Response to the initial Request for Information for the 2017-2027 Decadal Survey for Earth Science and Applications from Space

Ocean Biology and Biogeochemistry community initial input towards the next Decadal Survey

1. ***What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?***

Open and coastal ocean ecosystems provide a wide range of socio-economic services to humanity, including food, recreation, commerce, transportation and many others. These systems modulate the global biogeochemical cycles of carbon, nitrogen, and other elements that sustain life on Earth and stabilize climate. **The grand challenge of our time, in the face of the increasing impact of humans on the environment and climate, is to derive actionable knowledge to ensure sustainable use of marine and coastal resources and a healthy global society.** This knowledge needs to be based on an improved understanding of the complex interactions among physical, ecological, biogeochemical and environmental oceanic processes. It requires frequent and repeated observations to detect change in coastal and offshore aquatic environments at local to global scales, attribute change to natural or anthropogenic causes, and develop tools to evaluate, predict, inform and - as necessary - mitigate potential responses of ocean ecosystems to future changes.

Key questions in Earth System Science are:

- ***How do the diversity and resilience of marine ecosystems change under present and future environmental conditions?***

Despite the importance of ocean ecosystems for society, our current understanding of the processes that drive change in trophic interactions and community composition remains poor. Changes in the physical, chemical and biological environment create stressors and ecological regime shifts that may have lasting consequences to ecosystems and our own well-being. To advance current understanding and improve model predictions, we need observations under low sunlight and even polar night conditions, at the spatial and temporal scales of bio-physical interactions in different habitats, including human uses, from the surface to depths of several tens to hundreds of meters and at frequencies of tens of minutes to diurnal scales. These observations are critical for securing ecological balance and better resource use.

- ***How do boundary habitats differ from open ocean habitats and how do they change?***

Coasts and estuaries, the benthos, the interface between ice and water, and fronts between water masses are examples of boundary habitats. They support some of the most productive and diverse ecosystems on Earth that sustain important fisheries, industries, human life and economy. However, our observing systems are not adequate to measure the physical processes, biogeochemical transformations, and habitat changes at these boundaries, or to understand how we can use the resources there in a sustainable way. To address these issues and capture highly dynamic events across a range of environments, we need repeated observations, with higher temporal and spatial resolution and signal to noise ratio, at and below the ocean surface and in high-latitude areas.

- ***How is ocean biogeochemistry being modified by changes in elemental cycling between ocean, land and atmospheric reservoirs?***

The distributions of elements central to Earth's climate and life, such as carbon, oxygen, nitrogen, and others, are impacted by changes in marine biogeochemical cycles. Processes such as marine photosynthesis, nitrogen fixation, food web processes, deposition of dust iron and other elements, carbon and nutrient runoff, tidal exchanges, and ice-induced stratification are key to understanding the impacts of ocean processes on carbon sequestration, changes in biogeochemical cycles, and how they are influenced by short-term and climate-scale changes. We need higher spatial and temporal resolution, global measurements, even below the ocean surface, and in polar regions to improve prediction models and plan resource management strategies.

- ***How can we better prepare for, respond to, recover from, mitigate and adapt to transient hazards and disasters?***

Remote sensing observations of the oceans at appropriate temporal, spatial and spectral resolution can be used to monitor extreme weather events, oil spills, harmful algal blooms and resulting impacts such as flooding/ erosion of coastal communities and associated floating debris and pollution. Science-based operational strategies to detect events and impacts on biology, biodiversity, and water quality that are directly relevant to our health and the resources we use, combined with the integration of those data in models, can provide solutions for society to better prepare and respond to those transient problems and disasters.

2. The opportunity

Over the past 50 years, the Earth Science community has gained a profound understanding of global ocean ecosystems and biogeochemistry, and how they are influenced by weather, climate, and human-driven change. The next planned mission, PACE, will continue the high-quality record of visible reflectance of the global ocean and will significantly advance capabilities with higher spectral resolution. Yet, the research done with previous satellite missions and ocean sensors has also shown considerable limitations. Current knowledge and technology can transform the observational capabilities of future-ocean observing satellite missions. ***Repeated, high frequency (~hourly), and high spatial resolution observations (~10-300m)*** would allow the study of critical land-ocean-ice-atmosphere boundary habitats, and monitor for extreme events. ***Space-based or suborbital observations using an active ocean profiling sensor*** would resolve variability below the surface ocean and enable more accurate quantification of plankton stocks and ocean productivity, and detailed evaluations of the interaction between ocean physical processes and ecosystem structure.

3. Why are space-based observations fundamental to addressing these challenges/questions?

The ocean is a challenging environment for ground-based observations. Ship-based studies are expensive and inherently limited in spatial and temporal scope. Airborne measurements of coastal processes can be useful, particularly for targeted regions, events or processes. Space-based observations, however, allow continuous monitoring of ocean ecosystems over an annual cycle, provide a synoptic view of the entire ocean, capture large scale variability, and allow for detection of temporal trends and differentiation in system functioning across regions and regimes. In addition, satellite observations provide a crucial link in upscaling the detailed information obtained from process-focused field studies to the coarser scale of climate model simulations. New space-based and suborbital observations can revolutionize process parameterizations, quantification of biogeochemical fluxes and stocks, and the study of complex interactions such as between marine biology and fronts/eddies or marine biogenic aerosols and lower atmosphere chemistry and clouds.

a. Do existing and planned U.S. and international programs provide the capabilities necessary to make substantial progress ? If not, what additional investments are needed?

Planned U.S. and international programs, such as PACE, will provide better determination of phytoplankton functional groups and, potentially, taxa, but will not lead to improvements in quantifying coastal habitats and the four dimensional dynamics of the global ocean. The operational US sensor VIIRS as well as the Landsat and Sentinel-2 sensors lack the spectral and temporal resolution and signal to noise ratio necessary to adequately measure changes in biogeochemistry and ecology in turbid coastal areas. There is no planned concept that provides observations of critical primary producer dynamics below the surface ocean.

b. What links are needed between space-based observations and other observations to increase the value of data for addressing key scientific questions and societal needs?

Despite the advances in satellite oceanography, operational weather, fisheries and conservation forecasting, agencies don’t routinely incorporate new remote sensing biogeochemical observations into assimilation models. They often consider such observations experimental and of insufficient temporal or spatial resolution. Incorporating new discoveries and high-quality, science-based remote sensing capabilities (space-based, airborne, underwater and autonomous sensor technologies) into the nation’s operational infrastructure needs to include improved linkages between science, policy and operations, renewed cooperative planning among U.S. agencies and the international community.

c. The anticipated scientific and societal benefits of new measurements

Past experience has shown that changes that could be observed by satellites have had significant positive impacts on human health, sustenance, property, and the economy. Pollution, sea level rise, sea-ice melt, land-use change, hazards, and disasters, alter the biogeochemical nature and biodiversity of the marine and freshwater habitats and wetlands with profound effects to local food webs and the quality of life. Our increasing dependence on these resources should rely on sustainable and appropriate management.

Such management directly depends upon observations and a clear understanding of the processes driving the change, the interactions with land, ice and atmosphere as well as the outcome these changes may have. Such an improved understanding will allow for better preparation, mitigation and potential recovery from transient, short-term and climate-level changes.

d. The science communities that would be involved

Designing the future observing systems for the next generation ocean science research requires a more integrative approach to observations, one that combines physical and biogeochemical measurements at different temporal and spatial scales. The physical oceanography and the ocean ecology, biology and biogeochemistry (OBB) communities would mutually benefit from combined missions. In addition, careful integration of the OBB community with the terrestrial and the cryosphere communities should be promoted, due to the importance of the exchanges across the boundaries. Lastly, the oceans play a major role in the global carbon cycle and the carbon-climate feedbacks, which are most naturally addressed in collaboration with terrestrial and atmospheric carbon cycle scientists.

Taking these into account, the OBB community is prepared to assist and participate in groups or panels addressing the carbon cycle, biogeochemistry and radiative forcing, and in groups focused on terrestrial and marine ecosystems.

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