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Oceanography

Fig. 1

Fig. 2

Fig. 3

Space oceanography at CNES during these two years has been marked by missions-related events. After more than 11 years in orbit JASON-1 has ceased its mission in July 2013, but SARAL, launched a few months before, has demonstrated in a very fast and easy way its capacity to fill the gap between ENVISAT and SENTINEL-3, as well as the gain in accuracy expected from the Ka-band new technology for the altimeter.

On July 2, 2013, JASON-1 altimetry satellite stops after 11 years of continuous ocean monitoring

Ocean observation satellite JASON-1 has been officially ended by NASA and CNES on July 2, 2013. JASON-1 had been launched from Vandenberg, CA, on December 7, 2001. That made it one of the longest-lived oceanography satellites with 11 years and a half in orbit, representing more than 53 000 revolutions around the Earth and more than 3 500 science publications. Measurements made by JASON-1 payload instruments allowed to monitor sea surface topography with an extreme precision. This observation gives us access to ocean currents, as well as climate monitoring and marine meteorology.

Started during the 90s, JASON-1 project insured the continuity of TOPEX-POSEIDON mission. It developed a long-term US-French cooperation, from TOPEX to SWOT, and it confirmed radar altimetry as a cornerstone of ocean monitoring by satellite. From TOPEX/POSEIDON to JASON-1, science objectives have remained essentially identical, however technology and responsibility sharing has deeply evolved. JASON-1 was the first satellite to use the French PROTEUS platform; the main instrument, the TAS-developed radar altimeter instrument POSEIDON-2, presented a new entirely digital design; the precise orbit determination system included one of the first GPS receivers of high precision. Other instruments included the microwave radiometer WMR and laser retroreflector array LRA and CNES-developed DORIS orbitography instrument. Those technological choices have proven to be right, thus paving the way for a reference altimetry line maintained with JASON-2 in 2008 and JASON-3 planned in 2015.

Thanks to measurements accuracy, long-term stability of instruments and continuous efforts of calibration-validation performed on the ground, JASON-1 was a major contributor to the monitoring of sea level rise, an essential climate variable. JASON-1 was carefully calibrated with respect to *in situ* measurements, compared to other space borne sensors, and the processing algorithms have been maintained to state-of-the art standards. Two key periods of formation flying inter calibration have been performed, first with its predecessor TOPEX in 2001, then with its successor JASON-2 in 2008, allowing to maintain measurement uncertainty below the 0.5 mm/year mark.

TOPEX/POSEIDON had demonstrated the capability of radar altimetry to observe ocean dynamics and variability. Therefore, in synergy with JASON-1 development, an ambitious international effort has allowed the parallel development of a dense network of *in situ* sensors (more than 300 ARGO floats have been deployed worldwide) and a concerted development of new models and numerical methods to describe and model ocean (GODAE: Global Ocean Data Assimilation Experiment). Today several institutions worldwide are continuously generating analysis and forecasts of ocean state, towards a large variety of applications. Those systems all have in common that they rely on this triptych: model – *in situ* – satellite. JASON series is a key element of it, being the reference mission on which all other altimeter missions are calibrated.

The worldwide scientific community is federated within the Ocean Surface Topography Science Team, whose annual meetings allow space agencies engineers to meet with downstream scientists, and share a common understanding of the ultimate objectives of the mission. As a consequence, the performance of the JASON-1 mission largely exceeded both written specifications and implicit science expectations.

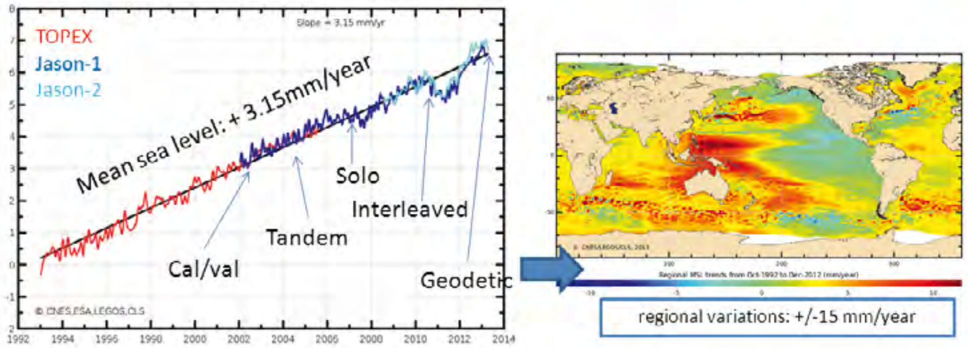

Fig. 4

On February 25, 2013, launch of SARAL and birth of Ka-band altimetry (ALTIKA)

The SARAL/ALTIKA project is a collaboration between France and India in environment monitoring. On a platform developed by the Indian space agency (ISRO), two independent payloads were embarked, ARGOS-3 and ALTIKA (+DORIS, +LRA), but their missions have the same objective: to promote the study of environment from space. ARGOS-3 is an element of the ARGOS system, dedicated to localisation, acquisition and distribution of environmental data. ALTIKA is an innovating Ka-band altimeter system, dedicated to accurate measurement of ocean surface topography. The data processing is integrated to the CNES ground segment SALP (Système d'Altimétrie et de Localisation Précise), which already operates the altimetry missions JASON-1, JASON-2 and CRYOSAT-2.

The SARAL mission is an essential component of the altimetry constellation from 2013 onwards, re-occupying the long-term ERS and ENVISAT ground track (Fig. 3). SARAL/ALTIKA is flying on the same orbit as ENVISAT to ensure a continuity of altimetry observations in the long term. On the other hand, the local time of passage over the equator is different due to specific cover requirements for the ARGOS instruments constellation.

On February 25, 2013, the ISRO-CNES SARAL mission was launch by PSLV from Sriharikota in India. On February 26, 2013, the first ALTIKA data were received at CNES for processing and verification. Because of the new features of ALTIKA, an extensive verification phase had been planned. However, the quality of the measurements made by ALTIKA was good from the very beginning of the mission. This allowed operational agencies (METEO-FRANCE, ECMWF, MyOcean, etc.) to start routine assimilation of SARAL data after only weeks.

SARAL/ALTIKA provides the first demonstration of Ka-band altimeter capabilities for fine resolution along-track applications, including coastal and inland water applications, which will be further developed for the future SWOT mission. The mission has a planned life of three years: the high level of interest for SARAL data in the scientific community makes it clear that every piece of the SARAL record will be used for many applications.

Other events

Other mission-related events have marked the period 2012-2014. CNES work on CRYOSAT-2 “SAR mode” over oceans have demonstrated that this new mode of acquisition – where the along-track resolution is enhanced by a factor 20 – designed initially for sea ice studies, can provide – on an operational basis – a better accuracy over open ocean as well, without any caveat. In consequence, this mode should be set default mode for the upcoming SENTINEL-3 mission.

CFOSAT, the China-France wind-wave observation mission, currently under development has been through a zone of turbulence because of changing rules in international export regulation. However China and France are pursuing their collaboration on this satellite, with a revised schedule that now foresee the launch for 2018. Meanwhile, the KUROS airborne demonstrator of the SWIM instrument have been successfully developed and operated by scientists from LATMOS, providing useful representative data to prepare CFOSAT data processing chains.

SWOT project is progressing at a very good pace at NASA and CNES (Fig. 1). The Science Definition Team has been set up, gathering oceanographers and hydrologists from both US and France. People have started working hard at the bi-yearly meetings, and every other day, to prepare for this mission.

[Fig. 1]
Artist view of the SWOT satellite.
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[Fig. 2]
The DORIS instrument onboard CRYOSAT-2 measures satellite trajectory and ground locations with great accuracy.
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[Fig. 3]
SARAL satellite.
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[Fig. 4]
Global sea level trend is a landmark product of the quality of “reference altimetry” period (1993-2010), thanks to the continuity of missions from TOPEX/POSEIDON, JASON-1 and JASON-2. Careful intercalibration of missions and continuous improvement in processing made this data an exemplary “essential climate variable” for global change studies. JASON-1 contribution is major, ensuring perfect continuity both upstream with TOPEX and downstream with JASON-2.
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EARTH SCIENCES - SCIENCES DE LA TERRE

Laboratory contribution

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Oceanography

The multisatellite-based adaptive strategy of the KEOPS2 cruise

La stratégie multisatellite de la campagne Keops2

➔ **Abstract:** *The KEOPS2 cruise aimed to study the onset of springtime phytoplanktonic bloom in the Kerguelen region, using an adaptive sampling strategy based on regionally optimized multi-satellite data. This information has been combined together by Lagrangian diagnostics and has allowed to identify in near-real time a set of sampling sites representative of larger region, to follow in time the development of spring-time primary production, and to greatly optimize ship time.*

➔ **Résumé :** La campagne océanographique Keops2 a étudié le développement de la floraison phytoplanctonique printanière dans la région de Kerguelen, en utilisant une stratégie adaptative basée sur des données multi-satellite optimisées pour cette région. Ces informations, en combinaison avec des diagnostics lagrangiens, ont permis d'identifier en temps quasi-réel un ensemble de sites représentatifs de la région, de suivre le développement de la production primaire et d'optimiser le temps bateau.

Current challenges in biogeochemical field studies

In biogeochemistry, oceanographic campaigns are essential tools, which provide observational ground for constraining models, test theoretical hypotheses and propose new paradigms. Nowadays, the planning of biogeochemical field studies faces two competing challenges for which the contribution of remote sensing is essential. The first challenge is the need of observational data on coupling mechanisms between physical and biogeochemical processes (e.g., [1]). Although biogeochemical processes are relatively well understood in zero dimension (well mixed) conditions, how the ocean's physical dynamics modulate them largely remains an open-ended question. In order to shed light on this issue, *in situ* observations have to encompass a large number of multidisciplinary measures (hydrology, horizontal and vertical transport and mixing properties, nutrients, trace elements, microbial communities and processes, etc.). This long list of parameters to acquire pushes towards lengthy occupation of sites, so that hardly more than one station can be visited during one day of field work.

The second challenge is the current interest for the so-called submesoscale. Model studies indicate that structures occurring at this spatiotemporal domain strongly modulate biogeochemical responses to physical forcing [2]. Is an abrupt change observed between two repeated stations the consequence of a temporal dynamics or the effect of sampling over a drifting filament? If there is no information on the position and temporal dynamics of filaments, a blind *in situ* survey which aims to avoid the synopticity problem should therefore scan a region at least few dozen kilometers by few dozen kilometers with a one kilometer and one day spatiotemporal resolution. Such submesoscale snapshot would correspond to a large number of profiles per day (> 100), which is probably achievable by a towed vehicle with a limited number of sensors and up to moderate depth (few 100s m), certainly not by an exhaustive, deep biogeochemical sampling.

The KEOPS2 experiment and the role of remote sensing

Nevertheless, ships are not alone during their field work in the open ocean, but are assisted by a network of satellites, several of which embark instruments able to resolve part of the submesoscale dynamics at the ocean surface. The KEOPS2 cruise is a recent interdisciplinary biogeochemical field campaign which visited the open ocean waters surrounding Kerguelen Islands (in the Indian sector of the Southern Ocean) in October-December 2011. The aim of the cruise was the description of the onset of the bloom in this region and in particular the quantification of the biogeochemical role of iron [3-4]. This part of the ocean is a remarkable example of strong submesoscale biogeochemical contrasts due to the presence of the Antarctic circumpolar current, which creates plumes of naturally iron-fertilized waters when it encounters topographic reliefs like Crozet and Kerguelen archipelagos. Iron-rich filaments giving rise to high level of primary production can be a few dozen kilometers apart from iron-poor waters.

The KEOPS2 cruise could benefit from regionally optimized satellite products produced by Ssalto/Duacs and CLS with support from CNES. These products include sea surface height anomalies at 1/8° (compared to 1/3° resolution of the standard AVISO product), a regional mean dynamic topography, 1/25° chlorophyll MODIS and MERIS composite images and sea surface temperature from MODIS/AQUA, MODIS/TERRRA, AVHRR/NOAA-19, AVHRR/METOP-A [5]. Chlorophyll and sea surface temperature images allowed identifying and tracking

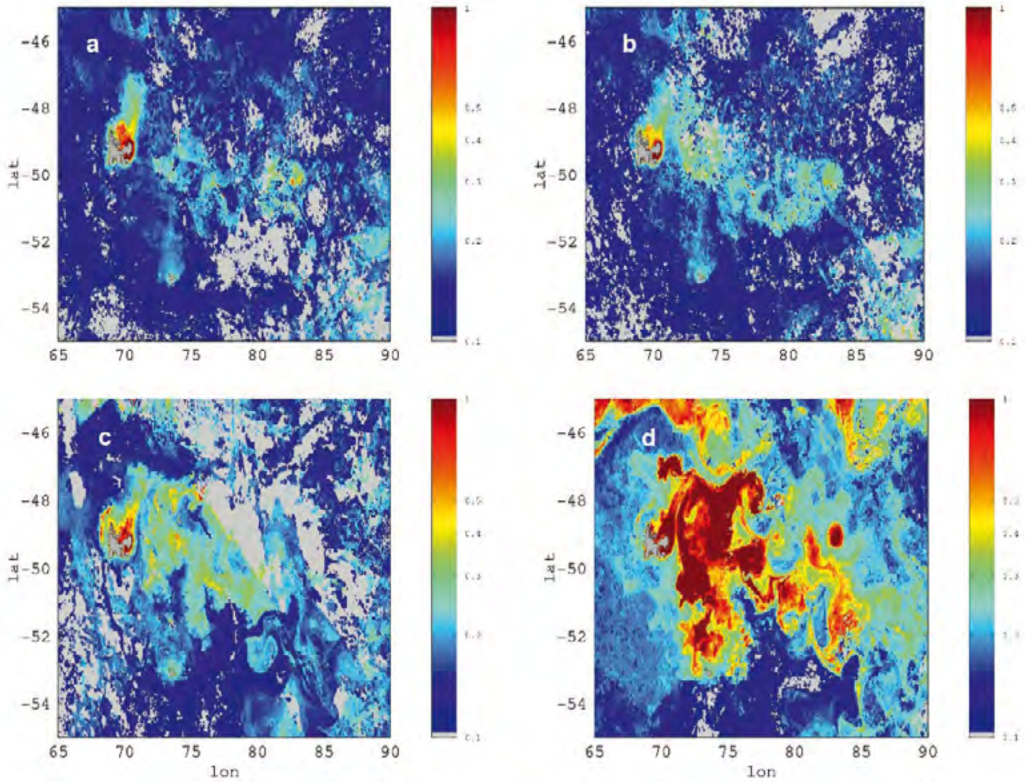


Fig. 1

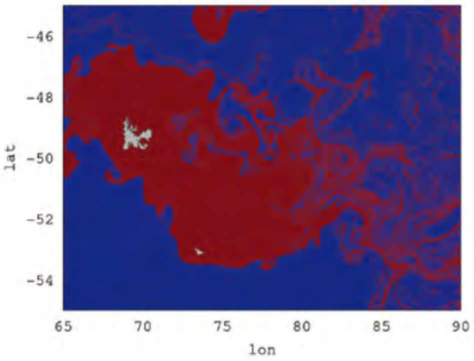


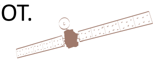
Fig. 2

[Fig. 1]
Development of the spring bloom during the KEOPS2 cruise in the Kerguelen region. The possibility of tracking these globular structures in near real time during the KEOPS 2 cruise allowed identifying the regions inside and outside the plume without a preliminary in situ mapping. From (a) to (d): 2011/9/28, 2011/10/9, 2011/10/28 and 2011/11/11.
© From [5]

[Fig. 2]
Prediction of the extension of the chlorophyll plume by a Lagrangian analysis of altimetry data before the occurrence of the bloom (when the sampling sites have been decided). Note the remarkable agreement between this map, computed with data from the 2011/9/28, and the extension of the chlorophyll plume (Fig.1d).
© From [6]

of the position of large-scale to submesoscale fronts for the duration of the cruise as well as the onset and evolution of phytoplanktonic bloom (Fig. 1). Altimetry has been analyzed with Lagrangian diagnostics [6] in near real time to estimate the position of the iron-rich water mass, *i.e.*, water parcels originating from the plateau (Fig. 2). Thanks to this Lagrangian calculation, the extension of the chlorophyll plume was forecast several days before the beginning of the bloom. After the bloom and still during the cruise, the Lagrangian analysis of altimetry data was confirmed by a comparison with ocean color images.

Either as interesting features on themselves (as focal regions of enhanced biophysical coupling) or as a source of confounding effects when disentangling spatial gradients from temporal trends, submesoscale features can hardly be ignored by current biogeochemical field studies. Therefore, satellite imageries provide key information for tracking submesoscale variability and adapting sampling strategies. This biogeochemical role of satellite data is expected to become even stronger with next missions aimed at fine scale dynamics like SWOT.



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Oceanography

SARAL/ALTIKA: a Ka-band altimetry mission

SARAL/AltiKa : une mission altimétrique en bande Ka

➔ **Abstract:** *The India-France SARAL/ALTIKA mission is the first Ka-band altimetry mission dedicated to oceanography. The mission objectives are the observation of the oceanic mesoscales and also include coastal oceanography, global and regional sea level monitoring, data assimilation and operational oceanography. Secondary objectives include ice sheet and inland waters monitoring. One year after its launch, the results widely confirm the nominal expectations in terms of accuracy and data quality in general.*

➔ **Résumé :** La mission franco-indienne SARAL/AltiKa est la première mission altimétrique en bande Ka dédiée à l'océanographie. Ses objectifs sont d'abord l'observation des mésoéchelles océaniques mais incluent aussi l'océanographie côtière, le suivi du niveau des mers à l'échelle globale et régionale, l'assimilation de données et l'océanographie opérationnelle. L'accès à un suivi des calottes polaires et des eaux continentales est également visé. Un an après le lancement, les résultats obtenus confirment largement les attentes en termes de précision et de qualité de mesures en général.

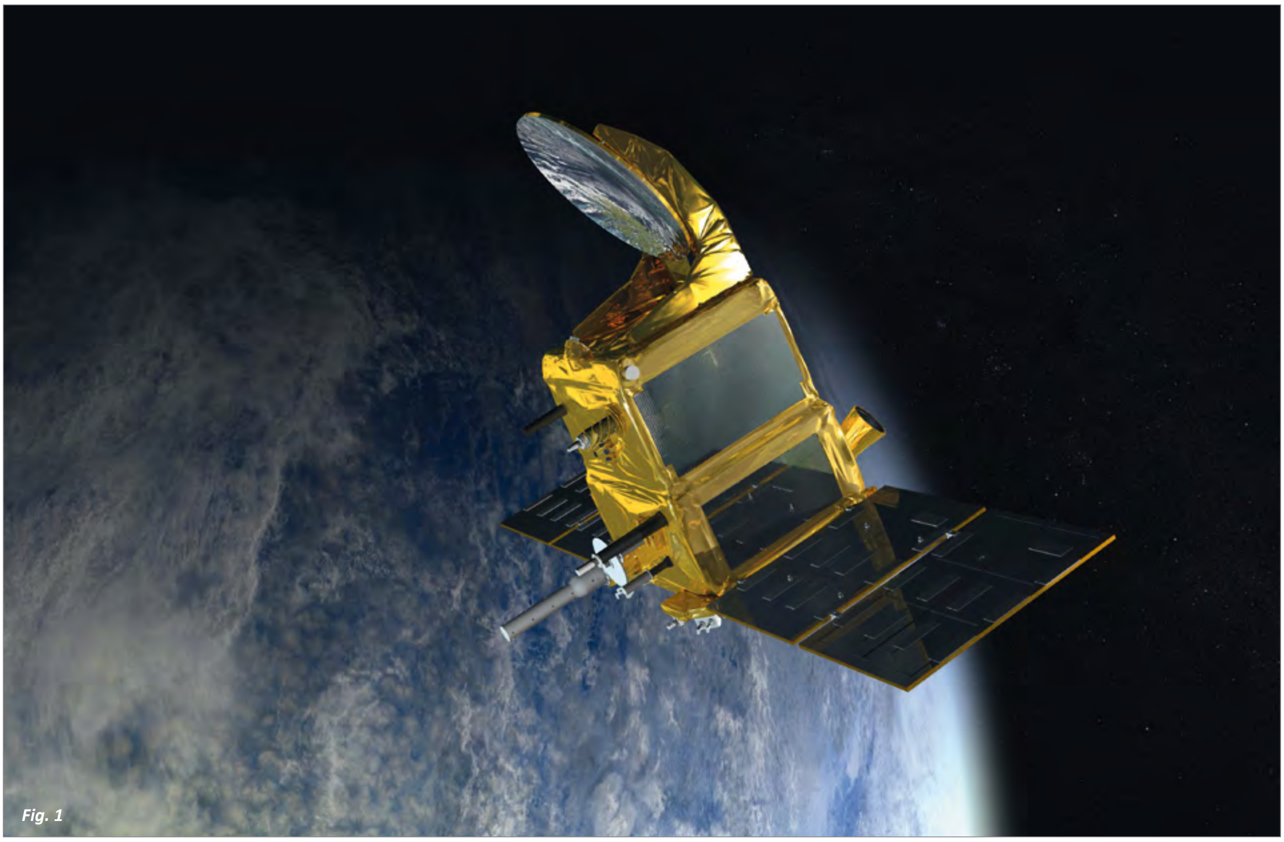
The SARAL-ALTIKA satellite mission is an India-France ISRO-CNES joint project. The satellite has been put into orbit by a PSLV vehicle supplied by ISRO, and launched from the ISRO Sriharikota launch base on February 25, 2013 (Fig. 1). SARAL (SAtellite for ARgos and ALTIKA) payload consists of an ARGOS instrument and an altimetry payload provided by CNES, including the ALTIKA radiometer-altimeter.

SARAL/ALTIKA was intended to be a gap filler mission between the RA-2 on-board ENVISAT and SENTINEL-3 [1]. As such, SARAL/ALTIKA is flying on the same orbit as ENVISAT. The special feature of SARAL/ALTIKA is that it is based on a wide-band Ka-band altimeter (35.75 GHz, 500 MHz), which is the first satellite altimeter dedicated to oceanography to operate at such a high frequency. The ALTIKA instrument therefore consists in a Ka-band altimeter based on proven concepts and already developed subsystems, as it inherits a lot from SIRAL (European Space Agency CRYOSAT mission) and POSEIDON-3 (on the JASON-2 mission), and an embedded dual frequency radiometer. As a result, the altimeter and the radiometer share the same antenna. Compared to past altimetry missions that were in Ku/C-band, the single frequency Ka-band altimeter allows an enhanced bandwidth. Also, the reduced ionosphere effects in Ka-band authorize a mono-frequency altimeter. Moreover, the enhanced bandwidth (480 MHz w.r.t 320 MHz for POSEIDON-3) induces a better vertical resolution. The spatial resolution is also improved, thanks to Ka-band (smaller footprint) and the increased PRF (4 kHz w.r.t. 2 kHz for POSEIDON-3).

The SARAL/ALTIKA main scientific objectives concern various themes like mesoscales in open-ocean, coastal areas, seasonal forecast and climate studies. Secondary objectives are the monitoring of continental water level and mean sea level variations, the observation of polar oceans, the wave and wind fields, the study of continental and sea ices, the access to low rain climatology, and marine biogeochemistry. Reference [2] gives an excellent indication of the first calibration/validation investigations and of the very first scientific explorations that have been undertaken with the SARAL/ALTIKA data.

Clearly, the quality of the first data is indubitable. It satisfies and even overcomes the expectations and the initial mission's requirements (Fig. 2). SARAL/ALTIKA was seen as a "medium accuracy, complementary mission" with regard to the JASON "reference mission". First results are at least in line with JASON-2. Also, the quality of SARAL/ALTIKA data in terms of accuracy, data latency and availability has allowed us to rapidly make the data available, leading especially to an efficient integration in several operational systems. The known effect of rain on the Ka-band was such to put some uncertainty on the full availability of data in some regions. This proved to be much less constraining than expected. On the other hand, improved ability in coastal area is confirmed and improved resolution in general is validated so far. Other domains of application such as inland waters and ice sheets monitoring also took an active part in looking at the first data with quite satisfactory findings so far.

As of today, all components of the SARAL/ALTIKA system are working properly. Excellent stability of the instruments of the ALTIKA mission is seen after one year in orbit. All operations are run smoothly between CNES, ISRO and EUMETSAT. The availability of data and products (OGDR, IGDR and GDR) has been made easily since the beginning. All products' quality is in line with mission's requirements and performance is similar to JASON-2 (the reference altimetry mission) and sometimes better. It represents the achievement of a very prolific cooperation between ISRO and CNES with performances exceeding mission expectations.



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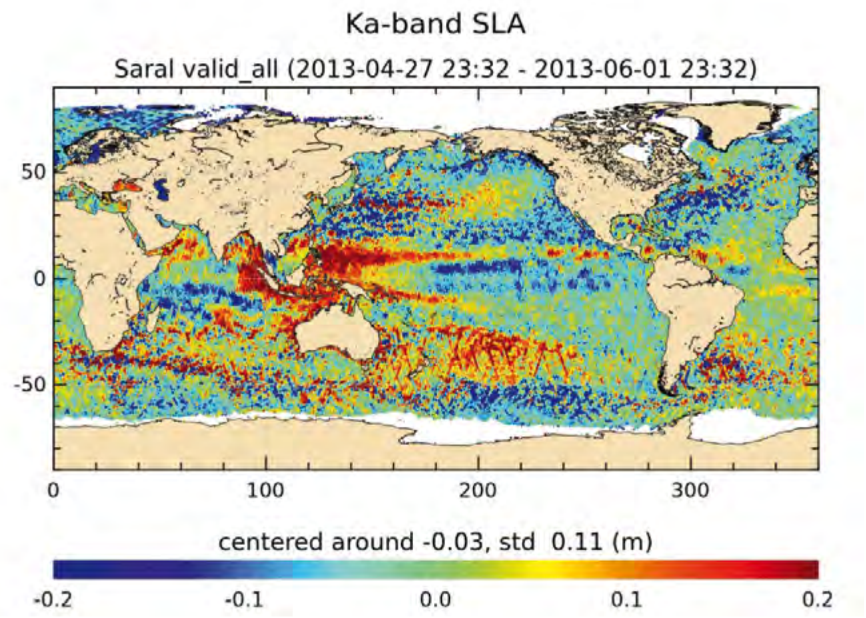
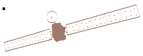


Fig. 2

[Fig. 1]
Artist view of the SARAL/ALTIKA satellite.
© CNES

[Fig. 2]
Sea level anomaly from SARAL/ALTIKA as measured during cycle 3.
© Jacques VERRON

The consideration of a SARAL/ALTIKA follow-on mission is made and would give the opportunity to ensure the continuity of the Ka-band altimetry survey of oceans, ice sheets, lakes and rivers while preparing and complementing the SWOT mission, and reinforcing the cooperation between CNES and ISRO.



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