Response to the 2017 NRC Decadal Survey Request for Information regarding the OCEAN ECOSYSTEM and OCEAN-AEROSOL INTERACTIONS components of the Aerosol, Cloud, and ocean Ecosystem (ACE) Mission

Lead authors on behalf of ACE science team: Michael Behrenfeld & Nicholas Meskhidze

Context: The 2007 NRC Decadal Survey Report identified the Aerosol, Cloud, and Ecosystem (ACE) mission as an essential Tier 2 mission addressing global and interdisciplinary science challenges associated with climate, marine ecology, and biogeochemistry. *The philosophy underlying of the ACE Mission is that aerosol, cloud, and ecosystem elements of the Earth System are fundamentally linked from both a mechanistic and observational standpoint*. For example, (1) polarimetry measurements of atmospheric properties over the ocean require accurate knowledge of marine ecosystem properties, (2) ocean color retrievals require accurate knowledge of atmospheric aerosol loads and vertical distributions, (3) understanding of aerosol and cloud properties over remote marine atmospheres is critically informed by simultaneous observations of ocean ecosystem properties and states, and (4) simultaneous measurements of aerosols and clouds are essential for addressing dominant climate change uncertainties associated with Earth's changing energy budget. Recognition of these and many other observational interdependencies and the opportunity to address diverse Earth System issues with a single set of consistent satellite sensors established the ACE mission as *the premier* global climate and ecosystem mission of the 2007 Decadal Survey Report. The scientific and applications need for this mission has only increased since its original recommendation.

As detailed in the Mission's Five Year Report, the ACE pre-formulation phase made (and continues to make) major progress toward refining mission requirements and establishing instrument technical readiness. For each of its primary elements, overarching science questions have been defined and linked to mission requirements though a detailed Science Traceability Matrix (STM) involving remote sensing, field, and modeling requirements. Together, the science and applications targets identified in these ACE STMs are cross-cutting among four of the Earth System Science themes identified in the second 2017 Decadal Survey Request for Information (DS-RFI2):

I. Global Hydrological Cycles and Water Resources
II. Weather and Air Quality
III. Marine Ecosystems and Natural Resource Management
IV. Climate Variability and Change

Satellite remote sensing envisioned for ACE combines active and passive sensors observing at microwave, sub-millimeter, infrared, visible and ultraviolet wavelengths and flown on multiple platforms in a coordinated sun-synchronous low-Earth orbit. The *Key Challenges and Questions for Earth System Science* addressed by the ACE mission were overviewed in a previous white paper submitted in response to the first DS-RFI (da Silva et al 2015). In response to the current DS-RFI2, we here describe science and applications targets for the Ocean Ecosystem and Aerosol-Ocean Interactions components of the ACE Mission. Three additional ACE white papers are being submitted in response to DS-RFI2 that similarly detail science and applications targets for ACE cloud and aerosol components.

1. ACE Ocean Ecosystems Element

1.1 *Science and Applications Targets*

The science and applications targets for the Ocean Ecosystem component of the ACE mission are defined by the 6 groups of overarching Focused Questions in the second column of the ACE Ocean Ecosystem STM (**Figure 1**). These Focused Questions (FQ) are:

FQ1. *What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing?* [OBB1]

FQ2. *How and why are ocean biogeochemical cycles changing? How do they influence the Earth system?* [OBB2]

FQ3. *What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing?* [OBB1,2,3]

FQ4. *How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system?* [OBB2]

FQ5. *How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics?* [OBB1,2]

FQ6. *What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing?* [OBB1,4]

Each FQ group traces directly to one or more of the four broader science objectives of NASA's Ocean Biology and Biogeochemistry Program's Strategic Plan, "*Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program*" (NASA OBB 2006), as indicated above by the bracketed [OBBx] designations. In the ACE Ocean Ecosystem STM (**Figure 1**), key activities (column 3: Approach) are identified to address FQ1 through FQ6 and then observational and modeling requirements are defined that enable these activities (4 rightmost columns). A complete description of the traceability between Focused Questions, Approaches, and Measurement/Modeling Requirements can be found in the ACE Mission document, (Starr et al. 2010). This recommended plan for the Ocean Ecosystem component of the ACE Mission has been scrutinized and evolved over many years by a diverse ACE Ocean Ecosystem Science Team and regularly vetted with the broad Earth Science Community. The ACE Ocean Ecosystem science objectives (FQ1-6) address primary uncertainties in marine ecosystem functioning, biodiversity, ecosystem health and services, and biogeochemistry (DS-RFI2 theme **Marine Ecosystems & Natural Resource Management**) and climate forcings and feedbacks of the ocean (DS-RFI2 theme **Climate Variability and Change**).

1.1 *Utility of Measured Geophysical Variables*

The ACE Ocean Ecosystem Science Team, in consultation with the broader Earth Science Community, identified 3 key satellite observational assets required for accomplishing mission science and applications targets: an advanced ocean color sensor, polarimeter, and lidar.

<u>Utility of the Ocean Color Sensor</u>: The ACE recommendation is for a UV-VIS-NIR-SWIR polar-orbiting ocean color sensor with 5 nm spectral resolution from 350 – 755 nm, 2-day global

coverage, 1000 – 1500 minimum SNR for 15 nm aggregate UV – VIS bands, glint avoidance, and minimal sensor artifacts (**Figure 1**). This instrument provides essential global retrievals on surface layer (to ~1 optical depth) (1) phytoplankton biomass, pigment concentrations, physiology, and taxonomic diversity, (2) particle abundance and size distribution, (3) concentrations of dissolved carbon pools, and (4) materials exchange at the land ocean interface. Multi-year sustained measurements from the ACE ocean color sensor allow assessment of ecosystem-climate interactions and forcings and consequences on biogeochemistry, atmospheric aerosols and clouds, and ecological events (e.g., frequency and distribution of harmful algal blooms). Importantly, details on the ACE ocean color sensor requirements and science objectives were fundamental to the Science Definition Team for developing requirements for the NASA PACE Mission ocean color sensor, which has a targeted launch date of 2022/2023.

Utility of the Polarimeter: For Ocean Ecosystem applications, the ACE polarimeter addresses two primary objectives: (1) improve atmospheric corrections for ocean color retrievals by characterizing of aerosol properties and (2) improve understanding of ocean ecosystems stocks and biogeochemistry by characterizing particle types through measurements of subsurface polarized water leaving radiance returns. For these objectives, requirements for the polarimeter include 60^{o} to 140^{o} observational angles at 5^{o} resolution and 1% degree of polarization (**Figure 1**). A more detailed set of requirements for the ACE polarimeter was defined by the cloud and aerosol components of the mission and are described below and in the other ACE white papers being submitted to the DS-RFI2. The ACE concept of coupling polarimetric observations with ocean color measurements was again instrumental in the same pairing being recommended for the upcoming PACE mission.

Utility and Readiness of the Lidar: **Ocean color and polarimetry measurement requirements defined for the PACE mission satisfy those for the Ocean Ecology component of the ACE mission. However, the essential element of ACE Ocean Ecosystem requirements not fulfilled by PACE is simultaneous measurements with a profiling lidar**. Inclusion of a lidar in the ACE instrument suite is essential. The lidar 'curtain' measurements of detailed atmospheric aerosol type and vertical distributions, when coupled with the broad swath polarimeter and ocean color UV-to-NIR/SWIR measurements, addresses the primary uncertainties in current atmospheric correction algorithms for ocean color retrievals. Furthermore, active lidar measurements of ocean subsurface properties allow:

(1) *Characterization of high latitude plankton populations (phytoplankton biomass and total particulate carbon) throughout the year*. High latitude regions host among the most productive ocean ecosystems on Earth and are also experiencing the most rapid climate-driven changes in environmental conditions. These regions are also among the most poorly observed by traditional ocean color sensors, often with no successful retrievals for many consecutive months.

(2) *Global characterization of vertical structure in ecosystem properties (biomass, particle abundance, light attenuation)*. Traditional ocean color measurements provide no information on the vertical structure in the marine environment. Consequently, unresolved vertical features remain one of the primary sources of uncertainty in plankton biomass assessments and, when these features occur within the upper ~3 optical depths, in ocean productivity assessments.

Since the 2007 NRC Decadal Survey Report, major advances have been made in demonstrating the feasibility and utility of lidar profiling of ocean ecosystems. In particular, the Azores 2012, SABOR 2014, and NAAMES 2015 field campaigns have demonstrated accurate, vertically-resolved retrievals of ocean optical properties with an airborne high spectral resolution lidar (HSRL). In addition, phytoplankton biomass, total particulate carbon concentrations, and diffuse attenuation coefficient retrievals have now been demonstrated using the CALIOP satellite lidar and, for the Azores 2012, validated with coincident ship-based measurements. CALIOP data have subsequently been used to demonstrate effective retrieval of complete phytoplankton annual cycles at northern and southern polar latitudes, which has been impossible with ocean color sensors. The CALIOP lidar, however, was not designed for ocean retrievals and has a sampling resolution that does not allow profiling of ocean ecosystem vertical structure. For ACE Ocean Ecosystem science and applications targets, an HSRL lidar is recommended with 0.5 km atmospheric and 2 m subsurface vertical resolution, <0.3% polarization misalignment, 0.0001 km^{-1} sr^{-1} aerosol backscatter sensitivity, and < 4 ns e-folding transient response (**Figure 1**).

1.3 *Summary Recommendation for the 2017 Decadal Survey*

Years of community-vetted planning for the ACE mission has resulted in a detailed plan for addressing primary science and applications targets for global ocean ecosystem research. Recommended ocean color and polarimeter components of the ACE mission for Ocean Ecosystem goals can be met by the PACE mission. However, **the absence of an ocean-atmosphere profiling lidar on PACE is viewed as a critical omission**. Major advances have been made in demonstrating the feasibility and utility of ocean lidar measurements since the 2007 DS report. Airborne HSRL technology is highly mature and discussions are currently underway for potential international collaboration with CNES on a lidar mission that could satisfy science requirements defined under the ACE mission. *We therefore recommend that the 2017 DS report strongly advocate the elevation of an ocean-atmosphere profiling lidar as a tier 1 mission flown in constellation with PACE.*

2. ACE Aerosol-Ocean Element

2.1 *Science and Applications Targets*

The science and applications targets for the Aerosol-Ocean component of the ACE mission are defined by the 6 groups of overarching Focused Questions in the second column of the ACE Aerosol-Ocean STM (**Figure 2**). These Focused Questions (FQ) are:

FQ1. *What is the flux of aerosols to the ocean and their temporal and spatial distribution?*

FQ2. *What are the physical and chemical characteristics, sources, and strengths of aerosols deposited into the oceans?*

FQ3. *How are the physical and chemical characteristics of deposited aerosols transformed in the atmosphere?*

FQ4. *How do ocean ecosystems respond to aerosol deposition?*

FQ5. *What is the spatial and temporal distribution of aerosols and gases emitted from the ocean and how are these fluxes regulated by ocean ecosystems?*

FQ6. *What are the feedbacks among ocean emissions of aerosols and gases, microphysical and radiative properties of the overlying aerosols and clouds, aerosol deposition,* *ocean ecosystems and the Earth's climate, and how is humankind changing these feedbacks?*

Each FQ group traces to NASA's Earth Science questions and research objectives recommended by the NRCs first decadal survey for Earth science, "*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*" (NRC, 2007). In the ACE Aerosol-Ocean STM (**Figure 2**), key activities (column 3: Approach) are identified to address FQ1 through FQ6 and then supporting field and laboratory observations and modeling requirements are defined that enable these activities (4 rightmost columns). A complete description of the traceability between Focused Questions, Approaches, and Measurement/Modeling requirements can be found in the ACE Mission document (Starr et al. 2010). This recommended plan for the Aerosol-Ocean component of the ACE Mission has been thoroughly scrutinized and evolved over many years of science team meetings and weekly teleconferences by a diverse ACE Aerosol-Ocean Team. The ACE Aerosol-Ocean science objectives (FQ1-6) are highly synergistic to ACE Ocean Ecosystems Element and address mutually interacting processes – *atmosphere to ocean interactions, marine biology to atmosphere interactions, aeolian fertilization of the oceans, release to the atmosphere of highly reactive trace gases by the marine ecosystem* – all of which have key effects on microphysical properties of maritime clouds. The detailed mechanisms for aerosol-ocean interaction processes and there radiative feedbacks in the Earth climate system are best understood through the combination of in situ data, satellite remote sensing and models. However, **to reduce the uncertainty about cloud-aerosol interactions over the ocean and thus improve climate prediction models, measurements of ocean ecosystem, aerosol, and cloud properties achievable with the Ocean Color Sensor, Polarimeter, High Spectral Resolution Lidar described above should be paralleled by simultaneous measurements of drizzle and precipitation rates with a Duel-frequency Doppler Radar (DfDR).** Specific measurement requirements for this DfDR are described in the Aerosol and Cloud white papers also being submitted in response to the DS-RFI2.

2.2 *Summary Recommendation for the 2017 Decadal Survey*

Over the past decade, in situ measurements, satellite remote sensing, and modeling efforts have substantially improved our understanding of the temporal and spatial distribution of aerosols and trace gases, their physical and chemical characteristics and controlling effects on ocean biological systems. However, past research has also revealed inherent complexity of aerosol-ocean ecosystems-cloud interactions with multiple forcings and feedbacks. Narrowing the gap in the current understanding of anthropogenic and natural contribution to a changing climate will require development of new space-based, field, laboratory instruments and modeling capabilities. This should include execution of focused field studies examining the aerosol fluxes to and from the ocean and subsequent changes to marine ecosystems in various oceanic regimes around the globe. By expanding available satellite-borne sensors to encompass aerosol forcing of ocean biological systems and cloud processes, major improvements can be realized in model representations of current climate, reproductions of past climate, and predictions of future climate. However, realizing this advances critically depends upon more realistic, observation-driven simulations of the aerosol-ocean and ecosystems-cloud system, with forcings and feedbacks operating on multiple spatiotemporal scales. *We therefore recommend that the 2017 DS report strongly advocate as a tier 1 mission a constellation of the PACE ocean color and polarimeter sensors with and HSRL lidar and duel-frequency doppler radar.*

References:

da Silva, A., Behrenfeld, M.J., Ferrare, R., Mace, G. 2015. The interdisciplinary science of the Aerosol-Cloud-Ecosystem (ACE) mission. *Response to the Decadal Survey RFI#1*.

NASA Ocean Biology and Biogeochemistry Program (OBB). 2006. Earth's Living Ocean: 'The Unseen World', An advanced plan for NASA'S Ocean Biology and Biogeochemistry Research.

NRC, 2007: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. National Academies Press, 428 pp.

Starr, D., et al. 2010. Aerosol, cloud and ecosytems (ACE) proposed satellite mission. A report to NASA HQ. See: http://acemission.gsfc.nasa.gov/documents/Draft_ACE_Report2010%20.pdf

Figure 1: ACE Ocean Ecosystem science traceability matrix (STM) linking focused science questions to observational and modeling requirements.

Category	Focused Questions*	Approach	Maps to Science Question
Ocean Biology	1 What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1]	Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), and productivity using bio-optical models & chlorophyll fluorescence	1, 2, 6
	2 How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2]	Measure particulate and dissolved carbon pools, their characteristics and optical properties	2, 3
		Quantify ocean photobiochemical & photobiological processes	2, 4
	3 What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing? [OBB1,2,3]	Estimate particle abundance, size distribution (PSD), & characteristics	1, 3, 2
		Assimilate ACE observations in ocean biogeochemical model fields of key properties (cf., air-sea CO_2 fluxes, export, pH, etc.)	2
	4 How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system? [OBB2]	Compare ACE observations with ground-based and model data of biological properties, land-ocean exchange in the coastal zone, physical properties (e.g., winds, SST, SSH, etc), and circulation (ML dynamics, horizontal divergence, etc)	3, 4, 5, 6
	5 How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1,2]	Combine ACE ocean & atmosphere observations with models to evaluate (1) air-sea exchange of particulates, dissolved materials, and gases and (2) impacts on aerosol & cloud properties	4
		Assess ocean radiant heating and feedbacks	5
	6 What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]	Conduct field sea-truth measurements and modeling to validate retrievals from the pelagic to near-shore environments	1, 4, 2, 5, 3, 6

Measurement Requirements	Instrument	Instrument Requirements
Water-leaving radiances in near-ultraviolet, visible, & near-infrared for separation of absorbing & scattering constituents and calculation of chlorophyll fluorescence Total radiances in UV, NIR, and SWIR for atmospheric corrections Cloud radiances for assessing instrument stray light	**Ocean Radiometer**	• 5 nm resolution 350 to 755 nm ▷ 1000 – 1500 SNR for 15 nm aggregate bands UV & visible and 10 nm fluorescence bands (665, 678, 710, 748 nm centers) ▷ 10 to 40 nm width atmospheric correction bands at 748, 765, 820, 865, 1245, 1640, 2135 nm • 0.1% radiometric temporal stability (1 month demonstrated prelaunch) • 58.3° cross track scanning • Sensor tilt (±20°) for glint avoidance • Polarization insensitive (<1.0%) • 1 km spatial resolution @ nadir • No saturation in UV to NIR bands • 5 year minimum design lifetime
High vertical resolution aerosol heights, optical thickness, & composition for atmospheric corrections Subsurface particle scattering & depth profile	**Lidar**	• 0.5 km aerosol vertical resolution • 2 m sub-surface resolution • < 0.3% polarization misalignment • 0.0001 $km^{-1}sr^{-1}$ aerosol backscatter sensitivity at 532 nm after averaging • < 4 ns e-folding transient response • Brillouin scattering capability; Receiver FOVs: 0-60 m; 0-120 m.
Broad spatial coverage aerosol heights and single scatter albedo for atmospheric correction. Subsurface polarized return for typing oceanic particles	**Polarimeter**	• Observation angles: 60° to 140° • Angle resolution: 5° • Degree of polarization: 1%

Supporting Field & Laboratory Measurements
- Primary production (NPP) measurement & round-robin algorithm testing
- Inherent optical properties (IOPs) instrument & protocols development, laboratory & field (coastal and open ocean) measurement comparisons
- Measure key phytoplankton groups across ocean biomes (coast/open ocean)
- Expanded global data sets of NPP, CDOM, DOM, pCO2, PSDs, IOPs, fluorescence, vertical organic particle fluxes, bio-available Fe concentrations

Ocean Biogeochemistry-Ecosystem Modeling
- Expand model capabilities to assimilate variables such as NPP, IOPs, and phytoplankton species/functional group concentrations.
- Improve model process parameterizations, e.g., particle fluxes

Platform Requir'ts	Other Needs
Orbit permitting 2-day global coverage of ocean radiometer measurements Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m. Storage and download of full spectral and spatial data Monthly lunar calibration at 7° phase angle through Earth observing port	Global data sets from missions, models, or field observations: *Measurement Requirements* (1) Ozone (2) Total water vapor (3) Surface wind velocity (4) Surface barometric pressure (5) NO_2 concentration (6) Vicarious calibration & validation** (7) Full prelaunch characterization (2% accuracy radiometric) *Science Requirements* (1) SST (2) SSH (3) PAR (4) UV (5) MLD (6) CO_2 (7) pH (8) Ocean circulation (9) Aerosol deposition (10) run-off loading in coastal zone

* ACE focused questions are traceable to the four overarching science questions of NASA's Ocean Biology and Biogeochemistry Program [OBB1 to OBB4] as defined in the document: *Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program* (under NRC review)

** See ACE Ocean Ecosystem white paper for specific vicarious calibration & validation requirements

Figure 2: ACE Aerosol-Ocean Interactions science traceability matrix (STM) linking focused science questions to observational and modeling requirements.

Category	Focused Questions	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
Aerosol -Ocean Inter-action	1 What is the flux of aerosols to the ocean and their temporal and spatial distribution	1) Identify microphysical and optical properties of aerosols, partition natural and anthropogenic sources, and characterize spectral complex index of refraction and particle size distribution	2 3 6	**Satellite** • Radiances & polarization at selected UV, visible and SWIR bands for aerosol types (dust, smoke, etc.), complex index of refraction, effective height, optical thickness, and size distribution with 2-day global coverage to resolve temporal evolution of plumes • Active (lidar) measurements of aerosol properties along orbit track to refine height distribution and composition • Drizzle detection and precipitation rates coincident with lidar & polarimeter data • Global phytoplankton pigment absorption, dissolved organics absorption, total & phytoplankton carbon concentration, ocean particle size distribution, phytoplankton fluorescence, Chl:C, and growth rate • Particle scattering & vertical distribution through active (lidar) subsurface returns	**Spectrometer** • requirements as stated in ocean STM **Polarimeter** • requirements as stated in aerosol STM **Lidar** • requirements as in ocean STM **Duel frequency Doppler radar** • requirements as stated in cloud STM	Orbit permitting 2-day global coverage for passive radiometer & polarimeter measurements Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m. Storage and download of full spectral and spatial data Monthly lunar calibration at 7º phase angle through Earth observing port Additional platform requirements for polarimeter, lidar and radar as detailed in Ocean, Aerosol, and Cloud STMs	**Supporting Global data** • Humidity profiles • Precipitation • Formaldehyde • Glyoxal • IO • BrO • NO_2 • SO_2 **Other Data** •Ground-based aerosol observational network
	2 What are the physical and chemical characteristics, sources, and strengths of aerosols deposited into the oceans?	2) Characterize dust aerosols, their column mass, iron content and other trace elements, and their regional-to-global scale transport and flux from events to the annual cycle	1 2				
	3 How are the physical and chemical characteristics of deposited aerosols transformed in the atmosphere?	3) Conduct appropriate field observations to validate satellite retrievals of aerosols and ocean ecosystem features	1 5				
	4 How do ocean ecosystems respond to aerosol deposition?	4) Use ACE space and field observations to constrain models to evaluate (1) aerosol chemical transformations and long range transport, (2) air-to-sea and sea-to-air exchange and (3) impacts on ocean biology	2 5 6				
	5 What is the spatial and temporal distribution of aerosols and gases emitted from the ocean and how are these fluxes regulated by ocean ecosystems?	5) Characterize aerosol chemical composition and transformation during transport (including influences of vertically distributed NO_2, SO_2, formaldehyde, glyoxal, IO, BrO) and partition gas-derived and mechanically-derived contributions to total aerosol column	2 3 5	**Supporting Field & Laboratory Measurements** • Dust chemical properties/solubility/ chemical transformation • Aerosol optical properties, heights, chemical composition, and partitioning of gas-derived and mechanically-derived contributions to total column load • DMS flux and dissolved concentration and precursors • Atmospheric boundary layer trace gases, NO_2 / SO_2 height distribution • Diffuse irradiance and in-water optics • Surface layer plankton species, phytoplankton carbon, fluorescence • observational network representative of global range in properties • process/mechanism oriented field and laboratory studies • sustain time series field measurements of key properties over active lifetime of mission			
	6 What are the feedbacks among ocean emissions of aerosols and gases, microphysical and radiative properties of the overlying aerosols and clouds, aerosol deposition, ocean ecosystems and the Earth's climate, and how is humankind changing these feedbacks?	6) Monitor global phytoplankton biomass, pigments, taxonomic groups, productivity, Chl:C, and fluorescence; measure and distinguish ocean particle pools and colored dissolved organic material; quantify aerosol-relevant surface ocean photobiological and photobiochemical processes	4 5 6				
		7) Relate changes in ocean biology/emissions to aerosol deposition patterns and events	3 5 4	**Modeling** • Conduct model tracer studies to determine sources, composition, and chemical attributes of aerosols • Model height distribution of NO_2 & SO_2 and dust chemistry • Use satellite data to constrain model aerosol source strengths • Model air-sea exchange rates and temporal variability, including sources of aerosols to atmosphere • Run coupled ocean biogeochemistry model to assess impacts and compare to observed response of ocean ecosystems			
		8) Demonstrate influences of ocean taxonomy, physiological stress, and photochemistry on cloud/aerosol properties, including organic aerosol transfer	1 2 3				