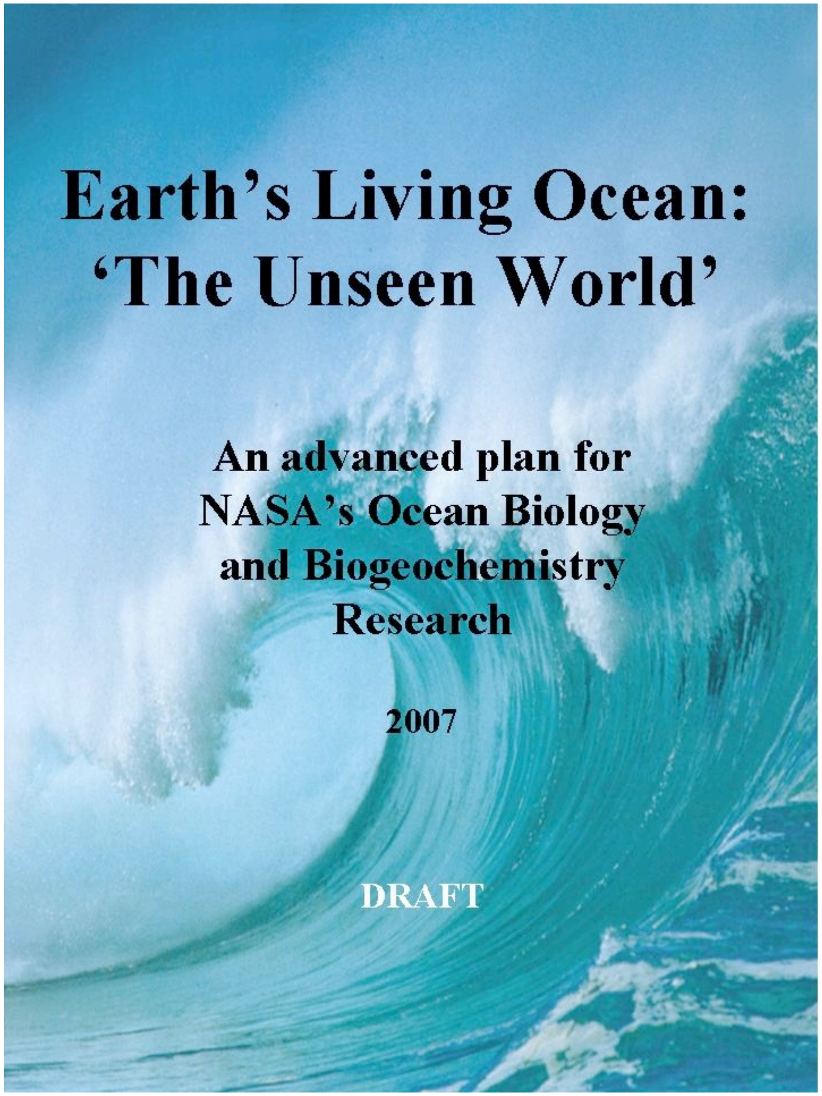
Overview & Status of The Decadal Survey Aerosol-Cloud-Ecology (ACE) Mission

Ocean Color Research Team Mtg.
May 4, 2009

Chuck McClain
ACE Ocean Team Leader

Community Plan for NASA Ocean Biology & Biogeochemistry Program



- A plan for the NASA OBB program
- <u>Science</u> to <u>Requirements</u> to <u>Strategies</u> to <u>Missions</u>
- Community plan
- Intended as a "living document"
- Under NRC review
  - Draft statement of task completed
  - NASA, NOAA, NSF, ONR

The 4 NASA OBB Questions

(1) How are ocean **ecosystems** and the **biodiversity** they support influenced by climate and environmental variability and change, and how will these changes occur over time?

(2) How do carbon and other elements transition between ocean pools and pass through the Earth System, and how do **biogeochemical fluxes** impact the ocean and Earth's climate over time?

(3) How (and why) is the diversity and geographical distribution of **coastal marine habitats** changing, and what are the implications for the well-being of human society?

(4) How do **hazards and pollutants** impact the hydrography and biology of the coastal zone? How do they affect us, and can we mitigate their effects?

Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program (under NRC review - draft at http://www.icess.ucsb.edu/~davey/TRANSFER/OBB_plan_OCRT2007.ppt)

Climate Data Records

- CDRs drive sensor stability and derived product accuracy requirements
- Ocean Products
  - **Normalized water-leaving radiances**
  - **Chlorophyll-a** & other plant pigment concentrations
  - Primary production
  - Inherent optical properties (IOPs; spectral absorption & scattering coefficients)
  - Particulate organic carbon concentration (POC)
  - Colored dissolved organic matter (CDOM)
  - Calcite concentration
  - *Functional group distributions*
  - *Particle size distributions*

Current OBB CDRs

Additional "current" products: limited validation data

Future products

- Ocean-Aerosol Products TBD
- In situ observation requirements being addressed by the NASA Calibration & Validation Office (separate presentation by Stan Hooker)
  - Includes on-orbit "vicarious" calibration
  - Includes improved instrumentation & protocols for expanded CDR suite

ACE Science Objectives

ACE is a aerosol-cloud and ocean ecosystem mission

"… to reduce the uncertainty in climate forcing in aerosol-cloud interactions and ocean ecosystem CO2 uptake" - **Decadal Survey pg 4-4**

Aerosol-cloud component science objectives are to:

1. decrease the uncertainty in aerosol forcing as a component in climate change
2. quantify the role of aerosols in cloud formation, alteration of cloud properties and changes in precipitation.

Ocean ecosystem goals are to:

1. characterize and quantify changes in the ocean biosphere
2. quantify the amount of dissolved organic matter, carbon, and other biogeochemical species to define the role of the oceans in the carbon cycle (e.g., uptake and storage).

The ocean ecosystem imager needs aerosol measurements to optimize their retrievals which is an important reason for the combined payloads.

ACE Sensor Suite

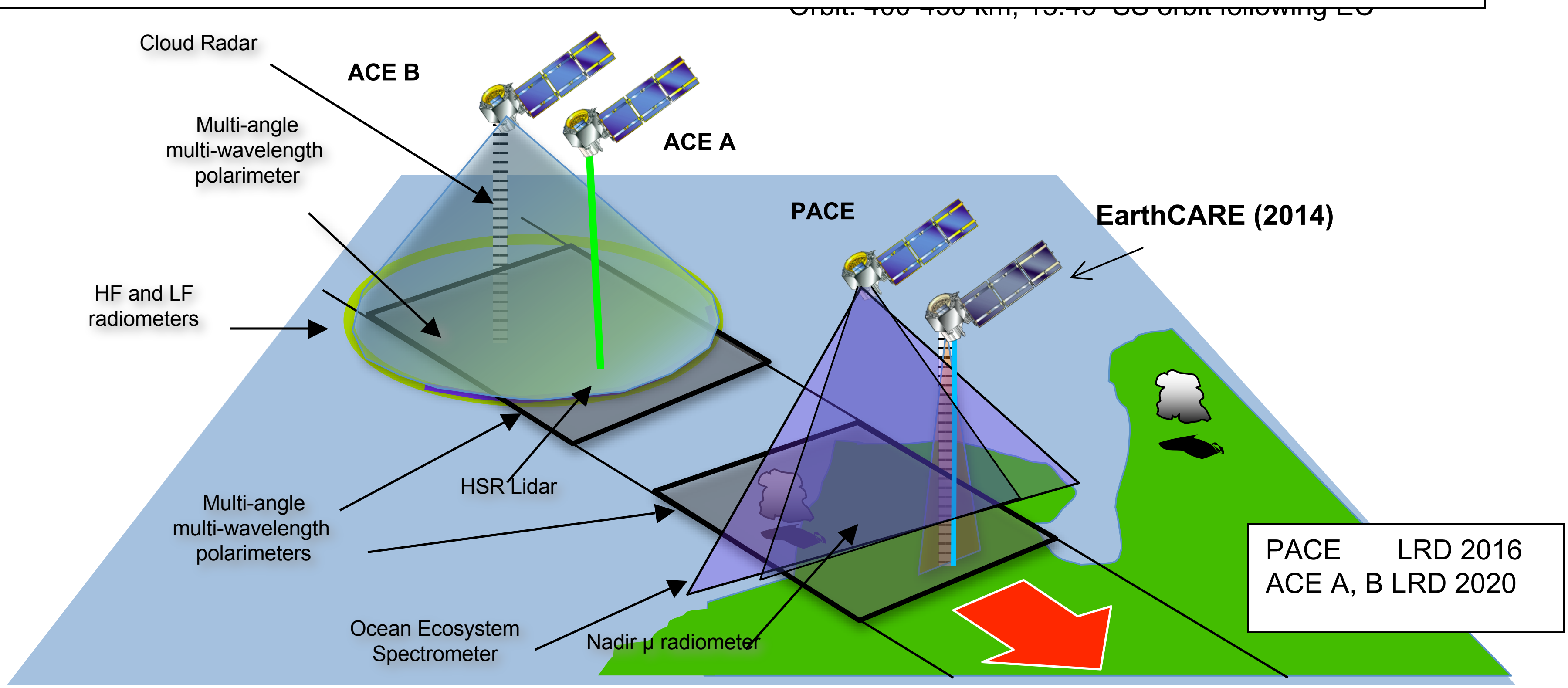
ACE Payload currently considers the following instrument candidates:

1. **Lidar** for assessing aerosol/cloud heights and aerosol properties. (TRL 4-6)
2. Dual frequency **cloud radar** for cloud properties and precipitation (TRL 4-6)
3. Multi-angle, swath **polarimeter** for imaging aerosol and clouds (TRL 4-6)
4. **Ocean color radiometer** for ocean ecosystems (TRL 5)
5. IR imager for cloud temperatures and heights (TRL 6)
6. High frequency microwave radiometer for cloud ice measurements (TRL 6)
7. Low frequency microwave radiometer for precipitation measurements (TRL 8)
8. Microwave temperature/humidity sounder (ATMS, TRL 9)

It is anticipated that all instruments will be openly competed.
The payload may require more than one spacecraft.

Instruments in underlined gray were mentioned in the NAS DS ACE description. The Science Working Group considers these overguide instruments critical to the mission.

Notional ACE+PACE : Observing Geometry



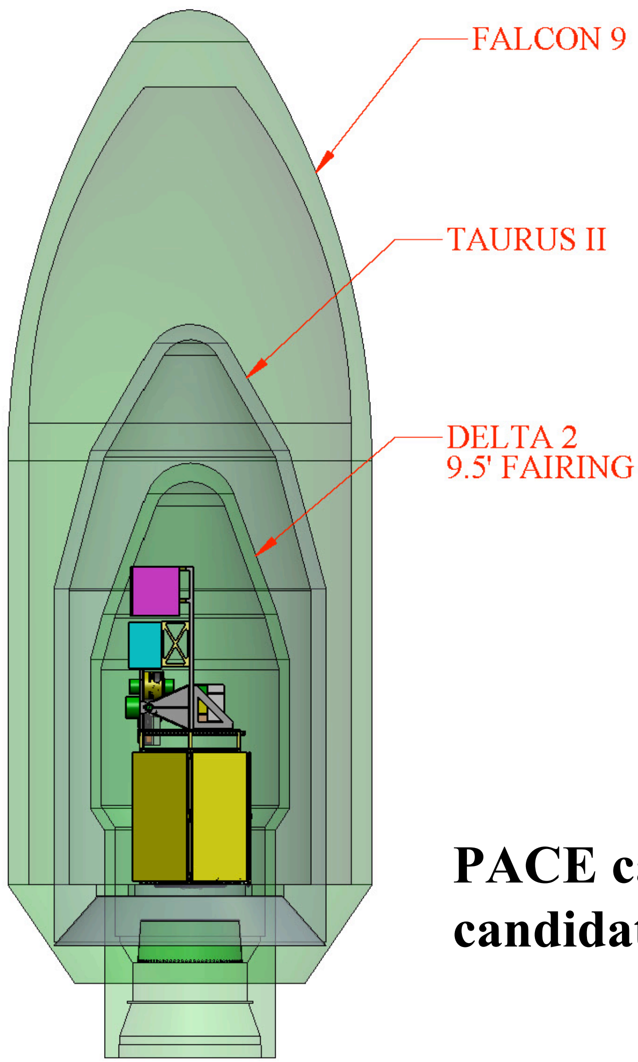
PACE - launches in 2016 with a polarimeter and the Ocean Ecosystem Spectrometer (OES), polarimeter, and nadir μ- wave radiometer (ATMS). PACE flies behind EarthCARE augmenting EC observations. The rest of ACE launches in ~2020. This configuration provides 8-10 years of measurements and continuity with EC. The PACE polarimeter and bus might be an international contribution.

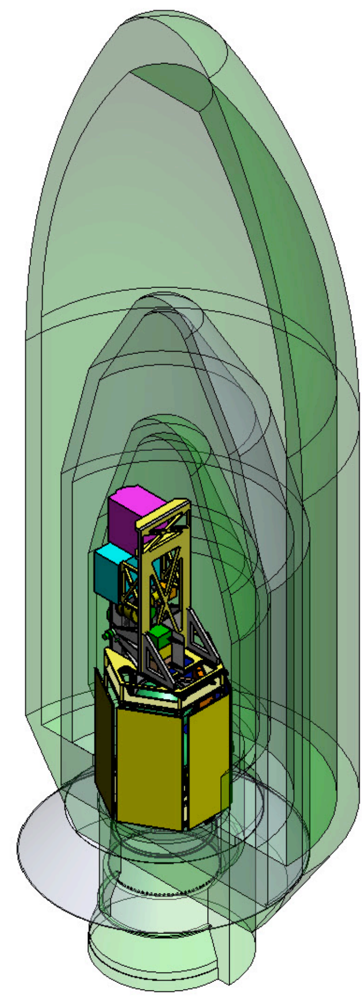
The Pre-ACE (PACE) Mission

Overview: PACE is a small mission (3 instruments) that would fly within 1 minute behind or in front of EarthCare. The additional measurements from PACE instruments would greatly augment the science of EC and provide new science as well.

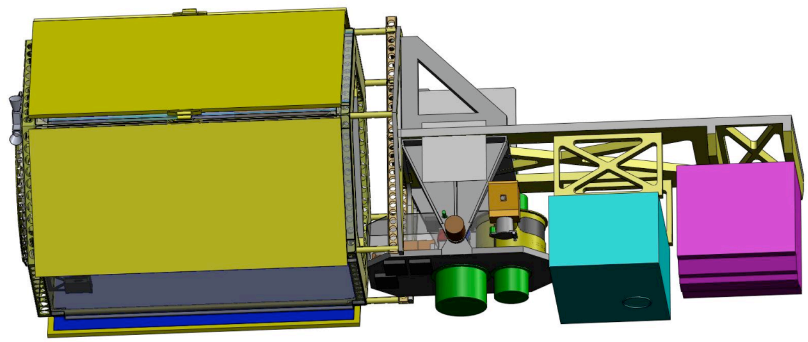
- EarthCare – one of the 6 ESA Earth Explorer satellites (LRD 2013) orbits at ~400 (or 450) km, PSS, 13:45 crossing time
- EarthCare payload consists of
  - Cloud Precipitation Radar (CPR): 94 GHz, -36dBz Doppler radar
  - High Spectral Resolution Lidar (HSRL @ 355nm)
  - Multi-angle BB IR Radiometer (2 channel, 0.2-4μ radiometer)
  - Multi-Spectral Imager (MSI) - 7 channel, 150 km swath imager (500m nadir pixels, 0.66, 0.865, 1.6, 2.2, 8.2, 10.8, 12. μ)
- EarthCare lacks a polarimeter and a wide swath multi-channel UV-visible spectrometer (Ocean Ecosystem Spectrometer, OES)
- PACE: A joint NASA-CNES (French space agency) mission
  - Fly OES, 3MI (polarimeter) and Advanced Technology Microwave Sounder (TMS) behind EarthCare
  - NASA provides OES & ATMS (also on NPOESS Preparatory Mission)
  - CNES provides 3MI

PACE Mission Design Study

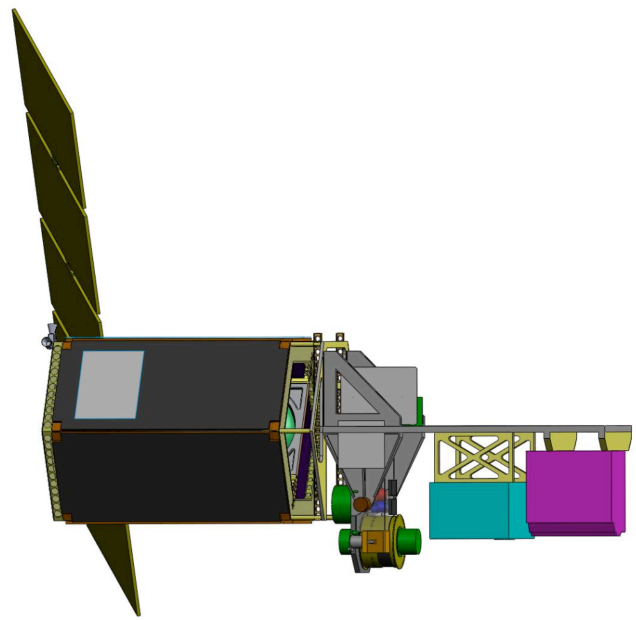


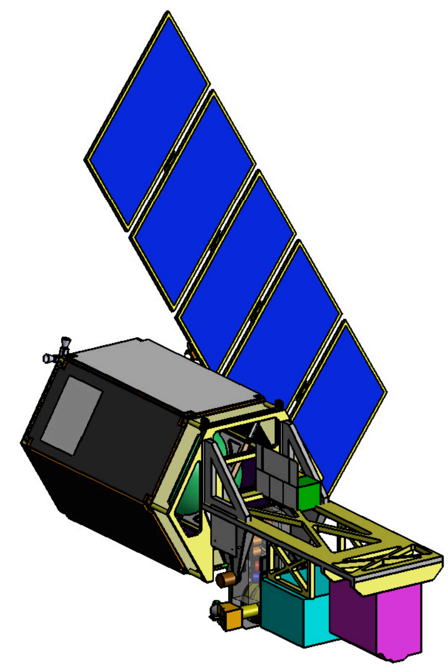


PACE can fit in several candidate launch vehicles



Solar panels and ocean radiometer in stowed position.





Solar panels and ocean radiometer deployed. All sensor fields of view are clear of obstructions (including ocean radiometer solar view.

ACE Study Schedule

- FY08
  - Science team formed
  - Science team meeting - June (NASA/GSFC)
  - Working groups organized
- FY09
  - ST meeting Nov. 2008 (University of Utah)
  - ST meeting Mar. 2009 (Oxnard, CA)
  - GSFC/Mission Design Lab, JPL/Team X studies began April 2009
  - EC meeting – 10-12 June 2009 (Kyoto)
  - Open ST meeting August (not official yet)
  - Follow-up ST meeting Sept. (not official yet)
  - Mission white paper, fall 2009
- FY10 Schedule
  - Additional science team meetings
  - Field campaign work including aircraft flight opportunities

ACE Science Working Groups

- Science Traceability Matrix Development
  - Ocean Biogeochemistry WG
  - Ocean-Aerosol Interactions WG
  - Aerosol WG
  - Cloud WG
  - Air Quality WG
- Field Program WG
- Other study topics
  - Ocean/Aerosol atmospheric correction convergence
  - Ocean radiometer/polarimeter integration
    - Conclusion: Not feasible
  - Lidar (atmospheric & ocean applications)
    - Multi-beam, HSRL
  - Polarimeter (performance characteristics)
  - Scanning radar (cloud retrievals)
  - Mission design

ACE Ocean Working Group

Chuck McClain: Chair

Paula Bontempi: Co-chair

- Zia Ahmad (NASA/GSFC*; **OBPG**)
- Bob Barnes (NASA/GSFC*; **OBPG**)
- Mike Behrenfeld (Oregon State U.)
- Emmanuel Boss (U. of Maine)
- Steve Brown (NIST)
- Jacek Chowdhary (NASA/GISS)
- Howard Gordon (U. of Miami)
- Stan Hooker (NASA/GSFC; **field campaign WG**)
- Yong Hu (NASA LaRC)
- Stephane Maritorena (UC/Santa Barbara)
- Gerhard Meister (NASA/GSFC*; **OBPG**)
- Norm Nelson (UC/Santa Barbara; **field campaign WG**)
- Dave Siegel (UC/Santa Barbara)
- Menghua Wang (NOAA/NESDIS)

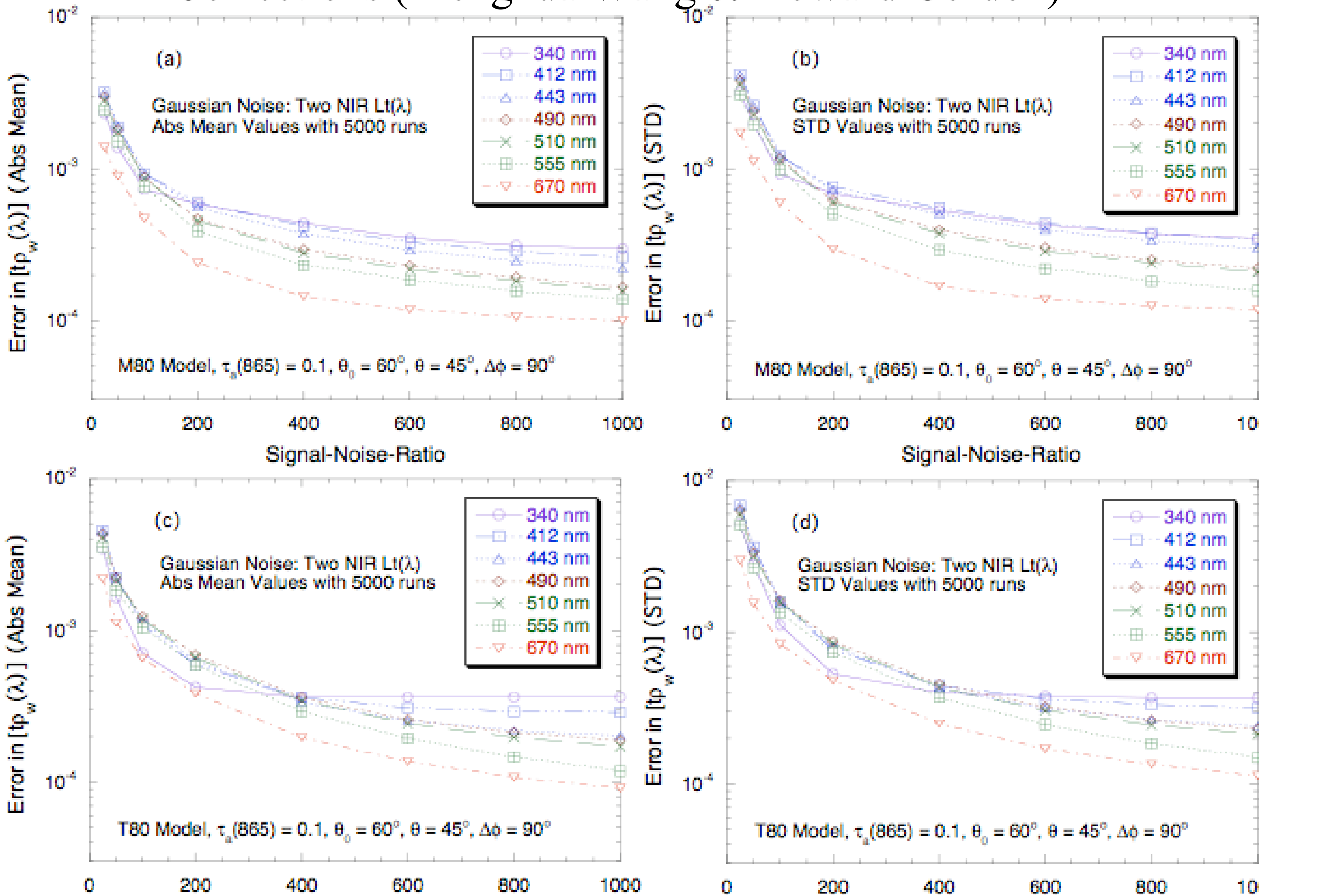
*contract staff

<u>WG Focus</u>

- Ocean biogeochemistry Science Traceability Matrix
- Ocean radiometer spectral coverage, band widths, SNR
- Aerosol lidar ocean applications and measurement requirements

Schedule: Weekly telecons

Sensitivity Studies for Sensor Requirements: Atmospheric Corrections (Menghua Wang & Howard Gordon)



Ocean-Aerosol Working Group

Chuck McClain: Chair
Paula Bontempi: Co-chair

Ocean WG Participants:
Zia Ahmad
Mike Behrenfeld
Jacek Chowdhary
Norm Nelson
Dave Siegel

- Susanne Bauer (NASA/GISS)
- Yuan Gao (Rutgers U.)
- Santiago Gasso (U. Maryland/Baltimore County)
- Joanna Joiner (NASA/GSFC)
- Natalie Mahowald (Cornell U.)
- Paty Matrai (Bigelow Lab. for Ocean Science)
- Nicholas Meskhidze (NC State U.)
- Joe Prospero (U. of Miami)
- Lorraine Remer (NASA/GSFC; **aerosol STM chair**)
- Eric Saltzman (UC/Irvine)
- Stanley Sanders (JPL)

Schedule: Weekly telecons

Ocean Requirements Support Group

- **Participants**
  - **OBPG:** Gerhard Meister (lead), Chuck McClain (co-lead), Bryan Franz, Fred Patt, Zia Ahmad, Sean Bailey, Jeremy Werdell, Gene Eplee
  - **Others:** Steve Brown (NIST), Jim Butler (GSFC), Rick Stumpf (NOAA/NOS)
- **Focus:** detailed ocean sensor performance specifications and test requirements
  - Spectral-out-of-band-response, polarization sensitivity, stray light response, SNR’s, Ltyp’s, Lmax’s, etc.
  - Review SeaWiFS, MODIS, & VIIRS specs
- **Schedule: Weekly meetings**

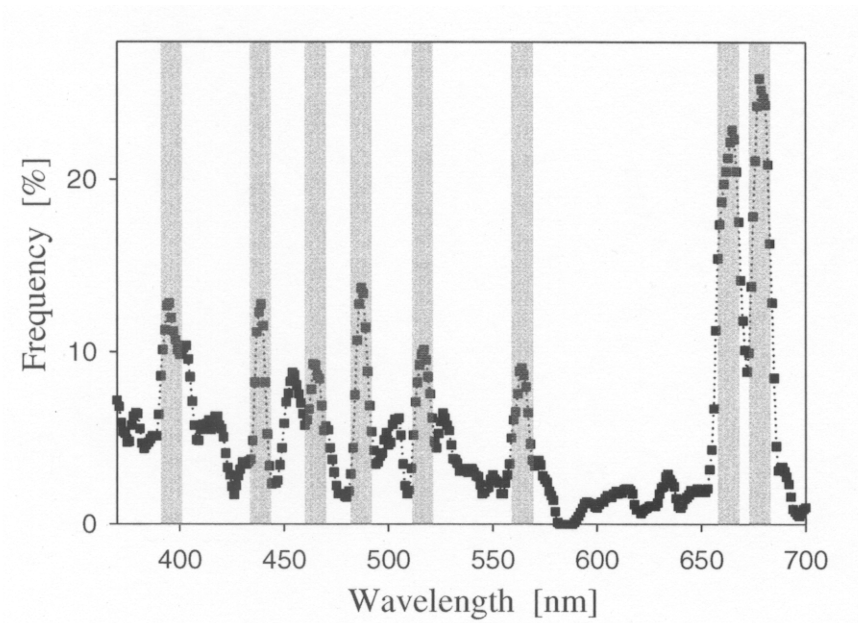
ACE Ocean Questions

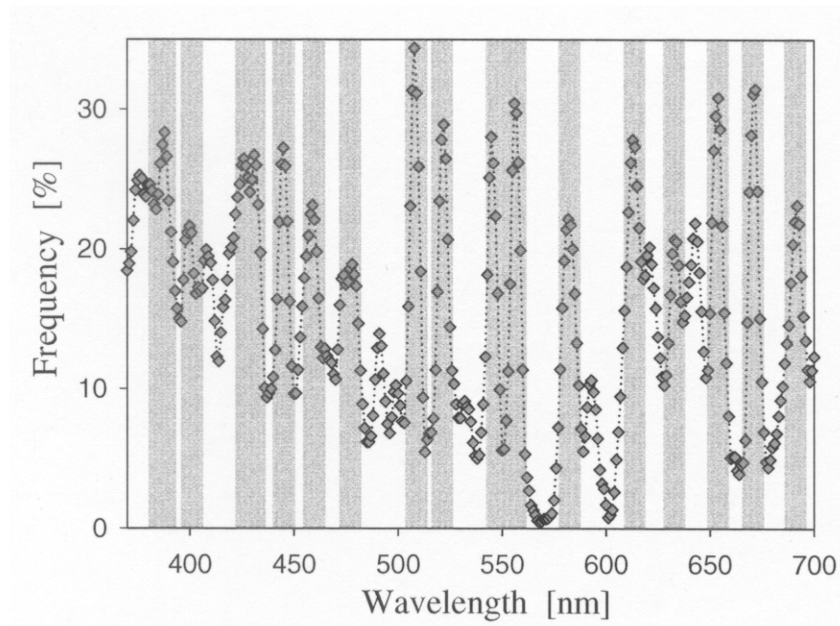
- Ocean ecosystems
  - What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1]
- Ocean biogeochemical cycles
  - How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2]
- Land-ocean interactions
  - What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing? [OBB3 w/1&2]

ACE Ocean Questions *cont.*

- **Ocean-atmosphere interactions**
  – How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and the Earth system? [OBB2]
    - Links to the international Surface Ocean-Lower Atmosphere Study (SOLAS)
- Bio-physical ocean interactions
  – How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1&2]
- Algal blooms & consequences
  – What is the distribution of algal blooms and their relation to harmful algal & eutrophication events? How are these events changing? [OBB4 & OBB1]

Phytoplankton Functional Groups: Spectral Derivative Analyses





SDA requires 5nm spectral resolution from 360-755 nm.

Approach

- Quantify phytoplankton biomass, pigments, optical properties, key (functional/HABS) phytoplankton groups, and productivity using bio-optical models & chlorophyll fluorescence.
- Measure particulate & dissolved carbon pools, their characteristics & optical properties
- Quantify ocean photobiochemical & photobiological processes.
- Estimate particle abundance, size distributions, & characteristics
- Assimilate ACE observations in ocean biogeochemical model fields of key properties (cf., air-sea CO_2 fluxes, export, pH, etc.)
- Compare ACE observations with ground-based & 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.)
- Combine ACE ocean & atmosphere observations with models to evaluate (1) air-sea exchange of particulates, dissolved materials, & gases and (2) impacts on aerosol & cloud properties.
- Assess ocean radiant heating & feedbacks
- Conduct field sea-truth measurements & modeling to validate retrievals from the pelagic to near-shore environments

Accurate satellite & field observations

Robust calibration & validation program

Targeted process studies

Advanced modeling & data assimilation

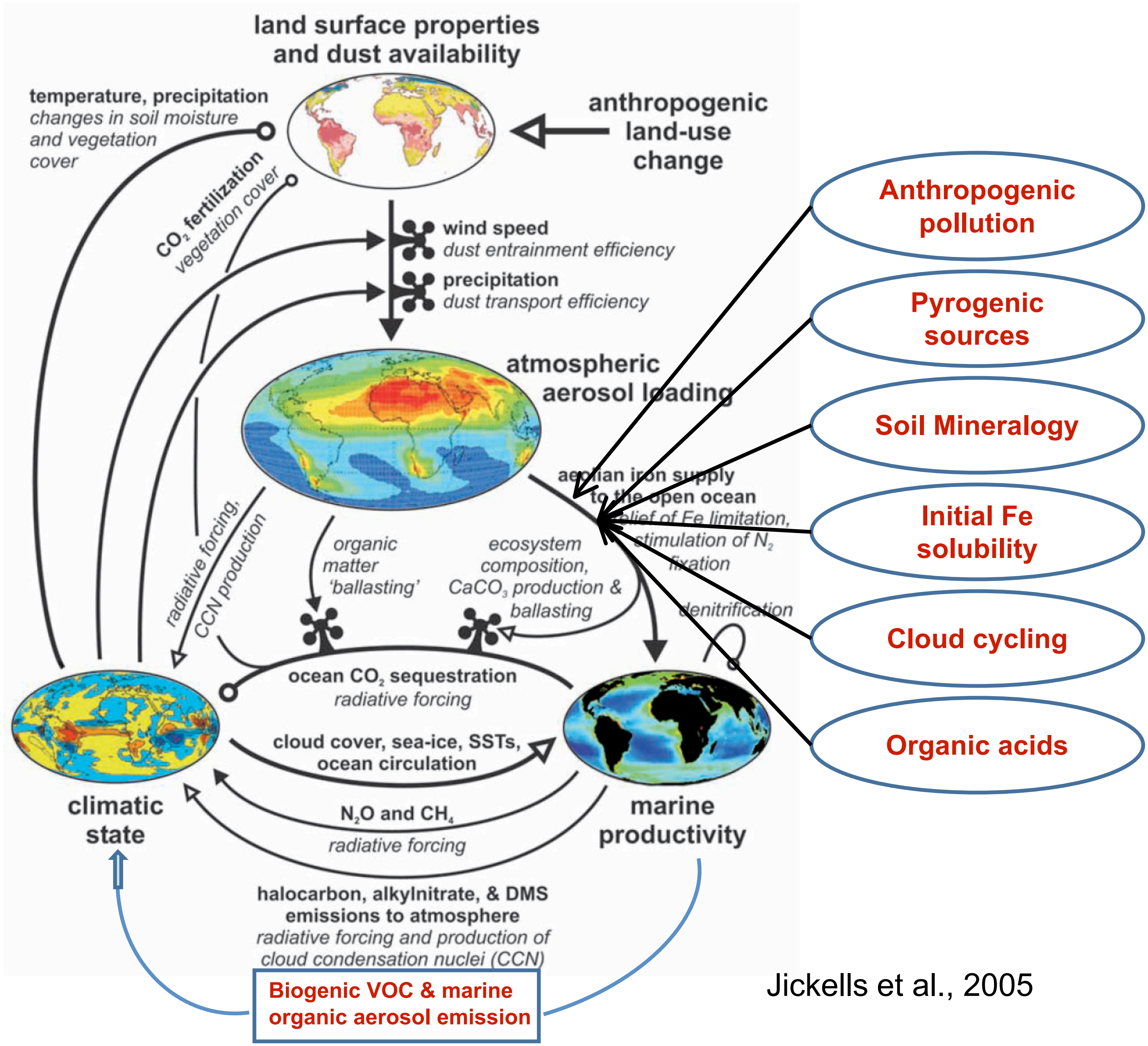
Ocean Biology STM

Goddard Space Flight Center

Category	Focused Questions*	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
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 (functional/HABS) phytoplankton groups, and productivity using bio-optical models and chlorophyll fluorescence	1, 2, 6	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 (667, 678, 710, 748 nm centers) ▷ 10 to 40 nm width atmospheric correction bands at 748, 865, 1245, 1640 nm (SNR T.B.D.) • 0.1% radiometric temporal stability (1 month demonstrated prelaunch) • 58.3° cross track scanning • Sensor tilt (±20°) for glint avoidance • Polarization insensitive (<0.5%) • 1 km spatial resolution @ nadir • No saturation in UV to NIR bands • 5 year minimum design lifetime	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
	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, & characteristics	1, 3, 2				
	4 How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system? [OBB2]	Assimilate ACE observations in ocean biogeochemical model fields of key properties (cf., air-sea CO_2 fluxes, export, pH, etc.)	2				
		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	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. (under discussion)		
	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				
	6 What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]	Assess ocean radiant heating and feedbacks	5	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%		
		Conduct field sea-truth measurements and modeling to validate retrievals from the pelagic to near-shore environments	1, 4, 2, 5, 3, 6				

* 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)

Ocean-Aerosol Interactions



Jickells et al., 2005

Aerosol-Ocean STM

Goddard Space Flight Center

Category	Focused Questions	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
Aerosol -Ocean Inter-action	1 What is flux of aerosols to the ocean and their temporal and spatial distribution	1) Characterize dust aerosols, their column mass, iron content and other trace elements/ toxins, and their regional-to-global scale transport and flux from events to the annual cycle	1 2		**Spectrometer** • multiwavelength UV-VIS • capable of high quality ocean color **Polorimeter** • details **Lidar** • details	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) Vicarious calibration & validation (2) Full prelaunch characterization (2% accuracy radiometric) (3) Blah blah *Science Requirements* (1) SST (2) SSH (3) PAR (4) Blah blah **OMI** **IASI** **CRIS**
	2 What are the physical characteristics and the source of aerosols deposited into the oceans?	2) Characterize aerosol chemical composition and transformation during transport (including influences of vertically distributed nitrous oxide, NOx, sulfur dioxide, formaldehyde, and glyoxyl) and partition gas-derived and mechanically-derived contributions to total aerosol column	2 3				
	3 How are the physical and chemical characteristics of deposited aerosols transformed in the atmosphere?	3) Observe urban aerosol plumes, quantify their nutrients/toxin burdens, and characterize their transport and fate	1 3				
	4 What is the spatial and temporal distribution of aerosols and gases emitted from the ocean and how are these fluxes regulated by ocean ecosystems?	4) Monitor global phytoplankton biomass, pigments, taxonimic groups, productivity, Chl:C, and fluorescence; measure and distinguish ocean particle pools and colored dissoved organic carbon; quantify aerosol-relevant surface ocean photobiological and photobiochemical processes	2				
		5) Relate changes in ocean properties to aerosol deposition patterns and events	3 4		**Field/Airborne** •		
	5 How do ocean ecosystems respond to aerosol deposition?	6) Demonstrate influences of ocean taxonomy, physiological stress, and photochemistry on cloud/aerosol properties, including organic aersol transfer	5				
	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?	7) Assimilate ACE space and field observations in 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	4 5				
		8) Conduct appropriate field observations to validate satellite retrievals of aerosols and ocean feedbacks	1 5	**Modeling** • blah blah			
		9) Identify microphysical and optical properties of aerosols, including spectral complex index of refractive and particle size distribution	2 3				

ACE Ocean Field Program WG

- Ocean members of ACE Joint Campaign WG:
  Stan Hooker, Norm Nelson, Mary Russ

- Objectives
  - Support **science goals** outlined in the Ocean Science Traceability Matrix
  - Support **calibration and validation activities**, in particular, the requirements for producing and maintaining climate data records (i.e., protocols, reference materials, uncertainty budgets, performance metrics, and national metrology institute traceability)

- Schedule: Biweekly telecons

ACE Oceans Technology Development Matrix

Science Discipline	Field Parameter	Community Protocol	Reference Material	Uncertainty Budget	Performance Metrics	NMI Traceability	Deployment Tech. M	T	G	R	A	S	Ocean Biology Science Questions					
Optical	Oceanic AOPs											C	1	2	3	4	5	6
	Oceanic IOPs										?		1	2	3	4		
	Atm. Optical Properties													2		4	5	
Carbon	CDOM											C		2	3	4	5	
Cycle	DOC											C		2	3	4		
	POC/N/P											C	1	2	3	4		
	PIC											C	1	2	3	4		
	Carbon Flux												1	2		4		6
	TSM													2	3	4		
Nitrogen	PON/DON												1	2	3	4		
Cycle	Ammonium		?			?								2	3	4		6
	Nitrate/Nitrite		?			?			?				1	2	3	4		
Biological	PP											C	1	2		4	5	6
	HPLC pigments											C	1	2		4		6
	Natural fluorescence											C	1	2				6
	MAAs												1					6
	Micro Taxonomy			?									1	2		4		6
	Pico Taxonomy			?									1	2		4		6
	O2		?											2			5	6
Physical	Salinity					?						C			3	4	5	6
	Temperature											C	1		3	4	5	6
	Surface meteorology		?										1			4	5	6
	Particle size/abundance		?								?		1		3	4		
Chemical	DMS, DMSp												1	2		4		
	Silicate		?			?							1	2	3	4		
	Phosphate/DOP		?			?							1	2	3	4		6
	pCO2		?													4		
	Trace nutrients		?										1	2		4	5	
	pH	?	?											2		4		
	Analytical Level	*Experimental*	*Research*	*Semi-Quantitative*	*Quantitative*	*CDR*	Moor.	Tower	Glider	R/V	A/C	Sat.						

Ocean Ecosystems Calibration and Validation Requirements

1. A field parameter for a satellite CDR (denoted C in deployment technology) must be at an analytical level of quantitative analysis with traceability.
2. All protocols and reference materials must be upgraded to community standards (green).
3. All field parameters must be conducted at the indicated analytical level (bold outline).
4. Field parameters must achieve their indicated analytical levels at the highest level (green).
5. A deployment technology must be at the highest level of capability (green) to be used in calibration and validation exercises.

Readiness Capabilities for Analytical Levels and Deployment Technologies

- (pink) Little capability demonstrated, significant work to be done.
- (yellow) Some capability demonstrated, but more work needs to be done.
- (green) Mature capability (calibration and validation quality).

ACE Ocean Field Effort
Focused Campaigns

- **Philosophy: Address STM questions and collect cal/val or algorithm development data concurrently**

- Pre-launch cal/val efforts focused on STM questions plus technology & algorithm development
- Post-launch efforts focused on STM questions and validation
- **Explore opportunities for multi-disciplinary studies (e.g., ocean-aerosol working group topics)**
- **Coordinate with national/international steering groups (SOLAS, OCB, CLIVAR) for field program access**
- Implementation needs -- resources and science teams, dates, advance planning.

ACE Ocean Field Effort - Campaigns Case studies - white papers

- Ocean productivity / particle flux
  - Connect carbon fixation to the biological pump with additional information on community structure
- Soluble iron and productivity
  - Ocean-aerosol connections, paleoclimatology
- Fate of carbon in the coastal transition zone
  - Partition the biological, chemical, and photobiological sinks of terrestrial carbon under a mixed terrestrial/oceanic aerosol
- Asian aerosol impact on Pacific productivity
  - Ocean-aerosol connections, ocean acidification

Instrument Applications: Oceans & Ocean-Aerosols

- **Baseline Product Generation**
  - **Ocean Radiometer**
    - 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
    - Support certain aerosol and cloud community measurements requirements
- **Research & Development Themes**
  - **Lidar**
    - Highly absorbing aerosols: aerosol heights for atmospheric corrections in the presence of highly absorbing aerosols (not required for non-absorbing aerosols)
    - Subsurface particle scattering & depth profile
  - **Polarimeter**
    - Highly absorbing aerosols: Broad spatial coverage highly absorbing aerosol areal distribution, heights & single scattering albedo for quality flag and atmospheric correction
    - Subsurface polarized return for typing oceanic particles

Instrument Requirements: Radiometer
(preliminary-refinements under discussion)

- 5 nm resolution 350 to 755 nm (functional group derivative analyses)
- 1000 – 1500:1 SNR for 15 nm aggregate bands UV & visible
  - 1125:1 for 360 nm @ Ltyp
  - 1500:1 for bands between 380-665 nm @ Ltyps
- 10 nm fluorescence bands (667, 678, 710, 748 nm band center)
  - 1500:1 SNR for 667, 678, & 710 nm @ Ltyps
  - 600:1 SNR for 748 nm @ Ltyp
- 10 to 40 nm bandwidth aerosol correction bands at 748, 820, 865, 1245, 1640 nm
  - 600:1 SNR for 748, 820 & 865 nm @ Ltyps
  - 300:1 SNR at 1245 nm & 250 SNR at 1640 nm @ Ltyps
- Stability
  - 0.1% radiometric stability knowledge (mission duration)
  - 0.1% radiometric stability (1 month prelaunch verification)
- 58.3^{o} cross track scanning
- Sensor tilt (20^{o}) for glint avoidance
- Polarization: < 0.7% sensor radiometric sensitivity, 0.2% prelaunch characterization accuracy
- < 2% prelaunch radiance calibration accuracy
- 1 km spatial resolution @ nadir
- No saturation in UV to NIR bands
- 5 year minimum design lifetime

Remaining Specs:
Relative spectral response
Stray light
Temperature sensitivity
Response vs. scan
etc.

Platform Requirements

- 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^{o} phase angle through Earth observing aperture and optics (only)
- Daily solar diffuser calibrations

Other Requirements

Global data sets from missions, models, or field observations

- **Measurement requirements**
  - Ozone concentrations
  - Total water vapor
  - Relative humidity
  - Surface wind velocity
  - Surface barometric pressure
  - NO_2 concentration
  - Vicarious calibration & validation data
    - 0.2% calibration accuracy on-orbit
  - Full prelaunch characterization
- **Science requirements**
  - Sea surface temperature
  - Sea surface height
  - Photosynthetically available radiation
  - UV radiances
  - Mixed layer depths
  - CO_2
  - pH
  - Ocean circulation fields
  - Aerosol Fe deposition
  - Run-off loading in coastal zone

- Additional measurement and science requirements from Ocean-Aerosol WG under discussion

Ocean Radiometer multi-spectral band specifications: preliminary

Notes:

Units: mW/cm^2 µm str

Ltyp's based on fits to MODIS and SeaWiFS observations

Based on SeaWiFS observations, Lmax's result in <0.2% pixels saturated

SNR ratios to SeaWiFS: 412-670 nm (1.5-1.7) 765 nm (1.15), 865 nm (1.5)

Analysis of MODIS ocean products showed cirrus contamination to be insignificant.

		5-Mar-05	Ltyp	Lmax	SNR
			(Ahmad)	(Barnes)	(required)
Band Center	Band-width	Application/Comments			
360	15	CDOM-chlorophyll separation; strong NO2 absorption	7.220	37.6	1125
385	15	CDOM-chlorophyll separation; strong NO2 absorption; avoid precipitous drop in solar spectrum at 400 nm	6.110	38.1	1500
412	15	CDOM-chlorophyll separation; SeaWiFS (20 nm) & MODIS (15 nm) bands; strong NO2 absorption	7.860	60.2	1500
425	15	CDOM-chlorophyll separation, strong NO2 absorption	6.950	58.5	1500
443	15	Chlorophyll-a absorption peak; SeaWiFS (20 nm) & MODIS (10 nm) bands; strong NO2 absorption	7.020	66.4	1500
460	15	Assessory pigments & chlorophyll	6.830	72.4	1500
475	15	Assessory pigments & chlorophyll	6.190	72.2	1500
490	15	SeaWiFS (20 nm) & MODIS (10 nm) bands; chlorophyll band-ratio algorithm	5.310	68.6	1500
510	15	SeaWiFS (20 nm) band; chlorophyll-a band-ratio algorithm; strong O3 absorption	4.580	66.3	1500
532	15	Aerosol lidar transmission band; MODIS (10 nm) band; strong O3 absorption	3.920	65.1	1500
555	15	Bio-optical algorithms (e.g., band-ratio chlorophyll); MODIS-548 nm, SeaWiFS-555 nm; strong O3 absorption	3.390	64.3	1500
583	15	Phycoerythrin, strong O3 absorption	2.810	62.4	1500
617	15	Strong O3 absorption; bounded at 628 nm by water vapor absorption band	2.190	58.2	1500
640	10	Between O3 & water vapor absorption peaks	1.900	56.4	1500

Ocean Radiometer multi-spectral band specifications *cont.*: preliminary

655	15	Chlorophyll a&b, strong O3 absorption, weak water vapor absorption	1.670	53.5	1500
665	10	Fluorescence line height baseline, bandwidth constrained by water vapor absorption line & 678 band	1.600	53.6	1500
678	10	Fluorescence line height; band center offset from fluorescence peak by O2 absorption line	1.450	51.9	1500
710	15	Fluorescence line height baseline; HABS detection; terrestrial "red edge"; straddles water vapor absorption band	1.190	48.9	1500
748	10	Atmospheric correction-open ocean; MODIS band, between O2 A-band & water vapor absorption peaks	0.930	44.7	600
765	40	Atmospheric correction-open ocean; SeaWiFS band, O2 A-band absorption	0.830	43.0	600
820	15	Water vapor concentration/corrections. There are other water vapor absorption features that could be used.	0.590	39.3	600
865	40	Atmospheric correction-open ocean; SeaWiFS band (40 nm bandwidth); MODIS band-869 (15 nm bandwidth)	0.450	33.3	600
1245	20	Atmospheric correction-turbid water; MODIS band; bandwidth constrained by water vapor & O2 absorption peaks	0.088	15.8	300
1640	40	Atmospheric correction-turbid water; MODIS-1640 nm, moved to 1610 tobroaden bandpass & improve SNR	0.029	8.2	250

Represents one option for a required function

Notes: Franz MODIS Lmax values show the effects of sensor degradation
Ahmad Ltyp values based on curve fit to Franz MODIS Ltyp's

Units: mW/cm2 um str

Lmax (Barnes) assumes albedo of 1.1 with 0 degree incidence angle