EARTH'S LIVING OCEAN

DRAFT

THE 2017-2027 ADVANCED SCIENCE PLAN FOR NASA'S OCEAN BIOLOGY AND BIOGEOCHEMISTRY RESEARCH

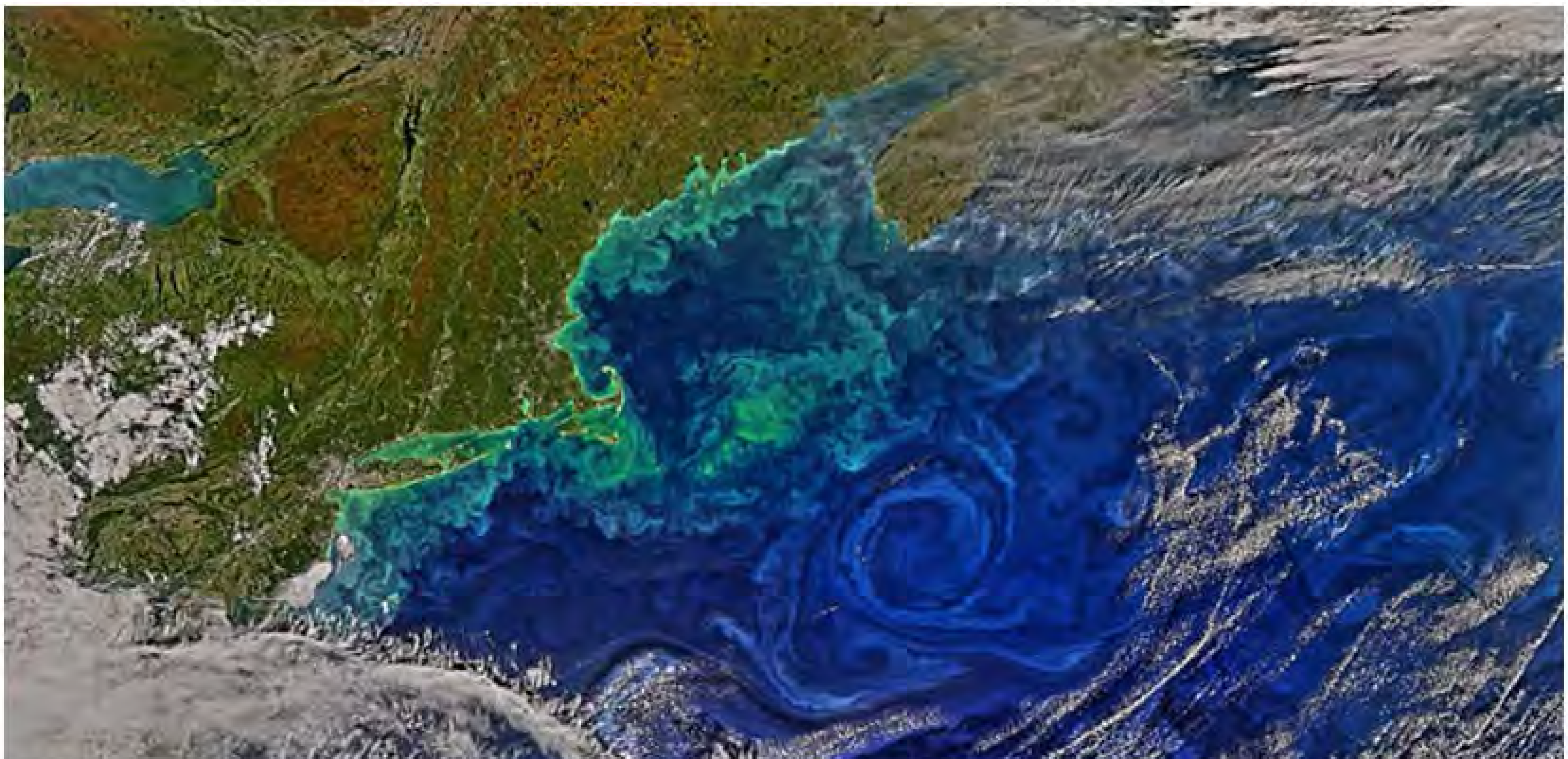


Image: NASA Ocean Biology Processing Group

Working Group

Working Group:

Mike Behrenfeld	Oregon State Univ.
Heidi Dierssen	Univ. of Connecticut
John Dunne	NOAA-Geophysical Fluid Dynamics Lab.
Matthew Long	Univ. Corp. for Atmospheric Research
Antonio Mannino	NASA-Goddard Space Flight Center
Patricia Matrai	Bigelow Lab. for Ocean Sciences
Frank Muller-Karger	Univ. of South Florida
Raymond Najjar	Penn. State Univ.
Anastasia Romanou	Columbia Univ., NASA-Goddard Inst. for Space Science
Cecile S. Rousseaux	NASA-Goddard Space Flight Center
Maria Tzortziou	City Univ. of New York, NASA-Goddard Space Flight Ctr.

OBB Process

- Community Engagement
  - OCB Meeting at WHOI, July 2015
  - ASLO Ocean Sciences New Orleans Town Hall, Feb. 2016
  - Ocean Optics Conference XXIII Victoria, BC, October 2016
- Draft submitted to Overview Committee
  - D. Siegel, S. Doney, M. Roffer, G. McKinley
- Revised version submitted to Overview Committee April 2017
- Posted for public comment:
  - CCE: https://cce.nasa.gov/cce/index.htm
  - OBB: https://cce.nasa.gov/ocean_biology_biogeochemistry/index.html

Dear Reader,

Our Earth is home to over seven billion people. The ocean covers 71% of the Earth's surface, and global Earth-observing satellites allow us to see a view of our Earth and its ocean about every two days. The beauty of our ocean planet is profound and its importance to humanity, our health, and economy is staggering. As of 2010, 80% of the world's population lives within 60 miles of a coast. Fourteen percent of U.S. counties that are adjacent to the coast produce 45 percent of the nation's gross domestic product (GDP), with close to three million jobs (one in 50) directly dependent on the resources of the oceans and the Great Lakes. The Food and Agriculture Organization of the United Nations estimates that fisheries and aquaculture assure the livelihoods of 10-12% of the world's population, with more than 90% of those employed by capture fisheries working in small-scale operations in developing countries. From jobs to food to recreation to regulating climate, the ocean is vital to all life on Earth.

Comparison of our Living Earth to nearby planets exposes a stark contrast to our Earth's habitability. Satellite sensors have revolutionized our perceptions of the ocean environment and our understanding of the linkages among the ocean and other components of the Earth system. Satellite observations have revealed a diversity and complexity in ocean ecosystems that had not been appreciated through traditional oceanographic approaches.

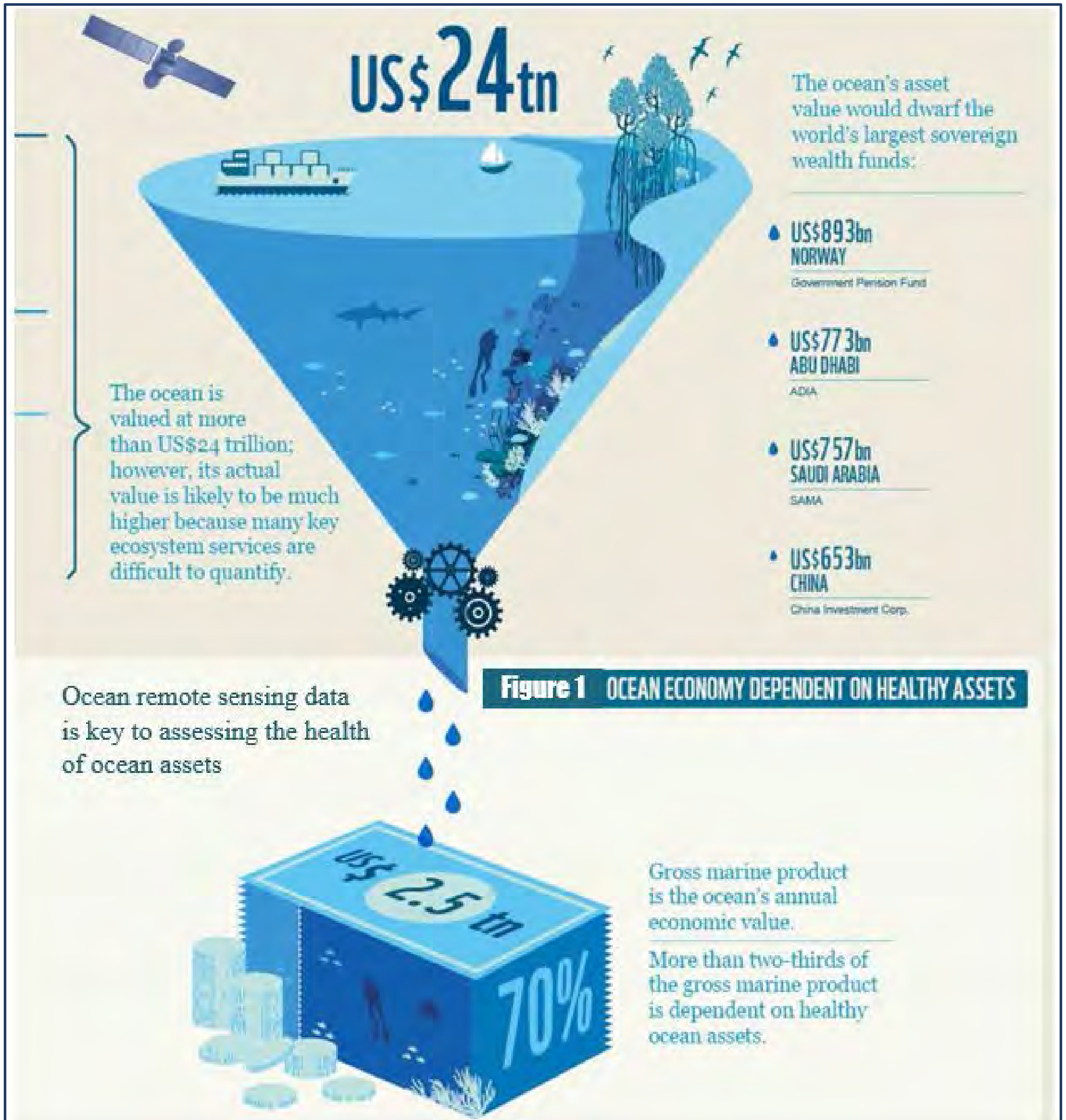
The explosive growth of human populations along coastal margins now places increasing pressure on these dynamic ecosystems, modifying natural processes and, in many cases, putting life, health, and property at risk from hazards inherent to the ocean. Despite this profound realization, the oceans remain largely unexplored, with many discoveries waiting to be made. The past four decades have given us only a brief glimpse of a constantly changing Earth system, in which natural and human factors interplay. We have learned that scientific observations from the vantage point of space help solve important global and regional problems. Advanced technologies and frequent, repeated satellite observations, as well as robust field and laboratory measurements of the ocean are essential to our ability to observe and predict changes.

NASA is leading national and international efforts to define future space technologies and missions. In this spirit, NASA's Ocean Biology and Biogeochemistry (OBB) program scientists engaged the research community in an effort to develop advanced scenarios and strategies to address the important science questions yet to be answered by the program. A working group of experts summarized the state of the science and collected research community comments both electronically and during presentations at a series of national and international meetings.

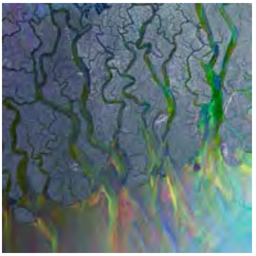
Sincerely,
Paula Bontempi
Chair, Biological Oceanography and Biogeochemistry Working Group (BOBWG)

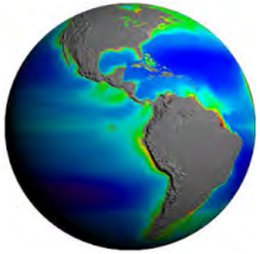
1 Table of Contents

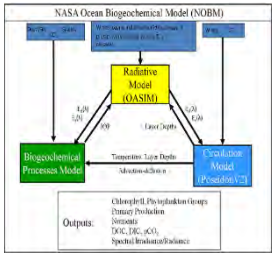
Benefits to the nation

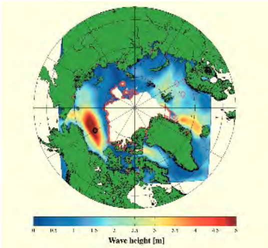


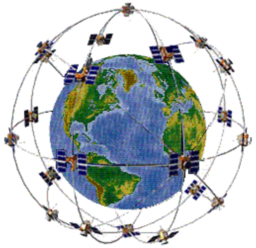
Revised / Updated Science Questions

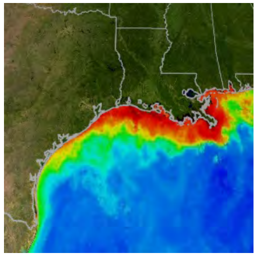








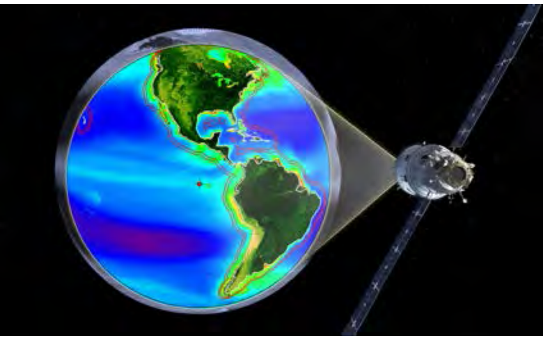


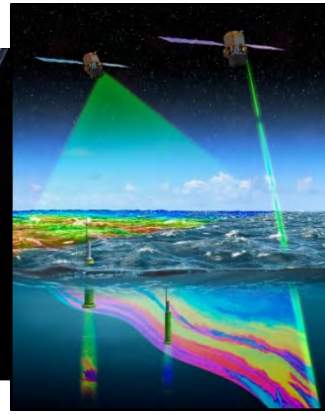


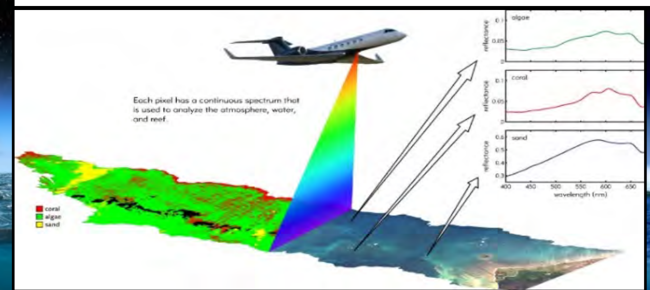
Revised Priority Science Questions

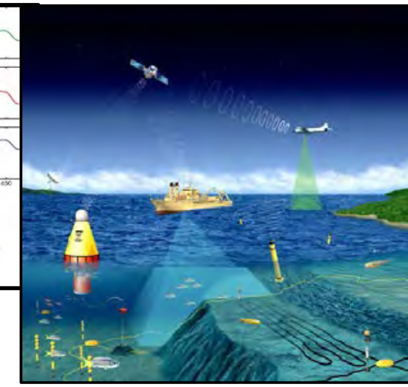
- *What processes drive change in ecosystem structure and biodiversity and how do contemporary changes in these globally expansive ecosystems inform improved management practices, predictions of change, and global ocean stewardship?*
- *How are the diversity, function, and geographical distribution of aquatic boundary habitats changing?*
- *How do carbon and other elements transition into, between and out of ocean pools? What are the quantitative links between ocean biogeochemical cycles and climate?*
- *How can knowledge of the spatial extent, dispersion, intensity, and frequency of transient hazards and natural disasters in the aquatic environment improve forecasting and mitigation?*

Observational Strategies









- **Continuity** of global ocean spectrometry from polar-orbiting Low-Earth Orbit for phytoplankton biodiversity and productivity measurements;
- A global-observing, ocean-focused satellite **Light-detection And Ranging (LIDAR)** to provide information about the vertical structure of particulate matter and phytoplankton physiological state;
- **Imaging spectrometer observations from geostationary platforms** and other orbits or coastal, inland waters and basin-scale high-temporal coverage of changes in carbon stocks, phytoplankton biodiversity, physiology and productivity, and lateral fluxes of aquatic constituents;
- Combined **high spatial, high spectral, high temporal, high signal to noise (H4) observations** for coastal aquatic and wetland habitat and biological diversity assessments;
- **Portable sensors on orbit and suborbital, including assets on or in the water,** for mapping and tracking fine-scale features in aquatic habitats, mid-ocean processes, infrastructure development in coasts and on seabed, and to inform science and responders about transient hazards and natural disasters;
- **Field data and campaigns** to conduct process studies of aquatic ecosystems and for calibration and validation of satellite imagery;
- **Advanced marine ecosystem modeling** (regional and climate modeling) and analysis tools.

Each observational technology is described following:

1. Science questions
2. Platforms
3. Sensors
4. Technology Needs
5. Ancillary Requirements

7 Modeling & Analysis

7.1 Marine ecosystem modeling

Modules for marine ecosystem structure and biodiversity are becoming an important part of ocean numerical models, which are often coupled to atmosphere, sea-ice and land models. These modeling systems are widely used to study climate and climate change impacts on marine physics and biogeochemistry. At finer resolutions, these models are used to address coastal, Great Lakes and estuarine applications, bloom dynamics and ecosystem responses to sea-ice changes and continental runoff inputs. In more simplified versions, numerical models have been used for investigating isolated processes, testing parameterizations such as sinking and settling, remineralization, and absorption and backscattering.

7.2 Data assimilation

As more observational and reanalysis data become available, in addition to improved computational resources and new insight on the importance of specific processes and regions, inverse modeling and new statistical analysis tools have been developed accordingly. These inform the global & regional scale modeling discussed in the previous section, as well as provide operational quality products for better estimation of albedo, phytoplankton distributions and upper ocean heating. Some of the breakthroughs in this area of research are described below.

7.3 Advanced statistical analysis techniques

7.3.1 Biomes

Defining coherent regions of the marine environment by common functional characteristics is a major challenge in oceanography. Since it is impossible to make comprehensive direct observations of the environment, an ability to define oceanographic regions with common functional characteristics enables scaling of limited observations. There are two approaches to biome definitions that are useful. The first and most standard is to define and apply threshold criteria to a

8 EDUCATION/PUBLIC OUTREACH

Breathtaking views of Earth, the Water Planet, from space have captivated the imaginations of people around the world and increased awareness of both the beauty and the fragility of our planet. Satellite images of the global ocean have allowed us to explore the ecology, biogeochemistry and hazards of previously uncharted waters, revealed the coupling between physics and biology, the constant exchanges between the land and the ocean, as well as the complex interactions and feedbacks between Earth systems and human societies. These images of the Earth's ocean not only result in new knowledge and discoveries, but provide valuable assets to engage public audiences, inform decisions, inspire students, and encourage the pursuit of science, technology, engineering, and math (STEM) studies.

9 PARTNERSHIPS

The NASA OBB program will continue to engage the national and international basic and applied science communities to address a number of objectives. Specifically, coordination with the Committee on Earth Observation Satellites (CEOS) is critical to cooperate in the provision of launch services and observing technologies; in particular, the possibility of merging data from different sensors and establish virtual observing constellations is unique. Coordination with the International Ocean-Colour Coordinating Group (IOCCG) will continue to promote the development and application of ocean-color data, and develop community consensus on radiometry (OCR) and products. These collaborations will ensure that necessary data streams for observational and forecasting systems are sustained, and that the international community can develop and advance priority science questions, pursue partnerships in space-based sensor development and measurement capabilities, and synergize field collection and processing, including vicarious calibration and data product validation activities.

SIGNIFICANCE OF PACE

The NASA **Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission** scheduled to launch in the next decade will provide unparalleled global, space-based hyperspectral measurements of water leaving radiances and associated aerosol and cloud information. Precise measurements in the short-wave infrared wavelengths also will enable advanced methods to remove atmospheric effects as required to yield highly accurate observations of the ocean surface. The PACE Mission will continue a climate data record of high quality ocean color measurements that is still less than two decades in length. PACE represents a major breakthrough in our ability to understand and model global ocean biogeochemical cycles, climate, and trophic interactions. It will provide a hyperspectral dimension to detect absorption, scattering, and fluorescence properties of our global ocean observations that will ideally be continued into future operational climate quality monitoring of ocean color. And, as outlined below, it has many other applications that will benefit the nation.

PACE Ocean Color data will be vital for…

Ecosystem and Human Health

- Fisheries management
- Detection of harmful algal blooms (HABs)
- Monitoring of sea ice extent and passages
- Mapping of currents /applications to shipping industry, scheduling/fuel economy strategies
- Search And Rescue Satellite Aided Tracking
- Improved models of pathogens, bacteria

Climate System

- Mapping/assessment of C sources/fluxes
- Improvement of climate models skills
- Ecosystem vulnerability assessments
- Support for policy analyses, development of climate change adaptation strategies

Disasters

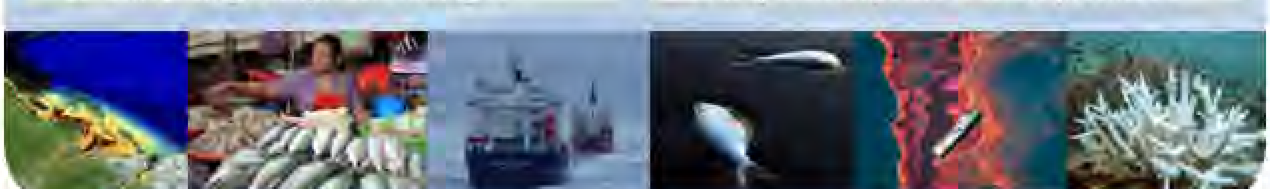
- Impacts of storms and hurricanes
- Oil-spills and seeps
- Flood disaster response.

Water Resources & Quality

- Water quality monitoring, eutrophication, hypoxic/anoxic conditions
- Management of water resources in lakes, coastal areas, open oceans

Ecological Forecasting

- Forecasting and early warnings of HABs
- Forecasting of endangered species
- Ecosystem response to future pressures



DSCOVR: EPIC

Earth Polychromatic Imaging Camera

I will miss you Chuck