NRC DECADAL SURVEY WHITE PAPER – CHALLENGES AND OPPORTUNITIES OF SPACE-BASED AND OTHER OBSERVATIONS FOR MARINE ECOSYSTEM SCIENCE

Our ability to describe ocean, coastal, and Great Lakes (collectively referred to as marine) ecosystems, understand how they function, and forecast their future state is limited by the difficulties in measuring and monitoring the dynamic 4-dimensional environment, much of which is not visible from the surface. Synoptic, long-term observations from space, integrated successfully with *in situ* and human observations, are a key component of an effective monitoring strategy.

Advanced marine ecosystem science, supported by high-quality and reliable observations, is needed to inform policy and management decisions that promote healthy, productive, diverse, and sustainable ecosystems. Scientists must determine the status, trends, and future states of these ecosystems and their populations; understand physical, chemical, and biological drivers, mechanisms, and processes and impacts; assess the vulnerability of ecosystems to current and emerging human activities and climate and environmental changes; and inform effective and robust management strategies. This requires an increase in the collection and use of high-quality environmental data, at appropriate temporal and spatial scales, to describe and understand these ecosystems and improve regional forecasts and projections. ***The purpose of this White Paper is to highlight the key research questions and challenges facing marine ecosystem science, particularly in the context of informing Federal resource management, and outline the observational requirements necessary to support this science over the next decade.***

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?

Marine ecosystem science and management face many challenges, requiring basic and applied research supported by ongoing, quality observations. This paper focuses on four key questions, based on the NOAA 5-year R&D Plan[1], that incorporate a number of important challenges and benefit from sustained and new observing systems and technologies to measure and monitor marine ecosystems from space and *in situ* platforms.

[1] National Oceanic and Atmospheric Administration. Research and Development at NOAA: Five Year Research and Development Plan 2013-2017, 78pp.

- ***What is the value of marine ecosystems?***

In addition to their direct economic benefits, marine ecosystems provide vital life support functions and recreational opportunities, sustain wildlife habitats, and reduce environmental and human health risks. Quantitative valuation of these ecosystem services is difficult and too easily discounted in policy decisions. Better valuation requires identifying and monitoring key ecosystem attributes, processes, and exchanges. It also requires better methods to measure ecosystem production, assess marine populations, monitor habitat protection and restoration efforts, and quantify coastal habitat benefits. Advancing and implementing new observing and analysis techniques will result in more accurate information on the comprehensive value that ecosystems provide.

- ***How do environmental changes affect marine ecosystems and the economic and ecological services they provide?***

A better understanding of how marine ecosystems are affected by climate and environmental change and human activities will enable more robust assessments and forecasts, leading to improved management that promotes sustainable, healthy, and productive ecosystems. Scientists need to identify, understand, monitor, and forecast changes in ecologically critical watershed, coastal, and open ocean habitats, their populations, and the drivers that shape them; and document commercial and recreational activities, their interactions, and effects on marine populations and habitats. Observing and tracking changes in the environment and human activities in Polar regions are particularly important.

- ***What exists in the unexplored areas of our oceans?***

The ocean remains largely unexplored. Satellite observations are critical to mapping and characterizing remote and unexplored ocean areas, particularly in the US EEZ and Extended EEZ. From satellite observations and the development of new technologies to observe and describe these regions, scientists can acquire new knowledge and share it with operational users and partners in ocean exploration, research, and management.

- ***How can emerging observational technologies improve ecosystem-based management?***

Effective ecosystem-based management requires a synthesis of scientific information from relevant physical, chemical, ecological, and human processes in relation to specified management objectives. Innovative technologies to improve remote sensing and alternative *in situ* platforms are needed to provide more accurate and precise synoptic information of key

marine populations and environmental influences on their production, distribution, and health; and to improve abundance estimates, regional assessments and forecasts, and address measure uncertainty.

2. **Why are these challenge/questions timely to address now especially with respect to readiness?**

The interdependence of ecosystems and economies makes coastal communities vulnerable to chronic – and potentially catastrophic – natural and human-induced hazards, including oil spills, toxins, plastics, harmful algal blooms, hypoxia, pathogen outbreaks, unsafe seafood, changes in streamflow, and severe weather. Demands for seafood, energy, recreation, and other pressures will continue to stress ecosystem health and sustainability. Reduced fish stocks, illegal fishing, and declines of iconic species result in lost opportunities for employment, economic growth, and recreation. Climate change and ocean acidification alters nearshore and open ocean habitats, which subsequently affects recreational, economic, and conservation activities.

The demand exists – and is growing - for better observations and science for effective community planning, resource management, and business decisions, and to help spur private and business innovation in marine sectors. At a time when environmental conditions are changing at an increasing rate, our capability to collect and incorporate environmental data into operational marine resource assessments, forecast models, and decision-making processes must be improved. A critical limitation to progress in these areas is high-quality, long-term climate data records, a majority of which require satellite data with higher spatial, temporal, and spectral resolution than currently exists. NOAA and NASA are both working to ensure these capabilities will continue into the future, but we are increasingly relying on international partners for the continuity of satellite data streams.

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

Satellite observations have revolutionized how we see and understand the ocean. They provide context for connecting global synoptic variability to regional information and decision making, and demonstrate air-sea-ice interactions on multiple spatial and temporal scales that must be considered when addressing ecosystem condition. They reveal that managing a resource requires incorporating data from far beyond regional boundaries to understand the full range of pressures and risks to that resource. Space-based observations are instrumental in understanding and forecasting climate change and reducing its effects, exploring and characterizing remote areas, providing for the sustainable use and enjoyment of marine resources, improving human and marine environmental health, protecting lives and property from hazards, and enhancing

economic vigor, quality of life, maritime safety, and national security. Their products serve multiple users and purposes, resulting in great return on the investment in R&D and operational observing infrastructure.

Federal agencies are moving toward fully integrated ecosystem science and ecosystem-based management of marine resources and activities. This has given new impetus for better monitoring and understanding of the environmental factors influencing fish stock and protected species, and for including environmental variability as an integral part of the ecosystem assessment process. Most of the spatial features that characterize ecosystems and their variability (i.e., ocean fronts, eddies, convergence zones, river plumes) cannot be resolved adequately without the repeating synoptic view satellite data provide.

The future success of ecosystem-based management, and the science that supports it, will depend on a diverse and complex set of interconnected information sources, hardware, and data and model developers. Data from NOAA and partner satellites, combined with *in situ* ocean observing systems, are a critical foundation. Much of the data used in marine research are collected by systems dedicated to regular operations (e.g., the Geostationary Operational Environmental Satellite constellation). Other data needs are unique to marine ecosystem research. We need more high-quality, synoptic, and regular environmental data to describe, understand, and forecast ocean changes and their ecosystem impacts, and to develop and apply analytical models and tools to increase our knowledge and understanding of the mechanisms and impacts of environmental changes on marine resources and ecosystems.

R&D in support of observing systems must focus on what needs to be measured to support agency operational and research mission goals. Much of this focus is on how to effectively and efficiently make new types of observations, variables, and products, as well as how to improve the accuracy, coverage, resolution, effectiveness, and cost of measuring existing parameters. The Federal space-based observing system portfolio needs to balance growing demands for data with concerns about maintaining existing systems and implementing emerging technologies. Escalating costs to support existing and emerging observations require rigorous analysis and determination of the most effective observing portfolio.

Satellites are part of the global integrated ocean observing network, which provides real-time data and a growing archive of information about marine ecosystems. ***We stress that space-based observations alone are insufficient to address the challenges faced in marine ecosystem science.*** Integrated earth systems models, for example, require data derived from a broad spectrum of satellite, *in situ*, and human observations. However, satellites are an essential component of the observing and monitoring systems that science and management need, and that the Nation must continue to supply.