Oceans Community Letter

April 6, 2006

To: Dr. Richard Anthes and Prof. Berrien Moore
Co-Chairs of the NRC Earth Sciences Decadal Survey

From: Concerned Members of the Oceans Community
(See the attached list of signatories)

Subject: Ocean Satellite Representation in the Decadal Survey

We are writing to you in your capacity as co-chairs of the National Research Council Earth Science Decadal Survey, tasked with establishing a prioritized list to be used by NASA, NOAA and USGS in formulating future Earth-observing satellite missions for research and operational applications. We appreciate the difficulty in synthesizing the input from the diverse individual Earth sciences communities and we thank the Executive Committee and the members of the Survey's seven thematic panels for their efforts to achieve this goal in a balanced manner.

The reports that are posted in the *Survey Updates* link on http://qp.nas.edu/decadalsurvey/ are helpful for keeping the Earth sciences communities abreast of the progress of the Survey. Likewise, the invitation for individuals to comment on the Survey in the *Community Input* link encourages broad representation of the Earth sciences community.

We understand that the Survey is still evolving, but that time is running short for major changes in the Survey's recommendations. Based on the information available in the *Survey Updates* link and presented at recent Town Hall meetings, we are very concerned that satellite missions to acquire essential ocean observations have not to date been adequately addressed by the thematic panels. In the interest of efficiency, we are communicating our concerns in the form of a Community Letter rather than individual inputs. That these concerns are widely shared in the oceanographic community is evidenced by the number of signatories to this letter.

An overview of our input to the Decadal Survey is presented below in an Executive Summary. In the Supporting Material that follows the Executive Summary, details are provided for each of the important oceanographic variables that are measured from space.

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Executive Summary

Understanding upper-ocean dynamics, chemistry, and biology is critical to understanding the Earth system as a whole. Most of the world's living organisms live in the oceans. The ocean covers more than 70% of the Earth's surface and is the largest heat reservoir in the climate system. Ocean circulation and ocean-atmosphere interaction therefore fundamentally drive weather and climate variability, as well as ecosystem dynamics. There are clear U.S. societal benefits of improved understanding of the ocean: more than half the U.S. population (and more than 20% of all of humanity) lives within 50 miles of the coast; ocean activities support over 28 million U.S. jobs; U.S. consumers spend over $55 billion annually for fishery products; and nearly 1/3 of U.S. oil (and 1/4 of natural gas) production takes place on the outer continental shelf.

Because oceans cover such a large fraction of the Earth's surface, satellite-borne instruments are essential for obtaining measurements with the required coverage and resolution for ocean studies. The indispensable roles of ocean satellite missions have been highlighted in many recent reports, including the U.S. Commission on Ocean Policy report *An Ocean Blueprint for the 21st Century* (http://www.oceancommission.gov/), and the *U.S. Detailed National Report on Systematic Observations for Climate: U.S. Global Climate Observing System (U.S-GCOS Program)* (http://www.eis.noaa.gov/gcos/soc_long.pdf). Ocean-observing satellites must have a prominent place in the Decadal Survey.

The importance of oceanography was recognized in the original Decadal Survey document posted in the *Study Organization Background* link that summarizes the rationale for establishment of the seven thematic panels of the Survey. This document states that "…disciplines such as oceanography and atmospheric chemistry, although not visible in the title of a given panel, will influence the priorities of several panels, not just one. For example, oceanography will be a key discipline represented in all of the panels"

We feel that this assurance is not borne out in either the information posted to date in the *Survey Updates* link on http://qp.nas.edu/decadalsurvey/, or in the membership of the seven panels. The Decadal Survey falls far short in its discussions of missions supporting research on ocean circulation, air-sea interactions, and ocean-based ecosystems, despite their critical importance to multiple thematic panels.

Satellite observations of the ocean have become "mainstream" in the sense that they are now used routinely by many scientific researchers who are not thoroughly versed in the technical details of the measurements. That the satellite data are so widely accepted is a measure of the technological maturity of the measurement approaches, the confidence of the research community in the quality of the datasets, and the importance of the ocean satellite data for a broad range of scientific problems. We urge the Decadal Survey to include serious consideration of satellite measurements of the following oceanographic variables, each of which has been identified as high priority in the previously cited *GCOS Report*, *Ocean Blueprint* report, and many other recent reports:

- Ocean surface vector wind measurements with at least the accuracy and coverage of QuikSCAT to continue the QuikSCAT data record in support of a wide range of research and applications addressed by the *Climate Variability and Change Panel*, the *Weather Panel*, and the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel.* Available technology can enhance the utility of satellite measurements of ocean surface vector winds by providing accurate, high-resolution (~5 km) measurements near coasts and in the presence of moderate-to-high rain rates. Such improvements will enable a wide variety of new applications, directly supporting research and operations issues addressed by the above three thematic panels of the Decadal Survey.

- All-weather measurements of sea surface temperature (SST) with at least the accuracy, resolution, and coverage of the EOS-Aqua AMSR-E, which will support research and operations addressed by the *Climate Variability and Change Panel* and the *Weather Panel*.
- Continuation of infrared measurements of SST from the operational satellite system in support of research and applications addressed by the *Climate Variability and Change Panel,* the *Weather Panel,* and the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*.
- An altimeter system to measure sea surface height (SSH) with sufficient accuracy and coverage to continue the data record of global ocean circulation and sea level rise initiated by the TOPEX/Poseidon and Jason missions to enable research addressed by the *Climate Variability and Change Panel*.
- A wide-swath altimeter with a resolution of order 1 km to support research addressed by five of the seven panels of the Survey: the *Climate Variability and Change Panel,* the *Weather Panel,* the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel,* the *Water Resources and the Global Hydrologic Cycle Panel,* and the *Solid Earth Hazards, Resources and Dynamics Panel*.
- Ocean color measurements with global coverage and at least the radiance accuracy, bandwidth, and spectral sampling of MODIS to provide quantitative information on upper ocean processes controlling primary production and the ocean's role in the carbon cycle – issues of vital concern to the *Climate Variability and Change Panel*.
- Sea surface salinity (SSS) measurements with at least the accuracy and coverage of Aquarius to extend the expected 3-year time series of SSS to be initiated by Aquarius starting in 2009. This will advance the understanding of the relationships between SSS and the hydrological cycle, and thus will contribute directly to research important to the *Climate Variability and Change Panel* and the *Water Resources and the Global Hydrologic Cycle Panel*.

We hope that the Decadal Survey will galvanize NASA and NOAA to develop realistic plans to assure sustained acquisition of the complete suite of critical ocean measurements summarized above. If plans for acquiring these measurements of surface vector winds, SSH, all-weather SST, ocean color, and SSS are not explicitly included in the recommendations of the Decadal Study, we fear that essential oceanographic time series will be terminated, and that important and exciting new studies of climate, weather, and biogeochemical variability will not be fully exploited owing to a lack of supporting satellite measurements.

To be relevant, the Decadal Survey must realistically consider the uncertainties of NPOESS and the slow progress toward transition of satellite measurements from research to operations. The pre-operational NPP and operational NPOESS missions – which will not acquire all of the needed ocean surface measurements, even if flown as currently planned – are suffering from enormous cost overruns and multi-year schedule delays that will devastate the continuity of present ocean time series. The NPOESS program plan further does not adequately address the instrument stability requirements or the calibration and validation required to ensure the scientific utility of long-term NPOESS datasets for climate and ecosystem-scale research, nor has NOAA demonstrated a sustainable plan to produce and support such datasets from NPOESS.

Supporting Material

Ocean Vector Winds

Satellite measurements of ocean surface vector winds are not addressed by any of the panels of the Decadal Survey. Surface wind stress is the primary forcing of upper-ocean circulation. All non-satellite ocean wind observations have inadequate coverage. Furthermore, while satellites measure the wind stress itself, conventional wind measurements require additional information on surface ocean currents and atmospheric stratification in order to obtain estimates of surface stress. Lacking global in situ observations, oceanographers and climate researchers have long relied on estimates of surface wind forcing based on global atmospheric general circulation models used for numerical weather prediction (NWP). The 6.5-year time series of broad-swath, near-all-weather QuikSCAT measurements is highlighting the inadequacies of these model-based surface vector wind estimates. Continuation and enhancement of the QuikSCAT global ocean wind time series with high spatial resolution and wide-swath coverage is essential for improving the accuracies of ocean circulation models under development for the climate studies that are important to the *Climate Variability and Change Panel*.

One of the remarkable discoveries from the QuikSCAT data is the existence of systematic large-amplitude, small-scale features in the wind field that are found ubiquitously in the vicinity of strong SST fronts. In these regions, SST modifies the surface wind field in such a way as to produce order one or larger perturbations in the wind stress curl field on scales of a few hundred kilometers. These intense small-scale perturbations of the wind stress curl field, which drive open-ocean upwelling/downwelling, have significant feedback effects on ocean, ecosystem, and local atmospheric dynamics (which are important to the *Climate Variability and Change Panel,* the *Weather Panel,* and the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel)*, but are at best poorly resolved in the wind fields from NWP models. The high-resolution, broad-swath measurements initiated by QuikSCAT must be continued in order to resolve and understand the dynamics and thermodynamics of these small-scale, persistent air-sea interactions and to represent these features accurately in global NWP and ocean general circulation models through assimilation of the satellite wind observations.

QuikSCAT data are presently used extensively in operational weather forecasting and marine hazard predictions that are important to the *Weather Panel*. QuikSCAT wind speed and direction measurements are assimilated routinely into global NWP systems at NCEP, ECMWF, and other international meteorological agencies. The satellite data contribute routinely to hurricane and marine forecasts produced by the NOAA Tropical Prediction and Ocean Prediction Centers. Since 2001, the availability and analyses of QuikSCAT measurements have allowed the NOAA Ocean Prediction Center to institute a new "hurricane force winds" warning level in the midlatitude ocean that was not possible from the sparsely distributed *in situ* observations available prior to QuikSCAT. The lack of continued satellite-based high-quality surface wind observations would result in decreased forecast skills in both numerical and manual operational applications.

Accuracy, resolution, and coverage requirements for research and operational uses of ocean surface vector wind measurements have been documented in numerous reports published over the past decade, including the NPOESS *Integrated Operational Requirements Document* (http://www.osd.noaa.gov/rpsi/IORDII_011402.pdf), the *GCOS Report*, and the requirements database summarized by the *WMO/Committee on Earth-Observing Satellites* (http://alto-stratus.wmo.ch/sat/stations/SatSystem.html). At present, QuikSCAT is the only operating, validated, broad-swath satellite instrument acquiring vector wind measurements with the required accuracy, spatial resolution and coverage. However, QuikSCAT is well beyond its design life and cannot be expected to continue operating for more than a few more years.

While the QuikSCAT measurements have revealed much exciting new information about ocean wind forcing, present data have important limitations for some applications. QuikSCAT measurements are inaccurate in heavy rain, and are not routinely produced closer than 30 km to land. Large changes in the physical, thermodynamic, and biological properties of coastal and marginal seas are occurring on a wide range of time scales. Accurate, high-resolution vector wind measurements near coasts are fundamental for advancing knowledge of coastal ocean dynamics and ecosystems. Hurricane forecasters also need wind observations with higher resolution than can be obtained from the QuikSCAT data. Technology now exists for increasing the resolution of spaceborne vector wind measurements to ~5 km and improving the accuracy of wind retrievals in raining conditions. Such high-resolution, all-weather measurements should be high-priority recommendations of the *Weather Panel* and the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*.

NASA has no plans for a follow-on to QuikSCAT. The ASCAT scatterometer to be launched on the European METOP satellite in June 2006 has only half the spatial resolution of QuikSCAT and provides only ~70% of the QuikSCAT coverage, with a 720-km gap between parallel swaths centered on the satellite ground track. Previous experience with NSCAT, which had a nadir gap less than half as wide as that of ASCAT, found that the existence of a nadir gap compromised the utility of satellite measurements of ocean vector winds for forecasting of hurricanes and midlatitude storms. It appears that passive polarimetric radiometry also cannot satisfy all of the needs of both the research and the operational communities. In any case, the experimental WindSat polarimetric radiometer launched in January 2003 is now beyond its baseline mission lifetime. The accuracy of WindSat vector wind retrievals over a wide range of conditions is still under investigation, but analyses of preliminary data indicate that the measurement errors are 30% larger than those of QuikSCAT winds. Moreover, WindSat cannot provide wind estimates closer than 50 km to land or ice, its measurement accuracy is degraded at wind speeds below ~7 m/s, and its coverage is only 60% that of QuikSCAT. The only plans for future measurements of ocean vector winds from U.S. satellites are from the CMIS polarimetric radiometer on NPOESS, which is similar (but not identical) to the WindSat instrument.

The continuity of the ocean vector wind data record established by QuikSCAT is thus in serious jeopardy. There are no present plans in the U.S. to fly any satellite instruments for broad-swath, all-weather measurements of vector winds before CMIS on NPOESS. Recent technical and fiscal challenges in that program have resulted in proposals to delete the CMIS instrument entirely or to replace CMIS with a WindSat-like radiometer that would launch no earlier than the second NPOESS mission. An eventual sampling gap after the ending of the QuikSCAT data record of high-resolution, broad-swath measurements of ocean vector winds is now inevitable and, as noted above, can only partially be addressed by the lower-resolution, dual narrow-swath ASCAT on the European METOP satellite. It is crucial that planning begin immediately for a follow-on to QuikSCAT that will provide measurements of ocean vector winds with at least the accuracy, resolution and coverage of QuikSCAT, and preferably with the capability to measure vector winds with a higher resolution of ~5 km and in raining conditions.

Sea Surface Temperature

Remotely sensed SST measurements are not identified in the draft recommendations from any of the panels of the Decadal Survey. Since SST is among the most important variables for climate diagnostics, it is especially surprising that satellite measurements of SST are not identified as a high-priority measurement by the *Climate Variability and Change Panel.* Because of the strong relationship between convection and SST in the tropics, understanding tropical climate dynamics is critically dependent on understanding the processes that regulate SST and its coupling with the atmosphere. Most of the observationally based research on interannual and decadal climate variability in the tropics, as well as in midlatitudes, has been based on the Reynolds SST analyses and the AVHRR Pathfinder fields, both of which are derived from satellite infrared (IR) measurements. Because *in situ* measurements are noisy and have sparse coverage, it is essential that these satellite measurements of SST be continued in order to maintain the continuity of global time series of climate change.

Satellite IR measurements of SST are also important to coastal oceanographic applications. In cloud-free conditions, the IR observations have been used for several decades to provide high-resolution maps of the upwelling and circulation patterns in coastal and nearshore oceanographic studies. As these circulation patterns play an essential role in physical-biological interaction in these regions, satellite IR measurements of SST are important to the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*.

The lack of discussion of SST in the Decadal Survey perhaps reflects an assumption by the panels that SST data will be provided by operational satellites. Such an assumption is risky. Depending on issues such as how long the MODIS IR radiometers on EOS-Terra and EOS-Aqua continue to operate, if and when NOAA-N is launched, and whether the technical issues for VIIRS on NPP and NPOESS can be resolved, there is the potential for a period of 18 or more months when the only source of IR measurements of SST will be the European METOP satellite. This is a precarious situation, especially in view of the need for measurements from more than one simultaneous IR satellite instrument because of sparse sampling of SST in cloudy regions. In any case, since the Decadal Survey is tasked with recommending satellite missions for both research and operational applications, it is imperative that continuation of the IR measurements of SST by operational satellites be explicitly called out as a high-priority recommendation, at least by the *Weather Panel.*

The availability of all-weather microwave satellite measurements of SST by the TMI on TRMM and the AMSR-E on EOS-Aqua has revealed many limitations of traditional IR measurements. The ocean is typically more than 60% cloud covered at any given time. Despite the lower resolution of individual measurements (about 50 km, compared with about 1 km for IR observations) and the inability to obtain accurate microwave SST measurements closer than about 100 km to coasts, global fields of open-ocean SST can be constructed from microwave measurements with higher resolution in both space and time than can be achieved from IR observations because of the loss of IR measurements in the vast areas of the World Ocean that are frequently cloud covered. Furthermore, microwave SST measurements are insensitive to dust aerosols which impart a cold bias to SST estimates from IR instruments. Microwave measurements of SST therefore offer the potential for significant advances in climate studies, and the best SST fields are likely to be produced by objectively combining available high spatial resolution, clear-sky IR measurements with all-weather microwave measurements. Presently, however, the only plans for future microwave measurements of SST are from the CMIS on NPOESS. As noted previously, CMIS may be delayed or descoped to accommodate the cost overruns of the NPOESS mission. Continuation of the existing microwave SST data records without interruption should be a high priority recommendation of the *Climate Variability and Change Panel*.

Microwave measurements of SST together with QuikSCAT observations of surface winds are presently yielding important new insight into the coupled ocean-atmosphere interaction noted previously. As part of this effort, the AMSR-E and QuikSCAT data are providing a basis for assessing improvements introduced to the boundary layer mixing parameterization used in the numerical weather prediction models. In addition to improving the accuracy of model estimates of low-level winds, improved boundary layer parameterizations can be expected to lead to more accurate estimates of air-sea heat and moisture fluxes in the operational forecast models. These improvements will benefit the models used to produce the ECMWF and NCEP reanalysis fields. The flux fields from these reanalysis products are used as surface boundary conditions for global ocean circulation models under development for climate studies, thus indicating an indirect benefit of satellite microwave measurements of SST for climate research that should be considered important to the *Climate Variability and Change Panel.*

SST is also of fundamental importance to air-sea interaction on shorter time scales. It is the surface boundary condition of the atmosphere over the ocean and is therefore essential for the *Weather Panel*. The sensitivity of operational weather forecast models to specification of SST is clear from comparisons of ECMWF surface wind fields immediately before and after the May 2001 introduction of a major improvement in the accuracy and resolution of the SST fields used as the ocean boundary condition in the ECMWF model. The higher resolution SST fields resulted in an abrupt increase in the energy of small-scale variability in the surface wind stress curl field that is important to ocean circulation.

Accurate microwave measurements of SST are also potentially important for hurricane and midlatitude storm prediction because of frequent heavy cloud cover. Since the microwave SST data have not been available in real time, it has not been possible to utilize them in operational forecasting of tropical cyclones and hurricanes. The Global Ocean Data Assimilation Experiment (GODAE) is presently spearheading an effort to establish both the scientific foundations and the logistical mechanisms for delivering accurate SST fields from all available IR and microwave instruments to the weather forecast centers in near real time to improve forecasts and analyses of low-level wind fields. The success of this GODAE High-Resolution SST (GHRSST) Pilot Project effort, and its transition to full operational implementation, are critically dependent on a continuing stream of high-quality satellite SST data. Such real-time availability should be a high-priority recommendation of the *Weather Panel*.

Sea Surface Height

Global sea level rise is one of the most direct available measures of the integrated effects of global warming. The TOPEX/Poseidon (T/P) altimeter launched in 1992 established a 10-year record of accurate measurements of SSH. This long data record has been continued with the Jason altimeter. The average sea level rise of 3.2 mm/year deduced from the 13.5-year T/P-Jason dataset is being used to validate predictions from climate models. It is thus surprising that the draft recommendations of the *Climate Variability and Change Panel* that are posted on the Survey web site make no mention of continuation of this important climate data record.

The T/P-Jason data record will be extended with the Ocean Surface Topography Mission (OSTM) that is scheduled to launch in 2008. There are presently no U.S. plans for altimeter missions beyond OSTM, yet it is estimated that accurate detection of the acceleration of global sea level rise predicted by climate models will require a 30-year record of highly accurate altimeter data. The altimeters that may be launched on European satellites (e.g., an ENVISAT follow-on) cannot satisfy the requirements for measuring global sea level rise since they would be sun-synchronous and would therefore alias the solar tides and, more importantly, a variety of slowly modulated diurnal signals (e.g., ionospheric range delays, internal tides and atmospheric tides), into the mean SSH. The continuity of global sea level rise measurements beyond OSTM is therefore essential for studies of climate change, and satellite altimetry must be a very high priority recommendation of the *Climate Variability and Change Panel.*

The T/P and Jason data have also been used extensively to study large-scale and mesoscale variability of global ocean circulation, resulting in fundamental advances in the understanding of ocean dynamics and in the distribution of eddies in the global ocean. These data are providing critically important validation of eddy-resolving models of the ocean circulation that are under development for climate studies. SSH provides a measure of the integrated effects of upper-ocean variability. As such, these altimeter measurements are the only satellite observation of a dynamical ocean variable that is being assimilated into global ocean models for forecasting of the El Niño phenomenon and other important climate signals such as the Pacific Decadal Oscillation. Continuation of the T/P-Jason-OSTM data record is therefore crucially important for the ocean component of climate studies, thus providing additional rationale for including satellite altimetry as a high-priority recommendation of the *Climate Variability and Change Panel*.

On shorter time scales, recent studies have shown that hurricane prediction is more dependent on upper-ocean heat content than on SST. SSH provides the necessary measure of the integrated upper ocean heat content. This was demonstrated from SSH maps constructed from satellite altimeter data that showed the interactions of Hurricanes Katrina and Rita with the Gulf of Mexico Loop Current. This ocean influence on the intensities and trajectories of the hurricanes was much clearer in SSH than in SST. Altimetry is important to other weather applications as well. Altimeter sea-state and ice edge measurements are being assimilated routinely into ECMWF and other numerical weather prediction/analysis systems, resulting in improved wave, weather, and marine environmental forecasts. Continued altimeter measurements of SSH, sea state and ice extent should therefore be an important recommendation of the *Weather Panel*.

The oceanographic community had proposed to include a Wide-Swath Ocean Altimeter (WSOA) on the OSTM satellite platform. WSOA was dropped from the mission because of concerns about programmatic risk to the core OSTM mission. WSOA would have provided high-resolution measurements of SSH on approximately a 10-km grid across a 200-km swath centered on the satellite ground track. Such measurements would provide the first synoptic maps of the global oceanic eddy field that affects the oceanic general circulation through eddy transfers of momentum, heat, and the chemical properties of seawater, which would improve the understanding of the role of the oceans in global climate. High spatial resolution altimetry is therefore also important to the *Climate Variability and Change Panel*.

Technology now exists to obtain accurate measurements of SSH with a spatial resolution of about 1 km across a 120 km swath using a synthetic aperture radar altimeter system. In addition to providing very high resolution maps of the eddy field, such an altimeter system can measure SSH very close to land, thus providing valuable dynamical information about nearshore surface currents that are important to the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*.

In addition to the oceanographic applications outlined above, high-resolution measurements of SSH offer opportunities for synergism with other panels of the Decadal Survey. A synthetic aperture radar altimeter system can provide measurements of lake and river levels and areal coverage, identified as important by the *Water Resources and the Global Hydrologic Cycle Panel*. Likewise, the *Solid Earth Hazards, Resources and Dynamics Panel* has highlighted the need for such measurements to resolve small-scale variations in ocean bathymetry. Together with the previously summarized needs of the *Climate Variability and Change Panel*, the *Weather Panel* and the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*, the scientific needs of five of the seven thematic panels of the Survey could be met by a single high-resolution altimetry mission.

We note that studies of global sea level rise and ocean circulation would benefit greatly from continuation of GRACE-like missions to determine time variations in the Earth's gravity field on scales smaller than the present ~300 km resolution limitation of GRACE. Such satellite-derived gravity measurements provide a means to partition the sea level rise into contributions from the steric effects of thermal expansion and the non-steric effects of ice melt. For ocean circulation studies, the gravity measurements enhance the utility of altimeter measurements by providing the absolute SSH and surface geostrophic velocity, rather than only the temporally varying contributions relative to unknown means. These gravity measurements also hold the promise of providing time change in pressure gradients at depth, which are related to the deep ocean circulation.

Ocean Color

Satellite measurements of ocean color are identified as critically important to the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*. It appears that the recommendations of this panel adequately represent the needs for ocean color measurements for applications in the coastal ocean. However, given the uncertainties in the sensor performances and launch schedules for NPP and NPOESS, continuity of high-quality measurements of ocean color for global open-ocean studies is not assured beyond the presently in-orbit SeaWiFS and MODIS missions. The available recommendations of the Decadal Survey therefore do not adequately address the overall needs for satellite measurements of ocean color.

High-quality ocean color measurements are critical for understanding and determining the net carbon export from the upper ocean. The rate of atmospheric CO_2 increase is a sensitive function of the processes by which the upper ocean takes up and sequesters CO_2 from the air. The accuracies of climate projections are thus limited by the availability of adequate ocean color data. Surprisingly, there is no mention in the recommendations of the *Climate Variability and Change Panel* of the essential role of ocean color measurements in climate studies.

To date, open-ocean satellite measurements of ocean color have provided only biomass surrogates to support limited productivity and carbon flux estimates. The VIIRS on NPP and NPOESS will only collect basic ocean color data, similar to SeaWiFS but lacking the long-term calibration afforded by regular lunar observations. A full spectral capability between 345 nm and 800 nm, coupled with narrow-band measurements near 317 nm and broader-band IR measurements (865-1375 nm, for accurate atmospheric correction), are needed to move beyond the present rudimentary measurements. This enhanced spectral capability will allow quantitative examination of dissolved organic matter, phytoplankton species groups, and fluorescence variability under complex atmospheric and oceanic conditions. Spatial and temporal sampling characteristics can be similar to SeaWiFS/MODIS (1 km nadir, 2-day global repeat, noon ascending node). Monthly direct calibration (e.g., from lunar viewing) is essential to ensure adequate stability.

Deep water inputs and terrestrial runoff cause the coastal ocean to be a region of enhanced primary productivity and microbial activity. The coastal interplay between fresh and salt water has significant impacts on microbial and photo-oxidation processes. The coastal ocean supports a complex food web, and these ecosystems are under significant pressure from human activity. Coastal ocean ecosystems are thus at the intersection of global-scale changes in ocean and atmospheric forcing as well as intense human activity in the ocean and on the land. These pressures, along with the changes in physical forcing as a result of climate change, will have profound impact on coastal ecosystems and biogeochemistry, which is important to the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel*.

A hyperspectral sensor with high temporal resolution of at least several times per day and spatial resolution of a few hundred meters will allow identification of phytoplankton functional groups, dissolved organic materials, variable fluorescence, and other properties necessary to study ecosystem structure and biogeochemical processes. A geostationary satellite mission with these capabilities has been recommended by the *Land-Use Change, Ecosystem Dynamics and Biodiversity Panel.* We note, however, that the Hyperspectral Environmental Suite/Coastal Water (HES-CW) instrument planned for the next generation of operational geostationary satellites (GOES-R) will not satisfy all of the stringent coastal-water requirements, and many important science questions concerning ecosystem structure and biogeochemical processes will therefore not be addressed.

Sea Surface Salinity

Sea surface salinity (SSS) variations are governed by fresh water fluxes resulting from precipitation, evaporation, river runoff, and the freezing and melting of ice. SSS is thus an important diagnostic variable for determining and monitoring the hydrologic cycle, climate change, and the interactions between climate variations and ocean circulation changes that are important to the *Water Resources and the Global Hydrologic Cycle Panel* and the *Climate Variability and Change Panel.*

SSS can be estimated under nearly all-weather conditions from measurements of low-frequency (~1.4 GHz) microwave radiation. The selected ESSP Aquarius mission with a planned launch in 2009 will acquire open-ocean SSS measurements with 150 km spatial resolution and global accuracies better than 0.2 psu on monthly time scales. In contrast with the ESA SMOS mission, Aquarius will use a shared antenna to obtain radar measurements of ocean backscatter at 1.4 GHz for coincident estimates of wind speed that are essential for corrections of the radiometer measurements to enable salinity estimates with the required accuracy. As a proof-of-concept mission, however, Aquarius is designed to operate for only 3-years (with a required minimum life of 1 year). It is therefore unlikely that the Aquarius mission alone will be able to provide a sufficiently long SSS time series for studies of long-term variability. Furthermore, the coarse spatial resolution of the Aquarius measurements precludes accurate estimates of SSS within ~400 km of land or ice where surface salinity variations are largest and are of considerable interest oceanographically. No other planned U.S. operational mission or instrument will provide SSS measurements.

We note that both SSS and soil moisture measurements are made using the same 1.4 GHz microwave frequency band. However, soil moisture demands many times higher spatial resolution than SSS, while SSS requires more than an order of magnitude better precision and calibration stability than is necessary for soil moisture determination. With newly available antenna and instrument technologies, it may be possible to develop a mission capable of satisfying the needs of both communities. The high-resolution measurements from such a mission would enable SSS and hydrological studies in coastal regions, marginal seas and near ice boundaries, all of which are presently inaccessible by satellite remote sensing.