The NASA Decadal Survey Observing System Study for Aerosols, Clouds, Convection, and Precipitation (ACCP)

S. Braun[1], A. da Silva[1], R. Ferrare[2], M. Kacenelenbogen[5], D. Kirschbaum[1], A. Omar[2], W. Petersen[4], G. Stephens[3], D. Waliser[3], and D. Winker[2]

1 Goddard Space Flight Center 2 NASA Langley Research Center 3 JPL California Institute of Technology 4 Marshall Space Flight Center 5 Goddard Earth Sciences Data and Information Services Center

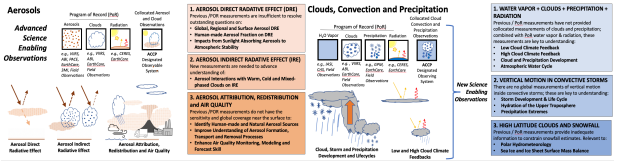
Introduction and 2017 NASA Decadal Survey

The Decadal Survey report was released in January of 2018 and called for a new program element for designated cost-capped medium- and large-size missions to address observables essential to the overall Earth Science program. The designated observables included Aerosols (A); Clouds, Convection, and Precipitation (CCP); Mass Change; Surface Biology and Geology; and Surface Deformation and Change. A and CCP priorities and desired observable capabilities are shown below, and provide the key guidance for a NASA study on a combined ACCP observing system. The study includes definition of the science goals and objectives, identification of potential applications, and an exploration of a wide spectrum of observing system architectures (orbital and sub-orbital) that NASA HQ can use to move forward with a potential mission Phase-A start in the 2022 time frame.

CCP Observable Priorities	CCP Desired Observable Capabilities	Aerosol Observable Priorities	Aerosol Desired Observable Capabilities
Coupled cloud-precipitation state and dynamics for monitoring the global hydrological cycle and understanding contributing processes including cloud feedback.	Radar(s), with multi-frequency passive microwave and sub-mm radiometer.	Aerosol properties, aerosol vertical profiles, and cloud properties to understand their effects on climate and air quality.	Backscatter lidar and multichannel, multi-angle/polarization imaging radiometer flown together on the same platform.

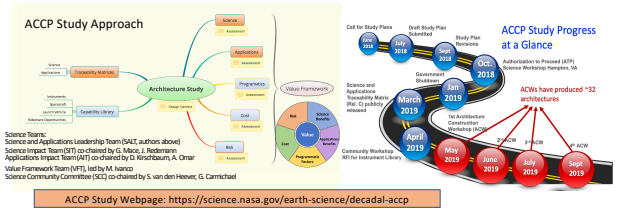
Why We Need ACCP

Descriptions of key aspects of A and CCP are below. ACCP is motivated by the strong coupling of the two designated observables. Aerosols are a fundamental and enabling component to the formation of clouds and precipitation. Precipitation removes aerosols and deep convection and other storms loft and redistribute aerosols.



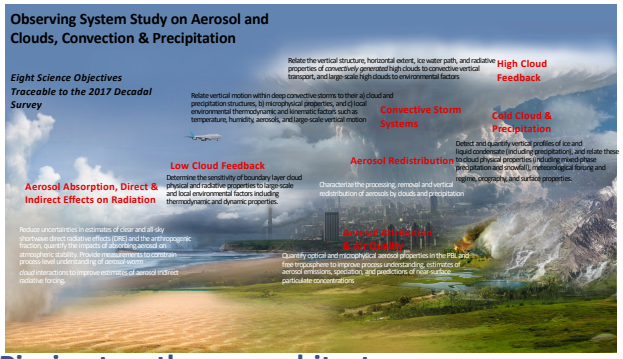
ACCP Study Plan and Progress

In June 2018, NASA HQ requested multi-NASA Center study plans for developing science goals & objectives and architecture concepts for Decadal Survey Designated Observables (DOs), with two DOs transitioning into potential missions in the 2021-2022 time frame (launches in the mid-late 2020s).

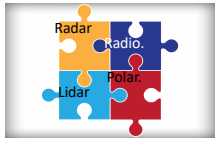


ACCP Study Webpage: https://science.nasa.gov/earth-science/decadal-accp

ACCP Science Objectives



Piecing together an architecture



A full architecture includes
- Instruments
- Spacecraft buses
- Ground systems
- Launch vehicles
- Mission operations
- Suborbital campaigns
- Science team (data analysis and algorithms)

ACCP Instrument Library Summary

Radars	Radiometers	Lidars	Polarimeters	Spectrometers	Other
W, Ka, Ka, scanning, Doppler W, Ka, scanning, Doppler W, Ka, nadir, Doppler **W, Ka, nadir, Ka Doppler** **W, Ka, nadir, no Doppler** Ku, Ka, scanning, Ku Doppler Ku, Ka, scanning, no Doppler W, scanning, Doppler **W, nadir, no Doppler** **Ku, nadir, Doppler** **Ku, scanning, no Doppler** **Ku, nadir, no Doppler** Ku, nadir, Doppler Ku, scanning, no Doppler	11, 19, 24, 37, 89, 166, 183 11, 19, 24, 37, 89 **24, 31, 85, 89, 166, 183** **19, 24, 34** 118, 183 **87, 164, 174, 178, 191** **118, 183, 243, 310, 380, 660, 880** **883** **183** **183, 326** **670** **220, 660 GHz/ 8.6, 11, 12 microns** **91, 118, 183, 285** Radiometer channels in GHz	**532 bs, 1064 bs** 532 bs, 1064 bs 355 HSRL, 532 HSRL 532 bs, 1064 bs 532 HSRL, 1064 bs 355 HSRL, 532 HSRL, 1064 bs 355 HSRL, 532 bs, 1064 bs **1064 bs** **532 bs, 1064 bs** backscatter HSRL+high Spectral Resolution Lidar	14 channels, 5 angles **14 channels, 5-0 angles** Hyperspectral, 1 angle **Hyperspectral, 5 angles** **10 channels, 60 angles** **11 channels, 60 angles** **12 channels, 60 angles** **15 channels, 60 angles** **9 channels, 255 angles** **8 channels, 120 angles** Channels in VIS, VNIR, SWIR	**LWIR, 3 channels** **VIS/NIR/SWIR, hyperspectral** **LWUV/VIS/NIR/SWIR, hyperspectral** **LWIR/FIR, 8 channels** **TIR, 60 channels** LWIR=Longwave IR LWUV=Longwave ultraviolet VIS=visible NIR=near IR SWIR=Shortwave IR FIR=far IR TIR=Thermal IR	**Ocean s/c wind vectors** **GNSS Sfc reflectometry** **GNSS sounding** **Aerosol limb imaging** **Water vapor limb imaging** **Stereo visible imaging radiometers**

Small satellite capable sensors indicated in bold.

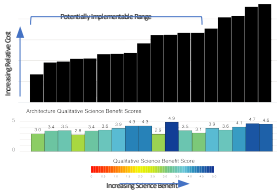
- NASA HQ will likely select many of the instruments through an open solicitation
- Finding an observing system that meets objectives within the cost cap is ultimately dependent on knowledge of available capabilities (instrument library above)

Initial Architecture Studies

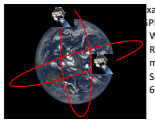
Four Architecture Construction Workshops (ACW) explored ~32 different architectures (two examples shown below):
- Polar-orbiting observing system architectures for single and two-satellite (non-smallsat) solutions
- Smallsat (<180 kg) solutions, including various constellations in both polar and mid-latitude (e.g., GPM) orbits
- Hybrid smallsat/largesat approaches
- Lower-inclination orbit constellation of cubesats for diurnal sampling

Rough cost estimates and perceived qualitative science benefits were determined for most ACW1-3 architectures (see right). Higher fidelity cost estimates and quantitative benefit scores are the subject of future work.

Relative costs and qualitative science benefit scores for ACW1-3 architectures



Example 1: Dual-satellite, single-orbit architecture with:
W, Ka-band non-scanning radar, Ku Doppler non-scanning radar
Radiometer with 118, 183 GHz, and several sub-mm channels
Dual-wavelength HSRL lidar
Hyperspectral spectrometer
60-angle polarimeter



Example 2: Dual-satellite, dual-orbit (Polar & GPM) architecture, both with:
W, Ka-band non-scanning radar, Doppler at Ka
Radiometer with 118, 183 GHz, and several sub mm channels
Smallsat dual-wavelength backscatter lidar
60-angle polarimeter

Quantitatively Evaluating Science Benefit

All architectures need to be assessed in terms of their science and applications benefits, costs, risks, and other programmatic factors. This analysis is done using a Value Framework. Key parameters for assigning a science benefit score include the ***utility*** of geophysical variables for achieving the science objectives and the ***quality*** of the geophysical variables that are derived from each architecture. An illustrative example of the concept is shown to the right. Notionally, the science benefit for a given science objective is the sum of the product of the utility and quality scores for all of the geophysical variables contributing to that objective.

The value framework will allow for a fairly objective cost-benefit assessment of the architectures considered within the observing system study.

$$B = \sum UQ$$

B = Family/Customer Satisfaction

TRADITIONAL HAMBURGER RECIPE

Ingredients	Utility	Quality
Patty	0.60	1.0 = ½ lbs, 100% Angus Beef, Charbroiled 0.4 = vegan "Impossible" burger
Bun	0.20	0.8 = sesame seed topped whole wheat bun 0.4 = small, white bread bun
Cheese	0.10	0.9 = Cheddar 0.6 = American 0.3 = Mozzarella
Tomato	0.04	etc
Lettuce	0.04	etc
Onions	0.01	etc
Ketchup	0.01	etc

Utility is the importance of the Ingredient to the Recipe
Quality is the quality of the given ingredient relative to a best possible
(NOTE: Utility is probably more subjective than Quality)

Summary and Future Plans

A multi-NASA Center study is underway to provide concepts and an assessment of potential observing system architectures for an Aerosols, Clouds, Convection, and Precipitation (ACCP) observing system. A preliminary set of minimum and enhanced science objectives, geophysical variables, and observables has been identified, and a set of architecture construction workshops have explored a wide range of potential observing system architectures and their roughly estimated costs. Future plans include:

- More detailed collaborative design center (CDC) studies starting in October focused on prioritized architectures with expected high science benefit and within an acceptable cost range. The ACCP study will do ~6 CDC studies over the next 12-16 months.
- Value framework scoring of architectures following each CDC, considering science & applications benefits along with cost, risk, and programmatic factors.
- Suborbital workshop in March 2020 time frame to identify and prioritize science objectives for focused airborne campaigns.
- Final report to NASA HQ in September 2021
- Notional launch date in 2028-29 time frame

Comments on the ACCP study can be sent to a-ccp-comments@lists.nasa.gov