The goals of the Ocean Surface Topography Science Team are to provide the scientific underpinning for production of the best possible satellite-derived ocean surface topography and sea level data sets and to demonstrate the Earth science and applications arising from analyses of the ocean surface topography data. Specifically, this announcement sought projects to utilize the growing time series of multiple satellite altimeters. The team will be involved in scientific preparations for the Ocean Surface Topography Mission (OSTM), a cooperative mission between NASA, CNES, the National Oceanic and Atmospheric Administration (NOAA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) planned for launch in June 2008. This solicitation also includes intercalibration/validation analyses of the Jason/OSTM missions during and after the verification phase. A number of the selected projects stress the use and application of satellite altimetry in basic research and operational projects in physical oceanography and related fields consistent with the strategic goals of NASA’s Earth Science Program as part of its focus area on climate and climate variability. NASA selected 27 out of 56 proposals.

William Bertiger/Jet Propulsion Laboratory
Precision Orbit Determination To Support Altimetry

The position of the satellite in satellite altimetry directly effects the accuracy of the measurement of sea surface height. A radial error of 1 cm in positioning is a one cm error in the sea surface height. Over the years, our team has driven the errors in precise orbit determination (POD) of altimetry satellites down to the sub-cm level. We wish to continue our quest to improve precision orbit determination with a focus on GPS data for altimetry missions which started Topex/Poseidon and continued through JASON. We will continue to improve our force modeling and data processing techniques applying them to both historical JASON data and the upcoming OSTM satellite. For OSTM we will perform the necessary on-orbit tuning of the POD force model and data processing to quickly obtain orbits with accuracy comparable to the best determined JASON orbits. Over the life of the four-year proposal, we intend to make significant improvements in the POD of both JASON and OSTM. These efforts will address both POD for ultimate accuracy and near real-time data delivery of POD for operations applications of satellite altimetry.

Charon Birkett/University of Maryland
The Application of Multiple Satellite Radar Altimetry Data Sets to Inland Surface Water Projects

This proposal seeks to explore several inland water investigations using archival (T/P, ERS-1, ERS-2), current (Jason-1, GFO, ENVISAT) and future Ocean Surface Topography Mission (OSTM) mission data. The main science focus is on river dynamics,
the use of lakes as proxy indicators of climate change, and the forecasting of
drought/flood episodes in remote regions. A multi-altimeter approach provides a more
global outlook, combining the temporal and spatial resolution merits of each instrument,
while each series (NASA/CNES or ESA) offers 15-20 years of observation. A strong
calibration/validation theme runs throughout this proposed program with respect to the
OSTM mission, focusing particularly on the problems inherent in the merger of multiple
datasets. The utilization of all data sets is also at the forefront, seeking refined radar echo
interpretation and atmospheric correction methods to improve target detection and
elevation accuracy. Technical results will feed directly into a USDA-funded near real
time operations program that monitors large lakes and reservoirs around the world for
irrigation resources concerns. The main objectives of this program are:
1. To examine the overall performance of the OSTM radar altimeter over inland
   water targets.
2. To refine echo interpretation and data evaluation methods to improve elevation
   accuracy and target resolution.
3. To examine the merits and problems inherent in combining the
   NASA/CNES/ESA/NRL data sets,
4. To undertake 3 science investigations,
   i) Evaluate the contribution of satellite radar altimetry to the determination of river
      discharge and river dynamics.
   ii) Search for and interpret the correlations between observed lake/reservoir/river
       stage variations over a 20 year period and climatic indices such as ENSO and NAO. The
       long-term goals here are the evaluation of regional vulnerability to drought and floods.
   iii) Determine GRACE volume storage changes and correlate the results with
       altimetric lake and tributary stage variations.

Shannon Brown/ Jet Propulsion Laboratory
Error Characterization and Intercalibration of the Wet Path Delay Measurements
from the Topex/Poseidon, Jason-1 and OSTM Microwave Radiometers

We propose to produce a seamless 20-year climate record of global wet tropospheric
content that in turn will facilitate a seamless record of altimetric global sea surface height
(SSH) over the same period, by rigorously calibrating and validating the measurements
from the passive microwave radiometers onboard the Topex/Poseidon (T/P), Jason-1, and
Ocean Surface Topography Mission (OSTM) satellites. We will generate a homogeneous
record of vapor and liquid content of the troposphere with consistent quality and stability
across the T/P, Jason-1, and OSTM missions by characterizing the temporal and
geographically correlated errors in the radiometer measurements, as well as errors
correlated with the geophysical state of the atmosphere and surface, and mitigating those
errors through the recalibration of the radiometers and the development of new
geophysical algorithms. A particular focus of the error characterization will be the
assessment of errors near coastlines and sea ice boundaries. Along with this error
assessment, new algorithms will be developed to reduce land contamination errors.

Our goal is to ensure that the wet path delay measurements from the TMR, JMR, and
AMR maintain accuracies of better than 1 cm per sample, less than 0.3 mm/year in global
averages, and better than 5 mm per month in regional averages over a few hundred kilometers. The long term stability of the wet tropospheric path delay record will be assessed using on-Earth stable brightness temperature references, such as a vicarious cold reference and the Amazon rainforest, and wet troposphere content measurements from coastal Global Positioning System (GPS) sites, the Special Sensor Microwave Imager (SSM/I), the Tropical Rainfall Measuring Mission's Microwave Imager (TMI), global radiosondes and the ECMWF numerical weather prediction model. This investigation will promptly identify anomalies in the wet path delay measurements from these radiometers, such as unexpected offsets or drifts, notify users, and recommend corrections.

Philip Callahan/Jet Propulsion Laboratory
Hurricane Studies with Altimeter Data

We propose to extract altimeter data for each tropical storm data from QuikSCAT reprocessing and continuing through the OSTM cal/val phase. We will use the data to study air-sea interaction and to characterize hurricane effects that may be of use both scientifically and operationally. From the altimeter records we will use Ku and C band SWH and sigma0, skewness from retracking, and the radiometer measurements as well as atmospheric model fields. Where QuikSCAT data are collocated in time and space they will provide measurements of sigma0 as well as wind speed and direction. As appropriate, we will investigate effects in both scatterometer and altimeter measurements. Effects will be investigated both statistically and by case studies. The work will aim to derive operationally useful methods for improving storm forecasting and assessment. Topics to be investigated include:
- air-sea interaction, particularly the altimeter's ability to measure spray/spume and the development of hurricanes;
- the effect of wave height on scatterometer measurements;
- rain effects.

If additional data types such as SST, ocean heat content, other radiometer data, or model information have been collocated with the QuikSCAT data, we will use those in investigating some of these effects.

Significance:
- improved understanding of the measurement and effects of spray/spume in tropical storms;
- improved understanding of changes in small scale surface roughness around tropical storms;
- improved understanding of the effect of rain on both scatterometer data (a significant error source) and altimetry.
Dudley Chelton/Oregon State University  
An Investigation of Global Mesoscale Variability

Extensive observational and theoretical work over the past decade has focused on dynamical interpretation of observations of SSH from the TOPEX/Poseidon (T/P) altimeter as linear Rossby waves modified by background mean currents and bottom topography. The doubling of resolution afforded by merging the measurements from two simultaneously operating altimeters reveals previously unresolved features that suggest a paradigm shift to a view of the ocean as being dominated by nonlinear eddies rather than Rossby waves. Altimetry is the only way to obtain essentially synoptic, global observations of the eddies.

The objective of this proposed research is to validate and extend an automated eddy identification and tracking procedure and apply it globally to altimeter data and to the output of eddy-resolving ocean general circulation models (OGCMs), in order to investigate the dynamics of mesoscale variability. The procedure to be used is the fifth in a hierarchy of procedures that we have developed, each of which addressed issues of concern in previous versions. While we believe that our current procedure is robust and produces eddy trajectories that can be interpreted dynamically, continued testing and verification, and possible further refinements, will be conducted as part of the proposed research. Application to the output of OGCMs allows quantification of the strengths and limitations of the procedure in the presence of known sampling errors and measurement noise in the altimeter data. The OGCMs also provide information about subsurface variability, which is essential to understanding some of the dynamical questions about mesoscale variability. An important aspect of the proposed research is to investigate the degree to which the subsurface characteristics of eddies can be inferred from SSH measurements alone. The host of dynamical questions to be addressed in the proposed research will lead to a greatly improved understanding of mesoscale and large-scale ocean circulation.

William Emery/University of Colorado  
A New Method for Mapping Mesoscale Circulation over the Shelf: Retracking Altimetric Waveforms to Conform to Geostrophic Currents Inferred from Satellite Imagery

A major challenge facing present day satellite altimetry is mapping the mesoscale circulation in coastal regions where the bottom topography shallows abruptly, and onboard water vapor corrections become contaminated by the land. Waveforms reflected from coastal oceans differ from open oceans, such that the onboard satellite-tracking algorithm cannot accurately compute the coastal sea surface heights (SSHs). Retracking takes advantage of the 10 or 20 Hz measurements available in the waveforms as opposed to the 1 Hz measurements used in the standard altimetric retrievals. We propose to retrack altimetric data off the U.S. west/east coast study regions using as “truth” synthetic dynamic heights inferred from coincident geostrophic currents computed from sequential infrared and ocean color images. This method performs well against standard altimetric tracking in the open ocean and we hypothesize that the method could be extended into the shallow coastal regions where the retracking becomes important. Thus
we can design the optimal retracker. To be consistent with this higher spatial resolution retracked SSHs we will use all available atmospheric water vapor data (from models or radiometers) and the best available tidal models to correct our altimeter heights. It is anticipated that this method can be extended to the Gulf of Mexico, Australia and Europe. This project fulfills theme one in the OSTST call and contributes significantly to themes two and three of this call. It contributes important steps forward to NASA’s ocean currents and coastal environment objectives by linking infrared and ocean color imagery directly to coastal ocean altimetry to depict coastal mesoscale circulation.

Bruce Haines/Jet Propulsion Laboratory, California Institute of Technology
The Harvest Experiment: Calibration of the Emerging Climate Record from TOPEX/Poseidon, Jason-1 and OSTM.

The principal objective of the proposed work is to rigorously calibrate the long-term altimetric record of global sea level, and its constituent measurements, using in situ data collected at the PXP Harvest Oil Platform. Located off the coast of central California, the Harvest platform was established as the NASA primary verification site for TOPEX/POSEIDON (T/P) prior to its launch in 1992. The calibration experiment has provided accurate and continuous in-situ data for over 15 years, enabling unprecedented monitoring of the emerging climate record from T/P and Jason-1.

The joint U.S./France Ocean Surface Topography Mission (planned 2008 launch) will follow the same ground track as its predecessors, implying that Harvest will continue to serve a vital role in validating data from precise space-borne radar altimeter systems. Estimates of the OSTM measurement system bias and stability will be routinely supplied to the Ocean Surface Topography Science Team (OST/ST) 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, and to understand and minimize the errors in the in-situ systems.

Weiqing Han/The University of Colorado
Interannual Variability And Decadal Change Of Thermocline Depth And Upper-Ocean Heat Content In The Indian Ocean

The overall goal of the proposed research is to utilize the 15-year multiple satellite altimeter data, other satellite data, in situ observations combined with ocean and global coupled climate models, to provide a thorough understanding of the causes for the interannual variability and decadal change of thermocline depth and the upper-ocean heat content in the IO. The objectives to achieve this goal are to: [1] explore the spatial pattern and basin-mean interannual variability of sea level, thermocline depth and heat content especially in the upper ocean; quantify the relative importance of wind-induced circulation, surface radiative fluxes, turbulent heat fluxes and remote forcing from the Pacific via the Indonesian Throughflow (ITF) on the variability; [2] estimate the decadal variations and change of IO thermocline, heat storage and heat content, and investigate the causes for the variability and change; [3] assess the rectification of ISOs into the interannual variability and decadal change of the upper-ocean heat content; [4] identify
and document mesoscale eddies and explore their influence on the thermocline depth and heat transport. The project will directly contribute to the goals of the Ocean Surface Topography Science Team (OSTST) by utilizing satellite altimetry to basic research, and serve the strategic goals of NASA Earth Science Program: Study Earth from space to advance scientific understanding and meet societal needs. The project is a team effort among the University of Colorado (W. Han and J. Weiss), the National Center for Atmospheric Research (G. Meehl and A. Hu), and the University of Tokyo, Japan (Y. Masumoto).

Steven Jayne/Woods Hole Oceanographic Institution
Global Upper Ocean Velocity

We propose to use altimeter data in conjunction with data from the Gravity Recovery and Climate Experiment (GRACE) satellite, surface and subsurface drifters, and hydrographic data from the Argo array to estimate the time-averaged, three dimensional velocity in the upper ocean and sea surface height relative to the geoid. All of these ocean observing systems provide complementary information about circulation in the upper ocean, but no standardized analysis product using all of these data exists.

In the proposed analysis, three dimensional maps of upper ocean velocity will be produced using an extended optimal interpolation (OI) formalism that includes weak constraints and other data beyond geostrophic velocity and dynamic pressure. As additional data become available, for example Argo float velocity and profile data, they will be incorporated into the analysis. Pre-Argo float data will be used in conjunction with altimeter and drifter data to estimate decadal changes in ocean circulation over the past 10 years. The circulation maps that result from this work will be explored to understand the general circulation of the ocean.

This work will provide the oceanographic community with a standard analysis product for velocity similar to the temperature and salinity analyses that have found widespread utility. The product will also provide a metric against which circulation from numerical ocean models can be measured. As models are used throughout the oceanographic community for process studies, data assimilation, real-time forecasting, and climate change simulations, it is critically important to have a benchmark with which to measure their fidelity. In particular, output from the Estimating the Circulation and Climate of the Ocean (ECCO) data assimilation models will be compared with maps of upper ocean velocity. This will provide valuable feedback to the ECCO project by allowing critical evaluation of the model against a purely observational analysis of upper ocean circulation.

Kathryn Kelly/University of Washington
Assessing Meridional Transports in the North Atlantic Ocean

The conceptual model of the ocean heat conveyor has warm water flowing poleward primarily through the Gulf Stream (GS) and the North Atlantic Current (NAC) as the upper limb of the Atlantic Meridional Overturning Circulation (AMOC). This paradigm
has been challenged by recent observations showing little coherence along the boundary currents and little cross-gyre exchange between the subtropical and subpolar gyres of the North Atlantic. For the AMOC to cause observed decadal anomalies of heat and freshwater, there must be a robust mechanism to move water properties poleward between ocean gyres that responds coherently to forcing. However, our previous research shows that upper ocean transport anomalies in the subpolar/subtropical boundary, the NAC, do not correspond to anomalies in GS transport. Instead, anomalies are generated when the GS sends more flow either into the NAC or back into the subtropical gyre, with the pathway switching on interannual time scales. The dependence of the NAC anomalies on this switching, rather than on GS anomalies, suggests that monitoring the Florida Current may be inadequate to characterize the AMOC. Estimates of cross-gyre exchange inferred from observations are much smaller than the overturning transport in climate models, because both surface drifters and subsurface floats tend to remain in the gyre in which they were deployed. However, the exchange could be accomplished by meridional excursions of the gyre boundary (NAC) itself, as seen in recent observations. A combination of high-resolution ocean modeling and analysis of altimetry and related observations is proposed, focusing on the impact on property transports of the switching of transport between gyres and of excursions of the gyre boundary, and whether these changes are forced by winds. A detailed examination of this critical region will aid in the design of an AMOC observing system, in response to the Ocean Research Priorities Plan.

Gary Lagerloef/Earth & Space Research

Studies Of Upper Ocean Dynamics Related To The Pacific Decadal Oscillation Using Satellite Altimeter Data And Derived Velocity Fields

This proposal is to investigate the ocean dynamics associated with the climate mode known as the Pacific Decadal Oscillation (PDO). The U.S. CLIVAR program has a primary goal to understand the major patterns of climate variability on decadal time scales and evaluate their predictability. It identifies the PDO as having an unusually large expression in North America, and it significantly impacts water resources in the western U.S. and Canada, thereby affecting hydropower, agriculture, wildfires brought on by drought conditions, and biological populations, including salmon (US CLIVAR Office, 2000). The satellite altimeter data record now exceeds 15 years, and near the middle of that record was a strong climatic shift in the North Pacific that bore many signatures of the PDO changing from warm phase to cool. Our research will be the first to apply direct measurements of surface currents from satellite altimeter and vector wind data, which we have developed and refined under prior and ongoing research support, in order to investigate the large scale ocean circulation variability associated with this important climate signal. We will specifically investigate the role of ocean transport of surface properties and the ocean’s dynamic response to stochastic wind forcing in governing the observed responses of sea surface temperature (SST) and topography, and examine leading indices that may provide a measure of predictability. This research directly addresses NASA’s Strategic Sub-goal (3A) to study Earth from space to advance scientific understanding and meet societal needs, and the objectives of the Ocean Surface Topography Science Team (OSTST) to support studies in physical oceanography utilizing Jason/OSTM mission data, as well as the combined 15-year TP/Jason data,
jointly with other satellite and in situ data to resolve the large-scale redistribution of heat and mass in the upper ocean and exchanges with the atmosphere, covering studies of open ocean circulation, including intraseasonal-to-interannual variability.

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**Robert Leben/University Of Colorado**

**Operational Ocean Circulation Monitoring for the Study of Mesoscale Dynamics**

Mesoscale eddies are the most energetic component of the ocean's general circulation, ranging in diameter from tens to hundreds of kilometers. In an analogy to the atmosphere, mesoscale eddies are the storms and weather systems of the Earth's oceans - the "ocean weather". Just as atmospheric weather affects almost every terrestrial activity, mesoscale eddies affect day-to-day activities in the upper ocean environment. During the TOPEX/Poseidon mission, we developed a near real-time altimeter data system to process and post maps of sea level variations associated with mesoscale eddies and fronts. This system has operated continuously since 1996 and is used for a wide variety of web-based operational, scientific, educational, and outreach activities. The objectives of the proposed work are to continue operation of this system while performing basic research to assess and improve high-resolution ocean products for mesoscale monitoring. A quantitative assessment will be made using an objective census of the population, structure, and distribution of mesoscale eddies as resolved in the current generation of altimeter products. This census data will be used to better understand the limitations of current products at mesoscale wavelengths and to develop improved altimeter products for the operational and scientific communities. Altimeter products will be developed and tested with the goal of producing new operational and research data sets with improved depictions of the mesoscale eddy field. Robust processing improvements will be incorporated in the near real-time data system to improve operational monitoring of the ocean mesoscale. More complete knowledge of the distribution and movement of ocean eddies will lead to a better understanding of the role mesoscale circulation plays in the ocean's general circulation and biogeochemistry, both of which affect the daily activities of humans and marine fauna in the local ocean environment and, to an unknown extent, the Earth's climate system.

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**Frank Lemoine/NASA Goddard Space Flight Center**

**Calibration and Validation of the Precise Orbits for OSTM-Extending the TOPEX, Jason-1 and Jason-2 Climate Data Record for MSL Studies**

The quality and the precision of the satellite orbit is a critical component of the OSTM mission and provides the central reference frame for the altimeter data. The analysis of OSTM altimeter data and data from TOPEX/Poseidon and Jason-1 requires that the orbits for all three missions be in a consistent reference frame, and calculated with the best possible standards to minimize error and maximize the data return from the 15+ year time series, particularly with respect to the demanding application of measuring mean sea level change. For OSTM, we propose to (1) validate the performance of the tracking systems on OSTM, by processing data from all available tracking systems on the spacecraft (SLR, DORIS, GPS, and altimeter crossovers), and intercomparing the resultant orbits internally and with external POD analysis centers; (2) Produce a
consistent set of orbits for Jason-1 and OSTM during the tandem phase in order to facilitate the calibration of the altimeter; (3) On an on-going basis following the tandem phase validate the orbit POE’s produced by the OSTM project; (4) Test model improvements in view of continuing to improve the quality of the entire time series of orbits for TOPEX/Poseidon, Jason-1 and OSTM, by taking advantage of improvements to the nonconservative force models for these satellites, investigating other force and measurement model improvements, and testing and validating the performance of the tracking stations and the terrestrial reference frame from which the tracking station coordinates and velocities are derived. The products from this investigation will include: (1) Precise orbits for both Jason-1 and OSTM during the tandem mission phase consistent with the ITRF2005 orbits of Beckley et al. (2007); (2) Improved orbits for, TOPEX/Poseidon, Jason-1 and OSTM, using the modeling improvements necessary to produce a consistent and accurate orbit time series for the OSTST.

Nikolai Maximenko/IPRC/SOEST, University of Hawaii

Dynamics Of Anisotropic Mean And Time-Varying Structures Of Ocean Circulation

This project will study a new family of anisotropic, oceanic features, commonly referred as 'zonal jets' discovered recently using satellite altimetry, high-resolution mean dynamic topography and advanced ocean circulation models. While these features reveal a broad diversity of characteristics and physics, this project aims to investigate the dynamics of two distinct types that have been validated by in situ observations and are reproduced by advanced numerical models. The first type is evident in high-resolution mean dynamic ocean topography, and corresponds to zonally elongated features that are especially distinct in the eastern parts of all subtropical oceans. Each such jet-like feature appears to have some kind of source at its eastern tip. These features include known jets such as the Hawaiian Lee Countercurrent and the Azores Current and suggest a rich diversity of possible sources. The second type is quasi-periodic nearly zonal jet-like structures that propagate toward the equator and appear confined within subtropical gyres. Sea level simulated by the high-resolution ocean model for the Earth Simulator and by the Regional Ocean Model System shows much similarity with the altimetry data. However, differences remain significant and reflect either difference of forcing, or the impact of incomplete dynamics or parameter choices. We will use high-resolution satellite observations of the ocean surface topography, as well as other satellite data and historical and modern in-situ observations, in combination with analysis of high-resolution ocean model simulations and experiments to explore the internal dynamics and sources of these jet-like structures.

Laury Miller/NOAA Lab for Satellite Altimetry

Sea Level Rise from Satellite Altimetry

According to the IPCC Fourth Assessment Report (FAR) (IPCC, 2007), global mean sea level may increase by 0.5 m over the next 50 to 100 years, and more if significant accelerations occur in the next couple of decades. There is already evidence of a recent acceleration. Current satellite altimeter observations show sea level rising at ~3 mm/yr,
nearly twice as fast as the tide gauge measured rate over the past 100 years. Does the altimeter record reflect a long-term change or just natural decadal variability? What processes are responsible for this apparent increase and how reliable are the IPCC/FAR model projections? The answers to these questions are critically important to understanding the causes of sea level rise and it’s impact on society. Here we propose to determine the current sea level budget as accurately as possible using a combination of TOPEX/Jason/Jason-OSTM altimeter observations of total sea level change, GRACE gravity observations of ocean mass change, and Argo profile observations of ocean density change. We will use this information to evaluate the performance of the FAR model simulations and a model reanalysis with the goal of trying to improve the reliability of long-term projections of sea level rise. At the core of this work will be an intensive effort to verify, calibrate, and improve the accuracy of observations from multiple altimeter missions. This proposal encompasses the study of heat and mass change in the ocean by different types of satellite and in-situ observations, consistent with NASA research goals in the areas of climate and climate variability.

Robert Nerem/University of Colorado
Building and Understanding a Climate Data Record of Sea Level Change

Sea level change is a sensitive indicator of climate change because it responds both to changes in ocean temperature (where most of the excess heat from climate change is being absorbed) as well as to exchanges of water mass between the continents and the oceans (which is dominated over long time periods by the melting of ice in glaciers and ice sheets and changes in the water cycle). Therefore, the record of sea level change collected by the TOPEX/Poseidon and Jason-1 (and soon Jason-2) satellite altimeter missions is critically important for climate change studies. However, the use of satellite altimeter data for this purpose pushes the accuracy limits of the measurements, and thus great care must be taken to monitor the performance of the instruments, investigate anomalies, improve the measurement corrections, and place the measurements in a well-defined Earth-fixed reference frame. In addition, interpreting the observed changes in sea level, identifying the causes of the changes, and eventually separating the natural and anthropogenic variations is a challenging area of research. We propose to carefully build a climate data record of sea level change using TOPEX/Poseidon, Jason-1, and Jason-2 altimeter data, make it publicly available (http://sealevel.colorado.edu), and then analyze that record to better understand how our changing climate is affecting sea level. The interpretation of the record will help scientists make better predictions of future sea level change, ascertain the socio-economic impacts of sea level rise, and corroborate and improve global climate models. By the end of this investigation, a two decade, fully calibrated climate record of sea level change will be available, giving us our first opportunity to study decadal changes in sea level and their relation to climate change and other variations in the Earth system.
Erricos Pavlis/University of Maryland, Baltimore County
Eastern Mediterranean Altimeter Calibration Network - e-MACnet (Continuation of DynMSSLaC & GAVDOS)

NASA’s strategic goal to “study Earth from space to advance scientific understanding and meet societal needs”, prompted “GAVDOS”, a joint NASA-EU R&D project that over the past ten years evolved into a regional network of tide gauges monitored with continuous GPS in Western Crete, Greece. Unique in the area, it collects continuous precise monitoring of sea level and environmental parameters. Its data and our analysis products help answer strategic questions about Earth system changes, their cause and how Earth responds to these, NASA research objectives 2, 4, 5, and 7.
While e-MACnet offers a wide range of existing, in-place hardware and facilities, we are continuously expanding, improving services, products, quality-control and near-real-time information dissemination. This proposal requests NASA’s support to: extend operations and maintenance of the facility; continue the combination, analysis and interpretation of all radar altimeter data in the area; prepare for the upcoming Jason-2 launch and calibration phase; and integrate our facilities with IOC’s Tsunami Warning System network (ICG/NEMTWS).
The proposal builds upon the original GAVDOS project’s legacy. It relies on collaborations with other European groups, e.g. the French group at the western Mediterranean calibration facility in Corsica, and contributes to other projects, e.g. GOOS, GGOS, MedGLOSS, ICG/NEMTWS, ESEAS, etc.
We support a vital aspect of NASA’s ocean science program: the collection of in situ data in support of satellite missions and contribute to regional environmental monitoring of a poorly instrumented area. The proposed offshore buoy will extend the network utility and contribute to the tsunami hazard mitigation goal and coastal science for the region.
Unlike other calibration sites, our network, situated under a cross-over of two tracks, i.e. two calibrations per repeat cycle, and with a third site now (Kasteli), provides a total of three observations per repeat cycle.

Rui Ponte/Atmospheric and Environmental Research, Inc.
Studies Of The Large-Scale Ocean Variability Using Satellite Altimetry

The launch of the Ocean Surface Topography Mission (OSTM) promises to build on 15 years of continuous high quality altimeter measurements from TOPEX/POSEIDON and Jason-1. As with all altimetry missions, the challenge continues to be to improve the quality of the observations while advancing their use in studies of the ocean circulation.
This proposal deals with both aspects of this challenge by using all altimeter data and other in situ and space-based oceanic observations, ocean models either in barotropic or baroclinic configurations, and estimation techniques that efficiently synthesize the information in the observations and models. Altimeter comparisons using tandem mission data and separate analysis of various noise terms (radar noise, environmental corrections, etc.) are intended to derive spatial and temporal characteristics of the errors for OSTM and other missions. Modeling and data assimilation methodologies will be applied to estimate atmospherically-driven high frequency sea level variability, which is poorly sampled by the altimeters, with the goal of providing improved de-aliasing procedures for
altimeter data processing. More generally, data and model analyses are planned to address the characteristics and dynamics of the large-scale sea level variability. Topics to be explored include the dynamics of ocean loading by surface pressure, freshwater flux and long-period tides, the relation between coastal sea level and the large-scale (deep ocean) signals at seasonal and longer timescales, the relative contributions of surface heat and moisture fluxes, density advection, and mixing to regional sea level variability, the possibility of nonlinear interactions between strong rapid signals driven by synoptic atmospheric systems and the slow (climate) timescales, and the causes of interannual fluctuations in mean sea level. The proposed work addresses NASA strategic objectives of advancing scientific understanding of planet Earth by using space-based observations, particularly regarding sea level variability and its impact on human societies around the globe.

Bo Qiu/University of Hawaii at Manoa
Investigating Midlatitude Ocean and Climate Dynamics using Satellite Altimetry and Modeling Analysis

The goal of this proposed study is to characterize and understand the nature and causes of the large-scale fluctuations in the midlatitude North and South Pacific Oceans on time scales from interannual to decadal. An understanding of these fluctuations will lead to increased predictability of the upper ocean circulation and thermal structures, both of which are important to the climate variability on longer time scales.

This study proposes to conduct careful analyses of the multi-year altimetry data from the T/P, Jason-1 and OSTM missions. We plan to first document the large-scale SSH fluctuations on the interannual-to-decadal time scales. The observed signals will be compared against other oceanic data and atmospheric variables with the guidance of our understanding of the ocean dynamics. Our next step is to clarify the causes for the observed low-frequency changes. To do so, we propose to use both simplified dynamic models and ocean general circulation model outputs with realistic topography and surface boundary conditions. Through combining the altimetric data and the ocean models with various complexity, we seek to identify the roles played by different physical processes. Efforts will also be directed to clarify the extent to which the large-scale, low-frequency changes in the midlatitude ocean circulation affect the anomalous SST signals and the dynamics underlying the interaction of oceanic motions with various horizontal length scales.

This proposed study directly contributes to the two research themes set out by the OST/ST: 1) To support studies in physical oceanography utilizing TP/Jason/OSTM mission data, as well as other satellite and in situ data and/or models, and 2) To support studies of higher-resolution merged altimetric data sets for the purpose of examining the role of mesoscale eddies and western boundary currents in the general circulation of the ocean.
Richard Ray/NASA Goddard Space Flight Center
Altimetric Studies of Ocean Surface Tides and Internal Tides

This proposal is for a continuation of our current OSTST investigation, which uses satellite altimetry and other data to study ocean tides, both surface and internal. Special emphasis will be given to the study of open-ocean internal tides, their variability and energetics, and the improved determination of shallow-water tides. Owing in part to our previous investigations, internal tides are thought to play an important role in deep ocean turbulence, diapycnal mixing, and the maintenance of abyssal stratification. A precise account of the energy fluxes to these processes, however, is far from clear. Studies of internal-tide generation, propagation, dissipation, and variability should shed much light on the question, and altimetry provides an invaluable dataset for obtaining global and quantitative constraints. Moreover, the question of variability of low-mode internal tides has important implications especially for future wide-swath altimeter missions; it determines whether the altimetry can be corrected for internal tides by using swath data themselves, or must be left uncorrected (but allowed for). We propose to use a combination of approaches involving 3-D modeling, empirical mapping, model/data comparisons, and data assimilation to address these problems. In addition, because we have recently developed useful techniques for mapping compound tides, we propose to continue that work, which will lead to improved surface tide models, including especially improvements in shallow seas. This, of course, benefits all users of altimetry, as well as significant portions of the entire geophysical community. We also believe it is timely to revisit the small fortnightly Mf tide, since this tide has just recently (in June 2006) reached its 18.6-year maximum amplitude, leading to much improved signal:noise in our data. Our previous work with Mf led to an understanding of its basin-wide characteristics in terms of simple kinematics and geostrophy, but an improved mapping may lead to better understanding of frictional and dissipative effects. Finally, in order to contribute to the OSTST's calibration activities for Jason-2, we propose to compare the significant wave height data against buoy data and other altimetry, and to untangle some previously published, but contradictory, results involving Jason-1.

Peter Rhines/University of Washington
Pathways of Meridional Circulation in the Ocean Climate System

Key branches of the global oceanic overturning can be located and monitored with an observing system based on satellite altimetry and in situ observations, particularly hydrography, floats and drifters. The elusive arteries of meridional overturning circulation (MOC) at high latitude strongly affect global heat balance, yet they cannot fully and accurately be represented in numerical climate models. These pathways are the focus of the proposed work. Satellite altimetric measurements have matured to the point where decadal variability is clear and longer term trends are beginning to be established. At the same time our robotic Seagliders patrolling the subpolar Atlantic (Eriksen & Rhines, 2007), ARGO floats and surface drifters are providing much sharper 3-dimensional space-time coverage of the MOC. Extending our earlier research on the deceleration and shrinking of the subpolar gyre of the North Atlantic, we will now address the transition between subtropics and the subpolar regions where the deep sinking
of the MOC occurs. Using a jet-finding technique we will collaborate with Rintoul and Sokolov of CSIRO, Australia in comparing MOC pathways in the Southern Ocean and the high northern latitudes of the Atlantic and Pacific.

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**Y. Tony Song/Jet Propulsion Laboratory**  
\textit{Strait and Inter-Ocean Transport Estimation Using Altimetry SSH and Gravimetry OBP}

Problem to be solved: Strait and inter-ocean transport are of fundamental interest to physical oceanography [Whitehead, 1989; Killworth, 1995; Godfrey, 1996] and ocean climate considerations [Hansen et al., 2001; Gordon et al., 2003], but are poorly understood and difficult to measure because long-term direct measurements of strait circulations are an expensive alternative and their implementation remains logistically challenging. We hypothesize that the magnitude and variability of strait transport varies with sea-surface height (SSH) and ocean bottom pressure (OBP) gradients between two inter-connected oceans. The combined 15-year TP/Jason-1 and other altimetry data has been the great resource of ocean surface topography, and the Gravity Recovery and Climate Experiment (GRACE) mission has been delivering temporal gravity data for five years with some oceanographic applications [e.g., Chambers et al., 2004; Song and Zlotniki, 2004; 2007; Zlotnicki et al., 2006]. Now it is the perfect time to combine the altimetry and gravimetry data for a better estimate of inter-ocean transport, based on the three years time series of Indonesian throughflow (ITF) measurements from the INSTANT program [Sprintall et al. 2004; Gordon et al, 1999], ongoing-projects measuring the throughflows in the Luzon, Mindoro, Karimata and Makassar Straits [Susanto and Gordon, 2005], and modelling support from a high-resolution global model with a terrain-following coordinate system for better resolving the strait geometry.

Approach and Objectives: Recently, we have developed a theoretical method by combining the "geostrophic control" formula of Garrett and Toulany [1982] and the "hydraulic control" theory of Whitehead et al. [1974]--allowing the use of SSH and OBP variables for estimating inter-ocean transport and separating the transport into surface and bottom fluxes [Song, 2006], providing a potential use of satellite measurements for operational applications. The problem of strait and inter-ocean transport estimation has not been studied in the previous OSTST program. Here we seek to break new ground by combining satellite and in-situ observations with analytical and numerical models for the challenging problem. Based on the previous studies and the INSTANT-related measurements, we propose:

1. To develop a methodology allowing a better use of satellite SSH and OBP data for studying strait circulation and inter-ocean transport.
2. To derive a proxy of inter-ocean exchange/throughflow products by combining satellite data with in-situ measurements and model simulations.
3. To focus on two case-studies for a better understanding the controlling mechanisms of the Indonesian throughflow and the sea-ice/glacier melting and resulting freshwater fluxes effect on the Denmark Strait overflow.
Expected Results: The proposed research will result in: (1) an improved understanding of Indonesian throughflow and Denmark Strait overflow; (2) an innovative methodology for utilizing satellite SSH and OBP; and (3) a demonstration of using future higher-resolution satellite data from OSTM and GRACE follow-on missions. The project is strongly aligned with NASA's long-term priorities of studying the ocean from space and will address the research themes of the OSTST: (1) To support studies in physical oceanography utilizing Jason/OSTM mission data, as well as the combined 15-year TP/Jason data, jointly with other satellite (ERS-1/-2, ENVISAT, GFO) and in situ data and/or models, in support of both basic research and operational applications; and (2) to investigate the use of gravity mission data with altimeter data for improving the understanding of the mean ocean circulation.

Paul Strub/Oregon State University
Interactions Between Coastal and Offshore Circulation

We propose research that includes both methodological development and scientific analyses of coastal currents and their interactions with the offshore circulation in both eastern and western boundary currents (EBCs and WBCs). The objectives are to develop methods to extend the altimeter sea surface height (SSH) fields into the region within 50 km of the coast; and to address the over-riding scientific question in each system, —To what extent does the offshore circulation affect the coastal circulation?— We will use: altimeter SSH, scatterometer winds, IR and microwave SST, and surface Chlorophyll-a concentrations to characterize the large-scale and regional forcing of, and response within, the coastal regions. High-resolution numerical models will extend the satellite analyses beneath the surface and quantify the dynamical relationships governing the circulation.

Three coastal regions will be compared: the California Current System (CCS) off the western U.S.; the Peru-Chile Current System (PCCS) off western South America; and the Southwestern Atlantic Current System (SWACS) off eastern South America. Including the SWACS, with its wide coast and strong western boundary currents, will allow us to develop and test coastal altimetric techniques in regions with both narrow and wide shelves, and with both strong (WBCs) and weak (EBCs) offshore currents.

We will initially use the 3-year period from Autumn 2002-2005, when 4 altimeters were operating and ancillary satellite data are available for winds, SST and CHL. This period provides the best coverage and will allow us to compare analyses using the full data set to analyses of subsets of the data that match the sampling during other periods. Analyses of the complete 15+ year altimeter period will encompass strong El Niño-La Niña signals and reversals in the signs of the PDO, NAO and SAO. During the initial Jason-2 period (and throughout the Jason-2 mission), our activities will include validation studies for Jason-2 in our regions of interest, as requested by NASA.

The proposed research builds on results from our present OSTM project, which examines distant and local forcing for the large-scale eastern boundary currents, but does not include the more coastal areas or the South American WBC (SWACS). These coastal areas include some of the oceans' most productive ecosystems and fisheries, with important economic consequences when those systems change. Thus, the research will accelerate the realization of societal benefits in the form of increased understanding of
circulation and changes in the coastal ocean, where human activities strongly impact, and are impacted by, ocean conditions. By combining satellite data and models, we will increase our ability to interpret both satellite and model fields, eventually leading to better interpretations of coastal model predictions, nested within basin-scale models of climate change. This research will also help prepare for coastal applications of future high-resolution altimeters, such as the WATER-HM.

Douglas Vandemark/University of New Hampshire  
**Altimetry and operational wind-wave prediction - combined use to enhance both systems**

Maritime wave forecasting owes much to global ocean sea state data supplied daily by satellite altimeters. This research will further expand altimeter data application to wave forecasting, and also apply global wave model data to improved Jason and OSTM sea level estimates. Specifically, we will assess numerical wind-wave forecast performance pertaining to wave breaking and wave-current interaction processes using altimeter-derived ocean surface currents and altimeter backscatter and sea state data from multiple satellites. We will also complete the development of an alternative approach to operationally correct for OSTM altimeter sea level error due to an unresolved dependence on ocean wave conditions. Altimeter-informed analysis of wind-wave processes will be performed using twin experiments with the Wavewatch 3 model. NOAA/NDBC wave buoy data will be central to algorithm developments and validation, with key model improvements implemented into the operational NCEP Wavewatch 3 product. The altimeter sea state bias correction will be developed using an empirical algorithm informed by a combination of wave model and altimeter data. We address two solicitation objectives - the support of wind/wave generation studies utilizing Jason/OSTM mission data, and the completion of comparison studies between Jason and OSTM including the development of and assessment of new geophysical algorithms likely to improve the quality of data. Societal needs are addressed by enhancing both satellite altimeter accuracy and altimeter applications to operational marine wave forecasting and strengthening ties between these important activities. This impact includes science-driven improvements to wind-wave forecast model performance in prediction of sea state and breaking waves, and evaluation of a new and exciting application of satellite-derived ocean surface current data to wave propagation prediction on the high seas. Improvements to sea level through the revised sea state bias correction model are expected to move OSTM altimeter accuracy towards the 2.5 cm goal.

John Wilkin/Rutgers University  
**Improving coastal circulation analysis and prediction through refined altimeter data processing and variational data assimilation into a regional ocean model**

The goal of the work proposed here is to develop and validate an improved coastal ocean analysis system that (i) comprises a reprocessed coastal altimeter data stream derived using regional de-aliasing corrections and other required near-coast data filtering and error correction approaches, and (ii) incorporates these data into a high-resolution
regional ocean model using advanced 4-dimensional variational methods for data assimilation.

The coastal altimeter product will include data starting from the Topex/Poseidon mission through to OSTM and will be implemented within the Radar Altimeter Database System (RADS). The ocean model will be the Regional Ocean Modeling System (ROMS) which is widely used for continental shelf applications, and includes 4-Dimensional Variational data assimilation algorithms well suited to the assimilation of along-track altimeter data.

We will prototype the system in the Gulf of Maine and Mid-Atlantic Bight (GoM-MAB) region where there exist extensive complimentary data sets for validation from Regional Associations of the U.S. Integrated Ocean Observing System (IOOS). The waters of the region are used heavily for maritime activities, and the system we develop will be targeted toward practical applications related to numerous societal needs. The methodologies will be generic with a view to application in coastal regions globally.

To achieve these goals we have assembled a team with extensive prior experience in altimeter data processing (D. Vandemark, R. Scharroo), advanced altimeter data assimilation (J. Zavala-Garay, J. Wilkin), and both data analysis (G. Han) and modeling (Han, Wilkin) of the circulation of the GoM-MAB region. We have also established a formal collaboration with the European team led by L. Roblou that pioneered coastal altimeter studies in the Mediterranean Sea and has submitted a complimentary proposal entitled MARINA (MARgin Integrated Approach) to the CNES Ocean Surface Topography Mission announcement.

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**Carl Wunsch/MIT**  
**Applications of Satellite Altimetry, Gravity, Winds and In Situ Data to Problems of the Ocean Circulation**

Altimetry has become a mature subject, in which the main objective is to exploit the now-long record for information about the ocean circulation. Nonetheless there continue to be questions about data errors that have an impact on the ability to make inferences. Here the focus is two-fold: the continued combination of altimetry with as much of the in situ and other satellite data as is feasible in the context of a least-squares fit of a general circulation model; and exploitation of the 15 years of high accuracy altimetry for improvement of an existing strawman spectral description of low-frequency ocean variability.

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**Victor Zlotnicki/California Institute of Technology**  
**Altimeter Data And ECCO2 Ocean State Estimates Used To Study The Variability Of Antarctic Circumpolar Current Fronts And The Formation Of Antarctic Intermediate Water**

The Southern Ocean is a significant component of the global overturning circulation and of the oceanic carbon cycle yet it is also a region where there are few in-situ observations, large uncertainties, and the potential for important climate feedback
mechanisms. The proposed study will use the 15+ years of available radar altimeter data, high-resolution ocean state estimates from the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project, and in-situ data (hydrography and Argo floats), in order to study time changes in the formation of Antarctic Intermediate Water (AAIW). This is a step towards an improved description and understanding of Southern Ocean airsea exchange processes, a prerequisite for improved representation of these processes in numerical climate models, and for more reliable predictions of how these processes might respond to changes in Greenhouse gas forcing. Specifically the proposed study will (i) estimate interannual changes in Antarctic Circumpolar Current (ACC) frontal locations and their relation to Antarctic Intermediate Water (AAIW) formation rates, (ii) better describe and understand processes responsible for the ventilation of intermediate waters, and (iii) quantify the sensitivity of ACC frontal variability and of AAIW formation rates to changes in wind patterns. The proposed work will provide feedback to the ECCO2 project towards improving the representation of intermediate water formation, it complements ongoing and planned Climate Variability and Predictability (CLIVAR) efforts to better observe and understand climate-related variables in the Southern Ocean, it is consistent with the NASA strategic objective to "understand the role of oceans, atmosphere, and ice in the climate system and improve predictive capability for its future evolution", and it addresses the first research theme in the ROSES-2007-A07 by "supporting studies in physical oceanography utilizing Jason/OSTM mission data, as well as the combined 15-year TP/Jason data, preferably jointly with other satellite and in situ data and/or models, in support of basic research".