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SARAL

AltiKa and ARGOS-3 on SSB

SARAL/ALTIKA JOINT CALVAL PLAN

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TERMINOLOGY AND ABREVIATION

Acronym	Definition
AD	Applicable Document
ALK	AltiKa altimeter/radiometer equipment
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic Data
CALVAL	CALibration and VALidation
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etudes Spatiales
CoI	Co-Investigator
DIODE	DORIS Immediate Orbit on-board Determination
DORIS	Détermination d'Orbite et Radiopositionnement Intégré par Satellite
DR	Document de Référence
DUACS	Data Unification and Altimeter Combination System
ENVISAT	ENVIronmental SATellite
ERS-1&2	European Remote Sensing Satellite
GFO	Geosat Follow On
GIM	Global Ionosphere Maps
GPS	Global Positioning System

Acronym	Definition
GTS	Global Telecommunication System
IERS	International Earth Rotation Service
IMS-2	Indian Mini Satellite -2
ISRO	Indian Space Research Organisation
ISTRAC	ISRO Telemetry, Tracking and Command network
LEOP	Launch and Early Orbit Phase
LRA	Laser Reflector Array
MOE	Medium Orbit Ephemeris
MoU	Memorandum of Understanding
N/A	Not Applicable
NRT	Near Real Time
O/I/S/-GDR	Operational/Interim/Sensor Geophysical Data Record
OFL	OFfLine
OSTST	Ocean Surface Topography Science Team
PDGS	Payload Data Ground Segment
PI	Principal Investigator
PIM	Payload Integrated Module
POD	Precise Orbit Determination
POE	Precise Orbit Ephemerides
PSLV	Polar Satellite Launch Vehicle
PTR	Point Target Response
RD	Reference Document
RMS	Root Mean Square
RSS	Root Sum Square
SALP	Système d'Altimétrie et de Localisation Précise
SCC	Satelitte Control Center
SLR	Satellite Laser Ranging
SNR	Signal to Noise Ratio
SODAP	Switch-On and Data Acquisition Phase
SPA	Scalable Processor for Altimetry
SRP	Solar Radiation Pressure
SSALTO	Segment Sol ALTimétrie et Orbitographie

Acronym	Definition
SSB	Sea State Bias
SSB (Platform)	Small Satellite Bus
SSH(A)	Sea Surface Height (Anomaly)
SWH	Significant Wave Height
TBC	To Be Confirmed
TBD	To Be Defined
T/P	Topex/Poseidon
T/S	Temperature/Salinity
TAS	Thales Alenia Space
USO	Ultra Stable Oscillator

APPLICABLE AND REFERENCE DOCUMENTS

Supprimer les paragraphes inutiles. Si aucune référence n'est nécessaire, préciser N/A.

APPLICABLE DOCUMENTS

Reference	Title of document
SRL-SYS-SP-052-CNES	AltiKa/SARAL Mission Rationale and Requirements
SRL-SYS-SP-010-CNES	SARAL System Requirements

REFERENCE DOCUMENTS

Reference	Title of document
ALK-SY1-SP-056-CNES	AltiKa/SARAL Operational Service Specification
SRL-SYS-PL-392-CNES	AltiKa/SARAL Joint Science Plan
SALP-MU-M-OP-15984-CN	SARAL/AltiKa Products Handbook

TBC AND TBD LIST

TBC/TBD	Section	Brief description

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1. PURPOSE: CALVAL OVERVIEW

1.1 CALVAL OBJECTIVES AND REQUIREMENTS

The CALVAL plan objective is to validate finally the data quality and certify the performance of SARAL/AltiKa data with respect to the error budget specifications and goals. It will be achieved through intense verification and calibration during the verification phase (9-10 months since beginning of cycle 1), as well as through routine and long-term CALVAL activities after.

CALVAL involves many steps, a series of quality controls designed to ensure a continuous supply of data:

- **During CALVAL phase**, the quality control will be achieved through 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.
- **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.

1.2 CALVAL ORGANIZATIONS AND RESPONSABILITIES

The CALVAL plan will be conducted by the **2 partners CNES and ISRO project teams**, and by the **international SARAL/AltiKa Science Team (PIs)** selected at the end of the SARAL/AltiKa Announcement of Opportunity selection process.

The SARAL/AltiKa Verification Phase is expected to last 9 to 10 months. It overlaps the Assessment Phase (expected duration 2 months) in time, beginning when the satellite is in the operational orbit with the instruments engineering assessment completed, and continuing until the data received from the satellite, the instruments and the processing algorithms are satisfactorily calibrated and validated. During this phase, *in situ* data will be collected from the dedicated calibration sites to be used in the verification process. Extensive comparisons of the various products generated by all the teams involved in this phase will be carried on. This phase includes :

- the **Near Real Time (NRT) Verification Phase (5 months)** concluded by the first Verification Workshop to verify the Near Real Time (NRT) algorithms and products.
- the **Offline (OFL) Verification Phase (9 months)** concluded by a final Verification Workshop to verify the Offline (OFL) algorithms and products.

The Final Verification Workshop shall take place no later than eleven (11) months from launch.

The following graph shows the various operational phases following the SARAL/AltiKa launch.

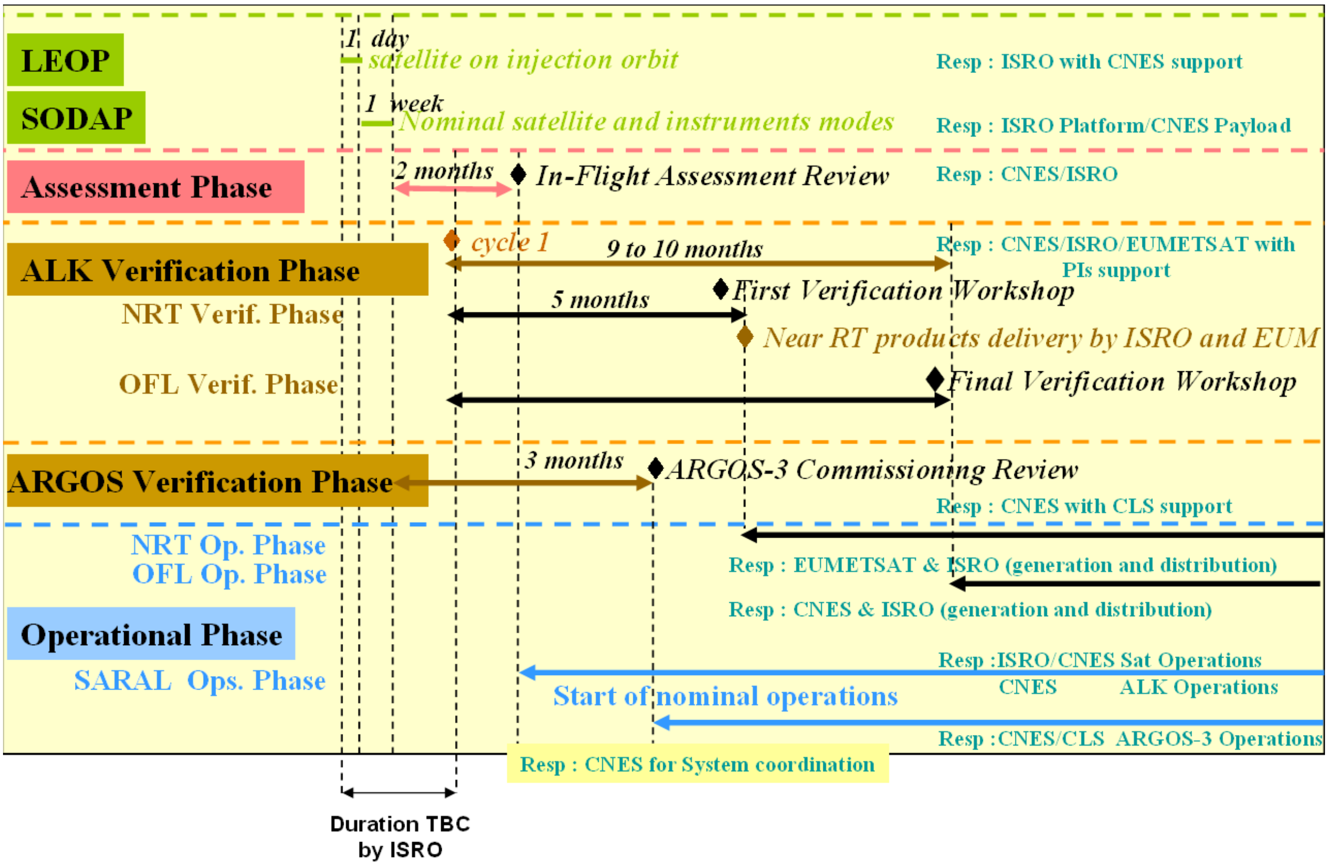


Figure 1 : SARAL/AltiKa mission phases and associated responsibilities

Organisation

At project level, **CNES will lead and conduct the SARAL/AltiKa assessment and verification phases**, and perform evaluation and calibration activities to verify the SARAL/AltiKa performance achieved on-orbit. A regular reporting of CALVAL activities and results will be organized.

CNES with the support of **EUMETSAT, and ISRO**, **will start processing near real time data as soon as possible** using the latest version of the near real time processing system called TM_NRT. After validation of OGDR products ratified by the first Verification Workshop, ISRO and EUMETSAT will begin operational production of OGDR and release to SARAL/AltiKa PIs. Indian users will obtain the OGDR from ISRO, and non-Indian users from EUMETSAT.

In the meantime, **CNES will start processing the first off-line products (IGDR) as soon as possible** using the latest version of the off-line processing system called SPA. IGDR products will firstly be made available to ISRO and analyzed. Release and distribution of IGDR by CNES to PIs will only begin once IGDR products have been validated.

CNES and ISRO will start processing GDR products after POE (Precise Orbit Ephemeris), altimeter and radiometer in-flight calibrations have been fully performed. GDR will be subject to nominal cycle-by-cycle validation before release to PIs.

Reporting and archival plans

During the assessment and verification phases, regular CALVAL progress meetings will be organized at the project level. Inputs from and to SARAL/AltiKa Science Team PIs will circulate through e-mail, dedicated ftp sites, and websites (http://smsc.cnes.fr/SARAL, http://www.aviso.oceanobs.com). In addition, one in-flight assessment meeting (at project level), plus two dedicated verification workshops (open to the Science Team) will be organized in cooperation between the 2 partners, to report results, findings and recommendations:

- **First SARAL/AltiKa verification workshop** will have as a goal to **validate OGDR** as operational products for the whole community.
- **Second Science Team workshop** will be the final verification workshop with the goal to **validate I/GDR** and allow for the offline products delivery and data reprocessing.

In addition to these meetings, verification progress reports will be mailed and/or put on the AVISO web site. This process should lead to the validation by the Science Team of the performances of the system and of the I/GDR contents. It will also lead to approval of a revised error budget, including calibration and drift quantities, and recommendations to the project for improvements and/or changes, if any, prior to routine GDR distribution.

During the operational phase, the verification activities will continue, on a routine basis, to continuously check the integrity of the system. Verification reports will be produced, on a regular basis, by CNES with inputs from the ISRO project element and from the Science CALVAL team. Any anomaly or foreseen change in the system will be reported to CNES for action.

Eventually the SARAL/AltiKa Science Team meetings should be merged to OSTST (Ocean Surface Topography Science Team) meetings in order to serve as a forum to discuss new findings in the overall altimetry scientific community. Note that the 2010 OSTST meeting has taken place on October 18-20th in Lisbon (http://www.ostst-hydro-2010.com) and that the Second SARAL/AltiKa Science workshop will be organized in India early 2011 (March 15-17th, in Ahmedabad in ISRO/SAC premises. Web pages of the meeting: http://www.aviso.oceanobs.com/fr/courses/sci-teams/altika-science-team/2011-altika-science-workshop/index.html).

2. INTRODUCTION: SARAL/ALTIKA MISSION

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 Jason-2 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 SARAL/AltiKa mission is part of the **operational satellite altimetry system**, jointly with JASON-2, and enables to ensure the **service continuity** which is nowadays provided by ENVISAT altimeter jointly with JASON-2 and JASON-1.

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 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 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, modeling, **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 modeling 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 [Ref: SRL-SYS-PL-392-CNES].

2.3 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 ESR1/2 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 4.6 cm or better (at 1 Hz)** in order to meet the mission objectives. The SARAL/AltiKa satellite is specified and designed to fulfil the mission objectives and will be launched from mid-2011 [TBC] to take over for ENVISAT mission.

The ocean topography is obtained through three basic measurements (Figure 2):

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

2) the range delay through the atmosphere (troposphere and ionosphere). The onboard radiometer is used to correct for tropospheric delay while the ionospheric delay will be negligible at the Ka frequency.

3) the altitude of the satellite above the reference ellipsoid derived from precise orbit determination (DORIS + LRA).

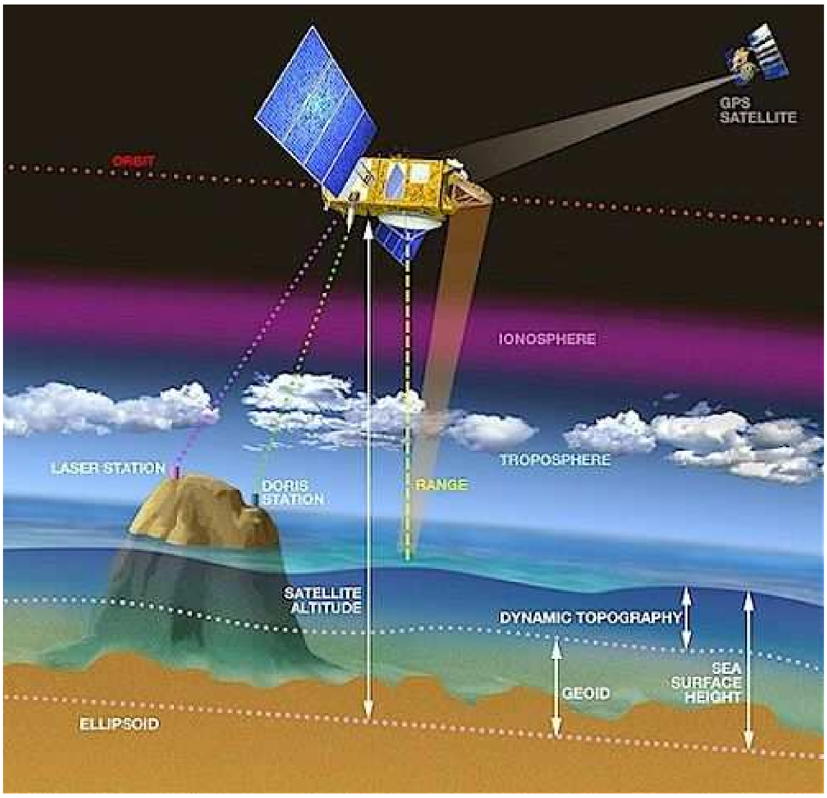


Figure 2 : Geometry of the sea surface height measurement by altimetry

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 : http://www.altimetry.info/html/alti/welcome_en.html

2.3.1 SATELLITE

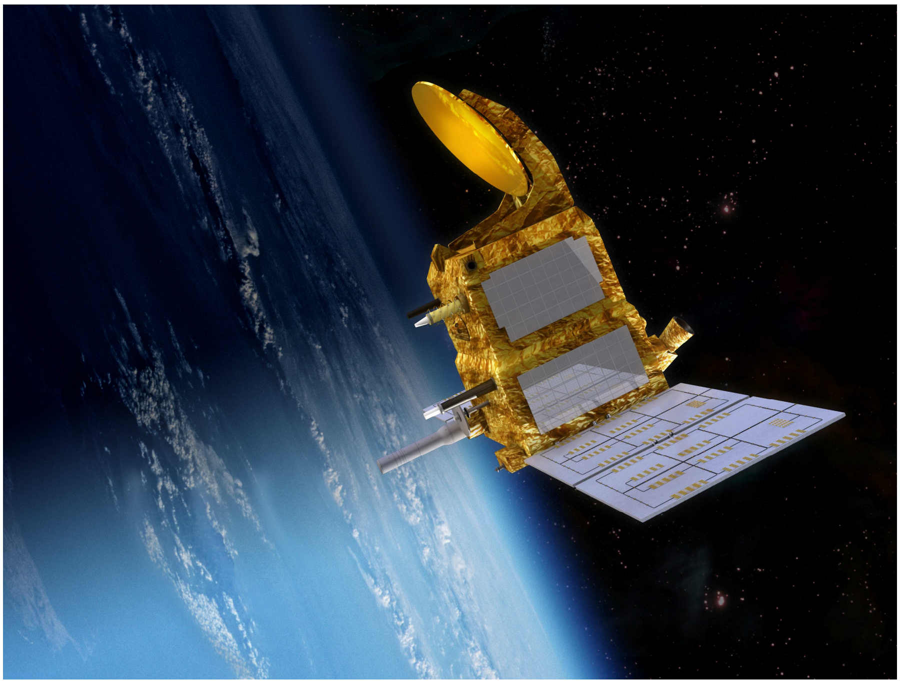


Figure 3 : Artist view of the SARAL satellite (credit GEKO / CNES)

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** composed of the following instruments:
  - An **altimeter-radiometer AltiKa**

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

- **Ka-band 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.

- **Dual-frequency radiometer**

The bi-frequency (23.8 / 34 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 34 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.

- A **DORIS** system for precise orbit determination

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 JASON-2. 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 ultrastable oscillator.

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

- A **LRA** (Laser Retro-reflector Array) instrument 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 **ARGOS-3 instrument**

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

The satellite will be **launched by a PSLV vehicle** supplied by **ISRO**, from the main ISRO launch base, the **Satish Dhawan Space Centre, SHAR SRIHARIKOTA**, (13°43.2N ; 80°13.8E)100 km North from Chennai (Figure 4).

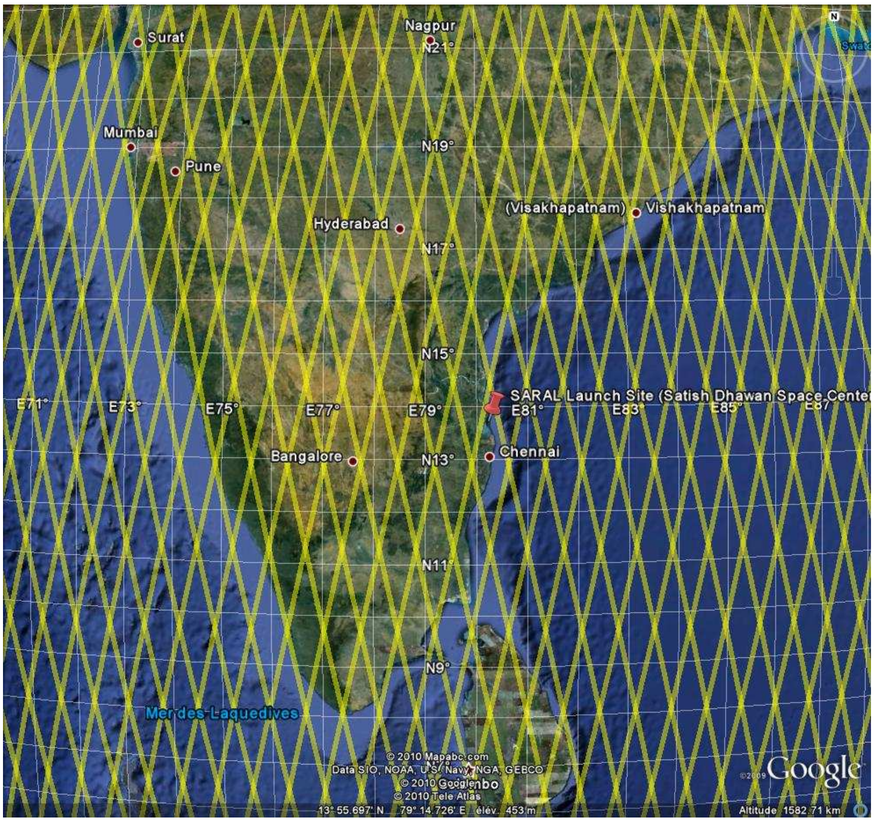


Figure 4: Location of SARAL/AltiKa launch base (red pinpoint) and ground tracks over southern India

2.3.2 GROUND SEGMENT

ISRO and CNES will jointly establish and operate a ground segment including all elements and all facilities required to operate the SARAL satellite and the AltiKa and ARGOS-3 missions, acquire their telemetry, process, distribute, and archive data and Data Products, deliver near real time and off line services to operational and research users.

The ground segment (placed under the SARAL project responsibility, and associated elements under DORIS or ARGOS-3 programs responsibilities) consists in:

- a flight operation segment,
- a payload data segment
- and a data communication network.

2.3.2.1 SARAL FLIGHT OPERATION SEGMENT

It includes :

- a **Satellite Control Centre** located in Bangalore, India provided and operated by **ISRO/ISTRAC**; this center will operate and monitor the satellite during the complete mission life time.

The SCC implements the following functions : mission operations scheduling, spacecraft control and monitoring, on-board software maintenance, operational orbit determination and control, attitude determination and control, on-board software maintenance, acquisition of data (housekeeping telemetry, commands, manoeuvres information, …).

- an **S-band Ground Stations Network** provided and operated by **ISRO/ISTRAC**. The configuration planned to be used for SARAL is one S-band station located in Bangalore, India, complemented by other ground stations for LEOP and contingency situations if needed.

The S-band Ground Station performs satellite housekeeping telemetry capture, its recording and distribution to the control center then to the mission centers. The S-band Ground Station also performs the telecommand uplink to the satellite. The S-band stations monitoring and maintenance is performed in the frame of the ISRO/ISTRAC TTC Network support.

2.3.2.2 SARAL PAYLOAD DATA SEGMENT

The SARAL Payload Data Ground Segment (PDGS) is implementing :

- X-band stations network management and payload telemetry data retrieval,
- Payload data processing, archiving and distribution,
- Mission Planning/monitoring,
- Data Quality Control,
- Users Management.

It includes :

- a set of elements/means that composes the AltiKa/SARAL mission ground segment,
- a set of elements/means that composes the ARGOS-3/SARAL mission ground segment,
- a X-band Polar Ground Stations Network operated by SSC under CNES contract. The planned configuration is to use the Kiruna, Sweden and Inuvik, Canada stations operated by SSC.

The X-band Ground Stations Network performs SARAL payload telemetry capture, its processing and distribution to the mission centers via EUMETSAT Data Server.

The main elements of the AltiKa/SARAL mission ground segment are :

- a **CNES AltiKa mission ground system** mainly based on multi-missions elements shared with all the CNES altimetry missions and including specific AltiKa functionalities. All entities involved that are used to fulfil the AltiKa/SARAL mission are under the CNES SALP service responsibility. This includes :
  - o a multi-mission altimetry center named SALP and called **"CNES AltiKa mission center"** in this document. The SALP multi-mission center is composed of :
    - the SSALTO multi-missions ground system (Segment Sol multimission ALtimétrie et Orbitographie). Its functions consist in instrument programming and monitoring (altimeter/radiometer and DORIS), commands requests generation (altimeter/radiometer and DORIS), AltiKa mission management and operation plan definition, Precise Orbit Determination (POD) for POD algorithm definition, POD data production and validation, scientific altimeter data processing and validation of altimetry product, data dissemination to users and archiving,
    - the GIM (ionospheric correction) and T-UGO2D (barotrope correction) facilities provide ancillary data for geophysical corrections,
    - DUACS serves the main operational oceanography and climate forecasting projects in Europe and worldwide,
    - the CALVAL facility provides quality assessment of the products before dissemination to users,

   - DORIS system integrity tool kit insures the quality of the DORIS signal transmitted by the DORIS beacons
 - o the DORIS system beacons network and associated maintenance service
 - o the NRT and SPA facilities management (operations support and maintenance)
 - o the SALP experts, for the long-term quality check

- an **ISRO mission center** with
  - o a near real time AltiKa processing system provided by CNES
  - o an off-line AltiKa processing system provided by CNES
  - o dissemination of the generated products
  - o archiving and user services
- a **EUMETSAT mission center** with :
  - o a near real time AltiKa processing system provided by CNES
  - o NRT dissemination of the generated products
  - o archiving of the generated NRT products
  - o and distribution infrastructure of payload instrument data and auxiliary data to both CNES and ISRO.

2.3.2.3 SARAL DATA COMMUNICATION NETWORK

The SARAL Data Communication Network is set up to allow data exchanges between all the elements specific to the SARAL mission, located in Bangalore, Shadnagar, Toulouse, Darmstadt, Kiruna/Esrange for Polar X-Band Stations.

The main data communication interfaces are between CNES site and ISRO site for Command&Control functions, and between the missions centers (Eumetsat, CNES and ISRO, and CLS/ARGOS) and the Polar X-Band stations access point.

2.3.3 ORGANIZATION

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 and ARGOS-3 mission payload
  - Support for SARAL Payload Module integration and test
  - Ground System & Operations
    - o Polar X-band stations
    - o Compatibility of L-band stations network required for the ARGOS-3/SARAL mission
    - o Data communication network
    - o AltiKa Mission Centre
    - o NRT and OFL product processing software development, installation, training and support to operations (ISRO and EUMETSAT)
    - o NRT product processing, archiving, distribution to users outside India, with the support of EUMETSAT
    - o OFL product processing and distribution to users outside India

  - o DORIS product processing and distribution
  - o Data providing to the ARGOS Global Processing Centers
  - o 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
    - o Satellite Control Centre
    - o S-band network stations
    - o X-band Hyderabad station (not necessarily on an operational basis)
    - o Data communication network
    - o NRT and OFL products processing and distribution to users within India
    - o 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.

2.4 DATA PRODUCTS

The data products will be described in detail in the document "SARAL/AltiKa Products Handbook" [Ref: SALP-MU-M-OP-15984-CN].

Three different data products shall be produced and distributed to the users:

1. Operational Geophysical Data Record (**OGDR**) produced in near real time (3 hours)
2. Interim Geophysical Data Record (**IGDR**) produced in 1 to 1.5 days
3. Geophysical Data Record (**GDR**) produced in about 40 days

The first one is a Near-Real Time (NRT) product. The other two are Offline (OFL) products.

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

Taken into account Jason-1&2 heritage, products will be split into several files:

1. One file close to current Jason-1&2 NRT-**SSHA,** limited to 1Hz sampling.
2. One file close to current Jason-1&2 **I/GDR**, containing 1Hz and 40Hz values.
3. One file close to current Jason-1&2 **S-I/GDR**, containing 1Hz, 40Hz and waveforms values. This file will not be generated in NRT.

In terms of files, we will so have :

- Operational Geophysical Data Record (**OGDR**) in 2 files : **SSHA-OGDR** + **OGDR**
- Interim Geophysical Data Record (**IGDR**) in 3 files : **SSHA-IGDR** + **IGDR** + **S-IGDR**
- Geophysical Data Record (**GDR**) in 3 files : **SSHA-GDR** + **GDR** + **S-GDR**

2.4.1 NEAR-REAL TIME PRODUCTS

2.4.1.1 PRODUCT DESCRIPTION

The near real time level 2 product is the **Operational Geophysical Data Record product** (OGDR).

To be considered as a fully operational product from the core mission, the OGDR product shall be nominally computed from telemetry : AltiKa altimeter/radiometer and DORIS. **Its primary goal is to provide wind/wave data to meteorological users**, whereas it is designed to also provide altimeter range, environmental and geophysical corrections together with a real-time orbit in order to make near real-time sea-surface height anomalies available to ocean users.

To satisfy **meteorological** purposes, it essentially contains:

- time,
- location,
- Ka-Band significant waveheight,
- Ka-band sigma naught,
- wind speed (from Ka-band data and meteorological model),
- water vapour correction (from the radiometer and meteorological model)
- Ka-band altimeter range and associated corrections
- orbit data (altitude)
- geophysical corrections (tides, sea state bias, …)
- geophysical references (geoid, mean sea surface, local mean sea surface, …)
- quality information to help users editing the data.

To satisfy **oceanography** purposes, the OGDR data products shall explicitly provide a sea-surface height anomaly measurement, **ssh**, that is usually derived by :

ssh = altitude_from_orbit
- (altimeter_range_ka + ionospheric_correction_from_model
+ dry_tropospheric_correction_from_model + wet_tropospheric_correction_from_radiometer
+ sea_state_bias)
- (mean_sea_surface + solid_earth_tide + ocean_tide + pole_tide + inverse_barometer)
+ bias

Each of the values that are used in the previous equation to derive **ssh** shall be individually provided in the data product.

The onboard DIODE orbit will be used to compute location and altitude information. This will make the product compliant with a typical 30 cm RMS orbit accuracy level for the radial component of the orbit.

Note that, like the Jason-2 OGDR product, the SARAL/AltiKa OGDR product needs ground computations to derive all environmental and geophysical corrections. In particular, this will imply the management of external data such as the atmospheric pressure fields to compute the dry troposphere correction and the inverse barometer response. The forecast outputs of the model will have to be used.

Taking into account Jason-1&2 heritage, **OGDR products** will be split into two files :

- one file close to current Jason-2 **NRT-SSHA**, limited to 1Hz sampling.
- one file close to current Jason-2 **I/GDR**, containing 1Hz and 40Hz values.

2.4.1.2 CONSTRAINTS DUE THE NEAR REAL TIME CHARACTER OF THE PRODUCT

Due to the **3-hour data latency** imposed to the OGDR product, ground processing will be optimized in terms of performance and management of some external data.

Among various consequences :

- o The DORIS/DIODE navigator data are used to provide the orbit input to the OGDR product. Following SARAL/AltiKa error budget specifications, the RMS orbit accuracy for the radial component has been set down to 30 cm (with the objective that the 10 cm level may be reached with no major difficulty).
- o The segmentation of OGDR products is driven by the dump over the earth terminals.
- o Only elementary and automatic controls are performed on the OGDR product to allow for a fast verification of the product before dissemination..

2.4.2 OFFLINE PRODUCTS

Level 2 data are produced from the altimeter level 1b parameters, combined with a precision orbit from POD, microwave radiometer data from the radiometer, and a series of auxiliary data.

Taking into account Jason-1&2 heritage, **Level 2 OFL products** will be split into several files :

- one file close to current Jason-1&2 **NRT-SSHA**, limited to 1Hz sampling. This file is very popular for oceanic applications. Product file size is very small (and this remains important for users).
- one file close to current Jason-1&2 **I/GDR**, containing 1Hz and 40Hz values.
- one file close to current Jason-1&2 **SGDR**, containing 1Hz, 40Hz and waveforms values.

The **IGDR/GDR products** essentially contain information concerning : range + orbital altitude, associated instrumental, environment and geophysical corrections, wave height, backscatter coefficient and wind speed, water vapour from the radiometer. The GDR product formally contains the same information as the IGDR product with a series of parameters computed with updated and more accurate inputs such as the orbit.

In particular, it is noticeable that ground retracking of altimeter waveforms is systematically applied. Several retracking techniques will be applied, allowing user to select the most relevant one for their application.

The IGDR product is a not fully validated OFL product.

The **GDR product** is a **fully validated OFL product** : in depth validation is performed on a cycle basis before delivery to end users. This validation is performed by CNES/SALP team. For each cycle, a validation email will be sent. The GDR cycle can only be released to end users once validated. Notice that this validation loop will be set up in place during operational phase only.

The **S-IGDR/S-GDR products** contain all information included in the IGDR/GDR plus information from level 1.0 and level 1b (for instance, waveforms) altimeter data.

Those products are dedicated to altimeter experts interested in qualifying the performances of the instrument itself; they also answer requirements from users looking at altimeter measurements for non usual ocean conditions. Indeed, such users as land/lake/ice users often perform their own processing of altimeter data using dedicated waveform retracking methods and all environment and geophysical corrections.

2.4.3 SUMMARY AND PRODUCT DIAGRAM

The basic geophysical altimeter product list and the main characteristics of each product are summarized in Table 1.

Major characteristics of the product	OGDR	IGDR	GDR
Content	Not fully validated geophysical level 2 product	Not fully validated geophysical level 2 product	fully validated geophysical level 2 product
Alt. ground retracking	Applied	Applied	Applied
Orbit information source	30cm DORIS Navigator	4 cm preliminary orbit	3 cm Precise orbit
Structure	Acquisition segment	pass	pass
Packaging	segment	day	cycle
Ground Processing mode	systematic	systematic	systematic
Data latency /availability	3 hours / 75% 5 hours / 95%	1 to 1.5 calendar days / 90%	40 days 90%
Ground Processing centres	EUMETSAT and ISRO	CNES	CNES and ISRO
Validation by experts	No	No	Yes CNES/SALP

Table 1: List of geophysical altimetric products and main characteristics.

In the table, "ground processing" refers to the operations to be performed in order to get a given product.

Note : The CNES mission centre shall have the capability to produce OGDR products during the verification phase with no constraint on production delays. CNES shall also be able to continue the OGDR production during the observational phase for specific verification and expertise goals.

The following diagram (Figure 5) illustrates the availability of the systematic geophysical level 2 user products as a function of time and orbit availability.

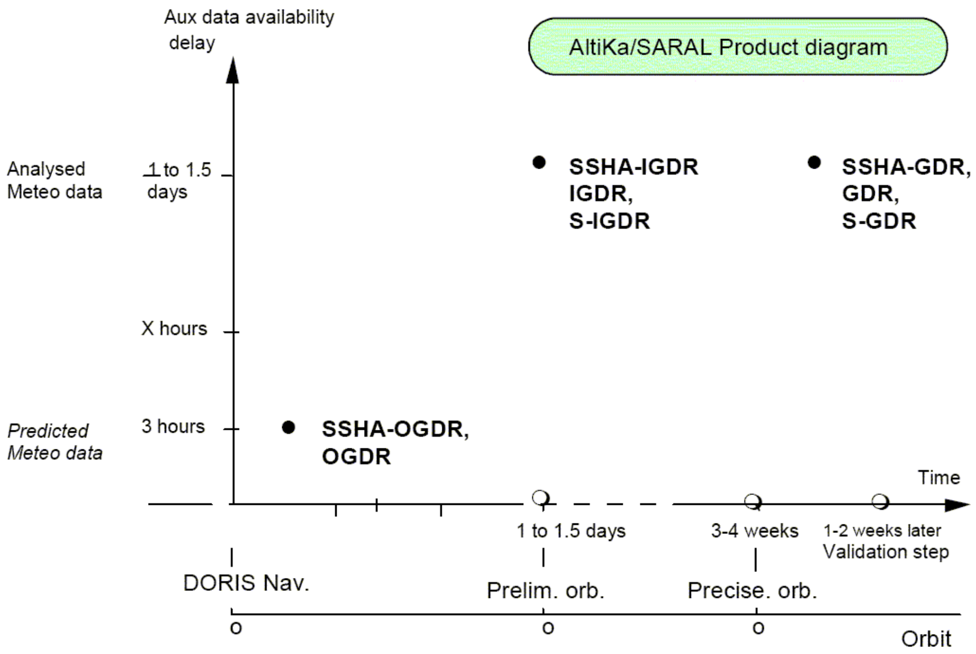


Figure 5 : SARAL/AltiKa product diagram

2.4.4 PRODUCTS DISSEMINATION

Dissemination responsibilities are defined as in the following Table 2. Dissemination mode information tells if the dissemination is systematic or on request, and if it is done electronically or using media.

PRODUCT	DISSEMINATION MODE	DISSEMINATION CENTER
SSHA-OGDR **OGDR**	Systematic – Electronic (1)	EUMETSAT / ISRO
SSHA-IGDR **IGDR** **S-IGDR**	Systematic – Electronic (2)	CNES / ISRO
SSHA-GDR **GDR** **S-GDR**	Systematic – Electronic (2) / Media (3)	CNES / ISRO

Table 2 : Description of dissemination responsibilities among the 3 partners (CNES, ISRO and EUMETSAT)

(1) The products shall be disseminated on-line by EUMETSAT and ISRO using some of the following methods :
- o FTP “Collect” (i.e, data are placed on a local FTP server and retrieved by the customer),
- o FTP “Deliver” (i.e, data are dispatched to an FTP server on the customer site)
- o Satellite broadcast (EUMETCAST system for EUMETSAT)

- TBD other system

(2) The products shall be disseminated on-line by CNES or ISRO using the following methods :
- FTP “Collect” (i.e, data are placed on a local FTP server and retrieved by the customer),
- TBD other system

(3) For offline dissemination, the following media shall be used :
- DVDs
- Other, TBD

3. PRE-LAUNCH PERFORMANCE ASSESSMENT

3.1 INTRODUCTION

Among the mandatory steps of the **CALVAL objectives and requirements**, arguably the most important ones are **the certification of the actual performance with respect to the error budget specifications and goals**, and the delivery of comprehensive performance estimation to the end-users of SARAL/AltiKa.

So far the performance assessment of altimetry missions has been summarized by a 'classical' budget error, that is to say a table with all satellite-related sources of errors along with the corresponding root squared sum (RSS). The classical performance assessment intends to describe the performance of an altimeter measurement system, that is to say the noise, the corrections and orbit errors, and the absolute error (bias) and the stability (drift).

The global error budget is given in terms of RMS for 1 Hz sea-surface height, for 2m SWH and 7.8 dB sigma naught. Table 3 shows the global SARAL/AltiKa error budget specifications, as well as desirable goals to be reached over the mission lifespan. These requirements apply to all open-ocean measurements.

	OGDR 3 Hours	IGDR 1.5 days	GDR 40 days	GOALS
Altimeter noise *(1) (2)*	1.5	1.5	1.5	1
Ionosphere	0.6	0.3	0.3	0.3
Sea state bias *(3)*	2	2	2	2
Dry troposphere	1.5	0.7	0.7	0.7
Wet Troposphere	1.2	1.2	1.2	1
Altimeter range after corrections (RSS)	4.5	3.5	3.5	2
Orbit *(4)* (Radial component) (RMS)	Req : 30 (5) Goal : 10	Req : 4 Goal : 2.5	Req : 3 Goal : 2	2
Total RSS Sea Surface Height	**Req : 30.5**	**Req : 5.3**	**Req : 4.6**	**2.8**
Significant Wave Height (H1/3) *(6)*	10 % or 0.5m	10% or 0.4 m	10% or 0.4 m	5% or 0.25m
Sigma naught Relative Value *(7)*	0.2 dB	0.2 dB	0.2 dB	0.1 dB
Wind speed	2 m/s	1.7 m/s	1.7 m/s	1 m/s
Sigma naught Absolute Value after in-flight calibration	0.7 dB	0.7 dB	0.7 dB	0.5 dB

Table 3 : SARAL/AltiKa error budget (in cm) : requirements and goals

(for 1 sec average, 2 meters SWH, 7.8 dB sigma naught)

(1) after ground retracking at 2 m SWH
(2) Average over 1 sec
(3) due to errors on SWH and wind
(4) The orbit is referenced to the center of gravity of the satellite; the radial component is defined as the perpendicular to the reference ellipsoid, crossing the satellite
(5) Real time DORIS on board ephemeris
(6) whichever is greater
(7) The relative value includes the noise and the non-calibrated drifts errors

		H 1/3 = 2 m	H 1/3 = 4 m	H 1/3 = 6 m	H 1/3 = 8 m
		σ0 = 7.8 dB	σ0 = 6.5 dB	σ0 = 6.1 dB	σ0 = 6 dB
Altimeter Noise in cm - 1 sec average	Requirements	1.5	2.2	2.8	3.3
	Goal	1	1.4	1.8	2

Table 4 : AltiKa altimeter noise specification and goal, as a function of Significant Wave Height (H 1/3)

(for 1 sec average)

Generally speaking SARAL/AltiKa has been specified based on the Jason-2 and Envisat state of the art, including particularities from AltiKa payload technology and data processing and algorithms as well as ancillary data. **The sea-surface height shall be provided with a globally averaged RMS accuracy of 4.6 cm (1 sigma), or better, assuming 1 second averages**.

The instrumental and environmental corrections shall be provided with the appropriate accuracy to meet this requirement. In addition to these *requirements*, a set of measurement-system *goals* has been 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 2.8 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.

3.2 PRE-LAUNCH SARAL/ALTIKA PERFORMANCE BUDGET

This section provides some insights and details on the 'classical' error budget given in Table 3 : A pre-launch error estimation is presented for each contribution, based either on dedicated analysis, either on published results. A global performance budget is finally presented.

3.2.1 ALTIMETER PERFORMANCES

3.2.1.1 RANGE NOISE

The following Table 5 gives **AltiKa range noise** that has been measured during altimeter acceptance tests, performed by CNES with the support of TAS (Thalès Alenia Space). These results were obtained during instrument with antenna tests. Note that during these tests, the SNR was about 10 dB.

		H 1/3 = 2 m	H 1/3 = 4 m	H 1/3 = 6 m	H 1/3 = 8 m
Altimeter Noise in cm - 1 sec average	Measured	0.9	1.4	1.6	2.1
	Requirements	*1.5*	*2.2*	*2.8*	*3.3*

Table 5 : AltiKa measured altimeter range noise (1 s average)

3.2.1.2 SURFACE WAVE HEIGHT

The following Table 6 gives **AltiKa SWH noise** that has been measured during altimeter acceptance tests. These results were obtained during instrument with antenna tests. Note that during these tests, the SNR was about 10 dB.

		H 1/3 = 2 m	H 1/3 = 4 m	H 1/3 = 6 m	H 1/3 = 8 m
SWH Noise in cm - 1 sec average	Measured	5.2	7.1	8.3	9.1
	Requirements	*40*	*40*	*60*	*80*

Table 6 : AltiKa measured SWH range noise (1 s average)

3.2.1.3 SIGMA-0

Sigma naught Relative Value :

Estimation of the waveforms level gives a negligible noise on this parameter. The variability will be linked to the corrections, but as PTR characteristics are very stable, the sigma0 noise is expected to be compliant with the 0.2 db required.

Sigma naught Absolute Value before launch :

For Sigma0 restitution, several instrument parameters are needed : antenna gain, wave guides losses, duplexer losses between calibration and emission / reception paths, … Each parameter has been measured at instrument level with an accuracy that has to be taken into account in error budget.

With AltiKa results, the worst case is ± 0.5 dB on the sigma0 restitution. This can not be calibrated at instrument level, and thus gives the order of magnitude of the absolute maximum expected bias.

Note that this error is an absolute one, which shall be reduced by in flight calibrations (comparisons with other altimeters …).

3.2.2 RADIOMETER PERFORMANCE: WET TROPOSPHERE CORRECTION

The following table gives the expected contribution of the **wet troposphere path delay** to the overall altimeter-derived sea surface height error budget.

The two first error contributors (“Restitution Algorithm Error : Regression” and “Restitution Algorithm Error : Radiative Transfer Model”) indicated here come from ENVISAT error budget. Updating and optimization for AltiKa on the restitution algorithm will be performed before launch and should decrease this error.

Moreover, the error related to “Radiometer Noise and Calibration Error and Antenna Pattern Correction” is derived from requirements. Measured radiometer performances are slightly better than the requirements in terms of sensitivity.

The RSS total error for the radiometer wet tropospheric correction given in this Table 7 is thus expected to be a worst case.

	ALTIKA
Error Source	Path Delay Error (cm)
Restitution Algorithm Error (regression)	0.54
Restitution Algorithm Error (Radiative Transfer model)	0.85
Radiometer Noise and Calibration Error and Antenna Pattern Correction (with requirements inputs)	< 0.69
Antenna beam size difference for 2 radiometer channels	0.10
Decorrelation Error between Radiometer and Altimeter main beams	0.10
Radiometer Wet Tropo Correction RSS Total Error (cm)	**< 1.23**

Table 7 : AltiKa estimated Wet Tropospheric correction noise (1 s average)

3.2.3 ORBIT

3.2.3.1 ON-BOARD DIODE ORBIT

DIODE (DORIS Immediate Orbit on-board Determination), the real-time on-board orbit determination software, will provide the orbit in SARAL/AltiKa NRT products. Different versions of this “Navigation software” have already been flown on-board different satellites, beginning with SPOT4 (1998), SPOT5, Jason-1, Jason-2, Envisat, and the recently launched CryoSat-2. Their accuracies depend on specificities of the orbit, and of course on the version of the Navigation software, but mostly on accurate knowledge of the satellite characteristics (gravity center, sensitivity to surface forces, …).

In the best configuration in-flight today (on-board Jason-2), **accuracy of on-board DORIS/DIODE orbits is currently oscillating between 1 and 5 cm radial RMS** as compared to the Precise Orbit Ephemerides (POE) contained in the delayed-time GDR products, allowing valuable NRT use of Jason-2 OGDR products. Performance validation is made by comparison with ultimate POE orbits (delayed-time GDR products), while operational Near-Real-Time validation is done everyday by comparison with Medium Orbit Ephemerides (contained in the delayed-time IGDR products) : Figure 6 shows temporal series of daily radial differences between DIODE NRT orbit and MOE orbit on Jason-2, over about 3 months.

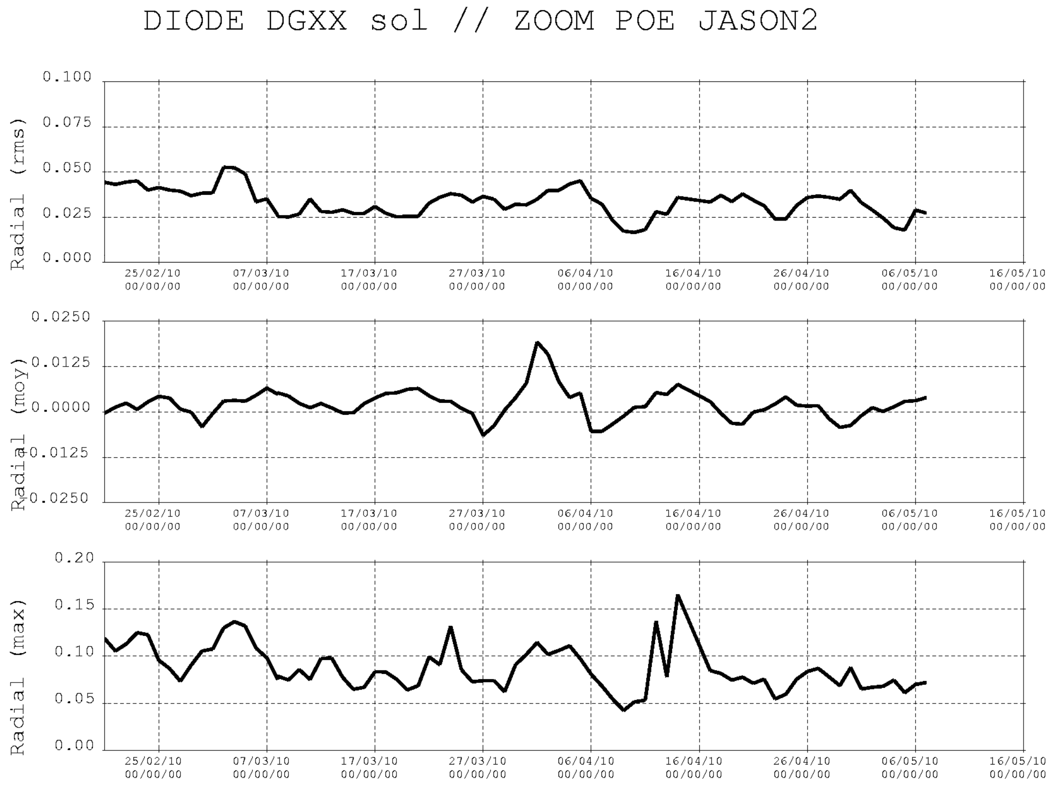


Figure 6 : Three characteristics of the daily comparison (DIODE minus POE) : radial RMS, MEAN, and MAX values (m) – over the period 20/02/2010 to 06/05/2010.

On-board SARAL/AltiKa, a very recent version –similar to the current Jason-2 version- has been delivered, and precise values of the satellite characteristics have been requested. Specification is “below 30 cm RMS on the radial component w.r.t. the final POE orbit”. **The first measurements will indicate the performances really achieved.**

3.2.3.2 GROUND ORBIT : MOE AND POE

CNES POD (Precise Orbit Determination) team produces two types of precise orbits:

- Rapid orbits (MOE) produced within 1 hour of data availability, for IGDR products
- Precise orbits (POE) delivered within a few weeks, for GDR products

SARAL Accuracy (Radial RMS over few days, short term) is specified as follows:

- MOE: Requirement of 4cm and goal of 2.5cm, with DORIS-only measurements
- POE: Requirement of 3cm and goal of 2cm, with DORIS and SLR measurements
- The POD performances shall be achieved as long as the DORIS data gap is shorter than 6 hours

Based on the experience gained on previous missions, provided that the quality of tracking data, dynamic and measurement model is at the same level as previous missions, **SARAL short term accuracy is achievable with DORIS-only measurements.**

As shown on Figure 7, best Jason-2 orbits compare to better than 1cm radially (including DORIS-only orbits).

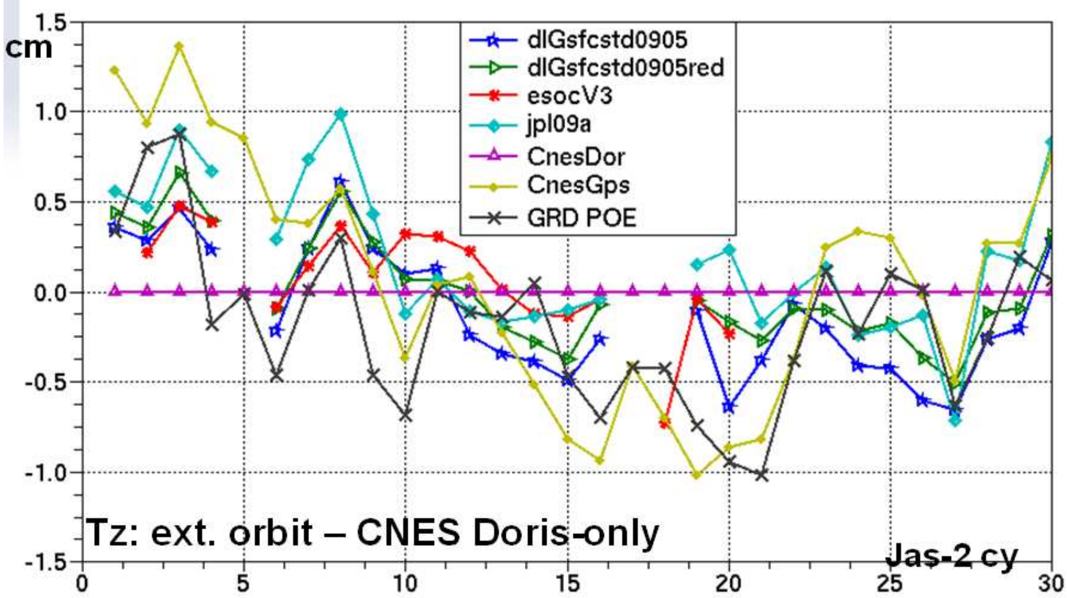


Figure 7 : Orbit accuracy indicators: intercomparison of different Jason-2 orbits (external orbit "minus" CNES DORIS-only orbit)

Most interest is in the geographically correlated orbit difference and in the long term movement of the orbit centering: as shown in Figure 8, map differences between different orbit solutions lead to highlight such orbit error related geographical patterns.

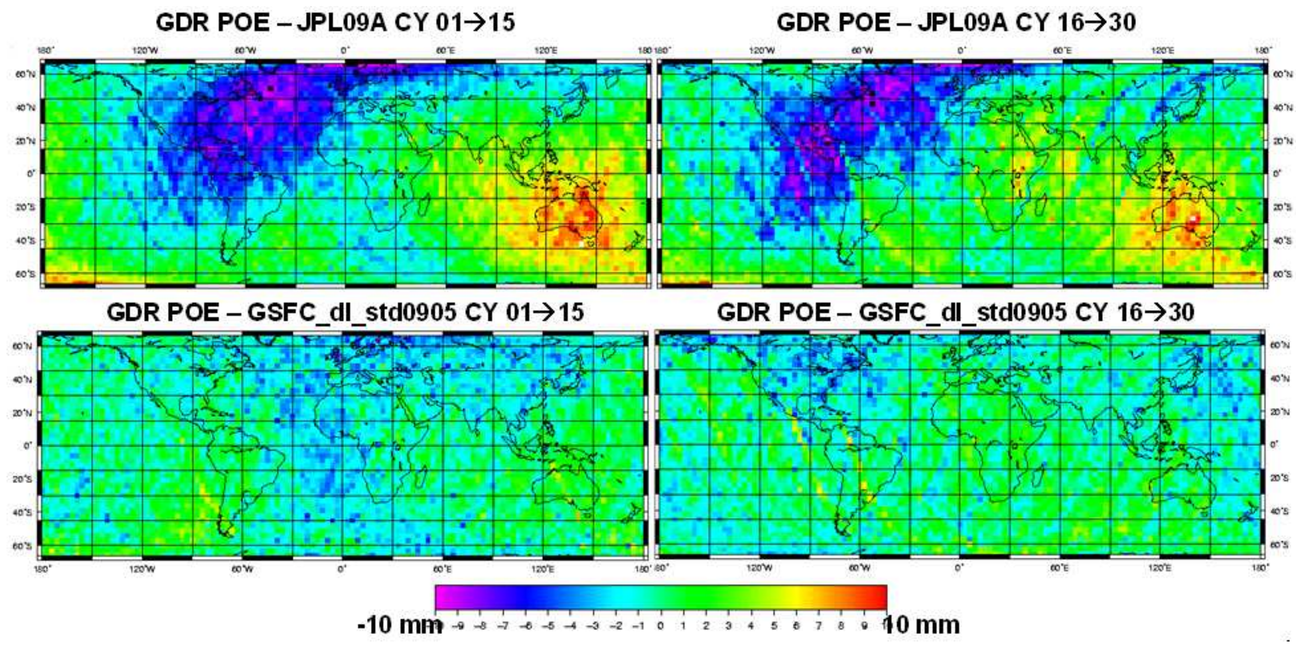


Figure 8 : Orbit accuracy indicators: intercomparison maps of different Jason-2 orbits

Finally, long term stability (from 1cm RMS to 1mm/year challenge) is the ultimate goal, that is required for global mean sea level and climate change studies. For the Jason series, the orbit contribution to mean sea level trend error is estimated to be globally well below 1mm/year (more concern is on instrument stability, e.g. radiometer). Concerning ENVISAT, inconsistent mean sea level trend have been obtained when separating ascending from descending tracks, which leads suspect orbit stability.

3.2.4 IONOSPHERE CORRECTION

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 electron 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 (Total Electron Content) grids computed from GPS-based observations and ionosphere model (the JPL Global Ionosphere Maps – GIM – model).

GIM model has been validated through comparisons with T/P, Jason-1 and Envisat dual frequency ionosphere corrections. Figure 9 shows than GIM model compares best with dual-frequency corrections than all other models. The resulting global RMS difference between both TEC estimations is lower than 10 TECU (in period of high solar activity), which translates into a **maximum Ka ionosphere correction error of 0.3cm**.

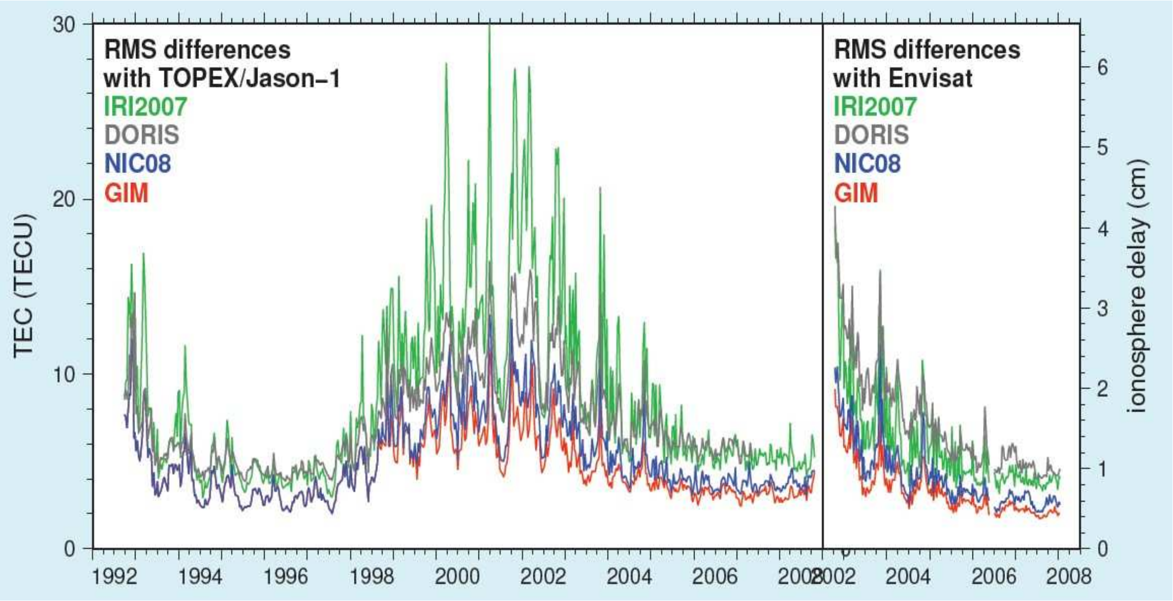


Figure 9 : Global RMS differences of TEC/iono correction models with dual-frequency estimation from T/P, J1 & Envisat (from *Scharroo et al., OSTST Nice 2008*)

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 (the error associated with this extrapolation is negligible), in order to compute in advance the ionosphere correction for OGDR. The error done in this approximation has not been evaluated precisely, and could be at the order of magnitude of the correction itself (a few cm maximum), considering the high spatio-temporal variability of the TEC. Anyway, the error budget specification for OGDR being dominated by orbit error allocation (30 cm with a 10 cm goal), this ionosphere correction error is not a major problem and will be characterized in flight.

3.2.5 DRY TROPOSPHERE CORRECTION

The dry gases within the troposphere also delays the radar-altimeter signals. The **dry tropospheric range correction** in units of cm can be approximated by the Saastamoinen formula:

$$\Delta R_{dry} = -0.002277 P_o \ast (1 + 0.0026\cos 2\varphi)$$

where Po is the sea level pressure in millibars and φ the latitude. A sea level pressure error of 5 mbar (or hPa) implies to a range error of about 1 cm.

The dry troposphere correction is currently obtained from the best suited meteorological models, the ECMWF analyzed surface pressure fields. Errors in the dry-troposphere correction has been partially characterized using differences between ECMWF and other model pressure outputs (as NCEP, see Figure 10) : estimated differences are generally very small (less than 0.25 cm RMS), but present higher values in the Southern Ocean near Antarctica (reaching 0.5 cm RMS). However, it should be kept in mind that the competing models assimilate many of the same meteorological observations, these differences representing thus probably a lower bound of the real dry troposphere correction errors.

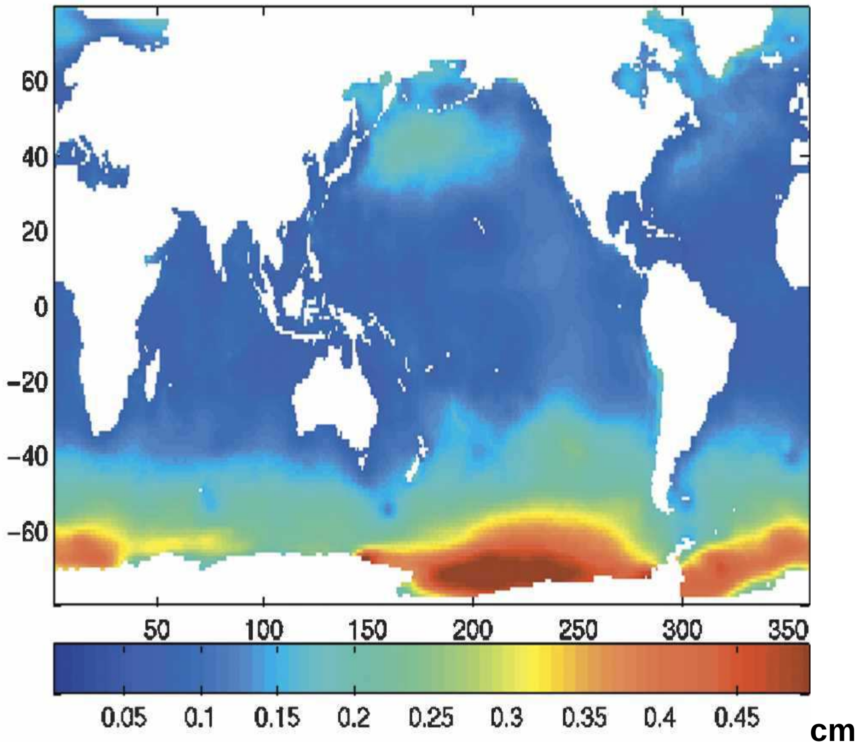


Figure 10 : Standard deviation of the error *(difference between ECMWF and NCEP operational analyses for 2001-03)* associated with the dry tropospheric correction, from Ponte et al. (2007)

Comparison with *in situ* data provides a more accurate, though spatially limited, portrayal of the dry troposphere correction errors. Uncertainties in ECMWF analyzed surface pressure fields have been estimated by Salstein et al. (2008) by comparing ECMWF products with P_{surf} observations from ships, buoys and stations over the period 2001-2005. Figure 11 shows that errors are globally around 2.5 hPa in terms of surface pressure fields, which translates into a **global error of the dry troposphere correction of 0.5 cm**. Locally, higher errors are found at high latitude, especially in the Southern Ocean.

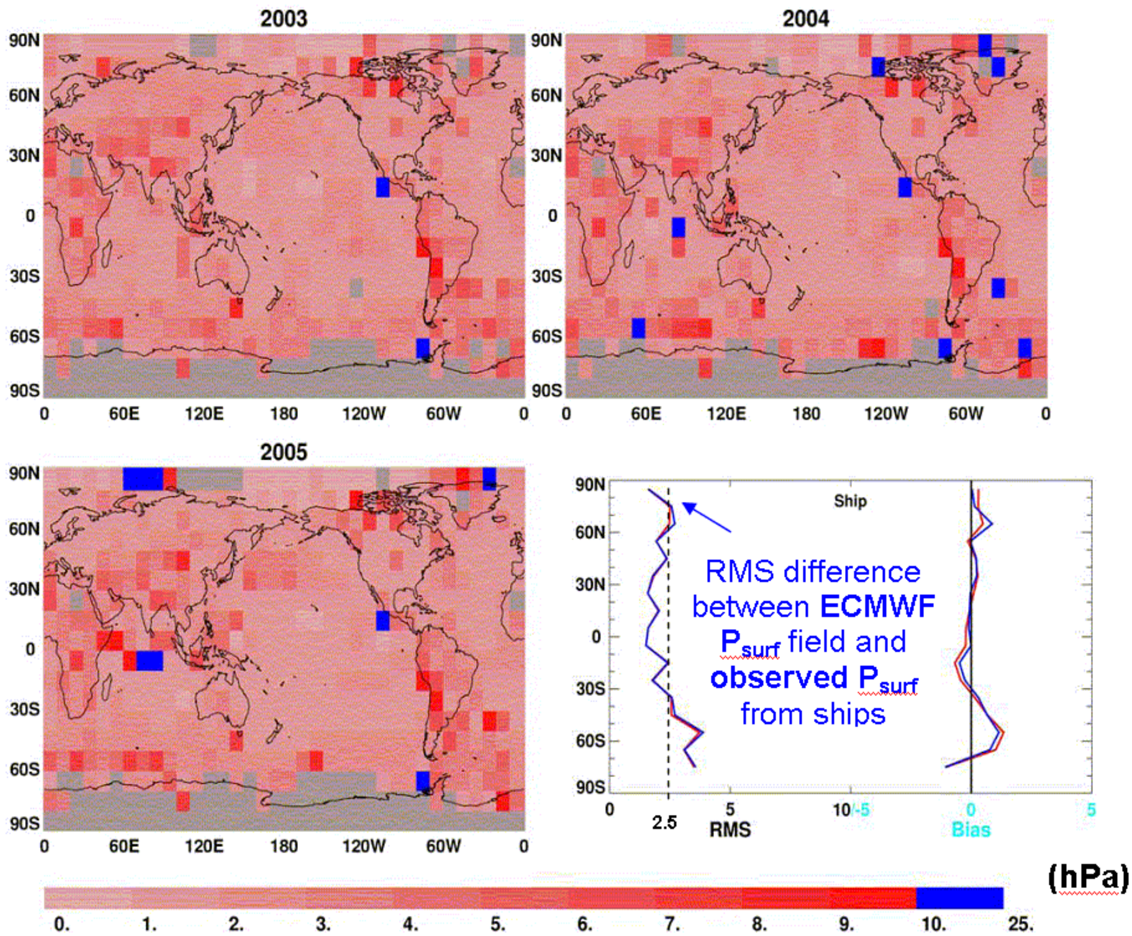


Figure 11 : RMS difference between ECMWF P_{surf} field and observed P_{surf} from ships, from Salstein et al. (2008)

As can be seen hereinabove, the pressure fields provided by weather centers have now reached a high level of accuracy.

For OGDR processing, predicted ECMWF P_{surf} fields are used instead of analyzed fields. The error associated with these predicted fields has been estimated by comparing predicted with analyzed fields. The RMS difference found between both is 0.2 cm (reference : study SALP-NT-MA-EA-21397), which leads to a total dry troposphere correction error on the order of 0.55cm for OGDR.

3.2.6 WIND SPEED

The absolute accuracy of sigma naught has to be better than 0.7 dB (for a sigma naught varying between 5.9 dB and 15 dB). The sigma drift over 1 year will be measured with an accuracy of 0.1 dB as a goal. The derived wind speed accuracy will be better than 1.7 m/s for 1 Hz averages (for a range between 3 m/s and 20 m/s).

Wind speed is usually computed from SWH and sea surface backscatter coefficient (sigma naught), using empirical model functions which have been computed from previous altimetry mission data. As for Jason-2, the algorithm used at the beginning of the mission will be the one computed by Collard et al. (2004) who tuned a global model function (from a neural network solution) on Jason-1 data from crossovers analysis between J1 & QuikSCAT scatterometer data over the year 2003. Global comparison of Jason-2 wind speed with ECMWF model and *in situ* buoys observations lead to a global error of less than 1.5 m/s for OGDR data (from S. Abdalla, ECMWF), which shows the accuracy of such empirical models.

However, for the case of AltiKa, as no previous mission in Ka-band already existed, **the impact of moving from Ku-band to Ka-band can not be fully and accurately characterized** (probably biases, different probability density function, …). Some campaigns have been performed with airborne Ka-band radar altimeter, that can be used to have a preliminary estimation of sigma naught versus wind speed relationships, however the amount of such data is very limited and may lack representativity. Vandemark et al. (2004) showed that **aircraft Ka-band radar data nearly mimic Ku-band satellite altimeter observations in their mean wind depende**nce: this result leads to have some confidence when relying first on Jason-2-inherited wind speed algorithm for SARAL/AltiKa wind speed products.

At present time, **no wind speed error estimation** can be provided.

A consolidated wind speed solution will be computed about one year after launch, as a whole seasonal cycle is needed in order to cover a complete range of meteorological conditions (required for the computation of a representative wind speed model). External global wind speed data from scatterometers will be available at this time (probably ASCAT and SeaWinds).

3.2.7 SEA STATE BIAS

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.

Associated errors on the SSB estimate for past missions give an error of 1 cm to 2 cm for the typical SWH of 2 m, but this error can reach more critical values in the high-latitude regions that experience consistently high SWH. Anyway, SSB is currently the biggest factor in altimeter error budgets.

SSB is usually bilinearly interpolated from a table (empirical model derived from analyses of the altimeter data) **as a function of SWH and wind speed**.

As AltiKa wind speed product will probably not be reliable at the very beginning of the mission (see 3.2.6), a preliminary SSB algorithm will be implemented for AltiKa (a % of SWH). At present time, **no SSB error estimation** can be provided.

A consolidated SSB solution will be computed about one year after launch, as for wind speed.

3.2.8 ESTIMATED PRE-LAUNCH PERFORMANCE BUDGET

As shown in the pre-launch performance assessment of each parameter contributing to the total error budget, we can **expect very good SARAL/AltiKa data quality**. However, some particular contributors have **unknown or hard to estimate error contributions**, simply because AltiKa mission is so **innovative** (Ka-band altimeter) that a lack of information and experience prevents us to get a precise pre-launch error estimation: this is the case for “sea state bias correction”, “ionosphere correction for OGDR”, and “wind speed” error estimations.

Fortunately, other contributors to the total sea surface height error present such good performances (note for example the especially higher than expected instrumental performances: "altimeter noise" is ~1cm, largely below the 1.5cm specification…) that some **margins** are allowed.

Considering specifications presented in Table 3, "sea state bias correction" error could be as high as 3.1cm (versus 2cm specification and currently estimated 1-2cm error for Ku-band altimeter missions) and "ionosphere correction" for OGDR as high as 2.4cm (on the order of the signal itself, and versus a 0.6cm specification), without threatening the total "sea surface height" error budget of laying within specifications.

As a consequence, **we are very confident that performance specifications will be met**.

3.3 EXTERNAL GEOPHYSICAL ERROR BUDGET

As described in previous section, an error specification is given for each of the parameters contributing to the total sea surface height (Sea surface height = Altitude – [Range + Wet troposphere correction + Dry troposphere correction + Ionosphere correction + Sea state bias correction]), as well as for significant wave height, wind speed and sigma naught. This is a responsibility of the SARAL/AltiKa project to make its best to meet the specifications on these parameters: this is the classical, system-oriented performance assessment, and results of this **pre-launch performance budget are very encouraging**.

However, this classical approach does mix very different error types (e.g. high frequency noise versus large scale orbit errors), and does not take into account external corrections and references. Indeed, the final AltiKa data user is most of the time not only interested in SSH but mainly in **SLA:**

SLA = SSH – [Mean sea surface + Tides height + Dynamical atmospheric correction])

SLA includes other geophysical and surface reference terms that are proposed in the OSTST context: no specification is put at project-level on these parameters, but a great work is done by OSTST on their error budget estimation and improvement.

A plenary session on "Sea level error budget: current status, needs and future improvements" was held during the June, 2009 OSTST, that lead to many debates and outputs, highlighting the need for moving from a global system error budget to application-specific error budgets. For more details, see http://www.aviso.oceanobs.com/fr/courses/ostst/ostst-2009-seattle/presentations/ or http://sealevel.jpl.nasa.gov/OSTST2009/.

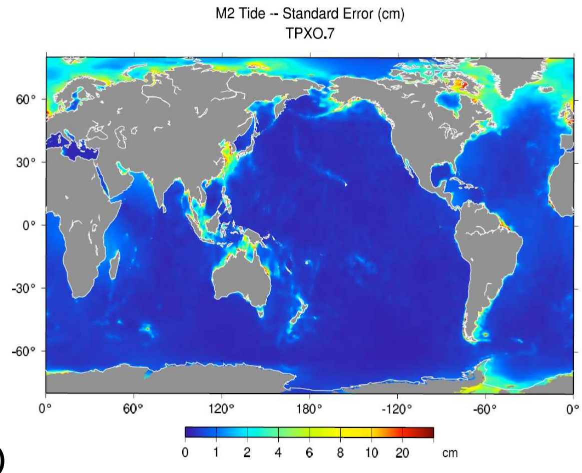
In Table 8 we give a **synthesis of current knowledge on external geophysical error budget.**

	Order of magnitude	Error	Reference
Geocentric ocean tides	**Amplitude ~60-80 cm m in deep ocean for M2** **> 1m or even several m in specific regions in shallow waters**	**Centimetric error in deep ocean** **Several cm (locally > 10 cm) in shallow waters/coastal zones due to modelling errors and omition errors**	R. Ray / F.Lyard OSTST, Seattle, 2009
Solid earth tides	**20 cm**	**~ 1 mm**	Cartwright & Eden, 1973

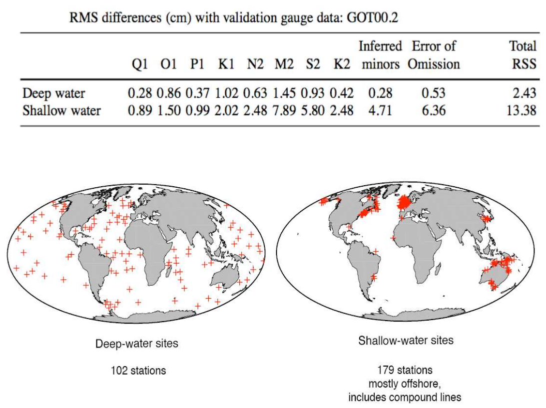
Pole tides	**2 cm**	**~ 1 mm**	Wahr, 1985, 1995
DAC = Inverse barometer + HF fluctuations	**HF variations of several tens of cm (rms=15 cm) localised at high latitudes and in shallow waters**	**about 1 cm in deep ocean and locally (shallow waters) > 3 cm.** **But these raw estimations might be underestimated (pers. Com. L. Carrere and R. Ponte 2011)**	Ponte et al., 2007 Carrère & Lyard, 2003 / Lamouroux, 2006

Table 8 : Tides and Dynamical atmospheric correction error budget

An example of ocean tides model error assessment in shown below (Figure 12):



a)


RMS differences (cm) with validation gauge data: GOT00.2

	Q1	O1	P1	K1	N2	M2	S2	K2	Inferred minors	Error of Omission	Total RSS
Deep water	0.28	0.86	0.37	1.02	0.63	1.45	0.93	0.42	0.28	0.53	2.43
Shallow water	0.89	1.50	0.99	2.02	2.48	7.89	5.80	2.48	4.71	6.36	13.38

b)

Figure 12 : a) Standard error of M2 tide component in TPX0.7 model, and b) RMS difference of GOT00.2 tide model with tide gauges for 8 tide components, from R. Ray, OSTST Seattle, 2009

Of major importance for scientific users are also the surface references (Mean sea surface, Mean dynamic topography…). Figure 13 presents the standard error assessment of the mean sea surface “MSS_CL01”

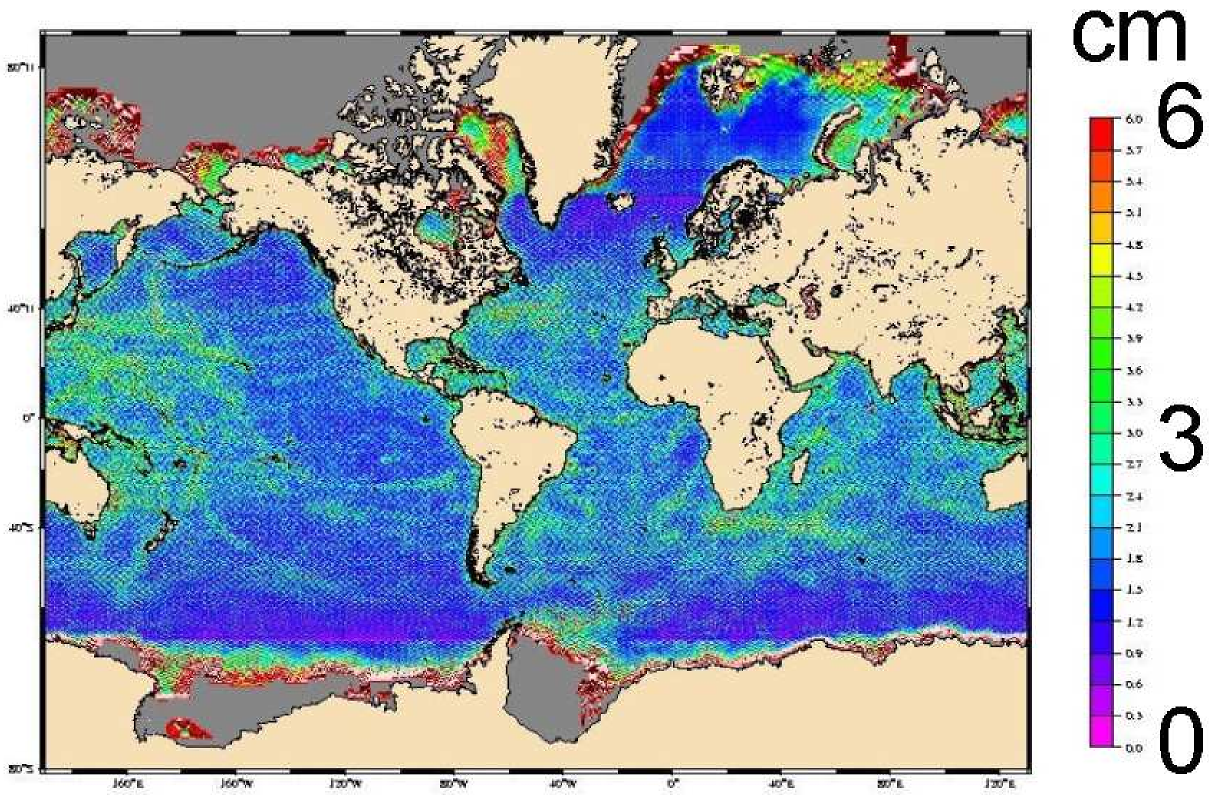


Figure 13 : MSS_CLS01 standard error estimation (from the optimal interpolation process)

As shown on previous examples, **current external geophysical models and surface references developed for altimetry applications, present generally very good performances in open ocean (errors ~ a few cm) but suffer of large errors near the coast (locally > 10cm).** This is why a huge work has been set up by spatial agencies (CNES and ESA) along with scientists, for the development and improvement of altimetry data products near the coast : this is the main objective of both COASTALT (www.coastalt.eu) and PISTACH (http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/coastal-and-hydrological-products/index.html) projects to develop dedicated algorithms and to improve geophysical corrections and models in the coastal zone. Summary, presentations and recommendations of the Coastal Altimetry Workshops held since 2008 can be found by linking on www.coastalt.eu. **The 4th Coastal Altimetry Workshop has taken place on October 14-15th 2010 in Porto**, preceding the OSTST 2010. The readers of the present document are invited to join and contribute to the following Coastal Altimetry workshops.

4. CALVAL IMPLEMENTATION

4.1 INTERNAL SENSOR CALIBRATION

4.1.1 ALTIKA ALTIMETER

Requirements on the performance of the AltiKa altimeter are very demanding. Many instrumental features have to be checked (functionally) and characterized notably with respect to the ground acceptance test measurements. It concerns mainly: the tracking capabilities, the shapes of point target response (PTR) and the low pass filter (LPF), the values of CNG attenuators. The impacts of the various configurations of the altimeter performance shall be evaluated in details. The high level requirements for the in-flight assessment of the altimeter will be provided by the CNES entity responsible for the instruments. In the following paragraphs, the main altimeter functionalities that will be carefully checked are recalled.

4.1.1.1 TRACKING MODES

As for Poseidon-3, the variety of acquisition and tracker modes available on AltiKa will request an extensive validation and inter-comparison phase.

The following Table 9 gives the various tracker modes authorized on AltiKa altimeter:

Acquisition mode	Tracking mode	Objectives / Comments
Autonomous	Median Tracker	Median tracker **validated on Jason2**.
	EDP Tracker	Alternative discriminator, to be tested, should improve the tracker behaviour above **continental ice** surfaces
DIODE coupling	Median Tracker	To reduce the duration of the acquisition mode and increase data availability on **coastal zones** (water/land transitions) and on **continental waters** (lakes)
	EDP Tracker	Alternative discriminator, to be tested, should improve the tracker behaviour above **continental ice** surfaces
DIODE + DEM		Open loop acquisition and tracking with DIODE and Digital Elevation Model coupling, to increase data availability on **coastal, inland water areas**, and possibly on **selected land surfaces**

Table 9 : Synthesis of the AltiKa tracker algorithms

Note that **it will be possible to evaluate the DIODE+DEM mode even if not operating on board**. The telemetry can actually contain simultaneously, the Median or EDP tracker data and tracker data computed with this DIODE+DEM mode. This possibility will allow a complete cross comparison of the modes characteristics. During the verification phase of the DIODE+DEM mode, partial updates of the DEM used to compute the on board tracker positions could be considered in order to correct for inappropriate DEM information.

Tracking modes will be validated during the CALVAL phases. The objectives are to check the operability and the performances of each tracker modes. **Before the end of the assessment phase, the SARAL/AltiKa project team must have all the results and comparison studies between these modes to be able to select which acquisition and tracking modes(s) will be used during the mission.** It appears very important, to clearly identify the performances of each mode over ocean but also over sea/land transitions, over hydrological areas and over continental ice areas. This has to be done in terms of data availability, data coverage and global altimetric performances in a classical CALVAL measurements quality sense.

It suggests that at least one sub-cycle (7 days) of data in each configuration would be acquired, with full cycle (35 days) in DIODE+DEM mode [TBC]. This point is indeed important to be able to compare modes for the (quasi) same ground tracks, the same oceanic conditions (minus the natural variability of the ocean) and globally for the same amount of data. Moreover, it would allow the evaluation of the overall measurement system using dedicated verification sites as well as distributed tide gauges.

The validation plan for the DIODE+DEM mode will be detailed in the next document issue.

4.1.1.2 INTERNAL CALIBRATIONS

The altimeter provides measurements between the overflown surface and the physical point where the deramp process is applied inside the instrument. The altimeter range is then computed between the antenna and the ocean surface. **The measured range has consequently to be corrected for the internal group delay that is computed precisely on ground before launch**. Of particular importance are the group delays introduced by the diplexer and the antenna. The measured delays will be treated as corrections in the ground processing. However, a **part of the group delay can be computed (and monitored) thanks to the PTR measurement. It will thus be possible to continuously update this contribution after launch**.

Two internal calibration modes are implemented in AltiKa instrument (as for Poseidon1/2/3):

- the first mode (CAL1) gives the measurement of the instrument point target response (PTR) by feeding the signal from the emission channel back to the receiver channel
- the second mode (CAL2) gives the transfer function of the altimeter receiving chain.

These calibration modes (with various parameters configurations) **are fully characterized before launch** during the ground acceptance test. During the assessment phase, a complete set of scenario must be played in order to functionally validate a large set of possible configurations of the calibration parameters. The objective is to guarantee the good instrumental operating and to characterize the various features of the calibration responses.

Then, and for the whole life of the mission, the two modes of calibration (in the same configurations) will be activated several times a day (by tele-commands) with a double objective:

- ✓ The first objective is to continuously characterize the shapes and positions of the Point Target Response and Low Pass Filters in order to daily introduce updated corrections in the altimeter processing chains that generate the level 2 products. The main corrections using calibration results are the following: correction of the waveforms by the low pass filter before to be retracked, computation of the total power of the PTR in order to correct the sigma0 estimation, computation of the difference of internal paths between the emission and reference channels in order to correct the range estimation.
- ✓ The second objective is to ensure an unceasing monitoring of the instrument, allowing us to follow the electronics aging and to check the good health of the equipments.

A comparison between measurements before and after launch shall be performed to quantify possible drifts on the main features due to the launch.

At the end of the CALVAL phase, a filter representative of the filter during the whole period must be provided in order to be used in the data reprocessing.

CNG (Numerical Gain Command)

In the altimeter receiving chain, **two numerical gain commands (CNG) are present in order to adjust the amplitude of the echo return to a nominal value**. In the ground processing, the sigma naught coefficient is determined thanks to the estimated power computed by the retracking algorithm and the numerical gain commands that were used on board. It is then necessary to **precisely know the real attenuation value that has been applied which is not exactly the required value**.

The CNG values have been measured during the ground acceptance test. However, they are open to derive with time due to the aging of the components. It is thus **necessary to regularly calibrate the CNG thanks to a method based on the analysis of a PTR** set of measurements. This calibration will have to be done during the assessment phase and repeated regularly (once or twice a year) during the whole life of the mission.

Simulator of performances

Developed first in the frame of the SSALT Poseidon-1 altimeter onboard Topex, a simulator of performances has been consolidated and updated with characteristics and new functionalities of Poseidon-2, Poseidon-3 and AltiKa altimeters (new tracking modes, updated instrumental characteristics, Point Target Response and Low Pass filter, CNG tables, various hardware characteristics ...). **This simulator** (validated notably by the good agreement between the ground tests performance of Poseidon-2 instrument and simulation results) **might be used during the AltiKa assessment phase**. Performances computed with the pre-launch AltiKa acceptance test measurements will serve as references for the in-flight assessment phase.

Note that for Poseidon-2/3, **this simulator of performances was also used to generate the Look Up Tables corrections (for range, significant wave-height and sigma naught coefficient) computed before and after launch** (in order to account for possible evolutions of the instrumental characteristics). It will be used likewise for AltiKa LUT. In the current retracking algorithms, it is retained to approximate the PTR keeping constant the σp parameter (representative of the width of the PTR when approximated by an unique Gaussian function). The biases resulting for such an approximation are corrected using the so called Look Up Correction table. For the first cycles of SARAL/AltiKa, LUT will be computed with on-ground pre-launch measurements. They will be updated (if needed) at the end of the verification phase in order to be accounted for in the first reprocessing of the data.

Altimeter measurements

Measured altimeter parameters will be evaluated after launch. **First of all, the science parameters will be studied: e.g., range, SWH, backscatter coefficient, mispointing angle, waveforms**. These studies will include noise-level estimates using Fourier Transform analysis as well as computation of along-track statistics (mean and standard deviation) over the ocean and other surfaces. Histograms and dispersion diagrams will also be computed for these parameters. The results will be compared to equivalent results from Poseidon-2/3.

Further details on parameters monitoring planed activities are given in 4.3.1.

4.1.1.3 CROSS MANOEUVERS

A key issue for the altimetric estimation is the **precise pointing of the antenna at nadir**. Moreover, **AltiKa is more sensitive to platform mispointing**, as the antenna beamwidth is reduced with respect to Poseidon3 one. Pointing specifications to guarantee altimeter performances have been estimated to a platform mispointing that should be less than 0.15° (3 sigma). In case of pla tform mispointing, altimeter performances will be very rapidly degraded, and for a mispointing higher than 0.4°, a complete loss of data is expected. Thus, even if the retracking algorithm can cope with mispointing angles up to 0.4 degree [TBC], it appears very important to calibrate to pointing of the platform.

Consequently, **cross manoeuvers** are highly recommended during the in flight assessment phase, which **will give the estimation of the bias between satellite reference axis and instrument reference axis**. Small angle excursions in pitch and roll of ± 0.3° with a angular velocity rate of 0.01 °/s shall be done. **The mispointing angle will be estimated from AltiKa waveforms and compared with satellite attitude data**.

Various other operating parameters will be also evaluated, such as the correction terms generated by the tracking loops (AGC, coarse and fine altitude corrections…). Here again, comparisons with simulated results will be performed.

These cross manoeuvers will be performed typically every 6 months.

4.1.2 ALTIKA RADIOMETER

AltiKa radiometer provides an estimate of the columnar water-vapor delay used to correct the altimeter range. **The AltiKa radiometer is functionally very closed to the MWR on ENVISAT mission**.

It is calibrated using 2 calibrations sources:

- a hot calibration point is obtained through an adapted load at ambient temperature,
- a sky horn pointing to deep space is used for cold reference.

A radiometric model is used for Brightness Temperature (BT) restitution. This model takes into account a lot of parameters related to the instrument design and characterization. These parameters have been optimised during acceptance radiometer tests. These tests were done in thermal vacuum conditions, using radiometric target in front of antenna horns : measurements have been performed for several BT targets at several ambient temperatures. The resultant optimized radiometric model will be used and validated at ground processing after the launch.

At instrument level, with regards to the knowledge of the radiometer behaviour acquired during the acceptance tests and then during all the SARAL PIM (Payload Integrated Module) and satellite tests, **some specific points can be interesting to analyse during in flight assessment phase**:

- Comparison of calibration measurements with ground tests results for the hot and cold points
- Analysis of thermal dependences
- Check of the variation of radiometric receivers gain and offset : from calibration measurements, receivers parameters can be retrieved and monitored. If necessary, these parameters can be updated in AltiKa on board database.
- Dedicated modes can be used. The radiometer measurement cycle duration is 200 ms. By default, the configuration is to perform one calibration every 3 seconds, meaning that one cycle on the hot source and one on the cold source are done. In order to better characterize the radiometer performances on these well known calibration targets, other calibration patterns measurements can be used by changing the radiometer configuration (via a telecommand). For instance the number of hot and/or cold measurements by seconds should be increased to get a precise value of the absolute bias for these targets, without being disturbed by small payload thermal evolutions.
- Several ways to apply calibration measurements shall be tested. In particular, several periods between calibrations and different averaging strategies shall be tested.

In addition, a systematic calibration/validation of ocean BT measurements by comparison to other microwave radiometers over stable areas and to simulations will be performed, as well as a geophysical calibration/validation of radiometer-derived wet troposphere correction by comparison to *in situ*, spaceborne and model data.

4.1.3 DORIS

The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receiver measures the Doppler shift to terrestrial beacons broadcasting on two frequencies. This information is used to compute over fixed measurement intervals the average range rate of the SARAL/AltiKa satellite with respect to the beacon(s). The information is used to determine the satellites 3D position in real time from an onboard orbit determination system called DIODE (Détermination Immédiate d'Orbite par DORIS Embarqué). The range-rate measurements are also an essential component of the POD activity. **The measurements will be thoroughly evaluated as part of the orbit determination verification activity** (cf. 4.2).

4.1.4 LASER REFLECTOR ARRAY

The laser retroreflector array (LRA) is a nadir-oriented array that is used for precise calibration of the satellite altitude. The measurement principle is telemetry, called Satellite Laser Ranging (SLR). **The LRA reflects laser shots from ground stations network. The analysis of the time delay of these laser shots, from ground and return after being reflected by the LRA, permits to determine the orbit of the satellite within a few millimetres precision**. The LRA is an optomechanical device with nine corner cubes. As it is totally passive, no specific operational constraint and no calibration are needed. The quality of the resultant range data will be thoroughly evaluated as part of the POD verification activity (see 4.2.2).

4.2 ORBIT DETERMINATION VERIFICATION

4.2.1 ON-BOARD DIODE ORBIT

DIODE (DORIS Immediate Orbit on-board Determination), the real-time on-board orbit determination software, will provide the orbit in SARAL/AltiKa NRT OGDR products. Different versions of this “Navigation software” have already been flown on-board different satellites, beginning with SPOT4 (1998), SPOT5, Jason-1, Jason-2, Envisat, and the recently launched CryoSat-2. Their accuracies depend on specificities of the orbit, and of course on the version of the Navigation software, but **mostly on accurate knowledge of the s/c characteristics (gravity center, sensitivity to surface forces, …).**

As for Jason-2, the performance validation of DIODE orbit contained in the NRT OGDR products, will be made by comparison with ultimate POE orbits contained in the GDR products, as shown e.g. in Figure 6. For operational near-real time survey, a daily validation will also be performed by comparison of DIODE orbit with Medium Orbit Ephemerides contained in the IGDR products.

On-board SARAL/AltiKa, a very recent version –similar to the current Jason-2 version- has been delivered, and **precise values of the satellite characteristics have been requested**. Specification is “below 30 cm RMS on the radial component w.r.t. the final POE orbit”. The first measurements will indicate the performances really achieved.

4.2.2 GROUND PRECISE ORBIT

The precise orbit determination (POD) verification activity will rely on a **cooperative investigation among project POD teams and Science Team investigators working in this area**. CNES has the responsibility for producing the precise orbit estimates that will be included on the SARAL/AltiKa science data products. The CNES POD verification effort will take advantage of all available tracking data to produce, on a routine basis, an estimate of the orbit error, as well as an evaluation of the performance of the tracking instruments.

4.2.2.1 OVERVIEW

The methods developed to verify the accuracy of the precise orbits of previous altimetry missions will apply in much the same way to the SARAL/AltiKa mission. **Initial efforts will be aimed at verifying that the short term radial accuracy meets the mission requirements**. With short term radial accuracy we intend the RMS of the radial difference between the computed and true orbit over few days, an estimate of which is usually obtained by the analysis of high elevation SLR residuals, altimeter residuals at crossover points and orbit overlaps.

The focus will then move to the **assessment of the long term coherence of the orbits**, involving various modelling issues and in particular the reference frames used to process Doris, and Satellite Laser Ranging (SLR) tracking measurements.

The verification activities will be conducted both during the orbit production process (operational verification) and afterwards (expert verification):

- The goal of the ***operational verification*** is to ensure, as well as possible, that the orbits included on the IGDRs and GDRs meet mission accuracy requirements. Operational verification is performed by the operations team during the production of the orbits, and results are summarized in the verification report which is provided along with the orbit. The project POD team analyzes the results of the verification and authorizes the delivery of the orbit.
- The ***expert verification*** focuses on a more detailed understanding of the nature of the orbit error, and of its impact on the end users. It includes long term monitoring of the orbit quality, especially to enable the early detection of potential drifts. This verification is performed both by the project POD team and by members of the POD Working Team (The POD Working team is yet to be defined). This verification is conducted year round, and without a formal time constraint between the production of an orbit and its expert verification. The project POD team expert verification starts during the orbit production process. The members of the POD Working Team conduct their verification efforts once the orbits are officially available. Results from all the verification centers are eventually presented at the SARAL/AltiKa scientific workshops.

The tools of orbit verification are traditionally divided among internal and external tests:

- ***Internal tests*** do not need any data other than those used for orbit production. Their key feature is the fact that they can be performed during the orbit production process itself. On the other hand, they usually lack the ability to identify systematic errors.
- ***External tests*** are based on the use of data not included in the orbit determination or on orbits produced by different groups using different software and/or configurations. These tests are therefore dependent on the availability of these data. However, they are very powerful at detecting systematic errors and long term trends. In addition, external tests performed using altimeter data evaluate the orbit quality in terms which are relevant to the oceanographic users.

In the case of AltiKa, **SLR will be the essential tool for validating Doris-based orbits** (like MOE orbits). As SLR data will be included in the final POE product, we will not emphasize this traditional split between internal and external tests for this mission. The list of existing tests is given in Table 10.

Many ancillary parameters are estimated in the orbit determination process. Some of those represent meaningful physical quantities for which valid ranges are known. Others can be correlated with external information. When collected together, these verifications give a different vision of the inner workings of the orbit determination process. As an example, observing the amplitude of the adjusted empirical forces gives a good indication of errors in the modelling of the satellite surface forces. The particular solar illumination conditions of SARAL/AltiKa orbit (sun-synchronous) make the signature of SRP model error more difficult to recognize and isolate (no clear beta pattern). However SRP force (and related model error) will mainly act cross-track on SARAL platform which might be a favorable condition [TBC]. The parameters that should be monitored are given in Table 11.

4.2.2.2 SATELLITE SPECIFIC MODELS

It should be noted that prior to any verification activity, the accurate knowledge of the satellite specific models is fundamental for the correct computation of measurement models and surface forces.

In particular, we draw the attention on the fidelity of the following information:

- the position of the instruments (Doris, Altimeter) phase centers and of the LRA reference point with respect to the satellite center-of-mass , and the LRA range correction
- the physical properties (optical, infrared) of the spacecraft external surfaces (satellite drawings with dimensions and photographs taken as close as possible to launch date from all directions)
- the satellite thermal fluxes
- the attitude description (either provided by a model or by measured quaternion or both)
- the time-tag of the manoeuvres for orbit control

Table 10 : Precise Orbit Determination Verification Tests

Test	Description	Usage	Notes
Data residuals analysis	Analysis of the statistical distribution of the residuals (Doris Doppler, Doris Phase and pseudo-range, SLR range) Analysis of the temporal distribution of the residuals (spectral analysis)	After each orbit determination step MOE and POE	
Data residuals interpretation	Decomposition of the residuals into time and range biases and analysis of the fluctuations and trends in these biases	Part of the MOE and POE final quality verification	The meaning of this test is limited because a cut-off criteria is applied to these biases during data editing
High elevation SLR residuals	Selected high elevation laser tracking passes provide an accurate measure of the spacecraft range when it is close to the zenith and thus is a good estimate of the spacecraft altitude	Part of the POE final quality verification	Limited by the use of SLR in the solution
Single data orbit cross-comparison	DORIS and SLR can be used independently to produce SARAL orbits which are then compared together to evaluate systematic errors.	Part of the POE production process Validates the MOE after delivery	

Overlaps	Orbits computed for the same time period using different data sets are compared. This test can be used in different ways - overlap between successive orbits (comparison over the few hours in common) - overlap between a 7-day arc and a shorter arc (in this case all the data of the short arc is common to both orbits) - overlap between orbits computed over the same time period by splitting the data into two independent subsets - etc.	Part of the POE operational verification process	These tests provide a good evaluation of the orbit quality Overlaps with reduced dynamics orbits which contain data in common do not provide any information because the orbit very closely follows the data
Altimeter data cross-over residuals	Residuals of the altimeter measurements at cross-over points are computed	Part of the POE final quality verification Validates the MOE after delivery	The residual signal due to tide model errors and ocean variability is so high that this test does not provide a good estimate of orbit error. However, it is useful to evaluate the relative quality of different orbits.
Comparison between orbits	Orbits computed by different groups using different configuration and/or different software are compared; when long series are available, the main focus is put on geographically correlated radial differences and on the North/South shift between different solutions; special care is taken in observing the stability of these characteristic signatures over time	Expert verification POE only	The contributors to the Alika expert verification activities need to be defined

Table 11 : Precise Orbit Determination Ancillary Parameters and Associated Tests

Parameter	Function	Test
Dynamical parameters		
Drag coefficient	Correct errors in the atmosphere density model	Should correlate with solar activity variations
Solar radiation pressure coefficient	Correct global error in the surface force model	Should be nearly constant

Amplitude of 1/rev terms	Absorb errors in the surface force model at the orbital period	Variation with solar angle indicative of problems with solar radiation pressure model
Amplitude of the stochastic empirical force	Absorbs residual dynamical model errors	Level should remain at the 10^{-9} m/s^2 level
DORIS system parameters that might be monitored		
Frequency bias per pass	Absorbs frequency offset of beacons	Long term evolution should be compatible with USO quality clock
Troposphere bias per pass	Empirical value of the zenith troposphere delay	Should remain within realistic values depending on the beacon location
On-board USO frequency	Measures frequency of the on-board oscillator	Long term evolution should be relatively smooth
Polar motion	Adjusted value of the Earth orientation parameters	Can be obtained in a combined solution with other DORIS equipped satellites Should be close to the IERS predicted value
Station coordinates	Estimated location of the beacons	Can be obtained in a combined solution with other DORIS equipped satellites Help detect beacon problems
SLR parameters that are usually monitored		
Range bias per pass Time bias per pass	Absorbs station calibration errors	Should be relatively constant per station and should correlate well with data obtained with other satellites

4.2.2.3 SPECIALIZED STUDIES FROM PIS

***Calmant et al*.** [Appendix] will use the "**short arc**" geometric method of orbit determination [TBC], using data from dense satellite laser ranging (SLR) networks, to validate SARAL/AltiKa MOE (Medium Orbit Ephemeris) and POE (Precise Orbit Ephemeris) orbits. This "short arc" geometric method of orbit determination is able to provide orbit control at the 1-cm level over at least two important areas: Europe and the USA. *Bonnefond et al.* [1995] have demonstrated the technique using T/P orbits over the Mediterranean Sea, and it has been further widely used and applied for Jason-1&2 orbit validation by *Bonnefond and colleagues.*

Figure 14 : Jason-1&2 MOE orbit validation by the laser-based Short-Arc Technique (from *Bonnefond et al., OSTST, Seattle, 2009*)

Scharroo et al. [Appendix] proposes to compare the SARAL/AltiKa DORIS orbits against orbits produced by other institutes, if any.

4.3 GLOBAL ALTIMETER DATA ANALYSIS

Project teams will routinely analyze the global SARAL/AltiKa altimeter data with the **goal of characterizing the overall measurement system performance in relation to the pre-launch requirements**. The project teams will exchange and jointly interpret selected CALVAL results from the fully validated off-line science products before concurring on release of the data to the users. Some PIs of the SARAL/AltiKa Science Team also plan CALVAL studies of the global altimeter data.

4.3.1 ALTIKA GLOBAL STATISTICAL ANALYSIS

In their approach, **CNES** with the support of *Dibarboure et al.* [Appendix] **will largely follow the model of the SSALTO/CALVAL activities implemented for TOPEX/Poseidon, JASON-1 and JASON-2**. CALVAL comparisons will be performed over different data periods (e.g. a portion of a track, a track, one cycle, several cycles, several years) to achieve the goals of systematic quality assessment of SARAL/AltiKa data, and of long-term monitoring of altimeter and radiometer parameters and geophysical corrections. In addition, these analyses will provide a way to assess algorithm improvements throughout the SARAL/AltiKa mission.

The CALVAL tools developed by SSALTO (and AVISO) have been extensively used for T/P, ERS-1 and ERS-2, ENVISAT, GFO, JASON-1 and JASON-2. These tools will be exploited for SARAL/AltiKa and support the following capabilities:

1) data editing, missing measurements determination;

2) crossover calculation and analysis;

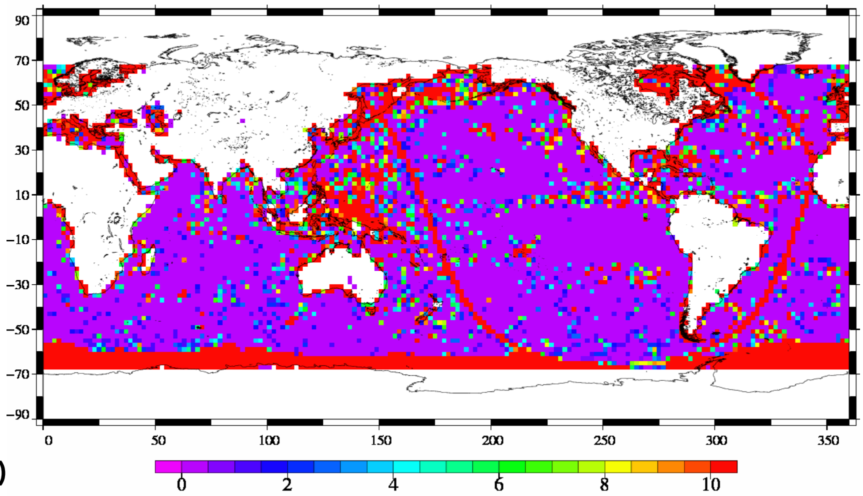
3) along-track sea-level anomaly calculation and analysis;

4) computation of geophysical corrections and/or sea-surface height, sea-level anomalies, and wave-number spectra;

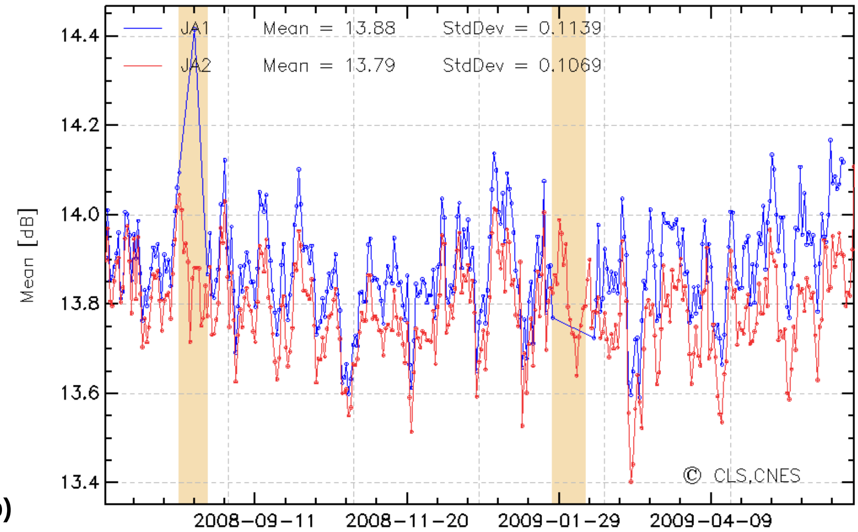
5) representation of statistical output and visualization.

Using these tools, SSALTO/CALVAL will compute and compile information on various CALVAL quantities. For example, the data coverage will be characterized and the missing measurements before and after data editing will be analyzed. This will allow the estimation of altimeter tracking capabilities over all surface types and geographical coverage of all geophysical corrections. In terms of data analysis, SSALTO/CALVAL will generate various plots of all the measurement system parameters (**along-track and 2-d map representations**), along with histograms and scatter diagrams to support detection of anomalous data. Along-track wave number spectra (globally or geographically averaged) will be computed for all measurement parameters (e.g. geophysical corrections, sea surface height).

The Figure 15 and Figure 16 below show some examples of global statistical analysis performed on JASON-2 data :

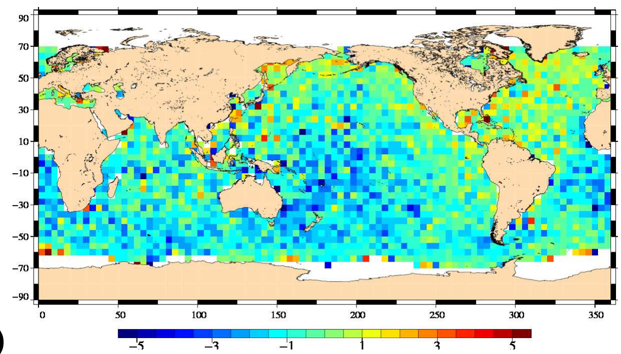


a)

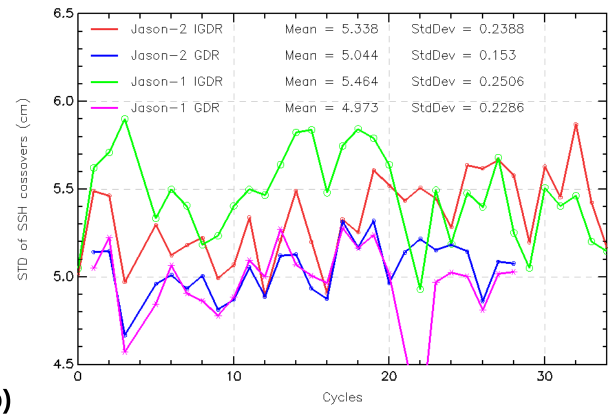


b)

Figure 15 : a) Edited measurements (%) for JASON-2 (cycle 2), b) Daily monitoring of SIGMA-0 for JASON-1 and JASON-2



a)



b)

Figure 16 : a) Mean of SSH differences at crossovers (IGDR JASON-2, cycles 1-20), b) Monitoring of standard deviation at mono-missions SSH crossovers

Other examples can be seen either in cyclic CALVAL reports issued during JASON-2 verification phase (ftp://oststost_ja$02@193.49.97.197/documentation/Validation_Report/) or in the JASON-2, JASON-1 or ENVISAT annual validation reports available on http://www.aviso.oceanobs.com/fr/CALVAL/index.html.

Analysis of **sea-surface height differences at global crossover points** will be used by SSALTO/**CALVAL to estimate the measurement system precision**. Crossover comparisons with other altimetry missions (mainly JASON-2) will also be performed [see next paragraph]. The sensitivity of the crossover differences to different corrections and algorithms will be quantified (e.g. variance explained by each correction). The long wavelength orbit error will be estimated by global minimization of crossover differences. Both sea-state bias (parametric and non-parametric models) and time tag bias will be estimated at crossovers.

Repeat track analysis will also be used **to estimate the measurement system precision**. Repeat-track data (between two successive cycles and relative to a collinear mean) will also serve to measure the influence of alternative correction terms and models. Low-frequency sea-level-anomaly signals (drift, seasonal signals) will be geographically analyzed, and global sea-level trends will be deduced from cycle-averaged time series of sea-surface height. Analyses of sea level anomaly wave number spectra will provide an estimation of instrumental noise.

During the 9-month verification phase, specialized ad hoc investigations will be performed to assess the impact of algorithm and orbit choices on bias and drift and other measures of long-term and large-scale correlated errors. These studies will continue at a reduced level throughout the mission life, with the goal of characterizing the overall measurement system at the 5 cm and 1 mm/yr levels in terms of range bias and drift respectively.

A parallel global CALVAL effort will be undertaken by some of the SARAL/AltiKa Science Team PIs:

- ***Chao et al.*** [Appendix] plan to integrate SARAL/AltiKa data into the JPL global altimeter verification system that has been developed to support Jason-class altimeter missions and which enables to characterize and mitigate systematic errors through the combination and reduction of multi-mission data.
- ***Richman et al.*** [Appendix] will integrate SARAL/AltiKa data into the NRL (Naval Research Lab) altimeter processing system that has been used for daily processing of all altimeter data sets from Geosat to Jason-2. The error characteristics of orbit solution, crossover RMS and flagged data will be tracked and made available to the Science Team through a web interface.

4.3.2 CROSS-CALIBRATION WITH JASON-2

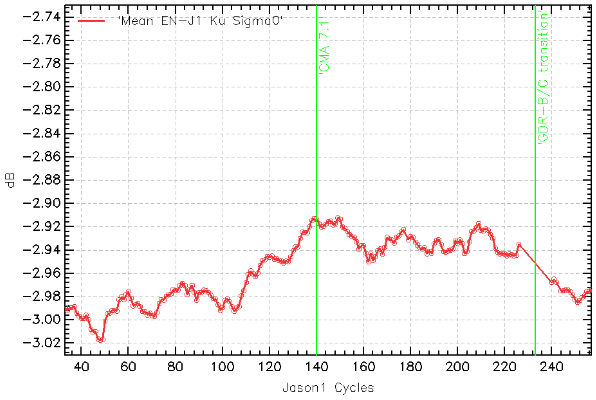
The objective of the altimeter cross-calibration is to compare the performance of SARAL/AltiKa against that of other altimeter missions. At the time of the SARAL/AltiKa launch, the only healthy reference altimetric satellite flying on a repeat orbit will be JASON-2 and hopefully JASON-1.

Unfortunately, no tandem mission will be possible with ENVISAT (as for JASON-2 following JASON-1 by 1 minute apart during 6 months) as ENVISAT will have been moved in late October 2010 on a lower and drifting orbit in order to extend its life time.

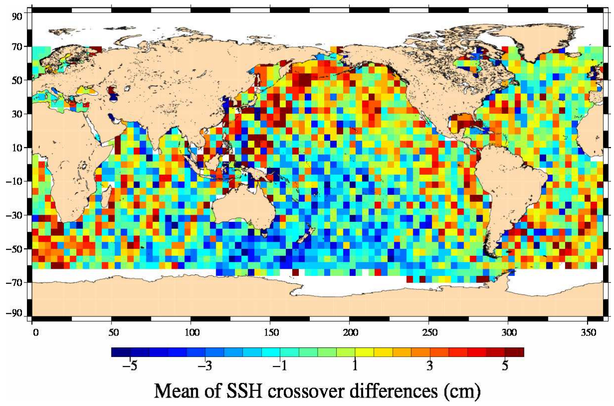
The CNES project team, with the support of *Dibarboure et al.* [Appendix], **plans to conduct extensive cross-calibration among SARAL/AltiKa and JASON-2.** The objectives are to monitor SARAL/AltiKa performance—including bias and drift errors—and to help foster new scientific applications. Special processing will be set up to homogenize references, parameters and models as much as possible, before cross-calibration is performed.

This task will be undertaken throughout the SARAL/AltiKa mission life, and will benefit from other altimeters flying at the same time (simultaneous operation is also expected with JASON-1 and CRYOSAT-2). The essential goals of this activity are to detect any instrumental or algorithmic problem in the SARAL/AltiKa measurement system. To this end, the SARAL/AltiKa parameters will be continuously compared against analogous parameters from other altimetric missions. This activity will also better enable oceanographic studies using combined data sets through the improvement of models and algorithms.

The Figure 17 below show some example of past cross-calibration results between JASON-1 and ENVISAT:



a)



b)

Figure 17 : a) Cycle-by-cycle monitoring of sigma-0 mean differences (ENVISAT - JASON-1), b) Mean of SSH crossover differences for ENVISAT – JASON-1 IGDRs (cycles 239 to 244)

Other examples of cross-calibration results between JASON-2 and ENVISAT (same kind of configuration than SARAL/AltiKa versus JASON-2) can be found in some cyclic CALVAL reports issued during JASON-2 verification phase or in the cyclic and annual validation reports available on http://www.aviso.oceanobs.com/en/calval/systematic-calval/index.html.

It should be emphasized that **the SARAL/AltiKa Science Team PIs will also be active in cross-calibration activities**. Investigations addressing the characterization of long-term changes from multiple altimeter missions must consider the cross-calibration question, and are expected to contribute significantly to this aspect of CALVAL, along with the results of the *in situ* calibrations:

- ***Bosch et al.*** [Appendix], for example, plan to perform globally relative calibration w.r.t. all other altimeters operating simultaneously (Jason1, Jason2, ENVISAT, CryoSat2, HY-2, …): Their common multi-mission crossover analysis will use crossover differences in all combinations and provide for every mission analysed a complete time series of radial errors, relative range biases, geographically correlated error pattern and a statistical characterisation in terms of auto-covariance functions.
- ***Scharroo et al.*** [Appendix] propose to ingest the SARAL/AltiKa altimeter products into the NOAA/TU Delft Radar Altimeter Database System (RADS). This platform will allow comparison with data from all currently flying and past altimeters and validation of the SARAL/AltiKa product content against numerous off-line models through: intersatellite comparisons and cross calibrations; ensuring continuation of ERS-1/ERS-2/Envisat 35-day coverage; extending and validating sea level rise time series.
- ***Nerem et al.*** [Appendix] will compare the global mean sea level (GMSL) computed from SARAL/AltiKa to GMSL obtained from other satellite altimeters currently in operation. Through this process, they intend to identify any discrepancies between the different altimeters and possibly identify the presence of any systematic errors present in the SARAL/AltiKa data that need to be studied in closer detail.

- ***Menemenlis et al*****.** [Appendix] will carry out detailed evaluation of the SARAL/AltiKa data for global-ocean data assimilation studies through comparison to Jason-2 data (mapping analysis, wavenumber-frequency analysis of the difference, crossover differences…).
- ***Griffin et al*****.** [Appendix] will compare the spatial resolution and noise statistics of the AltiKa data with those of the other altimeter missions.
- ***Birol et al*****.** [Appendix] plan to perform regional multi-mission crossover analysis, based on their X-Track data processing software (in various coastal and high-latitude areas), as part of their AltiKa performance analysis.
- ***Fenoglio-Marc et al*****.** [Appendix] will compute relative residual biases and trends between SARAL/AltiKa and other in-flight altimetry missions.
- ***Calmant et al*****.** [Appendix] seek to evaluate inter-satellite bias and differential response of distinct land cover, over the Amazon basin. The difference between Ka and Ku bands, and differences due to the spot size will be analyzed at the crossing between SARAL/AltiKa and Jason-2/ENVISAT over all types of surfaces. The difference between Ka penetration and green and red coherent light (ICEsat) will also be shown at the crossing between AltiKa and ICESat.

4.3.3 SPECIFIC STUDIES

4.3.3.1 RAIN EFFECT

An overall assessment of rain effect on SARAL/AltiKa data availability and quality will be performed by CNES using rain flags in order to monitor global % 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.

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 by also dense cloud. A new rain/cloud 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 during the commissioning phase.

Some SARAL/AltiKa Science Team PIs will also tackle with the attenuation by rain in Ka band:

- ***Chapron et al*****.** [Appendix] intend to first assess the performances of the operational rain flag and evaluate the different parameters (especially the noise level on the off-nadir angle estimate necessary to the Matching Pursuit algorithm). The performances and the stability of the algorithm will then be tested on the first few cycles of data. Such algorithm detects intervals displaying short-scale coherent sharp features associated to rainy situations allowing the setting of the flag. It was developed based on simulated data. *Chapron et al.* propose thus to perform some fine-tunings of the algorithm after launch based on real data along with a global validation of its results. In particular, the validation will be achieved using available rain (such as the Global Precipitation Climate Project) and cloud (such as MODIS) products. In a second step, the results will be further validated using comparison with independent collocated rain measurements, from sensors such Tropical Rainfall Measuring Mission (TRMM) or AMSR-E.

- ***Quartly et al.*** [Appendix] propose to investigate SARAL/AltiKa SSH data quality by paying particular attention to the effect of rain, through segregating the data according to moisture indicators from the passive radiometer, and the extraction of possible rain events through high-pass filtering. Radiometer data will be used to divide passes into "dry" and "moist" segments. Histograms and Fourier analysis of spatial variability may be calculated on a regional basis for these two sets, and their comparison used as an indicator of the mean effect of rain. This could then be compared with results achieved using other altimetric outputs (e.g. operational flag based on peakiness or waveform-derived mispointing, by Tournadre et al., 2009) as a proxy for rain.
- ***Lillibridge et al.*** [Appendix] also intend to assess systematic loss of data in regions of high rain rate or atmospheric water vapour, while *Richman et al.* [Appendix] will examine the impact of expected precipitation and cloud interactions on global mesoscale performance in their global data assimilation experiment, particularly near land.

In addition to rain flag validation and new developments, **particular attention will be devoted to the development of retracking algorithms dedicated to recover traditionally lost waveforms affected by rain cells and/or other effect such as sigma0-blooms, sea-ice…**

Several studies on the classification of conventional altimeter echoes were performed by CLS for CNES and demonstrated the feasibility of classification of these waveforms, over all kind of surfaces and also over rain cells and sigma blooms, using statistical techniques applied to parameters describing the waveforms. The developed classification algorithms demonstrated their high capabilities when applied to Envisat and Jason-1 waveforms using only one frequency band (Ku) and also to simulated Ka band waveforms over rain cells and sigma blooms.

Mercier et al. [Appendix] propose to assess these classification techniques on SARAL/AltiKa real waveforms. After validation of the classification techniques, using external data, they propose to develop new retracking algorithms for these areas. Depending on the classification results, one or more different algorithms could be needed. For the Ku band a new model was developed for sea-ice, sigma0 blooms and rain cells echoes and an adaptative analysis window retracking algorithm. These techniques were tested on simulated Ka band waveforms. It is proposed to analyse them and to adapt them to Ka band real data.

4.3.3.2 COASTAL AND INLAND WATER ZONE

Given the foreseen enhanced performances of SARAL/AltiKa altimeter in coastal zones, it is of primary importance to quantify the improvement brought wrt previous and other in-flight altimeters. This will be done first at global scale by statistically analysing the data coverage and quality in coastal areas, by comparison to results obtained with other altimetry missions (Jason-2, Envisat…) using the same processing standards and editing/flagging procedures. Such a rough analysis should allow first to evaluate the performance of SARAL/AltiKa mission in the coastal zone relative to other altimetry missions, independently of any improvements brought by dedicated processing algorithms, like the ones developed in the frame of the CNES-funded PISTACH project (see http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/coastal-and-hydrological-products/index.html).

In a second step, **it will be useful to adapt and apply the PISTACH prototype to the SARAL/AltiKa data** in order to fully exploit its capabilities **in the coastal and inland water areas**. The PISTACH project that delivers on a pseudo-operational basis improved Jason-2 IGDRs to the scientific community was the opportunity to develop new processing algorithms for waveform retracking, propagation and geophysical corrections specifically dedicated to coastal zones and continental waters. The PISTACH processing, combined with the improved performances of Jason-2 altimeter near the coasts, gives access to high-resolution (20 Hz i.e. ~350 m) along track altimetric measurements, with an ensured continuity from the open ocean up to the shoreline. Such data now allow a finer description of short scale (5-20 km) coastal phenomenon such as river plumes, coastal upwellings and circulations…, etc. The most significant gain, wrt classical 1Hz Level2 altimetry products is expected on the representation of local gradients and hence currents. Over continental waters, the implementation of new retracking algorithms taking into account the peculiarity of river waveforms already showed significant improvement in the retrieval of reliable water surface heights (Souza et al., 2009).

Mercier et al. [Appendix] propose to adapt retracking algorithms developed in PISTACH for Jason-2 waveforms to SARAL/AltiKa waveforms, taking into account their peculiarities and taking advantage of new retracking/filtering techniques, and to realize an evolution/upgrade of the PISTACH prototype so that it could be also applied to the SARAL/AltiKa data and operated during SARAL/AltiKa mission lifetime.

Other PIs interested in coastal altimetry applications propose to assess SARAL/AltiKa data performances in a coastal or inland water environment, by comparing SARAL/AltiKa data to local measurements from *in situ* networks. These studies are detailed in section 4.3.4.2 dedicated to "Regional coastal and inland water *in situ* experiments". Some of them also plan to apply and test specific processing of SARAL/AltiKa in these particular areas (e.g. "X-track processing" by ***Birol et al.*** [Appendix]), and/or to assess the different retracking algorithms that will be available in SARAL/AltiKa products (MLE4 over ocean, SEA-ICE, ICE1, ICE2).

4.3.3.3 POLAR OCEANS AND SEA-ICE

The lack of sea level time series in high latitude regions is challenging our knowledge of ocean changes, especially in Arctic Ocean circulation and sea level. No data is available above 65° latitude from T/P and Jason-1&2 altimetry missions, whereas SSH measurements from ERS1/2, Envisat and GFO are either absent due to seasonal ice-coverage, either too much degraded due to presence of sea-ice in the altimeter and/or radiometer footprint.

Current studies (e.g. CNES-CLS PhD Thesis of P. Prandi) have analysed altimetry data coverage and quality in the Arctic Ocean, leading to highlight the strong limitations of operational altimeter data processing for polar ocean studies. P. Prandi intends to use improved dedicated processing in order to recover a maximum of altimetry data and generate a complete altimetry database over Arctic Ocean, that will be used to study mean and regional sea level changes in this Arctic region, its causes and impacts, and its contribution to global mean sea level variations, in cooperation with ***Birol et al.*** [Appendix] study.

SARAL/AltiKa data will be crucial for polar ocean studies, especially in the current context of global climate change with already evidenced high vulnerability of the Arctic region.

As for coastal evaluation, the likely improvement brought by SARAL/AltiKa wrt previous and other in-flight altimeters will be done first **at global scale by statistically analysing the data coverage and quality in polar areas** (above ~50° latitude), by comparison to results obtained with other altimetry missions (Jason-2, Envisat…) using the same processing standards and editing/flagging procedures.

In a second step, **it will be necessary to implement specific processing and editing procedures in order to fully exploit SARAL/AltiKa capabilities in high-latitude regions**, and thus recover a maximum of exploitable data.

The presence of sea-ice at high latitude being the problem, it is essential first to provide a reliable sea-ice flag. ***Chapron et al.*** [Appendix] propose to continue their study of sea-ice type identification with altimetry through classification of microwave signatures. They will analyse the differences in sea-ice type identification when one uses Ka-band data instead of Ku-band ones in the classification algorithm. In particular this frequency will offer better spatial resolution and so expected better separation of sea-ice measurements from sea-ice free ocean measurements, allowing to set a reliable ice-flag for oceanographic applications, but also new applications of altimetry data within sea-ice monitoring issues.

4.3.3.4 LAND ICE SURFACES

A global systematic validation of SARAL/AltiKa data over land ice (ice-sheets and ice-covered regions) could be implemented through cross-calibration with Cryosat-2 data [TBC].

A dedicated *in situ* CalVal experiment in Antarctica is planed by ***Watson et al.*** [Appendix], see section 4.5.3.1 for more details.

Rémy et al. [Appendix], will also focus on the reduction of altimeter errors over ice surfaces via the analysis of the first SARAL/AltiKa measurements in order to check the continuity with past and present ice missions, such as EnviSat and also to study the impact of the particular Ka frequency.

4.3.4 COMPARISON TO GLOBAL AND REGIONAL *IN SITU* NETWORKS

While the information from the dedicated calibration sites [see 4.5] prove invaluable for detecting absolute biases in altimeters measurement systems, **the most reliable external information on the stability of the sea surface height (SSH) measurements are usually afforded by the global tide-gauge network**.

Some regional comparison to *in situ* data studies can also help in monitoring bias/drift of the altimeter system, as well as assessing the performance of SARAL/AltiKa data with respect to other altimeter missions, especially in particular areas such as coastal zones, tropical rainy areas, ….

4.3.4.1 GLOBAL *IN SITU* NETWORKS

Beyond the verification phase, **it is necessary to perform regular long-term CALVAL in order to monitor biases and drifts of SARAL/AltiKa overall system**: in addition to previously mentioned analysis, CNES will perform a routine comparison of AltiKa data with global networks of *in situ* data, as soon as enough *in situ* data are available (~1 to 2 years 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 mission lifetime.

As *in situ* datasets (Tide Gauges (TG), Temperature/Salinity (T/S) profiles) provide independent measurements of sea surface height variations, methods have been developed to assess the global mean sea level trend from such data. The basic idea of the data processing is that differences between *in situ* and altimetric measurements should not have any drift or bias over long time scales.

The most reliable external information on the stability of the sea-surface height measurement is afforded by the global tide-gauge network. Cooperating tide gauges in this network are rarely found along the satellite's ground track; moreover, only a few are directly collocated with GPS or DORIS to provide information on vertical land motion when determining the stability of the altimeter measurement system; however, these limitations can be overcome by combining calibration time series from the many distributed tide gauges into a single ensemble result. The resulting drift estimate provides information that is complementary to the calibration estimates from the dedicated sites [see 4.5].

In the frame of previous altimetry missions (T/P, JASON-1, ENVISAT, JASON-2), **CNES with the support of ESA, have implemented generic and continuous altimetry/in-situ validation activities**:

- First, **altimetric data are compared with tide gauge measurements using 4 different tide gauge networks** (GLOSS/CLIVAR, SONEL, BODC database and OPPE).

An example of result of altimetry/TG comparison for mean sea level trend assessment is shown below, a significant discrepancy appearing on ENVISAT data (drift of differences ENVISAT - TG ~ -1.2mm/yr):

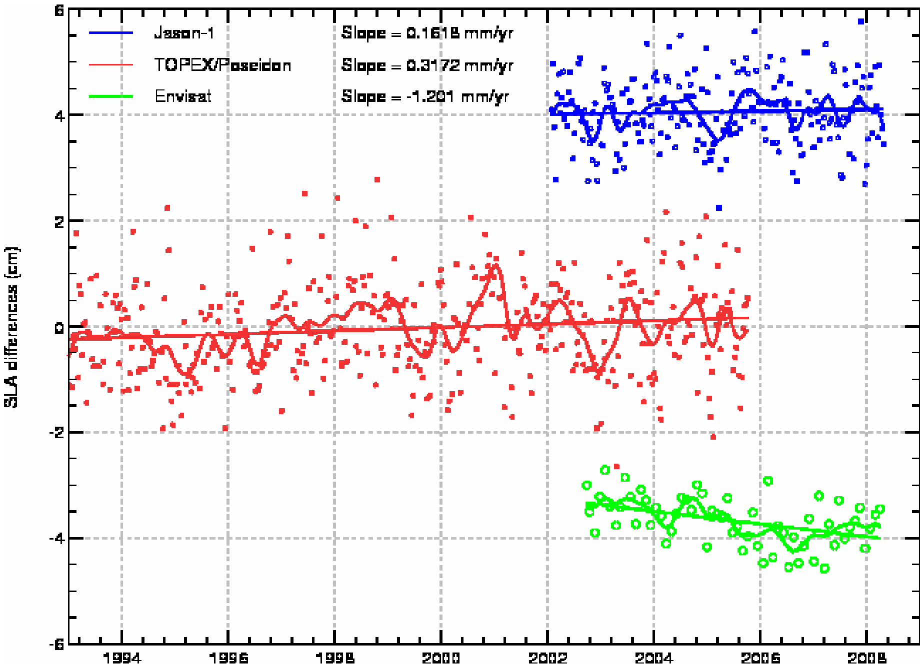


Figure 18 : Altimetric and tide gauge MSL comparisons for JASON-1, T/P and ENVISAT altimeter missions (trends are deduced from non-filtered SLA differences)

- Secondly, an **innovative method** using the whole set of free-drifting profiling floats of the ARGO network is used: **altimetric data are compared to sea level heights computed from T/S profiles since 2004**.

Both *in situ* datasets complement each other since tide gauges concern coastal areas while T/S profiles are widespread enough to detect potential drifts in the open ocean.

SARAL/AltiKa data will also be validated using these tools by ***Dibarboure et al***. [Appendix] and included in the multi-mission analysis. Annual reports will be available on Aviso website (an example of 2008 annual validation report of altimetric data by comparison with *in situ* measurements can be downloaded here: http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/insitu/annual_report_insitu_2008.pdf).

Scharroo et al. [Appendix], as part of their calibration and long-term monitoring activities of SARAL/AltiKa, intend to compare altimeter sea level data against a well-selected global set of tide gauges, in collaboration with the University of South Florida (G. Mitchum).

4.3.4.2 REGIONAL COASTAL AND INLAND WATER *IN SITU* EXPERIMENTS

Some regional or local comparisons of SARAL/AltiKa data to various *in situ* observations are proposed by Science Team PIs.

4.3.4.2.1 Tide gauges networks

***Esselborn et al**.* [Appendix] **plan to assess the degree of coherence between SARAL/AltiKa and tide gauges SSH observations at different spatiotemporal scales**, using 14 tide gauges installed in the Indian Ocean in the framework of the German Indonesian Tsunami Early Warning System (GITEWS) by GFZ. For the study of global mean sea level, local time series of differences between tide gauge and SSH will help to monitor the long term stability of SARAL/AltiKa measurements.

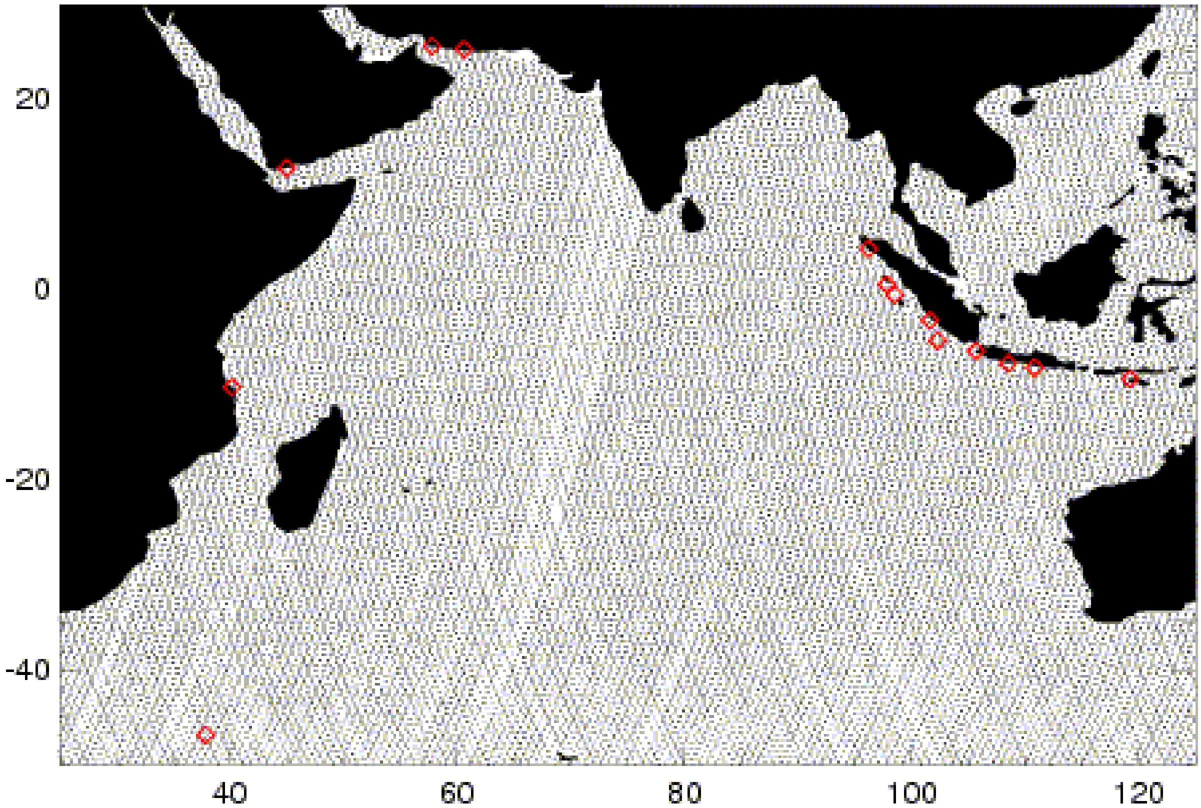


Figure 19 : Tide-gauges location (red circles) used in *Esselborn et al.* study

***Birol et al**.* [Appendix], within their regional CALVAL activities, **plan to assess SARAL/AltiKa performance relative to other in-flight altimeter missions**, by comparing altimeter SSH data to coastal tide gauges observations, in various selected areas: NW Mediterranean Sea, Bay of Biscay, western Gulf of Bengal, Papua New-Guinea & Salomon islands area, Southern Ocean around Kerguelen Plateau, Adelie Land region close to Antarctica, and Arctic Ocean. An analysis of the consistency between time series of SARAL/AltiKa altimetric SSH and tide gauge data will also be done.

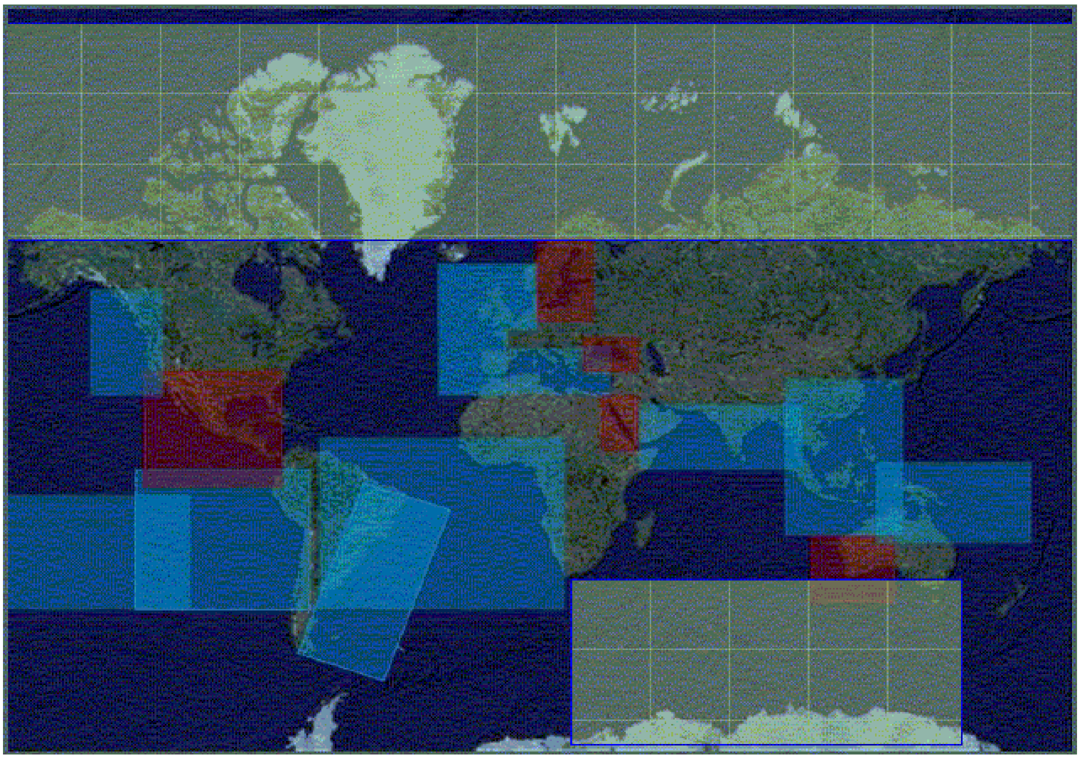


Figure 20 : Selected areas in *Birol et al.* study

***Fenoglio-Marc et al*.** [Appendix] **will validate SARAL/Altika SSH data in some coastal regions** (Europe and Indian Ocean) and assess its advantages with respect to other altimeter missions, using tide-gauges and collocated GPS measurements when available.

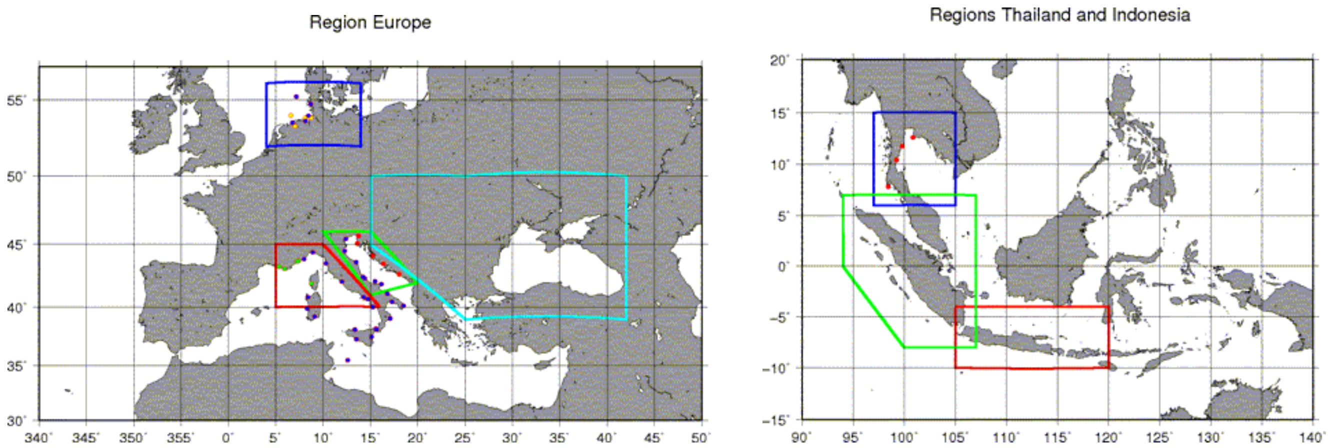


Figure 21 : Selected regions and tide-gauges location used in *Fenoglio-Marc et al.* study

***Quartly et al*.** [appendix] **will compare SARAL/AltiKa SSH data with observations from a large network of tide gauges along the European coastline**. This analysis will also be performed on parts of the North Indian Ocean, as in that region some tide gauges had previously shown a poor correlation with altimeter data (Mehra et al., 2010). If this was partially due to the nearest valid altimeter measurement being too far offshore, then the increased proximity of SARAL/AltiKa's measurements should lead to a marked improvement.

Calmant et al. [appendix] will rely on more than 80 operational water level recorders along Texas and Louisiana Gulf coastline, to validate **the SARAL/AltiKa SSH in this particular zone made by 70% of lagoons or bays**, with a much calmer ocean, which will allow for a more accurate estimate of the water level with almost no wave interaction. These places are then particularly adapted to testing the performance of the various retrackers.

4.3.4.2.2 High-frequency radar networks

Ichikawa et al. [Appendix] propose to evaluate performances of SARAL/AltiKa in the coastal region and to establish proper data processing methods for estimation of coastal surface geostrophic velocity anomaly, by comparisons with the high-resolution surface velocity data obtained by the High-Frequency radar system located in the Tsushima Strait between Japan and Korea.

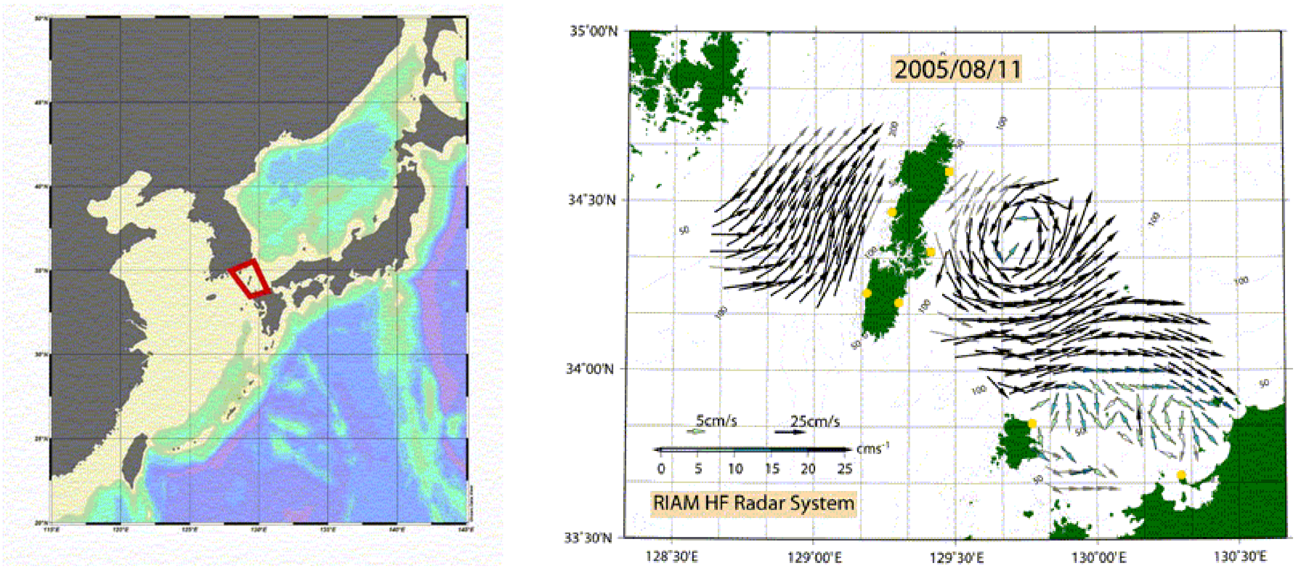


Figure 22 : Selected region (red square) and HF radars location (yellow points) used in *Ichikawa et al.* study

4.3.4.2.3 Multiple *in situ* observational datasets

Arnault et al. [Appendix] propose, as a first step of their study, to validate SARAL/AltiKa SSH data in producing oceanic meso-scale information in a tropical, coastal and rainy environment (in 4 different regions of the Tropical Atlantic) thanks to oceanographic cruises, moorings, ARGO floats and tide gauges observations.

Durand et al. [Appendix] will use a complete *in situ* observational dataset composed of XBT transects carried out on a commercial vessel, an autonomous underwater glider, a current meters mooring and a dedicated oceanographic cruise, in order to build a synergy with SARAL/AltiKa data for western boundary current study in the South-West Pacific, and first to validate SARAL/AltiKa SSH data.

Deng et al. [Appendix] will validate SARAL/AltiKa SSH data using regional high frequency radar and tide gauge observations, in terms of derived geostrophic velocities in their region of interest (coastal Leeuwin Current off Western Australila).

***Pascual et al**.* [Appendix] will use *in situ* data acquired with oceanographic equipment (tide gauges, moored buoys, gliders, specific ship campaigns) to validate their multi-missions altimetry dataset with a special focus on SARAL/AltiKa data in their coastal ocean zone of interest (Balearic Sea).

***Vialard et al**.* [Appendix], in their objective to explore the potential of SARAL/AltiKa products to monitor coastal current variability in the Northern Indian Ocean, will compare SARAL/AltiKa derived geostrophic currents to available current records (ADCP moorings) along the west coast of India.

***Calmant et al**.* [appendix] plan to validate SARAL/AltiKa SSH using *in situ* tide gauges, as well as XBT, CTD, XCTD and ARGO floats measurements available in the Indian coastal area region, and to assess the performance of various retracking algorithms in this costal area. Short scale geostrophic currents features will also be validated.

4.3.4.2.4 River and lake gauges

***Birkett et al**.* [Appendix] plan to examine the overall performance of SARAL/AltiKa over various inland water targets, including quantity and quality of data in terms of elevation accuracy, acquisition speeds and minimum target size observable. Validation exercises will thus be performed utilizing North and South American ground-base gauge datasets (courtesy of NOAA, USGS, Environment Canada, and collaborative sources) and synergistic altimeter data from Jason-2. Focus will be on gains via improved mission tracking logic, along-track resolution, and operation at the Ka-band.

***Calmant et al**.* [Appendix] will perform a global comparison of altimetry time series with readings at gauges available in the Amazon basin. At all cases of tracks passing right over a gauge, the SARAL/AltiKa time series will be compared to the gauge readings, paying attention to the performance of the various retracking algorithms. In this basin, the width of the river can change dramatically between high and low level seasons. The detection of such changes will be seeked in GDR parameters such as the backscatter coefficient with help of imagery.

***Vialard et al**.* [Appendix] propose to evaluate SARAL/AltiKa performances and data quality over large rivers by comparing SARAL/AltiKa-derived river heights with *in situ* river height observations provided by the Bangladesh Water Development Board. Cross-comparisons with Jason-2 and Envisat measurements against the same *in situ* observations should help to understand the new opportunities brought by SARAL/AltiKa compared to these previous Ku-band altimeters.

***Lee et al**.* [Appendix] propose to build an error budget for SARAL/AltiKa inland waters level measurements by comparing them to *in situ* and concurrent altimeter observations over Congo basin and Arctic lakes. An optimal retracker for the SARAL/AltiKa waveforms obtained from snow/ice covered lake surface will also be investigated using available *in situ* data over Arctic lakes.

4.4 ALTIMETER CORRECTION TERMS : EXTERNAL VERIFICATION

4.4.1 WET TROPOSPHERE CORRECTION

As part of their investigation, ***Eymard et al**.* [Appendix] plan to **calibrate and validate SARAL/AltiKa radiometer measurements**, using a similar methodology as developed for Envisat microwave radiometer. The calibration exercise is based on:

- systematic comparison between SARAL/AltiKa microwave radiometer and Jason-1/JMR, Jason-2/AMR and Envisat/MWR brightness temperatures over stable areas (hot targets: Amazonian and Congo rain forests, that are similar to black bodies at microwave frequencies; and coldest ocean)
- the systematic comparison between SARAL/AltiKa brightness temperatures over ocean and simulations by a radiative transfer model over coincident meteorological fields from ECMWF model.

Validation of geophysical parameters (wet troposphere correction, liquid water content, radar attenuation) will be performed using comparison with *in situ* measurements by radiosondes for water vapour, as a long-term survey activity. Preliminary comparisons shall be performed with in-flight spaceborne measurements and ECMWF operational model analyses. Model reanalyses (e.g. ERA-interim) will be preferred for long-term monitoring of SARAL/AltiKa radiometer water vapour time series stability.

Considering the good spatial resolution of SARAL/AltiKa radiometer (between 10 & 15km for both channels), **it is expected that the land contamination effect should be less critical than for current altimetry missions**. *Eymard et al.* will analyse the quality of the brightness temperatures and wet troposphere correction observed when approaching the coast, and evaluate the retrieval wet troposphere algorithms previously developed for coastal altimetry applications.

The technique for **measuring columnar water vapour from terrestrial GPS tracking stations data located on a ground track,** will be applied and compared to SARAL/AltiKa radiometer wet path delay, by ***Calmant et al***. and ***Mertikas et al***. [Appendix] at their absolute calibration sites equipped with GPS and meteorological stations, **for detection of a potential long-term drift in the SARAL/AltiKa path delays**. By using the meteorological parameters from a local weather station, the dry component is subtracted from the total troposphere path delay derived from GPS. The resulting wet troposphere path delay is then computed by a linear interpolation at the time of closest approach and compared to radiometer-derived value.

4.4.2 IONOSPHERE CORRECTION

As detailed in 3.2.4, **SARAL/AltiKa products will rely on JPL GPS-based GIM** (Global Ionosphere Maps) **model**, as AltiKa is a mono-frequency altimeter which prevents from computing a dual-frequency ionosphere correction as for previous Ku-C missions. However, being at Ka-band leads to a smaller (divided by 7 compared to a Ku-band altimeter) amplitude of this ionosphere correction. **The expected error on ionosphere correction for (I)GDR products is less than 0.3cm**, but could be larger for OGDR near-real-time products (mainly due to the 24h GIM fields latency).

CNES plans to globally evaluate and monitor the ionosphere correction. For (I)GDR products, this will be done mainly by comparison to other best performing models (like NIC09 from *Scharroo and Smith, 2010*). For OGDR products, the assessment of ionosphere correction will be realized by comparison to the (I)GDR products value and external models (e.g. NIC09 from *Scharroo and Smith. 2010*).

4.4.3 SEA STATE BIAS

The sea-state bias (SSB) correction is presently one of the most significant sources of error in the altimeter measurement system. This shall be especially true for SARAL/AltiKa, as sea-state effects in Ka-band are presently unknown: this is why the first SSB algorithm for SARAL/AltiKa products will consist in a simple "3.5% of SWH", before some refinement can be implemented in the operational products SSB algorithm.

Conducting CALVAL studies on this issue is necessary to improve and tune the algorithms and to verify their respective performances.

Mercier et al. [Appendix] plan to assess the operational SSB correction algorithm. The SSB obtained for SARAL/Altika will be extensively compared to the SSB models of other altimetric missions (Jason-2, Jason-1, TOPEX, ENVISAT, GFO) derived with the same technique, successively after a few cycles, after 1-year, and beyond for stability analysis. This assessment will help to improve our knowledge of the sea state and electromagnetic bias with a particular focus on the frequency dependence since SARAL/Altika is the first instrument providing data in Ka-band. Differences between Ku- and Ka-band solutions will be analyzed.
Then, they plan to develop a new operational and alternative SSB correction for SARAL/AltiKa: to improve actual SSB models, it has been shown lately that use of additional information from operational wave model

(WaveWatch3) as input can improve significantly the SSB estimates [Tran et al, 2006; Tran et al, 2010]: such development could be pursued to provide a new operational and alternative SSB correction.

Chapron et al. [Appendix] also propose to continue the development of alternate SSB solutions to the operational version by taking into account additional surface wave parameters provided from state of the art numerical wave model that have been shown to reproduce the dynamics of the high frequency moments of the wave spectrum (Ardhuin et al., 2009, 2010). Further, the differences between solutions based on S- C- Ku- and Ka-band data will be analysed, and interpreted in combination with numerical wave model results for the long wave part of the spectrum.

4.5 DEDICATED *IN SITU* CALIBRATION SITES

Absolute calibration of altimeters through comparison of sea level measured by altimeter and local sensors (tide gauges, GPS-buoys) is mandatory, as it is the only way to estimate the absolute bias of the altimeter. In the case of any gap between successive altimetry missions, absolute calibration is thus the way of assuring the continuity of long sea level time series, which is necessary to monitor climate signals such as global mean sea level change at the mm/year level.

Absolute calibration and *in situ* validation of the overall measurement system will be performed using dedicated verification sites. The principal objective of these programs is to use observations from local sensors (like tide gauges or cinematic GPS-buoys) directly on or near SARAL/AltiKa ground tracks to calibrate the sea-surface height and ancillary measurements made by the satellite as it passes (nearly) overhead.

The variety of contexts (open and coastal ocean, inland waters, land and ice surfaces) of the different verification sites proposed by ***Calmant et al***., ***Cheng et al***., ***Mertikas et al***. and ***Watson et al***. [Appendix], should lead to an enlarged absolute calibration and validation of SARAL/AltiKa measurements and associated parameters. Such a distributed and varied distribution, with a possibility of checking if specific conditions lead to different estimation of absolute bias of the instruments, should enable a robust assessment of the SARAL/AltiKa altimetry system.

SARAL/AltiKa will pass over dedicated verification sites every 35 days as they trace out their repeat ground track. In the traditional "overhead" concept of altimeter calibration, direct comparisons of the sea level and ancillary measurements derived independently from the satellite and *in situ* data are used to develop a time series of absolute calibration estimates for the satellite sensors (altimeter and radiometer) and the overall measurement system.

Dedicated verification sites offer the advantage of direct overflight geometry, and a survey tie to the geocenter. The direct overflight geometry reduces errors introduced by decorrelation of SSH and environmental parameters as the cross-track distance to the ground track increases. The tie to the geocenter enables the computation of an absolute bias in the measurement system, and also accommodates the separation of vertical land motion at the experiment site from potential instabilities in the altimeter range system. In addition, dedicated verification sites typically feature several collocated sensors to help discriminate between different sources of error. The instrument suite may include water vapor radiometers, meteorological sensors, GPS, Doris, and SLR, and buoys in addition to tide gauges.

In situ calibration of radar altimeter is operated at the vertical of a dedicated CALVAL site. A direct comparison of altimetric data with *in situ* data is operated. This configuration leads to handle the differences compared with the altimetric measurements system at a global scale: the Geographically Correlated Errors at regional (orbit, sea state bias, atmospheric corrections…) and local scales (geodetic systematic errors, land contamination for the instruments, e.g. the radiometer). It is intended to share *in situ* CALVAL experiments conducted at various sites. The reason is that local conditions are different for several observations site. So that geophysical conditions and a common protocol for computing the SSH bias, could permit to increase statistically the sea surface bias estimation.

4.5.1 OPEN AND COASTAL OCEAN SITES

4.5.1.1 CORSICA (MEDITERRANEAN SEA)

The **Corsica site**, which includes Ajaccio-Aspretto site, Senetosa Cape site, and Capraia (Italy) in the western Mediterranean has been chosen to permit the **absolute calibration of radar altimeters. This is the prime CNES verification site.**

CALVAL operations and analysis at Corsica CNES site will be carried out by ***Calmant et al***. [Appendix].

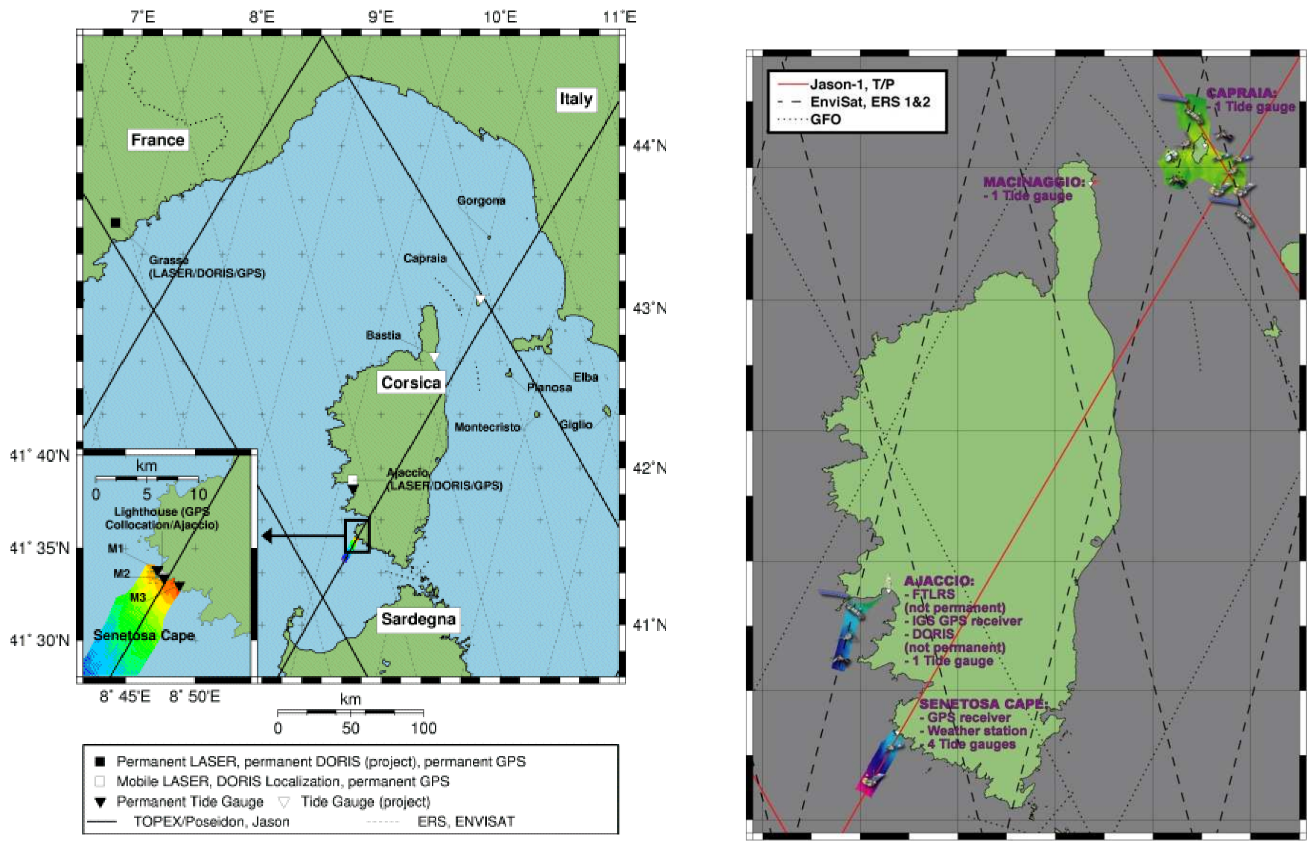


Figure 23 : General configuration of the Corsica calibration site. The colored surfaces correspond to local geoids determined by using the Catamaran-GPS method described in Bonnefond et al. (2003b)

Thanks to the French Transportable Laser Ranging System (FTLRS) for accurate orbit determination, and to various geodetic measurements of the sea level, the objective is to measure the altimeter biases and their drifts. On the other hand, it is also an opportunity to contribute to the orbit tracking of oceanographic and geodetic satellites and to perform the analysis of the different error sources, which affect altimetry. [TBC : availability of FTLRS for SARAL/AltiKa?]

The extension of this calibration experiment includes now Capraia island (including Macinaggio tide gauge). A dedicated GPS campaign has been achieved in 2004 to measure the geoid slopes under the Jason-1, EnviSat and GFO tracks around the island. In October 2005, a similar campaign has been achieved for the EnviSat ground track close to Ajaccio.

The Corsica calibration site that has been operational in Senetosa since 1998, in the frame of the TOPEX/Poseidon and Jason-1 missions, is now able to perform the altimeter calibration at two new locations (Ajaccio and Capraia), for the EnviSat satellite and thus SARAL/AltiKa which will fly over the same groundtrack. It gives a unique opportunity to link all existing altimetric missions with common processes. For example, the wet tropospheric path delays to be compared with the AltiKa radiometer can be derived from the Ajaccio permanent GPS receiver and the airport weather station (as it is already done in Senetosa for Jason-1). Thanks to the vicinity of the Senetosa site, another great opportunity is to used the same GPS buoy to regularly perform independent calibrations under the EnviSat-SARAL/AltiKa ground track that can be compared and combined with Ajaccio tide gauge ones.

As for the TOPEX/Poseidon, Jason-1 and Jason-2, results for SARAL/AltiKa altimeter bias and drift will be regularly compared with those obtained from at least one other Indian calibration sites.

Using SARAL/AltiKa in the Corsica calibration site, experience with Envisat calibration:

As SARAL/AltiKa will follow the same ground tracks as ENVISAT, here we present some results of the ENVISAT *in situ* CALVAL at the Corsica site. ENVISAT tracks are offshore from the principal instrumented site (Figure 24). The ENVISAT satellite flights over a few km away from Ajaccio site.

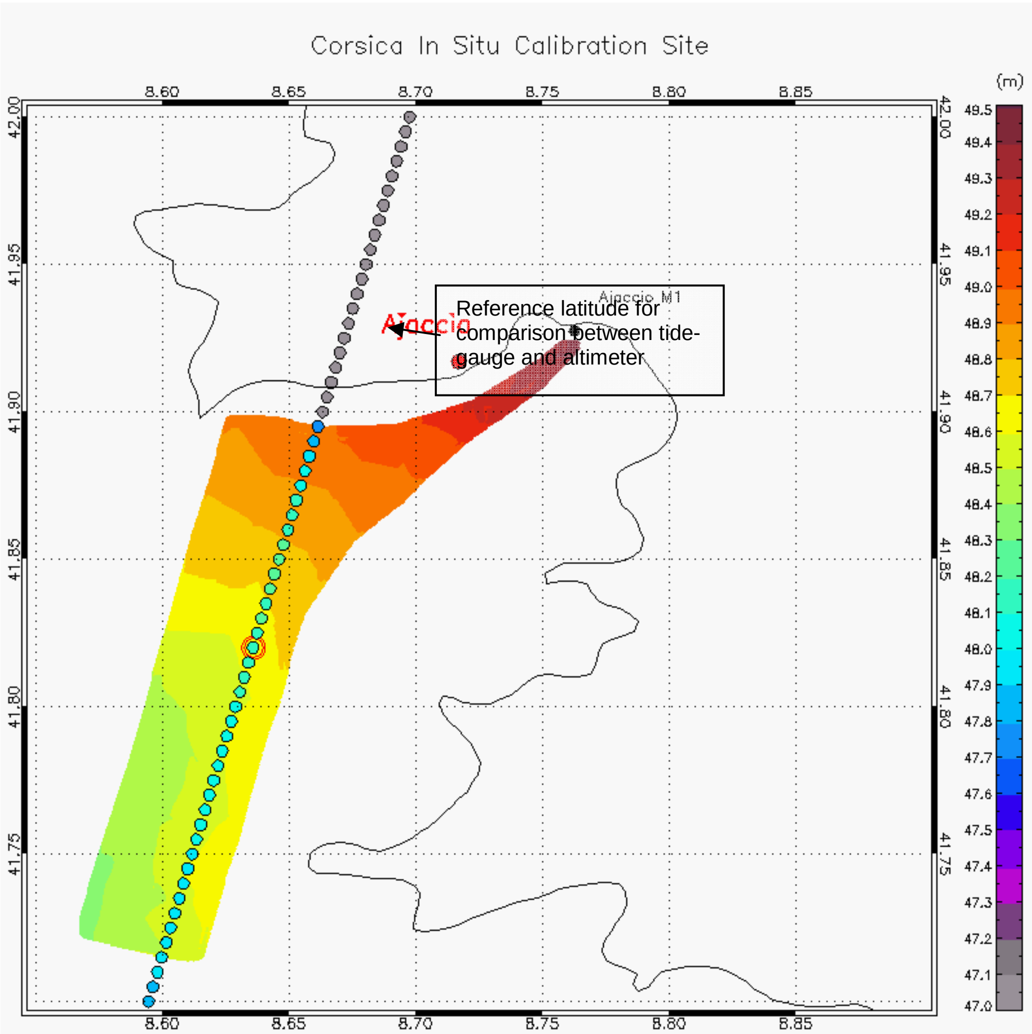


Figure 24 : Location of the marine mean sea surface, the ENVISAT track nr. 130 near the Ajaccio site

From studies in Corsica calibration site, the ENVISAT altimeter calibration results are presented in Figure 25. It shows that altimeter and tide-gauge are very well coordinated and they observe the same sea level phenomena.

a)

b)

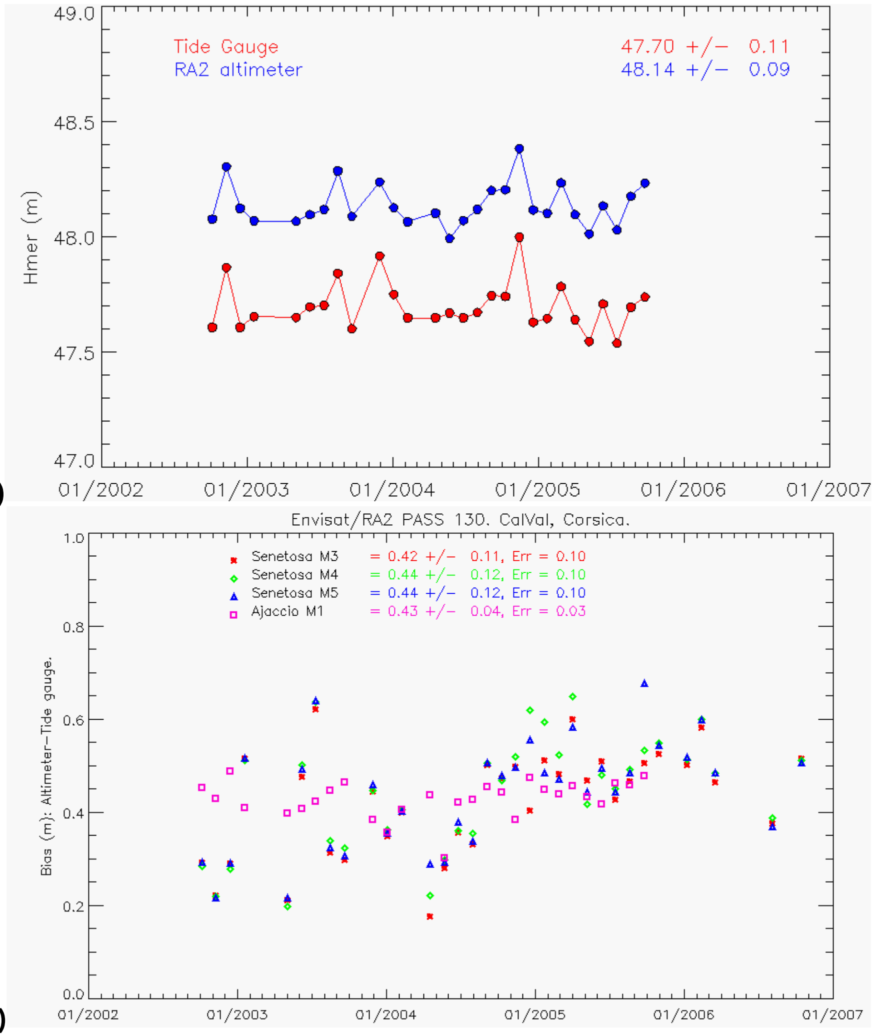


Figure 25 : a) Sea height (in m) measured by the M1 tide-gauge in Ajaccio and by the ENVISAT altimeter, b) *In situ* calibration results for the ENVISAT altimeter in Corsica from 2003 to 2007.

In situ calibration at the Ajaccio site provides a sea surface height bias of 43cm with a standard deviation of +/-4cm. This bias is quite stable because it has been determined with the direct calibration method. These results have been established using 34 ENVISAT cycles, from January 2003 to January 2007.

4.5.1.2 ISRO SITE

It was proposed and agreed on both side (ISRO & CNES) to deploy a dedicated SARAL/AltiKa *in situ* calibration site in India, that could be based on an existing Indian tide gauge site. Considering the long experience of French teams on the altimeter CALVAL activities, it was also agreed that the selection and upgrade of the Indian calibration site should be performed jointly (ISRO & CNES), considering criteria described in section 4.5.4.

It is proposed to utilize existing tide and radar gauges in Indian region for SARAL/AltiKa absolute calibration and validation of geo-physical products. Figure 26 and Figure 27 respectively show the number of gauges (30 approx.) deployed along eastern and western coast lines of India and the geoid.

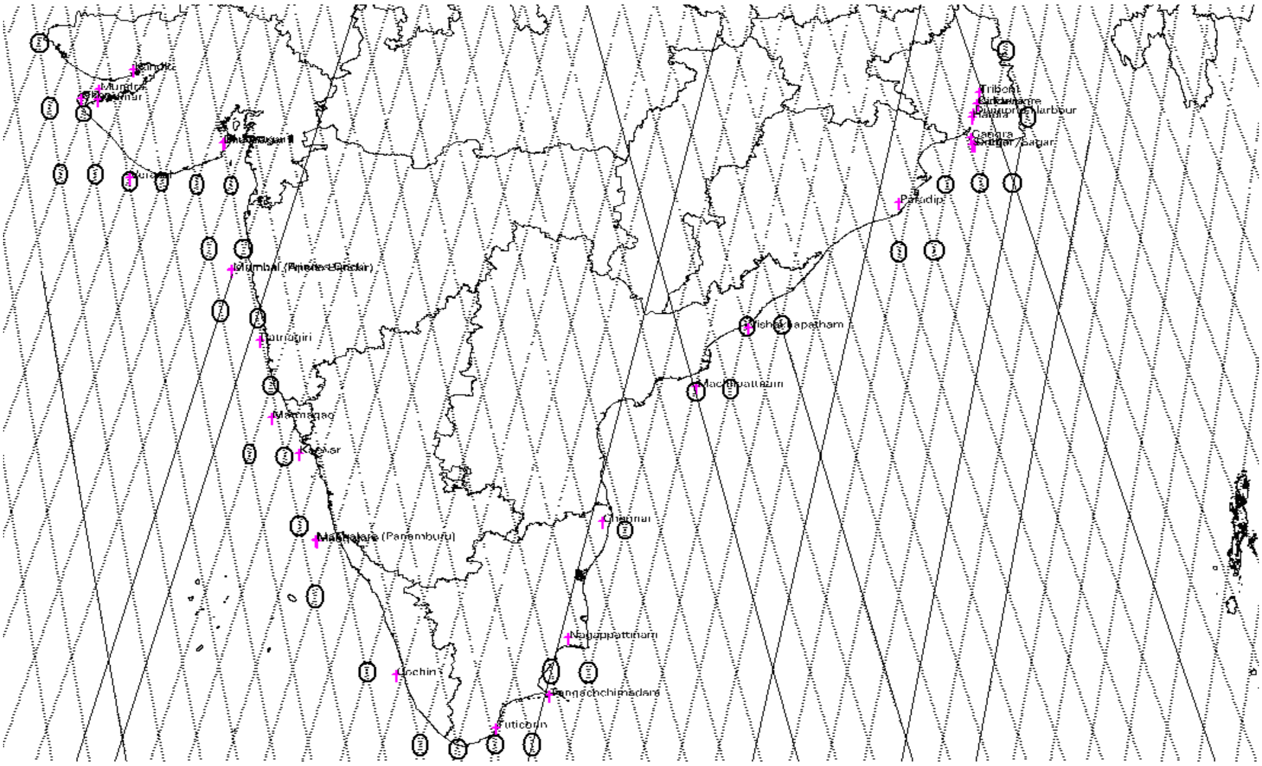


Figure 26 : Location of the tide gauges deployed along shores of India

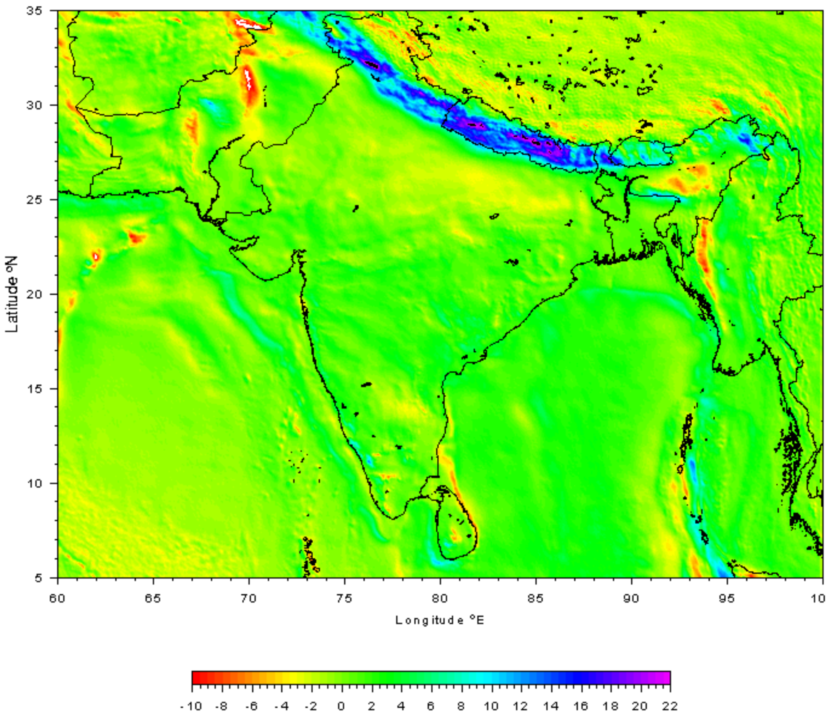


Figure 27 : Geoid over India

Apart from these coast line gauges, dedicated open ocean and in-land water sites will be used. **A CAL-VAL site at Kavaratti island is operational for ocean color CAL-VAL in Lakshadweep. (**Figure 28**). in Arabian sea. This site also has tide and radar gauges**.

The Envisat-SARAL/AltiKa track as shown in Figure 28 is about 8 km off Kavaratti island. Bangaram island as shown in Figure 29 is below Envisat-SARAL/AltiKa pass and hence a radar gauge is planned to be installed near this island. Bombay high offshore platform is in the open ocean in India and is situated below the pass. Therefore, it is planned to install one radar gauge on this platform to continuously monitor sea level and the bias.

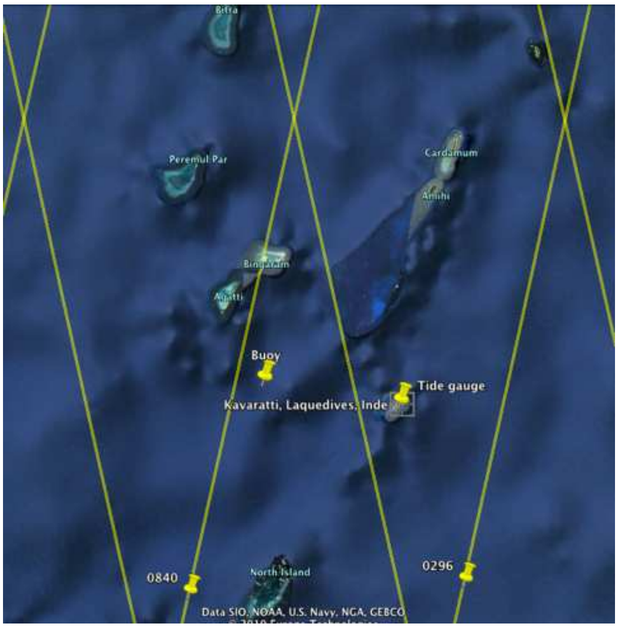


Figure 28 : SARAL/AltiKa ground tracks over Lakshadweep islands

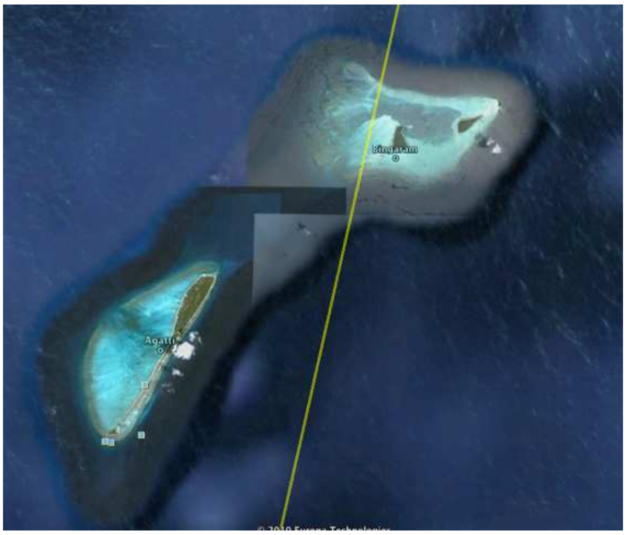


Figure 29 : zoom over Bangaram island

Sardar Sarovar Reservoir as shown in Figure 30 is proposed for in-land reservoir water level measurement. This reservoir is used for the flood control, irrigation, drinking water mission, etc. Wular Lake (also spelt Wullar) is one of the largest fresh water lakes in Asia. It is situated in the Indian state of Jammu and Kashmir between the cities of Sopore and Bandipore. The lake was formed as a result of tectonic activity. Radar gauges will be installed in these in-land sites..

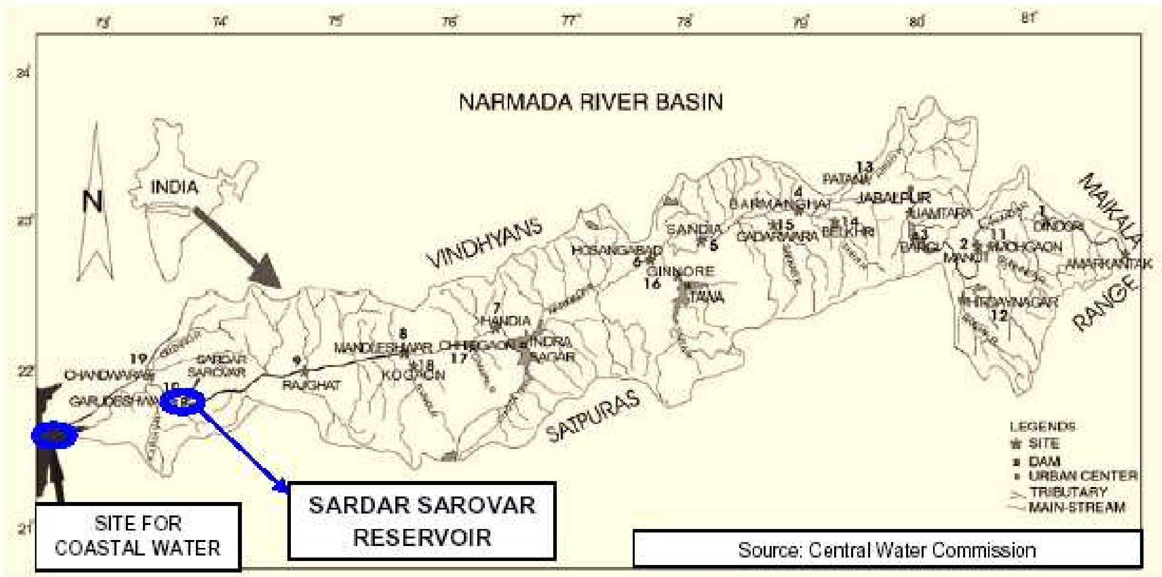


Figure 30 : Location of the Sardar Sarovar Reservoir

Kavaratti CAL-VAL site presently being used for ocean color CAL-VAL could be augmented with GPS buoy and associated infrastructures to become another international site for operational altimeter calibration as no site exists in the Indian region. Dedicated efforts will be required to develop this site for SARAL/AltiKa altimeter calibration with cooperation from CNES. Necessary funding from the project is envisaged. CAL-VAL operations and analysis will be carried out by ***Shukla A.K. et al**.* [Appendix].

4.5.1.3 TAÏWAN SEAS

***Cheng et al**.* [Appendix] **will set up an *in situ* absolute calibration site in Taiwan Seas**, based on the currently available tide gauges and Continuous GPS (CGPS) stations (Figure 31). Coastal tide gauges are selected as the main *in situ* measurement and GPS buoy, or GPS-equipped vessel, will be utilized to map the mean water surface gradient that is required for absolute calibration of SARAL/AltiKa. The data from the CGPS stations in the vicinity will be included to form a GPS geodetic network, on which the buoy/vessel GPS kinematic processing will be based.

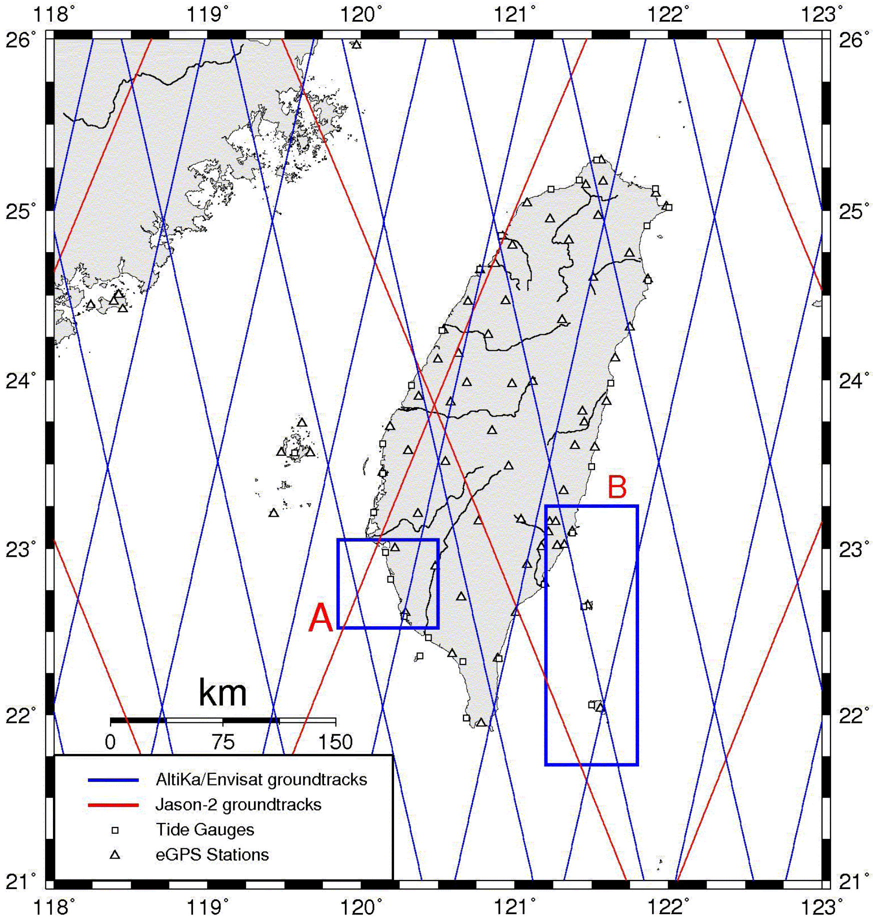


Figure 31 : SARAL/AltiKa theoretical grountracks near Taïwan.

The proposed calibration site is anticipated to provide continuous calibration result and expected to contribute to the overall SARAL/AltiKa CALVAL global activities. The SARAL/AltiKa SSH bias will be made available to the altimeter community to improve the accuracy of SARAL/AltiKa SSH measurements in the surrounding oceans of Taiwan. The bias estimate of SARAL/AltiKa can also be compared to the calibration result of other altimeter mission in the same region, for example, the Jason-1 calibration in Taiwan (Chiu et al., 2007). Such information is helpful in the determination of relative bias between different altimeter missions.

Here *Cheng et al.* proposed P1-P6 in Taiwan (Figure 32) as the candidate locations for SARAL/AltiKa absolute calibration based on the analysis of the direction and the location of the SARAL/AltiKa theoretical ground tracks and the available tide gauges and CGPS stations. However, further investigation in the waveform is needed to check the data consistency. Also, the ease of carrying out the GPS buoy campaign should also be considered. As a result, the best location among all 6 candidates will be chosen as the main calibration site for SARAL/AltiKa's CALVAL activities in Taiwan.

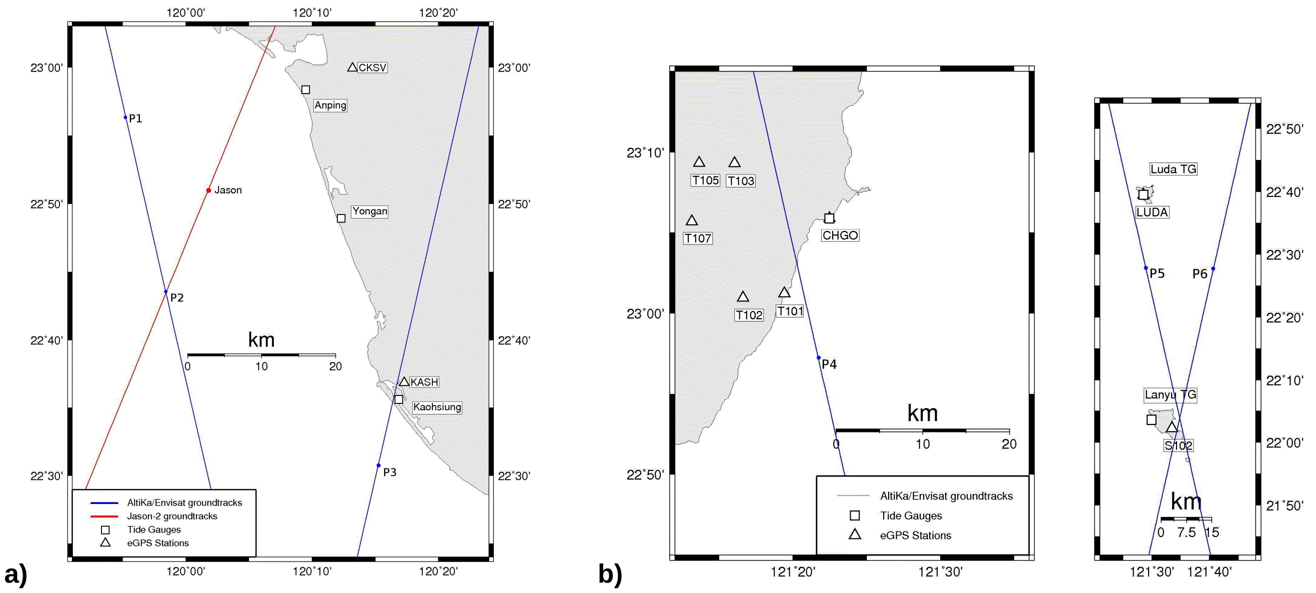


Figure 32 : Blowup maps for the inset A (a) and B (b) in Figure 31 : the red dot represents the current Jason-1/2 CALVAL activities, while P1-P6 are six proposed candidate locations for SARAL/AltiKa absolute calibration with the coastal tide gauges at Anping, Kaohsiung, Chengkung, Luda and Lanyu.

4.5.1.4 GAVDOS (MEDITERRANEAN SEA)

Mertikas et al. [Appendix] propose to **use and adapt the permanent facility on the Island of Gavdos and Crete**, in order to monitor, calibrate and validate SARAL/AltiKa data.

On the small island Gavdos, 40 km south of Crete, the Laboratory of Geodesy and Geomatics Engineering in the Technical University of Crete, Greece, has established in 2001 and has been operating as of 2004 a permanent facility for calibrating satellite radar altimeters (Figure 33). The Gavdos permanent facility is situated under a crossing point of the Jason orbits and adjacent to the orbits of Envisat-SARAL/AltiKa. The dedicated calibration facility includes tide gauges, permanent GPS satellite receivers, meteorological and oceanographic instruments, a DORIS satellite beacon, an electronic transponder (a new one under construction), communications systems for the transmission of data, etc.

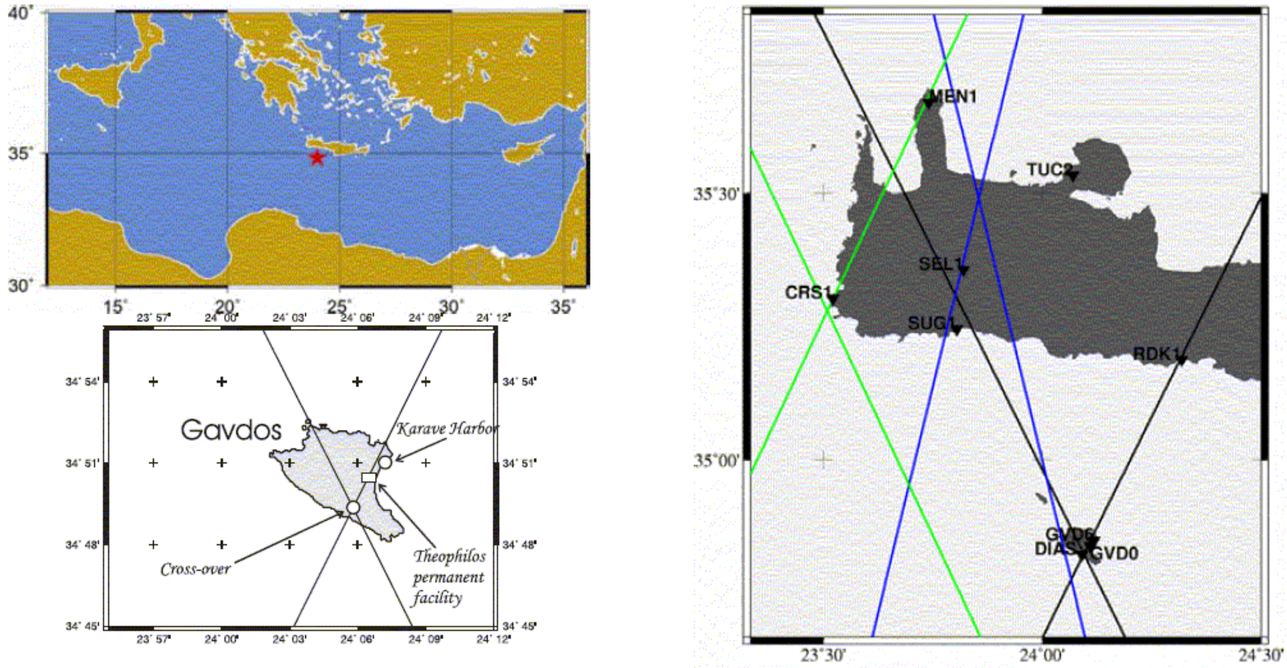


Figure 33 : Location of the Gavdos permanent facility, the continuously operating geodetic arrays over western Crete East Mediterranean, and repeating ground tracks of altimetry missions (blue : Envisat-SARAL/AltiKa, black : Jason-2, green : GFO).

The proposed CALVAL activities include the estimation of the absolute SSH bias of SARAL/AltiKa as well as monitoring its drifts. It will be carried out by comparing SARAL/AltiKa SSH with the absolute sea level measured by the *in situ* instruments of the dedicated site. Furthermore, if the new modular microwave transponder is appropriately modified to work with the 35.75 GHz frequency, two independent methods will be employed for the estimation of the absolute bias of SARAL/AltiKa. In addition, radiometer measurements made by the satellites will be checked against the zenith path delays as they would be determined by the existing array of the 8 continuously operating GNSS stations.

These CALVAL activities will be achieved by developing and modifying dedicated techniques, successfully applied to Jason, for SARAL/AltiKa. Modifications on the existing CALVAL methodology and instruments necessary to adjust to the new SARAL/AltiKa mission requirements will be performed at the Gavdos facility. The possibility (a) of developing another CALVAL site under the SARAL/AltiKa pass on the south coast of Crete, and (b) of modifying the microwave transponder, already being developed by GeoMatLab, to be operational with the SARAL/AltiKa, will be explored.

4.5.1.5 BASS STRAIT AND STORM BAY (TASMANIA, AUSTRALIA)

Watson et al. [Appendix] propose to contribute to CALVAL estimates of SARAL/AltiKa SSH absolute bias and drift, by using **Australian *in situ* calibration facilities over ocean at Bass Strait and Storm Bay** (Figure 34).

The methodology applied will closely follow that adopted for the CALVAL of T/P, Jason-1&2 missions at the Australian facilities (Watson et al., 2003; 2004, Watson 2005, Bonnefond et al., 2009). Additional GPS buoy deployments would be required on SARAL/AltiKa tracks.

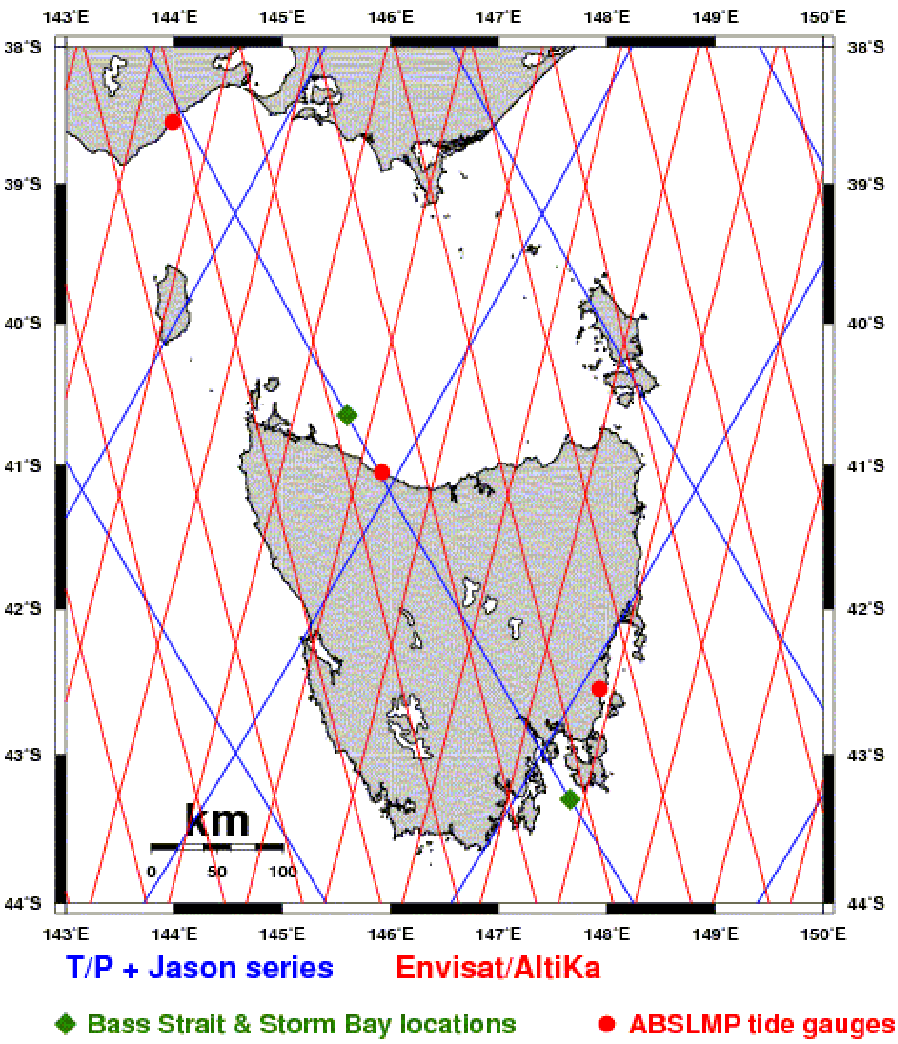


Figure 34 : CALVAL facilities at Bass Strait and Storm Bay (green dots), both located around Tasmania, Australia. SARAL/AltiKa tracks in red, Jason-2 in blue.

4.5.1.6 SABINE BANK (SOUTH-WEST PACIFIC)

Since 1999, two offshore pressure gauges have been recording sea level variations nearly continuously near Vanuatu islands under satellite tracks. These two gauges are emplaced on two seamounts that are located close to several satellite altimetry ground tracks (Figure 35). One of the gauges, on Sabine Bank, is located close to an Envisat (and SARAL/AltiKa in the future) cross-over point and the second one is located close to a cross-over between TP/Jason old and new tracks, which means that we have a continuous series of data from TP to Jason-2, close to the tide gauge. In addition to the tide gauge data, on-land GPS are recording continuously for geodynamical purpose at several locations in the vicinity, which can be useful for tropospheric or ionospheric corrections comparison.

Calmant et al. [Appendix] propose to continue the work initiated earlier, with SARAL/AltiKa data in addition to ongoing Jason-2 CALVAL activities.

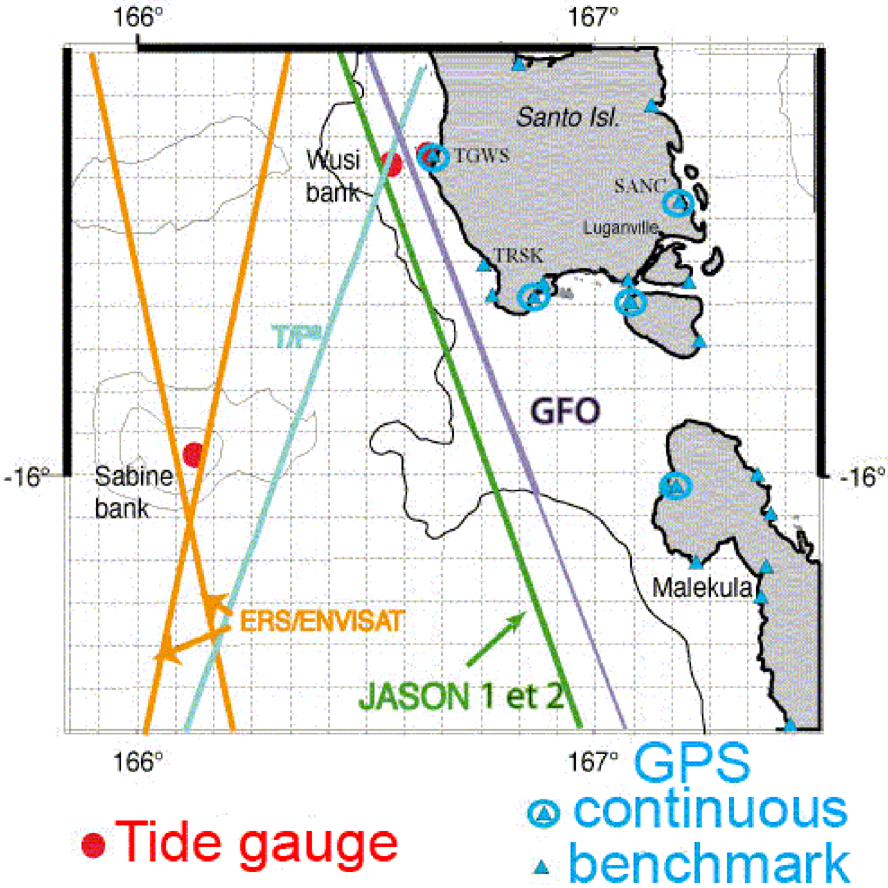


Figure 35 : Position of the two tide gauges (Sabine Bank and Wusi Bank) and different satellite tracks, offshore the Vanuatu islands.

Sabine Bank is a small but high seamount which creates short wavelength signature in the geoid surface, a signal that was not fully recovered by previous satellite altimetric data. The map of sea surface that has been collected with GPS will be used to test the performance of SARAL/AltiKa in mapping short-scales of sea surface variations with respect to previous altimetry missions.

4.5.1.7 TERRES AUSTRALES ET ANTARCTIQUE FRANÇAISES (INDIAN OCEAN)

Europa island is a former volcano emplaced in the Mozambic channel. Both TP/JASON and ERS-Envisat-SARAL/AltiKa tracks pass in its close vicinity (Figure 36) which offers a good opportunity to conduct CALVAL operations. As proposed by ***Calmant et al***. [Appendix] equipment at Europa will consist of a bottom pressure sensor moored few hundreds meter from the shore at few meters depth, a few km away from the SARAL/AltiKa ground track. A permanent GPS is currently maintained at Europa. This GPS will be used to tie the tide gauge reference to the reference of the satellite by the use of GPS buoy session deployed above the bottom pressure sensor.

Calmant et al. also plan kinematic GPS campaigns between the tide gauge and the ground track in order to estimate the geoid slope. If necessary a regional tidal model will be developed in the region in order to properly correct for tide and high frequency dynamic.

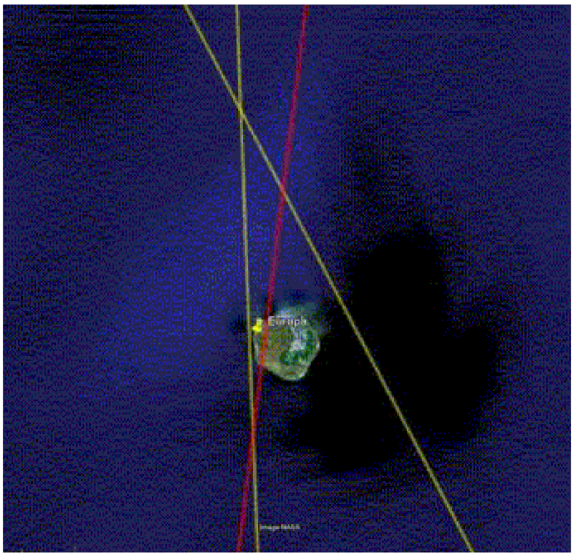


Figure 36 : Europa island: Envisat-SARAL/AltiKa tracks 298 & 399 in yellow, Jason-2 track 157 in red. Pin shows the tide gauge location.

4.5.1.8 HARVEST PLATFORM (CALIFORNIA)

Chao et al. [Appendix] propose to reconcile SARAL/AltiKa data with the absolute altimeter calibration results from the Harvest platform. [*Haines et al.*, 2010] **Established in 1992, Harvest is the longest continuously operating, dedicated altimeter calibration site in the world**. While the SARAL mission will not pass directly over the platform, its data will be linked to the Harvest record using a regional approach. This will enable a quasi-absolute calibration of the SARAL mission, and strengthen the connection with the long-term (climate scale) record from T/P, Jason-1 and Jason-2.

4.5.2 INLAND WATER AND FLAT LAND SITES

4.5.2.1 ISSYK-KUL LAKE (CENTRAL ASIA)

Already 5 cruises on **Lake Issyk-kul (Kirgyzstan)** have been conducted by ***Calmant et al*** [Appendix] in 2004, 2005, 2008 and 2009 for purposes of altimetry calibration (Figure 37). All in-flight altimetry missions have paths over Issykkul (6 SARAL/AltiKa tracks are concerned), which provides opportunity to compute the lake height time series with each satellite separately and then to compare to the other ones. The lake level has been monitored for decades with 3 gauges installed around the lake that provide daily level values. The use of independent very precise *in situ* measurements over a period of 11 years (1999 to 2009) at daily resolution allows to use all altimetry data over the same time interval. This improves the final precision of the calculation of absolute altimeter bias. Another advantage is the basement of a 30m long vessel available and equipped for scientific application. A coastal meteorological station completes the scientific instruments available.

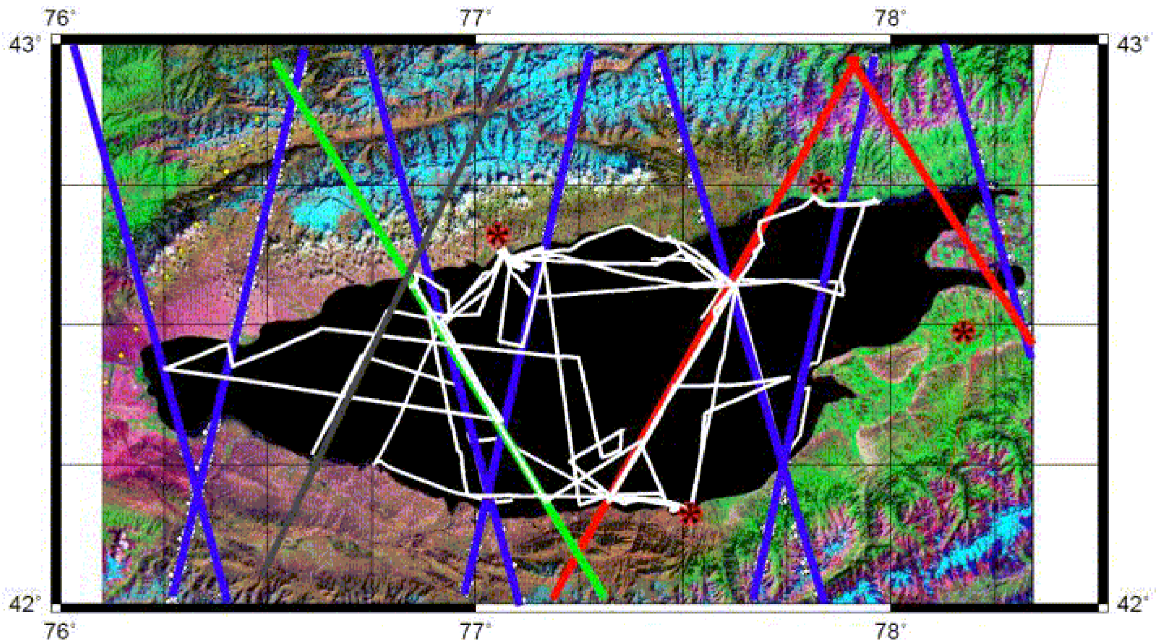


Figure 37 : Altimetry satellites tracks (SARAL/AltiKa & Envisat, Jason-2, Jason-1 & GFO), GPS cruises tracks performed since 2004 (white), and location of instrumental sites (gauge, permanent or meteorological station) (red stars).

In 2009 a permanent GPS station has been installed in Kyzyl Suu village (Southern bank). Another station is usually deployed during the campaigns to form a 2-station network. This network serves as a geodetic reference for the cinematic GPS and to compute tropospheric corrections. Meteorological stations to be installed in 2010 will provide independent estimates of the atmospheric pressure and humidity allowing to fix the tropospheric corrections and compare it with the SARAL/AltiKa radiometer-derived and models estimations. New water level gauges (bottom pressure instruments) will also be installed in 2010 to have automatic measurement of the lake level every minutes, hence also estimate some high frequency effect like seiche.

Among results already found at Issyk-kul lake verification site, there have been evidences that the tropospheric corrections above this inland water site were wrong for all the current missions, namely Envisat, T/P, Jason–1, Jason-2 and GFO. Mission biases were also computed [Crétaux et al., 2009], in good accordance with results from other CALVAL sites, although with differences that may be due to specific problem on the Sea State Bias corrections (Shum et al., 2003, Crétaux et al., 2009). This has reinforced the need to have redundant CALVAL site on continental areas, where this effect is very negligible.

4.5.2.2 AMAZON BASIN (SOUTH AMERICA)

Envisat and SARAL/AltiKa tracks 063 and 478 form a crossover intersecting both the Amazon and the Madeira rivers at their confluence (Figure 38). There, at Iracema village, a gauge has been installed and leveled that enables a full comparison with the ENVISAT and SARAL/AltiKa heights (Figure 39).

Ship campaigns cruising will be regularly conducted by ***Calmant et al***. [Appendix] along the tracks at the dates of SARAL/AltiKa passes to collect GPS profiles along the tracks. If funded, a permanent GPS station and a meteo station will be installed at Iracema in order to improve the leveling of the gauge and thus reduce possible biases in the cinematic GPS profiles. *Calmant et al.* also intend to develop a new mobile, carrying 3 GPS antenna to better remove the motions of the mobile from the surface profiles.

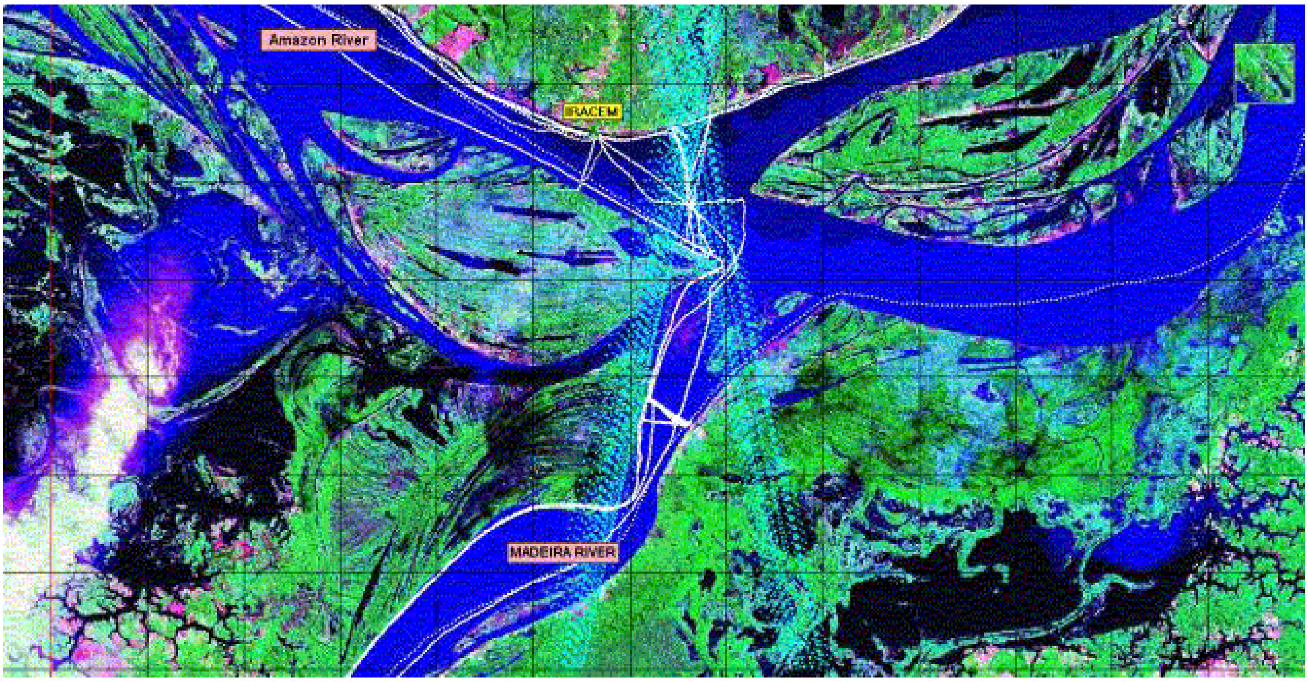


Figure 38 : Blue dots show the Envisat & SARAL/AltiKa tracks 063 & 478; White lines are for the existing cinematic GPS surveys crossing the area, yellow label indicates the position of the Iracema gauge.

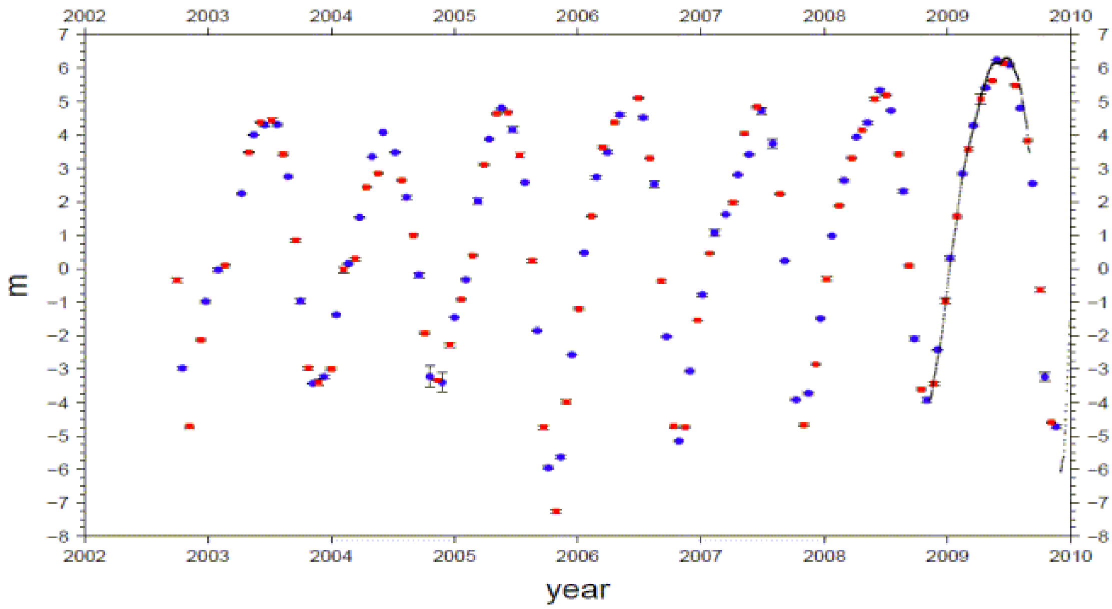


Figure 39 : Water height time series at Iracema: black points = gauge readings, blue dots = track 478, red dots = track 063. Global RMS between Envisat measurements and gauge readings is 19cm.

4.5.2.3 MARBLEHEAD, LAKE ERIE (GREAT LAKES, USA)

Cheng et al. [Appendix] will also set up an *in situ* absolute calibration site in **Marblehead, Lake Erie (Great Lakes)**, based on the currently available tide gauges and Continuous GPS (CGPS) stations (Figure 40).

The candidate locations are selected based on the direction and the location of the SARAL/AltiKa groundtracks and the available accurate coastal tide gauge in the vicinity. A GPS buoy, or GPS-equipped vessel, will be utilized to provide necessary mean water surface gradient from the tide gauge to the nominal SARAL/AltiKa footprints, on which the SARAL/AltiKa sea surface height (and other instrument or correction) biases, if any, are to be estimated.

Two candidates P1-P2 are proposed in Lake Erie of the Great Lakes (Figure 40). There is also a continuous calibration site at Marblehead in Lake Erie for T/P, Jason-1/-2 (Cheng et al., 2010; Shum et al., 2003; Cheng et al., 2002). However, the SARAL/AltiKa pass that passes Marblehead is clearly useless because of the land contamination caused by the islands near Marblehead. Further investigation on the waveform and the data quality of the radiometer is required in order to select the main location in Lake Erie among the proposed candidates.

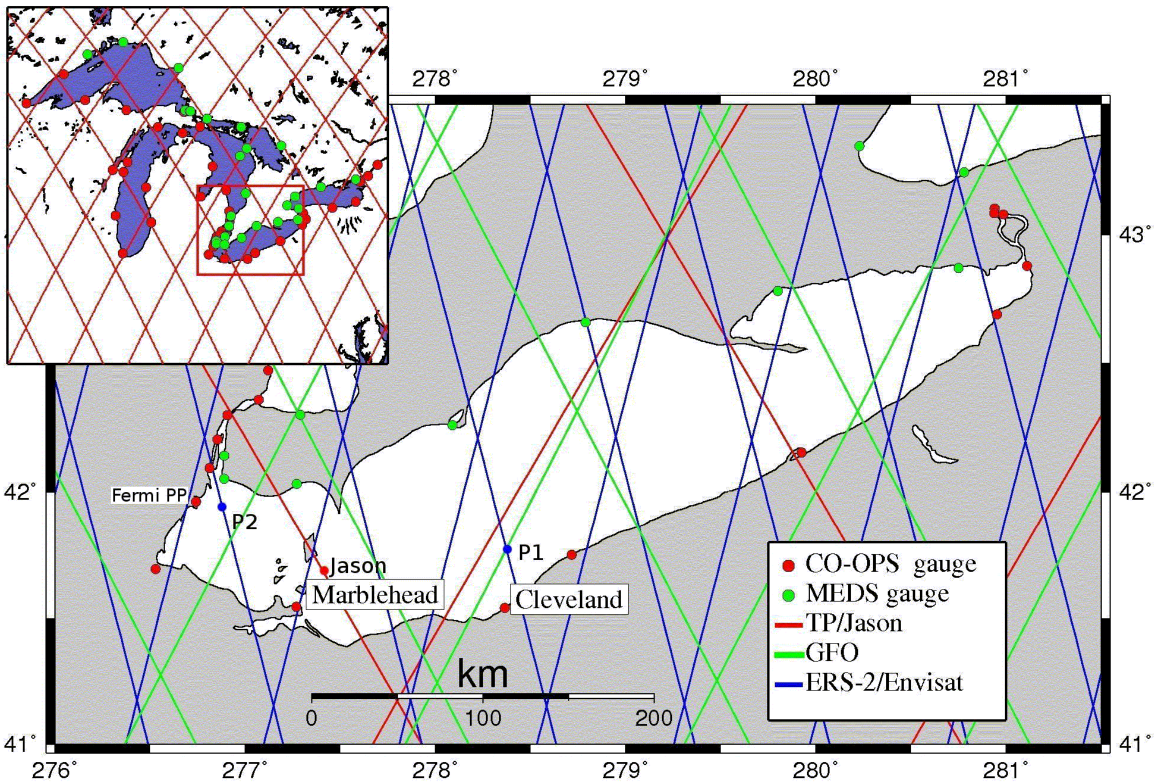


Figure 40 : SARAL/AltiKa theoretical grountracks along with that of Jason and GFO over Lake Erie. P1 and P2 are the proposed candidate locations for SARAL/AltiKa absolute calibration in the Great Lakes with the coastal tide gauges at Cleveland, Marblehead and Fermi Power Plant.

4.5.2.4 UYUNI SALAR (SOUTH AMERICA)

Over the Salars de Uyuni, SARAL/AltiKa will have 4 tracks on the part of the Salars which is seasonally inundated (Figure 41). The uses of altimetry over such regions, is in one hand very promising, because one could measure the elevation of water of inundated parts, but the long revisit time diminishes the chance to get altimetry data at the time of flood peak. Moreover the time series acquired during the flood may have very little number of measurements as flood over a given location can pass very quickly as it is the case on the Salars de Uyuni.

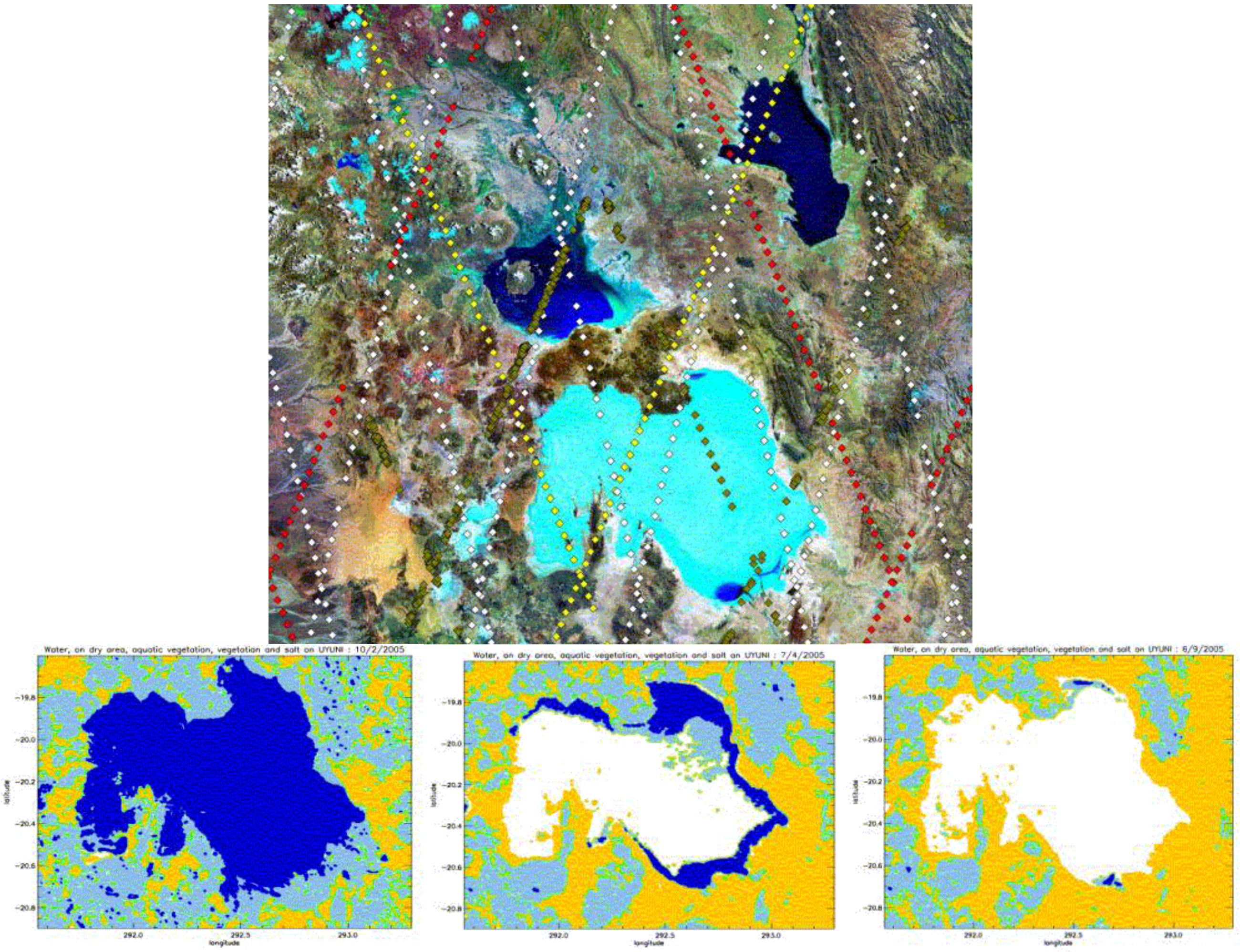


Figure 41 : Position of altimetry tracks (white : SARAL/AltiKa, yellow : Jason-1, red : Jason-2, green: GFO) on the Salar de Uyuni, and MODIS images of the Salar in winter (fully inundated), spring (after evaporation of central part) and late summer (totally dry).

Thanks to SARAL/AltiKa enhanced capabilities, one may hope to get more precise calculation of water height over narrow surface water as it is observed on the Salars than it is observed with classical altimetry in Ku Band. However, precise quantification of the performance of Altika in such areas is needed.

Calmant et al. [Appendix] propose to run a CALVAL experiment on the Uyuni Salar as follow:

- A first campaign in dry season (Summer 2010) to measure the bathymetry of the Salars on the grid at a spatial resolution of 3-4 km from kinematic GPS. This could then be used for:
- Assessment of SARAL/AltiKa performance on flat area
- Estimation of water volume of the Salars during flooding period thanks to Altika measurements.
- Comparison of volume of water between estimation made by combination of Modis and Bathymetry, and estimation made by combination of bathymetry and altimetry

A second campaign should be done in winter 2011/2012 when water is covering the Salars in order to assess the accuracy of the Altika measurement on water surface over the Salars de Uyuni and cross calibrated with Envisat and or Jason-2.

4.5.3 LAND ICE SITES

4.5.3.1 LAW DOME (ANTARCTICA)

Watson et al. [Appendix] propose to contribute to CALVAL activities through absolute SSH bias determination for SARAL/AltiKa over ice, using Australian facilities at the Antarctic Cryosat-2 facility on **Law Dome, near Casey Station in East Antarctica.**

The Antarctic ice calibration would involve the use of ground based surveys using Skidoos equipped with GPS, regional GPS base stations to validate meteorological products, and airborne survey data (Australian equipped aircraft using LiDAR, plus additional data potentially available from other international collaborators working towards CryoSat-II calibration and validation). Fieldwork in Antarctica is planned over the Austral summer of 2010/11 and 2011/12.

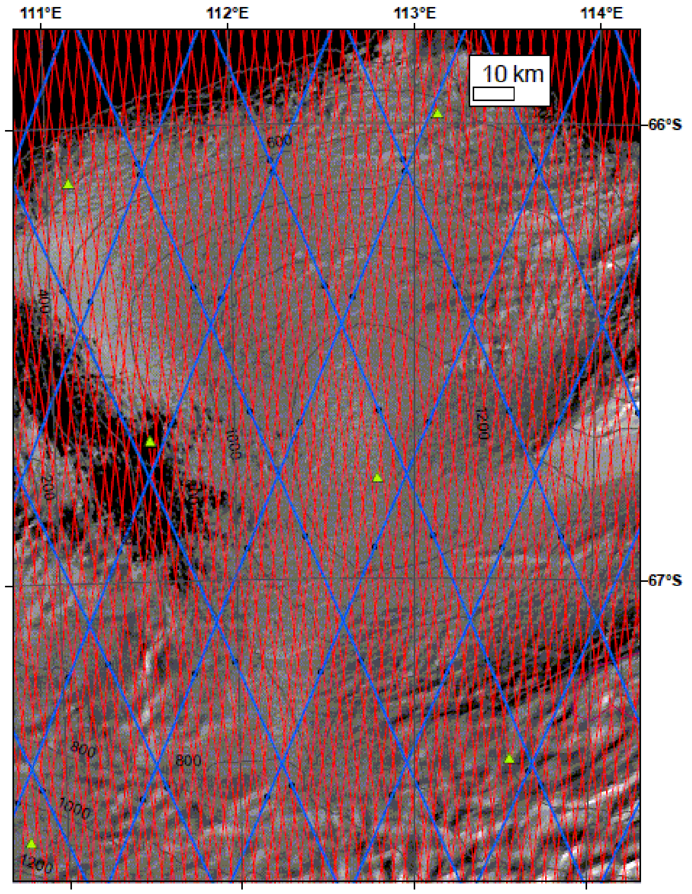


Figure 42 : Ice CALVAL facilities at Law Dome, East Antarctica. The Cryosat-2 calibration region extends across the north western region of this map. Cryosat-2 tracks in red, SARAL/AltiKa in blue.

4.5.4 CHOICE FOR OPTIMAL CALIBRATION SITE

4.5.4.1 CRITERIA TO BE CONSIDERED

Geographic criterion:

- **Distance to the satellite track**: Even if the satellite does not exactly fly-over the calibration site, the altimeter calibration is possible. Nevertheless, the distance to the satellite track should be minimized. Moreover, the site can be used for cross-validation of altimeter if it is properly located;
- **Distance to the coast**: Altimeters measurement techniques being optimized above the sea surface, signals are affected by land approaching coast. That's why the choice of a calibration site away from the coast is good even if it causes power supply problem, offshore communication systems, protective area, difficult access for maintenance or scientific teams, etc.;
- **Stability of the site:** the calibration site on ground should be chosen on a stable seismic zone:
    - o Ground composition (rocks, concrete or moving soil) should be considered. Instruments have to be installed and fixed on very stable bedrock,
    - o Moreover, the seismic potential of the zone should be evaluated. In fact, global seismic hazard maps are available to determine if a potential site is placed on a dangerous area,
    - o Finally, zones where works are undertaken in the neighborhood can cause shocks or vibrations to the instruments;
- **Bathymetry:** Potential calibration sites should be located in areas where the local bathymetry is relatively smooth and flat. Otherwise, the bathymetry gradient has to be well known.
- **Geoid:** A calibration site should be located in a zone where the geoid is relatively flat. Mainly in the case where the site is far away from the altimeter track. The geoid is directly related to the local bathymetry. The local gradient of the geoid can be measured or modeled (e.g. OSU91, EGM96, etc.);
- **Pollution:** The cleanliness state of the site is important because it has to be clean of potential human or natural pollution to provide a better quality of sea water. Deposit or dilution can affect the water nature and the repeatability of the calibration. For example, if water is moss-covered, it can disturb measurement of sea level especially in the case where radar gauges are used. In fact, the transmitted signal will not be well backscattered on this kind of rough surface and the measurement will be wrong;
- **World distributed sites network:** In order to minimize the geographically correlated errors, the number of absolute calibration sites has to be increased in the northern and southern hemispheres.

Equipment:

- **Presence of a maximum of devices interesting for calibration:** The chosen site has to be well instrumented with redundant sea-level systems such as:
    - o Tide-gauges, GPS buoys, etc.,
    - o A permanent GPS station,
    - o a DORIS station, a SLR station (Satellite Laser Ranging) to minimize orbital errors,
    - o Meteorological station, water vapor radiometers;
- All these instruments can be installed for calibration purpose but **the aim is also to benefit from long time series of measurements. So existing sites should be preferred to new ones**. Several collocated sensors can help discriminate between different sources of errors;
- **Benchmarks for geodetic positioning:** To attach the instruments to a geodetic reference, benchmarks should be located on the site not very far away from instruments that require a geodetic attachment such as tide-gauges. Moreover, an easy access for leveling is important to provide a good geodetic positioning;

- **Communication system:** Near real time data transmission can be an advantage for a CALVAL site, depending on the access easiness. The data flow received with a daily or hourly rate (set by the user) allow the detection of data anomalies on site. For example, problem in data recording.
- **Energy supply:** Power can be provided to the various devices via main installations or via autonomous systems that allow a self-powered functioning. A main installation or a back-up generator can be used as redundant power options. In fact, the interruptions of power supply have to be limited as much as possible. The use of batteries implies a regular replacement by a maintenance team.

Note on local geoid improvement:

From experience in Mediterranean Sea near Corsica, a gravimetric data have been shown to be contaminated by errors up to 10 mgal. Referring to the *in situ* CALVAL technique, it becomes an important parameter for the CALVAL phases for which the goal is to perform a 1cm precision on sea surface height. Thus, the existing capacity of aerial gravimetry to build a geoid is enhanced to be explored. Main objective is to select the best field for the studied area near calibration sites for SARAL/AltiKa.

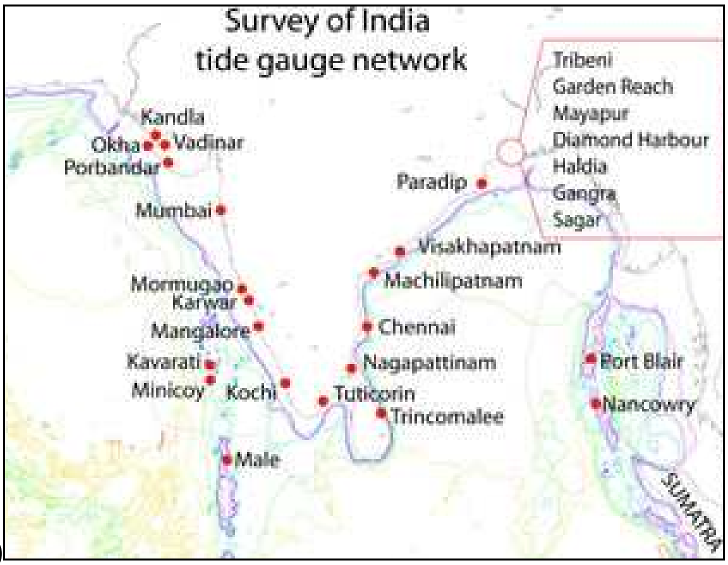
4.5.4.2 ASSESSMENT OF TIDE GAUGES AS POTENTIAL ALTIMETER CALIBRATION SITES

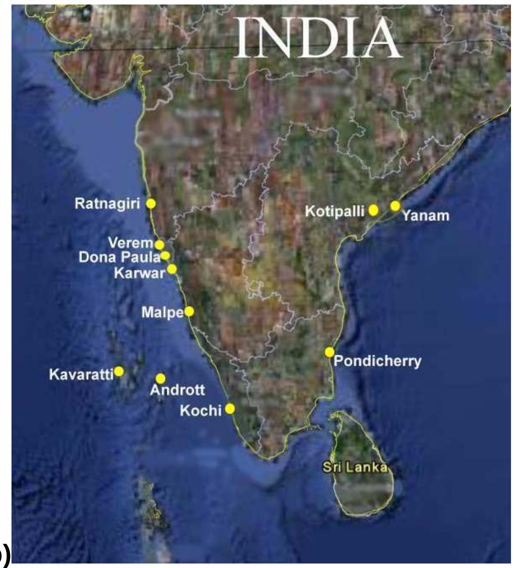
CNES has developed a method that aims to assess the quality of tide gauges as potential altimeter calibration site, by comparing past long altimeter time series (T/P, Jason-1&2, Envisat) with tide gauge long time series : this method allows to detect jump or drifts in the tide gauge time series, and to assess the tide gauge quality as potential altimeter calibration site by different comparison statistics (distance of altimeter track to tide gauge, vertical movement at tide gauge site, time series variability…).

An example of tide gauge fact sheet is shown below (Figure 44). The results for some of the tide gauges that are freely and publicly available (same network as the one used for 4.3.4) can be seen on http://www.aviso.oceanobs.com/fr/calval/in-situ-global-statistics/index.html.

CNES has proposed to apply this method to the Indian tide gauge data (or buoys.. whatever sea level measurements), in order to assess their quality in the precise context of SARAL/AltiKa CALVAL. The final aim was to select together an Indian calibration site for SARAL/AltiKa, by considering the highest available tide gauge data quality at present time. Once the site is chosen, it would be certainly necessary to upgrade it for example by implementing some geodetic (GPS, DORIS, SLR station...) and/or meteo infrastructures in its vicinity [see 4.5.4].

Already many sea level survey infrastructures (tide gauges, buoys…) exist in India along Indian coasts and islands, on which we can rely – at least partly - for SARAL/AltiKa CALVAL. Especially, Kavaratti, which is already an *in situ* calibration for OCEANSAT-2 ocean color mission from ISRO, has been considered as a potential interesting *in situ* dedicated CALVAL site for SARAL/AltiKa.

a) 

b) 

c) 

Figure 43 : Location of tide gauges from the a) Survey of Indian network, b) National Institute of Oceanography NIO & c) position of SARAL/AltiKa and JASON-2 ground tracks around the Kavaratti site.

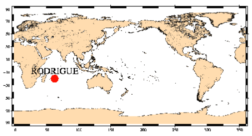
The common selection of a dedicated SARAL/AltiKa calibration site in India requires that Indian tide gauges long sea level time series should be delivered to the CNES CALVAL working team, which will analyse the data and give a feedback to ISRO. Moreover, CALVAL activities based on comparison of SARAL/AltiKa SSH data with global *in situ* tide gauges network (see section 4.3.4.1) would highly benefit from an extended *in situ* network which would include these tide gauges, as not a single tide gauge data along Indian coasts is available at now in the database.

However at present time, CNES does not have access to any Indian tide gauge sea level time series in its global tide-gauge database. According to the presently existing rules in India, sea-level data from the Exclusive Economic Zone (EEZ) region of India can not be provided to any foreign agency. *This point is under discussion between French and Indian ministries, in order to find an agreement in the particular context of the joint SARAL/AltiKa mission CALVAL*.

TIDE GAUGE : WO0105

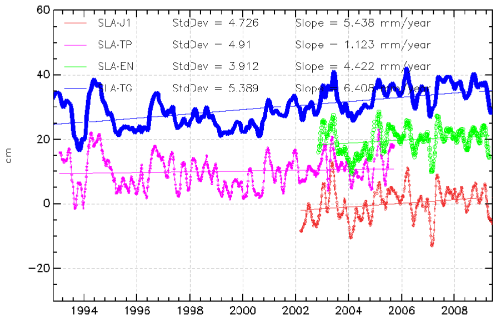
Tide Gauge identification

Tide Gauge Network	WOCE
Location (Lat/Lon)	-19.67 deg / 63.42 deg
Time series coverage	From 08/11/1986 to 31/07/2009
Vertical movements drift	NO

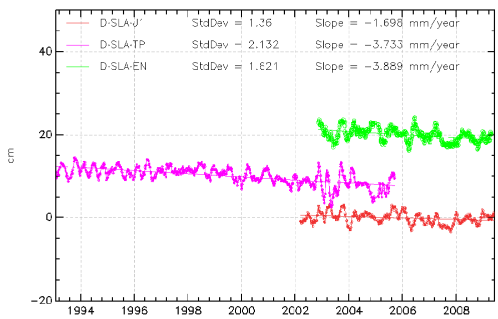


Temporal SSH comparisons with T/P, Envisat, Jason-1 and Jason-2

Monitoring of SSH

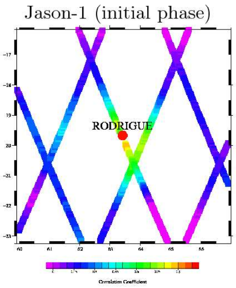


Monitoring of SSH differences

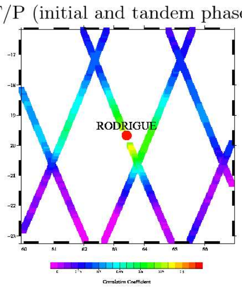


Maps of SSH correlation with Jason-1, T/P and Envisat

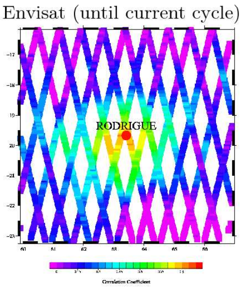
Jason-1 (initial phase)



T/P (initial and tandem phase)



Envisat (until current cycle)



Tide Gauge reliability

	T/P	T/P (tandem)	Jason-1	Jason-2	Envisat
Minimal distance from TG	xx kms	xx kms	xx kms	xx kms	xx kms
TG crustal drift	- mm/yr	- mm/yr	- mm/yr	- mm/yr	- mm/yr
Maximal SSH correlation	0.82	0.88	0.87	-	0.93
Non-filtered SSH diff RMS	5.3 cm	7.3 cm	4.9 cm	- cm	5.6 cm
Filtered SSH diff RMS	1.6 cm	2.4 cm	1.5 cm	- cm	1.8 cm
SSH differences slope	-3.1 mm/yr	-2.8 mm/yr	-1.7 mm/yr	- mm/yr	-3.9 mm/yr
Quality control	OK	OK	OK	-	OK

Figure 44 : Fact sheet of the Rodrigue tide gauge : statistics of time series comparison between TG and altimetry missions (T/P, JASON-1 and 2, ENVISAT)

4.6 VALIDATION OF WIND/WAVE MEASUREMENTS

Nota bene : **Concerning wind speed, as AltiKa altimeter is an innovative altimeter mission in Ka-band, the relation "wind speed to sigma-0" will have to be tuned, and a new wind algorithm to be probably defined**.

For the first SARAL/AltiKa cycles, a "Collard wind" solution inherited from JASON-2 will be implemented and evaluated. This choice of first applying a Ku-band wind speed algorithm, was driven by studies showing that aircraft Ka-band radar data nearly mimic Ku-band satellite altimeter observations in their mean wind dependence (Vandemark et al., 2004).

A comparison will be done between sigma0 coefficients for SARAL/AltiKa and JASON-2 in order to characterize discrepancies between both sigma-0 histograms (bias, different probability density function…). This should allow us to re-compute, if necessary, a preliminary wind solution after a few months.

A consolidated wind algorithm will then have to be computed, about one year after launch, from crossover analysis between SARAL/AltiKa and ASCAT and/or SeaWinds scatterometer data [a priori using the same kind of global neuronal network method than in Collard et al. 2004], and then again validated though comparisons with observations (buoys, scatterometers, altimeters…) and models.

From the first cycles, wind speed and wave height (SWH) measurements will be validated through comparisons with *in situ* data (e.g., from buoys), other satellite data and model output.

Janssen et al. [appendix] will monitor and validate SARAL/AltiKa global near real time wind and wave measurements provided in the OGDR products, using tools that were used for the monitoring and validation of ERS-1/2, ENVISAT and Jason-1/2. Model fields (ECMWF) and *in situ* (ocean buoy/platform) observations will be used for the validation purpose. Scatter plots and various statistics will be computed (see Figure 45), on daily, weekly and monthly bases. Long term analysis will also be carried out. When satisfied with the quality of the data, data assimilation experiments will be carried out to assess the impact that SARAL/AltiKa significant wave height data on wave forecasting results.

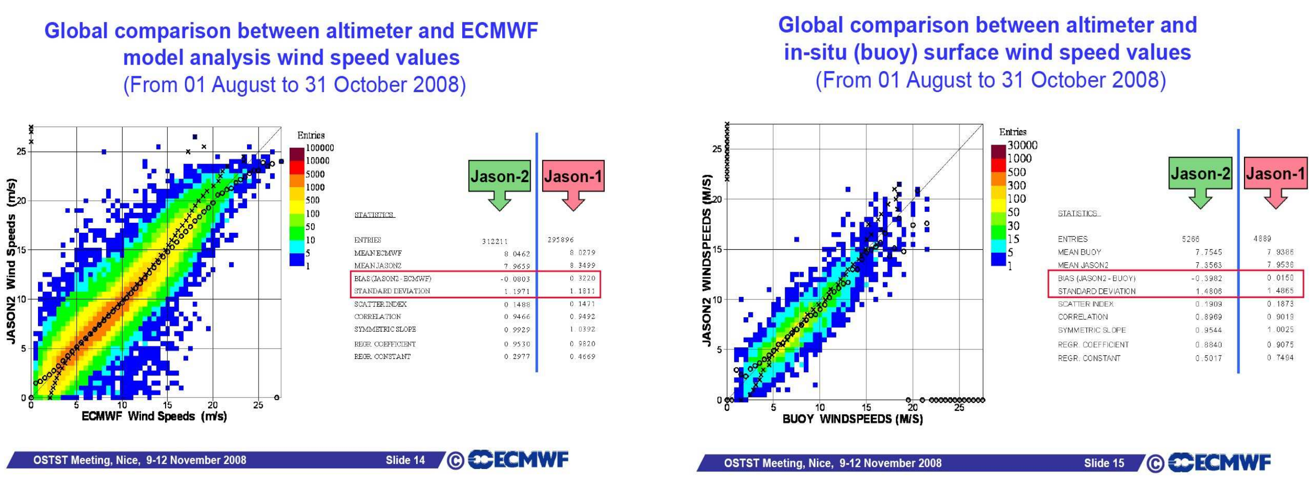


Figure 45 : Scatter plots of Jason-2 altimeter OGDR winds versus ECMWF model (left) and *in situ* buoys observations (right) for the first 3 months of the mission

Chapron et al. [appendix] also propose to validate SARAL/AltiKa significant wave height data using the altimeter validation procedures developed in LOS/IFREMER : the SWH quality will be assessed using comparisons with buoy data from several buoy networks (US NDBC, Europe, Canadian MEDS, …), and systematic cross-comparisons with other in-flight altimeters. Corrections to the measurements will be suggested if needed.

Lillibridge et al. [appendix] will carry out an early evaluation of SARAL/AltiKa OGDR wind/wave products and their timeliness. The 3-5 hour timeliness requirements for wind/wave applications will be assessed based on data availability from the SARAL/Altika project. A thorough CALVAL analysis at the NOAA Laboratory for Satellite altimetry will be used to determine the impact in the datasets of rain/water vapor losses and potential gains from measurements made in the Ka vs. Ku-band. Cross-calibration with Jason-2 OGDRs will be used to determine biases in wind/wave measurements between the two missions.

Calmant et al. [appendix], in their wide *in situ* calibration experiment, plan to use *in situ* wave record gauges and GPS cinematic buoys (in the high frequency part of the motion's spectrum) measurements, to validate SWH values proposed in the SARAL/AltiKa GDR products. In particular, the WAVCIS coastline monitoring project operates 8 operational wave-monitoring offshore stations south of New-Orleans, that will be used to validate SARAL/AltiKa surface wave heights. Wave-recording gauges at Vanuatu site will also be used for comparisons.

Quartly et al. [appendix] will use metocean buoys or nearby meteorological stations on some small islands in the Mediterranean, as ground truth to assess whether SARAL/AltiKa wind/wave estimates from the coastal zone are as accurate as those for open ocean locations.

Scharroo et al. [appendix] will perform cross-calibration of wind speed and SWH measurements between SARAL/AltiKa and Jason-1/2, and also compare the SARAL/AltiKa data against external models like WaveWatch 3 for wind speed and wave height (provided by the University of New Hampshire).

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APPENDIX : INVESTIGATOR CALVAL PLANS

PIs/CoIs CONTRIBUTIONS TO SARAL/AltiKa CALVAL PLAN

ON-SITE VERIFICATION

Calmant et al.	Corsica, Issyk-kul Lake, Sabine Bank, TAAFs, Amazon Basin & Uyuni Salar
Shukla et al.	Kavaratti Island, Bangaram Island, Sardar Sarovar Reservoir
Cheng et al.	Taïwan Seas & Lake Erie
Mertikas et al.	Gavdos
Watson et al.	Bass Strait, Storm Bay & Law Dome

GLOBAL AND REGIONAL *IN SITU* VERIFICATION

Dibarboure et al.	Global
Scharroo et al.	Global
Esselborn et al.	Indian Ocean
Birol et al.	NW Mediterranean Sea, Bay of Biscay, western Gulf of Bengal, Papua New Guinea & Salomon islands, Kerguelen Plateau, Adelie, Arctic Ocean
Fenoglio-Marc et al.	European coastlines & Indian Ocean
Quartly et al.	European coastlines & North Indian Ocean
Calmant et al.	Texas & Louisiana Gulf coastlines
Ichikawa et al.	Tsushima Strait
Arnault et al.	Tropical Atlantic
Durand et al.	South-West Pacific
Deng et al.	Off Western Australia
Pascual et al.	Balearic Sea
Vialard et al.	Northern Indian Ocean & Bangladesh large rivers
Calmant et al.	Indian coastlines & Amazon basin
Birkett et al.	American inland waters
Lee et al.	Arctic lakes

GLOBAL STATISTICAL & CROSS-CALIBRATION ANALYSIS

Dibarboure et al.

Chao et al.

Richman et al.

Bosch et al.

Scharroo et al.

Nerem et al.

Menemenlis et al.

Griffin et al.

Birol et al.

Fenoglio-Marc et al.

Calmant et al.

SPECIFIC STUDIES: RAIN EFFECT, SEA ICE

Chapron et al.

Quartly et al.

Lillibridge et al.

Mercier et al.

Watson et al.

Rémy et al.

WET TROPOSPHERE CORRECTION

Eymard et al.

Calmant et al.

Mertikas et al.

SEA SURFACE BIAS

Mercier et al.

Chapron et al.

WIND & WAVES

Janssen et al.

Chapron et al.

Lillibridge et al.

Calmant et al.

Quartly et al.

Scharroo et al.

ON-SITE VERIFICATION

Calmant et al.

LEGOS-IRD, FRANCE

ALTIKAMALA

S. Calmant, M.M. Ali, V. Ballu, P. Bonnefond, A. Braun, K. Cheng, J.F. Cretaux, C. Henry, G. Jan, H. Lee, F. Mercier, V. Romanovski, J. Santos Da Silva, F. Seyler, C.K. Shum, G. Stone, L. Testut

The groups joined in this proposal have all long term expertise in the calibration and/or validation of altimetry products. The French collaborators of the proposal already joined in a collective proposal for JASON-2, FOAM. The objective of the project being to arrive at a global vision of the cal/val of a mission, the group has been enlarged in order to also enlarge the studied parameters and geographical spread of studied places. The cal/val will extend from the orbit analysis, the different ranges distributed in the GDRs in various contexts (open sea, coastal area, lakes, rivers, land), the meteo corrections and some parameters distributed in the GDRs such as the wave height. Also, this proposal will pay a particular attention of the short wavelength signatures in the altimetry data since AltiKa will be the first mission to distribute 40 Hz measurements on reduced footprints owing to the Ka band pulse. At Lake Issyk-kul and Amazon river stems, dense mapping of the water surface will be performed with GPS buoys.

Shukla A.K. et al.

SAC/ISRO,INDIA

Absolute calibration of Saral/Altika altimeter measurements in open ocean, coastal region & in-land water and validation of Geo-physical products

A.K.Shukla, K.N.Babu, Suchandra A. Bhowmick, Abhineet Shyam,

Rishi Kumar Gangwar, Kaushal B.Mehta

Continuous monitoring of the sea level change is an important concern for scientific community. Availability of space borne altimeter data over global oceans has unveiled new possibilities for scientists to monitor and understand the oceanic phenomenon with all its potential. ISRO-CNES joint effort Saral/Altika will carry a high frequency *Ka*-band altimeter, the first of its kind, and act as a partner to global constellation of ocean topography missions. This mission is dedicated to realize precise, repetitive global measurements of sea surface height, significant wave height and wind speed for developing operational oceanography and understanding of climate. Calibration of the altimeter and validation of retrieved geophysical products are very much significant for assuring the altimeter measurements with desired range of accuracies. For calibration and validation purposes, a set of monitoring and calibration sites are required over Indian Ocean. Extensive validation is also needed for inter comparison of SARAL/AltiKa products with existing altimeter measurement systems e.g. JASON -2. Use of necessary model data and utilization of existing sea level measurement networks in India is envisaged in the project. The following activities will be carried out during the mission life :

- Absolute calibration of Altika payload in terms of its range over Indian region (monitoring long term range bias against in-situ)
- Validation of Geo-physical products using in-situ and models
- Time series studies and long tem monitoring of above parameters
- Cross-calibration of various altimeters (data analysis at cross over points)
- Comparison of Geo-physical products of various altimeters
- Identification and utilization of in-situ & model data for CAL-VAL task

- Development of required facilities for CAL-VAL at Kavaratti in collaboration with CNES (R&D element)

Cheng et al.

National Chung Cheng University, TAÏWAN

Absolute Calibration for AltiKa Altimeter Data in Taïwan Seas and the Great Lakes

K.C. Cheng, S. Calmant, J.F. Cretaux, C. Hwang, C.Y. Kuo, H. Lee, C.K. Shum, H.Z. Tseng

Two calibration sites for AltiKa absolute calibration in Taiwan seas and at Marblehead, Lake Erie, the Great Lakes are proposed. The candidate locations are selected based on the direction and the location of the AltiKa groundtrack and the available accurate coastal tide gauge in the vicinity. A GPS buoy, or GPS-equipped vessel, will be utilized to provide necessary mean water surface gradient from the tide gauge to the nominal AltiKa footprints, on which the AltiKa sea surface height (and other instrument or correction) biases, if any, are to be estimated. This regional calibration and monitoring effort is proposed to be part of the AltiKa global calibration proposal (PIs: S. Calmant & J.F. Crétaux) and our data (including various field work data sets) will be made available in near-real time the overall dissemination to quantify and validate AltiKa instrument bias.

Mertikas et al.

Technical University of Crete, GREECE

GAVDOS-AltiKa: Monitoring, Calibration and Validation of SARAL/AltiKa satellite altimeter measurements using the permanent facility on the island of Gavdos and Crete, Greece

S. Mertikas, A. Daskalakis, V. Tserolas, E. Koutroulis

On the small island Gavdos, 40 km south of Crete, the Laboratory of Geodesy and Geomatics Engineering in the Technical University of Crete, Greece, has established in 2001 and has been operating as of 2004 a permanent facility for calibrating satellite radar altimeters. The location of Gavdos island, in the center of East Mediterranean, constitutes a strategic point for the calibration of satellite altimeters on a world level, and also for monitoring absolute sea level and climate change on a continuous and long-term basis.

The Gavdos permanent facility is situated under a crossing point of the Jason orbits and adjacent to the orbits of Envisat and subsequently of the SARAL/Altika. The dedicated calibration facility includes tide gauges, permanent GPS satellite receivers, meteorological and oceanographic instruments, a DORIS satellite beacon, an electronic transponder (a new one under construction), communications systems for the transmission of data, etc. Given the importance and the strategic location of the Gavdos installations, this research proposal aims at the absolute calibration and validation of the SARAL/AltiKa mission during and after its verification phase.

To achieve this, modifications on the existing Cal/Val methodology and instruments to adjust to the new SARAL/AltiKa mission requirements will be performed at the Gavdos facility. We will also examine the possibility (a) of developing another Cal/Val site under the SARAL/AltiKa pass on the south coast of Crete, and (b) of modifying the microwave transponder, already being developed by GeoMatLab, to be operational with the SARAL/AltiKa.

The proposed Cal/Val activities include the estimation of the absolute satellite altimeter bias of AltiKA as well as monitoring its drifts. This will be achieved by developing and modifying dedicated techniques, successfully applied for Jason, and for SARAL/AltiKa. Interpretation of space borne data will be performed in comparison with dedicated in-situ data and models. These tasks will require the SARAL/AltiKa mission data products.

Watson et al.

University of Tasmania, AUSTRALIA

An Australian contribution to SARAL/AltiKa calibration and validation over ocean and ice

C. Watson, N. White, J. Church, P. Tregoning

We propose to contribute to the ISRO cal/val operations through the provision of GPS buoys and related expertise (still to be fully negotiated) for use at the facility offshore from Kavaratti Island. Initial correspondence in this regard was initiated by Dr A.K.Shukla, team leader of the ISRO SARAL/AltiKa cal/val team. We anticipate continuing this correspondence over the coming months to refine the specific collaboration.

At the time of writing, we are not yet funded to contribute to the cal/val of SARAL/AltiKa using the Australian facilities in Bass Strait and Storm Bay, in addition to the Antarctic CryoSat-II facility on Law Dome, near Casey Station in East Antarctica. Pending funding, we would be interested in contributing to the cal/val of absolute SSH bias and bias drift using in-situ data from these facilities. We would determine absolute bias using techniques developed for T/P and Jason-1 at the Bass Strait site (GPS buoys and moored oceanographic instruments). In Antarctica we plan a series of repeated airborne and ground surveys that could be modified to incorporate SARAL/AltiKa ground tracks. With regard to bias drift, we propose to use a technique involving the global tide gauge network in conjunction with Australian based analyses of GPS data for the purpose of removing land motion.

GLOBAL AND REGIONAL *IN SITU* VERIFICATION / GLOBAL STATISTICAL & CROSS-CALIBRATION ANALYSIS

Dibarboure et al.

CLS, FRANCE

Validation, Cross-calibration and Multi-mission Merging for High-Resolution Altimetry, Ocean Circulation studies and Coastal Applications

G. Dibarboure, S. Labroue, Y. Faugère, J. Dorandeu, L. Carrère, N. Picot, E. Bronner, J. Lambin, A.Lombard, M. Ablain, S. Guinehut, M.H. Rio, G. Larnicol, C. Dufau, M.I. Pujol, P.Y. LeTraon, S. Mulet, P. Prandi

The objective of the investigation is twofold:

· O1: to take benefit of multi-mission altimetry and other sources of independent data to improve the altimetry performance assessment methods,

· O2: to quantify the contribution of multiple altimeter data sets and its combination with in situ for an improved understanding of the variability of the general circulation and climate changes.

Although both objectives are significantly different, they are intricately linked as a good knowledge of measurement performance and errors are mandatory to build high quality multi-mission or multisensor datasets.

The objective O1 is a prerequisite for the use of multi-mission datasets in both delayed mode and near real time and for studies of long-term, low-frequency oceanic signals, or signal and error aliasing. This analysis includes but is not limited to:

- Improvements of existing calibration and cross-calibration methods for present and future altimeter missions. Dedicated studies will be carried out to better estimate the altimeter system error budget, depending on the different contributions (instrument, orbit precision, geophysical corrections) and for different applications (e.g.: mesoscale studies, mean Sea Level estimations). Significant changes in cross-calibration algorithms will be able to use multiple reference missions in an operational framework, thanks to the POD accuracy provided by Jason-2 and SARAL.
- Altimetry / In Situ systematic comparisons to validate the altimeter measurements. Tide gauge measurements but also temperature/salinity profiles and surface velocity data (drifters, moorings) will be used in inter-comparison methods to validate the signals derived from altimeter missions.
- Studies of low-frequency oceanic signals from altimeter long time series. At the time of the SARAL/AltiKa, more than 20 years of altimeter data (from GEOSAT) will be available, after precise assessment and cross-calibration, for studying decadal and low frequency signals. Comparisons between signals deduced from altimetry and signals from other sources of independent data (SST, In Situ, GOCE) will be carried out.
- Studies of AltiKa specificities on error budget analyses and performance monitoring. The list includes but is not limited to the analysis of: reduced high-frequency noise with and without improved ground processing (e.g.: SLOOP, PISTACH) and the associated impact on oceanic spectrum observability and the monitoring of coastal currents, different ionosphere error and aliasing and long-term stability, dealiasing of the long ERS/ENVISAT tidal measurements thanks to the local time change of SARAL.

The objective O2 takes the outputs of O1 (L2P cross-calibrated / edited datasets, and error budgets, aliasing knowledge) as a baseline to allow:

- The development and improvement of altimeter products both for delayed mode and real time altimeter data sets. Intercalibration issues, improvement of geophysical corrections and problem of aliasing of high frequency signals will be investigated. The impact of GOCE mission on the quality of altimeter products will be also analysed.

- The calculation of Mean Dynamic Topography currently used to reference the Sea Level Anomalies. GRACE and GOCE data and additional in-situ observations (temperature and salinity profiles, drifters) will be used to improve previous estimations of MDT.
- The development of Global Ocean Observed Products (GOOP) that combined altimeter and in-situ data to produce 3D thermohalin and currents fields. This work will include the development of a methodology of comparison and combination of ocean observations.
- Mesoscale and its role in the ocean circulation variability and climate changes studies will be led from the analysis of merged altimeter data sets and from GOOP. This work will include the comparison with high resolution primitive equation models. Development of ocean indicators is also foreseen.

Scharroo et al.

Altimetrics, USA

Cross-calibration and validation of AltiKa altimeter data in the framework of the decadal sea level record

R. Scharroo, E. Leuliette, G. Mitchum

The proposing team will aim to ingest the AltiKa altimeter products as rapidly as possible into the NOAA/TU Delft Radar Altimeter Database System (RADS). This platform will allow comparison with data from all currently flying and past altimeters and validation of the AltiKa product content against numerous off-line models. We propose to carry-out a number of studies, including: (1) intersatellite comparisons and cross calibrations; (2) ensuring continuation of ERS-1/ERS-2/Envisat 35-day coverage; (2) extending and validating sea level rise time series. We will provide feedback to the AltiKa project to assist in the validation and calibration efforts.

Esselborn et al.

GFZ, GERMANY

Comparison of Coastal AltiKa and tide gauges data around the Indian Ocean

S. Esselborn, T. Schöne

We plan to use Altika data for studying the oceanic regime in the vicinity of 14 tide gauges installed in the Indian Ocean in the framework of the German Indonesian Tsunami Early Warning System (GITEWS) by GFZ. The majority of these tide gauges (9) is located at the Indonesian coast but there are also tide gauges in Tanzania, Yemen, Iran and South Africa. A better understanding of the governing oceanic processes might ultimately help to identify unusual events in the tide gauge signals.

All gauges provide high quality data from distinct independent sensors with sampling rates of one minute and include a GPS station. The best selection of correction models for Altika SSH data in the vicinity of these tide gauges needs to be analyzed. Using the combination of tide gauge and AltiKa data typical spatial scales on different temporal scales shall be explored by applying a variety of statistical methods. In addition these tide gauges can help to monitor the long term stability of the AltiKa system. Therefore time series of collocated SSH and tide gauge height data will be investigated.

Since one of our main interests lies on the study of global mean sea level variations and trends we plan to use AltiKa data for this as well. We intend to derive global mean sea level trends from ERS2, ENVISAT, and AltiKa making use of the repeated groundtracks and the overlapping time periods between the single missions (colinear analysis). The trends derived will be compared to the corresponding trends derived from Topex, Jason1, and Jason2.

From these two independent sets of data the long term trends and variations on basin scales will be derived and further investigated.

Expected outcome:

- frequency dependent description of the relation between tide gauge and altimetry
- spatial scales of coastal signals from altimetry
- local time series of differences between tide gauge and AltiKa SSH
- global mean sea level trend from ERS2, ENVISAT, SARAL/AltiKa

Birol et al.

LEGOS, FRANCE

Regional analysis of SARAL/AltiKa data at the Centre de Topographie des Océans et de l'Hydrosphère (CTOH)

F. Birol, A. Cazenave, R. Morrow, L. Testut

The Centre de Topographie des Océans et de l'Hydrophère (CTOH) is a French National Observational Service dedicated to satellite altimetry studies (http://ctoh.legos.obs-mip.fr). The main objective of the CTOH is to maintain homogeneous altimetric data bases for the long-term monitoring of sea level, lake and river levels, the cryosphere, and the planet's climate. Today, the CTOH data base includes the most recent altimetric corrections applied to a large number of altimetric missions (Topex/Poseidon, Jason-1, Jason-2, ENVISAT, Geosat-Follow-on). The CTOH provides a particular support for scientists working in the emerging fields of coastal altimetry, continental hydrology (over lakes, rivers and flood plains), and the cryosphere.

For this AltiKa project, the CTOH aims to continue its program of providing an accurate altimetric data base to the Altika Principal Investigators and co-Investigators working at LEGOS. The work on the SARAL-AltiKa data base will include a validation of the altimetric corrections supplied with the GDR data, and proposing up-to-date corrections in specific research areas, including open ocean regions, coastal zones, in polar seas and over terrestrial continental surfaces.

This proposal highlights specifically our on-going CAL/VAL and altimetry activities for the oceanic surfaces – in particular for the marginal seas, and in the polar regions of the Artic Ocean and the Southern Ocean. Extending satellite altimetric products into the shelf and coastal seas and into polar regions remains a very challenging exercise. The standard altimetry products, tuned for open ocean conditions, are either absent or the data are not accurate enough. For some years, a dedicated data processing system has been developed at LEGOS : the X-Track software. The first analyses performed over the NW Mediterranean Sea and the Gulf of Bengal show a substantial improvement in both the quantity and the accuracy of the retrieved data. They also show that a range of shelf and coastal ocean dynamics can be observed and/or monitor with altimetric data.

As the X-Track software has been shown to successfully recover a substantial amount of data in marginal seas for other altimetric missions, the first objective with the SARAL-AltiKa altimetric data is to evaluate this software in different coastal and polar regional applications (detailed below), and to compare the results obtained with official CAL/VAL activities for other missions (for example, Jason-1 and -2, ENVISAT, CryoSat). We also plan further developments in the X-Track processing system.

To have an optimal space time sampling of these regions, we also aim to compute improved multi-mission altimetric products on selected coastal and polar areas. These regions include the North West (NW) Mediterranean Sea, the Bay of Biscay, the Kerguelen plateau, the complex Papua New-Guinea Salomon islands area, the northern Indian Ocean, the Arctic Ocean, and the Southern Ocean. To better resolve the short scales of the coastal and high latitude dynamics, we also plan to develop advanced multi-data products (combining altimetric, tide gauge and satellite SST data). Therefore, we will first investigate the complementarity, consistency and sources of differences between altimetric, SST and tide gauge observations and develop techniques and software to properly combine these different data. We also plan to use the derived information to document the mesoscale and sub-mesoscale processes observed in the different area of interest, with satellite altimetry used alone or in combination with other satellite and in-situ observations. Finally, the actual resolution of satellite altimetry missions for the observation of sea level variability in coastal and polar areas will be analysed.

Fenoglio-Marc et al.

Darmstadt University of Technology, GERMANY

Regional Coastal Altimetry in Europe and Asia-Indonesia (RCA_EUR-IND)

L. Fenoglio-Marc, M. Becker, S. Lestari, R. Weiss

This research proposal aims at the utilisation of AltiKa payload data for scientific studies in coastal altimetry. The aim of the investigation is twofold: (a) to monitor the long-term sea level variability and (b) to determine the mean geoid and the mean sea surface topography (SST).

At first the suitability of Saral/Altika data in coastal regions and the advantages with respect to the data of the previous and contemporaneous altimeter missions will be assessed. The analysis will include the analysis of the waveform shapes and of the quality of the sea level near to the coasts. The Saral/Altika data will then be used together with the complementary Jason-2 data and the data of the other past and contemporaneous altimeter missions. The data will be homogenised to the other multi-mission data and used in synergy.

The primary objective consists in building in selected costal areas a regional model for the sea level variability. Reasons for the observed changes are investigated using the synergy between

altimeter data and other data and models (sea surface temperature, wind speed, atmospheric pressure, temperature and salinity data, GRACE and GOCE data).

The second objective consists in the improvement of the marine geoid and of the permanent part of Sea Surface Topography, this last will be estimated as difference between the mean sea surface (MSS) obtained from the multi-mission altimeter data and the marine geoid.

The analysis will be performed regionally in Europe (Mediterranean Sea, Black Sea, North Sea) and in the Indian Ocean (Thailand and Indonesia), where on-going projects exists.

Ichikawa et al.

Kyushu University, JAPAN

Detection of Coastal Velocity Variations in the Tsushima Strait

K. Ichikawa, A. Morimoto, Y. Yoshikawa

This proposal consists of two major targets. The first and fundamental one is to evaluate performances of the Ka-band altimeter in the coastal region and to establish proper data processing methods for estimation of coastal surface geostrophic velocity anomaly, by comparisons with the high-resolution surface velocity data obtained by the High-Frequency (HF) radar system located in the Tsushima Strait between Japan and Korea. The other and advanced target is to study causes and effects of the velocity variations in the Tsushima Strait by extending the spatially limited observation area of the HF radar system using multiple AltiKa sub-satellite tracks.

Arnault et al.

LOCEAN-IRD, FRANCE

Tropical Atlantic Regional Studies using SARAL/Altika

S. Arnault, B. Bourlès, A. Aman, J. Boutin, R. Chuchla, Y. DuPenhoat, R. Folorunsho, J.L. Mélice, A. Niang, P. Penven, S. Thiria, A.M. Tréguier

Previous studies have evidenced the complexity of the tropical Atlantic Ocean variability, both in time and in space. Thanks to altimetry missions such as TOPEX/Poseidon, Jason1&2, ERS1&2, ENVISAT, associated with in situ experiments (ARAMIS, EGEE-AMMA, PIRATA...) and numerical model results (Clipper, Drakkar, Mercator-ocean...), important progresses have been accomplished these last years to demonstrate the ability of using altimetry in the tropics, and to document large scale oceanic processes. Knowledge of equatorial mass and heat transports, tropical wave phenomena for instance has been improved thanks to these combined efforts.

The new coming SARAL/Altika altimetric mission aims to provide data complementary to Jason 2 as a follow-on to the successful couples previously evocated. But its characteristics will offer higher performances useful in coastal oceanography. This proposal intends to analyze the impact of this new generation altimeter in 4 regions of the tropical Atlantic ocean. Region 1 is located on the western side of the basin, in the North Equatorial Counter Current retroflexion area. This region is known for its intense meso-scale variability. Regions 2 and 3 are characterized by local upwellings (Mauritania and Benguela). Region 4, along the northern coast of the Gulf of Guinea, presents a large range of ocean dynamics. These regions benefit from quite a number of in situ data thanks to oceanographic cruises, moorings and floats. High resolution numerical models have also been run and/or regional models been locally adapted. Thus a combined approach using in-situ data, multi-satellite data, numerical model results, mathematical approach such as neuronal inversion together with the SARAL Altika altimetry will be appropriate both to validate the altimeter in producing oceanic meso-scale information in a tropical and rainy environment, and then to obtain more information on these dynamics and variabilities.

Durand et al.

LEGOS-IRD, FRANCE

AltiGlideX: Towards a synergy of AltiKa, gliders and XBTs for the monitoring of boundary currents in the South-West Pacific

F. Durand, C. Maes, A. Ganachaud

We propose a physical oceanography research project, under the umbrella of the SPICE international program (South-West Pacific Circulation and Climate Experiment) recently endorsed by CLIVAR. The scientific framework concerns the role of the South-West Pacific basin in the variability of thermocline waters and in the low-frequency modulation of El Nino – Southern Oscillation (ENSO). Our project aims at monitoring and understanding the variability of oceanic mass transport of one of the major circulation pathways of the South-Western Pacific basin, located along the East coast of New Caledonia (167°E-168°E, 22°S-17°S). The his torical data available over the area, though rather limited in this remote region, show indeed a marked variability of ocean current from the surface through thermocline depth and below. This variability apparently occurs over a broad spectrum, from intra-seasonal to inter-annual timescales.

From our past studies, it is clear that spaceborne altimetry offers a considerable opportunity to monitor the variability of boundary currents. Among AltiKA core missions lies the accurate observation of sea level and associated currents in the coastal ocean, thanks to the specific capability of the altimeter in Ka band. We thus propose to build a synergy between the remotely sensed AltiKa data and a suite of in situ observations, comprising an autonomous underwater glider, a repeated series of shipborne XBT surveys, and a current-meter mooring.

Indeed, the key issue is for us to be able to validate the AltiKA dataset in this costal region where our boundary current lies. Once this is done, the synopticity and the continuity of the satellite mission shall open the possibility to access a continuous, long-term description of the current variability. This will allow an advanced description of the hydrodynamics of the boundary current, which is a key-component of the climate system of the tropical Pacific area.

Deng et al.

University of Newcastle, AUSTRALIA

Satellite AltiKa Altimetry for Monitoring of Mesoscale Variability of the Leeuwin Current off Western Australia in Indian Ocean

X. Deng, N.H. Idris

Understanding of ocean circulation and mesoscale variability in coastal regions remains fairly inadequate due mainly to the limit in spatial resolution of observations. In this project, we propose to investigate the dynamics of the Leewin Current (LC) off the Western Australian coast in the southeast boundary of the Indian Ocean using the Indian-French ISRO/CNES SARA/AltiKa Ka-band radar altimeter measurements. The LC is a narrow (~50km), long (~5500km, Ridgeway and Condie 2004), and meandering coastal current over the continental shelf slope offshore of Western Australia (WA) in the Southeast Indian Ocean. Its poleward flow pattern dominates the dynamics of the southeast Indian Ocean (Cresswell and Golding, 1980). However, the coastal water is poorly observed by the present generation of radar altimeters since they cannot measure the sea surface close to shore. Satellite altimeter data from the SARAL/AltiKa mission, in particular the high-rate along-track 40Hz observations, are expected to greatly enhance the data spatial resolution near the coast. In this project, we will monitor the mesoscale variability of the LC using satellite altimetry data from SARAL/AltiKa. The data will be validated and complemented with sea surface height measurements from multi-satellite altimetry mission including Topex, Envisat, Jason-1 and Jason-2. The aim is to enhance the spatial and temporal resolution of the data and to provide better understanding of the mesoscale current variability. Geostrophic equations will be used to derive geostrophic surface current velocities from these altimetry data. Validation of the results will be carried out by comparing the derived LC velocities with those from models and in situ measurements.

Pascual et al.

IMEDEA, SPAIN

On the use of <u>S</u>ARAL/<u>A</u>ltika products for coastal and <u>ME</u>soscale studies in the <u>BA</u>learic Sea: synergy with other sensors (SAMEBA)

A. Pascual, J. Bouffard, S. Ruiz, J. Tintoré

This proposal aims at analyzing and using Saral/Altika products in combination with alternative sensors (both *in situ* and from remote-sensing) for a better monitoring and understanding of coastal and mesoscale processes in the Balearic Sea. Specifically, it is intended: **(1)** to process, validate and intercalibrate multi-sensor datasets dedicated to coastal ocean studies. In this context, we will implement the technological existent advances in satellite altimetry in the coastal area that up to now have not been fully exploited for scientific applications at regional scales because of relatively poor sampling and inaccuracy of corrections. The main efforts will thus consist in the application of coastal-oriented corrections and the review of the data recovery strategies near the coast (new editing strategies, high frequency along track sampling associated to improved quality control procedures …). This is an international priority in which this proposal is particularly well positioned. In the meantime the so far unexploited possibilities from the merging of existing in situ data sources with remote sensing data to monitor coastal dynamics will also be investigated **(2)**. The developed system will be implemented initially in the coastal area of the Balearic Islands where the scientific knowledge and the necessary *in situ* data exist. A third **(3)** objective will consist in scientific applications i.e. to exploit multi-sensor data (in situ and remote sensing) in the context of regional hydrodynamic modelling of coastal and mesoscale circulation, with focus in the North Western Mediterranean (NWMED).

The project would be carried out at IMEDEA, a center of international experience in operational oceanography thanks to its scientific background and recent technological initiatives, as well as to the international collaborations maintained for years (in March 2008 with concrete effective participation in the European research projects: ECOOP, MOON Mediterranean Operational Oceanography Network, and MyOcean as part of the GMES Marine Core Service).

Vialard et al.

LOCEAN-IRD, FRANCE

Sea level variability in the Northern Indian Ocean Coastal Waveguide

J. Vialard, F. Papa, F. Durand, M. Lengaigne

The Indian Ocean is the only tropical Ocean to be bounded north by a landmass. This unique fact results in a very important role of the coastal waveguide in the Indian Ocean in transmitting signals from the equatorial band to the rest of the basin at intraseasonal, seasonal and interannual timescales. The northern Indian Ocean wave guide also links the Bay of Bengal (a dilution basin strongly influenced by Ganges and Brahmapoutra runoffs) to the Arabian Sea, with much higher salinities, and displays strong salinity contrasts and variations at several timescale. In this project, we want to take advantage of the fine resolution offered by the SARAL/AltiKa instrument to:

- improve estimates of the runoffs in the Bay of Bengal (objective A)
- evaluate the impacts of runoff variability on salinity and estimate the influence of salinity on sea level in the coastal waveguide of the Northern Indian Ocean (objective B)
- improve the description of the intraseasonal response of the Indian Ocean to atmospheric forcing, and explore the potential of the SARAL/AltiKa products to monitor coastal current variability in the Northern Indian Ocean (objective C)

Birkett et al.

University of Maryland, USA

The application of the SARAL/AltiKa radar altimeter to Inland Surface Water Projects

C.M. Birkett, B. Beckley, C. Reynolds

This proposal requests access to AltiKa radar altimeter data for several inland water investigations that currently use archival (T/P, ERS-1, ERS-2, GFO, Jason-1), and current (Jason-2/OSTM, ENVISAT) altimeter data sets. The science focus encompasses elements of river dynamics and hydraulics, climate change, and drought/flood forecasting. The operational application focuses on the delivery of lake and reservoir surface water level products to the USDA/FAS for water resources and irrigation concerns. A multi-altimeter approach provides a more global outlook, combining the temporal and spatial resolution merits of each mission, while twenty years of combined observations improves statistical analyses. Central to all studies is a technical program focusing on instrument performance and the improvement of target detection and elevation accuracy. Funding for this 2011-2013 program will be sought from NASA and the US Dept. of Agriculture. The main objectives are,

- To examine the overall performance of the AltiKa radar altimeter over various inland water targets. This includes an examination of the quantity and quality of data in terms of elevation accuracy, acquisition speeds and minimum target size observable. Validation exercises will be performed utilizing ground-based gauge data and synergistic altimeter data from the Jason-2/OSTM mission.
- To include the AltiKa data in the USDA lake and reservoir operational program. Th 35-day repeat data will continue the time line of measurements provided by ERS and ENVISAT.
- To add the AltiKa data to several ongoing science investigations,

- The contribution of satellite radar altimetry to the determination of river discharge and river dynamics. Focus will be on large river basins, such as the Missouri, the Yukon, the Amazon, the Paraguay etc. Emphasis is on tandem or synergistic missions for improved spatial resolution.
- The investigation of correlations between observed lake/reservoir/river elevation variations and climatic indices such as ENSO and NAO. The objectives here are the determination of long-term trend and the evaluation of vulnerability to drought and floods. Focus will range from global (closed and climatically sensitive lakes) to regional (African river basins) studies.

Lee et al.

Ohio State University, USA

Surface water dynamics over the Congo Basin and over Arctic lakes using AltiKa altimeter data

H. Lee, D. Alsdorf, K. Andreadis, M. Durand, C.K. Shum, Y. Yi, H.C. Yung, J.W. Kim, K.H. Tseng, S. Calmant, J.F. Crétaux, C. Kuo

We propose to conduct hydrologic research using AltiKa altimeter measurements over the Congo Basin and over Arctic lakes (Alaska, West Siberia, and Peace-Athabasca Delta, PAD, in Canada). We propose to perform AltiKa’s backscattering coefficient and waveform peakiness analysis to classify water returns over the Congo Basin. Various retracking algorithms will be tested to determine the optimal one for AltiKa’s waveforms obtained from vegetated wetlands and from ice/snow covered Arctic lakes (scheduled from mid-2010 to mid-2011). Success in the project will enable the creation of time series of water height variations in the Congo River channels and wetlands, and over Arctic lakes. In combination with other satellite borne observations, including multiple conventional Ku-band altimeters, Tropical Rainfall Measuring Mission (TRMM) precipitation estimates, classifications from JERS-1 SAR mosaics produced by the Global Rain Forest Mapping Project (GRFM), and water masks for Arctic lakes, the project will provide valuable insights toward understanding the terrestrial water dynamics in the Congo Basin and in Arctic lakes (scheduled from mid-2011 to mid-2013).

AltiKa is the first Ka-band altimeter, thus we will also conduct technical studies for understanding the expected radar response of Ka-band with vegetation canopies, inundated vegetation, the effects of snow and ice over water lake surfaces, and the sensitivity of Ka-band measurements to rain, especially over the Congo Basin. These studies are key for better understanding the expected response of the Ka-band instrument onboard the planned Surface Water and Ocean Topography mission (SWOT).

Chao et al.

JPL, USA

Synergistic Applications of SARAL/ALTIKA Radar Altimetry in Regional Oceanographic Investigations

Y. Chao, P.S. Callahan, S.D. Desai, B.J. Haines, J.K. Hausman, W.T. Liu

We propose to use the SARAL/ALTIKA radar altimetric data to investigate regional oceanographic processes. Specifically, we will combine the SARAL/ALTIKA sea surface height and significant wave height data with other satellite altimetric data (e.g., Jason-1, OSTM/Jason-2, Envisat) and other complementary oceanographic data sets to investigate mesocale eddies, fronts, tropical cyclones and coastal processes. Regional Ocean Modeling System (ROMS) will be used to assimilate SARAL/ALTIKA data along with other in situ and remote sensing observations. Accessing both the GDR and IGDR/OGDR is requested to enable real-time data analysis and model forecasting.

To support merging of the AltiKa data seamlessly with data from other missions, we will capitalize on the global altimeter verification system that has been developed at JPL to support Jason-class altimeter missions. At the foundation of this system are specialized geographical altimeter data bases, referred to as stack files, which enable efficient evaluation of geophysical data records (GDR) from multiple missions [*Kruizinga*, 1997]. The stack files contain not only global sea-surface height, but also most of the correction terms and ancillary environmental parameters. The stack files, and the programs and scripts that interface with it, are the computational engines of the JPL altimeter science verification system that has evolved over the past 12 years to support the validation of TOPEX/POSEIDON, Jason-1 and Jason-2 GDRs. The stack file data bases will be populated with the various AltiKa GDR products, implying that the SARAL mission will be integrated in the intensive, altimeter science-support activities at JPL.

Another strength of the JPL verification system is the ability to characterize and mitigate systematic errors through the combination and reduction of multi-mission data. The AltiKa data from the various GDR products will be combined with Jason-2 data (at crossover locations), and the residuals will be filtered and smoothed (in time) to simultaneously estimate residual orbit error, sea-state and range biases. The filter/smoother from the JPL (GIPSY) precise orbit determination (POD) software will be used for this exercise, enabling a variety of stochastic model treatments. This approach is expected to reduce errors in merged AltiKa and Jason-class products, and lead to more homogenous results for dense ground track patterns spanning two or more missions. A similar approach could be eventually used to improve the accuracy of low-latency (near real time) sea-surface height products for operational oceanographic applications.

The SARAL/AltiKa data will also be reconciled with the absolute altimeter calibration results from the Harvest platform. [*Haines et al.*, 2010] Established in 1992, Harvest is the longest continuously operating, dedicated altimeter calibration site in the world. While the SARAL mission will not pass directly over the platform, its data will be linked to the Harvest record using a regional approach. This will enable a quasiabsolute calibration of the SARAL mission, and strengthen the connection with the long-term (climate scale) record from T/P, Jason-1 and Jason-2.

Richman et al.

Naval Research Laboratory, Navy, USA

Application of SARAL/AltiKa altimeter sea surface height data to global mesoscale ocean prediction Oceanographic Investigations

J. Richman, G. Jacobs, H. Hurlbut, J. Cummings, C. Barron, B. Helber, J. Metzger, J. Dykes, O.M. Smedstad, D. May, L. Russell

Sea Surface Height (SSH) observations from SARAL/AltiKa will be used in experiments to forecast the global ocean mesoscale circulation. Processing of the SSH data will be conducted within the software that was developed at the Naval Research Laboratory for application to TOPEX/Poseidon, ERS-1, ERS-2, Jason-1, GFO, ENVISAT and Jason-2. The error characteristics of orbit solution, crossover RMS and flagged data will be tracked and made available through a web interface. The processed data will be provided to the global 1/12 degree resolution HYCOM model developed at NRL which is presently being coupled to the Los Alamos developed CICE model. Data assimilation will be conducted through a daily cycling analysis presently using MultiVariate Optimal Interpolation, which is presently being changed to a 3D Variational assimilation. Forecasts will be made to 72 hours in the daily cycling. Error statistics relative to in situ data from ARGO, drifting floats and other ship of opportunity data available through GTS will be accumulated. These statistics are presently being accumulated on a daily basis so that once the SARAL/AltiKa data is assimilated we will be able to determine how the error statistics change with the new data stream.

Bosch et al.

Deutsches Geodätisches Forschungsinstitut (DGFI), GERMANY

Global Cross Calibration of SARAL/AltiKa altimeter data for improved estimates of Ocean Tides and Ocean Topography (CASA4OT2)

W. Bosch, D. Dettmering, R. Savcenko, J. Schröter

The project will use SARAL/AltiKa data in order to

- perform – on a global scale – relative calibration w.r.t. all other altimeters operating simultaneously (Jason1, Jason2, ENVISAT, CryoSat2, HY-2, …). The common mul-ti-mission crossover analysis will use crossover differences in all combinations and provide for every mission analysed a complete time series of radial errors, relative range biases, geographically correlated error pattern and a statistical characterisation in terms of auto-covariance functions.
- use the calibrated data record that SARAL/AltiKa acquires over the ERS/ENVISAT ground track to extend a stacked data base, suitable for along-track time series analy-sis. This data base will be used for an extended empirical ocean tide analysis, to fur-ther improve the EOT08a ocean tide model.
- estimate along-track profiles of absolute dynamic ocean topography (DOT) by sub-tracting the geoid from sea surface heights – both consistently filtered to account for their different spectral properties. These DOT profiles shall be compared and com-bined with the velocity field derived from ARGO floats and numerical models.

Nerem et al.

University of Colorado, USA

Measuring global mean sea level variations from the SARAL/AltiKa mission

R.S. Nerem, R. Leben

Sea level is a measurement of considerable interest for the study of climate because it reflects the mass and heat storage changes in the global ocean and provides an important barometer for how the Earth is responding to climate change. Furthermore, secular sea level rise, i.e., nonperiodic variations in sea level, has significant societal, economic, environmental, and scientific consequences. There has been an emphasis in recent years on quantifying sea level in the past, present, and future, with the particular focus on global mean sea level (GMSL).

The inadequacies of climate models has made observational data vital for studying and understanding secular sea level rise. Tide gauges have been the primary source of sea level measurements over the last century, and, while providing relatively long records, the spatial resolution of tide gauges is poor, thus making accurate estimates of GMSL difficult. Over the last two decades, satellite altimetry has also provided measurements of sea. The near-global coverage and accurate measurements provided by satellite altimeters allow changes in GMSL and regional sea level to be determined quickly and more accurately than is possible from the sparsely distributed in situ gauges. Despite the improved spatial sampling, however, the satellite altimetry record spans only 17 years. For this reason, the continuation of the altimetric record and the launching of new satellite altimeters has become a priority in recent years.

The precision satellite altimetry era began in late 1992 with the launch of TOPEX, and later continued with altimeters like Envisat, Jason-1 and Jason-2. The altimeter record shows that GMSL has been rising at a rate of 3.4 mm/year over the period from 1993-2009. While this exact rate is not widely accepted, all recent studies agree that sea level has been rising between 3 to 3.5 mm/year from 1993 to the present. Estimating a trend from a given data set is a trivial task, but estimating the uncertainty in the trend is a more challenging proposition. Significant effort has been put into calibrating, correcting, and verifying altimetry data so that the uncertainty in the trends may be quantified. Typically uncertainty estimates are based solely on formal errors from the least-squares fit to the data. This does not account for the systematic errors that altimetry is susceptible to. For instance, Jason-1 data has recently undergone a significant reprocessing to correct errors related to the sea state bias model, the on-board tracking algorithm, and bias jumps in the microwave radiometer. The new data has significantly lower trends in GMSL over the period from 2002 to 2007.

Measuring and analyzing GMSL provides one of the most stringent tests on the veracity of altimetry data. Combined with the data records from other altimeters, it is possible to detect the presence of systematic errors in newly launched satellite altimeters and also calibrate and validate the measurements of sea level. With the desire to keep the satellite altimetry record going into the future, such studies of GMSL will provide for the seamless transition between satellite altimeters and could lead to lowering of the uncertainty in estimates of the secular trend in GMSL.

Menemenlis et al.

JPL, USA

Evaluation and utilization of SARAL/AltiKa data for global ocean data assimilation

D. Menemenlis, L.L. Fu, I. Fukumori, T. Lee

We request access to SARAL/AltiKa data for (i) evaluation and (ii) utilization in global ocean data assimilation studies that are part of Estimating the Circulation and Climate of the Ocen (ECCO) follow-on efforts. The ECCO project was established in 1998 as a component of the World Ocean Circulation Experiment (WOCE) with the goal of combining a General Circulation Model (GCM) with diverse observations in order to produce a quantitative depiction of the time-evolving global ocean state.. Such combinations, also known as data assimilation, are important because available remotely sensed and in situ observation are sparse and incomplete compared ot the scales and properties of ocean circulation. These combinations also provide rigorous consistency tests for both models and data. In contrast to numerical weather prediction, which also combines models and data, ECCO estimates are physically consistent. In particular, ECCO estimates do no contain discontinuities when and where data are ingested; the estimated state satisfies conservation principles as described by the model equations, e.g., conservation of heat and momentum; and the estimated forcing are consistent with the estimated model state. These characteristics are important to the attribution of the estimated variability, for example, in relation to forcing and to budget analyses.

Griffin et al.

CSIRO, AUSTRALIA

Assimilation of AltiKa sea level data into the Australian Bluelink ocean nowcasting and forecasting systems

D.A. Griffin, P. Oke

Sea level measurements from coastal tidegauges and the three existing altimeters (Jason-1, Jason-2 and Envisat) forms the basis of two classes of sea level analysis systems (one simple, one complex) developed and run routinely by the Australian Bluelink project. The simple system produces a map of sea level anomaly using optimal interpolation, to which a hydrography-based estimate of the surface dynamic height is added as an estimate of the time-mean, and from which the geostrophic component of the surface velocity is derived. In the more complex system, the sea level data are assimilated into a primitive-equation hydrodynamic model by Multivariate Ensemble Optimal Interpolation, using the covariances of all model state variables to project the sea level observations onto the model's sea level, velocity, temperature and salinity fields without i) an assumption of geostrophy, or ii) an assumption of isotropic statistics, or iii) dependence on historical in-situ observations. Both approaches have their strengths and weaknesses but both are critically dependent on the density and quality of the incoming sea level data. Errors or gaps in the incoming data are readily apparent in the routinely-generated system diagnostics and performance analyses (which include comparisons of diagnosed fields with independent or quasi-independent observations from other satellites, drifting buoys, Argo floats, etc). We propose to include the AltiKa data in a trial (non-public) version of the Bluelink systems as a way of assessing the quality and impact of the data in the context of an established system.

SPECIFIC STUDIES : RAIN EFFECT, SEA ICE / SEA SURFACE BIAS / WIND & WAVES

Chapron et al.

IFREMER, FRANCE

Sea ice, rain, spectral analysis and high resolution measurements with Altika

B. Chapron, J. Tournadre, P. Queffeulou, F. Girard-Ardhuin, P.Y. LeTraon, G. Dibarboure, Y. Quilfen, P. Klein, N. Tran, D.C. Vandemark

Estimation of sea state bias correction using numerical wave models:

The work proposed on the sea state bias (SSB) correction is to continue development of alternate solutions to the operational version by taking into account additional surface wave parameters provided from a numerical wave model within the sea state bias model, following the methodology of Vandemark et al. (2002). With a new Ka-band instrument, it is expected that the so-called tilt contribution to the SSB shall be lowered for moderate to higher wind speeds. However, the so-called modulation contribution (hydrodynamical and aerodynamical) are poorly known for a Ka-band instrument, and efforts shall be dedicated to SSB corrections under low-wind contributions.

Cloud/rain flag:

Due to the mono-frequency characteristic of the SARAL/Altika altimeter, the rain flag used for Topex and Jason 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. A new rain/cloud flag based on the analysis of the along-track variation of the off-nadir angle estimate has been defined and tested using Jason-1 data (Tournadre et al , 2009a-b) 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 during the commissioning phase. The proposed work proposed is to continue the calibration and validation works as performed previously for the Jason and Envisat missions and to capitalize on the experience acquired during this past mission and on the definition of rain flag (Topex, Jason-1 and 2, Envisat).

In a first step, the performances of the rain/flag will be tested and the different parameters will be evaluated (in particular the noise level on the off-nadir angle estimate necessary to the Matching Poursuit algorithm). The performances and the stability of the algorithm will then be tested on the first few cycles of data. The validation of the results will be in a first step validated using available rain (such as the GPCP ones (Global Precipitation Climate Project)) and cloud (such as MODIS) products. In a second step, the results will be further validated using comparing with independent collocated rain measurements, from sensors such as the Tropical Rainfall Measuring Mission (TRMM) or AMSR-E.

Sea-ice studies:

The work proposed on sea-ice is to continue study of sea-ice type identification (i.e. sea-ice free ocean, seasonal sea-ice, multi-year sea-ice, and wet sea-ice) with altimetry. The approach used consists in classification of microwave signatures. Previous and on-going analyses are based on Envisat measurements (i.e. Ku-band radar cross-section and brightness temperatures). It is proposed to perform such innovative analysis on SARAL/Altika data.

Assessment of Saral/Altika significant wave height and normalized radar cross section measurements, and merging with existing altimeter wave data sources:

We propose to validate the Altika significant wave height (swh) and normalized radar cross section (NRCS) measurements using the altimeter validation procedures developed in the Laboratoire d'Océanographie Spatiale (LOS/IFREMER). Once validated the Altika data will be merged with an existing altimeter swh and nrcs data base, improving the efficiency of such data for application in various fields such as wave modelling and wave climate studies.

Quartly et al.

National Oceanography Center, Southampton (NOC), UK

KaNUTE

G. Quartly, P. Challenor, P. Cipollini, D. Cromwell, J. Gomez-Enri, M. Lekouara, M. Tsimplis, S. Vignudelli

This proposal summarises NOCS's wide-ranging plans for evaluation of the quality of AltiKa data and their use in a variety of applications concerning oceanographic variability. To achieve these goals we will collaborate closely with colleagues in the University of Cadíz and Consiglio Nazionale delle Ricerche (CNR). The data evaluation will be global to achieve the desired accuracy and robustness, with major components looking at the flagging of data for likely contamination by rain, and waveform analysis to characterise the mean shape of a radar return and the statistics of its variability. These should be completed within the first 18 months. The applications that will be subsequently evaluated concern i) portability of innovative retracking techniques developed for Ku-band waveforms to Kaband, ii) study of spatial variability in σ0, encompassing changes in wind, rain and slicks, and iii) proximity and accuracy of sea surface height (SSH) data in the coastal zone. The SSH evaluation and utilization will involve comparisons with tide gauges and combination with satellite-derived temperature and chlorophyll products. To obtain the most robust results, this will require 3 years of GDR data. This work will be achieved by cross-over from other already-funded proposals e.g. COASTALT, and by seeking other national/international financial support.

Mercier et al.

CLS, FRANCE

Waveforms Analysis and Improved Altimetric Parameters Estimations for AltiKa

F. Mercier, P. Thibaut, Ngan Tran, L. Amarouche, S. Calmant, J. Tournadre, A. Kouarev

The studies proposed are a follow up of the work performed by our team at CLS for the previous altimetric missions: TOPEX/POSEIDON, Jason-1, Jason-2, ENVISAT and contribute to the following objectives of the SARAL/AltiKa Joint Announcement of Opportunity through the assessment and the improvement of the estimation of the altimetric parameters:

- Reprocessing activities (development and assessment of new retrieval algorithms and/or models likely to improve the quality of the data over open ocean and in particular zones: coastal oceans, inland waters, ice surfaces and rain/clouds)
- Scientific application studies: mesoscale variability, coastal altimetry, continental water monitoring, polar oceans observations, continental and sea-ice studies, low rain and clouds climatology, …
- Operational applications studies (example: iceberg detection)

The proposed work is organized around 6 themes all dealing with a state-of-the-art analysis of the altimetric waveforms and parameters, and all taking advantages of the high-level expertise of our team and partners from IFREMER and LEGOS in this domain:

- Theme #1: *Analysis of the AltiKa performances*
- Theme #2: *Derivation/assessment of the Sea State Bias (SSB).*
- Theme #3: *Development of new retracking algorithms for SARAL waveforms affected by rain cells, sigma blooms*
- Theme #4: *Evolution and Application of the PISTACH prototype to the AltiKa data*

- Theme #5: *Icebergs detection in AltiKa altimetric echoes*
- Theme #6: *Continental Lake-Ice Thickness measurements*

Lillibridge et al.

NOAA, USA

Demonstration Project for Operational Applications of AltiKa Altimetry

J. Lillibridge, J. Sienkiewicz

NOAA utilizes altimetric significant wave height and surface wind speed measurements for high seas monitoring and ocean wave model validation. The operational system is 'data starved' due to the nadir-only measurements from conventional altimeters, resulting in sparse spatial coverage. We propose to conduct a demonstration project to show the utility of including AltiKa's Ka-band altimetry in the high-seas monitoring system. This will include quantifying data loss due to water vapor and rain, and potential gains from measurements made in the Ka vs. Ku-band. We will require access to the near real-time OGDR data to assess if the timeliness of the products is sufficient to meet operational center needs.

Janssen et al.

ECMWF, UK

Global Validation and Assimilation of SARAL/AltiKa Wind and Wave Products

P.A.E.M. Janssen, S. Abdalla, J.R. Bidlot

The aim of this project is to monitor and validate the global near real time (NRT) ocean wind and wave products of SARAL/AltiKa (fast delivery "OGDR" product) which we encourage to make available in BUFR format. The impact of using SARAL/AltiKa OGDR significant wave height information in data assimilation at ECMWF will be assessed as well.

All fast delivery SARAL/AltiKa OGDR data products available in NRT will pass a monitoring and validation process to check their quality. The tools that were developed inhouse and used for the monitoring and validation of ERS-1/2, ENVISAT and Jason-1/2 altimeter data, will be utilised to monitor and validate the quality of SARAL/AltiKa wind and wave products. Model fields and in-situ observations will be used for the validation purpose. When satisfied with the quality of the data, data assimilation experiments will be carried out to assess the impact that SARAL/AltiKa significant wave height data on wave forecasting results. Depending on their impact, SARAL/AltiKa wave height data will be assimilated in the operational ECMWF wave model.

WET TROPOSPHERE CORRECTION

Eymard et al.

LOCEAN, FRANCE

In-flight calibration validation, processing and exploitation of the microwave radiometer onboard SARAL/AltiKa

L. Eymard, F. Karbou, E. Obligis, B. Picard

The main objective of our investigation will be to improve the quality of the wet tropospheric correction for the AltiKa mission, focusing on the following points:

- Preparation of the in-flight calibration/validation of the brightness temperatures and refinements of the current methods used to control the long-term stability of the brightness temperatures and wet tropospheric correction to improve the overall wet tropospheric correction accuracy in a mean sea level monitoring perspective;
- Improvement of the wet tropospheric correction over coastal areas and inland waters;
- Improvement of the wet tropospheric correction over Ice;
- Exploitation of the synergy between altimeter and radiometer measurements.

DIFFUSION CNES			
Name	**Sigle**	**Bpi**	**Ex.**
NOUBEL J.	DCT/PO/AL	2002	X
SENGENES P.	DCT/PO/AL	2002	X
COUTIN-FAYE S.	DCT/PO/AL	2002	X
PICOT N.	DCT/PO/AL	2002	X
JAYLES C.	DCT/PO/AL	2002	X
GUINLE T.	DCT/ME/OT	612	X
BRONNER E.	DCT/ME/OT	612	X
LOURME E.	DCT/ME/OT	612	X
DESJONQUERES JD	DCT/SI/AR	601	X
STEUNOU N.	DCT/SI/AR	601	X
RODRIGUEZ SUQUET R.	DCT/SI/AR	601	X
CERRI L.	DCT/SB/OR	1323	X
MERCIER Fl.	DCT/SB/OR	1323	X
LOMBARD A.	DCT/SI/IM	2111	X
MAISONGRANDE P.	DCT/SI/LG	3200	X
THOUVENOT E.	DSP/OT	2903	X
LAMBIN J.	DSP/OT	2903	X