ACE Objectives, Current Status and the 2017 Decadal Survey

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The Aerosols-Clouds-Ecosystem (ACE) 2007 Decadal Survey mission

- Broad science objectives
- Science traceability to measurements
- Current Status of ACE

Aerosol, Clouds & Precipitation in the 2017 Decadal Survey

- Relevant Science questions
- Relevant Designated Missions

Summary
2007 Decadal Survey

Available from https://www.nap.edu
What is ACE?

ACE is a tier-2 2007 Decadal Survey mission focusing on Aerosol, Cloud systems, ocean Ecosystems, and the interactions among them.

ACE Goals

Improved understandings of Earth system interactions among aerosols, cloud and precipitation systems, and ocean ecosystems, specifically

- Quantify direct radiation effect of aerosols
- Assess indirect effects of aerosols through modification of hydrometeor profiles in cloud systems
- Observe and distinguish those ocean ecosystem components that actively take up and/or store carbon dioxide
- Measure and quantify the linkage between the ocean ecosystems and atmospheric aerosols

Achievement of these goals will result in enhanced capabilities to observe and predict changes to the Earth's hydrological cycle and energy balance in response to climate forcings.
ACE 2011-2015 Progress Report
and Future Outlook
by
ACE Science Study Team
Arlindo da Silva, Robert Swap, Hal Maring,
Michael Behrenfeld, Richard Ferrare, and Gerald Mace
with contributions from
Brian Cairns, David Diner, Lisa Callahan, Chris Hostetler, J. Vanderlei Martins, David
Starr, Matthew McGill, Simone Tanelli
September 2016
Available from https://acemission.gsfc.nasa.gov/
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</table>
| **Sources, Processes, Transport, Sinks (SPTS)** | Q1. What are key sources, sinks, and transport paths of airborne sulfate, organic, BC, sea salt, and mineral dust aerosol?  
Q2. What is the impact of specific significant aerosol events such as volcanic eruptions, wild fires, dust outbreaks, urban/industrial pollution, etc. on local, regional, and global aerosol burden? | Column:  
- \( \tau(\lambda) \)  
- \( \tau_{\text{abs}}(\lambda) \)  
- \( m(\lambda) \)  
- \( \rho_{\text{eff}}(\lambda) \)  
- \( \rho_{\text{vir}}(\lambda) \)  
- Morphology  
Vertically Resolved:  
- \( \tau_{\text{abs}}(\lambda) \)  
- \( m(\lambda) \)  
- \( \rho_{\text{eff}}(\lambda) \)  
- \( \rho_{\text{vir}}(\lambda) \)  
- Morphology | High Spectral Resolution Lidar (HSRL)  
- Backscatter (355, 532, 1064 nm)  
- Extinction (355, 532 nm)  
- Depolarization (two wavelengths of 355, 532, 1064 nm)  
Imaging Polarimeter  
- Minimum 6 to 8 wavelengths spanning either UV or 410 nm to either 1630 nm or 2250 nm  
- Multiangle TBD, range ±50°  
- Polarization accuracy 0.5%  
- Combination polarized and nonpolarized channels  
- Resolution: 250 m in at least one channel | Integrated satellite, modeling, and data assimilation approach is required to meet science objectives.  
Expand high-resolution global and regional modeling capabilities to assimilate cloud and aerosol microphysical parameters such as number concentration and optical properties.  
Required ancillary data:  
- Land surface albedo map  
- Ground network \( \tau(\lambda) \), shortwave and longwave \( F_s \) and \( F_{\text{net}} \)  
- Ground and airborne: column and vertically resolved \( \tau(\lambda) \), \( \tau_{\text{abs}}(\lambda) \), \( m(\lambda) \) (2 modes), morphology, \( P_{\text{abs}}(0) \)  
- Space measurements: Top of atmosphere shortwave and longwave \( F_s \), collocated \( T(z), q(z), V(z), \) fire strength, frequency, location |
| **Direct Aerosol Radiative Forcing (DARF)** | Q3. What is the direct aerosol radiative forcing (DARF) at the top of atmosphere, within atmosphere, and at the surface?  
Q4. What is the aerosol radiative heating of the atmosphere due to absorbing aerosols, and how will this heating affect cloud development and precipitation processes? | Cloud Top:  
- \( \tau_{\text{eff},c} \)  
- \( \rho_{\text{eff},c} \)  
- Thermodynamic phase | | |
| **Cloud-Aerosol Interactions (CAI)** | Q5. How do aerosols affect cloud micro and macro physical properties and the subsequent radiative balance at the top, within, and bottom of the atmosphere?  
Q6. How does the aerosol influence on clouds and precipitation via nucleation depend on cloud updraft velocity and cloud type?  
Q7. How much does solar absorption by anthropogenic aerosol affect cloud radiative forcing and precipitation?  
Q8. What are the key mechanisms by which clouds process aerosols and influence the vertical profile of aerosol physical and optical properties? | Vertically Resolved:  
P1. \( N_a \)  
P2. \( \tau_{\text{abs}}(\lambda) \)  
P3. \( \rho_{\text{eff}}(\lambda) \)  
P4. \( N \)  
P5. LWC  
P6. Precip  
Cloud Top:  
P7. Cloud top height  
P8. Cloud albedo  
P9. LWP  
P10. \( \tau \)  
P11. \( \rho_{\text{eff},c} \)  
P12. Cloud radiative effect  
Cloud Base:  
P13. Cloud base height  
P14. Updraft velocity | Threshold (i.e. minimum)  
**HSRL:**  
P1. \( \rho_{\text{eff}}(\lambda) \)  
P2. \( \tau(\lambda) \)  
P3. \( \tau_{\text{abs}}(\lambda) \)  
P4. \( m(\lambda) \)  
P5. \( \rho_{\text{eff},c} \)  
P6. Cloud radiative effect  
P7. Cloud base height  
P8. Updraft velocity |  
**W band Radar:**  
P4. \( \rho_{\text{eff}}(\lambda) \)  
P5. \( \tau(\lambda) \)  
P7. \( \tau_{\text{abs}}(\lambda) \)  
P13. Cloud base height  
P14. Updraft velocity |  
**Narrow swath High-Resolution VIS-MWIR Imager:**  
P9. \( \rho_{\text{eff}}(\lambda) \)  
P11. \( \tau(\lambda) \)  
P10. \( \tau_{\text{abs}}(\lambda) \)  
P12. Cloud radiative effect  
P13. Cloud base height  
P14. Updraft velocity |  
**Baseline (additions to threshold):**  
\( W + Ka \) Band Doppler radar
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| **T1. Morphology** | **Q1. Climate Sensitivity**<br>What is the sensitivity of the climate system to cloud structure and variability? | GP1. Hydrometeor Layer Detection | **TM1. Threshold Mission**<br>2-Frequency (W-, Ka-bands), Scanning Doppler Radar (with radiometer channels) | We define the threshold
ACE Clouds Mission as those elements of this matrix that are in bold font. We suggest that
boldface science objectives and questions in columns 1 and 2 could ultimately be addressed by the measurements
listed as the Threshold Mission in the Measurement Requirements Column. |
<p>| | <strong>Q1. Climate Sensitivity</strong>&lt;br&gt;What is the role of natural and anthropogenic aerosol in modulating cloud system occurrence and properties? | GP2. Simultaneously occurring Cloud and Precipitation Thermodynamics Phase profile | <strong>TM2. High Spectral Resolution Lidar</strong>&lt;br&gt;Baseline Mission |
| | <strong>Q1. Climate Sensitivity</strong>&lt;br&gt;What microphysical processes dictate the lifecycle and coverage of clouds under various atmospheric conditions? | GP3. Simultaneously occurring Cloud and precipitation microphysical properties profiles (Water Content, particle size, and number concentration) | <strong>TM3. Narrow Swath Vis Imager (0.6 microns, 1.6 microns, 2.1 microns)</strong>&lt;br&gt;Baseline Mission |
| | <strong>Q1. Climate Sensitivity</strong>&lt;br&gt;What dictates the processes that cause and modulate precipitation in cloud systems? | GP4. Precipitation Rate Profile in light and heavy (&gt; 5 mm/hr) precipitation | <strong>BM1. 3 Frequency (W-, Ka-bands), Scanning Doppler Radar (with radiometer channels)</strong>&lt;br&gt;(replaces TM1) |
| | <strong>Q2. Climate forcing – Solar [14]</strong>&lt;br&gt;How will shortwave cloud forcing change as the climate warms? | GP5. Profiles of Cloud Optical Depth, single scattering albedo, and asymmetry parameter | <strong>BM2. High Spectral Res. Lidar (HSRL)</strong>&lt;br&gt;(replaces TM2) |
| | <strong>Q2. Climate forcing – Solar [14]</strong>&lt;br&gt;Will the coupling between cloud occurrence and morphology with atmospheric motions and thermodynamic structure result in fundamental changes to the planetary albedo? | GP6. Surface, TOA Cloud Radiative Effects | <strong>BM3. High Resolution Narrow Swath VNIR SWIR Polarimeter</strong>&lt;br&gt;(Replaces TM3) |
| | <strong>Q2. Climate forcing – Solar [14]</strong>&lt;br&gt;What is the role of aerosol in changing the microphysical properties of tropical anvils and modulating their coverage, persistence, and feedbacks to the water cycle in the upper troposphere? | GP7. Latent Heating Profile in light and heavy (&gt; 5 mm/hr) precipitation | <strong>BM4. Narrow Swath High Freq. (183, 389 GHz) Microwave</strong>&lt;br&gt;(Replaces TM3) |
| | <strong>Q3. Climate forcing – Infrared [14]</strong>&lt;br&gt;How will longwave cloud forcing change as the climate warms? | GP8. Radiative Heating Profile | |
| | <strong>Q3. Climate forcing – Infrared [14]</strong>&lt;br&gt;What is the coupling between thermodynamic structure convective processes and the properties of convective anvils in modulating the coverage and properties of tropical cirrus? | GP9. Cloud-Scale Vertical Motion | |
| | <strong>Q3. Climate forcing – Infrared [14]</strong>&lt;br&gt;What is the role of aerosol in changing the microphysical properties of tropical anvils and modulating their coverage, persistence, and feedbacks to the water cycle in the upper troposphere? | GP10. Aerosol/CCN number concentration profile | |
| <strong>T2. Microphysics</strong> | <strong>Q4. Water Cycle and Energy Transport [14]</strong>&lt;br&gt;What is the role of cloud processes (specifically mixed phase) in snow and rain production in middle and high latitude cloud systems? | **| |
| | <strong>Q4. Water Cycle and Energy Transport [14]</strong>&lt;br&gt;What role does the seasonal cycle of middle latitude cloud radiative forcing play in the poleward transport of heat and how is this radiative forcing partitioned as function of cloud genre? | **| |
| | <strong>Q4. Water Cycle and Energy Transport [14]</strong>&lt;br&gt;What is the role of convection versus large-scale dynamics in producing precipitation in the middle and high latitudes? | **| |
| <strong>T3. Microphysical Processes</strong> | **| **| |
| <strong>T4. Energetics</strong> | **| **| |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Focused Questions*</th>
<th>Approach</th>
<th>Measurement Requirements</th>
<th>Instrument Requirements</th>
<th>Platform Requir'ts</th>
<th>Other Needs</th>
</tr>
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<tbody>
<tr>
<td>Ocean Biology</td>
<td><strong>1</strong> What are the standing stocks, composition, &amp; productivity of ocean ecosystems? How and why are they changing? [OBB1]</td>
<td>Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABs), and productivity using bio-optical models &amp; chlorophyll fluorescence</td>
<td>Water-leaving radiances in near-ultraviolet, visible, &amp; near-infrared for separation of absorbing &amp; scattering constituents and calculation of chlorophyll fluorescence</td>
<td>• 5 nm resolution 350 to 755 nm ➤ 1000 - 1500 SNR for 15 nm aggregate bands UV &amp; 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) ➤ 58.8° cross track scanning ➤ Sensor tilt (&lt;20°) for glint avoidance ➤ Polarization insensitive (&lt;1.0%) ➤ 1 km spatial resolution @ nadir ➤ No saturation in UV to NIR bands ➤ 5 year minimum design lifetime</td>
<td>Orbit permitting 2-day global coverage of ocean radiometer measurements</td>
<td>Global data sets from missions, models, or field observations:</td>
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<td><strong>2</strong> How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2]</td>
<td>Measure particulate and dissolved carbon pools, their characteristics and optical properties</td>
<td>Total radiances in UV, NIR, and SWIR for atmospheric corrections</td>
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<td><strong>3</strong> What are the material exchanges between land &amp; ocean? How do they influence coastal ecosystems, biogeochemistry &amp; habitats? How are they changing? [OBB1,2,3]</td>
<td>Quantify ocean biogeochemical processes</td>
<td>Cloud radiances for assessing instrument stray light</td>
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<td><strong>4</strong> How do aerosols &amp; clouds influence ocean ecosystems &amp; biogeochemical cycles? How do ocean biological &amp; photochemical processes affect the atmosphere and Earth system? [OBB2]</td>
<td>Estimate particle abundance, size distribution (PSD), &amp; characteristics</td>
<td>High vertical resolution aerosol heights, optical thickness, &amp; composition for atmospheric corrections</td>
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<td><strong>5</strong> How do physical ocean processes affect ocean ecosystems &amp; biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1,2]</td>
<td>Assimilate ACE observations in ocean biogeochemical model fields of key properties (cf., air-sea CO₂ fluxes, exports, pH, etc.)</td>
<td>Subsurface particle scattering &amp; depth profile</td>
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<td><strong>6</strong> What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]</td>
<td>Combine ACE ocean &amp; atmosphere observations with models to evaluate (1) air-sea exchange of particulates, dissolved materials, and gases and (2) impacts on aerosol &amp; cloud properties</td>
<td>Broad spatial coverage aerosol heights and single scatter albedo for atmospheric correction. Subsurface polarized return for typing oceanic particles</td>
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** 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, PSt, 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/function group concentrations.
- Improve model process parameterizations, e.g., particle fluxes

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* 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

** Specific vicarious calibration & validation requirements are defined in the ACE Ocean Ecosystem requirements document developed as part of ACE pre-formulation activities
With the release of the 2017 Decadal Survey the ACE Pre-formulation Study is in close-out mode
- Activities to conclude by September 2018
- A Final Report will be produced by then
- A workshop is being planned in late April 2018 for assessing ACE accomplishments and provide community feedback on the 2017 DS
  - by invitation only
Thriving on Our Changing Planet

A Decadal Strategy for Earth Observation from Space


#EarthDecadal
Panels

Global Hydrological Cycles and Water Resources

Co-Chairs: Jeff Dozier, UC Santa Barbara and Ana Barros, Duke University

The movement, distribution, and availability of water and how these are changing over time

Weather and Air Quality: Minutes to Subseasonal

Co-Chairs: Steve Ackerman, University of Wisconsin and Nancy Baker, NRL

Atmospheric Dynamics, Thermodynamics, Chemistry, and their interactions at land and ocean interfaces

Marine and Terrestrial Ecosystems and Natural Resource Management

Co-Chairs: Compton (Jim) Tucker, NASA GSFC and Jim Yoder, WHOI

Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services

Climate Variability and Change: Seasonal to Centennial

Co-Chairs: Carol Anne Clayson, WHOI and Venkatachalam (Ram) Ramaswamy, NOAA GFDL

Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System

Earth Surface and Interior: Dynamics and Hazards

Co-Chairs: Dave Sandwell, Scripps and Doug Burbank, UC Santa Barbara

Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate
Path from Science & Applications to Observational Priorities

Blue: Science & Applications; Green: Observables

Appendix A
Program of Record
Fundamental to achieving many of the prioritized science and applications objectives

Table 3.5
8 Targeted Observables
to be implemented in support priority science & applications objectives (of 22 final Observable candidates)

ESAS-Recommended Observing System Priorities 2017-2027

Table 3.3
24 of 103 Science & Applications Objectives identified as Most Important

ESAS-Recommended Science/Applications Priorities 2017-2027

Appendix B - SATM
103 Science & Applications Objectives supporting 35 Science & Applications Questions

Appendix D
290 total Community RFI Responses describing desired science & applications and related observations
Recommended NASA Flight Program Elements

**Program of Record.** The series of existing or previously planned observations, which should be completed as planned. Execution of the ESAS 2017 recommendation requires that the total cost to NASA of the Program of Record flight missions from FY18-FY27 be capped at $3.6B.

- **Designated.** A new program element for ESAS-designated cost-capped medium- and large-size missions to address observables essential to the overall program and that are outside the scope of other opportunities in many cases. Can be competed, at NASA discretion.

- **Earth System Explorer.** A new program element involving competitive opportunities for medium-size instruments and missions serving specified ESAS-priority observations. Promotes competition among priorities.

- **Incubation.** A new program element, focused on investment for priority observation opportunities needing advancement prior to cost-effective implementation, including an Innovation Fund to respond to emerging needs. Investment in innovation for the future.

- **Venture.** Earth Venture program element, as recommended in ESAS 2007 with the addition of a new Venture-Continuity component to provide opportunity for low-cost sustained observations.
## Recommended NASA Priorities: Designated

<table>
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<tr>
<th>TARGETED OBSERVABLE</th>
<th>SCIENCE/APPLICATIONS SUMMARY</th>
<th>CANDIDATE MEASUREMENT APPROACH</th>
<th>Designated</th>
<th>Explorer</th>
<th>Incubation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</td>
<td>Aerosol properties, aerosol vertical profiles, and cloud properties to understand their direct and indirect effects on climate and air quality</td>
<td>Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform</td>
<td>X</td>
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<tr>
<td>Clouds, Convection, &amp; Precipitation</td>
<td>Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes</td>
<td>Radar(s), with multi-frequency passive microwave and sub-mm radiometer</td>
<td>X</td>
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<td>Mass Change</td>
<td>Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth’s atmosphere, oceans, ground water, and ice sheets</td>
<td>Spacecraft ranging measurement of gravity anomaly</td>
<td>X</td>
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<td>Surface Biology &amp; Geology</td>
<td>Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass</td>
<td>Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR</td>
<td>X</td>
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<tr>
<td>Surface Deformation &amp; Change</td>
<td>Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost</td>
<td>Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction</td>
<td>X</td>
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<td><strong>Atmospheric Winds</strong></td>
<td>3D winds in troposphere/PBL for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation</td>
<td>Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td><strong>Planetary Boundary Layer</strong></td>
<td>Diurnal 3D PBL thermodynamic properties and 2D PBL structure to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.</td>
<td>Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height</td>
<td></td>
<td></td>
<td>X</td>
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Liens from last decade into this one are substantial
Very little flexibility to absorb funding challenges until mid decade
Committee sought to keep liens lower on next decade
  Allows more flexibility for next decadal survey
  Some carry over of programs into subsequent decade is required
Since its recommendation by the first 2007 Decadal Survey the ACE Study has made significant progress:

- Advancing measurement concepts:
  - Lidars, Multi-angle Polarimeters and Radars
- Airborne campaigns as proof of concept
- Algorithm development --- GRASP-ACE will contribute to it

New 2017 Decadal Survey proposes two new Designated Missions that can build upon ACE accomplishments:

- Aerosols
- Cloud-Convection-Precipitation (CCP)

NASA HQ will soon provide guidance regarding new Pre-formulation Studies to advance these concepts (FY19)