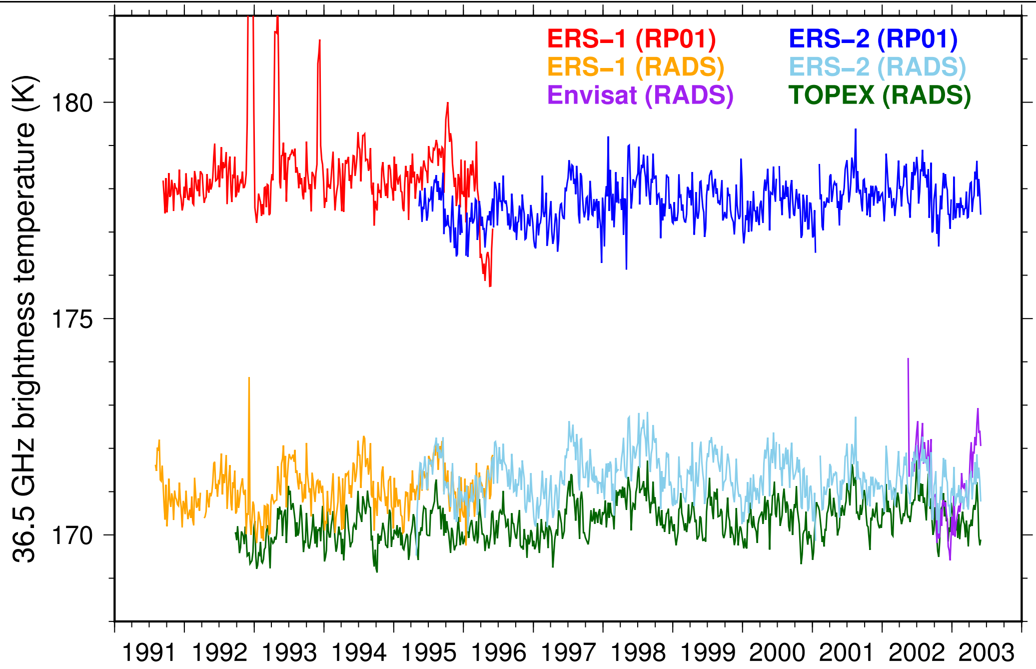

Figure 20. Time series of 36.5 GHz brightness temperature differences with respect to TOPEX' 37 GHz channel, as determined from dual-satellite crossovers, without bias correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: Envisat (RADS).

Again, various techniques have been used to determine the biases in these data compared to the Envisat "standard".

Comparison	**ERS-1**	**ERS-2**
Crossover difference with TOPEX (21 GHz)	5.40 / 14.39	5.41 / 13.62
Crossover difference with ERS-2, Envisat	–0.04 / 0.09	–2.93 / 5.07
Collinear difference with ERS-2, Envisat	–0.01 / 0.16	–3.03 / 5.38
Bias estimate (to be used with NN algo, assuming Envisat = 0)	–3.0 / 5.1	–3.0 / 5.2

Table 4. Comparison and bias estimates of the 23.8 GHz brightness temperatures. Values in Kelvin. Pairs of values are for RADS/REAPER respectively.

Comparison	**ERS-1**	**ERS-2**
Crossover difference with TOPEX (37 GHz)	0.33 / 7.99	0.43 / 7.08
Crossover difference with ERS-2, Envisat	0.01 / 0.68	0.08 / 6.70
Collinear difference with ERS-2, Envisat	0.03 / 0.84	0.04 / 6.68
Bias estimate (to be used with	0.0 / 7.60	0.0 / 6.69

NN algo, assuming Envisat = 0)		

Table 5. Comparison and bias estimates of the 36.5 GHz brightness temperatures. Values in Kelvin. Pairs of values are for RADS/REAPER respectively.

3.7.3 Radiometer wet tropospheric correction

The daily means of the radiometer wet tropospheric corrections are shown below. The correction determined by the radiometer is much too large (by about 2 centimeter in the mean value). This is the case both for ERS-1 and ERS-2. With the biases corrected as in the Tables above, the mean wet tropospheric correction aligns nicely again with the ERA Interim model. However, there is an excursion in the ERS-1 data in October 1995 related to the anomalous bump in the brightness temperatures reported earlier.

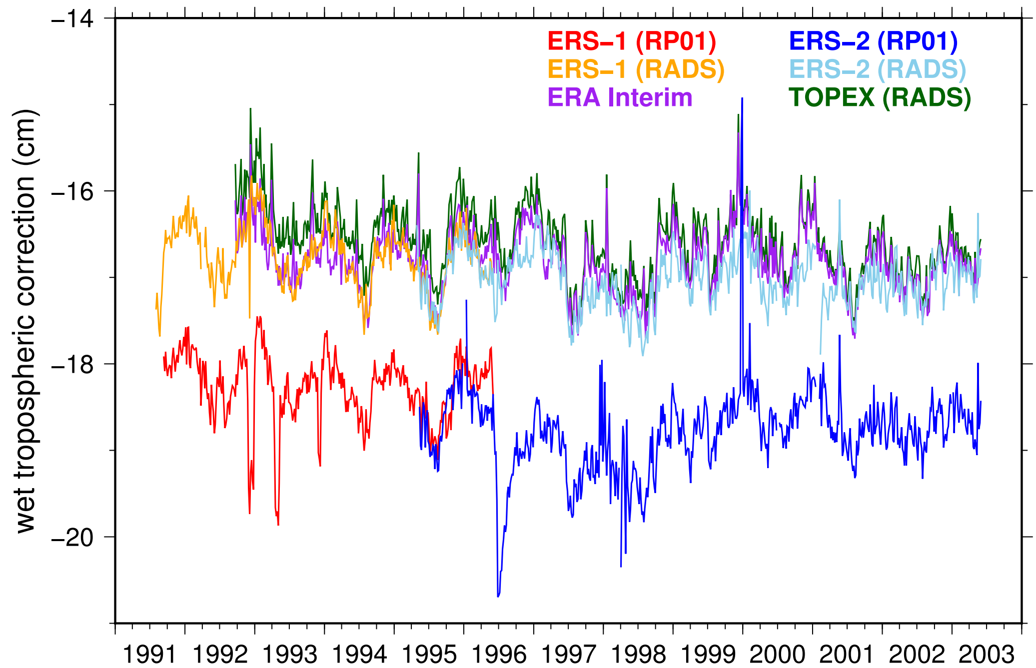

Figure 21. Time series of wet tropospheric correction, averaged in 5-day intervals. Orange: ERS-1 (RADS); red: ERS-1 (RP01); light blue: ERS-2 (RADS); dark blue: ERS-2 (RP01); purple: ERA Interim, green: TOPEX (RADS)..

Figure 22 shows that the change in brightness temperatures does not merely constitute a bias in the radiometer wet tropospheric correction. There is not only a bias but also a different slope.

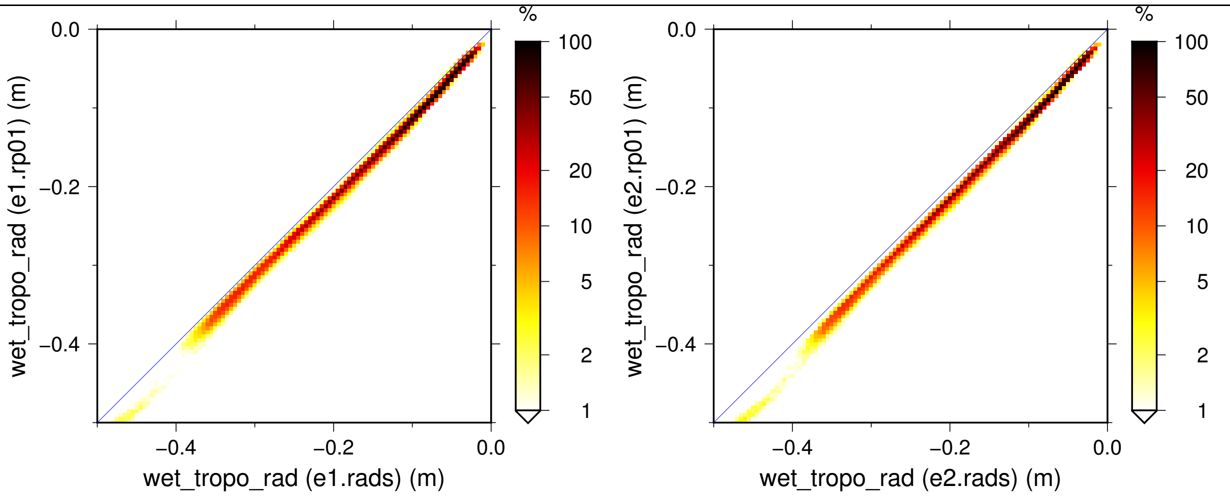

Figure 22. Comparison between the wet tropospheric corrections available on RADS (horizontal) and REAPER (vertical). Colours represent densities of points in a logarithmic scale. Left: ERS-1. Right: ERS-2.

4 Sea state bias model for the REAPER data

The derivation of the sea state bias model follows the one reported in [R5].

Before injecting the REAPER data into the computation of the sea state bias, the following changes were made:

- Apply a timing bias of 0.68 milliseconds (added to the time tags) and adjust the orbital altitude accordingly.
- Remove data flagged for bad orbit quality or PTR outliers as described above.
- Use the DTU10 mean sea surface as reference.
- Use the ERA Interim wet tropospheric correction in order to avoid the issues with biased brightness temperatures discussed above.
- Do not apply any sea state bias correction.

The resulting sea state bias models are in sigma0-SWH space (Figure 23). They are slightly different, particularly because of the differences between ERS-1 and ERS-2 low wave heights.

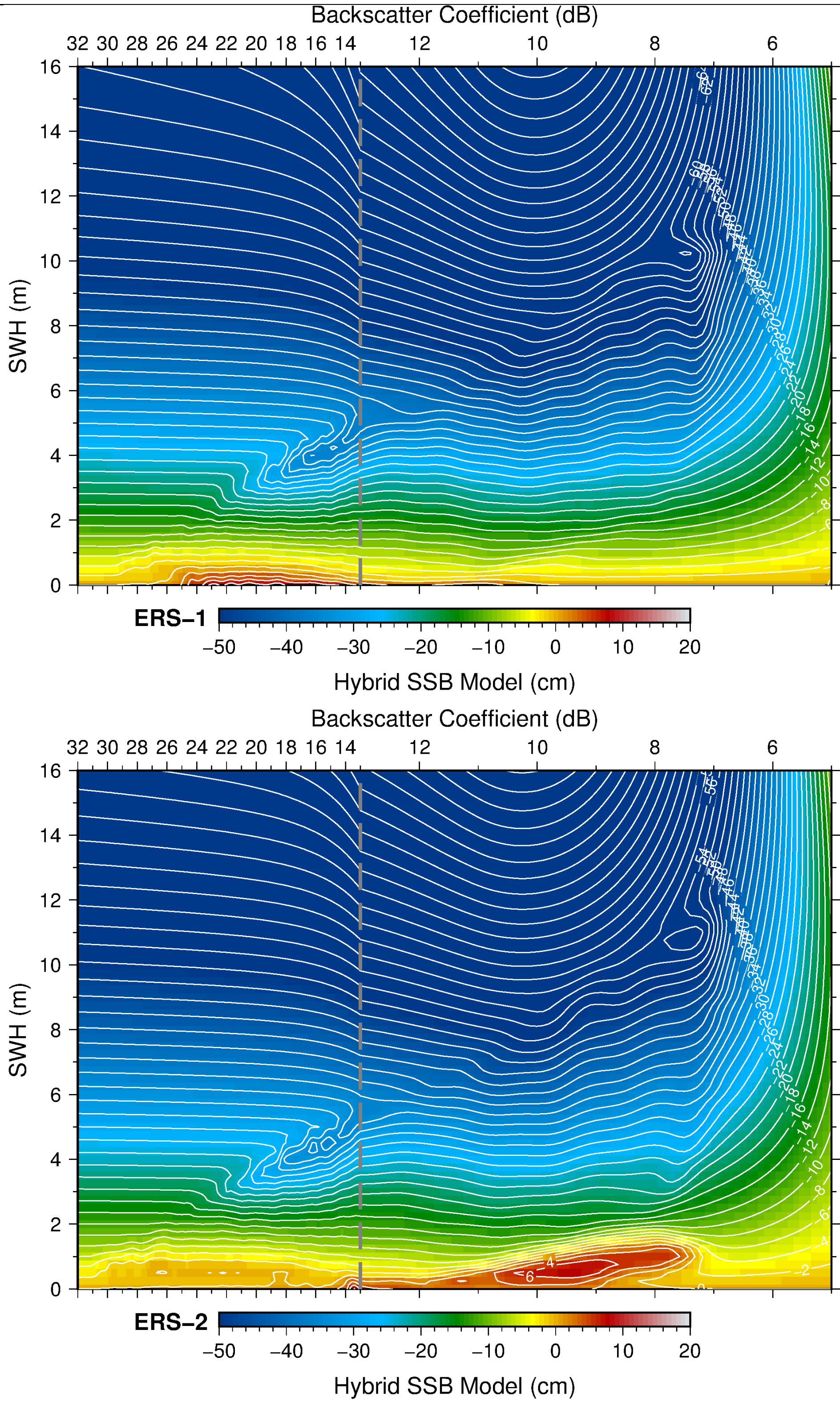

Figure 23. Hybrid sea state bias models for ERS-1 (top) and ERS-2 (bottom).

5 File Format and Conventions

This section discusses issues with the data format, metadata and the description in the Product Specification [AD1]. This applies to all versions of the REAPER products.

5.1 NetCDF Conventions

The REAPER Level 2 files are binary netCDF files. NetCDF is a format to produce "self-documenting" binary files that is popular in the meteorological and geophysical scientific world. NetCDF files contain metadata information for each variable contained in the file, though netCDF itself does barely or not prescribe how this metadata information should be filled. However, there are various conventions set up to standardise the metadata information such that humans and computer tools alike can parse them with ease. The most common conventions that apply to a very wide range of data types are COARDS [R1] and CF [R2], the latter of which is also used for the current Jason-1 and Jason-2 GDR data. Since COARDS can be considered a subset of CF, any COARDS-compliant product is CF-compliant.

It should be lauded that REAPER uses the netCDF format, rather than the CEOS-type format used in the past for ERS-1 and ERS-2, which contained no description of the data variables contained in the product whatsoever. Moreover, since version 01.08, the REAPER products have also become CF-complaint, which was a major change from the previous versions.

In the CF-compliant version the metadata information is clearly much more informative and follows proscribed conventions. In the next sections I will discuss any remaining discrepancies of the REAPER data with the CF conventions, remaining errors, or opportunity for improvements.

5.2 Variable Naming

There are very few conventions on how variables should be named, but there are some clear guidelines on how to do this, following the experience already obtained in the Jason-1 and Jason-2 products where netCDF products are now common.

- Do not use any special characters except the underscore. The REAPER L2 products comply with this standard.
- Use lower case only. Since version 01.08 the REAPER data comply with this convention.
- Use the suffix `_20hz` for 20-Hz data, and no suffix for 1-Hz data. The rationale behind this is that it simplifies the (reduced) Meteo products that contain 1-Hz data only. Also this avoids needing to add the suffix `_1hz` to the standard deviation and number of valid points, which can be identified by the suffices `_rms` and `_numval`, respectively. REAPER v01.08 uses this standard.
- Further inconsistencies in the naming of variables that existed before version 01.08 have been removed.

5.3 Time Dimension

The REAPER products used a very awkward way of defining the time, using three variables `time_day` (short), `time_milsec` (long) and `time_micsec` (short). A much more convenient way is to store time is in a single double floating point variable `time`, and use the convention to use the same name for the dimension of the 1-Hz data. This convention is now properly implemented in REAPER v01.08.

5.4 Variable Attributes

The CF conventions [R1] define a large number of conventions to describe each variable in a netCDF dataset. When they are used systematically it largely improves the understanding of the data for users, as well as generic netCDF reading tools, including those provided by popular software products like Matlab.

Since version 01.08 all variables now carry attributes that follow the CF conventions, where applicable: `long_name`, `standard_name`, `source`, `units`, `scale_factor`, `add_offset`, `coordinates`, `_FillValue`, `comment`, `flag_values`, `flag_meanings`. This greatly facilitates the reading of the data by netCDF tools or custom software.

5.5 Geophysical Corrections

Until version 01.06 the geophysical corrections in REAPER are all added to the altimeter range. Fortunately, this unwise decision was reverted, and the altimeter range was since version 01.06 only corrected for instrumental effects.

Since version 01.08 the REAPER data also use the `_FillValue` attribute to indicate invalid values of corrections, thus making the awkward `f_corr_error_1hz` field superfluous.

5.6 Remaining Issues

While a lot has been improved in the file format, a few errors slipped through. The remaining issues are listed below, together with a suggestion of how to fix them in due course without having to reprocess all the REAPER data.

5.6.1 atmos_corr_sig0

The variable `atmos_corr_sig0` has the wrong `long_name`: in stead of "`square of the off nadir angle computed from Ku waveforms`" it should be "`atmospheric attenuation correction to backscatter coefficient`".

For clarity it would be wise to add the `comment` attribute: "`This correction is already applied to ocean_sig0`".

In addition to the above, the `scale_factor` is wrong: 0.0001 should be 0.01. Otherwise the integer values appear correct, so only the scale was in error.

5.6.2 hf_fluctuations_corr

The variable name, the `long_name`, and the `standard_name` of `hf_fluctuations_corr` wrongly suggests that this is only the high-frequency part, but it is not. It is, in fact, the total inverse barometer correction, like I prefer. It may be wise to remove that `standard_name`.

5.6.3 ocean_tide_non_equil

Somehow I thought that `ocean_tide_non_equil` was *not* part of `ocean_tide_sol1` and `ocean_tide_sol2`, but later figured out it was. Maybe that should be made clearer in a comment attribute. See Section 3.2.8.

5.6.4 mission (global attribute)

The global attribute `mission` is still not always set to "`E1`" or "`E2`". It is only once in error on ERS-1 data, but many times in error from ERS-2 cycle 36 onwards. For example, in file `E2_REAP_ERS_ALT_2M_19980924T160448_19980924T160804_RP01.nc`

```
      :mission = "0 " ;
```

5.6.5 Suggested fix

Most of these issues can simply be fixed by using the `ncatted` command supplied with the NCO package (http://nco.sourceforge.net). Example:

```
ncatted -h \
-a long_name,atmos_corr_sig0,o,c,"atmospheric attenuation correction to backscatter coefficient" \
-a scale_factor,atmos_corr_sig0,o,d,0.01 \
-a comment,atmos_corr_sig0,c,c,"This correction is already applied to ocean_sig0" \
-a mission,global,o,c,"E2" \
E2_REAP_ERS_ALT_2M_19980924T160448_19980924T160804_RP01.nc \
E2_REAP_ERS_ALT_2M_19980924T160448_19980924T160804_RP02.nc
```

5.7 Pass Files

Files are currently given by data dump. These files partly overlap, which makes them rather inconvenient to handle.

It is recommended that these files are provided as pass files, running between the respective roll-over points at the Arctic and Antarctic. Odd pass numbers should be ascending passes, even number descending passes.

6 Orbit and range quality flags

As discussed before, in Sections 3.1.3 and 3.3.2, there is a lack of a quality flag for the orbital altitude, to indicate bad quality orbits as a result of manoeuvres. I identified these orbits (or orbit segments) by looking at pass data that had large outliers with long-period variations. En passant, I identified a few outliers that are more likely due to errors in the PTR values.

Both are captured in the files e1_flags.dat and e2_flags.dat provided as deliverables to the REAPER project. Both files are ASCII and their meaning is explained in the headers to the files, starting with a hash (#). Those two files are printed verbatim below.

6.1 File e1_flags.dat

```
# e1_flags.dat
#
# This file contains information about raising flags in the RADS
# data files. Each line holds the instruction for the setting
# of one flag.
#
# The meaning of each of the columns is as follows:
# (1) Flag to be set or cleared (11 = quality of range, 15 = quality of orbital alti-
tude)
# (2) Set (1) or clear (0)
# (3) Cycle
# (4)-(5) Pass range
# (6) Selection code for additional editing (-1=none, 2=latitude)
# (7)-(8) Limits for additional editing on field specified in (6)
# (9) Remark
#
# Original records used with OPR v6 data
11 1  34   77   77 -1   0   0  'Degradation of range'
15 1  35    2   14 -1   0   0  'Set degraded orbit flag'
15 1  61    1   86 -1   0   0  'Set degraded orbit flag'
15 1  62    1   86 -1   0   0  'Set degraded orbit flag'
15 1  63    1   57 -1   0   0  'Set degraded orbit flag'
11 1  65   49   50 -1   0   0  'Degradation of range'
11 1  65   61   61 -1   0   0  'Degradation of range'
11 1  65   79   79 -1   0   0  'Degradation of range'
11 1  83  672  672  2  40  60  'Degradation of range after switch-on'
15 1  86  375  376 -1   0   0  'Set degraded orbit flag'
11 1  86  995  995  2   0  20  'Degradation of range after switch-on'
11 1  87  192  192  2 -90 -70  'Degradation of range'
11 1  92  995  995  2   0  20  'Degradation of range after switch-on'
15 1 100  356  365 -1   0   0  'Set degraded orbit flag'
11 1 100  414  414 -1   0   0  'Degradation of range'
11 1 104    2   86 -1   0   0  'Degradation of range'
11 1 122   39   57 -1   0   0  'Degradation of range'
11 1 137   76   77 -1   0   0  'Degradation of range'
15 1 151  268  283 -1   0   0  'Set degraded orbit flag'
11 1 155  995  995  2   0  20  'Degradation of range after switch-on'
#
# Added as part of REAPER project, 2014-04-01
# Orbit flags
15 1 152  986 1001 -1   0   0  'Set degraded orbit flag'
11 1 154  898  903 -1   0   0  'Set degraded orbit flag'
#
# Added as part of REAPER project, 2014-06-15
```

```
# Orbit flags
15 1  16   22   42 -1   0   0  'Set degraded orbit flag'
15 1  48   48   57 -1   0   0  'Set degraded orbit flag'
15 1  55   18   19 -1   0   0  'Set degraded orbit flag'
15 1  63   82   86 -1   0   0  'Set degraded orbit flag'
15 1  64    1    7 -1   0   0  'Set degraded orbit flag'
15 1  65   52   53 -1   0   0  'Set degraded orbit flag'
15 1  65   60   63 -1   0   0  'Set degraded orbit flag'
15 1  71    6    8 -1   0   0  'Set degraded orbit flag'
15 1  71   50   74 -1   0   0  'Set degraded orbit flag'
15 1  83  201  244 -1   0   0  'Set degraded orbit flag'
15 1  83  273  293 -1   0   0  'Set degraded orbit flag'
15 1  83  364  379 -1   0   0  'Set degraded orbit flag'
15 1  83  453  487 -1   0   0  'Set degraded orbit flag'
15 1  87  566  567 -1   0   0  'Set degraded orbit flag'
15 1  90  389  389 -1   0   0  'Set degraded orbit flag'
15 1  90  178  224 -1   0   0  'Set degraded orbit flag'
15 1  90  533  549 -1   0   0  'Set degraded orbit flag'
15 1  94  513  523 -1   0   0  'Set degraded orbit flag'
15 1 101  108  168 -1   0   0  'Set degraded orbit flag'
15 1 102   55   77 -1   0   0  'Set degraded orbit flag'
15 1 138   52   52 -1   0   0  'Set degraded orbit flag'
15 1 140 1093 1098 -1   0   0  'Set degraded orbit flag'
15 1 142 2156 2166 -1   0   0  'Set degraded orbit flag'
15 1 142 2184 2185 -1   0   0  'Set degraded orbit flag'
15 1 143   15   17 -1   0   0  'Set degraded orbit flag'
15 1 144  520  520 -1   0   0  'Set degraded orbit flag'
# Range flag (probably OLC PTR)
11 1  46   44   44 -1   0   0  'Degradation of range, probably OLC'
11 1  35   61   61 -1   0   0  'Degradation of range, probably OLC'
11 1  54   54   54 -1   0   0  'Degradation of range, probably OLC'
11 1  57   20   20 -1   0   0  'Degradation of range, probably OLC'
11 1  79    5    5 -1   0   0  'Degradation of range, probably OLC'
11 1  82    1   86 -1   0   0  'Degradation of range, probably OLC'
11 1  87  566  566  2 -90 -30  'Degradation of range'
11 1 140 3620 3620  2 -90 -30  'Degradation of range, probably OLC'
11 1 142 3567 3567 -1   0   0  'Degradation of range, probably OLC'
11 1 142 4580 4580 -1   0   0  'Degradation of range, probably OLC'
11 1 149  241  241 -1   0   0  'Degradation of range, probably OLC'
```

6.2 File e2_flags.dat

```
# e2_flags.dat
#
# This file contains information about raising flags in the RADS
# data files. Each line holds the instruction for the setting
# of one flag.
#
# The meaning of each of the columns is as follows:
# (1) Flag to be set or cleared (11 = quality of range, 15 = quality of orbital alti-
tude)
# (2) Set (1) or clear (0)
# (3) Cycle
# (4)-(5) Pass range
# (6) Selection code for additional editing (-1=none, 2=latitude)
# (7)-(8) Limits for additional editing on field specified in (6)
# (9) Remark
#
```

```
11 1 19  904 1002 -1   0   0  'Eliminate data ERS-2 Cycle 19 pass 904 - Cycle 20 pass
51, reason unknown'
11 1 20    1   51 -1   0   0  'Eliminate data ERS-2 Cycle 19 pass 904 - Cycle 20 pass
51, reason unknown'
11 1 23  203  203  2  25  24  'Eliminate data between 25N and 45N, UTC jump'
11 1 27  612  612  2 -60 -45  'Eliminate data between 45S and 60S, anomaly in internal
calibration'
11 1 31  396  396  2  -7   1  'Eliminate data between 7S and 1N, anomaly in internal
calibration'
11 1 31  402  402  2  20  60  'Eliminate data between 20N and 60N, anomaly in internal
calibration'
11 1 32  402  402  2 -55 -20  'Eliminate data between 55S and 20S, anomaly in internal
calibration'
11 1 35  276  276  2  45  65  'Eliminate data between 45N and 65N, anomaly in internal
calibration'
11 1 36  246  246  2  35  40  'Eliminate data between 35N and 40N, telemetry problems'
11 1 36  555  555  2 -70 -40  'Eliminate data between 70S and 40S, telemetry problems'
11 1 36  973  973  2  50  60  'Eliminate data between 50N and 60N, telemetry problems'
11 1 37  660  660  2  -5  40  'Eliminate data between 5S and 40N, slope of unknown
reason'
11 1 39  682  682  2 -21 -15  'Eliminate data between 15S and 21S, telemetry problems'
11 1 48   78   78  2  25  40  'Eliminate data between 25N and 40N, payload restart'
11 1 52  920  920  2  20  30  'Eliminate data between 20N and 30N, telemetry problem'
11 1 54  202  202  2  50  90  'Eliminate data above 50N, telemetry problem'
#
# Added as part of REAPER project, 30-03-2014
# Orbit flags
15 1  4  260  260 -1   0   0  'Set degraded orbit flag'
15 1  7  575  583 -1   0   0  'Set degraded orbit flag'
15 1  7  986  999 -1   0   0  'Set degraded orbit flag'
15 1  8  312  346 -1   0   0  'Set degraded orbit flag'
15 1 79  424  461 -1   0   0  'Set degraded orbit flag'
15 1 83  212  227 -1   0   0  'Set degraded orbit flag'
# Range flag (probably OLC PTR)
11 1  9  898  898 -1   0   0  'Degradation of range, probably OLC'
11 1  9  992  992  2  10  90  'Degradation of range, probably OLC'
#
# Added as part of REAPER project, 15-06-2014
# Orbit flags
15 1 14    5    7 -1   0   0  'Set degraded orbit flag'
15 1 17  210  227 -1   0   0  'Set degraded orbit flag'
15 1 19  333  432 -1   0   0  'Set degraded orbit flag'
15 1 23  202  211 -1   0   0  'Set degraded orbit flag'
15 1 25  411  413 -1   0   0  'Set degraded orbit flag'
15 1 30  925  939 -1   0   0  'Set degraded orbit flag'
15 1 32  934  949 -1   0   0  'Set degraded orbit flag'
15 1 36   43   43 -1   0   0  'Set degraded orbit flag'
15 1 37  754  769 -1   0   0  'Set degraded orbit flag'
15 1 50  477  483 -1   0   0  'Set degraded orbit flag'
15 1 52   90   92 -1   0   0  'Set degraded orbit flag'
15 1 53  328  328 -1   0   0  'Set degraded orbit flag'
15 1 53  612  614 -1   0   0  'Set degraded orbit flag'
15 1 54  493  495 -1   0   0  'Set degraded orbit flag'
15 1 54  942  945 -1   0   0  'Set degraded orbit flag'
15 1 54  949  959 -1   0   0  'Set degraded orbit flag'
15 1 57  404  445 -1   0   0  'Set degraded orbit flag'
15 1 59   30   30 -1   0   0  'Set degraded orbit flag'
15 1 59   32   32 -1   0   0  'Set degraded orbit flag'
```

```
15 1 60  788  930 -1   0   0  'Set degraded orbit flag'
15 1 60  988 1002 -1   0   0  'Set degraded orbit flag'
15 1 61   10   20 -1   0   0  'Set degraded orbit flag'
15 1 62  321  339 -1   0   0  'Set degraded orbit flag'
15 1 68  166  170 -1   0   0  'Set degraded orbit flag'
15 1 68  605  607 -1   0   0  'Set degraded orbit flag'
15 1 69  120  131 -1   0   0  'Set degraded orbit flag'
15 1 69  214  333 -1   0   0  'Set degraded orbit flag'
15 1 72  454  461 -1   0   0  'Set degraded orbit flag'
# Range flag (probably OLC PTR)
11 1 14  906  906  2  -5  20  'Degradation of range, probably OLC'
11 1 15  622  622  2  30  90  'Degradation of range, probably OLC'
11 1 27  811  811  2 -15  90  'Degradation of range, probably OLC'
11 1 35  291  291 -1   0   0  'Degradation of range, probably OLC'
11 1 40  639  639 -1   0   0  'Degradation of range, probably OLC'
11 1 45  639  639 -1   0   0  'Degradation of range, probably OLC'
11 1 48   78   78  2   0  90  'Degradation of range, probably OLC'
11 1 56  777  777 -1   0   0  'Degradation of range, probably OLC'
11 1 58  832  832 -1   0   0  'Degradation of range, probably OLC'
11 1 59  527  527 -1   0   0  'Degradation of range, probably OLC'
11 1 60  222  222  2 -30   0  'Degradation of range, probably OLC'
11 1 68  298  298 -1   0   0  'Degradation of range, probably OLC'
11 1 68  328  328 -1   0   0  'Degradation of range, probably OLC'
11 1 68  611  611 -1   0   0  'Degradation of range, probably OLC'
11 1 70  177  177  2   0  90  'Degradation of range, probably OLC'
11 1 71  162  162  2   0  90  'Degradation of range, probably OLC'
```