COASTALT

# Envisat Coastal Altimetry Product Handbook

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| 1 rev 1 | 17 December 2009 | Moved tables of pass numbers to Appendix |
| 1.1 | 22 March 2010 | Release to match v1.1 of the output product |
| 2.0 | 11 July 2011 | Updated to correspond to v2.0 rev2 products<br>Addition of new applicable documents for wet tropospheric correction, latest specification, extension orbit and level 2 processing<br>Added information on Envisat extension orbit phase<br>Added information on IPF & CMA processing version for 2010<br>Added description of GPD wet tropospheric correction and related fields<br>Added description of distance from coast field<br>Added Case Studies<br>Corrected and updated References<br>Corrected and updated Acronyms |
| 2.0.1 | 16 September 2011 | Corrected page formatting (missing headers and missing or incorrect page numbers)<br>Corrected table formatting for consistency throughout<br>Corrected in response to ESA RID:<br>- minor typographic corrections throughout<br>- added §3.3.1 on the COASTALT processor and references to applicable docuemnts<br>- added thermal noise term and added or corrected definition for terms in equation 1&2<br>- Replaced equation 5 with correct equation<br>- Removed reference to Maximum Likelihood Estimator (MLE)<br>- Corrected references to §3.5 and §3.5.2 (from §0) |

## Contributors to this issue:

| | | |
|---|---|---|
| Written by:<br>H. SNAITH<br>Revised by:<br>P. CIPOLLINI | NOC-S | Date<br>July 2011 |

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# 1 Introduction

Envisat is the follow-on altimetry mission to ERS-1 and ERS-2, with altimetry measurements generated by the RA-2 radar altimeter. The mission supports ten different onboard instruments dedicated to the global observation of our environment.

This manual is designed to support those using the RA-2 radar altimeter and the MWR microwave radiometer ***in the coastal zone*** – specifically enclosed and semi-enclosed seas, and ocean within 200 km of the coast.

## 1.1 Scope of the document

The purpose of this document is to assist users of the COASTALT (ESA development of COASTal ALTimetry) Coastal Geophysical Data Record (CGDR) products by providing a comprehensive description of product content and format, together with supporting information on the altimetry measurement system in the coastal zone and how to use this new product.

The COASTALT products are based on the Envisat Sensor Geophysical Data Record (SGDR) products [AD 2], which are fully validated Level 2 products. The new data within the COASTALT product are experimental in terms of content and have not been validated. Hence the CGDR product is a mix of validated and experimental content, and users should be cautious in interpreting their results, particularly where the new content has been used.

The SGDR products, including algorithms and auxiliary data used in their production, are described in a series of documents [AD 1, AD 2, AD 3, AD 4 and AD 5]. This Handbook will not attempt to reproduce this information in full, but will reference appropriate sections. However, some sections may be reproduced for clarity.

This document will concentrate on new elements included in the CGDR products and how they may be compared to the source SGDR outputs included in the CGDR.

## 1.2 Handbook Overview

This document is a combination of a guide to data use and a reference handbook and not all readers will need to use all the sections.

**Section 1** provides background information about the COASTALT products and this document

**Section 2** is an overview of the Envisat mission and the COASTALT initiative

**Section 3** provides information of product evolution history

**Section 4** is an introduction to using the COASTALT data, including recipes for generating commonly required outputs, such as sea level.

**Section 5** is an introduction to the COASTALT altimeter algorithms

**Section 6** provides case studies for the use of COASTALT products.

**Section 7** provides a description of the content and format of the COASTALT products.

**Annexe A** contains references

**Annexe B** contains acronyms

**Annexe C** contains tables of the ENVISAT 35-day repeat pass definitions

## 1.3 Document reference and contributors

When referencing this document, please use the following citation:

> "ENVISAT Coastal Product Handbook",
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This document has been collated and edited by Helen Snaith, with material sourced from the ENVISAT Product Handbook [AD 1], ESA's ENVISAT web pages [http://earth.esa.int/envisat] and the Jason-2 Handbook [RD 14], with permission. Other contributors are Susana Barbosa (case studies over W Iberia), Jesus Gómez-Enri (case study over Gulf of Cadiz) and Paolo Cipollini.

## 1.4 Conventions

### 1.4.1 Vocabulary

#### 1.4.1.1 Altimetric distances

In order to reduce confusion in discussing altimeter measurements and corrections, the following terms are used in this document as defined below:

**Distance** and **Length** are general terms with no special meaning in this document.

**Height** is the distance above a reference surface. The reference surface used is the *reference ellipsoid* (see §1.4.1.3). Positive is upwards (away from the centre of the earth).

**Range** is the distance from the satellite to the surface of the Earth, as measured by the altimeter. Thus, the altimeter measurement is referred to as "range" or "altimeter range," not height.

**Altitude** is the *height* of the satellite or altimeter, usually given as the height of the centre of mass of the satellite. This distance is computed from the satellite orbit (ephemeris) data.

**Sea Surface Height** is the *height* of the sea surface. The sea surface height is the difference of the altimeter range from the satellite altitude. Strictly, it is the difference of the altimeter range, corrected for atmospheric delays, from the satellite altitude.

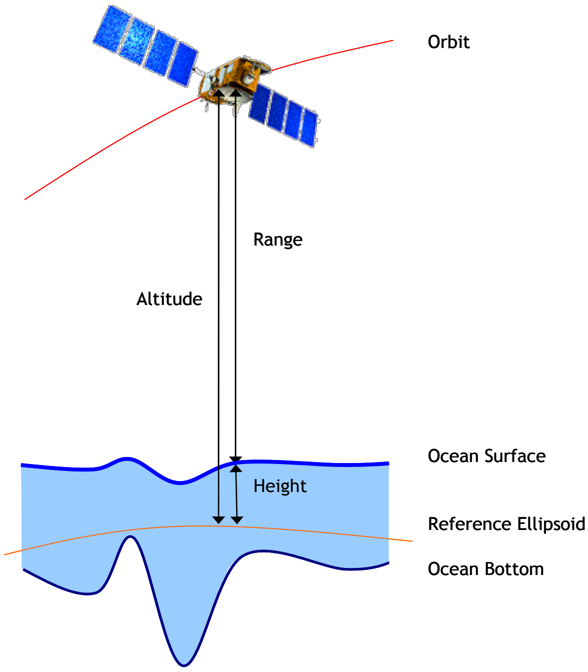


**Figure 1 Altimetric distances – relationship between altitude, range and height**

**The Geoid** is an equipotential surface – *i.e.* a surface along which the gravity potential remains constant. The shape of this surface is controlled by the earth's gravity field.

**Sea Surface Topography**, or dynamic topography, is that part of the sea surface height caused by ocean currents. It is equal to the departure of the *sea surface height* from the *geoid* height, once geophysical effects, such as tides, atmospheric pressure effects and sea state bias have been removed.

#### 1.4.1.2 Orbits, Revolutions, Passes, and Repeat Cycles

An **Orbit** is one circuit of the earth by the satellite as measured from one ascending node crossing to the next. An **ascending node** occurs when the sub satellite point crosses the earth's equator going from south to north. A **Revolution** (REV) is synonymous with orbit.

A **Pass** is half a revolution of the earth by the satellite from extreme latitude to the opposite extreme latitude. For altimetry data, it is normal to organize data by pass to avoid having data boundaries in the middle of the oceans. Ascending passes are odd numbered and descending passes are even numbered. For Envisat, an **Ascending Pass** begins at latitude -82˚ and ends at +82˚. A **Descending Pass** is the opposite (+82˚ to -82˚).

From launch until 22 October 2010, Envisat maintained a **35 day exact repeat cycle.** During this phase, after each **repeat cycle** of 1002 passes, taking 35 days, Envisat revisited the same ground-track within a margin of ±1 km. That means that every location along each pass of the Envisat ground-track was measured every 35 days.

On 2 November 2010 Envisat began a new phase, with a **30 day near-repeat cycle**. During this extension orbit phase, there are 862 passes per cycle. The inclination of the orbit is not maintained and hence the ground tracks are not repeated exactly, but with slight changes in inclination. The inclination drift induces a rotation of the orbital plane around 38° (North for descending tracks, South for ascending tracks), hence at these latitudes there is no longitudinal drift of the tracks and they will repeat almost exactly. For other latitudes, the passes will drift over time, as shown in Figure 2. The resultant drift at the equator is expected to be approximately 15 km over 3 years.

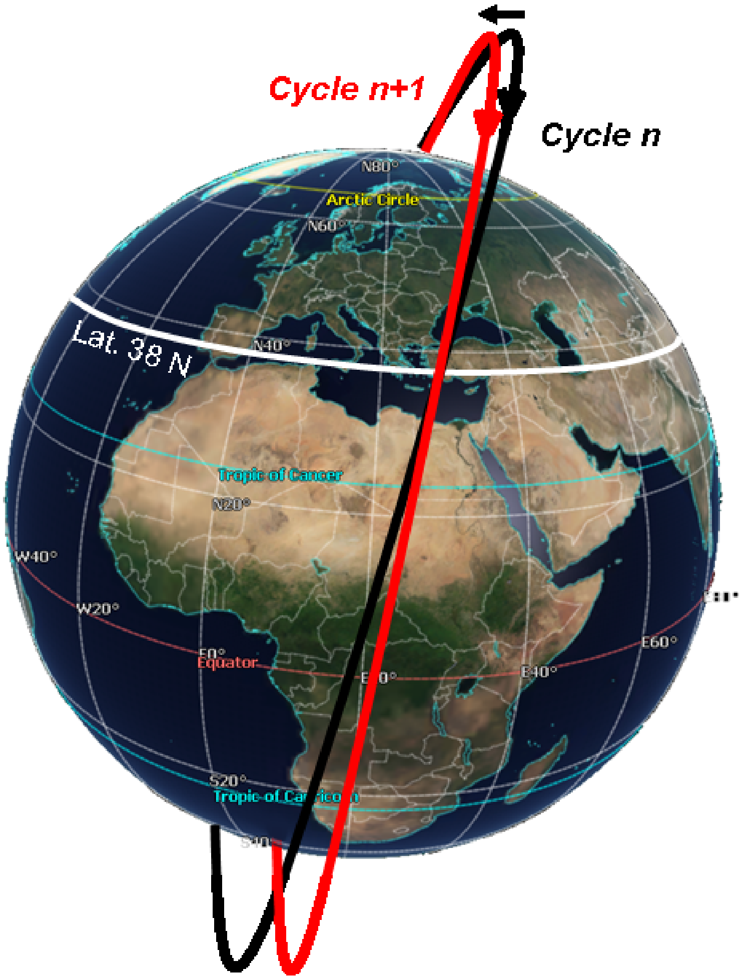


**Figure 2: Impact of the inclination drift for the same track of two successive cycles (exaggerated inclination change). [AD 12]**

The passes are numbered 1 to 1002 for the 35-day phase and 1 to 862 for the 30-day phase, with pass number 1 defined as the pass that has its ascending node closest to zero longitude (actually 0.1355˚E for the 35-day phase, 0.6°E, drifting west with time for the 30-day phase) and the cycles are defined so that this is the first pass within a cycle.

***Important note*** – there is potential for confusion as the orbits are numbered starting from the northward equator crossing, but the ascending pass is numbered from the southern extreme of the orbit, hence an ascending pass, strictly, includes the data from two consecutive orbits (the last quarter of one orbit and the first quarter of the following orbit). This has led to confusion in the file naming convention, as explained in §4.2.

#### 1.4.1.3 Reference Ellipsoid

The **Reference Ellipsoid** is a first-order definition of the non-spherical shape of the Earth as an ellipsoid of revolution. The reference ellipsoid used for the Envisat mission is the WGS84 ellipsoid, defined as having an equatorial radius of 6378.137 km and a flattening coefficient of 1/298.2572236.

### 1.4.2 Correction Conventions

All environmental and instrument corrections are computed so that they should be ***added*** to the quantity which they correct. That is, a correction is applied to a measured value by

Corrected Quantity = Measured Value + Correction

This means that a correction to the altimeter range for an effect that lengthens the apparent signal path (e.g., wet troposphere correction) is computed as a negative number. Adding this negative number to the uncorrected (measured) range reduces the range from its original value toward the correct value.

Example: Corrected Range = Measured Range + Range Correction.

Similarly, any value reported as a *difference* should be added to the average value to give the full value.

Example: <18 Hz latitude> = <1 Hz averaged latitude> + <18Hz latitude differences from 1Hz>

### 1.4.3 Time Convention

Times are UTC and referenced to **January 1, 2000 00:00:00.00**.

For information on how leap seconds are dealt with, see AD 2.

### 1.4.4 Unit Convention

Wherever possible, values are reported in SI units, as defined in the UD-units package (where the definitions exists), so as to be compliant with the CF-conventions (see §7.1.3). All distances and distance corrections are reported in meters, although this may require application of a scale factor, as reported in the product, with the exception of the distance from coast, which is reported in km.

### 1.4.5 Flagging and Editing

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. For example, flags may be used to provide information on the operation mode of the instrument. The flag values and flag meanings of simple flags are defined in their attributes in the CGDR products. For complex flags the user should refer to the ENVISAT handbook for the definition, or §4.3.3.1 has summary definitions.

Additional editing is usually required to determine the data quality. In some cases, flags have been pre-determined, using quality criteria *e.g.* data exceeding given thresholds. However, in most cases, users will also need to apply their own data quality editing criteria. The criteria recommended for the SGDR data are given in §4.3.3. There are, as yet, no modifications to these criteria for the new parameters in the CGDR products.

# 2 Envisat Mission Overview

## 2.1 Background

Envisat (ENVIronmental SATellite) is an advanced polar-orbiting Earth observation satellite, launched in March 2002, which provides measurements of the atmosphere, ocean, land and ice. The Envisat satellite has an ambitious and innovative payload that ensures the continuity of the data measurements of the ERS satellites. The Envisat data supports Earth science research and allows monitoring of the evolution of environmental and climatic changes.

Its primary objectives are:

- to provide for continuity of the observations started with the ERS satellites, including those obtained from radar-based observations;
- to enhance the ERS mission, notably the ocean and ice mission;
- to extend the range of parameters observed to meet the need of increasing knowledge of the factors determining the environment;
- to make a significant contribution to environmental studies, notably in the area of atmospheric chemistry and ocean studies (including marine biology).

These are coupled with two linked secondary objectives:

- to allow more effective monitoring and management of the Earth's resources;
- to better understand solid Earth processes.

The mission intends to continue and improve upon measurements initiated by ERS-1 and ERS-2, and to take into account the requirements related to the global study and monitoring of the environment.

The mission is an essential element in providing long-term continuous data sets that are crucial for addressing environmental and climatological issues. It will at the same time further promote the gradual transfer of applications of remote sensing data from experimental to preoperational and operational exploitation.

Envisat, as an undertaking of ESA member states plus Canada, constitutes a major contribution to the international effort of space agencies worldwide to provide the data and information required to further the understanding, modelling, and prediction of environmental and climatic changes.

## 2.2 Satellite Description

Envisat is a very large platform, when compared to other altimeter mission platforms, due to its multi-sensor objectives. This has consequences for the orbit determination and other factors important for precision altimetry.

The major driver for the Envisat satellite configuration was the need to maximise the payload instrument mounting area and to meet the viewing requirements within the constraints of the Ariane 5 fairing and interfaces. The overall satellite budgets for Envisat are given in Table 2-1

**Table 2-1 Envisat budgets**

| | | |
|---|---|---|
| **Launch configuration** | | |
| **Dimensions** | | |
| Launch Configuration, | length 10.5 m<br>envelope diameter 4.57 m | |
| In-Orbit configuration | 26 m * 10 m * 5 m | |
| **Mass Budget** | | |
| Service Module | 2673 kg | |
| Payload Equipment Bay | 1021 kg | |
| Payload Carrier | 2078 kg | |
| Fuel | 319 kg | |
| Payload Instruments | 2118 kg | |
| **Total** | **8211 kg** | |
| **Power Budget** | | |
| | **Average Power (W)** | |
| | **Sunlight** | **Eclipse** |
| Payload | 1841 | 1886 |
| Payload Module | 860 | 527 |
| Service Module | 859 | 684 |
| **Total Load** | **3560** | **3097** |
| **System Capability** | **3847** | **3291** |

## 2.3 Sensors

Envisat carries nine instruments, which are summarized below. The key instruments for altimetry are the Radar Altimeter (RA-2), the Microwave Radiometer (MWR), DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite) and the Laser Retroreflector (LRR) (used for precision orbit determination).

### 2.3.1 ASAR

An Advanced Synthetic Aperture Radar (ASAR), operating at C-band, ASAR ensures continuity with the image mode (SAR) and the wave mode of the ERS-1/2 AMI.

### 2.3.2 MERIS

MERIS is a programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range. Fifteen spectral bands can be selected by ground command, each of which has a programmable width and a programmable location in the 390 nm to 1040 nm spectral range.

### 2.3.3 AATSR

The prime scientific objective of the Advanced Along Track Scanning Radiometer (AATSR) is to establish continuity of the ATSR-1 and ATSR-2 data sets of precise sea surface temperature (SST), thereby ensuring the production of a unique 10 year near-continuous data set at the levels of accuracy required (0.3 K or better) for climate research and for the community of operational as well as scientific users who have been developed through the ERS-1 and ERS-2 missions.

### 2.3.4 RA-2

The Radar Altimeter 2 (RA-2) is an instrument for determining the two-way delay of a radar echo from the Earth's surface to a very high precision: less than a nanosecond.

If the orbit of the satellite is determined by independent means (such as by DORIS) the RA-2 data can be used to accurately map the Earth's topography. In addition, signal analysis of the returning radar echo can be used to provide insight into ground characteristics. The RA-2 is a nadir looking pulse limited radar operating at a nominal frequency of 13.575 GHz (Ku-band). A second channel, operating at a nominal frequency of 3.2 GHz (S-band) is also used, primarily to estimate the effects of the ionosphere on the Ku-band channel.

***Note:*** the S-band of the RA-2 ceased functioning on 18 January 2008 and since then the RA-2 has been operated as a single frequency altimeter.

**Table 2-2 RA-2 Characteristics**

| | |
|---|---|
| GEOMETRIC: | Approx. 19 km footprint.<br>Spatial sampling approx. 390 meters along track.<br>47 cm height resolution at 320 MHz max chirp bandwidth. |
| RADIOMETRIC: | Nadir looking pulse:<br>Main Nominal frequency = 13.575 GHz (Ku-band)<br>Error Nominal frequency = 3.2 GHz (S-band) |

The RA-2 Instrument operates in three modes. These consist of Measurement Mode, RF and Digital Built-In Test Equipment (BITE) Mode, and IF Calibration Mode. Science data is gathered within the Measurement Mode, while the other modes are used for testing and calibration of the instrument.

#### 2.3.4.1 Measurement Mode

The Measurement Mode consists of two primary phases. The first is Acquisition Phase, when the instrument attempts to locate the initial ground height. To do this, the instrument first initiates a Noise Power Estimation cycle to establish a noise power estimate, then proceeds with a Detection cycle in which the location of the leading edge of the return echo is established. The final step in the Acquisition Phase is the Automatic Gain Control (AGC) Setting cycle in which the instrument attempts to estimate the received signal power in order to set the appropriate gain settings needed to keep the return signal amplitude within the proper dynamic range of the receiving equipment. The second step of Measurement Mode is the Tracking Phase, in which the instrument acquires the science data. The transition from Acquisition to Tracking phases is performed automatically or started directly by macrocommand. During tracking it is possible to change tracking parameters without interruption of measurements. Periodic calibration is also performed while in the Tracking Phase of Measurement Mode. Operational products are constructed from the data obtained when the instrument is in the Tracking Phase of Measurement mode.

#### 2.3.4.2 RF and Digital BITE Mode

The aim of these two modes is to test the RF Tx/Rx channel and the digital signal processing modules. BITE is executed from Measurement Mode by macrocommand. During BITE the tracking is interrupted. RF and Digital BITE are executed cyclically until a mode change request is received. Data generated while in this mode are included in Level 0 Products only.

#### 2.3.4.3 IF Calibration Mode

The purpose of this mode is to measure the IF filter shape. This is done by measuring the spectra of averaged noise samples. Data generated while in this mode are included in Level 0 Products only.

### 2.3.5 MWR

The main objective of the microwave radiometer (MWR) is the measurement of atmospheric humidity as supplementary information for tropospheric path correction of the radar altimeter signal, which is influenced both by the integrated atmospheric water vapour content and by liquid water. In addition, MWR measurement data are useful for the determination of surface emissivity and soil moisture over land, for surface energy budget, investigations to support atmospheric studies, and for ice characterisation.

The MWR instrument on board Envisat is a derivative of the radiometers used on the ERS-1 and ERS-2 satellites. It is a dual-channel nadir-pointing Dicke-type radiometer, operating at frequencies of 23.8 GHz and 36.5 GHz.

### 2.3.6 GOMOS

GOMOS measures atmospheric constituents by spectral analysis of the spectral bands between 250 nm to 675 nm, 756 nm to 773 nm, and 926 nm to 952 nm. Additionally, two photometers operate in two spectral channels; between 470 nm to 520 nm and 650 nm to 700 nm, respectively.

### 2.3.7 MIPAS

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is a Fourier transform spectrometer for the measurement of high-resolution gaseous emission spectra at the Earth's limb. It operates in the near to mid infrared where many of the atmospheric trace-gases playing a major role in atmospheric chemistry have important emission features.

### 2.3.8 SCIAMACHY

SCIAMACHY is an imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere.

### 2.3.9 DORIS

The Doppler Orbitography and Radio-positioning Integrated by Satellite instrument is a microwave tracking system that can be utilized to determine the precise location of the Envisat satellite. DORIS operates at dual frequency and so also provides information on ionospheric electron content that can be used to determine the delay to the RA-2 signal due to the ionosphere.

### 2.3.10 LRR

The LRR is a passive device, which is used as a reflector by ground-based SLR stations using high-power pulsed lasers. In the case of Envisat, tracking using the LRR is principally accomplished by the International Laser Ranging Service (ILRS).

## 2.4 Orbit

Envisat flies in a sun-synchronous polar orbit of about 800-km altitude. The repeat cycle of the reference orbit for the primary phase was 35 days, and for most sensors, being wide swath, it provided complete coverage of the globe within one to three days. The exceptions are the profiling instruments MWR and RA-2, which do not provide real global coverage, but span a tight grid of measurements over the globe. This grid is the same 35-day repeat pattern as that established by ERS-1 and ERS-2.

The mean classical orbit elements for the 35-day phase are given in the table below.

**Table 2-3 Envisat 35-day phase orbit parameters**

| Orbit parameter | Value |
|---|---|
| Orbits per Day | 14 11/35 |
| Repeat Cycle (days) | 35 |
| Orbits in Cycle | 501 |
| Orbit Period (min) | 100.59 |
| Mean Local Solar Time at descending node | 10:00 |
| Inclination (deg) | 98.55 |
| Semi-Major Axis [Orbit Radius] (km) | 7159.5 |
| Orbit Velocity (km/s) | 7.45 |
| Mean Altitude (km) | 799.8 |
| Orbital Altitude Range (km) | 780 - 820 |

The orbit maintenance requirements during the primary phase were that the deviation of the actual ground track from the nominal one was kept below 1 km and that the mean local nodal crossing time matched the nominal one to better than five minutes. The requirements for the extension phase have been relaxed so that there is no requirement for an exact repetition of the ground track and the mean local nodal crossing time is to match the nominal one to better than 10 minutes.

The orbit maintenance strategy aims for minimum disturbance of the payload operation. In-plane manoeuvres are used for altitude adjustment to compensate for the effects of air-drag.

This altitude decay controls the ground-track repeatability, mainly in the equatorial regions. The frequency of these manoeuvres is determined by the rate of orbital decay, which is in turn determined by the air density, and this is a function of solar activity. The nominal rate for these in-plane manoeuvres is twice a month. They do not interrupt the operations of most sensors.

During the 35-day exact repeat phase, out-of-plane corrections were used to correct the steady drift of inclination mainly caused by solar and lunar gravity perturbations. The solar wind also influences the inclination, but its contribution is typically one order of magnitude smaller than the one given by solar and lunar gravity. Inclination drift degrades the ground-track maintenance at high latitudes. The drift rate does not depend on air density and corrections were required every few months. As they are out-of-plane they require a 90 degree rotation of the spacecraft, to align the thrusters with the required thrust direction, and so these manoeuvres were performed in eclipse to avoid the risk of optical sensors viewing the sun.

During the extension orbit phase, from 2 Nov 2010, the orbit altitude was reduced to 782.4 km and, in order to save fuel and so extend the life of the satellite, the out-of-plane corrections that prevent inclination drift have been stopped. The resultant orbit has a 30-day 'near repeat' of 431 orbits per cycle, with minimal drift at 38°N (for descending tracks) and 38°S (for ascending tracks) (see Figure 2).

**Table 2-4 Definition of cycle numbering for the Envisat mission**

| 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 |
| | … | … | … |
| 94 | 45145 | … | 18 Oct 2010 21:59:59 |
| 95 | … | 45272 | |
| 96 | 45273 | 45703 | 27 Oct 2010 21:59:29 |
| 97 | 45704 | 46134 | 26 Nov 2010 21:59:59 |
| … | … | … | … |

The definition of the orbit numbering and cycles, as given in §1.4.1.2, is that the first relative orbit within a cycle is the orbit with the smallest offset from zero longitude. However, the absolute orbit number is continuous from the beginning of the mission. As the satellite was not injected directly into its final operational orbit, there are several cycles at the beginning of the mission where cycles did not contain 501 orbits (1002 passes) and the relationship of absolute to relative orbit number is not simple. Table 2-4 shows the definition of the cycle numbering used for Envisat over the first 10 cycles. From cycle 5 onwards, the platform was in its primary repeat orbit and hence for cycle 5 until cycle 94, the relationship between relative orbit, cycle and absolute orbit can be given as:

| |
|---|
| Absolute orbit = relative orbit + ((cycle – 5) * 501) + 555 |

The relative orbits within each 35-day cycle (from cycles 5 - 94) are defined by their equator crossing longitudes and times, as given in Table A-1 and Table A-2 . The track separation is 0.719° longitude between adjacent tracks in the same sense (ie between adjacent ascending or descending passes).

Cycle 95 covered the orbit manoeuvres to transfer Envisat to the extension orbit phase, with its 30-day near-repeat orbit. There are no altimetry data between 22 October and 2 November 2010 whilst the manoeuvres were carried out.

For the extension orbit phase, the relationship between relative orbit, cycle and absolute orbit can be given as:

| |
|---|
| Absolute orbit = relative orbit + ((cycle – 96) * 431) + 45272 |

The track separation during the extension orbit phase is 0.835° longitude between adjacent tracks in the same sense.

# 3 Envisat RA-2 Products

## 3.1 RA-2 Data Processing

The RA-2 series of products is summarized in Table 2-1 and the product tree of Figure 3.

**Table 3-1 RA-2 Products**

| Product ID | Description |
|---|---|
| RA2_CAL_0P | RA2 Calibration and BITE Mode Level 0 |
| RA2_ME__0P | RA2 Measurement Mode Level 0 |
| RA2_MW__1P | Geolocated and calibrated Altimeter Waveforms with TOA Microwave Brightness Temperatures |
| RA2_FGD_2P | FDGDR: Fast delivery Geophysical Data record from RA-2 and Water Vapour/Liquid Content from MWR. Available 3 hours after data acquisition |
| RA2_IGD_2P | IGDR: Intermediate Geophysical Data record from RA2 and Water Vapour/Liquid Content from MWR. Processed off-line and available 3-5 days after acquisition |
| RA2_GDR_2P | GDR: Geophysical Data Record from RA-2 and Water Vapour/Liquid Content from MWR. Processed off-line and available 50 days after acquisition |
| RA2_WWV_2P | FDMAR/IMAR: Wind/Wave product with height and MWR information for NRT dissemination to Meteocean users (2 products released at different levels of consolidation: FDMAR built from RA2_FGD_2P or IMAR built from RA2_IGD_2P) |
| RA2_MWS_2P | SGDR: Sensor Geophysical Data Record from RA-2, Water Vapour/Liquid content from MWR and Individual Uncalibrated Waveforms from RA-2. Available after 50 days from data take. |

The COASTALT processor uses data from the level 2 SGDR product (RA2_MWS_2P) to generate the output product. This product contains 1 Hz averaged and 18 Hz RA-2 and MWR data, as well as 1 Hz geophysical corrections and flags. The SGDR also contains the 18 Hz waveform data used by the COASTALT processor.

*Important Note:* the "1 Hz" averages are actually averages of 20 18 Hz samples, and as such are at 0.9 Hz. However, they are referred to as 1 Hz for simplicity and for comparison with the equivalent averaged values from other altimetric missions.

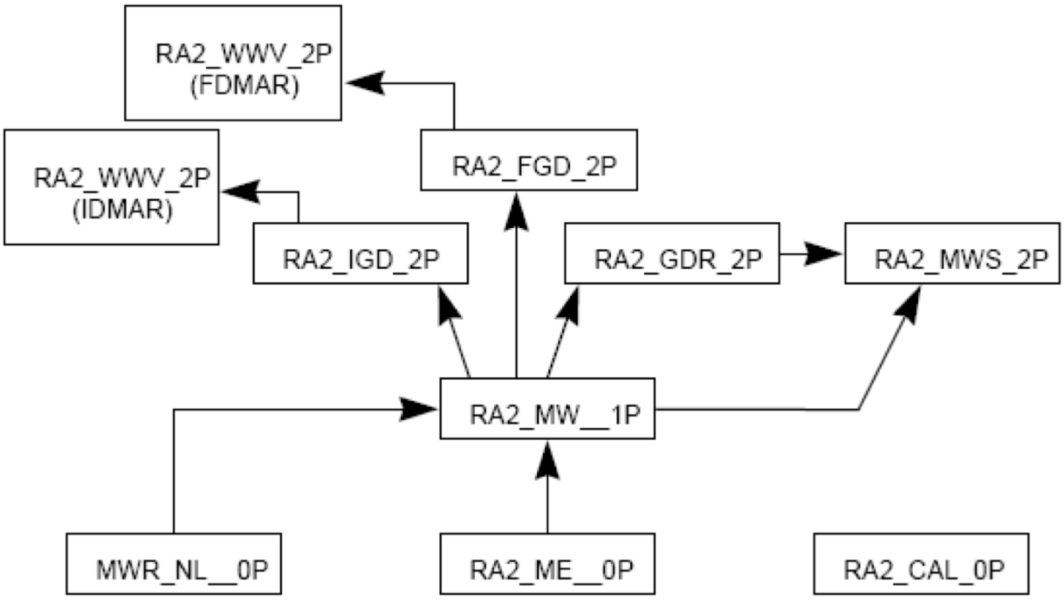


**Figure 3: RA-2 Product Tree**

## 3.2 Product History

The precise content of the Level 2 product is determined by the CMA (level 2) processing software version, and also by the software versions used to generate the lower level products, in particular the level 1B, IPF, software version. The software version of the level 2 (CMA) processing chain is included in the SGDR header information, and is retained in the CGDR global attributes. However, the Level 1B (IPF) software version information has only been included in the SGDR data since CMA version 7.1 and is not yet included in the CGDR products. The versions of the software used to generate the latest SGDR products are given in Table 3-2 and the changes to software version, as they affect the SGDR data, are given in Table 3-3 and Table 3-4.

**Table 3-2 Software Versions used to generate the latest Envisat SGDR products [AD 8]**

| Cycles | IPF version | CMA version |
|---|---|---|
| 9 to 10 | 4.58 | 6.3 |
| 11 to 12 | 4.57 | 6.3 |
| 13 to 15 | 4.56 | 6.3 |
| 16 to 18 | 4.54 | 6.1 |
| 19 to 24 | 4.56 | 6.2 |
| 25 to 26 | 4.56 | 6.3 |
| 27 to 28 | 4.57 | 6.3 |
| 29 to 37 | 4.58 | 6.3 |
| 38 to 47p790 | 5.02 | 7.1 |
| 47p791 to 48p849 | 5.06 | 9.0 |
| 48p850 to 51p007 | 5.02 | 7.1 |
| 51p008 to 58p843 | 5.03 | 8.0 |
| 58p844 to 64 | 5.06 | 9.0 |
| 65 to 67 | 5.06 | 9.1 |
| 68 to 84 | 5.06 | 9.2 |
| 85- | 6.02L04 | 9.3.02 |

Where the change in version occurs within a cycle, the last, or first, pass within that cycle that a version applies to is denoted using p<pass>

The change from IPF 4.58/CMA6.3 to IPF 5.02/CMA7.1 was significant, with a recomputed Sea-State bias table to account for the impact of the new orbit and the new geophysical corrections (MOG2D, GOT00 ocean tide correction with the S2 component corrected once only, new wind speed algorithm [RD 1]). The new SSB correction is shifted by approximately +2.0 cm from the previous one. New standards are used for the computation of the Envisat Precise Orbit Estimation. One of the main evolutions is the use of the GRACE gravity model EIGEN GC03C. This new model implies a strong reduction of the geographically correlated radial orbit errors. In order to take into account the dynamical effects and wind forcing, a new correction is computed from the MOG2D barotropic model [RD 6] forced by pressure (without S1 and S2 constituents) and wind.

Other changes are less significant, but impact on the resultant height data can still be seen.

There are specific issues in some software versions, regarding the availability of particular header data or variables.

***Note***: For CMA versions prior to 6.3, the pass number is not reported in the header information (the pass number field does not exist) and so is not reported in the CGDR global attributes. For CMA versions 6.1 to 6.2_05 the relative orbit number reported in the header (and hence reported in the CGDR) is actually the pass number, and the relative orbit number is not reported in the product. For all versions of CMA prior to 9.0, the relative orbit number provided in the **filename** *for ascending passes* is the orbit number of the orbit *at the start of the pass*, rather than the orbit that starts at the ascending node crossing *during* the pass. However, the relative orbit number reported in the file **header** (from CMA 6.3 onwards) is the expected value (ie the orbit number starting during the pass), ie that an ascending pass and the *following* descending pass have the same relative orbit number.

**Table 3-3 IPF software version changes affecting SGDR products [AD 8; AD 9]**

| Version | Changes |
|---|---|
| IPF 4.56 | -Extrapolation of AGC value to the Waveform centre (49.5) for both Ku- and S-band<br>-Correction for an error found in the evaluation of S-band AGC |
| IPF 4.57 | No impact on data |
| IPF 4.58 | -Addition of a Pass Number Field in Fast Delivery Level 2 products |
| IPF 5.02 | -MWR Side Lobe correction upgrade<br>-USO clock period units correction<br>-Rain Flag tuning to compensate for the increase of the S-band Sigma0<br>-Monthly IF mask taken into account<br>-DORIS Navigator CFI upgrade (RA-2 and MWR)<br>-S-band anomaly flag |
| IPF 5.03 | -Correction for an error found in the Channel 2 brightness temperature<br>-Correction for an error in the window delay (for the 80 and 20 MHz bandwidths)<br>-S-band anomaly flag upgrade, now properly implemented<br>-Correction of Rx-Fine parameter<br>-MWR second channel corrected (Side Lobes correction) |
| IPF 5.06 | None |
| IPF 6.02 | New S-band Waveform Reconstruction Algorithm on RA-2 Level 1B Data<br>New USO Correction Algorithm on RA-2 Level 1B Data |

**Table 3-4 CMA software version changes affecting SGDR products [AD 8; AD 9]**

| Version | Changes |
|---|---|
| CMA 6.1 | -MSS CLS01<br>-Rain flag<br>-MWR neural algorithm<br>-Sea Ice tuning<br>-Sea State Bias Table file<br>-GOT00.2 Ocean Tide Sol 1 Map file<br>-FES 2002 Ocean Tide Sol 2 Map file<br>-FES 2002 Tidal Loading Coeff Map |
| CMA 6.2 | No impacts on Envisat products |
| CMA 6.3 | -Updated OCOG retracking thresholds Ice1 Conf file<br>-Increased GDR data coverage by the use of both consolidated and non-consolidated data prods in inputs.<br>- Addition of PASS_NO header item |
| CMA 7.1 | -Improving the mispointing estimation<br>-Addition of square of the SWH in Ku and S-band<br>-Addition of GOT2000.2 loading tide<br>-FES2004 tide and loading tide<br>-New DEM AUX file (MACESS) merge of ACE land elevation data and Smith and Sandwell ocean bathymetry<br>-New orbit standards<br>-New SSB solution<br>-new wind table<br>-MOG2D upgraded<br>-New S1S2 wave model in dry troposphere<br>-GOT00.2 includes two extra waves, S1 and S2<br>-GIM model ionospheric correction added in the products |
| CMA 8 | -No impacts |
| CMA 9 | -Correction of an anomaly in the relative orbit field in the file name. No scientific impact. |
| CMA 9.1 | -Separating the processing of Jason-1 and Envisat No scientific impact. |
| CMA 9.2 | -New POD orbit configuration.<br>-New Dynamic Atmospheric Correction (DAC/MOG2D High Resolution) |
| CMA 9.3 | -Updated Rain Flag Algorithm<br>-New Sea-Ice Flag Algorithm |

## 3.3 COASTALT: Envisat data in the coastal zone

The primary aim of the COASTALT project is to make the status of pulse- limited coastal altimetry operational, by defining and testing a new Envisat coastal radar altimeter product that ESA can routinely generate and distribute.

In order to achieve these aims, the project has developed a coastal processor that can:

- ingest the ESA Envisat level-2 SGDR products.
- reprocess the waveform data, using a number of alternative retrackers to generate high resolution (18 Hz) data which may be more useful in coastal areas.
- generate new geophysical corrections from these new data.
- generate higher data rate geophysical correction data, by interpolation, as necessary for correcting the higher rate range data.
- output all the relevant original and new fields into a single file per pass, in a self describing format.

The basic coastal product includes fields that can be determined for any coastal region, using the data from the altimeter itself, or instruments mounted on the same platform, and global models. This product does not include fields that would require specific auxiliary information, such as a region-specific tidal model, or *in situ* observational data. The current version, v2.0 [AD 7], of the product allows the generation of a USO correction field, using auxiliary data files provided by ESA along-side the SGDR data. The processor also uses auxiliary data files, provided by ESA, to allow correct calibration of the backscatter values from the processor. If any of the necessary auxiliary files are absent during the processing, then the relevant fields will be unfilled and the calibrations not applied. Additional fields may be added to the product, using the standalone product enhancer (*addcorr*).

The output product has been designed to allow use of the new, retracked, range, significant wave height and backscatter values, together with the geophysical corrections that rely on them (such as ionospheric correction and sea-state bias corrections). They also contain the comparable original data, to enable users to readily compare the SGDR and COASTALT values. One enhancement of the source data is to provide geophysical correction fields at the higher (18 Hz) data rate. This involves interpolation of the existing 1 Hz values. All geophysical corrections provided on the SGDR have been interpolated, using a simple linear interpolation, to provide 18 Hz correction values in the v2.0 CGDR products.

### 3.3.1 The COASTALT Processor

The COASTALT Processor is designed to be able to be used by experienced investigators to generate their own products, specific to their area of interest. To this end, the processor has been designed to be flexible in its use [AD 16]. Many of the parameters are defined by configuration files accessed at run-time, which can be tailored to specific requirements. In addition, the processor has a 'plug and play' capability [AD 17], allowing a user to implement their own re-tracking software, outputting the resultant retracking parameters as well as the fields of the basic product.

The output product can be restricted to include only data falling within a pre-defined coastal region. This is achieved by use of a coastal mask file, defined in the configuration file when the product is generated. The name of the coastal mask used is stored as a global attribute within the file (see §7.2). The coastal masks used in standard CGDR data have been generated using the coastal mask tool provided with the processor [AD 18].

## 3.4 Models used

The CGDR products are based on the Envisat Level 2 SGDR products. The input SGDR values have not been altered during translation to the CGDR product, except in the case of some flags (detailed below) and the generation of interpolated values. All algorithm specifications for variables determined directly from the SGDR values can be found in the Envisat documentation [AD 1].

**Note:** As the Envisat Level 2 products have not been generated with a single, consistent version of the level 1b IPF processing chain, nor a single version of the level 2 CMA processing chain (see §3.2), there are changes in input data format and content that have not been corrected in the output CGDRs.

The table below summarizes the models and standards that are adopted in this version of the CGDR. Section 3.5 provides more details on models added in the COASTALT processor, whilst more general information on included models is provided in §5.

**Table 3-5 Models and standards**

| Parameter | Model |
|---|---|
| Orbit | Based on DORIS and laser tracking data. Specific model dependant on software processing version. |
| Altimeter Retracking | "Ocean" retracking (from SGDR)<br>Brown model as defined in [AD 1]<br>COASTALT Brown retracking<br>A Brown theoretical Ocean Retracker (BOR) [AD 6] – a modified version of [RD 20]<br>COASTALT Specular retracking<br>A Specular Beta-parameter Retracker (SBR) [AD 6]<br>COASTALT Mixed retracking<br>A Mixed Brown and Specular Retracker (MBS) [AD 6] |
| Altimeter Instrument Corrections | Consistent with "Ocean" retracking algorithm [AD 1] |
| USO Correction | From an instrumental method based on the comparison between the USO clock and an external clock: the platform clock [RD 11] |
| Dry Troposphere Range Correction | From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides |
| Wet Troposphere Range Correction from Model | From ECMWF model |
| Wet Tropospheric Correction from Radiometer | Obtained with a neural algorithm from the 23.8 GHz and 36.5 GHz brightness temperatures (in K) interpolated to RA-2 time tag, and the ocean backscatter coefficient for Ku-band (dB), not corrected for atmospheric attenuation [RD 24] |
| Wet Tropospheric Correction from Dynamic Linear Model | Obtained using the DLM algorithm, an interpolation based primarily on the radiometer wet tropospheric correction (see §3.5.2) |
| Ionospheric Correction | from the dual frequency Ocean re-tracked range measurements (until S-band failure on 18 Jan 2008)<br>from the DORIS daily maps of Total Electron Content<br>from the GIM model for products processed with CMA v7.1 or higher<br>The following are only available until S-band failure on 18 Jan 2008:<br>from the COASTALT Brown retracked dual frequency ranges (until S- |

| Parameter | Model |
|---|---|
| | band failure on 18 Jan 2008)<br>from the COASTALT Specular retracked dual frequency ranges (until S-band failure on 18 Jan 2008)<br>from the COASTALT Mixed retracked dual frequency ranges (until S-band failure on 18 Jan 2008) |
| Sea State Bias | empirical function of Ku-band's significant wave height and the RA-2 wind speed, derived from one year of Envisat data (cycles 25 to 35), using crossover SSH differences and applying the non parametric estimation technique [RD 18] |
| Inverse Barometer Correction | Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides |
| Non-tidal High-frequency Dealiasing Correction | Mog2D High Resolution ocean model. Ocean model forced by ECMWF winds and atmospheric pressures after removing S1 and S2 atmospheric tides – difference of this value and the inverse barometer correction is reported [RD 6] |
| Tide Solution 1 | GOT00.2b – total geocentric tide [RD 7, RD 33], including the load tide and the long-period equilibrium tide contributions |
| Tide Solution 2 | FES2004 – total geocentric tide [RD 25], including the load tide [RD 16] and the long-period equilibrium tide contributions |
| Solid Earth Tide Model | From Cartwright and Taylor tidal potential [RD 8] |
| Pole Tide Model | Equilibrium model [RD 43] |
| Wind Speed from Model | ECMWF model 10 m u and v wind components |
| Altimeter Wind Speed Model | Algorithm based on a fit between Envisat Ku-band Sigma0 and the collocated ECMWF model wind speed, adjusted based on in-situ wind measurements [RD 1]. |
| Rain Flag | If the expected Ku/S-band rain-free relationship minus the uncorrected Ku ocean backscattering coefficient, and if the MWR liquid water content are bigger than certain thresholds |
| Mean Sea Surface | CLS01 [RD 22] |
| Mean Dynamic Topography | CLS Rio 05 [RD 35] |
| Geoid | EGM96 [RD 28] |
| Bathymetry Model | MACESS Global Digital Elevation Model [RD 13] |

## 3.5 COASTALT Specific Models

### 3.5.1 COASTALT retrackers

Three physically based waveform retrackers are implemented and run in parallel in the COASTALT processor in its standard configuration. They are:

- a conventional Brown theoretical Ocean Retracker
- a Specular Beta-parameter retracker with Exponential trailing edge
- an experimental Mixed Brown Specular retracker

#### 3.5.1.1 Retracker 1: Brown theoretical ocean retracker (BOR)

This is an implementation of the well-known Brown ocean waveform retracker, known to perform well for altimeter waveforms over the open ocean and (typically) up to ~10 km from the coast.

The complete expression of the power $P_r(t)$ at time $t$ is given by:

$$P_r(t) = \frac{const1 * sigma0}{h^3} \exp\left\{-\frac{4}{\varphi}\sin^2\xi - \frac{4c}{\varphi h}(t-t_0)\cos 2\xi\right\} I_0\left(\frac{4}{\varphi}\sqrt{\frac{c(t-t_0)}{h}}\sin 2\xi\right)$$

Eq. 1

$$\left\{erfc\left(\frac{-(t-t_0)}{\sqrt{2}\sigma_c}\right) - \frac{1}{\sqrt{2\pi}}\exp\left(\frac{-(t-t_0)^2}{2\sigma_c^2}\right)\frac{\lambda SWH^3}{24c^3\sigma_c^3}He_2\left(\frac{(t-t_0)}{\sigma_c}\right)\right\} + Tn \qquad \text{for } t \ge t_0$$

And

$$P_r(t) = \frac{const1 * sigma0}{h^3} \exp\left\{-\frac{4}{\varphi}\sin^2\xi\right\}$$

Eq. 2

$$\left\{erfc\left(\frac{-(t-t_0)}{\sqrt{2}\sigma_c}\right) - \frac{1}{\sqrt{2\pi}}\exp\left(\frac{-(t-t_0)^2}{2\sigma_c^2}\right)\frac{\lambda SWH^3}{24c^3\sigma_c^3}He_2\left(\frac{(t-t_0)}{\sigma_c}\right)\right\} + Tn \qquad \text{for } t < t_0$$

with

- $sigma0$ the normalised radar backscatter cross-section at nadir
- $h$ the satellite height
- $\xi$ the mispointing angle (from nadir)
- $c$ the velocity of light in vacuo
- $t_0$ the time origin ($=2h/c$) corresponding to the mid-point on the waveform leading edge
- $I_0(t)$ the modified Bessel function of the first kind [RD 2]
- $Tn$ the thermal noise
- $erfc(x)$ the complementary error function [RD 2]
- $\lambda$ the ocean skewness
- $SWH$ the Significant Wave Height
- $He_2$ the Hermite polynomial of order 2

and

$$const1 = \frac{G_0^2 \lambda_R^2 c \eta P_T \sigma_P}{4(4\pi)^2 l_p} \sqrt{\frac{\pi}{2}} \qquad \text{Eq. 3}$$

$$\varphi = \frac{\Psi_B^2}{2\ln 2} \qquad \text{Eq. 4}$$

$$\sigma_c = \sqrt{\sigma_p^2 + \frac{4\sigma_s^2}{c^2}} \qquad \text{Eq. 5}$$

with

- $G_0$ the antenna gain parameter
- $\lambda_R$ the radar wavelength
- $\eta$ the pulse compression ratio
- $P_T$ the transmitted power
- $\sigma_p$=0.53*(compressed pulse width) [AD 2]
- $l_p$ the two-way propagation loss over and above the free-space loss
- $\Psi_B$ the antenna beam in radians
- $\sigma_s$ the standard deviation of the sea surface elevation, related to the significant wave height by $\sigma_s \sim SWH/4$.

These are the equations implemented in the NOC-S BOR retracker, which has been used successfully to retrack Envisat RA-2 Ku-band waveforms [RD 20].

In the first instance, the implementation of the NOC-S BOR retracker in the COASTALT processor will make the following simplifications:

- four parameters retrieval: range ($t_0$), *SWH* ($\sigma_s$), Sigma$_0$, Thermal Noise
- Linear wave statistics (skewness and cross-skewness set to zero)
- Least-square fitting (with provision for weighted least square fitting in future)

#### 3.5.1.2 Retracker 2: Specular Beta-parameter retracker (SBE)

This waveform model is the Specular Beta-parameter retracker with exponential trailing edge, as outlined in Deng & Featherstone [RD 12]. This functional form is well suited to fit waveforms with a rapidly decaying trailing edge. The algorithm fits a 5- or 9-parameter function to the waveform reflected from one or two scattering surfaces.

The general function for the model is:

$$SBE(t) = \beta_1 + \sum_{i=1}^{n} \beta_{2i} \exp(-\beta_{5i} Q_i) P\left(\frac{t-\beta_{3i}}{\beta_{4i}}\right) \qquad \text{Eq. 6}$$

where

$$Q_i = \begin{cases} 0 & for\ t < \beta_{3i} - 2\beta_{4i} \\ t - (\beta_{3i} - 2\beta_{4i}) & for\ t \ge \beta_{3i} - 2\beta_{4i} \end{cases} \qquad \text{Eq. 7}$$

(NB – equation corrected from Eq A10 in [RD 12]) and

$$P(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-q^2}{2}\right) dq$$ Eq. 8

and n = 1 or 2 is the number of the ramp in the waveform that corresponds to the single- or double-reflecting surfaces in the 5- and 9-parameter form respectively.

In the COASTALT processor, the 5-parameter form of the retracker has been implemented, with provision for a future implementation of the 9-parameter form.

The waveform fitting has been performed using ordinary least squares, with provision made for weighted least square in future.

#### 3.5.1.3 Retracker 3: Mixed Brown Specular retracker (MBS)

The functional form of this retracker consists of the linear superposition of the Brown model (Eq. 1-2) and the 5-parameter Specular Beta-parameter model (Eq. 6), i.e.

$$MBS(t) = BOR(t) - SBE(t)$$ Eq. 9

This is an experimental retracker which aims to address the retracking of coastal waveforms, which display a specular peak embedded within a Brown-type ocean waveform. Such highly variable waveform shapes are frequently observed during the analysis of waveforms in the coastal zone in WP3.1 (*e.g.* see Figure 4).

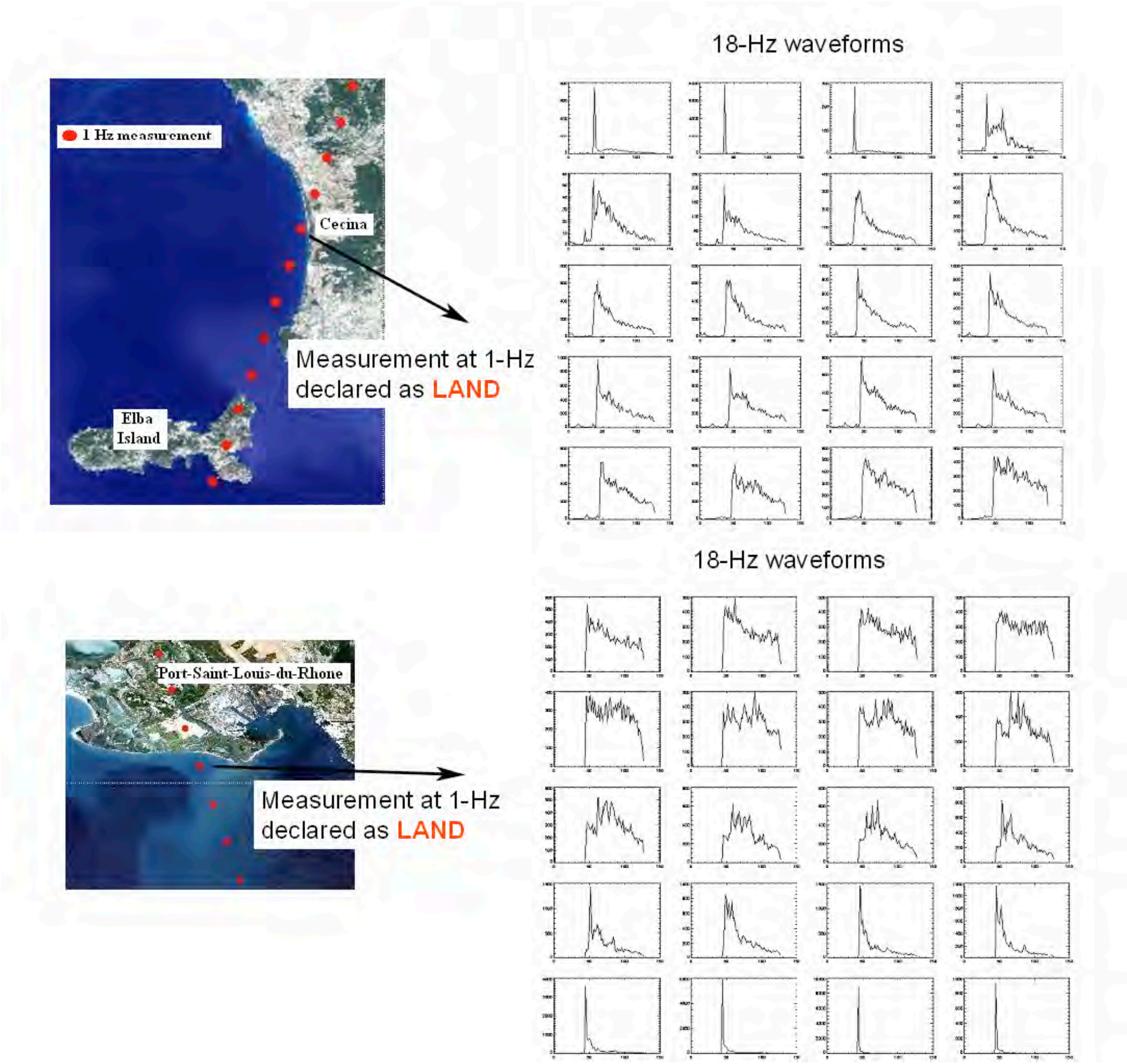


**Figure 4: Examples of 18Hz Ku-band waveforms in the coastal zone in the North-West Mediterranean test site (from AD 11)**

### 3.5.2 Wet Tropospheric Correction from Dynamically Linked Model

The wet tropospheric correction is calculated using the Dynamically Linked Model approach. The method is described in detail in AD 10. It is based on the radiometer-derived wet tropospheric correction; with 'gaps' filled using calibrated atmospheric model derived correction. In the case of the CGDR data, the source for the model correction is the ECMWF model.

There are two cases to be considered depending on the length of the coastal data segment over which radiometer wet trop correction is missing or bad:

#### 3.5.2.1 "Long" (>60km) radiometric wet tropospheric correction gap

This is the typical case when the satellite is approaching or receding from a large land-mass, as illustrated in Figure 5.

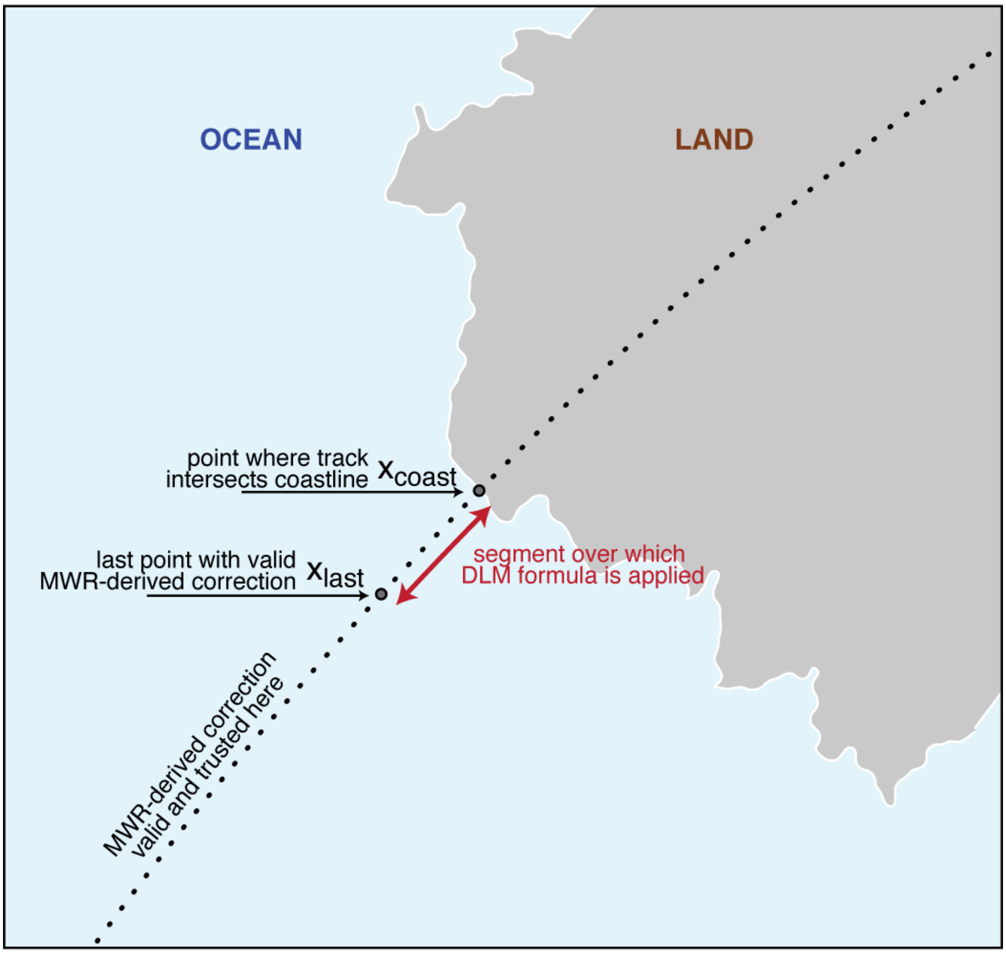


**Figure 5: Typical configuration for a "long" radiometric wet tropospheric correction gap**

In this case, the bias in the model correction with respect to the observed radiometer-derived correction is calculated at the last point with valid radiometer data as:

$$bias = R_{MOD}(x_{last}) - R_{MWR}(x_{last}) \qquad \text{Eq. 10}$$

and the new model wet trop correction up to the coastline $x_{coast}$ reads:

$$R_{wettropo}(x) = R_{MOD}(x) - bias \quad \text{for } x = x_{last} \text{ to } x_{coast} \qquad \text{Eq. 11}$$

### 3.5.2.2 "Short" (<60km) or "ocean-only" wet tropospheric correction gap

This is the more complex case where the gap with missing or bad radiometer wet tropospheric correction is less than 60 km, or the radiometer data is contaminated by land located across-track from the nadir. Both examples are illustrated in Figure 6.

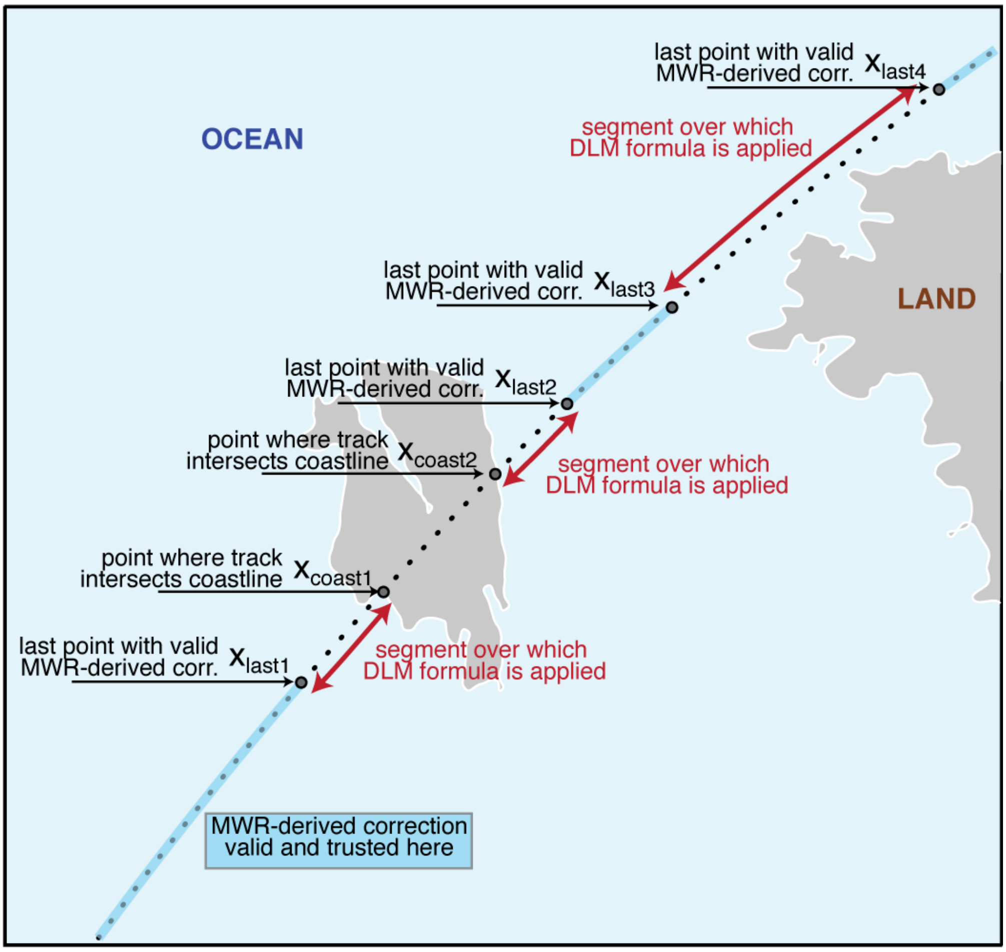


**Figure 6: Configuration for short (less than 60km) radiometer data gap or contamination by land located across-track from nadir.**

In both cases, the bias between the model wet tropospheric correction and the radiometer wet tropospheric correction is calculated from the last valid radiometer data point on both sides of the gap, i.e.

$$bias1 = R_{MOD}(x_{last1}) - R_{MWR}(x_{last1}) \quad \text{Eq. 12}$$

$$bias2 = R_{MOD}(x_{last2}) - R_{MWR}(x_{last2}) \quad \text{Eq. 13}$$

and the new model correction becomes:

$$R_{wettropo}(x) = R_{MOD}(x) - [\,(1-\alpha)\bullet bias1 + \alpha\bullet bias2\,] \quad \text{Eq. 14}$$

where

$$\alpha = (x - x_{last1}) / (x_{last2} - x_{last1}) \quad \text{Eq. 15}$$

represents the linear variation of the correction from *bias1* at $x_{last1}$ to *bias2* at $x_{last2}$.

#### 3.5.2.3 Use of the DLM in the CGDR

In the CGDR, the dynamically linked model is used to generate the 18 Hz radiometer wet tropospheric correction (hz18_mwr_wet_trop). The radiometer interpolation flag (mwr_wet_trop_interp_flag) can be used to determine the source of the correction value. The DLM correction is determined initially at 1 Hz using the SGDR supplied 1 Hz model and MWR derived wet tropospheric corrections. Where the MWR derived value is flagged as good (the Measurement Confidence Data flag, meas_conf_data_flags, bits 8-12 and the radiometer land flag, radio_landocean_flag, all set zero) the 1 Hz DLM correction value is set equal to the MWR correction value and the MWR interpolation flag value is set to 0. Gaps in the 1 Hz values are then filled using the DLM, as described above. Where the DLM has interpolated over a short gap, the interpolation flag is set to 1. Where the DLM has been used to interpolate a long gap, the interpolation flag is set to 2. Where no interpolation has been possible the 1 Hz DLM value is left default and the interpolation flag is set to 3.

This 1 Hz DLM value is then interpolated to the 18 Hz times using the same, simple linear interpolation scheme as used for the other 18 Hz correction values.

### 3.5.3 Distance from coast

In the COASTALT CGDR products, the distance from coast is computed at 18 Hz by linear 2-d interpolation of a distance map onto the locations of the 18 Hz points. Since version 2.0.2 of the CGDR the distance map has been computed using the GSHHS (Global Self-consistent, Hierarchical, High-resolution Shoreline) high-resolution shoreline data set, amalgamated from two databases (the CIA world database WDBII, and the World Vector Shoreline database) and maintained by P. Wessell and W. H. F. Smith [RD 44].

The algorithm used is an approximation, and for each gridpoint in the distance map, is derived by:

1) determining the distance of the gridpoint from its projection onto each side of each polygon in the GSHHS database (within a limited region for speed of calculation)
2) determining the distance of the gridpoint from all the vertices of each polygon
3) selecting the shortest distance calculated.

Distances are computed in degrees, in the cartesian plane (neglecting curvature), and then converted into km using a fixed conversion factor of 111 km/degree (hence the approximation), which is only acceptable for short lengths (<200 km) and at low-to-mid latitudes (<60°).

# 4 Using the CGDR data

## 4.1 Overview

This section will give the reader a guide to the use of the CGDR data. These products are experimental, and provided primarily for research purposes. They have not yet been fully validated, and users should proceed with caution, particularly in regard to the coastal specific fields. While this handbook tries to be correct and complete, note that nothing can replace the information to be gained at conferences and other meetings from those using these data.

**The reader must proceed with caution and at his or her own risk.**

The instruments on Envisat make direct observations of the following quantities of interest to satellite altimetry users: altimeter range, ocean significant wave height, ocean radar backscatter cross-section (primarily a function of surface wind speed), ionospheric electron content in the nadir direction and tropospheric water content. Ground based laser station and DORIS station measurements of the satellite location and speeds are used in precision orbit determination (POD). The DORIS stations also measure the ionospheric electron content along the line of sight to the satellite. All of these measurements are useful in themselves, but they are made primarily to derive the sea surface height with the highest possible accuracy. Such a computation also needs external data (not collected aboard Envisat), e.g., atmospheric pressure. In addition, instrument health and calibration data are collected onboard and used to make corrections to the main measurements and to monitor the instrument stability in the long term.

This CGDR contains all relevant corrections needed to calculate the sea surface height. For the other geophysical variables in the CGDR: ocean significant wave height, tropospheric water content, ionospheric electron content (derived by a simple formula) and wind speed, the necessary instrument and atmospheric corrections have already been applied.

The following sections explain the organisation of the products, and the rationale for how the corrections should be applied.

## 4.2 Organisation of the Product

The CGDR products are arranged as one file per pass, as for the source SGDR products.

The product names are based on the convention used for the Envisat Level 2 Products, namely:

Filename = <product_ID><processing_stage_flag><originator_ID>
<start_day>_<start_time>_<duration>
<phase><cycle>_<relative_orbit>_<absolute_orbit>_<counter>.nc

With:

| | | |
|---|---|---|
| <product_ID> | RA2_MWS_2P | |
| <processing_stage_flag> | O | Processing stage flag (N-V, where letter closer to V are higher levels of consolidation |
| <originator_ID> | F-P | A 3 character ID code for the originator of the Level 2 products (F-P is the French PAF, AVISO) |
| <start_day> | yyyymmdd | UTC date of first record in file in year month day order |
| <start_time> | Hhmmss | UTC time of first record in file in hour minute second format |
| <duration> | Ssssssss | duration of product in seconds |
| <phase> | A | mission phase – single character A or B |
| <cycle> | CCC | the cycle, a three digit number, eg 021 = cycle 21 |
| <relative_orbit> | XXXXX | the relative orbit number within the cycle, a five digit number from 00001 to 00501, eg 00042 is relative orbit 42 |
| <absolute_orbit> | XXXXX | the absolute orbit number since the start of the mission, a five digit number, eg 02456 |
| <counter> | XXXX | incremental counter for product, from 0000 to 9999 then wraps to 0000 |

For example:

Product:

RA2_MWS_2POF-P20040408_201943_00003017A025_00443_11018_0391.nc

is based on the SGDR product:

RA2_MWS_2POF-P20040408_201943_00003017A025_00443_11018_0391.N1

Which is a level 2 RA2 / MWR product, at processing stage O, originating from the French PAF, with the first record in the file from 8th April 2004, 20:19:43, including 3017 seconds of data from phase A, cycle 25, relative orbit 443, absolute orbit 11018 and was product 391 generated (in base 10000).

**Note 1** – the data for a single orbit (south pole to south pole) will be contained in two separate files. The two files will have the same <phase>, <cycle>, <relative_orbit> and <absolute_orbit>.

**Note 2** – due to changes in the software generation, the <relative_orbit> and <absolute_orbit> in the product filename are not consistently applied. For cycles 0 – 57 the ascending pass (from southern extreme to northern extreme) of each orbit was assigned a filename with the <relative_orbit> corresponding to the orbit at the *start* of the pass, not the orbit that starts during the pass. From cycle 58, the <relative_orbit> assigned to the pass was the orbit that starts at the equator crossing of the pass, as this assigns passes 1 and 2 to orbit 1, which is more intuitive and consistent with numbering used for other altimetry mission. For consistency with the source data, the CGDR products use the *same* filename as the source SGDR products and hence have the same inconsistency in file naming.

*Users are advised to check the global attributes of the CGDR files to ensure they have the correct pass (see §3.2 for more details).*

The CGDR product is arranged with related values clustered together in the product. Hence, the first section of the product contains the dimension variables and coordinate variables then the orbit information (including the positional information). The complete list of variables included in the products is given in AD 7.

Within each section, there will be variables reported at "1 Hz" and variables reported at 18 Hz. The "1 Hz" variables (actually, 0.9 Hz) represent an average of 20 of the 18 Hz values. The 18 Hz variables are represented as 2 dimensional variables, with the primary dimension equal to the dimension of the 1 Hz data, and the second dimension being 20 – the number of samples in the 1 Hz average. The 1 Hz average is calculated as occurring at the centre- point of the 18 Hz values, ie between the location of the $10^{th}$ an $11^{th}$ 18 Hz values.

In general the 1 Hz and 18 Hz variables will have the same variable name, with the 18 Hz versions having the variable name prefixed by hz18_, eg the primary coordinate variables are **lat** and **lon**, whilst the coordinate variables associated with the 18 Hz values are **hz18_lat** and **hz18_lon**.

Within each section, if a Ku-band value and an S-band derived value are reported, the S-band value will immediately follow the corresponding Ku-band value

## 4.3 Typical computation from altimetry data

In this section references are made to specific CGDR parameters by name using the name of the variable as described in the netCDF data sets. These names were initially defined by the parameter descriptions from the Envisat Level-2 product definition documents, for ease of referencing of the source algorithms. Some minor modification has occurred for internal consistency within the product.

**WARNING**: Default values, provided in the _FillValue attribute, are given to data when computed values are not available, **the user must screen parameters to avoid using those with default values**. Also the user must check flag values. The related flags are given in the description of each variable (see §7.1.1.4) although some discussion of flags appears in this section.

**In all cases –** the user must ensure that all values are available at the same frequency. 1 Hz version of 18 Hz values can be calculated by averaging over the 20 samples. 18 Hz data can be generated by interpolating the 1 Hz values, using time as the interpolation base variable and remembering that the 1 Hz average represents the centre of the associated 18 Hz measurements (between the 10th and 11th points). All SGDR corrections available on the CGDR have also been interpolated to 18 Hz for ease of use of the data.

### 4.3.1 Corrected Altimeter Range

The main data of the CGDR are the altimeter ranges. The CGDR provides ranges measured at Ku-band (range_ku) and S-band (range_s). The Ku-band range is used for most applications. The given ranges are corrected for instrumental effects (not including the correction for the USO clock error). These corrections are separately reported for each of the Ku and S-band ranges (net_instr_corr_range_ku and net_instr_corr_range_c).

The given ranges must be corrected by the user for path delay in the atmosphere through which the radar pulse passes, the nature of the reflecting sea surface and errors in the USO clock timing. All range corrections are defined and they should be **ADDED** to the range. A corrected (Ku-band) range is given by:

| | |
|---|---|
| Corrected Range = | Range<br>+ Wet Troposphere Correction<br>+ Dry Troposphere Correction<br>+ Ionosphere Correction<br>+ Sea State Bias Correction<br>+ USO Correction |

#### 4.3.1.1 Range:

This may be one of the SGDR range values, or one of the COASTALT retracked ranges, as given in Table 4-1.

**Table 4-1 Available range values in the CGDR**

| 1 Hz range value | 18 Hz range value | source |
|---|---|---|
| | hz18_[ku/s]_trk_cog | the onboard tracker value (not recommended) |
| [ku/s]_band_ocean_range | hz18_[ku/s]_band_ocean | SGDR Ocean retracker |
| | brown_range_[ku/s] | COASTALT Brown retracker |
| | specular_range_[ku/s] | COASTALT Specular retracker |
| | mixed_range_[ku/s] | COASTALT mixed retracker |

The COASTALT Brown retracker output gives ranges very similar to the SGDR retracker, although there will be some differences, most markedly in the coastal areas.

The ranges from the specular and mixed retrackers have not yet been validated and should be used with caution. In open ocean conditions, the mixed retracker is expected to produce very similar results to the Brown retracker, but this may not be the case, particularly in areas with very smooth water surfaces (very low wind conditions).

**Note:** it is not recommended that users change range source within a single analysis, as there may be unknown biases between the retracker ranges.

#### 4.3.1.2 Wet Troposphere Correction

**Table 4-2 Available wet tropospheric correction values in all CGDR products**

| 1 Hz correction | 18 Hz correction | source |
|---|---|---|
| mod_wet_tropo_corr | hz18_mod_wet_tropo_corr | ECMWF Model |
| mwr_wet_tropo_corr | | MWR |
| | hz18_mwr_wet trop | Dynamically Linked Model |

The model wet tropospheric correction will exist for all 1 Hz measurements, but the MWR measurement is expected to more accurately capture short-scale tropospheric processes affecting the water vapour concentration. The Dynamically Linked Model is designed to allow the MWR correction to be used closer to the coast, where the radiometer data become corrupted by land in the footprint (see §3.5.2). If the user wishes a 'pure' MWR 18 Hz correction, then use of hz18_mwr_wet_trop when the associated flag (mwr_wet_trop_interp_flag) is equal to zero will provide only MWR derived values, with the quality control already applied.

For some limited regions, enhanced CGDR products may be available, that contain an additional wet tropospheric correction, at 18 hz, generated using the novel GPD algorithm [AD 13, AD 14, AD 15, RD 15]. The GPD correction has been generated at 1 Hz by University of Porto, then interpolated to 18 Hz, using simple linear interpolation, before addition to the CGDR products.

**Table 4-3 Additional wet tropospheric correction values in a limited number of enhanced CGDR products**

| 1 Hz correction | 18 Hz correction | source |
|---|---|---|
| | hz18_GPD_wet_tropo_corr | GPD algorithm [AD 15, RD 15] |

**Note: the GPD wet tropospheric correction, and its associated flag, error and variance (see** Table 7-4**), are not part of the COASTALT 'baseline' CGDRs but are added to some versions of the CGDRs by use of the standalone product enhancer (*addcorr*).** The user should check for presence of these variables in their products.

#### 4.3.1.3 Dry Troposphere Correction

Only one dry tropospheric correction is provided: the ECMWF model correction at 1 Hz (mod_dry_tropo_corr), together with the correction interpolated to 18 Hz (hz18_mod_dry_top_corr).

#### 4.3.1.4 Ionosphere Correction

There are a number of ionospheric corrections available on the CGDR, given in Table 4-4. The DORIS and model corrections are available for both the Ku and S-band ranges. The other corrections, determined from the Ku and S-band ranges given by a particular retracker, apply only to the Ku-band and should be used with their respective ranges.

**Table 4-4 Available ionospheric correction values in the CGDR**

| 1 Hz correction | 18 Hz correction | source |
|---|---|---|
| ion_corr_doris_[ku/s] | hz18_ion_corr_doris_[ku/s] | DORIS ionospheric measurements |
| ion_corr_mod_[ku/s] | hz18_ion_corr_mod_[ku/s] | GIM ionospheric model (from CMA 7.1 onwards) |
| ra2_ion_corr_ku | hz18_ra2_ion_corr_ku | Dual frequency ranges from Ocean retracker |
| | iono_corr_brown_ku | Dual frequency ranges from COASTALT Brown retracker |
| | iono_corr_spec_ku | Dual frequency ranges from COASTALT Specular retracker |
| | iono_corr_mixed_ku | Dual frequency ranges from COASTALT Mixed retracker |

**IMPORTANT**: See Section 4.3.5 "Smoothing the Ionosphere Correction".

**NOTE**: as the S-band ceased operation on 18 January 2008 (cycle 65), all dual frequency ionospheric correction values after this date will be set to the default value

#### 4.3.1.5 Sea State Bias Correction

The sea state bias correction, determined from the SGDR Ocean retracker ranges, wave heights and wind speeds, is available for both Ku and S-band, and also at both 1 Hz (sea_bias_ku, sea_bias_s) and 18 Hz (hz18_sea_bias_ku, hz18_sea_bias_s). Use the appropriate sea state bias correction, to correct the Ku and S-band ranges. As this correction is determined empirically, it is probable that the table used to determine the relationship of wave height and wind speed to sea state bias correction will be different for the different retrackers. However, this has not yet been determined.

### 4.3.2 Sea Surface Height and Sea Level Anomaly

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 = | Altitude<br>- Corrected Range |

For most oceanographic purposes, the effects of non-geostrophic processes on the sea surface height will also be removed using geophysical corrections.

**Note:** all the geophysical parameters here are ***heights***, as defined in §1.4.1.1, and as such are positive *upwards*.

| | |
|---|---|
| Corrected Sea Surface Height = | Altitude<br>- Corrected Range<br>- Solid Earth Tide Height<br>- Geocentric Ocean Tide Height<br>- Pole Tide Height<br>- Inverted Barometer Height Correction<br>- HF fluctuations of the Sea Surface |

**Note:** for coastal applications, where comparison with tide gauges or other measurement systems is to be undertaken, not all the geophysical corrections may need to be applied. In particular, the inverted barometer correction may be omitted.

The sea level anomaly (SLA), also referred to as Sea Surface Height Anomaly, is defined here as the sea surface height minus the mean sea surface. It is given by:

| |
|---|
| Sea Level Anomaly = Corrected Sea Surface Height - Mean Sea Surface |

The SLA contains information about:

- Real changes in ocean topography related to ocean currents
- Differences between the true dynamic response to atmospheric pressure and the applied inverse barometer and model high frequency response.
- Differences between tides and the tide models
- Differences between the mean sea surface model and the true mean sea surface at the altimeter location
- Un-modelled or mis-modelled measurement effects (skewness, sea state bias, altimeter errors, tropospheric corrections, ionospheric correction, etc.)
- Orbit errors

There is naturally also random measurement noise.

#### 4.3.2.1 Altitude

The orbit altitude (see parameter altitude in §1.4.1.1). This is available at 1 Hz (alt_cog_ellip) and 18 Hz (hz18_alt_cog_ellip).

#### 4.3.2.2 Corrected Range

See section 4.3.1.

#### 4.3.2.3 Tide Effects

The total tide effect on the sea surface height is the sum of three values from the CGDR:

$$\boxed{\text{Tide Effect = Geocentric Ocean Tide + Solid Earth Tide + Pole Tide}}$$

(See also section 5.7 and subsections)

**Geocentric Ocean Tide**

The geocentric ocean tide provided on the CGDR is the sum total of the ocean tide, with respect to the ocean bottom, and the loading tide height of the ocean bottom.

$$\boxed{\text{Geocentric Ocean Tide = Ocean Tide + Load Tide}}$$

The CGDR provides a choice of two geocentric ocean tide values, each also available interpolated to 18 Hz (see Table 4-5). Each uses a different model for the sum total of the ocean tide and loading tide heights from the diurnal and semidiurnal tides, but both include an equilibrium representation of the long-period ocean tides at all periods except for the zero frequency (permanent tide) term.

***Note:*** the CGDR also explicitly provides the loading tide height from each of the two models that are used to determine the two geocentric ocean tide values, at 1 Hz (tidal_load_ht_sol1, tidal_load_ht_sol2) and interpolated to 18 Hz (Hz18_tidal_load_ht_sol1, Hz18_tidal_load_ht_sol2). Obviously, the geocentric ocean tide values and loading tide values **should not** be used simultaneously, since the loading tide height would be included twice.

**Table 4-5 Available ocean tide correction values in the CGDR**

| 1 Hz correction | 18 Hz correction | source |
|---|---|---|
| tot_geocen_ocn_tide_ht_sol1 | hz18_tot_geocen_ocn_tide_ht_sol1 | GOT00.2b |
| tot_geocen_ocn_tide_ht_sol2 | hz18_tot_geocen_ocn_tide_ht_sol2 | FES2004 |

**Solid Earth Tide**

A single solution, at 1 Hz (solid_earth_tide_ht) and interpolated to 18 Hz (hz18_solid_earth_tide_ht), is provided.

**NOTE:** Zero frequency (permanent tide) term also not included in this parameter.

**Pole Tide**

A single solution, at 1 Hz (geocen_pole_tide_ht) and interpolated to 18 Hz (hz18_geocen_pole_tide_ht), is provided.

#### 4.3.2.4 Surface Air Pressure Effects

The effect of the surface air pressure is split into two – the inverse barometer, or the direct response of the ocean to atmospheric pressure, and the high frequency response of the ocean to changes in the atmospheric pressure. Both terms are included on the CGDR.

**Inverted Barometer Height Correction**

A single solution, at 1 Hz (inv_barom_corr) and interpolated to 18 Hz (hz18_inv_barom_corr), is provided (see also §5.8).

**HF Fluctuations of the Sea Surface**

A single solution, at 1 Hz (dib_hf) and interpolated to 18 Hz (hz18_dib_hf), is provided (see also §5.8).

#### 4.3.2.5 Geophysical Surface - Mean Sea Surface or Geoid

The geophysical fields Geoid (geoid_ht, hz18_geoid_ht) and Mean Sea Surface (m_sea_surf_ht, hz18_m_sea_surf_ht) are heights (*ie* distances above the reference ellipsoid), as is the Sea Surface Height. The quantity normally required for oceanography is the dynamic topography, or the height of the sea surface above the geoid (see §1.4.1.1). However, the properties of the geoid at high frequency are only known through inference from the mean sea surface, which approximates to the geoid. Hence, use of the geoid for determining dynamic topography is only appropriate for long-wavelength oceanographic features. Instead, it is more normal to reference to the mean sea surface, to determine the sea level anomaly.

See also discussions of mean sea surface and geoid in sections 5.2 and 5.3.

### 4.3.3 Data Editing Criteria

The following criteria are recommended in the Envisat level 2 product handbook [AD 2]. They strictly apply only to the values taken directly from the SGDR product.

***User should review these criteria before using them and may wish to modify them!***

First, check the following conditions to retain only ocean data and remove any bad, missing, or flagged data:

- operating mode set to RA-2 nominal tracking
- waveform quality flags set to OK (= 0)

Over the ocean, users are advised to edit the data according to Table 4-6.

For coastal application it will be necessary to relax some of these criteria – in particular regarding tide correction values and standard deviation of range.

**Table 4-6 Recommended editing criteria**

| Min. Value | Parameters | Max. Value | Unit |
|---|---|---|---|
| -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 | 2 | m |
| -0.5 | 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 | 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 |
| 0 | S-band anomaly flag | 0 | |

#### 4.3.3.1 Use of Flags

A series of quality control flags are available on the CGDR products to assist in identifying missing, or poor quality data.

Some flags (see Table 4-7) provide general information on the quality, or potential quality, of the altimeter signal and processing. These flags may be used to identify the potential cause of poor data. The complex flags from the SGDR (meas_conf_data_flags, instr_flags, mwr_instr_flag and interpole_flag) are further defined in Table 4-8, Table 4-9,

Table 4-10 and Table 4-11).

**Table 4-7 General Quality Flags Available in the CGDR Products**

| Flag | dimension | Flag meaning |
|---|---|---|
| inst_mode_id_flags | Time | Instrument mode ID<br>16: acquisition<br>32:Tracking<br>33: Preset_Tracking<br>34: Preset_Loop_Output<br>48: IF_Cal<br>65: BITE_RF<br>67: BITE_DGT |
| meas_conf_data_flags | time | see Table 4-8 |
| ave_ku_chirp | time | minimum of 18 hz chirp id values<br>0: at least one record at 320 MHz<br>1: at least one record at 80 MHz (others are at 20 MHz)<br>2: all input records are at 20 MHz |
| ku_chirp_id_flags | time,samples | 0: 320 MHz<br>1: 80 MHz<br>2: 20 MHz<br>Default values (bits set to 1) are output in the event of non tracking records (records not in Tracking, Preset Tracking or Preset Loop Output), wherever the sum of all Ku and S waveforms samples are set to 0, or if Ku AGC or Ku onboard Rx delay are out of bounds |
| error_flag_chirp_id_flags | time | Error flag for chirp band id<br>0: valid<br>1: invalid |
| instr_flags | time | see Table 4-9 |
| instr_id_data_level_flags | time,samples | Instrument mode ID at data block level<br>0: spare<br>1: acquisition<br>2:Tracking<br>3: IF_Cal<br>4: BITE_RF<br>5: BITE_DGT<br>6: Preset_Tracking<br>7: Preset_Loop_Output<br>8: Alignment_failed |
| num_meas_ku_calibr | time | Number of Ku flight calibration factors (currently from 0 to 5) used at L1B to obtain the smoothed Sigma0 and time delay PTR flight calibration factors |
| num_meas_s_calibr | time | Number of S flight calibration factors (currently from 0 to 5) used at L1B to obtain the smoothed Sigma0 and time delay PTR flight calibration factors |
| mwr_instr_flag | time | see<br>Table 4-10 |

| Flag | dimension | Flag meaning |
|---|---|---|
| altim_landocean_flag | Time | Altimeter Surface type flag<br>0: oceans or semi-enclosed seas<br>1: enclosed seas or lakes<br>2: continental ice<br>3: land |
| radio_landocean_flag | time | Radiometer land/ocean flag<br>0: Ocean<br>1: Land, or radiometer not available |
| rain_flag | time | 0: no rain<br>1: rain |
| interpole_flag | time | see Table 4-11 |

**Table 4-8 Definition of variable meas_conf_data_flags**

| Bit Nos | Description | Values |
|---|---|---|
| 28-31 | Orbital processing status | **0011**: Adjusted precise DORIS orbit<br>**0100**: Estimated precise DORIS orbit during manoeuvre<br>**0101**: Estimated precise DORIS orbit after interpolation (data gap)<br>**0110**: Estimated precise DORIS orbit extrapolated on a time interval <1 day<br>**0111**: Estimated precise DORIS orbit extrapolated on a time interval >1 day but <2 days<br>**1000**: Estimated precise DORIS orbit extrapolated on a time interval >2 days or after manoeuvre |
| 27 | spare | 0 |
| 26-25 | Meteo data state | 0: 2 maps nominal<br>1: 2 maps degraded<br>2: 1 map<br>3: no map |
| 24 | Processing error (arithmetic faults) | 0: ok (no error)<br>1: error |
| 23 | spare | 0 |
| 22 | Ku Sea Ice retracking status | 0: ok (no error)<br>1: error |
| 21 | S Ice 2 retracking status | 0: ok (no error)<br>1: error |
| 20 | Ku Ice 2 retracking status | 0: ok (no error)<br>1: error |
| 19 | S Ice 1 retracking status | 0: ok (no error)<br>1: error |
| 18 | Ku Ice 1 retracking status | 0: ok (no error)<br>1: error |
| 17 | S Ocean retracking status | 0: ok (no error)<br>1: error |

| Bit Nos | Description | Values |
|---|---|---|
| 16 | Ku Ocean retracking status | 0: ok (no error)<br>1: error |
| 15-13 | spare | 0 |
| 12 | Brightness Temperature Range check (channel 2) | 0: in range<br>1: our of range |
| 12 | Brightness Temperature Range check (channel 1) | 0: in range<br>1: our of range |
| 10-8 | validity | - |
| 7 | S-band anomaly flag (from cycle 51 onwards) | 0: no errors<br>1: error |
| 6 | Wave form samples fault identifier | 0: no errors<br>1: error |
| 5 | Rx delat Fault Identifier | 0: no error<br>1: Rx distance out of range |
| 4 | AGC Fault Identifier | 0: no error<br>1: AGC out of range |
| 3 | Fault Identifier | 0: no errors detected<br>1: errors detected by on- board |
| 2 | USO validity flag | 0: no errors detected<br>1: anomaly in USO value detected |
| 1 | OBDH validity flag | 0: no errors detected<br>1: anomaly in OBDH value detected |
| 0 | Packet Length Error flag | 0: no error detected<br>1: error detected and attempt to recover made |

**Table 4-9 Definition of variable instr_flags**

| Bit Nos | Description | Values |
|---|---|---|
| 31-7 | spare | 0 |
| 6 | Flag for availability of S flight calibration corrections | 0: calibration parameters available<br>1: Calibration parameters not available -- default values used |
| 5 | Flag for availability of Ku flight calibration corrections | 0: calibration parameters available<br>1: Calibration parameters not available -- default values used |
| 4-2 | PTR calibration band identifier field | 0: 320 MHz (Ku)<br>1: 80 MHz (Ku)<br>2: 20 MHz (Ku)<br>4: 160 MHz (S)<br>7: PTR samples not available |
| 1-0 | Error flag for decoded redundancy flags | 0: no mismatch detected<br>1: mismatch in Red_vec_HPA<br>2: mismatch in Red_vec_RFSS<br>3: mismatch in Red_vec_HPA and Red_vec_RFSS |

**Table 4-10 Definition of variable mwr_instr_flag**

| Bit Nos | Description | Values |
|---|---|---|
| 15 | Temp Flag (Tmp_flg) Indicates uniformity of CEU temperature | 0: temperature consistency<br>1: temperature inconsistency |
| 14 | OBDH Flag (OBDH_flg) flag to indicate data is missing | 0: no error<br>1: error |
| 13 | Red Flag: ICU channel redundancy indicator | 0: normal channel<br>1: redundant channel |
| 12 | Power Bus Protection Flag (PBP_flg) Power Bus protection indicator | 0: no protection<br>1: protection |
| 11 | Over Prot. flag Overvoltage/Overload protection indicator | 0: no protection<br>1: protection |
| 10-0 | spare | 0 |

**Table 4-11 Definition of variable interpole_flag**

| Bit numbers | Description | Values |
|---|---|---|
| 15-4 | spare | 0 |
| 3 | Meteorological data interpolation flag | 0: ok (valid interpolation)<br>1: interpolation invalid |
| 2 | Ocean tide solution 2 interpolation flag | 0: ok (valid interpolation)<br>1: interpolation invalid |
| 1 | Ocean tide solution 2 interpolation flag | 0: ok (valid interpolation)<br>1: interpolation invalid |
| 0 | Mean Sea Surface interpolation flag | 0: ok (valid interpolation)<br>1: interpolation invalid |

For any specific variable, if there are associated flags, these will be identified using the “ancillary_variables” attribute. When using any variable from the CGDR file, the user should first check to see if any ancillary flag or map variables are defined, and then check these ancillary variables to determine the validity of the original variable.

Where possible, the SGDR flags applicable to 18 Hz variables have been unpacked to generate 18 Hz flags, and for each 18 Hz data point, the associated flag value will be set to zero (OK) or 1 (not ok). The variable-specific flags available in the COASTALT CGDR products are defined in Table 4-12.

**Table 4-12: Variable-specific flags available in the CGDR products**

| Flag | Flag meaning | Related Variables |
|---|---|---|
| map_18hz_ku_trk | 0: 18 hz value valid / used in 1 hz average<br>1: 18 hz value not valid/ used in 1 hz average | hz18_ku_trk_cog |
| map_18hz_ku_ocean_flags | 0: 18 hz value valid/ used in 1 hz average<br>1: 18 hz value not valid/ used in 1 hz average | hz18_ku_band_ocean<br>num_18hz_ku_ocean |
| map_18hz_s_ocean_flags | 0: 18 hz value valid/ used in 1 hz average<br>1: 18 hz value not valid/ used in 1 hz average | hz18_s_band_ocean<br>num_18hz_s_ocean |
| map_18hz_k_cal_ku_flags | 0: 18 hz value valid/ used in 1 hz average<br>1: 18 hz value not valid/ used in 1 hz average | hz18_k_cal_ku |
| slp_mod_flags | 0: slope model valid for 18 hz value<br>1: slope model not valid for 18 hz value | elev_echo_pt<br>hz18_diff_mean_ech_pt |
| ku_ocean_retrk_qua_flags | Ku-band ocean retracking quality flags<br>0: valid measurement<br>1: invalid i.e. 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 | hz18_ku_band_ocean |
| s_ocean_retrk_qua_flags | S-band ocean retracking quality flags<br>0: valid measurement<br>1: invalid i.e. 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 | hz18_s_band_ocean |
| mwr_qua_interp_flag | MWR Quality interpolation flag (for 1 Hz data)<br>0: interpolation OK; no gap between the two MWR measurements around the RA-2 time<br>1: interpolation OK; but gap between the two selected MWR measurements<br>2: extrapolation was used<br>3: neither interpolation nor extrapolation used.<br>The default value is output when no MWR data are available | mwr_wet_trop |
| mwr_wet_trop_interp_flag | Interpolation method used for 18Hz MWR wet trop value.<br>0: interpolated between 2 valid 1Hz MWR wet tropospheric correction values<br>1: interpolated between 2 valid 1Hz MWR wet tropospheric correction values, using model correction<br>2: extrapolated from 1 valid 1Hz MWR wet tropospheric correction values using model correction<br>3: no interpolation (invalid value) | hz18_mwr_wet_trop |

In addition to the flag variables, a number of variables are provided which can be used in determining either the probably quality, or cause of poor quality, data. These variables are given in Table 4-13.

**Table 4-13 Other quality Control Variables**

| Variable | Flag meaning |
|---|---|
| ku_peak | Peakiness of Ku-band waveform |
| s_peak | Peakiness of S-band waveform |
| gof_brown_ku | Goodness of fit of the Brown model to Ku-band waveform |
| gof_brown_s | Goodness of fit of the Brown model to S-band waveform |
| gof_spec_ku | Goodness of fit of the Specular model to Ku-band waveform |
| gof_spec_s | Goodness of fit of the Specular model to S-band waveform |
| gof_mixed_ku | Goodness of fit of the Mixed model to Ku-band waveform |
| gof_mixed_s | Goodness of fit of the Mixed model to S-band waveform |
| ocean_depland_elev | Ocean depth / land elevation |
| distance_from_coast | Distance to closest coast (see §3.5.3) |

For those limited, regionally enhanced CGDRs which have had the GPD wet tropospheric correction data added, three quality control variables (Table 4-14) are provided to determine the quality of this correction.

**Table 4-14 Additional quality control variables for GPD correction (in limited regional enhanced CGDRs)**

| Variable | Dimension | Meaning |
|---|---|---|
| *hz18_GPD_interp_flag* | time, samples | 0: from valid open-ocean MWR correction<br>1: from GPD algorithm<br>3: points interpolated over land<br>9: 18 Hz interpolation not available |
| *hz18_GPD_formal_error* | time, samples | GPD correction formal error |
| *hz18_GPD_signal_variance* | time, samples | GPD correction variance |

#### 4.3.3.2 Detection of S-Band Anomaly

During the Commissioning Phase, it was discovered that the RA-2 data are affected by the so-called S-Band anomaly. The anomaly results in the accumulation of the S-Band echo waveforms, happens randomly after an acquisition sequence and is only stopped by switching the RA-2 into Stand-By mode. When this anomaly occurs, the S-Band waveforms are not meaningful and so all the S-Band parameters and the Dual Frequency ionosphere corrections are not reliable. Notably, the S-Band Sigma0 is unrealistically high during these events.

A method has been developed to flag the impacted data over all surfaces [RD 29]. This flag is available in the SGDR product from cycle 51 (see Table 4-8).

For cycles prior to cycle 51, an efficient method of detecting ocean data where the S-Band Anomaly occurs, is to applying a threshold of 5 dB on the (Ku-S) Sigma0 differences.

For cycle 10, 33% of the data are impacted (before any solution had been found), whilst for cycles 11-30, between 0 and 8% of the data are affected by the S-Band anomaly. From cycle 31 onwards, ESA performed some operation modifications to decrease the duration of these events: instrument switch-offs (Heater 2 mode) were performed twice a day over the Himalayan and Rocky mountain region. This prevents the S-Band anomaly from lasting more than half a day. Thanks to this procedure the proportion of impacted data decreased from 4.2% (cycles 11 to 30) to 2.2% (cycles 31 to 38) [AD 8].

On the 27th of June 2007 (cycle 60) an on-board patch solving the problem was successfully uploaded. Between then and the S-Band loss in January 2008, no occurrences of the anomaly have been detected.

An algorithm for the S-Band waveform reconstruction has been developed, but has not yet been implemented in the SGDR data.

### 4.3.4 Mean Sea Surface and Adjustment of the Cross Track Gradient

To study sea level changes between two dates, it is necessary to take the difference between sea surface heights from different cycles at the exact same latitude-longitude, to remove errors in the time-invariant geoid, which is not well known at short-wavelengths. However, the satellite ground track is allowed to drift by $\pm$1 km from its nominal position and so each repeat cycle of the satellite samples a different geoid profile. Differencing these profiles will introduce an error due to the poorly known cross-track geoid gradient. This error was estimated by [RD 3] as about 2 cm km$^{-1}$ over most of the ocean. However, this is effect is much larger where the expected geoid slopes are greater, *eg* over continental shelf slopes or coastal region. In addition, measurements are provided approximately every 1.1 s along the pass (about 7 km) for the “1 Hz” data, or every 0.055 s for the 18 Hz data (about 0.35 km). The position of these measurements along-track will be at different latitude-longitude locations on different cycles. Hence, even if the passes repeated exactly, it would be necessary to interpolate along the pass.

The Mean Sea Surface height is known to much greater accuracy, courtesy of previous altimetry missions, than the geoid height. Hence the use of SLA is of benefit in looking at repeated data. Interpolation of SLA to a repeated track location generates smaller errors than interpolating the Sea Surface Height.

Over the open ocean it is common to interpolate data to a common set of along-track points, or "reference" track. Whilst this approach may be beneficial in the open ocean, the smaller spatial scales of the coastal zone might make this less beneficial, and alternative approaches, including the use of a locally generated mean sea surface as carried out in the X-TRACK processor [RD 36] might be more appropriate.

### 4.3.5 Smoothing Ionosphere Correction

The ionospheric (range) correction is expected to be negative, but positive values of the dual frequency ionospheric correction values may occur due to instrument noise effects. To reduce the noise, it is recommended that these parameters are averaged over 100 km or more [RD 23].

In order to provide a reversible correction, no averaging is performed on the dual frequency ionospheric corrections provided on the CGDR. Users may smooth the ionospheric correction along-track before applying, although care should be taken close to land. Typical and maximum smoothing scales are 100-150 km for local times between 06 and 24 hours and 150-200 km for local times between 00 and 06 hours. The shorter (longer) smoothing time is also more appropriate during times of high (low) solar activity

### 4.3.6 Generation of 1 Hz Averages

Each 1 Hz value from the altimeter measurements (range, wave height and sigma-0) is derived from the linear regression of the valid 18 Hz parameters determined from the retracking algorithms.

The number of valid 18 Hz measurements (num_18hz_[ku/s]_ocean, num_18hz_[ku/s]_ocean_swh and num_18hz_[ku/s]_ocean_bscat for ocean retracked range, wave height and backscatter) that are used to derive each of the 1 Hz measurements is provided on the CGDRs, together with the map identifying which values these are (map_18hz_[ku/s]_ocean_flags and map_18hz_k_cal_ku_flags for range and backscatter), and the root-mean-square of the differences between the valid 18 Hz measurements and the derived 1 Hz measurement (sd_18hz_[ku,s]_ocean, sd_18hz_[ku,s]_swh and sd_18hz_[ku/s]_ocean_bscat).

For coastal regions, users may wish to generate averaged values from the 18 Hz measurements.

# 5 Altimetric data

This section presents a short discussion of the main quantities on the CGDR, with emphasis on the parts of the system that may provide particular challenges in the coastal zone.

An excellent overview of the theoretical and practical effects of radar altimetry is the "Satellite Altimetry" Chapter in [RD 10].

## 5.1 Altimeter Range

An altimeter operates by sending out a short pulse of radiation and measuring the time required for the pulse to return from the sea surface. This measurement, the altimeter range, gives the distance between the instrument and the sea surface, provided that the velocity of the propagation of the pulse and the precise arrival time are known. The dual frequency altimeter on Envisat performs range measurements at the Ku and S-band frequencies enabling measurements of the range and the path total electron content. While both range measurements are provided on the CGDR the Ku-band range measurement has higher accuracy than the S-band measurement.

The ranges reported on the CGDR have already been corrected for a variety of calibration and instrument effects, including calibration errors, pointing angle errors, centre of gravity motion, and terms related to the altimeter acceleration such as Doppler shift and oscillator drift. **Note:** there is a known error in the correction due to jumps in the Ultra Stable Oscillator (USO) that has *not* been applied to this version of the data, but the relevant correction (uso_clock_correction) is provided and must be added to the range as explained in §4.3.1. The sum total of these corrections also appears on the CGDR for each of the Ku and C band ranges.

In the coastal ocean, there is an increased probability that there will be land in the altimeter footprint, and this produces a very different return signature to ocean surfaces. The standard Brown model retracker will not recognise these returned signals and will be unable to provide valid range, wave height and sigma-0 values. In these circumstances, the COASTALT specular, or mixed retrackers, may provide valid range information.

## 5.2 Geoid

The geoid is an equipotential surface of the Earth's gravity field that is approximated by the mean sea surface. The time-mean ocean currents are the primary cause of deviation of the mean sea surface from the geoid. The reference ellipsoid is a bi-axial ellipsoid of revolution.

The geoid undulation, over the entire Earth, has a root mean square value of 30.6 m with extreme values of approximately 83 m and -106 m. Although the geoid undulations are primarily long wavelength phenomena, short wavelength changes in the geoid undulation are seen over seamounts, trenches, ridges, etc., in the oceans, and approaching coasts, particularly across the continental shelf slopes. The calculation of a high resolution geoid requires high resolution surface gravity data in the region of interest as well as a potential coefficient model that can be used to define the long and medium wavelengths of the Earth's gravitational field. Surface gravity data are generally only available in certain regions of the Earth and spherical harmonic expansions of the Earth's gravitational potential are usually used to define the geoid globally. Currently, such expansions are available to degree and order 360 (approximately

100 km) and in some cases higher, although the majority of the information at higher degree and order (shorter wavelengths) comes from the mean sea surface determinations used in the geoid modelling.

## 5.3 Mean Sea Surface

A Mean Sea Surface (MSS) represents the average sea surface height over an appropriate time period, usually designed to remove annual, semi-annual, seasonal, and mesoscale sea surface height signals, as well as minimising noise. A MSS field is usually provided as a grid with spacing consistent with the altimeter and other data used in the generation of the grid values. A MSS grid can be useful for data editing purposes, for the calculation of along track and cross track geoid gradients, for the calculation of gridded gravity anomalies, for geophysical studies, for a reference surface to which sea surface height data from different altimeter missions can be reduced, etc. The CGDR provides a global MSS model that is generated from multiple satellite altimetry missions. This model relies on previous altimetry data, which has poor sampling in the coastal zone. Hence the errors in the mean sea model in the coastal regions are larger than in the open ocean.

Longer time spans of data that become available in the future, along with improved data handling techniques will improve the current MSS models. Care must be given to the retention of high frequency signal and the reduction of high frequency noise.

## 5.4 Mean Dynamic Topography

A Mean Dynamic Topography (MDT) represents the Mean Sea Surface referenced to a geoid and corrected for geophysical effects. A MDT is generally generated as a grid with spacing consistent with the altimeter and other data used in the generation of the grid values. The MDT provides an absolute reference surface for the ocean circulation. The CGDR provides a global MDT model that is a combined product based on the GRACE mission, altimetry and in situ data (hydrologic and drifters data).

As the MSS from altimetry forms a major contributor to the MDT, then the same consideration must be given to the lack of data in coastal regions increasing the model errors.

## 5.5 Geophysical Corrections

Atmospheric components act to retard the radar pulse, which increases the calculated range and the sea surface height estimate is too low. The retardation effect is controlled by the composition of the atmosphere, which is the electron content of the ionosphere, the dry gas composition of the troposphere and its water content, both as vapour and in clouds (the most variable parameter). The ionospheric effect produces a range increase of only around 20 cm whilst the dry gases result in an increase of order 2.3 m. The highly variable water vapour content can cause increases of between 5 and 40 cm.

Discussions of these effects are given in [RD 10]].

### 5.5.1 Troposphere (dry and wet)

The propagation delay caused by the troposphere is a combination of the effect of the dry gas and water components. The dry tropospheric correction uses model atmospheres, derived from empirical data on the vertical structure of the atmosphere. The CGDR dry tropospheric correction uses the surface pressure of the ECMWF model, interpolated onto the satellite tracks. The dry tropospheric correction is then calculated using;

$$dry\_tropo\_corr = -2.277\,p\left(1+\left(0.0026\cos 2\phi\right)\right)$$

where;
$p$ is surface atmospheric pressure (mbar)
$\phi$ is latitude

Despite being the largest transmission path correction at more than 2 m, it is estimated as being accurate to 2-3 cm and so is not a major contributor to residual errors. Typical errors in the model pressure field vary from 1 mbar in the northern Atlantic Ocean to a few mbars in the southern Pacific Ocean. A 1-mbar error in pressure translates into a 2.3 mm error in the dry tropospheric correction. There may be changes in atmospheric pressure in coastal regions, but these are not anticipated to have a major impact on the errors introduced by this correction.

The water content of the troposphere is a far more variable parameter than the atmospheric pressure. In addition, it is possible that coastal atmospheric effects may generate even higher spatial variability in this parameter in coastal regions, making it of particular importance in coastal altimetry. The water content can be found in one of two ways. A passive radiometer, such as the MWR flown on Envisat, allows direct measurement of water content by comparison of the different channels of the MWR along its ground track. One major draw-back of this method in the coastal zone is the size of the MWR footprint. At more than 30 km from the coast, the MWR measurements, and hence the wet tropospheric delay correction, may be contaminated by land in the footprint, making the correction unusable.

An alternative method is to use a numerical atmospheric model (ECMWF for CGDR) output of surface air temperature and water vapour pressure. This correction is believed to have an accuracy of within 5 cm, limited by poor meteorological station coverage over large areas of the world's oceans and poor estimates of water vapour content in regions such as the inter-tropical convergence zone in the model. As for the dry tropospheric correction, the model grid is interpolated onto the satellite track.

The major advantage of the model value is that it is available even where there is land contamination in the MWR footprint, or anomalous sensor behaviour makes the MWR measurements unusable.

The Dynamically Linked Model (DLM, see §3.5.2) aims to extend the MWR correction to cover short gaps in coverage, or extend the MWR correction towards the coast. Small gaps in the MWR available are filled by simple linear interpolation. Approaching land, the model extrapolates the MWR correction, using the model correction profile, offset to remove any bias between this correction and the MWR value at the closest approach to land. For larger gaps, eg over small islands, where the MWR value is available at either end of the gap, then a slope, as well as a bias, is applied to the model correction, to ensure the DLM correction has no step changes along-track.

The novel GPD Wet Tropospheric Correction [AD 13, AD 14, AD 15 RD 15] is also available in some, regional enhanced, CGDR products, This correction uses GNSS signals to derive the path delay. When available, the correction is also supplied with associated variance of the correction and the formal error (see Table 7-4). See [RD 15] for more details.

### 5.5.2 Ionosphere

At the frequencies used by the RA-2, propagation delay caused by the ionosphere is proportional to the integrated free electron density, also known as the total electron content (TEC). The delay is inversely proportional to frequency squared and introduces a range increase of approximately 0.2 to 20 cm at 13.6 GHz. For mid-latitudes diurnal and solar source (sun-spot) effects have been recorded as causing variation from approximately 5 to $100\times10^{16}$ electrons $m^{-2}$ [RD 4] with lower values occurring overnight and in the Summer. The frequency dependence of the delay can be utilized by means of a dual frequency altimeter such as RA-2, for which comparison of the two measured heights determines the local ionospheric effect. As this correction is determined by the Ku and S-band range measurements, corrected for sea-state bias effects, the dual-frequency correction is dependant on the retracking method and care must be taken to use an appropriate correction for the range selected. Also, see §4.3.5 on smoothing the ionospheric correction.

The electron content can also be determined by alternative methods. The CGDR provides corrections based on the ionospheric measurements provided by the DORIS instruments, and also from a global ionospheric model, the Global Ionosphere Maps (GIM). These corrections may be used over non ocean surfaces (ice, land, etc.).

### 5.5.3 Ocean Waves (sea state bias)

The interaction of the radar pulse with the sea surface is influenced by the local sea-state through several mechanisms. Ocean wave troughs are inherently more likely to contribute to the return radar signal, as they scatter back towards the satellite, whereas wave crests scatter away from the satellite. Hence the return pulse is biased toward the troughs of the waves. This bias, known as the EM bias, means the range tends to be overestimated relative to the mean surface position [RD 37]. The EM-bias is dependant on the wave height and frequency of the radar pulse and should be the same for all instruments operating at the same frequency. Ocean waveforms also tend to be 'peaky' – ie have narrow peaks, and broad, wide troughs, introducing a skewness bias from the assumption that the probability density function of heights is symmetric. Finally, there is a tracker bias, which is a purely instrumental effect, instrument dependant. The sum of EM bias, skewness bias and tracker bias is called 'sea state bias'.

The current estimates of sea state bias are obtained using empirical models derived from analyses of the altimeter data. The sea state bias is computed from a bilinear interpolation of a table of sea state biases versus significant wave height and wind speed, based on empirical fits. For a typical significant wave height (SWH) of 2 m, the sea state bias is about 10 cm, and the error (bias) in the sea state bias correction is approximately 1-2 cm. The noise of the sea state bias estimates depends mainly on the noise on the significant wave height estimates. The relationship between SWH, wind speed and sea state bias will not necessarily be the same for coastal regions as for open ocean. In addition, the relationship will be different for different trackers. However, the analysis requires large volumes of data, which have not previously been available in the coastal areas, and has not yet been carried out using the alternative retrackers used in COASTALT, and so the open ocean relationship is the best currently available.

## 5.6 Rain Flag

Liquid water along the pulse's path reduces the energy returned to the altimeter, mainly at Ku-band. In heavy rain, there are competing effects from attenuation and surface changes. The effect is more pronounced on the Ku-band return than on the S-band. The small-scale nature of rain cells tends to produce rapid changes in the strength of the echo as the altimeter crosses rain cells. Both effects degrade the performance of the altimeter. Data contaminated by rain should be ignored.

The rain flag on the CGDR is set if the expected Ku/S-band rain-free relationship, minus the uncorrected Ku ocean backscattering coefficient, and if the MWR liquid water content, interpolated to RA-2 time, are both larger than certain thresholds. This flag may be unreliable in coastal regions, where the MWR measurements are not available. It may be possible to use the Ku-band rain attenuation correction (ku_rai_corr) [RD 42] to determine if there is rain in the footprint. This value uses the difference between the Ku-band sigma-0 measurement and a predicted Ku-band value, determined using the S-band sigma-0 and the normal relationship between S-band and Ku-band sigma-0 values.

## 5.7 Tides

Tides are a significant contributor to the observed sea surface height [RD 26]. While they are of interest in themselves, they have more variation than all other time-varying ocean signals and they must removed to study ocean circulation effects. The Envisat orbit is not ideal for studying tides, as the key diurnal and semidiurnal tides are aliased to low frequencies (or infinity) by the sun-synchronous orbit.

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 axis and is unrelated to luni-solar forcing.

CGDRs do not explicitly provide values for the pure ocean tide, but instead provide values for a quantity referred to as the geocentric ocean tide, which is the sum total of the ocean tide and the load tide. Values of the load tide that were used to compute the geocentric ocean tide are also explicitly provided, so the pure ocean tide can be determined by subtracting the load tide value from the geocentric ocean tide value. Note that the permanent tide is not included in either the geocentric ocean tide or solid earth tide corrections that are provided on the CGDRs. Hence the sea surface heights calculated will be in the mean-tide reference frame, which should be considered when combining with external geodetic heights, which might use a zero-tide or tide-free reference frame.

### 5.7.1 Geocentric Ocean Tide

As mentioned above, the geocentric ocean tide refers to the sum total of the ocean tide and the load tide. The CGDR provides two choices for the geocentric ocean tide, tot_geocen_ocn_tide_ht_sol1 and tot_geocen_ocn_tide_ht_sol2, each of which is computed as the sum total of the diurnal and semidiurnal ocean and load tides as predicted by a particular model, and an equilibrium representation of the long-period ocean tides at all periods except for the zero frequency (constant) term. The two load tide values provided on the GDR, tidal_load_ht_sol1 and tidal_load_ht_sol2, provide the respective load tide values that for the total geocentric tide solutions.

### 5.7.2 Long period Ocean Tide

The long-period ocean tides are a subject of continuing investigation. To first order, they can be approximated by an equilibrium representation. However, the true long-period ocean tide response is thought to have departures from an equilibrium response that increase with decreasing period. The two principal long-period ocean tide components, Mf and Mm, with fortnightly and monthly periods respectively, are known to have departures from an equilibrium response with magnitudes less than 1-2 cm.

The CGDR 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 long_period_ocn_tide_ht). Note that both geocentric ocean tide values on the CGDR already include the equilibrium long-period ocean tide and should therefore not be used simultaneously.

### 5.7.3 Solid Earth Tide

The solid Earth also responds to external gravitational forces. The response of the Earth is fast enough that it can be considered to be in equilibrium with the tide generating forces. Then, the surface is parallel with the equipotential surface, and the tide height is proportional to the potential. The two proportionality constants are the so-called Love numbers. It should be noted that the Love numbers are largely frequency independent, an exception occurs near a frequency corresponding to the K1 tide constituents due to a resonance in the liquid core [RD 43 and RD 39].

The CGDR computes the solid earth tide, or body tide, as a purely radial elastic response of the solid Earth to the tidal potential (see parameter solid_earth_tide_ht). The adopted tidal potential is the Cartwright [RD 8] 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.

### 5.7.4 Pole Tide

The pole tide is a tide-like motion of the ocean surface that is a response of both the solid Earth and the oceans to the centrifugal potential that is generated by small perturbations to the Earth's rotation axis. These perturbations primarily occur at periods of 433 days (called the Chandler wobble) and annual. These periods are long enough for the pole tide displacement to be considered to be in equilibrium with the forcing centrifugal potential. The CGDR provides a single field for the radial geocentric pole tide displacement of the ocean surface (see geocen_pole_tide_ht parameter), and includes the radial pole tide displacement of the solid Earth and the oceans.

The pole tide is easily computed as described in [RD 43]. Modelling 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. Note that the pole tide on the IGDR and GDR may differ, since the pole tide on the GDR is computed with a more accurate time series of the Earth's rotation axis.

## 5.8 Inverse Barometer Effect

### 5.8.1 Inverted Barometer Correction

As atmospheric pressure increases and decreases, the sea surface tends to respond hydrostatically, falling or rising respectively. Generally, a 1-mbar increase in atmospheric pressure depresses the sea surface by about 1 cm. This effect is referred to as the inverse barometer (IB) effect.

The instantaneous IB effect on sea surface height in millimeters is computed from the surface atmospheric pressure (mod_surf_atm_pres), $P_{atm}$ in mbar:

$$\boxed{inv\_barom\_corr = -9.948*(P_{atm} - P)}$$

where P is the time varying mean of the global surface atmospheric pressure over the oceans.

The scale factor 9.948 is based on the empirical value [RD 44] of the IB response at mid latitudes. Some researchers use other values. Note that the surface atmospheric pressure is also proportional to the dry tropospheric correction, and so the parameter inv_barom_corr changes by approximately 4 to 5 mm as mod_dry_tropo_corr changes by 1 mm (assuming a constant mean global surface pressure). The uncertainty of the ECMWF atmospheric pressure products is somewhat dependent on location. Typical errors vary from 1 mbar in the northern Atlantic Ocean to a few mbars in the southern Pacific Ocean. A 1 mbar error in pressure translates into a 10 mm error in the computation of the IB effect.

### 5.8.2 Barotropic/Baroclinic Response to Atmospheric Forcing

The High Frequency Wind and Pressure Response correction, dib_hf, complements the Inverted Barometer (IB) correction. Like both tides and IB, the ocean response to wind and pressure (after removing the IB part) has energy at periods shorter than the 70 day implied by the 35day repeat cycle of Envisat. This correction can be thought of as a departure from the IB response to pressure, although strictly it is the difference between the response to wind and pressure minus the IB. This response is calculated using a barotropic model. The parameter dib_hf is a correction to the inverse barometer correction inv_barom_corr.

## 5.9 Sigma 0

The backscatter coefficients, sigma-0 Ku and S-band values (see parameters ku_ocean_bscat_coeff and s_ocean_bscat_coeff), reported on the CGDR are corrected for atmospheric attenuation using ku_atm_atten_corr and s_atm_atten_corr.

## 5.10 Wind Speed

The model functions developed to date for altimeter wind speed have all been purely empirical. The model function establishes a relation between the wind speed, and the sea surface backscatter coefficient and significant wave height. A wind speed is calculated through a mathematical relationship with the Ku-band backscatter coefficient and the significant wave height (see ra2_wind_sp) using the algorithm proposed by Abdalla [RD 1]. The wind speed model function is evaluated for 10 m above the sea surface.

A 10 m (above surface) wind vector (in east-west and north-south directions) is also provided on the CGDR (see parameters mod_wind_sp_u and mod_wind_sp_v). This wind speed vector is determined from an interpolation of the ECMWF model. The best accuracy for the wind vector varies from about 2 $ms^{-1}$ in magnitude and 20 degrees in direction in the northern Atlantic Ocean, to more than 5 $ms^{-1}$ and 40 degrees in the southern Pacific Ocean.

## 5.11 Bathymetry Information

The CGDR provides a parameter bathymetry that gives the ocean depth or land elevation of the data point. Ocean depths have negative values, and land elevations have positive values. This parameter is given to allow users to make their own "cut" for ocean depth.

# 6 Coastal Case Studies

## 6.1 Western Iberia: Applying Quality Control to Sea Surface Heights

In this case study, we present a method for applying quality control (QC) to coastal altimetry data. For QC retracked heights the following quantity was considered:

$$\text{retracked height} = \text{altitude} - (\text{range} + \text{USO})$$

where:

altitude is the satellite ellipsoidal height; range is the ku-band range from the COASTALT mixed retracker; USO is the USO correction.

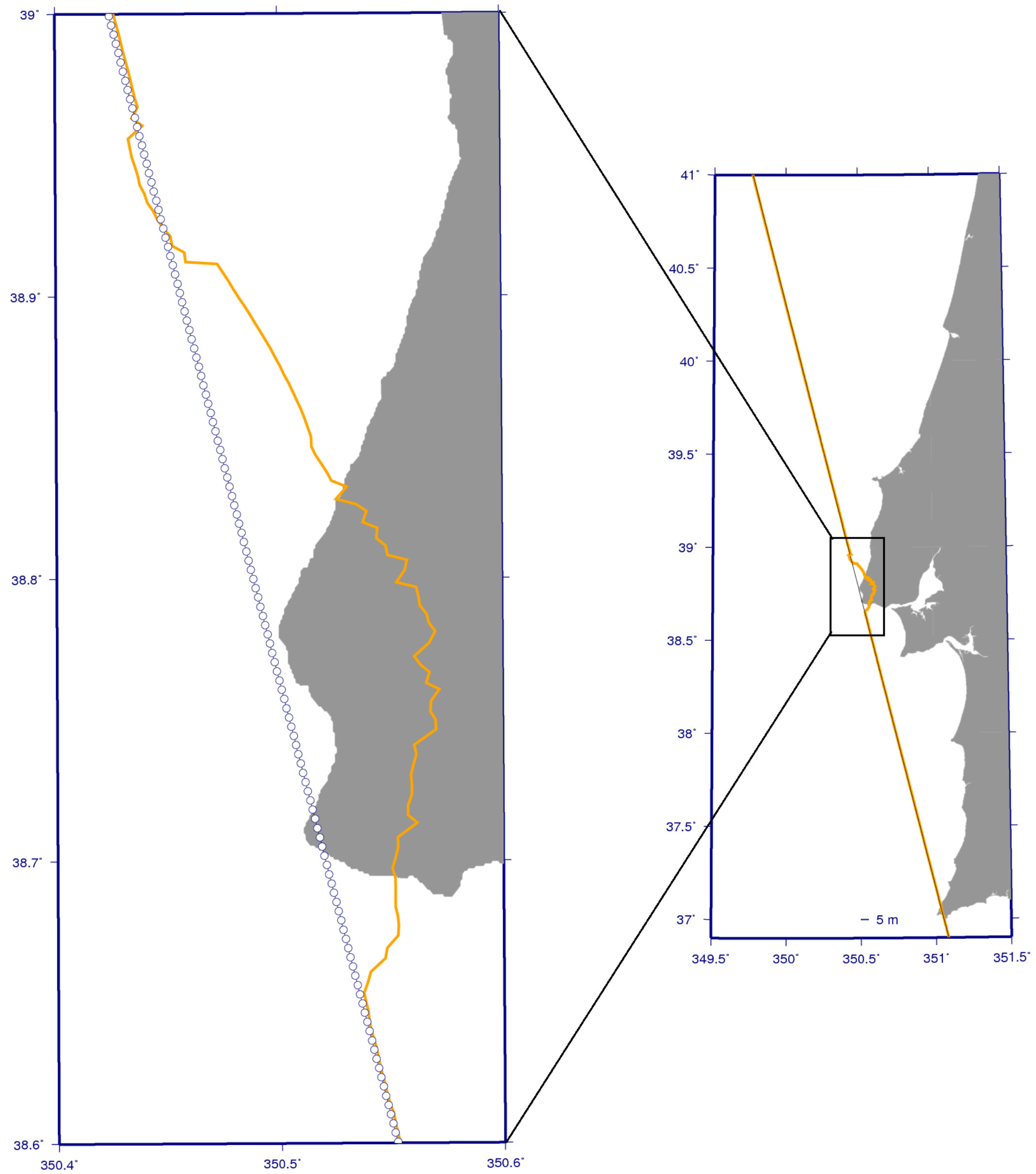


**Figure 7: retracked heights (——) plotted as along-track anomalies for identification of anomalous along-track measurements (○) close to the coast.**

The inspection of maps of retracked heights plotted as along-track anomalies allows an assessment of the validity of retracked heights close to the coast, as illustrated in Figure 7 for pass 001 along the west Iberia margin (cycle 10).

Time series of sea-level anomalies can be derived from stacked altimetry measurements as

$$SLA=[altitude - (range + corrections)] - mssh$$

Where

mssh is the mean sea surface height

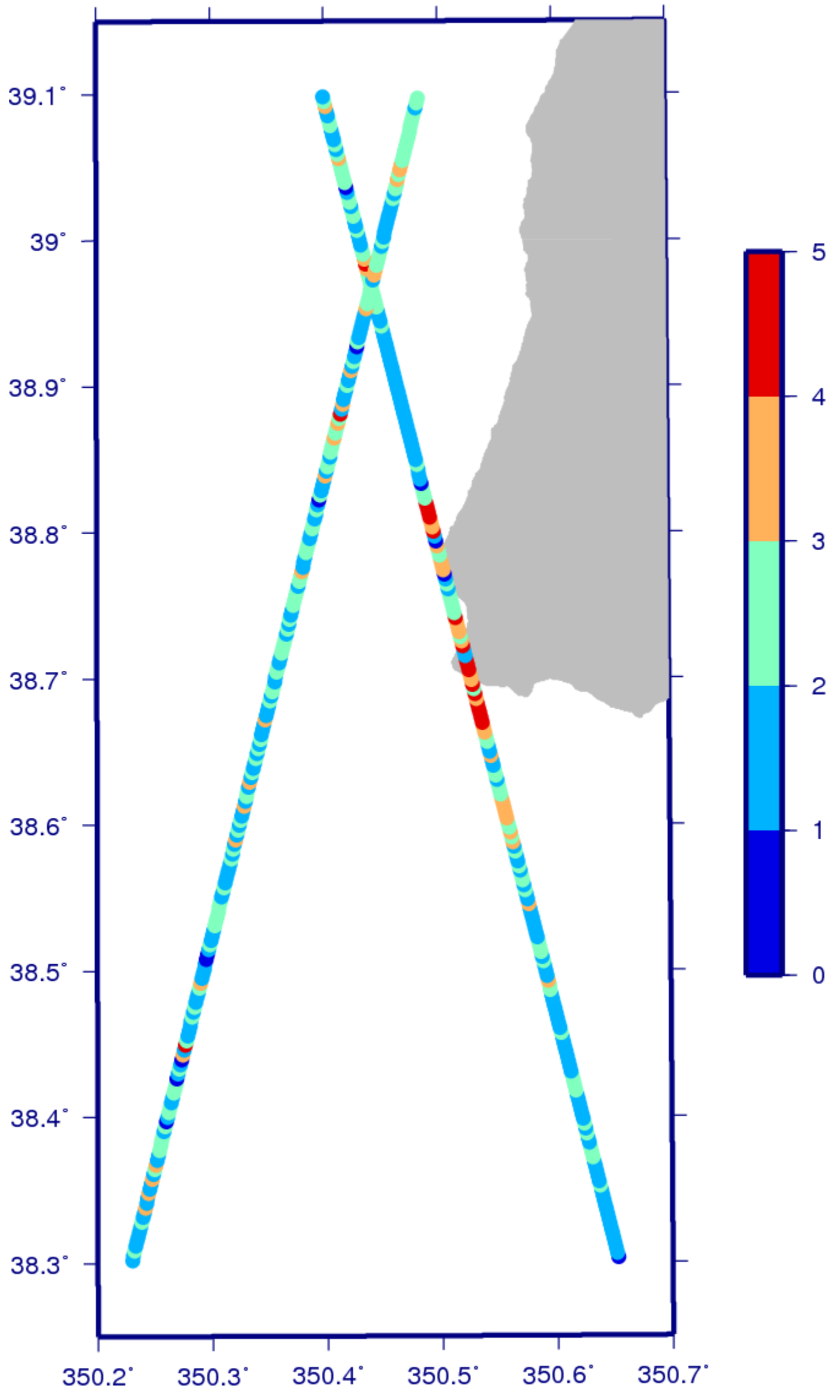


**Figure 8: Map of the number of cycles identified as having outlying values**

Each time series (at a given along-track location) is inspected for potential outlying values, set as anomalies exceeding 2.5 times the standard deviation of the series over the whole period. Figure 8 shows the number of values identified as outliers for a region around the Cascais tide gauge, west Iberia coast. At most along-track locations less than 3 cycles were identified as having outlying values, with that number increasing up to 5 very close to the coast. The corresponding cycle numbers are displayed in Figure 9, which shows that for the whole set of along-track points, cycles 39 and 66 were the cycles most often identified as outliers.

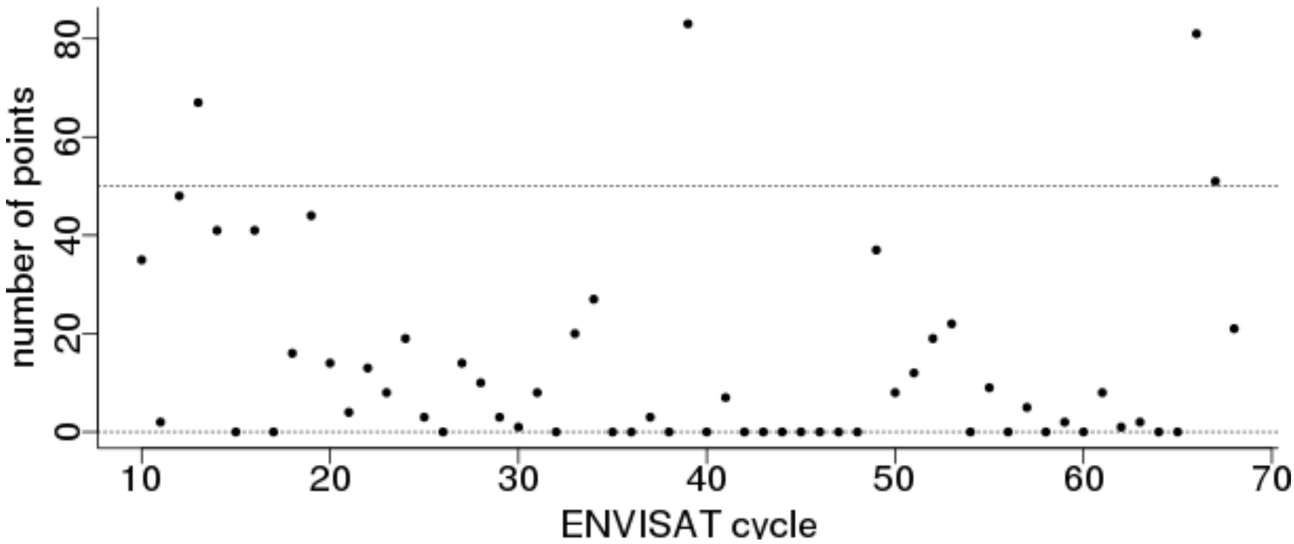


**Figure 9: Number of the along-track points (in Figure 8) for which each ENVISAT cycle was identified as outlying (exceeding 2.5 the standard deviation of the SLA series)**

## 6.2 Iberian Peninsula: Evaluation of Wet Tropospheric Corrections

In this case study, we present an example of evaluation of the new wet tropospheric corrections available on the CGDR for a specific region, by comparison of resulting anomalies with tide gauge data. The wet tropospheric correction (WTC) accounts for the highly variable water vapour content in the troposphere. Due to the large footprint of microwave radiometers, the radiometer-derived wet tropospheric delays are problematic near the coast. Three approaches are considered for the wet tropospheric correction:

WTC from the Dynamically Linked Model (DLM)

WTC from the ECMWF model

WTC from a GNSS-based method (GPD)

In order to assess the effect of the three types of WTC correction on COASTALT data, the resulting time series of sea-level anomalies (computed using the same formula as in §6.1) are compared with tide gauge (TG) observations, linearly interpolated to the satellite overpass time. Time series of differences are obtained by subtracting the tide gauge observations from the corresponding altimetry data. The standard deviation of the differences between COASTALT and Cascais tide gauge data are summarised in Figure 10, which shows very similar results for the three corrections, though the GNSS-based wet troposphere correction (GPD) yields slightly less variable and smaller differences to the in-situ tide gauge values.

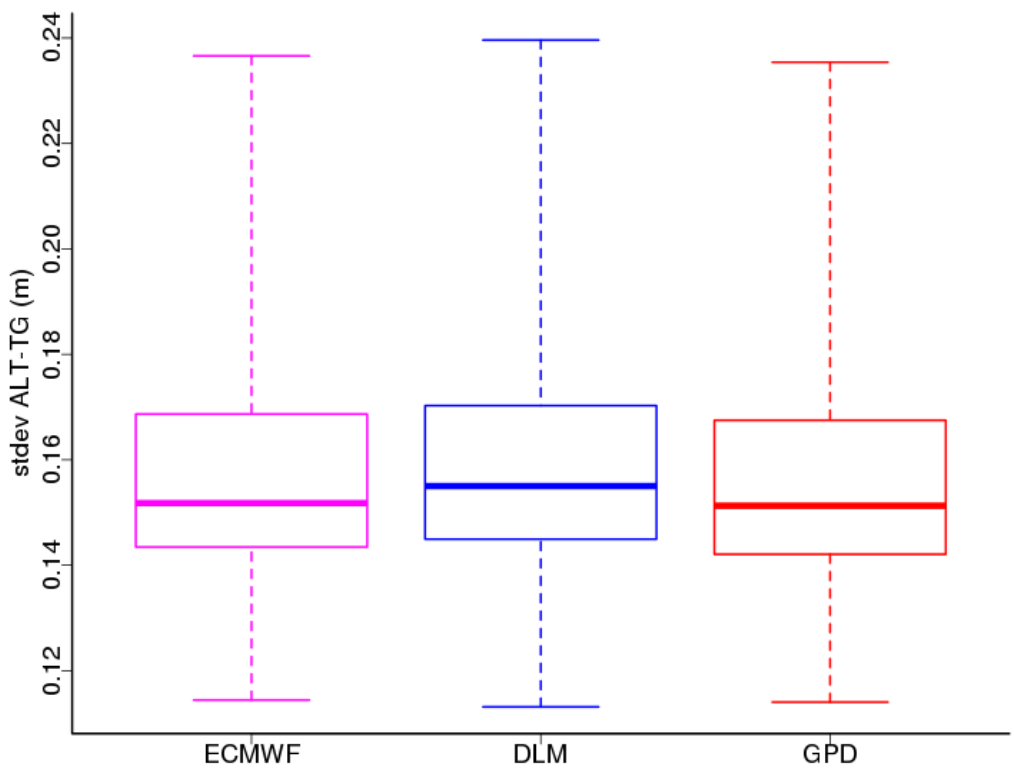


**Figure 10: Standard deviation of differences between COASTALT and tide gauge values at the Cascais tide gauge for the three wet troposphere corrections**

## 6.3 Gulf of Cadiz: Validating Significant Wave Height Data

In this work we analyzed the accuracy of ENVISAT RA-2 wave measurements in the Gulf of Cadiz, addressing the problem of satellite altimetry data improvement near the shoreline. The Gulf of Cadiz is a wide basin located in the southwestern of the Iberian Peninsula connecting the Atlantic Ocean and the Mediterranean Sea through the Strait of Gibraltar (Figure 11). The continental shelf from the east of Cape Santa Maria to the west of the Bay of Cadiz is quite broad (~ 50km). The coast is predominated by marshes, beaches and estuarine zones, and receives significant fluvial inputs associated with the discharge of major rivers such as the Guadiana and the Guadalquivir [RD 17]. This crucial environment has undergone substantial rapid agricultural, fisheries, and anthropogenic development, particularly in recent decades.


**Figure 11: Location of the study area showing ENVISAT track 223 and the AWAC (A) and Gulf of Cadiz (G) coastal buoys. Ground tracks are depicted with yellow dots indicating the position of the 1 Hz measurements (Google Earth copyright).**

An eight-year data set (2002-2009; cycles 11 through 84) along ENVISAT pass 223 was selected, that crosses the continental shelf of the Gulf of Cadiz in front of the Guadalquivir River mouth (Figure 11). The dataset includes the 1 Hz (approx. 7.5 km along track spacing) SWH (Significant Wave Height) from the SGDR Brown fit (ku_sig_wv_ht) and the 18 Hz (350 m along-track spacing) SWH from the COASTALT Brown retracker (brown_swh_ku). In a first step, the COASTALT 18 Hz SWH data were reduced to 1 Hz (by averaging twenty points) and inter-compared with the SGDR sourced data. To remove remaining spurious records, data were rejected if the land flag was set (altim_landocean_flag=1), the peakiness value was over 20 (ku_peak>1.8), any SWH value was reported as zero or default value and if the number of valid 18 Hz SWH measurements was less than 18 (num_18hz_ku_ocean_swh<18 for the SGDR data). The time series were further processed with the removal of all the observations for which SWH > 15 m or SWH < 0.15 m. In a second step, we validated the SWH data against ground-truth data available in the study area.

These data have been compared to *in situ* data from two Wave Buoys (AWAC - A and Gulf of Cadiz - G). The results of regression analysis of the buoy in an exposed location (G) showed very high correlation for both datasets: SGDR (N=797) and COASTALT (N=787), and were statistically significant at the 95% level, with most regression line slope close to, but slightly more than 1.0. The closest 1 Hz track point to the buoy (20 km) offered the best fit in both data streams: 0.17 m rms, 0.006 m bias and R=0.97 (SGDR) and 0.15 m rms, 0.007 m bias and R=0.96 (COASTALT), presenting consistent altimeter products typical of more offshore locations.

The outcomes of the sheltered water moored AWAC located in the estuarine zone of the Guadalquivir River (10 km from the coast), a very dynamic area, are presented in Figure 12. The regression analysis gives high correlation for both datasets and good agreement is inferred for the track points located 10-15 km away from the shore-line. The rms (m), bias (m) and R values along-track for each altimeter point and for the two data streams are displayed with respect to distance to coast and the separation from the in-situ station. Due to near-shore ground-truth data availability the number of observation is lower than for the offshore station, with N=161. The SGDR data show a bias, overestimating SWH with respect to the buoy measurements over the entire segment of along-track analyzed, especially in the first two points. The bias slightly increases with distance from the buoy. Figure 12 also indicates that variability increases monotonically with satellite/buoy distance. The best fit corresponds to the minimum along-track point's distance to the buoy (~11 km in point 4). Figure 13 presents the scatter of SWH from ground-based observations against altimeter GDR retrieval for track point 4 (dots), showing that the total collocations are situated above the 1:1 line with a positive bias in the satellite data. Average scatter about the regression line amounts to 0.36 m rms, 0.28 m bias, and with a correlation coefficient R=0.78. It is known that in coastal systems the background energy may significantly vary within the region and affect the wave spectra differently [RD 19]. Firstly, the effects associated with the remaining dispersion are interpreted due to local variations in wave climate because of the proximity to land. Secondly, the low correlation of two track points 1 and 2 (1.5 and 9 km distance from coast, respectively) demonstrated that, in addition to the coastal processes, the effects of land contamination in the altimeter footprint might distort the retrieval of SWH.

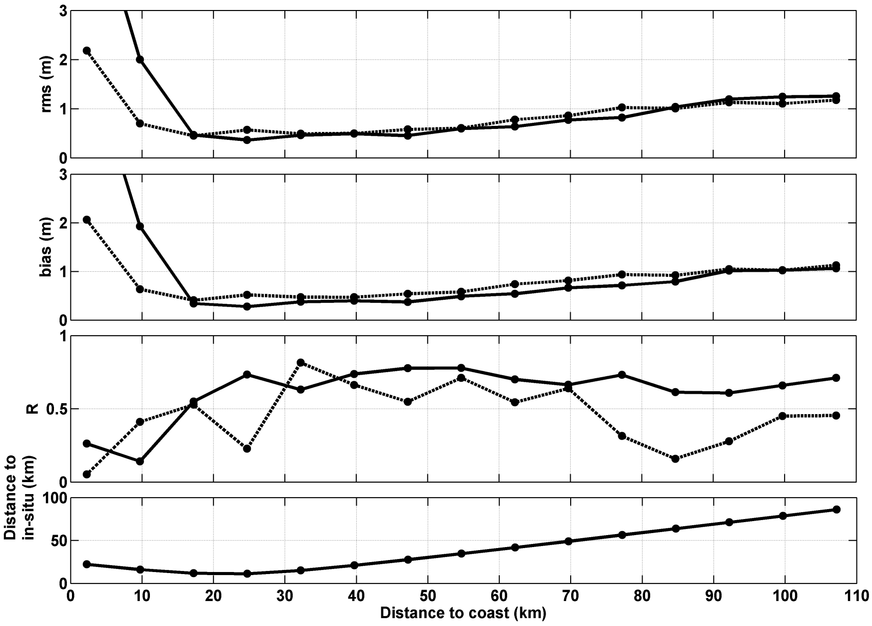


**Figure 12: Statistics (rms, bias and R) resulting from the comparisons of significant wave height from the altimeter products against in-situ observations from the AWAC coastal buoy with respect to the distance to coast. Continues lines correspond to SGDR datasets and dashed lines to COASTALT CGDR. The distance to in-situ emplacement of each track point in the bottom of the plot.**

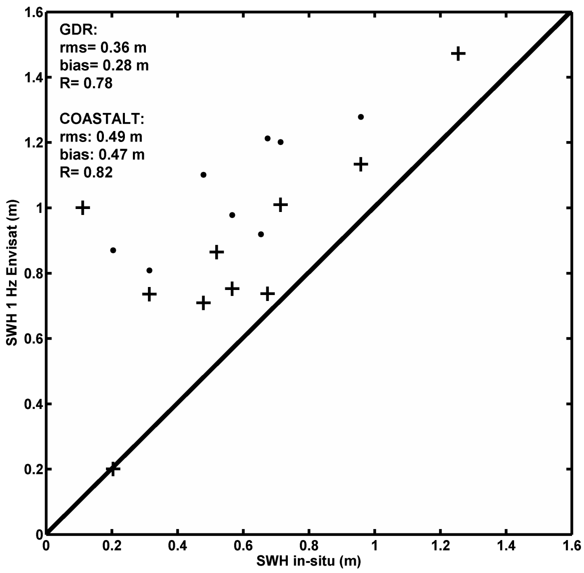


**Figure 13: Comparison of significant wave height records from the AWAC coastal buoy versus altimeter 1 Hz of track point 4 from the SGDR data (dots) and of track point 5 from COASTAL measurements (crosses).**

The COASTALT records show quite a good correspondence with the in-situ data, similar to the SGDR data, with a total of 120 collocations (Figure 12). Overall, there is a positive bias in the CGDR data (higher nearshore). This agrees well with previous work and with the SGDR comparisons, suggesting that altimeter systematically overestimates SWH with respect to ground-truth observations. The differences decrease as we approach the buoy location (as for the SGDR data) and, accordingly, the best fit appeared is at track point number 5, at 20 km from the buoy, with a correlation factor of 0.82, 0.49 m rms and 0.47 m bias. The scatter at point 5 can be observed in Figure 13 (crosses), representing an overestimation of the satellite data (regression line slope greater than 1).

In general, the rms between the two respective data streams was found to be similar, with the exception of the two closest points to coast, where there were lower differences for the COASTALT data. In fact, the second 1 Hz point (COASTALT) has rms and bias values of the same order of magnitude as the offshore points.

Apart from the discrepancy for the two points nearest to shore, the comparative statistics of both analyses are very similar, with both the COASTALT and SGDR records persistently overestimating wave conditions with respect to the in-situ observations. In general, the results demonstrate extremely good agreement between the buoy and the altimeter SGDR and COASTALT measurements. The altimeter estimates of SWH are characterized by stable performance, indicating that the spatial and temporal variability of the wave field is well reproduced in this coastal region. The results from the two points closest to shore clearly demonstrate the influence of land contamination on SWH retrieval, from both SGDR (more intensely) and COASTALT retrackers, providing a limit of approx. 15 km from shore for reliable use of the altimetry SWH data in this region. However, the retracker used in COASTALT seems to retrieve marginally less noisy SWH.

Full details of this work can be found in [RD 5].

# 7 Data description

The CGDR products are primarily sourced from the SGDR products. A limited number of auxiliary files have been used in generating the current version of the CGDR products. The auxiliary files used are detailed in the global attributes of the product and include the configuration data file, the characterization data file and the USO correction data file. Other parameters regarding waveform fitting have been derived from ESA documentation.

## 7.1 Data format

Envisat CGDR products contain both "1Hz" and "18 Hz" values in netCDF format. The 1 Hz values are held in 1 dimensional variables, whilst the 18 Hz data are held in 2 dimensional variables: the first dimension corresponds to the 1 Hz data dimension, and the second dimension is 20, the number of samples used in each 1Hz average value.

The COASTALT CGDR data product uses the netCDF (network Common Data Form) data format. NetCDF is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. The format was chosen as it is extremely flexible, self-describing, platform independent and has been adopted as a de-facto standard for many operational oceanography systems. Although the latest version of netCDF (v 4) has advantages in terms of data compression, CGDR files are produced in netCDF v 3 format, to retain maximum compatibility with existing software and for simplicity of installation, as it does not require the additional HDF 5 and compression libraries. The v3 files are compatible with v4 libraries and software.

In addition, the data and metadata within the files follow the Climate and Forecast netCDF conventions CF-1.4 wherever applicable, in order to take advantage of generic software and tools developed to read and manipulate data files that conform to these standards.

### 7.1.1 The NetCDF Data Model

A netCDF file contains **dimensions**, **variables**, and **attributes**, which all have a name by which they are identified. Each of these components has corresponding characteristics, which define what it holds and how it can be used. These components can be used together to capture the meaning of data and relations among data fields in an array-oriented data set.

#### 7.1.1.1 Dimensions

A dimension may be used to represent a real physical dimension, for example, time, latitude, longitude or height. Variables may share common dimensions, relating them to the same grid. A dimension might also be an index for other quantities (waveform index for example).

The following dimensions are used in the CGDR product files:

**Table 7-1 Dimensions used in the CGDR data sets**

| Dimension Name | Value |
|---|---|
| time | Number of 1 Hz measurements in the file |
| samples | 20 (number of elementary 18 Hz measurements within each 1 Hz average) |

#### 7.1.1.2 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 represented as follows:

**Table 7-2 netCDF variable types**

| 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 7-3 Variables included in the CGDR products. Variables calculated or mapped to two dimensions by the COASTALT processor are shown in *italics*.**

| Variable | Variable type | Dimension |
|---|---|---|
| **Coordinate and Auxiliary Coordinate Variables** | | |
| *time* | double | time |
| *samples* | short | samples |
| mdsr_time | double | time |
| *hz18_time* | double | time, samples |
| lat | int | time |
| lon | int | time |
| *hz18_lat* | int | time, samples |
| *hz18_lon* | int | time, samples |
| hz18_diff_1hz_lat | short | time, samples |
| hz18_diff_1hz_lon | short | time, samples |
| hz18_lat_diff | short | time, samples |
| hz18_lon_diff | short | time, samples |
| src_pack_cnt | int | time |
| *crs* | int | |
| **Confidence Flags** | | |
| inst_mode_id_flags | int | time |
| meas_conf_data_flags | int | time |
| **Orbit Information** | | |
| alt_cog_ellip | int | time |
| *hz18_alt_cog_ellip* | int | time, samples |
| hz18_diff_1hz_alt | short | time, samples |
| instant_alt_rate | short | time |
| **Range Information** | | |
| hz18_ku_trk_cog | int | time, samples |
| hz18_s_trk_cog | int | time, samples |
| *map_18hz_ku_trk* | short | time, samples |
| ku_band_ocean_range | int | time |
| s_band_ocean_range | int | time |
| hz18_ku_band_ocean | int | time, samples |
| hz18_s_band_ocean | int | time, samples |
| sd_18hz_ku_ocean | short | time |
| sd_18hz_s_ocean | short | time |
| num_18hz_ku_ocean | short | time |
| num_18hz_s_ocean | short | time |
| *map_18hz_ku_ocean_flags* | short | time, samples |
| *map_18hz_s_ocean_flags* | short | time, samples |

| Variable | Variable type | Dimension |
|---|---|---|
| **Range Correction Information** | | |
| hz18_ku_instr_corr | short | time, samples |
| hz18_s_instr_corr | short | time, samples |
| hz18_ku_dopp_corr | short | time, samples |
| hz18_s_dopp_corr | short | time, samples |
| hz18_ku_dopp_slp_corr | short | time, samples |
| hz18_s_dopp_slp_corr | short | time, samples |
| mod_dry_tropo_corr | short | time |
| inv_barom_corr | short | time |
| mod_wet_tropo_corr | short | time |
| mwr_wet_tropo_corr | short | time |
| ra2_ion_corr_ku | short | time |
| ra2_ion_corr_s | short | time |
| ion_corr_doris_ku | short | time |
| ion_corr_doris_s | short | time |
| ion_corr_mod_ku | short | time |
| ion_corr_mod_s | short | time |
| sea_bias_ku | short | time |
| sea_bias_s | short | time |
| dib_hf | short | time |
| **Significant Wave Height Information** | | |
| ku_sig_wv_ht | short | time |
| s_sig_wv_ht | short | time |
| square_ku_sig_wv_ht | int | time |
| square_s_sig_wv_ht | int | time |
| sd_18hz_ku_swh | short | time |
| sd_18hz_s_swh | short | time |
| num_18hz_ku_ocean_swh | short | time |
| num_18hz_s_ocean_swh | short | time |
| *slp_mod_flags* | short | time, samples |
| elev_echo_pt | int | time |
| hz18_diff_mean_ech_pt | short | time, samples |
| **Backscatter Information** | | |
| ku_ocean_bscat_coeff | short | time |
| s_ocean_bscat_coeff | short | time |
| sd_18hz_ku_ocean_bscat | short | time |
| sd_18hz_s_ocean_bscat | short | time |
| num_18hz_ku_ocean_bscat | short | time |
| num_18hz_s_ocean_bscat | short | time |

| Variable | Variable type | Dimension |
|---|---|---|
| hz18_k_cal_ku | short | time, samples |
| hz18_k_cal_s | short | time, samples |
| *map_18hz_k_cal_ku_flags* | int | time, samples |
| **Backscatter Correction Information** | | |
| ku_net_instr_corr_agc | short | time |
| s_net_instr_corr_agc | short | time |
| ku_atm_atten_corr | short | time |
| s_atm_atten_corr | short | time |
| ku_rai_corr | int | time |
| **Off-nadir Angle Information** | | |
| off_nad_ang_platf | short | time |
| off_nad_ang_wvform | short | time |
| **Geophysical Information** | | |
| m_sea_surf_ht | int | time |
| geoid_ht | int | time |
| ocean_depland_elev | int | time |
| tot_geocen_ocn_tide_ht_sol1 | short | time |
| tot_geocen_ocn_tide_ht_sol2 | short | time |
| long_period_ocn_tide_ht | short | time |
| tidal_load_ht_sol1 | short | time |
| tidal_load_ht_sol2 | short | time |
| solid_earth_tide_ht | short | time |
| geocen_pole_tide_ht | short | time |
| mod_surf_atm_pres | short | time |
| mwr_wvapour_cont | short | time |
| mwr_liq_vapour_cont | short | time |
| ra2_elec_cont | short | time |
| ra2_wind_sp | short | time |
| mod_wind_sp_u | short | time |
| mod_wind_sp_v | short | time |
| **MWR Information** | | |
| interpole_238_temp_mwr | short | time |
| interpole_365_temp_mwr | short | time |
| interpole_sd_238_temp_mwr | short | time |
| interpole_sd_365_temp_mwr | short | time |
| **Flags and other Quality Information** | | |
| ave_ku_chirp | short | time |
| *ku_chirp_id_flags* | short | time, samples |
| error_flag_chirp_id_flags | int | time |

| Variable | Variable type | Dimension |
|---|---|---|
| instr_flags | int | time |
| *instr_id_data_level_flags* | short | time, samples |
| num_meas_ku_calibr | short | time |
| num_meas_s_calibr | short | time |
| mwr_instr_flag | short | time |
| *ku_ocean_retrk_qua_flags* | short | time, samples |
| *s_ocean_retrk_qua_flags* | short | time, samples |
| ku_peak | short | time |
| s_peak | short | time |
| altim_landocean_flag | short | time |
| radio_landocean_flag | short | time |
| mwr_qua_interp_flag | short | time |
| rain_flag | short | time |
| interpole_flag | short | time |
| **New Brown Model Tracker Outputs** | | |
| *brown_range_ku* | double | time, samples |
| *brown_swh_ku* | double | time, samples |
| *brown_sigma0_ku* | double | time, samples |
| *brown_t0_ku* | double | time, samples |
| *brown_noise_ku* | double | time, samples |
| *gof_brown_ku* | double | time, samples |
| *brown_range_s* | double | time, samples |
| *brown_swh_s* | double | time, samples |
| *brown_sigma0_s* | double | time, samples |
| *brown_t0_s* | double | time, samples |
| *brown_noise_s* | double | time, samples |
| *gof_brown_s* | double | time, samples |
| **Specular Tracker Outputs** | | |
| *spec_range_ku* | double | time, samples |
| *specular_beta4_ku* | double | time, samples |
| *specular_beta2_ku* | double | time, samples |
| *specular_beta3_ku* | double | time, samples |
| *specular_beta5_ku* | double | time, samples |
| *specular_beta1_ku* | double | time, samples |
| *gof_spec_ku* | double | time, samples |
| *spec_range_s* | double | time, samples |
| *specular_beta4_s* | double | time, samples |
| *specular_beta2_s* | double | time, samples |
| *specular_beta3_s* | double | time, samples |

| Variable | Variable type | Dimension |
|---|---|---|
| *specular_beta5_s* | double | time, samples |
| *specular_beta1_s* | double | time, samples |
| *gof_spec_s* | double | time, samples |
| **Mixed Tracker Outputs** | | |
| *mixed_range_ku* | double | time, samples |
| *mixed_swh_ku* | double | time, samples |
| *mixed_sigma0_ku* | double | time, samples |
| *mixed_t0_ku* | double | time, samples |
| *mixed_beta4_ku* | double | time, samples |
| *mixed_beta2_ku* | double | time, samples |
| *mixed_beta3_ku* | double | time, samples |
| *mixed_beta5_ku* | double | time, samples |
| *mixed_noise_ku* | double | time, samples |
| *gof_mixed_ku* | double | time, samples |
| *mixed_range_s* | double | time, samples |
| *mixed_swh_s* | double | time, samples |
| *mixed_sigma0_s* | double | time, samples |
| *mixed_t0_s* | double | time, samples |
| *mixed_beta4_s* | double | time, samples |
| *mixed_beta2_s* | double | time, samples |
| *mixed_beta3_s* | double | time, samples |
| *mixed_beta5_s* | double | time, samples |
| *mixed_noise_s* | double | time, samples |
| *gof_mixed_s* | double | time, samples |
| **New range corrections** | | |
| *uso_clock_correction* | int | time, samples |
| *hz18_dry_trop_mod* | short | time, samples |
| *hz18_inv_barom_corr* | short | time, samples |
| *Hz18_mod_wet_tropo_corr* | short | time, samples |
| *hz18_mwr_wet_trop* | short | time, samples |
| *hz18_ra2_iono_corr_ku* | short | time, samples |
| *hz18_ra2_iono_corr_s* | short | time, samples |
| *hz18_iono_corr_doris_ku* | short | time, samples |
| *hz18_iono_corr_doris_s* | short | time, samples |
| *hz18_iono_corr_mod_ku* | short | time, samples |
| *hz18_iono_corr_mod_s* | Short | time, samples |
| *iono_corr_brown_ku* | short | time, samples |
| *iono_corr_spec_ku* | short | time, samples |
| *iono_corr_mixed_ku* | short | time, samples |

| Variable | Variable type | Dimension |
|---|---|---|
| *hz18_sea_bias_ku* | short | time, samples |
| *hz18_sea_bias_s* | short | time, samples |
| *hz18_dib_hf* | short | time, samples |
| **New geophysical corrections** | | |
| *hz18_m_sea_surf_ht* | int | time, samples |
| *hz18_geoid_ht* | int | time, samples |
| *hz18_ocean_depland_elev* | int | time, samples |
| *hz18_tot_geocen_ocn_tide_ht_sol1* | short | time, samples |
| *hz18_tot_geocen_ocn_tide_ht_sol2* | short | time, samples |
| *hz18_long_period_ocn_tide_ht* | short | time, samples |
| *hz18_tidal_load_ht_sol1* | short | time, samples |
| *hz18_tidal_load_ht_sol2* | short | time, samples |
| *hz18_solid_earth_tide_ht* | short | time, samples |
| *hz18_geocen_pole_tide_ht* | short | time, samples |
| **New flags and quality indicators** | | |
| *coastalt_mask_flag* | short | time, samples |
| *distance_from_coast* | short | time, samples |
| *mwr_wet_trop_interp_flag* | short | time, samples |

**Table 7-4 Additional variables included in some limited region enhanced CGDR products.**

| Variable | Variable type | Dimension |
|---|---|---|
| *hz18_GPD_wet_tropo_corr* | double | time, samples |
| *hz18_GPD_interp_flag* | short | time, samples |
| *hz18_GPD_formal_error* | double | time, samples |
| *hz18_GPD_signal_variance* | double | time, samples |

#### 7.1.1.3 Coordinate variables and auxiliary coordinate variables

A variable with the same name as a dimension is called a **coordinate variable**. It typically defines a physical coordinate corresponding to that dimension. In accordance with the Climate and Forecast conventions, a coordinate variable is declared for each dimension. Missing values are not allowed in coordinate variables and they must be strictly monotonic. The two coordinate variables in the CGDR products are **time** and **samples**.

An **auxiliary coordinate variable** is a netCDF variable that contains coordinates data but is not a coordinate variable as defined above. Unlike coordinate variables, there is no relationship between the name of an auxiliary coordinate variable and the name(s) of its dimension(s). Typical auxiliary coordinate variables are latitude and longitude

#### 7.1.1.4 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** and contain similar information to that found in product headers for the Envisat level 2 format files. These attributes are defined in accordance with the CF-conventions (see §7.1.3).

The following table shows the variable attributes used in the CGDR product. There are no mandatory attributes and only attributes appropriate to each variable are assigned.

**Table 7-5: Variable attributes**

| Attribute | Description |
|---|---|
| _FillValue | A value used to represent undefined or missing data |
| ancillary_variables | Identifies a variable that contains closely associated data, e.g., the measurement uncertainties of instrument data. |
| add_offset | If present, this number is to be added to the data after they are read by an application. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added. |
| comment | Miscellaneous information about the data or the methods used to produce it |
| coordinates | Identified auxiliary coordinate variables. |
| flag_masks | Describe a number of independent Boolean conditions using bit field notation by setting unique bits in each flag_masks value. The flag_masks attribute is the same type as the variable to which it is attached, and contains a list of values matching unique bit fields. A flagged condition is identified by performing a bitwise AND of the variable value and each flag_masks value; a non-zero result indicates a true condition. Used in conjunction with flag_meanings. |
| flag_meanings | Use in conjunction with flag_values or flag_meanings to provide descriptive words or phrase for each flag value. |
| flag_values | Provide a list of the flag values. The flag_values attribute is the same type as the variable to which it is attached. Used in conjunction with flag_meanings. |
| institution | Institution which provides the data |
| long_name | A descriptive name that indicates a variable's content. This name is not standardized. |
| quality_flag | Name of the variable(s) (quality flag) representing the quality of the current variable |
| references | References that describe the data or methods used to produce it. |
| scale_factor | If present, the data are to be multiplied by this factor after the data are read by an application. See also add_offset attribute. |
| source | Data source (model features, or observation) |
| standard_name | A standard name that references a description of a variable's content in the CF standard name table. |

### 7.1.2 The Common Data Language

The Common Data Language (CDL) is used to describe the content of a data set.

CDL is a human readable notation of the netCDF format. The netCDF utility **ncdump** converts netCDF binary objects to CDL text. The netCDF utility **ncgen** can create netCDF binary file from a CDL text file.

A CDL description of a NetCDF data set takes the form:

**netcdf *name* {**
  dimension: …
  variables: …
  data: …
}

where the *name* is used only as a default in constructing file names by the ncgen utility. The value of name reported by ncdump is the filename of the netCDF binary source file. The CDL description consists of three optional parts, introduced by the keywords “dimensions”, “variables” and “data”. NetCDF dimension declarations appear after the dimensions keyword, netCDF variables and attributes are defined after the variables keyword and variable data assignments appear after the data keyword. CDL statements are terminated by a semicolon. Spaces, tabs and newlines can be used freely for readability. Comments in CDL follow the characters ‘//’ on any line.

Example:

**netcdf example {**
    dimensions:  // dimensions are declared first
    time = 1000;

**variables:**

  **double time(time);    // variable <type> <name>(<dimension>)**
    time:long_name = "time” ;  // variable attributes
    time:units = "seconds since 2000-01-01 00:00:00.0” ; //time is a coordinate variable.

  **int lon(time);**
    lon:long_name = "longitude” ;
    lon:standard_name = "longitude” ;
    lon:units = "degrees_east” ;
    lon:scale_factor = 1.0e-06;  //lon is an auxiliary coordinate variable

  **short altim_landocean_flag (time);**
    altim_landocean_flag:long_name = "Altimeter surface type flag” ;
    altim_landocean_flag:_FillValue = 127s;
    altim_landocean_flag:flag_values = 0s, 1s, 2s, 3s;
    altim_landocean_flag:flag_meanings = "ocean enclosed_seas_lakes continental_ice land” ;
    altim_landocean_flag:coordinates = "lon lat” ;
//altim_landocean_flag is a flag fully described by the flag_meanings and flag_values attributes:

//altim_landocean_flag = 0 -> ocean
//altim_landocean_flag = 1 -> enclosed seas or lakes
//altim_landocean_flag = 2 -> continental ice
//altim_landocean_flag = 3 -> land
//If altim_landocean_flag is not computed, it will take the value 127 (_FillValue attribute).

**int alt_cog_ellip(time);**
alt_cog_ellip:long_name = "Altitude of CoG above reference ellipsoid" ;
alt_cog_ellip:_FillValue = 2147483647 ;
alt_cog_ellip:units = "m" ;
alt_cog_ellip:add_offset = 8.0e+05;
alt_cog_ellip:scale_factor = 0.001;
alt_cog_ellip:coordinates = "lon lat" ;
//alt_cog_ellipis is packed. The data are stored in 32-bit (long) integers. The value of the altitude of the satellite can be recovered using:
//alt_cog_ellips = (alt_cog_ellip(long) * scale_factor) + add_offset

### 7.1.3 CF convention

The Climate Forecast Conventions for netCDF are a set of 'rules' for describing climate related variables. They represent an agreed set of descriptions in terms of attributes and values that should be used to describe specific geophysical parameters. Variables names are not prescribed in the CF-conventions, however, the names of attributes and the values that some attributes can take, is defined.

## 7.2 Global attributes

Global attributes (the equivalent of Main Product Header and Specific Product Header parameters for SGDR products) may be displayed from a COASTALT CGDR data file using **"ncdump –h"** command.

A list (not necessarily exhaustive) of the global attributes available in the COASTALT CGDR is given below (attribute name and description).

**Table 7-6 Global Attributes used in CGDR files**

| Attribute Name | Description |
|---|---|
| Conventions | netCDF convention followed. This attribute should be set to "CF-1.4" to indicate that the file is compliant with the Climate and Forecast netCDF convention |
| title | COASTALT : Envisat Coastal dataset |
| institution | Institution carrying out processing, e.g. NOCS |
| history | Creation: <date of creation> of COASTALT product |
| source | radar altimeter RA-2 |
| product | COASTALT Product Name: Following the Envisat product naming convention from level 2 source data file |
| **Processing Information** | |
| Product_spec | Version of product specification document applicable to product |

| Attribute Name | Description |
|---|---|
| Product_ref | Reference documents for Product processing and handbook |
| Software_version | Version of L2 SGDR Software used to generate product |
| Proc_time | UTC time of L2 SGDR product generation |
| Product_revision | Version of COASTALT processor used to generate product |
| **Data time and orbit information** | |
| Sensing_start | UTC start time of data sensing for this pass |
| Sensing_stop | UTC stop time of data sensing for this pass |
| Phase | Phase letter |
| Cycle | Cycle number |
| Relative_orbit | Relative orbit number |
| Absolute_orbit | Absolute orbit number |
| Pass_number | Pass number from pole to pole |
| State_vector_time | UTC time of Envisat state vector |
| Delta_ut1 | DUT1=UT1-UTC (s) |
| X_position | X Position in Earth-fixed reference (m) |
| Y_position | Y Position in Earth-fixed reference (m) |
| Z_position | Z Position in Earth-fixed reference (m) |
| X_velocity | X velocity in Earth-fixed reference ($m\ s^{-1}$) |
| Y_velocity | Y velocity in Earth-fixed reference ($m\ s^{-1}$) |
| Z_velocity | Z velocity in Earth-fixed reference ($m\ s^{-1}$) |
| Vector_source | Source of orbit vectors |
| Envisat_source | Source Envisat Level 2 product SPH Descriptor (RA2_MWR_SGDR) |
| Envisat_source_ref | Reference documents for Envisat L2 product Source |
| RA2_first_record_time | UTC Time of first record in this product |
| RA2_last_record_time | UTC Time of first record in this product |
| RA2_first_lat | Geodetic Latitude of the first record in this product (degrees N) |
| RA2_first_lon | Geodetic Longitude of the first record in this product (degrees E) |
| RA2_last_lat | Geodetic Latitude of the last record in this product (degrees N) |
| RA2_last_lon | Geodetic Longitude of the last record in this product (degrees E) |
| **SBT to UTC Conversion Information** | |
| UTC_SBT_time | UTC corresponding to SBT (currently defined to be given at the time of the ascending node state vector |
| Sat_binary_time | Satellite binary time (SBT) 32 bit integer time of satellite clock |
| Clock_step | Clock step size (pico s) |
| **Leap second information** | |
| Leap_utc | UTC time of the occurrence of the leap second |
| Leap_sign | Leap second sign: +001 is positive, -001 if negative |
| Leap_err | Leap second error, 1 if leap second occurs within processing segment, 0 otherwise |

| Attribute Name | Description |
|---|---|
| **Instrument Status Information** | |
| RA2_flag_manoeuver | Orbit manoeuvre indicator |
| RA2_MANOEUVER_START_UTC | UTC of start of manoeuvre |
| RA2_MANOEUVER_STOP_UTC | UTC of end of manoeuvre |
| RA2_RV_RFSS_DEF | Hardware configuration for RF subsystem (A or B) |
| RA2_RV_HPA_DEF | Hardware configuration for HPA subsystem (A or B) |
| **RA-2 Processing Information** | |
| RA2_TIME_SHIFT_MIDFRAME | Offset to apply to time tag to derive datation of the first waveform in a source packet <10-6s> |
| RA2_TIME_INTERVAL | Time interval between two waveforms <10-6s> |
| RA2_IF_MASK_SEL | IF Mask selection flag |
| RA2_IF_MASK_PROC | IF shape compensation processing mode |
| RA2_USO_SEL | USO selection flag |
| RA2_USO_PROC | USO compensation processing mode |
| RA2_CONFIGURATION_DATA | RA-2 Level 1B Configuration File |
| RA2_CHARACTERISATION_DATA | RA-2 Level 1B Characterisation Data File |
| USO_CORRECTION_DATA | USO Correction Data File |
| AVERAGE_GLOBAL_PRESSURE | Average of the global pressure over the ocean computed from the meteo field, the closest time to the first measurement. This field must be set to all zeros. <10Pa> |
| SOLAR_ACTIVITY_INDEX | Interpolated value for the solar activity index used for the first measurement |
| **Reference Model Information** | |
| METEO_MODEL_VERSION | Version of the meteorological model |
| DORIS_IONOSPHERIC_MODEL _VERSION | Version of the ionospheric model |
| Coastal_mask_version | Name of coastal mask file applied |

## 7.3 Data Sets

The complete set of variables and attributes supplied in the CGDR files are specified in the current Product Specification Document [AD 7].

A complete list of variables and their attributes for any given CGDR file can be obtained using the **"ncdump –h"** command. This generates a CDL listing of the dimensions and variables, but not the data section of the netCDF file.

## 7.4 Software

This section lists some software that may be used to browse and use data from CGDR products.

### 7.4.1 Software provided with netCDF: "ncdump"

« ncdump » converts netCDF files to ASCII form (CDL)

See http://www.unidata.ucar.edu/software/netcdf/docs/ncdump-man-1.html.

The main options are:

- -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

### 7.4.2 netCDF Utilities

#### 7.4.2.1 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 http://www.epic.noaa.gov/java/ncBrowse/

#### 7.4.2.2 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/

### 7.4.3 Specialist Altimetry Software : BRAT

The Basic Radar Altimetry Toolbox, BRAT, is a tool designed to use radar altimetry data. It is able:

- to read all altimetry data from official data centres, from ERS-1 and 2, Topex/Poseidon, Geosat Follow-on, Jason-1, Envisat, Jason-2 and Cryosat, from Sensor Geophysical Data Record to gridded merged data, including the COASTALT CGDR products
- to do some processing and computations
- to visualise the results

The Basic Radar Altimetry Toolbox can be divided in four main components:

- Data reading (also called "ingestion")
- Processing routine functions

- Visualisation functions
- Graphic User Interface (GUI)

Alongside BRAT is a Radar Altimeter Tutorial (RAT), which provides an introduction and use cases for radar altimetry.

See http://www.altimetry.info/html/data/toolbox_en.html

# Annexe A References

## Applicable Documents

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AD 2 ENVISAT RA-2/MWR Level 2 User Manual, v1 rev.2, 20/06/2006

AD 3 EnviSat-1 Product Specifications, ANNEX A: PRODUCT DATA CONVENTIONS PO-RS-MDA-GS-2009, Is.: 3, Rev.: D, Date: 05/05/2004

AD 4 EnviSat-1 Product Specifications, Volume 5: RA-2 Product Structure PO-RS-MDA-GS-2009, Is.: 3, Rev.: D, Date: 22/11/2007

AD 5 EnviSat-1 Product Specifications, Volume 14: RA-2 Product Specifications PO-RS-MDA-GS-2009, Is.: 4, Rev.: C, Date: 30/01/2009

AD 6 COASTAL Waveform Retracker Software Technical Specifications. COASTALT STS001 v1.2, 28 July 2009.

AD 7 COASTALT Product Specification v2.0 rev 3 12 July 2011.

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AD 10 COASTALT WP2 Technical Note Improvement of Corrections in Coastal Areas, NOCS report, 11 September 2008, 34pp.

AD 11 COASTALT WP3.1 Technical Note Coastal waveform retracking: definition development and prototyping, U. Cádiz, 27pp.

AD 12 Impact of the Envisat Mission Extension on SAR data, ESA Technical Note, revision 1.0, 12 October 2010 (http://earth.esa.int/pub/ESA_DOC/ENVISAT/Impact_of_Envisat_Mission_Extension_on_SAR_data_-_1_01.pdf)

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AD 17 COASTALT EWP1 – Deliverable D1.2b. Processor: Plug and Play User Guide COASTALT Processor – version 2.0 revision 3, Version 1 25 July 2011.

AD 18 COASTALT Coastal Mask Tool – User Manual Version 1, ESA/ESRIN Contract No. 21201/08/I-LG Contract report

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# Annexe B List of acronyms

| | |
|---|---|
| AATSR | Advanced Along Track Scanning Radiometer |
| AD | Applicable Document |
| AGC | Automatic Gain Control |
| ASAR | Advanced Synthetic Aperture Radar |
| ATSR | Along Track Scanning Radiometer |
| AVISO | Archivage, Validation et Interprétation des données des Satellites Océanographiques |
| BRAT | Basic Radar Altimetry Toolbox |
| CGDR | Coastal Geophysical Data Record |
| CLS | Collecte Localisation Satellites |
| COASTALT | ESA development of Coastal Altimetry |
| DORIS | Détermination d'Orbite et Radiopositionnement Intégrés par Satellite |
| DLM | Dynamically Linked Model |
| DTM | Digital Terrain Model |
| ECMWF | European Center for Medium range Weather Forecasting |
| EGM | Earth Gravity Model |
| EM | ElectroMagnetic |
| Envisat | Environmental Satellite |
| ESA | European Space Agency |
| FES | Finite Element Solution |
| GDR | Geophysical Data Records |
| GIM | Global Ionosphere Maps |
| GOMOS | Global Ozone Monitoring by Occultation of Stars |
| GNSS | Global Navigation Satellite System |
| GPD | GNSS-derived Path Delay |
| HF | High Frequency |
| IB | Inverse Barometer |
| IGDR | Interim Geophysical Data Records |
| LRR | Laser Retroreflector |
| JPL | Jet Propulsion Laboratory |
| MDT | Mean Dynamic Topography |
| MIPAS | Michelson Interferometer for Passive Atmospheric Sounding |
| MSS | Mean Sea Surface |
| NASA | National Aeronautics and Space Administration |
| NetCDF | Network Common Data Form |
| NOAA | National Oceanic and Atmospheric Administration |
| NOC | National Oceanography Centre |
| NOC-S | National Oceanography Centre, Southampton |
| NRT | Near Real Time |
| OSTST | Ocean Surface Topography Science Team |

| | |
|---|---|
| POD | Precision Orbit Determination |
| RA-2 | Radar Altimeter-2 |
| RD | Reference Document |
| RMS | Root Mean Square |
| SAR | Synthetic Aperture Radar |
| SCIAMACHY | SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY |
| SGDR | Sensor Geophysical Data Record |
| SLA | Sea Level Anomaly |
| SLR | Satellite Laser Ranging |
| SSB | Sea State Bias |
| SSH | Sea Surface Height |
| SSHA | Sea Surface Height Anomaly |
| SWH | Significant Wave Height |
| TEC | Total Electron Content |
| USO | Ultra Stable Oscillator |
| UTC | Coordinated Universal Time |

# Annexe C Envisat 35-day Repeat Phase Pass Definitions

The tables in this Annexe provide the definitions of the passes within the Envisat 35-day repeat cycle phase (phase 2) in terms of their equator crossing longitude and equator crossing time (relative to the start of the cycle). The two tables provide the same information, but in the first instance the definitions are ordered by pass number (equivalent to time order) whilst in the second table, the passes are ordered by equator crossing longitude.

**Table A-1 Equator Crossing Longitude and Time (in order of Pass Number)**
**(the longitudes are the average values for cycles 10 – 79)**
**(RO = Relative Orbit, P = Pass, D = Day Shift)**

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 1 | 1 | 0.13 | 0 | 21:59:29 | 2 | 167.57 | 0 | 22:49:47 | 252 | 503 | 167.56 | 18 | 10:49:47 | 504 | 335.00 | 18 | 11:40:05 |
| 2 | 3 | 334.98 | 0 | 23:40:05 | 4 | 142.42 | 1 | 0:30:23 | 253 | 505 | 142.41 | 18 | 12:30:23 | 506 | 309.85 | 18 | 13:20:41 |
| 3 | 5 | 309.83 | 1 | 1:20:41 | 6 | 117.27 | 1 | 2:10:59 | 254 | 507 | 117.26 | 18 | 14:10:59 | 508 | 284.70 | 18 | 15:01:17 |
| 4 | 7 | 284.68 | 1 | 3:01:17 | 8 | 92.12 | 1 | 3:51:35 | 255 | 509 | 92.11 | 18 | 15:51:35 | 510 | 259.55 | 18 | 16:41:53 |
| 5 | 9 | 259.53 | 1 | 4:41:53 | 10 | 66.97 | 1 | 5:32:11 | 256 | 511 | 66.96 | 18 | 17:32:11 | 512 | 234.40 | 18 | 18:22:29 |
| 6 | 11 | 234.38 | 1 | 6:22:29 | 12 | 41.82 | 1 | 7:12:47 | 257 | 513 | 41.81 | 18 | 19:12:47 | 514 | 209.25 | 18 | 20:03:05 |
| 7 | 13 | 209.23 | 1 | 8:03:05 | 14 | 16.67 | 1 | 8:53:23 | 258 | 515 | 16.66 | 18 | 20:53:23 | 516 | 184.10 | 18 | 21:43:40 |
| 8 | 15 | 184.08 | 1 | 9:43:40 | 16 | 351.52 | 1 | 10:33:58 | 259 | 517 | 351.51 | 18 | 22:33:58 | 518 | 158.95 | 18 | 23:24:16 |
| 9 | 17 | 158.93 | 1 | 11:24:16 | 18 | 326.37 | 1 | 12:14:34 | 260 | 519 | 326.36 | 19 | 0:14:34 | 520 | 133.80 | 19 | 1:04:52 |
| 10 | 19 | 133.78 | 1 | 13:04:52 | 20 | 301.22 | 1 | 13:55:10 | 261 | 521 | 301.21 | 19 | 1:55:10 | 522 | 108.65 | 19 | 2:45:28 |
| 11 | 21 | 108.63 | 1 | 14:45:28 | 22 | 276.07 | 1 | 15:35:46 | 262 | 523 | 276.06 | 19 | 3:35:46 | 524 | 83.50 | 19 | 4:26:04 |
| 12 | 23 | 83.48 | 1 | 16:26:04 | 24 | 250.92 | 1 | 17:16:22 | 263 | 525 | 250.91 | 19 | 5:16:22 | 526 | 58.35 | 19 | 6:06:40 |
| 13 | 25 | 58.33 | 1 | 18:06:40 | 26 | 225.77 | 1 | 18:56:58 | 264 | 527 | 225.76 | 19 | 6:56:58 | 528 | 33.20 | 19 | 7:47:16 |
| 14 | 27 | 33.18 | 1 | 19:47:16 | 28 | 200.62 | 1 | 20:37:34 | 265 | 529 | 200.61 | 19 | 8:37:34 | 530 | 8.05 | 19 | 9:27:52 |
| 15 | 29 | 8.04 | 1 | 21:27:52 | 30 | 175.47 | 1 | 22:18:10 | 266 | 531 | 175.46 | 19 | 10:18:10 | 532 | 342.90 | 19 | 11:08:28 |
| 16 | 31 | 342.89 | 1 | 23:08:28 | 32 | 150.32 | 1 | 23:58:46 | 267 | 533 | 150.31 | 19 | 11:58:46 | 534 | 317.75 | 19 | 12:49:04 |
| 17 | 33 | 317.74 | 2 | 0:49:04 | 34 | 125.17 | 2 | 1:39:22 | 268 | 535 | 125.16 | 19 | 13:39:22 | 536 | 292.60 | 19 | 14:29:40 |
| 18 | 35 | 292.59 | 2 | 2:29:40 | 36 | 100.03 | 2 | 3:19:58 | 269 | 537 | 100.01 | 19 | 15:19:58 | 538 | 267.45 | 19 | 16:10:16 |
| 19 | 37 | 267.44 | 2 | 4:10:16 | 38 | 74.88 | 2 | 5:00:34 | 270 | 539 | 74.86 | 19 | 17:00:34 | 540 | 242.30 | 19 | 17:50:52 |
| 20 | 39 | 242.29 | 2 | 5:50:52 | 40 | 49.73 | 2 | 6:41:10 | 271 | 541 | 49.71 | 19 | 18:41:10 | 542 | 217.15 | 19 | 19:31:28 |
| 21 | 41 | 217.14 | 2 | 7:31:28 | 42 | 24.58 | 2 | 8:21:46 | 272 | 543 | 24.56 | 19 | 20:21:46 | 544 | 192.00 | 19 | 21:12:03 |
| 22 | 43 | 191.99 | 2 | 9:12:03 | 44 | 359.43 | 2 | 10:02:21 | 273 | 545 | 359.41 | 19 | 22:02:21 | 546 | 166.85 | 19 | 22:52:39 |
| 23 | 45 | 166.84 | 2 | 10:52:39 | 46 | 334.28 | 2 | 11:42:57 | 274 | 547 | 334.26 | 19 | 23:42:57 | 548 | 141.70 | 20 | 0:33:15 |
| 24 | 47 | 141.69 | 2 | 12:33:15 | 48 | 309.13 | 2 | 13:23:33 | 275 | 549 | 309.11 | 20 | 1:23:33 | 550 | 116.55 | 20 | 2:13:51 |
| 25 | 49 | 116.54 | 2 | 14:13:51 | 50 | 283.98 | 2 | 15:04:09 | 276 | 551 | 283.96 | 20 | 3:04:09 | 552 | 91.40 | 20 | 3:54:27 |
| 26 | 51 | 91.39 | 2 | 15:54:27 | 52 | 258.83 | 2 | 16:44:45 | 277 | 553 | 258.82 | 20 | 4:44:45 | 554 | 66.25 | 20 | 5:35:03 |
| 27 | 53 | 66.24 | 2 | 17:35:03 | 54 | 233.68 | 2 | 18:25:21 | 278 | 555 | 233.67 | 20 | 6:25:21 | 556 | 41.10 | 20 | 7:15:39 |
| 28 | 55 | 41.09 | 2 | 19:15:39 | 56 | 208.53 | 2 | 20:05:57 | 279 | 557 | 208.52 | 20 | 8:05:57 | 558 | 15.95 | 20 | 8:56:15 |
| 29 | 57 | 15.94 | 2 | 20:56:15 | 58 | 183.38 | 2 | 21:46:33 | 280 | 559 | 183.37 | 20 | 9:46:33 | 560 | 350.80 | 20 | 10:36:51 |
| 30 | 59 | 350.79 | 2 | 22:36:51 | 60 | 158.23 | 2 | 23:27:09 | 281 | 561 | 158.22 | 20 | 11:27:09 | 562 | 325.66 | 20 | 12:17:27 |
| 31 | 61 | 325.64 | 3 | 0:17:27 | 62 | 133.08 | 3 | 1:07:45 | 282 | 563 | 133.07 | 20 | 13:07:45 | 564 | 300.51 | 20 | 13:58:03 |
| 32 | 63 | 300.49 | 3 | 1:58:03 | 64 | 107.93 | 3 | 2:48:21 | 283 | 565 | 107.92 | 20 | 14:48:21 | 566 | 275.36 | 20 | 15:38:39 |
| 33 | 65 | 275.34 | 3 | 3:38:39 | 66 | 82.78 | 3 | 4:28:57 | 284 | 567 | 82.77 | 20 | 16:28:57 | 568 | 250.21 | 20 | 17:19:15 |
| 34 | 67 | 250.19 | 3 | 5:19:15 | 68 | 57.63 | 3 | 6:09:33 | 285 | 569 | 57.62 | 20 | 18:09:33 | 570 | 225.06 | 20 | 18:59:51 |
| 35 | 69 | 225.04 | 3 | 6:59:51 | 70 | 32.48 | 3 | 7:50:09 | 286 | 571 | 32.47 | 20 | 19:50:09 | 572 | 199.91 | 20 | 20:40:26 |
| 36 | 71 | 199.89 | 3 | 8:40:26 | 72 | 7.33 | 3 | 9:30:44 | 287 | 573 | 7.32 | 20 | 21:30:44 | 574 | 174.76 | 20 | 22:21:02 |
| 37 | 73 | 174.74 | 3 | 10:21:02 | 74 | 342.18 | 3 | 11:11:20 | 288 | 575 | 342.17 | 20 | 23:11:20 | 576 | 149.61 | 21 | 0:01:38 |
| 38 | 75 | 149.59 | 3 | 12:01:38 | 76 | 317.03 | 3 | 12:51:56 | 289 | 577 | 317.02 | 21 | 0:51:56 | 578 | 124.46 | 21 | 1:42:14 |
| 39 | 77 | 124.44 | 3 | 13:42:14 | 78 | 291.88 | 3 | 14:32:32 | 290 | 579 | 291.87 | 21 | 2:32:32 | 580 | 99.31 | 21 | 3:22:50 |
| 40 | 79 | 99.29 | 3 | 15:22:50 | 80 | 266.73 | 3 | 16:13:08 | 291 | 581 | 266.72 | 21 | 4:13:08 | 582 | 74.16 | 21 | 5:03:26 |
| 41 | 81 | 74.14 | 3 | 17:03:26 | 82 | 241.58 | 3 | 17:53:44 | 292 | 583 | 241.57 | 21 | 5:53:44 | 584 | 49.01 | 21 | 6:44:02 |
| 42 | 83 | 48.99 | 3 | 18:44:02 | 84 | 216.43 | 3 | 19:34:20 | 293 | 585 | 216.42 | 21 | 7:34:20 | 586 | 23.86 | 21 | 8:24:38 |
| 43 | 85 | 23.84 | 3 | 20:24:38 | 86 | 191.28 | 3 | 21:14:56 | 294 | 587 | 191.27 | 21 | 9:14:56 | 588 | 358.71 | 21 | 10:05:14 |
| 44 | 87 | 358.69 | 3 | 22:05:14 | 88 | 166.13 | 3 | 22:55:32 | 295 | 589 | 166.12 | 21 | 10:55:32 | 590 | 333.56 | 21 | 11:45:50 |
| 45 | 89 | 333.55 | 3 | 23:45:50 | 90 | 140.98 | 4 | 0:36:08 | 296 | 591 | 140.97 | 21 | 12:36:08 | 592 | 308.41 | 21 | 13:26:26 |
| 46 | 91 | 308.40 | 4 | 1:26:26 | 92 | 115.83 | 4 | 2:16:44 | 297 | 593 | 115.82 | 21 | 14:16:44 | 594 | 283.26 | 21 | 15:07:02 |
| 47 | 93 | 283.25 | 4 | 3:07:02 | 94 | 90.69 | 4 | 3:57:20 | 298 | 595 | 90.67 | 21 | 15:57:20 | 596 | 258.11 | 21 | 16:47:38 |
| 48 | 95 | 258.10 | 4 | 4:47:38 | 96 | 65.54 | 4 | 5:37:56 | 299 | 597 | 65.52 | 21 | 17:37:56 | 598 | 232.96 | 21 | 18:28:14 |
| 49 | 97 | 232.95 | 4 | 6:28:14 | 98 | 40.39 | 4 | 7:18:32 | 300 | 599 | 40.37 | 21 | 19:18:32 | 600 | 207.81 | 21 | 20:08:49 |
| 50 | 99 | 207.80 | 4 | 8:08:49 | 100 | 15.24 | 4 | 8:59:07 | 301 | 601 | 15.22 | 21 | 20:59:07 | 602 | 182.66 | 21 | 21:49:25 |
| 51 | 101 | 182.65 | 4 | 9:49:25 | 102 | 350.09 | 4 | 10:39:43 | 302 | 603 | 350.07 | 21 | 22:39:43 | 604 | 157.51 | 21 | 23:30:01 |
| 52 | 103 | 157.50 | 4 | 11:30:01 | 104 | 324.94 | 4 | 12:20:19 | 303 | 605 | 324.92 | 22 | 0:20:19 | 606 | 132.36 | 22 | 1:10:37 |
| 53 | 105 | 132.35 | 4 | 13:10:37 | 106 | 299.79 | 4 | 14:00:55 | 304 | 607 | 299.77 | 22 | 2:00:55 | 608 | 107.21 | 22 | 2:51:13 |
| 54 | 107 | 107.20 | 4 | 14:51:13 | 108 | 274.64 | 4 | 15:41:31 | 305 | 609 | 274.62 | 22 | 3:41:31 | 610 | 82.06 | 22 | 4:31:49 |
| 55 | 109 | 82.05 | 4 | 16:31:49 | 110 | 249.49 | 4 | 17:22:07 | 306 | 611 | 249.47 | 22 | 5:22:07 | 612 | 56.91 | 22 | 6:12:25 |
| 56 | 111 | 56.90 | 4 | 18:12:25 | 112 | 224.34 | 4 | 19:02:43 | 307 | 613 | 224.32 | 22 | 7:02:43 | 614 | 31.76 | 22 | 7:53:01 |
| 57 | 113 | 31.75 | 4 | 19:53:01 | 114 | 199.19 | 4 | 20:43:19 | 308 | 615 | 199.17 | 22 | 8:43:19 | 616 | 6.61 | 22 | 9:33:37 |
| 58 | 115 | 6.60 | 4 | 21:33:37 | 116 | 174.04 | 4 | 22:23:55 | 309 | 617 | 174.02 | 22 | 10:23:55 | 618 | 341.46 | 22 | 11:14:13 |
| 59 | 117 | 341.45 | 4 | 23:14:13 | 118 | 148.89 | 5 | 0:04:31 | 310 | 619 | 148.87 | 22 | 12:04:31 | 620 | 316.31 | 22 | 12:54:49 |
| 60 | 119 | 316.30 | 5 | 0:54:49 | 120 | 123.74 | 5 | 1:45:07 | 311 | 621 | 123.72 | 22 | 13:45:07 | 622 | 291.16 | 22 | 14:35:25 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 61 | 121 | 291.15 | 5 | 2:35:25 | 122 | 98.59 | 5 | 3:25:43 | 312 | 623 | 98.57 | 22 | 15:25:43 | 624 | 266.01 | 22 | 16:16:01 |
| 62 | 123 | 266.00 | 5 | 4:16:01 | 124 | 73.44 | 5 | 5:06:19 | 313 | 625 | 73.42 | 22 | 17:06:19 | 626 | 240.86 | 22 | 17:56:37 |
| 63 | 125 | 240.85 | 5 | 5:56:37 | 126 | 48.29 | 5 | 6:46:55 | 314 | 627 | 48.27 | 22 | 18:46:55 | 628 | 215.71 | 22 | 19:37:12 |
| 64 | 127 | 215.70 | 5 | 7:37:12 | 128 | 23.14 | 5 | 8:27:30 | 315 | 629 | 23.12 | 22 | 20:27:30 | 630 | 190.56 | 22 | 21:17:48 |
| 65 | 129 | 190.55 | 5 | 9:17:48 | 130 | 357.99 | 5 | 10:08:06 | 316 | 631 | 357.98 | 22 | 22:08:06 | 632 | 165.42 | 22 | 22:58:24 |
| 66 | 131 | 165.40 | 5 | 10:58:24 | 132 | 332.84 | 5 | 11:48:42 | 317 | 633 | 332.83 | 22 | 23:48:42 | 634 | 140.27 | 23 | 0:39:00 |
| 67 | 133 | 140.25 | 5 | 12:39:00 | 134 | 307.69 | 5 | 13:29:18 | 318 | 635 | 307.68 | 23 | 1:29:18 | 636 | 115.12 | 23 | 2:19:36 |
| 68 | 135 | 115.10 | 5 | 14:19:36 | 136 | 282.54 | 5 | 15:09:54 | 319 | 637 | 282.53 | 23 | 3:09:54 | 638 | 89.97 | 23 | 4:00:12 |
| 69 | 137 | 89.95 | 5 | 16:00:12 | 138 | 257.39 | 5 | 16:50:30 | 320 | 639 | 257.38 | 23 | 4:50:30 | 640 | 64.82 | 23 | 5:40:48 |
| 70 | 139 | 64.80 | 5 | 17:40:48 | 140 | 232.24 | 5 | 18:31:06 | 321 | 641 | 232.23 | 23 | 6:31:06 | 642 | 39.67 | 23 | 7:21:24 |
| 71 | 141 | 39.65 | 5 | 19:21:24 | 142 | 207.09 | 5 | 20:11:42 | 322 | 643 | 207.08 | 23 | 8:11:42 | 644 | 14.52 | 23 | 9:02:00 |
| 72 | 143 | 14.50 | 5 | 21:02:00 | 144 | 181.94 | 5 | 21:52:18 | 323 | 645 | 181.93 | 23 | 9:52:18 | 646 | 349.37 | 23 | 10:42:36 |
| 73 | 145 | 349.35 | 5 | 22:42:36 | 146 | 156.79 | 5 | 23:32:54 | 324 | 647 | 156.78 | 23 | 11:32:54 | 648 | 324.22 | 23 | 12:23:12 |
| 74 | 147 | 324.20 | 6 | 0:23:12 | 148 | 131.64 | 6 | 1:13:30 | 325 | 649 | 131.63 | 23 | 13:13:30 | 650 | 299.07 | 23 | 14:03:48 |
| 75 | 149 | 299.05 | 6 | 2:03:48 | 150 | 106.49 | 6 | 2:54:06 | 326 | 651 | 106.48 | 23 | 14:54:06 | 652 | 273.92 | 23 | 15:44:24 |
| 76 | 151 | 273.90 | 6 | 3:44:24 | 152 | 81.34 | 6 | 4:34:42 | 327 | 653 | 81.33 | 23 | 16:34:42 | 654 | 248.77 | 23 | 17:25:00 |
| 77 | 153 | 248.76 | 6 | 5:25:00 | 154 | 56.19 | 6 | 6:15:18 | 328 | 655 | 56.18 | 23 | 18:15:18 | 656 | 223.62 | 23 | 19:05:35 |
| 78 | 155 | 223.61 | 6 | 7:05:35 | 156 | 31.04 | 6 | 7:55:53 | 329 | 657 | 31.03 | 23 | 19:55:53 | 658 | 198.47 | 23 | 20:46:11 |
| 79 | 157 | 198.46 | 6 | 8:46:11 | 158 | 5.89 | 6 | 9:36:29 | 330 | 659 | 5.88 | 23 | 21:36:29 | 660 | 173.32 | 23 | 22:26:47 |
| 80 | 159 | 173.31 | 6 | 10:26:47 | 160 | 340.74 | 6 | 11:17:05 | 331 | 661 | 340.73 | 23 | 23:17:05 | 662 | 148.17 | 24 | 0:07:23 |
| 81 | 161 | 148.16 | 6 | 12:07:23 | 162 | 315.60 | 6 | 12:57:41 | 332 | 663 | 315.58 | 24 | 0:57:41 | 664 | 123.02 | 24 | 1:47:59 |
| 82 | 163 | 123.01 | 6 | 13:47:59 | 164 | 290.45 | 6 | 14:38:17 | 333 | 665 | 290.43 | 24 | 2:38:17 | 666 | 97.87 | 24 | 3:28:35 |
| 83 | 165 | 97.86 | 6 | 15:28:35 | 166 | 265.30 | 6 | 16:18:53 | 334 | 667 | 265.28 | 24 | 4:18:53 | 668 | 72.72 | 24 | 5:09:11 |
| 84 | 167 | 72.71 | 6 | 17:09:11 | 168 | 240.15 | 6 | 17:59:29 | 335 | 669 | 240.13 | 24 | 5:59:29 | 670 | 47.57 | 24 | 6:49:47 |
| 85 | 169 | 47.56 | 6 | 18:49:47 | 170 | 215.00 | 6 | 19:40:05 | 336 | 671 | 214.98 | 24 | 7:40:05 | 672 | 22.42 | 24 | 8:30:23 |
| 86 | 171 | 22.41 | 6 | 20:30:23 | 172 | 189.85 | 6 | 21:20:41 | 337 | 673 | 189.83 | 24 | 9:20:41 | 674 | 357.27 | 24 | 10:10:59 |
| 87 | 173 | 357.26 | 6 | 22:10:59 | 174 | 164.70 | 6 | 23:01:17 | 338 | 675 | 164.68 | 24 | 11:01:17 | 676 | 332.12 | 24 | 11:51:35 |
| 88 | 175 | 332.11 | 6 | 23:51:35 | 176 | 139.55 | 7 | 0:41:53 | 339 | 677 | 139.53 | 24 | 12:41:53 | 678 | 306.97 | 24 | 13:32:11 |
| 89 | 177 | 306.96 | 7 | 1:32:11 | 178 | 114.40 | 7 | 2:22:29 | 340 | 679 | 114.38 | 24 | 14:22:29 | 680 | 281.82 | 24 | 15:12:47 |
| 90 | 179 | 281.81 | 7 | 3:12:47 | 180 | 89.25 | 7 | 4:03:05 | 341 | 681 | 89.23 | 24 | 16:03:05 | 682 | 256.67 | 24 | 16:53:23 |
| 91 | 181 | 256.66 | 7 | 4:53:23 | 182 | 64.10 | 7 | 5:43:40 | 342 | 683 | 64.08 | 24 | 17:43:40 | 684 | 231.52 | 24 | 18:33:58 |
| 92 | 183 | 231.51 | 7 | 6:33:58 | 184 | 38.95 | 7 | 7:24:16 | 343 | 685 | 38.93 | 24 | 19:24:16 | 686 | 206.37 | 24 | 20:14:34 |
| 93 | 185 | 206.36 | 7 | 8:14:34 | 186 | 13.80 | 7 | 9:04:52 | 344 | 687 | 13.78 | 24 | 21:04:52 | 688 | 181.22 | 24 | 21:55:10 |
| 94 | 187 | 181.21 | 7 | 9:55:10 | 188 | 348.65 | 7 | 10:45:28 | 345 | 689 | 348.63 | 24 | 22:45:28 | 690 | 156.07 | 24 | 23:35:46 |
| 95 | 189 | 156.06 | 7 | 11:35:46 | 190 | 323.50 | 7 | 12:26:04 | 346 | 691 | 323.49 | 25 | 0:26:04 | 692 | 130.92 | 25 | 1:16:22 |
| 96 | 191 | 130.91 | 7 | 13:16:22 | 192 | 298.35 | 7 | 14:06:40 | 347 | 693 | 298.34 | 25 | 2:06:40 | 694 | 105.77 | 25 | 2:56:58 |
| 97 | 193 | 105.76 | 7 | 14:56:58 | 194 | 273.20 | 7 | 15:47:16 | 348 | 695 | 273.19 | 25 | 3:47:16 | 696 | 80.63 | 25 | 4:37:34 |
| 98 | 195 | 80.61 | 7 | 16:37:34 | 196 | 248.05 | 7 | 17:27:52 | 349 | 697 | 248.04 | 25 | 5:27:52 | 698 | 55.48 | 25 | 6:18:10 |
| 99 | 197 | 55.46 | 7 | 18:18:10 | 198 | 222.90 | 7 | 19:08:28 | 350 | 699 | 222.89 | 25 | 7:08:28 | 700 | 30.33 | 25 | 7:58:46 |
| 100 | 199 | 30.31 | 7 | 19:58:46 | 200 | 197.75 | 7 | 20:49:04 | 351 | 701 | 197.74 | 25 | 8:49:04 | 702 | 5.18 | 25 | 9:39:22 |
| 101 | 201 | 5.16 | 7 | 21:39:22 | 202 | 172.60 | 7 | 22:29:40 | 352 | 703 | 172.59 | 25 | 10:29:40 | 704 | 340.03 | 25 | 11:19:58 |
| 102 | 203 | 340.01 | 7 | 23:19:58 | 204 | 147.45 | 8 | 0:10:16 | 353 | 705 | 147.44 | 25 | 12:10:16 | 706 | 314.88 | 25 | 13:00:34 |
| 103 | 205 | 314.86 | 8 | 1:00:34 | 206 | 122.30 | 8 | 1:50:52 | 354 | 707 | 122.29 | 25 | 13:50:52 | 708 | 289.73 | 25 | 14:41:10 |
| 104 | 207 | 289.71 | 8 | 2:41:10 | 208 | 97.15 | 8 | 3:31:28 | 355 | 709 | 97.14 | 25 | 15:31:28 | 710 | 264.58 | 25 | 16:21:46 |
| 105 | 209 | 264.56 | 8 | 4:21:46 | 210 | 72.00 | 8 | 5:12:03 | 356 | 711 | 71.99 | 25 | 17:12:03 | 712 | 239.43 | 25 | 18:02:21 |
| 106 | 211 | 239.41 | 8 | 6:02:21 | 212 | 46.85 | 8 | 6:52:39 | 357 | 713 | 46.84 | 25 | 18:52:39 | 714 | 214.28 | 25 | 19:42:57 |
| 107 | 213 | 214.26 | 8 | 7:42:57 | 214 | 21.70 | 8 | 8:33:15 | 358 | 715 | 21.69 | 25 | 20:33:15 | 716 | 189.13 | 25 | 21:23:33 |
| 108 | 215 | 189.11 | 8 | 9:23:33 | 216 | 356.55 | 8 | 10:13:51 | 359 | 717 | 356.54 | 25 | 22:13:51 | 718 | 163.98 | 25 | 23:04:09 |
| 109 | 217 | 163.96 | 8 | 11:04:09 | 218 | 331.40 | 8 | 11:54:27 | 360 | 719 | 331.39 | 25 | 23:54:27 | 720 | 138.83 | 26 | 0:44:45 |
| 110 | 219 | 138.81 | 8 | 12:44:45 | 220 | 306.25 | 8 | 13:35:03 | 361 | 721 | 306.24 | 26 | 1:35:03 | 722 | 113.68 | 26 | 2:25:21 |
| 111 | 221 | 113.66 | 8 | 14:25:21 | 222 | 281.10 | 8 | 15:15:39 | 362 | 723 | 281.09 | 26 | 3:15:39 | 724 | 88.53 | 26 | 4:05:57 |
| 112 | 223 | 88.51 | 8 | 16:05:57 | 224 | 255.95 | 8 | 16:56:15 | 363 | 725 | 255.94 | 26 | 4:56:15 | 726 | 63.38 | 26 | 5:46:33 |
| 113 | 225 | 63.36 | 8 | 17:46:33 | 226 | 230.80 | 8 | 18:36:51 | 364 | 727 | 230.79 | 26 | 6:36:51 | 728 | 38.23 | 26 | 7:27:09 |
| 114 | 227 | 38.21 | 8 | 19:27:09 | 228 | 205.65 | 8 | 20:17:27 | 365 | 729 | 205.64 | 26 | 8:17:27 | 730 | 13.08 | 26 | 9:07:45 |
| 115 | 229 | 13.07 | 8 | 21:07:45 | 230 | 180.50 | 8 | 21:58:03 | 366 | 731 | 180.49 | 26 | 9:58:03 | 732 | 347.93 | 26 | 10:48:21 |
| 116 | 231 | 347.92 | 8 | 22:48:21 | 232 | 155.36 | 8 | 23:38:39 | 367 | 733 | 155.34 | 26 | 11:38:39 | 734 | 322.78 | 26 | 12:28:57 |
| 117 | 233 | 322.77 | 9 | 0:28:57 | 234 | 130.21 | 9 | 1:19:15 | 368 | 735 | 130.19 | 26 | 13:19:15 | 736 | 297.63 | 26 | 14:09:33 |
| 118 | 235 | 297.62 | 9 | 2:09:33 | 236 | 105.06 | 9 | 2:59:51 | 369 | 737 | 105.04 | 26 | 14:59:51 | 738 | 272.48 | 26 | 15:50:09 |
| 119 | 237 | 272.47 | 9 | 3:50:09 | 238 | 79.91 | 9 | 4:40:26 | 370 | 739 | 79.89 | 26 | 16:40:26 | 740 | 247.33 | 26 | 17:30:44 |
| 120 | 239 | 247.32 | 9 | 5:30:44 | 240 | 54.76 | 9 | 6:21:02 | 371 | 741 | 54.74 | 26 | 18:21:02 | 742 | 222.18 | 26 | 19:11:20 |
| 121 | 241 | 222.17 | 9 | 7:11:20 | 242 | 29.61 | 9 | 8:01:38 | 372 | 743 | 29.59 | 26 | 20:01:38 | 744 | 197.03 | 26 | 20:51:56 |
| 122 | 243 | 197.02 | 9 | 8:51:56 | 244 | 4.46 | 9 | 9:42:14 | 373 | 745 | 4.44 | 26 | 21:42:14 | 746 | 171.88 | 26 | 22:32:32 |
| 123 | 245 | 171.87 | 9 | 10:32:32 | 246 | 339.31 | 9 | 11:22:50 | 374 | 747 | 339.29 | 26 | 23:22:50 | 748 | 146.73 | 27 | 0:13:08 |
| 124 | 247 | 146.72 | 9 | 12:13:08 | 248 | 314.16 | 9 | 13:03:26 | 375 | 749 | 314.14 | 27 | 1:03:26 | 750 | 121.58 | 27 | 1:53:44 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 125 | 249 | 121.57 | 9 | 13:53:44 | 250 | 289.01 | 9 | 14:44:02 | 376 | 751 | 288.99 | 27 | 2:44:02 | 752 | 96.43 | 27 | 3:34:20 |
| 126 | 251 | 96.42 | 9 | 15:34:20 | 252 | 263.86 | 9 | 16:24:38 | 377 | 753 | 263.85 | 27 | 4:24:38 | 754 | 71.28 | 27 | 5:14:56 |
| 127 | 253 | 71.27 | 9 | 17:14:56 | 254 | 238.71 | 9 | 18:05:14 | 378 | 755 | 238.70 | 27 | 6:05:14 | 756 | 46.13 | 27 | 6:55:32 |
| 128 | 255 | 46.12 | 9 | 18:55:32 | 256 | 213.56 | 9 | 19:45:50 | 379 | 757 | 213.55 | 27 | 7:45:50 | 758 | 20.98 | 27 | 8:36:08 |
| 129 | 257 | 20.97 | 9 | 20:36:08 | 258 | 188.41 | 9 | 21:26:26 | 380 | 759 | 188.40 | 27 | 9:26:26 | 760 | 355.83 | 27 | 10:16:44 |
| 130 | 259 | 355.82 | 9 | 22:16:44 | 260 | 163.26 | 9 | 23:07:02 | 381 | 761 | 163.25 | 27 | 11:07:02 | 762 | 330.69 | 27 | 11:57:20 |
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| 132 | 263 | 305.52 | 10 | 1:37:56 | 264 | 112.96 | 10 | 2:28:14 | 383 | 765 | 112.95 | 27 | 14:28:14 | 766 | 280.39 | 27 | 15:18:32 |
| 133 | 265 | 280.37 | 10 | 3:18:32 | 266 | 87.81 | 10 | 4:08:49 | 384 | 767 | 87.80 | 27 | 16:08:49 | 768 | 255.24 | 27 | 16:59:07 |
| 134 | 267 | 255.22 | 10 | 4:59:07 | 268 | 62.66 | 10 | 5:49:25 | 385 | 769 | 62.65 | 27 | 17:49:25 | 770 | 230.09 | 27 | 18:39:43 |
| 135 | 269 | 230.07 | 10 | 6:39:43 | 270 | 37.51 | 10 | 7:30:01 | 386 | 771 | 37.50 | 27 | 19:30:01 | 772 | 204.94 | 27 | 20:20:19 |
| 136 | 271 | 204.92 | 10 | 8:20:19 | 272 | 12.36 | 10 | 9:10:37 | 387 | 773 | 12.35 | 27 | 21:10:37 | 774 | 179.79 | 27 | 22:00:55 |
| 137 | 273 | 179.77 | 10 | 10:00:55 | 274 | 347.21 | 10 | 10:51:13 | 388 | 775 | 347.20 | 27 | 22:51:13 | 776 | 154.64 | 27 | 23:41:31 |
| 138 | 275 | 154.62 | 10 | 11:41:31 | 276 | 322.06 | 10 | 12:31:49 | 389 | 777 | 322.05 | 28 | 0:31:49 | 778 | 129.49 | 28 | 1:22:07 |
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| 144 | 287 | 3.72 | 10 | 21:45:07 | 288 | 171.16 | 10 | 22:35:25 | 395 | 789 | 171.15 | 28 | 10:35:25 | 790 | 338.59 | 28 | 11:25:43 |
| 145 | 289 | 338.58 | 10 | 23:25:43 | 290 | 146.01 | 11 | 0:16:01 | 396 | 791 | 146.00 | 28 | 12:16:01 | 792 | 313.44 | 28 | 13:06:19 |
| 146 | 291 | 313.43 | 11 | 1:06:19 | 292 | 120.86 | 11 | 1:56:37 | 397 | 793 | 120.85 | 28 | 13:56:37 | 794 | 288.29 | 28 | 14:46:55 |
| 147 | 293 | 288.28 | 11 | 2:46:55 | 294 | 95.72 | 11 | 3:37:12 | 398 | 795 | 95.70 | 28 | 15:37:12 | 796 | 263.14 | 28 | 16:27:30 |
| 148 | 295 | 263.13 | 11 | 4:27:30 | 296 | 70.57 | 11 | 5:17:48 | 399 | 797 | 70.55 | 28 | 17:17:48 | 798 | 237.99 | 28 | 18:08:06 |
| 149 | 297 | 237.98 | 11 | 6:08:06 | 298 | 45.42 | 11 | 6:58:24 | 400 | 799 | 45.40 | 28 | 18:58:24 | 800 | 212.84 | 28 | 19:48:42 |
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| 153 | 305 | 137.38 | 11 | 12:50:30 | 306 | 304.82 | 11 | 13:40:48 | 404 | 807 | 304.80 | 29 | 1:40:48 | 808 | 112.24 | 29 | 2:31:06 |
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| 159 | 317 | 346.48 | 11 | 22:54:06 | 318 | 153.92 | 11 | 23:44:24 | 410 | 819 | 153.90 | 29 | 11:44:24 | 820 | 321.34 | 29 | 12:34:42 |
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| 162 | 323 | 271.03 | 12 | 3:55:53 | 324 | 78.47 | 12 | 4:46:11 | 413 | 825 | 78.45 | 29 | 16:46:11 | 826 | 245.89 | 29 | 17:36:29 |
| 163 | 325 | 245.88 | 12 | 5:36:29 | 326 | 53.32 | 12 | 6:26:47 | 414 | 827 | 53.30 | 29 | 18:26:47 | 828 | 220.74 | 29 | 19:17:05 |
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| 166 | 331 | 170.43 | 12 | 10:38:17 | 332 | 337.87 | 12 | 11:28:35 | 417 | 833 | 337.86 | 29 | 23:28:35 | 834 | 145.30 | 30 | 0:18:53 |
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| 168 | 335 | 120.13 | 12 | 13:59:29 | 336 | 287.57 | 12 | 14:49:47 | 419 | 837 | 287.56 | 30 | 2:49:47 | 838 | 95.00 | 30 | 3:40:05 |
| 169 | 337 | 94.98 | 12 | 15:40:05 | 338 | 262.42 | 12 | 16:30:23 | 420 | 839 | 262.41 | 30 | 4:30:23 | 840 | 69.85 | 30 | 5:20:41 |
| 170 | 339 | 69.83 | 12 | 17:20:41 | 340 | 237.27 | 12 | 18:10:59 | 421 | 841 | 237.26 | 30 | 6:10:59 | 842 | 44.70 | 30 | 7:01:17 |
| 171 | 341 | 44.68 | 12 | 19:01:17 | 342 | 212.12 | 12 | 19:51:35 | 422 | 843 | 212.11 | 30 | 7:51:35 | 844 | 19.55 | 30 | 8:41:53 |
| 172 | 343 | 19.53 | 12 | 20:41:53 | 344 | 186.97 | 12 | 21:32:11 | 423 | 845 | 186.96 | 30 | 9:32:11 | 846 | 354.40 | 30 | 10:22:29 |
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| 174 | 347 | 329.23 | 13 | 0:03:05 | 348 | 136.67 | 13 | 0:53:23 | 425 | 849 | 136.66 | 30 | 12:53:23 | 850 | 304.10 | 30 | 13:43:40 |
| 175 | 349 | 304.08 | 13 | 1:43:40 | 350 | 111.52 | 13 | 2:33:58 | 426 | 851 | 111.51 | 30 | 14:33:58 | 852 | 278.95 | 30 | 15:24:16 |
| 176 | 351 | 278.93 | 13 | 3:24:16 | 352 | 86.37 | 13 | 4:14:34 | 427 | 853 | 86.36 | 30 | 16:14:34 | 854 | 253.80 | 30 | 17:04:52 |
| 177 | 353 | 253.79 | 13 | 5:04:52 | 354 | 61.22 | 13 | 5:55:10 | 428 | 855 | 61.21 | 30 | 17:55:10 | 856 | 228.65 | 30 | 18:45:28 |
| 178 | 355 | 228.64 | 13 | 6:45:28 | 356 | 36.07 | 13 | 7:35:46 | 429 | 857 | 36.06 | 30 | 19:35:46 | 858 | 203.50 | 30 | 20:26:04 |
| 179 | 357 | 203.49 | 13 | 8:26:04 | 358 | 10.92 | 13 | 9:16:22 | 430 | 859 | 10.91 | 30 | 21:16:22 | 860 | 178.35 | 30 | 22:06:40 |
| 180 | 359 | 178.34 | 13 | 10:06:40 | 360 | 345.77 | 13 | 10:56:58 | 431 | 861 | 345.76 | 30 | 22:56:58 | 862 | 153.20 | 30 | 23:47:16 |
| 181 | 361 | 153.19 | 13 | 11:47:16 | 362 | 320.62 | 13 | 12:37:34 | 432 | 863 | 320.61 | 31 | 0:37:34 | 864 | 128.05 | 31 | 1:27:52 |
| 182 | 363 | 128.04 | 13 | 13:27:52 | 364 | 295.48 | 13 | 14:18:10 | 433 | 865 | 295.46 | 31 | 2:18:10 | 866 | 102.90 | 31 | 3:08:28 |
| 183 | 365 | 102.89 | 13 | 15:08:28 | 366 | 270.33 | 13 | 15:58:46 | 434 | 867 | 270.31 | 31 | 3:58:46 | 868 | 77.75 | 31 | 4:49:04 |
| 184 | 367 | 77.74 | 13 | 16:49:04 | 368 | 245.17 | 13 | 17:39:22 | 435 | 869 | 245.16 | 31 | 5:39:22 | 870 | 52.60 | 31 | 6:29:40 |
| 185 | 369 | 52.59 | 13 | 18:29:40 | 370 | 220.02 | 13 | 19:19:58 | 436 | 871 | 220.01 | 31 | 7:19:58 | 872 | 27.45 | 31 | 8:10:16 |
| 186 | 371 | 27.44 | 13 | 20:10:16 | 372 | 194.88 | 13 | 21:00:34 | 437 | 873 | 194.86 | 31 | 9:00:34 | 874 | 2.30 | 31 | 9:50:52 |
| 187 | 373 | 2.29 | 13 | 21:50:52 | 374 | 169.73 | 13 | 22:41:10 | 438 | 875 | 169.71 | 31 | 10:41:10 | 876 | 337.15 | 31 | 11:31:28 |
| 188 | 375 | 337.14 | 13 | 23:31:28 | 376 | 144.58 | 14 | 0:21:46 | 439 | 877 | 144.56 | 31 | 12:21:46 | 878 | 312.00 | 31 | 13:12:03 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 189 | 377 | 311.99 | 14 | 1:12:03 | 378 | 119.43 | 14 | 2:02:21 | 440 | 879 | 119.41 | 31 | 14:02:21 | 880 | 286.85 | 31 | 14:52:39 |
| 190 | 379 | 286.84 | 14 | 2:52:39 | 380 | 94.28 | 14 | 3:42:57 | 441 | 881 | 94.26 | 31 | 15:42:57 | 882 | 261.70 | 31 | 16:33:15 |
| 191 | 381 | 261.69 | 14 | 4:33:15 | 382 | 69.13 | 14 | 5:23:33 | 442 | 883 | 69.11 | 31 | 17:23:33 | 884 | 236.55 | 31 | 18:13:51 |
| 192 | 383 | 236.54 | 14 | 6:13:51 | 384 | 43.98 | 14 | 7:04:09 | 443 | 885 | 43.96 | 31 | 19:04:09 | 886 | 211.40 | 31 | 19:54:27 |
| 193 | 385 | 211.39 | 14 | 7:54:27 | 386 | 18.83 | 14 | 8:44:45 | 444 | 887 | 18.81 | 31 | 20:44:45 | 888 | 186.25 | 31 | 21:35:03 |
| 194 | 387 | 186.24 | 14 | 9:35:03 | 388 | 353.68 | 14 | 10:25:21 | 445 | 889 | 353.66 | 31 | 22:25:21 | 890 | 161.10 | 31 | 23:15:39 |
| 195 | 389 | 161.09 | 14 | 11:15:39 | 390 | 328.53 | 14 | 12:05:57 | 446 | 891 | 328.52 | 32 | 0:05:57 | 892 | 135.95 | 32 | 0:56:15 |
| 196 | 391 | 135.94 | 14 | 12:56:15 | 392 | 303.38 | 14 | 13:46:33 | 447 | 893 | 303.37 | 32 | 1:46:33 | 894 | 110.80 | 32 | 2:36:51 |
| 197 | 393 | 110.79 | 14 | 14:36:51 | 394 | 278.23 | 14 | 15:27:09 | 448 | 895 | 278.22 | 32 | 3:27:09 | 896 | 85.66 | 32 | 4:17:27 |
| 198 | 395 | 85.64 | 14 | 16:17:27 | 396 | 253.08 | 14 | 17:07:45 | 449 | 897 | 253.07 | 32 | 5:07:45 | 898 | 60.51 | 32 | 5:58:03 |
| 199 | 397 | 60.49 | 14 | 17:58:03 | 398 | 227.93 | 14 | 18:48:21 | 450 | 899 | 227.92 | 32 | 6:48:21 | 900 | 35.36 | 32 | 7:38:39 |
| 200 | 399 | 35.34 | 14 | 19:38:39 | 400 | 202.78 | 14 | 20:28:57 | 451 | 901 | 202.77 | 32 | 8:28:57 | 902 | 10.21 | 32 | 9:19:15 |
| 201 | 401 | 10.19 | 14 | 21:19:15 | 402 | 177.63 | 14 | 22:09:33 | 452 | 903 | 177.62 | 32 | 10:09:33 | 904 | 345.06 | 32 | 10:59:51 |
| 202 | 403 | 345.04 | 14 | 22:59:51 | 404 | 152.48 | 14 | 23:50:09 | 453 | 905 | 152.47 | 32 | 11:50:09 | 906 | 319.91 | 32 | 12:40:26 |
| 203 | 405 | 319.89 | 15 | 0:40:26 | 406 | 127.33 | 15 | 1:30:44 | 454 | 907 | 127.32 | 32 | 13:30:44 | 908 | 294.76 | 32 | 14:21:02 |
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| 205 | 409 | 269.59 | 15 | 4:01:38 | 410 | 77.03 | 15 | 4:51:56 | 456 | 911 | 77.02 | 32 | 16:51:56 | 912 | 244.46 | 32 | 17:42:14 |
| 206 | 411 | 244.44 | 15 | 5:42:14 | 412 | 51.88 | 15 | 6:32:32 | 457 | 913 | 51.87 | 32 | 18:32:32 | 914 | 219.31 | 32 | 19:22:50 |
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| 208 | 415 | 194.14 | 15 | 9:03:26 | 416 | 1.58 | 15 | 9:53:44 | 459 | 917 | 1.57 | 32 | 21:53:44 | 918 | 169.01 | 32 | 22:44:02 |
| 209 | 417 | 168.99 | 15 | 10:44:02 | 418 | 336.43 | 15 | 11:34:20 | 460 | 919 | 336.42 | 32 | 23:34:20 | 920 | 143.86 | 33 | 0:24:38 |
| 210 | 419 | 143.84 | 15 | 12:24:38 | 420 | 311.28 | 15 | 13:14:56 | 461 | 921 | 311.27 | 33 | 1:14:56 | 922 | 118.71 | 33 | 2:05:14 |
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| 212 | 423 | 93.54 | 15 | 15:45:50 | 424 | 260.98 | 15 | 16:36:08 | 463 | 925 | 260.97 | 33 | 4:36:08 | 926 | 68.41 | 33 | 5:26:26 |
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| 217 | 433 | 327.80 | 16 | 0:08:49 | 434 | 135.23 | 16 | 0:59:07 | 468 | 935 | 135.22 | 33 | 12:59:07 | 936 | 302.66 | 33 | 13:49:25 |
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| 233 | 465 | 285.40 | 17 | 2:58:24 | 466 | 92.84 | 17 | 3:48:42 | 484 | 967 | 92.83 | 34 | 15:48:42 | 968 | 260.27 | 34 | 16:39:00 |
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| 236 | 471 | 209.95 | 17 | 8:00:12 | 472 | 17.39 | 17 | 8:50:30 | 487 | 973 | 17.38 | 34 | 20:50:30 | 974 | 184.82 | 34 | 21:40:48 |
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| 238 | 475 | 159.65 | 17 | 11:21:24 | 476 | 327.09 | 17 | 12:11:42 | 489 | 977 | 327.08 | 35 | 0:11:42 | 978 | 134.52 | 35 | 1:02:00 |
| 239 | 477 | 134.50 | 17 | 13:02:00 | 478 | 301.94 | 17 | 13:52:18 | 490 | 979 | 301.93 | 35 | 1:52:18 | 980 | 109.37 | 35 | 2:42:36 |
| 240 | 479 | 109.35 | 17 | 14:42:36 | 480 | 276.79 | 17 | 15:32:54 | 491 | 981 | 276.78 | 35 | 3:32:54 | 982 | 84.22 | 35 | 4:23:12 |
| 241 | 481 | 84.20 | 17 | 16:23:12 | 482 | 251.64 | 17 | 17:13:30 | 492 | 983 | 251.63 | 35 | 5:13:30 | 984 | 59.07 | 35 | 6:03:48 |
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| 248 | 495 | 268.16 | 18 | 4:07:23 | 496 | 75.60 | 18 | 4:57:41 | 499 | 997 | 75.58 | 35 | 16:57:41 | 998 | 243.02 | 35 | 17:47:59 |
| 249 | 497 | 243.01 | 18 | 5:47:59 | 498 | 50.45 | 18 | 6:38:17 | 500 | 999 | 50.43 | 35 | 18:38:17 | 1000 | 217.87 | 35 | 19:28:35 |
| 250 | 499 | 217.86 | 18 | 7:28:35 | 500 | 25.30 | 18 | 8:18:53 | 501 | 1001 | 25.28 | 35 | 20:18:53 | 1002 | 192.72 | 35 | 21:09:11 |
| 251 | 501 | 192.71 | 18 | 9:09:11 | 502 | 0.15 | 18 | 9:59:29 | | | | | | | | | |

**Table A-2 Equator Crossing Longitude and Time (in order of Longitude)**
**(the longitudes are the average values for cycles 10 – 79)**
**(RO = Relative Orbit, P = Pass, D = Day Shift)**

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 1 | 1 | 0.13 | 0 | 21:59:29 | 2 | 167.57 | 0 | 22:49:47 | 366 | 731 | 180.49 | 26 | 9:58:03 | 732 | 347.93 | 26 | 10:48:21 |
| 230 | 459 | 0.85 | 16 | 21:56:37 | 460 | 168.29 | 16 | 22:46:55 | 94 | 187 | 181.21 | 7 | 9:55:10 | 188 | 348.65 | 7 | 10:45:28 |
| 459 | 917 | 1.57 | 32 | 21:53:44 | 918 | 169.01 | 32 | 22:44:02 | 323 | 645 | 181.93 | 23 | 9:52:18 | 646 | 349.37 | 23 | 10:42:36 |
| 187 | 373 | 2.29 | 13 | 21:50:52 | 374 | 169.73 | 13 | 22:41:10 | 51 | 101 | 182.65 | 4 | 9:49:25 | 102 | 350.09 | 4 | 10:39:43 |
| 416 | 831 | 3.01 | 29 | 21:47:59 | 832 | 170.45 | 29 | 22:38:17 | 280 | 559 | 183.37 | 20 | 9:46:33 | 560 | 350.80 | 20 | 10:36:51 |
| 144 | 287 | 3.72 | 10 | 21:45:07 | 288 | 171.16 | 10 | 22:35:25 | 8 | 15 | 184.08 | 1 | 9:43:40 | 16 | 351.52 | 1 | 10:33:58 |
| 373 | 745 | 4.44 | 26 | 21:42:14 | 746 | 171.88 | 26 | 22:32:32 | 237 | 473 | 184.80 | 17 | 9:40:48 | 474 | 352.24 | 17 | 10:31:06 |
| 101 | 201 | 5.16 | 7 | 21:39:22 | 202 | 172.60 | 7 | 22:29:40 | 466 | 931 | 185.52 | 33 | 9:37:56 | 932 | 352.96 | 33 | 10:28:14 |
| 330 | 659 | 5.88 | 23 | 21:36:29 | 660 | 173.32 | 23 | 22:26:47 | 194 | 387 | 186.24 | 14 | 9:35:03 | 388 | 353.68 | 14 | 10:25:21 |
| 58 | 115 | 6.60 | 4 | 21:33:37 | 116 | 174.04 | 4 | 22:23:55 | 423 | 845 | 186.96 | 30 | 9:32:11 | 846 | 354.40 | 30 | 10:22:29 |
| 287 | 573 | 7.32 | 20 | 21:30:44 | 574 | 174.76 | 20 | 22:21:02 | 151 | 301 | 187.68 | 11 | 9:29:18 | 302 | 355.12 | 11 | 10:19:36 |
| 15 | 29 | 8.04 | 1 | 21:27:52 | 30 | 175.47 | 1 | 22:18:10 | 380 | 759 | 188.40 | 27 | 9:26:26 | 760 | 355.83 | 27 | 10:16:44 |
| 244 | 487 | 8.75 | 17 | 21:25:00 | 488 | 176.19 | 17 | 22:15:18 | 108 | 215 | 189.11 | 8 | 9:23:33 | 216 | 356.55 | 8 | 10:13:51 |
| 473 | 945 | 9.47 | 33 | 21:22:07 | 946 | 176.91 | 33 | 22:12:25 | 337 | 673 | 189.83 | 24 | 9:20:41 | 674 | 357.27 | 24 | 10:10:59 |
| 201 | 401 | 10.19 | 14 | 21:19:15 | 402 | 177.63 | 14 | 22:09:33 | 65 | 129 | 190.55 | 5 | 9:17:48 | 130 | 357.99 | 5 | 10:08:06 |
| 430 | 859 | 10.91 | 30 | 21:16:22 | 860 | 178.35 | 30 | 22:06:40 | 294 | 587 | 191.27 | 21 | 9:14:56 | 588 | 358.71 | 21 | 10:05:14 |
| 158 | 315 | 11.63 | 11 | 21:13:30 | 316 | 179.07 | 11 | 22:03:48 | 22 | 43 | 191.99 | 2 | 9:12:03 | 44 | 359.43 | 2 | 10:02:21 |
| 387 | 773 | 12.35 | 27 | 21:10:37 | 774 | 179.79 | 27 | 22:00:55 | 251 | 501 | 192.71 | 18 | 9:09:11 | 502 | 0.15 | 18 | 9:59:29 |
| 115 | 229 | 13.07 | 8 | 21:07:45 | 230 | 180.50 | 8 | 21:58:03 | 480 | 959 | 193.43 | 34 | 9:06:19 | 960 | 0.86 | 34 | 9:56:37 |
| 344 | 687 | 13.78 | 24 | 21:04:52 | 688 | 181.22 | 24 | 21:55:10 | 208 | 415 | 194.14 | 15 | 9:03:26 | 416 | 1.58 | 15 | 9:53:44 |
| 72 | 143 | 14.50 | 5 | 21:02:00 | 144 | 181.94 | 5 | 21:52:18 | 437 | 873 | 194.86 | 31 | 9:00:34 | 874 | 2.30 | 31 | 9:50:52 |
| 301 | 601 | 15.22 | 21 | 20:59:07 | 602 | 182.66 | 21 | 21:49:25 | 165 | 329 | 195.58 | 12 | 8:57:41 | 330 | 3.02 | 12 | 9:47:59 |
| 29 | 57 | 15.94 | 2 | 20:56:15 | 58 | 183.38 | 2 | 21:46:33 | 394 | 787 | 196.30 | 28 | 8:54:49 | 788 | 3.74 | 28 | 9:45:07 |
| 258 | 515 | 16.66 | 18 | 20:53:23 | 516 | 184.10 | 18 | 21:43:40 | 122 | 243 | 197.02 | 9 | 8:51:56 | 244 | 4.46 | 9 | 9:42:14 |
| 487 | 973 | 17.38 | 34 | 20:50:30 | 974 | 184.82 | 34 | 21:40:48 | 351 | 701 | 197.74 | 25 | 8:49:04 | 702 | 5.18 | 25 | 9:39:22 |
| 215 | 429 | 18.09 | 15 | 20:47:38 | 430 | 185.53 | 15 | 21:37:56 | 79 | 157 | 198.46 | 6 | 8:46:11 | 158 | 5.89 | 6 | 9:36:29 |
| 444 | 887 | 18.81 | 31 | 20:44:45 | 888 | 186.25 | 31 | 21:35:03 | 308 | 615 | 199.17 | 22 | 8:43:19 | 616 | 6.61 | 22 | 9:33:37 |
| 172 | 343 | 19.53 | 12 | 20:41:53 | 344 | 186.97 | 12 | 21:32:11 | 36 | 71 | 199.89 | 3 | 8:40:26 | 72 | 7.33 | 3 | 9:30:44 |
| 401 | 801 | 20.25 | 28 | 20:39:00 | 802 | 187.69 | 28 | 21:29:18 | 265 | 529 | 200.61 | 19 | 8:37:34 | 530 | 8.05 | 19 | 9:27:52 |
| 129 | 257 | 20.97 | 9 | 20:36:08 | 258 | 188.41 | 9 | 21:26:26 | 494 | 987 | 201.33 | 35 | 8:34:42 | 988 | 8.77 | 35 | 9:25:00 |
| 358 | 715 | 21.69 | 25 | 20:33:15 | 716 | 189.13 | 25 | 21:23:33 | 222 | 443 | 202.05 | 16 | 8:31:49 | 444 | 9.49 | 16 | 9:22:07 |
| 86 | 171 | 22.41 | 6 | 20:30:23 | 172 | 189.85 | 6 | 21:20:41 | 451 | 901 | 202.77 | 32 | 8:28:57 | 902 | 10.21 | 32 | 9:19:15 |
| 315 | 629 | 23.12 | 22 | 20:27:30 | 630 | 190.56 | 22 | 21:17:48 | 179 | 357 | 203.49 | 13 | 8:26:04 | 358 | 10.92 | 13 | 9:16:22 |
| 43 | 85 | 23.84 | 3 | 20:24:38 | 86 | 191.28 | 3 | 21:14:56 | 408 | 815 | 204.20 | 29 | 8:23:12 | 816 | 11.64 | 29 | 9:13:30 |
| 272 | 543 | 24.56 | 19 | 20:21:46 | 544 | 192.00 | 19 | 21:12:03 | 136 | 271 | 204.92 | 10 | 8:20:19 | 272 | 12.36 | 10 | 9:10:37 |
| 501 | 1001 | 25.28 | 35 | 20:18:53 | 1002 | 192.72 | 35 | 21:09:11 | 365 | 729 | 205.64 | 26 | 8:17:27 | 730 | 13.08 | 26 | 9:07:45 |
| 229 | 457 | 26.00 | 16 | 20:16:01 | 458 | 193.44 | 16 | 21:06:19 | 93 | 185 | 206.36 | 7 | 8:14:34 | 186 | 13.80 | 7 | 9:04:52 |
| 458 | 915 | 26.72 | 32 | 20:13:08 | 916 | 194.16 | 32 | 21:03:26 | 322 | 643 | 207.08 | 23 | 8:11:42 | 644 | 14.52 | 23 | 9:02:00 |
| 186 | 371 | 27.44 | 13 | 20:10:16 | 372 | 194.88 | 13 | 21:00:34 | 50 | 99 | 207.80 | 4 | 8:08:49 | 100 | 15.24 | 4 | 8:59:07 |
| 415 | 829 | 28.15 | 29 | 20:07:23 | 830 | 195.59 | 29 | 20:57:41 | 279 | 557 | 208.52 | 20 | 8:05:57 | 558 | 15.95 | 20 | 8:56:15 |
| 143 | 285 | 28.87 | 10 | 20:04:31 | 286 | 196.31 | 10 | 20:54:49 | 7 | 13 | 209.23 | 1 | 8:03:05 | 14 | 16.67 | 1 | 8:53:23 |
| 372 | 743 | 29.59 | 26 | 20:01:38 | 744 | 197.03 | 26 | 20:51:56 | 236 | 471 | 209.95 | 17 | 8:00:12 | 472 | 17.39 | 17 | 8:50:30 |
| 100 | 199 | 30.31 | 7 | 19:58:46 | 200 | 197.75 | 7 | 20:49:04 | 465 | 929 | 210.67 | 33 | 7:57:20 | 930 | 18.11 | 33 | 8:47:38 |
| 329 | 657 | 31.03 | 23 | 19:55:53 | 658 | 198.47 | 23 | 20:46:11 | 193 | 385 | 211.39 | 14 | 7:54:27 | 386 | 18.83 | 14 | 8:44:45 |
| 57 | 113 | 31.75 | 4 | 19:53:01 | 114 | 199.19 | 4 | 20:43:19 | 422 | 843 | 212.11 | 30 | 7:51:35 | 844 | 19.55 | 30 | 8:41:53 |
| 286 | 571 | 32.47 | 20 | 19:50:09 | 572 | 199.91 | 20 | 20:40:26 | 150 | 299 | 212.83 | 11 | 7:48:42 | 300 | 20.27 | 11 | 8:39:00 |
| 14 | 27 | 33.18 | 1 | 19:47:16 | 28 | 200.62 | 1 | 20:37:34 | 379 | 757 | 213.55 | 27 | 7:45:50 | 758 | 20.98 | 27 | 8:36:08 |
| 243 | 485 | 33.90 | 17 | 19:44:24 | 486 | 201.34 | 17 | 20:34:42 | 107 | 213 | 214.26 | 8 | 7:42:57 | 214 | 21.70 | 8 | 8:33:15 |
| 472 | 943 | 34.62 | 33 | 19:41:31 | 944 | 202.06 | 33 | 20:31:49 | 336 | 671 | 214.98 | 24 | 7:40:05 | 672 | 22.42 | 24 | 8:30:23 |
| 200 | 399 | 35.34 | 14 | 19:38:39 | 400 | 202.78 | 14 | 20:28:57 | 64 | 127 | 215.70 | 5 | 7:37:12 | 128 | 23.14 | 5 | 8:27:30 |
| 429 | 857 | 36.06 | 30 | 19:35:46 | 858 | 203.50 | 30 | 20:26:04 | 293 | 585 | 216.42 | 21 | 7:34:20 | 586 | 23.86 | 21 | 8:24:38 |
| 157 | 313 | 36.78 | 11 | 19:32:54 | 314 | 204.22 | 11 | 20:23:12 | 21 | 41 | 217.14 | 2 | 7:31:28 | 42 | 24.58 | 2 | 8:21:46 |
| 386 | 771 | 37.50 | 27 | 19:30:01 | 772 | 204.94 | 27 | 20:20:19 | 250 | 499 | 217.86 | 18 | 7:28:35 | 500 | 25.30 | 18 | 8:18:53 |
| 114 | 227 | 38.21 | 8 | 19:27:09 | 228 | 205.65 | 8 | 20:17:27 | 479 | 957 | 218.58 | 34 | 7:25:43 | 958 | 26.01 | 34 | 8:16:01 |
| 343 | 685 | 38.93 | 24 | 19:24:16 | 686 | 206.37 | 24 | 20:14:34 | 207 | 413 | 219.29 | 15 | 7:22:50 | 414 | 26.73 | 15 | 8:13:08 |
| 71 | 141 | 39.65 | 5 | 19:21:24 | 142 | 207.09 | 5 | 20:11:42 | 436 | 871 | 220.01 | 31 | 7:19:58 | 872 | 27.45 | 31 | 8:10:16 |
| 300 | 599 | 40.37 | 21 | 19:18:32 | 600 | 207.81 | 21 | 20:08:49 | 164 | 327 | 220.73 | 12 | 7:17:05 | 328 | 28.17 | 12 | 8:07:23 |
| 28 | 55 | 41.09 | 2 | 19:15:39 | 56 | 208.53 | 2 | 20:05:57 | 393 | 785 | 221.45 | 28 | 7:14:13 | 786 | 28.89 | 28 | 8:04:31 |
| 257 | 513 | 41.81 | 18 | 19:12:47 | 514 | 209.25 | 18 | 20:03:05 | 121 | 241 | 222.17 | 9 | 7:11:20 | 242 | 29.61 | 9 | 8:01:38 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 486 | 971 | 42.53 | 34 | 19:09:54 | 972 | 209.97 | 34 | 20:00:12 | 350 | 699 | 222.89 | 25 | 7:08:28 | 700 | 30.33 | 25 | 7:58:46 |
| 214 | 427 | 43.24 | 15 | 19:07:02 | 428 | 210.68 | 15 | 19:57:20 | 78 | 155 | 223.61 | 6 | 7:05:35 | 156 | 31.04 | 6 | 7:55:53 |
| 443 | 885 | 43.96 | 31 | 19:04:09 | 886 | 211.40 | 31 | 19:54:27 | 307 | 613 | 224.32 | 22 | 7:02:43 | 614 | 31.76 | 22 | 7:53:01 |
| 171 | 341 | 44.68 | 12 | 19:01:17 | 342 | 212.12 | 12 | 19:51:35 | 35 | 69 | 225.04 | 3 | 6:59:51 | 70 | 32.48 | 3 | 7:50:09 |
| 400 | 799 | 45.40 | 28 | 18:58:24 | 800 | 212.84 | 28 | 19:48:42 | 264 | 527 | 225.76 | 19 | 6:56:58 | 528 | 33.20 | 19 | 7:47:16 |
| 128 | 255 | 46.12 | 9 | 18:55:32 | 256 | 213.56 | 9 | 19:45:50 | 493 | 985 | 226.48 | 35 | 6:54:06 | 986 | 33.92 | 35 | 7:44:24 |
| 357 | 713 | 46.84 | 25 | 18:52:39 | 714 | 214.28 | 25 | 19:42:57 | 221 | 441 | 227.20 | 16 | 6:51:13 | 442 | 34.64 | 16 | 7:41:31 |
| 85 | 169 | 47.56 | 6 | 18:49:47 | 170 | 215.00 | 6 | 19:40:05 | 450 | 899 | 227.92 | 32 | 6:48:21 | 900 | 35.36 | 32 | 7:38:39 |
| 314 | 627 | 48.27 | 22 | 18:46:55 | 628 | 215.71 | 22 | 19:37:12 | 178 | 355 | 228.64 | 13 | 6:45:28 | 356 | 36.07 | 13 | 7:35:46 |
| 42 | 83 | 48.99 | 3 | 18:44:02 | 84 | 216.43 | 3 | 19:34:20 | 407 | 813 | 229.35 | 29 | 6:42:36 | 814 | 36.79 | 29 | 7:32:54 |
| 271 | 541 | 49.71 | 19 | 18:41:10 | 542 | 217.15 | 19 | 19:31:28 | 135 | 269 | 230.07 | 10 | 6:39:43 | 270 | 37.51 | 10 | 7:30:01 |
| 500 | 999 | 50.43 | 35 | 18:38:17 | 1000 | 217.87 | 35 | 19:28:35 | 364 | 727 | 230.79 | 26 | 6:36:51 | 728 | 38.23 | 26 | 7:27:09 |
| 228 | 455 | 51.15 | 16 | 18:35:25 | 456 | 218.59 | 16 | 19:25:43 | 92 | 183 | 231.51 | 7 | 6:33:58 | 184 | 38.95 | 7 | 7:24:16 |
| 457 | 913 | 51.87 | 32 | 18:32:32 | 914 | 219.31 | 32 | 19:22:50 | 321 | 641 | 232.23 | 23 | 6:31:06 | 642 | 39.67 | 23 | 7:21:24 |
| 185 | 369 | 52.59 | 13 | 18:29:40 | 370 | 220.02 | 13 | 19:19:58 | 49 | 97 | 232.95 | 4 | 6:28:14 | 98 | 40.39 | 4 | 7:18:32 |
| 414 | 827 | 53.30 | 29 | 18:26:47 | 828 | 220.74 | 29 | 19:17:05 | 278 | 555 | 233.67 | 20 | 6:25:21 | 556 | 41.10 | 20 | 7:15:39 |
| 142 | 283 | 54.02 | 10 | 18:23:55 | 284 | 221.46 | 10 | 19:14:13 | 6 | 11 | 234.38 | 1 | 6:22:29 | 12 | 41.82 | 1 | 7:12:47 |
| 371 | 741 | 54.74 | 26 | 18:21:02 | 742 | 222.18 | 26 | 19:11:20 | 235 | 469 | 235.10 | 17 | 6:19:36 | 470 | 42.54 | 17 | 7:09:54 |
| 99 | 197 | 55.46 | 7 | 18:18:10 | 198 | 222.90 | 7 | 19:08:28 | 464 | 927 | 235.82 | 33 | 6:16:44 | 928 | 43.26 | 33 | 7:07:02 |
| 328 | 655 | 56.18 | 23 | 18:15:18 | 656 | 223.62 | 23 | 19:05:35 | 192 | 383 | 236.54 | 14 | 6:13:51 | 384 | 43.98 | 14 | 7:04:09 |
| 56 | 111 | 56.90 | 4 | 18:12:25 | 112 | 224.34 | 4 | 19:02:43 | 421 | 841 | 237.26 | 30 | 6:10:59 | 842 | 44.70 | 30 | 7:01:17 |
| 285 | 569 | 57.62 | 20 | 18:09:33 | 570 | 225.06 | 20 | 18:59:51 | 149 | 297 | 237.98 | 11 | 6:08:06 | 298 | 45.42 | 11 | 6:58:24 |
| 13 | 25 | 58.33 | 1 | 18:06:40 | 26 | 225.77 | 1 | 18:56:58 | 378 | 755 | 238.70 | 27 | 6:05:14 | 756 | 46.13 | 27 | 6:55:32 |
| 242 | 483 | 59.05 | 17 | 18:03:48 | 484 | 226.49 | 17 | 18:54:06 | 106 | 211 | 239.41 | 8 | 6:02:21 | 212 | 46.85 | 8 | 6:52:39 |
| 471 | 941 | 59.77 | 33 | 18:00:55 | 942 | 227.21 | 33 | 18:51:13 | 335 | 669 | 240.13 | 24 | 5:59:29 | 670 | 47.57 | 24 | 6:49:47 |
| 199 | 397 | 60.49 | 14 | 17:58:03 | 398 | 227.93 | 14 | 18:48:21 | 63 | 125 | 240.85 | 5 | 5:56:37 | 126 | 48.29 | 5 | 6:46:55 |
| 428 | 855 | 61.21 | 30 | 17:55:10 | 856 | 228.65 | 30 | 18:45:28 | 292 | 583 | 241.57 | 21 | 5:53:44 | 584 | 49.01 | 21 | 6:44:02 |
| 156 | 311 | 61.93 | 11 | 17:52:18 | 312 | 229.37 | 11 | 18:42:36 | 20 | 39 | 242.29 | 2 | 5:50:52 | 40 | 49.73 | 2 | 6:41:10 |
| 385 | 769 | 62.65 | 27 | 17:49:25 | 770 | 230.09 | 27 | 18:39:43 | 249 | 497 | 243.01 | 18 | 5:47:59 | 498 | 50.45 | 18 | 6:38:17 |
| 113 | 225 | 63.36 | 8 | 17:46:33 | 226 | 230.80 | 8 | 18:36:51 | 478 | 955 | 243.73 | 34 | 5:45:07 | 956 | 51.16 | 34 | 6:35:25 |
| 342 | 683 | 64.08 | 24 | 17:43:40 | 684 | 231.52 | 24 | 18:33:58 | 206 | 411 | 244.44 | 15 | 5:42:14 | 412 | 51.88 | 15 | 6:32:32 |
| 70 | 139 | 64.80 | 5 | 17:40:48 | 140 | 232.24 | 5 | 18:31:06 | 435 | 869 | 245.16 | 31 | 5:39:22 | 870 | 52.60 | 31 | 6:29:40 |
| 299 | 597 | 65.52 | 21 | 17:37:56 | 598 | 232.96 | 21 | 18:28:14 | 163 | 325 | 245.88 | 12 | 5:36:29 | 326 | 53.32 | 12 | 6:26:47 |
| 27 | 53 | 66.24 | 2 | 17:35:03 | 54 | 233.68 | 2 | 18:25:21 | 392 | 783 | 246.60 | 28 | 5:33:37 | 784 | 54.04 | 28 | 6:23:55 |
| 256 | 511 | 66.96 | 18 | 17:32:11 | 512 | 234.40 | 18 | 18:22:29 | 120 | 239 | 247.32 | 9 | 5:30:44 | 240 | 54.76 | 9 | 6:21:02 |
| 485 | 969 | 67.68 | 34 | 17:29:18 | 970 | 235.12 | 34 | 18:19:36 | 349 | 697 | 248.04 | 25 | 5:27:52 | 698 | 55.48 | 25 | 6:18:10 |
| 213 | 425 | 68.39 | 15 | 17:26:26 | 426 | 235.83 | 15 | 18:16:44 | 77 | 153 | 248.76 | 6 | 5:25:00 | 154 | 56.19 | 6 | 6:15:18 |
| 442 | 883 | 69.11 | 31 | 17:23:33 | 884 | 236.55 | 31 | 18:13:51 | 306 | 611 | 249.47 | 22 | 5:22:07 | 612 | 56.91 | 22 | 6:12:25 |
| 170 | 339 | 69.83 | 12 | 17:20:41 | 340 | 237.27 | 12 | 18:10:59 | 34 | 67 | 250.19 | 3 | 5:19:15 | 68 | 57.63 | 3 | 6:09:33 |
| 399 | 797 | 70.55 | 28 | 17:17:48 | 798 | 237.99 | 28 | 18:08:06 | 263 | 525 | 250.91 | 19 | 5:16:22 | 526 | 58.35 | 19 | 6:06:40 |
| 127 | 253 | 71.27 | 9 | 17:14:56 | 254 | 238.71 | 9 | 18:05:14 | 492 | 983 | 251.63 | 35 | 5:13:30 | 984 | 59.07 | 35 | 6:03:48 |
| 356 | 711 | 71.99 | 25 | 17:12:03 | 712 | 239.43 | 25 | 18:02:21 | 220 | 439 | 252.35 | 16 | 5:10:37 | 440 | 59.79 | 16 | 6:00:55 |
| 84 | 167 | 72.71 | 6 | 17:09:11 | 168 | 240.15 | 6 | 17:59:29 | 449 | 897 | 253.07 | 32 | 5:07:45 | 898 | 60.51 | 32 | 5:58:03 |
| 313 | 625 | 73.42 | 22 | 17:06:19 | 626 | 240.86 | 22 | 17:56:37 | 177 | 353 | 253.79 | 13 | 5:04:52 | 354 | 61.22 | 13 | 5:55:10 |
| 41 | 81 | 74.14 | 3 | 17:03:26 | 82 | 241.58 | 3 | 17:53:44 | 406 | 811 | 254.50 | 29 | 5:02:00 | 812 | 61.94 | 29 | 5:52:18 |
| 270 | 539 | 74.86 | 19 | 17:00:34 | 540 | 242.30 | 19 | 17:50:52 | 134 | 267 | 255.22 | 10 | 4:59:07 | 268 | 62.66 | 10 | 5:49:25 |
| 499 | 997 | 75.58 | 35 | 16:57:41 | 998 | 243.02 | 35 | 17:47:59 | 363 | 725 | 255.94 | 26 | 4:56:15 | 726 | 63.38 | 26 | 5:46:33 |
| 227 | 453 | 76.30 | 16 | 16:54:49 | 454 | 243.74 | 16 | 17:45:07 | 91 | 181 | 256.66 | 7 | 4:53:23 | 182 | 64.10 | 7 | 5:43:40 |
| 456 | 911 | 77.02 | 32 | 16:51:56 | 912 | 244.46 | 32 | 17:42:14 | 320 | 639 | 257.38 | 23 | 4:50:30 | 640 | 64.82 | 23 | 5:40:48 |
| 184 | 367 | 77.74 | 13 | 16:49:04 | 368 | 245.17 | 13 | 17:39:22 | 48 | 95 | 258.10 | 4 | 4:47:38 | 96 | 65.54 | 4 | 5:37:56 |
| 413 | 825 | 78.45 | 29 | 16:46:11 | 826 | 245.89 | 29 | 17:36:29 | 277 | 553 | 258.82 | 20 | 4:44:45 | 554 | 66.25 | 20 | 5:35:03 |
| 141 | 281 | 79.17 | 10 | 16:43:19 | 282 | 246.61 | 10 | 17:33:37 | 5 | 9 | 259.53 | 1 | 4:41:53 | 10 | 66.97 | 1 | 5:32:11 |
| 370 | 739 | 79.89 | 26 | 16:40:26 | 740 | 247.33 | 26 | 17:30:44 | 234 | 467 | 260.25 | 17 | 4:39:00 | 468 | 67.69 | 17 | 5:29:18 |
| 98 | 195 | 80.61 | 7 | 16:37:34 | 196 | 248.05 | 7 | 17:27:52 | 463 | 925 | 260.97 | 33 | 4:36:08 | 926 | 68.41 | 33 | 5:26:26 |
| 327 | 653 | 81.33 | 23 | 16:34:42 | 654 | 248.77 | 23 | 17:25:00 | 191 | 381 | 261.69 | 14 | 4:33:15 | 382 | 69.13 | 14 | 5:23:33 |
| 55 | 109 | 82.05 | 4 | 16:31:49 | 110 | 249.49 | 4 | 17:22:07 | 420 | 839 | 262.41 | 30 | 4:30:23 | 840 | 69.85 | 30 | 5:20:41 |
| 284 | 567 | 82.77 | 20 | 16:28:57 | 568 | 250.21 | 20 | 17:19:15 | 148 | 295 | 263.13 | 11 | 4:27:30 | 296 | 70.57 | 11 | 5:17:48 |
| 12 | 23 | 83.48 | 1 | 16:26:04 | 24 | 250.92 | 1 | 17:16:22 | 377 | 753 | 263.85 | 27 | 4:24:38 | 754 | 71.28 | 27 | 5:14:56 |
| 241 | 481 | 84.20 | 17 | 16:23:12 | 482 | 251.64 | 17 | 17:13:30 | 105 | 209 | 264.56 | 8 | 4:21:46 | 210 | 72.00 | 8 | 5:12:03 |
| 470 | 939 | 84.92 | 33 | 16:20:19 | 940 | 252.36 | 33 | 17:10:37 | 334 | 667 | 265.28 | 24 | 4:18:53 | 668 | 72.72 | 24 | 5:09:11 |
| 198 | 395 | 85.64 | 14 | 16:17:27 | 396 | 253.08 | 14 | 17:07:45 | 62 | 123 | 266.00 | 5 | 4:16:01 | 124 | 73.44 | 5 | 5:06:19 |
| 427 | 853 | 86.36 | 30 | 16:14:34 | 854 | 253.80 | 30 | 17:04:52 | 291 | 581 | 266.72 | 21 | 4:13:08 | 582 | 74.16 | 21 | 5:03:26 |
| 155 | 309 | 87.08 | 11 | 16:11:42 | 310 | 254.52 | 11 | 17:02:00 | 19 | 37 | 267.44 | 2 | 4:10:16 | 38 | 74.88 | 2 | 5:00:34 |
| 384 | 767 | 87.80 | 27 | 16:08:49 | 768 | 255.24 | 27 | 16:59:07 | 248 | 495 | 268.16 | 18 | 4:07:23 | 496 | 75.60 | 18 | 4:57:41 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 112 | 223 | 88.51 | 8 | 16:05:57 | 224 | 255.95 | 8 | 16:56:15 | 477 | 953 | 268.87 | 34 | 4:04:31 | 954 | 76.31 | 34 | 4:54:49 |
| 341 | 681 | 89.23 | 24 | 16:03:05 | 682 | 256.67 | 24 | 16:53:23 | 205 | 409 | 269.59 | 15 | 4:01:38 | 410 | 77.03 | 15 | 4:51:56 |
| 69 | 137 | 89.95 | 5 | 16:00:12 | 138 | 257.39 | 5 | 16:50:30 | 434 | 867 | 270.31 | 31 | 3:58:46 | 868 | 77.75 | 31 | 4:49:04 |
| 298 | 595 | 90.67 | 21 | 15:57:20 | 596 | 258.11 | 21 | 16:47:38 | 162 | 323 | 271.03 | 12 | 3:55:53 | 324 | 78.47 | 12 | 4:46:11 |
| 26 | 51 | 91.39 | 2 | 15:54:27 | 52 | 258.83 | 2 | 16:44:45 | 391 | 781 | 271.75 | 28 | 3:53:01 | 782 | 79.19 | 28 | 4:43:19 |
| 255 | 509 | 92.11 | 18 | 15:51:35 | 510 | 259.55 | 18 | 16:41:53 | 119 | 237 | 272.47 | 9 | 3:50:09 | 238 | 79.91 | 9 | 4:40:26 |
| 484 | 967 | 92.83 | 34 | 15:48:42 | 968 | 260.27 | 34 | 16:39:00 | 348 | 695 | 273.19 | 25 | 3:47:16 | 696 | 80.63 | 25 | 4:37:34 |
| 212 | 423 | 93.54 | 15 | 15:45:50 | 424 | 260.98 | 15 | 16:36:08 | 76 | 151 | 273.90 | 6 | 3:44:24 | 152 | 81.34 | 6 | 4:34:42 |
| 441 | 881 | 94.26 | 31 | 15:42:57 | 882 | 261.70 | 31 | 16:33:15 | 305 | 609 | 274.62 | 22 | 3:41:31 | 610 | 82.06 | 22 | 4:31:49 |
| 169 | 337 | 94.98 | 12 | 15:40:05 | 338 | 262.42 | 12 | 16:30:23 | 33 | 65 | 275.34 | 3 | 3:38:39 | 66 | 82.78 | 3 | 4:28:57 |
| 398 | 795 | 95.70 | 28 | 15:37:12 | 796 | 263.14 | 28 | 16:27:30 | 262 | 523 | 276.06 | 19 | 3:35:46 | 524 | 83.50 | 19 | 4:26:04 |
| 126 | 251 | 96.42 | 9 | 15:34:20 | 252 | 263.86 | 9 | 16:24:38 | 491 | 981 | 276.78 | 35 | 3:32:54 | 982 | 84.22 | 35 | 4:23:12 |
| 355 | 709 | 97.14 | 25 | 15:31:28 | 710 | 264.58 | 25 | 16:21:46 | 219 | 437 | 277.50 | 16 | 3:30:01 | 438 | 84.94 | 16 | 4:20:19 |
| 83 | 165 | 97.86 | 6 | 15:28:35 | 166 | 265.30 | 6 | 16:18:53 | 448 | 895 | 278.22 | 32 | 3:27:09 | 896 | 85.66 | 32 | 4:17:27 |
| 312 | 623 | 98.57 | 22 | 15:25:43 | 624 | 266.01 | 22 | 16:16:01 | 176 | 351 | 278.93 | 13 | 3:24:16 | 352 | 86.37 | 13 | 4:14:34 |
| 40 | 79 | 99.29 | 3 | 15:22:50 | 80 | 266.73 | 3 | 16:13:08 | 405 | 809 | 279.65 | 29 | 3:21:24 | 810 | 87.09 | 29 | 4:11:42 |
| 269 | 537 | 100.01 | 19 | 15:19:58 | 538 | 267.45 | 19 | 16:10:16 | 133 | 265 | 280.37 | 10 | 3:18:32 | 266 | 87.81 | 10 | 4:08:49 |
| 498 | 995 | 100.73 | 35 | 15:17:05 | 996 | 268.17 | 35 | 16:07:23 | 362 | 723 | 281.09 | 26 | 3:15:39 | 724 | 88.53 | 26 | 4:05:57 |
| 226 | 451 | 101.45 | 16 | 15:14:13 | 452 | 268.89 | 16 | 16:04:31 | 90 | 179 | 281.81 | 7 | 3:12:47 | 180 | 89.25 | 7 | 4:03:05 |
| 455 | 909 | 102.17 | 32 | 15:11:20 | 910 | 269.61 | 32 | 16:01:38 | 319 | 637 | 282.53 | 23 | 3:09:54 | 638 | 89.97 | 23 | 4:00:12 |
| 183 | 365 | 102.89 | 13 | 15:08:28 | 366 | 270.33 | 13 | 15:58:46 | 47 | 93 | 283.25 | 4 | 3:07:02 | 94 | 90.69 | 4 | 3:57:20 |
| 412 | 823 | 103.60 | 29 | 15:05:35 | 824 | 271.04 | 29 | 15:55:53 | 276 | 551 | 283.96 | 20 | 3:04:09 | 552 | 91.40 | 20 | 3:54:27 |
| 140 | 279 | 104.32 | 10 | 15:02:43 | 280 | 271.76 | 10 | 15:53:01 | 4 | 7 | 284.68 | 1 | 3:01:17 | 8 | 92.12 | 1 | 3:51:35 |
| 369 | 737 | 105.04 | 26 | 14:59:51 | 738 | 272.48 | 26 | 15:50:09 | 233 | 465 | 285.40 | 17 | 2:58:24 | 466 | 92.84 | 17 | 3:48:42 |
| 97 | 193 | 105.76 | 7 | 14:56:58 | 194 | 273.20 | 7 | 15:47:16 | 462 | 923 | 286.12 | 33 | 2:55:32 | 924 | 93.56 | 33 | 3:45:50 |
| 326 | 651 | 106.48 | 23 | 14:54:06 | 652 | 273.92 | 23 | 15:44:24 | 190 | 379 | 286.84 | 14 | 2:52:39 | 380 | 94.28 | 14 | 3:42:57 |
| 54 | 107 | 107.20 | 4 | 14:51:13 | 108 | 274.64 | 4 | 15:41:31 | 419 | 837 | 287.56 | 30 | 2:49:47 | 838 | 95.00 | 30 | 3:40:05 |
| 283 | 565 | 107.92 | 20 | 14:48:21 | 566 | 275.36 | 20 | 15:38:39 | 147 | 293 | 288.28 | 11 | 2:46:55 | 294 | 95.72 | 11 | 3:37:12 |
| 11 | 21 | 108.63 | 1 | 14:45:28 | 22 | 276.07 | 1 | 15:35:46 | 376 | 751 | 288.99 | 27 | 2:44:02 | 752 | 96.43 | 27 | 3:34:20 |
| 240 | 479 | 109.35 | 17 | 14:42:36 | 480 | 276.79 | 17 | 15:32:54 | 104 | 207 | 289.71 | 8 | 2:41:10 | 208 | 97.15 | 8 | 3:31:28 |
| 469 | 937 | 110.07 | 33 | 14:39:43 | 938 | 277.51 | 33 | 15:30:01 | 333 | 665 | 290.43 | 24 | 2:38:17 | 666 | 97.87 | 24 | 3:28:35 |
| 197 | 393 | 110.79 | 14 | 14:36:51 | 394 | 278.23 | 14 | 15:27:09 | 61 | 121 | 291.15 | 5 | 2:35:25 | 122 | 98.59 | 5 | 3:25:43 |
| 426 | 851 | 111.51 | 30 | 14:33:58 | 852 | 278.95 | 30 | 15:24:16 | 290 | 579 | 291.87 | 21 | 2:32:32 | 580 | 99.31 | 21 | 3:22:50 |
| 154 | 307 | 112.23 | 11 | 14:31:06 | 308 | 279.67 | 11 | 15:21:24 | 18 | 35 | 292.59 | 2 | 2:29:40 | 36 | 100.03 | 2 | 3:19:58 |
| 383 | 765 | 112.95 | 27 | 14:28:14 | 766 | 280.39 | 27 | 15:18:32 | 247 | 493 | 293.31 | 18 | 2:26:47 | 494 | 100.75 | 18 | 3:17:05 |
| 111 | 221 | 113.66 | 8 | 14:25:21 | 222 | 281.10 | 8 | 15:15:39 | 476 | 951 | 294.02 | 34 | 2:23:55 | 952 | 101.46 | 34 | 3:14:13 |
| 340 | 679 | 114.38 | 24 | 14:22:29 | 680 | 281.82 | 24 | 15:12:47 | 204 | 407 | 294.74 | 15 | 2:21:02 | 408 | 102.18 | 15 | 3:11:20 |
| 68 | 135 | 115.10 | 5 | 14:19:36 | 136 | 282.54 | 5 | 15:09:54 | 433 | 865 | 295.46 | 31 | 2:18:10 | 866 | 102.90 | 31 | 3:08:28 |
| 297 | 593 | 115.82 | 21 | 14:16:44 | 594 | 283.26 | 21 | 15:07:02 | 161 | 321 | 296.18 | 12 | 2:15:18 | 322 | 103.62 | 12 | 3:05:35 |
| 25 | 49 | 116.54 | 2 | 14:13:51 | 50 | 283.98 | 2 | 15:04:09 | 390 | 779 | 296.90 | 28 | 2:12:25 | 780 | 104.34 | 28 | 3:02:43 |
| 254 | 507 | 117.26 | 18 | 14:10:59 | 508 | 284.70 | 18 | 15:01:17 | 118 | 235 | 297.62 | 9 | 2:09:33 | 236 | 105.06 | 9 | 2:59:51 |
| 483 | 965 | 117.98 | 34 | 14:08:06 | 966 | 285.42 | 34 | 14:58:24 | 347 | 693 | 298.34 | 25 | 2:06:40 | 694 | 105.77 | 25 | 2:56:58 |
| 211 | 421 | 118.70 | 15 | 14:05:14 | 422 | 286.13 | 15 | 14:55:32 | 75 | 149 | 299.05 | 6 | 2:03:48 | 150 | 106.49 | 6 | 2:54:06 |
| 440 | 879 | 119.41 | 31 | 14:02:21 | 880 | 286.85 | 31 | 14:52:39 | 304 | 607 | 299.77 | 22 | 2:00:55 | 608 | 107.21 | 22 | 2:51:13 |
| 168 | 335 | 120.13 | 12 | 13:59:29 | 336 | 287.57 | 12 | 14:49:47 | 32 | 63 | 300.49 | 3 | 1:58:03 | 64 | 107.93 | 3 | 2:48:21 |
| 397 | 793 | 120.85 | 28 | 13:56:37 | 794 | 288.29 | 28 | 14:46:55 | 261 | 521 | 301.21 | 19 | 1:55:10 | 522 | 108.65 | 19 | 2:45:28 |
| 125 | 249 | 121.57 | 9 | 13:53:44 | 250 | 289.01 | 9 | 14:44:02 | 490 | 979 | 301.93 | 35 | 1:52:18 | 980 | 109.37 | 35 | 2:42:36 |
| 354 | 707 | 122.29 | 25 | 13:50:52 | 708 | 289.73 | 25 | 14:41:10 | 218 | 435 | 302.65 | 16 | 1:49:25 | 436 | 110.09 | 16 | 2:39:43 |
| 82 | 163 | 123.01 | 6 | 13:47:59 | 164 | 290.45 | 6 | 14:38:17 | 447 | 893 | 303.37 | 32 | 1:46:33 | 894 | 110.80 | 32 | 2:36:51 |
| 311 | 621 | 123.72 | 22 | 13:45:07 | 622 | 291.16 | 22 | 14:35:25 | 175 | 349 | 304.08 | 13 | 1:43:40 | 350 | 111.52 | 13 | 2:33:58 |
| 39 | 77 | 124.44 | 3 | 13:42:14 | 78 | 291.88 | 3 | 14:32:32 | 404 | 807 | 304.80 | 29 | 1:40:48 | 808 | 112.24 | 29 | 2:31:06 |
| 268 | 535 | 125.16 | 19 | 13:39:22 | 536 | 292.60 | 19 | 14:29:40 | 132 | 263 | 305.52 | 10 | 1:37:56 | 264 | 112.96 | 10 | 2:28:14 |
| 497 | 993 | 125.88 | 35 | 13:36:29 | 994 | 293.32 | 35 | 14:26:47 | 361 | 721 | 306.24 | 26 | 1:35:03 | 722 | 113.68 | 26 | 2:25:21 |
| 225 | 449 | 126.60 | 16 | 13:33:37 | 450 | 294.04 | 16 | 14:23:55 | 89 | 177 | 306.96 | 7 | 1:32:11 | 178 | 114.40 | 7 | 2:22:29 |
| 454 | 907 | 127.32 | 32 | 13:30:44 | 908 | 294.76 | 32 | 14:21:02 | 318 | 635 | 307.68 | 23 | 1:29:18 | 636 | 115.12 | 23 | 2:19:36 |
| 182 | 363 | 128.04 | 13 | 13:27:52 | 364 | 295.48 | 13 | 14:18:10 | 46 | 91 | 308.40 | 4 | 1:26:26 | 92 | 115.83 | 4 | 2:16:44 |
| 411 | 821 | 128.75 | 29 | 13:25:00 | 822 | 296.19 | 29 | 14:15:18 | 275 | 549 | 309.11 | 20 | 1:23:33 | 550 | 116.55 | 20 | 2:13:51 |
| 139 | 277 | 129.47 | 10 | 13:22:07 | 278 | 296.91 | 10 | 14:12:25 | 3 | 5 | 309.83 | 1 | 1:20:41 | 6 | 117.27 | 1 | 2:10:59 |
| 368 | 735 | 130.19 | 26 | 13:19:15 | 736 | 297.63 | 26 | 14:09:33 | 232 | 463 | 310.55 | 17 | 1:17:48 | 464 | 117.99 | 17 | 2:08:06 |
| 96 | 191 | 130.91 | 7 | 13:16:22 | 192 | 298.35 | 7 | 14:06:40 | 461 | 921 | 311.27 | 33 | 1:14:56 | 922 | 118.71 | 33 | 2:05:14 |
| 325 | 649 | 131.63 | 23 | 13:13:30 | 650 | 299.07 | 23 | 14:03:48 | 189 | 377 | 311.99 | 14 | 1:12:03 | 378 | 119.43 | 14 | 2:02:21 |
| 53 | 105 | 132.35 | 4 | 13:10:37 | 106 | 299.79 | 4 | 14:00:55 | 418 | 835 | 312.71 | 30 | 1:09:11 | 836 | 120.15 | 30 | 1:59:29 |
| 282 | 563 | 133.07 | 20 | 13:07:45 | 564 | 300.51 | 20 | 13:58:03 | 146 | 291 | 313.43 | 11 | 1:06:19 | 292 | 120.86 | 11 | 1:56:37 |
| 10 | 19 | 133.78 | 1 | 13:04:52 | 20 | 301.22 | 1 | 13:55:10 | 375 | 749 | 314.14 | 27 | 1:03:26 | 750 | 121.58 | 27 | 1:53:44 |

| RO | Ascending Passes | | | | Descending Passes | | | | RO | Ascending Passes | | | | Descending Passes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | Long. | D | UTC | P | Long. | D | UTC | | P | Long. | D | UTC | P | Long. | D | UTC |
| 239 | 477 | 134.50 | 17 | 13:02:00 | 478 | 301.94 | 17 | 13:52:18 | 103 | 205 | 314.86 | 8 | 1:00:34 | 206 | 122.30 | 8 | 1:50:52 |
| 468 | 935 | 135.22 | 33 | 12:59:07 | 936 | 302.66 | 33 | 13:49:25 | 332 | 663 | 315.58 | 24 | 0:57:41 | 664 | 123.02 | 24 | 1:47:59 |
| 196 | 391 | 135.94 | 14 | 12:56:15 | 392 | 303.38 | 14 | 13:46:33 | 60 | 119 | 316.30 | 5 | 0:54:49 | 120 | 123.74 | 5 | 1:45:07 |
| 425 | 849 | 136.66 | 30 | 12:53:23 | 850 | 304.10 | 30 | 13:43:40 | 289 | 577 | 317.02 | 21 | 0:51:56 | 578 | 124.46 | 21 | 1:42:14 |
| 153 | 305 | 137.38 | 11 | 12:50:30 | 306 | 304.82 | 11 | 13:40:48 | 17 | 33 | 317.74 | 2 | 0:49:04 | 34 | 125.17 | 2 | 1:39:22 |
| 382 | 763 | 138.10 | 27 | 12:47:38 | 764 | 305.54 | 27 | 13:37:56 | 246 | 491 | 318.46 | 18 | 0:46:11 | 492 | 125.89 | 18 | 1:36:29 |
| 110 | 219 | 138.81 | 8 | 12:44:45 | 220 | 306.25 | 8 | 13:35:03 | 475 | 949 | 319.17 | 34 | 0:43:19 | 950 | 126.61 | 34 | 1:33:37 |
| 339 | 677 | 139.53 | 24 | 12:41:53 | 678 | 306.97 | 24 | 13:32:11 | 203 | 405 | 319.89 | 15 | 0:40:26 | 406 | 127.33 | 15 | 1:30:44 |
| 67 | 133 | 140.25 | 5 | 12:39:00 | 134 | 307.69 | 5 | 13:29:18 | 432 | 863 | 320.61 | 31 | 0:37:34 | 864 | 128.05 | 31 | 1:27:52 |
| 296 | 591 | 140.97 | 21 | 12:36:08 | 592 | 308.41 | 21 | 13:26:26 | 160 | 319 | 321.33 | 12 | 0:34:42 | 320 | 128.77 | 12 | 1:25:00 |
| 24 | 47 | 141.69 | 2 | 12:33:15 | 48 | 309.13 | 2 | 13:23:33 | 389 | 777 | 322.05 | 28 | 0:31:49 | 778 | 129.49 | 28 | 1:22:07 |
| 253 | 505 | 142.41 | 18 | 12:30:23 | 506 | 309.85 | 18 | 13:20:41 | 117 | 233 | 322.77 | 9 | 0:28:57 | 234 | 130.21 | 9 | 1:19:15 |
| 482 | 963 | 143.13 | 34 | 12:27:30 | 964 | 310.57 | 34 | 13:17:48 | 346 | 691 | 323.49 | 25 | 0:26:04 | 692 | 130.92 | 25 | 1:16:22 |
| 210 | 419 | 143.84 | 15 | 12:24:38 | 420 | 311.28 | 15 | 13:14:56 | 74 | 147 | 324.20 | 6 | 0:23:12 | 148 | 131.64 | 6 | 1:13:30 |
| 439 | 877 | 144.56 | 31 | 12:21:46 | 878 | 312.00 | 31 | 13:12:03 | 303 | 605 | 324.92 | 22 | 0:20:19 | 606 | 132.36 | 22 | 1:10:37 |
| 167 | 333 | 145.28 | 12 | 12:18:53 | 334 | 312.72 | 12 | 13:09:11 | 31 | 61 | 325.64 | 3 | 0:17:27 | 62 | 133.08 | 3 | 1:07:45 |
| 396 | 791 | 146.00 | 28 | 12:16:01 | 792 | 313.44 | 28 | 13:06:19 | 260 | 519 | 326.36 | 19 | 0:14:34 | 520 | 133.80 | 19 | 1:04:52 |
| 124 | 247 | 146.72 | 9 | 12:13:08 | 248 | 314.16 | 9 | 13:03:26 | 489 | 977 | 327.08 | 35 | 0:11:42 | 978 | 134.52 | 35 | 1:02:00 |
| 353 | 705 | 147.44 | 25 | 12:10:16 | 706 | 314.88 | 25 | 13:00:34 | 217 | 433 | 327.80 | 16 | 0:08:49 | 434 | 135.23 | 16 | 0:59:07 |
| 81 | 161 | 148.16 | 6 | 12:07:23 | 162 | 315.60 | 6 | 12:57:41 | 446 | 891 | 328.52 | 32 | 0:05:57 | 892 | 135.95 | 32 | 0:56:15 |
| 310 | 619 | 148.87 | 22 | 12:04:31 | 620 | 316.31 | 22 | 12:54:49 | 174 | 347 | 329.23 | 13 | 0:03:05 | 348 | 136.67 | 13 | 0:53:23 |
| 38 | 75 | 149.59 | 3 | 12:01:38 | 76 | 317.03 | 3 | 12:51:56 | 403 | 805 | 329.95 | 29 | 0:00:12 | 806 | 137.39 | 29 | 0:50:30 |
| 267 | 533 | 150.31 | 19 | 11:58:46 | 534 | 317.75 | 19 | 12:49:04 | 131 | 261 | 330.67 | 9 | 23:57:20 | 262 | 138.11 | 10 | 0:47:38 |
| 496 | 991 | 151.03 | 35 | 11:55:53 | 992 | 318.47 | 35 | 12:46:11 | 360 | 719 | 331.39 | 25 | 23:54:27 | 720 | 138.83 | 26 | 0:44:45 |
| 224 | 447 | 151.75 | 16 | 11:53:01 | 448 | 319.19 | 16 | 12:43:19 | 88 | 175 | 332.11 | 6 | 23:51:35 | 176 | 139.55 | 7 | 0:41:53 |
| 453 | 905 | 152.47 | 32 | 11:50:09 | 906 | 319.91 | 32 | 12:40:26 | 317 | 633 | 332.83 | 22 | 23:48:42 | 634 | 140.27 | 23 | 0:39:00 |
| 181 | 361 | 153.19 | 13 | 11:47:16 | 362 | 320.62 | 13 | 12:37:34 | 45 | 89 | 333.55 | 3 | 23:45:50 | 90 | 140.98 | 4 | 0:36:08 |
| 410 | 819 | 153.90 | 29 | 11:44:24 | 820 | 321.34 | 29 | 12:34:42 | 274 | 547 | 334.26 | 19 | 23:42:57 | 548 | 141.70 | 20 | 0:33:15 |
| 138 | 275 | 154.62 | 10 | 11:41:31 | 276 | 322.06 | 10 | 12:31:49 | 2 | 3 | 334.98 | 0 | 23:40:05 | 4 | 142.42 | 1 | 0:30:23 |
| 367 | 733 | 155.34 | 26 | 11:38:39 | 734 | 322.78 | 26 | 12:28:57 | 231 | 461 | 335.70 | 16 | 23:37:12 | 462 | 143.14 | 17 | 0:27:30 |
| 95 | 189 | 156.06 | 7 | 11:35:46 | 190 | 323.50 | 7 | 12:26:04 | 460 | 919 | 336.42 | 32 | 23:34:20 | 920 | 143.86 | 33 | 0:24:38 |
| 324 | 647 | 156.78 | 23 | 11:32:54 | 648 | 324.22 | 23 | 12:23:12 | 188 | 375 | 337.14 | 13 | 23:31:28 | 376 | 144.58 | 14 | 0:21:46 |
| 52 | 103 | 157.50 | 4 | 11:30:01 | 104 | 324.94 | 4 | 12:20:19 | 417 | 833 | 337.86 | 29 | 23:28:35 | 834 | 145.30 | 30 | 0:18:53 |
| 281 | 561 | 158.22 | 20 | 11:27:09 | 562 | 325.66 | 20 | 12:17:27 | 145 | 289 | 338.58 | 10 | 23:25:43 | 290 | 146.01 | 11 | 0:16:01 |
| 9 | 17 | 158.93 | 1 | 11:24:16 | 18 | 326.37 | 1 | 12:14:34 | 374 | 747 | 339.29 | 26 | 23:22:50 | 748 | 146.73 | 27 | 0:13:08 |
| 238 | 475 | 159.65 | 17 | 11:21:24 | 476 | 327.09 | 17 | 12:11:42 | 102 | 203 | 340.01 | 7 | 23:19:58 | 204 | 147.45 | 8 | 0:10:16 |
| 467 | 933 | 160.37 | 33 | 11:18:32 | 934 | 327.81 | 33 | 12:08:49 | 331 | 661 | 340.73 | 23 | 23:17:05 | 662 | 148.17 | 24 | 0:07:23 |
| 195 | 389 | 161.09 | 14 | 11:15:39 | 390 | 328.53 | 14 | 12:05:57 | 59 | 117 | 341.45 | 4 | 23:14:13 | 118 | 148.89 | 5 | 0:04:31 |
| 424 | 847 | 161.81 | 30 | 11:12:47 | 848 | 329.25 | 30 | 12:03:05 | 288 | 575 | 342.17 | 20 | 23:11:20 | 576 | 149.61 | 21 | 0:01:38 |
| 152 | 303 | 162.53 | 11 | 11:09:54 | 304 | 329.97 | 11 | 12:00:12 | 16 | 31 | 342.89 | 1 | 23:08:28 | 32 | 150.32 | 1 | 23:58:46 |
| 381 | 761 | 163.25 | 27 | 11:07:02 | 762 | 330.69 | 27 | 11:57:20 | 245 | 489 | 343.61 | 17 | 23:05:35 | 490 | 151.04 | 17 | 23:55:53 |
| 109 | 217 | 163.96 | 8 | 11:04:09 | 218 | 331.40 | 8 | 11:54:27 | 474 | 947 | 344.32 | 33 | 23:02:43 | 948 | 151.76 | 33 | 23:53:01 |
| 338 | 675 | 164.68 | 24 | 11:01:17 | 676 | 332.12 | 24 | 11:51:35 | 202 | 403 | 345.04 | 14 | 22:59:51 | 404 | 152.48 | 14 | 23:50:09 |
| 66 | 131 | 165.40 | 5 | 10:58:24 | 132 | 332.84 | 5 | 11:48:42 | 431 | 861 | 345.76 | 30 | 22:56:58 | 862 | 153.20 | 30 | 23:47:16 |
| 295 | 589 | 166.12 | 21 | 10:55:32 | 590 | 333.56 | 21 | 11:45:50 | 159 | 317 | 346.48 | 11 | 22:54:06 | 318 | 153.92 | 11 | 23:44:24 |
| 23 | 45 | 166.84 | 2 | 10:52:39 | 46 | 334.28 | 2 | 11:42:57 | 388 | 775 | 347.20 | 27 | 22:51:13 | 776 | 154.64 | 27 | 23:41:31 |
| 252 | 503 | 167.56 | 18 | 10:49:47 | 504 | 335.00 | 18 | 11:40:05 | 116 | 231 | 347.92 | 8 | 22:48:21 | 232 | 155.36 | 8 | 23:38:39 |
| 481 | 961 | 168.28 | 34 | 10:46:55 | 962 | 335.72 | 34 | 11:37:12 | 345 | 689 | 348.63 | 24 | 22:45:28 | 690 | 156.07 | 24 | 23:35:46 |
| 209 | 417 | 168.99 | 15 | 10:44:02 | 418 | 336.43 | 15 | 11:34:20 | 73 | 145 | 349.35 | 5 | 22:42:36 | 146 | 156.79 | 5 | 23:32:54 |
| 438 | 875 | 169.71 | 31 | 10:41:10 | 876 | 337.15 | 31 | 11:31:28 | 302 | 603 | 350.07 | 21 | 22:39:43 | 604 | 157.51 | 21 | 23:30:01 |
| 166 | 331 | 170.43 | 12 | 10:38:17 | 332 | 337.87 | 12 | 11:28:35 | 30 | 59 | 350.79 | 2 | 22:36:51 | 60 | 158.23 | 2 | 23:27:09 |
| 395 | 789 | 171.15 | 28 | 10:35:25 | 790 | 338.59 | 28 | 11:25:43 | 259 | 517 | 351.51 | 18 | 22:33:58 | 518 | 158.95 | 18 | 23:24:16 |
| 123 | 245 | 171.87 | 9 | 10:32:32 | 246 | 339.31 | 9 | 11:22:50 | 488 | 975 | 352.23 | 34 | 22:31:06 | 976 | 159.67 | 34 | 23:21:24 |
| 352 | 703 | 172.59 | 25 | 10:29:40 | 704 | 340.03 | 25 | 11:19:58 | 216 | 431 | 352.95 | 15 | 22:28:14 | 432 | 160.38 | 15 | 23:18:32 |
| 80 | 159 | 173.31 | 6 | 10:26:47 | 160 | 340.74 | 6 | 11:17:05 | 445 | 889 | 353.66 | 31 | 22:25:21 | 890 | 161.10 | 31 | 23:15:39 |
| 309 | 617 | 174.02 | 22 | 10:23:55 | 618 | 341.46 | 22 | 11:14:13 | 173 | 345 | 354.38 | 12 | 22:22:29 | 346 | 161.82 | 12 | 23:12:47 |
| 37 | 73 | 174.74 | 3 | 10:21:02 | 74 | 342.18 | 3 | 11:11:20 | 402 | 803 | 355.10 | 28 | 22:19:36 | 804 | 162.54 | 28 | 23:09:54 |
| 266 | 531 | 175.46 | 19 | 10:18:10 | 532 | 342.90 | 19 | 11:08:28 | 130 | 259 | 355.82 | 9 | 22:16:44 | 260 | 163.26 | 9 | 23:07:02 |
| 495 | 989 | 176.18 | 35 | 10:15:18 | 990 | 343.62 | 35 | 11:05:35 | 359 | 717 | 356.54 | 25 | 22:13:51 | 718 | 163.98 | 25 | 23:04:09 |
| 223 | 445 | 176.90 | 16 | 10:12:25 | 446 | 344.34 | 16 | 11:02:43 | 87 | 173 | 357.26 | 6 | 22:10:59 | 174 | 164.70 | 6 | 23:01:17 |
| 452 | 903 | 177.62 | 32 | 10:09:33 | 904 | 345.06 | 32 | 10:59:51 | 316 | 631 | 357.98 | 22 | 22:08:06 | 632 | 165.42 | 22 | 22:58:24 |
| 180 | 359 | 178.34 | 13 | 10:06:40 | 360 | 345.77 | 13 | 10:56:58 | 44 | 87 | 358.69 | 3 | 22:05:14 | 88 | 166.13 | 3 | 22:55:32 |
| 409 | 817 | 179.05 | 29 | 10:03:48 | 818 | 346.49 | 29 | 10:54:06 | 273 | 545 | 359.41 | 19 | 22:02:21 | 546 | 166.85 | 19 | 22:52:39 |
| 137 | 273 | 179.77 | 10 | 10:00:55 | 274 | 347.21 | 10 | 10:51:13 | | | | | | | | | |