Aerosol-Cloud-ocean Ecosystem (ACE) Decadal Survey Mission

GEO-CAPE Workshop

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ACE Science

Objective: … reduce the uncertainty in estimates of climate forcing due to aerosol-cloud interactions and ocean ecosystem CO_2 uptake – NAS Decadal Survey pg 4-4

- Aerosol-cloud science objectives are:
  - Decrease the uncertainty in aerosol forcing as a component in global climate change, and
  - Quantify the role of aerosols in cloud formation, alteration of cloud properties and changes in precipitation.
- Ocean ecosystem goals are to:
  - Continue the record of changes in the ocean biosphere
  - Assess the amount of dissolved organic matter and the role of the oceans in carbon uptake.
- This combination because:
  - A number of common science questions
  - The ocean ecosystem spectro-radiometer needs aerosol type and height measurements to improve ocean color retrievals.
  - The ocean ecosystem spectro-radiometer makes useful measurements of aerosols and clouds.

ACE Instruments

- Mission and Payload: … LEO, sun-synchronous early-afternoon orbit. The orbit altitude of 500-650 km. The NAS Decadal Survey mission consisted of four instruments:
  - A multi-beam cross-track dual wavelength backscatter lidar for measurement of cloud and aerosol heights and layer thickness,
  - A cross-track scanning cloud radar* with channels at 94 GHz and possibly 34 GHz for cloud droplet size, glaciation height, and cloud height,
  - A highly accurate multiangle - multiwavelength polarimeter to measure cloud and aerosol properties (cross-track and along-track swath with ~1 km pixel size),
  - A multi-band cross-track visible/UV spectro-radiometer with ~1 km pixel size, including Aqua MODIS, NPP VIIRS, and Aura OMI aerosol retrieval bands and *additional bands for ocean color and dissolved organic matter*."
  - Additional measurements (temperature and humidity sounding, IR measurement of cloud temperature and height, …).

* Doppler would be desirable

SWG Recommendation for ACE Mission

- Instruments and technology
  - HSR Lidar for assessing the heights of aerosol and cloud properties.
  - Dual frequency Doppler cloud radar for cloud properties and precipitation
  - Multi-angle, swath polarimeter for imaging aerosol and clouds
  - Ocean ecosystem multi-channel spectrometer (OES)
  - IR multi-channel imager for cloud temperatures and heights
  - High frequency swath radiometer for cloud ice measurements
  - Low frequency swath radiometer for precipitation measurements
  - Microwave temperature/humidity sounder
- The ACE mission – with its advanced instruments will probably not launch until well into the next decade

Black – Specified by NAS Decadal Survey

Red – Science Definition Team Recommendations

Implementation Strategies for ACE

- Phased Implementation of ACE could:
  - Provide a way to handle instruments with differing technical readiness levels
  - Provide increased capability to optimize measurements post-launch (formation flight)
  - Increase flexibility enabling greater international collaboration and participation
  - Decrease peaks in the cost profile
  - Increase overall cost

Possible Phased ACE Coordinated with EarthCARE

- A possible Phased ACE could complement instruments on EarthCARE (ACE-1)
  - Ocean Ecosystem Spectrometer – ocean color, aerosols and clouds
  - CNES Polarimeter (Polder A) – aerosols and clouds
  - ATMS µ-wave sounder (cloud, water vapor, temperature µ-wave sounding)
- Benefits
  - Augment the measurements of EarthCARE by providing better context to the EarthCARE lidar and radar measurements
  - Extend and improve the Ocean Ecosystem and aerosol data sets beyond A-Train/MODIS

Ocean Ecosystems STM

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Category	Focused Questions*
Ocean Biology	**1** What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1]
	2 How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2]
	3 What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing? [OBB1,2,3]
	4 How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system? [OBB2]
	5 How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1,2]
	6 What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]

Approach	Maps to Science Question
Quantify phytoplankton biomass, pigments, optical properties, key (functional/HABS) phytoplankton groups, and productivity using bio-optical models and chlorophyll fluorescence	1, 2, 6
Measure particulate and dissolved carbon pools, their characteristics and optical properties	2, 3
Quantify ocean photobiochemical & photobiological processes	2, 4
Estimate particle abundance, size distribution, & 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
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
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
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 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) • 58.3º cross track scanning • Sensor tilt (±20º) for glint avoidance • Polarization insensitive (<0.5%) • 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. (under discussion)
Broad spatial coverage aerosol heights and single scatter albedo for atmospheric correction. Subsurface polarized return for typing oceanic particles	**Polarimeter** • Observation angles: 60º to 140º • Angle resolution: 5º • Degree of polarization: 1%

Platform Requir'ts

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 7º phase angle through Earth observing port

Other Needs

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

Aerosol-Ocean STM

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Category	Focused Questions	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs

Category

Aerosol-Ocean Inter-action

Focused Questions

1. What is the flux of aerosols to the ocean and their temporal and spatial distribution
2. What are the physical and chemical characteristics, sources, and strengths of aerosols deposited into the oceans?
3. How are the physical and chemical characteristics of deposited aerosols transformed in the atmosphere?
4. How do ocean ecosystems respond to aerosol deposition?
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?
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?

Approach (Maps to Science Question)

Approach	Maps to Science Question
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
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) Conduct appropriate field observations to validate satellite retrievals of aerosols and ocean ecosystem features	1, 5
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) 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
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
8) Demonstrate influences of ocean taxonomy, physiological stress, and photochemistry on cloud/aerosol properties, including organic aerosol transfer	1, 2, 3

Measurement Requirements

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

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

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

Instrument Requirements

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

Platform Requir'ts

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 7° phase angle through Earth observing port

Additional platform requirements for polarimeter, lidar and radar as detailed in Ocean, Aerosol, and Cloud STMs

Other Needs

Supporting Global data

- Humidity profiles
- Precipitation
- Formaldehyde
- Glyoxal
- IO
- BrO
- NO_2
- SO_2

Other Data

- Ground-based aerosol observational network

Cloud STM

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ACE Cloud Science Traceability Matrix –**DRAFT as of June 30, 2009.**

Category	Topical Themes	Focused Science Questions [2]
Morphology	Occurrence and macroscale structure (vertical and horizontal) of clouds and precipitation and interaction with large - scale meteorological and thermodynamic forcing.	A3 (1, 2, 6,10), B1 (1,2,3,6,7,9) C3 (1,2,4,7,11,18) D1 (1,2,7,11,13,15,18,19), D2 (1,4,5,8,9,11,14) E1 (1 ,4,5,7,9,10,11,14, 15)
Microphysics	Microphysical Processes that form, maintain, and cause changes to profiles of aerosol, clouds, precipitation and the interactions between them.	A2 (1,2,5,11,14), A3 (1,2,10) , A4(1,11,14,15) B2 (8,10,11,12,13,17) B3 (10,11,12,15 -18,20) C2 (5,9,13,19) C4 (5, 9,12,13,15,16,20) D2 (1,4,5,8,9,11,14) , D3(1, 4,5,9 -12,16,17) E3 (5,6,7,9,10,11)
Aerosol	The specific role of aerosol in modifying the occurrence and properties of clouds and precipitation.	B4 (6,8,10,11,12,13,19) C1 (1,2,5,7,12,14) , C2(5,9,13,19) , C3 (1,2,4,7,11,18) , C4 (5, 9,12,13,15,16,20) D3 (1, 4,5,9 -12,16,17) E2 (4,5,7,9,10) , E3(4,5,7,9,10)
Energetics	Maintenance of and changes to the energetic balance of the atmosphere and earth system due aerosol, clouds, and precipitation.	A1 (1,2,3,7,9) A4 (1,7,9,10) B3 (10,11,12,15 -18,20) D1 (1,2,7,11,13,15,18,19) E4 (4,5,7,9,10)

Geophysical Param eters and Error Tolerance Requirements [3]

	Narrow Nadir Swath	Wide Swath
1. Cloud Layer Detection	2%	5% (optical depth > 0.3)
2. Cloud Top Height	250m (R), 100 m (G)	1500 m (ice) 1000 m (liq)
3. Cloud Base Height	250m (R), 100 m (G)	
4. Cloud Top Phase	5%	20%
5. Pre cipitation Detection	10%	20%
6. Vertical Motion		
7. Multilayer Cloud Detection	5%	
8. Cloud Phase Profile	20%	
9. Precipitation Profile	10%	
10. Water Content Profile	10-25%	
11. Cloud Water Path	10%	25%
12. Cloud Particle Size Profile	10-25%	
13. Precipitation Particle Size Profile	10%	
14. Precipitation Rate Profile	20-50%	
15. Cloud Column Optical Depth	10%	20%
16. Layer Effective Radius	10%	20% (liq) 30% (ice)
17. Extinction Profile	5%	
18. Radiative Effect	10% or 25 W m^{-2}	10 W m^{-2} (TOA)
19. Latent Heating	5 K day^{-1} km^{-1}	
20. Radiative Heating Rate Profile	10% or 1 K day^{-1} km^{-1}	

Measurement and Instrument Requirements [4]

1. **W Band Radar – Z, V_d (1-20)**
   - Z Error: 2 dB (1,10,12)
   - Vd Error: 0.2 m/s (5,6,9,10,13,19)
   - MDS: -35 dBZ (1 ,10,12)
   - Vert Res: 250 m (2,3,7)
   - Horiz. Res : 1000m (1,2,3,5,19)
2. **Ka Band Radar – Z, V_d, (1,2,3,5,7,9,10,11,14,19,20)**
   - Z Error: 2 dB (9,13)
   - Vd Error: 0.5 m/s (11,15,16)
   - MDS: -10 dBZ (5,9,13,14)
   - Vert Res: 250 m (9,13)
   - Horiz. Res: 1000m (5,10,9,16)
   - Scanning – 50 km swath (1,5,9,13)
3. **High Spectral Res. Lidar –extinction (1,2,4,7,10,12,17,15,20)**
   - Ext Error – 1/km (10,12,20)
   - Vert Res: 50 m (2,10, 16)
   - Horiz. Res: 1 00m (1, 2, 4, 10,17,20)
4. **High-Resolution VIS-SWIR Imager or Cameras (primary =1,2,11,15,16,18; assist = 10, 12, 17)**
   - Wavelengths: 0.670 a nd 0.865 nm
   - Resolution – 50 to 100 m
   - Swath – 100km (min)
   - Wavelengths: 1.6 or 2.1 µm
   - Resolution – 200 m (min)
   - Swath – 100 km (min)
   - Multiangle (G)
5. **Wide Swath Vis -IR Imager, (primary = 1,4,7, 11,12 1,2,4,7,11,15,16,18 ; assist = 10, 12, 17)**
   - # of Channels: 7 (MR) to 17 (G)
   - Wavelengths: 0.42 to 14 µm
   - Resolution – 500 to 1000 m
   - Swath – 1000 - 2000 km
6. **Low Freq. Microwave**
   - Channels: x GHz
   - Abs Accuracy: x
   - Resolution: x km
7. **High Freq. Microwave**
   - Channels:x GHz
   - Abs Accuracy: x
   - Resolution: x

Aerosols Science Questions and Goals

Contents:

- The three scientific themes:
    1. Sources, processes, transport and sinks (SPTS)
    2. Direct and semi-direct aerosol radiative forcing (DARF)
    3. Aerosol indirect effects and forcing through microphysics
- Science traceability matrices for each theme
- Outstanding questions and issues

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

(1) What is the global and regional aerosol mass budget?
What is the mass flux into the global or regional atmosphere and out of the atmosphere, partitioned by species, and as a function of time?

(2) What is the impact of specific significant aerosol events such as wild fires, dust outbreaks, urban/industrial pollution, volcanic eruptions etc. on the local, regional and global aerosol burden?

SPTS

(3) What is the direct aerosol radiative forcing (DARF) at the top-of-atmosphere, within-atmosphere and at the surface? Here, DARF is defined as the mean radiative flux perturbation due to the *anthropogenic* component of present-day aerosols (in units of Wm^{-2})

(4) What is the aerosol radiative heating of the atmosphere due to absorbing aerosols, and how will this heating affect cloud development and precipitation processes?

DARF

Science Questions → Goals → Approach → Parameter Requirements → Instrument Requirements

- *Primary and secondary particle generation processes*
- *Injection heights*
- *Anthropogenic versus natural*
- *International/intercontinental source-receptor relationships*
- *Deposition and relationship to ecosystems*
- *AOT, total column mass, PM2.5 relationships*
- *Aerosol events, assimilation and forecasting*

- *Consequences to surface energy balance and evaporation rates.*
- *Direct aerosol radiative forcing in cloud fields and far from clouds.*
- *Regional, seasonal and vertical distribution of aerosol heating.*
- *Partitioning between different aerosol and cloud types.*
- *Covariance between aerosol heating and different cloud types/precipitation processes.*

Science Questions → **Goals** → Approach → Parameter Requirements → Instrument Requirements

- Constrain total aerosol mass burden in atmosphere to ±4.5 Tg, which represents cutting present uncertainties in half. Constrain uncertainty in total AOD from 0.025 to less than 0.02, constrain Mass Extinction Efficiencies (MEE), individual species, sources, deposition.
- Represent PM2.5 concentrations on the ground from satellite observations with R > 0.8.
- Quantify hemispheric transport of pollution to ±50%, representing cutting uncertainties in half
- Quantify contribution of major aerosol events to total air quality burdens and regional and global aerosol radiative forcing.

- A firmer basis for measurement-based estimates of global and regional DARF and its uncertainties by confronting issues not properly addressed by observations in the past.
- The first ever measurement-based estimate of the global direct aerosol radiative forcing <u>at the bottom of the atmosphere to within ± 1 Wm^{-2},</u> equivalent to estimating **the global evaporation rate at the surface of ± 1 mm/month** (~ 1% of global rates).
- Measurement-based estimates of the aerosol radiative heating of the atmosphere, <u>vertically-resolved into layers</u>, at an accuracy of ± 0.25 ^{o}K/day for 1.5 km layers.

ACE – Next Steps

- SWG Workshop 14-16 October
- Phased Implementation presented to NASA upper management
- The role of suborbital observations needs to be refined beyond mission preparation and cal/val. Suborbital observations identified in STM's? Cooperative field campaigns?
- Need to put more emphasis on aerosol-cloud interactions.
- Need to incorporate more large scale modelers?
- Significant progress has been made on STMs. Are we headed in the right direction?
- STMs and White Papers are ready to go to Technical Editors.