ACE

Aerosol/Cloud/Ecosystems Mission

# ACE Objectives, Current Status and the 2017 Decadal Survey

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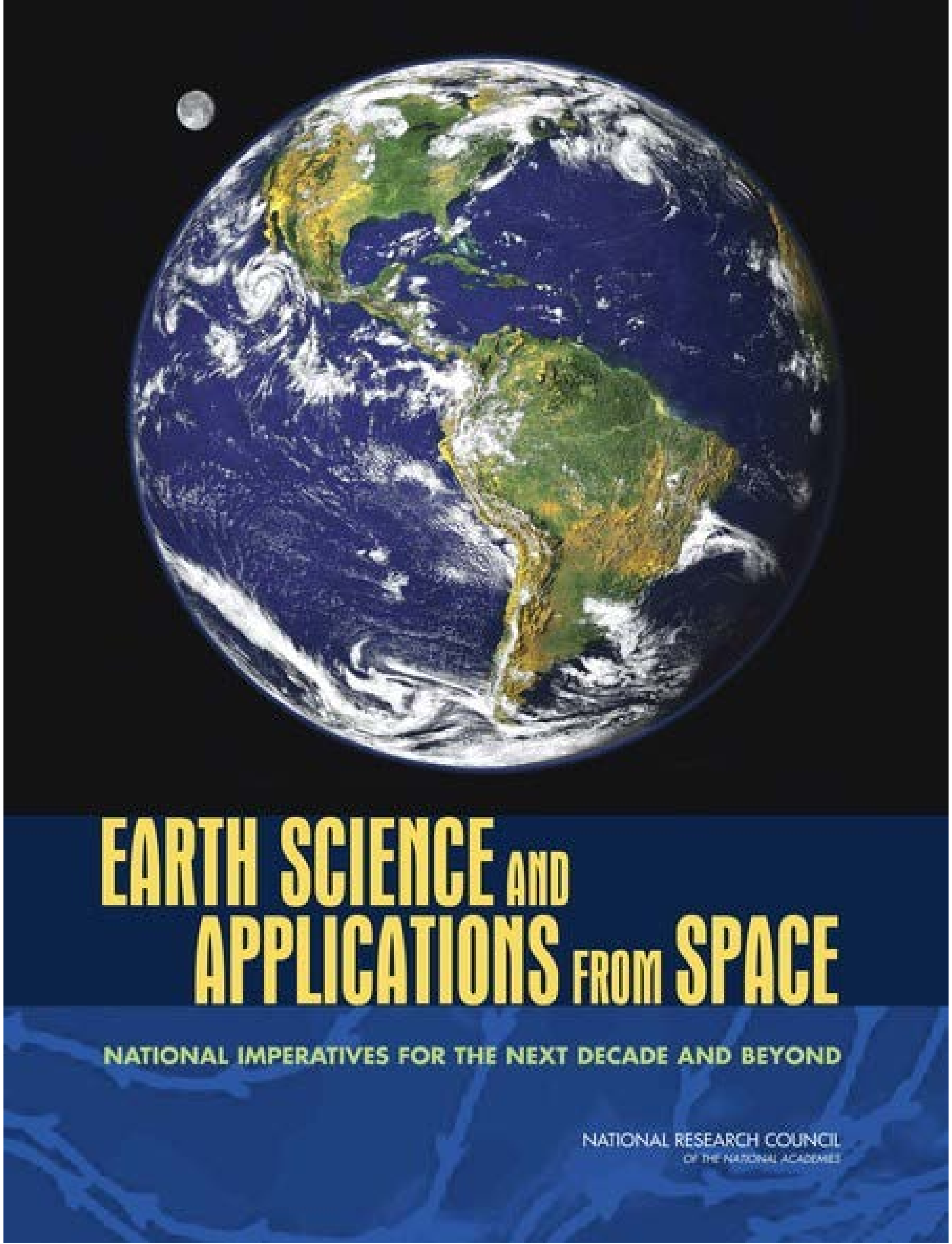
# Outline

- 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

# ACE

Aerosol/Cloud/Ecosystems Mission

- **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

Aerosol/Cloud/Ecosystems Mission

# ACE 2011-2015 Progress Report

# and Future Outlook

*by*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Available from https://acemission.gsfc.nasa.gov/

NASA Earth Science
Decadal Survey Studies

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# Table 2.1 ACE Aerosol Science Traceability Matrix

| Themes | Focused Science Questions | Geophysical Parameters | Measurement Requirements | Mission Requirements |
|---|---|---|---|---|
| **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?<br>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: Q1 Q2 Q3 Q4<br>• $\tau_a(\lambda)$<br>• $\tau_{a,abs}(\lambda)$<br>• $m_a(\lambda)$<br>• $r_{eff\,a}(\lambda)$<br>• $v_{eff\,a}(\lambda)$<br>• Morphology<br>Vertically Resolved: Q1 Q2 Q3 Q4 | High Spectral Resolution Lidar (HSRL)<br>• Backscatter (355, 532, 1064 nm)<br>• Extinction (355, 532 nm)<br>• Depolarization (two wavelengths of 355, 532, 1064 nm)<br>Imaging Polarimeter<br>• Minimum 6 to 8 wavelengths spanning either UV or 410 nm to either 1630 nm or 2250 nm | Integrated satellite, modeling, and data assimilation approach is required to meet science objectives.<br><br>Expand high-resolution global and regional modeling capabilities to assimilate cloud and aerosol microphysical parameters such as number concentration and optical properties.<br><br>Required ancillary data:<br>• Land surface albedo map<br>• Ground network $\tau_a(\lambda)$, shortwave and longwave $F_d$ and $F_{net}$<br>• Ground and airborne: column and vertically resolved $\tau_a(\lambda)$, $\tau_{a,abs}(\lambda)$, $m_a(\lambda)$ (2 modes), morphology, $P_{a,pol}(\theta)$<br>• Space measurements: Top of atmosphere shortwave and longwave $F_u$, 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?<br>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? | • $\tau_{a,abs}(\lambda)$<br>• $m_a(\lambda)$<br>• $r_{eff\,a}(\lambda)$<br>• $v_{eff\,a}(\lambda)$<br>• Morphology<br>Cloud Top: Q3 Q4<br>• $\tau_c$<br>• $\bar{\tau}_{eff,c}$<br>• $\bar{v}_{eff,c}$<br>• Thermodynamic phase | • Multiangle TBD, range ±50°<br>• Polarization accuracy 0.5%<br>• Combination polarized and nonpolarized channels<br>• Resolution: 250 m in at least one channel | |
| **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?<br>Q6. How does the aerosol influence on clouds and precipitation via nucleation depend on cloud updraft velocity and cloud type?<br>Q7. How much does solar absorption by anthropogenic aerosol affect cloud radiative forcing and precipitation?<br>Q8. What are the key mechanisms by which clouds process aerosols and influence the vertical profile of aerosol physical and optical properties? | Vertically Resolved: Q5 Q6 Q7 Q8<br>P1. $N_a$<br>P2. $\tau_{a,abs}(\lambda)$<br>P3. $r_{eff,a}$<br>P4. $N_c$<br>P5. LWC<br>P6. Precip<br>Cloud Top: Q5 Q6 Q7 Q8<br>P7. Cloud top height<br>P8. Cloud albedo<br>P9. LWP<br>P10. $\tau_c$<br>P11. $r_{eff,c}$<br>P12. Cloud radiative effect<br>Cloud Base: Q5 Q6 Q7 Q8<br>P13. Cloud base height<br>P14. Updraft velocity | **Threshhold (i.e. minimum)**<br>**HSRL:** P1 P2 P3 P10<br>**Imaging Polarimeter:** P1 P2 P3<br>**W band Radar:** P4 P5 P7 P13 P14<br>**Narrow swath High-Resolution VIS-MWIR Imager:** P9,P11<br>*Baseline* (additions to threshold):<br>W + Ka Band Doppler radar P6 P14 | |

# Table 2.2 ACE Cloud Science Traceability Matrix

| Themes | Focused Science Questions | Geophysical Parameters | Measurement Requirements | Mission Requirements |
|---|---|---|---|---|
| **T1. Morphology**<br>**Document occurrence, macroscale structure, and decadal scale changes of clouds and precipitation and their interaction with large-scale meteorological and thermodynamic forcing.** | **Q1. Climate Sensitivity**<br>**What is the sensitivity of the climate system to cloud structure and variability? T1 T2 T3 T4**<br>• *What is the role of natural and anthropogenic aerosol in modulating cloud system occurrence and properties?* T1<br>• **What microphysical processes dictate the lifecycle and coverage of clouds under various atmospheric conditions? T1 T2**<br>• *What dictates the processes that cause and modulate precipitation in cloud systems?* T3 | **GP1. Hydrometeor Layer Detection** Q1 Q2 Q3 Q4<br>GP2. *Simultaneously occurring* **Cloud and Precipitation Thermodynamics Phase profile** Q1 Q2 Q3 Q4<br>**GP3.** *Simultaneously occurring* **Cloud and precipitation microphysical properties profiles (Water Content, particle sieze, and number concentration)** Q1 Q2 Q3 Q4<br>GP4. **Precipitation Rate Profile in light** *and heavy (> 5 mm/hr)* **precipitation** Q1 Q2 Q3 Q4<br>GP5. **Profiles of Cloud Optical Depth,** *single scattering albedo, and asymmetry parameter* Q1 Q2 Q3 Q4<br>**GP6. Surface, TOA Cloud Radiative Effects** Q1 Q2 Q3 Q4<br>GP7. **Latent Heating Profile in light** *and heavy (> 5 mm/hr)* **precipitation** Q1 Q3 Q4<br>GP8. *Radiative Heating Profile* Q1 Q2 Q3 Q4<br>GP9. **Cloud-Scale Vertical Motion** Q1 Q4<br>GP10. *Aerosol/CCN number concentration profile* Q1 Q2 Q3 | M1.<br>M2. **Threshold Mission**<br>**TM1. 2-Frequency (W- , Ka-bands), Scanning Doppler Radar (with radiometer channels)** GP1 GP2 GP3 GP4 GP5 GP6 GP7 GP8 GP9<br>**TM2. High Spectral Resolution Lidar** GP1 GP2 GP3 GP5 GP6 GP8 GP10<br>**TM3. Narrow Swath Vis Imager (0.6 microns, 1.6 microns, 2.1 microns)** GP2 GP3 GP5 GP6 GP8 GP10<br>*Baseline Mission*<br>*BM1. 3-Frequency (W- , Ka-, Ku-bands), Scanning Doppler Radar (with radiometer channels)* GP1 GP2 GP3 GP4 GP5 GP6 GP7 GP8 GP9 *(replaces TM1)*<br>*BM2. High Spectral Res. Lidar (HSRL)* GP1 GP2 GP3 GP5 GP6 GP8 GP10 *(replaces TM2)*<br>*BM3. High Resolution Narrow Swath VNIR-SWIR Polarimeter* GP6 GP8 GP10 *(Replaces TM3)*<br>*BM4. Narrow Swath High Freq. (183, 389 GHz) Microwave* GP2 GP3 GP4 GP5 GP6 GP7 GP8 | We define the threshold ACE Clouds Mission as those elements of this matrix that are in **bold** font. We suggest that boldface science objective and questions in columns 1 and 2 could ultimately be addressed by the measurements listed as the Threshold Mission in the Measurement Requirements Column.<br><br>Elements of this matrix in *italicized font* are defined as a *Baseline Mission* and designate important science questions that require a more aggressive set of coordinated measurements that are listed in italicized font.<br><br>The set of baseline and threshold ACE clouds retrieval algorithms will be synergistic such that multiple measurements contribute to the retrieval of a geophysical parameter. For instance while microwave brightness temperatures cannot generally be used to retrieve cloud microphysics, when passive microwave is combined with multi frequency Doppler radar, the microwave brightness temperatures provides an important constraint on the retrieval algorithm. |
| **T2. Microphysics**<br>**Document the microphysical properties of liquid, ice, and mixed phase clouds and precipitation with a specific focus on high latitude snow and light liquid precipitation (less than 1 mm/hr) at all latitudes that influences cloud morphology and lifecycle and ultimately radiative balance.** | **Q2. Climate Forcing – Solar (T4)**<br>**How will shortwave cloud forcing change as the climate warms? T1 T2 T3 T4**<br>• **Will the coupling between cloud occurrence and morphology with atmospheric motions and thermodynamic structure result in fundamental changes to the planetary albedo? T1 T2**<br>• *What is the specific role of aerosol in modulating the properties of clouds and the planetary albedo under a changing climate? (T2, T3)* | | | |
| **T3. Microphysical Processes**<br>**Identify the occurrence of microphysical processes that cause changes to profiles of aerosol, clouds, and precipitation properties.** *Concurrently quantify the process rates of important microphysical processes such as autoconversion and accretion in liquid and ice-phase stratiform and convective clouds.* | **Q3. Climate Forcing – Infrared (T4)**<br>**How will longwave cloud forcing change as the climate warms? T1 T2 T3 T4**<br>• **What is the coupling between thermodynamic structure convective processes and the properties of convective anvils in modulating the coverage and properties of tropical anvil cirrus T1 T2 T3**<br>• *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?* T1 T2 T3 | | | |
| T4. Energetics<br>*Understand the maintenance of and changes to the energetic balance of the atmosphere and earth system due aerosol, clouds, and precipitation.* | **Q4. Water Cycle and Energy Transport (T4)**<br>**What is the role of cloud processes (specifically mixed phase) in snow and rain production in middle and high latitude cloud systems? T1 T2 T3 T4**<br>• **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? T4**<br>• *To what degree do various microphysical processes when coupled with large-scale dynamics modulate the precipitation production within middle and high latitude frontal systems?* T2 T3<br>• **What is the role of convection versus large-scale dynamics in producing precipitation in the middle and high latitudes? T1 T3** | | | |

# Ocean Ecosystems STM

| 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 groups (functional/HABS), and productivity using bio-optical models & 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 (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 |
| 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 | Instrument Requirements |
|---|---|---|
| Water-leaving radiances in near-ultraviolet, visible, & near-infrared for separation of absorbing & scattering constituents and calculation of chlorophyll fluorescence<br><br>Total radiances in UV, NIR, and SWIR for atmospheric corrections<br><br>Cloud radiances for assessing instrument stray light | Ocean Radiometer | • 5 nm resolution 350 to 755 nm<br>▷ 1000 – 1500 SNR for 15 nm aggregate bands UV & visible and 10 nm fluorescence bands (665, 678, 710, 748 nm centers)<br>▷ 10 to 40 nm width atmospheric correction bands at 748, 765, 820, 865, 1245, 1640, 2135 nm<br>• 0.1% radiometric temporal stability (1 month demonstrated prelaunch)<br>• 58.3° cross track scanning<br>• Sensor tilt (±20°) for glint avoidance<br>• Polarization insensitive (<1.0%)<br>• 1 km spatial resolution @ nadir<br>• No saturation in UV to NIR bands<br>• 5 year minimum design lifetime |
| High vertical resolution aerosol heights, optical thickness, & composition for atmospheric corrections<br><br>Subsurface particle scattering & depth profile | Lidar | • 0.5 km aerosol vertical resolution<br>• 2 m sub-surface resolution<br>• < 0.3% polarization misalignment<br>• 0.0001 $km^{-1}sr^{-1}$ aerosol backscatter sensitivity at 532 nm after averaging<br>• < 4 ns e-folding transient response<br>• 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°<br>• Angle resolution: 5°<br>• 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<br><br>Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m.<br><br>Storage and download of full spectral and spatial data<br><br>Monthly lunar calibration at 7° phase angle through Earth observing port | Global data sets from missions, models, or field observations:<br><br>*Measurement Requirements*<br>(1) Ozone<br>(2) Total water vapor<br>(3) Surface wind velocity<br>(4) Surface barometric pressure<br>(5) $NO_2$ concentration<br>(6) Vicarious calibration & validation **<br>(7) Full prelaunch characterization (2% accuracy radiometric)<br><br>*Science Requirements*<br>(1) SST<br>(2) SSH<br>(3) PAR<br>(4) UV<br>(5) MLD<br>(6) $CO_2$<br>(7) pH<br>(8) Ocean circulation<br>(9) Aerosol deposition<br>(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*

** Specific vicarious calibration & validation requirements are defined in the ACE Ocean Ecosystem requirements document developed as part of ACE pre-formulation activities

# Status of ACE

- 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

Available from http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm

# 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*

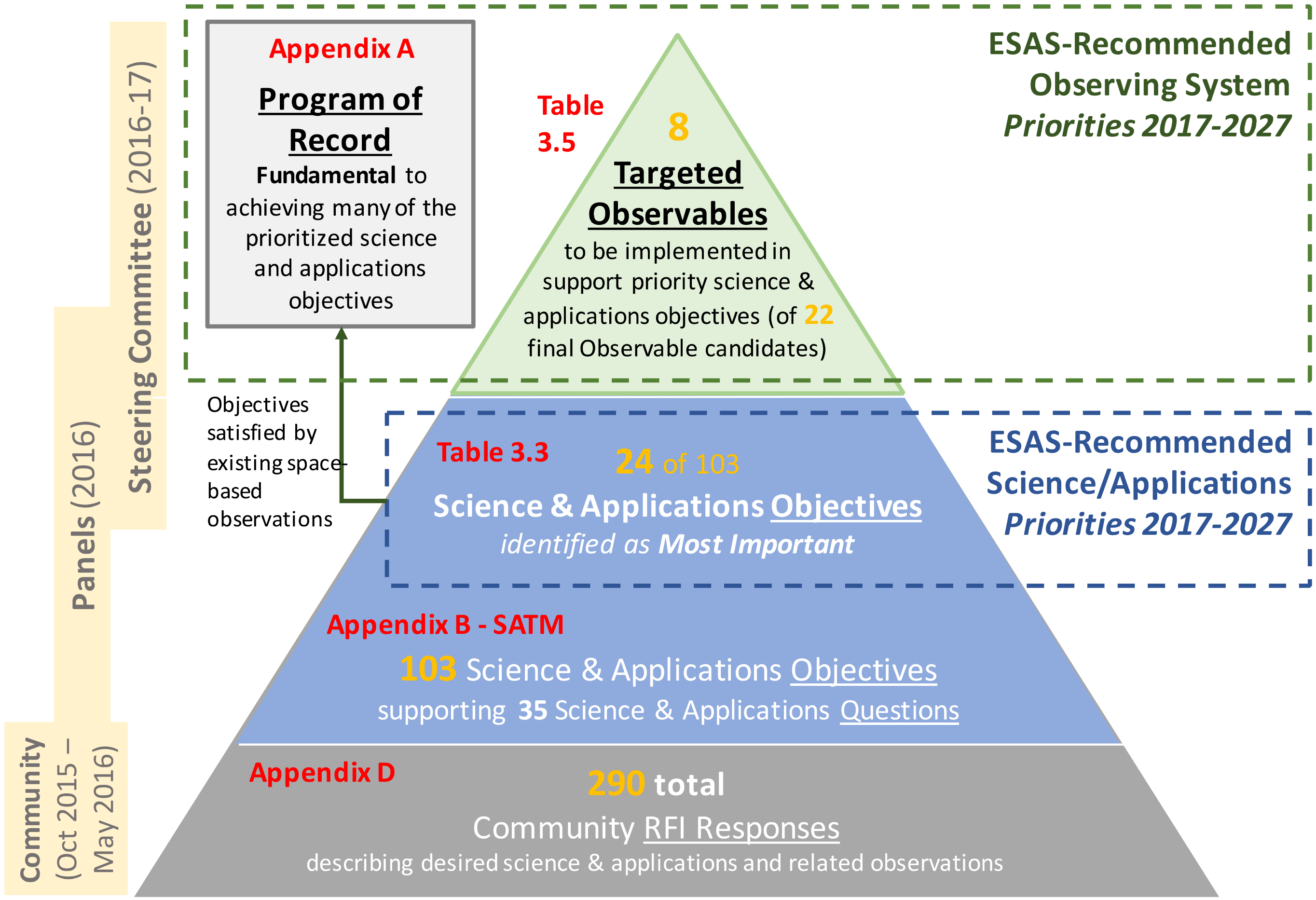
### Earth Surface and Interior: Dynamics and Hazards

*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



# 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***.

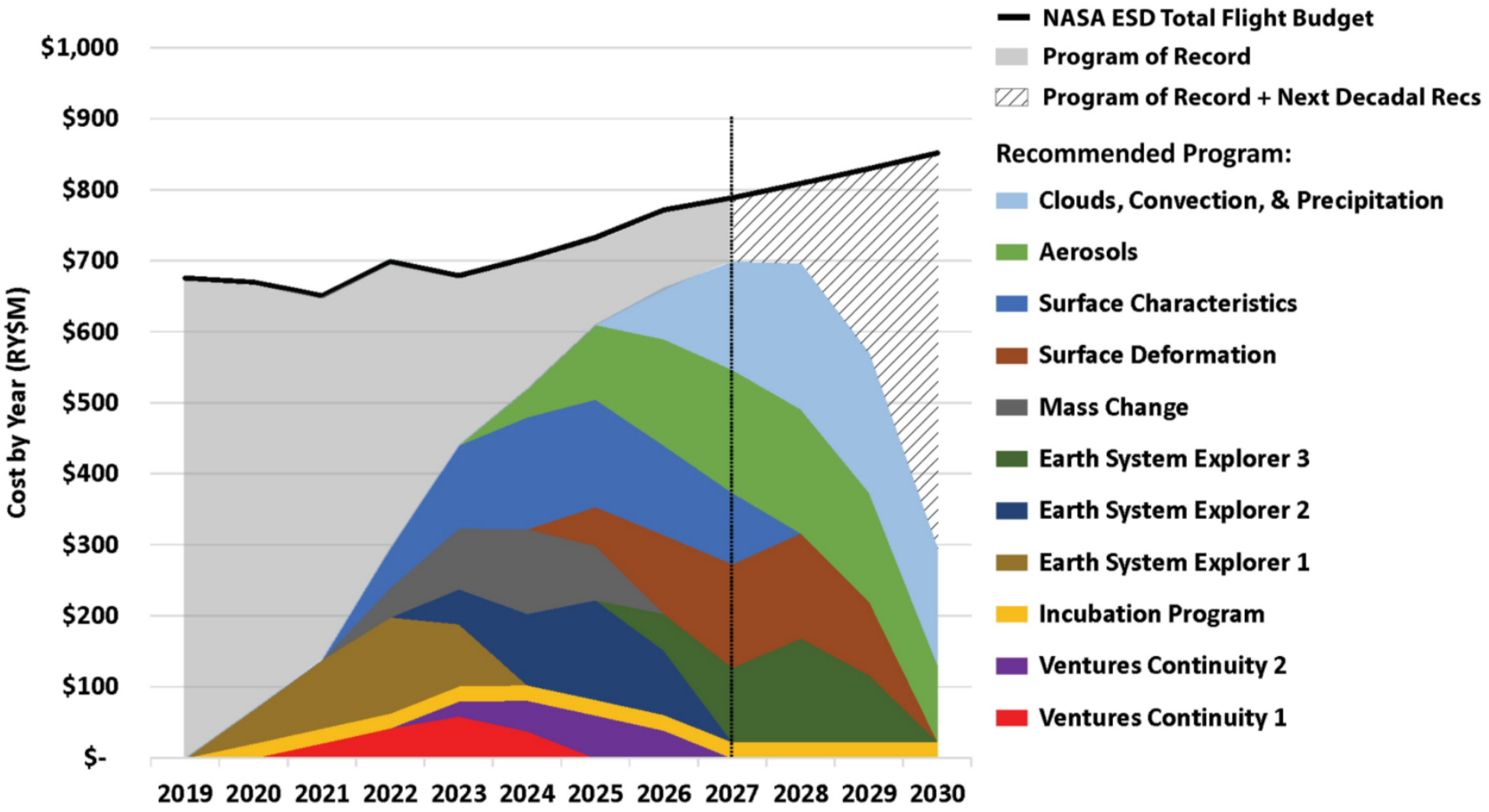
# Recommended NASA Priorities: Designated

| TARGETED OBSERVABLE | SCIENCE/APPLICATIONS SUMMARY | CANDIDATE MEASUREMENT APPROACH | Designated | Explorer | Incubation |
|---|---|---|---|---|---|
| **Aerosols** | **Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality | Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform | X | | |
| **Clouds, Convection, & Precipitation** | **Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes | Radar(s), with multi-frequency passive microwave and sub-mm radiometer | X | | |
| **Mass Change** | **Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets | Spacecraft ranging measurement of gravity anomaly | X | | |
| **Surface Biology & Geology** | **Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass | Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR | X | | |
| **Surface Deformation & Change** | **Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost | Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction | X | | |

# Recommended NASA Priorities: Incubation/Other

| TARGETED OBSERVABLE | SCIENCE/APPLICATIONS SUMMARY | CANDIDATE MEASUREMENT APPROACH | Designated | Explorer | Incubation |
|---|---|---|---|---|---|
| **Atmospheric Winds** | **3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation | Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar** | | X | X |
| **Planetary Boundary Layer** | **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. | 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 | | | X |

# NASA Budget Compliance




- 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

# Summary

- 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 iy
- 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)