ENVISAT ALTIMETRY
Level 2 Product Handbook

Envisat Altimetry Level 2 User Manual V 2.0 March 2018

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DOCUMENT STATUS SHEET

Issue	Date	Reason for change
0.1	06/06/2005	First version
1.0	05/01/2006	QWG review
1.1	20/06/2006	Spelling correction
1.3	20/01/2010	Review version in line with Linux IPF 6.02L04 and for BoM reprocessing
1.4	09/08/2011	Review version to take account of ENVISAT Orbit Change in October 2010, and IPF 6.04
2.0	27/06/2018	Review version for ENVISAT Baseline v3.0

1 RA-2/MWR PRODUCT USER GUIDE

1.1 Introduction

ENVISAT is the follow-on altimetry mission to ERS1 and ERS2. This mission supports ten different onboard instruments dedicated to the global observation of our environment. Our interest relates to ocean and ice observation using the RA-2 radar altimeter and the MWR microwave radiometer.

A complete description of the new RA-2 and MWR instruments can be found in the RA-2/MWR Product handbook, at http://envisat.esa.int/handbooks/ [RD1].

In this document, the NRT (Near Real Time) product term is used for FDGDR and/or FDMAR data processed with the IPF processing chain, whereas the OFL (Offline) product term is used for IGDR, IMAR, GDR and SGDR data processed with the IPF for Level 1b and CMA processing chain for Level 2.

From version 2.0, this document describes only the Offline products generated by the reprocessing of ENVISAT Phase-F data, after the end of the operational mission. The latest product version for the ENVISAT Phase F is Processing Baseline v3.0.

For the description of FDGDR and/or FDMAR NRT (Near Real Time) products or IGDR, IMAR, GDR and SGDR OFL (Offline) products generated during ENVISAT Phase-E, please refer to the release v1.4 of this manual. The last product version for the ENVISAT Phase E was the Processing Baseline v2.1.

The data products considered as valid for altimetry are the ones starting from the 25th of September 2002 onwards. The ENVISAT mission ended on 08 April 2012, following the unexpected loss of contact with the satellite.

1.2 Handbook Purpose and Overview

This user manual is a complement to the complete Product Handbook [RD1] which describes all the data from Level 0 to Level 2 including Level 1B. The aim of this user manual is to provide the user with information that is limited to the formats and content of the Level 2 Geophysical Data Record (GDR) product.

Section 1 gives an overview of the Altimetric system's health

Section 2 provides general information about the convention used to build the product

Section 3 provides information on the re-processing chains

Section 4 describes the NetCDF structure of the overall products

Section 5 provides a description of each product's field

Section 6 gives some altimetry applications and information on the error budget

Section 7 describes some software and tools useful for EnviSat

Section 8 gives some general information

Section 9 is the glossary

Section 10 includes the references

Annex 1 provides a table that includes the cycle number and its start and end date for the first hundred cycles

1.3 Altimetric system health overview

1.3.1 Altimetric mission overview

From April 2002 to October 2010, ENVISAT 's orbital period is 35 days, like ERS-2 and some of the ERS-1 phases.

The RA-2 S-band module is definitively lost since January 18th, 2008.

To ensure an additional 3 years lifespan, the ENVISAT satellite moved to a new lower orbit on October 22th, 2010. From November 2nd, 2010, for the ENVISAT extension orbit, the ground track changes and consequently the repeat cycle changes: 30 days with 431 orbits per cycle instead of 35 days-501 orbits per cycle.

In April 2012, few weeks after celebrating its tenth year of service, ENVISAT has stopped sending data to Earth. ESA declared the end of mission for ENVISAT on May 9th, 2012.

For further information, refer to ESA website https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat

1.3.2 Altimetric mission health

1.3.2.1 USO clock frequency instabilities

The Ultra Stable Oscillator (USO) is the specific clock of the RA2 instrument. It is used for range measurements. The time measured by this clock will determine how long has the echo been travelling. From that measured time, provided on-board in USO clock counts, the distance travelled and therefore the range can be computed. This clock was built to show a highly stable behaviour to provide, in turn, very accurate range measurements. It has a nominal counter clock frequency of 100 KHz, increased onboard up to 80 MHz to reach the nominal Tx/Rx clock frequency.

However, the USO clock frequency has not been completely stable throughout the mission and so there is a need to apply certain corrections for different periods. These “anomalies” and the applied solutions to correct for them are described below.

1.3.2.1.1 USO anomaly

The Ultra Stable Oscillator (USO) onboard ENVISAT has gone through periods of different behaviour since the beginning of the mission. Figure 1 synthesizes the periods when it was affected by the USO anomaly

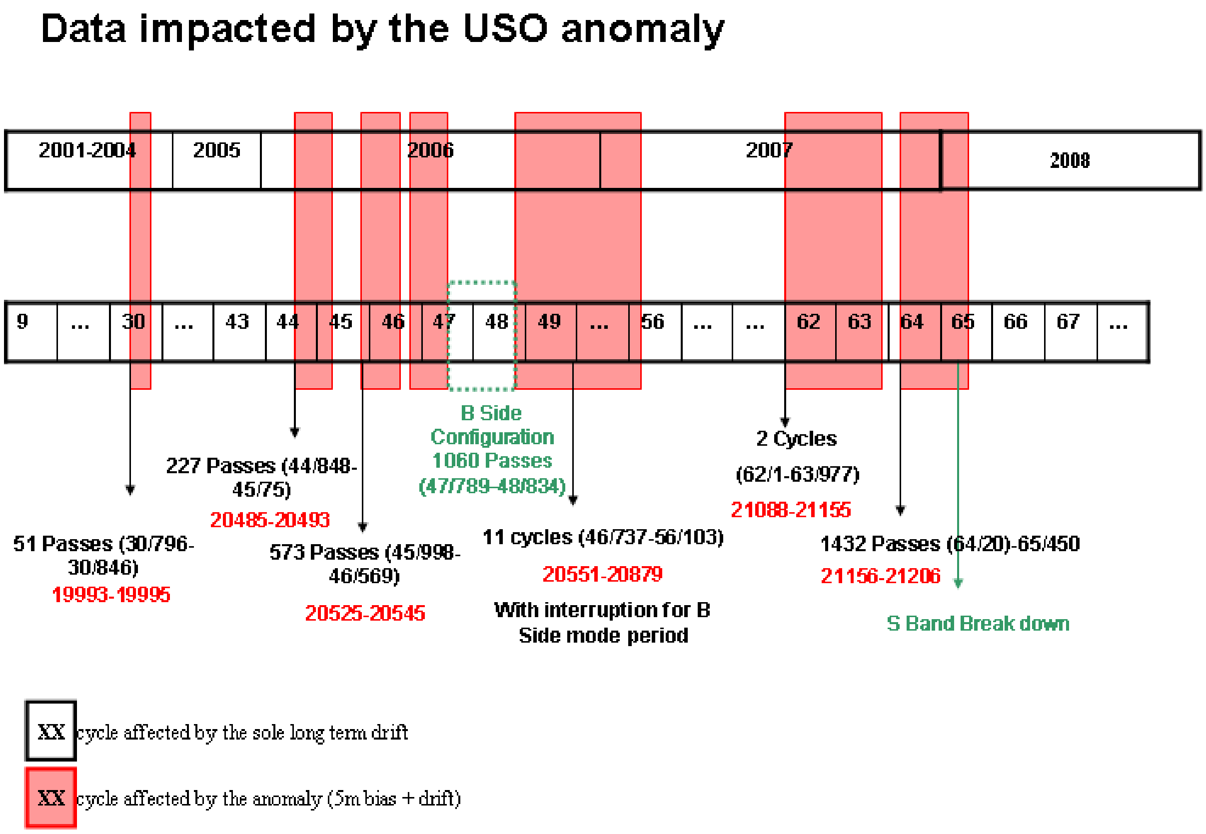

Figure 1: USO anomalies chronology

The USO Clock Period anomaly was almost permanently present during 2006 and 2007. It started in cycle 44, on date 1 Feb 2006 12:04:30, Orbit = 205181. It happened directly after the recovery of the RA-2 on-board anomaly, which occurred on the 2006/02/01 at 05:17:56. During the anomalous period, the altimetric range jumped by several meters (about 5.6m) w.r.t. the Mean Sea Surface due to an anomaly in the USO clock period. Moreover, oscillations at the orbital period with an amplitude of 20-30 cm affect the Sea Level Anomaly making the range unusable for both Ku and S Band. The anomaly persisted intermittently until the 15th of May 2006 14:21:50, Orbit = 21994, when the instrument was switched to its RFSS B-side. It appeared again when the instrument was switched back to its nominal RFSS A-side on date 21 June 2006 13:20:15, Orbit = 22523. The anomaly reappeared after the instrument recovery on date 27th of September 2007 11:13:30 and disappeared again for an unknown reason on date 3rd of December 2007 03:00:00. The anomaly was back again on the 4th of December 2007 13:50:00 and it lasted until the 23rd January 2008 14:11:35, orbit = 30840. Note that the correction comes back to its nominal value in several steps, causing small uncertainties in the associated correction.

For all V3.0 reprocessed data, even in the USO anomaly period, the range is corrected from the proper USO Period in the L1b processing stage.

1.3.2.1.2 Description of the agreed solution to correct the data from USO

Due to the two possible scenarios, anomalous or non-anomalous periods, two different solutions have been agreed for the current USO correction within the L1b processing.

Both solutions have in common that the error on the USO clock period is derived from a comparison between the time measured by the USO clock in a known time lag (one Source Packet) and the time measured by the platform clock in the same time lag. The platform clock is referenced to an atomic clock on ground.

The differences are described below.

The solution for non-anomalous periods is based in a moving window average of the USO clock frequency during 3000 seconds. By this mean, the orbital sub-millimeter oscillations of the USO clock frequency are corrected.

For anomalous periods the results must take into account a higher orbital variability of the USO clock frequency of 30cm in range error. Therefore, first a running window average of 100 values is computed, and after, a smoothing spline interpolation is applied, with a smoothing factor calibrated for this particular case.

In heating periods after an instrument switch off, the USO clock frequency is particularly impacted, showing a sudden drop until the thermal conditions on-board are stabilized. A dedicated processing was done for this specific scenario, applying spline interpolation tuning the smoothing factor for each particular case, or smoothing by polynomial fitting if necessary.

Note that this correction is done at L1b processing, as it is an instrumental correction. Hence, L2 processing starts from a range already clean from any USO clock frequency variations impact.

1.3.2.2 S-Band power drop

The RA2 S-Band transmission power dropped on 17 January 2008. This occurred in the region of the South Atlantic Anomaly, showing similar characteristics as for the RA-2 RFSS Side B S-Band power drop anomaly which occurred in May 2006. Since then none of the S-Band parameters, nor any parameters that depend on the S-Band, are valid, and MUST NOT be used from the following date: **17 January 2008, 23:23:40, UTC, orbit = 30759**. The parameters that depend on the S-Band are the:

- Dual ionospheric correction in both bands which are no longer valid. Users are advised to use the GIM ionospheric correction.
- Rain flag, which is no longer valid.

Investigations have been conducted and the failure of the S-Band power stage is considered to be permanent since **17 January 2008, 23:23:40, UTC, orbit = 30759**.

1.3.2.3 RA2 B-Side Operation and Fixed Chirp bandwidth

Due to the USO anomaly it was decided to switch the RA2 instrument to its B-Side between the 15th May 2006 and 21st June 2006 and to operate using fixed Chirp bandwidth on 12-13th May 2006.

Before the switch to the B-side operation, on 12th-13th May, a special operation was executed to limit RA-2 Chirp Bandwidth to:

- 80MHz, starting from 12 May at.15.51.37,
- 20 MHz, starting from 13 May at.03.57.57,
- 320MHz, starting from 13 May at.15.10.17.

During cycle 47 the instrument sub-system Radio Frequency Module (RFM) was switched to its B-side on **May 15th, 2006 at 14:21:50, Orbit = 21994**. After a few days of promising operations with the RFM B-side, its S-band transmission power dropped on 20th May 2006 at 13:24:57, Orbit=22065, making all the S Band related parameters invalid.

Due to the lost of the S-Band, the ENVISAT RA-2 instrument was successfully reconfigured to its nominal side (RFSS A-side) and commanded back into Measurement Mode on **June 21th, 2006 at 13.20.15.000 UTC time, Orbit = 22523**. Subsequent analysis of the RA-2 data showed expected behaviour of the RA-2 parameters but also confirmed the persistence of the abnormal RA-2 Ultra-Stable Oscillator (USO) behaviour affecting the Altimetric Range by a few meters.

1.3.2.4 36.5 GHz channel gain drift

Since the beginning of the mission, all MWR instrumental parameters (sky horn counts, hot load counts, gain, and residual temperature) measured at 36.5 GHz have been drifting with time.

A thorough analysis of the instrument behaviour has been performed. The conclusion was that the gain drift was the same, whatever the observed brightness temperature. This observation shows that the problem does not come from the detection stage, as suspected, but probably further in the amplification stage (defective amplifier).

The actual impact on the geophysical data is still under investigation, but up to now, no significant drift has been observed in the L1B and L2 data.

2 CONVENTIONS

2.1 Vocabulary

The radar altimetry user community has developed a vocabulary of common terms which have a specific meaning. While these are (mostly) clear to experienced users the terms can be confusing to newcomers. This section explains the common terms and conventions used within this User Manual.

AGC (automatic gain control) is the setting of the onboard receiver attenuator as transmitted by telemetry.

Altitude is the distance of a satellite's centre of mass above a reference point on the earth. The reference point will usually be on a geodetic reference frame or at the centre of the Earth. The altitude is given by the orbit computation.

Default value: when a physically meaningful value cannot be computed, a default value is provided. It is in most cases the maximum value of the field. There may be exceptions, in which case a particular description of the default value is provided.

Elementary measurements are the twenty measurements in the source packet.

Flags are used to convey quality information or operating modes. They are usually set to zero to mean ‘OK’ and 1 for ‘not OK’. Any spare flags are set to zero. There may be exceptions, in which case a particular description of the flag's use is provided.

Footprint is the area on the Earth's surface illuminated by the radar pulse. The altimeter boresight is pointed at nadir and the antenna half-power beamwidth is 1.3 degrees. At a height of 800 km this corresponds to a circular area 18 km across. However the short duration of the radar pulse normally means that a much smaller area of illumination is seen by the instrument. This is often referred to as the Pulse Limited Footprint.

Geophysical corrections are used to adjust the measurement for environmental effects (e.g. tropospheric, ionospheric) or to remove a geophysical signal of no (or even detrimental) interest to the application pursued (e.g. tides). These corrections are external to the measurement and come from other sources of data and models.

Height is the elevation of the mean surface observed at nadir above the reference ellipsoid. As a first approximation it is calculated from range and altitude (height = altitude - range).

Instrument source packet is a group of twenty elementary measurements packaged onboard and downlinked by telemetry. It holds the basic science data.

Individual echoes, or individual waveforms, are the 1800 Hz un-averaged waveforms. No other radar altimeter provided individual echoes prior to RA-2.

Orbit is one revolution around the Earth, when referring to the amount of data. Otherwise it refers to the positioning of the satellite; its orbital altitude. The Level 2 NRT products are organised by data flow, generally covering one orbit.

Pass is a half orbit going from pole to pole, ascending or descending. There are 1002 passes per cycle until the October 2010 orbit change, 862 after the orbit change (phase E3). The Level 2 OFL products are organised by pass.

Range is the one-way distance from the satellite to the mean surface below. It is referenced to the satellite's centre of gravity. It is the principal measurement of the radar altimeter. Range is estimated from the echo waveforms as part of the process called retracking.

Reference Ellipsoid is the WGS 84, defined by: Equatorial radius = 6378.137 km and Flattening coefficient = 1/298.2572236.

Sea level is synonymous with sea surface height (SSH).

Sea surface height = Satellite Altitude – (Measured Range + Corrections).

Sea surface topography, or dynamic topography, is the departure of the sea surface from an equipotential surface, the marine geoid.

Sigma0 is the backscatter estimate calculated from the AGC and the power level of the radar echo. The signal path attenuation, as calculated from the in-flight calibration records, is applied. To compute an accurate Sigma0, geophysical corrections such as liquid water and water vapour attenuation must be applied.

Slope refers to the gradient of the leading edge of the radar echo, so called the leading-edge slope.

Significant **W**ave **H**eight **(SWH)** is a measure of the sea state approximately equal to the average of the highest one-third of ocean waves in a given area or period of time and is calculated from the radar echo leading edge slope.

Time delay is the basic onboard instrument measurement converted to standard physical units. It is the two-way travel time of the radar pulse from the satellite to the surface and back. It is uncalibrated. The measurement is referenced to the centre of the range window: that is bin 63 (in the range 0 - 127) for the Ku-band window, and bin 31 (in the range 0 - 63) for the S-band window.

2.2 Filenaming conventions

The naming convention for products is described in "ENVISAT-1 Product Specifications Volume A: Product Data Conventions" [RD2].

2.2.1 Processing Baseline 3.0

With the Phase-F reprocessing (baseline v3.0) the ENVISAT RA2/MWR Level 2 product file name follows the Sentinel-3 file name convention (see web page at https://earth.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/naming-conventions) adapted to ENVISAT RA2/MWR products.

It is defined according to the following convention (96 characters):

MMM_SS_L_TTTTTT_yyyymmddThhmmss_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS _<instance ID>_GGG_<class id>.<extension>

Where:

MMM: mission ID (e.g. ENV for ENVISAT)
SS: data source for the instrument data (e.g. RA for RA2)
L: processing level: one digit or one underscore "_" (e.g.: "2" for Level-2 products or underscore "_" if processing level is not applicable.).
TTTTTT: data type ID (e.g. GDR___ for "standard" products, MWS___ for "enhanced" products)
yyyymmddThhmmss: Data Start time (15 characters).
YYYYMMDDTHHMMSS: Data Stop time (15 characters).
YYYYMMDDTHHMMSS: creation date of the product (15 characters)
<instance ID>: DDDD_CCC_LLLL___, 16 characters, either upper-case letters or digits or underscores "_".
DDDD: orbit duration Sensing data time interval in seconds
CCC: cycle number at the start sensing time of the product
LLLL: relative track number within the cycle at the start sensing time of the product (one track = half orbit)
3 underscores "_"
GGG: product generating centre, three characters (e.g. PAC for F-PAC processing center)
<class id>: platform, eight characters, either upper-case letters or digits or underscores: **P_XX_NNN**, where:
P : one upper-case letter indicating the platform (e.g. R for reprocessing or one underscore"_" if not relevant).
XX : two upper-case letters/digits indicating the timeliness of the processing workflow (e.g. NT for Non-Time Critical – i.e. consolidated products- or two underscores"__" if not relevant).
NNN: three letters/digits. Free text for indicating the baseline collection (e.g. 003 for reprocessing baseline v3.0) or data usage (e.g. test, GSV, etc) or three underscores

"___" if not relevant.
<extension>: 2 characters, the filename extension (e.g. nc for netCDF).

Example of the “standard” product filename (96 characters):

ENV_RA_2_GDR____20150101T102500_20150101T114000_20150101T115000_6101_003_1001____PAC_R_NT_003.nc

Example of the “enhanced” product filename (96 characters):

ENV_RA_2_MWS____20150101T102500_20150101T114000_20150101T115000_6101003_1001____PAC_R_NT_003.nc

2.2.2 Previous Processing Baselines (2.1 and earlier)

filename = <product_ID> <processing_stage_flag><originator_ID><start_day> <“_”> <start_time> <“_”> <duration> <phase>

<cycle> <“_”> <relative_orbit> <“_”> <absolute_orbit> <“_”><counter><“.”> <satellite_ID> <.extension>

For Level 2 GDR the product ID, WWW_XXX_YZ is:

- RA2_GDR_2P: For the reprocessed standard dataset including geophysical data records from RA-2 and MWR
- RA2_MWS_2P: For the reprocessed enhanced dataset including sensor data records from RA-2 and MWR, as well as Individual Waveforms from RA-2.

2.3 Correction Conventions

The geophysical correction given in the Level 2 products already has the appropriate sign and is to be added to the range.

The correction that has to be added to the measured range is usually as follows:

Geophysical Corrections = Inverse Barometer + Sea State Bias + Ionospheric Correction + Ocean Tide + Polar Tide + Earth Tide + Wet Tropospheric Correction + Dry Tropospheric Correction.

The instrumental range correction has already been added to the range. This correction is based on Doppler correction, time delay flight calibration and time delay ground calibration:

Instrumental Range Correction = Doppler correction + Time Delay Flight Correction + Time Delay Ground Correction

2.4 Time Conventions

The convention for the ENVISAT mission is to use a Modified Julian Day, which is referenced to Coordinated Universal Time from a datum of 1st January 2000.

2.5 Flagging and Editing

The L1b processed data are the ones with:

- operating mode set to RA-2 nominal tracking,
- waveform quality flags set to OK (= 0) meaning that the waveform samples are not set to 0.

Over the ocean, users are advised to edit the data according to:

Min. Value	Parameters	Max. Value	Unit (SI)
-2	SSH – mean sea surface height	2	m
10	Number of 18 Hz valid points for Ku-band	20	/
0	Range Standard deviation	0.25	m
-0.2	Off-Nadir angle square of the satellite from waveforms	0.16	deg^2
-2.5	Dry tropospheric correction	-1.9	m
-2	Inverse barometer correction or MOG2D correction	2	m
-0.5	MWR Wet tropospheric correction	-0.001	m
-0.4	Ionospheric correction	-0.04	m
0	Significant wave height	11	m
-0.5	Sea State Bias	0.01	m
7	Backscatter coefficient	30	db
-5	Ocean tide correction	5	m
-0.5	Long period equilibrium	0.5	m
-1	Earth tide correction	1	m
-5	Polar tide correction	5	m
0	Wind speed	30	m/s

Table 1: Proposed editing data over Ocean

The SSB threshold maximum value has been relax to +1cm to avoid a slight over editing due to the management of SWH null values, in accordance with CalVal recommendations ([RD16])

2.6 Default Values

Any field of the Level 2 output product which cannot be computed or determined during processing will be set to its default value.

- For an MCD indicator (one bit of a bit field) the default value is “1”, except for ‘spare’ bits which must be set to “0”.
- For an ASCII field, the default value is the corresponding string of blank characters.
- For any other field, the default value is the maximal value of the corresponding field (e.g. 65535 for an unsigned 2-byte integer).

3 PRODUCT EVOLUTION HISTORY

The processing baseline of the data produced during the latest ENVISAT reprocessing is identified by the version number "003" in the name of the data products.

The Table 2 below summarizes the models and standards that are adopted in this version of the ENVISAT GDRs.

Model	Baseline v3.0
Orbit	GDR-E orbit standard (from DORIS+SLR+GPS tracking data).
Dry Troposphere Range Correction	Two models: - Computed from ECMWF analysed atmospheric pressures and a model for S1 and S2 atmospheric tides - Computed from the integration of ECMWF ERA-Interim profiles at the altitude of the measurement and a model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from Model	Three models: - ECMWF analysis - Computed from the integration of ECMWF ERA-Interim profiles at the altitude of the measurement and a model for S1 and S2 atmospheric tides - GPD+
Sea State Bias	Derived from 1 year of ENVISAT altimeter data with version " **Baseline v3.0**" geophysical models ([RD10])
Mean Sea Surface	Two models: - CNES-CLS 15 ([RD7]) - DTU15 ([RD19])
Mean Dynamic Topography	CNES-CLS 13 ([RD20])
Geoid	EGM2008 ([RD5])
Bathymetry Model	ACE-2 ([RD9])
Inverse Barometer Correction	Two models: - Computed from ECMWF analysed atmospheric pressures after removing S1 and S2 atmospheric tides - Computed from ECMWF ERA-Interim atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency Dealiasing Correction	Two models: - Mog2D High Resolution ocean model.Ocean model forced by ECMWF analysed atmospheric pressures after removing S1 and S2 atmospheric tides - Mog2D High Resolution ocean model.Ocean model forced by ECMWF ERA-Interim atmospheric pressures after removing S1 and S2 atmospheric tides

Model	Baseline v3.0
Tide Solution 1	GOT4.10c ([RD11])
Tide Solution 2	FES2014b ([RD12])
Equilibrium long-period ocean tide model	From Cartwright and Taylor tidal potential
Non-equilibrium long-period ocean tide model	Mm, Mf, Mtm, Msqm, Sa, Ssa from FES2014b ([RD12])
Solid Earth Tide Model	From Cartwright and Taylor tidal potential
Pole Tide Model	From Wahr 1985
Wind Speed from Model	Two models: - ECMWF analysed 10u/10v wind speed - ECMWF ERA-Interim 10u/10v wind speed
Altimeter Wind Speed Model	Saleh Abdalla 2007 ([RD13])
Rain Flag	Derived from comparisons to thresholds of the radiometer-derived integrated liquid water content and of the difference between the measured and the expected Ku-band backscatter coefficient
Ice Flag	Derived from comparison of the model wet tropospheric correction to a dual-frequency wet tropospheric correction retrieved from radiometer brightness temperatures, with a default value issued from a climatology table
Slope models for Greenland and Antarctica	From MSSL 2010 ([RD29])

Table 2: Models and standards (ENVISAT Processing Baseline v3.0)

4 RA-2/MWR LEVEL 2 PRODUCTS

4.1 Introduction

During the Phase-E of the ENVISAT mission, there were six kinds of RA-2/MWR Level 2 products: the near real time with the FDGDR and FDMAR products, the interim GDR with the IGDR and IMAR products, and the offline with the GDR and SGDR products.

During the Phase-F of the ENVISAT mission, only the offline reprocessed GDR and SGDR products are still generated during dedicated reprocessing campaign. The description of the historical whole set of products is kept in this section only for the recall.

The Fast Delivery GDR products, **FDGDR**, were processed at the receiving stations and were transmitted in less than three hours, for weather forecasting, sea-state and real-time ocean-circulation applications. An ocean-related parameter subset of the FDGDR called **FDMAR** (for Marine Abridged Record) was extracted to reduce the volume of on-line data transfers. FDMAR was converted into the BUFR format commonly used by meteorological offices.

Less than three days later, the so-called Interim GDR, **IGDR**, for ocean-circulation monitoring and forecasting applications was delivered, replacing the original meteorological predictions with more precise analyses, and the preliminary orbit with an improved orbit solution. An **IMAR** ocean-related parameter was extracted from the IGDR product.

The final **GDR** and **SGDR** products containing the most precise instrument calibrations and orbit solutions were delivered after 30 days (not more than 50 days).

The near real time products, FDGDR and FDMAR, were processed inside the Payload Data Handling Stations at PDHS-E (ESRIN) and PDHS-K (Kiruna).

The Interim Geophysical Data Record (IGDR and IMAR), the final precision Geophysical Data Record (GDR) and SGDR products were processed offline at F-PAC, the French Processing and Archiving Centre in Toulouse.

As the GDR and SGDR products, the reprocessed GDR and SGDR products are processed offline at F-PAC, the French Processing and Archiving Centre in Toulouse.

Figure 2 summarises the organisation, the inter-relationships and latency of the product generation. The terminology used to name products is based on the nomenclature traditionally used in altimetry, with the product names stored in the first field of the specific product header.

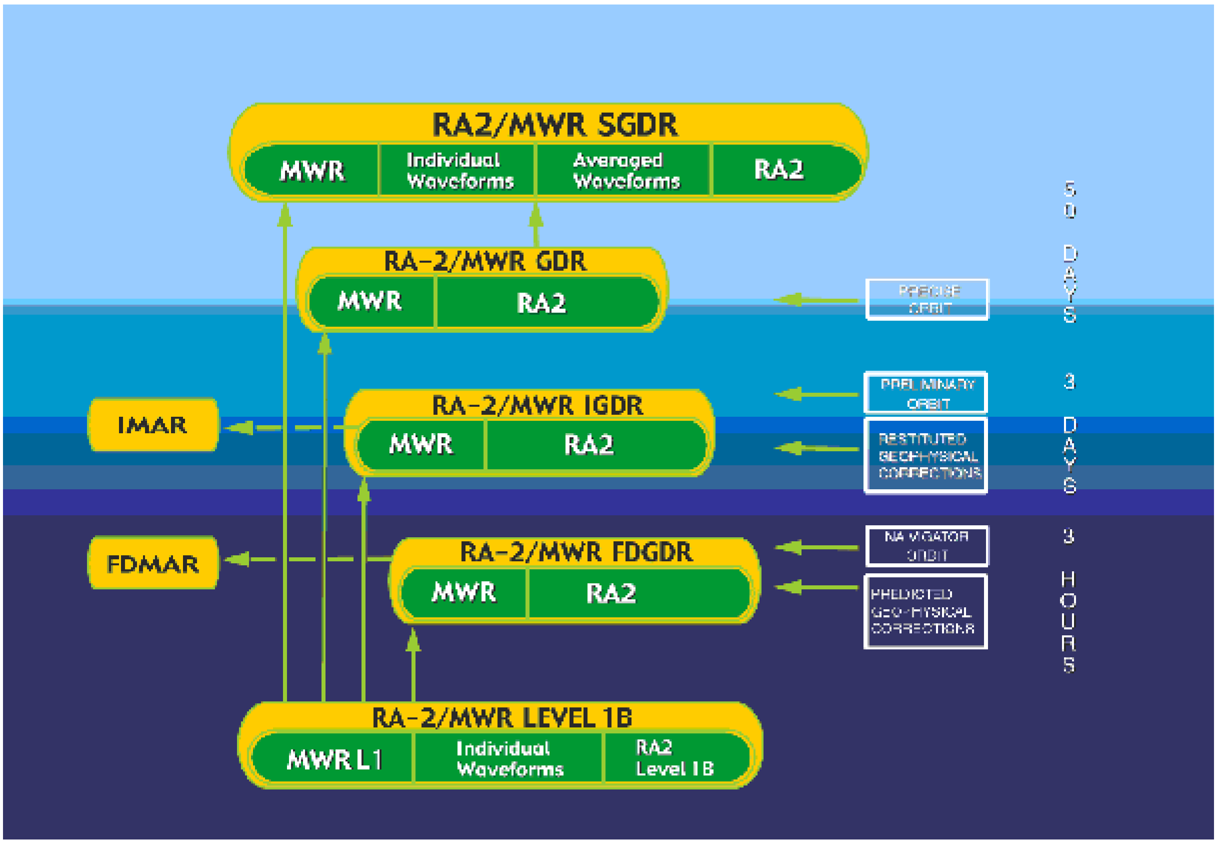

Figure 2: The RA-2/MWR Product Tree

The Level 2 geophysical data are converted to geophysical units (with retracking); the product mainly contains parameters for time tagging, geolocation, output from retrackers (range, wind speed, significant wave height, etc.) at 1 Hz, plus some 18 Hz parameters (range, orbital altitude). All geophysical products, including the near-real time products, are retracked (waveform data are fully processed by the ground-based processor to extract the geophysical parameters). In order to retrieve the geophysical parameters over all types of surface (ocean, ice, sea ice, etc.), four specialised retrackers are continuously run in parallel (over all surfaces):

- Ocean retracker: optimised for ocean surfaces and based on a modification of the Hayne model [Hayne, 1980].
- Ice-1 retracker: optimised for general continental ice sheets, a model-free retracker called the 'Offset Centre of Gravity Echo Model'; it is used for ERS and will ensure measurement continuity [RD26].
- Ice-2 retracker: optimised for ocean-like echoes from the continental ice-sheet interior, it is a Brown-based model retracking algorithm [RD27].
- Sea-Ice retracker: optimised for specular returns from sea ice, it is a threshold retracking scheme for peaky waveforms [RD28].

The usual necessary geophysical corrections are available in the Level-2 products. The ionospheric correction comes from the dual-frequency altimeter, backed-up by the GIM model. The wet tropospheric correction comes from the onboard microwave radiometer, backed-up by a value computed from ECMWF fields. Users requiring the altimeter waveforms will find them conveniently stored in the Level 2 SGDR product, along with the co-located geophysical corrections and the outputs of the four retrackers. In other words, the SGDR holds the GDR data augmented by averaged and individual waveforms.

A new NetCDF format has been defined for the ENVISAT Level-2 products in the frame of the ENVISAT Phase-F. This new format is applicable to ENVISAT Processing Baseline 3.0 and onward.

4.2 Standard and enhanced datasets

Accounting for both ENVISAT and Sentinel-3 heritages, products are split into two data sets:

- "standard" data set : One file close to ENVISAT GDR in terms of fields content, containing 1Hz and 18Hz values
- "enhanced" data set : One file close to ENVISAT SGDR in terms of fields content, containing 1Hz, 18hz and waveforms values

The equivalent of ENVISAT Phase-E FGDR products would have been a "reduced" dataset. This kind of product, very useful during the Phase-E of an altimetric mission, is not generated anymore in the frame of the Phase-F reprocessing.

4.3 Product format

The format of ENVISAT Level 2 User Products is the NetCDF-4 Classic, which combines the simpler data model of NetCDF-3 with the HDF5-based storage capabilities of NetCDF-4.

A NetCDF file contains dimensions, variables, and attributes, which all have both a name by which they are identified. These components can be used together to capture the meaning of data and relations among data fields in an array-oriented data set.

4.3.1 Dimensions

A dimension may be used to represent a real physical dimension, for example, time, latitude, longitude, or height. A dimension might also be used to index other quantities (waveforms index for example).

The following dimensions are used in the ENVISAT Level 2 User Products files:

		Data set	
Dimension name	**Value**	**standard**	**enhanced**
time_01	number of 1-Hz measurements	X	X
time_20	number of 20-Hz measurements	X	X
time_2k	number of 2-kHz measurements		X
fft_sample_ind_ku	128 (indexes of samples in Ku-band waveforms)		X
dft_sample_ind_ku	2 (indexes of additional dft samples in Ku-band waveforms)		X
fft_sample_ind_s	64 (indexes of samples in S-band waveforms)		X

4.3.2 Attributes

NetCDF attributes are used to store data about the data (ancillary data or metadata), similar in many ways to the information stored in data dictionaries and schema in conventional database systems. Most attributes provide information about a specific variable. These are identified by the name of that variable, together with the name of the attribute.

Some attributes provide information about the data set as a whole. They are called global attributes.

The Table 3 below shows the variable attributes used in the ENVISAT Level 2 User Products. There are no mandatory attributes.

Attribute	Description
_FillValue	A value used to represent missing or undefined data
add_offset	If present, this number is to be added to the date after it is read by an application. If both *scale_factor* and *add_offset* attributes are present, the date are first scaled before the offset is added.
Calendar	Reference time calendar
comment	Miscellaneous information about the data or the methods used to produce it
coordinates	Identified auxiliary coordinates variables.
Flag_meanings	Use in conjunction with *flag_values* to provide descriptive words or phrase for each flag value.
Flag_values	Provide a list of the flag values. Use in conjunction with *flag_meanings*.
Long_name	A descriptive name that indicates a variable's content. This name is not standardized.
Scale_factor	If present, the date are to be multiplied by this factor after the data are read by an application. See also *add_offset* attribute.
Units	Unit of a variable's content. The value of this attribute must be a string that can be recognized by the UNIDATA's Udunits package.
Valid_max	Largest theoretical valid value of a variable (this is not the maximum of actual data).
Valid_min	Smallest theoretical valid value of a variable (this is not the minimum of actual data).

Table 3: Variable's attributes

The list of the global attributes provided in standard and enhanced datasets is provided in [RD3].

4.3.3 Variables

Variables are used to store the bulk of the data in a NetCDF file. A variable represents an array of values of the same type. A scalar value is treated as a 0-dimensional array. A variable has a name, a data type, and a shape described by its list of dimensions specified when the variable is created. A variable may also have associated attributes, which may be added, deleted or changed after the variable is created.

A variable data type is one of a small set of NetCDF types. In this document the variable types will be represent as follows:

Variable type	Description

char	characters
byte	8-bit data signed
short	16-bit signed integer
int	32-bit signed integer
float	IEEE single precision floating point (32 bits)
double	IEEE double precision floating point (64 bits)

Table 4: NetCDF variable type

The description of the variables provided in standard and enhanced datasets is provided in [RD3].

5 ALTIMETRIC DATA

This section presents a short description of the main quantities on the GDR products.

Warning: all the S-Band parameters, as well as the parameters that depend on the S-Band, are no longer valid, and MUST NOT be used from the following date:

January 17th, 2008, 23:23:40, UTC, orbit = 30759

The Ku-band parameters that depend on the S-band and that therefore must not be used from this date are the following:

- RA-2 ionospheric correction on Ku-band
- RA-2 total electron content
- Altimeter rain flag
- Continental ice flag computed from both Ku-Band and S-Band (ice_sheet_snow_facies_flag_01)

5.1 Orbit and location

Orbit altitude

The 1 Hz altitude is obtained by interpolating the OSVs available in the DORIS precise (for GDR and SGDR) orbit files. These orbit ephemerides are produced by CNES with a radial accuracy better than 1.5 cm (RMS).

Orbit altitude rate

The 18 Hz altitude differences from 1 Hz altitude are computed from the elementary altitudes (extracted from the input L1b records) and the corresponding averaged altitude.

The 1 Hz altitude rate is obtained by interpolating the OSVs available in the DORIS precise orbit files.

Elevation of echoing point

The 1 Hz Elevation of echoing point corresponds to the mean slope-corrected elevation of the echoing points in the geodetic coordinate frame. The 1 Hz value is obtained by averaging only valid elevation measurements (i.e. tracking records for which the Ice-1 leading edge was inside bounds). Where a slope correction is invalid, the elevation value used relates to the elevation at the orbit nadir position corrected for tracker range offset.

The elevation differences of echoing point are computed by subtracting the mean elevation from the elementary elevation values.

Default values (set to 0) are output for non tracking records or for records where the Ice-1 leading edge is out of bounds.

Slope model present flags

Invalid records correspond to input data block not in Tracking/Preset Tracking/Preset Loop Output, or if the position of the input record is not within the models, currently only existing for Greenland and Antarctica). Bit 0 applies to the first data block. Unused bits are set to 0.

Latitude

The Geodetic Latitude is the 1 Hz latitude value defined as the latitude of the source packet centre (i.e. average of blocks 9 and 10). It is not corrected for surface slope and so represents the orbit track position. Positive north and negative south.

The full 18 Hz latitude can be reconstructed by adding the 18 Hz latitude difference to the 1 Hz latitude value.

The 18 Hz slope-corrected latitude differences are computed by subtracting the central 1 Hz latitude value (i.e. an average of the latitude locations for blocks 9 and 10) from the 18 Hz slope-corrected latitudes of the echoing point, calculated in the geodetic reference frame. Default values for the latitudes (i.e. input L1b latitude values) are used to compute these differences in the event of non tracking records and where a slope correction is not available.

Longitude

The Longitude is the 1 Hz longitude value defined as the longitude of the source packet centre (i.e. average of blocks 9 and 10). It is not corrected for surface slope and so represents the orbit track position. Positive East, 0 at Greenwich, and negative West.

The 18 Hz slope-corrected longitude differences are computed by subtracting the central 1 Hz longitude value (i.e. an average of the longitude locations for blocks 9 and 10) from the 18 Hz slope-corrected longitudes of the echoing point, calculated in the geodetic reference frame. Default values for the longitudes (i.e. input L1b longitude values) are used to compute these differences in the event of non tracking records and where a slope correction is not available.

The full 18 Hz longitude is reconstructed by adding the 18 Hz longitude difference to the 1 Hz longitude value.

5.2 Range

5.2.1 Tracker range

The 18 Hz Ku tracker range referenced to the CoG represents the Ku-band onboard rough estimates of the altimeter range (distance between the satellite and the overflown surface), produced by the model-free tracker. Specific ground processing (retracking of the waveforms) is requested to retrieve accurate estimates of the altimeter range over ocean, ice and sea ice.

The elementary tracker range values are derived from the L1b Ku window delay values and then corrected for the distance between the satellite's CoG and the RA-2 antenna's phase centre, and adjusted for the Doppler effects.

Default values are output if the corresponding elementary measurement is not Tracking/Preset Tracking/Preset Loop Output, if the input Ku and S waveform samples are all set to 0, or if the AGC_Ku or Ku Rx delay value is out of bounds.

5.2.2 Range

Corrected range

The range provided in ENVISAT GDR has already been corrected for a variety of calibration and instrument effects, including calibration errors, pointing angle errors, center of gravity motion, and terms related to the altimeter acceleration such as Doppler shift and oscillator drift. The sum total of these corrections is provided in the GDR products for each of the Ku and S band ranges (see net_instr_cor_range_20_ku and net_instr_cor_range_20_s). The drift of the USO frequency is accounted for in the range as well. Although it is an instrumental correction, it is not included in the sum of instrumental corrections.

Retracking quality

Invalid records correspond to non tracking record, sum of all Ku and S waveform filters set to 0, Ku AGC or Ku onboard Rx delay out of bounds, leading edge out of bounds or average power smaller than a multiple of the noise power).

5.2.3 Range instrumental corrections

Doppler correction

The Doppler corrections are computed from the 20 Hz orbital altitude rates with respect to the reference ellipsoid.

The 18 Hz Ku-band delta-Doppler range correction is calculated for a sloping surface. It is obtained by subtracting the flat surface Doppler correction from the general slope corrected Doppler.

The default value is output if the elementary measurement is not Tracking/Preset Tracking/Preset Loop Output, if there is a data gap between adjacent orbit values, if the next record is invalid, or if this is the last record of a file.

Net instrumental correction

The 18 Hz Ku/S-band net instrumental correction on the range is the sum distance antenna-COG (accounting for center of gravity motion), internal path correction, Doppler correction, modeled instrumental errors correction and system bias

For Processing Baseline V3.0, the modeled instrumental errors correction and the system bias on range are set to zero.

5.2.4 Range corrections due to tidal effects

There are several contributions to the tidal effect: the ocean tide, the load tide, the solid earth tide and the pole tide. The ocean tide, load tide and solid earth tide are all related to luni-solar forcing of the earth, either directly as is the case of the ocean and solid earth tide, or indirectly as is the case with the load tide since it is forced by the ocean tide. The pole tide is due to variations in the earth's rotation and is unrelated to luni-solar forcing.

Geocentric ocean tide

The two geocentric ocean tide values provided on the ENVISAT GDR, solution 1 and solution 2, are computed with diurnal and semidiurnal ocean and load tide values predicted by the GOT and FES models, respectively.

Both geocentric ocean tide fields (ocean_tide_sol1_01 and ocean_tide_sol2_01) also include the load tides from the respective models (load_tide_sol1_01 and load_tide_sol2_01), and the equilibrium long-period ocean tide (ocean_tide_equil). These two fields (ocean_tide_sol1 and ocean_tide_sol2) also include the S1 oceanic response to atmospheric pressure based on the model from Ray and Egbert (2004). The FES model also includes the M4 ocean tide. Note that the load tide fields (load_tide_sol1 and load_tide_sol2) only include the load tides from the GOT and FES models, and do not contain the load tides from the S1, M4, or equilibrium long-period ocean tides.

Both models are interpolated to provide the geocentric ocean and load tides at the location of the altimeter measurement, and an interpolation quality flag is provided in the GDRs to indicate the quality of this interpolation (see interp_flag_ocean_tide_sol1 and interp_flag_ocean_tide_sol2).

Long period ocean tide

The ENVISAT GDR explicitly provides a value for an equilibrium representation of the long-period ocean tide that includes all long-period tidal components excluding the permanent tide (zero frequency) component (see parameter ocean_tide_eq_01). Note that both geocentric ocean tide values on the GDR (ocean_tide_sol1 and ocean_tide_sol2) already include the equilibrium long-period ocean tide and should therefore not be used simultaneously.

The ENVISAT GDR provides a separated parameter for a non-equilibrium representation of the long-period ocean tides (see parameter ocean_tide_non_eq_01). This parameter is provided as a correction to the equilibrium long-period ocean tide model so that the total non-equilibrium long period ocean tide is formed as a sum of ocean_tide_eq_01 and ocean_tide_non_eq_01. Note that geocentric ocean tide values on the GDR (ocean_tide_sol1 and ocean_tide_sol2) do not include the non-equilibrium representation of the long-period ocean tides.

Solid earth tide

The solid earth tide provided in the ENVISAT GDR is computed as a purely radial elastic response of the solid Earth to the tidal potential (see parameter solid_earth_tide_01). The adopted tidal potential is the *Cartwright and Tayler* [1971] and *Cartwright and Edden* [1973] tidal potential extrapolated to the 2000 era, and includes degree 2 and 3 coefficients of the tidal potential. The permanent tide (zero frequency) term is excluded from the tidal potential that is used to compute the solid earth tide parameter for the ENVISAT GDR. The elastic response is modeled using frequency independent Love numbers. The effects of the resonance in the core are accounted for by scaling the tide potential amplitude of the K1 tidal coefficient and some neighboring nodal terms by an appropriate scale factor.

Pole tide

The pole tide is the geocentric tide height due to polar motion (see pole_tide_01 parameter).

The pole tide is computed as described in *Wahr* [1985]. Modeling the pole tide requires knowledge of proportionality constants, the so-called Love numbers, and a time series of perturbations to the Earth's rotation axis, a quantity that is now measured routinely with space techniques. Distinct Love numbers are used over ocean and over land.

The polar coordinates are obtained from the IERS centre (International Earth Rotation and Reference Systems Service), that updates the position of the pole approximately twice a week.

5.2.5 Range corrections due to atmospheric effects

Dry and wet tropospheric corrections from model

Two sets of dry and wet tropospheric corrections from ECMWF meteorological fields are provided in the products. The first set is computed from ECMWF analysis (see parameters mod_dry_tropo_cor_01 and mod_wet_tropo_cor_01). The second set is computed from ECMWF ERA-Interim reanalysis (see parameters mod_dry_tropo_cor_reanalysis_01 and mod_wet_tropo_cor_reanalysis_01).

Both dry tropospheric corrections are derived from the ECMWF surface pressure corrected from the S1 and S2 signals (diurnal and semi-diurnal) thanks to the use of climatology of S1 and S2 and a specific modelling of these atmospheric tides ([RD17]).

The wet tropospheric correction from ECMWF analysis is computed from the ECMWF wet tropospheric correction grids.

The wet tropospheric correction from ECMWF ERA-Interim reanalysis is computed by integration of the humidity and temperature profiles at the real measurement altitude.

In addition to ECMWF-derived WTC correction, the ENVISAT products now include GPD Plus (GPD+) Wet Tropospheric Corrections (see parameter gpd_wet_tropo_cor_01). The GPD+ WTC method is the merged of two WTC retrieval methods called DComb (Data Combination) and GPD (GNss-derived Path Delay) ([RD24]). The flag GPD_wet_tropo_cor_qual_01 indicates the validity of this correction. It is considered invalid whenever it is outside the limits [-0.5m, 0m]. This may be because e.g. the model-value used as first guess is outside these limits or because the estimate is considered invalid due to internal criteria established inside the GPD algorithm.

Inverted barometer correction

The inverted barometer height correction is computed according to the following formula:

H_Baro (mm) = - b [Psurf - Pbar]

where b = 9.948 mm/hPa, Psurf is the surface atmospheric pressure at the location and time of the altimeter measurement, and Pbar is the instantaneous mean of the atmospheric pressure over the global ocean.

The High Frequency Wind and Pressure Response correction is the difference between the MOG2D estimate and the inverse barometer, where MOG2D is the sum of the high frequency variability of the sea surface height and the low frequency component of the inverse parameter with a filtering between HF/LF at 20 days ([RD17]).

This parameter is provided in the ENVISAT GDR products as a correction to the inverse barometer correction.

The ENVISAT GDR provides two sets of inverted barometer corrections and high frequency corrections. The first set comes from ECMWF analysis (see parameters inv_bar_cor_01 and hf_fluct_cor_01), the second set comes from ECMWF ERA-Interim reanalysis (inv_bar_cor_reanalysis_01 and hf_fluct_cor_reanalysis_01).

Dual frequency ionospheric correction

The ENVISAT GDR provides an altimeter ionospheric correction determined from the range at the two Ku-Band and S-Band frequencies (see parameters iono_cor_alt_01_ku and iono_cor_alt_01_s).

Ku-Band and S-Band sea state bias corrections are first added to the Ku-Band and S-Band altimeter ranges to correct them, because sea state bias may be different for the two frequencies. Let Rc_Ku and Rc_S be the corresponding corrected values.

The ionospheric corrections Iono_alt_Ku and Iono_alt_S (in mm) are given for the two frequencies by the following equations:

$\text{Iono\_RA2\_Ku} = \delta f_{Ku} * (\text{Rc\_Ku} - \text{Rc\_S})$

$\text{Iono\_RA2\_S} = \delta f_{S} * (\text{Rc\_Ku} - \text{Rc\_S})$

with:

$\delta f_{Ku} = (\text{f\_S})^2 / [(\text{f\_Ku})^2 - (\text{f\_S})^2]$

$\delta f_S = (f\_Ku)^2 / [(f\_Ku)^2 - (f\_S)^2]$

where f_Ku and f_S are the transmitted frequencies (in Hz)

Filtered ionospheric correction

The ENVISAT GDR provides a filtered ionospheric correction (see parameter filtered_iono_cor_alt_01_ku).

The filtering is computed through an iterative method issued from CNES SLOOP project, where median and Lanczos filtering are applied ([RD23]) (see parameter filtered_iono_cor_alt_01_ku).

GIM Ionospheric correction

The ENVISAT GDR provides a ionospheric correction derived from Global Ionospheric Map (GIM) (see parameter iono_cor_gim_01_ku).

RA-2 total electron content.

The RA-2 total electron content (e^-/m^2) is given by:

$TEC\_RA\text{-}2 = RA\text{-}2\_ion\_corr\_ku * (f\_Ku)^2/(-40250)$

Where f_Ku is the Ku-band radar wavelength.

5.2.6 Range corrections due to atmospheric effects

Sea state bias is the difference between the apparent sea level as 'seen' by an altimeter and the actual mean sea level.

The sea state biases for Ku-band and S-band are computed, in mm, by bilinear interpolation from a table given as function of Ku-band's significant wave height and the RA-2 wind speed.

The look-up table in Ku-band was derived from one year of ENVISAT data, using crossover SSH differences and applying the non parametric estimation technique ([RD10]).

5.3 Significant wave height

Significant wave height

The significant wave height (SWH) provided in ENVISAT GDR has already been corrected for the instrument effects. These corrections are provided in the GDR products (see parameters mod_instr_cor_swh_01_ku, net_instr_cor_swh_20_ku and net_instr_cor_swh_20_s).

Square of the significant wave height

According to user requirements, the square of the significant wave height is estimated and filled in ENVISAT GDR. The purpose is to keep all the values even when the square is negative. This occurs when the SigmaC parameter (estimated by the ocean retracking) is smaller than the response width of the target point, due to speckle.

Standard deviation of 18 Hz significant wave height

The ENVISAT GDR provides the RMS of the "ocean" significant waveheight.

This parameter is set to default value whenever the number of valid elementary Ku ocean SWH values used for the averaging is less than a minimum threshold (currently set to 6).

5.4 Wind speed

Altimeter wind speed

The altimeter wind speed is computed (in m/s), using a linear interpolation in the input wind table, according to the algorithm proposed by Abdalla [RD13]. The algorithm is based on a fit between ENVISAT Ku-band Sigma0 and the collocated ECMWF model wind speed. The result was then adjusted based on *in-situ* wind measurements.

Wind speed from model

The ENVISAT GDR provides two sets of two parameters for the U and V component of the model 10-metre wind vector. The first set comes from ECMWF analysis (see parameters wind_speed_mod_u_01 and wind_speed_mod_v_01), the second ones comes from ECMWF ERA-Interim reanalysis (wind_speed_mod_u_reanalysis_01 and wind_speed_mod_v_reanalysis_01).

5.5 Mispointing

Off nadir angle of the satellite from platform data

The squared off-nadir angle (in radians) from the platform is derived from the interpolated pitch and roll mispointing angles.

Off nadir angle of the satellite from waveform data

The squared off-nadir angle (in radians) from the waveform is derived from the slope of the trailing edge of the waveform. This slope is derived from the Ice-2 retracking algorithm.

5.6 Estimations dedicated to land ice or sea ice surfaces

Three specialised retrackers are dedicated to land ice or sea ice surfaces:

- Ice-1 retracker: optimised for general continental ice sheets, a model-free retracker called the 'Offset Centre of Gravity Echo Model'; it is used for ERS and will ensure measurement continuity ([RD26]).
- Ice-2 retracker: optimised for ocean-like echoes from the continental ice-sheet interior, it is a Brown-based model retracking algorithm ([RD27]).
- Sea-Ice retracker: optimised for specular returns from sea ice, it is a threshold retracking scheme for peaky waveforms ([RD28]).

The specificities of the ENVISAT GDR parameters outputs from these retrackers are described below.

18 Hz Ice-1 ranges

See parameters range_ice1_20_ku, range_ice1_20_s.

If retracking fails due to a bad waveform, the onboard range estimate is used.

18 Hz Sea-Ice ranges

See parameter range_sea_ice_20_ku.

If retracking fails due to a bad waveform, the onboard range estimate is used.

18 Hz Ice-1 ranges

See parameters range_ice2_20_ku, range_ice2_20_s.

If retracking fails due to a bad waveform, the onboard range estimate is used.

Ice-1 retracking quality

Invalid records correspond to non tracking record, sum of all Ku waveform filters set to 0, leading edge out of bounds or average power smaller than a multiple of the noise power.

Sea-ice retracking quality

Invalid records correspond to non tracking record, sum of all Ku waveform filters set to 0, leading edge out of bounds or average power smaller than a multiple of the noise power.

Ice-2 retracking quality

Invalid records correspond to non tracking record, sum of all Ku and S waveform filters set to 0, Ku AGC or Ku onboard Rx delay out of bounds, leading edge out of bounds or average power smaller than a multiple of the noise power.

18 Hz slope of the first/second part of the trailing edge from the Ice-2 retracker

See parameters slope_first_trailing_edge_ice2_20_ku, slope_first_trailing_edge_ice2_20_s, slope_second_trailing_edge_ice2_20_ku, slope_second_trailing_edge_ice2_20_s.

Default values are output whenever the Ku (resp. S) waveform leading edge is not found or the maximum amplitude-thermal noise ratio is too low, as when coming from the Ice-2 retracker.

Echo and geo corrections

See parameters echo_cor_range_20_ku, geo_cor_range_20_ku, and associated quality flags echo_cor_range_qual_20_ku and geo_cor_range_qual_20_ku.

These corrections are determined by LEGOS/CTOH over Antarctica ([RD21]).

The echo correction parameter provides the range correction for echo shape variation with time. The geographical correction parameter provides the range correction for the across-track shift induced geographical variations.

5.7 MWR-derived parameters

The ENVISAT Microwave Radiometer (MWR) measures the brightness temperatures in the nadir path at 23.8 GHz and 36.5 GHz. Brightness temperatures measurements are combined with the estimation of the Ku-band backscatter coefficient to obtain the path delay in the satellite range measurement due to the water vapor content.

Radiometer wet tropospheric correction

The MWR wet tropospheric correction (see parameter rad_wet_tropo_cor_01) is retrieved using a neural network algorithm. A global and representative database has been built using ECMWF analyses from surface and atmospheric parameters, and simulations of the brightness temperatures and backscattering coefficient in Ku-band.

The architecture of the network (one layer of 12 hidden neurons) and the weights of each neuron are determined to produce the most accurate estimate of the wet tropospheric correction.

Classically, the inputs of the retrieval algorithm are 23.8 GHz and 36.5 GHz brightness temperatures (tb_238_01 and tb_365_01) interpolated to RA-2 time tag and the Ku-band backscatter coefficient not corrected for atmospheric attenuation ([RD8]).

Note that a new instrumental calibration was derived in April 2015 leading to the use of a new set of neural network coefficients. These latter were updated in order to benefit from improvements in ECMWF model used in their estimation.

Alternatively, lapse rate (decreasing rate of the atmosphere temperature with altitude, climatological values) and the sea surface temperature are used as additional inputs in a new neural algorithm in order to provide a path delay with an improved accuracy (see parameter rad_wet_tropo_cor_sst_gam_01). For ENVISAT GDR, the sea surface temperature is the NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (or daily OISST) ([RD22]). Climatologically values are used for the lapse rate.

Brightness temperatures

In ENVISAT GDR, the brightness temperatures and the standard deviation of brightness temperatures are interpolated to the altimeter time tag.

Atmospheric attenuation correction

The backscatter coefficient two-way MWR atmospheric attenuation (in dB) is nominally retrieved from the radiometer brightness temperatures, together with the Ku-band backscatter coefficient. Whenever this retrieval cannot be performed, the atmospheric attenuation is retrieved from the model wet tropospheric correction (mod_wet_tropo_cor_01), and the flag indicating the use of climatological values is set to “climato_used”.

5.8 Quality indicators

Peakiness

The peakiness is the ratio of the maximum amplitude and the mean amplitude of the waveform, weighted by the ratio of the number of samples on the right of the tracking point and the total number of samples of the waveform (128). This independent waveform quality assessment parameter is computed irrespective of surface type.

The 1 Hz peakiness value is obtained by arithmetic averaging of the 18 Hz peakiness values of the tracking records.

Ku-band rain attenuation

The rain attenuation (dB) is calculated using the ocean backscatter coefficient for Ku-band, σ0_Ku (dB) ([RD6]) by:

Rain_Att = Exp_Sigma0_Ku - σ0_Ku

where the expected Ku-band backscatter coefficient, Exp_Sigma0_Ku, is determined by linear interpolation from the input table, as a function of the S-band backscatter coefficient.

Sea-Ice flag

The sea-ice flag is computed from MWR brightness temperatures and RA-2 Ku band backscatter cross-section ([RD14]).

It provides the sea-ice type as first-year ice, multi-year ice, ambiguous ice observed during summer, mixture of types or no sea-ice (i.e. ocean). It has been developed with a twofold purpose: (1) to detect sea-ice corrupted sea surface height data within quality control processing for ocean applications; and (2) to help cryosphere analysis by the provision of the sea-ice type estimated from the altimeter mission data.

This flag is associated with 4 values indicating the membership of the pixel to each class (see parameters open_water_class_01_ku, first_year_ice_class_01_ku, multi_year_ice_class_01_ku and wet_ice_class_01_ku). The membership values correspond to intermediate information for expertise purpose of the algorithm only. They are provided in percentage given between 0 and 1.

Ice-sheet snow facies type flag

The ice-sheet snow facies type flag is computed from MWR brightness temperatures and RA-2 Ku and S band backscatter cross-section (see parameter ice_sheet_snow_facies_flag_01). A second ice-sheet snow facies type flag computed from MWR brightness temperatures and RA-2 Ku band backscatter cross-section only (see parameter ice_sheet_snow_facies_flag_01_ku). This second flag allow retrieving the information even after the loss of the S band.

This flag is dedicated to ice-sheet studies. It consists in a snow flag that aims to separate different snow regions within the polar ice sheets based on their microwave signatures. This approach broadens the description of the snow pack by considering characteristics such as surface roughness, snow grain size along with snow melt effects. The difference in snow morphology is due to variable conditions in local climate which is governed by local topography. Such partition of the ice sheet might help to better understand relationships between microwave signatures and snow morphology and might represent a tool for tracking the effects of climate change ([RD25])

Altimeter rain flag

The rain flag is computed from Ku- and S- band altimeter backscatter coefficients, and from the MWR liquid water content, interpolated to RA-2 time ([RD15]):

This flag is calibrated only over ocean.

Radiometer land/ocean flag

When MWR data are not available, this flag is set to its default value which is 1 (land).

5.9 Individual Echoes

A Level-2 SGDR enhanced product includes the Individual Echoes. These I&Q echoes are stored on-board at 1800 Hz rate (100 times more than conventional 18Hz) during a limited period of time without the averaging step. A dedicated RAIES (Radar Altimeter Individual EchoeS) L1B processor have been developed for processing the individual echoes, accounting for the on-board pending steps and on-ground L1B science processing up to the same level of the common science products.

The results are appended to the SGDR products, including the power and phase individual waveforms, power scaling factor, tracker range, geolocation, altitude, time tagging and others (see parameters suffixed with "_2k"). A confidence flag is included to warn the first measurement after a macro-command, having many of these cases non-valid data (see parameter db_conf_flag_2k).

Each of these high frequency science echoes shows a very noisy shape, which is new for a typical L1B product user. The speckle noise, intrinsic to the altimetry individual measurements, is usually reduced onboard after averaging, but here is present.

The fact that individual echoes come as IQ data, and not power waveforms, makes it valuable for studies focused on the phase of science echoes. The data rate itself also permits expert users to develop advanced algorithms to retrieve interesting geophysical observations.

6 ALTIMETRY APPLICATIONS

6.1 Sea Level Anomaly (SLA)

The sea surface height (SSH) is the height of the sea surface above the reference ellipsoid.

It is calculated by subtracting the corrected range from the Altitude:

Sea Surface Height = Orbit - Corrected Range

The corrected (Ku band) range is given by:

Corrected Range =	Range + Wet Troposphere Correction + Dry Troposphere Correction + Ionosphere Correction + Sea State Bias Correction

The sea level anomaly (SLA) is the difference between the observed sea surface height and the mean sea level. The SLA allows us to monitor ocean variability due to seasonal variations and climatic phenomena. The SLA formula is defined below:

Sea Level Anomaly =	Sea Surface Height - Mean Sea Surface - Solid Earth Tide Height - Geocentric Ocean Tide Height - Pole Tide Height - Inverted Barometer Height Correction - HF Fluctuations of the Sea Surface Topography

Orbit:

Use the 1-Hz orbit altitude (alt_01) for the computation at 1-Hz.

Use the 18-Hz orbit altitude (alt_20) for the computation at 18-Hz.

Range:

Use the 1-Hz Ku-band ocean range (range_ocean_01_ku) for the computation at 1-Hz.

Use the 18-Hz Ku-band ocean range (range_ocean_20_ku) for the computation at 18-Hz.

Wet Troposphere Correction:

Use MWR-Gamma/SST correction (rad_wet_tropo_cor_sst_gam_01) or GPD+ correction (gpd_wet_tropo_cor_01) for the computation at both 1-Hz and 18-Hz.

Dry Troposphere Correction:

Use model correction (mod_dry_tropo_cor_01) for the computation at both 1-Hz and 18-Hz.

Ionosphere Correction:

Before the 17 January 2008, 23:23:40, UTC, orbit = 30759: use filtered ionospheric correction (filtered_iono_cor_alt_01_ku) for the computation at both 1-Hz and 18-Hz.

After the 17 January 2008, 23:23:40: use the GIM ionospheric correction (iono_cor_gim_01_ku) for the computation at both 1-Hz and 18-Hz.

Sea State Bias Correction:

Use Ku-band sea state bias correction (sea_state_bias_01_ku) for the computation at both 1-Hz and 18-Hz.

Tide Height:

Use Solid Earth Tide Height (solid_earth_tide_01), geocentric ocean tide solution 2 (ocean_tide_sol2_01), pole tide height (pole_tide_01) for the computation at both 1-Hz and 18-Hz.

Mean sea surface:

Use 1-Hz mean sea surface solution 1 (mean_sea_surf_sol1_01) for the computation at 1-Hz.

Use 18-Hz mean sea surface solution 1 (mean_sea_surf_sol1_20) for the computation at 18-Hz.

WARNING

The users are advertised to check the default values and the quality flags associated with the variables when using the data (See the variable attributes "_fillValue" and "quality_flag" described in section 4.3.2).

An example of an ENVISAT SLA map is shown below.

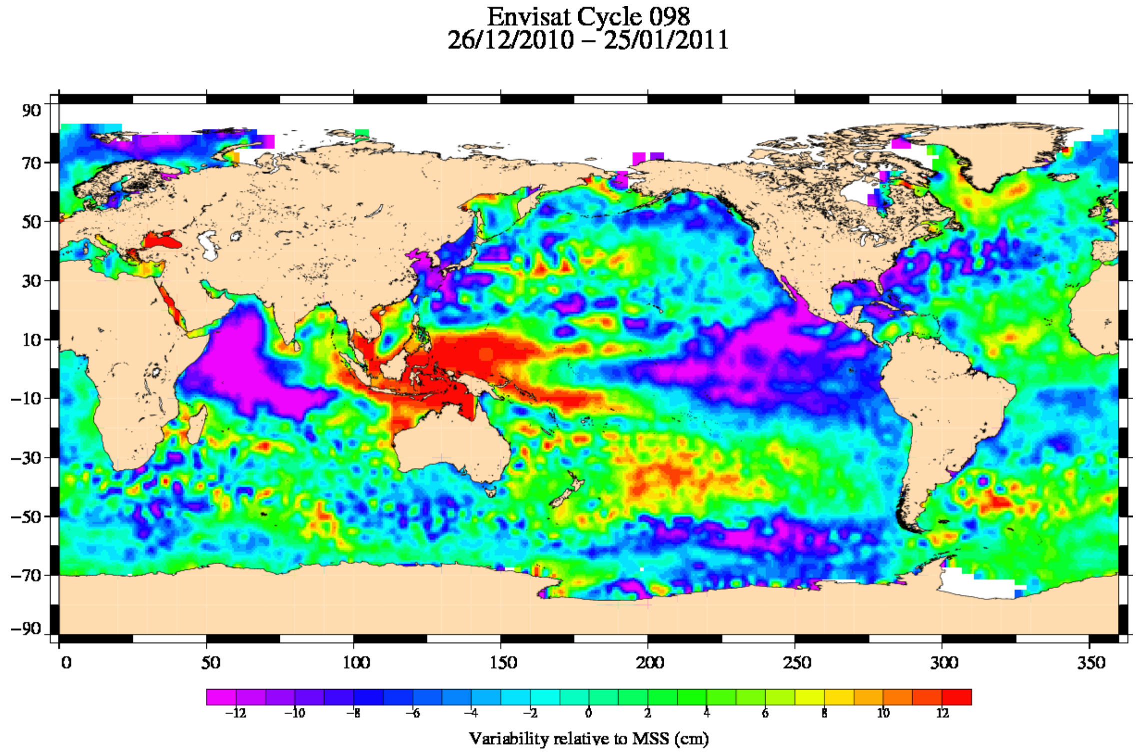

Figure 3: Variability relative to MSS (cm)

6.2 Monitoring trends in Mean Sea Level

The global mean level of the oceans is one of the most important indicators of climate change. It incorporates the reactions from several different components of the climate system. Precise monitoring of changes in the mean level of the oceans, particularly through the use of altimetry satellites, is vitally important, for understanding not just the climate but also the socioeconomic consequences of any rise in sea level.

For more information concerning scientific studies related to MSL for altimetric missions including Envisat, see the following address:

https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html

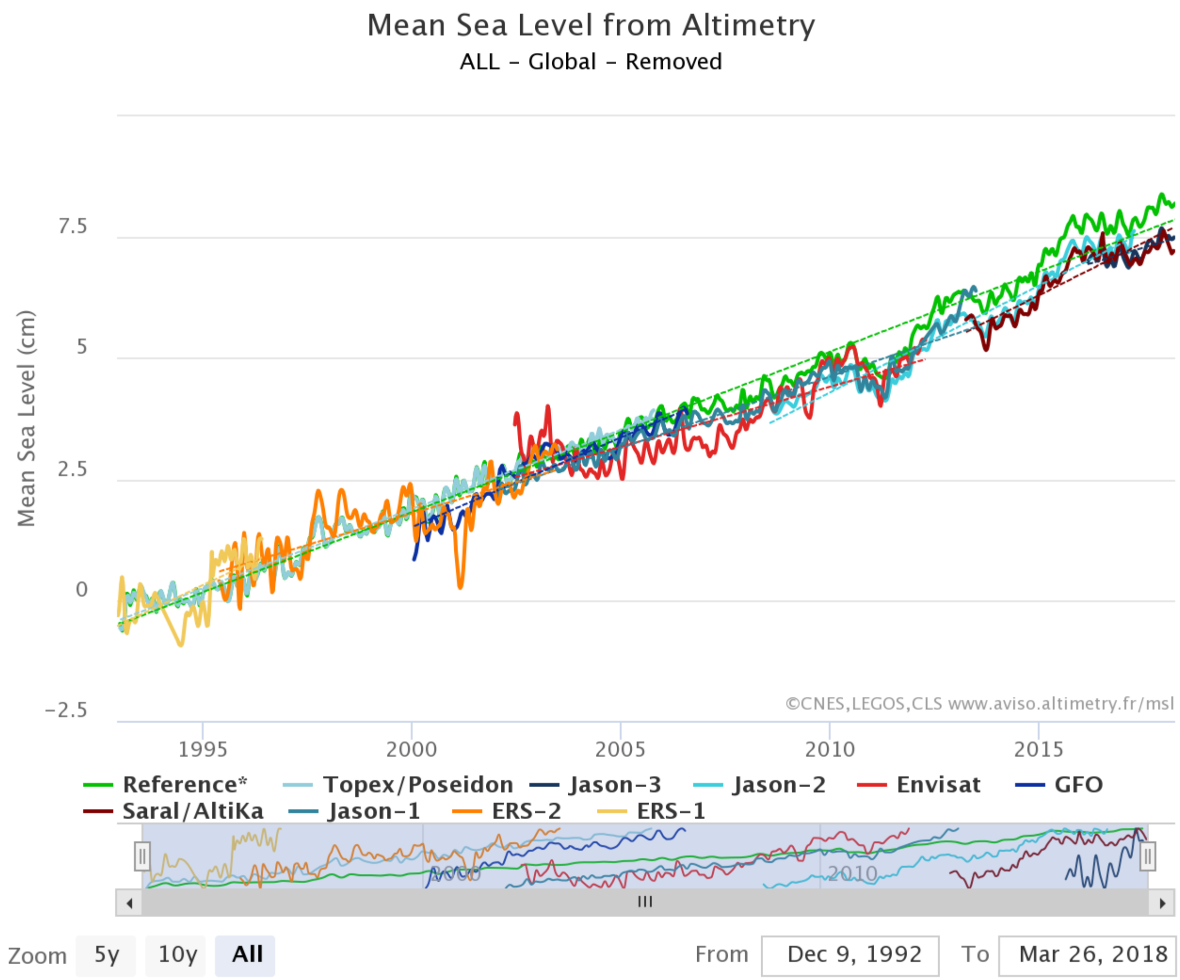

Figure 4: Global Mean Sea Level

6.3 *Wind and waves*

The significant wave height is obtained by analyzing the shape and intensity of the altimeter radar beam reflected from the sea surface (radar echo). A long time delay in the return signal indicates that waves are high, whereas conversely, a short delay indicates that the sea surface is calm.

A map of wave heights measured by ENVISAT is shown below.

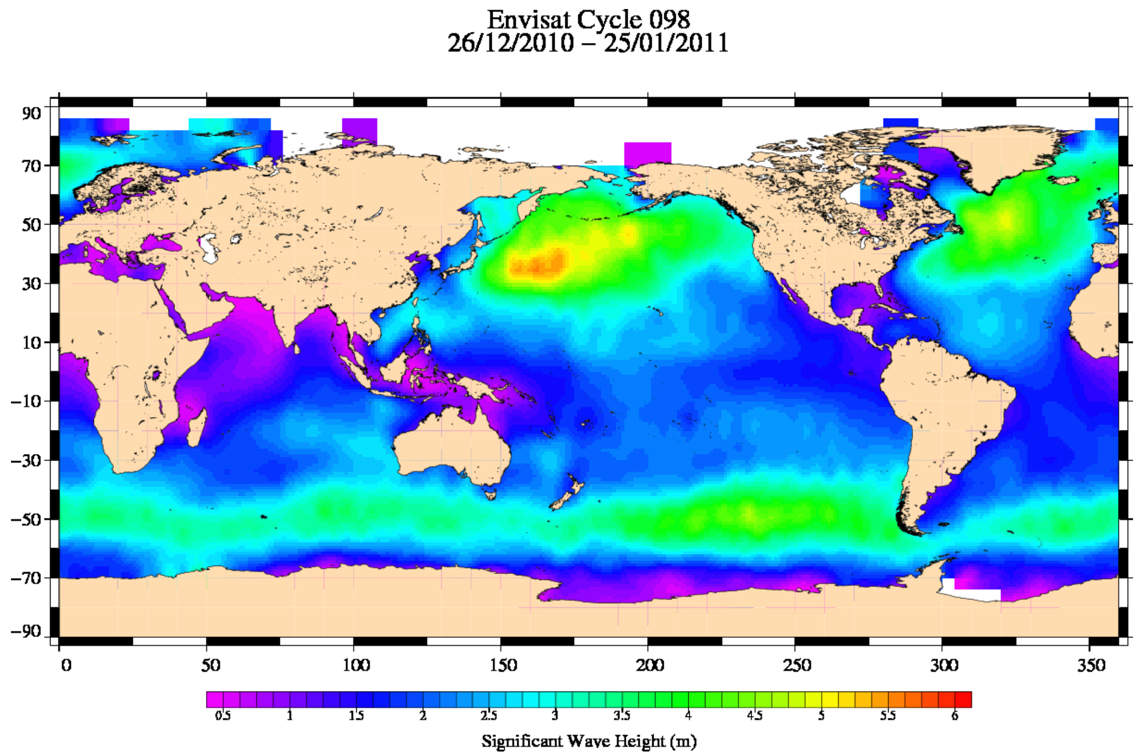

Figure 5: Significant wave height

A map of altimeter wind speed measured by ENVISAT is shown below. These figures highlight the relationship between wind speed and significant wave height: the faster the wind, the higher the waves.

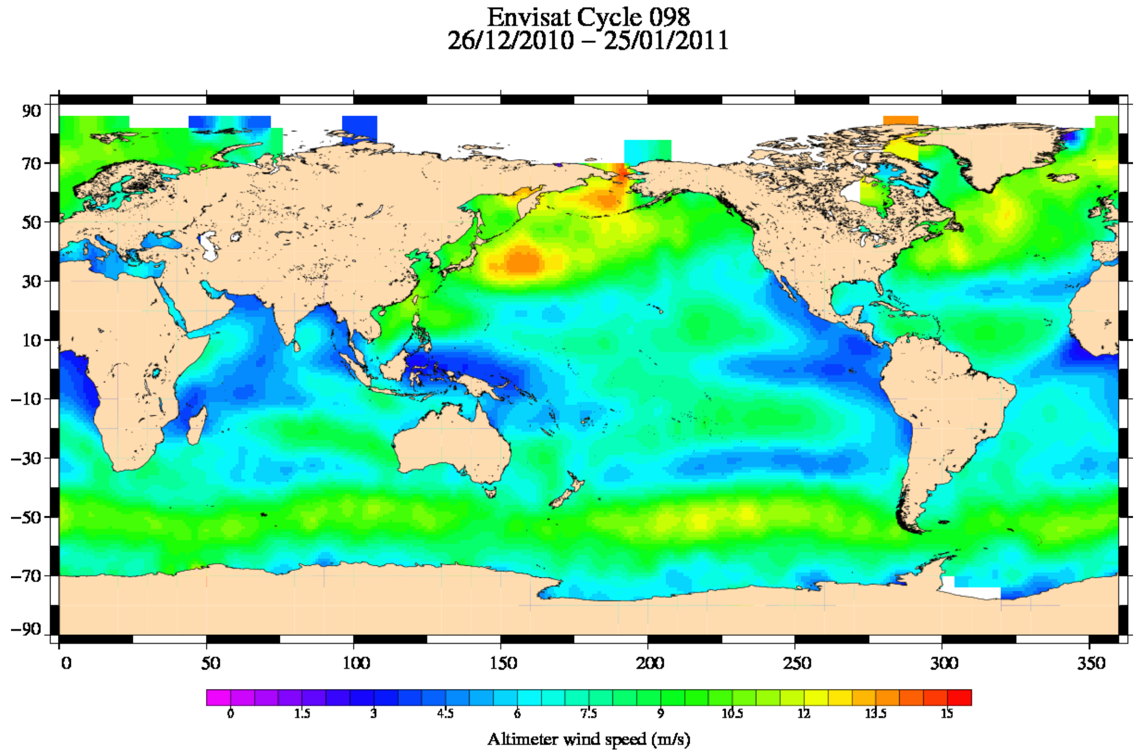

Figure 6: Altimeter wind speed

6.4 Reprocessing v3.0 impact and error budget

The statistical evaluation of ENVISAT mission V3.0 reprocessing on altimetric measurements over ocean is available in [RD30].

The error budget estimated for the whole mission for ENVISAT altimeter level 2 products has updated to account for the homogeneous reprocessed v3.0 data set is provided in [RD31]. The main figures are synthetized in Table 5 below (extracted from [RD31]).

Envisat Altimetry	Specified	Observed	Comments
Altimeter noise	4.5cm	2cm	Altimeter noise computed on post launch data (see 2.1/)
Sea State Bias	2cm	0.5cm	SSB error estimated from differences between different empirical models. Value at 2 m SWH. (see 2.2/)
Ionosphere	0.2cm	0.7cm	Derived from cross-sensor comparisons (see 2.3/)
Dry troposphere	0.7cm	0.7cm	From uncertainties in ECMWF atmospheric fields used to derive the correction. Value at 2-3 hPa sea level pression. (see 2.4/)
Wet troposphere	1.4cm	1.5cm	Comparisons with ECMWF correction. (see 2.5/)
Total range error (TRE): $\sqrt{\sum Terms^2}$	**5cm**	**2.9cm**	
Range drift/SSH	$<$ 0.5cm/y	0.2cm/y	From in situ tide gauge comparison over 2005-2010 (see 2.6/)
Radial Orbit error (ROE)	2cm	1.7cm	From POD operational monitoring (see 2.7/)
Sea height error: $\sqrt{(TRE)^2+(ROE)^2}$	**5.4cm**	**3.5cm**	
Significant Wave Height	5% or 25 cm	25cm	Comparison versus ECMWF WAM global value (see 2.8/)
Wind Speed	2.0m/s	1.3m/s	Comparison versus ECMWF global fields (see 2.9/)

Table 5: Error budget of ENVISAT Altimetry mission – V3.0 reprocessing

6.5 Monitoring the Cryosphere (Polar Land and Sea Ice)

The mass balance and dynamics of the polar ice in Antarctica , Greenland and the Arctic are a critical climate indicator and contributor to global sea levels [RD18] and can be calculated from a time series of corrected elevation and backscatter measurements from the ENVISAT RA-2, (as well as ERS-1,2 and Cryosat-2) at orbit crossover locations.

In the polar oceans, sea-ice thickness, an essential climate variable affecting the earth's energy budget and ocean salinity can be derived from RA-2 measurements and be used in regional sea-ice models.

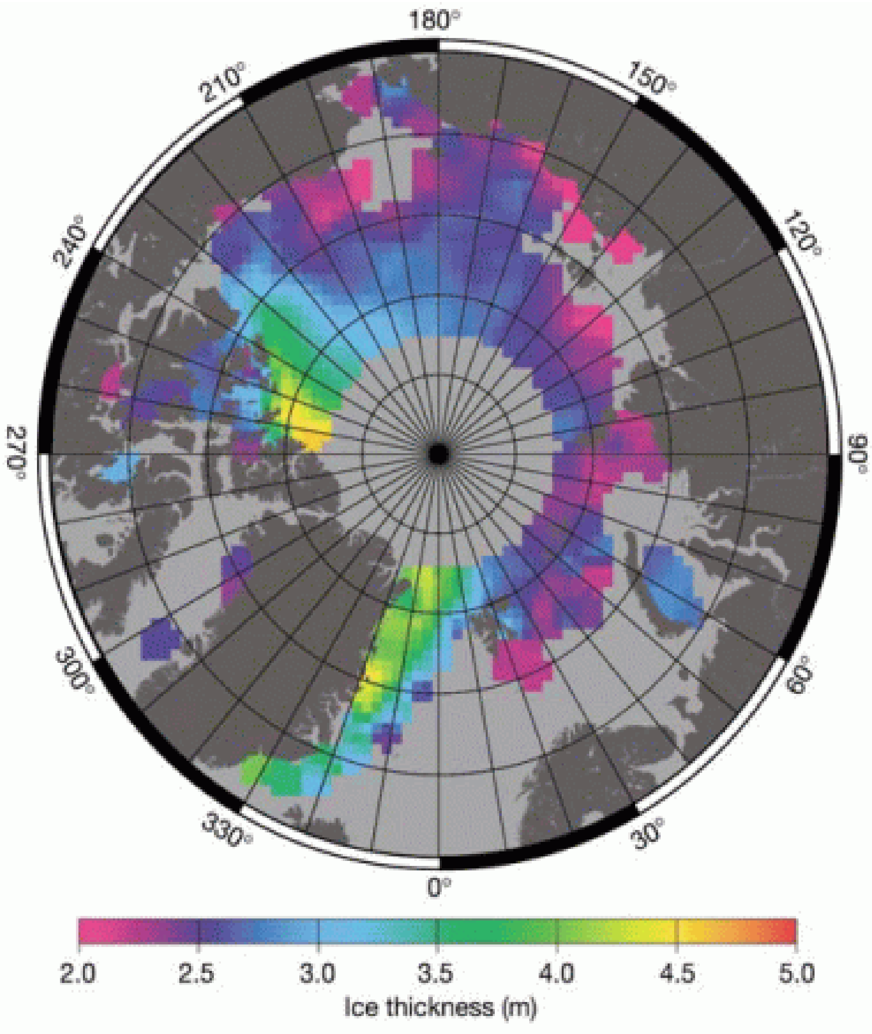

Figure 7: Sea-Ice Thickness derived from Radar Altimeter data

6.6 Links to altimetry applications

The various altimetry applications (Operational oceanography, Ocean circulation and its variations, Tides, Marine weather and atmospheric studies, Climate, El Niño, Level of oceans, enclosed seas and lakes, Hydrology, etc) are well described at the following link:

http://www.aviso.oceanobs.com/en/applications/index.html

The River and Lake System has been put live on 23 July 2009, and Near Real Time results from this augmented system are now being generated at the following link:

http://www.cse.dmu.ac.uk/EAPRS/products_riverlake.html

7 SUPPORTING SOFTWARE AND TOOLS

This section lists some software that may be used to browse and use data from standard and enhanced data sets.

7.1.1 ncdump

"ncdump" is a converter provided with the NetCDF library aimed at converting netCDF file to text form (CDL)

See https://www.unidata.ucar.edu/software/netcdf/netcdf-4/newdocs/netcdf/ncdump.html

The main options are the following :

-h	Show only the header information in the output, that is the declarations of dimensions, variables, and attributes but no data values for any variables
-c	Show the values of coordinate variables (variables that are also dimensions) as well as the declarations of all dimensions, variables, and attribute values
-v *var1,...,varn*	The output will include data values for the specified variables, in addition to the declarations of all dimensions, variables, and attributes
-x *var1,...,varn*	Output XML (NcML) instead of CDL. The NcML does not include data values

7.1.2 ncbrowse

"ncBrowse" is a Java application that provides flexible, interactive graphical displays of data and attributes from a wide range of netCDF data file conventions.

See https://www.nodc.noaa.gov/woce/woce_v3/wocedata_1/utils/netcdf/ncbrowse/index.htm

7.1.3 netCDF Operator (NCO)

The netCDF Operators, or "NCO", are a suite of programs known as **operators**. Each operator is a standalone, command line program which is executed at the UNIX shell-level, like, e.g., `ls` or `mkdir`. The operators take netCDF files as input, then perform a set of operations (e.g., deriving new data, averaging, hyperslabbing, or metadata manipulation) and produce a netCDF file as output. The operators are primarily designed to aid manipulation and analysis of gridded scientific data. The single command style of NCO allows users to manipulate and analyze files interactively and with simple scripts, avoiding the overhead (and some of the power) of a higher level programming environment.

See http://nco.sourceforge.net/

7.1.4 Broadview Radar Altimetry Toolbox

This is a free tool developed with the aim of working with all altimetry data from ESA missions (e.g. EnviSat, CryoSat-2 & Sentinel-3) and third party missions like the Jason series. It allows the user to read products from Sensor Geophysical Data Record to gridded merged data, also supporting processing, computations and visualisation of results.

More information on this tool can be found at:

http://www.altimetry.info/toolbox

8 GENERAL USER INFORMATION

More information can be found at https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/ra2/products-and-algorithms/processor-releases

or http://www.aviso.altimetry.fr/en/data/calval/latest-results.html for the performance reports, or at http://earth.eo.esa.int/pub/RA2_MWR/aux_data/ for all the RA-2 auxiliary data files.

For any questions, the ESA help desk is: eohelp@esa.int.

9 GLOSSARY

ANX	Ascending Node crossing
CCN	Contract Change Notice
CFI	Customer-Furnished Item
CI	Configuration Item
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECMWF	European Centre for Medium-Range Weather Forecasts
ESL	Expert Support Laboratory
FAT	Factory Acceptance Test
FEP	Front-End Processor
FOS	Flight Operations Segment
F-PAC	Processing and Archiving Centre in France
FTP	File Transfer Protocol
GDR	Geophysical Data Record
GUI	Graphical User Interface
I/F	Interface
IGDR	Interim Geophysical Data Record
IPF	Instrument Processing Facility
MCD	Measurement Confidence Data
MLST	Mean Local Solar Time
MWR	Microwave Radiometer
NRT	Near Real Time
OFL	Off-Line
PAC	Processing and Archiving Centre
PDAS	Payload Data Acquisition Station (same as PDAS-F)
PDAS - F	Payload Data Acquisition Station at Fucino
PDCC	Payload Data Control Centre
PDHS - E	Payload Data Handling Station at ESRIN
PDHS - K	Payload Data Handling Station at Kiruna
PDS	Payload Data Segment
PF_HS	Processing Facility Host Structure
PNO	Public Network Operator
RA-2	Radar Altimeter
SLA	Sea Level Anomaly
S/W	Software

10 REFERENCES

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RA-2/MWR Product Handbook: http://envisat.esa.int/handbooks/

RD2

EnviSat-1 Product Specifications, ANNEX A: PRODUCT DATA CONVENTIONS

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11 ANNEXES

11.1 Annex 1

DEFINITION OF CYCLES			
CYCLE	**FIRST ABSOLUTE ORBIT**	**LAST ABSOLUTE ORBIT**	**ANX UTC**
1	1	19	01 Mar 2002 02:53:55
2	20	369	02 Mar 2002 10:45:18
3	370	485	26 Mar 2002 21:59:53
4	486	555	04 Apr 2002 00:37:34
5	556	1056	08 Apr 2002 21:59:29
6	1057	1557	13 May 2002 21:59:29
7	1558	2058	17 Jun 2002 21:59:29
8	2059	2559	22 Jul 2002 21:59:29
9	2560	3060	26 Aug 2002 21:59:29
10	3061	3561	30 Sep 2002 21:59:29
11	3562	4062	04 Nov 2002 21:59:29
12	4063	4563	09 Dec 2002 21:59:29
13	4564	5064	13 Jan 2003 21:59:29
14	5065	5565	17 Feb 2003 21:59:29
15	5566	6066	24 Mar 2003 21:59:29
16	6067	6567	28 Apr 2003 21:59:29
17	6568	7068	02 Jun 2003 21:59:29
18	7069	7569	07 Jul 2003 21:59:29
19	7570	8070	11 Aug 2003 21:59:29
20	8071	8571	15 Sep 2003 21:59:29
21	8572	9072	20 Oct 2003 21:59:29
22	9073	9573	24 Nov 2003 21:59:29
23	9574	10074	29 Dec 2003 21:59:29
24	10075	10575	02 Feb 2004 21:59:29
25	10576	11076	08 Mar 2004 21:59:29
26	11077	11577	12 Apr 2004 21:59:29
27	11578	12078	17 May 2004 21:59:29
28	12079	12579	21 Jun 2004 21:59:29
29	12580	13080	26 Jul 2004 21:59:29

DEFINITION OF CYCLES			
CYCLE	FIRST ABSOLUTE ORBIT	LAST ABSOLUTE ORBIT	ANX UTC
30	13081	13581	30 Aug 2004 21:59:29
31	13582	14082	04 Oct 2004 21:59:29
32	14083	14583	08 Nov 2004 21:59:29
33	14584	15084	13 Dec 2004 21:59:29
34	15085	15585	17 Jan 2005 21:59:29
35	15586	16086	21 Feb 2005 21:59:29
36	16087	16587	28 Mar 2005 21:59:29
37	16588	17088	02 May 2005 21:59:29
38	17089	17589	06 Jun 2005 21:59:29
39	17590	18090	11 Jul 2005 21:59:29
40	18091	18591	15 Aug 2005 21:59:29
41	18592	19092	19 Sep 2005 21:59:29
42	19093	19593	24 Oct 2005 21:59:29
43	19594	20094	28 Nov 2005 21:59:29
44	20095	20595	02 Jan 2006 21:59:29
45	20596	21096	06 Feb 2006 21:59:29
46	21097	21597	13 Mar 2006 21:59:29
47	21598	22098	17 Apr 2006 21:59:29
48	22099	22599	22 May 2006 21:59:29
49	22600	23100	26 Jun 2006 21:59:29
50	23101	23601	31 Jul 2006 21:59:29
51	23602	24102	04 Sep 2006 21:59:29
52	24103	24603	09 Oct 2006 21:59:29
53	24604	25104	13 Nov 2006 21:59:29
54	25105	25605	18 Dec 2006 21:59:29
55	25606	26106	22 Jan 2007 21:59:29
56	26107	26607	26 Feb 2007 21:59:29
57	26608	27108	02 Apr 2007 21:59:29
58	27109	27609	07 May 2007 21:59:29
59	27610	28110	11 Jun 2007 21:59:29
60	28111	28611	16 Jul 2007 21:59:29
61	28612	29112	20 Aug 2007 21:59:29

DEFINITION OF CYCLES			
CYCLE	**FIRST ABSOLUTE ORBIT**	**LAST ABSOLUTE ORBIT**	**ANX UTC**
62	29113	29613	24 Sep 2007 21:59:29
63	29614	30114	29 Oct 2007 21:59:29
64	30115	30615	03 Dec 2007 21:59:29
65	30616	31116	07 Jan 2008 21:59:29
66	31117	31617	11 Feb 2008 21:59:29
67	31618	32118	17 Mar 2008 21:59:29
68	32119	32619	21 Apr 2008 21:59:29
69	32620	33120	26 May 2008 21:59:29
70	33121	33621	30 Jun 2008 21:59:29
71	33622	34122	04 Aug 2008 21:59:29
72	34123	34623	08 Sep 2008 21:59:29
73	34624	35124	13 Oct 2008 21:59:29
74	35125	35625	17 Nov 2008 21:59:29
75	35626	36126	22 Dec 2008 21:59:29
76	36127	36627	26 Jan 2009 21:59:29
77	36628	37128	02 Mar 2009 21:59:29
78	37129	37629	06 Apr 2009 21:59:29
79	37630	38130	11 May 2009 21:59:29
80	38131	38631	15 Jun 2009 21:59:29
81	38632	39132	20 Jul 2009 21:59:29
82	39133	39633	24 Aug 2009 21:59:29
83	39634	40134	28 Sep 2009 21:59:29
84	40135	40635	02 Nov 2009 21:59:29
85	40636	41136	07 Dec 2009 21:59:29
86	41137	41637	11 Jan 2010 21:59:29
87	41638	42138	15 Feb 2010 21:59:29
88	42139	42639	22 Mar 2010 21:59:29
89	42640	43140	26 Apr 2010 21:59:29
90	43141	43641	31 May 2010 21:59:29
91	43642	44142	05 Jul 2010 21:59:29
92	44143	44643	09 Aug 2010 21:59:29
93	44644	45144	13 Sep 2010 21:59:29

DEFINITION OF CYCLES			
CYCLE	FIRST ABSOLUTE ORBIT	LAST ABSOLUTE ORBIT	ANX UTC
94	45145	45221	18 Oct 2010 21:59:29
95	45222	45273	24 Oct 2010 07:05:25
96	45274	45704	27 Oct 2010 21:57:36
97	45705	46135	26 Nov 2010 21:58:25
98	46136	46567	26 Dec 2010 21:59:10
99	46567	46997	25 Jan 2011 21:59:53
100	46998	47428	24 Feb 2011 22:00:33
101	47429	47859	26 Mar 2011 22:01:10
102	47860	48290	25 Apr 2011 22:01:44
103	48291	48721	25 May2011 22:02:15
104	48722	49152	24 Jun2011 22:02:42
105	49153	49583	24 Jul 2011 22:03:07
106	49584	50014	23 Aug 2011 22:03:28
107	50015	50445	22 Sep 2011 22:03:46
108	50446	50876	22 Oct 2011 22:04:02
109	50877	51307	21 Nov 2011 22:04:14
110	51308	51738	21 Dec 2011 22:04:23
111	51739	52169	20 Jan 2012 22:04:30
112	52170	52600	19 Feb 2012 22:04:33
113	52601	53031	20 Mar 2012 22:04:34
114	53032	53462	19 Apr 2012 22:04:31
115	53463	53893	19 May 2012 22:04:26
116	53894	54324	18 Jun 2012 22:04:17
117	54325	54755	18 Jul 2012 22:04:06
118	54756	55186	17 Aug 2012 22:03:51
119	55187	55617	16 Sep 2012 22:03:34
120	55618	56048	16 Oct 2012 22:03:13
121	56049	56479	15 Nov 2012 22:02:50
122	56480	56910	15 Dec 2012 22:02:23
123	56911	57341	14 Jan 2013 22:01:54
124	57342	57772	13 Feb 2013 22:01:22

DEFINITION OF CYCLES			
CYCLE	**FIRST ABSOLUTE ORBIT**	**LAST ABSOLUTE ORBIT**	**ANX UTC**
125	57773	58203	15 Mar 2013 22:00:46
126	58204	58634	14 Apr 2013 22:00:08
127	58635	59065	14 May 2013 21:59:27
128	59066	59496	13 Jun 2013 21:58:42
129	59497	59927	13 Jul 2013 21:57:55
130	59928	60358	12 Aug 2013 21:57:05
131	60359	60789	11 Sep 2013 21:56:12
132	60790	61220	11 Oct 2013 21:55:15
133	61221	61651	10 Nov 2013 21:54:16
134	61652	62082	10 Dec 2013 21:53:14
135	62083	62513	09 Jan 2014 21:52:09
136	62514	62944	08 Feb 2014 21:51:01
137	62945	63375	10 Mar 2014 21:49:50
138	63376	63806	09 Apr 2014 21:48:35
139	63807	64237	09 May 2014 21:47:18
140	64238	64668	08 Jun 2014 21:45:58
141	64669	65099	08 Jul 2014 21:44:35
142	65100	65530	07 Aug 2014 21:43:09
143	65531	65961	06 Sep 2014 21:41:40
144	65962	66392	06 Oct 2014 21:40:08
145	66393	66823	05 Nov 2014 21:38:33
146	66824	67255	05 Dec 2014 21:36:55
…	…	…	…

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
1	0	21:59:29
2	1	23:40:04
3	1	01:20:40
4	1	03:01:16
5	1	04:41:52
6	1	06:22:28
7	1	08:03:04
8	1	09:43:40
9	1	11:24:16
10	1	13:04:52
11	1	14:45:28
12	1	16:26:04
13	1	18:06:40
14	1	19:47:16
15	1	21:27:51
16	2	23:08:27
17	2	00:49:03
18	2	02:29:39
19	2	04:10:15
20	2	05:50:51
21	2	07:31:27
22	2	09:12:03
23	2	10:52:39
24	2	12:33:15
25	2	14:13:51
26	2	15:54:27
27	2	17:35:03
28	2	19:15:39
29	2	20:56:14
30	3	22:36:50
31	3	00:17:26
32	3	01:58:02

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
33	3	03:38:38
34	3	05:19:14
35	3	06:59:50
36	3	08:40:26
37	3	10:21:02
38	3	12:01:38
39	3	13:42:14
40	3	15:22:50
41	3	17:03:26
42	3	18:44:02
43	3	20:24:37
44	4	22:05:13
45	4	23:45:49
46	4	01:26:25
47	4	03:07:01
48	4	04:47:37
49	4	06:28:13
50	4	08:08:49
51	4	09:49:25
52	4	11:30:01
53	4	13:10:37
54	4	14:51:13
55	4	16:31:49
56	4	18:12:25
57	4	19:53:00
58	4	21:33:36
59	5	23:14:12
60	5	00:54:48
61	5	02:35:24
62	5	04:16:00
63	5	05:56:36
64	5	07:37:12
65	5	09:17:48

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
66	5	10:58:24
67	5	12:39:00
68	5	14:19:36
69	5	16:00:12
70	5	17:40:48
71	5	19:21:23
72	5	21:01:59
73	6	22:42:35
74	6	00:23:11
75	6	02:03:47
76	6	03:44:23
77	6	05:24:59
78	6	07:05:35
79	6	08:46:11
80	6	10:26:47
81	6	12:07:23
82	6	13:47:59
83	6	15:28:35
84	6	17:09:11
85	6	18:49:46
86	6	20:30:22
87	7	22:10:58
88	7	23:51:34
89	7	01:32:10
90	7	03:12:46
91	7	04:53:22
92	7	06:33:58
93	7	08:14:34
94	7	09:55:10
95	7	11:35:46
96	7	13:16:22
97	7	14:56:58
98	7	16:37:34

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
99	7	18:18:09
100	7	19:58:45
101	7	21:39:21
102	8	23:19:57
103	8	01:00:33
104	8	02:41:09
105	8	04:21:45
106	8	06:02:21
107	8	07:42:57
108	8	09:23:33
109	8	11:04:09
110	8	12:44:45
111	8	14:25:21
112	8	16:05:57
113	8	17:46:32
114	8	19:27:08
115	8	21:07:44
116	9	22:48:20
117	9	00:28:56
118	9	02:09:32
119	9	03:50:08
120	9	05:30:44
121	9	07:11:20
122	9	08:51:56
123	9	10:32:32
124	9	12:13:08
125	9	13:53:44
126	9	15:34:20
127	9	17:14:55
128	9	18:55:31
129	9	20:36:07
130	10	22:16:43
131	10	23:57:19

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
132	10	01:37:55
133	10	03:18:31
134	10	04:59:07
135	10	06:39:43
136	10	08:20:19
137	10	10:00:55
138	10	11:41:31
139	10	13:22:07
140	10	15:02:43
141	10	16:43:18
142	10	18:23:54
143	10	20:04:30
144	10	21:45:06
145	11	23:25:42
146	11	01:06:18
147	11	02:46:54
148	11	04:27:30
149	11	06:08:06
150	11	07:48:42
151	11	09:29:18
152	11	11:09:54
153	11	12:50:30
154	11	14:31:06
155	11	16:11:41
156	11	17:52:17
157	11	19:32:53
158	11	21:13:29
159	12	22:54:05
160	12	00:34:41
161	12	02:15:17
162	12	03:55:53
163	12	05:36:29
164	12	07:17:05

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
165	12	08:57:41
166	12	10:38:17
167	12	12:18:53
168	12	13:59:29
169	12	15:40:04
170	12	17:20:40
171	12	19:01:16
172	12	20:41:52
173	13	22:22:28
174	13	00:03:04
175	13	01:43:40
176	13	03:24:16
177	13	05:04:52
178	13	06:45:28
179	13	08:26:04
180	13	10:06:40
181	13	11:47:16
182	13	13:27:51
183	13	15:08:27
184	13	16:49:03
185	13	18:29:39
186	13	20:10:15
187	13	21:50:51
188	14	23:31:27
189	14	01:12:03
190	14	02:52:39
191	14	04:33:15
192	14	06:13:51
193	14	07:54:27
194	14	09:35:03
195	14	11:15:39
196	14	12:56:14
197	14	14:36:50

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
198	14	16:17:26
199	14	17:58:02
200	14	19:38:38
201	14	21:19:14
202	15	22:59:50
203	15	00:40:26
204	15	02:21:02
205	15	04:01:38
206	15	05:42:14
207	15	07:22:50
208	15	09:03:26
209	15	10:44:02
210	15	12:24:37
211	15	14:05:13
212	15	15:45:49
213	15	17:26:25
214	15	19:07:01
215	15	20:47:37
216	16	22:28:13
217	16	00:08:49
218	16	01:49:25
219	16	03:30:01
220	16	05:10:37
221	16	06:51:13
222	16	08:31:49
223	16	10:12:25
224	16	11:53:00
225	16	13:33:36
226	16	15:14:12
227	16	16:54:48
228	16	18:35:24
229	16	20:16:00
230	16	21:56:36

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
231	17	23:37:12
232	17	01:17:48
233	17	02:58:24
234	17	04:39:00
235	17	06:19:36
236	17	08:00:12
237	17	09:40:48
238	17	11:21:23
239	17	13:01:59
240	17	14:42:35
241	17	16:23:11
242	17	18:03:47
243	17	19:44:23
244	17	21:24:59
245	18	23:05:35
246	18	00:46:11
247	18	02:26:47
248	18	04:07:23
249	18	05:47:59
250	18	07:28:35
251	18	09:09:11
252	18	10:49:46
253	18	12:30:22
254	18	14:10:58
255	18	15:51:34
256	18	17:32:10
257	18	19:12:46
258	18	20:53:22
259	19	22:33:58
260	19	00:14:34
261	19	01:55:10
262	19	03:35:46
263	19	05:16:22

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
264	19	06:56:58
265	19	08:37:34
266	19	10:18:09
267	19	11:58:45
268	19	13:39:21
269	19	15:19:57
270	19	17:00:33
271	19	18:41:09
272	19	20:21:45
273	20	22:02:21
274	20	23:42:57
275	20	01:23:33
276	20	03:04:09
277	20	04:44:45
278	20	06:25:21
279	20	08:05:57
280	20	09:46:32
281	20	11:27:08
282	20	13:07:44
283	20	14:48:20
284	20	16:28:56
285	20	18:09:32
286	20	19:50:08
287	20	21:30:44
288	21	23:11:20
289	21	00:51:56
290	21	02:32:32
291	21	04:13:08
292	21	05:53:44
293	21	07:34:20
294	21	09:14:55
295	21	10:55:31
296	21	12:36:07

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
297	21	14:16:43
298	21	15:57:19
299	21	17:37:55
300	21	19:18:31
301	21	20:59:07
302	22	22:39:43
303	22	00:20:19
304	22	02:00:55
305	22	03:41:31
306	22	05:22:07
307	22	07:02:43
308	22	08:43:18
309	22	10:23:54
310	22	12:04:30
311	22	13:45:06
312	22	15:25:42
313	22	17:06:18
314	22	18:46:54
315	22	20:27:30
316	23	22:08:06
317	23	23:48:42
318	23	01:29:18
319	23	03:09:54
320	23	04:50:30
321	23	06:31:06
322	23	08:11:41
323	23	09:52:17
324	23	11:32:53
325	23	13:13:29
326	23	14:54:05
327	23	16:34:41
328	23	18:15:17
329	23	19:55:53

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
330	23	21:36:29
331	24	23:17:05
332	24	00:57:41
333	24	02:38:17
334	24	04:18:53
335	24	05:59:29
336	24	07:40:04
337	24	09:20:40
338	24	11:01:16
339	24	12:41:52
340	24	14:22:28
341	24	16:03:04
342	24	17:43:40
343	24	19:24:16
344	24	21:04:52
345	25	22:45:28
346	25	00:26:04
347	25	02:06:40
348	25	03:47:16
349	25	05:27:51
350	25	07:08:27
351	25	08:49:03
352	25	10:29:39
353	25	12:10:15
354	25	13:50:51
355	25	15:31:27
356	25	17:12:03
357	25	18:52:39
358	25	20:33:15
359	26	22:13:51
360	26	23:54:27
361	26	01:35:03
362	26	03:15:39

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
363	26	04:56:14
364	26	06:36:50
365	26	08:17:26
366	26	09:58:02
367	26	11:38:38
368	26	13:19:14
369	26	14:59:50
370	26	16:40:26
371	26	18:21:02
372	26	20:01:38
373	26	21:42:14
374	27	23:22:50
375	27	01:03:26
376	27	02:44:02
377	27	04:24:37
378	27	06:05:13
379	27	07:45:49
380	27	09:26:25
381	27	11:07:01
382	27	12:47:37
383	27	14:28:13
384	27	16:08:49
385	27	17:49:25
386	27	19:30:01
387	27	21:10:37
388	28	22:51:13
389	28	00:31:49
390	28	02:12:25
391	28	03:53:00
392	28	05:33:36
393	28	07:14:12
394	28	08:54:48
395	28	10:35:24

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
396	28	12:16:00
397	28	13:56:36
398	28	15:37:12
399	28	17:17:48
400	28	18:58:24
401	28	20:39:00
402	29	22:19:36
403	29	00:00:12
404	29	01:40:48
405	29	03:21:23
406	29	05:01:59
407	29	06:42:35
408	29	08:23:11
409	29	10:03:47
410	29	11:44:23
411	29	13:24:59
412	29	15:05:35
413	29	16:46:11
414	29	18:26:47
415	29	20:07:23
416	29	21:47:59
417	30	23:28:35
418	30	01:09:11
419	30	02:49:46
420	30	04:30:22
421	30	06:10:58
422	30	07:51:34
423	30	09:32:10
424	30	11:12:46
425	30	12:53:22
426	30	14:33:58
427	30	16:14:34
428	30	17:55:10

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
429	30	19:35:46
430	30	21:16:22
431	31	22:56:58
432	31	00:37:34
433	31	02:18:09
434	31	03:58:45
435	31	05:39:21
436	31	07:19:57
437	31	09:00:33
438	31	10:41:09
439	31	12:21:45
440	31	14:02:21
441	31	15:42:57
442	31	17:23:33
443	31	19:04:09
444	31	20:44:45
445	32	22:25:21
446	32	00:05:57
447	32	01:46:32
448	32	03:27:08
449	32	05:07:44
450	32	06:48:20
451	32	08:28:56
452	32	10:09:32
453	32	11:50:08
454	32	13:30:44
455	32	15:11:20
456	32	16:51:56
457	32	18:32:32
458	32	20:13:08
459	32	21:53:44
460	33	23:34:20
461	33	01:14:55

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	DAY SHIFT	ANX UTC
462	33	02:55:31
463	33	04:36:07
464	33	06:16:43
465	33	07:57:19
466	33	09:37:55
467	33	11:18:31
468	33	12:59:07
469	33	14:39:43
470	33	16:20:19
471	33	18:00:55
472	33	19:41:31
473	33	21:22:07
474	34	23:02:43
475	34	00:43:18
476	34	02:23:54
477	34	04:04:30
478	34	05:45:06
479	34	07:25:42
480	34	09:06:18
481	34	10:46:54
482	34	12:27:30
483	34	14:08:06
484	34	15:48:42
485	34	17:29:18
486	34	19:09:54
487	34	20:50:30
488	35	22:31:06
489	35	00:11:41
490	35	01:52:17
491	35	03:32:53
492	35	05:13:29
493	35	06:54:05
494	35	08:34:41

ANX TIMES (valid only to end cycle 93)_		
RELATIVE ORBIT	**DAY SHIFT**	**ANX UTC**
495	35	10:15:17
496	35	11:55:53
497	35	13:36:29
498	35	15:17:05
499	35	16:57:41
500	35	18:38:17
501	35	20:18:53