NASA’s Physical Oceanography Program supports basic research and analysis activities that enable development of NASA’s current and future physical oceanography satellite missions and the scientific interpretation of data from them. NASA utilizes the unique vantage point of space to enable rapid collection of global ocean data sets and contributes significantly to the World Climate Research Program’s Climate Variability and Predictability (CLIVAR) Program. In particular, NASA is playing a central role in providing the next generation of data products for sea surface temperature and sea surface salinity. Additionally, an emerging area of increased emphasis is research on the coastal ocean. While NASA’s focus will remain global in nature, it is recognized that many of the practical problems with respect to human interaction with the ocean lie within the coastal seas. In response to its announcement, NASA received 37 proposals and selected 11, reflecting the foci described above.

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**Antonio Busalacchi/University of Maryland**

**Implementation of Satellite Sea Surface Salinity Data into Ocean and Coupled Models**

We propose to investigate the implementation of satellite SSS and subsurface salinity (Sz) into data assimilation methodologies for initialization of climate predictions. Specifically, our research will include an estimation of the salinity signature of model biases, and further investigate assimilation improvements brought about by including both SSS and Sz, and validation of simulations and predictions with ocean data assimilation. We would also like to look at the salinity variability in the model especially in terms of the seasonal to decadal time-scale variability with quantitative depiction of the available observations and model results in the same recharge-discharge phase space, and the subsurface patterns of lagged correlations between salinity and ENSO indices to explain the role of salinity in improving statistical predictions of ENSO. Finally, short-term ENSO predictions will be performed with and without SSS assimilation to assess the role of the new data stream ENSO dynamics. All of these proposed avenues of research are directly applicable to the goals stated in NASA Physical Oceanography NRA, namely analysis and interpretation of the ocean circulation using satellite and in situ data and understanding and estimation of sea surface salinity.

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**Sandra Castro/University of Colorado**

**Uncertainty Characterization of Satellite Sea Surface Temperature Products in the Presence of Diurnal Warming**

The launch of new satellite sensors providing retrievals of sea surface temperature (SST) and the Global Ocean Data Assimilation Experiment (GODAE) High-Resolution Sea Surface Temperature Pilot Project (GHRSSST-PP) have spawned new efforts to merge
data from different sensor types and led to the release of many new SST products. While blending the data requires accurate characterization of the uncertainties in each product and a key emphasis of the GHRSST-PP was to provide uncertainty estimates with each retrieval, many of the error specifications are still being developed and evaluated. The presence of diurnal warming, in particular, adds uncertainty that is only poorly understood. The objective of this proposal is to develop and provide a detailed characterization of the uncertainty in satellite-derived SST products accounting for components related to diurnal warming, the skin effect, and other retrieval processes.

Comprehensive uncertainty estimates in the presence of diurnal warming will be constructed through comparisons against in situ observations and analysis and application of diurnal warming models. The sensors considered will include GOES, SEVIRI, TMI, AMSR-E, AVHRR, and AATSR. The retrieval uncertainty will be estimated as a simultaneous function of multiple environmental and sensor parameters to accurately capture regional variability. Uncertainty estimates in diurnal warming will be constructed from a combination of model uncertainty given perfect forcing data, uncertainty in the available forcing data, and uncertainty due to incomplete knowledge of the forcing data. Estimates of the uncertainty associated with the skin effect will be drawn from evaluation of recent radiometric skin temperature measurements. The validity of the uncertainty estimates and the relative effectiveness of different formulations will be assessed through consistency analyses, reduction in product differences, and application to simplified blending tests. The refined uncertainty estimates will be integrated into the GHRSST-PP products and specifications through active project membership and participation.

Dudley Chelton/Oregon State University
Mesoscale Variability in the VOCALS Region

The VAMOS (Variability of the American Monsoon Systems) Ocean-Cloud-Atmosphere-Land Study (VOCALS) has been established as part of international CLIVAR to improve the understanding and prediction of the southeast Pacific coupled climate system on diurnal to interannual time scales. The focus of VOCALS is the persistent low-level stratocumulus cloud deck that covers much of the region. It is believed that oceanic eddies play an important role in maintaining the cold water that is partly responsible for the existence of this cloud deck. Sea-surface height (SSH) fields constructed from a sequence of paired simultaneously operating altimeters reveal the existence of frequent eddies of both polarities (cyclonic and anticyclonic) in the VOCALS region. The objective of this proposed research is to characterize the physical and biological properties of the surface characteristics of eddies in the VOCALS region based on satellite measurements of SSH, sea-surface temperature (SST) and ocean color from which the upper-ocean biological properties of the eddies can be inferred. Surface wind measurements from QuikSCAT will also be analyzed, since air-sea heat flux depends on the wind speed. QuikSCAT data will also be used to investigate the role that the relative velocity between air and the water surface may play in eddy-induced upwelling. The vertical characteristics of the eddies will be assessed from comparisons of the satellite observations with the output of high-resolution ocean
models, including the global Parallel Ocean Program (POP) model run at the Los Alamos National Laboratory, as well as regional models that will be developed as part of the VOCALS program. The eddy characteristics determined from the satellite data will also be compared with ship and mooring-based in situ observations collected during the VOCALS Regional Experiment (REx) to be conducted in November 2008.

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**Changming Dong/University of Californian, Los Angeles**

**Comprehensive Study of Submesoscale and Mesoscale Eddies on the Lee Side of Islands and Along Upwelling Fronts Using GHRSSST-PP, In-situ and High-resolution Numerical Modeling Data**

The ability to observe the ocean surface from space with high resolution has revealed "a host of the phenomena which had not been accessible to traditional ocean sampling" (Munk et al, 2000). The high resolution, satellite-borne SST data provided by GHRSSST-PP can boost our understanding of the submesoscale processes (O(10) km), which is a new development in Physical Oceanography.

Using satellite-borne high-resolution SST data and in situ data with submesoscale-resolving high-resolution numerical modeling, we propose a comprehensive study of the submesoscale processes. Based on GHRSSST-PP SST product, a public-assessable satellite submesoscale and mesoscale eddies SST dataset (SSMESD) will be developed. The ship-borne data from the RODA and CAIBEX projects, supported by Spain government around the Canary Islands and NW African coast, and data from the Southern California Coastal Ocean Observational System (SCCOOS) project in Southern California Bight will be used in the project. Incorporating the SSMESD and in situ data into submesoscale-resolving high resolution model will lead to a better understanding the 3-D dynamics of submesoscale eddies.

The product SSMESD from the project will benefit not only the research community but also marine resources, fisheries and human perturbation impact studies. The project is based on international and regional collaborations: UCLA PI and Co-I, two European collaborators, one JPL collaborator and one NOAA collaborator. Such collaboration during the project will further broaden and deepen the academic and social influence of this research project.

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**Sarah Gille/University of California San Diego**

**Diurnal Variability at the Ocean Surface**

Diurnal cycles in sea surface temperature (SST), wind forcing, and surface heat fluxes influence climate processes at the air-sea interface. The objectives of this work are to assess the diurnal cycle in satellite wind and SST data and to evaluate the impact on the upper ocean of diurnal wind, SST, and surface fluxes.

Satellites that observe wind and SST are usually launched on sun-synchronous orbits: observations are collected at two local times, roughly 12 hours apart. SST diurnal
variations are difficult to evaluate from satellite data alone, as daytime and nighttime satellite passes can have different calibrations. For this study, to complement the work of the GHRSSST effort, we will complete an independent assessment of diurnal variations in near-surface temperature based on AMSR-E microwave SSTs and top-of-profile Argo float measurements. Preliminary results show a clear diurnal cycle with an amplitude that decreases with increasing latitude. Wind calibrations do not depend on time of day, and diurnal variations in winds can be detected by comparing daytime and nighttime satellite observations, preferably from more than one satellite, as was possible during the six-month QuikSCAT/ADEOS-2 tandem mission and as is now possible with QuikSCAT and ASCAT. In the proposed work, we will refine the earlier estimates by using high spatial-resolution scatterometer winds. We will also extend the record in time with new multi-mission wind measurements in order to assess how the amplitude and phasing of diurnal wind cycles changes seasonally and interannually.

SST and wind information will be combined to evaluate the net impact of the diurnal cycle on climates. A bulk mixed-layer model will allow examination of the sensitivity of upper ocean processes to the relative phasing of maximum wind, SST, and solar forcing. Research will evaluate the physical processes responsible for diurnal cycle impacts on climate.

W. Timothy Liu/Jet Propulsion Laboratory
Evaluation of Meridional Transport of Water and Heat in the Atlantic Ocean Using Satellite Data

Our on-going effort to improve the estimation of ocean-atmospheric fluxes in momentum, water, and heat using a combination of spacebased measurements will be applied to study the meridional Ekman and net transports of water and heat in the Atlantic Basin. The meridional heat and water transports computed from the spacebased fluxes will be compared with meridional transports derived in past decades. Only long-term annual means were available from observations in the past and they were derived either from hydrographic transects or surface flux climatology of ship reports, the long-term averaging allowed the neglect of the change of storage of mass and heat. Any study of temporal variation in the past was unconvincing because the hydrographic transects were made at different seasons many years apart. There were also large uncertainties because only the shear of geostrophic current could be derived from the temperature/salinity profiles and a level of no motion had to be assumed to get the meridional transport. The poor quality and sampling of ship data to derive the surface fluxes were also problematic. Recent advances on this subject have only been made through ocean circulation models, with all the uncertainties on constraints and physics. We will examine the improvement that could be made with a new generation of spacebased sensors and techniques. Method of estimating the temporal change of mass and heat storage will also be developed so that the annual and interannual variations of the transport can be studied. The meridional overturning currents implied from the difference between the net transport through the depth of the ocean and the wind-driven (Ekman) transport at the surface will be examined in terms of atmosphere forcing through wind-stress curl and buoyancy at various time scales. This study will be a clear and
significant demonstration of NASA’s unique contribution to the understanding of climate change through synergistic application of a whole suite of spacebased observations.

Vikram Mehta/The Center for Research on the Changing Earth System (CRCES)
A Diagnostic Study of the Interannual to Decadal Variability of the West Pacific Warm Pool Using Satellite Remote Sensing Based and ECCO-assimilated Oceanographic Data Products

We propose a diagnostic study of physical oceanographic aspects of interannual to decadal variability of the western Pacific Warm Pool (WPWP), especially the physics of WPWP sea-surface temperature (SST) variability. Our previous research suggests that interactions among the WPWP SST, the Hadley Circulation, and Shallow Tropical Circulations (STCs) and associated ocean heat transport can provide a negative feedback to the WPWP SST at decadal timescale because of the STCs’ advective timescale. In the proposed project, we will test and further develop this hypothesis, and develop a hypothesis about the physics of interannual WPWP SST variability; isolate dominant, empirical patterns of oceanic component of interannual to decadal WPWP variability; and carry out a detailed budget analysis of interannual and decadal SST variability in the WPWP region.

The proposed research will be conducted via analyses of oceanographic data from the late 1980searly 1990s to present, based on remote sensing by NASA and other satellites and oceanographic data products from the Estimating the Circulation & Climate of the Ocean (ECCO) project. We will use TOPEX/POSEIDON sea-surface height, ERS and QuickSCAT surface wind stress, OSCAR surface currents, a blended SST product using in situ SST measurements and SSTs derived from infrared radiance measurements by Advanced Very High Resolution Radiometer (AVHRR) instruments on NOAA satellites in the proposed research. We will also use temperatures, velocities, and heat budget estimates from 15 years (1992-2006) ECCO-GODAE products and a 51 years (1950-2000) “German ECCO” product in the proposed research. There are several shortcomings of each of these data sets; however, these are the best, large-scale, high-resolution, known-quality, and at least a decade long oceanographic data sets currently available for the WPWP region and they contain very useful information about the physics of SST variability in spite of their deficiencies.

The proposed research will be the first, systematic, large-scale study to quantify oceanic component of interannual to decadal variability of the WPWP using remote sensing based and ECCO-assimilated ocean data, and is expected to identify important physical processes responsible for interannual to decadal variability of the WPWP SST for subsequent intensive research. The proposed research will address NASA’s scientific discovery mission; and will also address a specific research objective (3A.5) to understand the role of oceans, atmosphere, and ice in the climate system and improve predictive capability for its future evolution. The proposed research is consistent with the NASA-Ocean Physics Program’s research themes of analysis and interpretation of the ocean circulation using satellite and in situ data, especially analysis of satellite altimetry, surface wind stress, and other relevant data in support of the U.S. CLIVAR Program; and understanding and estimation of SST and salinity.
In addition to benefiting scientific user communities (including those focused on tropical oceanography and meteorology, global and regional water cycles, ocean and coupled ocean-atmosphere modeling, and climate variability and change), this research could stimulate existing national and international ocean and climate research programs to broaden their objectives to include study of the WPWP. Also, since the WPWP variability appears to make major impacts on global, especially U.S., climate in spite of its relatively small amplitude, the proposed exploratory WPWP research could stimulate in situ and remote sensing-based programs to observe and quantify these subtle signals.

Peter Minnett/University of Miami, RSMAS

Diurnal Thermal Variability at the Ocean Surface

Significant warming of the top few meters of the ocean will occur during the day under clear sky, calm conditions. Since sea surface temperature (SST) retrievals by satellites are of the temperature of the thin surface layer, this diurnal warming effect strongly influences these measurements. The Global Ocean Data Assimilation Experiment (GODAE) High-Resolution Sea Surface Temperature (GHRSSST) project focuses on producing an improved SST product through the combination of observations from complementary infrared and microwave sensors. Merging retrievals with different penetration depths and observation times requires the development of a thermal model of the near-surface ocean layer. Diurnal warming is strongly influenced by wind speed and changes in wind speed due to inter-annual variability influence the diurnal warming and therefore the air-sea heat and gas fluxes.

The GHRSSST project is providing a unique dataset to study the global distribution and characteristics of diurnal variability at the ocean surface. Level-2 Pre-processed (L2P) data from SEVIRI, GOES, MODIS, AMSR-E provide SST, Surface solar irradiance, and surface wind speed within a single file. Since diurnal warming is essentially determined by the radiative forcing and ocean mixing, these provided parameters are ideal for investigating the characteristics of diurnal warming at the ocean surface. The wealth of ship-based measurements of surface skin temperature from the M-AERI and of surface forcing from a wide range of ancillary sensors provide an excellent data set for this study that complements the satellite retrievals.

Stephen Riser/University of Washington

Estimation of Near-surface Salinity from Argo Floats and Use in Validation of Aquarius Salinity Data

It is proposed herein to examine two important problems in anticipation of NASA’s Aquarius satellite mission, designed to measure the surface salinity of the global ocean on weekly time scales and presently scheduled for launch in the spring of 2010. Firstly, using available data from the global Argo float array, it is proposed to begin making weekly maps of surface salinity for the world ocean and to begin estimating spatially-dependent statistics from these maps such as mean values, standard deviations, and seasonal variability. Estimates in some ocean basins can be made beginning in 2002, and true global coverage probably has been available since mid-2005. The salinity data
from the Argo array represent the single largest and highest quality salinity data ever collected from the world ocean (while other data, such as from WOCE were of even higher quality, their global spatial and temporal resolution were quite low compared to Argo). It is proposed to use these near real-time maps and the statistics resulting from the ensemble to validate the salinities estimated from Aquarius, immediately after launch of the satellite and continuing into the future as it continues to collect data. The second task proposed here is to develop the capability of measuring surface salinity from Argo floats so that direct validation of Aquarius data using in situ ocean surface salinities can be made. At present, the shallowest Argo salinity measurement is made at a depth of about 5 meters in order to keep sea surface films from fouling the float conductivity cell. It is proposed here to test and employ two new, auxiliary CTD systems on a few floats that could measure salinity all the way up to the air-sea interface and transmit the data in real-time as part of the Argo data stream. Approximately 10 floats would be equipped with these sensors, with the sensors tested, evaluated, and ready for use at the time of the Aquarius launch.

Josh Willis/Jet Propulsion Laboratory
Monitoring the Atlantic Meridional Overturning Circulation Using a Combination of SST, Altimeter, and Argo Data

The Atlantic Meridional Overturning Circulation (MOC) encompasses the headwaters of the global thermohaline circulation, a critical mechanism for the redistribution of heat within the Earth's climate system. As anthropogenic influences on the climate system mount, changes in the heat and mass transports of the MOC are expected to occur. Such changes will undoubtedly affect the regional climate in Europe and may ultimately have global impacts as well. Despite the fact that the North Atlantic is one of the most thoroughly studied oceans in the world, relatively little is known about the magnitude and frequency of natural or anthropogenic variability of the MOC on interannual to decadal time scales. Although cruises and moorings have provided snapshots and local time series, a basin-scale perspective of the MOC can only be gained by analysis of global oceanographic data sets. In the proposed study, data from satellite altimeters will be combined with profile and subsurface displacement data from the Argo array of profiling floats to estimate changes in the MOC on interannual to decadal time scales. As shown in Willis and Fu [2007], altimeter data can be combined with subsurface displacements and temperature and salinity measurements from the Argo array to make multi-year mean estimates of upper ocean geostrophic velocity. This analysis will be repeated using subsurface float data from the mid-1990s that pre-dates Argo in the N. Atlantic. Comparison of the pre-Argo velocity fields with the more recent analysis will provide an estimate of decadal variability in the upper limb of the MOC. As new data becomes available, maps of geostrophic velocity will be computed on yearly or bi-yearly intervals as data coverage permits. In addition to geostrophic velocity, Argo provides adequate data to chart the evolution of the three-dimensional temperature and salinity fields on seasonal to interannual time scales including surface maps of these quantities. Surface maps will be compared with existing and future satellite based measurements of SST and SSS to provide independent verification of processing techniques and to characterize the surface expressions of changes in the MOC. In
addition, maps of temperature and salinity will be combined with geostrophic velocity to estimate large-scale, interannual heat and freshwater transports associated with the MOC.

Rong-Hua Zhang/Earth System Science Interdisciplinary Center
Using Satellite Observations to Derive TIW Induced Atmospheric Feedback Effects for Climate and Ecosystem Modeling Studies

Tropical instability waves (TIWs) are a meso-scale phenomenon in the eastern tropical Pacific. Recent high-resolution space-based observations reveal significant two-way air-sea interactions associated with TIWs in the region; their roles in budgets of heat, salt, momentum and biogeochemical fields in the ocean have been recently demonstrated. At present, climate models still suffer from substantial biases, partly arising from uncertainty in the representation of computationally unresolved scales, such as TIWs in the tropical oceans. Indeed, realistic simulations of atmospheric response to TIW-induced sea surface temperature (SST_TIW) anomalies are a great challenge since the details of the response mechanisms in the marine boundary layer and its interactions to the overlying free troposphere are not well-known. Currently, most climate models could not realistically take into account TIW-induced meso-scale atmospheric response to SST_TIW anomalies due to a lack of high resolution in the horizontal and vertical. Therefore, the TIW-induced feedbacks from the atmosphere to the ocean and the corresponding meso-scale coupled air-sea interaction processes are still missing in basin-scale climate and ecosystem models. The possible rectified effect of TIWs has not been appropriately taken into account on large-scale mean climate and ecosystem and their variability.

We propose to use satellite observations to derive the TIW related atmospheric feedback effects. Using remote sensing data, several empirical parameterizations are being developed to derive TIW-induced wind stress anomalies (\(\text{Tau}\_\text{TIW}\)) in response to SST_TIW variability in the eastern tropical Pacific Ocean. Wind data are based on space-time blending of QSCAT-DIRTH satellite observations and NCEP analysis fields; SST data are from the Tropical Rainfall Measuring Mission (TRMM) microwave imager (TMI). The TIW-induced atmospheric response will then be taken into account in large-scale ocean and coupled ocean-atmosphere models to investigate the impacts of TIWs on large-scale mean climate and ecosystem and their variability in the tropical Pacific. So the model system can take into account both meso-scale (TIWs) and large-scale (ENSO) ocean-atmosphere interactions. Our working hypothesis is that TIWs in the eastern tropical Pacific can contribute to irregularity of ENSO through their rectified effect on large-scale ocean states. Various numerical experiments will be conducted to quantify the extent to which TIWs can contribute to seasonal-to-interannual climate variability and predictability in the region. A unique product of the proposed research will be to provide an empirical scheme for TIW induced atmospheric wind stress variability that can be used in coupled climate models that at present are unable to explicitly resolve TIWs in the atmosphere. The proposed research will identify a new process that can be responsible for ENSO irregularity in the tropical Pacific climate system.