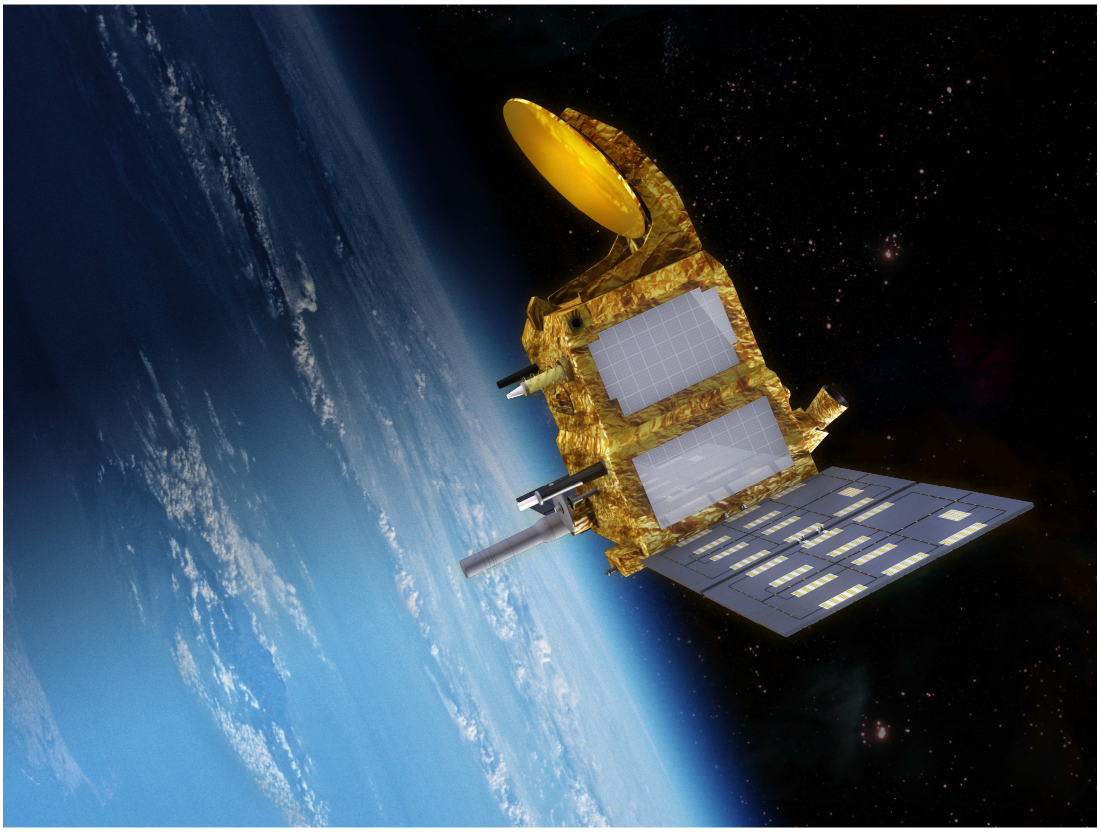
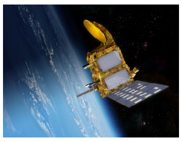


SARAL/AltiKa Products Handbook

References:
CNES : SALP-MU-M-OP-15984-CN
ISRO: TBD

Issue: 3 rev 1

Date: January 26th , 2021



Chronology Issues:

Issue:	Date:	Reason for change:
1rev0	March 9, 2011	Initial Issue
1rev1	November 9, 2011	Taking into account the Change Request SALP-FT-8343: - New tidal model: GOT4.8 - New Mean Sea Surface: MSS_CNES-CLS11 - New Mean Dynamic Topography : MDT_CNES-CLS09 - Trailing edge variation flag used instead of rain flag - Disclaimer about altimeter wind speed, sigma-0 values and ice flag at the beginning of the mission - Introduction of the NetCDF extension (.nc) on all SARAL/AltiKa level 2 products - “alt_echo_type” flag removed
1rev2	December 12, 2011	- Precision of the producing agency in the name of the product, update of global attributes (documentation update only). - Update of GDR-D orbit table. - Modification of the signification of the trailing edge variation flag (SALP-FT-8343rev2).
2rev0	January 7, 2013	- New version of the SARAL/Altika Product handbook before launch (SALP-FT-8775): o Information about OGDR-BUFR files produced at EUMETSAT. o Update of the table “Differences between Auxiliary Data for O/I/GDR Products”. o Update of the error budget table. o Minor text modifications.
2rev1	March 14, 2013	- Disclaimers and precisions for several parameters for the beginning of the mission (SAFLP-FT-8969). Editing criteria revised. - Specific color (green) chosen to highlight warnings and disclaimers. - Launch date and first information (cycle 0/1) completed.
2rev2	June 18, 2013	- New version of the SARAL/Altika Product handbook before public dissemination of O/IGDRs (SALP-FT-9122): o New OGDR directories added for AVISO dissemination. Update of the ftp link to download the SARAL products. o Update of error budget table (SWH specification)
2rev3	July 19, 2013	- First evolutions of SARAL/AltiKa products after launch (SALP-FT-9060) o Modeled instrumental errors corrections for range, sig0 and swh are given by Look-Up-Tables updated with real measurements instead of ground measurements. o Threshold added on MQE to create 1Hz from 40Hz measurements. o Atmospheric attenuation is given by radiometer

Chronology Issues:

Issue:	Date:	Reason for change:
		measurements instead of 0. o Calibrations are averaged over a 7 days window for the low pass filter and 3 days for the internal path delay and total power. o A first linear relation has been computed between the measured brightness temperatures and the simulated one. This linear relation will be applied on the 23.8 GHz only before neural network (retrieval algorithm for wet tropospheric correction). - Document updates: o Update of mass value (405kg) o Utpdate of table 1: Precision about GIM ionospheric correction (predicted for OGDR and restituted for I/GDR). o Modification of verb tense (past instead of future) o Correction of OGDR-BUFR filename o Removal of EUMETSAT document reference o Note on the SARAL orbit (not exactly on ENVISAT repetitive ground track at the beginning of the mission) o Note on rad_liquid_water parameter that is not reliable as an anomaly has been noticed in the neural network.
2rev4	December 9, 2013	- Modification of the ecmwf_meteo_map_avail flag meaning and comment (SALP-FT-8904). - 2nd phase of evolutions after launch (SALP-FT-9207) o New tables implemented for wind speed and sea state bias. Impact on wind_speed_alt and sea_state_bias parameters. o New tide model taken into account (FES2012 instead of FES2004). - AVISO+ new website address.
2rev5	July 1, 2016	SARAL: new AltiKa mission phase, based on a drifting orbit (SALP-FT-10487)
3rev0	February 22nd, 2017	- SARAL/AltiKa products GDR-E (SALP-FT-10163) - FES2014b taken into account in SARAL and ENVISAT products (SALP-FT-10686) THIS PRODUCT HANDBOOK VERSION IS LIMITED TO INTERNAL USE ONLY. IT WILL BE DISSEMINATED TO END-USERS WHEN ALL MODIFICATiONS FOR GDR-F STANDARD WILL BE INCLUDED IN THIS DOCUMENT.
3rev1	January 26th, 2021	- SARAL/AltiKa GDR-F products (SALP-FT-10621, SALP-FT-10788, SALP-FT-11122, SALP-FT-11663)

Written by (*):		Approved :
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List of tables and figures

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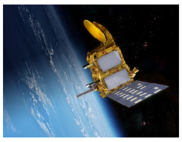

Applicable documents / reference documents

AD 1 : SARAL/AltiKa System Requirements
SRL-SYS-SP-010-CNES

AD 2 : ISRO-CNES AltiKa Joint Science Plan
SRL-SYS-PL-392-CNES

AD 3 : Algorithm Theoretical Baseline Definition: Altimeter Level 1b Processing
SALP-ST-M2-EA-15884-CN

AD 4 : Algorithm Theoretical Baseline Definition: Radiometer Level 1b Processing
SALP-ST-M2-EA-15885-CN

AD 5 : Algorithm Theoretical Baseline Definition: Altimeter Level 2 Processing
SALP-ST-M2-EA-15886-CN

RD 1 : OSTM/Jason-2 Products Handbook
SALP-MU-M-OP-15815-CN

RD 2 : SARAL/AltiKa CalVal Plan
ALK-SY1-PL-198-CNES

RD 3 : SALP Products Specification - Volume 20 : AltiKa / SARAL User Products
SALP-ST-M-EA-15839-CN

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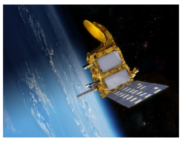


1. Introduction

SARAL/AltiKa is a follow-on mission to ENVISAT ESA's mission and will have the same ground track. The satellite name SARAL stands for SAtellite for ARgos and ALtiKa. This mission continues the series of successful altimetric missions such as TOPEX/Poseidon and Jason missions. While they were conducted under a cooperation between the French Space Agency, "*Centre National d'Etudes Spatiales*" (CNES), the United States National Aeronautics and Space Administration (NASA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the National Oceanic and Atmospheric Administration (NOAA), SARAL/AltiKa is a new collaboration between CNES and ISRO (Indian Space Research Organization).

1.1. Overview of the SARAL/AltiKa product family

The purpose of this document is to assist users of the SARAL/AltiKa products (Operational Geophysical Data Record : OGDR, Interim Geophysical Data Record : IGDR, and Geophysical Data Record : GDR) by providing a comprehensive description of product content and format. We will so refer to (O)(I)GDR in this document when the information is relevant for all the products.

(O)(I)GDR products are identical except for the following differences regarding the auxiliary data used in the processing:

Auxiliary Data	Impacted Parameter	OGDR	IGDR	GDR
Orbit	Satellite altitude, Doppler correction, …	DORIS Navigator	Preliminary (DORIS MOE)	Precise (DORIS+Laser POE)
Meteo Fields	Dry/wet tropospheric corrections, U/V wind vector, Surface pressure, Inverted barometer correction, …	Predicted	Restituted	
	Waves	Not available	MFWAM	
Pole Location	Pole tide height	Predicted		Restituted
Mog2D	HF ocean dealiasing correction	Predicted	Preliminary	Precise
GIM	Ionosphere correction	Predicted	Restituted	
Platform Pointing	Platform pitch, roll, yaw and mispointing angles	Not available		HK Telemetry
SST	sst, wet tropospheric correction	Seasonal ma or static		Restituted

Table 1 : Differences between Auxiliary Data for O/I/GDR Products

GDR products, unlike OGDR and IGDR products, are fully validated products.

1.1.1. Product contents

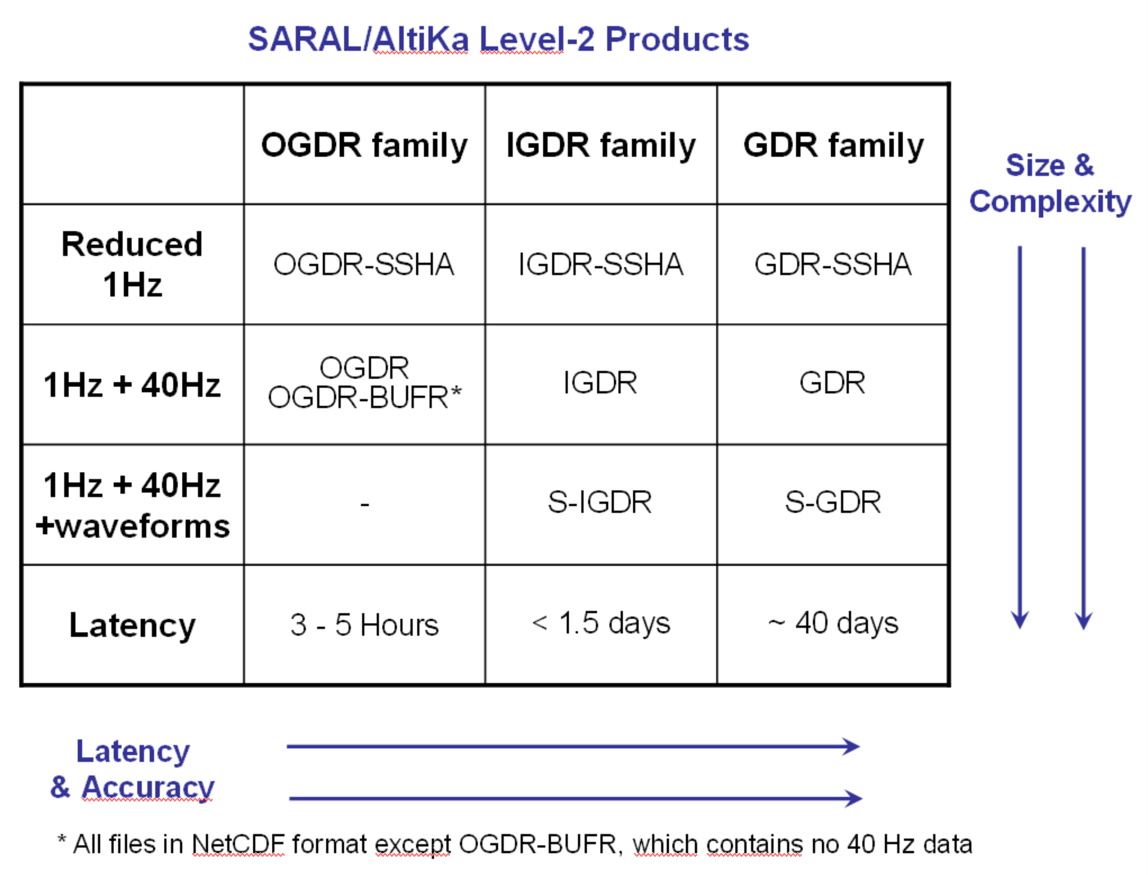
The Level-2 products from this mission comprise a family of nine different types of geophysical data records (GDRs). As illustrated in Table 1 below, there are three families of GDRs, distinguished by increasing latency and accuracy, going from the Operational GDR (OGDR), to the Interim GDR (IGDR), to the final GDR. Within each of these three families there are up to three types of files in NetCDF-4/HDF5 classic model format (one in BUFR Format), with increasing size and complexity:

1. a reduced 1 Hz subset of the full dataset in NetCDF-4 classic model format (O/I/GDR-SSHA);

2. the native NetCDF formatted datasets (O/I/GDRs) which contain 1Hz records as well as 40 Hz high-rate values; the OGDRs given in BUFR format contain only 1Hz records.

3. an expert sensor product containing the full radar-echo waveforms in NetCDF-4 classic model format (S-IGDR/S-GDR, not applicable to the OGDR).

For the OGDR family, a specific product in BUFR format containing exclusively 1 Hz data is available, designed to cover the needs of the operational community for near real time observations in World Meteorological Organisation (WMO) standardised formats for assimilation in Numerical Weather Prediction (NWP) models.



SARAL/AltiKa Level-2 Products

	OGDR family	IGDR family	GDR family
Reduced 1Hz	OGDR-SSHA	IGDR-SSHA	GDR-SSHA
1Hz + 40Hz	OGDR OGDR-BUFR*	IGDR	GDR
1Hz + 40Hz +waveforms	-	S-IGDR	S-GDR
Latency	3 - 5 Hours	< 1.5 days	~ 40 days

* All files in NetCDF format except OGDR-BUFR, which contains no 40 Hz data

Table 1. Summary of operational, interim, and final geophysical data record products (O/I/GDR) from the SARAL/AltiKa mission.

All nine files contain sea surface height, ocean surface wind speed, significant wave height information and all required corrections. The NetCDF files differ in the amount and type of auxiliary data included but the product format is the same.

1.1.2. Filename conventions

The product names are based on the following convention:

SRL_<O/I/G>P<N/R/S>_2P<v><S/P><ccc>_<pppp>_<yyyymmdd_hhnnss>_<yyyymmdd_hhnnss>.aaaa.nc

With : <O/I/G> : product family (O : OGDR, I : IGDR, G: GDR)
<N/R/S> : product type (N : native, R: reduced, S : sensor)
<v> : product version (set to 'T' during CalVal phases, then set to the current altimetric version from data standards)
<S/P> : product duration (S : segment for OGDR, P : pass for I/GDR)

<ccc>: cycle number of 1st product record
<pppp> : pass number of 1st product record (1-1002)
<yyyymmdd_hhnnss> : date of 1st product record
<yyyymmdd_hhnnss> : date of last product record
<aaaa> : Name of the agency producing the data (EUM/CNES/ISRO)

So for the OGDR we have:

OGDR:	SRL_OPN_2PvSccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc
OGDR-SSHA:	SRL_OPR_2PvSccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc

for the OGDR-BUFR, the filename is not relevant if you are accessing the files via GTS (see below for details on access to NRT data). Otherwise, if you are accessing the files from the archives (UMARF) or EUMETCast, the filenames of the OGDR-BUFR are at the EUMETSAT/UMARF and on EUMETCast:

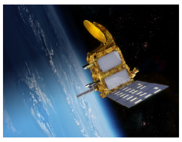
W_XX-EUMETSAT-Darmstadt,SURFACE+SATELLITE,SARAL+OGDR_C_EUMS_yyyymmddhhnnss_v_ccc_pppp_yyyymmddhhnnss.bin

for the IGDR:

IGDR:	SRL_IPN_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc
IGDR-SSHA:	SRL_IPR_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc
S-IGDR:	SRL_IPS_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc

and for the GDR:

GDR:	SRL_GPN_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc
GDR-SSHA:	SRL_GPR_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc
S-GDR:	SRL_GPS_2PvPccc_pppp_yyyymmdd_hhnnss_yyyymmdd_hhnnss.aaaa.nc



1.2. Handbook Overview

This is a combination of a guide to data use and a reference handbook, so not all sections will be needed by all readers.

Section 1 provides information on product evolution history

Section 2 provides background information about the (O)(I)GDR and this document

Section 3 is an overview of the SARAL/AltiKa mission

Section 4 is an introduction to using the SARAL/AltiKa data

Section 5 is an introduction to the SARAL/AltiKa altimeter algorithms

Section 6 provides a description of the content and format of the SARAL/AltiKa (O)(I)GDRs

Appendix A contains references

Appendix B contains acronyms

Appendix C describes how to order information or data from CNES, EUMETSAT and ISRO, and lists related Web sites.

1.3. Document reference and contributors

When referencing this document, please use the following citation:

“SARAL/AltiKa Products Handbook”,

CNES :	**SALP-MU-M-OP-15984-CN**
ISRO :	**XXX**

Main authors of this document are: F. BIGNALET-CAZALET from CNES.

As parts of this handbook are heritage from Jason-1/2 handbook and SARAL/AltiKa Calval Plan, other contributors include:

- Ashok K. SHUKLA from ISRO,
- N. PICOT, E. BRONNER and A. GUILLOT from CNES,
- J.P. DUMONT and V. ROSMORDUC from CLS,
- J. LILLIBRIDGE from NOAA,
- R. SCHARROO from ALTIMETRICS,
- S. DESAI from NASA/JPL,
- H. BONEKAMP and J. FIGA from EUMETSAT.

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
- **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 distance of the satellite or altimeter above a reference point. The reference point used is the reference ellipsoid. This distance is computed from the satellite ephemeris data
- **Height** is the distance of the sea surface above the reference ellipsoid. The sea surface height is the difference of the altimeter range from the satellite altitude above the reference ellipsoid

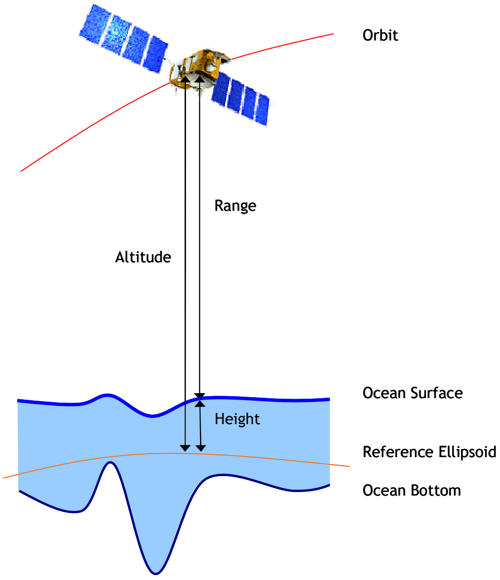


Figure 1 : Altimetric distances – Altitude, Range and Height

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.

The OGDR data is organized into files (“segments”) which corresponds to the amount of data dumped over an Earth terminal (typically 2 hour-data sets).

The (I)GDR data is organized into pass files in order to avoid having data boundaries in the middle of the oceans, as would happen if the data were organized by orbit. A **Pass** is half a revolution of the earth by the satellite from extreme latitude to the opposite extreme latitude.

For SARAL/AltiKa, an **Ascending Pass** begins at the latitude -81.49 deg and ends at +81.49 deg. A **Descending Pass** is the opposite (+81.49 deg to -81.49 deg). The passes are numbered from 1 to 1002 representing a full repeat cycle of the SARAL/AltiKa ground track. Ascending passes are odd numbered and descending passes are even numbered.

After one **repeat cycle** of 501 orbits, SARAL/AltiKa revisits the same ground-track within a margin of ±1 km. That means that every location along the SARAL/AltiKa ground-track is measured every approximately 35 days.

On the **geodetic orbit** (from July 2016), a virtual “cycle” duration of 35 days with 1002 passes (sub cycle ~ 16 days) is kept while cycle number jumps to #100.

1.4.1.3. Reference Ellipsoid

The **Reference Ellipsoid** is the first-order definition of the non-spherical shape of the Earth as an ellipsoid of revolution with equatorial radius of 6378.1363 kilometers and a flattening coefficient of 1/298.257 (same reference ellipsoid as used by the Jason-1-2-3 GDR-D, SARAL/AltiKa and the T/P missions).

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 tropospheric 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.

1.4.3. Time Convention

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

A UTC leap second can occur on June 30 or December 31 of any year. The leap second is a sixty-first second introduced in the last minute of the day. Thus the UTC values (minutes:seconds) appear as: 59:58 ; 59:59 ; 59:60 ; 00:00 ; 00:01.

1.4.4. Unit Convention

All distances and distance corrections are reported in tenths of millimeters (10^{-1} mm).

1.4.5. Flagging and Editing

In general, flagging consists of three parts: instrument flags (on/off), telemetry flags (preliminary flagging and editing) and data quality flags (geophysical processing flags).

Instrument flags provide information about the state of the various instruments on the satellite.

Telemetry flags are first based on instrument modes and checking of telemetry data quality. Only severely corrupted data are not processed (i.e. data that cannot be correctly read on ground). Flag setting is designed to get a maximum amount of data into the “Sensor Data Records” (part of the SGDR data sets). Science data are processed only when the altimeter is in tracking mode.

Quality flags are determined from various statistical checks on the residuals after smoothing or fitting through the data themselves. These flags are set if gaps in the data are detected, or residuals have exceeded predetermined thresholds, or if the gradients of the data exceed predetermined thresholds.

2. SARAL/AltiKa Mission Overview

2.1. Altimetric background

Three previous high-accuracy altimetric missions, TOPEX/POSEIDON (T/P, launched in August 1992 and which last until October 2005), Jason-1 (launched in December 2001) and Jason-2 (launched in June 2008) have been the key elements of a major turning point in physical oceanography, in terms of both scientific research and applications. Exceeding most initial specifications in terms of accuracy, T/P quickly became a unique tool to make significant progress in the understanding and modeling of ocean circulation and consequently on its climatic impact. The success of the T/P mission was mainly due to an appropriate optimization of the system: instruments, satellite, and orbit parameters were all specifically designed to fulfill the objectives of the mission. The T/P follow-on mission, Jason-1, was engaged soon after with the aim to provide the same level of performance, but with a significant decrease in weight and power needs, hence a much lower mission cost. In addition, near-real time applications were included in the main objectives of the mission. Jason-2 presents better tracking performance and continue the success story of altimetric missions.

These missions, individually as well as combined have made essential contributions in other domains, like mean sea level surveys, tides, marine meteorology, geophysics and geodesy. Most notably the tandem mission phase, where Jason-1 and T/P or Jason-1 and Jason-2 were flying on the same orbit separated by only 70 s or 1 min, provided a unique opportunity for intercalibration of both systems, hence improving further the scientific data quality. High accuracy radar altimeter missions are uniquely capable to globally and continuously observe the ocean and to better understand the short to long term changes of ocean circulation. They are now considered as essential components of global ocean observation systems. These systems integrate altimetric and other satellite and in-situ data into models and require the continuity and permanence of ocean measurements to produce time series over several decades.

The near-real time and short term capability of Jason-1, Jason-2 as well as ENVISAT (from ESA, launched in March 2002) have fed several pilot experiments that demonstrated the growing importance of operational ocean observation products and short-range ocean prediction for a variety of applications (ship routing, environmental hazards, support to maritime industries).

Also worth mentioning is the importance of wave and wind data provided by altimeter systems over oceans. This information is routinely used in meteorological and research entities, either for calibration of other data sets, assimilation in weather and wave models, or for statistical analysis.

N.B.: Please note that this User Handbook mainly deals with ocean application. Inland water, land ice and sea-ice experts should adapt their editing and processing strategy based on their own experience. Any question could also be sent to aviso@altimetry.fr.

2.2. Introduction to SARAL/AltiKa mission

2.2.1. Mission overview

The SARAL mission results from the common interest of both CNES and ISRO in studying ocean from space using altimetry system and in promoting maximum use of the ARGOS Data Collecting System.

In the present document, we focus on the AltiKa part of the overall SARAL mission.

Radar altimetry by satellite is a technique used in oceanography to measure, globally over the oceans, the sea level needed to understand ocean circulation and its variability. The importance of altimetry data to better understand the ocean circulation and its impact on the climate of the Earth led to the TOPEX/Poseidon and Jason series of satellites complemented by ERS1-2, GFO and ENVISAT. With the launch of these missions began a data collection that must continue well into the century in order to monitor the inter-annual evolution and separate transient phenomena from secular variations.

SARAL/AltiKa mission belongs to the global altimetry system and then participates to the precise and accurate observations of ocean circulation and sea surface elevation for its life time.

Thus it is the aim of AltiKa part of the SARAL mission to provide altimetric measurements designed to study ocean circulation and sea surface elevation with the same accuracy as the one provided by ENVISAT mission and complementary to Jasons mission.

The AltiKa project developed by CNES is based on a large Ka-band altimeter (35.75 GHz, 500MHz), 1st oceanographic altimeter using such a high frequency. The use of the Ka-band frequency will supply more accurate measurements (improvement of the spatial and vertical resolution) enabling a better observation of ices, coastal areas, continental water bodies as well as the waves height. The drawback of this Ka-band frequency is its sensitivity to rain that can lead to signal attenuation.

The SARAL/AltiKa mission is part of the operational satellite altimetry system, jointly with Jason-3.

By ensuring the observations continuity and widening the observation areas, CNES answers the wish of the oceanography community by bringing a description:

- for the meso-scale in open ocean,
- in coastal areas,
- for the seasonal forecast,
- for the hydrology,
- for the climate studies.

AltiKa data will thus contribute, along with data from others altimetry missions, to the development of operational oceanography, to our climate understanding and to the development of forecasting capabilities through data assimilation methods improvement in coupled ocean-atmosphere coupling models, bio-chemistry models, etc.

2.2.2. Mission objectives

SARAL/AltiKa main scientific objective is to provide data products to oceanographic research user community in studies leading to improve our knowledge of the **ocean meso-scale variability**, thanks to the improvement in spatial and vertical resolution brought by SARAL/AltiKa.

Ocean meso-scale variability is defined as a class of high-energy processes, with wave lengths within a 50km to 500km range, and with periods of a few days to one year. Kinetic energy of meso-scale variability is one order of magnitude more than mean circulation's one. Description of meso-scale is thus essential for understanding ocean dynamics, including mean circulation and its climatic effects (through interactions of meso-scale turbulence with the mean flow).

SARAL/AltiKa main scientific objective is divided in sub-themes including:

- intrinsic scientific studies of ocean at meso-scale dynamics: observations, theoretical analyses, modelling, **data assimilation**, parameterization, ...
- improvement of our understanding of the oceanic component in the **climate system**: investigation of local processes at small or medium scale poorly known and understood at present, but which have an impact on the modelling of climate variability at large spatial and temporal scales.

- contribution to the study of **coastal dynamic processes**, especially small or medium scale phenomena, whose retrieval will enable to anticipate many downstream applications.
- contribution to **operational oceanography** which is seeking large amounts of *in situ* and space observation data.

SARAL/AltiKa secondary objectives are notably the monitoring of the main **continental waters level** (lakes, rivers, closed seas), the monitoring of **mean sea level** variations, the observation of **polar oceans**, the analysis and forecast of **wave and wind fields**, the study of **continental ices** (thanks to improved performances of Ka-band) and **sea ices**, the access to **low rains** climatology (enabled in counterpart to the sensitivity of Ka-band to clouds and low rains) and the **marine biogeochemistry** (notably through the role of the meso and sub-meso-scale physics).

Further details on science and applications of SARAL/AltiKa data products can be found in the **ISRO-CNES SARAL/AltiKa Joint Science Plan** document [AD2].

2.3. SARAL/AltiKa Mission

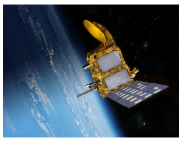
The SARAL/AltiKa mission is built on the heritage of T/P and Jason-1/2, with two driving ambitions:

- Ensuring continuity of high quality measurements for ocean science
- Providing operational products for assimilation and forecasting applications

The SARAL mission has been set forth as a cooperation between CNES and ISRO. The sharing of responsibilities between CNES and ISRO, as defined in the SARAL MoU, is as follow :

→ CNES responsibilities :

- Project Management: responsibility shared with ISRO
- Overall SARAL system engineering
- Integrated Payload Module (PIM), including
    - AltiKa mission payload
    - ARGOS-3 mission payload
- Support for SARAL Payload Module integration and test
- Ground System & Operations
    - Polar X-band network stations
    - Compatibility of L-band stations network required for the ARGOS-3/SARAL mission
    - Data communication network
    - AltiKa Mission Centre
    - NRT and OFL product processing software development, installation, training and support to operations (ISRO and EUMETSAT)
    - NRT product processing, archiving, distribution to users outside India, with the support of EUMETSAT
    - OFL product processing and distribution to users outside India
    - DORIS product processing and distribution
    - Data providing to the ARGOS Global Processing Centers
    - Archiving of all telemetry and products, and auxiliary data



- User services
- AltiKa System Coordination with other altimetry missions in the frame of the SALP service ; expertise and long term CALVAL

→ ISRO responsibilities :

- Project Management : responsibility shared with CNES
- SARAL satellite engineering
- SSB Platform
- PSLV Launch vehicle and services
- SARAL Satellite integration and test
- Ground System & Operations
    - Satellite Control Centre
    - S-band network stations
    - X-band Hyderabad Shadnagar station (TBCnot necessarily on an operational basis)
    - Data communication network
    - NRT and OFL products processing and distribution to users within India
    - Archiving of all telemetry and products, and auxiliary data
- User services

The SARAL satellite is planned to operate for a nominal period of five (5) years, with an objective at 7 years. However, the operations will be conducted throughout the whole SARAL satellite lifetime.

SARAL/AltiKa was launched on **February 25th 2013, at 12:31 GMT by a PSLV** vehicle (C20) supplied by **ISRO**, from the main ISRO launch base, the **Satish Dhawan Space Centre, SHAR SRIHARIKOTA**, 100 km North from Chennai. It reached its nominal repetitive orbit on March 13th 2013. The start of cycle 0 on occurred on March 13th 2013 at 06:36 GMT. The start of cycle 1 occurred on March 14th 2013 at 05:39 GMT, the pass 1 began at 06:05 GMT (ascending node #1, long 0.13°, lat 0°).

2.4. SARAL/AltiKa Requirements

The major elements of the mission include:

- **An Earth orbiting satellite carrying an altimetric system** for measuring the height of the satellite above the sea surface
- **A precision orbit determination system** for referring the altimetric measurements to geodetic coordinates
- **A data analysis and distribution system** for processing the satellite data, verifying their accuracy, and making them available to the scientific community
- **A Principal Investigator program** for feedback from operational applications and scientific studies based on the satellite observations

The sea-surface height measurement must be made with an accuracy of 3.2 cm or better (at 1 Hz) in order to meet the mission objectives. The SARAL/AltiKa satellite is specified and designed to fulfill the mission objectives (see AD 1) and to take over from the Jason-1/2 mission. As for Jason-1/2, distribution of altimetric products (non-validated) in near real time is planned. The interim

(IGDR) and definitive (GDR) science products are delivered later (within 1.5 days for IGDR and within 40 days for GDR), following the model used for Jason-1 and Jason-2.

To ensure that science and mission goals are accomplished by the SARAL/AltiKa mission, the following requirements were established.

2.4.1. Accuracy of Sea-level Measurements

Generally speaking SARAL/AltiKa has been specified based on the Jason-2 state of the art, including improvements in payload technology, data processing and algorithms or ancillary data (e.g: precise orbit determination and meteorological model accuracy). The sea-surface height shall be provided with a globally averaged RMS accuracy of 4.2 cm (1 sigma), or better, assuming 1 second averages.

The instrumental and environmental corrections are provided with the appropriate accuracy to meet this requirement. In addition to these requirements, a set of measurement-system goals was established based on the anticipated impact of off-line ground processing improvements. These improvements are expected to enable reduction of sea-surface height errors to 3.2 cm RMS. Knowledge of the stability of the system is especially important to the goal of monitoring the change in the global mean sea level, hence a specification on the system drift with a 1 mm/year goal.

The following table provides a summary of the preliminary error budget.

(for 1s average, 2m SWH, 1dB $\sigma0$)	**OGDR** **3 Hours**	**IGDR** **1.5 days**	**GDR** **40 days**	**GOALS**
Altimeter noise[1]	1.5 cm	1.5 cm	1.5 cm	**1 cm**
Ionosphere	0.6 cm	0.3 cm	0.3 cm	**0.3 cm**
Sea state bias	2 cm	2 cm	2 cm	**2**
Dry troposphere	1.5 cm	0.7 cm	0.7 cm	**0.7 cm**
Wet Tropospheric Correction	1.2 cm	1.2 cm	1.2 cm	**1 cm**
Altimeter range after corrections (RSS)	3.2 cm	2.9 cm	2.9 cm	**2.6 cm**
Orbit (Radial component) (RMS)	Req : 30 cm Goal : 10 cm	Req : 4 cm Goal : 2.5 cm	Req : 3 cm Goal : 2 cm	**2 cm**
Total RSS Sea Surface Height	Req : 30.2 cm	Req : 4.9 cm	Req : 4.2 cm	**3.2 cm**
Significant Wave Height (H1/3)[2]	10 % or 6.3 cm	10% or 6.3 cm	10% or 6.3 cm	**5% or 3.9 cm**

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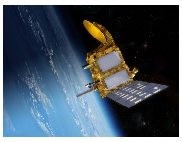
[1] Note that an altimeter noise of 1 cm has been measured during instrument testing.

[2] Note that SWH noise of 5 cm has been measured during instrument testing.



Wind speed	2 m/s	1.7 m/s	1.7 m/s	**1 m/s**

Table 2. Preliminary AltiKa Data Products error budget

2.4.2. Sampling Strategy

As for Jason-1 and Jason-2, sea level shall be measured along a fixed grid of subsatellite tracks such that it is possible to investigate and minimize the spatial and temporal aliases of surface geostrophic currents and to minimize the influence of the geoid on measurements of the time-varying topography.

2.4.3. Tidal Aliases

As for Jason-1 and Jason-2, sea level shall be measured such that tidal signals are not aliased into semiannual, annual, or zero frequencies (which influences the calculation of the permanent circulation) or frequencies close to these.

2.4.4. Duration and coverage

Sea level shall be measured for a minimum of five years, with the potential to extend this period for an additional two years.

The SARAL/AltiKa satellite shall overfly the reference ENVISAT ground tracks.

2.5. Mission Description

SARAL/AltiKa will use an Earth orbiting satellite equipped with a radar altimeter and other instruments to directly measure sea-surface elevation along the fixed grid of sub-satellite ground tracks traced out by the ERS1/2 and ENVISAT satellites. In so doing, SARAL/AltiKa will continue the data collection started with ERS1/2 and followed by ENVISAT. The sea-surface height measurement must be made with an accuracy of 4.2 cm or better (at 1 Hz) in order to meet the mission objectives. The SARAL/AltiKa satellite is specified and designed to fulfill the mission objectives and was launched in 2013 to take over for ENVISAT mission.

The ocean topography is obtained through three basic measurements:

1) the satellite range above the sea surface derived from the altimeter,

2) the tropospheric range delay measured by the radiometer to correct the altimeter range,

3) the altitude of the satellite above the reference ellipsoid derived from precise orbit determination.

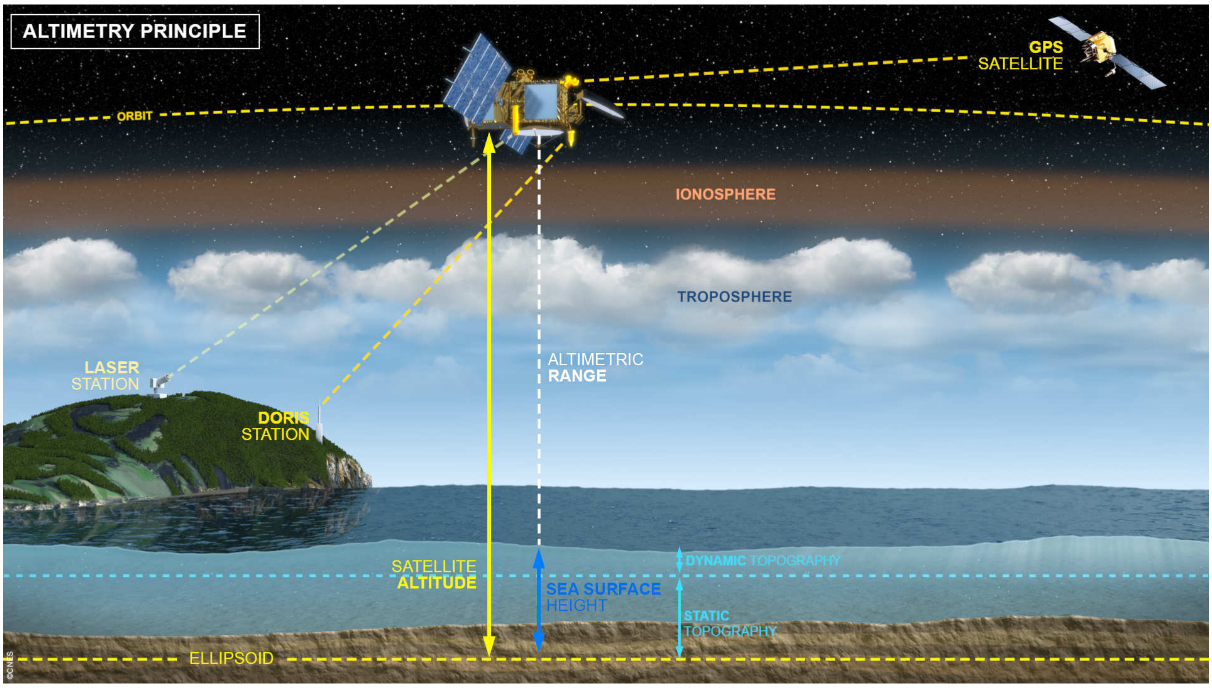


Figure 2. Geometry of the sea surface height measurement by altimetry

The altimeter uses radar pulses to determine precisely the distance between the satellite and the ocean surface by measuring the time taken by the emitted pulse to return. The shape and the amplitude of the echo enable the estimation of wave height and wind speed respectively. Geophysical corrections are then applied to compensate for the measurement errors introduced by propagation through the troposphere and ionosphere and errors induced by sea state.

Further information and details about radar altimetry principles and processing can be found on the following link : https://www.aviso.altimetry.fr/en/techniques/altimetry.html

2.6. Satellite Description

The 405 kg satellite consists of a **SSB/ IMS-2 platform** and a **SARAL/AltiKa specific payload module**. The platform provides all housekeeping functions including propulsion, electrical power, command and data handling, telecommunications, and attitude control. The payload module provides mechanical, electrical, thermal, and dynamical support to the SARAL/AltiKa instruments.

The SARAL satellite is mainly composed of:

- a **spacecraft bus IMS-2** (Small Satellite Bus). This platform, developed by **ISRO**, is designed for satellites in the range of about 500 kg at launch.
- a **payload** developed by **CNES.**

The SARAL payload (see Figure 3) includes the following components:

- An **Altimeter**, provided by CNES – the main mission instrument and a dual frequency microwave **radiometer**, provided by CNES – to correct the altimeter measurement for atmospheric range delays induced by water vapor.

The **AltiKa** instrument consists of a Ka-band altimeter and an embedded dual frequency radiometer.

- The radio positioning **DORIS system**, provided by CNES – for precision orbit determination using dedicated ground stations
- A **Laser Reflector Array (LRA)**, provided by CNES – to calibrate the orbit determination system.

And the **ARGOS-3** instrument (and associated components) that has its own mission on-board the SARAL satellite as part of the ARGOS system.

Details about the satellite description can be found at: http://smsc.cnes.fr/SARAL/index.htm.

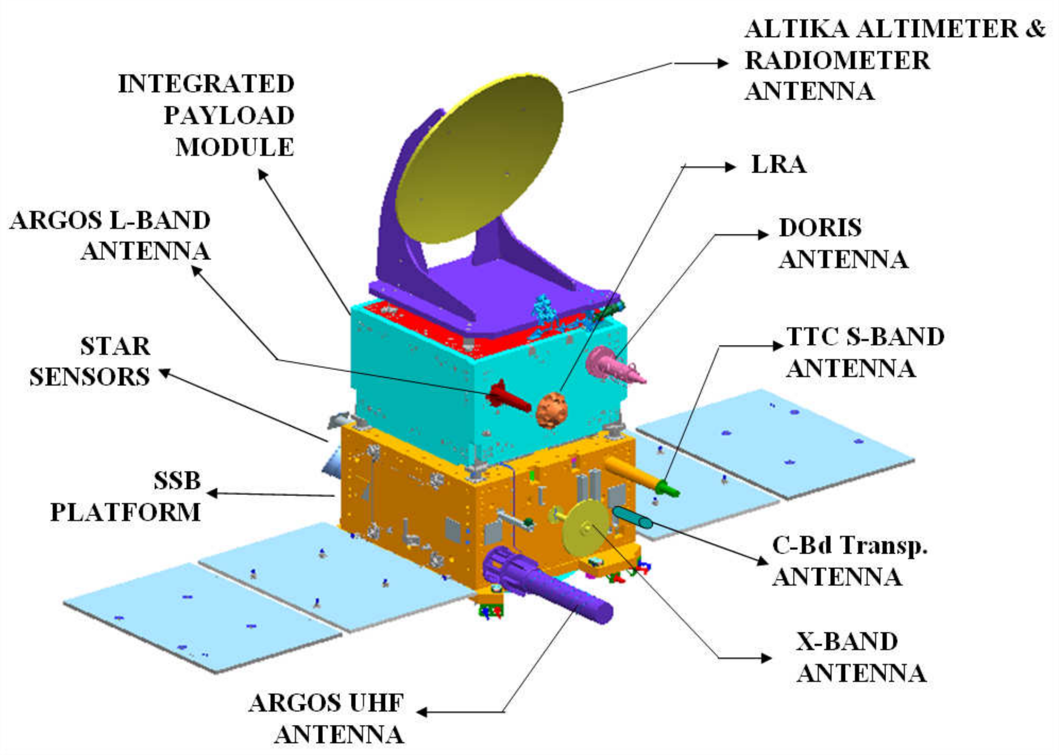


Figure 3 : AltiKa & Argos-3 payloads accommodation on SSB platform : SARAL satellite.

2.6.1. Satellite Characteristics

The main features of the SARAL/AltiKa satellite are summed up in the following table.

Satellite mass	405 kg
Satellite power	570 W
Platform mass	250 kg
Platform power	205 W
Payload mass	160 kg
Payload power	250 W
Altimeter mass	55 kg
Altimeter power	78 W
Launch Vehicle	PSLV
Launch Site	Satish Dhawan Space Center, SHAR SRIHARIKOTA

Table 3 : Main features of the SARAL/AltiKa satellite

2.6.2. Sensors

2.6.2.1. AltiKa Altimeter

The mono-frequency Ka-band (35.75 GHz) radar altimeter is the main part of AltiKa instrument. Its functions are based on proven concepts and already developed sub-systems, as it inherits from Siral (CRYOSAT mission) and Poseidon3 (Jason-2 mission).

The use of a single frequency is possible because ionosphere effects are negligible at such high frequencies (proportionality to the inverse of the squared frequency).

The main advantage of this higher frequency (Ka versus classical Ku/C altimeters) is the reduced altimeter footprint that leads to a better spatial resolution. The added advantage of AltiKa is due to its enhanced bandwidth (500 MHz), which leads to higher vertical resolution. Thus, globally, an error budget improvement is expected.

However, Ka-band has also drawbacks, mainly linked to its higher sensitivity to rainy and cloudy conditions.

The altimeter antenna is a fixed offset paraboloid (1 meter diameter) and directed toward nadir of the satellite. It will be located on the top of the satellite.

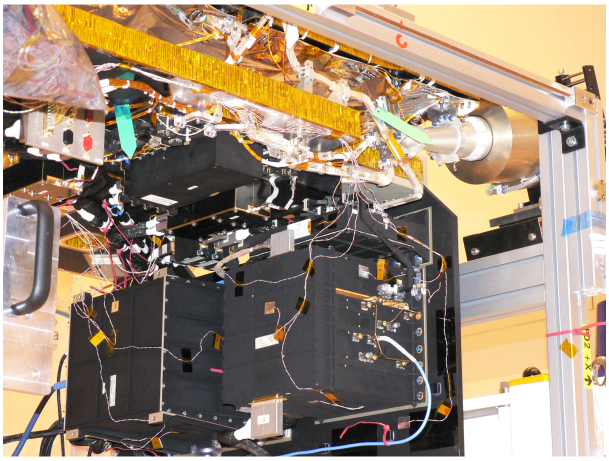


Figure 4 : SARAL/AltiKa Instrument

2.6.2.2. Dual frequency microwave radiometer

The bi-frequency (23.8 GHz / 37 GHz) radiometer is used to correct altimetry measurements from wet troposphere crossing effects. The 23.8 GHz channel is the primary water vapor sensing channel, meaning higher water vapor concentrations will lead to larger 23.8 GHz brightness temperature values. The addition of the 37 GHz channel, which has less sensitivity to water vapor, facilitate the removal of the contributions from cloud liquid water, which also act to increase the 23.8 GHz brightness temperature.

The antenna, shared with the altimeter, is fed by a two frequency coaxial corrugated horn feed.

A corrugated cold sky horn is used for the gain calibration of the 2 radiometer channels.

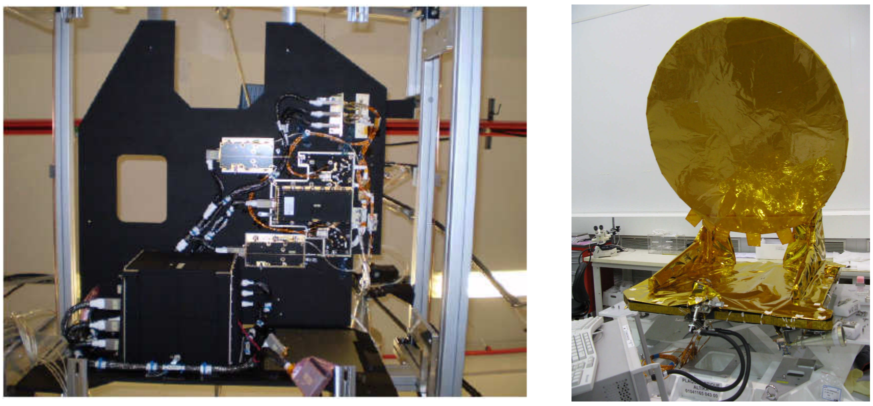


Figure 5 : SARAL/AltiKa radiometer Instrument and antenna (shared with altimeter)

2.6.2.3. DORIS System

The complete DORIS system includes the DORIS on-board package, a network of approximately 60 beacons located around the world and a ground system.

The on-board package includes the electronic box hosting the receiver itself and the ultra stable oscillator and an omnidirectional antenna.

The DORIS on-board package is of the same version than the one embarked on SARAL/ALTIKA. It includes a 7-beacon receiving capability and an on-board real time function (DIODE for « Détermination Immédiate d'Orbite par DORIS Embarqué ») to compute the orbit ephemeris in real time.

The DORIS on-board package is dual string (in cold redundancy), each DORIS chain is automatically connected to the single antenna through a switching box inside the DORIS unit . Each receiver is connected to its own ultra-stable oscillator.

The DORIS antenna is located on the Earth panel of the satellite.

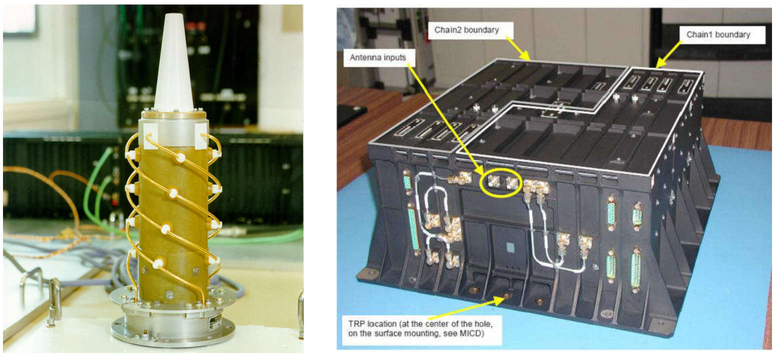


Figure 6 : SARAL/AltiKa DORIS Receiver Antenna and Instrument

2.6.2.4. Laser Reflector Array (LRA)

It is used for precise calibration of other POD instruments, through analysis of laser shots from the ground then reflected by the LRA mirrors.

The laser reflector array is placed on the nadir face of the satellite. It consists of several quartz corner cubes arrayed as a truncated cone with one in the center and the others distributed azimuthally around the cone.

The LRA is provided by CNES.

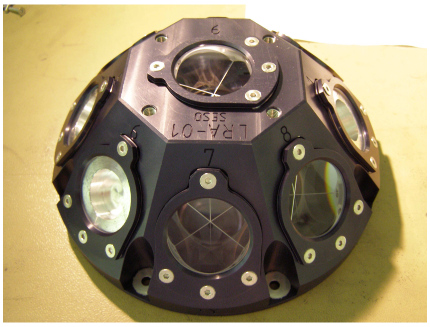


Figure 7 : SARAL/AltiKa Laser Reflector Array

2.6.2.5. ARGOS-3 Instrument

ARGOS is a **Data Collection and Localization System dedicated to environmental applications** (more than 18000 active platforms). This is a CNES / EUMETSAT / NOAA cooperation and ISRO will join the ARGOS Program with SARAL. Now in its 3rd generation of instruments embarked on EUMETSAT/Metop and NOAA/POES (NOAA-N'), ARGOS-3 on SARAL will fill the 3rd orbit (@ 18h00) of ARGOS-3 system.

Figure 8 : Applications of the ARGOS system

ARGOS-3 UHF and L band antennas are located on the Earth face of the satellite.

Figure 9 : SARAL/AltiKa UHF antenna

Figure 10 : SARAL/AltiKa ARGOS-3 reception instrument

2.6.3. Orbit

2.6.3.1. Repetitive Orbit (From launch until July 2016)

The SARAL/AltiKa satellite flies on the same ground-track as ENVISAT with a 501-orbit, 1002-pass, 35-day exact repeat cycle. Orbital characteristics and the equator crossing longitudes for SARAL/AltiKa are given in Tables 10 and 11.

At the beginning of the mission, the orbit was NOT exactly on the ENVISAT repetitive ground track. A deviation of the order of 2.5 km at high latitudes was observed. It has been corrected by an in plane correction maneuver made by ISRO on July 29th 2013.

To locate a pass on the Earth, Google Earth can be used. More information are given on the AVISO Website about the pass locator:

https://www.aviso.altimetry.fr/en/data/tools/pass-locator.html

Figure below is a plot of the ground track on a world map (as there are 501 ground tracks, they are represented as ascending and descending passes).

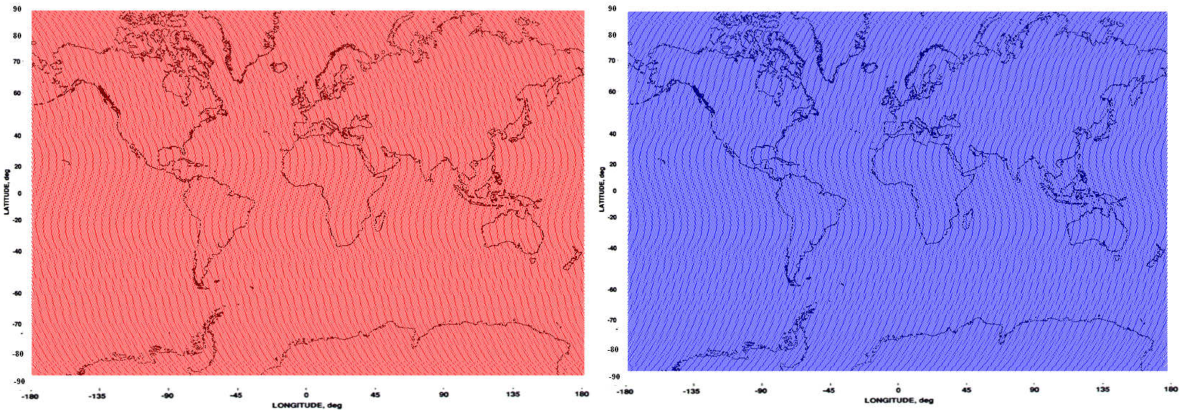


Figure 11 : ENVISAT and SARAL/AltiKa ground track coverage every 35 days (ascending and descending passes)

The main characteristics of SARAL Sun-Synchronous Orbit are:

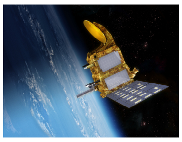
→ The mean classical orbit elements are given in the table below.

Orbit element	Value
Repeat period	35 days
Number of revolution within a cycle	501
Apogee altitude	814 km
Perigee altitude	786 km
Inclination	98.55 deg
Argument of perigee	90.0 deg
Local time at ascending node	06:00
Earth Longitude of equator ascending crossing of pass1	0.1335 deg
Ground track control band	+/- 1 km

Table 4 : Mean classical orbit elements

→ The orbit auxiliary data are given in the table below.

Auxiliary Data	Values
Semi major axis	7159.496 km
Eccentricity	$1.165\ 10^{-3}$
Nodal period	100.59 mn
Number of orbits per day	14+11/35
Equatorial cross track separation	75 km
Inertial nodal rate	0.9856 deg/day



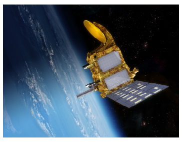
Mean Orbital speed	7.47 km/s

Table 5 : Orbit auxiliary data

This orbit overflies two verification sites funded by CNES and ISRO. The prime CNES verification site is located at Cape Senetosa on the island of Corsica (8°48' E, 41°34' N, ascending pass 85).

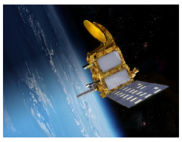
A satellite orbit slowly decays due to air drag, and has long-period variability because of the inhomogeneous gravity field of Earth, solar radiation pressure, and smaller forces. Periodic maneuvers are required to keep the satellite in its orbit. The frequency of maneuvers depends primarily on the solar flux as it affects the Earth's atmosphere, and there are expected to be one maneuver (or series of maneuvers) every 15 to 30 days.

Each orbit maintenance maneuver is performed using only one thrust to minimize impacts on the ground orbit solution. Orbit computation is optimized to minimize the orbit error during such periods. Science data are taken during orbit maintenance maneuvers and are distributed (an orbit state flag is provided in the products).



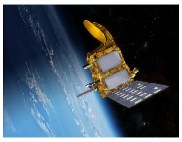
2.6.3.1.1. Equator Crossing Longitudes (in order of Pass Number)

Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)
1	0.13	**40**	49.73	**80**	266.74	**120**	123.74	**160**	340.75	**200**	197.75
2	167.58	**41**	217.14	**81**	74.14	**121**	291.15	**161**	148.16	**201**	5.16
3	334.98	**42**	24.58	**82**	241.59	**122**	98.59	**162**	315.60	**202**	172.61
4	142.43	**43**	191.99	**83**	48.99	**123**	266.00	**163**	123.01	**203**	340.01
5	309.83	**44**	359.43	**84**	216.44	**124**	73.45	**164**	290.45	**204**	147.46
6	117.28	**45**	166.84	**85**	23.84	**125**	240.85	**165**	97.86	**205**	314.86
7	284.68	**46**	334.28	**86**	191.29	**126**	48.30	**166**	265.30	**206**	122.31
8	92.13	**47**	141.69	**87**	358.70	**127**	215.70	**167**	72.71	**207**	289.71
9	259.54	**48**	309.13	**88**	166.14	**128**	23.15	**168**	240.15	**208**	97.16
10	66.98	**49**	116.54	**89**	333.55	**129**	190.55	**169**	47.56	**209**	264.56
11	234.39	**50**	283.98	**90**	140.99	**130**	358.00	**170**	215.00	**210**	72.01
12	41.83	**51**	91.39	**91**	308.40	**131**	165.40	**171**	22.41	**211**	239.41
13	209.24	**52**	258.83	**92**	115.84	**132**	332.85	**172**	189.85	**212**	46.86
14	16.68	**53**	66.24	**93**	283.25	**133**	140.25	**173**	357.26	**213**	214.26
15	184.09	**54**	233.68	**94**	90.69	**134**	307.70	**174**	164.70	**214**	21.71
16	351.53	**55**	41.09	**95**	258.10	**135**	115.10	**175**	332.11	**215**	189.11
17	158.94	**56**	208.53	**96**	65.54	**136**	282.55	**176**	139.55	**216**	356.56
18	326.38	**57**	15.94	**97**	232.95	**137**	89.95	**177**	306.96	**217**	163.96
19	133.79	**58**	183.38	**98**	40.39	**138**	257.40	**178**	114.40	**218**	331.41
20	301.23	**59**	350.79	**99**	207.80	**139**	64.80	**179**	281.81	**219**	138.81
21	108.64	**60**	158.24	**100**	15.24	**140**	232.25	**180**	89.25	**220**	306.26
22	276.08	**61**	325.64	**101**	182.65	**141**	39.65	**181**	256.66	**221**	113.67
23	83.49	**62**	133.09	**102**	350.09	**142**	207.10	**182**	64.10	**222**	281.11
24	250.93	**63**	300.49	**103**	157.50	**143**	14.50	**183**	231.51	**223**	88.51
25	58.34	**64**	107.94	**104**	324.94	**144**	181.95	**184**	38.95	**224**	255.96
26	225.78	**65**	275.34	**105**	132.35	**145**	349.35	**185**	206.36	**225**	63.36
27	33.19	**66**	82.79	**106**	299.79	**146**	156.80	**186**	13.80	**226**	230.81
28	200.63	**67**	250.19	**107**	107.20	**147**	324.20	**187**	181.21	**227**	38.21
29	8.04	**68**	57.64	**108**	274.64	**148**	131.65	**188**	348.65	**228**	205.66
30	175.48	**69**	225.04	**109**	82.05	**149**	299.05	**189**	156.06	**229**	13.07
31	342.89	**70**	32.49	**110**	249.49	**150**	106.50	**190**	323.50	**230**	180.51
32	150.33	**71**	199.89	**111**	56.90	**151**	273.91	**191**	130.91	**231**	347.92
33	317.74	**72**	7.34	**112**	224.34	**152**	81.35	**192**	298.35	**232**	155.36
34	125.18	**73**	174.74	**113**	31.75	**153**	248.76	**193**	105.76	**233**	322.77
35	292.59	**74**	342.19	**114**	199.19	**154**	56.20	**194**	273.20	**234**	130.21
36	100.03	**75**	149.59	**115**	6.60	**155**	223.61	**195**	80.61	**235**	297.62
37	267.44	**76**	317.04	**116**	174.04	**156**	31.05	**196**	248.05	**236**	105.06
38	74.88	**77**	124.44	**117**	341.45	**157**	198.46	**197**	55.46	**237**	272.47
39	242.29	**78**	291.89	**118**	148.89	**158**	5.90	**198**	222.90	**238**	79.91
40	49.73	**79**	99.29	**119**	316.30	**159**	173.31	**199**	30.31	**239**	247.32



Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)
240	54.76	**280**	271.77	**320**	128.77	**360**	345.78	**400**	202.78	**440**	59.79
241	222.17	**281**	79.17	**321**	296.18	**361**	153.19	**401**	10.19	**441**	227.20
242	29.61	**282**	246.62	**322**	103.62	**362**	320.63	**402**	177.64	**442**	34.64
243	197.02	**283**	54.02	**323**	271.03	**363**	128.04	**403**	345.04	**443**	202.05
244	4.46	**284**	221.47	**324**	78.47	**364**	295.48	**404**	152.49	**444**	9.49
245	171.87	**285**	28.87	**325**	245.88	**365**	102.89	**405**	319.89	**445**	176.90
246	339.31	**286**	196.32	**326**	53.33	**366**	270.33	**406**	127.34	**446**	344.34
247	146.72	**287**	3.72	**327**	220.73	**367**	77.74	**407**	294.74	**447**	151.75
248	314.16	**288**	171.17	**328**	28.18	**368**	245.18	**408**	102.19	**448**	319.19
249	121.57	**289**	338.58	**329**	195.58	**369**	52.59	**409**	269.59	**449**	126.60
250	289.01	**290**	146.02	**330**	3.02	**370**	220.03	**410**	77.04	**450**	294.04
251	96.42	**291**	313.43	**331**	170.43	**371**	27.44	**411**	244.45	**451**	101.45
252	263.86	**292**	120.87	**332**	337.88	**372**	194.88	**412**	51.89	**452**	268.89
253	71.27	**293**	288.28	**333**	145.28	**373**	2.29	**413**	219.30	**453**	76.30
254	238.71	**294**	95.72	**334**	312.73	**374**	169.73	**414**	26.74	**454**	243.74
255	46.12	**295**	263.13	**335**	120.13	**375**	337.14	**415**	194.15	**455**	51.15
256	213.56	**296**	70.57	**336**	287.58	**376**	144.58	**416**	1.59	**456**	218.59
257	20.97	**297**	237.98	**337**	94.98	**377**	311.99	**417**	169.00	**457**	26.00
258	188.41	**298**	45.42	**338**	262.43	**378**	119.43	**418**	336.44	**458**	193.44
259	355.82	**299**	212.83	**339**	69.83	**379**	286.84	**419**	143.85	**459**	0.85
260	163.26	**300**	20.27	**340**	237.28	**380**	94.28	**420**	311.29	**460**	168.29
261	330.67	**301**	187.68	**341**	44.68	**381**	261.69	**421**	118.70	**461**	335.70
262	138.11	**302**	355.12	**342**	212.13	**382**	69.13	**422**	286.14	**462**	143.14
263	305.52	**303**	162.53	**343**	19.53	**383**	236.54	**423**	93.55	**463**	310.55
264	112.96	**304**	329.97	**344**	186.98	**384**	43.98	**424**	260.99	**464**	117.99
265	280.37	**305**	137.38	**345**	354.38	**385**	211.39	**425**	68.39	**465**	285.40
266	87.82	**306**	304.82	**346**	161.83	**386**	18.83	**426**	235.84	**466**	92.85
267	255.22	**307**	112.23	**347**	329.23	**387**	186.24	**427**	43.24	**467**	260.25
268	62.67	**308**	279.67	**348**	136.68	**388**	353.68	**428**	210.69	**468**	67.70
269	230.07	**309**	87.08	**349**	304.08	**389**	161.09	**429**	18.10	**469**	235.10
270	37.52	**310**	254.52	**350**	111.53	**390**	328.53	**430**	185.54	**470**	42.55
271	204.92	**311**	61.93	**351**	278.94	**391**	135.94	**431**	352.95	**471**	209.95
272	12.37	**312**	229.37	**352**	86.38	**392**	303.38	**432**	160.39	**472**	17.40
273	179.77	**313**	36.78	**353**	253.79	**393**	110.79	**433**	327.80	**473**	184.80
274	347.22	**314**	204.22	**354**	61.23	**394**	278.23	**434**	135.24	**474**	352.25
275	154.62	**315**	11.63	**355**	228.64	**395**	85.64	**435**	302.65	**475**	159.65
276	322.07	**316**	179.07	**356**	36.08	**396**	253.08	**436**	110.09	**476**	327.10
277	129.47	**317**	346.48	**357**	203.49	**397**	60.49	**437**	277.50	**477**	134.50
278	296.92	**318**	153.92	**358**	10.93	**398**	227.93	**438**	84.94	**478**	301.95
279	104.32	**319**	321.33	**359**	178.34	**399**	35.34	**439**	252.35	**479**	109.35

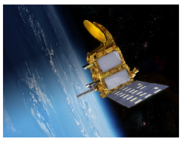
Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)
480	276.80	**520**	133.80	**560**	350.81	**600**	207.82	**640**	64.82	**680**	281.83
481	84.20	**521**	301.21	**561**	158.22	**601**	15.22	**641**	232.23	**681**	89.23
482	251.65	**522**	108.65	**562**	325.66	**602**	182.67	**642**	39.67	**682**	256.68
483	59.05	**523**	276.06	**563**	133.07	**603**	350.07	**643**	207.08	**683**	64.08
484	226.50	**524**	83.51	**564**	300.51	**604**	157.52	**644**	14.52	**684**	231.53
485	33.90	**525**	250.91	**565**	107.92	**605**	324.92	**645**	181.93	**685**	38.93
486	201.35	**526**	58.36	**566**	275.36	**606**	132.37	**646**	349.37	**686**	206.38
487	8.76	**527**	225.76	**567**	82.77	**607**	299.77	**647**	156.78	**687**	13.79
488	176.20	**528**	33.21	**568**	250.21	**608**	107.22	**648**	324.22	**688**	181.23
489	343.61	**529**	200.61	**569**	57.62	**609**	274.63	**649**	131.63	**689**	348.64
490	151.05	**530**	8.06	**570**	225.06	**610**	82.07	**650**	299.07	**690**	156.08
491	318.46	**531**	175.46	**571**	32.47	**611**	249.48	**651**	106.48	**691**	323.49
492	125.90	**532**	342.91	**572**	199.91	**612**	56.92	**652**	273.92	**692**	130.93
493	293.31	**533**	150.31	**573**	7.32	**613**	224.33	**653**	81.33	**693**	298.34
494	100.75	**534**	317.76	**574**	174.76	**614**	31.77	**654**	248.77	**694**	105.78
495	268.16	**535**	125.16	**575**	342.17	**615**	199.18	**655**	56.18	**695**	273.19
496	75.60	**536**	292.61	**576**	149.61	**616**	6.62	**656**	223.62	**696**	80.63
497	243.01	**537**	100.01	**577**	317.02	**617**	174.03	**657**	31.03	**697**	248.04
498	50.45	**538**	267.46	**578**	124.46	**618**	341.47	**658**	198.47	**698**	55.48
499	217.86	**539**	74.86	**579**	291.87	**619**	148.88	**659**	5.88	**699**	222.89
500	25.30	**540**	242.31	**580**	99.31	**620**	316.32	**660**	173.33	**700**	30.33
501	192.71	**541**	49.71	**581**	266.72	**621**	123.73	**661**	340.73	**701**	197.74
502	0.15	**542**	217.16	**582**	74.16	**622**	291.17	**662**	148.18	**702**	5.18
503	167.56	**543**	24.56	**583**	241.57	**623**	98.58	**663**	315.58	**703**	172.59
504	335.00	**544**	192.01	**584**	49.01	**624**	266.02	**664**	123.03	**704**	340.03
505	142.41	**545**	359.41	**585**	216.42	**625**	73.43	**665**	290.43	**705**	147.44
506	309.85	**546**	166.86	**586**	23.86	**626**	240.87	**666**	97.88	**706**	314.88
507	117.26	**547**	334.27	**587**	191.27	**627**	48.28	**667**	265.28	**707**	122.29
508	284.70	**548**	141.71	**588**	358.71	**628**	215.72	**668**	72.73	**708**	289.73
509	92.11	**549**	309.12	**589**	166.12	**629**	23.13	**669**	240.14	**709**	97.14
510	259.55	**550**	116.56	**590**	333.57	**630**	190.57	**670**	47.58	**710**	264.58
511	66.96	**551**	283.97	**591**	140.97	**631**	357.98	**671**	214.98	**711**	71.99
512	234.40	**552**	91.41	**592**	308.42	**632**	165.42	**672**	22.43	**712**	239.43
513	41.81	**553**	258.82	**593**	115.82	**633**	332.83	**673**	189.83	**713**	46.84
514	209.25	**554**	66.26	**594**	283.27	**634**	140.27	**674**	357.28	**714**	214.28
515	16.66	**555**	233.67	**595**	90.67	**635**	307.68	**675**	164.68	**715**	21.69
516	184.10	**556**	41.11	**596**	258.12	**636**	115.12	**676**	332.13	**716**	189.13
517	351.51	**557**	208.52	**597**	65.52	**637**	282.53	**677**	139.54	**717**	356.54
518	158.95	**558**	15.96	**598**	232.96	**638**	89.97	**678**	306.98	**718**	163.98
519	326.36	**559**	183.37	**599**	40.37	**639**	257.38	**679**	114.39	**719**	331.39



Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)	Pass	Long (°)
720	138.83	**760**	355.84	**800**	212.85	**840**	69.85	**880**	286.86	**920**	143.86
721	306.24	**761**	163.25	**801**	20.25	**841**	237.26	**881**	94.26	**921**	311.27
722	113.68	**762**	330.69	**802**	187.70	**842**	44.70	**882**	261.71	**922**	118.71
723	281.09	**763**	138.10	**803**	355.10	**843**	212.11	**883**	69.11	**923**	286.12
724	88.54	**764**	305.54	**804**	162.55	**844**	19.55	**884**	236.56	**924**	93.56
725	255.94	**765**	112.95	**805**	329.95	**845**	186.96	**885**	43.96	**925**	260.97
726	63.39	**766**	280.39	**806**	137.40	**846**	354.40	**886**	211.41	**926**	68.42
727	230.79	**767**	87.80	**807**	304.80	**847**	161.81	**887**	18.81	**927**	235.82
728	38.24	**768**	255.24	**808**	112.25	**848**	329.25	**888**	186.26	**928**	43.27
729	205.64	**769**	62.65	**809**	279.65	**849**	136.66	**889**	353.67	**929**	210.67
730	13.09	**770**	230.09	**810**	87.10	**850**	304.10	**890**	161.11	**930**	18.12
731	180.49	**771**	37.50	**811**	254.51	**851**	111.51	**891**	328.52	**931**	185.52
732	347.94	**772**	204.94	**812**	61.95	**852**	278.95	**892**	135.96	**932**	352.97
733	155.34	**773**	12.35	**813**	229.36	**853**	86.36	**893**	303.37	**933**	160.37
734	322.79	**774**	179.79	**814**	36.80	**854**	253.80	**894**	110.81	**934**	327.82
735	130.19	**775**	347.20	**815**	204.21	**855**	61.21	**895**	278.22	**935**	135.22
736	297.64	**776**	154.64	**816**	11.65	**856**	228.65	**896**	85.66	**936**	302.67
737	105.04	**777**	322.05	**817**	179.06	**857**	36.06	**897**	253.07	**937**	110.07
738	272.49	**778**	129.49	**818**	346.50	**858**	203.50	**898**	60.51	**938**	277.52
739	79.89	**779**	296.90	**819**	153.91	**859**	10.91	**899**	227.92	**939**	84.92
740	247.34	**780**	104.34	**820**	321.35	**860**	178.35	**900**	35.36	**940**	252.37
741	54.74	**781**	271.75	**821**	128.76	**861**	345.76	**901**	202.77	**941**	59.77
742	222.19	**782**	79.19	**822**	296.20	**862**	153.21	**902**	10.21	**942**	227.22
743	29.59	**783**	246.60	**823**	103.61	**863**	320.61	**903**	177.62	**943**	34.62
744	197.04	**784**	54.05	**824**	271.05	**864**	128.06	**904**	345.06	**944**	202.07
745	4.44	**785**	221.45	**825**	78.46	**865**	295.46	**905**	152.47	**945**	9.47
746	171.89	**786**	28.90	**826**	245.90	**866**	102.91	**906**	319.91	**946**	176.92
747	339.30	**787**	196.30	**827**	53.31	**867**	270.31	**907**	127.32	**947**	344.32
748	146.74	**788**	3.74	**828**	220.75	**868**	77.76	**908**	294.76	**948**	151.77
749	314.15	**789**	171.15	**829**	28.16	**869**	245.16	**909**	102.17	**949**	319.17
750	121.59	**790**	338.60	**830**	195.60	**870**	52.61	**910**	269.61	**950**	126.62
751	289.00	**791**	146.00	**831**	3.01	**871**	220.01	**911**	77.02	**951**	294.02
752	96.44	**792**	313.45	**832**	170.45	**872**	27.46	**912**	244.46	**952**	101.47
753	263.85	**793**	120.85	**833**	337.86	**873**	194.86	**913**	51.87	**953**	268.88
754	71.29	**794**	288.30	**834**	145.30	**874**	2.31	**914**	219.31	**954**	76.32
755	238.70	**795**	95.70	**835**	312.71	**875**	169.71	**915**	26.72	**955**	243.73
756	46.14	**796**	263.15	**836**	120.15	**876**	337.16	**916**	194.16	**956**	51.17
757	213.55	**797**	70.55	**837**	287.56	**877**	144.56	**917**	1.57	**957**	218.58
758	20.99	**798**	238.00	**838**	95.00	**878**	312.01	**918**	169.01	**958**	26.02
759	188.40	**799**	45.40	**839**	262.41	**879**	119.42	**919**	336.42	**959**	193.43

Pass	Long (°)	Pass	Long (°)
960	0.87	**1000**	217.87
961	168.28	**1001**	25.28
962	335.72	**1002**	192.72
963	143.13		
964	310.57		
965	117.98		
966	285.42		
967	92.83		
968	260.27		
969	67.68		
970	235.12		
971	42.53		
972	209.97		
973	17.38		
974	184.82		
975	352.23		
976	159.67		
977	327.08		
978	134.52		
979	301.93		
980	109.37		
981	276.78		
982	84.22		
983	251.63		
984	59.07		
985	226.48		
986	33.92		
987	201.33		
988	8.77		
989	176.18		
990	343.62		
991	151.03		
992	318.47		
993	125.88		
994	293.33		
995	100.73		
996	268.17		
997	75.58		
998	243.02		
999	50.43		

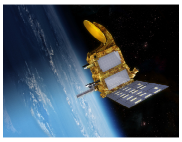
Table 6 : Equator Crossing Longitudes (in order of Pass Number)



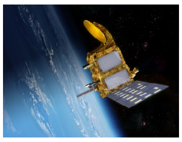
2.6.3.1.2. Equator Crossing Longitudes (in order of Longitude)

Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)
1	0.13	**186**	13.8	**328**	28.18	**470**	42.55	**612**	56.92	**754**	71.29
502	0.15	**143**	14.5	**285**	28.87	**427**	43.24	**569**	57.62	**711**	71.99
459	0.85	**644**	14.52	**786**	28.9	**928**	43.27	**68**	57.64	**210**	72.01
960	0.87	**601**	15.22	**743**	29.59	**885**	43.96	**25**	58.34	**167**	72.71
917	1.57	**100**	15.24	**242**	29.61	**384**	43.98	**526**	58.36	**668**	72.73
416	1.59	**57**	15.94	**199**	30.31	**341**	44.68	**483**	59.05	**625**	73.43
373	2.29	**558**	15.96	**700**	30.33	**842**	44.7	**984**	59.07	**124**	73.45
874	2.31	**515**	16.66	**657**	31.03	**799**	45.4	**941**	59.77	**81**	74.14
831	3.01	**14**	16.68	**156**	31.05	**298**	45.42	**440**	59.79	**582**	74.16
330	3.02	**973**	17.38	**113**	31.75	**255**	46.12	**397**	60.49	**539**	74.86
287	3.72	**472**	17.4	**614**	31.77	**756**	46.14	**898**	60.51	**38**	74.88
788	3.74	**429**	18.1	**571**	32.47	**713**	46.84	**855**	61.21	**997**	75.58
745	4.44	**930**	18.12	**70**	32.49	**212**	46.86	**354**	61.23	**496**	75.6
244	4.46	**887**	18.81	**27**	33.19	**169**	47.56	**311**	61.93	**453**	76.3
201	5.16	**386**	18.83	**528**	33.21	**670**	47.58	**812**	61.95	**954**	76.32
702	5.18	**343**	19.53	**485**	33.9	**627**	48.28	**769**	62.65	**911**	77.02
659	5.88	**844**	19.55	**986**	33.92	**126**	48.3	**268**	62.67	**410**	77.04
158	5.9	**801**	20.25	**943**	34.62	**83**	48.99	**225**	63.36	**367**	77.74
115	6.6	**300**	20.27	**442**	34.64	**584**	49.01	**726**	63.39	**868**	77.76
616	6.62	**257**	20.97	**399**	35.34	**541**	49.71	**683**	64.08	**825**	78.46
573	7.32	**758**	20.99	**900**	35.36	**40**	49.73	**182**	64.1	**324**	78.47
72	7.34	**715**	21.69	**857**	36.06	**999**	50.43	**139**	64.8	**281**	79.17
29	8.04	**214**	21.71	**356**	36.08	**498**	50.45	**640**	64.82	**782**	79.19
530	8.06	**171**	22.41	**313**	36.78	**455**	51.15	**597**	65.52	**739**	79.89
487	8.76	**672**	22.43	**814**	36.8	**956**	51.17	**96**	65.54	**238**	79.91
988	8.77	**629**	23.13	**771**	37.5	**913**	51.87	**53**	66.24	**195**	80.61
945	9.47	**128**	23.15	**270**	37.52	**412**	51.89	**554**	66.26	**696**	80.63
444	9.49	**85**	23.84	**227**	38.21	**369**	52.59	**511**	66.96	**653**	81.33
401	10.19	**586**	23.86	**728**	38.24	**870**	52.61	**10**	66.98	**152**	81.35
902	10.21	**543**	24.56	**685**	38.93	**827**	53.31	**969**	67.68	**109**	82.05
859	10.91	**42**	24.58	**184**	38.95	**326**	53.33	**468**	67.7	**610**	82.07
358	10.93	**1001**	25.28	**141**	39.65	**283**	54.02	**425**	68.39	**567**	82.77
315	11.63	**500**	25.3	**642**	39.67	**784**	54.05	**926**	68.42	**66**	82.79
816	11.65	**457**	26	**599**	40.37	**741**	54.74	**883**	69.11	**23**	83.49
773	12.35	**958**	26.02	**98**	40.39	**240**	54.76	**382**	69.13	**524**	83.51
272	12.37	**915**	26.72	**55**	41.09	**197**	55.46	**339**	69.83	**481**	84.2
229	13.07	**414**	26.74	**556**	41.11	**698**	55.48	**840**	69.85	**982**	84.22
730	13.09	**371**	27.44	**513**	41.81	**655**	56.18	**797**	70.55	**939**	84.92
687	13.79	**872**	27.46	**12**	41.83	**154**	56.2	**296**	70.57	**438**	84.94
186	13.8	**829**	28.16	**971**	42.53	**111**	56.9	**253**	71.27	**395**	85.64

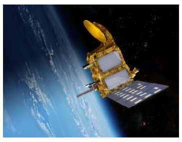
Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)
896	85.66	**36**	100.03	**178**	114.4	**320**	128.77	**462**	143.14	**604**	157.52
853	86.36	**995**	100.73	**135**	115.1	**277**	129.47	**419**	143.85	**561**	158.22
352	86.38	**494**	100.75	**636**	115.12	**778**	129.49	**920**	143.86	**60**	158.24
309	87.08	**451**	101.45	**593**	115.82	**735**	130.19	**877**	144.56	**17**	158.94
810	87.1	**952**	101.47	**92**	115.84	**234**	130.21	**376**	144.58	**518**	158.95
767	87.8	**909**	102.17	**49**	116.54	**191**	130.91	**333**	145.28	**475**	159.65
266	87.82	**408**	102.19	**550**	116.56	**692**	130.93	**834**	145.3	**976**	159.67
223	88.51	**365**	102.89	**507**	117.26	**649**	131.63	**791**	146	**933**	160.37
724	88.54	**866**	102.91	**6**	117.28	**148**	131.65	**290**	146.02	**432**	160.39
681	89.23	**823**	103.61	**965**	117.98	**105**	132.35	**247**	146.72	**389**	161.09
180	89.25	**322**	103.62	**464**	117.99	**606**	132.37	**748**	146.74	**890**	161.11
137	89.95	**279**	104.32	**421**	118.7	**563**	133.07	**705**	147.44	**847**	161.81
638	89.97	**780**	104.34	**922**	118.71	**62**	133.09	**204**	147.46	**346**	161.83
595	90.67	**737**	105.04	**879**	119.42	**19**	133.79	**161**	148.16	**303**	162.53
94	90.69	**236**	105.06	**378**	119.43	**520**	133.8	**662**	148.18	**804**	162.55
51	91.39	**193**	105.76	**335**	120.13	**477**	134.5	**619**	148.88	**761**	163.25
552	91.41	**694**	105.78	**836**	120.15	**978**	134.52	**118**	148.89	**260**	163.26
509	92.11	**651**	106.48	**793**	120.85	**935**	135.22	**75**	149.59	**217**	163.96
8	92.13	**150**	106.5	**292**	120.87	**434**	135.24	**576**	149.61	**718**	163.98
967	92.83	**107**	107.2	**249**	121.57	**391**	135.94	**533**	150.31	**675**	164.68
466	92.85	**608**	107.22	**750**	121.59	**892**	135.96	**32**	150.33	**174**	164.7
423	93.55	**565**	107.92	**707**	122.29	**849**	136.66	**991**	151.03	**131**	165.4
924	93.56	**64**	107.94	**206**	122.31	**348**	136.68	**490**	151.05	**632**	165.42
881	94.26	**21**	108.64	**163**	123.01	**305**	137.38	**447**	151.75	**589**	166.12
380	94.28	**522**	108.65	**664**	123.03	**806**	137.4	**948**	151.77	**88**	166.14
337	94.98	**479**	109.35	**621**	123.73	**763**	138.1	**905**	152.47	**45**	166.84
838	95	**980**	109.37	**120**	123.74	**262**	138.11	**404**	152.49	**546**	166.86
795	95.7	**937**	110.07	**77**	124.44	**219**	138.81	**361**	153.19	**503**	167.56
294	95.72	**436**	110.09	**578**	124.46	**720**	138.83	**862**	153.21	**2**	167.58
251	96.42	**393**	110.79	**535**	125.16	**677**	139.54	**819**	153.91	**961**	168.28
752	96.44	**894**	110.81	**34**	125.18	**176**	139.55	**318**	153.92	**460**	168.29
709	97.14	**851**	111.51	**993**	125.88	**133**	140.25	**275**	154.62	**417**	169
208	97.16	**350**	111.53	**492**	125.9	**634**	140.27	**776**	154.64	**918**	169.01
165	97.86	**307**	112.23	**449**	126.6	**591**	140.97	**733**	155.34	**875**	169.71
666	97.88	**808**	112.25	**950**	126.62	**90**	140.99	**232**	155.36	**374**	169.73
623	98.58	**765**	112.95	**907**	127.32	**47**	141.69	**189**	156.06	**331**	170.43
122	98.59	**264**	112.96	**406**	127.34	**548**	141.71	**690**	156.08	**832**	170.45
79	99.29	**221**	113.67	**363**	128.04	**505**	142.41	**647**	156.78	**789**	171.15
580	99.31	**722**	113.68	**864**	128.06	**4**	142.43	**146**	156.8	**288**	171.17
537	100.01	**679**	114.39	**821**	128.76	**963**	143.13	**103**	157.5	**245**	171.87



Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)
746	171.89	**888**	186.26	**28**	200.63	**170**	215	**312**	229.37	**454**	243.74
703	172.59	**845**	186.96	**987**	201.33	**127**	215.7	**269**	230.07	**411**	244.45
202	172.61	**344**	186.98	**486**	201.35	**628**	215.72	**770**	230.09	**912**	244.46
159	173.31	**301**	187.68	**443**	202.05	**585**	216.42	**727**	230.79	**869**	245.16
660	173.33	**802**	187.7	**944**	202.07	**84**	216.44	**226**	230.81	**368**	245.18
617	174.03	**759**	188.4	**901**	202.77	**41**	217.14	**183**	231.51	**325**	245.88
116	174.04	**258**	188.41	**400**	202.78	**542**	217.16	**684**	231.53	**826**	245.9
73	174.74	**215**	189.11	**357**	203.49	**499**	217.86	**641**	232.23	**783**	246.6
574	174.76	**716**	189.13	**858**	203.5	**1000**	217.87	**140**	232.25	**282**	246.62
531	175.46	**673**	189.83	**815**	204.21	**957**	218.58	**97**	232.95	**239**	247.32
30	175.48	**172**	189.85	**314**	204.22	**456**	218.59	**598**	232.96	**740**	247.34
989	176.18	**129**	190.55	**271**	204.92	**413**	219.3	**555**	233.67	**697**	248.04
488	176.2	**630**	190.57	**772**	204.94	**914**	219.31	**54**	233.68	**196**	248.05
445	176.9	**587**	191.27	**729**	205.64	**871**	220.01	**11**	234.39	**153**	248.76
946	176.92	**86**	191.29	**228**	205.66	**370**	220.03	**512**	234.4	**654**	248.77
903	177.62	**43**	191.99	**185**	206.36	**327**	220.73	**469**	235.1	**611**	249.48
402	177.64	**544**	192.01	**686**	206.38	**828**	220.75	**970**	235.12	**110**	249.49
359	178.34	**501**	192.71	**643**	207.08	**785**	221.45	**927**	235.82	**67**	250.19
860	178.35	**1002**	192.72	**142**	207.1	**284**	221.47	**426**	235.84	**568**	250.21
817	179.06	**959**	193.43	**99**	207.8	**241**	222.17	**383**	236.54	**525**	250.91
316	179.07	**458**	193.44	**600**	207.82	**742**	222.19	**884**	236.56	**24**	250.93
273	179.77	**415**	194.15	**557**	208.52	**699**	222.89	**841**	237.26	**983**	251.63
774	179.79	**916**	194.16	**56**	208.53	**198**	222.9	**340**	237.28	**482**	251.65
731	180.49	**873**	194.86	**13**	209.24	**155**	223.61	**297**	237.98	**439**	252.35
230	180.51	**372**	194.88	**514**	209.25	**656**	223.62	**798**	238	**940**	252.37
187	181.21	**329**	195.58	**471**	209.95	**613**	224.33	**755**	238.7	**897**	253.07
688	181.23	**830**	195.6	**972**	209.97	**112**	224.34	**254**	238.71	**396**	253.08
645	181.93	**787**	196.3	**929**	210.67	**69**	225.04	**211**	239.41	**353**	253.79
144	181.95	**286**	196.32	**428**	210.69	**570**	225.06	**712**	239.43	**854**	253.8
101	182.65	**243**	197.02	**385**	211.39	**527**	225.76	**669**	240.14	**811**	254.51
602	182.67	**744**	197.04	**886**	211.41	**26**	225.78	**168**	240.15	**310**	254.52
559	183.37	**701**	197.74	**843**	212.11	**985**	226.48	**125**	240.85	**267**	255.22
58	183.38	**200**	197.75	**342**	212.13	**484**	226.5	**626**	240.87	**768**	255.24
15	184.09	**157**	198.46	**299**	212.83	**441**	227.2	**583**	241.57	**725**	255.94
516	184.1	**658**	198.47	**800**	212.85	**942**	227.22	**82**	241.59	**224**	255.96
473	184.8	**615**	199.18	**757**	213.55	**899**	227.92	**39**	242.29	**181**	256.66
974	184.82	**114**	199.19	**256**	213.56	**398**	227.93	**540**	242.31	**682**	256.68
931	185.52	**71**	199.89	**213**	214.26	**355**	228.64	**497**	243.01	**639**	257.38
430	185.54	**572**	199.91	**714**	214.28	**856**	228.65	**998**	243.02	**138**	257.4
387	186.24	**529**	200.61	**671**	214.98	**813**	229.36	**955**	243.73	**95**	258.1

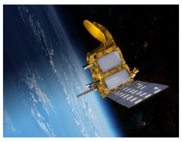


Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)	Pass	Long(°)
596	258.12	**738**	272.49	**880**	286.86	**20**	301.23	**162**	315.6	**304**	329.97
553	258.82	**695**	273.19	**837**	287.56	**979**	301.93	**119**	316.3	**261**	330.67
52	258.83	**194**	273.2	**336**	287.58	**478**	301.95	**620**	316.32	**762**	330.69
9	259.54	**151**	273.91	**293**	288.28	**435**	302.65	**577**	317.02	**719**	331.39
510	259.55	**652**	273.92	**794**	288.3	**936**	302.67	**76**	317.04	**218**	331.41
467	260.25	**609**	274.63	**751**	289	**893**	303.37	**33**	317.74	**175**	332.11
968	260.27	**108**	274.64	**250**	289.01	**392**	303.38	**534**	317.76	**676**	332.13
925	260.97	**65**	275.34	**207**	289.71	**349**	304.08	**491**	318.46	**633**	332.83
424	260.99	**566**	275.36	**708**	289.73	**850**	304.1	**992**	318.47	**132**	332.85
381	261.69	**523**	276.06	**665**	290.43	**807**	304.8	**949**	319.17	**89**	333.55
882	261.71	**22**	276.08	**164**	290.45	**306**	304.82	**448**	319.19	**590**	333.57
839	262.41	**981**	276.78	**121**	291.15	**263**	305.52	**405**	319.89	**547**	334.27
338	262.43	**480**	276.8	**622**	291.17	**764**	305.54	**906**	319.91	**46**	334.28
295	263.13	**437**	277.5	**579**	291.87	**721**	306.24	**863**	320.61	**3**	334.98
796	263.15	**938**	277.52	**78**	291.89	**220**	306.26	**362**	320.63	**504**	335
753	263.85	**895**	278.22	**35**	292.59	**177**	306.96	**319**	321.33	**461**	335.7
252	263.86	**394**	278.23	**536**	292.61	**678**	306.98	**820**	321.35	**962**	335.72
209	264.56	**351**	278.94	**493**	293.31	**635**	307.68	**777**	322.05	**919**	336.42
710	264.58	**852**	278.95	**994**	293.33	**134**	307.7	**276**	322.07	**418**	336.44
667	265.28	**809**	279.65	**951**	294.02	**91**	308.4	**233**	322.77	**375**	337.14
166	265.3	**308**	279.67	**450**	294.04	**592**	308.42	**734**	322.79	**876**	337.16
123	266	**265**	280.37	**407**	294.74	**549**	309.12	**691**	323.49	**833**	337.86
624	266.02	**766**	280.39	**908**	294.76	**48**	309.13	**190**	323.5	**332**	337.88
581	266.72	**723**	281.09	**865**	295.46	**5**	309.83	**147**	324.2	**289**	338.58
80	266.74	**222**	281.11	**364**	295.48	**506**	309.85	**648**	324.22	**790**	338.6
37	267.44	**179**	281.81	**321**	296.18	**463**	310.55	**605**	324.92	**747**	339.3
538	267.46	**680**	281.83	**822**	296.2	**964**	310.57	**104**	324.94	**246**	339.31
495	268.16	**637**	282.53	**779**	296.9	**921**	311.27	**61**	325.64	**203**	340.01
996	268.17	**136**	282.55	**278**	296.92	**420**	311.29	**562**	325.66	**704**	340.03
953	268.88	**93**	283.25	**235**	297.62	**377**	311.99	**519**	326.36	**661**	340.73
452	268.89	**594**	283.27	**736**	297.64	**878**	312.01	**18**	326.38	**160**	340.75
409	269.59	**551**	283.97	**693**	298.34	**835**	312.71	**977**	327.08	**117**	341.45
910	269.61	**50**	283.98	**192**	298.35	**334**	312.73	**476**	327.1	**618**	341.47
867	270.31	**7**	284.68	**149**	299.05	**291**	313.43	**433**	327.8	**575**	342.17
366	270.33	**508**	284.7	**650**	299.07	**792**	313.45	**934**	327.82	**74**	342.19
323	271.03	**465**	285.4	**607**	299.77	**749**	314.15	**891**	328.52	**31**	342.89
824	271.05	**966**	285.42	**106**	299.79	**248**	314.16	**390**	328.53	**532**	342.91
781	271.75	**923**	286.12	**63**	300.49	**205**	314.86	**347**	329.23	**489**	343.61
280	271.77	**422**	286.14	**564**	300.51	**706**	314.88	**848**	329.25	**990**	343.62
237	272.47	**379**	286.84	**521**	301.21	**663**	315.58	**805**	329.95	**947**	344.32



Pass	Long (˚)	Pass	Long(˚)
446	344.34	**588**	358.71
403	345.04	**545**	359.41
904	345.06	**44**	359.43
861	345.76		
360	345.78		
317	346.48		
818	346.5		
775	347.2		
274	347.22		
231	347.92		
732	347.94		
689	348.64		
188	348.65		
145	349.35		
646	349.37		
603	350.07		
102	350.09		
59	350.79		
560	350.81		
517	351.51		
16	351.53		
975	352.23		
474	352.25		
431	352.95		
932	352.97		
889	353.67		
388	353.68		
345	354.38		
846	354.4		
803	355.1		
302	355.12		
259	355.82		
760	355.84		
717	356.54		
216	356.56		
173	357.26		
674	357.28		
631	357.98		
130	358		
87	358.7		

Table 7 : Equator Crossing Longitudes (in order of Longitude)



2.6.3.2. Geodetic Orbit (From July 2016 until End Of Life)

From July 4th 2016, SARAL enters a new phase called SARAL-DP (Drifting Phase). Its altitude of 800km is increased by 1 km and no more maneuvers are performed on the satellite, except for collision avoidance. This phase has a cycle numbering beginning at 100 and the pass 1 starts at the first South Pole crossing after the altitude increase maneuver.

2.6.4. The SARAL/AltiKa Project Phases

The satellite mission has two main phases (verification and operational).

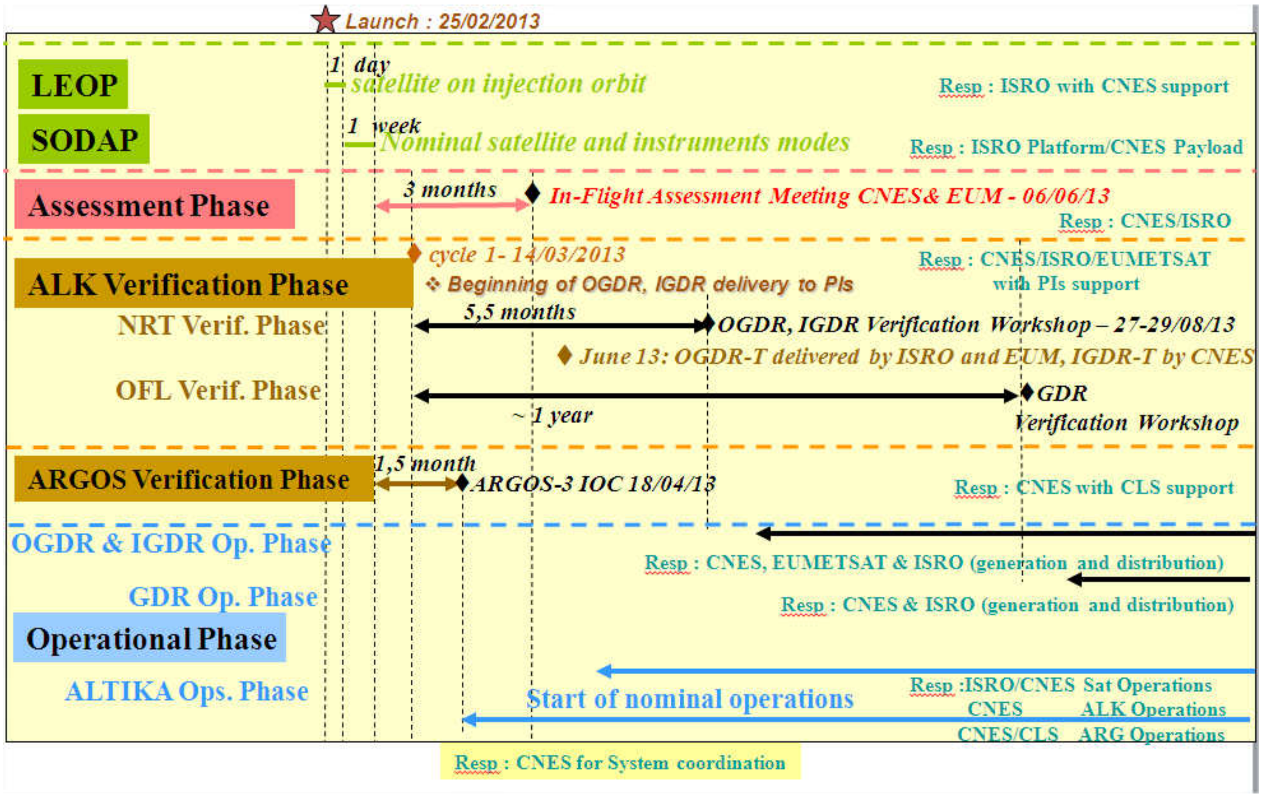


Figure 12 : SARAL Mission Phases and associated responsibilities

2.6.4.1. The verification phase

The verification phase (9 -10 months since beginning of cycle 1) began shortly after launch, when the satellite reached the operational (nominal repetitive) orbit and the satellite and sensor systems were functioning normally. This phase continued until the data received from the sensors were satisfactorily calibrated and verified.

During this calibration/validation phase, the quality control will be achieved through many steps as a series of quality controls designed to ensure a continuous supply of data : regular cyclic data product analysis (complete parameter analysis and diagnostics, missions/edited measurements, crossovers and along-track analysis, orbit analysis, …), cross-calibration with other altimeters (Jason-2,…), instrumental expertise for altimeter and radiometer monitoring, and by performing absolute calibration at dedicated *in situ* calibration sites.

This verification phase is divided in 2 phases which overlap:

1. One dedicated to the validation of the near real time products (OGDRs).
2. The second phase dedicated to the validation of the off-line products (IGDR and GDR).

2.6.4.2. The operational (routine and long-term CALVAL activities)

The operational phase begins after the successful validation of each product type, and when all necessary algorithm and processing changes are implemented to have SARAL/AltiKa performances at the same level as other altimetric satellites. Beyond the CALVAL phase, it is necessary to perform regular long-term CALVAL in order to monitor biases and drifts of AltiKa overall system: in addition to previously mentioned analysis, comparison of SARAL/AltiKa data with global and regional networks of *in situ* data (tide gauges, T/S profiles, …) will be performed as soon as enough *in situ* data are available (~1 year after launch). These different analysis will also be implemented in order to calibrate and validate new ground processing algorithms that could be proposed and implemented during the CALVAL phase.

Considering the specificities of SARAL/AltiKa mission, particular attention will be given to evaluate and monitor the mission performances over coastal and inland water areas, over polar oceans and ice surfaces, as well as under rainy/cloudy conditions, with respect to previous and other in-flight altimetry missions.

2.7. Data Processing and Distribution

Processing centers perform functions such as science data processing, data verification and orbit determination.

There are three levels of processed data:

- Telemetry data (raw data or level0)
- Sensor Data Records (engineering units or level1)
- Geophysical Data Records (geophysical units or level2)

There are two kinds of data processing and distribution:

- **Real-time processing and distribution** (EUMETSAT and ISRO/NRSC)

  The operational geophysical data record (OGDR) is available with a latency of 3-5 hours. Note that this is a non-validated product that uses orbits computed by the on-board DORIS Navigator (DIODE) and that does not contain all the environmental/geophysical corrections.

- **Delayed-mode processing and distribution** (CNES and ISRO/SAC)

  The interim geophysical data record (IGDR) is available per pass with a latency of less than 1.5 days. Note that this is not a fully validated product, although it uses a preliminary orbit and includes all the environmental/geophysical corrections (preliminary for some of them). This product is generated by CNES only.

  The geophysical data record (GDR) is a fully validated product that uses a precise orbit and the best environmental/geophysical corrections. This product is available per repeat cycle with a latency of 40 days. Validation is performed by CNES teams to ensure in depth validation. GDR products are generated both by CNES and ISRO/SAC.

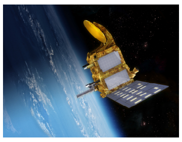
Geophysical data records are disseminated to users as they become available, as well as ingested in two main archives (at CNES and ISRO), where they are made available to the scientific community, ISRO being in charge of data dissemination to Indian community and CNES to the rest of the scientific community.

The NRT and offline data are provided through different sources and means as discussed below. Note that the telemetry acquisition strategy, designed to minimize the risk of science data loss, sometimes results in files containing data which overlaps in time. The NRT ground processing does not remove these overlaps, so it is possible to encounter two or more OGDR products which have overlapping start and stop sensing times. CNES-EUMETSAT-ISRO centers are disseminating SARAL/AltiKa products according to the interagency agreement.

- **CNES via AVISO data service**: http://www.aviso.altimetry.fr

  "Archiving, Validation and Interpretation of Satellite Oceanographic data" is the French multi-satellite data distribution center dedicated to space oceanography, developed by CNES.

  AVISO distributes and archives SARAL/AltiKa delayed-time data (IGDR, GDR).



- **EUMETSAT**: http://www.eumetsat.int

EUMETSAT is the European Organisation for the Exploitation of Meteorological Satellites. Its role is to deliver weather and climate-related satellite data, images and products– 24 hours a day, 365 days a year.

EUMETSAT distributes operational data (OGDR).

- **ISRO**: http://www.isro.org/

The objective of ISRO is to develop space technology and its application to various national tasks.

ISRO distributes (at national level) operational data (OGDR) and archives delayed-time data (GDR).

2.7.1. Access to NRT data

The OGDR and OGDR-SSHA files are produced at ISRO and EUMETSAT. OGDR-BUFR files are produced at EUMETSAT.

Telemetry data downlinked to CNES's polar X-band ground stations at Kiruna (Sweden) and Inuvik (Canada) are used to produce OGDR products.

In near real time, ISRO disseminates the complete set of OGDR files via ftp and EUMETSAT disseminates the complete set of OGDR files on EUMETCast. The complete set of OGDR files consists of OGDR, OGDR-SSHA and OGDR-BUFR.

The OGDR-BUFR data are additionally available in near real-time from the Global Telecommunications System (GTS).

Details on data dissemination services from ISRO and EUMETSAT agencies are described below.

Note that, for user convenience, CNES distributes OGDR products (native and reduced) from EUM on its AVISO ftp server. CNES declines any responsibility in case of products latency or gaps happening on the ftp server.

2.7.2. Access to off-line data

The IGDR families are produced solely by CNES while GDR families are produced by CNES and ISRO. They are available for French and foreign users on the AVISO ftp server (http://www.aviso.altimetry.fr). For Indian users, off line GDR products are available on MOSDAC (http://www.mosdac.gov.in). Both of these archival facilities also provide a variety of auxiliary files used to produce the O/I/GDR datasets, and ISRO also provides the OGDR family of datasets.

Data dissemination services from ISRO and CNES agencies are described below.

2.7.3. Documentation and Sample Reader Software

This SARAL/AltiKa User's Handbook document describes only the native product format. A description of the O/I/GDR product format and contents is provided in the CNES document "SALP-ST-M-EA-15839-CN: SALP Products Specification - Volume 20 : AltiKa / SARAL User Products" (see RD 4). All documents are available through the data dissemination services.

Tools such as sample reading routines in Fortran-90, C, and IDL are also available through the data dissemination services on the AVISO website and on the ISRO website (TBC by ISRO). The toolbox BRAT is also recommended to read and study AltiKa data (see 6.4.3).

A BUFR reading software library can be obtained from:
https://confluence.ecmwf.int/display/ECC/Releases

2.8. Access to data via ISRO

2.8.1. Access to NRT data

TBD by ISRO

2.8.2. Access to off line data

TBD by ISRO

2.9. Access to data via EUMETSAT

2.9.1. NRT data access

Operational users requiring near real-time access (within a few hours of acquisition) can receive data via EUMETCast, which is the prime dissemination mechanism for EUMETSAT satellite data and meteorological products. EUMETCast is also used to deliver data supplied by several external data providers.

EUMETCast is an environmental data and product dissemination system based on standard Digital Video Broadcast (DVB) technology. It uses commercial telecommunication geostationary satellites to broadcast data and products to a wide user community. EUMETSAT operates three EUMETCast broadcasts: EUMETCast Europe in Ku-band via Hotbird-6 EUMETCast Africa in C-band via AtlanticBird-3 and EUMETCast South America in C-band via NewSkies-806. The coverage zones of these broadcasts are shown in Figure below. The SARAL/AltiKa products are currently disseminated over all beams.

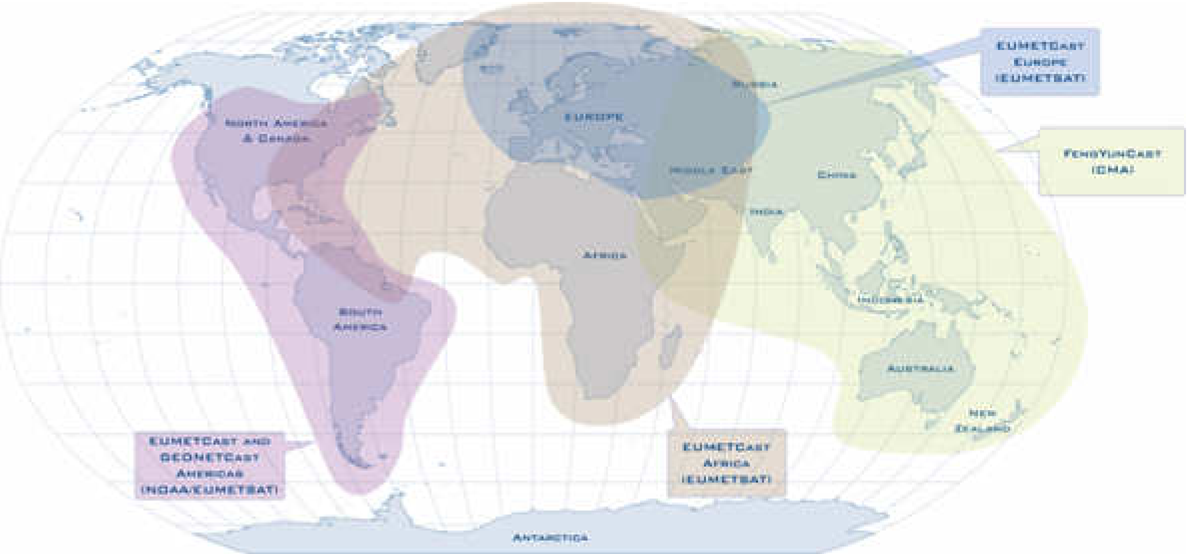
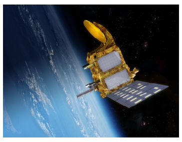


Figure 11 : GEONETCast Coverage Zones

EUMETCast is part of a wider data dissemination cooperation network known as GEONETCast, defined as a global network of satellite based data dissemination systems providing environmental data to a world-wide user community. The current partners within the GEONETCast initiative



include the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO) and EUMETSAT, as well as many prospective data provider partners.

EUMETCast is a multi-service dissemination mechanism and other environmental data streams and products are also delivered via EUMETCast :

- Space-based observations from the Meteosat, Metop, GOES, MT-SAT and FY2 satellites – at their most frequent, these data are delivered to Users within 5-minutes of processing
- MODIS level 1and 2 products covering selective geographical regions
- Numerical Weather Forecasts
- In-situ observational data
- Land application products covering Europe, Africa and South America
- Marine meteorological and ocean surface products covering the Atlantic, Mediterranean Sea and Yellow Sea
- Atmospheric chemistry products

EUMETCast has an installed user base of over 2500 stations worldwide.

A typical EUMETCast reception station comprises a standard PC with DVB card inserted and a satellite off-set antenna fitted with a digital universal V/H LNB. All components of the reception station are commercially available. The hardware costs for a single PC station for EUMETCast Europe (Ku-band) reception start at around €1,500. In addition, EUMETCast Client Software package is required for handling the incoming DVB and storing it as data files. This package is available directly from EUMETSAT at a one of fee of €100and forms part of any registration process.

Further information on EUMETCast can be found on the EUMETSAT Web site at:

http://www.eumetsat.int/Home/Main/What_We_Do/EUMETCast/index.htm?l=en or alternatively follow the links to 'What We Do'-'EUMETCast'. Note that the coverage of EUMETCast is achieved through different beams, and the user location will determine the technical requirements of the EUMETCast reception station equipment.

The SARAL/AltiKa products available via EUMETCast are the EUMETSAT and ISRO injected OGDR, OGDR-SSHA and OGDR-BUFR. To access these on EUMETCast, users are requested to register online via the EUMETSAT Web site, or to contact the EUMETSAT User Service Helpdesk. As for Jason-2 near real-time products, already disseminated by EUMETSAT via EUMETCast, the SARAL/AltiKa products will be disseminated on all EUMETCast channels (Europe, Americas and Africa).

All enquiries related to EUMETCast can be addressed to the EUMETSAT User Helpdesk, email ops@eumetsat.int, who will be happy to assist with information on reception station manufacturers, reception station setup and data access registration to the SARAL/AltiKa service, or indeed to other near real-time EUMETSAT data services.

2.9.2. Access to archived data

The SARAL/AltiKa products generated and distributed by EUMETSAT in near real-time (i.e., OGDR, OGDR-SSHA and OGDR-BUFR) are also archived in the multi-mission EUMETSAT Archive. Any user can access SARAL/AltiKa data from the EUMETSAT archive upon registration. Information on registration, the archive itself and how to use it can be found at http://archive.eumetsat.org/umarf or follow the links to 'Access to Data' and then 'Archive Service'. Data delivery media include, among others, direct ftp push to a provided IP address, including the possibility of establishing standing orders, or download by the user from an html page. Note however that this is not a near real-time data access, but that it can take up to several hours and occasionally even days to get the data.

2.10. Access to data on GTS

2.10.1.1. GTS access for OGDR-BUFR files

All of the OGDR-BUFR data, injected by EUMETSAT, will appear on the World Meteorological Organization's GTS network. End users with a GTS presence (typically large meteorological agencies) can retrieve the data by keying on the WMO/GTS headers specific to the SARAL/AltiKa data: 'ISZX02 EUMS' for EUMETSAT OGDR-BUFR files. The original files are comprised of approximately 15 minute BUFR 'messages' which will appear separately on the GTS.

2.11. CNES data distribution

2.11.1. Details of off line data access via CNES

Users have access to SARAL/AltiKa public data through a dedicated AVISO ftp server with an anonymous account (nevertheless, please note that users shall be registered before downloading products in order to be identified by AVISO helpdesk and to receive altimetric news. Registration form is available at: https://www.aviso.altimetry.fr/en/data/data-access/registration-form.html

Off line IGDR and GDR products are available on the following server:

- IP address / server name : ftp-access.aviso.altimetry.fr
- User account : anonymous
- Home directory : /geophysical-data-record/saral

With the following ftp server directory tree:

documentation	→	directory containing product spec, product handbook, reading tools, …
ogdr_f[3]	→	directory containing OGDR native products
ssha_ogdr_f	→	directory containing OGDR reduced products
igdr_f	→	directory containing IGDR native products (with a sub directory for each cycle and sub directory containing the latest data)
sigdr_f	→	directory containing S-IGDR (with a unique sub directory containing the latest data)
ssha_igdr_f	→	directory containing IGDR reduced products (with a sub directory for each cycle and a sub directory containing the latest data)
gdr_f	→	directory containing GDR native products (with a sub directory for each cycle)
sgdr_f	→	directory containing S-GDR (with a sub directory for each cycle)
ssha_gdr_f	→	directory containing GDR reduced products (with a sub directory for each cycle)
gdr_f_validation_report	→	directory containing GDR validation reports

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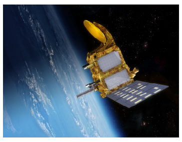
[3] « _t » stands for "test version" when products are disseminated during commissioning phase.



For any questions on SARAL/AltiKa data dissemination on AVISO servers please contact the user helpdesk: aviso@altimetry.fr

3. Product evolution history

3.1. Models and Standards History

3.1.1. Models and standard on Version "T" Products

The version of the data produced during the Cal/Val phase of the SARAL/AltiKa mission is identified by the version letter “T” in the name of the data products. This “T” calibration/validation version will be extensively validated by PIs during the verification phase.

This product version adopts models and standards that are consistent with version “d” of the Jason-1 and Jason-2 (I)GDR products (see RD 1).

The table below summarizes the models and standards that are adopted in this version of the SARAL/AltiKa (O)(I)GDRs.

Model	Product Version "T”
Orbit	Based on Doris on-board navigator solution for OGDRS. DORIS tracking data for IGDRs DORIS+SLR tracking data for GDRs.
Altimeter Retracking	“Ocean” retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: - Epoch (tracker range offset) ⇒ altimeter range - Composite Sigma ⇒ SWH - Amplitude ⇒ Sigma0 - Square of mispointing angle “Ice 1” retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: - Epoch (tracker range offset) ⇒ altimeter range - Amplitude ⇒ Sigma0 “Ice 2” retracking The aim of the ice2 retracking algorithm is to make the measured waveform coincide with a return power model, according to Least Square estimators. Retrieval of the following parameters: - Epoch ⇒ altimeter range - Width of the leading edge - Amplitude ⇒ Sigma0 - Slope of the logarithm of the waveform at the trailing edge ⇒ Mispointing angle - the thermal noise level (to be removed from the waveform samples) “Sea Ice” retracking

Model	Product Version "T"
	In this algorithm, waveform parameterisation based on peak threshold retracking is applied to the Ka-band waveform. From this parameterisation, a tracking offset and backscatter estimate are determined. Tests are made on the extent of the tracking offset, and extreme values are flagged as retracking failures. The sea-ice waveform amplitude is determined by finding the maximum value of the waveform samples and the tracking offset is determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the above sea-ice amplitude. A tracking offset is determined. The Centre Of Gravity offset correction must be included in the range measurement as the correction is not available separately in the L2 product. - Amplitude ⇒ Sigma0 - Tracking offset ⇒ altimeter range - Centre Of Gravity offset correction ⇒ correction to altimeter range measurement N.B.: Please note that ice1, sea ice and ice2 retrackings have been lightly validated and that these algorithms should be tuned to Ka-band.
Altimeter Instrument Corrections	Consistent with MLE4 retracking algorithm
SARAL/AltiKa Radiometer Parameters	Using on-board calibration
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Tropospheric Range Correction from Model	From ECMWF model
Ionosphere correction	Based on Global Ionosphere TEC Maps from JPL
Sea State Bias	Empirical solution (from NOAA Laboratory for Satellite Altimetry) fitted on 6 months of SARAL GDR_T data
Mean Sea Surface	MSS_CNES-CLS11
Mean Dynamic Topography	MDT_CNES-CLS09
Geoid	EGM96
Bathymetry Model	DTM2000.1
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 on (I)GDRs. None for OGDRs. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Tide Solution 1	GOT4.8 (from GSFC)
Tide Solution 2	FES2012 (from LEGOS/NOVELTIS/CNES/CLS)
Equilibrium long-period ocean tide model	From tidal potential of "Cartwright and Edden [1973] Corrected tables of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264." ;
Non-equilibrium long-period ocean tide model	Mm, Mf, Mtm, and Ssa from FES2012
Solid Earth Tide Model	From tidal potential of "Cartwright and Edden [1973] Corrected tables of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264." ;
Pole Tide Model	Equilibrium model
Wind Speed from Model	ECMWF model
Altimeter Wind Speed Model	One-dimensional model, as a function of backscatter coefficient, tuned to AltiKa's backscatter measurements. John Lillibridge et al. [2014] - One and Two-Dimensional Wind Speed Models for Ka-band Altimetry - JTECH-D-13-00167.1
Trailing edge variation Flag	Derived from Matching Pursuit algorithm (from J. Tournadre, IFREMER)

Model	Product Version "T"
Ice Flag	Derived from comparison of the model wet tropospheric correction to a dual-frequency wet tropospheric correction retrieved from radiometer brightness temperatures, with a default value issued from a climatology table

Table 8 : Version "T" models and standards

3.1.2. Models and standards on Version "f" Products

The current product version corrects a few minor issues in the version 'T' GDRs, adopts new models, and includes of new fields improving the data quality.

The table below summarizes the models and standards that are adopted in this version of the SARAL/AltiKa (O)(I)GDRs. Section 3.1.2 provides more details on some of these models.

Model	Product Version "f"
Orbit	Based on Doris on-board navigator solution for OGDRS. DORIS tracking data for IGDRs (orbit standard "POE-F"). DORIS+SLR tracking data for GDRs. (orbit standard "POE-F").
Altimeter Retracking	"Ocean" retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: - Epoch (tracker range offset) ⇒ altimeter range - Composite Sigma ⇒ SWH - Amplitude ⇒ Sigma0 - Square of mispointing angle "Ice 1" retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: - Epoch (tracker range offset) ⇒ altimeter range - Amplitude ⇒ Sigma0 "Ice 2" retracking The aim of the ice2 retracking algorithm is to make the measured waveform coincide with a return power model, according to Least Square estimators. Retrieval of the following parameters: - Epoch ⇒ altimeter range - Width of the leading edge - Amplitude ⇒ Sigma0 - Slope of the logarithm of the waveform at the trailing edge ⇒ Mispointing angle - the thermal noise level (to be removed from the waveform samples) "Ice 3" retracking Ice 3 retracking is a TFMRA retracking based on [Davis 1997] and [Helm 2014] "Sea Ice" retracking In this algorithm, waveform parameterisation based on peak threshold retracking is applied to the Ka-band waveform. From this

Model	Product Version "f"
	parameterisation, a tracking offset and backscatter estimate are determined. Tests are made on the extent of the tracking offset, and extreme values are flagged as retracking failures. The sea-ice waveform amplitude is determined by finding the maximum value of the waveform samples and the tracking offset is determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the above sea-ice amplitude. A tracking offset is determined. The Centre Of Gravity offset correction must be included in the range measurement as the correction is not available separately in the L2 product. - Amplitude ⇒ Sigma0 - Tracking offset ⇒ altimeter range - Centre Of Gravity offset correction ⇒ correction to altimeter range measurement N.B.: Please note that ice1, ice2, ice3 and sea ice retrackings have been lightly validated and that these algorithms should be tuned to Ka-band.
Altimeter Instrument Corrections	Consistent with MLE4 retracking algorithm
SARAL/AltiKa Radiometer Parameters	Pure Empirical Neural Network approach (learning database from measurements) (see §5.6.2) - Wet Tropospheric Correction and Water Vapour 5-inputs algorithm: brightness temperatures (23.8 GHz, 37 GHz), altimeter backscattering coefficient, SST and γ_{800} - Atmospheric Attenuation and Cloud liquid water content 3-inputs algorithm: brightness temperatures (23.8 GHz, 37 GHz), altimeter backscattering coefficient
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Tropospheric Range Correction from Model	From ECMWF model. 2 solutions: integration from sea surface level or using altimetry range.
Ionosphere correction	Based on Global Ionosphere TEC Maps from JPL
Sea State Bias	[Tran, 2019] empirical solutions fitted on one year of SARAL GDR-F data Two solutions: - 2D model from SWH and altimeter wind-speed (standard version) - 3D model from SWH, altimeter wind-speed and t02 mean wave period from model (improved version)
Mean Sea Surface Solution 1	MSS_CNES-CLS2015
Mean Sea Surface Solution 2	DTU 2015
Mean Dynamic Topography	MDT_CNES-CLS-2018
Geoid	EGM2008
Bathymetry Model	ACE2 (from EAPRS Laboratory)
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 atmospheric pressures after removing S1 and S2 atmospheric tides
Tide Solution 1	GOT4.10c (from GSFC)
Tide Solution 2	FES2014b (from LEGOS/NOVELTIS/CNES/CLS)
Equilibrium long-period	From tidal potential of "Cartwright and Edden [1973] Corrected tables

Model	Product Version “f”
ocean tide model	of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264." ;
Non-equilibrium long-period ocean tide model	Mm, Mf, Mtm, MSqm, Sa and Ssa from FES2014b
Solid Earth Tide Model	From tidal potential of "Cartwright and Edden [1973] Corrected tables of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264." ;
Pole Tide Model	[Desai, 2015] with MPL [Desai, 2017]
Internal Tide	HRET-v7.0 [Zaron, 2017] model including 4 internal waves (M2, K1, O1,S2)
Wind Speed from Model	ECMWF model
Altimeter Wind Speed Model	Tran2014 two-dimensional model, from backscatter coefficient and significant wave height, tuned with AltiKa’s measurements.
Trailing edge variation Flag	Derived from Matching Pursuit algorithm (from J. Tournadre, IFREMER)
Ice Flag	Two flags: a sea-ice flag [Tran, 2015a] and an ice-sheet snow flag [Tran, 2015b]. They are based mainly on MLE3 backscatter coefficient and brightness temperatures.

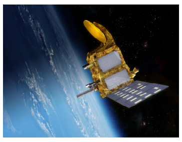
Table 9 : Version “f” models and standards

3.2. Models and Editing on Version “f” Products

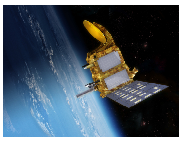
3.2.1. Orbit models

SARAL/AltiKa orbit standards are based on version “POE-F” orbit model. Its characteristics are summarized below. Previous standard used on SARAL/AltiKa mission (POE-E) is also recalled:

	POE-E	POE-F
Gravity model	EIGEN-GRGS.RL03-v2.MEAN-FIELD Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year up to deg/ord 80; C21/S21 modeled according to IERS2010 conventions Solid Earth tides: from IERS2003 conventions Ocean tides: FES2012 Oceanic/atmospheric gravity: 6hr NCEP pressure fields (70x70) + tides from Biancale-Bode model Pole tide: solid Earth and ocean from IERS2010 conventions Third bodies: Sun, Moon, Venus, Mars and Jupiter	**EIGEN-GRGS.RL04-v1.MEAN-FIELD** Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year **up to deg/ord 90; C21/S21 non modified** Unchanged Ocean tides: **FES2014** Oceanic/atmospheric gravity: **3hr dealiasing products from GFZ AOD1B RL06** Unchanged Unchanged



Surface forces	Radiation pressure model: calibrated semi-empirical solar radiation pressure model Earth radiation: Knocke-Ries albedo and IR satellite model Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and MSIS-86 for other satellites	Unchanged Unchanged Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and **MSIS-00 for other satellites**
Estimated dynamical parameters	Stochastic solutions	Unchanged
Satellite reference	Mass and center of gravity: post-launch values + variations generated by Control Center Attitude model: For Jason satellites: quaternions and solar panel orientation from control center, completed by nominal yaw steering law when necessary Other satellites: nominal attitude law	Unchanged **Refined nominal attitude laws**
Displacement of reference points	Earth tides: IERS2003 conventions Ocean loading: FES2012 Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), cubic+linear mean pole model from IERS2010 S1-S2 atmospheric pressure loading, implementation of Ray & Ponte (2003) by van Dam	Unchanged Ocean loading: **FES2014** Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), **new linear mean pole model** Unchanged
Geocenter variations	Tidal: ocean loading and S1-S2 atmospheric pressure loading Non-tidal: seasonal model from J. Ries, applied to DORIS/SLR stations	Unchanged Non-tidal: **full non-tidal model (semi-annual, annual, inter-annual) derived from DORIS data and the OSTM/Jason-2 satellite, applied to DORIS/SLR stations and GPS satellites**
Terrestrial Reference Frame	Extended ITRF2008 (SLRF/ITRF2008, DPOD2008, IGS08)	**Extended ITRF2014 (SLRF/ITRF2014, DPOD2014, IGS14)**
Earth orientation	Consistent with IERS2010 conventions and ITRF2008	Consistent with IERS2010 conventions and **ITRF2014**



Propagations delays	SLR troposphere correction: Mendes-Pavlis	Unchanged
	SLR range correction: constant 5.0 cm range correction for Envisat, elevation dependent range correction for Jason	SLR range correction: **geometrical models for all satellites**
	DORIS troposphere correction: GPT/GMF model	DORIS troposphere correction: **GPT2/VMF1 model**
	DORIS beacons phase center correction	Unchanged
Estimated measurement parameters	DORIS: one frequency bias per pass, one troposphere zenith bias per pass	DORIS: one frequency bias **and drift (for “SAA stations”)** per pass, one troposphere zenith bias per pass, **horizontal tropospheric gradients per arc**
	SLR: Reference used to evaluate orbit precision and stability	Unchanged
Tracking Data corrections	Jason-1 Doris data: updated South Atlantic Anomaly model (J.-M. Lemoine et al.) applied before and after DORIS instrument change	Unchanged
	DORIS time-tagging bias for Envisat and Jason aligned with SLR before and after instrument change	Unchanged
Doris Weight	1.5 mm/s (1.5 cm over 10 sec)	**Process data down to as low elevation angles as possible (from 10° to 5° elevation cut-off angle) with a consistent down-weighting law**
	For Jason-1, SAA DORIS beacons weight is divided by 10 before DORIS instrument change	Unchanged
SLR Weight	15 cm Reference used to evaluate orbit precision and stability	Unchanged

Table 10 : POE-E/POE-F orbit standard

3.2.2. Mean Sea Surface

3.2.2.1. MSS_CNES-CLS15

The first MSS solution (_sol1) provided in Saral/AltiKA GDR is the MSS_CNES-CLS 2015

The MSS_CNES-CLS 2015 model is computed from 20 years of satellite altimetry data from a variety of missions. Its main characteristics are the following :

Name	MSS_CNES-CLS15
Reference ellipsoid	T/P
Referencing time period	1993-2013 (20 years)
Spatial coverage	Global (80°S to 84°N) - Oceanwide where altimetric data are available. Undefined on continents.
Spatial resolution	Regular grid with a 1/60° (1 minutes) spacing (i.e. ~2 km)
Grid	21600 points in longitude / 9841 points in latitude
MSS determination technique	Local least square collocation method on a 3' grid where altimetric data in a 200-km radius are selected. Estimation on a 1' grid based on SSH-Filtered MSS values (remove/restore technique to recover the full signal). The inverse method uses local anisotropic covariance functions which improve the shortest wavelengths.
Estimation error level	YES (in cm) - The Optimal Interpolation method provides a calibrated formal error
Altimetric dataset	T/P-J1-J2: 20 years mean profile (first orbit), T/P tandem & J1 tandem: 3.7 years profile GFO: 7 years mean profile ERS-2/EnviSat: 15 years mean profile, 1 year ERS-1 (geodetic phase) J1 & Cryosat-2: geodetic phase

Table 11 : MSS_CNES-CLS15 model characteristics

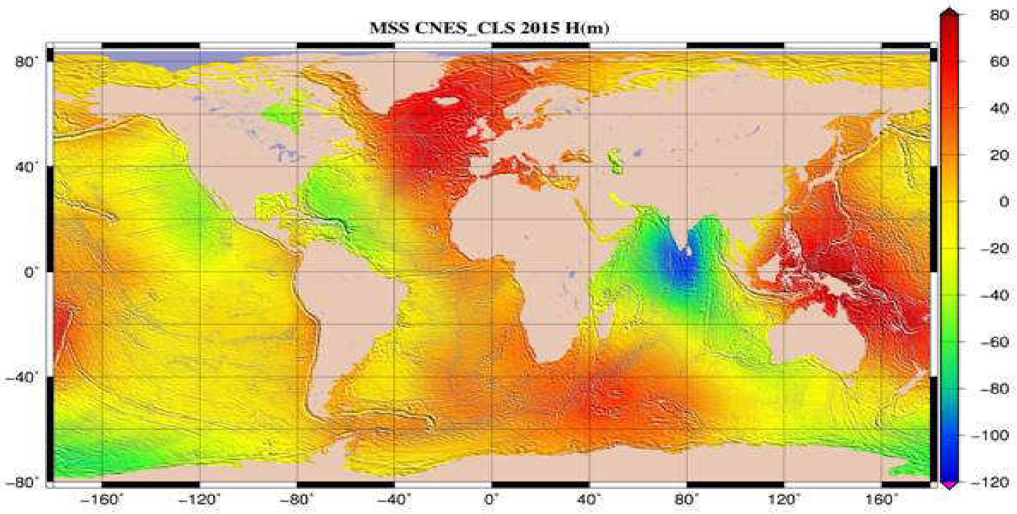


Figure 13 : Mean Sea Surface MSS_CNES-CLS15.

Refer to http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mss/index.html for more details on this model.

3.2.2.2. MSS_DTU-2015

The second MSS solution (_sol2) provided in Saral/AltiKA GDR is the MSS_DTU15

Refer to [Andersen 2015]

3.2.3. Mean Dynamic Topography

The MDT_CNES-CLS18 model is computed from satellite altimetry data from a variety of missions. Its main characteristics are the following :

Name	MDT_CNES-CLS18
Referencing time period	1993-2012 (20 years)
Domain	Global - no Black Sea - no dedicated processing in the Arctic - the Med Sea come from the regional SOCIB MDT (Rio et al., 2014)
Spatial resolution	Regular grid with a 1/8°
Grid	2880 points in longitudes / 1440 points in latitude
MDT determination technique	Reference of the altimeter Sea Level Anomalies, computed relative to a 20 years (1993-2012) mean profile, in order to obtain absolute measurements of the ocean dynamic topography. Combined product based on GRACE and GOCE gravimetric data, altimetry and in situ data (hydrologic and drifters data)

Table 12 : MDT_CNES-CLS18 model characteristics

This sea surface height (mean sea surface height above geoid) corresponds to mean geostrophic currents and its changes.

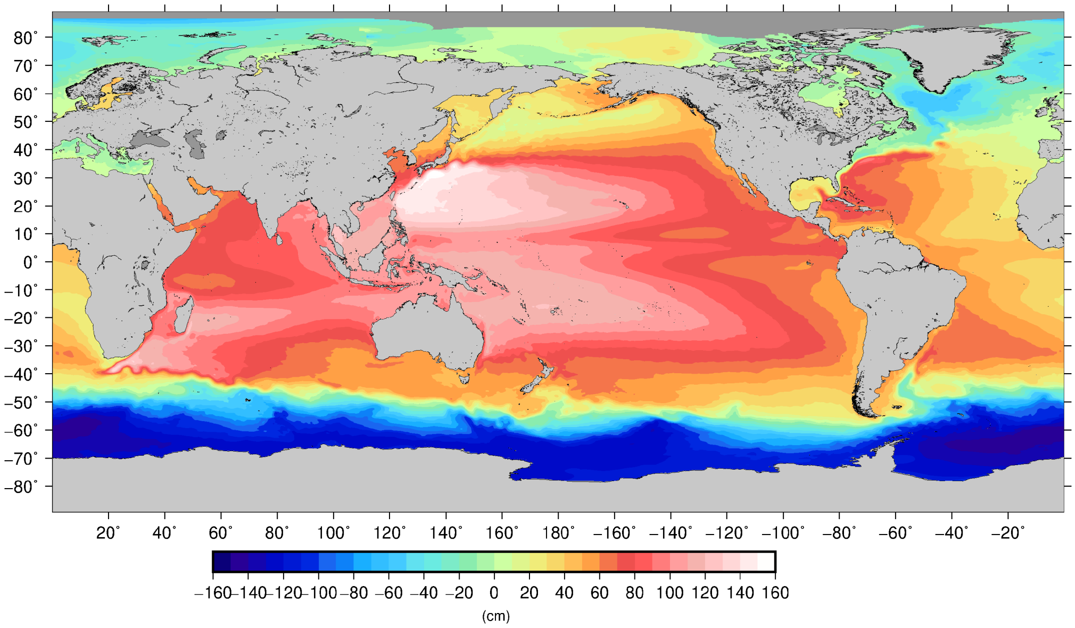


Figure 14 : Mean Dynamic Topography MDT_CNES-CLS18

Refer to http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mdt.html for more details on this model.

3.2.4. Geoid

SARAL/AltiKa (O)(I)GDRs use the EGM2008 geoid [Pavlis *et al.*, 2012]. The EGM2008 gravitational model has been used to calculate point values of geoid undulation on a 5 x 5 minute grid that spans the latitude range +90.0 deg. to -90.0 deg. The EGM2008 model is complete to spherical harmonic degree and order 2159 and contains additional coefficients up to degree 2190 and order 2159. It has been corrected appropriately so as to refer to the mean tide system as far as the permanent tide is concerned [*Rapp et al.*, 1991]. The reference ellipsoid used here is that defined for T/P.

EGM2008 is a spherical harmonic model of the Earth's gravitational potential, developed by a least squares combination of the ITG-GRACE03S gravitational model and its associated error covariance matrix. This grid was formed by merging terrestrial, altimetry-derived, and airborne gravity data. See “http://onlinelibrary.wiley.com/doi/10.1029/2011JB008916/full” for more information.

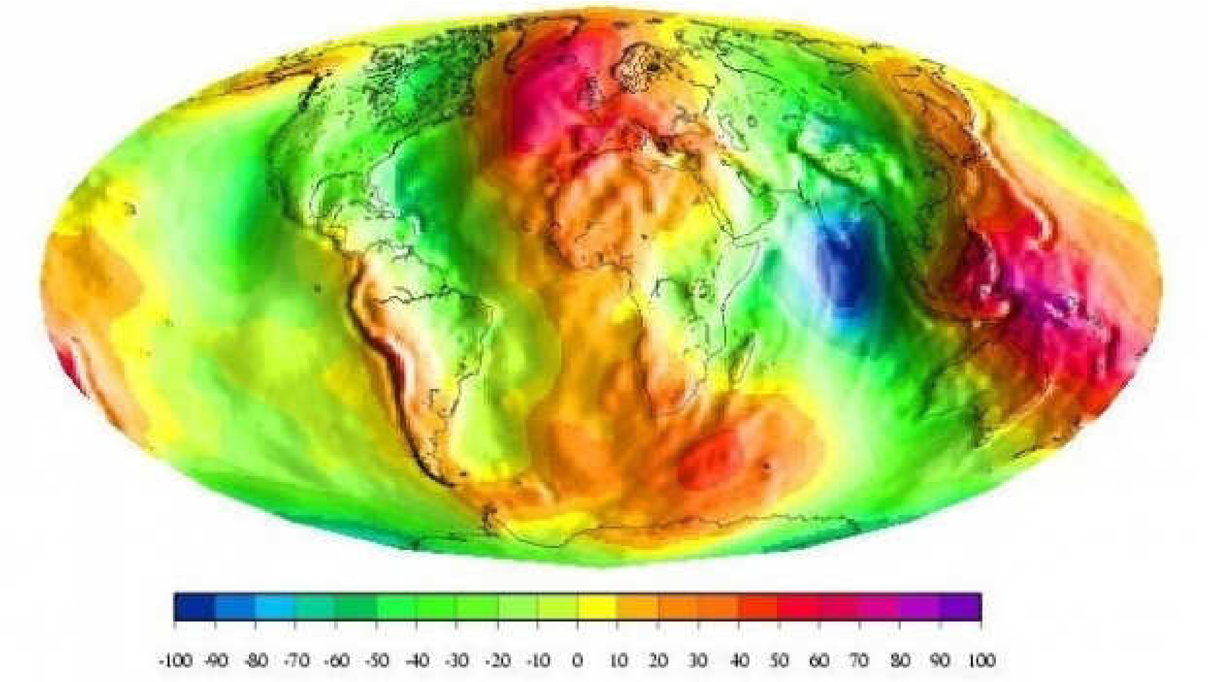


Figure 15 : EGM2008 geoid (m) Credit GRGS

3.2.5. Bathymetry

The value of this parameter is determined from the ACE2 (Altimeter Corrected Elevations) digital elevation model at 30” resolution [Berry, P.A.M.; Smith,R.; Benveniste,J., 2008].

ACE2 digital elevation model has been created by synergystically merging the SRTM dataset with Satellite Radar Altimetry within the region bounded by ±60N.

Over the areas lying outside the SRTMs latitude limits other sources have been used such as including GLOBE and the original ACE DEM, together with new matrices derived from reprocessing the ERS1 Geodetic Mission dataset with an enhanced retracking system, and the inclusion of data from other satellites.

3.2.6. Ocean Tides

The two geocentric tide values provided on the SARAL/AltiKa (O)(I)GDR, ocean_tide_sol1 and ocean_tide_sol2, are computed using the GOT4.10c and the FES2014b tidal models respectively.

Both geocentric ocean tide fields (ocean_tide_sol1 and ocean_tide_sol2) also include the load tides from load_tide_sol1 and load_tide_sol2 fields, and the equilibrium long-period ocean tide (ocean_tide_equil). The GOT4.10c model includes the M4 non-linear ocean tide and FES2014b includes several non-linear waves : M4, M6, M8, MN4, MS4, MKS2, N4, S4, MSf.

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

3.2.6.1. GOT4.10c Ocean Tide Model

Solution GOT4.10c [Ray, 2013; Ray, personal communication], is the last version of GOT models developed by R. Ray.

This model is different from previous version GOT4.8 as it is now based on Jason-1 and Jason-2 data, ERS-1 and ERS-2 and GFO.

None T/P data has been used in this solution.

The solution consists of independent near-global estimates of 10 constituents (K1, K2, M2, M4, N2, O1, P1, Q1, S1, S2). An a priori model was used that consisted of the hydrodynamic model FES 2004 [Lyard et al. 2006] and several other local hydrodynamic models.

Note that GOT4.10c model uses the new tidal geocenter correction proposed by Shailen and Ray (2014). Moreover the dry-tropospheric correction for the Jason satellites never had the S2 air-tide error that the original T/P data had.

GOT4.10c solution does not use the Cg correction, as it is a T/P correction.

GOT4.10c solution is provided on a 0.5° grid; moreover the ocean tide grids have been extrapolated on one pixel over coasts and ocean tide values are set to zero on lakes and enclosed-seas.

3.2.6.2. FES2014b Ocean Tide Model

FES2014 is the last version of the FES (Finite Element Solution) tide model developed in 2014-2016. It is an improved version of the FES2012 model, which was fully revised version of the global hydrodynamic tide solutions initiated by the works of Christian Le Provost in the early nineties. This new FES2014 model has been developed, implemented and validated by the LEGOS, NOVELTIS and CLS, within a CNES funded project [Lyard et al. 2021].

FES2014 takes advantage of longer altimeter time series and better altimeter standards, improved modeling and data assimilation techniques, a more accurate ocean bathymetry and a refined mesh in most of shallow water regions. Special efforts have been dedicated to address the major non-linear tides issue and to the determination of accurate tidal currents.

FES2014 is based on the resolution of the tidal barotropic equations (T-UGO model) in a spectral configuration.

A new global finite element grid (~2.9 million nodes, 50% more than FES2012) is used and model physic has been improved, leading to a nearly twice more accurate 'free' solution (independent of in situ and remote-sensing data) than the previous FES2012 version. Then the accuracy of this 'free' solution was improved by assimilating long-term altimetry data (Topex/ Poseidon, Jason-1, Jason-2, TPN-J1N, and ERS-1, ERS-2, ENVISAT) and tidal gauges through an improved representer assimilation method.

A preliminary version, noted FES2014a, has been produced in 2015 based on GOT4v8ac loading tide. Then new tide loading effects have been computed using FES2014a oceanic tide (J.P. Boy, Univ. Strasbourg). These FES2014a tide loading effects have been used to produce the final model version noted FES2014b, which is used in Saral GDRs:

FES2014b geocentric (elastic) tide = FES2014b oceanic tide + FES2014a loading tide.

Final FES2014b solution shows strong improvement compared to FES2012 and GOT4V10, particularly in coastal and shelf regions and also in some deep ocean areas and in the Arctic region.

34 tidal constituents have been computed: N2, EPS2, J1, K1, K2, L2, La2, M2, M3, M4, M6, M8, Mf, MKS2, Mm, MN4, MS4, MSf, MSqm, Mtm, Mu2, N2, N4, Nu2, O1, P1, Q1, R2, S1, S2, S4, Sa, Ssa, T2.

FES2014b solution is provided on a 1/16° grid; moreover the ocean tide grids have been extrapolated on ten pixels over coasts and ocean tide values are set to zero on lakes and enclosed-seas.

See "http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes.html" for more information.

3.2.7. Sea Surface Height Bias Recommendation

The Sea State Bias (SSB) can be defined as the difference between the apparent sea level as "seen" by the altimeter and the actual mean sea level. It is composed of: the Electromagnetic bias (EMB), and skewness and tracker biases that affect the accuracy of altimeter measurements and are all dependent on SWH. The EMB (main contributor) results from the fact that the radar senses an average sea surface lower than the true average sea surface, due to amplification from wave troughs. This bias can be expressed as a percentage of SWH, with the percentage being a complex function of the sea-surface slope and elevation statistical distribution.

Consolidated empirical SSB solutions have been developed from the Altika's measurements [Tran, 2019]. They are provided in the form of table . The standard 2D version is expressed as a function of SWH and altimeter wind speed while the improved 3D version uses additionally a mean wave period estimate from wave model to better describe the local wave conditions.

3.2.8. Data Editing Criteria

The following editing criteria are a recommended guideline for finding good records from the (O)(I)GDR version “f” to calculate the sea level anomaly from the Ku band range. The 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:

Parameter	Value	Meaning
surf_class	0	Open oceans
ice_flag	0	open-ocean free of sea-ice
trailing_edge_variation_flag	0	Not distorted data

Table 13 : Recommended editing criteria

Then, filter the data as follows to retain only the most valid data :

Parameter	Validity conditions
range_numval	20 ≤ x
range_rms	0 ≤ x (mm) ≤ 200
altitude – range	-130 000 ≤ x (mm) ≤ 100 000
model_dry_tropo_corr	-2 500 ≤ x (mm) ≤ - 1 900
rad_wet_tropo_corr	-500 ≤ x (mm) ≤ -20
iono_corr_gim	-100 ≤ x (mm) ≤ 40
sea_state_bias	-500 ≤ x (mm) ≤ 0
ocean_tide_sol1	-5 000 ≤ x (mm) ≤ 5 000
solid_earth_tide	-1 000 ≤ x (mm) ≤ 1 000
pole_tide	-150 ≤ x (mm) ≤ 150
swh	0 ≤ x (mm) ≤ 11 000
sig0	3 ≤ x (dB) ≤ 30
wind_speed_alt	0 ≤ x (m/s) ≤ 30
off_nadir_angle_wf	-0.09 ≤ x (deg^2) ≤ 0.09
sig0_rms	x (dB) ≤ 1
sig0_numval	20 < x

Table 14 : Recommended filtering criteria

To restrict studies to deep water, apply a limit, e.g., water depth of 1000m or greater, using the bathymetry parameter (ocean depth in meters.)

These data editing criteria are valid for open ocean studies only .

4. Using the (O)(I)GDR data

4.1. Overview

This section gives the reader a guide to the use of the SARAL/AltiKa (O)(I)GDR data. 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. Further information is also available on the web servers provided in Annex C, please direct questions and comments to the contacts given there.

The instruments on SARAL/AltiKa make direct observations of the following quantities: altimeter range, ocean significant wave height, ocean radar backscatter cross-section (a measure of wind speed) 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 SARAL/AltiKa), e.g., atmospheric pressure, etc. 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 (O)(I)GDR contains all relevant corrections needed to calculate the sea surface height. For the other "geophysical variables" in the (O)(I)GDR: ocean significant wave height, tropospheric water content and wind speed, the needed instrument and atmospheric corrections have already been applied.

The following sections provides guidance on how to use them.

4.2. Typical computation from altimetry data

In this section references are made to specific (O)(I)GDR parameters by name using the name of the variable as described in the NetCDF data sets.

WARNING

Default values are given to data when computed values are not available (See section 0) so you must screen parameters to avoid using those with default values. Also you must check flag values. The related flags are given in the description of each variable (See section 0) although some discussion of flags appears in this section.

4.2.1. Corrected Altimeter Range

The main data of the (O)(I)GDR are the altimeter ranges. The (O)(I)GDR provides ranges measured at Ka band. The given range is corrected for instrumental effects (net_instr_corr_range_ka). The given range must be corrected for path delay in the atmosphere through which the radar pulse passes and the nature of the reflecting sea surface. All range corrections are defined and they should be ADDED to the range. The corrected (Ka band) range is given by :

Corrected Range = Range + Wet Tropospheric Correction
+ Dry Tropospheric Correction
+ Ionospheric Correction
+ Sea State Bias Correction

Wet Tropospheric Correction :

Use radiometer correction (rad_wet_tropo_corr)

Dry Troposphere Correction :

Use model correction (model_dry_tropo_corr).

Ionosphere Correction :

Use model ionosphere correction (iono_corr_gim).

Sea State Bias Correction :

Use sea state bias correction in standard version (sea_state_bias) for homogeneity with other altimeter products or use improved version (sea_state_bias_3d_mp2) for fine regional studies.

N.B: Please note that range, sig0 and swh are subject to modeled instrumental errors corrections (modeled_instr_corr*). These corrections are given in Look-Up-Tables updated with real measurements instead of ground measurements.

4.2.2. 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 - Corrected Range

The sea level anomaly (SLA), also referred to as Residual Sea Surface, is defined here as the sea surface height minus the mean sea surface and minus known geophysical effects, namely tidal and inverse barometer. It is given by:

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

The SLA contains information about:

- Real changes in ocean topography related to ocean currents
- Dynamic response to atmospheric pressure
- Differences between tides and the tide models
- Differences between the mean sea surface model and the true mean sea surface at the SARAL/AltiKa location
- Unmodeled or mismodeled measurement effects (skewness, sea state bias, altimeter errors, tropospheric corrections, ionospheric correction, etc.)
- Orbit errors

There is naturally also random measurement noise. Understanding the first four items as a function of space and time is the purpose of SARAL/AltiKa.

Altitude :

Orbit altitude (see parameter altitude)

Corrected Range :

See section 4.2.1.

Tide effects (solid earth tide height, geocentric ocean tide height, pole tide height) **:**

See sections 4.2.2.1 and 5.9.

Inverted Barometer Height Correction :

Use inv_bar_corr (see also section 5.10.5).

HF Fluctuations of the Sea Surface Topography :

Use hf_fluctuations_corr (see also section 5.10.5).

Mean Sea Surface :

See sections 4.2.2.2 and 5.4.

4.2.2.1. Tide Effects

The total tide effect on the sea surface height is the sum of three values from the (O)(I)GDR:

Tide Effect = Geocentric Ocean Tide + Solid Earth Tide + Pole Tide

An alternative Tide Effet (not provided in the (O)(I)GDR ssha) can include the Non Equilibrium Long Period and the Internal Tide :

Alternative Tide effect = Geocentric Ocean Tide
+ Non Equilibrium Long Period
+ Solid Earth Tide
+ Pole Tide
+ Internal Tide

(See also section 5.10 and subsections)

Geocentric Ocean Tide :

The geocentric ocean tide provided on the (O)(I)GDR is the sum total of the ocean tide and the loading tide.

Geocentric Ocean Tide = Ocean Tide + Load Tide

The (O)(I)GDR provides a choice of two geocentric ocean tide values, ocean_tide_sol1 and ocean_tide_sol2. 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 that the (O)(I)GDR also explicitly provides the loading tide height from each of the two models that are used to determine the two geocentric ocean tide values, load_tide_sol1, load_tide_sol2. Obviously, the geocentric ocean tide values and loading tide values should not be used simultaneously, since the loading tide height would be modeled twice.

Non Equilibrium long-period Tide :

Use ocean_tide_non_equil

Geocentric Ocean Tide = Ocean Tide + Load Tide
+ Non Equilibrium Long-Period Tide

Adding the field ocean_tide_non_equil to the geocentric ocean tide, allows computing a more complete geocentric ocean tide signal including the dynamic ocean long-period tide signal and the corresponding SAL effect for 6 long period tidal frequencies.

Solid Earth Tide :

Use solid_earth_tide

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

Pole Tide :

Use pole_tide

The tide values all have the same sign/sense in that positive numbers indicate that the surface is farther from the center of the Earth.

Internal Tide :

Use internal_tide

The (O)(I)GDR provides one internal tide value, computed from Zaron (HRET-v7.0 [Zaron, 2017]) model. It models the internal tides surface signatures which remain coherent with the four main barotropic tide frequencies.

4.2.2.2. Geophysical Surface - Mean Sea Surface or Geoid

The geophysical fields Geoid (geoid) - actually geoid undulation, but called simply geoid - and Mean Sea Surface (mean_sea_surface_sol1 or mean_sea_surface_sol2) are distances above the reference ellipsoid, as is the Sea Surface Height. These values are for the location indicated by latitude and longitude. If the values of these fields are needed at a different location within the current frame, along-track interpolation may be done using the high rate (40/second) range and altitude values.

As the geoid is derived from the mean sea surface, the latter is the better-known quantity. The residual surface with respect to the geoid is sometimes called the "dynamic topography" of the ocean surface.

See also discussions of mean sea surface and geoid in sections 5.3 and 5.4.

4.2.3. Mean Sea Surface and Adjustment of the Cross Track Gradient

In order to study sea level changes between two dates, it is necessary to difference sea surface heights from different cycles at the exact same latitude-longitude, so that the not well-known time-invariant geoid cancels out. However, the (O)(I)GDR samples are not given at the same latitude-longitude on different cycles. They are given approximately every 1 sec along the pass (about 6 km, the time difference and distance vary slightly with satellite height above the surface), and the satellite ground track is allowed to drift by ±1 km. This introduces a problem: on different cycles the satellite will sample a different geoid profile. This effect is the so-called cross-track geoid gradient, and *Brenner and Koblinsky* [1990] estimated it at about 2 cm/km over most of the ocean, larger over continental slopes, reaching 20 cm/km at trenches. Even if the passes repeated exactly, one would have to interpolate along the pass (say, to a fixed set of latitudes) because a 3 km mismatch in along pass position would cause approximately a 6 cm difference in the geoid, which would mistakenly be interpreted as a change in oceanographic conditions.

Both problems are simultaneously solved if the quantity one interpolates along a given pass is the difference :

Residual Height – Mean Sea Surface

Then the real geoid changes across the track are automatically accounted for (to the extent the MSS model is close to the true geoid) because the MSS is spatially interpolated to the actual satellite latitude-longitude in the (O)(I)GDR. The residual height term above is the residual sea surface height after applying all the tidal, atmospheric and ionospheric corrections, etc. Otherwise, those need to be interpolated separately.

One possible approach is to interpolate along track to a set of common points, a "reference" track. The reference could be:

- An actual pass with maximum data and/or minimum gaps, or
- A specially constructed fixed track (see below).

The procedure is the following:

- For each common point, find neighboring points in the pass of interest (POI).
- In the POI, interpolate along track to the common point, using longitude as the independent variable, for each quantity of interest - sea surface height (see above), mean sea surface, geoid, tides, etc.
- As stated above, the quantity to compare at each common point is :

  ΔSSH = Interpolated POI SSH - Interpolated POI MSS

- Other geophysical corrections must be applied to ΔSSH, depending on the type of investigation

The geoid model in the (O)(I)GDR could substitute the MSS model, but its use will result in reduced accuracy in the interpolation because the resolution of the geoid undulation is lower than that of the MSS.

Desirable features of a fixed reference track include:

- Equal spacing of points (good for FFT)
- Independent variable = (point longitude - pass equator crossing longitude)
- Equator is a point (simplifies calculation)
- Point density similar to original data density

With these specifications, it is possible to make only two fixed tracks, one ascending and one descending, which will serve for all passes. The template pass is then shifted by the equator crossing longitude (global attribute of the product, see 0) of each pass. Recall that the equator longitude is from a predicted orbit (not updated during GDR processing). Improved accuracy can be obtained by interpolating in the latitude, longitude values. When one interpolates to the reference track, it is good practice to check that the interpolated latitude from the data records used is close to the latitude on the reference track.

4.2.4. Range Compression

Each 1Hz frame of the AltiKa Ka band range measurement (see range parameter) is derived from the linear regression of the respective valid 40 Hz range measurements (see range_40hz parameter).

An iterative outlier detection scheme is adopted in this linear regression and the resulting 40 Hz measurements are identified by setting the corresponding bit in the parameters (range_used_40hz) to 1. Measurements not considered as outliers have the parameters (range_used_40hz) set to 0.

The number of valid 40 Hz measurements that are used to derive each of the 1 Hz measurements is provided on the (O)(I)GDRs (see range_numval parameter), as are the root-mean-square of the differences between the valid 40 Hz measurements and the derived 1 Hz measurement (see range_rms parameter). N.B.: Please note that a threshold of $2,3.10^{-3}$ is applied on this MQE[4] used to create 1 Hz data from 40 Hz data.

Specialized applications, such as over land, ice, lakes or rivers, may require that the users perform their own compression algorithm on the 40 Hz measurements.

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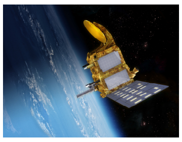
[4] MQE : Mean Quadratic Error



5. Altimetric data

This section presents a short discussion of the main quantities on the (O)(I)GDR.

An excellent overview of the theoretical and practical effects of radar altimetry is the “Satellite Altimetry” Chapter by *Chelton et al* [2001].

5.1. Precise Orbits

CNES has the responsibility for producing the orbit ephemeris for the SARAL/AltiKa data products. The SARAL/AltiKa OGDRs provide a navigator orbit that has radial accuracies better than 30 cm (rms), the IGDRs provide a preliminary orbit that has radial accuracies better than 4 cm (rms), while the GDRs provide a precise orbit that has radial accuracies better than 3 cm (rms).

5.2. 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, called 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 mono frequency altimeter on SARAL/AltiKa performs only range measurements at Ka band frequencies (see range parameter).

The range reported on the SARAL/AltiKa (O)(I)GDR has already been corrected for a variety of calibration and instrument effects, including calibration errors, pointing angle errors, center of gravity motion, and terms related to the altimeter acceleration such as Doppler shift and oscillator drift. The sum total of these corrections also appears on the (O)(I)GDR for Ka band range (see net_instr_corr_range parameter).

N.B: After analysis of the altimeter flight calibration stability, the calibrations are averaged over a 7 days window for the low pass filter (identical to GDR-D Jason-2) and 3 days for the internal path delay and total power (not used on Jason-2). This will slightly decrease the daily noise observed in the altimeter calibration data.

In order to compute the Doppler correction on the altimeter range (doppler_corr), we use the orbital altitude rate (orb_alt_rate). The reference surface for the orbital altitude rate is the combined mean_sea_surface_sol1/geoid surface (if not available, the default surface is the ellipsoid).

5.3. Geoid

The geoid is an equipotential surface of the Earth's gravity field that is closely associated with the location of the mean sea surface. The reference ellipsoid is a bi-axial ellipsoid of revolution. The center of the ellipsoid is ideally at the center of mass of the Earth although the center is usually placed at the origin of the reference frame in which a satellite orbit is calculated and tracking station positions given. The separation between the geoid and the reference ellipsoid is the geoid undulation (see geoid parameter).

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. 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 360 and in some cases higher.

For ocean circulation studies, it is important that the long wavelength part of the geoid be accurately determined.

5.4. Mean Sea Surface

A Mean Sea Surface (MSS) represents the position of the ocean surface averaged over an appropriate time period to remove annual, semi-annual, seasonal, and spurious sea surface height signals. A MSS is given as a grid with spacing consistent with the altimeter and other data used in the generation of the grid values. The 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 SARAL/AltiKa (O)(I)GDR provides a global MSS model that is generated from multiple satellite altimetry missions (see mean_sea_surface_sol1/mean_sea_surface_sol2 parameters).

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.

5.5. Mean Dynamic Topography

A Mean Dynamic Topography (MDT) represents the Mean Sea Surface referenced to a geoid and corrected from geophysical effects. A MDT is given as a grid with spacing consistent with the altimeter and other data used in the generation of the grid values. The MDT provides the absolute reference surface for the ocean circulation. The SARAL/AltiKa (O)(I)GDR provides a global MDT model (see mean_topography parameter) that is a combined product recovering several years based on GRACE mission, altimetry and in situ data (hydrologic and drifters data).

5.6. Geophysical Corrections

The atmosphere and ionosphere slow the velocity of radio pulses at a rate proportional to the total mass of the atmosphere, the mass of water vapor in the atmosphere, and the number of free electrons in the ionosphere. In addition, radio pulses do not reflect from the mean sea level but from a level that depends on wave height and wind speed. The errors due to these processes cannot be ignored and must be removed. Discussions of these effects are given in *Chelton et al*. [2001].

5.6.1. Dry Troposphere

The propagation velocity of a radio pulse is slowed by the "dry" gases and the quantity of water vapor in the Earth's troposphere. The "dry" gas contribution is nearly constant and produces height errors of approximately -2.3 m. The water vapor in the troposphere is quite variable and unpredictable and produces a height calculation error of -6 cm to -40 cm. However, these effects can be measured or modeled as discussed below.

The gases in the troposphere contribute to the index of refraction. In detail, the refractive index depends on pressure and temperature. When hydrostatic equilibrium and the ideal gas law are assumed, the vertically integrated range delay is a function only of the surface pressure, see *Chelton et al*. [2001]. The dry meteorological tropospheric range correction is principally equal to the surface pressure multiplied by -2.277mm/mbar, with a small adjustment also necessary to reflect a small latitude dependence (see model_dry_tropo_corr parameter).

$$\text{model\_dry\_tropo\_corr} = -2.277 * P_{atm} * [1 + 0.0026 * \cos(2 * \text{phi})]$$

where P_{atm} is surface atmospheric pressure in mbar, phi is latitude, and model_dry_tropo_corr is the dry troposphere correction in mm. There is no straightforward way of measuring the nadir surface pressure from a satellite, so it is determined from the European Center for Medium Range Weather Forecasting (ECMWF) numerical weather prediction model using the surface pressure fields. For OGDR processing, predicted ECMWF P_{surf} fields are used and for (I)GDR processing analyzed fields are used.

5.6.2. Wet Tropospheric Correction

The amount of water vapor present along the path length contributes to the index of refraction of the Earth's atmosphere. Its contribution to the delay of the radio pulse, the wet tropospheric correction (WTC), can be estimated by measuring the atmospheric brightness temperature near the water vapor line at 22.2356 GHz and providing suitable removal of the background. The SARAL/AltiKa dual frequency radiometer measures the brightness temperatures in the nadir path at 23.8 and 37.0 GHz: the water vapor signal is sensed by the 23.8 GHz channel, while the 37 GHz channel removes other atmospheric contributions (surface emission, cloud cover influence) [*Keihm et al.*, 1995, *Eymard et al.*, 1995].

In combination to the two brightness temperatures, the altimeter backscattering is also part of the retrieval and provides surface roughness information [*Obligis et al.*, 2006].

In the lack of a 18.7 GHz channel as in CNES/JPL Jason's radiometer series, the performances of the WTC estimation have found to be improved with the use of two additional input parameters [*Obligis et al.*, 2009]:

- the sea surface temperature (SST) completes the information of the backscattering coefficient for a better estimation of the surface emissivity
- the atmospheric temperature lapse rate (γ_{800}, the slope of the temperature decrease from the surface to the top of atmosphere) improves the performances of the retrieval, reducing systematic biases over upwelling regions, as west of South America over Peruvian coast, where, due to the Hadley cell circulation, strong temperature inversion occurs at the top of the atmospheric boundary layer with an accumulation of humidity near the surface and dry air above

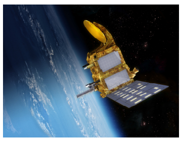
A neural network is applied to a learning database to set the retrieval algorithm based on these 5 input parameters.

A pure empirical approach is applied in the current version of the product: the database is built from the measured brightness temperature, the measured altimeter backscattering coefficient (and SST, and γ_{800}) and the corresponding ECMWF WTC interpolated along the instrument timeline. At a global scale, this pure empirical approach performs well, with mesoscale performances close to Jason-2 [*Picard et al.* 2015].

Input parameters are combined to obtain the path delay in the satellite range measurement due to the water vapor content (see rad_wet_tropo_corr parameter).

Note that the same approach is used to estimate the total column water vapor (see rad_water_vapor). For the cloud liquid water content, a 3-inputs algorithm (brightness temperatures and altimeter backscattering coefficient) is applied.

The ECMWF numerical weather prediction model provides also a value for the wet tropospheric correction. An interpolated value from this model is included in the (O)(I)GDR, as a backup to the measurement from the radiometer (see model_wet_tropo_corr parameter). This backup will prove



useful when land contamination, or anomalous sensor behavior makes the radiometer measurement of the wet tropospheric correction unusable.

The ECMWF meteorological fields are interpolated to provide the model dry and wet tropospheric corrections at the time and location of the altimeter measurement (see model_dry_tropo_corr and model_wet_tropo_corr) and an interpolation quality flag is provided on the (O)(I)GDR to indicate the quality of this interpolation (see interp_flag_meteo).

Two additional parameters provide an enhanced solution for model dry and wet tropospheric corrections recommended for hydrological application [*Valladeau et al.,* 2015] (see model_dry_tropo_corr_meas_alt and model_wet_tropo_corr_meas_alt): for those two, the correction is computed taking into account the true altitude of the along-track surface. In a dedicated algorithm, the altimeter range is used as the surface altitude in the 3D meteorological fields for the integration along pressure levels.

5.6.3. Atmospheric Attenuation

The wet component of the Ka-band atmospheric attenuation is about six times larger than for Ku-band.

As for the wet tropospheric correction, two corrections are available.

A model solution is established from ECMWF analysis based on the equations provided by Lillibridge et al., 2014 (see model_atmos_corr_sig0). Pressure, temperature, humidity and cloud liquid water content ECMWF profiles are combined through polynomial relation to compute the model atmospheric attenuation.

The radiometer solution (see atmos_corr_sig0) is retrieved with the same pure empirical approach detailed in the previous section, using a 3-inputs algorithm (brightness temperatures and altimeter backscattering coefficient) using the model atmospheric attenuation as a reference for the learning step.

5.6.4. Ionosphere

The group velocity of the altimeter radar pulses is slowed by the presence of free electrons in the Earth's ionospheric layer. As the Total Electronic Content (TEC) is highly variable in time (diurnal, seasonal, solar cycle variations) and in space (latitude dependent), accurate measurement of the resulting delay requires generally fine sampling coincident with the radar measurements. The ionospheric dispersion being linear, the delay is usually computed by combining the dual-frequency measurements of the radar altimeter (e.g. for T/P, Jason-1 and 2 : Ku and C bands).

In the case of AltiKa, only one frequency is available (Ka), which prevents from using such a classical dual frequency approach. However, it is shown that ionosphere correction (= 40300 x TEC / frequency^2) is an order of magnitude smaller in Ka-band than in Ku-band (actually divided by 7). For amplitudes of the ionosphere correction in Ku-band in the range 2-25 cm, equivalent effect in Ka-band is only 0.3-3.6 cm.

Thus, for AltiKa, external ancillary data are used to compute ionosphere correction, in the form of TEC grids computed from GPS-based observations and ionosphere model (the JPL Global Ionosphere Maps – GIM – model). Other auxiliary data such as solar activity coefficients (within IRI95) are used to correct the satellite altitude.

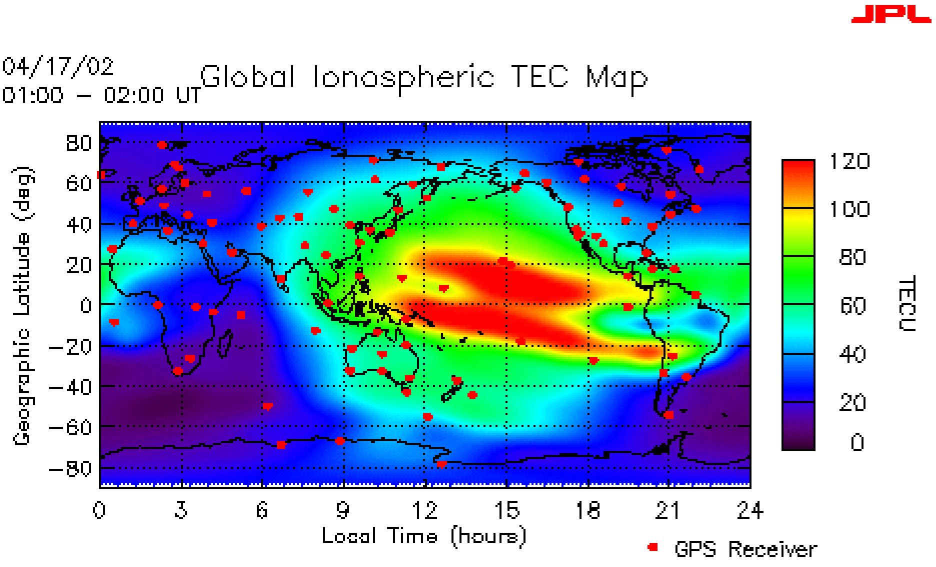


Figure 16. Example of Global Ionosphere Maps from JPL

GIM model has been validated through comparisons with T/P, Jason-1, Jason-2 and ENVISAT dual frequency ionosphere corrections.

As GIM fields are distributed with a 24 hours latency, the correct fields will not be available on time for OGDR processing. In that case, the last GIM field available will be used, as well as an extrapolated MOE orbit, in order to compute in advance the ionosphere correction for OGDR.

The ionospheric GIM correction solution may be used over non ocean surfaces (ice, land, etc.).

5.6.5. Ocean Waves (sea state bias)

Unlike the preceding effects, sea-state effects are an intrinsic property of the large footprint radar measurements. The surface scattering elements do not contribute equally to the radar return; troughs of waves tend to reflect altimeter pulses better than do crests. Thus the centroid of the mean reflecting surface is shifted away from mean sea level towards the troughs of the waves. The shift, referred to as the electromagnetic (EM) bias, causes the altimeter to overestimate the range (see *Rodriguez et al.*, [1992]). In addition, a skewness bias also exists from the assumption in the onboard algorithms that the probability density function of heights is symmetric, while in reality it is skewed. Finally, there is a tracker/processing bias, which is a combination of instrumental and processing choice effect. The sum of EM bias, skewness bias, and tracker/processing bias is called 'sea state bias' (see sea_state_bias parameter).

The accuracy of the sea state bias models remains limited and continues to be a topic of research. The current most accurate estimates are obtained by using empirical models derived from analyses of the altimeter data themselves. The sea state bias is computed from a bilinear interpolation of a table of sea state biases versus significant wave height and wind speed for the standard version [Labroue, 2004]. The 3D version consists in a table with a third input, the mean wave period provided by a wave model to better describe the local wave conditions and thus improves the sea state bias estimates [Tran et al, 2010].

5.7. Trailing edge variation flag

5.7.1. Introduction : Rain & Cloud effect on SARAL/Altika

Ka-band is highly sensitive to rainy and cloudy conditions. It means that an overall assessment of rain effect on SARAL/AltiKa data availability and quality should be performed during the verification phase in order to monitor global percentage and spatio-temporal evolution of lost data due to rain and cloud effect, and thus give a consolidated budget for data loss due to rain attenuation and waveform distortion.

Attenuation by rain is expected to be much more significant at Ka-band than Ku-band, although even in the tropics, actual data loss is only expected to be 5-10% (Tournadre et al., 2009). However, the reliable detection and flagging of rain-contaminated data is important for the quality of the overall altimeter product.

5.7.2. SARAL/AltiKa Trailing edge variation flag

Due to the mono-frequency characteristic of the SARAL/AltiKa altimeter, the rain flags used for T/P and Jason-1&2 altimeters can not be used as they rely on the differential attenuation by rain of the signal at Ku and C band. Furthermore, the use of Ka band implies that not only rain can significantly alter the altimeter measurement but also dense cloud, that is why we prefer using “trailing edge variation effect” instead of “rain effect”.

A new “trailing edge variation flag” based on the analysis of the along-track variation of the off-nadir angle estimate (the so-called “Matching Pursuit” algorithm) has been defined and tested using Jason-1 data (Tournadre et al., 2009) and will be used operationally to detect the data potentially affected by atmospheric liquid water. This new approach to altimeter data rain flagging has to be validated and calibrated.

5.7.3. Limitations

Please note that the trailing_edge_variation_flag parameter should be used carefully. In fact, as mentioned above, this flag detects surfaces changes caused by rain, sigma-blooms, cloud, etc. The meaning of the flag is: non short scale variation/short scale variation. To be considered only as a rain flag users should correlate this flag with water vapor content or liquid water content (see rad_water_vapor and rad_liquid_water parameter). This auxiliary information comes from the radiometer measurements.

5.8. Ice Flags

The range measurement from the altimeter is likely to have larger errors when the pulse is reflected off ice surfaces. The ice surface is not at sea level, but at some unknown distance above it. For this reason the SARAL/ AltiKa (O)(I)GDR provides an ice flag (see ice_flag parameter) to indicate when the data point is likely to be over ice.

The ice flag is set if the absolute value of the difference between the model wet tropospheric correction and the dual frequency wet tropospheric correction retrieved from 23.8 GHz and 37.0 GHz brightness temperatures exceeds a specified threshold, OR if the number of valid 40-Hz altimeter range of the processed measurement is smaller than a specified threshold. If the corresponding computations cannot be performed, then the ice flag is set if a climatological map predicts ice at the given location, and if the wind speed derived from the altimeter measurement is less than 1 m/s, i.e., the backscatter is larger than normally expected from the ocean.

In “f” standard, two additional “ice” flags have been computed for Altika mission following developments performed previously for the Envisat altimetry mission. They take advantage of having both passive and active microwave sensors on the same platform with co-registered measurements (i.e. backscatter and brightness temperatures).

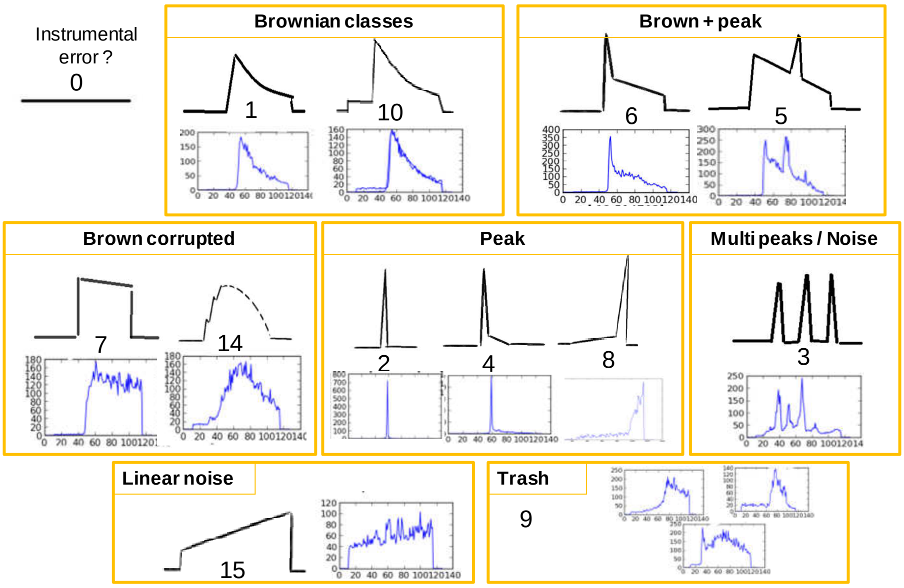
The first flag is a multi-state sea-ice flag. It provides the sea-ice type as first-year ice, multi-year ice, ambiguous ice observed during summer, mixture of types or no sea-ice (i.e. ocean). Its performance has been evaluated based on collocations between the along-track Altika data with daily grids of sea ice type from the Ocean and Sea Ice Satellite Application Facility (OSI-SAF) [Tran, 2015a]. It has been developed with a twofold purpose: (1) to detect sea-ice corrupted sea surface height data within quality control processing for ocean applications; and (2) to help cryosphere analysis by the provision of the sea-ice type estimated from the altimeter mission data. (see open_sea_ice_flag parameter)

The second flag is dedicated to ice-sheet studies. It consists in a snow flag that aims to separate different snow regions within the polar ice sheets based on their microwave signatures. This approach broadens the description of the snow pack by considering characteristics such as surface roughness, snow grain size along with snow melt effects. The difference in snow morphology is due to variable conditions in local climate which is governed by local topography. Such partition of the ice sheet might help to better understand relationships between microwave signatures and snow morphology and might represent a tool for tracking the effects of climate change [Tran, 2015b]. (see ice_sheet_snow_facies_flag parameter)

5.9. Waveform Classification Flag

For each waveform, an index is provided aiming at giving to the user, an indication of the general shape of the measurement. This index or classification number can be useful to select measurements that can be exploited and to discard the others. It can also be useful to know which retracking strategy is the most appropriate depending on the shape of the return power (peaky, diffuse, oceanic, multi-peaks, noisy, …). In particular, it can give an information about the surface on which the radar wave has reflected. This is particularly useful when trying to edit non-oceanic returns (which do not conform to the Brown model), when trying to distinguish lead and ice floe returns if working on sea ice regions, or when trying to distinguish inland water from ground returns for hydrology purposes.

Many different waveform shapes can be found depending on the reflective surface and on its complex structure (mix of more or less reflective surfaces at different altitudes and different positions with respect to the nadir of the altimeter). Class numbers have been defined and attributed to waveform shapes. They are provided in the following figure.



Description of the Saral/AltiKa waveform classes

Different technics can be used to compute this identification number. For Saral/AltiKa, a Neural Network supervised classifier has been used to attribute a class number to each individual waveform.

Class 1 corresponds to open ocean radar echoes with homogeneous backscattering conditions (Brownian shape waveforms). Class 2 corresponds to peaky echoes observed over leads and polynyas (Peacock and Laxon, 2004). The sea ice reflections are identified by classes 4, 6 and 10 depending on the ice type (respectively high reflective ice, ice with a rough surface and snow-covered ice). The other classes correspond to complex surfaces that can be found in coastal conditions or in hydrology with multiple backscattering surfaces.

5.10. Tides

Tides are a significant contributor to the observed sea surface height [*LeProvost*, 2001]. While they are of interest in themselves, they have more variation than all other time-varying ocean signals. Since they are highly predictable, they are removed from the data in order to study ocean circulation.

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.

SARAL/AltiKa (O)(I)GDRs 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 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 SARAL/AltiKa (O)(I)GDRs.

	Ocean Tide effects			*Load Tide effects*		
	short period	*long period eq*	*long period non eq*	*short period*	*long period eq*	*long period non eq*
ocean_tide	*Yes*	*Yes*	*No*	*Yes*	*No*	*No*
load_tide	*No*	*No*	*No*	*Yes*	*No*	*Yes*
ocean_tide_eq	*No*	*Yes*	*No*	*No*	*No*	*No*
ocean_tide_non_eq	*No*	*No*	*Yes*	*No*	*No*	*Yes*

5.10.1. Geocentric Ocean Tide

As mentioned above, the geocentric ocean tide refers to the sum of the ocean tide and the load tide. The SARAL/AltiKa (O)(I)GDR provides two choices for the geocentric ocean tide, ocean_tide_sol1 and ocean_tide_sol2, each of them is computed as the sum of the ocean and load tides as predicted by a particular model for high frequencies (diurnal, semi-diurnal and non-linear tides with higher frequencies), and an equilibrium representation of the long-period ocean tides at all long-periods except for the zero frequency (constant) term which is not included.

The two load tide values provided on the GDR, load_tide_sol1 and load_tide_sol2, provide the respective load tide values that were used to compute ocean_tide_sol1 and ocean_tide_sol2.

As the ocean tide is set to zero on lakes and enclosed-seas, parameters ocean_tide_sol1 and ocean_tide_sol2 are equal to the load tide value on these surfaces.

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

The SARAL/AltiKa (O)(I)GDR provides a parameter for a non-equilibrium representation of the long-period ocean tides (see parameter ocean_tide_non_equil). This parameter is provided as a correction to the equilibrium long-period ocean tide model so that the total non-equilibrium long period ocean tide is formed as a sum of ocean_tide_equil and ocean_tide_non_equil. The non-equilibrium long-period ocean tide provided in SARAL/AltiKa (O)(I)GDR comes from FES2014b tide model, but the parameter ocean_tide_non_equil can be used either with the ocean_tide_sol1 or the ocean_tide_sol2.

FES2014b model provides a dynamic solution for 6 long-period tidal frequencies: Mf, Mm, MSqm, Mtm, Sa, Ssa.

Parameter ocean_tide_equil is set to zero on lake and enclosed-seas, and the ocean tide part of the parameter ocean_tide_non_equil is also set to zero on these surfaces.

5.10.3. Solid Earth Tide

The solid Earth responds to external gravitational forces similarly to the oceans. 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 [*Wahr*, 1985 and *Stacey*, 1977].

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

5.10.4. 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 SARAL/AltiKa (O)(I)GDR provides a single field for the radial geocentric pole tide displacement of the ocean surface (see pole_tide parameter), and includes the radial pole tide displacement of the solid Earth and the oceans.

The pole tide is easily computed as described in [Wahr, 1985] and [Desai et al, 2017]. This new algorithm accounts for self-gravitation, loading, conservation of mass, and geocenter motion (spatial dependence). Over the oceans the pole tide includes the response of the solid earth, ocean, and loading effect; over land it includes only the impact on the solid earth and loading.
The mean pole location variation model includes a bias AND a drift (temporal dependence), and the computed pole tide does NOT include the effects of the Earth's displacement response to that mean pole (drift).
Modeling the pole tide requires knowledge of proportionality constants, the so-called Love numbers, and a time series of perturbations to the Earth's rotation axis, a quantity that is now measured routinely with space techniques. 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.

5.10.5. Internal Tide

Internal tides are baroclinic tides generated by the arrival of a barotropic tide on an underwater seamount or shelfbreak region; they can reach amplitudes of several 10th of meters at the thermocline level and they have a signature of several cm at the surface with wavelengths about 50-250 km for the first mode and shorter wavelengths for higher modes.

To reach higher accuracy ocean signals using the SARAL/AltiKa (O)(I)GDR, we need to be able to separate all tides signals, including the small scale internal tides surface signatures, from other oceanic signals.

The global ocean tide models described in previous sections are barotropic tide models, so by essence they do not correct from the internal tides signature at the surface.

The SARAL/AltiKa (O)(I)GDR provides a value for the internal tide surface signature, taking into account the main M2,S2,K1,O1 tidal frequencies from the Zaron's model HRET v7.0 [Zaron, 2017]; see parameter internal_tide.

5.11. Inverse Barometer Effect

5.11.1. 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 (see parameter inv_bar_corr) is computed from the surface atmospheric pressure, P_{atm} in mbar:

$$\text{inv\_bar\_corr} = -9.948 * (P_{atm} - P)$$

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 [*Wunsch*, 1972] 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_bar_corr approximately changes by 4 to 5 mm as model_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.

Note that the time varying mean global pressure over the oceans, P, during the first eight years of the T/P mission had a mean value of approximately 1010.9 mbar, with an annual variation around this mean of approximately 0.6 mbar. However, the T/P data products provided a static inverse barometer correction referenced to a constant mean pressure of 1013.3 mbar.

$$IB(T/P) = -9.948 * (P_{atm} - 1013.3)$$

Sea surface heights that are generated after applying an inverse barometer correction referenced to a mean pressure of 1013.3 mbar are therefore approximately -9.948*(1010.9-1013.3) = 23.9 mm lower than those that are generated after applying an inverse barometer correction referenced to a time varying global mean pressure, and the difference between the two sea surface heights has an annual variation of approximately 9.948*0.6 = 6 mm.

5.11.2. Barotropic Response to Atmospheric Forcing

The High Frequency Ocean Response correction, hf_fluctuations_corr, complements the Inverted Barometer (IB) correction. Like both tides and IB, the ocean response to wind and pressure has significant energy at short periods (mostly below 20 days), and the 35-day repeat cycle of SARAL/AltiKa implies that this energy is aliased in the lower frequency band.

The ocean response to wind and pressure is mostly dynamic and is significantly energetic at short periods so that the static IB correction is not sufficient; several models approaches have been developed and showed that a barotropic model allows a good representation of this variability (Ponte 1991, Stammer et al. 1999, Ali and Zlotnicki 2000, Mathers 2000, Tierney et al. 2000, Carrere 2003, Vinogradova and Ponte 2008).

For the SARAL/Altika GDRs, the parameter hf_fluctuations_corr is based on the barotropic ocean model MOG2D, forced by ECMWF operational wind and pressure fields (Carrere and Lyard, 2003); it provides strictly the difference between the ocean response to wind and pressure minus the IB for High Frequencies, so that hf_fluctuations_corr can be used as a correction to the inverse barometer correction inv_bar_corr.

The cut-off frequency between high-low frequencies is 20 days and corresponds to the Nyquist frequency of the reference TP/Jason altimeters which have a 10 days cycle. The parameter hf_fluctuations_corr is therefore capable of removing almost all the high-frequency (periods below 20 days) dynamic signal forced by the atmosphere (pressure and wind) and aliased in the altimetric measurement, except the errors and uncertainties of the model.

Notice that although the Nyquist frequency of SARAL/AltiKa sampling is 70 days, the parameter hf_fluctuations_corr does not provide any complementary correction to the IB in the 20 days-70 days band. This choice was done to keep homogeneity of the parameter with the reference missions and also because the ocean response is closer to the IB at these frequencies.

Notice that a slightly different hf_fluctuations_corr correction is provided for each (O)(I)GDR product, due to the use of a different centering of the temporal filtering window and of different atmospheric forcings :

- GDR : use of ECMWF operational analysis and an optimal filtering using a full and centered filtering window;
- IGDR: use of ECMWF operational analysis and a filtering window decentered in time but using model forecasts in the future
- OGDR: use of ECMWF operational forecasts and a filtering window decentered in time but using model forecasts in the future

5.12. Sigma 0

The backscatter coefficient, sigma0 Ka values (see parameters sig0), reported on the (O)(I)GDR are corrected for atmospheric attenuation given by radiometer measurements using atmos_corr_sig0.

For the Wind Speed algorithms, an appropriate bias is applied on sigma0 before the computation of the wind speed value, in order to fit the SARAL/AltiKA wind distribution to the operational ECMWF one.

5.13. Wind Speed

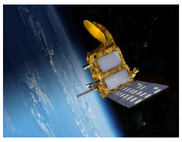
The Altika wind speed model is a two-dimensional table that depends on both backscatter coefficient and significant wave height measurements. Its calibration has been performed from a 1-year collocated dataset between Altika data and ASCAT-A scatterometer winds processed by KNMI/OSI-SAF. The performance of these new Ka-band altimeter wind speed models was assessed through validation with independent ocean wind speeds from ECMWF model, Jason-2 altimeter and buoys[Tran, 2014].

Note that for the calculation of wind speed, we use a table based on sigma_0 values limited between 0 and 30 dB.

A 10-meter (above surface) wind vector (in east-west and north-south directions) is also provided on the SARAL/AltiKa (O)(I)GDR (see parameters wind_speed_model_u and wind_speed_model_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 m/s in magnitude and 20 degrees in direction in the northern Atlantic Ocean, to more then 5 m/s and 40 degrees in the southern Pacific Ocean.

5.14. Bathymetry Information

The SARAL/AltiKa (O)(I)GDR 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. Data description

6.1. (O)(I)GDR content

The main characteristics of (O)(I)GDR products are summarized in the following table.

Features	OGDR	IGDR	GDR
Primary Goal	To provide wind/wave data to meteorological users. Also designed to provide altimeter range, environmental and geophysical corrections together with a real-time orbit in order to make NRT SSHA available to ocean users	To provide sea surface height data to operational oceanography users (with a more accurate orbit and additional environmental / geophysical corrections w.r.t. OGDR)	To fulfill the project science objectives (AD 2)
Content	Geophysical level 2 product (Altimeter/radiometer), including waveforms retracking		
	+ available environmental and geophysical corrections	+ all the environmental and geophysical corrections (preliminary for some of them)	+ all the environmental and geophysical corrections (precise)
Orbit	30 cm DORIS navigator	4 cm MOE (processed DORIS data)	3 cm POE (processed DORIS and laser data)
Delivery delay (after data acquisition)	Near-Real Time	Off-Line	Off-Line
	3-5 hours	1.5 calendar days	40 days
Validation	Not fully validated (elementary and automatic controls only)		Fully validated (in depth validation performed on a cycle basis before delivery)
Validation by Experts	No		Yes (CNES/SALP)
Structure	Segment	Pole to pole pass	
Ground Processing Centre	EUMETSAT and ISRO	CNES	CNES and ISRO

Table 15 : Main characteristics of (O)(I)GDR products

The differences between Auxiliary Data used for OGDR, IGDR and GDR products is given in section 1.1. The main fields recomputed for GDR with respect to IGDR are the following:

- Due to the update of orbit data:

  Latitude (“latitude”)

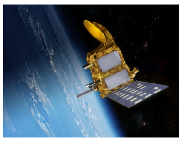
  Longitude (“longitude”)

  Altitude (“alt”,”orb_state_flag_rest”, “alt_40hz”)

  Orbital altitude rate (“orb_alt_rate”)

  Sum of the instrumental corrections (“net_instr_corr_range”)

  Corrected ground retracked altimeter ranges (“range)



Ionospheric correction (“iono_corr_gim”)

- Due to the update of platform data:

Distance antenna-COG correction (“cog_corr”)

Sum of the instrumental corrections (“net_instr_corr_range”)

Corrected ground retracked altimeter ranges (“range”)

Ionospheric correction (“iono_corr_gim”)

- Due to the update of pole locations:

Pole tide height (“pole_tide”)

- Due to the update of Mog2D data:

High frequency dealiasing correction (“hf_fluctuations_corr”)

- Due to the update of radiometer calibration coefficients:

All the radiometer-derived parameters, and mainly as far as altimeter parameters are concerned:

Radiometer wet tropospheric correction (“rad_wet_tropo_corr”)

Atmospheric attenuation (“atmos_corr_sig0”) N.B: this parameter is given by radiometer measurements

Backscatter coefficient (“sig0”)

Altimeter wind speed (“wind_speed_alt”)

Sea State Bias (“sea_state_bias”)

Ice flag (“ice_flag”)

6.2. Datasets

SARAL/AltiKa OGDR, IGDR and GDR products have the same information and format. The only difference is related to the auxiliary data used (orbit, meteo files, calibrations, …).

Accounting for Jason-2 GDR-D heritage, products are split into three data sets :

- “SSHA” data set : One file close to Jason-2 NRT-SSHA, limited to 1Hz sampling values
- “GDR” data set : One file close to Jason-2 IGDR, containing 1Hz and 40Hz values
- “SGDR” data set : One file close to Jason-2 SGDR, containing 1Hz, 40hz and waveforms values

The following figure shows the data sets available for each kind of product.

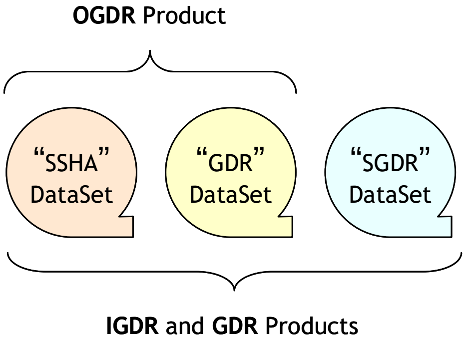


Figure 17 : Data set availability per product

OGDR products are also available in BUFR-formatted dataset for distribution via the World Meteorological Organization (WMO) Global Tele-communication System (GTS).

6.3. Product Description

The netCDF data format has been chosen to store the different data sets (one file per data set). This format is extremely flexible, self describing and has been adopted as a de-facto standard for many operational oceanography systems. What's more, the files follow the Climate and Forecast NetCDF conventions CF-1.1 because these conventions provide a practical standard for storing.

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

Full Product description (format, global attributes, groups, dimensions, variables names and their attributes) is provided in [DR9].

6.4. Software

This section lists some software that may be used to browse and use data from SSHA, GDR and SGDR data sets.

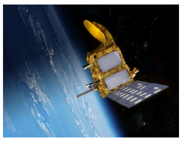
6.4.1. Software provided with netCDF : "ncdump"

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

See https://www.unidata.ucar.edu/software/netcdf/workshops/2011/utilities/index.html

The main options are the following :

-h	Show only the header information in the output, that is the declarations of dimensions, variables, and attributes but no data values for any variables
-c	Show the values of coordinate variables (variables that are also dimensions) as well as the declarations of all dimensions, variables, and attribute values



-v *var1,...,varn*	The output will include data values for the specified variables, in addition to the declarations of all dimensions, variables, and attributes
-x *var1,...,varn*	Output XML (NcML) instead of CDL. The NcML does not include data values

6.4.2. Additional general software

6.4.2.1. 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.pmel.noaa.gov/epic/java/ncBrowse/

6.4.2.2. 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/

6.4.3. Additional specific software : "BRAT"

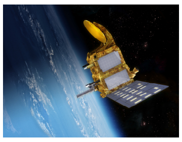
The "Basic Radar Altimetry Toolbox" is a collection of tools and tutorial documents designed to facilitate the use of radar altimetry data. It is able to read most distributed radar altimetry data from all the satellites, to do some processing, data editing and statistic over them, and to visualise the results. The Basic Radar Altimetry Toolbox is able to read ERS-1 and 2, TOPEX/Poseidon, GEOSAT Follow-on, Jason-1, Jason-2, ENVISAT, SARAL/AltiKa and CRYOSAT-2 missions altimetry data from official data centers (ESA, NASA/JPL, CNES/AVISO, NOAA, ISRO), and this for different processing levels, from level 1B (Sensor Geophysical Data Record) to level 3/4 (gridded merged data).

See http://www.altimetry.info/toolbox

6.5. OGDR BUFR product

The Global Telecommunications System (GTS) is the coordinated global system of telecommunication facilities and provides rapid collection, exchange and distribution of observations and processed information within the framework of the World Weather Watch. It is implemented and operated by National Meteorological Services of the World Meteorological Organisation (WMO) members and also by a few international organizations (ECMWF, EUMETSAT). The GTS consists of an integrated network of point-to-point circuits, and multi-point circuits which interconnect meteorological telecommunication centres.

SARAL/AltiKa BUFR products are designed primarily for dissemination via the GTS and they consequently follow the format conventions defined by the WMO for all data disseminated on the GTS. The WMO FM-94 BUFR (Binary Universal Form for the Representation of Meteorological data), is a binary code designed to represent, employing a continuous binary stream, any meteorological data. It has been designed to achieve efficient exchange and storage of meteorological and



oceanographic data. It is self defining, table driven and a very flexible data representation system, especially for big volumes of data.

The following table summarises how to identify SARAL/AltiKa OGDR data in BUFR format on the GTS.

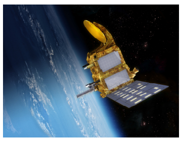
Product	Bulletin header	Originating station	Descriptor sequence
OGDR generated at EUMETSAT	ISZX02	EUMS	3-40-011
OGDR generated at CNES	ISZX02	LFPW	3-40-011

You will find more details on the BUFR format and the latest tables, on the WMO page:

https://www.wmo.int/pages/prog/www/WDM/Guides/Guide-binary-1A.html

Finally, note that ECMWF offers a comprehensive introduction to understanding BUFR format and provides various well documented encoding/decoding tools. All this can be accessed on this page:

https://www.ecmwf.int/en/learning/training/eccodes-grib-and-bufr-data-decoding-and-encoding-software



Annexe A - References

Andersen, Ole Baltazar; Stenseng, Lars; Piccioni, Gaia; Knudsen, Per - 2015- The DTU15 MSS (Mean Sea Surface) and DTU15LAT (Lowest Astronomical Tide) reference surface - ESA Living Planet Symposium 2016

Benada, J. R., 1997, "PO.DAAC Merged GDR (TOPEX/POSEIDON) Generation B User's Handbook", Version 2.0, JPL D-11007.

Bonnefond, P., P. Exertier, O. Laurain, Y. Menard, A. Orsoni, E. Jeansou and G. Jan, 2002, "Absolute calibration of Jason-1 and TOPEX/POSEIDON altimeters in Corsica (abstract)", Jason-1/TOPEX/POSEIDON Science Working Team, New Orleans, LA, USA.

Brenner, A. C., C. J. Koblinsky, and B. D. Beckley, 1990, A Preliminary Estimate of Geoid-Induced Variations in Repeat Orbit Satellite Altimeter Observations, *J. Geophys. Res.*, 95(c3), 3033-3040.

Callahan, P. S., 1984, Ionospheric Variations affecting Altimeter Measurements: A brief synopsis *Marine Geodesy*, 8, 249-263.

Cartwright, D. E. and R. J. Taylor, 1971, New computations of the tide-generating potential, *Geophys. J. R. Astr. Soc.*, 23, 45-74.

Cartwright, D. E. and A. C. Edden, 1973, Corrected tables of tidal harmonics, *Geophys. J. R. Astr. Soc.*, 33, 253-264.

Chambers et al., 1998, Reduction of geoid gradient error in ocean variability from satellite altimetry, *Marine Geodesy*, 21, 25-40.

Chelton, D. B., J. C. Ries, B. J. Haines, L. L. Fu, and P. S. Callahan, 2001, "Satellite Altimetry", *Satellite Altimetry and Earth Sciences*, ed. L.L. Fu and A. Cazenave, pp. 1-131.

Cruz Pol, S. L., C. S. Ruf, and S. J. Keihm, 1998, Improved 20-32 GHz atmospheric absorption model, *Radio Science*.

Davis, C.H. , 1997, A robust threshold retracking algorithm for measuring ice-sheet surface elevation change from satellite radar altimeters. IEEE Trans. Geosci. Remote Sens. 1997, 35, 974-979.

Desai S. , Wahr J., Beckley B., 2015, Revisiting the pole tide for and from satellite altimetry, Journal of Geodesy volume 89, pages1233-1243

Desai S. D. and Ries J.C., 2017, "Conventional model update for rotational deformation," in Fall AGU Meeting, New Orleans, LA, 2017

Eymard, L., Tabary, L., Gérard, E., Boukabara, S. A., & Cornec, A. Le. (1996), The microwave radiometer aboard ERS-1: Part II-validation of the geophysical products, *IEEE Transactions on Geoscience and Remote Sensing*. http://doi.org/10.1109/36.485108

Gaspar, P., F. Ogor, P. Y. Le Traon and O. Z. Zanife, 1994, Estimating the sea state of the TOPEX and POSEIDON altimeters from crossover differences, *J. Geophys. Res.*, 99, 24981-24994.

Gaspar, P., F. Ogor and C. Escoubes, 1996, Nouvelles calibration et analyse du biais d'etat de mer des altimetres TOPEX et POSEIDON, Technical note 96/018 of CNES Contract 95/1523.

Haines, B., D. Kubitschek, G. Born and S. Gill, 2002, "Monitoring Jason-1 and TOPEX/POSEIDON from an offshore platform: The Harvest experiment (abstract)", Jason-1/TOPEX/POSEIDON Science Working Team, New Orleans, LA, USA.

Imel, D., 1994, Evaluation of the TOPEX dual-frequency Ionosphere correction, *J. Geophys. Res.*, 99 (c12), pp 24895-24906.

Helm, V., Humbert, A., and Miller, H. (2014). Elevation and elevation change of greenland and antarctica derived from cryosat-2. The Cryosphere, 8(4):1539-1559.

Keihm, S. J., M. A. Janssen, and C. S. Ruf, 1995, TOPEX/POSEIDON microwave radiometer (TMR): III. Wet troposphere range correction algorithm and pre-launch error budget, *IEEE Trans. Geosci. Remote Sensing*, 33, 147-161.

Labroue S., P. Gaspar, J. Dorandeu, O.Z. Zanife, F. Mertz, P. Vincent and D. Choquet, 2004: Non parametric estimates of the sea state bias for the Jason-1 radar altimeter. Marine Geodesy 27 (3-4), 453-481.

Le Provost, C., 2001, "Ocean Tides", *Satellite Altimetry and Earth Sciences*, ed. L.L. Fu and A. Cazenave, pp. 267-303.

Le Provost, C., F. Lyard, M. L. Genco, F. Lyard, P. Vincent, and P. Canceil, 1995, Spectroscopy of the world ocean tides from a finite element hydrodynamic model, *J. Geophys. Res.*, 99, 24777-24797.

Lefèvre F., F. Lyard, C. Le Provost and E.J.O Shrama, Fes99 : a global tide finite element solution assimilating tide gauge and altimetric information, J. Atm. Oceano. Tech., submitted, 2001.

Lemoine, F. G. et al., 1998, The Development of the joint NASA GSFC and NIMA Geopotential Model EGM96, NASA/TP-1998-206861, 575 pp.

Lillibridge, J., Scharroo, R., Abdalla, S., & Vandemark, D. (2014), *One-and two-dimensional wind speed models for ka-band altimetry*, Journal of Atmospheric and Oceanic Technology, 31(3), 630-638. http://doi.org/10.1175/JTECH-D-13-00167.1

FES2014 global ocean tides atlas: design and performances

Lyard F., Allain D., Cancet M., Carrere L., and Picot N. (2021), under review Ocean Sciences: https://os.copernicus.org/preprints/os-2020-96/os-2020-96.pdf

Obligis, E., Eymard, L., Tran, N., Labroue, S., & Femenias, P. (2006), First three years of the microwave radiometer aboard Envisat: In-flight calibration, processing, and validation of the geophysical products. *Journal of Atmospheric and Oceanic Technology*, 23(6), 802–814. http://doi.org/10.1175/JTECH1878.1

Obligis, E., Rahmani, A., Eymard, L., Labroue, S., & Bronner, E. (2009), An improved retrieval algorithm for water vapor retrieval: Application to the envisat microwave radiometer, *IEEE Transactions on Geoscience and Remote Sensing*, 47(9), 3057-3064. http://doi.org/10.1109/TGRS.2009.2020433

Pavlis, N. and R. H. Rapp, 1990, The development of an isostatic gravitational model to degree 360 and its use in global gravity modeling, *Geophys. J. Int.*, 100, 369-378.

Picard, B., Frery, M.-L., Obligis, E., Eymard, L., Steunou, N., & Picot, N. (2015), SARAL/AltiKa Wet Tropospheric Correction: In-Flight Calibration, Retrieval Strategies and Performances, *Marine Geodesy*, 38(sup1), 277–296. http://doi.org/10.1080/01490419.2015.1040903

Rapp, R. H. et al., 1991, Consideration of Permanent Tidal Deformation in the Orbit Determination and Data Analysis for the TOPEX/POSEIDON Mission, NASA Tech. Memorandum 100775, Goddard Space Flight Center, Greenbelt, MD.

Rapp, R. H., Y. M. Wang, and N. K. Pavlis, 1991, The Ohio State 1991 geopotential and Sea Surface Topography Harmonic Coefficient Models, Rpt. 410, Dept. of Geodetic Science and Surveying, The Ohio State University, Columbus, OH.

Ray, R. D., 1999, A global ocean tide model from TOPEX/POSEIDON altimetry: GOT99.2, NASA Tech. Memorandum 1999-209478, Goddard Space Flight Center, Greenbelt, MD.

Rio M.-H., F. Hernandez, 2004, A mean dynamic topography computed over the world ocean from altimetry, in situ measurements, and a geoid model, J. Geophys. Res., 109, C12032.

Rio, M.-H., Schaeffer, P., Lemoine, J.-M., Hernandez, F. (2005). "Estimation of the ocean Mean Dynamic Topography through the combination of altimetric data, in-situ measurements and GRACE geoid: From global to regional studies." Proceedings of the GOCINA international workshop, Luxembourg.

Rodriguez, E., Y. Kim, and J. M. Martin, 1992, The effect of small-wave modulation on the electromagnetic bias, *J. Geophys. Res.*, 97(C2), 2379-2389.

Ruf, C., S. Keihm, B. Subramanya, and M. Janssen, 1994, TOPEX/POSEIDON microwave radiometer performance and in-flight calibration, *J. Geophys. Res.*, 99, 24915-24926.

Smith, W. H. F. and D. T. Sandwell, 1994, Bathymetric prediction from dense satellite altimetry and spare shipboard bathymetry, *J. Geophys. Res.*, 99, 21803-21824.

Stacey, F. D., 1977, *Physics of the Earth*, second ed. J. Wiley, 414 pp.

Stammer, D., C. Wunsch, and R. M. Ponte, 2000, De-aliasing of global high frequency barotropic motions in altimeter observations, *Geophys. Res. Lett.*, 27, 1175-1178.

Tapley, B. D. et al., 1994, Accuracy Assessment of the Large Scale Dynamic Ocean Topography from TOPEX/POSEIDON Altimetry, *J. Geophys. Res.*, 99 (C12), 24, 605-24, 618.
Tierney, C., J. Wahr, F. Bryan, and V. Zlotnicki, 2000, Short-period oceanic circulation: implications for satellite altimetry, *Geophys. Res. Lett.*, 27, 1255-1258.

Tournadre, J., and J. C. Morland, 1998, The effects of rain on TOPEX/POSEIDON altimeter data, *IEEE Trans. Geosci. Remote Sensing*, 35, 1117-1135.

Tran, N., D. Vandemark, S. Labroue, H. Feng, B. Chapron, H. L. Tolman, J. Lambin, and N. Picot (2010): *"Sea state bias in altimeter sea level estimates determined by combining wave model and satellite data", J. Geophys. Res., 115, C03020, doi:10.1029/2009JC005534, 2010.*

Tran N., D. Vandemark, H. Feng, A. Guillot, N. Picot (2014) Updated wind speed and sea state bias models for Ka-band altimetry, 2014 SARAL/AltiKa workshop, Lake Constance, Germany. Available at https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Poster_PEACHI_ssb_tran2014.pdf

Tran, N., 2014b, "PEACHI Task 1.3 : Wind speed", Technical report CLS-DOS-NT-14-15.

Tran, N., 2015a, "PEACHI Task 3.1 : sea-ice flag", Technical report CLS-DOS-15-0156.

Tran, N., 2015b, "PEACHI Task 2.2 : ice-sheet snow flag", Technical report CLS-DOS-15-0197.

Tran N., D. Vandemark, E.D. Zaron, P. Thibaut, G. Dibarboure, and N. Picot (2019): "Assessing the effects of sea-state related errors on the precision of high-rate Jason-3 altimeter sea level data", Advances in Space Research / special issue "25 Years of Progress in Radar Altimetry", doi:10.1016/j.asr.2019.11.034

Valladeau, G., Thibaut, P., Picard, B., Poisson, J. C., Tran, N., Picot, N., & Guillot, A. (2015). *Using SARAL/AltiKa to Improve Ka-band Altimeter Measurements for Coastal Zones, Hydrology and Ice: The PEACHI Prototype, Marine Geodesy, 38, 124-142. http://doi.org/10.1080/01490419.2015.1020176*

Watson, C., R. Coleman, N. White, J. Church and R. Govind, 2002, "In-situ calibration activities in Bass Strait, Auatralia (abstract)", Jason-1/TOPEX/POSEIDON Science Working Team, New Orleans, LA, USA.

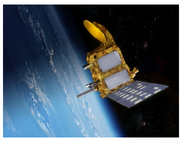
Witter, D. L., and D. B. Chelton, 1991, A Geosat altimeter wind speed algorithm and a method for altimeter wind speed algorithm development, *J. Geophys. Res.*, 96, 8853-8860.

Wunsch, C., 1972, Bermuda sea level in relation to tides, weather and baroclinic fluctuations, *Rev. Geophys. Space Phys.*, 10, 1-49.

Yi, Y., 1995, Determination of Gridded Mean Sea Surface from TOPEX, ERS-1 and GEOSAT Altimeter Data, Rpt. 434, Dept. of Geodetic Science and Surveying, The Ohio State University, Columbus, 9363-9368.

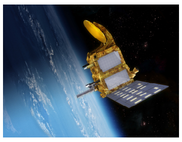
Zaron, E. D., 2017, Personal communication 2017; "HRET_v7.0"

Zlotnicki, V., 1994, Correlated environmental corrections in TOPEX/POSEIDON, with a note on ionospheric accuracy, *J. Geophys. Res.*, 99, 24907-24914.

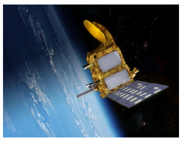


Annexe B - List of acronyms

AD	Applicable Document
AGC	Automatic Gain Control
AMR	Advanced Microwave Radiometer
AVISO	Archivage, Validation et Interprétation des données des Satellites Océanographiques
BRAT	Basic Radar Altimetry Toolbox
CLIVAR	Climate Variability and Predictability program
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etudes Spatiales
DIODE	Détermination Immédiate d'Orbite par Doris Embarque
DORIS	Détermination d'Orbite et Radiopositionnement Intégrés par Satellite
DTM	Digital Terrain Model
ECMWF	European Center for Medium range Weather Forecasting
EGM	Earth Gravity Model
EM	ElectroMagnetic
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FES	Finite Element Solution
FFT	Fast Fourier Transform
GDR	Geophysical Data Records
GIM	Global Ionosphere Maps
GODAE	Global Ocean Data Assimilation Experiment
GPS	Global Positioning System
GTS	Global Telecommunications System
HF	High Frequency
IB	Inverse Barometer
IGDR	Interim Geophysical Data Records
JGM	Joint Gravity Model
JPL	Jet Propulsion Laboratory
LPT	Light Particle Telescope
MDT	Mean Dynamic Topography
MLE	Maximum Likelihood Estimator
MSS	Mean Sea Surface
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NWP	Numerical Weather Prediction
OGDR	Operational Geophysical Data Records
OSTM	Ocean Surface Topography Mission
OSU	Ohio State University
POD	Precision Orbit Determination
POE	Precision Orbit Ephemerides
RD	Reference Document
RMS	Root Mean Square
RSS	Root Sum Square
SLA	Sea Level Anomaly
SLR	Satellite Laser Ranging
SSALTO	Segment Sol multimissions d'ALTimétrie, d'Orbitographie et de localisation précise
SSB	Sea State Bias
SSH	Sea Surface Height
SSHA	Sea Surface Height Anomaly
SWH	Significant Wave Height
T/P	Topex/Poseidon



TBC	To be confirmed
TBD	To be defined
TEC	Total Electron Content
UTC	Universal Time Coordinated
WMO	World Meteorological Organization
WTC	Wet Tropospheric Correction



Annexe C - Contacts

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ISRO

User Service Helpdesk:

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