Jason-1 mission

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Introduction

Soon after the launch of TOPEX/POSEIDON (T/P) in August 1992 and following a comprehensive analysis of the system's performance [JGR special issue, 1994], the T/P mission's Science Working Team recommended that studies be engaged on a follow-on to T/P. Early in 1993, the French Space Agency, Centre National d'Etudes Spatiales (CNES), and US National Aeronautics and Space Administration (NASA) agreed to jointly build and operate this follow-on satellite, Jason-1 (named after the leader of the Argonauts' famous quest to recover the Golden Fleece). The success of the T/P mission was mainly due to an effort to optimize the system: instruments and the satellite and orbit parameters were all specifically designed to fulfill the objectives of the mission. The Jason-1 mission embraces the spirit and heritage of the T/P mission, but it calls for a smaller satellite to reduce the costs. In addition, near-real time applications have been included in the main objectives of the mission.

The main motivation of the Jason-1 venture is to measure the sea-surface topography at the same performance level of T/P to determine the general circulation of the ocean and understand its role in the Earth climate, hydrological and biogeochemical cycles. It will provide measurements of the variability of global ocean surface topography for the study of the variation of ocean circulation on time scales from intraseasonal, interannual, to decadal, and the effects on climate change.
By measuring global mean sea level variation, it will improve the understanding of its relation to oceanic heat and water exchange with the atmosphere, land and ice sheet. Jason-1 data also will help in determining both deep ocean and coastal ocean tides. Combined with other satellite missions (e.g. ENVISAT) it will enhance the time and spatial resolution of ocean topography for the study of mesoscale and coastal processes. It will help in demonstrating the feasibility of producing routine estimates of the 3-dimensional state of the global oceans for both scientific and operational applications, being a key component of the International Climate Variability Program (CLIVAR), the Global Ocean Observation System (GOOS) and the Global Ocean Data Assimilation Experiment (GODAE). Jason-1 will demonstrate the operational value of satellite altimetry in weather and climate forecast, maritime navigation and offshore operation, and fisheries. It will provide global wind speed and wave height measurements for studies of their climatologies, and near-real time (within 3 hours) wave and wind-speed data for direct assimilation in sea-state forecast models. Observations from the measurement system (including ancillary data from DORIS, GPS, microwave radiometer, etc.) will facilitate applications to geodesy, geophysics, glaciology, hydrology, and atmospheric physics.

Starting in 1987, the Science Team of the TOPEX/POSEIDON mission, composed of 38 teams selected by NASA and CNES, participated actively in the mission requirements, the development of the project, including algorithms definition/improvement, the validation and publication of the results, and the planning of new missions as Jason-1. This successful extensive involvement of the science community has been repeated for Jason-1.
In 1997, CNES and NASA selected 68 international investigation teams, with close to 300 members, to establish the Jason-1 Science Team. This science team has been interacting with the project teams and meets once a year to discuss the progress of project activities and scientific inquiries. The 68 teams cover many different research fields, and address the main objectives of the Jason-1 mission as listed before. This document provides a description of the science investigations of these teams.

The Jason-1 mission objectives

The scientific objectives of the Jason-1 mission are primarily based on the T/P experience. T/P has made invaluable contributions to many aspects of physical oceanography [e.g., JGR special issue 1995; AVISO Newsletter 6, 1998]. However, the T/P time series is not long enough to fully resolve the spectrum of ocean variability. Many of the science issues will benefit from the extended time series that Jason-1 will produce. Indeed, some of these science issues, as well as pre-operational applications, require a continuous, high-accuracy altimetric survey as provided by T/P, Jason-1, and follow-on missions. This is why Jason-1 will offer the same performances and fly in the same orbit as T/P. After Jason-1 is launched, T/P will engage in a Tandem

Mission with Jason-1 by performing the following: during the Jason-1 verification phase, T/P will fly in the same orbit but sample the same spot of the ocean with a time separation of 1-10 minutes from Jason-1 for cross-calibration to ensure the consistency between the two missions for long-term monitoring; during the Jason-1 operational phase, T/P will fly in an orbit that produces groundtracks interleaving those of Jason-1 for improved spatial-temporal resolution for addressing new science objectives including mapping ocean current velocity statistics, eddy-mean-flow interactions, Rossby wave dispersion relation, coastal tides and currents, etc.
The expected contributions of Jason-1 investigators in various fields include the following [AVISO Newsletter, this issue]:

Mean dynamic topography characterization using altimetry data is vital to improving our understanding of the underlying physics and to model the phenomena involved so that we can refine ocean circulation models. However, our knowledge of the “mean” ocean is still hindered by our limited understanding of the short scales of the current reference level; that is, the geoid. New satellites to study the Earth’s gravity field will largely fill this gap in our knowledge (CHAMP was launched on July 15, 2000, GRACE is scheduled in 2001, and GOCE in 2003). These missions will provide data that, combined with Jason-1 altimetry measurements, will greatly improve our ability to map and monitor the absolute ocean circulation.

Intra-seasonal to inter-annual variability has a great effect on climate changes. Like T/P, Jason-1 will greatly contribute to observing this type of variability thanks to measurement accuracy that will at least match T/P with expected improved orbit accuracy and an appropriate time-space sampling of its 10-day repeat orbit. At the intra-seasonal scales (10-100 days), the large scale variability, which does not exceed a few centimetres, is mainly driven by oscillations that are coherent over thousands of kilometres, and which are a direct response to high-frequency wind forcing. Other oscillations at periods longer than 100 days are due to the propagation of Rossby waves across the ocean basins. Intra-seasonal variations are also present in the western boundary currents (Kuroshio, Gulf-Stream). The annual cycle, first observed at a global scale by T/P, is the result of close but complicated interactions between the ocean and the atmosphere (that is, solar radiation change, heat fluxes, wind forcing, etc.). Better characterizing this seasonal cycle and its geographic dependence is

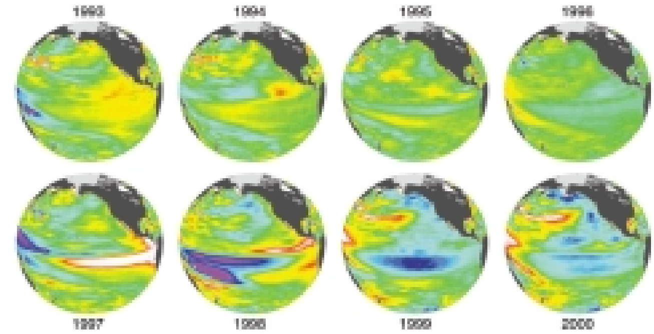

Figure 1: Yearly Averaged Ocean Topography of the Pacific Ocean from the T/P data 1993-2000. See the high sea level expansion (in white), created by the 97 El Niño, along the east equatorial Pacific which is replaced in 98-99 by La Nina negative anomaly (in blue) (Courtesy of NASA’s Jet Propulsion Laboratory.)

especially important for evaluating and continuously adjusting the ocean and climate models. This is among Jason-1’s primary objectives. The seasonal cycles differ from one year to the next because of inter-annual changes that have a direct impact on climate (figure 1). The “El Niño” episodes in the tropical Pacific, including the strong 1997-1998 event, are dramatic examples of such inter-annual anomalies corresponding to strong interactions between ocean and atmosphere. Other inter-annual events have been detected, like the North Atlantic Oscillation, but longer period changes (10 years and more) will not be observable until Jason-1 adequately complements the T/P time series. Understanding the mixing of these various modes and observing several years of such fluctuations over the globe will improve ocean models and climate forecasting.

Tide models of unprecedented accuracy (2-3 cm rms) have been produced for the main diurnal and semi-diurnal components based on T/P data. These results have improved our knowledge of tides and helped correct the altimetric data for tide effects. These tide models are the result of both the high-quality T/P data set and space-time sampling; that is, the orbit phasing that was optimized to discriminate the various tide components. However, Jason-1 data are required to accumulate further data and fully resolve the long-period ocean tides, as well as those unfavorably aliased constituents, such as K1 aliased close to the semi-annual period. In coastal regions, the expected merging of Jason-1 data with inter-leaved T/P during the tandem mission and other altimetric mission data, will help resolve the short scales of tides (internal waves, coastal tides, non linear tides).

Mesoscale variability has typical spatial scales of 30-300 km and time scales of 1-3 months. It is mainly associated with strong current instabilities, eddy formation, and propagation, which are very energetic and have a key role in heat transport from low to high latitudes.
This mesoscale energy concentration was revealed in the global variability maps that were among the first results obtained from altimetry. Also, in the coastal domain— which represents 8% of the ocean surface— there is a complex, short-scale activity involving many processes such as the accumulation of organic matter and fresh water transported by rivers, sea ice at high latitudes, dense water formation, and coastal tides, plus the influence of the open ocean through interactions between coastal currents and open ocean circulation. Understanding such complex processes requires the development of very specific models and the use of various data sources, including altimetry. Jason-1 does not have an adequate space sampling, but it will provide a high-quality data set to serve as a reference when merging different satellite data sets (e.g. Jason-1/T/P Tandem Mission; Jason-1 with ENVISAT), thus giving access to shorter scales

Mean sea level is a pertinent indicator of global warming. Because of thermal expansion, when temperature increases, the ocean occupies a larger volume. Another additional and important cause of sea level rise is ice melt due to temperature increase. If such a sea level rise lasted for hundred years, there would be dramatic social-economic and environmental consequences.
The exceptional accuracy of the T/P data has permitted us to confirm the rise already observed by tide gages. However, this signal, except for the effect of El Niño, represents only 1-2 mm per year, which demands extreme caution when interpreting the results. It requires millimetre-level control on the potential drifts of the altimetric system components (altimeter, corrections, orbit, system reference, etc.). The error in sea level trend estimation decreases as the time series becomes longer and longer, reinforcing the need for permanent altimetric observations and a precise interconnection between successive satellite time series. Jason-1, by ensuring the continuity of the T/P data set, will contribute to the quest for this essential, ultimate goal.

Sea state is also observed by altimetry. In addition to the range, an altimeter provides estimates of significant wave height and wind speed (derived from the shape and intensity, respectively, of the returned radar

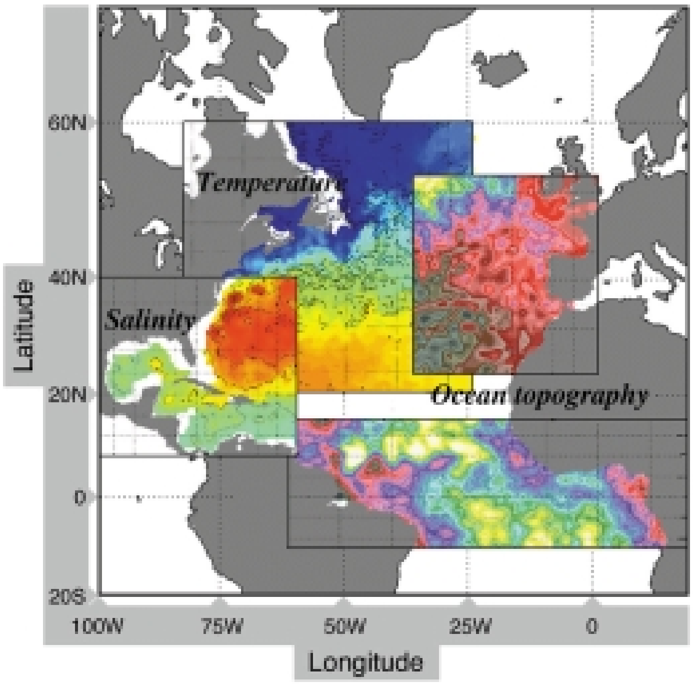

Figure 2: Example of MERCATOR bulletins providing a full description and forecasting of the North Atlantic for different parameters (ocean topography, ocean currents, temperature, salinity). The MERCATOR operational system, based on a 3D ocean model assimilating satellite, including altimetry, and in-situ data, will be extended to the global ocean as part of the GODAE experiment.

waveform), which are of both scientific and operational values to marine meteorology. Altimetric coverage of the sea state and wind speed observations in regions where conventional observations are particularly sparse allow comprehensive studies of these parameters, including time-space characteristics, propagation of swell, and interactions between sea state and currents. These studies, essential to the improvement of meteorological models, require long-term data collection. On the operational side, many weather forecast services now routinely assimilate altimetric data into sea state models. In this regard, the near-real time products of Jason-1, delivered within 3 hours and merged with other satellite real-time data, will be very helpful.

Geodesy, geophysics, glaciology, and hydrology are among the other topics which will benefit from Jason-1 measurements. Geodesists and geophysicists have extracted a great deal of information about tectonics from the short scales (10-100 km) of the altimetric mean sea surfaces derived from previous missions. Jason-1 data will further improve the accuracy. Orbits of satellites, as well as positions of ground tracking stations, will be determined very accurately using DORIS, GPS, and laser data from Jason-1, in addition to tracking and gravity data from other satellites. Such observations have an immediate impact on the reference system quality. They are also essential for updating the Earth rotation parameters, for measuring the vertical tectonic movements, for estimating the large-scale glacial rebound and atmospheric or oceanic load effects and for studying water mass exchange among main reservoirs (oceans, continental water, ice sheets). Monitoring these movements with the required millimetre accuracy is needed for separating them from sea level rise determined from altimetry and/or tides gages. It requires the accumulation of very precise positioning and gravity data simultaneously with highly accurate altimetric data, through Jason-1 missions and follow-ons. Additional interesting results are expected from Jason-1 data by scientists studying sea ice, enclosed seas, lakes, large rivers, and flat continental topography, despite the non optimized technical design and orbit geometry for such applications.

Operational applications that were successfully demonstrated during the T/P mission, will be developed and extended during the Jason-1 mission. As a key component of dedicated programs (GODAE), and jointly with other ocean observation satellites and in-situ networks, Jason-1 will mark the beginning of a new era in operational oceanography. Such operational experiments include 4D high resolution description and forecasting of the Ocean for further climate prediction (figure 2), applications in ship routing, off-shore activities, fisheries management, coastal environment survey and marine meteorology.

	TOPEX	Jason-1
Satellite mass Satellite power Platform mass	2500 kg 1000 W 980 kg	500 kg 450 W 270 kg
Platform power Payload mass	500 W 385 kg	300 W 120 kg
Payload power	380 W	147 W
Altimeter mass	230 kg	55 kg
Altimeter power	260 W	78 W
Launch	Dedicated AR4	Dual Delta II

Table 1

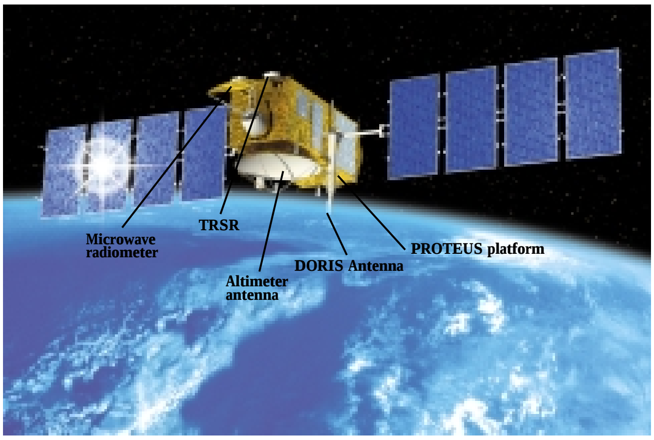

Figure 3: An artist's view of the Jason-1 satellite in orbit (Courtesy of CNES/NASA).

The Jason-1 system

As mentioned previously, the Jason-1 mission was designed to allow an optimum continuation of the T/P mission and meet the long-term observation requirements [AVISO Newsletter 7, 2000]. The satellite (figure 3) is designed for a 3-year minimum duration, with potential for an additional 2 years. Every 10 days, it will overfly within 1 km the reference T/P ground-tracks (66° inclination, 1336-km orbit), measuring sea level with equivalent or better accuracy than T/P. This mini-satellite will be the first to use the generic PROTEUS platform developed by a partnership between CNES and Alcatel Space Industries. The technology improvement and electronics compact packaging has led to a decrease of the satellite resource needs. Thus, the total weight and on-board power will be less than 500 kg and 450 W, respectively, compared with 2500 kg and 1000 W for T/P (table 1).

The Jason-1 payload includes the same package as for T/P. CNES provides the POSEIDON-2 altimeter, which is a solid-state, low-power-consumption, low-mass instrument. It is derived from the POSEIDON-1 altimeter but works at two frequencies (13.6 GHz and 5.3 GHz) to enable an ionospheric correction accuracy in accordance with the required error budget. The DORIS Precise Orbit Determination system, whose performance has been demonstrated on T/P, is also provided by CNES (figure 4). NASA and JPL developed the three-frequency microwave radiometer, which will be used to compute the troposphere path delay correction with the needed accuracy. A Global Positioning System (GPS) receiver

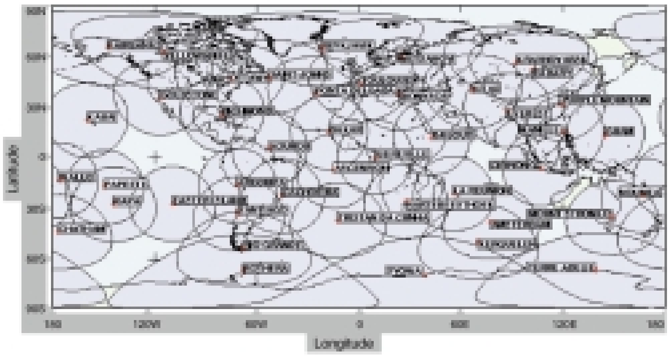

Figure 4: The permanent Doris global network is composed of about 50 beacons ensuring a unique coverage of the Jason satellite orbit

and a laser Retroreflector Array, also provided by NASA and JPL, will participate in the precise orbit determination effort. The U.S. Delta II vehicle will be used to launch the Jason-1 satellite, jointly with the TIMED (Thermosphere, Ionosphere, Mesosphere Dynamics) satellite, from Vandenberg Air Force Base in California.

The raw engineering Jason-1 data will be recorded onboard the satellite, then transmitted to the ground when over-flying the two main telemetry stations located in Aussagel near Toulouse, France, and Poker Flat, Alaska. One back-up station is located in Wallops, Virginia.
In addition to these Earth terminals, the control ground system will include a satellite control center located in CNES and a project operation control center (POCC) at the Jet Propulsion Laboratory in Pasadena, California. The mission ground system will be responsible for instrument programming/monitoring, as well as scientific product generation and distribution. It will comprise 1) a CNES center called SSALTO (Segment Sol Multimission Altimetry and Orbitography), which will work not only for Jason-1, but also for other DORIS missions and ENVISAT altimeter mission; and 2) a NASA center, which is part of the JPL POCC and derived from the T/P ground system.

Error budget and products

The error budget requirements for the Jason-1 Geophysical Data Record (GDR) are similar to those of the post-launch T/P GDR error budget (table 2).
The sea-surface height will be provided with a global and ultimate rms accuracy of 4.2 cm (1 sigma) over 1 s averages along T/P ground-tracks for typical sea-state conditions of 2 m SWH (Significant Wave Height) and 11 dB sigma-naught (the normalized radar backscatter coefficient). This error budget includes the altimeter noise, uncertainties in corrections of atmospheric path delays, sea-state related biases, and orbit error.
The Interim GDR (IGDR) error budget is the same as the GDR except for the orbit, which is not fully validated in IGDR. In addition to these requirements, goals, currently called “the 1-cm challenge”, 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 for the sea-level height over 1 s average. The drift of the system (after calibration) shall not exceed 1 mm/yr to meet the objective for mean sea level monitoring.

The GDR will constitute the final and fully validated products. They will be systematically delivered to data users within 30 days and archived as permanent records. They will contain, at a rate of 1 record per second, the best estimates of range measurement, the time tag and Earth location, plus the best associated instrumental and environmental corrections and the most accurate orbit altitude. All of these parameters will be validated during the verification phase of the mission. The GDR, structured like that of T/P, will contain additional geophysical parameters; that is, wave-height, sigma-naught and derived wind speed, atmospheric surface pressure, tides, mean sea-surface, and geoid. The altimeter radar instrument bias and drift and the relative bias between T/P and Jason-1 time series will be provided.

The IGDR and Operational Sensor Data Records (OSDR) will support near-real time applications, including mesoscale and coastal applications, climate forecasting, and marine meteorology. Wind speed, significant wave-height (SWH), and their forecast are of interest to many activities related to maritime industries. The key requirement for operational use of altimetric data in

Measurement	3 hours (OSDR)	3 days (IGDR)	30 days (GDR)	30 days (goal)
Range to surface (cm, corrected)	4.5	3.3	3.3	2.3
Radial orbit height (cm)	30	4	2.5	1
Sea-surface height (cm)	**N/A**	**5**	**4.2**	**2.5**
Significant wave height (cm)	50	50	50	25
Wind speed (m/s)	2	1.7	1.7	1.5

Table 2

models is to provide the data quickly. IGDR will be delivered within 3 days, mainly for mesoscale and climate applications. They will contain the same parameters as GDR, but not fully validated and not necessarily in their ultimate accuracy. OSDR will be provided within 3 hours, mainly to support marine meteorology applications. They will contain, at a rate of 1 record per second, all parameters needed for such applications. OSDR products will be less accurate than IGDR (table 2), as they are based on onboard processing for radar altimeter and orbit (DORIS navigator). SWH and wind speed will have a respective accuracy of 10% or 0.5 m—whichever is greater—and 2 m/s. For specific applications (over ocean, coastal areas, lake, land, or ice), the Sensor Geophysical Data Records (SGDR) containing waveforms will be made available to users.

As for T/P, the Jason-1 Science Working Team will actively participate in the Calibration/Validation effort for assessing, validating the geophysical data and products, checking and updating the error budget, cross-calibrating T/P and Jason data (taking advantage of the two-mission overlap), and adjusting the ground data processing algorithms [CALVAL plan, 2000]. These activities will be particularly intense during the verification phase, the first 6 to 8 months of the mission. This phase will anticipate the operational phase and the generation of GDR data that will be freely distributed to a growing population interested in using high accuracy altimetry in their scientific activities.

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