Jason–1 CALVAL Plan

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JASON-1 CALVAL PLAN

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1.0 INTRODUCTION

The Jason-1 Joint Verification Plan (JJVP) describes the activities of the Jason Joint Verification Team (JJVT), which consists of members of the project and the science working teams as well as external contributors. A similar plan developed for TOPEX/POSEIDON (T/P) [see T/P Joint Verification Plan, June 1992, JPL Pub 92–9] serves as a model for the JJVP. The JJVP focuses primarily on the verification phase of the mission. Some of the activities however are planned to continue over the life of the mission.

This document includes three sections: Section 1 provides an overview of the Jason-1 mission, i.e. the objectives, description of the mission and the data products. Section 2 is focused on the Jason-1 CALVAL organization, requirements and specifications in terms of performances. Section 3 presents the various experiments and analyses that will be conducted by project teams and investigators in order to support verification activities.

1.1 Mission Overview

The Jason-1 mission is considered to be the follow-on to the successful TOPEX/POSEIDON (T/P) mission. Jason-1 will have the same performance, and will fly over the same ground-tracks as the T/P mission, but using a smaller satellite (500 kg class versus 2500 kg for T/P) in order to reduce the cost. The T/P mission has capitalized on the full potential of altimetry in physical oceanography. A wide range of scientific research and applications in physical oceanography has passed a major turning point thanks to the arrival and the exploitation of uniquely accurate T/P measurements. This success is even greater than expected because the measurement system has performed well beyond the initial specifications, and thus has opened up many new perspectives on research. T/P is widely held to be a unique tool which has enabled significant progress in the understanding and modeling of ocean circulation and consequently on its climatic impact. It has also made essential contributions in other domains, like the monitoring of global mean sea level, and the study of tides, marine meteorology, geophysics and geodesy. The exceptional results obtained from the T/P mission and the need for longer time series have convinced scientists of the necessity of continuing beyond T/P by implementing the Jason-1 follow-on mission.

Soon after the launch of T/P in August 1992, and following a comprehensive analysis of the system performance, the Science Working Team of the T/P mission recommended studies to address a follow-on to T/P. Early in 1993, CNES and NASA started a new cooperation on this follow-on satellite, Jason-1. The main motivation was to provide the same level of performance as T/P, offering the capability to pursue the mission under the same conditions. The success of the T/P mission was due primarily to an appropriate optimization of the system: instruments, satellite, and orbital parameters were all specifically selected to fulfill the objectives of the mission. The Jason-1 mission was conceived in the same spirit, taking into account the T/P heritage, but keeping in mind the desire to build a smaller satellite (to reduce costs) which delivered the same level of performance. In addition, near-real time applications have been included in the main objectives of the mission. Jason-1 is the first in a series of missions designed to deliver T/P quality sea-level records well into the next millennium.

1.2 Mission Objectives

Like T/P, Jason-1 is designed to provide accurate sea-surface topography to determine the general circulation of the ocean and to understand its role in the Earth climate, and in the hydrological and biogeochemical cycles. Highly accurate global and homogeneous sea level measurements (approaching 1 cm at basin scale) are needed to precisely determine the ocean currents and associated climatic variations. Thus, the major focus of the Jason-1 mission is to pursue the unique accuracy, continuity and coverage of the T/P mission 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, geophysics and geodesy.

In addition, Jason-1 will support preparation of forthcoming operational ocean services. In particular, the mission will be used to develop and to test—in real-life conditions—data access systems and tools that will be running in quasi-real time within these operational structures. Several objectives have been identified in relation to CALVAL activities, and oceanographic campaign support, and to oceanographic (mesoscale and climate related) and meteorological applications.

Additional detail on these objectives is provided in the document “Jason-1 Science and Near-Real Time Requirements” (TP2-SB-J0-102-CNES).

1.3 Mission Description

Jason-1 will use an Earth orbiting satellite equipped with a radar altimeter and other instruments to directly measure sea-surface elevation along the fixed grid of sub-satellite ground tracks traced out by the T/P satellite. In so doing, Jason-1 will continue the data collection started with T/P. The sea-surface height measurement must be made with an accuracy of 4.2 cm or better (at 1 Hz) in order to meet the mission objectives. The Jason satellite is specified and designed to fulfill the mission objectives (Ref TP2-SB-J0-100-CNES) and is scheduled for launch in August 2001 to take over for T/P. Since Jason-1 is also intended as a precursor to future operational missions, distribution of altimetric products (non-validated) in near real time (3-hour data latency) is planned. The interim (IGDR) and definitive (GDR) science products will be delivered later (3 days and 30 days respectively of data latency), following the model used for T/P.

The ocean topography is obtained through two basic measurements: 1) the satellite range above the sea surface derived from the altimeter; and 2) the altitude of the satellite above the reference ellipsoid derived from precise orbit determination. The altimeter uses radar pulses to determine precisely the distance between the satellite and the ocean surface by measuring the time it takes for the emitted pulse to return. The shape and the amplitude of the echo enable the estimation of wave height and wind speed respectively. Geophysical corrections are then applied to compensate for the measurement errors introduced by propagation through the troposphere and ionosphere and errors induced by sea state.

The **Jason-1 payload** (Figure 1.1) includes:

Altimeter (Poseidon 2): The two-frequency solid-state altimeter, providing range with accurate ionospheric corrections, draws its heritage from the single frequency Poseidon altimeter and operates at 13.575 GHz and 5.3 GHz. It is a low power consumption, low-mass instrument. Poseidon 2 electronics are configured in two boxes: the processing unit (PCU) and the radiofrequency unit (RFU). The Poseidon 2 antenna (1.2-meter diameter) is located on the nadir face of the satellite.

Jason Microwave Radiometer (JMR): The three-frequency microwave radiometer consists of three separate channels at 18.7, 23.8 and 34.0 GHz, the central frequency being redundant. The 23.8 GHz channel is the primary water vapor sensor. The 34 GHz channel provides a correction for cloud liquid water and the 18.2 GHz channel provides the correction for effects of wind-induced enhancements in the sea surface background emission. The antenna will be a fixed-offset paraboloid and will be located on the front of the satellite.

Doris: The complete Doris system, a key component of the Precise Orbit Determination system, includes the Doris on-board package, a network of approximately 50 beacons located around the world and a ground system. The on-board package includes the receiver itself, the ultra-stable oscillator and an omni-directional antenna located on the nadir face of the satellite. It will include a dual beacon receiving capability and an on-board real time function (DIODE for «Détermination Immédiate d'Orbite par Doris Embarque») to compute the orbit ephemeris accurate to 30 centimeters (1 standard deviation).

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

TRSR: The Turbo Rogue Space Receiver (TRSR) is an advanced codeless Global Positioning System receiver featuring channels for tracking all GPS spacecraft in view on two L-band frequencies. The on-board package is comprised of dual redundant TRSR units and choke ring antennae. The purpose of the GPS data is to provide supplementary positioning data to Doris in support of the POD function and to enhance and/or improve gravity field models.

The **Jason satellite bus** is derived from the PROTEUS (Plate Forme Reconfigurable pour l'Observation de la terre, les Telecommunications et les Utilisations Scientifiques) small platform (500 kg class) jointly developed by CNES and ALCATEL. A Jason specific payload module is being added to this platform to accommodate the Jason-1 instruments.

NASA will provide **launch** of the Jason satellite. The launch vehicle will be a Delta II 7920, a two-stage liquid rocket with 9 solid propellant motors strapped to the first stage. Launch is scheduled for August 2001 from Vandenberg Air Force Base over the Western Test Range.

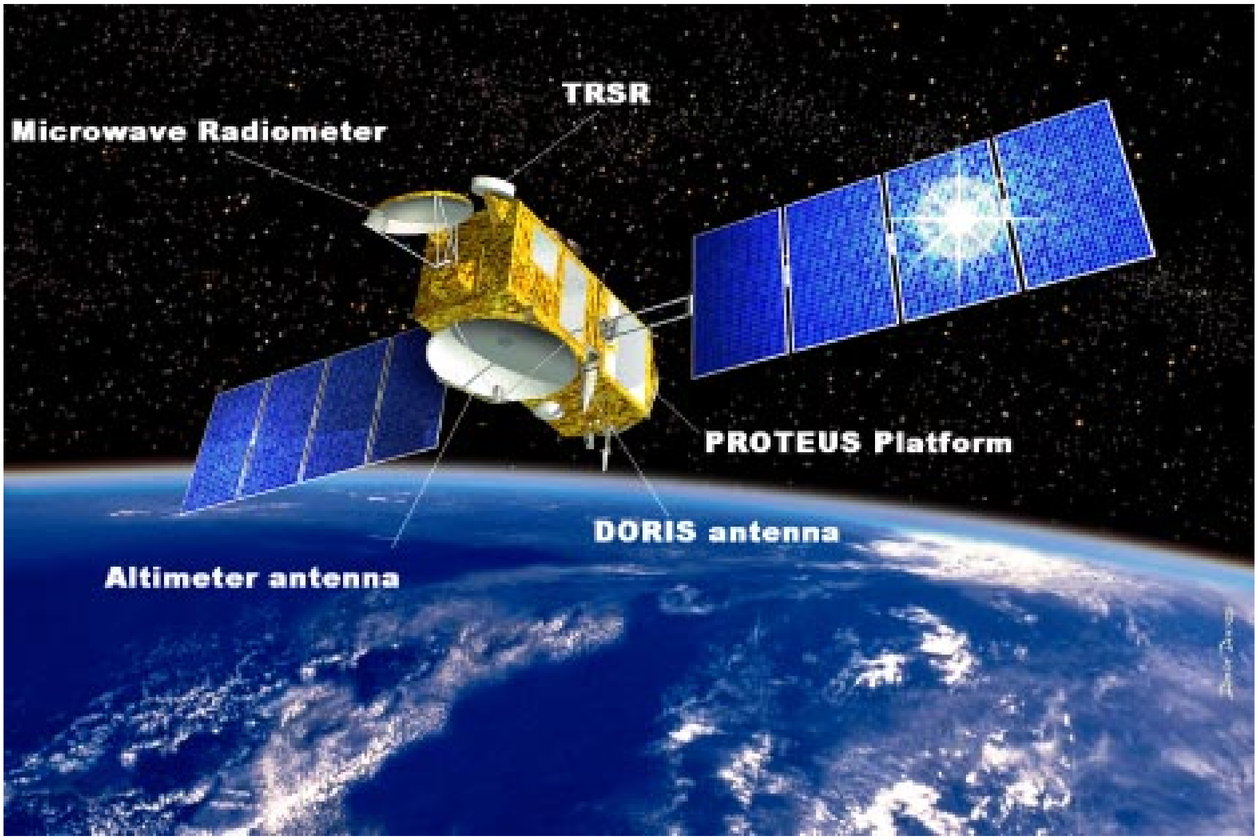

Figure 1.1: Artist view of the Jason-1 satellite

The **control ground system** includes the Satellite Control Center (SCC) located in Toulouse which monitors the satellite over the complete mission lifetime and controls the satellite until the end of the assessment phase. Also included in the control ground system is the Project Operation Control Center (POCC) in Pasadena. The POCC will control the satellite and associated instruments after the assessment phase until the end of the mission. The third component of the control ground segment is an earth terminal network for capturing telemetry and uploading satellite commands, with one terminal in Pokerflat (Alaska) and the second one in Aussaguel (France). A third earth terminal at the Wallops Flight Facility (Virginia) is planned as a backup.

The **CNES mission ground system** includes a mission center (SSALTO, Segment Sol Multimission Altimétrie et Orbitographie) that will program, monitor and generate command requests for Poseidon-2 and Doris. SSALTO also supports: 1) mission management and operation plan definition; 2) Precise Orbit Determination (POD); 3) algorithm definition and POD data production and validation; 4) scientific altimeter data processing and validation of altimetry products; 5) data distribution and archiving; and 6) the Doris system beacons network.

The **NASA mission center** (part of the JPL POCC) will program, monitor and generate command requests for the JMR and TRSR. The NASA mission center will also process and validate the scientific data products in parallel with the CNES mission center. Finally, they will be responsible for operational altimeter data processing and validation, data distribution and archiving.

1.4 Data Products

The data products are described in detail in the document "Jason-1 User Products" (CNES reference: SMM-ST-M-EA-10879-CN).

1.4.1 Real-time Products

The real-time level 2 product is the Operational Sensor Data Record **(OSDR**). It is a wind/wave product essentially dedicated to users interested in marine meteorology, though the range and orbit information can also be used for other purposes. The OSDR contains: time, location, Ku-Band significant wave height, Ku-band and C-band backscatter (sigma naught), wind speed (from Ku-band data), water-vapor content from the JMR, total electron content, on-board computed Ku-band and C-band altimeter ranges, orbit data (altitude) and quality information derived from onboard data to support editing. It should be noted that availability of near-real time products will be subject to some limitations: their segmentation will be driven by the amount of data dumped over a particular ground station. The OSDR product is a non-validated product. 75% of the OSDR data will be distributed within 3 hours after on-board acquisition, 95% within 5 hours after on-board acquisition.

1.4.2 Off-line Products

Level 2 data are produced from the altimeter level 1b data, combined with a precision orbit estimate, microwave radiometer data from the JMR, and a number of auxiliary data. There are three types of off-line level 2 products:

IGDR: The Interim Geophysical Data Records (IGDR) product essentially contains information on: range, orbital altitude, associated instrumental, environment and geophysical corrections, wave height, back-scatter coefficient and wind speed, brightness temperatures and water vapor from the JMR. Ground re-tracking of altimeter waveforms is systematically applied. The IGDR product is a non fully validated product. 95% of IGDR data will be distributed within 3 working days after on-board satellite acquisition.

GDR: The Geophysical Data Record (GDR) product formally contains the same information as the IGDR product with the exception of a few selected parameters (e.g., the precise orbit height, improved pole location) computed from updated and more accurate inputs. The GDR product is a fully validated and definitive product. 95% of GDR data will be distributed within 30 days after satellite acquisition.

SGDR: The SGDR product contains all information included in the GDR plus information from level 0 and level 1b altimeter data (e.g., waveforms). It is dedicated to altimeter experts interested in quantifying the performance of the instrument itself; it also responds to requirements from science users looking at altimeter measurements taken over non-ocean surfaces (e.g., land, lakes, and ice). Such users often perform their own processing of altimeter data using dedicated waveform re-tracking methods along with all environmental and geophysical corrections. The SGDR will be produced and distributed on request, and is a fully validated product.

The basic geophysical altimeter product list and the main characteristics of each product are summarized in Table 1.1.

Table 1.1: Basic Jason-1 Level 2 Data Products

Main characteristics of the product	**OSDR**	**IGDR**	**GDR**
Content	Non validated level 2 product of the Wind/Wave type	non validated geophysical level 2 product	Fully validated geophysical level 2 product
Alt. Ground retracking	Not applied	Applied	Applied
Orbit information source	DORIS Navigator	Preliminary orbit	Precise orbit
Data latency / Data availability	3 hours / 75% 5 hours / 95%	Shorter than 3 days 95%	3-4 weeks / 95%
Structure	Segment	Pass	Pass
Packaging	Segment	Daily	Cycle
Ground Processing mode	Systematic	Systematic	Systematic
Ground Processing centers	NASA Mission Center (CNES Mission Center**)	NASA and CNES Mission Centers	NASA and CNES Mission Centers

** CNES will systematically produce OSDR products during the verification phase with no constraint on production delays. CNES will continue the OSDR production during the observational phase for specific verification goals and certain expert analyses.

1.4.3 Expert Products

In addition to these standard level 2 products, a certain number of specific products will be made available to specialized users on request.

- Altimeter and Radiometer

Table 1.2 lists the main characteristics of the altimeter and radiometer products that can be used by expert users for specific instrument performance analysis. The radiometer products are described in details in the document: “JMR level 1.0 data products” (CNES reference: SMM-ST-M-EA-12081-CN)

Table 1.2: Jason-1 Altimeter and Radiometer Expert Data Products

Major characteristics of the product	**Altimetric SGDR**	**JMR Level 1.0**
Content	Fully validated geophysical data plus waveforms	Raw radiometer scientific data
Alt. ground retracking	applied	N/A
Orbit information source	Precise orbit	Navigator
Data latency / Data availability	3-4 weeks / 95%	Upon request
Structure	pass	Segments
Packaging	cycle	N/A
Ground Processing mode	On request	Systematic
Ground Processing centers	CNES Mission Center	NASA Control Center CNES Mission Center

- DORIS and GPS data

Table 1.3 lists the main characteristics of the tracking data products that can be used by orbit users for expert analyses and for computation of orbit ephemerides using independent orbit determination schemes. Details about content and format of the products listed in the table can be found in the document: “Positioning and Orbitography External Products” (CNES reference: SMM-ST-M-EA-10882-CN)

Table 1.3. Jason-1 Doris and GPS Expert Tracking Data Products

Major characteristics of the product	**DORIS level 1b**	**GPS Level 1b**
Content	pre-processed DORIS data	pre-processed GPS data
Data latency / Data availability	3-4 days (preliminary) to 3-4 weeks (final)	3 - 4 weeks (final)
Structure	1 file/day	1 file/day
Ground Processing mode	Systematic	Systematic
Ground Processing centers	CNES Mission Center	CNES Mission Center

- Other available user products

Table 1.4 lists the main characteristics of complementary orbit-ephemeris products that can be obtained for specific purposes (e.g., expert analysis of orbit product quality).

Table 1.4: Jason-1 Expert Ephemeris Data Products

Major characteristics of a product	**DORIS Navigator Orbit**	**Preliminary Orbit**	**Precise Orbit**
Content	Position, Velocity	Position, Velocity	Position, Velocity
Data latency	3 hours	Shorter than 3 working days	3-4 weeks
Structure	1 file/day or 1 file/segment	2 files/day (adjusted and predicted)	1 file/day
Packaging	day or segment	day	Cycle
Ground Processing mode	systematic	systematic	Systematic
Ground Processing centers	CNES mission center	CNES Mission Center	CNES Mission Center

2.0 CALVAL OVERVIEW

2.1 CALVAL Objectives and Requirements

During the assessment and the verification phase of the mission (the first 6 to 8 months after launch), all ground-processing algorithms and all critical output quantities and associated errors will be verified and calibrated. This will be done through statistical analysis and by comparison with external measurements. The calibration/verification accuracy will 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 will provide an estimation of the individual drifts of the system components. Instrument calibrations will be monitored at least weekly throughout the life of the mission.

During the verification phase, the Operational data products and Interim Geophysical Data Records (IGDR) will be provided within a short delay of few days (3–5 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 verification phase, a complete report on CAL/VAL activities will be presented to users, including a revised error budget and derived calibration and drift quantities and updated ground-processing algorithms. The verification effort will be pursued beyond the initial verification phase.

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

During the first 3 months of the verification phase, T/P and JASON-1—assuming they are both scientifically productive—will be separated by only 2 to 10 minutes along the same flight path. This formation-flying configuration will enable an optimum cross-calibration/validation of the two data sets, as recommended by the Science Working Team. The T/P IGDR will be provided simultaneously with JASON-1 IGDR for CAL/VAL purposes. Adequate calibrations and drifts will be provided to users to support connection of previous (T/P) and future (Jason-2...) time series with those of Jason-1. Following this preliminary 3-month cross-calibration phase, T/P will be moved to an interleaving ground track in order to increase space-time sampling and thus offer new opportunities for scientific issues.

2.2 CALVAL Organization and Responsibilities

Determination of the uncertainties in the instruments and in the level 2 geophysical products is a continuing process that involves participation of both the project teams and the SWT investigators. The principal objectives of joint verification are to: 1) assess the performance of the Jason-1 measurement system, including the altimeter and orbit-determination subsystems; 2) improve ground and on-board processing; and 3) enable an accurate connection to the TOPEX/POSEIDON time series. To succeed in these objectives, the general approach is to pool the talents and resources of the project and science teams. During the first 6-8 months of the mission, the JJVT will conduct an intensive verification to verify the integrity of the system—and to make adjustments where necessary—before authorizing routine production of the GDR. However, the verification effort will continue afterwards on a routine and permanent basis.

2.2.1 JJVT Organization

The JJVT will be organized to encourage quick and efficient interaction among its members. The two project CALVAL representatives will chair the JJVT. In addition, the team will include: 1) the two project scientists; 2) the CNES measurement-system engineer (MSE) and associate MSE from NASA/JPL; 3) the two system engineers; 3) the POD lead; 4) project representatives in charge of coordinating and reporting on the primary CALVAL topics (e.g., in-situ verification, instrument engineering, tropospheric and ionospheric corrections, sea-surface corrections, POD verification, wind/wave verification, T/P-Jason-1 cross-calibration); and 5) members of the Science Working Team participating in the JJVT.

The exchange of information and data will be done continuously through ftp, electronic mail and the Jason-1 CALVAL web site (http://calval.jason.oceanobs.com). The web site will be a convenient tool for editing widely and quickly CALVAL and quick-look results. During the verification phase, the OSDR products will be made accessible and the IGDR product will be routinely distributed to all investigators, including members of the JJVT. For additional expert analyses, the SGDR and other specific products will be provided on request. After the verification phase, the GDR products will be routinely produced for distribution to the entire scientific community.

2.2.2 Reporting and Archival Plans

During the assessment and verification phases, regular CALVAL progress meetings will be organized at the project level. Inputs from and to SWT members will circulate via ftp, e-mail and the CALVAL web site (http://calval.jason.oceanobs.com). In addition, one mid-term meeting—open to the whole JJVT—plus a final verification workshop at the end of the verification phase—open to the whole JJVT and SWT—will be held to report results, findings and recommendations. In addition to these meetings, verification progress reports will be mailed and/or put on the CALVAL web site (every 1 month), followed by summary reports with separate contributions from project representatives on the subject for which they are responsible (every 2 months). This process should lead to the validation by the SWT of the performances of the system and of the IGDR contents. It will also lead to approval of a revised error budget, including calibration and drift quantities, and recommendations to the project for improvements and/or changes, if any, in the SDS and POD, prior to routine GDR distribution.

During the operational phase, the verification activities will continue, on a routine basis, to continuously check the integrity of the system. Joint verification reports will be produced, on a regular basis (every 6 months), by CMA/CNES with inputs from the JPL project element and from the SWT CALVAL teams. Any anomaly or foreseen change in the system will be reported by CMA/CNES to the project for action. The SWT meetings will serve as a forum to discuss new findings in the scientific community.

2.3 Jason-1 Sampling Requirements

2.3.1 Jason-1 and TOPEX/POSEIDON Phasing

The Jason-1 launch will be scheduled so that the satellite can be placed in formation flight with T/P, assuming that T/P mission is still returning scientifically useful data. The two satellites will trace the same orbital path with one leading the other by one to ten minutes. This "verification tandem mission" will last about three months, and will provide a unique opportunity to carefully cross-calibrate the two systems from both the engineering and geophysical standpoints. Both systems (T/P and Jason-1) will be observing very nearly the same environment within their respective radar footprints, implying high correlation (and thus cancellation) of unmodeled environmental and geophysical signals that can complicate intercomparisons of data from the sensors (e.g., ALT versus Poseidon 2, TMR versus JMR). The close proximity of the two spacecraft in time and space will also enable straightforward analyses to confirm that the Jason-1 geophysical corrections closely match their T/P counterparts. Data from the T/P measurement systems have been extensively and continuously validated since 1992, and as such provide a powerful benchmark against which the Jason-1 data can be evaluated. Such cross-comparisons between T/P and Jason-1 are widely exploited in the CALVAL implementation described in subsequent sections of the plan.

After the "verification tandem phase", the Science Working Team (SWT) has proposed that the T/P satellite be maneuvered into an orbit for which the ground track interleaves the Jason-1 (current T/P) ground track. This interleaving of the T/P and Jason-1 ground tracks will enable the testing of new methodologies for some specific science applications (e.g., direct estimation of surface geostrophic currents and tides, better comprehension of coastal phenomena). At the same time, the Jason-1 satellite will be maintained on the existing T/P ground track to enable seamless continuation of the important scientific time series developed from T/P data beginning in 1992. This interleaving mission phase, called the "science tandem phase", will last until the end of the T/P mission. The present SWT recommendation is to have a separation of 1.4° for the interleaving Jason-1 and T/P tracks. Discussion of this plan; however, is ongoing and consideration is being given to whether ground-track separations of fewer than 1.4° might be more appropriate. Based on the latest simulation studies, this recommendation may be revisited by the SWT. Regardless of the exact choice for the dual ground-track configuration in the "science tandem phase", it will be possible to continue the T/P-Jason cross-calibration using global statistical analyses at the crossover points where the ground track intersect (see section 3.5.2).

2.3.2 In-flight Assessment Phase

The assessment phase begins with the insertion by the launcher of the satellite into the injection orbit. The overall goal of the assessment phase is to verify the global system performance before initiating routine operations. The specific objectives are to verify the proper functioning of the spacecraft systems and to characterize the technical performance of the satellite and ground systems. The tests shall take into account all the modes nominally used by the satellite and its instruments.

During the assessment phase, the SGDR and OSDR data as well as supplemental engineering data files shall be made available to the instrument experts in order to control and validate the instrument performances, as specified in the error budget. The assessment phase shall end after successful completion of the "in-flight assessment review". This review will present a synthesis of the technical performances of the system and its components, and include a status report on the adequacy of operational procedures. This review is planned for approximately 2 months after launch, and will authorize the start of data production for the subsequent verification phase.

2.3.3 Verification Phase

The verification phase begins when the instrument engineering assessment is completed and the operational orbit has been reached (nominal T/P ground track), i.e. about 2 months after launch. This phase, which is expected to last 6 months, will end when instrument and processing algorithms are fully calibrated, validated, tuned, and updated (if needed). (Assuming the T/P mission is still returning scientifically useful data, this beginning of the verification will also coincide with the "verification tandem mission", cf. Section 2.3.1.) During the verification period, intensive CALVAL activities will be conducted based on dedicated in-situ external observations, statistics, cross-comparisons between models, different algorithms, external satellite data (cf. Section 3). During this period, OSDR, IGDR and SGDR will be produced in a timely manner and will be made accessible to project engineers and to the JJVT. The main objective will be to assess the system post-launch accuracy for all error sources and to validate the Geophysical Data Products before distribution to science community. How to best exploit the T/P-Jason-1 formation flight—to accurately cross-calibrate the two systems and associated subsystems—will be one of the key issues (c.f. Section 2.3.1).

Operational validation of pass (and ground-station) dump products prior to release will imply more frequent sampling for routine CALVAL activities. This issue is especially important in view of the operational element of Jason-1 mission requirements.

At the end of the verification phase, the mission center will reprocess all the data acquired since the launch with the calibration data and the algorithms tuned during the verification phase. This will mark the start of GDR production.

2.3.4 Operational Phase

Regular "cycle-by-cycle" validation of geophysical parameters to enable the goal of "1 mm altimetry" and to continuously check the integrity of the system will continue for the life of the mission. "Cycle-by-cycle" validation implies over-flights of verification sites (point measurements), tide gauge calibrations (distributed measurements), and global analysis (see Section 3).

2.4 Jason-1 Measures of Success

For the purposes of verification, we consider the figures of merit commonly used to describe the performance of an altimeter measurement system, i.e. the noise, the media and orbit errors, and the absolute error (bias) and the stability (drift). The global error budget is usually given in terms of RMS for 1 Hz sea-surface height (1 measurement per second), for 2 m SWH and 11 dB sigma naught. Of course, this is not the only figure of merit to consider and it is important also to understand the spectral, geographical and temporal characteristics of measurement errors and how they affect the final ocean products. A number of techniques will be used throughout the mission to isolate and examine comprehensively a variety of error sources.

In the case of Jason-1, it has been specified that the system should be at least as good as that of the T/P system. Consequently, the requirements for the Jason-1 GDR are derived directly from the current (post-launch) T/P error budget (Table 1.5). The sea-surface height shall be provided with a globally averaged RMS accuracy of 4.2 cm (1 sigma), or better, assuming 1-s averages. The instrumental and environmental corrections shall be provided with the appropriate accuracy to meet this requirement. In addition to these *requirements*, a set of measurement-system *goals* has been established based on the anticipated impact of off-line ground processing improvements. These improvements are expected to enable reduction of sea-surface height errors to 2.5 cm RMS. Knowledge of the stability of the system is especially important to the goal of monitoring the change in the global mean sea level. (This is why it is expected to know the system drift within 1 mm/year as a goal.)

2.4.1 Single-Pass Measurement Accuracy

2.4.1.1 Range Noise

Random noise is the figure of merit most often associated with altimeter performance and is generally accepted as being of fundamental importance. Prior to launch, estimates of instrument noise will be obtained from theoretical design considerations and numerical laboratory tests (cf. Section 3.1.1). However, it is also important to understand the noise characteristics once the altimeter is in the operational space environment. This understanding will be gained by: 1) performing polynomial fits directly to small batches of altimeter data; 2) examining the spectral density derived from Fourier analysis; 3) comparing with T/P measurements during the tandem flight formation; and 4) comparing in-flight results with those from ground-simulations. The dependence of the monotonic increase in altimeter noise with increased SWH will be quantified by such analyses.

As for Topex altimeter, the noise figure for the Jason-1 altimeter will be a combination of the system noises from the Ku- and C-band channels (which provide the two frequencies necessary for correcting the ionospheric path delay). The best Poseidon-2 performance—as reflected in the (I)GDR product(s)—will be derived from ground-processing of waveform data. This is expected to yield performance similar to that of the TOPEX altimeter, i.e. 1.7 cm for 1-s along-track averages with 2-m SWH and 11-dB sigma naught. This noise shall not exceed 4 cm at 6 meters

SWH. A performance *goal* of 1.5 cm has been established for 2-m SWH. For the OSDR, the noise will be somewhat higher (2.5 cm) owing to the use of the on-board tracker.

Table 1.5: Jason-1 Error Budget for Data Products (Requirements and Goals)

Jason-1 Products and Performances (cm)

	OSDR 3 Hours	**IGDR 3 days**	**GDR 30 days**	**GOALS**
Altimeter noise	2.5	1.7	1.7	1.5
Ionosphere		0.5	0.5	0.5
EM Bias	2	2	2	1
Tracker Bias	2	1	1	0.2
Skewness	2	1	1	0.2
Dry troposphere		0.7	0.7	0.7
Wet Troposphere		1.2	1.2	1
Altimeter range RSS		**3.3**	**3.3**	**2.25**
RMS Orbit (Radial component)	**Spec: 30**	**< 4**	**2.5**	**1**
Total RSS sea surface height		**5**	**4.2**	**2.5**
Significant wave height	10 % or 0.5m	10% or 0.5 m	10% or 0.5 m	5% or 0.25 m
Wind speed	2 m/s	1.7 m/s	1.7 m/s	1.5 m/s
Sigma naught (absolute)	0.7 dB	0.7 dB	0.7 dB	0.5 dB
Sigma naught (relative)	0.2 dB	0.2 dB	0.2 dB	0.1 dB

2.4.1.2 Level 2 Sea-Surface Height

The sea-surface height above the ellipsoid is obtained by differencing the range measured by the radar altimeter—corrected from atmospheric and sea-state effects—and the altitude of the satellite given by the Precise Orbit Determination system (Figure 1.2).

The group velocity of the altimeter radar pulses is slowed by the presence of free electrons in the Earth’s ionospheric layer. As the total-electron content is highly variable in time and in space, accurate measurement of the resulting delay requires fine sampling coincident with the radar measurements. The ionospheric dispersion is linear, and thus the delay can be computed by combining the dual-frequency measurements of the radar altimeter. The typical accuracy of the resulting correction is 0.5 cm or better (excluding in the case of Topex/Poseidon a potential bias of up to 1 cm). Ionospheric delay also can be inferred from dual-frequency DORIS measurements, but with lesser accuracy, owing to the time-space interpolation required of the DORIS observations to provide a nadir measurement. The DORIS correction is considered a backup to the nominal (dual-frequency) altimeter correction. Comparing at a global scale the DORIS-based ionospheric correction with that of the nominal dual-frequency is an appropriate exercise for verifying the quality of this correction. Comparisons involving ionospheric corrections derived from globally distributed GPS tracking stations will also be conducted to assess the accuracy of this correction. Additional detail on validating the ionospheric delay correction is provided in Section 3.2.2.

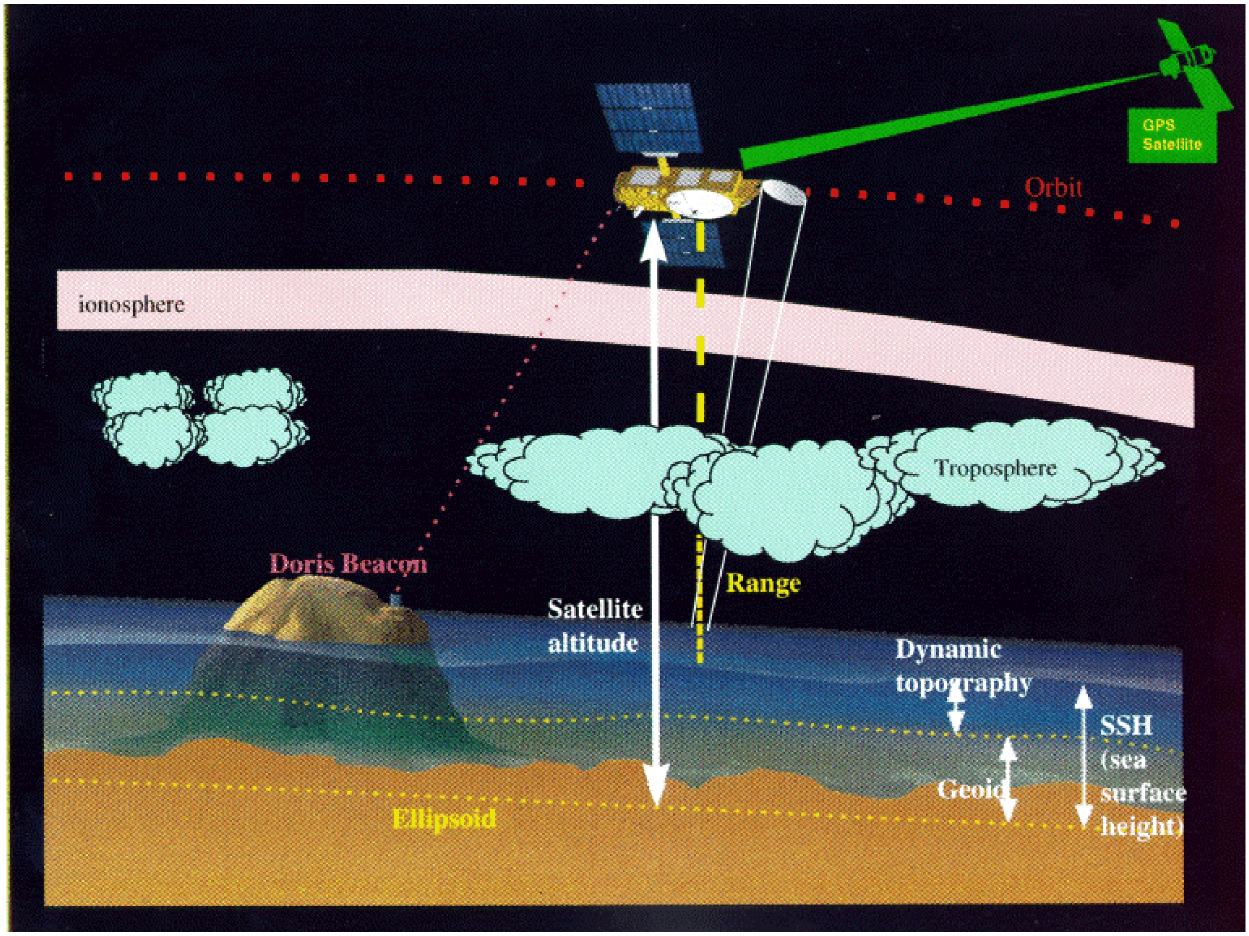

Figure 1.2: Geometry of the sea surface height measurement by altimetry

The troposphere also delays the radar-altimeter signals. The dry air mass of the atmosphere implies a delay of 0.27 cm per mbar. The ECMWF atmospheric pressure products used to derive this dry-troposphere correction have an RMS accuracy of about 3 mbar, implying an RMS accuracy of 0.7 cm for the correction itself. Errors in the dry-troposphere correction can be partially characterized using differences of various model pressure outputs (i.e. FNOC, ARPEGE, ECMWF); however, it should be kept in mind that the competing models assimilate many of the same meteorological observations. Radiosonde data may provide a more accurate, though spatially limited, portrayal of the errors.

The water vapor of the troposphere is another cause of altimetric path delay. The three-frequency radiometer on-board Jason-1 (JMR) will measure brightness temperatures to support retrieval of the wet-tropospheric correction with an accuracy better than 1.2 cm. Comparisons with ground-based radiometers, and radio-soundings, as well as other space-based radiometers (e.g., SSM/I) will be used to calibrate the JMR algorithms and to estimate the attendant uncertainties. The troposphere affects the radar signal at various time-space scales, from high frequencies and small scales (e.g., in the vicinity of atmospheric fronts and near the coasts) to low frequencies and large scales. Additional details on validating the wet tropospheric delay correction are provided in Section 3.2.1.

The Electromagnetic bias (EMB), and skewness and tracker biases affect the accuracy of altimeter measurements and are all dependent on SWH. The EMB results from the fact that the radar senses an average sea surface lower than the true average sea surface, due to amplification from wave troughs. This bias can be expressed as a percentage of SWH, with the percentage being a complex function of the sea-surface slope and elevation statistical distribution. Current attempts to model the EMB take into account SWH and wind speed as determined from the altimeter. Associated errors on the EMB estimate for T/P are on the order of 0.5% to 1% of SWH (the correction itself being between 1% and 4% of SWH). This gives an error of 1 cm to 2 cm for the typical SWH of 2 m, but this error can reach more critical values in the high-latitude regions that experience consistently high SWH. It is likely that EMB model variations with surface conditions will be better understood for JASON-1, thanks to on-going studies oriented towards better statistical and theoretical approaches and use of dual-frequency measurements. Consequently, it is expected as a goal to decrease the current error by a factor 2 (1 cm at 2-m SWH, or less than 0.5% at all SWH). Skewness in the sea-surface elevation distribution induces a range bias because the tracker is designed to measure the median rather than mean height of the reflecting surfaces. The skewness error is approximately λ*SWH/24, where λ is between 0.1 and 0.3, giving about 1 cm error for a λ error of 0.1 at 2 m wave-height. However, waveform processing is expected to provide a more accurate estimate of this effect (0.2 cm level as a goal). The tracker bias is related only to the performance of the tracking algorithm. It can differ from one instrument to another but is always proportional to SWH. This tracker bias shall not be higher than 1 cm for JASON-1, with a goal of 0.2 cm based on comprehensive waveform retracking. The complexity of the overall sea-state bias (EMB + tracker bias + skewness) makes it quite challenging to verify the performances of the proposed corrections. Statistical analyses, on-site and airborne experiments, and multi-altimeter cross-comparisons will be used to improve and verify the sea-state bias correction.

Based on the performances of the altimetric system and associated media corrections, the range of the satellite above the sea surface will be measured with an accuracy of 3.3 cm RMS at 1 Hz sampling for typical sea state conditions of 2-m SWH and 11 dB sigma naught. Expected off-line improvements in the processing are expected to decrease the overall range error to the RMS level of 2.25 cm.

A long-lead effort by NASA and CNES to improve gravity, force modeling, and reference system characterization, combined with the benefits of comprehensive tracking systems such as DORIS, laser ranging and GPS, have made the T/P POD a revolutionary achievement. The resulting RMS accuracy for the baseline precision T/P orbits is estimated to be 2.5 cm for the radial component. The same level accuracy on the radial component of the Jason-1 orbit will be maintained for the GDR (The requirement for the IGDR is 4 cm). Gravity-model improvements stemming from upcoming gravity missions (CHAMP, GRACE) will be exploited, along with improvements to the nonconservative force modeling, reference systems and measurement modeling. Particular emphasis will be placed on the reduction of geographically correlated errors. Optimal combinations of DORIS, laser ranging and GPS data should also support this objective. Consequently, a goal of 1-cm RMS accuracy on the radial component of the orbit has been set. Teams in charge of the POD will use tracking data and statistical analysis to tune their models, to minimize geographic correlated errors and to determine the spectral characteristics of residual errors (cf. Section 3.6)

The sea-surface height measurement obtained by combining the range derived from the altimeter and the altitude of the satellite derived from POD will be provided with an accuracy of 5 cm RMS and 4.2 cm RMS at 1 Hz sampling respectively for IGDR and GDR. The performance *goal* is 2.5 cm RMS. During the verification phase and throughout mission life, this sea-surface height measurement and its constituents will be calibrated and verified to ensure the accuracies are in compliance with the error budget. This CALVAL activity will rely on dedicated calibration sites, the global tide-gauge network, multi-satellite cross-comparisons and statistical analysis (Section 3).

The OSDR Jason-1 products, mainly used for near-real time applications in marine meteorology, require also a complete verification activity, especially during the verification phase. The quality of this product will be a slightly lower than IGDR and GDR, owing to the very short latency (from onboard processing). However, it will be in accordance with the requirements for the relevant near-real time applications.

2.4.2 Bias and drift

Since its launch in August 1992, T/P has collected several years of high quality altimetric data. Even though this was not among the primary objectives of the mission, these data have been used to monitor the global mean sea level (MSL) trend of 1-2 mm/year with an accuracy of better than 2 mm/year (as inferred from in situ calibrations). This uncertainty will decrease as the altimeter time series grows. The T/P experience has stressed the importance of carefully connecting T/P and Jason-1 data, and of controlling any drift in the system which could contaminate MSL monitoring. For Jason-1, a specific effort will be conducted to control, within 1 mm/year as a goal, any drift in the system.

The planned formation flight of T/P and Jason-1 during the verification phase will be very valuable for connecting the T/P and Jason-1 time series with the required accuracy. This objective will be pursued during the rest of the mission by using in situ calibration experiments. The same in situ experiments, as well as the global dedicated tide gauge network and statistical analysis, will be used to monitor drifts in the overall measurement system.

2.4.3 Level 2 Wind/Wave Estimates

The Jason-1 requirement on the accuracy of significant-wave-height measurements is 50 cm or 10% SWH (whichever is greater) for 1-s average (for SWH between 1 and 20 m). A goal of 25 cm or 5 % has been set based on the expected contributions from off-line ground retracking.

The absolute accuracy of sigma naught will be better than 1 dB (for a sigma naught varying between 7 dB and 16 dB). The sigma drift over 1 year will be measured with an accuracy of 0.2 dB to 0.1 dB as a goal. The derived wind speed accuracy will be better than 2 m/s for 1-s averages (for a range between 3 m/s and 20 m/s). An accuracy goal of 1.5 m/s has been set based on the expected contributions from off-line ground retracking.

Verifying significant wave height (SWH) to 0.25–0.5 m (depending on product latency) and wind speed (from sigma-naught) to 1.5–2.0 m/s (depending on latency) is also an objective of the CALVAL plan. The necessary comparisons will be performed extensively during the verification phase, based on cross-comparisons with in-situ measurements, model outputs and other satellite measurements and will continue on a regular basis afterwards.

2.5 Jason-1 CALVAL Standards

2.5.1. Standards Overview

Jason-1 CALVAL measurement standards will be developed during the verification phase and will be accessible through a link on the CALVAL web site (http://calval.jason.oceanobs.com). It is expected that the standards will simplify exchanges of information among CALVAL investigators, and will foster the development of consensus estimates for various CALVAL figures of merit (e.g., bias and drift). It should be noted that the “standards” in this case are guidelines intended to ease interpretation, exchange and possible combination of high-level results. They will address, for example, sign conventions and preferred altimeter correction terms (e.g., EM bias) to be used in the generation and reporting of errors in the higher-level geophysical estimates (e.g., sea-surface height). The guidelines should not preclude investigators from reporting results based on non-standards corrections. However, the nature and influence of correction should be clearly stated. A “strawman” set of standards for the T/P mission is presently accessible from the CALVAL web site, and provides a template for the Jason-1 mission.

As can be seen from the T/P template, the standards will reflect an emphasis on the verification of the principle geophysical measurements (cf. Section 2.4), the most important of which is sea-surface height (SSH). As a general guideline, geophysical quantities are preferred over sensor quantities in reporting results (when there is a choice). For example, the use of sea-surface height is preferred over altimeter range when reporting bias and drift from high-level calibration time series. This should not preclude the use of the latter convention if the objective is to calibrate the range measurements (C or Ku-band) themselves. While important, verification of corrections for the geophysical phenomena underlying the spatial and temporal variability of SSH (e.g., tides, pressure loading, geoid variations) is considered a secondary CALVAL objective. Treatment of the geoid and dynamical ocean effects are important elements of many science investigations, and as such, any correction relevant to them should be validated. However, the error budget requirements for both the T/P and Jason-1 data products pertain to the geocentric sea-surface height, and not to the segregation of this measurement into underlying phenomena.

The standards will also attempt to provide general guidelines for reporting error estimates. It is recognized that the development of standards for reporting error bars is very difficult. Every in-situ CALVAL experiment, for example, has a unique set of systematic errors. CALVAL investigators, however, will be encouraged to provide an estimate of the systematic error component (e.g. in bias an drift) in addition to the "random" error component (underlying which is a simplifying assumption that the point-to-point errors are random and normally distributed).

2.5.2. Consistency with TOPEX/POSEIDON

A principal objective of the Jason-1 CALVAL effort will be to carefully compare and cross-calibrate the measurements against those from T/P (c.f. Sections 2.3.1, 3.5.2). Consistency of T/P and Jason-1 data will be ensured though the generation of a "delta" T/P product during the verification phase. The product will include the corrections derived from Jason-1 models that are difference from those uses for T/P (e.g., tides, mean sea surface, inverted barometer, sea-state bias, model-based wet and dry troposphere and rain flag). The standards will embrace the use of these "Delta" products for T/P in all comparisons with Jason-1. CALVAL issues specific to T/P, to the extent the comparisons to Jason-1 are impacted, will also be addressed by the Jason-1 CALVAL standards on the web site.

3.0 CALVAL IMPLEMENTATION

3.1 Internal Sensor Calibration

3.1.1 Poseidon-2

Requirements on the performance of the Poseidon-2 (POS-2) altimeter are very demanding. The phase noise of the chirp generator, for example, must be lower than 3°. In addition, the level of spurious signals must be kept below -40 dB and the design of the filter must guarantee a constant group delay. Ensuring that these and other requirements are met relies heavily on an extensive pre-launch validation program that is realized through different well-defined steps. To begin, each functional component has been tested; then the radiofrequency and the processing units (RFU and PCU) were tested separately. The integrated altimeter (RFU + PCU) was tested in a stand-alone mode, using an echo simulator that generates ocean-representative echo signals for several values of SWH. Finally, the whole instrument with the antenna was tested.

Two internal calibration modes are implemented in the POS-2 instrument. The first mode (CAL1) gives the measurement of the instrument point target response (PTR) by feeding the signal from the emission channel back to the corresponding receiver. The second mode (CAL2) gives the altimeter transfer function. Another important measurement from the validation exercise is the group delay. As with various other phenomena, the group delay cannot be measured through the internal calibration and, as such, must be determined very precisely before launch. Of particular note are the group delays introduced by the diplexer and the antenna. The measured delays will be treated as corrections in the ground processing.

To characterize POS-2 performance before the launch, a performance simulator is used. The simulator output is used to optimize and validate algorithms, particularly those pertaining to the tracker loop and the on-board and ground retracking. In order to model as closely as possible the real operation of the altimeter, the simulator takes into account various hardware measurements. Moreover, the pre-launch internal calibrations will be provided to the simulator in order to support the development of a correction table describing dependencies of the instrument behavior on significant wave height, signal-to-noise ratio, mispointing and various other external parameters.

Once the different commands (tracking, calibration modes with different configurations) have been well tested after the launch, one of the first tasks will be to compare the results from the on-board internal calibrations with the pre-launch measurements. The calibration results will be processed on an ongoing basis in order to monitor the evolution of the main calibration parameters, such as the characteristics of the PTR (ISLR, central frequency value, level and asymmetry of the side lobes, …) from the CAL1 mode. The CAL2 results will be taken into account in correcting the transmitted waveforms.

In order to validate the POS-2 retracking and the correction tables, the actual transmitted waveforms will serve as input to the altimeter performance simulator. The performance data developed during the pre-launch altimeter testing phase will provide the foundation for confirming the POS-2 performance during the verification phase of the Jason-1 mission.

Measured altimeter parameters will be evaluated after launch. First of all, the science parameters will be studied: e.g., range, SWH, backscatter coefficient, waveforms. These studies will include noise-level estimates using Fourier Transform analysis as well as computation of along-track statistics (mean and standard deviation) over the ocean and other surfaces. Histograms will also be computed for these parameters. These statistics will be computed for the data from both the ground and onboard retracking procedures. The results will be compared against one another and also to equivalent results from POSEIDON-1.

Different operating parameters will be also evaluated, such as the correction terms generated by the tracking loops (AGC, coarse and fine altitude corrections…). Here again, comparisons with simulated results will be possible. Moreover, other data compression rates will be tested: in the default configuration, 124 samples are transmitted to the ground for both bands, but it will be interesting to modify the algorithm parameter values in order to increase the number of transmitted samples.

This Poseidon 2 engineering assessment under CNES responsibility will be complemented by internal calibration activities led by David Hancock and George Hayne at the NASA Wallops Flight Facility (WFF).

3.1.2 Jason Microwave Radiometer

The three-frequency Jason microwave radiometer (JMR) provides an estimate of the columnar water-vapor delay used to correct the altimeter range. When operating nominally, the JMR does not employ a “cold-sky” calibration mode; rather it relies on triple-redundant antenna temperature measurements on each of the three operating frequencies using a new continuous noise injection calibration system. The JMR engineering team at JPL will monitor and ensure the integrity of the noise-diode and antenna temperatures on an ongoing basis. Jason-1 science team investigators will perform intensive post-launch calibration of the JMR brightness temperatures and path-delay retrieval algorithms using ground truth as well as comparisons with data from other spaceborne radiometers and global models (cf. Section 3.3.1).

3.1.3 DORIS

The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receiver measures the Doppler shift to terrestrial beacons broadcasting on two frequencies. This information is used to compute over fixed measurement intervals the average range rate of the Jason-1 satellite with respect to the beacon(s). The information is used to determine the satellites 3D position in real time from an onboard orbit determination system called DIODE (Détermination Immédiate d'Orbite par DORIS Embarqué). The range-rate measurements are also an essential component of the POD activity. The measurements will be thoroughly evaluated as part of the POD verification activity (cf. Section 3.6).

3.1.4 TurboRogue Space Receiver

The TurboRogue Space Receiver (TRSR) provides dual-frequency (L band) measurements of phase (precise ambiguous range) and pseudorange to all GPS spacecraft in view simultaneously. The receiver also produces position estimates for the Jason-1 satellite. The TRSR has no calibration mode: during routine science operations, the receiver is placed in run mode and left to operate continuously. Measurements to all GPS spacecraft are biased by the imperfect TRSR clock; however, this offset is recovered along with the 3D satellite position estimate. The phase and pseudorange data are used for POD and will be thoroughly evaluated as part of the POD verification activity (cf. Section 3.6).

3.1.5 Laser Retroreflector Array

The laser retroreflector array (LRA) is a nadir-oriented array that draws its heritage from the Geosat Follow-On (GFO) mission. Serving as a target for ground-based laser ranging systems, the array supports collection of precise range information for POD. The array is entirely passive, and as such, there are no operation or calibration modes. The number of photoelectrons returned by the array will be evaluated using the detector input of the French transportable laser range system (FTLRS) at the CNES calibration site. A minimum of 5 returns is required; however, the LRA is designed to return 12 at 20^o elevation and 135 at 40^o. The quality of the resultant range data will be thoroughly evaluated as part of the POD verification activity (cf. Section 3.6).

3.2 In-situ Techniques for Evaluating the Overall Measurement System

In situ validation of the overall measurement system will be performed using dedicated verification sites, as well as distributed tide gauges. The principal objective of these programs is to use observations from tide gauges and other sensors directly on (or near) Jason-1 ground tracks to calibrate the sea-surface height and ancillary measurements made by the satellite as it passes (nearly) overhead.

3.2.1 Dedicated Calibration Sites

Both Jason-1 and its predecessor TOPEX/POSEIDON will pass over dedicated verification sites every 10 days as they trace out their repeat ground track. In the traditional "overhead" concept of altimeter calibration, direct comparisons of the sea level and ancillary measurements derived independently from the satellite and in situ data are used to develop a time series of absolute calibration estimates for the satellite sensors (altimeter and radiometer) and the overall measurement system.

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

3.2.1.1 Corsica/Capraia

The prime CNES verification site is located on the island of Corsica, and the experiment and current results are described in detail by *Exertier et al.* [Appendix]. Initially developed in 1996, the Corsica experiment site is currently delivering ground-truth data to support calibration of TOPEX/POSEIDON, which traces out the same ground track as that planned for Jason-1. The fiducial reference point for the distributed experiment is located at Aspretto Air base near Ajaccio and has been surveyed using SLR (FTLRS) as well as GPS and Doris (Figure 3.1). The primary sub-satellite experiment site is located 40 km south at Cape Senetosa, where the TOPEX/POSEIDON (also Jason-1) ascending ground track from pass number 85 reaches landfall. Three coastal tide-gauge locations and accompanying GPS monuments have been surveyed at Senetosa, and sea-level data are being used on an ongoing basis to study and refine the calibration techniques using TOPEX/POSEIDON data.

Using coastal tide gauges at Senetosa offers the advantage of reduced noise in the sea-level data owing to lower significant wave heights. Owing to land contamination of the radar footprint, however, the satellite altimeters (Jason-1 and TOPEX/POSEIDON) are not in track mode as they pass directly overhead the tide gauges. To address this, pelagic GPS techniques [e.g., *Key et al.*, 1998] have been applied to measure the geoid slope between the locations of the open-ocean altimeter measurements and the coastal tide gauges at the principal Cape Senetosa site. The pelagic GPS surveys—carried out using waverider buoys and catamarans in 1998 and 1999 respectively—have provided a highly accurate and repeatable map of the marine geoid in the vicinity of the experiment site. Corrections for the geoid gradient have already improved the repeatability of the TOPEX/POSEIDON bias estimates to a level commensurate with results from offshore calibration sites such as the Harvest oil platform (cf. Section 3.2.1.2).

An extension of the overall calibration program to Capraia Island, located between Corsica and Italy, will provide an additional verification opportunity along the same satellite track (Figure 3.1). The overall program is expected to benefit significantly from the availability of precise laser range measurements from the FTLRS at Aspretto.

3.2.1.2 Harvest

The prime NASA verification site for TOPEX/POSEIDON is the *Plains Resources* Harvest oil platform (Figure 3.2) located about 10 km off the coast of central California and directly under ascending pass 43 [*Christensen et al.*, 1994; *Born*, 1995]. The site is well instrumented, with redundant sea-level systems and a GPS receiver collecting continuous observations since before the launch of TOPEX/POSEIDON. Data from the GPS receiver have been used to monitor the platform subsidence—now estimated at 8 mm/yr—and provide measurements of columnar water vapor and total electron content at TOPEX/POSEIDON overflight times. Sea level systems placed by NOAA and the University of Colorado have been used to calibrate the SSH measurements, and data from an upward-looking JPL J-series water vapor radiometer (WVR) have been used to monitor the TOPEX microwave radiometer (TMR). Calibration time series dating back to the satellite's 1992 launch have been formed from the Harvest data; consequently, the potential systematic in situ error sources have undergone extensive evaluation. The calibration program for Jason-1, which will also fly directly over the platform, will benefit significantly from the occupation history at this site.

Upgrades to the Harvest experiment are underway in anticipation of the August 2001 launch of Jason-1 from nearby Vandenburg Air Force Base. In August 1999, a new TurboRogue Benchmark GPS receiver with advanced codeless tracking replaced the old (1992) model. The new receiver features significantly improved low-elevation tracking, which is expected to offer better performance for the estimation of the platform subsidence and columnar water vapor content. Upgrades to the NOAA and CU sea-level systems are underway and an improved WVR will be deployed before Jason-1 launch [*Ruf et al.*, Appendix; also Section 3.3.1]. *Haines et al.* [Appendix] describe the overall Harvest plans for Jason-1 along with expected results and contributions to the goals of the CALVAL program.

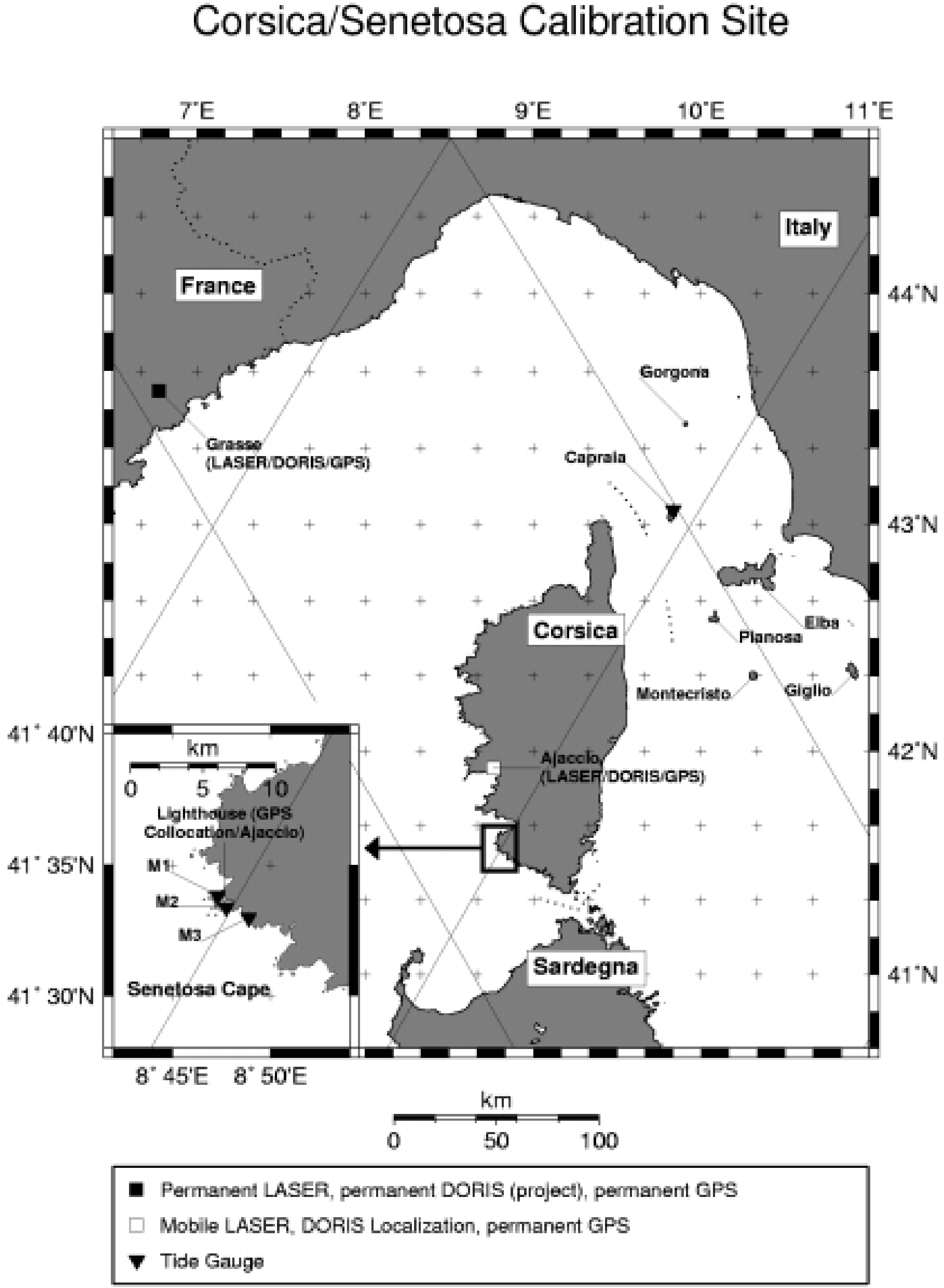

Figure 3.1 Corsica experiment for Jason-1 calibration/validation.

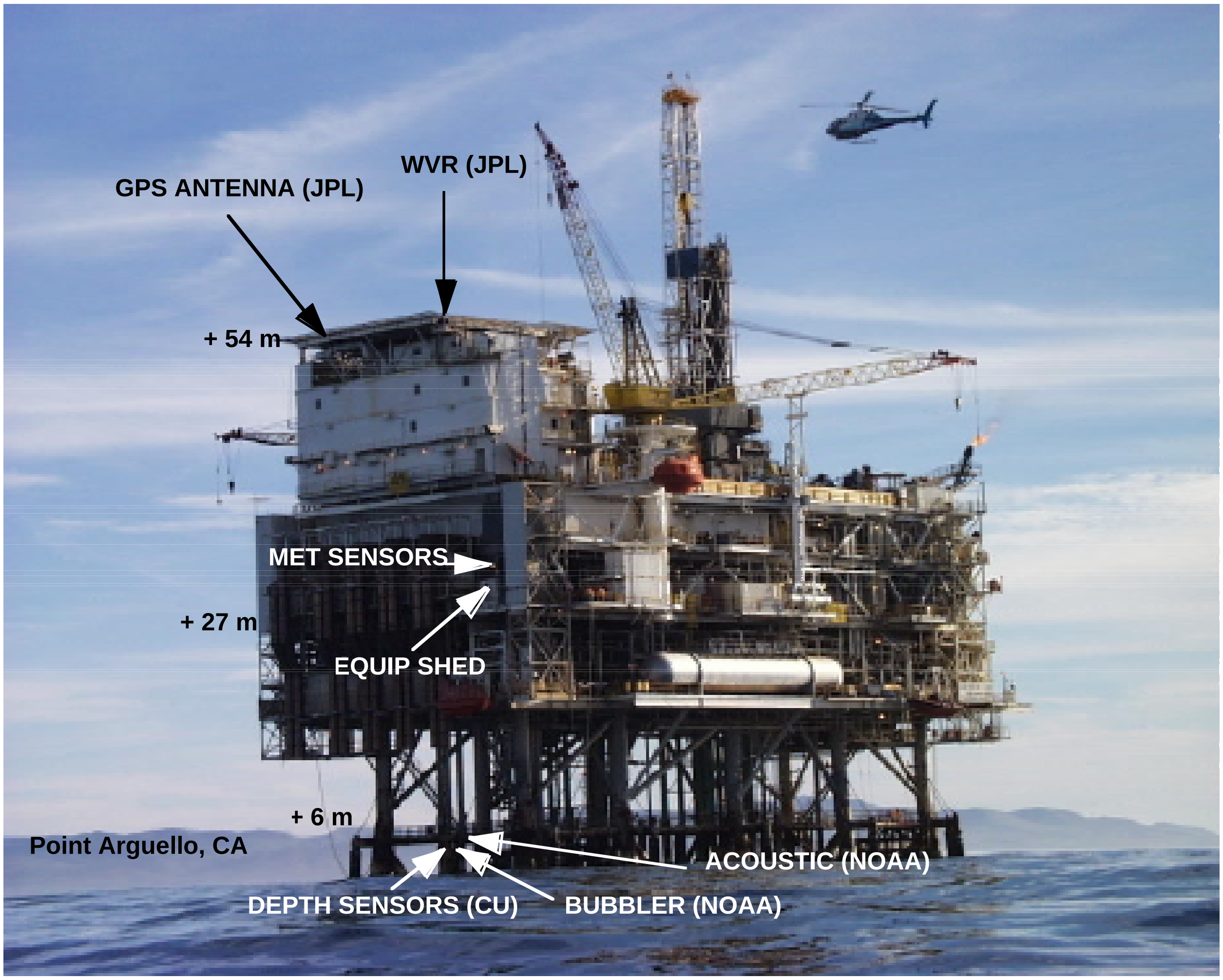

Figure 3.2 The *Plains Resources* Harvest Oil Platform off the coast of Central California. Locations of the instruments comprising the TOPEX/POSEIDON and Jason-1 CALVAL experiments are shown. The platform lies directly along an ascending ground track about 10 km from the coast (Photo courtesy of Chevron USA).

3.2.1.3 Other Dedicated Sites

Successful TOPEX/POSEIDON altimeter calibration facilities were established at Burnie along the Bass Strait by *White et al*. [1994] and for the English Channel by *Murphy et al*. [1996]. In anticipation of Jason-1 launch, the Southern Hemisphere site (Burnie) developed by *White et al.* [Appendix] is being equipped with a permanent GPS receiver to monitor vertical land motions. The Australian agencies participating in the Bass Strait experiment will also be cooperating in the identification of other potential calibration sites in Australia, notably those with proximate tide gauge and GPS receivers. Similarly, the group led by *Woodworth* [Appendix] will be extending the English Channel absolute calibration experiment to make use of additional UK tide gauges now collocated with GPS receivers. The UK facility also enjoys significant benefit from the satellite laser ranging (SLR) station at Herstmonceux.

Activity is also under way to develop additional calibration sites in the Mediterranean. As an extension of the GPS receiver array comprising the Crete REgional TEctonic (CRETE) Experiment, *Pavlis* [Appendix] is developing an altimeter calibration site on the island of Gadvos (60 km south of Crete), fortuitously located along the Jason-1 ground track. Coupled with planned absolute gravity measurements, information from the GPS array will provide important insight on segregating vertical tectonic motion from secular changes in sea level. The possibility of supporting the experiment with DORIS and satellite laser ranging (SLR) is also being explored. In anticipation of Jason-1 launch, a Spanish team led by *Martinez-Benjamin* [Appendix] is undertaking T/P calibration campaigns along the Catalonian coast in the northwest Mediterranean. A coastal tide gauge in the vicinity of Jason-1, ERS and Geosat Follow-On (GFO) tracks will anchor the facility.

Shum et al. and *Rentsch et al.* [both Appendix] are developing altimeter calibration facilities in the Gulf of Mexico and North Sea, respectively, in order to support multiple altimeter missions (ENVISAT and Geosat Follow-On in addition to Jason-1 and T/P). *Shum et al.* are also deploying a GPS receiver to support a calibration site along one the U. S. Great Lakes (Erie). Also noteworthy, *Provost* [Appendix] plans to deploy surface moorings under Jason-1 (T/P) crossover points (2) in regions of high energy and variability. In addition to wind and wave measurements (cf. Section 3.4), the experiments are expected to provide validation information for sea-level variability. Finally, several of the investigations [e.g. *Shum et al.*, *Haines et al.*, *Exertier et al.*, *Woodworth*, *Benjamin-Martinez et al.*, *Rentsch et al.*, all Appendix] contemplate the deployment of GPS buoys under the Jason-1 ground track for absolute "overhead" calibrations without the use of tide gauges [e.g., *Born et al.* 1994]. The advantage of a buoy deployment over a fixed calibration site is that the experiment can be carried out nearly anywhere on the globe. The best determinations of geocentric sea-surface height from a GPS buoy are achieved when a terrestrial (fiducial) GPS site is located nearby. However, recent advances in GPS technology enable accurate positioning even for isolated, roving GPS receivers [*Zumberge et al.*, 1998].

3.2.2 Distributed Tide-Gauge Calibration

While the information from the dedicated calibration sites proved invaluable for detecting biases in the TOPEX/POSEIDON measurement systems, the most reliable external information on the stability of the sea-surface height measurement was afforded by the global tide-gauge network. Cooperating tide gauges in this network are rarely found along the satellite's ground track; moreover, only a few are directly collocated with GPS or Doris to provide information on vertical land motion. When determining the stability of the altimeter measurement system; however, these limitations can be overcome by combining calibration time series from the many distributed tide gauges into a single ensemble result [*Mitchum*, 1998]. The resulting drift estimate provides information that is complementary to the calibration estimates from the dedicated sites.

The significance of this complementary information was amply demonstrated with the 1996 discovery by O. Zanife *et al.* of a TOPEX algorithm error which introduced both a global bias (13 cm) and slow drift (8 mm/yr) in the sea-surface heights. While the effects of the mean component of the error were readily observed by the dedicated calibration sites soon after launch [*Christensen et al.*, 1994; *Menard et al.*, 1994; *White et al.*, 1994], a multi-year calibration time series from the global tide-gauge network was needed to convincingly detect the slow drift [*Mitchum*, 1998; *Murphy*, 1998]. In retrospect, the combined results provided a remarkable portrait of the total effect of the algorithm error on the sea-surface height (Figure 3.3).

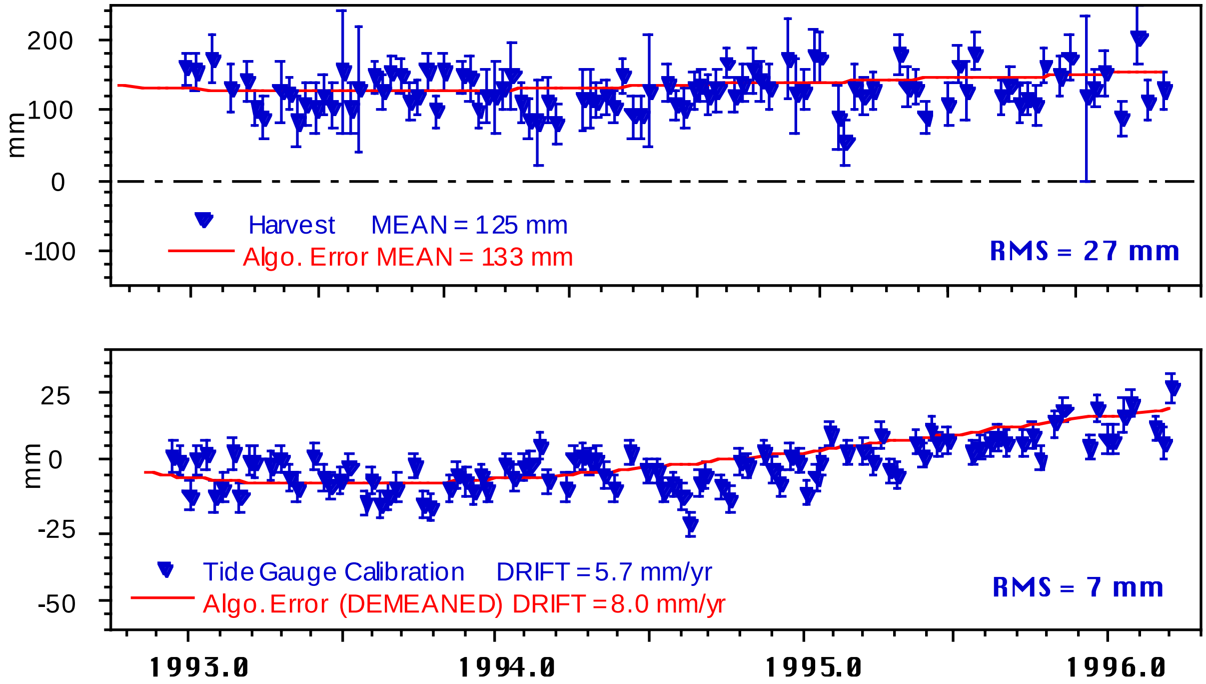

Figure 3.3 Effects of TOPEX oscillator drift error in sea-surface height calibration time series from Harvest (top) and the global tide-gauge network (bottom). Data from the absolute calibration sites [e.g., *Haines et al.*, 1996] were essential for measuring the mean effect, but data from many distributed tide gauges were needed to detect the slow drift [*Mitchum*, 1998].

The TOPEX/POSEIDON altimeter calibration experience helped underscore the urgency of obtaining estimates of vertical land motion at many of the tide gauges participating in the global network. While many GPS and DORIS tracking stations are located near enough to tide gauges to support useful computations of land motion (Figure 3.4), dedicated collocations at key island sites are still needed. This recognition helped spur international efforts to further enhance the global tide-gauge network by identifying 30 selected tide gauges where vertical land motion measurements are essential to support improved altimeter stability estimates [e.g., *Neilan et al.*, 1997; *Mitchum*, 1997]. The use of the tide-gauge network in this capacity has also been a significant agenda for GLOSS [*Woodworth*, 1998], leading to the identification of a subnet known as GLOSS-ALT. *Merrifield and Bevis* [Appendix] at the University of Hawaii Sea Level Center have embarked on a program to provide continuous GPS at 7 of the 30 gauges comprising the altimeter calibration network. Some of the remaining stations are already instrumented with GPS or Doris; thus a major component of the enhanced network will be in place for the 2001 launch of Jason-1.

In the Appendix, *Mitchum and Nerem* describe their plans to extend the global tide-gauge calibration technique to support the joint calibration of the TOPEX/POSEIDON and Jason-1 record of global mean sea level. They also provide figures of merit for the expected accuracy of the stability (drift) and relative bias estimates as a function of data span. In their SWT investigation, *Cazenave et al.* [Appendix] stress the importance of monitoring the vertical crustal motion at the tide-gauge locations, and accordingly, plan to correct the tide-gauge records using available estimates of crustal uplift or subsidence from nearby DORIS, GPS or SLR occupations. The Proudman Oceanographic Laboratory (POL), which hosts the Permanent Service for Mean Sea Level (PSMSL), will also employ tide-gauge data to provide validation of altimeter sea-level variabilities [*Woodworth*, Appendix]. They intend to examine trends in both deep-ocean and coastal areas, with the goal of contributing to the eventual blending of the historical "global" sea-level data from PSMSL with truly global altimetric estimates of sea-level change [*Warrick et al*., 1996]. *Azenhofer et al.* [Appendix] emphasize calibration of multiple altimeters (spanning Geosat to Jason-1) with tide gauges and other in-situ data sources.

It should be recognized, of course, that the stability estimates from the dedicated calibration sites described in Section 3.2.1 can also be combined in a similar fashion, and even assimilated with the estimates from the global tide-gauge network. Indeed, repeated bias estimates from the dedicated calibration sites typically feature the lowest scatter owing to the direct overflight geometry and high instrumentation. An open question for the Jason-1 CALVAL working group will be how to best exploit the contributions of both the dedicated calibration sites and global tide-gauge network in reaching consensus estimates for the bias and stability of the Jason-1 measurement system.

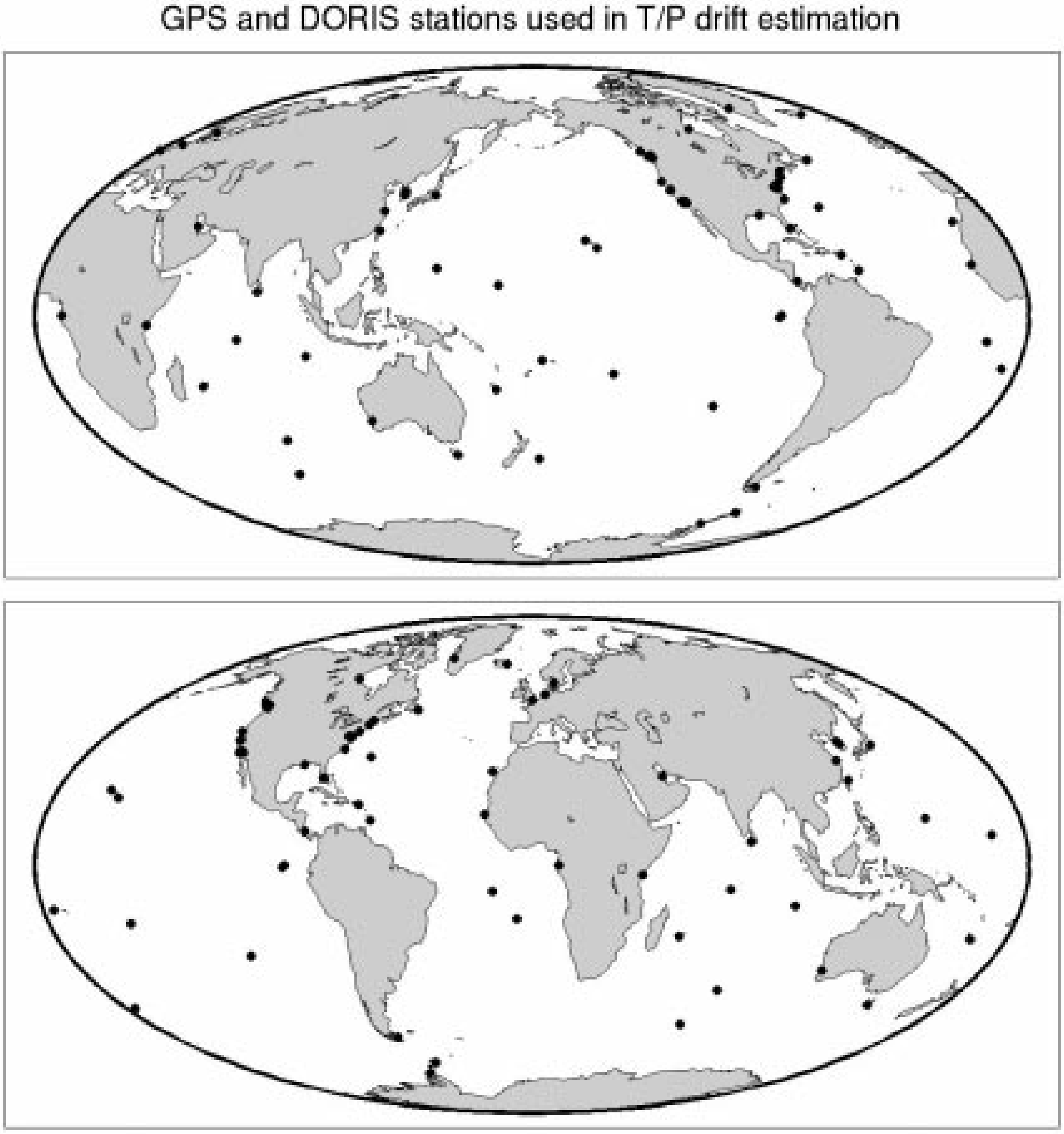

Figure 3.4 Global distribution of current GPS and DORIS tracking stations sufficiently close to tide gauges to provide information on land motion at the gauge locations. Maps courtesy of G. Mitchum (University of South Florida).

3.3 Altimeter Correction Terms: External Verification

3.3.1 Water Vapor Delay

As part of their SWT investigation, *Ruf and Keihm* [Appendix] will perform extensive in-flight validation of the JMR water-vapor path delay measurements to ensure that the single-pass accuracy requirement of 1.2-cm RMS is met or exceeded. The three components of their effort are: 1) assembly of a "ground-truth" database; 2) validation of JMR flight algorithms; 3) long-term assessment of the instrument and path-delay retrieval stabilities. The "ground truth" includes data from an upward looking radiometer (Harvest platform, cf. Section 3.2.1.2), radiosonde profiles and ECMWF fields. It also includes brightness temperature and path-delay measurements from the ERS and Topex microwave radiometers (TMR). During the verification phase, these datasets will be used to look for potential biases in the path delay measurements, and to support subsequent tuning of the retrieval algorithms and associated coefficients. As a longer time series of JMR data become available, possible scale and drift errors in the brightness temperature and path-delay measurements will be recoverable. In view of the ~1 mm/yr drift detected in the wet-path delay measurements from the TMR [*Keihm et al*., 1999], monitoring the long-term stability of the JMR will receive significant attention. Of particular interest are the long-term performance characteristics of the noise diodes, against which the JMR readings are referenced (cf. Section 3.1.2). Jason-1 represents the first mission on which this noise-diode technique has been adopted.

A CMA/CNES project element, led by J. Stum, also plans to support validation of the JMR data. Three types of routine comparisons are envisioned: 1) JMR vs TMR; 2) JMR vs spaceborne radiometers from ERS-2 and Envisat; 3) JMR vs ECMWF. The JMR vs TMR comparison exploits the plan to fly TOPEX-POSEIDON and Jason-1 a few minutes apart and along the same ground track during the initial verification phase. CMA will investigate how much the variance of Jason-1 and TOPEX-POSEIDON sea-surface height differences between two consecutive cycles is changed when using either the TMR or the JMR wet tropospheric correction. This should enable insight on which of the two radiometers is performing better. This characterization will also be performed as a function of path delay. Both the TMR and JMR path delay algorithms will be used in this study. In comparing the TMR and JMR data along track, it should be kept in mind that the channel frequencies are not the same. In order to predict the differences between 18/18.7, 21/23.8 and 37/34 GHz TMR/JMR brightness temperatures, the CMA team notes that theoretical channel correspondence functions should be computed before Jason-1 launch using radiation transfer theory.

Performance of the JMR 23.8 GHz channel will be assessed by CMA using comparisons with data from the ATSR/M and MWR (radiometers on ERS-2 and Envisat respectively). The comparisons will be performed at clear-sky dual satellite crossovers with less than 1-hour time lag, leading to about 700 comparison points covering the entire 23.8 GHz brightness temperature range over a 4-month period. This comparison could be continued after the Jason-1 verification phase, when TOPEX/POSEIDON and Jason-1 satellites are on interleaving tracks (i.e., direct TMR/JMR comparison is no longer feasible), to monitor possible drift of the path delay from the

23.8 GHz and 34 GHz channels. The CMA will also examine differences of the JMR and the ECMWF model estimates of water vapor in order to detect a possible bias or trend in the JMR path delay.

Other important in-flight validations of the Jason Microwave Radiometer (JMR) data will be conducted by SWT investigation teams. *Eymard and Obligis* [Appendix] will apply the calibration method of the brightness temperatures to data from the JMR. The method consists of comparison of the radiometer measurements against radiative transfer model simulations over coincident meteorological fields extracted from ECMWF. The technique was successfully used to adjust the calibration parameters of the ERS-1/2 radiometers. Validation of the JMR retrieved products will be performed using in situ measurements from ships and buoys, and with data collected during special campaigns (e.g., FETCH). Intercomparisons of JMR brightness temperatures and retrieved parameters with products from other satellites (SSMI, ERS-1/2, TMR) will also be undertaken, Finally, drift and anomaly control will be verified by directly comparing data from different sensor channels collected over natural targets (e.g, deserts).

Conclusions of the EOS PM validation workshop held in May, 1998, underscored the need for coordinated water vapor activities among investigators for Jason-1 and other EOS programs [*Koblinsky*, 1998]. In this context, *Emery* [Appendix] plans to investigate how the JMR data fit into the global water picture and also how they compare with alternative (non-altimetric) measurements of atmospheric moisture. In addition to comparisons with ECMWF and NCEP model products, he proposes an analysis of the integrated moisture products from the JMR with respect to those from AMSU and SSM/I(S). Opportunities for additional coordinated water vapor comparisons will be presented with the launches of Terra and EOS PM.

An emerging technique for measuring columnar water vapor relies on data from terrestrial GPS tracking stations. *Haines and Bar Sever* [1998] measured the drift in the TMR by comparing the zenith wet delay against GPS-based estimates as the TOPEX/POSEIDON satellite overflew selected GPS ground stations. *MacMillan* [Appendix] and *Haines et al.* [Appendix] both plan to calibrate TMR/JMR path delays using the GPS technique. The former study will also consider data from Very Long Baseline Interferometry (VLBI) sites. Of principal interest in both studies is the detection of a potential long-term drift in the TMR/JMR path delays. With hundreds of stations in the Intl. GPS Service (IGS) ground network, many coastal and island sites are suited to this purpose.

3.3.2 Ionosphere Delay

Various groups have conducted global evaluations of the dual-frequency ionosphere correction on TOPEX using a variety of comparison products, including the Doris-derived correction, empirical models such as Bent and IRI95 and GPS-based corrections provided by JPL and other sources. A key conclusion of the evaluations was that the TOPEX correction appeared to be stable and accurate, but too large by about 8 mm. Small features that might be attributable to mis-calibration of the C-band EM-bias were also observed. The TOPEX experience also suggested that global comparisons—using the whole coverage over the ocean, or a subset of the data in a specific area where the Doris or GPS networks are more dense, or where the local time is between midnight and 6 AM—may present the best means of evaluating the accuracy of the correction.

Those conclusions and some improvements in the model and assimilation techniques will enable the CNES and JPL project teams to provide an accurate calibration of the ionospheric correction for Jason-1. In addition to products from Bent, IRI95, Doris and GPS, the TOPEX data will be valuable for Jason-1 ionosphere calibration. Nearly direct comparisons between the ionospheric delay inferred from the two altimeters will be conducted during the “tandem” verification phase. The implication of "nearly direct" is that the time difference is short enough to support the assumption that the same ionospheric medium is measured by the 2 altimeters. However, this comparison, even with a time difference of about 5 minutes, might lead to some differences due to scintillations. The scintillations are concentrated at sunset, behaviour which can be accounted for in the comparison. This “tandem” calibration technique will provide a useful verification of the Jason-1 ionospheric correction after only a few repeat cycles.

Doris and GPS-based corrections will be crucial to evaluating the quality of the Jason-1 dual-frequency ionospheric correction. The JPL GPS-based global ionospheric maps (GIM) use dual-frequency (L-band) GPS measurements from over 100 ground receiver locations to produce a global map of vertical ionospheric total electron content (VTEC) with an accuracy of 0.3–1 cm at the Ku-band frequency of the primary TOPEX and POS-2 channels. The GIM provide a measure of integrated column density up to GPS altitudes (20,000 km), with a horizontal resolution of 2–5 degrees in latitude and longitude. A single-site mode is also available which provides a higher resolution map optimized for the region above a single receiver. The CNES Doris estimates—based on Doppler transmissions from terrestrial Doris beacons to the altimeter-bearing satellite—are supplied as an alternative correction on the GDR.

In their evaluations, CNES plans to use a subset of the data where the Doris (or GPS) network is dense enough and where ionosphere is known to be stable: e.g., the North Atlantic area or only the points with a local time between midnight and 6 AM. In addition to the JPL GIM estimates, CNES will use the IEEC estimates from the GPS tomographic technique, and the ionosphere maps from DLR/DFD. The model- and data-based corrections will also allow evaluation of the quality of the Jason-1 ionospheric correction during the validation phase in case of early failure of the TOPEX mission. As a result, a comparison with the Jason-1 (and TOPEX if available) correction at each location will be made with all the alternative corrections. With this, a reasonable assessment of the alternative corrections can be expected by the end of the verification phase.

To validate the Jason-1 ionospheric corrections, the JPL team will perform both overflight analysis and global comparisons of Jason-1 VTEC to GPS. During the overlap period (both T/P and Jason-1 flying), GIM’s single-site mode will be used to produce ionospheric calibration values for each overflight of Harvest [e.g., *Christensen et al*., 1994]. In addition to performing overflight analysis, JPL will compare VTEC from Jason-1 and GIM over the entire globe to yield a more statistically accurate determination of the bias and drift. The global technique will also be used to look for regional or short time-scale biases in the Jason-1 ionosphere measurements.

GIM's accuracy degrades as the distance to the nearest GPS receiver increases, so the comparison dataset will be pruned using several distance thresholds to study the effect of that distance on the determination of the bias and drift values.

3.3.3 Sea-surface Effects

The sea-state bias (SSB) correction is presently one of the most significant sources of error in the altimeter measurement system. Conducting CALVAL studies on this issue is necessary to improve and tune the algorithms and to verify their respective performances. In this spirit, *Vandemark et al.* [Appendix] are leading a SWT-sponsored investigation to better characterize the measurable surface parameters that bear on the modeling of the EM-bias portion of the SSB. Recent studies suggest a high correlation between radar EM bias and long-to-intermediate scale wave slope variance. The objective of *Vandemark et al.* is to collect open-ocean measurements of sea-surface slope, elevation and radar backscatter using a low-flying airborne platform. Data from the experiment will not provide direct calibration of the SSB correction; rather, they are intended to support important research on characteristics of the fundamental physical processes that map into the operational correction.

The effect of atmospheric pressure (AP) on sea level and the validity of the so-called inverse barometer (IB) correction are also issues requiring attention. In his SWT investigation, *Ponte* [Appendix] seeks to move closer to a fuller understanding of sea-level variability related to atmospheric pressure fluctuations. Where the IB approximation holds, the estimation of SL signals is limited by knowledge of the AP. In this context, *Ponte* plans to characterize the quality of various available AP fields with the goal of arriving at a specific recommendation for Jason-1. For high-frequency forcing regimes wherein the dynamic response is important, the investigation seeks to better estimate AP-driven signals using a variety of modeling and analysis techniques. More generally, the goal is to improve the representation and understanding of all (AP + wind driven) sea-level variability at periods shorter than 20 d which will be aliased into Jason-1 data [e.g., *Stammer et al.*, 1999].

3.4 Wind/Wave Measurements

Wind speed and wave height (SWH) measurements will be validated through comparisons with in-situ data (e.g., from buoys), other satellite data and model output. *Levefre* [Appendix] will validate the Jason-1 fast-delivery OSDR wind/wave product against Numerical Wave Prediction (NWP) models from both ECMWF and Météo France. A process for quality control of the Jason data will also be implemented, and alternative wind-speed model functions will be tested. *Cotton* [Appendix] will rely on collocated data from buoys and other altimeter missions [e.g., ERS/Envisat, TOPEX/POSEIDON, and GFO] to validate both the Jason-1 fast-delivery (OSDR) and off-line (IGDR/GDR) wind/wave products. A full assessment of the wind/wave products (accuracy, calibration parameters) is expected after three months of data have been collected. Ongoing calibrations will be carried out to monitor potential spurious wind/wave drifts, such as the SWH drift experienced the TOPEX Side A altimeter.

In an experiment supported by his SWT investigation, *Provost* [Appendix] will calibrate Jason-1 wind and wave products using in situ data collected in two regions of high energy and variability: 1) the Brazil-Malvinas confluence region; and 2) the Agulhas-Benguela convergence region. A Jason-1 crossover point in both regions will be instrumented with a surface mooring, featuring real-time transmission of wind speed, wave height and sea-surface height variability (cf. Section 3.2.1.3). Data from ship transects of the regions (the Atlantic Meridional Transect, and the Cape Town-to-Prince Edward Island cruise) will also be used. In addition to routine calibration and validation of the Jason-1 wind/wave products, *Provost* notes that the high-frequency data from the moorings will enable characterization of aliasing effects from the Jason-1 sampling.

Other contributions to the wind/wave calibration are expected from the University of Texas (D. Chambers) and from investigators using data from the Seawinds scatterometer on QuickSCAT (launched June, 1999), and ADEOS-II (scheduled 2002 launch). Data from the JMR—which provides an independent estimate of wind speed from the Jason-1 platform—are also expected to contribute.

3.5 Global Altimeter Data Analysis

Both project teams (CNES/CMA and JPL) will routinely analyze the global Jason-1 altimeter data with the goal of characterizing the overall measurement system performance in relation to the pre-launch requirements (Table 1.5). The project teams will exchange and jointly interpret selected CALVAL results from the fully validated off-line science products (i.e., GDR) before concurring on release of the data to the SWT. Certain members of the SWT also plan CALVAL studies of the global altimeter data.

3.5.1 Jason-1 Global Analysis

In their approach, CNES/CMA will largely follow the model of the AVISO/CALVAL activities implemented for TOPEX/Poseidon. CALVAL comparisons will be performed over different data periods (e.g. a portion of a track, a track, one cycle, several cycles, several years) to achieve the goals of systematic quality assessment of Jason-1 data and of long-term monitoring of altimeter parameters and geophysical corrections. In addition, these analyses will provide a way to assess algorithm improvements throughout the Jason-1 mission.

The CALVAL tools developed by AVISO have been extensively used for T/P, ERS-1 and ERS-2. These tools will be exploited in the CMA verification plans for Jason-1 [*Mambert et al.*, 1998], and support the following capabilities: 1) data editing, missing measurements determination; 2) crossover calculation and analysis; 3) along-track sea-level anomaly calculation and analysis; 4) calculation of geophysical corrections and/or sea-surface height, sea-level anomalies, and wave-number spectra; 5) representation of statistical output and visualization.

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

Analysis of sea-surface height differences at global crossover points will be used by CNES/CMA to estimate the measurement system precision. Crossover comparisons with T/P will also be performed (cf. 3.5.2). The sensitivity of the crossover differences to different corrections and algorithms will be quantified (e.g. variance explained by each correction). The long wavelength orbit error will be estimated by global minimization of crossover differences. Both sea-state bias (parametric and non-parametric models) and time tag bias will be estimated at crossovers.

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

A parallel CALVAL effort will be undertaken at JPL, where the Jason-1 science data team (SDT) will independently issue science products that are identical to those from CNES/CMA. Two levels of verification are envisioned: 1) quick-look and 2) definitive. The "quick-look" verification is highly automated procedure that is triggered by the release of operational (OSDR) and interim pass products (IGDR) from the JSDS. (Note that this verification is independent of the OSDR and IGDR processing controls that are part of the JSDS production effort.) Outputs of the quick-look process will include statistical profiles of pass parameters and data flags, as well as estimates of the radial orbit error. The process will generate automated e-mail summaries for the JPL CALVAL and JSDS teams, and issue special e-mail alerts when statistical metrics exceed thresholds determined on the basis of measurement system performance requirements and goals. During the verification phase, results of the quick-look analysis will be used in combination with similar results from CNES/CMA to determine thresholds for the production software.

The definitive verification at JPL will target the GDR product. Pass profiles of the GDR, similar to the summaries issued by the quick-look process, will be automatically generated and archived. In addition, the GDR will be globally validated using a specialized geographical altimeter data base. This database design, referred to as a stackfile [e.g., *Kruizinga*, 1997], enables efficient access to all altimeter and auxiliary data for a specific geographical location. The stackfile makes use of the fact that the Jason-1 mission will be flown in an orbit for which the groundtrack repeats within a ± 1 km cross track margin after 10 days. The altimeter and auxiliary data are assigned to geographical bins laid out along the groundtrack. The along-track size of each bin is approximately 1 second (~7 km) long and 2 km wide. Within each geographical bin all data are then "stacked" in time since the satellite will over fly the same location after one repeat period.

For each geographical bin time series may then be formed, which can be used for sea level time series of monitoring for drift or sudden changes in sea level or auxiliary data. The stackfile structure also allows an efficient means of computing crossover observations for Jason-1.

Throughout the lifetime of Jason-1, the stacks will be filled automatically with Level 2 GDR data as soon as the pass files are issued by the JSDS and profiled. Selected Jason-1 Level 1 and ancillary data sets will also be included to support more focused validation activities for the NASA sensors (e.g., JMR, TRSR, LLR). After each complete repeat cycle is added to the stackfiles, an automated report summarizing global intra-cycle statistics will be issued. During the 6-month verification phase, specialized ad hoc investigations will be performed to assess the impact of algorithm and orbit choices on bias and drift and other measures of long-term and large-scale correlated errors. These studies will continue at a reduced level throughout the mission life, with the goal of characterizing the overall measurement system at the 1 cm and 1 mm/yr levels in terms of range bias and drift respectively. Results from these studies will be provided in the regularly published Jason-1 CALVAL reports.

3.5.2 Cross Calibration

The objective of the altimeter cross-calibration is to compare the performance of Jason-1 against that of other altimeter missions. At the time of the Jason-1 launch, four other altimetric satellites may be flying: TOPEX/POSEIDON, ERS-2, ENVISAT and GFO.

TOPEX/POSEIDON is a special case, since Jason-1 is the follow-on mission to T/P. During their tandem calibration phase, T/P and Jason-1 will sample the ocean only a few minutes apart and along the same ground track allowing very accurate comparisons. Cross-calibration between T/P and Jason-1 will be useful for comparing performance and for estimating possible biases and drifts between the two systems. In this case the repeat-track analysis method will lead to the maximum number of (Jason-1 – T/P) differences, with full geographical coverage, and with high precision since geophysical variability will be close to zero. This method will allow comparison of all geophysical corrections (TMR and JMR comparisons are addressed in a specific section) and corrected sea surface height. It will also lead to an estimate of relative bias and drift, along with a characterization of the specific contributions of all underlying parameters.

The project teams also plan to perform spectral and regional analysis of (Jason-1 vs. T/P) differences in order to estimate long and short wavelength errors and geographical biases between the two altimeters. Comparisons to a mean sea surface will lead to nearly the same results as repeat-track analysis since the ground tracks are the same. Even though time lags will be greater, dual crossover analysis will be complementary: while all of the gravity-induced orbit error cancels out in repeat-track analysis methods, a component of it can be observed in the crossover differences.

Various other types of comparisons will be performed during the verification phase: e.g., comparison of geographical coverage, measurement densities, statistics of edited measurements using the same criteria, estimation of time-tag bias and sea-state bias. The results of the T/P

Jason-1 cross calibration will contribute to the goals of estimating bias and drift and assessing the data quality and error budget by the end of the verification phase. These assessments are needed to fully ensure the continuity of T/P-quality sea level data along the T/P ground track before T/P is moved to an interleaving orbit.

After the verification phase (when T/P has been moved to an interleaving orbit), ongoing cross-calibration will be necessary to ensure the long-term continuity of the T/P and Jason-1 missions. With the two satellites likely to be flying on interleaving tracks, repeat-track analysis will not be possible. However, since only the T/P ground tracks will be shifted, Jason-1 measurements will be used in repeat-track analysis methods to compute sea level residuals relative to T/P mean profiles (deduced from T/P data until Jason-1 launch). These former T/P mean profiles will thus be updated using Jason-1 data, and used to compute oceanic variability and mean sea level variations. Comparisons to mean sea surfaces (with now improved precision) will also be used to relate the two missions, even after the end of T/P. The ability of dual-satellite crossover methods to precisely cross-calibrate two different altimeters has been well established. It will thus be used between T/P and Jason-1, when they are on interleaved tracks. If needed (before T/P data are reprocessed), T/P data sets will have to be updated for improved algorithms and models used for Jason-1 after the verification phase.

In keeping with their multi-mission charter, the CNES/CMA project team also plans to conduct extensive cross-calibration among Jason-1 and altimetric missions such as ERS-2 and ENVISAT. The objectives are to monitor Jason-1 performance—including bias and drift errors—and to help foster new scientific applications. Special processing will be set up to homogenize references, parameters and models as much as possible, before cross-calibration is performed. This task will be undertaken throughout the Jason-1 mission life, and will benefit from other altimeters flying at the same time. The essential goals of this activity are to detect any instrumental or algorithmic problem in the Jason-1 measurement system. To this end, the Jason-1 parameters will be continuously compared against analogous parameters from other altimetric missions. This activity will also better enable oceanographic studies using combined data sets through the improvement of models and algorithms. As the basic tools, CNES/CMA will use comparisons against mean sea surfaces and at crossover locations.

It should be emphasized that the SWT will be active in cross-calibration activities. Investigations addressing the characterization of long-term changes from multiple altimeter missions must consider the cross-calibration question, and are expected to contribute significantly to this aspect of CALVAL. *Moore* [Appendix], for example, plans intensive cross-calibration of Jason-1 and TOPEX/POSEIDON using a variety of global analysis techniques. Other teams involved in the problem of long-term monitoring from multiple altimeter missions, but outside the Jason-1 SWT, will also contribute, e.g., *Shum et al. and Azenhofer et al.* [both Appendix]. The results from these analyses will of course be considered together with the results from the in situ calibrations (cf. Section 3.2).

3.6 Precise Orbit Determination Verification

The precise orbit determination (POD) verification activity will rely on a cooperative investigation among project POD teams (at CNES and JPL) and SWT investigators working in this area [*Ries et al.*, Appendix]. CNES has the responsibility for producing the precise orbit estimates that will be included on the Jason-1 science data products. The CNES POD verification effort for Jason will take advantage of all available tracking data to produce, on a routine basis, an estimate of the orbit error, as well as an evaluation of the performance of the tracking instruments.

3.6.1 Overview

The verification activities will be conducted both during the orbit production process (operational verification) and afterwards (expert verification). The goal of the *operational verification* is to ensure, as well as possible, that the orbits included on the IGDRs and GDRs meet mission accuracy requirements. Operational verification is performed by the operations team during the production of the orbits, and results are summarized in the verification report which is provided along with the orbit. The project POD team analyzes the results of the verification and authorizes the delivery of the orbit.

The *expert verification* focuses on a more detailed understanding of the nature of the orbit error, and of its impact on the end users. It includes long term monitoring of the orbit quality, especially to enable the early detection of potential drifts. This verification is performed both by the project POD team and by members of the POD Working Team (cf. Section 3.6.2). This verification is conducted year round, and without a formal time constraint between the production of an orbit and its expert verification. The project POD team expert verification starts during the orbit production process. Additional selected members of the POD Working Team also have access to the orbit data before delivery, for verification purposes. Others conduct their verification efforts once the orbits are officially available. Results from all the verification centers are collected by the POD project team for publication in a verification report. In addition, these results are presented at the SWT meetings.

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

In the case of Jason, the nature of the tests will depend on the orbit product under consideration. For the medium-accuracy orbit ephemeris (MOE), which is produced using only DORIS data, SLR and GPS data will be used for external tests. For the POE, which uses the three data sets in orbit production, these same tests will be internal tests. For this reason, we will not emphasize this traditional split between internal and external tests for Jason. The list of existing tests is given in Table 3.1.

Many ancillary parameters are estimated in the orbit determination process. Some of those represent meaningful physical quantities for which valid ranges are known. Others can be correlated with external information. When collected together, these verifications give a different vision of the inner workings of the orbit determination process. The parameters that should be monitored are given in Table 3.2.

3.6.2 POD Verification Support

As part of their SWT investigation, *Ries et al.* [Appendix] at The University of Texas have formed a POD Working Team (PWT) drawn from project and SWT representatives, many of whom served in a similar capacity on the successful TOPEX/POSEIDON PWT. By working with the operational CNES POD team, the PWT will examine, test and verify the progress toward meeting POD requirements. The PWT will focus on key topics: 1) prelaunch verification of CNES POD and procedures; 2) assessment of POD models and standards for Jason-1; and 3) postlaunch orbit accuracy validation and verification. The PWT will create an orbit verification CALVAL plan detailing results of prelaunch orbit comparisons (e.g., using T/P) and the models to be adopted for Jason-1 POD. A postlaunch verification report will be prepared with a detailed and fully supported assessment of the orbit accuracy. Model enhancements for approaching the 1 cm orbit challenge will be discussed, as well as the prospects for and benefits of recomputing T/P orbits. Additional detail on the overall PWT activity can be found in the Appendix.

The JPL POD project element will emphasize the GPS data from the TRSR, the Jason-1 GPS flight receiver developed at the center. Prior to launch, JPL will provide guidance to the CNES operational POD element on the processing of GPS data from the TRSR. JPL representatives will also serve on the PWT [*Ries et al.*, Appendix] and will participate in the development of POD standards and in the exchange of data and models. The project activity at JPL will also be closely linked with the JPL POD SWT investigation [*Watkins et al.*, Appendix]. This investigation is expected to provide a catalyst for realizing further improvements in the overall strategy for computing Jason-1 orbits from GPS, and the project activities will be well positioned to capitalize on these.

While the science investigation [*Watkins et al.*, Appendix] will seek to enable the achievement of the 1 cm orbit accuracy goal, the accompanying verification activity will focus on the implementation and on the development of tools for routine POD with the TRSR data. During the verification phase, GPS-based orbits will be generated routinely from the processing of the TRSR data. The orbit solution strategy will be intensively tuned, and products will be provided to the PWT for comparison and validation. Generation of GPS-based orbits will continue at JPL throughout the mission, as continuous validation and comparison will be critical for contributing to the 1-cm goal.

Table 3.1: Precise Orbit Determination Verification Tests

Test	Description	Usage	Notes
Data residuals analysis	Analysis of the statistical distribution of the residuals Analysis of the temporal distribution of the residuals (spectral analysis)	After each orbit determination step MOE and POE	
Data residuals interpretation	Decomposition of the residuals into time and range biases and analysis of the fluctuations and trends in these biases	Part of the MOE and POE final quality verification	The meaning of this test is limited because a cut-off criteria is applied to these biases during data editing
High elevation SLR residuals	Selected high elevation laser tracking passes provide an accurate measure of the spacecraft range when it is close to the zenith and thus is a good estimate of the spacecraft altitude	Part of the POE final quality verification	
Single data orbit cross-comparison	DORIS and GPS are used independently to produce Jason orbits which are then compared together to evaluate systematic errors. SLR residuals are computed for both of these orbits to evaluate the consistency of the 3 data types.	Part of the POE production process Validates the MOE after delivery	Systematic biases between data types due to incoherent reference systems might overwhelm these tests
Overlaps	Orbits computed for the same time period using different data sets are compared. This test can be used in different ways - overlap between successive orbits (comparison over the few hours in common) - overlap between a 10-day arc and a shorter arc (in this case all the data of the short arc is common to both orbits) - overlap between orbits computed over the same time period by splitting the data into two independent subsets - etc.		These tests provide a good evaluation of the orbit quality Overlaps with reduced dynamics orbits which contain data in common do not provide any information because the orbit very closely follows the data
Altimeter data cross-over residuals	Residuals of the altimeter measurements at cross-over points are computed	Part of the POE final quality verification Validates the MOE after delivery	The residual signal due to tide model errors and ocean variability is so high that this test does not provide a good estimate of orbit error. However, it is useful to evaluate the relative quality of different orbits.
Comparison between orbits	Orbits computed by different groups using different configuration and/or different software are compared	Expert verification POE only	UT/CSR will compute its own Jason orbit and compare it with the official product

Table 3.2: Precise Orbit Determination Ancillary Parameters and Associated Tests

Parameter	Function	Test
Dynamical parameters		
Drag coefficient	Correct errors in the atmosphere density model	Should correlate with solar activity variations
Solar radiation pressure coefficient	Correct global error in the surface force model	Should be nearly constant
Amplitude of 1/rev terms	Absorb errors in the surface force model at the orbital period	Variation with solar angle indicative of problems with solar radiation pressure model
Amplitude of the stochastic empirical force	Absorbs residual dynamical model errors	Level should remain at the 10^{-9} m/s^2 level
DORIS parameters		
Frequency bias per pass	Absorbs frequency offset of beacons	Long term evolution should be compatible with USO quality clock
Troposphere bias per pass	Empirical value of the zenith troposphere delay	Should correlate well with GPS value of same parameter at collocated sites
On-board USO frequency	Measures frequency of the on-board oscillator	Long term evolution should be relatively smooth
Polar motion	Adjusted value of the Earth orientation parameters	MOE only Should be close to the IERS predicted value
Station coordinates	Estimated location of the beacons	Obtained in a combined solution with other DORIS equipped satellites Help detect beacon problems
Ionosphere	Observed differential ionosphere delay	**TBD**
SLR parameters		
Range bias per pass Time bias per pass	Absorbs station calibration errors	Should be relatively constant per station and should correlate well with data obtained with other satellites
GPS parameters		
Troposphere bias	Empirical value of the instantaneous zenith troposphere delay	Should correlate well with DORIS value of same parameter at collocated sites Can be compared with IGS troposphere values
Clock offset	Offset of the station and satellite clocks	Should behave in a reasonable clock fashion Should correlate well with the IGS values

3.6.3 Specialized Studies

Exertier et al. [Appendix] have developed a POD verification plan based on a geometric evaluation of the Jason-1 orbit using data from dense satellite laser ranging (SLR) networks. Their "short arc" geometric method of orbit determination is able to provide orbit control at the 1-cm level over at least two important areas: Europe and the USA. *Bonnefond et al.* [1995] have demonstrated the technique using TOPEX/POSEIDON altimetry and orbits over the Mediterranean.

The continuous, 3-d nature of the GPS tracking system also enables a powerful quasi-geometric alternative to traditional POD techniques. In this alternative, referred to as reduced-dynamic tracking [e.g, *Bertiger et al*., 1994], the POD process is less sensitive to uncertainties in models of the forces that underlie the satellite motion. The TRSR design, featuring channels for tracking up to 16 GPS simultaneously, represents a significant improvement over the T/P GPS demonstration receiver. This is expected to enable kinematic orbit solutions that have negligible sensitivity to the force models. Owing to the fidelity of the force models developed for the T/P (Jason-1) orbit, the optimal solution may depart from kinematic. Studies will be undertaken by Watkins et al. [*Appendix*] and the JPL CALVAL team to determine the optimal weighting of dynamics and kinematics for Jason-1. The resulting reduced dynamic orbit solutions will be supplied to the POD verification team for comparisons (cf. Section 3.6.2).

The science investigation of *Watkins et al*. [Appendix] is also aimed at recovering powerful tracking information from the phase of the GPS L-band carrier in order to mitigate instabilities in the centering of the orbit solution. The goal is to determine the number of integer wavelengths in the L-band carrier signals transmitted by the GPS spacecraft and received at the TRSR. The result is a range measurement with sub-cm accuracy. The observation is similar in this context to SLR, but there are many more observations due to the large number of GPS satellites in common view at any given time.

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APPENDIX: INVESTIGATOR PLANS

PIs/COIs AND EXTERNAL COLLABORATOR CONTRIBUTIONS TO JASON-1 CALVAL PLAN

On-site verification	**Corsica-Capraia**	**P. Exertier et al.**
	Harvest site	**B. Haines**
	Bass Strait	**N. White, G. Coleman and J. Church**
	English Channel	**P. Woodworth**
	Catalonia	**Martinez-Benjamin**
	Crete	**E. C. Pavlis**
	North Sea	**M. Rentsch et al.**
	Gulf of Mexico	**C.K. Shum et al.**
Global in-situ verification and MSL monitoring		**G. Mitchum and S. Nerem**
		M. Merrifield and M. Bevis
		A. Cazenave et al.
		M. Anzenhofer et al.
TMR/wet tropo		**C. Ruf and S. Keihm**
		L. Eymard and E. Obligis
		W. Emery
		D. S. MacMillan
Sea surface effects		**R. Ponte**
		D. Vandemark
POD verification		**J. Ries et al.**
		M. Watkins
		P. Exertier et al.
Wind/Wave		**J.M. Lefevre**
		D. Cotton
		C. Provost

A.1 ON-SITE VERIFICATION

CONTRIBUTION TO ON SITE VERIFICATION

P.Exertier, P.Bonnefond, O.Laurain, F. Pierron, F. Barlier, OCA-CERGA

1. OBJECTIVES

The Corsica (Ajaccio, Senetosa, Capraia) site in the western Mediterranean area has been choosen to permit the absolute calibration of radar altimeters to be launched in the near future.

Thanks to the French Transportable Laser Ranging System for accurate orbit determination, and to various geodetic measurements of the local sea level and mean sea level, the objective is to measure the altimeter bias and its drift. The semi-permanent use of this site over a period of time of several years is expected in order to reduce the costs associated with such an experiment.

2. RESEARCH PLAN AND METHOD

Since the first probatory geodetic experiment which has been carried out in Corsica two years ago (4 month campaign in 1996-97), several environmental parameters interfering with the principle of altimetric measurement have been accurately measured. Our plan consists in improving these parameters along the end of the 90's and to evaluate their actual capabilities using the TOPEX/Poseidon (T/P) passes. The fact that tide gauge data are now available since several months is a very important point to test and to fit our data reduction methods, although several data gaps have not been avoided during this period.

The fiducial point of the verification site located near Ajaccio (Marine base at Aspretto) was first located and collocated by Satellite Laser Ranging (SLR) as well as GPS and DORIS. In the same time, the sub-site at the Cap of Senetosa, just under the T/P ground track 85, was equipped by GPS markers and a tide gauge. This first campaign of the FTLR system in Ajaccio has led to the conclusion that the wavelenght of the laser (IR) and the detector (photo-diode) inducing a precision in the range measurements of several centimeters had to be improved or changed. On the other hand, the tide gauge experience suggested to have back up solutions that is to say a minimum of two tide gauges each side of the T/P ground track. Finally, the relatively unknowledge of the quasi-geoid in the Senetosa area despite the determination of a precise mean sea profile from altimeter data led us to following conclusion. The geoid slope along and across the ground track 85 being at the level of 6 cm per km the mean sea surface had to be determined over an area of roughly 8 km by 18 km.

Since one year, the FTLRS is under improvements at the Observatoire de la Cote d'Azur. The laser wavelength has been changed to the green and the detector has been adapted to this change. Now, several tests are going to be made on a fixed terrestrial target to verify the gain in the range stability and precision. The next step is to track the LAGEOS satellite as well as T/P. Nevertheless, a technological study of the influence of the level of the return laser pulse on the detection has to be performed in the months to come contributing also to the improvement of the instrumental stability.

The Senetosa area has been completed by a geodetic experiment conducted in May 1998 involving several GPS-buoys, leveling, and 3 tide gauges. These tide gauges located each side of T/P ground tracks are expected to be used during the next year. Thanks to the buoys, covering a sea surface of about 10 km by 1-2 km, the GPS data in combination with the tide gauge data have been used to compute a quasi mean sea surface near the coast. The area between the last T/P altimeter measurements and the tide gauge locations has been thus completed. Now, we are computing a new value of the TOPEX calibration bias.

The next year will be dedicated to a second SLR tracking experiment with the FTLR and Grasse laser systems. Considering the 1-cm challenge to be reach for the local determination of the orbit using quasi-vertical SLR measurements, we plan to evaluate the precision of the FTLRS relative to other European SLR systems by tracking the LAGEOS and T/P satellites. The same site at Aspretto-Ajaccio will be used in order to re-iterate its geocentric positioning.

In the same time, a permanent GPS antenna as well as a permanent tide gauge will be installed in the small area of the Marine base (Aspretto, Ajaccio), near the fiducial SLR point.

In addition to the first campaign of GPS buoys, an extended campaign will take place next year in collaboration with CNES, IGN and JPL colleagues involved in CAL-VAL activities. This will permit to cover a sea surface as large as the surface covered by altimeter data in this area.

3. EXPECTED OUTPUTS

The expected outputs of this on site verification experiment is dedicated obviously to the determination of the calibration biais of Jason-1 and EnviSat radar altimeters.
On the other hand, it will be also an opportunity to contribute to the orbit tracking of oceanographic and geodetic satellites and to the analysis of the different error sources which affect altimetry.

In the field of positioning, we expect to contribute also to the decorrelation between the possible vertical displacements of our site (Earth crust) and the Mediterranean mean sea level.

Dual Calibration of the Topex/Poseidon and Jason-1 altimeter measurements systems using in situ data from the Harvest Oil Platform

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1. INTRODUCTION

Prior to the launch of TOPEX/Poseidon (T/P) in August 1992, NASA established its primary in situ verification site for the mission on the Texaco (now Plains Resources) Harvest oil platform located off the coast of central California. Data from tide gauges and a GPS receiver on the platform have been combined to yield an accurate record of the geocentric sea level spanning over 8 years. Over the same time period, the T/P satellite has passed directly over the platform (± 1 km) every 10 days as it traced out its repeat orbit. Direct comparisons of the sea level and ancillary measurements derived independently from the satellite and platform data have been used to create a near decadal-long time series of absolute calibration estimates for the T/P sensors (altimeter and radiometer) and the overall measurement system.

Shortly after the T/P launch, results from Harvest suggested that the TOPEX altimeter range measurements were short by –145 ± 29 mm [*Christensen et al*., 1994]. With data from additional overflights and improved GPS-based determinations of the platform geocentric height and velocity, *Haines et al.* [1996] reported a TOPEX bias of –125 ± 20 mm at the conclusion of the 3-year primary mission. The bias is now recognized as a consequence of an error in the software used to produce the TOPEX data for the mission scientists. The close agreement between the mean value of the software error (–133 mm) and the bias estimates testifies to the ability of the Harvest configuration to support detection of spurious signals in the T/P altimeter measurement systems. With the planned August 2001 launch of Jason-1 into the same orbit as T/P, the Harvest experiment promises to contribute significantly to the calibration of the measurement system.

Many upgrades to the Harvest experiment have been completed or are are underway in anticipation of the August 2001 launch of Jason-1 from nearby Vandenburg Air Force Base. In August 1999, a new TurboRogue Benchmark GPS receiver with advanced codeless tracking replaced the old (1992) model. The new receiver features significantly improved low-elevation tracking, which is expected to offer better performance for the estimation of the platform subsidence and columnar water vapor content. A second precision GPS receiver (Astech Z12) will be installed in the near future to provide competing measurements of the platform subsidence. Upgrades to the NOAA and CU sea-level systems are also planned. NOAA is updating both the Acoustic and Bubbler systems that comprise their Next-Generation Water Level Measurement System (NGWLMS) and CU is preparing to deploy a new laser system to replace the old pressure transducers. Finally, an improved WVR will be installed before Jason-1 launch [*Ruf et al.*, this Appendix].

2. OBJECTIVES

The principal objective of the proposed work is to rigorously cross calibrate and validate the Jason-1 and T/P altimeter measurement systems using in situ data collected at the Harvest oil platform located off the coast of central California. Information from closure analyses will be applied to yield consistent estimates of bias and drift in Jason-1, TOPEX and POSEIDON altimeter measurement systems. The bias and drift values will be routinely supplied to Jason-1 investigators and will be accompanied by rigorous error estimates. In addition, the collocation at Harvest will be exploited to help segregate the various potential sources of bias and drift in the satellite measurement systems (e.g., altimeter vs. radiometer).

As a complementary objective, we will provide estimates of variations in the global mean sea level based on the evaluation of Jason-1 and T/P data from the prime and extended missions. In addition, we will supply estimates of the bias and drift in the path delay (PD) measurements from the Jason-1 microwave radiometer (JMR). Finally, we will assess the prospects of extending or supplanting the current Harvest configuration with GPS buoys and/or coastal tide gauges.

2. RESEARCH PLAN

Closure evaluation on the Jason-1 launch will begin immediately upon the initiation of the Jason-1 verification phase. During this phase, it is expected that the Jason-1 and T/P satellite will fly in tandem, enabling very precise cross-calibration at Harvest owing to cancellation of common-mode errors (from, e.g., environmental corrections, local conditions, satellite orbits). At the conclusion of the Jason-1 verification phase, T/P will likely be moved into an interleaving orbit, implying that it will no longer pass over Harvest. We note, however, that the T/P time series will continue to benefit from improvements realized in the on-going Jason-1 calibration program (e.g., improved estimates of platform subsidence). Several systematic source of error in the closure time series will receive special emphasis in the research program. These include: 1) the effects of the open-ocean sea states on both the altimeter and tide gauge measurements; 2) the uncertainty in the rate of platform subsidence (presently estimated at 8 mm/yr from GPS); and 3) the contribution of the biases and long-term variations in the media delay corrections (ionosphere, wet path delay) to the misclosure. Following *Haines and Bar-Sever* [1998], the wet path delay (PD) measurements from the Jason-1 and Topex microwave radiometers will be calibrated using GPS data from Harvest, as well as terrestrial GPS stations that are close to open ocean ground tracks. We will also work closely with the investigation of *Ruf and Keihm* [this Appendix] to apply the observations from the platform upward-looking radiometer to the closure. Finally, we will undertake an experiment with GPS to further improve the measurement of the geoid gradient in the vicinity of Harvest and to further assess the potential contribution of pelagic GPS to altimeter calibration.

4. EXPECTED OUTPUT

Our goal is to calibrate the overall Jason-1 measurement system bias to better than 2 cm during the 6-month verification phase, and the relative T/P–Jason-1 bias to better than 1 cm. After three full years of observation, we expect the Jason-1 bias will be determined to better than one cm in an absolute sense. Statistical projections of the present Harvest results suggest that we could discriminate secular changes in the global mean sea level from absolute drift in the T/P altimeter measurement systems at the level of 1 mm/yr or better by the launch of Jason. We anticipate that the Jason-1 absolute calibration will be more accurate than that of T/P over common time periods, because of improvements to the overall measurement system. Finally, we expect to calibrate the JMR drift to better than 1 mm/yr after 2–3 years based on GPS observations. Meeting these projections will be contingent on understanding and reducing systematic contributions to the time series, a goal to which significant effort is being devoted.

Christensen E. J., et al., Calibration of TOPEX/Poseidon at Platform Harvest, J. Geophys. Res., 99, C12, 24,465-24,485, 1994.

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Jason-1 verification in Bass Strait and at other sites in the Australian Region

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[4]AUSLIG (Australian Surveying & Land Information Group)

1. OBJECTIVES

To estimate the magnitude of the Jason-1 altimeter bias (and the relative bias with respect to TOPEX/Poseidon (T/P)) and to monitor any long-term drift in the bias of the Jason-1 and T/P satellites by maintaining long-term altimeter calibration sites.

2. RESEARCH PLAN AND METHODOLOGY

2a. Multiple sites in the Australian Region (for altimeter bias drift)

Data from a number of sites (see Figure 1) will be used to estimate bias drift. Sites used will have either a permanent GPS receiver (green diamonds) or information about vertical movement from episodic GPS surveys (blue triangles). All sites have Sutron Aquatrak acoustic tide gauges.

In the past we have used instantaneous comparisons between satellite and tide gauge estimates of sea-surface height. We will also do analyses by removing the tidal signal and then comparing with the methods of Mitchum/Nerem (see elsewhere in this document).

2b. Detailed campaign at Burnie (absolute bias)

The tide gauge site at Burnie (White et al., 1994) will be the focus of a comprehensive campaign to estimate absolute bias. This will include:

- Measurements from a permanent GPS receiver collocated with the Burnie tide gauge (operational since May 1999)
- GPS buoy deployments through the verification period
- Deployment of a current meter array under the satellite ground track to allow estimation of oceanographic (apart from tidal) contributions to the sea-surface height at the comparison point, thus allowing a better estimate of the absolute bias.

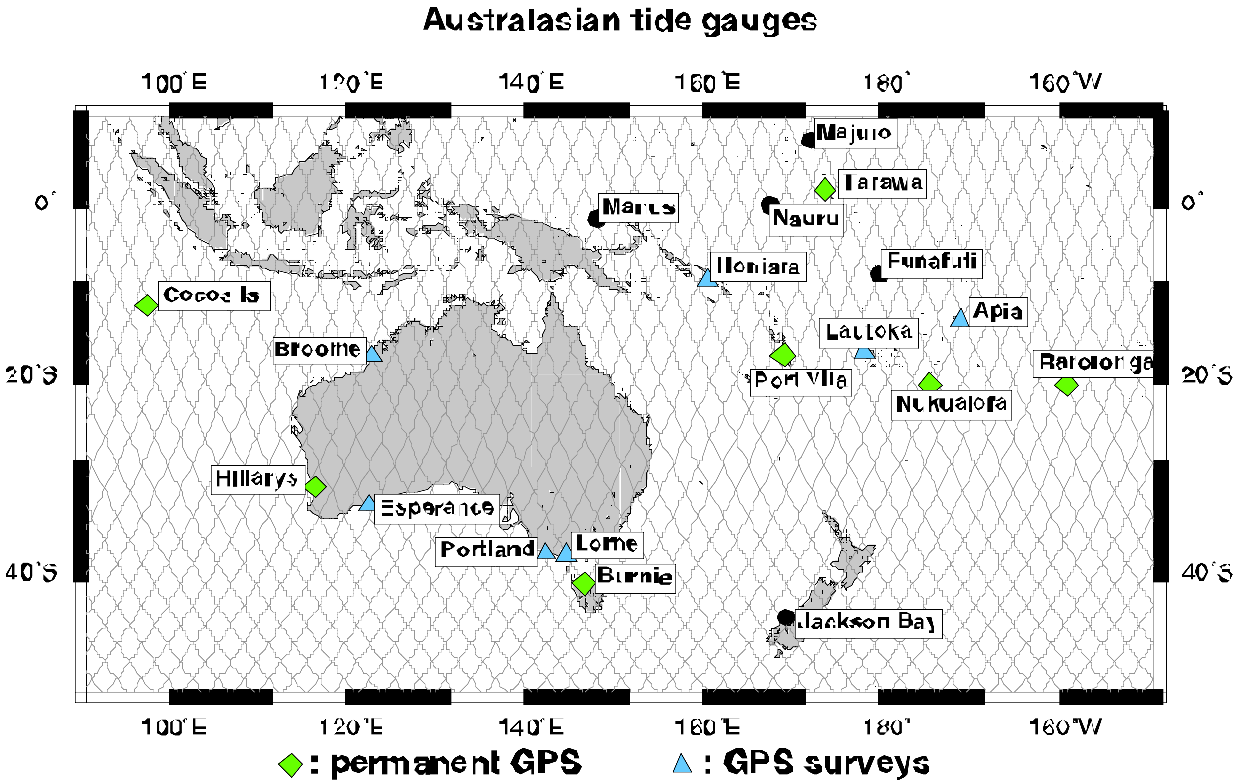

Figure 1: Sutron Aquatrak tide gauges in the Australasian region. Gauges with permanent GPS receivers nearby and those at which episodic GPS surveys have been performed are indicated.

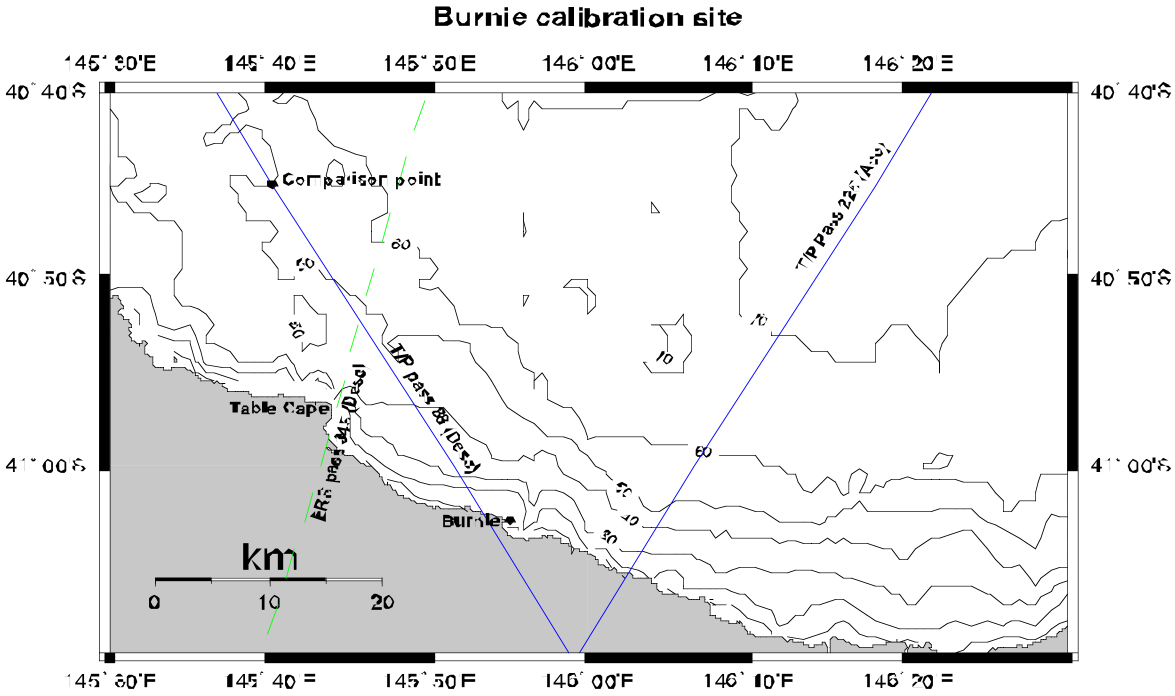

Figure 2 shows the Burnie area, with descending pass 88, the comparison point used for earlier studies (at 40°45'S) as well as Jason/T/P ascending pass 225 and ERS-1/2 pass 345.

There will be several (5-6) GPS buoy deployments during the intensive calibration period. Figure 3 shows the locations of shore-based GPS receivers that will be used (the permanent receiver at Burnie and temporary receivers at Rocky Cape & Table Cape) and the geometry for two different buoy locations (40°45'S & 40°50'S). (Note: the position shown here as the "Optimal buoy location" is the comparison point used in earlier studies. We may use a point closer in to shore. However, data return for T/P started to decrease appreciably from about 40°50'S on this pass).

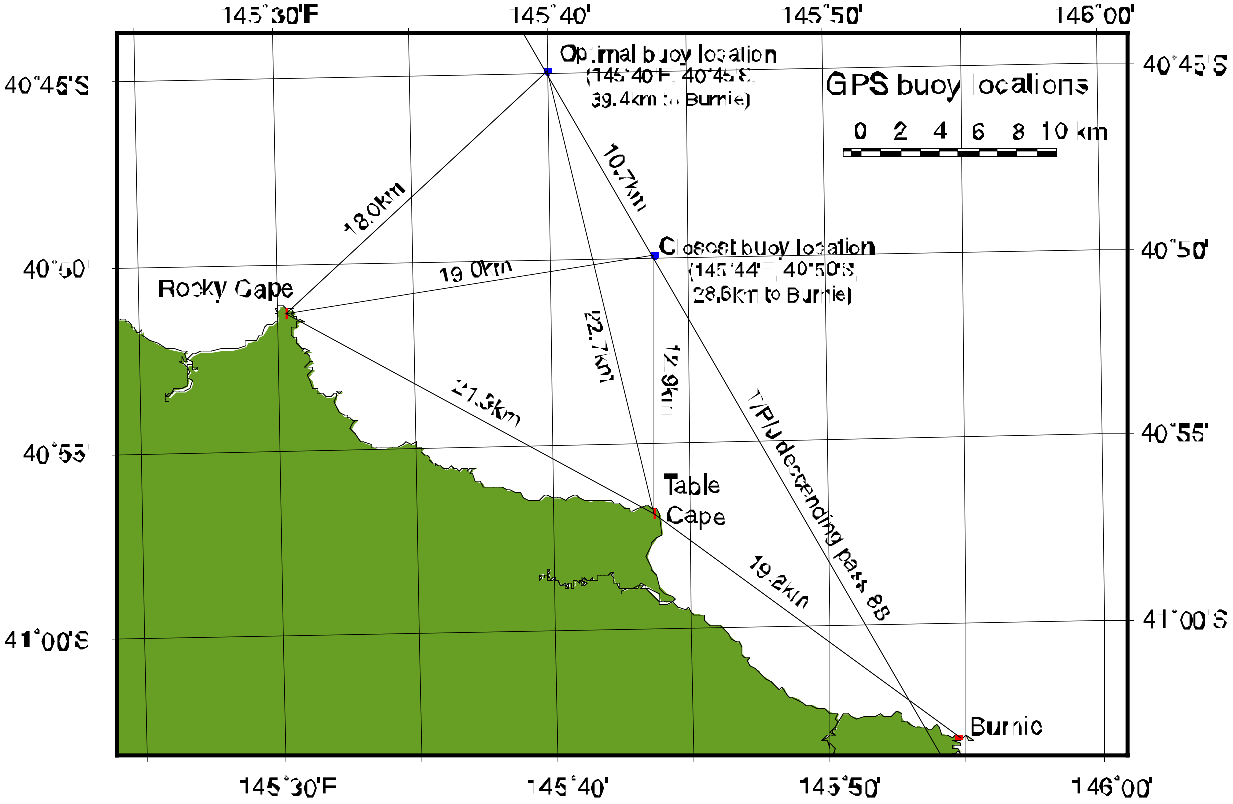

Figure 3. Burnie area with locations of GPS receivers.

In addition, a current meter array (see Figure 4) will be deployed for a period including the intensive calibration period (probably February to October, 2001). This will allow estimation of:

- Pressure difference from alongshore currents
- Onshore wind setup
- Steric height from T & S records from Seacat CTDs directly under the comparison point
- Pressure measurements from a bottom mounted pressure gauge under the comparison point.

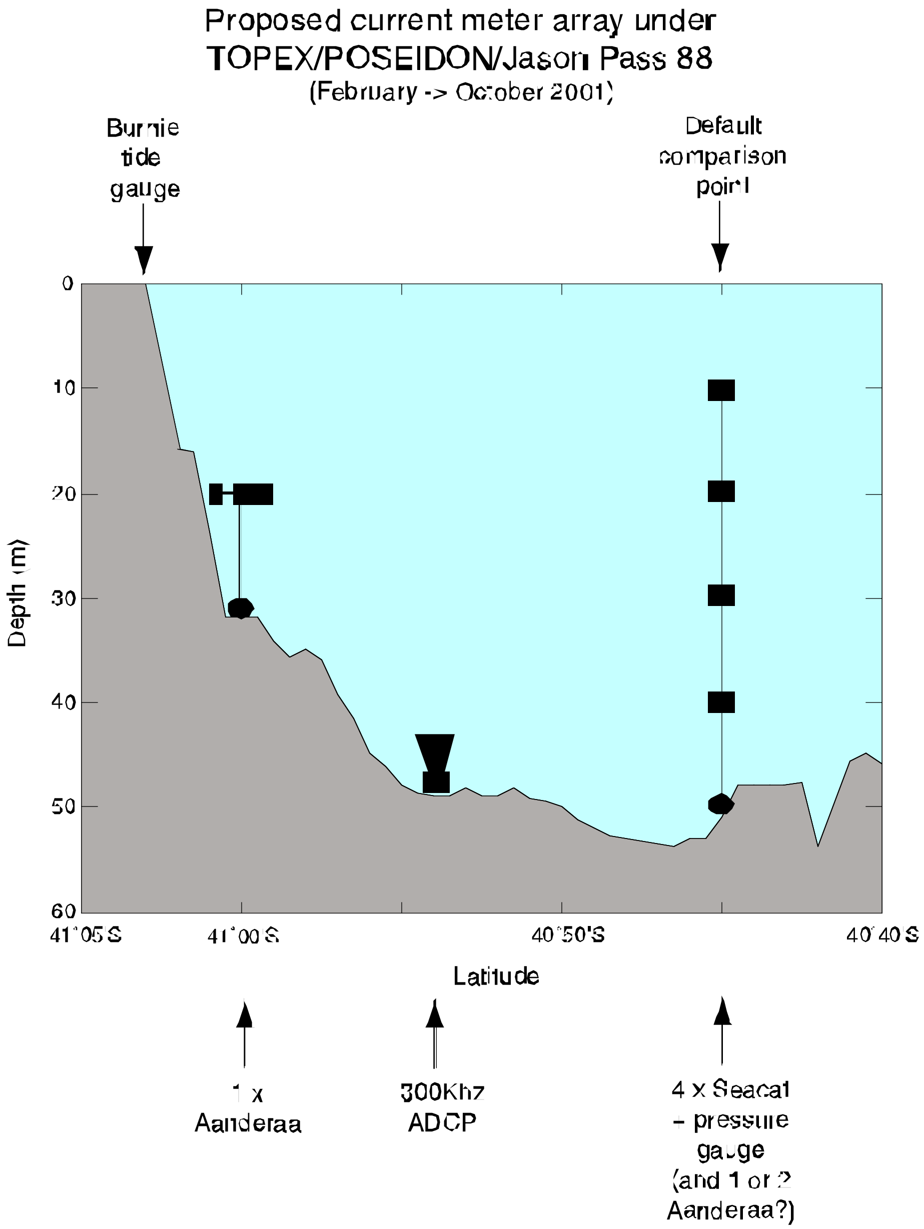

Figure 4. Proposed current meter array at Burnie.

3. EXPECTED OUTPUTS

(a) During the 6 month verification phase, bias drift measurements will be made. The rms errors associated with the various components of the bias drift estimates at the Burnie gauge are:

Acoustic tide gauge accuracy	1 mm
Pressure gauge accuracy	5 mm
Steric height accuracy	4 mm
Pressure difference from alongshore currents	4 mm
Onshore wind set up (assuming stress known to 0.01 N/m^2)	1 mm
Wave set up	2 mm

Assuming that all of the errors are independent, then the total uncertainty from these error sources is less than 8 mm. We also need to account for the Jason/T/P altimeter uncertainties which should be about 2 cm. While these uncertainties can be reduced substantially by averaging, over the 6 month verification period the bias drift can only be estimated to several mm/year.

Use of data from multiple gauges (see Figure 1) will bring this uncertainty down, as will continuation of this work through the lifetime of the satellite mission.

(b) An estimate of the rms errors associated with the various components of the in situ component of the absolute estimate of the bias are:

Absolute datum of the Burnie gauge	10 mm
Differential GPS sea surface height	10 mm
Acoustic tide gauge accuracy	1 mm
Pressure gauge accuracy	5 mm
Steric height accuracy	4 mm
Pressure difference from alongshore currents	4 mm
Onshore wind set up (assuming stress known to 0.01 N/m^2)	1 mm
Wave set up	2 mm

Assuming that all of the errors are independent, then the total uncertainty from these sources is less than 2 cm (17mm). A number of these terms are probably over-estimates of the uncertainty. However, the final uncertainty is dominated by the uncertainty of the Burnie datum and the differential GPS measurements. We also need to account for the Jason/T/P altimeter uncertainties which should be about 2 cm but which can be reduced substantially by averaging over the 6 month verification period.

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White, N.J., R. Coleman, J.A. Church, P.J. Morgan and S.J. Walker, 1994, A Southern Hemisphere Verification for the Topex/Poseidon Satellite Altimeter Mission, J. Geophys. Res., 99, 24505-24516.

Proudman Oceanographic Laboratory Contributions to the Jason CALVAL Plan

P. Woodworth, POL

1. OBJECTIVES

The objective is to provide a collaborative mechanism for ongoing altimeter calibration by use of either dedicated calibration sites and/or with the use of the global tide gauge network.

2. RESEARCH PLAN AND METHODOLOGY

2. 1. Methodology

Calibration of altimeter biases to date fall into two categories: 'absolute' calibrations at dedicated sites such as the Harvest Platform, and 'relative' calibrations which have made use of the extensive global tide gauge network (Mitchum, 1997, 1998).

In collaboration with Aston University, POL has undertaken both types of calibration for TOPEX/POSEIDON (T/P) and ERS-1/2, and it the intention of both laboratories that these exercises will be continued for the Jason series.

Regarding 'absolute' calibrations, the Herstmonceux laser ranger in the south of England, combined with the Newhaven tide gauge and with numerical models of tide-surge and geoid, provides a calibration facility for the English Channel (Murphy et al., 1996) which will be extended to make use of a number of other UK gauge sites now equipped with Global Positioning System (GPS) receivers.

Regarding 'relative' calibrations, the use of the global tide gauge network has been demonstrated to be of great utility for T/P and other repeat cycle missions by Mitchum (1994,1997, 1998). Murphy (1998) has shown that the gauge network can also be used to calibrate and inter-calibrate missions with different repeats and non-repeats with the use of crossover information.

2.2. Research Plan

A proposal has been constructed by Prof. C. K.Shum of Ohio State University for several laser-gauge facilities around the world to coordinate their efforts for ongoing 'absolute' altimetry calibration. In addition, the use of the global tide gauge network for ongoing calibration is a topic which has been discussed in detail at recent international workshops (Neilan et al., 1998), with the conclusion that the application is both feasible and cost-effective. Furthermore, the use of the network in this role has been a major driver for GLOSS (IOC, 1998), the new Implementation

Plan for which was largely edited at POL and which contains proposals for a dedicated subset of the global network called GLOSS-ALT largely following Mitchum's and Murphy's ideas. In both forms of calibration, the tide gauge data from the UK itself, from POL's South Atlantic network (Spencer et al., 1993) and from POL bottom pressure recorders will, of course, be made available to Jason research.

We intend to continue our activities in both the 'absolute' and 'relative' aspects of this work. In early 1998, an Aston-POL-Royal Greenwich Observatory proposal was submitted to the European Space Agency under the Envisat Announcement of Opportunity for a similar programme of CALVAL activity, which underlines our commitment to this field of work. In addition, at the time of writing, we understand that an internal POL programme called Oceans, Climate Change and Consequences for the Coastal Zone (OC4Z), which would include altimetry and sea level research, has been approved for 1999 start by the appropriate Research Board. The Aston-POL work to date has been carried out primarily by research students within the UK 'CASE' scheme, whereby students are shared between universities and research institutes. We anticipate that similar arrangements will be possible in future.

In addition, we shall continue collaboration with Nottingham University with regard to the use of GPS-buoys (Ashkenazi et al., 1996) which may also have a role to play in ongoing calibration.

3. EXPECTED OUTPUTS

3.1. Significance of the Results

This leads to a further aspect of our CALVAL activities which makes use of the fact that POL is the base of the Permanent Service for Mean Sea Level (PSMSL), the global data bank for long term sea level changes operated under the auspices of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) established by the International Council of Scientific Unions (ICSU).

The two main deficiencies of the PSMSL data set are known to be its geographical coverage and the problem of decoupling land movements from sea level change within tide gauge records. The former is being approached by the advances in altimetry and the development of GLOSS (IOC, 1998). The latter will be addressed by the use of GPS and other advanced geodetic devices at gauge sites (Neilan et al., 1998).

We shall build on experience of providing time series of monthly mean sea level anomalies from PSMSL and T/P data (Woodworth, 1996), by means of the construction of decade or longer time data sets from T/P and Jason in combination, calibrated by the techniques described above.

The PSMSL data set, which contains data from over 1750 stations (of which typically 1000 have data from any one year), will be employed to provide an independent validation of the altimetric sea level variability and trends in both deep ocean and coastal areas. This topic clearly addresses the major motivation for the Jason series, whereby the historical ‘global’ sea level data compiled by the PSMSL will eventually be enhanced by truly global altimetric estimates of sea level change (Warrick et al., 1996).

3.2. Other CALVAL Aspects

The approved POL/Liverpool Department of Earth Sciences set of proposals submitted to NASA and CNES under the Jason Announcement of Opportunity describes a number of other regional activities which can be regarded as contributing to Jason CALVAL. The reader is referred to that document for details.

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CONTRIBUTION TO JASON-1 CALVAL IN LLAFRANC/IBIZA/SAN FERNANDO

Juan Jose Martinez Benjamin, Marina Martinez Garcia (Universidad Politecnica de Cataluña, Barcelona), Miguel Sevilla (Instituto de Astronomia y Geodesia, Universidad Complutense de Madrid/CSIC)
Jorge Garate, Jose Martin Davila (Real Instituto y Observatorio de la Armada, San Fernando)
Miquel Angel Ortiz, Julia Talaya (Instituto Cartografico de Catalunya, Barcelona)
Jose Manuel Ferrandiz, Maria Isabel Vigo (Universidad de Alicante)
Begoña Perez, Enrique Alvarez (Clima Maritimo - Puertos del Estado, Madrid)

International Cooperation operating/planning absolute calibration sites:
JPL (Gerhard Kruizinga, Bruce Haines/Harvest platform)
OSU (C.K. Shum, Mike Parke/Lake Eire and the Gulf of Mexico)
CERGA (Pierre Exertier, Pascal Bonnefond, François Barlier/Corsica)
GFZ-Potsdam (Alexander Braun, Tilo Schoene/North Sea)
Naval Oceanographic Office -MS, USA(John Blaha)

1. OBJECTIVES

To provide a collaborative contribution in an international framework to JASON-1 altimeter calibration in the western Mediterranean Sea. To try to monitor the long-term drift in the bias of JASON-1 (and TOPEX/POSEIDON) by maintaining long-term altimeter calibration sites.

2. RESEARCH PLAN AND METHODOLOGY

Comparison of sea level from satellite altimetry (geophysical data records, GDR) and independent in situ observation of sea level at the same geographical location and time. A difference between these two sea levels is referred to as the altimeter bias and may be used to correct the altimeter measurements.

For altimeter calibration highly accurate orbits are required which will be validated by the local laser network in the western Mediterranean (San Fernando, Grasse,..).

Activities to be made are:
- Calibration from direct overflights using GPS buoys.
- Mean Sea Surface Mapping during GPS buoy campaign. Using this method is then possible to do altimeter calibration for other times when there is an overflight of JASON-1 (or any other altimeter satellite) and no GPS buoys are in the water. Basically the MSS mapping provides a

reference to which one can referenced the new altimeter measurement. The tide gauge would then provide the time variable part of the sea level. This is the indirect absolute calibration.

It would be possible to calibrate GFO-1 and ERS-2 at crossover location with JASON-1 (and TOPEX/POSEIDON). The selection of crossover locations will also enable calibration of GFO-1 and ERS-2 using coastal tide gauges.

Experience has been obtained in the CATALA campaign made in March 1999 in the Llafranc/Begur Cape area off 12 km from the coast in the NW Mediterranean Sea to get the TOPEX ALT-B bias. The processing GPS software are GIPSY, KARS, GEODYN,..).

3. EXPECTED OUTPUTS

a) Time series of altimeter bias (to allow decadal sea level change studies). The calibration allows to separate the altimeter bias change and sea level change in long term sea surface height measurements.
b) Quality assurance of the satellite altimeter system including media and geophysical corrections.
c) Contribution to global validation of satellite altimeter systems with data/analysis where local effects are diminished by combination of calibration results obtained by absolute calibration sites around the world.

CRETE: Crete REgional Tectonic Experiment, A Multi-purpose GPS Array

E. C. Pavlis, JCET/NASA

The Hellenic trench region is not only very interesting scientifically, it is also the focus of various research activities involving international groups. The large extent of the region and the large number of activities make too big of a job for any one group alone. The majority of these activities require the precise geolocation of their measurements, some at the millimeter level, others at much lower accuracy. To date, the most efficient and cost-effective way to achieve that is the use of the Global Positioning System (GPS). The northwest expanse of the arc has been surveyed extensively and is currently instrumented with continuous and semi-continuous tracking GPS receivers. The southern part of the arc, comprises Crete and even though it is the center of significant activity (now as well as in the past), it lacks of any permanent GPS instrumentation. A combination of a few permanent and continuous tracking sites with a few additional sites periodically occupied, would create a much needed local deformation monitoring network. The permanent sites would provide positioning support for a variety of projects: participate in the IGS network and provide local access to the ITRF, disseminate differential corrections for local users and regional campaigns, create the backbone which these campaigns can use to “tie” into a global and stable reference frame, provide a continuous record of tectonic activity at sites colocated with tide gauges, contribute data to local atmospheric sensing (troposphere, ionosphere), support oceanographic activities such as the calibration (and cross-calibration) of spaceborne and airborne altimeters, etc..

We propose the establishment of a permanent, IGS-class, central station and a group of “satellite stations” to monitor horizontal and vertical deformation over the central region of the Hellenic arc. The array will validate and discriminate between proposed geophysical models for the Hellenic subduction zone, establish connection of local tide gauges to the global terrestrial frame and monitor the local crustal uplift signal for sea-level change studies. Compare to results from laser ranging campaigns during the CDP and DOSE programs. Assimilate those results with the new data to further extend the record. Provide fiducial sites for differential positioning of airborne and shipborne geophysical surveys in the area within the European WEGENER project.

This will be accomplished through the establishment, operation, and maintenance of a continuous-tracking GPS array over the expanse of the island of Crete, Greece, in cooperation with the Mineral Resources Engineering Department at the Technical University of Crete (TUC/MRED), at Chania, Greece, which will host the IGS central site. An initial test with two sites was placed in operation in the spring of 1997. In August of 1997, the central site permanent installation was completed and the continuous tracking commenced. A second site at the Souda Bay tide gauge was occupied briefly in December 1997, providing data for the precise positioning of the tide gauge. Additional occupations and a permanent receiver at Souda Bay are part of this plan. TUC and the Hellenic Navy have signed a MOU for close cooperation on these matters. One of the original objectives of CRETE was the instrumentation with GPS of the two tide gauges on the island: at Souda Bay and Iraklion. This part of the activity would contribute to the Euro-GLOSS network. The current plan on data analysis issues is that the data from the array along with a subset of IGS data will be processed into daily (regional) and monthly (global) solutions. When the array grows to its final extent with GPS sites at Omalos, Iraklion, Souda, Roumeli, Falassarna and a yet-to-be-decided southwestern site, deformation parameters will be estimated periodically and compared to geophysical model predictions. GPS-derived vertical deformations will be compared to gravimetrically derived signatures on the basis of detailed dense gravity survey data which are available from other activities in the area.

As an extension of the original CRETE array, we also propose the establishment of an altimeter calibration site on the adjacent small island of Gavdos, located about 60 km to the south Crete (see attached figure below). The isle of Gavdos happens to be located under a groundtrack crossing point for the TOPEX/POSEIDON mission and since the upcoming JASON-1 mission will follow the same groundtrack, it is an excellent site for the calibration of both altimeters (and for other altimeters, such as ERS-2, GFO, ENVISAT). So far, this aspect of CRETE had been discussed only within the original group of collaborators and it was first proposed in public at the recent EGS'98 General Assembly in Nice, France. From the discussions with interested parties, we gather that a number of groups from different countries have shown interest in the project and in some cases have suggested the addition of some of their own equipment for the further enhancement and expansion of the investigation. The nature of the project restricts us to seek funding at local and national organizations such as NASA, NSF (National Science Foundation in US and similar agencies in the other countries), CNES, the European Union within its upcoming Fifth Framework funding cycle, etc. To be able to form a comprehensive proposal in time for submissions to all these agencies with varying funding cycles, we drafted this open letter to solicit comments from those already committed to the project and to find out who else and under which area would be willing to collaborate. This letter focuses especially on the development of a team to support the “Gavdos” calibration site even though most of the collaborators listed here are part of the larger CRETE project. The following list enumerates the groups already contacted and the area they have indicated their interest/support for:

- E. C. Pavlis, JCET/NASA, tectonics, sea-level change, data analysis, calibration
- S. Mertikas, MRED/TUC, GPS array operations/reliability, local network support
- F. Kouroumbali, Hellenic Navy (HN) Hydro. Serv., oceanography, HN liaison
- P. Drakopoulos, IMB of Crete, tide gauge operations/analysis, local oceanography
- H-G. Kahle, ETH, airborne altimetry, tectonics, (connection with Ionian sites?)
- I. Tziavos, AU of Thessaloniki, gravity/altimetry data analysis,regional geoid
- R. Rummel, TU München, altimetry/ gravity data analysis, regional DOT

- H. Sünkel, TU Graz, altimeter calibration with transponders (to be provided)
- BKG (former IfAG), expansion of the EUREF net, possibly provide GPS receivers

It is obvious from this list that there are a number of very important areas for which we have no contact or participation commitment yet. The most important ones are that of precise unambiguous ground-tracking of the satellite(s) and absolute gravity measurements for precise sea-level variation studies. We are asking the following groups to join us and cover these areas with their expertise and equipment:

- ILRS, periodic SLR tracking, Transportable Laser Ranging System at Roumeli site
- M. Costes, CNES, DORIS beacon(s) for T/P and JASON-1 tracking
- B. Richter, BKG (former IfAG), absolute gravity measurements

With regards to the SLR tracking, suffice to say that the site of Roumeli, mid-way on the north side of Crete, has been occupied several times by TLRS equipment during the MEDLAS campaigns as well as by GPS in the framework of WEGENER and EUREF. Since the SLR pad still exists and considering its proximity to power, communications, etc. this would be the site of choice. With DORIS on both altimetry missions, instrumenting the tracking site with DORIS provides an independent type of tracking data and a direct reference frame connection can be effected. Absolute gravity measurements would not only reference the already in existence detailed relative gravity networks on the island with respect to the European gravity net, but through repeated measurements they would also provide an independent measure of the expected vertical uplift of the southwestern side of Crete. Repeated every few years, absolute gravity measurements can help decouple tectonic uplift from secular sea-level variations.

GFZ Contribution to the Jason-1 Cal/Val in the North Sea

M. Rentsch, T. Schoene, A. Braun, A. Helm, GeoForschungsZentrum Potsdam
National and international partners for cooperation: E. Mittelstaedt, Federal Maritime and Hydrographic Agency of Germany (BSH), W. Gloeden, Deutscher Wetterdienst (DWD), R. Dietrich, G. Liebsch, Technical University Dresden, J.J. Martinez Benjamin et al., Universitat Politecnica de Catalunya, C.K. Shum, M. Parke, Ohio State University

1. Objectives

The contribution of GFZ to an absolute calibration of the Jason-1 radar altimeter is based on an existing network of buoys, tide gauges and meteorological stations in and around the North Sea. Additionally, a GPS buoy will be developed and operated for mean sea level monitoring. Thus, a calibration and long-term drift monitoring for the radar altimeter will be possible.

2. Research Plan and Methodology

2.1 Research Plan

Jason-1 altimeter ranges will be processed according to standard computing techniques along with the best available model/in situ data for the environmental corrections. The GPS equipped buoy will be deployed for monitoring the instantaneous sea level by real time kinematic (RTK) techniques at a triple crossover of TP/Jason-1, ERS-2/EnviSat and GFO-1 satellite tracks. Thus, sea surface profiles of Jason-1 can be compared with the buoy data as well as with the SSH measurements of the other altimeter missions. Using in situ wind and wave data, received by a dense network of buoys as well as tide gauges and onshore meteorological stations, correlations can be checked with wind speed and SWH derived from satellite onboard measurements.

2.2 Methodology

The North Sea is covered by several buoys operated by the BSH and the DWD for observing wind speed, sea state conditions and supplementary environmental parameters. Tide gauges and meteorological stations onshore and on the Island of Heligoland supplement the station network. The GPS equipped buoy, to be constructed at GFZ, will be deployed at a triple crossover of TP/Jason-1, ERS-2/EnviSat and GFO-1 satellite tracks in the vicinity of an existing wave buoy.

3. Expected Output

Mean sea level variations around the planned location of the GPS buoy can be estimated by time series of MSS profiles of TP each 10 days, starting in Sept. 1992, and ERS-2 each 35 days, starting in May 1995. Based on the long-term calibration of TP a cross calibration between TP and Jason-1 will be possible with high accuracy. Moreover, the MSS differences at the crossover point between TP and ERS-2 serve as additional information. Long term variations of wind speed and SWH, respectively the sea state condition, are derived by the surrounding buoy network and onshore meteorological stations. These parameters are then compared with the measurements taken from TP/Jason-1 and ERS-2/EnviSat and used for the corrections of the altimeter measurements.

4. Funding Sources

M. Rentsch, T. Schoene, A. Braun and A. Helm are funded by GFZ.

Absolute Calibration of Multiple Radar Altimeters for Global Change and Coastal Studies

C. Shum, and M. Parke, Ohio State University,
J. Blaha, Naval Research Laboratory
G. Jeffress, Texas A&M Corpus Christi,
D. Martin and G. Mader, NOAA/NOS,
C. Morris, Jet Propulsion Laboratory,
K. Schaudt, Marathon Oil Co.

Collaborating Calibration Site PIs:

J. Benjamin, Univsidad Politecnica de Catalunya:
Llafrancl and San Fernando (planned)
S. Calmant, ORSTOM de Noumea:
New Caledonia (planned)
R. Dietrich, G. Liebsch, TU Dresden:
Baltic Sea (operating)
M. Rentsch, A. Braun, Tilo Schoene, GeoForschungsZentrum Potsdam:
North Sea (planned)
N. White, Richard Coleman, CSIRO, Univ. of Tasmania:
Bass Strait/Burnie (operating)
P. Woodworth, P. Moore, POL and U. New Castle:
English Channel (operating)

1. OBJECTIVES

The primary objective is to provide absolute calibration and verification of Jason-1, and other altimeters, including T/P, ERS-2, GFO-1, Envisat, IceSat, complementing the two Project calibration sites, Harvest and Corsica, as well as the operating and proposed island tide gauge relative calibration project. Our goals include the (1) understanding the error characteristics of their instrument biases and their potential drifts, (2) monitoring biases and potential drifts between histroic, present and future altimetric instruments (altimeters and radiometers), and (3) improve the media, instrument and geophysical corrections of the altimeter systems by understanding the respective errors via absolute calibration and monitoring. The investigation is proposed to be conducted in close collaborations with increasing number of operating and planned absolute calibration sites to attempt to (1) understand different characteristics of the altimetric instrument and geophysical corrections which have geographical dependence, and (2) improve the instrument calibration accuracy by "averaging" data from many sites. The scientific objectives include the determination of long-term altimetric mean sea level change for the interpretation of the signals for their role in climate change.

2. RESEARCH PLAN AND METHODOLOGY

2.1 Research Plan

The investigation plans to operate low-cost absolute calibration site in the Gulf of Mexico at a triple crossover point (Jason, GFO, Envisat) at about 200 km into the Gulf and within 5 km of an offshore oil drilling platform (HI572C); and a site on a small island in Lake Erie (OSU's Stone Lab). We propose that within the Jason-1 Cal/Val activities, there will be a group/subgroup coordinating all operating and planned absolute calibration sites to (1) exchange data; (2) standardize data processing techniques; (3) share calibration technologies and instrumentations; and (4) jointly disseminate error budgets for each correction and the resulting sea surface height measurement for multiple altimeters. Our group will also conduct global verifications for concurrently flying altimeters and historic altimeters with the objectives to improve the determination of their relative biases (and drifts) and to improve their corrections including tide modeling in the coastal regions. The sites proposed to be involved in the coordination effort include the two Project sites (Harvest and Corsica), and the other operating or planned sites for this collaborative project (Bass Strait, English Channel, Catalunya, North Sea, Baltic Sea, South Pacific, Gulf of Mexico and Lake Erie).

2.2 Methodology

We will to deploy automated GPS-buoys at a triple crossover point in the Gulf of Mexico within 5 km to an offshore oil platform (H1572C), and near Gilbrator Island in Lake Erie. The oil platform will be instrumented with NOAA NGSL tide gauge, GPS receiver, and radio modem to receive data from the buoy. The Lake Erie site already has NOAA acoustic tide gauges, and GPS receiver will be installed on the Stone Laboratory as a fiducial site. We will primarily use GPS receivers to assess and intercompare altimetric radiometers and ionospheric delays, and tide gauges to assess composite sea level measurements from altimeters. We plan to improve the determination of relative biases (links) between present (ERS-2, T/P, GFO-1) and historic altimeters (Seasat, Geosat, ERS-1) using measurements from the absolute sites, global island tide gauges, and via global analyses of multiple altimeter measurements.

3. EXPECTED OUTPUTS

We hope to establish an error budget for altimeter systems from measurements obtained from the available absolute calibration sites, provide an updated link between the altimeters, coordinate with other sites for an improved estimate of altimeter biases and their drift (bias to within 2 cm; and drift approaching 2 mm/yr). The goal is to build a twenty year or longer consistent and verified measurement time series for global mean sea level change for climate-change studies..

4. FUNDING SOURCES

C. Shum has proposed to NASA for funding to support the proposed investigation.

A.2 GLOBAL IN-SITU VERIFICATION AND MSL MONITORING

Proposed Contribution to JASON-1 Cal/Val Activity

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Department of Marine Sciences
University of South Florida

R. Steven Nerem
Center for Space Research
The University of Texas at Austin

Abstract

We propose to continue and extend for JASON-1 the cal/val activities that we have been doing as part of the TOPEX/Poseidon (T/P) mission. In particular, the global tide gauge estimates of the stability of the TOPEX altimetric system that Mitchum has been doing will be continued into the JASON-1 mission, and these estimates will also continue to be improved. In addition, Nerem will take the lead in carrying out additional estimates of the stability and consistency of a "blended" T/P/JASON dataset by carrying out satellite to satellite comparisons.

Background

Since the beginning of the T/P mission, Mitchum has been producing an estimate of the stability of the T/P system by comparison of the altimetric data to the global tide gauge dataset. Although the usefulness of this calculation was questioned at first, the ability of the tide gauge analysis to accurately estimate temporal drift in the altimeter was convincingly demonstrated with the discovery of a TOPEX algorithm error, which was apparent in the tide gauge analysis for some time before the cause was known. Mitchum's basic method has been detailed in a paper in the Journal of Atmospheric and Oceanic Technology. As the mission has progressed, the method has continued to evolve and improve. The most recent modifications have been to include land motion estimates to the tide gauge time series, to carefully study the most appropriate smoothing and temporal/spatial lagging of the altimeter data relative to the tide gauge data, and the inclusion of more altimetric data near each gauge with appropriate weight functions applied. These results were presented at the recent Keystone meeting of the combined T/P/JASON SWT, and a manuscript is being prepared. In addition to the tide gauge analysis, several groups are also intercomparing measurements from different altimeters. During the JASON mission Nerem will also lead these types of analyses as a complement to our tide gauge approach. Our approach to the cal/val problem is quite different that that taken at dedicated cal/val sites (e.g., the Harvest platform), and is complementary rather than redundant.

Objectives

1 - Monitor the stability of the JASON altimetric system

For T/P Mitchum has routinely provided time series of the globally averaged TOPEX vertical offset relative to an arbitrary mean. That is, only temporal drift, and not absolute bias, is estimated. Analogous time series will be computed for JASON and the time series and basic statistics, such as a linear drift estimate, will be produced routinely.

2 - Estimate the T/P to JASON vertical offset

The mission plan for JASON is to determine the vertical offset between the T/P and JASON height datasets to 5 mm. We believe that the tide gauge analyses can provide useful and independent estimates of this offset at that level of accuracy, which would provide a valuable check on this important quantity. Again, the satellite to satellite intercomparisons will complement the tide gauge analysis.

Plan

1 - Monitoring the stability of the JASON altimetric system

The approach here is exactly the same as for the T/P mission. The method derived by Mitchum is completely general and can be applied to any altimeter. For example, an application of the method to the ERS time series is presently being undertaken. The tide gauge analyses would be complemented by the satellite to satellite intercomparisons; e.g., T/P to JASON and both to other altimetry missions such as the ERS or ENVISAT.

2 - Estimating the T/P to JASON vertical offset

We will first produce a combined T/P + JASON time series, which will then be examined for consistency with a simple "offset" model (e.g., a Heaviside function located at the junction point between T/P and JASON). This model leads to a magnitude for the offset, and an estimate of the error in the fit that can be used to determine whether the fitted offset is statistically significant, and hence needing further analysis, and the error itself can be quoted as an upper limit for the offset that could exist in the data. Note that the magnitude of the error estimate will decrease with time as more JASON data is added to the analysis, so that the determination of the offset will improve quickly.

Expected outcomes

Based on the experience with T/P we can make conservative estimates of the precision of our estimates. We say that these estimates are conservative because if the JASON error budget is smaller than that of TOPEX, then our errors will decrease proportionally. Also, continued improvement of the tide gauge method will reduce the errors further, as will the complementary satellite to satellite calculations.

For the measure of the basic stability of the JASON system, we can quantify the expected outcome by the standard deviation of the linear drift rate of the altimeter. One way to interpret this quantity is that this is how large, or small, a drift we can reliably identify. For T/P, with approximately 5 years of data this uncertainty is about 0.5 mm/yr. This error scales inversely as the length of the record to the 3/2 power, so we can compute estimates of what is expected for JASON a a function of record length. Accordingly, with 1, 2, and 3 years of data we would expect detection limits of about 5.6, 2.0, and 1.1 mm/yr, respectively.

For the determination of the vertical offset, we can again make a conservative a priori estimate of the precision by doing simulations with the T/P dataset. This is done by treating the T/P minus tide gauge estimate of the drift as if it were a combination of the T/P and an N-cycle JASON series. We then compute the offset as a simple average of the N "JASON" cycles minus the last N "T/P" cycles. This is repeated with all available subsets of that length, and the distribution of the offset estimates is used to estimate the precision, based on an assumption that there is no offset in the T/P series used in the simulations. More involved simulations could be done, but these calculations should give the correct order for the expected errors. The result of this simulation is that we should be able to detect a 5 mm offset once the JASON series is at least 20 cycles, or about half a year, long.

In Situ Tide Gauge/GPS Stations for Monitoring the Temporal Drift of Satellite Altimeters

Mark A. Merrifield and Mike Bevis, University of Hawaii Sea Level Center

1. OBJECTIVES

The University of Hawaii Sea Level Center (UHSLC) and the Pacific GPS Facility (PGF) will make collocated GPS and tide gauge measurements for the monitoring and correction of altimeter drift, and for helping to assure continuity between the Jason-1 and TOPEX/Poseidon datasets.

2. RESEARCH PLAN AND METHODOLOGY

Continuous GPS receivers are being installed at 4 existing tide gauge stations at Christmas Island and Johnston Island in the Central Pacific Ocean, Valparaiso, Chile in the South Pacific, and Mauritius in the Indian Ocean. These stations will add to the current GPS/tide gauge at Honolulu Harbor, and 2 other Atlantic Ocean sites (Bahamas, Azores) planned for 1999 yielding 7 stations operated by the UHSLC and PGF that will contribute to the altimeter calibration network proposed by Mitchum (1998).

To the extent possible given the on-site conditions, the GPS receivers will be positioned at the tide gauge sensors in an effort to minimize any relative motion between the sensors. This is a particular concern for tide gauge applications because most gauges are positioned on piers and coastal structures of unknown stability. The station configuration will also include a barometric pressure sensor in order to obtain estimates of integrated water vapor.

To ensure high quality data from both sensors and to perform frequent leveling ties to established benchmarks, maintenance trips will be made at 1-1.5 year intervals for all UHSLC tide gauges in the altimeter calibration network (11 of the total 30 stations). On-site observers will be used to perform routine maintenance of the stations, and to assist with the retrieval and transmission of the GPS data. The GPS data will be processed by International GPS Service (IGS) processing centers. The tide gauge data will be processed by the UHSLC. All tide gauge/GPS products will be distributed through the University of Hawaii in near-real time. Gary Mitchum of the University of South Florida will provide ongoing altimeter trend estimates using the combined data sets.

3. EXPECTED OUTPUT

The feasibility of the tide gauge/GPS monitoring procedure outlined by Mitchum (1997) will be enhanced considerably through this project. The collocated sensors will provide drift estimates with relatively accuracies. The considerable expertise available through the PGF and the UHSLC will ensure GPS and tide gauge data of the highest quality. All stations in the network will be monitored continuously by the UHSLC and 11 stations will receive high priority maintenance visits by UHSLC technicians. Incorporation of these tasks into the UHSLC operation will ensure long-term continuity of the calibration network for continued drift correction, and smooth transitions between altimeter data sets.

JASON-1 CALVAL Activities

A. Cazenave, J.F. Crétaux, Ch. Le Provost,

LEGOS/GRGS

1. OBJECTIVES

The 'Space Geodesy' team of LEGOS is currently involved in the precise determination of mean level changes by satellite altimetry at global and regional scales. For this objective, our current efforts in preparation to JASON-1 are devoted to (1) study (and in the future take into account) the effects on global sea level changes of temporal variations of the reference system in which sea level is measured and (2) perform global comparisons of altimetry-derived and tide gauge-derived sea level changes for calibration of altimeter satellites.

2. RESEARCH PLAN AND METHODOLOGY

For topic (1), we intend to study the effects of horizontal and vertical motions of the DORIS stations on the orbit of Topex-Poseidon (JASON-1 in the future), hence on global sea level changes. Using DORIS data on the SPOT-2/3/4/ and Topex-Poseidon satellites, we are currently determining solutions for the stations velocities and thus should be able to estimate the induced changes on the reference system on the sea level (through the satellite orbit). We are also currently determining the motions of the center of the reference system (geocenter motions due to mass redistributions in the fluid enveloppes) using DORIS data and intend to determine (and further take into account) the effect of such motions on global sea level changes.

Concerning topic (2), since the work of G. Mitchum, it is now recognized that external calibration of altimetry results with in situ tide gauge data is inevitable. We have recently developed a method of comparison mostly oriented to interannual mean sea level changes applications, and have compared sea level variations measured by Topex-Poseidon and nearby tide gauges over 1993-1997 (5 years). 60 tide gauges of the GLOSS network have been considered. The sea level drift was computed separatly using the tide-gauges and the T/P time series, as well as the drifts of sea level differences at each site. The main result of this study was that the Topex-Poseidon derived sea level drift estimated over 1993-1997 is 1.8 mm/yr lower than the tide-gauge derived sea level drift over the same period. This result is in full agreement with the recently discovered instrumental drift of the radiometer onboard Topex-Poseidon. Our future plans for topic (2) are the following: (1) perform similar comparison with ERS-1 data which has a denser coverage of the oceans,, and (2) correct tide-gauges records of vertical crustal motions in order to estimate 'absolute' sea level variations using geodetic data.

3. EXPECTED OUTPUT

The DORIS, GPS and SLR systems currently provide accurate vertical motions, and among the tide-gauges of the GLOSS network, some of them are located within a few kilometers of the geodetic stations. We have recently shown that at a few DORIS sites, the drift of the sea level differences between tide-gauges and Topex-Poseidon time series clearly reflect vertical crustal motions. This stresses the need for correcting systematically tide-gauges records of altitude variations at these sites before these can be usefully considered for sea level change studies. This is a main improvement which can be expected in the future for the calibration of altimeter satellites and it represents our main contribution to the JASON-1 CALVAL plan.

Determination and Interpretation of Long-Term Mean Sea Level change

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1. OBJECTIVES

Altimetry is the most important tool to measure global changes in the sea level. With data from future missions JASON-1 and Envisat-1, the successful TOPEX/POSEIDON and ERS missions and already flown US altimeter missions, almost 20 years of altimeter data will be available. Furthermore, starting from 2000 ocean mass redistribution from the new gravity missions CHAMP and GRACE with unprecedent accuracy will be measured. By combination of both first time a potential separation of the steric and mass component of sea level change can be detected. The primary objective is to conduct verifications of multiple altimeter data products and their orbits, to characterize their respective error budgets (coorections and the resulting inferred sea surface height), to determine relative biases between altimeter systems, and to produce a consistent multiple altimeter and long-term sea level data record covering the global ocean to +/- 82.5 degree latitude. The results of the analyses will be regional and global sea level change maps potentially separated into their steric and non-steric mass components for interpretation of the global climate change phenomena.

2. RESEARCH PLAN AND METHODOLOGY

2.1 Research Plan

The project will start with a complete and consistent reprocessing of all historical altimeter data (Seasat, Geosat, ERS-1), to ensure that no systematic effects between the missions are still present. Periodical updates of orbit solutions will be done when new high quality gravity field solutions from the gravity missions are available. Based on this, periodical estimates of sea level changes, separated in steric and mass components, will be produced. The consistent time series of TOPEX/POSEIDON and JASON-1 will be compared to the corresponding European altimeter missions. Anomalies of drift rates and regional sea level changes will be analyzed and compared with other physical quantities of the system Earth, e.g. sea surface temperatures or ice extent.

2.2 Methodology

The major objective of the proposal is a long-term sea level analysis starting in 1978 with the Seasat mission and ending with the JASON-1 mission. This means an altimeter time series of almost 30 years (with time gaps in between) provided that JASON-1 will have a mission time span of 5 years. This will allow the first ever medium-term investigation of the sea level. As the 30-year time span covers most of the known periodic variations of the ocean (5, 8, 20 years), a definite answer of the questions regarding sea level and, thus, climate change can be expected. Second, in combination with estimates of ocean mass redistributions from the new gravity missions starting in 2000, first time the separation of steric and mass component in the sea level signal can be measured.

The major task is the consistent reprocessing of historical and actual altimeter data to ensure that between different missions there are no systematics disturbing the continuous sea level observations. Products of the new gravity missions will support the reprocessing in the sense that all orbits will be consistently reprocessed based on latest high quality models. All geophysical corrections, which are necessary to derive sea surface heights from the retracked altimeter range measurement undergo an extended analysis to choose the best and most consistent models or measurements for all the missions. By this data harmonization, a consistent multi-mission altimeter data set will be produced, which will be the base for the sea level analysis. When incorporating the Geosat data set into the data analysis the major problem is the filling of the two years gap between Geosat and ERS-1 (or TOPEX). Two methods based on the use of distinct tide gauges and on the analysis of correlations with the sea surface temperature data sets are envisaged to overcome this problem. We will intercompare altimeter systems who are concurrently flying, and use tide gauges or other means to link present and historic missions.

The second task is to analyze the monthly gravity field solutions, which will be continuously available after the commissioning phase of CHAMP (begin 2000). Ocean mass redistributions can be quantified by the gravity changes, which in turn can be combined with the monthly sea surface changes from altimetry to separate the steric and time-variable parts of sea level change. By doing distinctive correlation analysis between the sea level and other climatological data, e.g. sea surface temperatures, the study will be embedded in an overall investigation of the Earth's environment system.

3. EXPECTED OUTPUTS

The base of the proposal and the most important issue is the generation of consistent time series for the different altimeter missions. This includes the generation of consistent satellite orbits from Geosat on, and consistent media corrections. The altimeter ranges from different satellite measurements and their corrections as well will undergo an extensive cross-calibration and inter-comparisons with in-situ data. Therefore, drift rates and other anomalies of the mentioned quantities will be provided. The goal is to provide the sea level trend with drift rate accuracy less than 1 mm/yr. Expected data products is a list of calibration/verification constants in terms of error budgets for the Jason-1 SWT. It is expected that with the new gravity missions CHAMP and GRACE ocean mass redistributions can be extracted from the sea level result, thus, giving for the the first time reasonable hints for open climate change questions.

4. FUNDING SOURCES

The expected funding source is from German National Funding for M. Azenhofer. C. Shum is expected to receive his own funding from US sources.

A.3 TMR/WET TROPOSPHERE DELAY

Jason Microwave Radiometer Wet Tropospheric Correction

Christopher S. Ruf, The Pennsylvania State University
Stephen J. Keihm, NASA Jet Propulsion Laboratory

1. OBJECTIVES

On orbit validation of the Jason Microwave Radiometer (JMR) will be conducted. Techniques which were developed for the TOPEX Microwave Radiometer (TMR) will be used wherever appropriate. In addition, new validation procedures will be developed to deal with significant differences in the JMR instrument design, relative to TMR. Our objectives include validation of the wet path delay (PD) estimated from raw measurements of the brightness temperature (TB), as well as validation of the absolute accuracy of the individual TBs themselves. There are three major components to the validation effort:

- Assembly of a ground truth data base
- Validation of JMR Flight Algorithms
- Long term assessment of the instrument and path delay retrieval stability

2. RESEARCH PLAN AND METHODOLOGY

1) Assembly of an on orbit ground truth data base for the Jason-1 Microwave Radiometer: The data base will include four independent measurements of wet tropospheric path delay and two independent references for radiometric brightness temperature. The first independent source of path delay measurements will be from ERS- and TMR satellite radiometers. Intercomparisons with TMR will be coincident in space but not in time with JMR, due to the phase offsets between their orbits. TMR will also provide an independent measure of the three brightness temperatures. ERS- radiometers will provide provide additional path delay comparisons. The econd source of path delay ground truth will be an upward looking microwave ater vapor radiometer (WVR) deployed at the Harvest Oil Platform. The third source of path delay ground truth will be derived from routine national weather service radiosonde profiles of atmospheric temperature, pressure and humidity, at selected ocean-island launch sites lying on or near the Jason-1 ground track. The fourth path delay comparison will be based on ECMWF-derived water vapor and temperature fields. The two reference brightness temperatures will be derived from depolarized regions of the tropical rain forest, for high levels of brightness, and calm, clear, dry sub-polar regions of the open ocean, for low levels of brightness.

2) Validation and (if necessary) calibration of JMR Flight Algorithms for the measurement of radiometric brightness temperature and the retrieval of wet tropospheric path delay: The ground truth data bases will be used during the early, `commissioning', phase of the mission to test the initial accuracy of all pertinent flight software, with particular emphasis on possible biases in

instrument calibration or path delay retrieval. As more flight data becomes available, possible scale errors in brightness and path delay will also be tested. Also, TMR intercomparisons will become possible once a significant time record is available.

3) Long term assessment of the instrument and path delay retrieval stability: The ground truth data bases will be updated and archived throughout the mission lifetime. JMR stability will be monitored against these data. Of particular interest in the case of instrument stability are the performance characteristics of the on-board reference noise diodes, against which JMR calibration is absolutely referenced. This approach to radiometer calibration has not been tried before by a flight mission. The effects of any instrument instability on the path delay retrievals will also be determined.

3. EXPECTED OUTPUTS

1) Validation of JMR path delay retrieval performance with 1-2 cm accuracy within the first 6 months after launch. Improved validation accuracy after 1 year.

2) Assessment of long term instrument and retrieval algorithm stability with an expected accuracy of approximately 1 mm/yr, continuing for the duration of the Jason-1 mission.

Calibration/validation of the JMR

Laurence Eymard and Estelle Obligis*
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***CLS, Ramonville, France**

1. OBJECTIVES

Our objectives are :
-to evaluate the quality of the in-flight calibration of brightness temperatures
-to analyze the causes of detected bad calibrations and propose corrections
-to validate the retrieved products using the operational algorithms and possibly new algorithms
-to monitor the long term variation of the in-flight calibration

2. RESEARCH PLAN AND METHODOLOGY

2.1 In flight calibration-validation

The calibration method of the brightness temperatures (Eymard et al, 1996) has been applied for the calibration of the ERS1/2 microwave radiometers. We propose to apply the same method to the JMR. It consists in the comparison between the radiometer measurements and radiative transfer model simulations over coincident meteorological fields extracted from ECMWF. They contain analyses of surface parameters and atmospheric profiles of pressure, temperature, humidity and cloud liquid water. The satellite measurements are taken in any grid mesh within an accuracy of ± 2 hours in time. The calibration can be checked within a few K, corresponding to the confidence expected on the radiative transfer model and the meteorological model. Recalibration consists of correcting the coefficients of the instrument transfer function corresponding to some critical microwave components, in order to fit the simulated brightness temperatures. The method permitted to adjust ERS1 and ERS2 calibrations, and was successfully checked using Topex and SSMI data.

The radiative transfer model has been developed in Université Catholique de Louvain (UCL) by (Guissard et al 1992), for the simulation of the microwave measurements of any spaceborne.(active and passive). It is based on the processing of bistatic scattering coefficients, considering separately the scattering for the large-scale waves and small-scale waves or ripples of the sea-surface, for foam-covered and foam-free configurations. The choice of the sea surface spectrum is quite important for the simulation of the brightness temperatures and the cross-sections. A new model, developed by Lemaire et al (1997), along with a new dielectric permittivity of the sea water (Guillou et al. 1997), fits well radar and radiometer data. The foam is modeled following Monahan and Lu s (1990) coverage, along with Stogryn s (1972) emissivity. The atmospheric water vapour and cloud absorption is modeled following Liebe (1993). The liquid water contents (cloud and precipitation) are taken into account. The choice of the model is very important. This one, with a very fine description of the surface and a classical modelisation of the atmospheric effects, provide reliable brightness temperatures with corresponding cross-sections.

The second step is the validation of the retrieved products. It is performed using in situ measurements from ships and buoys, in order to get a sufficient number of comparison points (within ± 1 hour, and half a degree). All routine measurements archived at ECMWF during the satellite life are to be used.

Finally, we will cross-check the direct model and algorithms reliability in selecting collocated measurements. The intercomparison of satellite data (ERS-2, T/P , SSMI and Jason) will be used in two different ways :
- first by comparing the measured brightness temperatures with each other, and also with those simulated by the model on the corresponding ECMWF fields.
- then by comparing the JMR standard products with the products provided by the other instruments, and also with the retrievals of proposed algorithms.

As the UCL model simulate both active and passive measurements, it’s possible, by running it on ECMWF fields, to formulate coupled algorithms taking into account brightness temperatures and backscattering coefficients. An important step of this work will consist in assessing the improvements du to the coupling of the altimeter and radiometer measurements.

We also hope to check the consistency and accuracy of the algorithms using data collected during special experiments, for example the FETCH experiment during March-April 98 in the Golf of Lion. In situ measurements collected during this experiment (radiosoundings, wave boys and shipborne microwave radiometer).allow a detailed study of the surface and of the related atmospheric.situation It will also be necessary to check the behavior of the algorithms in particular situations where they seem not to give satisfactory results, for example in situation of very dry atmosphere, and close to the coasts (problem of non fully-developed sea, side-lobe contamination by land emission).

2.2 Drift and anomaly control:

The drift control will be verified with the same method as for the calibration. In addition, a long term survey and a direct comparison of the sensors over natural targets (deserts, forests) will be used to analyze the drift on one particular channel with respect to the others. Using the model presented previously, it is also possible to simulate the radar signal. We propose to evaluate the performances of our calibration method when applied to active measurements (sensitivity to the small variations of cross-sections, comparison with independent methods). It will be necessary before applying coupled retrieval of geophysical parameters.

3. EXPECTED OUTPUTS

As the emissivity and reflectivity (used respectively for the calculation of the brightness temperature and reflectivity) are not independent parameters, the used of a combined method should improve the retrieval of the surface and atmosphere parameters and allow to reach a better accuracy on the wet tropospheric correction.(1,2 cm for TOPEX).

CONTRIBUTION TO JMR CALVAL

W. Emery, University of Colorado

1. I assume that there will be a number of comparisons done during the early phase of Jason and that these will include a comparison of the JMR with the TMR. Also we know that the TMR has "drifted" over time but we know how to characterize that change and factor it in. So we can do a quantitative comparison between the two microwave radiometers, their precision and accuracies.

2. It will be interesting to know how the JMR data fit into the global water mass picture and also how it compares with other non-altimetric measurements of atmospheric moisture.

a. Carry about comparisons with ECMWF and NCEP analyses that will depend on the analysis interval. The shorter and more instataneous pictures should agree better with the JMR data.

b. Comparisons with AMSU-b on the NOAA satellites. This is a new instrument and it will be interesting to see how well it does with the atmospheric moisture profiles. The integrated moisture will be compared with the JMR.

c. The SSM/IS is again a new sensor but follows a considerable heritage with the SSM/I. It is also possible that the ssmis will not yet be on orbit and this comparison will be with the ssm/i total atm water vapor. Again instantaneous products will be of greatest interest.

3. Finallly these comparisons with the global analyses and with SSM/I and AMSU data should be made regularly to monitor the performance of the JMR.

Calibration of the TOPEX/POSEIDON and Jason-1 microwave radiometers using VLBI and GPS derive tropospheric delays

D. S. MacMillan, NVI, Greenbelt

1. Objectives

The objective of our proposed work is to determine the rate of drift of the T/P and Jason-1 radiometers using estimates of the wet zenith tropospheric delay from very long baseline interferometry (VLBI) and global positioning system (GPS) measurements. One of the dominant sources of error in VLBI or GPS geodetic analysis is the correction for the delay of a radio signal as it passes through the neutral atmosphere. Because of the importance of this effect, substantial work has been done over the last 10 to 15 years to improve tropospheric modeling. The wet zenith delays estimated in geodetic analysis are now accurate enough to derive column precipitable water vapor content, which can be used to improve weather forecast models. The rms difference between wet zenith delays using these geodetic techniques and wet zenith delays derived from collocated water vapor radiometer (WVR) measurements are typically 5-10 mm. This level of precision should be sufficient to determine the ocean height drift rate due to the T/P radiometer with an uncertainty of about 0.2-0.4 mm/year for GPS sites that observe during the lifetime of T/P.

We will analyze the differences between wet zenith delays from the T/P or Jason-1 radiometer and the geodetic techniques to determine the drift rate of the radiometers. To avoid any drifts caused by algorithm and model changes that have been made in the processing of GPS data since the beginning of the T/P mission, we will reprocess the GPS data at Scripps. Similarly, the VLBI data will be reprocessed at GSFC. We will compare the results for collocated GPS and VLBI sites. Using rates computed for a globally distributed set of geodetic sites, we will investigate the possibility that the drift rate has geographical dependence.

2. Plan and Methodology

Long-term self consistency of wet zenith delays

Since we are interested in determining the long-term drift of the wet zenith delay inferred from the radiometer measurements, it is important to ensure that there are no systematic errors in the geodetic tropospheric delays that could lead to spurious long-term drifts. For this reason we will perform a reprocessing of each of the VLBI and GPS geodetic analyses using the same models and analysis strategies throughout the time period of data analyzed in order to make each of the resulting data sets self consistent. Possible sources of systematic error in the GPS solutions prior to reprocessing are changes in minimum elevation cutoff of observations used in a solution and changes in satellite modeling. The GPS data will be reprocessed at Scripps Institute of Oceanography and the VLBI data at GSFC.

Determine drift rates at island and coastal sites

The T/P orbit track lies 20-40 km from many GPS and VLBI sites. We will extract the geodetic troposphere parameters that are coincident with altimeter overpasses of a selected set of island and coastal geodetic sites. We expect that more GPS sites will become available as the Jason-1 mission progresses. Using this set of coincident measurements at each site, we will derive the radiometer drift rates. We will examine the consistency of the rates at sites where GPS and VLBI are collocated.

Continuity of T/P and Jason-1 data

It is expected that there will be an overlap of a few months between T/P and Jason-1. We will take advantage of this overlap to compare the radiometer corrections derived for the two altimeters. The launch plan for Jason-1 specifies that the orbit tracks of T/P and Jason-1 will be identical and that Jason-1 will pass over a given location within 1 to 5 minutes (as yet undecided) of the overpass of T/P. This configuration will continue for several months. The relative bias between the radiometers during the overlap will be estimated. We will take advantage of this to connect the calibrations (relative) of the T/P and Jason-1 radiometers determined using wet zenith delay data.

Geographical dependence of radiometer error

The drift of the radiometer derived water vapor content may depend on geographical location. If the gain of the radiometer is drifting with time at some rate, then the drift in derived water vapor content will depend on the amount of water vapor since the derived water vapor is a function of brightness temperature. If the drift has such a characteristic, then the drift will be greater for tropical regions, where atmospheric water vapor is large. In such a case, attempts to use tide gauge measurements to calibrate T/P heights may be incorrect since the global distribution of tide gauges is not uniform. We have available geodetic sites in a wide range of locations so that we can examine the geographical variation of the radiometer drift.

3. Expected Results

We expect that the proposed work will allow one to determine the average long-term drift rates and relative bias of the T/P and Jason-1 WVRs. Since we will use a set of globally distributed calibration sites, we may also be able to determine the geographic (primarily latitude dependent) rate of drift that would be associated with a long-term drift of the sensitivity of the radiometer to water vapor.

Many comparisons have been made between estimates of zenith wet delays using VLBI, GPS, and ground-based dual-frequency microwave radiometers. The rms differences between ground-based WVR and VLBI or GPS measurements of zenith wet delay are typically 5-10 mm. We estimate that the rms error in extrapolating from a site to an altimeter groundtrack 40 km away is about 5-10 mm. For geodetic sites where site measurements will have been made continuously for 8 years when Jason-1 is launched in 2000, the expected uncertainty in the T/P rate would then be 0.2-0.4 mm/year. After 3 years of Jason-1, the uncertainty in the Jason-1 rate would be 0.9-1.8 mm/year, which could be reduced by a factor of 2 if the T/P-Jason overlap period was used to establish the bias between the radiometers.

A.4 SEA SURFACE EFFECTS

Assessing effects of atmospheric surface pressure on Jason-1 sea level measurements

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1. OBJECTIVES

Our primary goal for Jason-1 investigation is to move closer to a full understanding and determination of sealevel (SL) variability related to fluctuations in surface atmospheric pressure (AP). In this regard, it is crucial that knowledge of the AP fields be improved. At forcing regimes for which the inverted barometer (IB) approximation holds, the estimation of respective SL signals is only limited by knowledge of AP and will be as good as the AP forcing fields. We thus seek to determine the quality of the various AP fields and their error characteristics, with the hope of arriving at the "best" AP products for use with Jason-1.

At forcing regimes for which dynamic response is important, in addition to good AP fields, one needs to model the dynamic SL signals as best as possible. Our investigation will address the estimation of high frequency, AP-driven dynamic signals using a variety of modeling and analysis techniques. One goal is to improve on the currently used IB correction by providing a best estimate of the full AP-driven signals. More generally, our goal is to improve the representation and understanding of all (including wind-driven) SL variability at periods shorter than 20 days, which will be aliased in the Jason-1 records.

2. RESEARCH PLAN AND METHODOLOGY

Our Jason-1 investigation will focus on four related areas: forcing AP fields, modeling issues, model and data comparisons, and the estimation problem. Significant efforts will be devoted to quantifying errors in AP fields, defining their statistics, and determining to the extent possible a "best" realization of AP variability over the global ocean. Comparisons of different operational and reanalyses products from the various weather centers will be carried out, together with comparisons with independent AP measurements (islands, gridded climatologies). Impact of different AP products on altimeter analysis will be assessed. Both the time mean AP and its variability, from sub-daily to seasonal and longer periods, will be examined, including the time variability of the spatial average of AP over the global oceans, which enters the IB approximation, and the signals related to the atmospheric tides.

A number of modeling activities is planned to improve the determination of the dynamic SL component. Model experiments will include the use of different formulations (finite element vs. finite difference), domain representation, model physics and parameterizations (e.g., baroclinic vs. barotropic, linear vs. quadratic bottom friction), sensitivity studies to forcing fields, comparisons between models, etc. Both AP and wind stress forcing is intended.

Our efforts will involve assessing consistency of the models with altimeter data and also with tide gauge records, seeking an estimate of SL signals driven by AP that improves on what is currently available, and interpreting data and models in the context of ocean dynamics. Combined analyses and comparisons between the various model runs (with different forcing fields and different realizations of SL) and data are planned, using several possible measures of fit (root-mean-square residuals, correlation analysis, multivariate regression analysis, coupled EOF analysis and measures of covariability, etc.). The influence of including AP-forced dynamic signals, instead of using a simple IB correction, on the data reduction will be assessed.

Finally, to attempt an "optimal" estimation of large-scale, high frequency SL signals, including AP-driven dynamic signals, model runs constrained by altimeter data using a reduced state, Kalman filtering technique are also intended. Dynamic interpolation through assimilation allows for such fast SL signals to be extracted despite limitations in data sampling. Efforts will involve developing and improving the assimilation technique, evaluating its performance, dynamically testing the IB hypothesis, separating wind- and AP-driven signals, and learning about barotropic large-scale circulation and dynamics.

3. EXPECTED OUTPUTS

We hope to significantly advance current understanding of the SL response to AP and to high frequency meteorological forcing in general. Expected outputs include: better knowledge of the forcing AP fields, from subdaily to seasonal and longer periods, and respective error characteristics, and consequent improvements in the IB correction; and better estimates of the high frequency dynamic SL signals associated with AP and also with wind stress forcing. Improved estimates of the rapid SL signals should make it possible to improve on the simple IB correction, in what regards removing AP-driven variability from the records, and, more generally, to remove aliased high frequency signals from the altimeter records.

Assessment of long wave effects on the sea state bias using aircraft measurements

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T. Crawford, B. Chapron, T. Elfouhaily, D. Thompson, E. Walsh

1. OBJECTIVES

It is commonly suggested that the 2 cm uncertainty remaining in this EM bias portion of the sea state bias correction can be reduced if one could access more relevant correlative parameters than the altimeter-derived significant wave height and wind speed. Before such a statement can begin to be realized operationally we must first determine the measurable surface parameters that are relevant. Recent studies point to a high correlation between radar EM bias and long-to-intermediate scale wave slope variance. The objective of this activity is to collect open ocean measurements of sea surface slope, elevation and radar backscatter using an already developed low-flying airborne platform.

The measurements should be taken near a directional wave buoy to insure documentation of the long wave directional spectra. The specific goals are to:

- Generate a data set for EM bias studies that covers a broad range of open-ocean sea state and wind conditions
- Measure wave slope statistics versus changes in wind/wave conditions
- Clarify the impact of long (> 10m) and intermediate scale waves (10m - 1m) on the EM bias measurement
- Determine if there is an altitude dependence in the aircraft EM bias measurements
- Attempt to measure changes in the EM bias versus fetch

Note: The data collection effort described here is part of a larger SSB algorithm study being performed by the listed investigators under the Jason-1 program. This text deals strictly with a field program we term the Wave Profile Experiment (WAPEX). WAPEX data collection will be completed prior to CAL/VAL document finalization but the future tense is used below.

2. RESEARCH PLAN AND METHODOLOGY

Our plan is to utilize a unique new aircraft platform for measuring sea surface slope statistics for the long to intermediate scales (waves of length > 1 m). NOAA's Long-EZ research aircraft recently added a three laser ranging system that provides two-dimensional surface slope and elevation data with high fidelity (< 2 cm range noise). This platform also carries a Ka-band nadir-looking scatterometer that can be used to estimate the radar EM bias as done in previous aircraft and tower experiments.

The Long-EZ aircraft will be used to collect the data. A key feature of the aircraft is the nominal flight altitude of 10-15 m. This, in effect, simulates a tower but at whatever prescribed location we wish. The primary instruments on the aircraft will be a gust probe package, GPS systems for aircraft attitude and vertical height determination, a three laser slope/elevation measurement system, and a down-looking Ka-band scatterometer (DLS). There will also be an IR sensor to measure SST. Primary Long-EZ output products will be available at a 50 Hz rate which translates to a data point every 1 m along track. Products will include:
- Ka-band radar normalized radar cross section (with absolute calibration)
- 1 and 2-D surface slope at 1 to 2 m horizontal resolution
- Surface elevation along aircraft track
- Near-surface fluxes
- SST

These data will be complemented by measurements made by the NDBC buoy 44014. This will be the center of the flight region. Flights will be planned to insure that most data are collected within 20 km of the buoy. 44014 is a directional wave buoy and the standard NDBC meteorological data are also available in real-time.

WAPEX measurement location: Centered at 36.6N, 74.8W, North Atlantic, 100 km off NC
Experiment period: 1-22 Nov. 1998
Flight Hours: 50-60, this translates to flights on most dates of the exp. period.

3. EXPECTED OUTPUTS:

Data from this experiment will not provide direct calibration or validation of the SSB correction algorithm but rather are part of the ongoing research to determine the physical processes and then how to incorporate them into the operational correction.

A.5 POD VERIFICATION

JASON-1 PRECISION ORBIT VERIFICATION

J. C. Ries, B. D. Tapley, R. J. Eanes, H. J. Rim, and R. S. Nerem

1. OBJECTIVES

The mission requirements for Jason-1 precision orbit determination are that the accuracy of the orbit to be placed on the Geophysical Data Records (GDR) must be at least the equivalent to those obtained for T/P. This is not an easily attained objective, and this ability must be developed and demonstrated by the CNES orbit determination system prior to launch. In addition, the GPS tracking on Jason-1 will be an essential part of the orbit production system, and this capability at CNES must be developed and verified.

The primary objectives of this investigation are: (1) help create and coordinate a Jason-1 Precision Orbit Determination (POD) Working Team which will provide oversight and monitoring of the preparations for Jason-1 POD production by CNES, (2) provide prelaunch verification of CNES orbit determination software, (3) evaluate and recommend the models and constants which should be adopted to ensure orbit accuracies equivalent to or better than currently obtained for Topex/Poseidon (T/P), and (4) provide accuracy verification of the actual orbits produced by CNES during the Jason-1 mission.

2. RESEARCH PLAN AND METHODOLOGY

Formation of Precision Orbit Determination Working Team
Noting the success of the POD effort for T/P, it appears prudent to form a similar Working Team to monitor the preparations by CNES to produce orbit for Jason-1 with the requisite accuracy. This team will draw on many of the same members as the T/P POD team. In particular, members with extensive experience with the determination of low-Earth satellites with GPS tracking will be recruited. By regularly meeting with the CNES team, progress toward demonstrating the required POD capabilities using SLR, DORIS and GPS data will be examined, tested and verified.

Prelaunch Verification of CNES Precision Orbit Software and Procedures
This verification activity will require the help and independent assessment of an external POD Working Team, since some errors are difficult to test internally. For example, the verification activities for T/P were invaluable in detecting small errors in both the NASA/GSFC and UT/CSR software systems which could not be detected easily by any other means. Fortunately, the task may be somewhat easier since T/P orbits are available for comparisons. However, should detailed comparisons of subroutines be required, the complete description of an initial set of tests is already available from the T/P verification efforts. Additional tests can be conducted as the final Jason-1 models become better defined or the comparisons tests indicate a discrepancy that requires detailed verification.

Precision Orbit Determination Models and Standards for Jason-1
In the same manner as T/P, the POD Working Team will assess whether the models adopted for Jason-1 meet the required accuracy. It is not sufficient to simply freeze models at the current configuration, since a number of them become outdated automatically. For example, SLR, DORIS and GPS station locations are not static, and as the time frame moves from the epoch over which the stations were estimated, the dependence on accurate velocities increases. Consequently, the

velocity estimates, as well as the epoch positions, must be constantly improved. This in turn affects the reference frame that is defined by these stations, and the associated Earth orientation time series is affected. Similarly, the software systems are constantly undergoing changes as state-of-the-art standards are incorporated. Parameter estimation strategies have been shown to be powerful tools in accommodating the residual surface force modeling errors, and the current assumptions regarding arc length and empirical parameters need to be examined to determine if they are still appropriate. It will be essential to determine that any changes made are beneficial, that they are incorporated correctly, and that they do not affect the tie between T/P and Jason-1 orbits. Even the 'static' gravity field is not truly static, but contains long-period and secular variations that will become significant as the epoch for the current gravity model (JGM-3) recedes into the past. This could lead to a slow but significant change in the nature and distribution of the geographically correlated orbit errors. Questions regarding whether to adopt improved models, which may require a reprocessing of the entire T/P mission, must be evaluated and a consensus attained.

Postlaunch Orbit Accuracy Validation and Verification
Unlike T/P, there will be an opportunity to test the CNES POD production system prior to the launch of Jason-1. T/P itself provides an opportunity to validate much of the POD system's accuracy and readiness. However, the DORIS and GPS receivers are newer designs, and a period of validation after launch is essential. For example, comparisons of the T/P orbits by different groups revealed several modeling and processing errors in the GPS and DORIS data which would have been difficult or impossible to detect without the independent comparisons between different techniques.

3. EXPECTED OUTPUTS

Prior to launch, an Orbit Verification (CAL/VAL) Plan will be created by the POD Working Team. This plan will detail the results of the orbit intercomparisons for T/P, the models to be adopted for Jason-1 POD, and the postlaunch orbit verification tasks.

A postlaunch Orbit Verification report will be prepared by the POD Working Team, which will detail the results of the orbit intercomparisons for Jason-1. An assessment of the Jason-1 orbit accuracy will be presented. Any inconsistencies will be noted, and areas of necessary improvement (if any) will be recommended. In particular, model enhancements that improve the orbit accuracy beyond that currently obtained for T/P will be presented, and benefits of a reprocessing of the T/P orbits will be evaluated.

One or more sets of alternative orbits for Jason-1, consistent with the modeling of T/P, will be made available for testing and evaluation. These will not necessarily cover the entire post-launch period, but the process would be in place if the SWT determined that such an effort was necessary.

CONTRIBUTION TO POD VERIFICATION

P.Exertier, P.Bonnefond, O.Laurain, F. Pierron, F. Barlier, OCA-CERGA

1. OBJECTIVES

The POD verification plan we are developing since several years is based on a geometric evaluation of the orbit of radar altimeters thanks to dense Satellite Laser Ranging (SLR) regional networks. This method of precise orbit determination although very local in time and space is able to provide orbit controls at the 1 cm level over at least two important areas around the world: Europe and USA.
The fact that these regional networks play also an important role in tracking the LAGEOS satellite to contribute to the global geocentric positioning is an occasion to simultaneously analyse both SLR tracking data. On a long term basis, the objective is to avoid the error propagation from the SLR data to the station coordinates and then into the altimetry.

2. RESEARCH PLAN AND METHODOLOGY

We have developed a short arc orbit technique for the orbit validations of altimeter satellites, and for positioning-colocation. It is based on SLR data, and on rigourous ajustment criterions. In the framework of the TOPEX/Poseidon (T/P) mission, the method has been applied with success for the alimetry of the Mediterranean [Bonnefond et al., 1995]. The proper error budget of the method, being at the level of 1-2 cm, has allowed to study the radial orbit error of T/P.

Today, thanks to a selective choice of SLR measurements, taking into account their intrinsic precision/accuracy and the precision of the station coordinates of the SLR network, the error budget of the method has been reduced to 1 cm and less. The studied area has been enlarged to the entire network. These new developments and capacities have been installed on a dedicated Internet site in order to permit the quasi-immediate validation of Jason-1 orbits.

Now, it is already possible to use this site to evaluate a given T/P orbit cycle. Results of the overall mission, concerning orbits and SLR residuals (eventually per station) are also presented.

3. EXPECTED OUTPUTS

Above the Europe area and, as a consequence, above the Mediterranean sea, the fact that the T/P orbit is largely covered by SLR is a very interesting aspect for altimetry. This permits to enlarge the possibilities of CAL-VAL activities, particularly with the choice of the Corsica island as on site verification area, and to improve the determination of the sea profiles on an absolute basis.

Improved orbits and reference frame stability from GPS tracking of JASON-1 to support basin-scale sea level studies.

M. Watkins, JPL, CA

1. OBJECTIVES

The TOPEX/POSEIDON (T/P) mission has contributed significantly to our understanding of the large scale variability of sea surface height. For T/P, a combination of satellite laser ranging (SLR) and DORIS Doppler data has provided the orbits and defined the reference frame in which to study sea surface height variations. T/P also carries a precise Global Positioning System (GPS) receiver which has operated well under non-Anti Spoofing conditions. There is some evidence that the reduced dynamic T/P GPS orbits provide slightly better radial orbit knowledge as measured by altimeter crossovers and orbit overlaps [Bertiger et al., 1994]. There has been, however, an unexplained translational offset in these precise GPS ephemerides relative to those of SLR/DORIS, which corresponds to a shift along the terrestrial z-axis of several centimeters. There is also some variability about the mean value this translation. This offset and its variations can degrade both estimates of large-scale circulation and sea-level variability. Particularly sensitive are observations of the change in global mean sea level and estimates of basin and hemispheric-scale variations in sea level stemming from seasonal steric or geostrophic changes. We propose the z shift is caused by the poor sensitivity of GPS to the location of the z-axis is due to the estimation of real-values phase ambiguities for all satellite-station pairs. Resolving these ambiguities can reduce this weakness.

To illustrate the importance of reference frame stability and its impact on the recovery of oceanographic parameters, Haines et al. (1995) have performed an Empirical Orthogonal Function (EOF) analysis on the differences between the reduced dynamic GPS and the JGM-2 and JGM-3 dynamic orbits projected into the global oceans. An EOF analysis reveals those (empirical) modes of spatial variability into orthogonal components. It was determined that the dominant modes of variability correspond to periodic shifting in the center-of figure. The key result of the EOF results was that the most energetic spatio-temporal variabilities associated with the orbit errors are not tide related, rather they have their origin in the definition of the ostensible geocenter, and as such are very large scale. The Z-shift variations in particular are important, because they can introduce basin-to-basin error in ocean topography that directly impact estimates of seasonal steric changes. This reference frame variability is probably the most important of the remaining questions about the use of the T/P orbit for sea level studies. Therefore, the objective is to improve the orbits for JASON-1 and improve the stability of the reference frame in which these orbits are defined by resolving double differenced carrier phase ambiguities.

2. RESEARCH PLAN AND METHODOLOGY

Recall that the primary observables from the GPS are one-way of flight (pseudorange), and carrier phase on two L-band frequencies. The carrier phase is a biased measurement, and a real-valued bias, representing the number of integer wavelengths to be added to the phase to describe the satellite receiver range, must be adjusted during the estimation process. This data type can be strengthened by determining the actual integer number of wavelengths, as opposed to the real-valued approximation. In practice, this can only be done for double difference ambiguities in order to remove small transmitter and receiver specific non-integer delays. Methods for this carrier phase ambiguity resolution (sometimes referred to as bias fixing) have been described in some detail in a number of references including Melbourne (1985) and Blewitt (1989). These methods rely on widelane ambiguities (the phase difference between L1 and L2) resolution either from ionospheric constraints or pseudorange data, combined with accurate narrowlane (ionosphere-free linear combination of L1 and L2) estimates. As the baseline length between the two sites (or one site and a low-Earth orbiter such as JASON-1) increases, one must rely either on increasingly sophisticated ionosphere models or utilize fairly precise pseudorange data to resolve the widelane ambiguity. Modern receivers are of sufficient quality to frequently satisfy this requirement, even under Anti-Spoofing conditions.

3. EXPECTED OUTPUTS

Resolution of phase biases between two ground receivers and GPS s/c ambiguities strongly improves the reference frame stability of the GPS s/c orbits [Watkins et al., 1998]. However, an additionally powerful improvement would be to resolve carrier phase biases involving one ground site, JASON-1, and two GPS s/c. The major limitation is the shortness of the phase-connected arcs that are available to a particular ground site and JASON-1. This severely limits the precision of the ionosphere-free phase bias and makes ambiguity resolution challenging even if the right widelane is obtained. If this type of ambiguity resolution be successful, the JASON-1 orbit will be more firmly connected to the GPS terrestrial reference frame than ever previously achieved. As an added benefit, it would also be possible to increase the process noise for the JASON-1 orbit and obtain excellent quality kinematic solutions for additional study and comparison with dynamic orbits.

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A.6 WIND/WAVE CALVAL

CONTRIBUTION TO WIND/WAVE CALIBRATION/VALIDATION

Jean-Michel Lefevre, Meteo-France

1 OBJECTIVES

Validation and calibration of the OSDR wind/wave data from JASON using data from Numerical Weather Predictions models and Numerical Wave Predictions Models (NWP). Indeed, the analyses of NWP provide a estimate statistically optimum estimate of the surface wind speed and of the Significant Wave Height (SWH) on a global regular latitude longitude grid of about 0.5 resolution. This estimate is generally given with a temporal frequency of six hours. Although for extreme values, the in situ data provide a more accurate estimate of the parameters in question than NWP do, the NWP analyses allow to validate and calibrate the data within an interval of value accessible to the altimeter.

2. RESEARCH PLAN AND METHODOLOGY

2.1. Archiving

WFA stores the data concerning the air sea interface and resulting from the NWP from the European Center for Medium Range Weather Forecasting. And from Meteo-France. WFA also stores the real time satellite data from ERS, and the wind/wave data from TOPEX/POSEIDON, as well as Sea Surface Temperature (SST) products and incidental solar fluxes from the Center of Space Meteorology of Lannion starting from meteorological satellites NOAA and Météosat. Finally WFA stores the meteorological ship and buoy observations transmitted on the Global Transmitting (GTS) for Meteorology.
One proposes to store the additional OSDR satellite data from JASON (wind speed, Radar cross section, SWH, flags...)

2.2. Data processing

WFA also offers products resulting from a certain number of processing:

- systematic processing: these processing have as a principal objective the monitoring and the quality control before storing the data. Its includes a quality control of the data, as well as graphic and statistical products, and the collocation with satellite measurements and with in-situ measurements.

- processing on request: many processings on the stored data can be carried out on request, relating to for example the calculation of derived statistical parameters or geophysics, or the re-analyzed fields by combining various sources of information.

One proposes to add new systematic processing to collocate the NWP model with JASON data. A processing for the quality control of the JASON data will be implemented as well as a procedure to reduce the problems of representativeness of the satellite data with respect to NWP model data
One also proposes to establish one procedure for testing several wind speed model functions.

In particular one proposes to carry out a global analysis and a regional analysis in two different ways:
- globally with ECMWF/WAM and ARPEGE/VAG NWP models.
- regionally with ECMWF/WAMED and ALADIN/VAGMED NWP models.

3. EXPECTED RESULTS

These analyses should allow first to evaluate the pertinence of OSDR wind/wave data , to calibrate them if it is needed. At last, they should make it possible to analyze and test several t wind speed algorithms.

4. TEAM

Jean Michel Lefèvre
Laurent Degheil
One student (3 months).

5 SHEDULE

6 month Before launch to launch : development of the software
Up to 6 month after launch : processing of the data, analyze of the results

A Coordinated Programme for Calibration/Validation of Altimeter Sea State Data

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1. OBJECTIVES

The objectives of this programme are to carry out a careful calibration and validation of the JASON Fast delivery and Offline GDR wind and wave data through comparison with co-located *in situ* buoy data. This procedure will be consistent with calibration procedures applied previously, and concurrently to other satellite altimeter data sets.

The programme will:

- Verify data format, and data flagging.
- Verify that the JASON wind/wave data meet required specifications.
- Assess whether calibration corrections are required.
- Ensure consistency of JASON data with TOPEX and other altimeter wind/wave data sets.
- Define recommended data quality checks.
- Regularly (3-monthly) repeat calibration procedure to check for calibration drift.

2. RESEARCH PLAN AND METHODOLOGY

Identical procedures will be applied to Fast Delivery (OSDR) and Offline GDR data. Where possible these procedures will run alongside similar analyses of TOPEX, Geosat Follow-On, ERS-2 and ENVISAT.

2.1. On receipt of first cycle of data

- Test and verify data format
- Compile statistics of data flags, frequency distributions of relevant parameters (significant wave height - H_s; radar backscatter- σ^0; wind speed - U10; pulse peakiness (if available) H_s, σ^0, U10 corrections, standard deviations of H_s, σ^0, U10, and range).
- Initial test of supplied data flags, assess use of further tests.

2.2. On receipt of first 1 months data, and repeat at every subsequent months until end of year 1. Repeat every subsequent 3 months.

- Further test of supplied data flags, through co-located buoy data
- Using quality checks identified above, extract co-located altimeter and buoy wind/wave data. Where buoy data providers agree, place co-located data on ftp/WWW site.
- Carry out principle compents regression procedures.
- Assess accuracy (absolute and relative) of JASON wind/wave parameters.
- Compare to results of same exercise carried out on TOPEX, ERS-2, Geosat Follow on and ENVISAT wind/wave data (where available).
- Generate and analyse distribution functions of JASON, TOPEX, ERS-2, Geosat Follow on and ENVISAT wind/wave parameters covering same period.
- Identify any significant problems with JASON data and make recommendations to CAL/VAL team.

3. EXPECTED OUTPUTS

First 10 day Data Cycle:
Verification of data format, assessment of data flagging. Recommendation of further quality tests.

First 3 x 10 day Data Cycles (1 month):
Preliminary assessment of accuracy of JASON wind/wave data. Identification of any major early problems with product.

First 9 x 10 day cycles (3 months):
Full assessment of validity of wind/wave product. Confirmation that product meets specification. Assessment based on projected minimum 100 altimeter/buoy co-locations.

First 18 x 10 day cycles (6 months):
Assessment of accuracy (calibration corrections, and rrms error) of wind/wave product from altimeter/buoy co-locations. Initial recommendation of any calibration corrections. Comparison of JASON product with TOPEX, GFO and ERS/ENVISAT through co-locations and distribution functions.
Assessment based on projected minimum 200 altimeter/buoy co-locations. Projected error bars on calibration will be available later this week.

Sites of opportunity for JASON CALVAL in the Brazil-Malvinas Confluence region and in the Agulhas-Benguela convergence region

Christine Provost, LODYC, Paris

1. OBJECTIVES

CALVAL of SSH, wind and wave height in 2 regions of very high energy and variability:
Brazil-Malvinas Confluence and Agulhas-Benguela Convergence

2 RESEARCH PLAN AND METHODOLOGY

2.1.Deployment of in situ instrumentation

in both regions, with at each site:

- a surface mooring under a JASON cross over. This surface mooring comprises a surface buoy equipped with meteorological sensors, accelerometers, pressure sensors and real time transmission to land. Below the buoy is a taut cable on which an autonomous vehicle the yoyuo profiler " makes repeated high accuracy V- CTD profiles from 1000m up to the surface (VCTD = horizontal velocity+ temperature+ conductivity+depth). At the end of a profile the yoyo transmits all the data acquired to the surface buoy which sends it to shore. Therefore we can obtain in real time sea surface height variability (from yoyo profiler), wind speed and wave height (from the buoy). All this equipment is being developed and tested within a european MAST programme called yoyo 2001.

- deep and shallow tides gauges, both tide gauges being on the same JASON track and both under cross-overs, those tide gauges being connected to referenced land tides gauges.

- a subsurface mooring equipped with an upward looking ADCP . This is not an absolute necessity for the CALVAL but would be of great help for the surface velocity issue.

All these in situ measurements will be high frequency measurements, and besides calval activities will permit to estimate the aliasing due to JASON time sampling.

The ship cruises to be used are:

- for the Brazil-Malvinas Area : the Bristish Antarctic Survey ship which performs the Atlantic Meridional Transect (AMT from the PML, UK) twice a year. Cooperation agreement with J. Aiken & D. Robbins from PML.
- for the Benguela/Agulhas region: a regular cruise from Cape Town to Prince Edwards Islands once a year in April. Cooperation with Lutjeharms, M. Rouault from Cape Town University.

2.2 Time schedule

subject to JASON Launch.Deployment of the moorings soon before or after Jason launch.

A- Brazil-Malvinas Confluence:
Deployment either April or September 2000 - Maintenance of the moorings during many years (they will proposed as part of GOOS)
First 6-8 months: cal-val of IGDR
Following years calval of IGDR and GDR

B- Benguela Agulhas Convergence
Deployment either in April 2000 or April 2001- Maintenance of the moorings during mainy years (they will proposed as part of GOOS)
First 6-8 months: cal-val of IGDR
Following years calval of IGDR and GDR

3 EXPECTED OUTPUTS

In relation to the performance requirements and to the CALVAL goals, e.g. calibrate/validate measurement system components at 1 cm level, calibrate measurement system drift at 1mm/yr level... The real-time transmission from the yoyo mooring will allow calibration/validation of the IGDR and of course of the GDR's for sea surface height, wave height ans wind.