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OSTM/Jason-2



OSTM/JASON-2 SCIENCE AND OPERATIONAL REQUIREMENTS

CENTRE NATIONAL D'ÉTUDES SPATIALES

Siège
2, place Maurice Quentin - 75039 Paris Cedex 01
Tél. : 01 44 76 75 00 / Téléfax 01 44 76 76 76 / Télex 214674
SIRET 775 665 912 00082

Centre de Toulouse
18, avenue Edouard Belin - 31401 Toulouse Cedex 9
Tél. : 05 61 27 31 31 / Téléfax : 05 61 27 31 79 / Télex 531081
SIRET 775 665 912 00033

RCS PARIS B 775 665 912 - CODE APE 731Z - N° d'identification TVA : FR 49 775 665 912

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

This document on science and operational requirements lists the highest level requirements placed by the Ocean Surface Topography Science Team upon the JASON-2 project to meet the objectives of the OSTM/JASON-2 mission. This source document, along with the Project Plan (RD2) and the Operations Services Specification (AD1) document, is at the origin of the system requirements document (AD2).

The OSTM/JASON-2 mission objectives are motivated by (1) scientific investigations built on the strong heritage from the T/P and Jason-1 missions, and (2) adding new capabilities for operational applications. This document is therefore organized into two main sections:

- The first one addresses the science objectives requirements and derived requirements on the mission, the performances, and the data access and calibration/validation activities.
- The second one addresses the operational application requirements and derived requirements on mission, performances, data access, and calibration/validation activities. All operational objectives involve the need for a timely dissemination of the products, but with various timelines. In order to avoid confusion, we will distinguish objectives and requirements according to the data latency:
 - A few hours for meteorological applications, which we will refer as near-real time (NRT) operational objectives.
 - A few days for operational oceanographic applications, which we will refer as short term applications and products.

1.2 BACKGROUND

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

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

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

The OSTM/JASON-2 mission is built on the heritage of T/P and JASON-1, with two driving ambitions: (1) ensuring continuity of high quality measurements for ocean science and (2) providing operational products for assimilation and forecasting applications. In this second purpose, this project is conducted within an extended partnership including the CNES and NASA space agencies, and the EUMETSAT and NOAA

operational agencies. The science and operational requirements listed below are derived from the T/P and JASON-1 experiments returns, with an added emphasis on operational products.

1.3 REFERENCE AND APPLICABLE DOCUMENTS

1.3.1 REFERENCE DOCUMENTS

Index	Reference	Title of document
RD1	TP3-J0-MOU-186-CNES	<i>MOU OSTM-Jason2</i>
RD2	TP3-J0-GP-104-CNES	<i>OSTM/JASON-2 Project Plan</i>

1.3.2 APPLICABLE DOCUMENTS

Index	Reference	Title of document
AD1	TP3-J0-STB-116-CNES	<i>OSTM/JASON-2 OPERATIONS SERVICES SPECIFICATION</i>
AD2	TP3-J0-STB-44-CNES	<i>OSTM/JASON-2 SYSTEM REQUIREMENTS</i>
AD13	TP3-J0-NT-87-CNES	<i>OSTM/JASON-2 ENGLISH/FRENCH GLOSSARY OF TERMS AND ACRONYMS</i>

1.4 TERMINOLOGY AND ABBREVIATIONS

See OSTM/Jason2 acronyms document (AD13)

2. SCIENTIFIC OBJECTIVES AND REQUIREMENTS

2.1 SCIENCE OBJECTIVES

Like T/P and JASON-1, OSTM/JASON-2 is designed to provide accurate sea surface topography to determine the general circulation of the ocean and understand its role in the Earth's climate, hydrological and biogeochemical cycles. Very accurate, i.e. within 1 cm at a basin scale, global and homogeneous sea level measurements are required to precisely determine the ocean currents, and associated climatic variations. Thus, the major focus of the OSTM/JASON-2 mission must be to pursue the unique accuracy, continuity and coverage of the T/P and Jason-1 missions for describing and understanding the ocean circulation, its variability on all scales, and its influence on climate. Additional objectives are related to tide modeling, marine meteorology, hydrology, geophysics and geodesy.

T/P was a main component of the WOCE program, early in the 1990's; JASON-1, in the 2000's, is supporting research programs such as CLIVAR, GOOS and GODAE which lead the way to forthcoming operational ocean observation systems. These systems rely not only on satellite based data (including altimetry) but also in-situ measurements and models, as has been done in meteorology for several decades.

In this regard, OSTM/JASON-2 must continue to serve and complete the scientific objectives initiated by T/P and JASON-1 but also needs to support on-going and future operational programs (see section 3.1.1 and 3.1.2 for short term and near real-time applications, respectively).

2.1.1 MEAN DYNAMIC TOPOGRAPHY

Satellite altimetry is a unique tool to retrieve the mean global ocean circulation. Such a determination is particularly important to describe and characterize the main features of the ocean circulation, i.e. location of the main currents, their intensity, their transport, and their interaction with temporal variability (i.e. mesoscale, seasonal, annual signals). The global ocean circulation, as determined from altimetry, is also useful to validate and initialize global ocean models and to adjust data assimilation techniques.

To depict the large scales of the mean ocean circulation, the orbits of altimetric satellites must be known very accurately, i.e. at least with the same quality as T/P and Jason-1. The T/P and Jason-1 data set has already covered more than 13 years, but because of the low-frequency variability of some ocean phenomena (decadal and inter-decadal scales), it cannot yet be considered as a climatological record. Future missions, having the same quality as T/P and Jason-1, are necessary to improve the estimate of the mean dynamic topography.

The largest uncertainty in determining the mean ocean circulation from altimetry is in the knowledge of the geoid, the needed reference surface, especially at the smaller scales (below 200 km). This geoid uncertainty has been greatly reduced by combining altimetry observations with models and by using gravimetric data from dedicated gravity satellite missions. The CHAMP mission, launched in 2000, and the GRACE mission, launched in 2002 are providing new gravimetric data sets able to resolve scales below 400 km with an accuracy better than 5 cm. The GOCE mission coming in 2006 will improve this geoid knowledge at shorter scales, below 200 km.

2.1.2 INTRA-SEASONAL TO INTERANNUAL VARIABILITY

The temporal changes in sea level are usually determined along the repeat tracks of altimetric satellites. This orbit configuration allows one to compute a mean sea level along the tracks which is then subtracted from individual profiles to recover the temporal signal, thereby eliminating the time-independent geoid effect. Ground track repeatability has to be as accurate as possible in order to avoid any contamination by cross-track geoid slopes. This is why T/P and Jason-1 were originally specified with an orbit repeating within 1 km of the mean track and why the same requirement on orbit repetition must be maintained for OSTM/Jason-2.

The ocean is changing on all temporal and spatial scales, from a few hours to a few years and from a few kilometers to basin scales. Apart from short timescale events (storm surge, tsunamis, M2 and S2 tides), the dominant energy comes from mesoscale eddies which typically have temporal scales of 1-3 months and spatial scales of 100-300 km. This type of ocean variability was observed by early altimetric missions (see next section). Other features include intra-seasonal to interannual oceanic variations whose large spatial scales have an impact on climate change. These signals were especially difficult to detect using early altimetric missions, because of their relatively large spatial scales and contamination by long-wavelength orbit errors.

The T/P and Jason-1 missions have made a major contribution to the observation of this type of large-scale spatial variability (at intra-seasonal to interannual time scales) thanks to an exceptional error budget and drastically reduced orbit error. The missions were fully optimized for this objective, the orbit cycle itself (10 days) being specified to offer an appropriate time-space sampling.

At the intra-seasonal scales (10-100 days), the large scale variability is mainly driven by oscillations which are coherent over thousands of kilometers and which are a direct response to the high-frequency wind forcing. The mean amplitude of this variability is quite weak and does not exceed a few centimeters, with a 1 cm level significance. T/P was the first mission to reveal its large scale structure and geographical distribution. Other oscillations at periods longer than 100 days are due to propagation of Rossby waves which transport energy across ocean basins and whose speed of propagation was measured using T/P observations resulting in a revision of existing theory. Intra-seasonal variations also have been detected in the western boundary currents (Kuroshio, Gulf-Stream) with T/P data. Jason-1 has augmented the T/P data set (especially during the tandem phase), improving the time-space sampling and consolidating the findings. It is certain that this intra-seasonal variability has an important role in ocean dynamics as well as in the ocean-atmosphere coupling, but further observations over longer periods are still necessary before fully understanding the mechanisms involved in this process.

The annual cycle of the ocean was observed for the first time on a global scale with the required accuracy using T/P data. This cycle is the result of close but complicated interactions between the ocean and the atmosphere (i.e. solar radiation change, heat fluxes, wind forcing...). The T/P observations have allowed a better characterization of this seasonal cycle and its geographic dependence as well as a better understanding of the associated ocean-atmosphere interactions. An accurate knowledge of the seasonal cycle is especially important to evaluate and to adjust at first order both ocean and climate models. However, as long as the altimetric time series is not long enough to completely resolve the interannual variability, there will be resulting uncertainties in the seasonal cycle. As the peak to peak amplitudes of the seasonal signal can reach 15 cm in some areas, it is desirable to have a 1 cm level of confidence in the observation of this signal. Such an objective can only be fulfilled by gathering several decades of T/P and Jason-1 quality altimetric data.

The seasonal cycles are different from one year to the next because of interannual changes which have a direct impact on climate. The «El Niño» episodes, in the tropical Pacific, are famous and dramatic examples of such interannual anomalies corresponding to strong interactions between ocean and atmosphere. Several warm ENSO (El Niño Southern oscillation) episodes were observed by T/P and Jason-1 especially the strong 1997-98 event. This altimetric based monitoring is leading to a better understanding of the mechanisms involved, such as the propagation of Kelvin waves and reflected Rossby waves. Prediction of these phenomena is a major issue in improving climate forecasting. Assimilation of altimetric data and other types of data in coupled ocean-atmosphere models will play a key role in this domain (see section on real time requirements). Other interannual

events, with a period of a few years, have also been observed by T/P and Jason-1 (e.g. the North Atlantic and North Pacific Decadal Oscillations). This highlights again the need for longer altimetric time series (over several decades) with the same characteristics and quality as T/P and Jason-1 (same orbit phasing, same accuracy). The amplitude of these interannual sea level changes can reach 10-15 cm over several thousands of kilometers in the zonal direction but an accuracy of 1 cm at basin scales is required to discriminate them from other effects and also to detect weak precursor effects which can have an amplitude on the order of only 1 cm.

2.1.3 MESOSCALE AND COASTAL OCEANOGRAPHY

The mesoscale signal has typical spatial scales of 100-300 km and time scales of 1-3 months. It is mainly associated with the formation and propagation of eddies which are very energetic and have a key role in heat transport from low to high latitudes. These eddies are mainly the consequence of mean flow instabilities and/or interaction of the mean flow with topography. They are present everywhere but they are especially concentrated in regions of strong currents such as the Gulf Stream, Kuroshio, and Antarctic Circumpolar Current. This mesoscale energy concentration was revealed in the global variability maps which were among the first results obtained by altimetry. They show that the maximum of the variability can reach more than 40 cm (near strong currents), while a minimum of less than 3 cm is still significant in regions of low variability. T/P and Jason-1 quality data are particularly useful to construct such maps, because of their exceptional accuracy allowing detection of even 1-3 cm low variability features. The space-time distribution of mesoscale energy can also be studied from altimetric along-track spectra. These statistical global results are useful for revealing the spatial and temporal distribution of mesoscale energy and to assess the capability of models to reproduce mesoscale signals.

The coastal domain represents 8% of the ocean surface. Many human and commercial activities are concentrated in these areas, requiring continuous monitoring and forecasting. It is a complex and fragile domain involving many processes such as the accumulation of organic matter and fresh water transported by rivers, strong winds, sea ice at high latitudes, dense water formation, coastal tides, and the interaction between coastal currents and open ocean circulation. Understanding such complex short space and time scale processes is not easy and requires the development of very specific models and the use of multiple data sources. Altimetry is among the data which are helpful for such studies, but, as for mesoscale studies, multi-mission merging and dedicated processing are needed to improve the resolution and utility of the data..

Indeed, the main limitation of T/P and Jason-1 in reproducing the ocean mesoscale activity and coastal processes is the spatial sampling because the repeat orbit cycle leads to an across-track spacing of about 300 km at mid-latitudes. This sampling cannot resolve all spatial scales of mesoscale and coastal signals which have typical wavelengths of less than 100 km at mid-latitude. The scales are even shorter at high latitudes (around 50 km), but fortunately the ground track separation decreases with latitude. Thus, to cover the whole mesoscale and coastal domain it is necessary to increase the spatial sampling by merging (in an optimal way with cross-calibration) different altimetric data sets, such as T/P, GEOSAT, and ERS-1/2 in the past, and JASON-1, GFO and ENVISAT which are currently operating. In this regard, the 2002-2005 T/P Jason-1 interleaved configuration has been of great value for improving spatial resolution and should be repeated with Jason-1 and Jason-2 after the tandem cross-calibration activities are complete. This multi-satellite combination is essential for resolving the totality of the mesoscale and coastal signal and to better understand its time-space evolution and its interaction with mean flow as well as seasonal and interannual ocean dynamics. In areas close to the coasts (less than 20 km) the difficulty is even larger because of the proximity of land which contaminates the altimetric and radiometric signals. Thus, adaptive tracker and/or specific retracking of altimeter waveforms and near-shore geophysical corrections (such as coastal tide models and marine boundary layer tropospheric corrections) are needed.

2.1.4 MEAN SEA LEVEL TREND

Mean sea level is a pertinent indicator of global climatic changes related to global warming. Because of thermal expansion from temperature increases, the ocean occupies a larger volume. One degree of temperature rise over one hundred meters of depth is enough to increase sea level by a few centimeters. Sea level can also rise due to mass inputs from melting glaciers (but not sea ice which is in isostatic equilibrium). Sea level rise, if it continues for hundreds of years, would have dramatic socio-economic and environmental consequences. This is why it is so important to monitor the actual sea level tendency. Until recently, the only instruments capable of monitoring the sea level trend were tide gages, which have shown about 15 cm of elevation over the past hundred years. T/P and Jason-1 data, have confirmed the sea level rise observed by tide gages over the last 13 years. However, this signal represents only about 2 millimeters per year on average, with a large regional variability, which demands extreme caution when interpreting the results. Despite the very encouraging results derived from T/P and Jason-1, the detection of such a small signal is very difficult. Indeed, it requires a millimeter-level control on the potential drifts of the altimetric system components (altimeter, geophysical corrections, orbit, system reference...). The error in sea level trend estimation will decrease as the time series becomes longer. This reinforces the need for multi-decadal (and continuous) altimetric observations. It also implies a precise intercalibration between successive satellite time series to fully resolve the measurement bias between missions. Through the successive altimetry missions in the wake of T/P, the foreseen long term objective is a mean data availability of 80% over time with no gap longer than 1 year. In parallel, further combination with satellite gravimetric measurements (e.g. GRACE mission) is being conducted, which helps separate the thermal expansion component from the global mass change component.

2.1.5 TIDES

Thanks to T/P and Jason-1 data, several ocean tide models of unprecedented accuracy (2-3 cm rms) have been produced for the main diurnal and semi-diurnal components (M2, S2, N2, K2, O1, P1 and Q1). These results have made a significant improvement in applying the altimetric data to ocean circulation studies, as tides are considered a major correction in the data. Tide knowledge improvement (by direct analysis of T/P data or by assimilation of the data into hydrodynamic models) is the result of the high quality T/P and Jason-1 data sets. It is also the consequence of the space-time sampling, i.e. the orbit phasing selected for T/P and Jason-1, which was optimized to discriminate the various tide components.

However, more data beyond the T/P and Jason-1 missions are needed to fully resolve all the components of the ocean tides and thus improve the tide solutions. Preliminary solutions exist for the long period tides but they need to be updated by longer altimetric time series. Thanks to the extreme accuracy of T/P and Jason-1 data it has been possible to observe the weak signal of the internal tides and to understand better the dissipation of the tides and their interaction with ocean circulation and ocean bottom topography. In coastal regions, the T/P and Jason-1 track spacing is too coarse to resolve the short scales of the ocean tides, but merging different altimetric satellite data (e.g. T/P, Jason-1 and ENVISAT) will improve the resolution and improve the determination of tides in the shallower regions.

2.1.6 MARINE METEOROLOGY

In addition to sea surface height, altimeters provide estimates of significant wave-height and wind speed (derived from radar backscatter) which are of both scientific and operational interest in marine meteorology. From a climatological point of view, it is very valuable to take advantage of the altimetric coverage of sea-state and wind speed observations in regions where conventional observations are especially sparse (like in the southern hemisphere). This allows comprehensive studies of the climatology of these parameters, their time-space characteristics, and their variations at intra-seasonal to interannual scales. Additional studies include propagation of swell, interactions between sea-state and currents, etc... These studies are especially useful to validate and initialize meteorological models, a preliminary step before running routine assimilation of altimetric data into meteorological models (see section on real-time applications). Merging multi-satellite data sets is attractive when studying sea-state parameters because this provides an improved time-space sampling for resolving their temporal and spatial variability. The accuracy of T/P and Jason-1 wind speed and wave-height measurements is also sufficient for OSTM/Jason-2

Altimetric sea-state and sea level data are also used to adjust, validate and improve models simulating dramatic and sudden events such as hurricane intensification or tsunamis. As an example, altimetry has been advantageously used to investigate the interactions between upper ocean thermal structure and the intensification of hurricanes. Results of such studies were used to improve forecasts based on the combination of altimetry, sea surface temperature and ocean models.

The water vapor content measured by radiometers on-board altimetric satellites are dedicated to the correction of altimetric data, but can also be used to monitor atmospheric characteristics in the troposphere and to constrain operational weather models (see relevant section). In the same way, studies of the ionosphere and upper atmosphere can take advantage of the ionospheric electron content measured by the dual-frequency altimeters and the atmospheric drag estimated during precise orbit determination. These global data give interesting information on the solar and geomagnetic characteristics of the atmosphere. Rain and ocean/atmosphere gas fluxes at the sea surface are other parameters which can be derived from the analysis of the dual-frequency radar altimeter measurements.

2.1.7 INLAND STUDIES

Because of the importance of understanding the hydrological cycle and of managing the Earth's water resources, inland water level and ice observations are becoming more and more crucial, especially to monitor the space-time variations of rivers, lakes, reservoirs and flooded regions. In this regard, altimetry is a very useful tool capable of measuring the water level, volume and discharge of these inland waters. Despite inappropriate technical design and orbit geometry for such applications, significant results have been obtained with T/P data over sea-ice, enclosed seas, lakes, large rivers and flat continental topography. These specific applications may use the GDR processing or special altimetric waveform retracking if needed (because of reflection characteristics which are different from the open ocean). The main requirement then is to have access to the level 1 altimetric data. It must be noted that Jason-1 is not performing as well as T/P over non-ocean surfaces, which needs to be improved for Jason-2. Another requirement is to have an orbit as accurate as possible. In this regard, a T/P like orbit is required. Combining T/P and future JASON data with other satellite data (i.e. ERS and ENVISAT) having higher spatial resolution will improve the spatial resolution which is essential for such applications.

2.1.8 GEOPHYSICS AND GEODESY

The ocean geoid has been much better known since altimetric data become available (the first altimetric ocean geoids were computed with GEOS 3 and SEASAT data). Sea level height measured by altimetry represents to first order the ocean geoid signal because of its much larger amplitude (10 to 100 times more) than the ocean dynamic topography. A very accurate altimetric mean sea surface, comprised of the geoid and mean dynamic topography, has been obtained using the high density GEOSAT, ERS and GFO altimeter data. T/P and Jason-1 data, despite having a larger spatial sampling, have usually been used as the reference data set, in terms of accuracy, to adjust the other satellite data sets. Geodesists and Geophysicists are extracting a great deal of information from the short scales (10-100 km) of these altimetric mean sea surfaces. Short wavelength tectonic features never observed before are now visible in the data. Meanwhile, oceanographers are using mean sea surfaces as a reference to extract ocean variability from altimetric data, but they are usually using along track averaged mean sea level to obtain higher accuracy. An ultimate goal for oceanographers is to discriminate the mean dynamic topography from the mean sea surface. This requires a «true» geoid accurate at short spatial scales. The combination of mean sea surfaces with ocean circulation models is an indirect way of retrieving the geoid. But satellite gravity missions, i.e. CHAMP and GRACE, have greatly improved the resolution and accuracy of marine geoids up to 400 km. The ESA GOCE mission, scheduled for launch at the end of 2006, should resolve even shorter scales.

The DORIS system is one of the three precise orbit determination systems (with GPS and laser) on-board the T/P and Jason-1 satellites. Satellite orbits, as well as the positions of ground tracking stations, are

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determined very accurately using DORIS data. The DORIS station positions are now incorporated into the International Terrestrial Reference Frame System (in addition to laser, VLBI, and GPS positions) to take advantage of the accuracy, homogeneity and global coverage of this system. Such additional observations have an immediate impact on reference system quality and related parameters like Earth rotation parameters, measurements of vertical displacements of stations due to tectonic movements, large scale glacial rebound, and atmospheric or oceanic load effects. Determining these movements with the required millimeter accuracy is essential to decorrelate them from sea level rise determined from altimetry and/or tides gages. The accumulation of very precise DORIS, GPS and laser data simultaneously with highly accurate altimetric data, through missions like T/P, Jason-1 and Jason-2/OSTM is certainly the best way to accomplish such an objective.

2.2 MISSION REQUIREMENTS

JASON-2 is intended to lay the foundation for a continuing program of long-term observations of the oceanic circulation and its variability.

JASON-2 mission shall be designed in a way which allows an optimum continuation of the T/P and JASON-1 scientific mission and the long term observation requirements, as mentioned previously.

JASON-2 mission shall be designed in a way which allows a maximum of altimeter echoes to be acquired and retracked over inland waters and sea ice, and over oceans as close as possible to the coast.

JASON-2 mission shall be designed to last for a 3 year minimum duration, with a potential for an additional 2 years, in order to ensure the long term observation monitoring objective and to allow for intercalibration with future follow-on missions.

JASON-2 mission shall include a verification phase (for a minimum duration of 6 months after launch) intended to qualify the system. This phase will be followed by the observational phase.

The JASON-2 mission control centers shall be designed in a way which allows for simultaneous operations of both the JASON-1 and JASON-2 satellites, if they are both scientifically productive.

JASON-2 performance (i.e. error budget) and orbit characteristics (i.e. repeat period, inclination and altitude) shall be identical to or better than JASON-1.

The launch of JASON-2 and further orbit maneuvers must be designed in a way which allows the satellite to overfly the reference JASON-1 ground tracks.

Orbit maneuvers shall be done in a way which satisfies the mission requirements for repeat track control, but with a minimum disturbance of the mission (e.g. perform maneuvers over land).

Sea level shall be measured along the reference JASON-1 ground tracks. These tracks are fixed to the Earth, within a maximum 1 km deviation from the mean ground track, to minimize the influence of the cross-track geoid effect on sea level measurements.

JASON-2 satellite mispointing shall not exceed 0.33° (3 sigma) to minimize geoid and other instrumental effects in altimeter data, and it shall be measured within 0.15° (3 sigma).

2.3 DATA REQUIREMENTS

The Geophysical Data Records (GDR) will be distributed in a timely, complete and well-documented manner to data users and shall contain all the parameters required to compute the derived ocean and geophysical parameters.

The GDR shall be made available to users, on a cycle basis, within 40 days of data acquisition by the satellite. They shall contain at least 95% of the ocean data during any 12 month period with no systematic geographical gaps, plus all the land and ice data for which the altimeter is tracking.

The GDR shall constitute the final and fully validated products. They shall be archived and systematically delivered to data users.

A complete documentation of the GDR data record files shall be distributed including the format of the files, definition of all the parameters and flags, the way to use the data and the algorithms used to generate the data. Any change in the data generation and/or processing shall be communicated to data users in a timely manner, and documentation shall be updated.

The GDR shall contain, at a rate of 1 record per second, the best estimates of altimetric range measurement, the time tag and earth location, plus the best associated instrumental and environmental corrections and the most accurate orbit altitude. They shall contain additional geophysical parameters, i.e. wave-height, sigma-naught and derived wind speed, atmospheric surface pressure, tides, mean sea surface and geoid. They also shall contain altimeter range and orbital altitude at a rate of 20 measurements per second.

The GDR shall be structured in a way similar to JASON-1 (pole to pole half revolutions with the same numbering as JASON-1) and shall use the same reference standards as JASON-1.

A specific effort shall be conducted to provide valid data as close as possible to the coast, as well as over ice and inland waters.

All information needed to connect JASON-1 and JASON-2 time series shall be provided to data users. This includes the altimeter radar instrument bias and drift and the relative bias between JASON-1 and JASON-2 time series.

For specific applications (retracking over ocean, coastal areas, lake, land or ice), the Sensor Geophysical Data Records (SGDR) containing waveforms shall be made available on request, to interested data users.

The SGDR shall contain waveforms of the raw altimetric measurements, plus all parameters needed to analyze those waveforms and to derive the appropriate geophysical parameters. They shall be available within 40 days of data acquisition by the satellite.

For specific applications, like orbit validation, preprocessed orbitography data (DORIS and GPS) shall be made available to interested users. Similarly, AMR level 1B data shall be made available if needed for radiometer validations.

2.4 PERFORMANCE REQUIREMENTS

2.4.1 ERROR BUDGET

The performance of the JASON-2 system shall be at least as good as that of the JASON-1 system. Consequently, the requirements, in terms of error budget are summarized in table I and are similar for the GDR to the post-launch JASON-1 error budget.

The performance in table I may be summarized as: The sea surface height shall be provided with a global and ultimate rms accuracy of 3.4 cm (1 sigma) over 1 second averages along JASON-1 ground-tracks for typical sea-state conditions of 2 m SWH and 11 dB sigma-naught.

The JASON-2 system and ground-processing algorithms shall be designed to minimize the geographically and temporally correlated errors.

The instrumental corrections, environmental corrections, and precise orbit determination shall be provided with the appropriate accuracy to meet the 3.4 cm requirement on the sea level height. This corresponds to a corrected range RMS error of 3 cm and precise orbit RMS error of 1.5 cm on the radial component.

The drift of the system (after calibration) shall not exceed 1mm/year.

In addition to these requirements, goals have been established. Such goals are based on expected off-line ground processing improvements and are likely to reduce the error to 2.5 cm rms on the sea level height over 1 second averages.

2.4.2 SWH, SIGMA NAUGHT AND WIND

As for JASON-1, the JASON-2 requirement on the accuracy of significant wave height measurements is 40 cm or 10% SWH (whichever is greater) for 1 s averages. The validity domain shall be 1 to 20 meters. A goal of 25 cm or 5 % is expected based on off-line ground-retracking.

The absolute accuracy of sigma naught shall be better than 0.7 dB (for a sigma naught varying between 7 dB and 16 dB) with a resolution in telemetry better than 0.1 dB. The sigma naught drift over 1 year shall be measured with an accuracy of 0.2 dB with 0.1 dB as a goal.

The derived wind speed accuracy shall be better than 1.5 m/s for 1 s averages (for a range between 3 m/s and 20 m/s).

2.5 CALVAL REQUIREMENTS

During the initial verification phase of the mission (at least the first 6 months after launch), all ground-processing algorithms and all critical output quantities and associated errors shall be verified and calibrated. It shall be done through statistical analysis and by comparison with external measurements. The calibration/verification accuracy shall be compatible with error budget specifications.

The parameters to be verified include altimetric range and associated corrections, orbit, wind speed and SWH. In addition to the biases, the calibration process shall provide an estimation of the individual drifts of the system components.

Laser retroreflectors on board JASON-1 shall be designed to provide orbit and altimeter height verification with overhead measurements to an accuracy of +/- 1 cm (1 sigma) using available laser stations.

During the verification phase, the Operational Geophysical Data Records (OGDR) and Interim Geophysical Data Records (IGDR) shall be provided with a delay of 1.5 days to the main science investigators so that they can participate in a timely manner in the CAL/VAL effort.

At the end of the initial verification phase, a complete report on CAL/VAL activities must be presented to users, including a revised error budget and derived calibration and drift quantities and updated ground-processing algorithms. The verification effort shall be pursued beyond the initial verification phase.

GDR production shall start at the end of the verification phase with the last updated algorithms. Calibrations (internal and external) shall be introduced into processing so that GDR quantities provide correct geophysical measurements.

Instrument calibrations and product quality shall be monitored at least weekly throughout the life of the mission. The calibrations, including internal instrument calibrations, shall be documented.

During the verification phase, JASON-1 and JASON-2, assuming they are both scientifically productive, shall be phased in a way which allows an optimum cross-calibration/validation of the two missions, as recommended by the Ocean Surface Topography Science Team. JASON-1 IGDR shall be provided simultaneously with JASON-2 IGDR for CAL/VAL purposes.

Adequate calibrations and drifts shall be provided to users to connect previous T/P, JASON-1 and further JASON time series with JASON-2 time series.

3. OPERATIONAL APPLICATIONS AND REQUIREMENTS

Among the objectives of JASON-1 was the development of operational data production and distribution: this objective has been achieved beyond initial expectations. Today, several operational ocean or meteorological services rely heavily on data products provided by altimetry satellites. For those services, the continuity in altimetric measurements as well as in the data access systems and tools is essential. As explained in the introduction of this document, two fairly distinct classes of operational applications exists, each leading to specific requirements for OSTM/JASON-2.

Short-term products: Operational applications related to ocean and climate monitoring (and/or forecasting) are mostly concerned with time scales of several days to months. A latency of a few days is acceptable, in particular as it allows a better orbit determination and hence a more accurate altimetric precision. Requirements for Interim Geophysical Data Records (IGDR) products will be derived from those short-term application needs.

Near Real Time products: Applications related to marine meteorology involve much shorter time scales, both in terms of phenomena observed and in terms of data flow needs. Near real time availability of the products is absolutely necessary, therefore corresponding operational services will use Operational Geophysical Data Records (OGDR) products.

Beyond purely operational applications, it should be noted that CALVAL activities also require a relatively short data delivery delay, because they may have a direct impact on the on-time GDR production. CALVAL participant are mainly using the short-term products (IGDR) but some specific activities (e.g. support for an in-situ ocean campaign) might require the use of near-real-time products.

Finally, an important aspect of all operational applications described in this document is that they all require the combination of altimetry measurements with other data, either from in-situ networks or from other satellite missions. Therefore the operational requirements for JASON-2 have to take into account this necessary integrated approach.

3.1 OBJECTIVES

3.1.1 SHORT- AND MID-TERM APPLICATIONS

3.1.1.1 TOWARDS OPERATIONAL OCEAN FORECAST SYSTEMS

In 1997 the Global Ocean Data Assimilation Experiment (GODAE) was initiated, which is now in the final stage of the demonstration phase. The objective of this international initiative is to set up “ *global system of observations, communications, modelling and assimilation, that will deliver regular, comprehensive information on the state of the oceans*”. In this framework, operational and research institutions from Australia, Japan, United States, United Kingdom, France, Norway, Italy, etc. have been developing global oceanic data assimilation and ocean forecast systems. Such systems are already running operationally and depend heavily on satellite ocean observation systems.

3.1.1.2 MESOSCALE AND COASTAL APPLICATIONS

The monitoring and forecasting of mesoscale ocean signals (30-300 km and 20-90 days of typical scales) has specific applications in domains like fishery activity, marine safety, monitoring of oil spills, marine fauna surveys, oil drilling, commercial navigation and military defense. One of the first quasi-operational applications of altimetry, conducted by NOAA with GEOSAT data in association with in-situ and satellite imagery data, was the survey of the meandering of Gulf-Stream and associated eddies.

Other near-real time experiments, on a daily basis, based on T/P and ERS2 data, are also conducted in the Kuroshio area, off Japan, and at a global scale by the US Navy. The French Navy also developed an operational system, called SOAP, based on T/P and ERS2 altimetric data assimilation in a quasi-geostrophic model, to survey the Azores region in the north-east Atlantic. This program, now called SOPRANE, has been extended to a large portion of the North Atlantic and relies on improved modeling and assimilation schemes. These preliminary experiments have shown all the benefits that can be gained from joint use of altimetric data and models to survey and forecast on weekly to monthly time scales the mesoscale activity. This part of the ocean signal is particularly important because of its high variability and rapid time-space evolution associated with strong energy transfer between the ocean surface and sub-surface and atmosphere. Monitoring and predicting the three dimensional structure of mesoscale activity is a sensitive issue for specific submarine applications. It also has civilian applications in fishery and fauna survey because of the preference of certain species to follow eddies, current meanders or oceanic fronts. In the Gulf of Mexico, eddies are mapped to help

in following the whale migration and in the Hawaii area for the lobster migration. Future experiments, based on T/P and SST data, intend to track eddies visited by tuna bands in the Indian Ocean.

Mesoscale as well as coastal activities have a rapid time-space evolution (under 5 days) which requires a dense time and spatial sampling (making desirable the combination of simultaneous altimeter satellites, e.g. JASON-1 and ENVISAT) and data available with a very short delay. The requirement on orbit accuracy is not so stringent because the short scales associated with mesoscale signal are decorrelated from long-wavelength orbit errors. However, there is an obvious interest in avoiding filtering of data, first to reduce the processing time but also because in the near future, data will be used by global models resolving not only mesoscale but also larger scale signals. Altimeter measurements must be provided with all parameters needed to correctly derive the sea level measurements. A specific effort must be conducted in the near-coast areas (less than 20 km from the coast) where dedicated processing and adequate corrections (as for tides and troposphere) may be needed. Past experiments conducted with T/P and ERS2 data showed that satisfactory results in terms of quality and predictability are obtained with data available within 2-3 days maximum having an rms accuracy of 5 cm or better for 1 s averages and an orbit error around 10 cm. In addition, GDR files are useful to perform a posteriori analyses for validating and assessing the quality of model predictions.

A particularly fruitful multi-mission experiment was the T/P – JASON-1 tandem phase, where the two satellites were flying side-by-side for more than 3 years. This produced a significant improvement in time and space characterization of ocean mesoscale variability.

3.1.1.3 CLIMATE APPLICATIONS

Prediction of El Niño type events is a particularly important issue because of the impact of such interannual anomalies on climate and consequently on economic and social activities of countries affected by these events. They have an impact not only over the tropical Pacific region, where they are generated and most apparent, but also on the entire earth's climate. Recent attempts to improve forecasts of ENSO events have been implemented using coupled ocean-atmosphere models fed by in-situ and satellite data, including altimetry. These first altimetric data assimilation runs have significantly improved the skill of the long term forecasting (6 months to 1 year in advance) as done by NOAA. In addition to ENSO, there are many ocean variations from intra-seasonal to interannual scales which have a great impact on climate involving typical scales from 300 to 3000 km and from 100 to 1000 days (even decadal signals have been detected). High quality altimetry is able to detect with an unprecedented accuracy the corresponding changes in sea level. As an example, the birth and death of Kelvin and Rossby waves, which are generated by wind fluctuations, can be captured very precisely by altimetry. Incorporation of such information into models is of primary interest to improving forecasts.

T/P and JASON-1 missions have fulfilled or exceeded initial objectives placed on the error budget, pushing back the limit of observability of large scale ocean signals. Significant signals with centimetric amplitudes are now detected without applying any data filtering, confirming the benefit of similar accuracy and sampling requirements for follow-on missions.

Consequently, the first constraint when operationally using altimetric data for climate applications concerns the sea level accuracy which shall be of an order of 5 cm or better. Sampling provided by the 10-day repeat orbit is appropriate for observing large spatial scale signals.

The other requirement is to have access to the data within a few days (3 days or less) in order to integrate them into coupled models as soon as possible. The compromise between accuracy versus data latency has to be made within these boundaries, keeping in mind that consistency between JASON-1 and OSTM/JASON-2 data products is desirable. As in the case of mesoscale applications, the geophysical data record files are also very useful to assess the quality of model predictions via hindcast reanalyses.

3.1.2 NEAR-REAL-TIME APPLICATIONS

3.1.2.1 MARINE METEOROLOGY APPLICATIONS

The two parameters measured by altimetry that have meteorological applications are wind speed and significant waveheight (SWH). Sea-state forecasts are crucial for many activities related to maritime industries (fishing, oil drilling, navigation...). New generation models have been implemented to provide better sea-state analysis and predictions. However, sea-state is a parameter which changes rapidly within a few hours requiring dense and frequent measurements and availability with a short delay of few hours. Conventional in-situ networks are not dense enough to constrain the models efficiently, especially in the southern hemisphere where in-situ data coverage is very sparse. Interest in satellite data is then obvious; multiple satellite inputs allow significant improvements in time and space resolution. Wind speed and SWH measured by altimetry have shown their potential through preliminary experiments of altimetric data assimilation into models using ERS, T/P, ENVISAT and JASON-1 data. Operational systems are already running in several meteorological centers providing reliable 12-24 hours forecasts.

As an illustration, the French national weather service Météo France is closely involved in satellite altimetry as well as being one of its main operational clients. It produces daily sea-state forecasts using numerical models assimilating real-time altimetry data. These forecasts are sent immediately to sailors as part of the service's mission to ensure their safety, or to support specific operations. Moreover, since July 2003 Météo France has been putting Jason-1 wind/wave data onto the Global Telecommunication System (GTS), where they are available in real time to the international meteorology community.

3.1.2.2 OTHER NEAR REAL TIME APPLICATIONS

Hurricanes are among the most frequent catastrophic events in warm seas. Their birth is now well understood, but forecasts of their path are of major importance for people living in coastal areas affected by tropical cyclones. Several parameters derived from altimetry can contribute to this forecast: first, as described in the previous section, wave height and wind speed data are used for marine meteorology and therefore benefit traditional hurricane forecasting. Second, the knowledge of mesoscale circulation is a valuable tool to be used for intensity forecasting. Indeed, advances in the mapping of mesoscale circulation have helped map deep, warm features, such as those associated with the Loop Current in the Gulf of Mexico. Since the heat content of the underlying ocean plays a major role in hurricane birth and intensification, cold and warm eddies can modify the intensity of hurricanes. The Tropical Cyclone Heat Potential (TCHP) is an altimeter-derived parameter proportional to the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm. In addition to maps of SST and ocean model output, maps of TCHP have proven to be very useful to monitor sudden intensification of tropical cyclones,

After the major earthquake that occurred in Sumatra in 2005, the tsunami wave that was generated was large enough (40-50 cm height) to be observed by altimetry satellites in the open ocean. This detection opens new perspectives for tsunami research and warning systems as in situ measurements in the deep ocean are very difficult to obtain. Typical tsunami waves will have a few centimeters amplitude, 30-minute period and wavelength of several hundred kilometers. From the operational point of view, satellite observations –when available in a timely manner, i.e. within less than 2 hours– might contribute to a better assessment of the tsunami amplitude by tsunami warning systems.

3.1.3 CALVAL ACTIVITIES AND OCEANOGRAPHIC CAMPAIGNS

The CALVAL activities, especially during the verification phase of the mission, are intended to verify the performance of the system with respect to external measurements and/or through statistical analysis. They also are dedicated to the calibration/validation of on-board instruments and validation and eventual improvements of ground processing algorithms (e.g. sea state bias algorithms and tide models during the T/P verification phase). They are based on a relatively short data delivery delay, because they are going to have a direct impact on the on-time GDR production. This is why CALVAL participants are primarily using Interim Geophysical Records

which are made available within less than 3 days. The sooner they have access to the data the shorter will be the timeline for final data production.

Another objective which relates to CALVAL activities and real-time ocean applications is support of ocean measurement campaigns. Oceanographic campaigns or cruises conducted in conjunction with altimetric missions (and more generally with satellite observations) need to have access as soon as possible to satellite data, in order to adjust and to coordinate the best in-situ observations with satellite ones. In this regard, access to IGDR and OGDR data files are required.

3.2 MISSION REQUIREMENTS

The OSTM/JASON-2 mission shall be designed in such a way which allows it to satisfy the operational objectives listed previously.

The OSTM/JASON-2 satellite on-board and ground systems, including on-board algorithms, earth terminals, data control and processing centers, have to be specified in such a way which allows timely acquisition and distribution to data users of Operational and Interim Geophysical Data Records.

The on-board DORIS DIODE system shall provide real-time orbit estimation for OGDR products.

3.3 DATA REQUIREMENTS

OGDR and IGDR products will be made available to data users through secure electronic links, offering a maximum of reliability, in order to reduce the transmission time delay.

A specific effort shall be conducted to provide valid data as close as possible to the coast, as well as over ice and inland waters.

A complete documentation of the different data record files shall be distributed including the format of the files, definition of all parameters and flags, the way to access and to use the data, and the description of the algorithms used to generate the data. Any change in data generation and processing will be sent to data users at the same time as the data.

3.3.1 SHORT-TERM PRODUCTS (IGDR)

The Interim Geophysical Data Records (IGDR) shall be designed to satisfy the short and mid-term application requirements including oceanographic requirements, as well as CALVAL requirements, oceanographic experiment support and applications in coastal area.

The IGDR shall contain the same parameters as the GDR, but will not be fully validated and will not have the ultimate precision of the GDR. They shall have the same structure as the GDR.

The IGDR shall be distributed within 1 to 1.5 calendar days of data acquisition by the satellite (goal: 1 day latency) and shall contain 95% of the ocean data during any 12 months period with no systematic geographic gap.

3.3.2 NRT PRODUCTS (OGDR)

OSTM/JASON-2 operational data products have to be provided to users with a very short delay of 3 to 5 hours. The OGDR shall contain, at a rate of 1 record per second, all parameters needed for meteorological and specific CALVAL applications (time-tag, location, wind speed, wave-height, sigma-naught and range for the two frequencies, radiometer measurements, orbit, and geophysical corrections to range).

The OGDR shall have the same structure as the GDR and IGDR. However their content is not fully validated and the precision is limited by the 3-hour latency constraint. It shall contain, at delivery time, at least 75% of the ocean data no older than 3 hours, and 95% of the ocean data no older than 5 hours.

OGDR parameters that depend on external geophysical data (e. g. atmospheric pressure fields) shall be calculated using up-to-date external input. In order to maintain the 3-hour timeline however, most recent external data shall be used to calculate the OGDR parameters.

If some external data are not available at the time of OGDR production, the most relevant replacement value shall be provided, which can be the most recent available data or a predicted value.

3.4 PERFORMANCE REQUIREMENTS

3.4.1 SHORT-TERM PRODUCTS (IGDR)

IGDR altimeter range and accompanying geophysical corrections shall have the same accuracy as the GDR but are not fully validated (table I).

The IGDR orbit shall be a 2.5 cm class orbit. The derived sea level measurement will have 3.9 cm accuracy for typical sea-state conditions of 2m SWH and 11 dB sigma-naught.

Accuracy requirements for IGDR SWH and wind speed products are the same as for the GDR (section 2.4.2).

3.4.2 NRT PRODUCTS (OGDR)

Three-hour operational products may have a lower accuracy (table I) as they are mainly based on on-board processing (waveform tracking). This may be particularly apparent in altimetric range noise and tracker bias corrections. The DORIS DIODE on-board orbit in these products shall be a 10 cm class orbit.

The accuracy on SWH in OGDR products shall be respectively 10% or 0.5 m (whichever is greater).

The accuracy on wind speed in IGDR products shall be 1.6 m/s.

3.5 CALVAL REQUIREMENTS

In order for users to validate the data access links and operational data processing systems for these data, it is recommended that simulated operational and IGDR data sets be made available as test files before the launch.

For the same access and operational processing validation objectives, OGDR and IGDR data files shall be produced soon after the launch of the satellite, i.e. after the assessment phase.

Routine OGDR and IGDR production shall start at the end of their respective verification phases with the last updated algorithms.

4. TABLE I: SPECIFICATIONS ON JASON-2 ERROR BUDGET

SPECIFICATIONS ON OSTM/JASON-2 ERROR BUDGET
 (for 1 sec average, 2 meters SWH, 11 dB sigma naught)

	OGDR 3 hours	IGDR 1 to 1.5 days	GDR 40 days	GOALS
Altimeter range RMS	5 cm	3 cm	3 cm	2.25 cm
RMS Orbit (Radial component)	10 cm (a)	2.5 cm	1.5 cm	1 cm
Total RSS sea surface height	11.2 cm	3.9 cm	3.4 cm	2.5 cm
Significant wave height	10% or 0.5 m (b)	10% or 0.4 m (b)	10% or 0.4 m (b)	5% or 0.25 m (b)
Wind speed	1.6 m/s	1.5 m/s	1.5 m/s	1.5 m/s
Sigma naught	0.7 dB	0.7 dB	0.7 dB	0.5 dB
System drift				1 mm/year (c)

- (a) Real time DORIS onboard ephemeris
 (b) Whichever is greater
 (c) On global mean sea level, after calibration

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