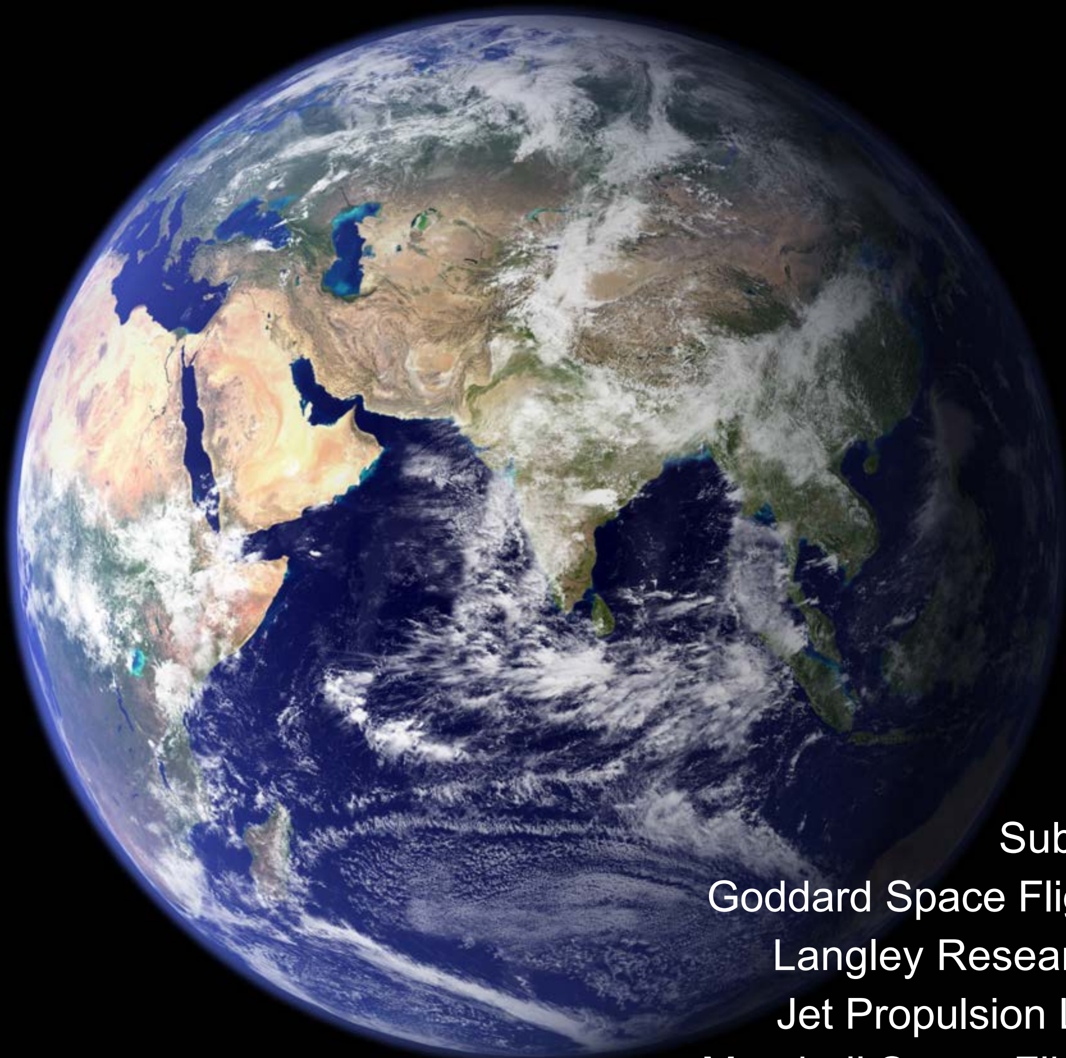
National Aeronautics and Space Administration

Aerosols and Cloud-Convection Precipitation (A-CCP) Study

Draft Study Plan in response to Designated Observables Guidance for Multi-Center Study Plans

An awe-inspiring, truly joint Center plan



Submitted by:
Goddard Space Flight Center
Langley Research Center
Jet Propulsion Laboratory
Marshall Space Flight Center
Ames Research Center
Glenn Research Center

July 16, 2018
(r3 Dec 4, 2108)

TO: Eric E. Ianson
Associate Director, Flight Programs
Earth Science Division
Science Mission Directorate

FROM: James Irons, Director, Earth Sciences Division, NASA/GSFC

SUBJECT: A-CCP Draft Study Plan in response to NASA's *Designated Observables Guidance for Multi-Center Study Plans* released on June 1, 2018

DATE: 16 July 2018

The Goddard Space Flight Center (GSFC), the Langley Research Center (LaRC), the Jet Propulsion Laboratory (JPL), in partnership with the George C. Marshall Space Flight Center (MSFC), the Ames Research Center (ARC), and the Glenn Research Center (GRC), are pleased to submit the *Aerosols and Cloud-Convection-Precipitation (A-CCP) Draft Study Plan* to support the Designated Observables that have been described as five of the highest-priority Earth observation Needs in the 2017 Earth Science Decadal Survey (DS). The scientific, technical, and programmatic requirements of this project are in line with the expertise and capabilities of the under-signed Centers.

GSFC, LaRC, JPL, MSFC, ARC, and GRC support the *A-CCP Draft Study Plan*, with William E. Cutlip from GSFC as the Study Coordinator. This includes all of the major functions needed to execute the pre-formulation study as described in the proposal, including providing the science leadership, project management, and systems engineering. The cost per fiscal year is \$5.6M (FY19), \$5.8M (FY20), and \$3.8M (FY21). The project will be ready to start on or before October 1st, 2018.

Questions of a technical or programmatic nature concerning the proposed project may be addressed directly to the Study Coordinator, Mr. William Cutlip, william.e.cutlip@nasa.gov, +1 (301) 821-0149.

Sincerely,

James R. Irons
Director, Earth Sciences Division
Goddard Space Flight Center

David F. Young
Director, Science Directorate
Langley Research Center

Diane Evans
Director, Earth Science and Technology Directorate
Jet Propulsion Laboratory

William E. Cutlip
A-CCP Study Coordinator
Goddard Space Flight Center

Charles R. Trepte
A-CCP Deputy Study Coordinator
Langley Research Center

Debora G. Vane
A-CCP Deputy Study Coordinator
Jet Propulsion Laboratory

A-CCP EXECUTIVE SUMMARY

In response to NASA's *Designated Observables Guidance for Multi-Center Study Plans* released on June 1, 2018, GSFC, LaRC, JPL, MSFC, GRC and ARC submit this Study Plan to the NASA Earth Science Division for the Aerosol (A) and Cloud, Convection, and Precipitation (CCP) Pre-formulation Study (A-CCP). The A-CCP team membership reflects the very best that NASA Centers have to bring to addressing the goal of the A-CCP study. GSFC, LaRC, and JPL all bring recognized expertise in the aerosol and cloud, convection, and precipitation science fields as well as established mission architecture design centers and systems engineering/subject matter experts. ARC and MSFC bring focused science expertise in the areas of field campaigns and applications, with MSFC also bringing design center experience and systems engineering/subject matter expertise. Rounding out the multi-Center aspect of the A-CCP team, GRC brings established mission design center expertise (COMPASS) and systems engineering/subject matter expertise. The A-CCP team will operate as one team, with the proposed management structure lending itself to clean lines of responsibility and authority, which also facilitates efficient communications between all partners.

The goal of the A-CCP study is to define objectives for the A and CCP Designated Observable (DO) observing systems, the desired capabilities associated with these observables, and observing systems approaches to achieve them. This study leverages the results from studies such as the Aerosol-Cloud-Ecosystems (ACE) study, those from existing and proposed Earth Venture concepts, and analysis already conducted on data from past field experiments and recent advances of modeling systems and Observing System Simulation Experiments (OSSEs).

Science/Application Objectives and Measurement Approaches

The 2017 Decadal Survey (DS) highlighted Earth System Science themes, science and application questions, and several high priority objectives that have led to the inclusion of A and CCP as DOs. The aerosol-related science questions outlined by the DS focus on two major themes: 1) Climate Variability and Change and 2) Weather and Air Quality. The Aerosol mission observables targeted to address these major objectives may potentially contribute to three additional themes: 3) Marine and Terrestrial Ecosystems, 4) Global Hydrological Cycle, and 5) Earth Surface and Interior; this study will examine these linkages.

The DS identified CCP as a DO focused on coupled cloud-precipitation states and dynamics for addressing cloud and precipitation processes relevant to a wide sector of the science objectives called out in the disciplinary panels, as well as gaps in the precipitation Program of Record (PoR). CCP was deemed critical for assessing low and high cloud feedbacks, advancing seasonal and interannual climate variability and prediction, and characterizing convective processes that are at the core of severe and extreme weather. CCP was deemed relevant to a large cross section of the panel's most important objectives.

The DS recognized the science merit in combining the A and CCP DOs for both enhancing the ability to address a number of Most Important (MI) objectives defined by the disciplinary panels and also to provide an expanded capability to address additional objectives beyond those addressed by individual DOs. The DS also identified Integrating Themes that can also be addressed through combinations of observables including potential combinations of DOs and the PoR. The combined A+CCP portion of this study will demonstrate how the combination of A and CCP observables will enhance the objectives of A and CCP individually, while providing the ability to expand the DS objectives addressed, and will closely connect to the A and CCP studies being performed in parallel.

To inform observing system architecture down-select decisions, the A-CCP team will develop and adopt a framework to characterize the value of each mission architecture, with the value of a mission architecture defined by its science, application, and programmatic benefits relative to its associated cost and risk. Leading into and during those decision processes, this Value Framework will provide a consistent and structured format that captures the key parameters for each mission architecture that will drive the down-select decision, supporting the facilitation of the discussions across this multi-center team and with Earth Science Division leadership. After the decisions are made, the framework can then be used to provide transparency into the analysis and factors that resulted in the decision, informing subsequent mission formulation and advocacy efforts.

The primary connection of the A-CCP study to the wider science community – including Academia – is realized through the Science Community Cohort (SCC). The SCC is an external group consisting of leading national and international scientists (and application practitioners) in the Aerosols and CCP communities. The SCC is co-chaired by Dr. Gregory Carmichael of the University of Iowa and Dr. Susan van den Heever of Colorado State University with Dr. Carmichael leading discussions in aerosol sciences and Dr. van den Heever leading discussions in CCP sciences. In consultation with ESD, it is one of our priorities to appoint the members of the SCC early in the study. The SCC provides science community perspective relating to science directions of the A-CCP study. The SCC will be provided with the science outputs of the study, the Value Framework Plan, and offer guidance to the Science/Applications Leadership Team (SALT) on possible revisions that would strengthen the overall A-CCP study. In addition, the SALT may organize town hall style meetings at the AGU, EGU, and AMS annual meetings to brief the broader scientific community on the status of the A-CCP study, collect input from the broader academic community, and to engage in discussions with potential national and international partners.

Architectural Approaches for Designated Observables

Essential to a successful observation system architecture activity is the integration of science, applications and engineering throughout the process. Maintaining this integrated approach during the A-CCP study will maximize the potential for end results that reflect an optimal balance between science needs and technical capabilities. To this end, the A-CCP study contains multiple check points where the science leadership team, applications team, and the independent science panel meet with the systems engineering team and the subject matter expert engineering panel to review aspects of the study.

The A-CCP team will use an integrated system architecture approach to map the performance-cost-risk trade space of the A-CCP DOs. This approach requires the use of prioritized science and application traceability matrices (SITMs), with varying levels of performance requirements (requirements (aka "desired capabilities") will include a prioritized list of geophysical variables along with necessary orbital, temporal, and spatial sampling), along with matching libraries of varying technical capability and technology readiness. The architecture formulation phase of the A-CCP study will begin with a joint review of the prioritized SITMs by the science leadership team, independent science panel, systems engineering team (made up of a single Study Plan Systems Engineer from each of the partner Centers, as applicable), and a subject matter engineering panel from each partner NASA Center and the Aerospace Corporation — as applicable. The intent of this joint review is to ensure that there is a shared understanding of the science objectives and related desired measurement capabilities, as well as any sensitivities and interdependencies inherent to the measurements.

To conduct assessments of a comprehensive set of observation systems architectures, technical capability and technology readiness libraries for the instruments, spacecraft, mission operations, ground and data systems, and access-to-space providers will be created. The instrument library will be developed by a multi-center team and contain entries of different instrument types (*e.g.*, radar, polarimeter, lidar) at varying levels of performance (*e.g.*, threshold and baseline), maturity [no less than TRL 6 by the A-CCP system level Preliminary Design Review (PDR)], and cost. Instrument concept specifics will be solicited from a wide array of providers, including NASA Centers and JPL, industry, and academia through the use of a Request For Information (RFI). The RFI will be released and followed up by an Industry/Academia Q&A day held at the GSFC.

Commercial data buys in lieu of conventional instrument deployment will also be considered, as will the data available from Other Government Agencies (OGAs) and foreign space agencies according to the existing PoR. Consistent with the study's approach to TRL, the discussion of commercial data buys and data available from OGAs and foreign space agencies will focus on existing offerings and projected offerings expected to be mature (TRL equal to or greater than 6) at the time of the A-CCP's observation system PDR. Risks associated with these alternative approaches will be identified and assessed vis-à-vis using NASA dedicated capabilities.

Consistent with the intent to provide a comprehensive assessment of observing system architectures to ESD, single spacecraft, multiple small satellites, and hybrid architectures will be evaluated for each potential science observable option (*e.g.*, Aerosols as a Single Observing System, CCP as a Single Observing System, and a Combined Aerosol and CCP Observing System). An architecture type can satisfy the SITMs at varying levels of value determined by the composition of a constellation. A constellation consists of a selection of one or more instrument(s) placed on one or more spacecraft flying in one or more orbit(s). Inherent to each architecture examined is appropriate launch and ground system capabilities. Phase E operation concepts could consider government and commercial solutions for communications, data processing, and storage.

To ensure transparency and unbiased results, the studies will be conducted at design centers located at GSFC, LaRC, JPL, GRC, MSFC, and the Aerospace Corporation. Each design center will be provided with the same set of technical/technology libraries to ensure uniformity of inputs for the respective studies, along with access to the Science Leadership Team, in the event that science-related questions arise. The design centers at MSFC, GRC, and the Aerospace Corporation will provide results independent of any perceived organizational bias tied to the use of instruments associated with a given Center.

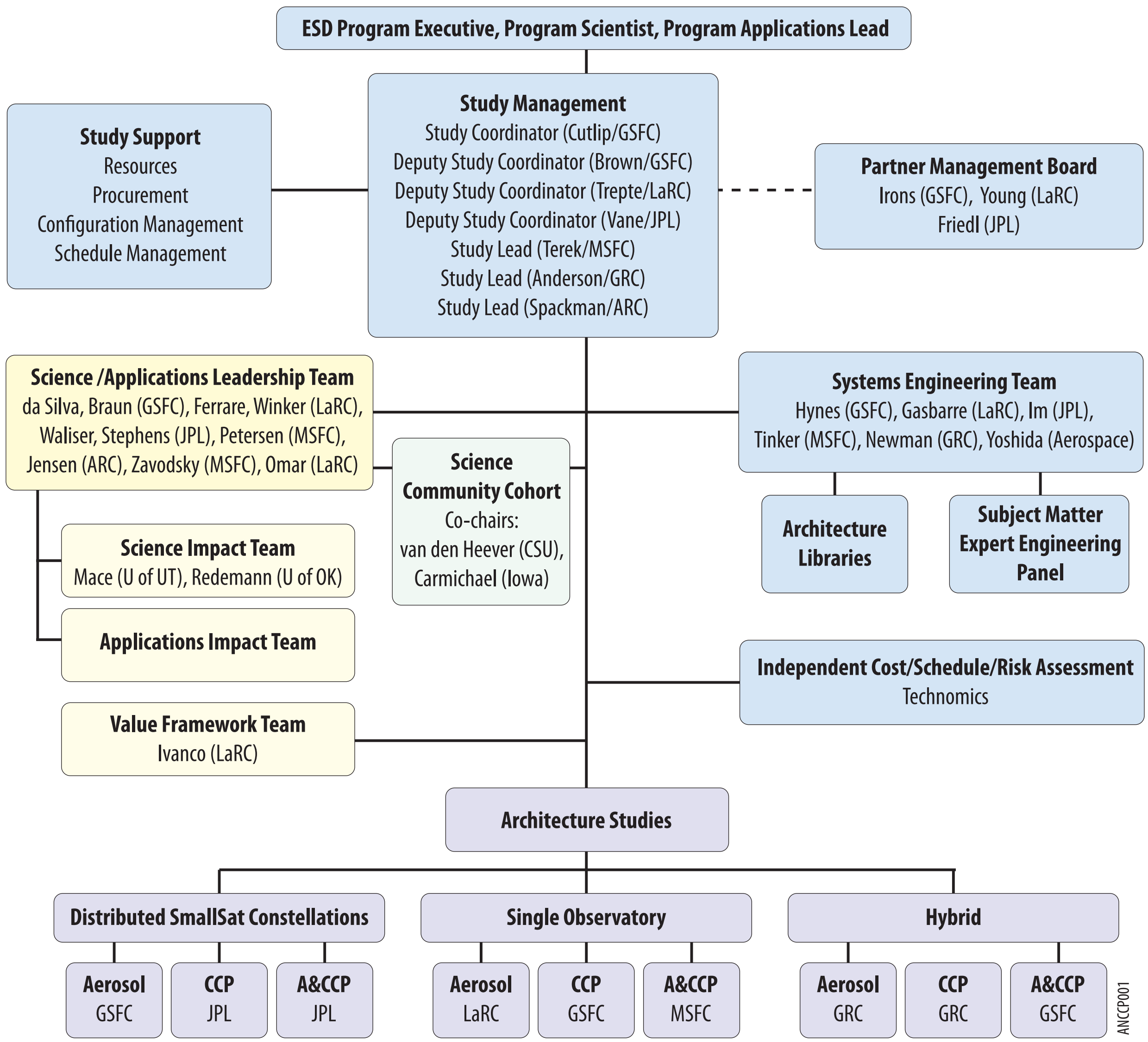
Independent Science, Cost and Schedule Assessment

The study team will perform a comprehensive assessment of the observing system architectures, applying a comprehensive framework to analyze the value of each architecture as defined by its provided benefits relative to its associated cost and risk (schedule and technical). LaRC's Systems Analysis and Concept Directorate (SACD), which has developed similar frameworks for supporting mission analysis efforts for other NASA mission directorates, will take the lead in setting up the structure for quantitatively and qualitatively assessing the value of the mission architectures, including science and programmatic figures of merit.

The A-CCP Study Coordinator will work closely with the study management team to formulate standardized data sheets that will contain the results from the individual architecture studies needed to perform independent cost/schedule/technical risk assessments. These independent assessments will be performed by Technomics.

Technomics employs a systematic process that ensures the development and documentation of credible, defensible cost estimates. The process employed in the A-CCP study will reflect features that are consistent with best practices, specifically the Government Accounting Office's (GAO's) prescribed "12 Steps of a High-Quality Cost Estimating Process." This process has numerous feedback loops in order to improve estimating approaches as additional information is compiled and results are analyzed.

The final "Reconciliation" step's focus for the A-CCP study will be the comparison of Center design-center-developed and Technomic cost estimates, followed by assessment of the magnitude of cost differences and investigation of the underlying assumptions, data, and methodologies driving those differences. The thorough application of all aspects of this step will ensure uniformity of the formatting of final results (*e.g.*, the estimates will be presented in tabular and graphical formats to ensure the results are easily interpreted), thus enabling the efficient application of results by ESD.



The A-CCP Study organization is designed for optimal communications between very experienced team members.

Study Management

The A-CCP team, led by Study Coordinator Mr. William Cutlip, is a truly multi-Center team grounded in management best practices reflective of over 40 years of successfully managing both large and small missions for NASA's Science and Mission Directorate (SMD). Key to the A-CCP team's management philosophy is an emphasis on open communication and acceptance of varying opinions in its decision-making process.

Overall study management is provided by NASA's GSFC, which brings a proven record of successfully managing mission architecture studies for SMD's Earth Sciences, Astrophysics, and Heliophysics divisions. The multi-Center aspect of the team is reflected in the essential use of Deputy Study Coordinators at LaRC and JPL, as well as Center Study Leads at MSFC, ARC, and GRC, as shown in the figure below.

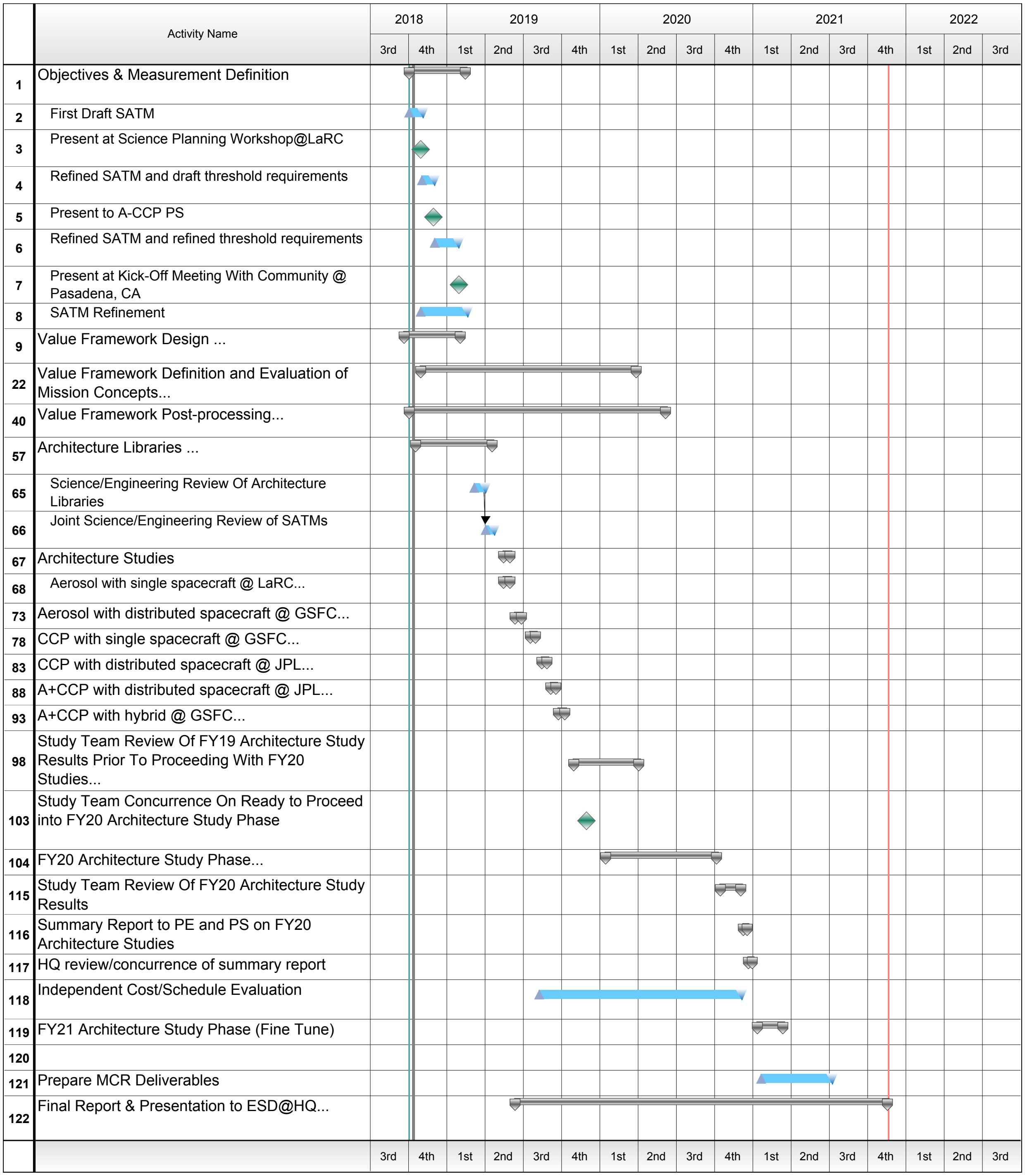
All the members of the Study Management Team (SMT) participate in weekly review meetings and discussions. The SMT coordinates priorities and resources across the planned study activities, communicating and managing changes in scope, as appropriate, with the NASA A-CCP Program Executive, Program Scientists, and Program Applications Leads.

The Science/Applications Leadership Team (SALT) brings together experts from across the aerosols, clouds, convection, and precipitation satellite remote sensing communities with broad experience in satellite instrumentation, airborne validation, modeling, data assimilation and retrieval algorithm development, scientific analysis, and applications. This team was brought together by GSFC to enable a broad exploration of the available architecture trade space. The SCC consists of external subject matter experts (SMEs) that provide science community perspective to corroborate (or challenge) the A-CCP science strategy and priorities.

The Systems Engineering Team (SET) provides requirements flow-down and traceability, leads and participates in the population of the architecture libraries, conducts trade studies including system modeling and analyses for the most promising architectures, and generates documents for reviews, including draft packages for the MCR. The SET will use the external subject matter expert team on an as-needed basis.

Schedule and Cost

The A-CCP study schedule is 35 months from ESD issuance of Authority To Proceed (ATP) to submittal of the final study report, which allows sufficient time for ESD's requested study deliverables. The A-CCP team has organized the study to support independent science and technical, as well as industry involvement. Workshops are planned in support of finalizing the SITMs and leveling of observing system architectures. Deliverables and related reconciliation periods are scheduled in support of transparency with ESD and to support the ultimate implementation of A-CCP observing systems by ESD.



Summary

Management of A-CCP emphasizes substantive inter-center involvement, examination of non-traditional architectures, engagement with the broader community, schedule control and risk management to meet the fundamental objectives of A-CCP DO within the cost cap. The Study Coordinator is committed to expedient decisions, and sufficient authority and responsibility have been delegated to the experienced Center staff for efficient operations. The study plan elements below addresses all of ESD's stated A, CCP, and A+CCP objectives and support a successful MCR.

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1.0 - SCIENCE/APPLICATION OBJECTIVES AND MEASUREMENT APPROACHES

1.1 Science Foundation from the 2017 Decadal Survey

The goal of this study is to define objectives for the Aerosol (A) and Cloud, Convection, and Precipitation (CCP) designated observable (DO) missions, the desired measurement capabilities (prioritized) associated with these observables, and measurement approaches to achieve them. This phase of the study can be expedited by exploiting a number of activities of past pre-formulation studies such as the Aerosol-Cloud-Ecosystems (ACE) study and those from existing and proposed Earth Ventures concepts. Measurement definition activities are also expected to benefit from analysis already conducted on data from past field experiments and recent advances of modeling systems and Observing System Simulation Experiments (OSSEs) that can be tailored to the needs of the present study. The study will also document how the measurement objectives of A and CCP augment existing NASA Earth Science Division (ESD) science objectives, as well as how these measurements contribute to other DOs identified by the 2017 Decadal Survey (DS). Furthermore, the study will also explore how measurement objectives can be addressed by the Program of Record (PoR). Science & Applications Traceability Matrices (SITMs) will be developed and finalized during the first six months of this study. As the breadth of the A-CCP science is already defined via the DS, this study will determine what subset of the science is feasible, given the NASA ESD-provided mission cost caps. As a general strategy, this study aims to provide multiple solutions to each measurement approach, making extensive use of innovative and emerging technologies, in addition to identifying less mature solutions that could benefit from further development.

We will define/develop a comprehensive list of Applied Sciences activities as part of the study to lay the groundwork for a Project Applications Plan. We will concurrently engage the user community to identify specific A-CCP dataset applications and impacts relevant to decision makers in areas such as air quality, wildland fire, weather, water, short-term climate, and disasters management fields. To this end, we plan to host at least one community workshop (set up to ensure remote attendance for those who can not attend in person), distribute/collect surveys to both inform preexisting and identify new stakeholders and the potential "community of practice". For example, we will build upon the air quality applications of MAIA and the applications of many existing weather applications, including severe weather, inherent to CCP. Representatives of these communities will be funded to participate in the study.

SALT member A. da Silva was the co-chair of the GEO-CAPE Global OSSEs Working Group and will ensure that OSSE capabilities and results developed under GEO-CAPE are used for the A-CCP study. Furthermore, GEO-CAPE's Program Scientist Jay Al-Saad is a member of the A-CCP Application Assessment Team and will provide an additional connection to the GEO-CAPE scope, especially for the air-quality aspects.

The delineation of the links between air-quality applications and A-CCP's aerosol science are being fully explored in the first phase of the study as we construct fully integrated Science and Application Traceability Matrices.

1.1.1 Aerosols

Science and Applications Objectives

The 2017 DS highlighted Earth System Science themes, science and application questions, and several high priority objectives that have led to the inclusion of aerosols as a DO. The aerosol-related science questions outlined by the DS focus on two major themes: 1) Climate Variability and Change and

Table 1-1: Most Important (MI) Decadal Survey Science Objectives of relevance to the Aerosol Designated Observable.

Theme	Science Objectives
Climate Variability and Change	• Reduce aerosol radiative forcing uncertainty by a factor of two (C-2h) • Quantify the contribution of the upper troposphere and stratosphere to climate feedbacks and change (C-2g) • Improve estimates of the emissions of natural and anthropogenic aerosols and their precursors via observational constraints (C-5a) • Quantify the effects of aerosols on cloud formation, height, and properties (C-5c) • Reduce uncertainties in low and high cloud feedback by a factor of two (C-2a)
Weather and Air Quality	• Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts (W-1a) • Improve the observed and modeled representations of natural, low-frequency modes of weather/climate variability (W-2a) • Improve our understanding of the processes that determine air pollution distributions and reduce uncertainties in PM concentrations (W-5a)

2) Weather and Air Quality. The Aerosol mission observables targeted to address these major objectives may potentially contribute to three additional themes: 3) Marine and Terrestrial Ecosystems, 4) Global Hydrological Cycle, and 5) Earth Surface and Interior; this study will examine these linkages. For the two major themes, the DS outlined the following major science objectives (**Table 1-1**):

In addition to these important objectives, the DS identified the following additional objectives as associated with Aerosol & Cloud Targeted Observable (TO-1) and Aerosol Vertical Profiles (TO-2) targeted observables: H-1c, H-2b, W-6a, W-9a, W-10a, S-1a, C-2h, C-3d, C-4d, C-5b, C-5d, C-7a, C-7b, C-8g, C-9a.

The DS Climate Variability and Change panel identified reducing uncertainties in both direct and indirect aerosol radiative forcing as one of the highest priorities, since the largest source of uncertainty in determining climate forcing in models is quantifying aerosol forcing. While reducing uncertainty in *direct* aerosol radiative forcing can contribute to reducing uncertainty in climate sensitivity, uncertainties in aerosol *indirect* forcing contributes the larger uncertainty. Addressing the indirect forcing uncertainty requires a greater understanding of the processes associated with aerosol-cloud-precipitation interactions, as described below in discussion of the combined A+CCP measurement approach. Measurements designed to improve our understanding of aerosols and reduce uncertainties in both direct and indirect aerosol radiative forcing will require vertical profiles of aerosols in order to determine the position relative to clouds, as well as absorbing gases such as water vapor. These aerosol measurements will also substantially improve efforts to determine the impacts of aerosols on air quality, aviation safety, and human health. Consequently, the Weather panel identified aerosols as one of the most important boundary layer properties essential for air quality forecasting and connecting health effects with pollution. Aerosols also vary the amount of radiation available to terrestrial and marine ecosystems, altering precipitation and thereby influencing the Water and Energy Cycle. Additionally, lidar observations of ice clouds in the tropical tropopause, and aerosol in the lower stratosphere, contribute to our understanding of stratospheric composition and change (C-2g). The DS also recognized that the Aerosols mission would contribute to the CCP objectives; they indicated that observations of optically thin high clouds and thicker low clouds from TO-1 and TO-2 would contribute substantially to understanding cloud climate feedbacks. The polarimetry measurement and vertically resolved aerosol properties afforded by A-CCP are expected to improve the characterization of surface PM2.5, a key parameter of interest to the environmental health an epidemiological communities.

Several of these objectives (*e.g.* reducing aerosol radiative forcing uncertainty; understanding sources, sinks, distributions of aerosols; quantifying effects of aerosols on clouds) are very similar to those of the 2007 DS recommended ACE mission. Consequently, this mission study will build on the extensive science, engineering, algorithm, and field mission studies and activities conducted during the ACE pre-formulation study to formulate the Aerosol DO mission objectives, instruments, and architecture.

Observable Priorities

The DS Steering Committee identified some aerosol observables needed to address these science questions and objectives. These observables, which include column and layer average parameters (aerosol optical depth, particle size, and speciation, as well as vertical profiles of aerosol extinction), form the basic set of aerosol and cloud parameters identified for addressing the science questions and objectives. Therefore, these aerosol observables will be the highest priority addressed in this mission study. The study will address how these observables can be directly measured, retrieved, and/or obtained in conjunction with advanced Earth system models.

The mission studies will investigate the observables suggested by the DS Climate and Weather panels. For example, the DS Climate panel recognized the need for more detailed aerosol measurements in order to quantify aerosol impacts on radiation and clouds, and to help separate and quantify the effects of both natural and anthropogenic aerosols on climate forcings. These key aerosol measurements, which include vertically resolved aerosol absorption, particle size, and concentration, are similar to those identified by the ACE pre-formulation activities to improve estimates of aerosol source strength and location, assess aerosol impacts on clouds and radiation, and translate retrieved aerosol optical depth (AOD) and aerosol type to mass, number concentration, and size distribution. The DS Weather and Air Quality panel placed increased emphasis, beyond that discussed by ACE, on aerosol observables targeted to reduce uncertainties in the processes that impact air quality and the consequences of aerosols on human health. Addressing objectives C-2h and W-5a requires advances in the ability to speciate aerosol and aerosol optical effects by type, beyond capabilities demonstrated in the ACE studies.

In order to address objectives associated with cloud feedbacks and aerosol-cloud interactions, the study will evaluate the extent to which some key cloud observables (*e.g.* cloud coverage, altitude, thickness, optical depth, ice water content) identified by the DS may be provided by the various Aerosol architectures in combination with the PoR. The study will also evaluate the Aerosol and CCP DOs in combination (see 1.1.3).

Based on similarity with ACE mission objectives, additional observables (nominally from the PoR for addressing the Aerosol DO mission objectives) will include top-of-the-atmosphere (TOA) longwave, shortwave, and net radiative fluxes, surface albedo, and profiles of atmospheric state parameters such as temperature and water vapor.

Desired Observable Capabilities

The DS Panels (climate, weather, etc.) gave suggested targets for several of the observables described above. These target observables represent the judgement of the panels and, as stated in the DS, are not definitive. Therefore, a major study task will be to investigate and determine a feasible (within cost-caps) set of appropriate algorithms and prioritized desired measurement capabilities needed for achieving these observables. These studies, which will address the measurement uncertainties, resolutions, spatial and temporal coverage, etc, will also build on some of the studies performed during the ACE mission pre-formulation activities. When formulating observable requirements, the mission study will consider the feasibility of new and innovative instrument designs, instrument/architecture costs, as well as the science objectives described above. A critical element of the proposed study will perform an extensive study of the PoR to investigate the extent to which the PoR can help satisfy, complement, and augment the target observables.

Measurement Approaches

The DS identified candidate measurement approaches to obtain the target observables. A multi-channel, multi-angle imaging polarimeter was identified for providing the necessary information content for column-averaged aerosol optical properties such as particle size, aerosol optical depth, as well as some information on aerosol speciation, cloud drop size, and concentration, primarily in the context of non-convective clouds. The ACE mission pre-formulation studies also called for a similar polarimeter and so have investigated various polarimeter approaches for estimating these parameters. The present study intends to leverage the most recent ACE airborne field campaign, the Aerosol Characterization from Polarimeter and Lidar (ACEPOL 2017), as well as from other field campaigns, to determine the required polarimeter and lidar characteristics within the context of the DS objectives, some of which are new relative to the ACE study. Since ACEPOL data analyses are still underway and unlikely to be completed before the conclusion of ACE, the A-CCP study expects to continue exploring ACEPOL data to define its measurement approach. These studies will explore various ranges of wavelengths, measurement angles, spatial and temporal resolutions, measurement swaths, and retrieval algorithms. In addition, we plan to build on relevant experience derived from the PoR, such as from the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and the Multi-Angle Imager for Aerosols (MAIA), to explore viable measurement approaches and instrument configurations for estimating the required target observables.

The DS also recognized the need for lidar measurements to provide vertically resolved aerosol properties and to profile optically thin clouds. Examples of backscatter lidars identified by the DS include the Cloud-Aerosol Lidar and Infrared Pathfinder (CALIOP) on CALIPSO, and the Cloud-Aerosol Transport System (CATS) lidar that flew on the International Space Station. While expressing some concerns about its cost, the DS also expressed the desire for High Spectral Resolution Lidar (HSRL), which provides more accurate profiles of calibrated aerosol backscatter and extinction. HSRL can also potentially estimate aerosol intensive information useful for investigating aerosol speciation.

The ACE study examined a multiwavelength HSRL for providing a suite of backscatter, extinction, and depolarization profiles for retrieving profiles of aerosol concentration and size, and studies have been conducted to explore the scalability of these measurements to space. The A-CCP study will examine the capability, technical feasibility, and cost associated with backscatter and HSRL lidars, including lower cost options, such as that demonstrated by the space-based CATS lidar. While ACE primarily focused on individual sensors, this study will go beyond the ACE activities by examining how various configurations of backscatter lidars, HSRL, and polarimeters can be combined with the PoR and data assimilation to provide estimates of the aerosol target observables needed to address the DS science objectives. In particular, this study will examine how the visible reflectance data from the Ocean Color Instrument (OCI), and polarized radiance data on PACE, can be used to advance the A-CCP measurement objectives. In contrast to ACE, this study will be conducted under rigorous cost-capped constraints.

Although use of unpolarized visible and near infrared (VIS-NIR) reflectance data has significant heritage in aerosol remote sensing, the study will explicitly examine the utility of higher spectrally resolved reflectance data, such as being proposed for the DS Surface Biology and Geology (SBG) mission. The potential of low cost miniaturized spectrometers that provide this information is a driver for this study and architecture options because such measurements will be examined.

The wealth of aerosol information provided by the PoR from geostationary and polar orbiting satellites, combined with high resolution modeling and data assimilation approaches, can provide powerful prior information for constraining A-CCP retrievals. Assimilated aerosol fields, such as those from the Global Modeling and Assimilation Office (GMAO) GEOS system can provide speciation and other relevant information on a global scale that can enhance — and benefit from — the lidar and polarimeter-based measurements to be provided by A-CCP. A case in point are the retrievals of profiles of aerosol absorption, particle size, and refractive index which will require approaches that combine the lidar and polarimeter measurements; such retrieval development is already underway using airborne lidar and polarimeter data from recent NASA field campaigns. Although HSRL-derived particle size and aerosol-type information are relatively coarse indices of aerosol speciation, additional speciation information from assimilated fields can be instrumental for achieving the A-CCP science objectives, even for less capable backscatter lidars. In this context, the unexamined potential of spectral radiance data for aerosol speciation from the recently selected Earth surface Mineral dust source InvesTigation (EMIT) EVI-4 will also be examined during this study.

We note that some of the measurements required to meet aerosol objectives go well beyond current satellite measurement capabilities, and may also exceed the satellite capabilities that are feasible and/or affordable for the DS Aerosol Mission. Therefore, the proposed study will also investigate how sub-orbital (*e.g.*, surface and airborne) data, paired with high-resolution global data assimilation systems, may be used to address the aerosol measurement needs and gaps.

1.1.2 Cloud-Convection-Precipitation

Science and Applications Objectives

The DS identified CCP as a DO focused on coupled cloud-precipitation states and dynamics for addressing cloud and precipitation processes relevant to a wide sector of the science objectives called out in the disciplinary panels, as well as gaps in the precipitation PoR. CCP was deemed critical for assessing low and high cloud feedbacks, advancing seasonal and interannual climate variability and prediction, and characterizing convective processes that are at the core of severe and extreme weather. CCP was deemed relevant to a large cross section of the panel's most important objectives.

In addition to these important objectives, the DS identified the following additional objectives as associated with CCP Targeted Observable (TO-5): H-3b, H-4b, W-9a, W-10a, S-1c, 4b, C-2h, C-3f, C-5d, C-7e, C-8h.

One of the principal objectives of the Climate Variability and Change panel centered around the problem of cloud feedbacks. The largest cloud- feedback uncertainties are those associated with low and high clouds. Low cloud feedbacks are intrinsically connected to the main branches of the atmospheric circulation and the interaction of this circulation with the planetary boundary layer. High cloud feedbacks are strongly shaped by convective processes and, in turn, the way convection is shaped by the atmospheric circulation. As has been noted by the community, improving our quantitative understanding of the connection between cloud, convective processes, and precipitation, as well as clouds, water vapor, and the atmospheric circulation, is essential for addressing these cloud- feedback uncertainties.

The weather panel noted the importance of convection to a number of objectives, from sub-seasonal to seasonal prediction and to weather extremes. The approach to advance our understanding of cloud systems, including extremes, and our ability to predict them, is to address fundamental physical and

Table 1-2: Most Important (MI) Decadal Survey Science Objectives of relevance to the Cloud-Convection-Precipitation Designated Observable.

Theme	Science Objectives
Hydrology	• Develop and evaluate an integrated Earth System analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins (H-1a) • Quantify rates of precipitation and its phase (rain and snow/ice) worldwide at convective and orographic scales suitable to capture flash floods and beyond (H-1b) • Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability (H-1c)
Climate Variability and Change	• Reduce uncertainties in low and high cloud feedback by a factor of two (C-2a) • Quantify the contribution of the upper troposphere and stratosphere to climate feedbacks and change (C-2g)
Weather and Air-Quality	• Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts (W-1a) • Improve the observed and modeled representations of natural, low-frequency modes of weather/climate variability (W-2a) • Determine how spatial variability in surface characteristics modifies regional cycles of energy, water, and momentum (stress) (W-3a) • Measure the vertical motion within deep convection to improve model representation of extreme precipitation and determine convective transport and redistribution of mass, moisture, momentum, and chemical species (W-4a)
Marine and Terrestrial Ecosystems	• Quantify the flows of energy, carbon, water, nutrients, etc, sustaining the life cycle of terrestrial and marine ecosystems and partitioning into functional types (E-3a)

dynamical processes that underlie a given type of event for which our understanding and prediction abilities are poor. Precipitation is essential for all hydrological applications and better representation of precipitation processes were deemed of critical importance to advance our capabilities in precipitation analyses. Precipitation is also an essential aspect to cloud and aerosol feedback processes, and to climate forcings by aerosol, also another major objective of the climate panel. Precipitation shapes the lifecycle of clouds and aerosol wet removal processes, and couples the clouds to the dynamical atmosphere via the latent heating produced. Together, these determine the lifetime of aerosol in the atmosphere and the properties of clouds influenced by aerosol.

Although some of these disciplinary objectives connect to the ACE mission concept, CCP goes beyond ACE by emphasizing the coupled cloud-precipitation processes covering non-precipitating to deep convective clouds, and calls for some illumination of cloud dynamics.

Observable Priorities

The DS report identifies a number of key observable priorities, including vertical profiling of shallow to deep convective clouds and their associated vertical motion, and microphysical and cloud optical properties. In the coming decade, use of new space-based observations, in conjunction with current observations, has the potential to significantly advance process understanding so as to properly assimilate precipitation information in high-resolution models used to better forecast precipitation. Thus, a strong case can be made that observing variables central to key processes, like hydrometeor properties and vertical velocities, will provide the required constraints to make high-quality model-based analyses and forecasts of precipitation at ~1 km and ~15 minute time steps a reality.

Key geophysical parameters that can address the CCP science objectives include hydrometeor layer detection (where in the vertical are the clouds/precipitation), cloud and precipitation phase (water, ice, or mixed phase), cloud and precipitation vertical profiles of microphysical properties (liquid/ice water content or path, mean particle diameter, number concentration), precipitation rate and latent heating profiles, cloud-scale vertical motion profiles, cloud optical properties.

Desired Observable Capabilities

The DS-suggested approach to addressing CCP goals focused on vertical profiling of cloud systems for improved characterization of cloud and precipitation properties, quantification of microphysical processes, and measurement of cloud system vertical motions that augment PoR capabilities that map clouds as well as precipitation at the surface. Vertical profiling of precipitation (through Ka- and Ku-band radars) and high-resolution mapping of precipitation is currently provided within the PoR by the Global Precipitation Measurement (GPM) mission. The GPM will likely continue to play a major role as part of the PoR through the following decade. Vertical profiling of both cloud and precipitation will be a major focus of the CCP architecture, and the derivation of desired capabilities for such profiling will be a key activity during the proposed study period. In addition, CCP will include examination and specification of the capabilities focused on measurement of cloud properties, transports by shallow to deep convection, and the relation of these properties to precipitation. The extent to which desired capabilities for cloud optical properties, along with surface and TOA radiative fluxes, can be fulfilled by the PoR or other DOs, such as SBG, will be examined.

Measurement Approaches

The DS panel's science and applications objectives to characterize cloud and precipitation properties, quantify related processes, and reduce the uncertainty about low and high cloud climate feedbacks led to a recommendation for a multi-frequency profiling radar with some Doppler capability and passive microwave measurements, including sub-mm radiometry, as CCP architecture core components.

The profiling of clouds and light (<1 mm hr^{-1}) precipitation requires W-band radar and, if very high sensitivity is needed for thin clouds, a cloud lidar (an objective of a combined A+CCP measurement concept described below). Heavier precipitation, such as that associated with deep convection, requires lower radar frequencies such as Ka and/or Ku band. Studies have shown (Grecu *et al.* 2018; Leinonen *et al.* 2018) that profiling of cloud/precipitation particle characteristics within clouds and of a precipitation rate over a broad range of precipitation intensities requires at least two radar frequencies, likely W band with Ka and/or Ku band. Passive microwave channels that can be readily included in a design with little cost impact can constrain total cloud liquid water (over oceans), while higher frequency microwave channels can constrain column ice water content. Passive microwave imagers may be needed to supply spatial context in cloud and precipitation liquid and ice, and to help separate the cloud liquid from precipitation when combined with radar measurements. The value of Doppler capabilities at different frequencies and of microwave radiances, coupled to the active profile measurements, will also be quantified, as will the contributions from visible and near infrared reflected radiance data available through the PoR and, possibly, SBG.

As the DS report noted, the technology central to the CCP objectives has evolved rapidly with the miniaturization of radar systems and microwave radiometers, with reduced cost of implementation, due to investments under the Earth Science Technology Office's (ESTO) In-space Validation of Earth Science Technology (INVEST) program. Addressing CCP objectives by exploiting these innovations, as well as alternative mature and emerging technologies, will be examined under this study.

As with the Aerosol mission, the proposed study will investigate how suborbital (i.e. aircraft) and surface data [*e.g.*, continental scale operational and research networks of scanning polarimetric radars, research grade platforms such as the NASA S-band dual-Polarimetric radar (NPOL)], and the Dual-frequency Dual-polarimetric Doppler Radar (D3R), may be used to address measurement needs and gaps. There is a great opportunity to also leverage Department of Energy sites such as the Southern Great Plains (SGP) or other locations with semi-permanent AMF deployment.

1.1.3 Synergistic Aerosols and Cloud-Convection-Precipitation

The DS recognized the science merit in combining the A and CCP DOs for both enhancing the ability to address a number of Most Important (MI) objectives defined by the disciplinary panels and also to provide an expanded capability to address additional objectives beyond those addressed by individual DOs. This understanding has been aptly underscored from lessons learned during the A-Train era, where formation flying by CloudSat with CALIPSO and the other passive-sensing A-Train assets, such as MODIS, Cloud and Earth's Radiant Energy System (CERES), Advanced Microwave Scanning Radiometer (AMSR-E), etc, facilitated far reaching and innovative science achievements that would not have been possible had the respective missions operated independently. The DS also identified Integrating Themes that can also be addressed through combinations of observables including potential combinations of DOs and the PoR. The combined A+CCP portion of this study will demonstrate how the combination of A and CCP observables will enhance the objectives of A and CCP individually, while providing the ability to expand the DS objectives addressed, and will closely connect to the A and CCP studies being performed in parallel.

Science and Applications Objectives

Enhancement of A by CCP — There are at least two potential ways CCP provides potential contributions to the Aerosol DO objectives. The ability of CCP to characterize rainfall processes, especially frequently occurring light rain, is central to understanding the evolution of aerosol and the rain-out processes that remove them. Because removal processes determine the amount of particulate matter at the surface, it has a direct impact on air-quality. This process therefore has a basic influence on many aspects of aerosol science from air-quality to understanding of the interactions of aerosol and clouds. A second way CCP potentially contributes to the Aerosol objectives depends on the specific combinations of observations that form the combined measurement approach. The combination of W-band radar observations of the ocean surface reflectivity, with lidar backscatter, can in some cases provide an independent and valuable integral constraint on the lidar backscatter, facilitating the retrieval of more accurate lidar extinction profiles (Synergized Optical Depth of Aerosols—SODA). Josset *et al.* (2008) studied and assessed the information against other measurement approaches.

Enhancement of CCP by A — There are a number of ways that both the CCP objectives will be enhanced when combined with the Aerosol DO. As noted previously, much has been learned from the A-Train observing system. These lessons suggest there are a number of ways the CCP objectives will be enhanced when combined with the aerosol DO. Enhancements include understanding how aerosols impact the onset of precipitation and potentially modify the vertical structure of cloud and precipitation hydrometeor properties. Lidar also provides observations of thin clouds, with higher vertical and horizontal resolution than radar and the ability to detect clouds near the surface composed of small drops, which are challenging for radar sensors. The study will identify the different ways the aerosol DO specifically enhances the CCP objectives and will quantify cost/benefits to the CCP of tradeoffs associated with different combinations of measurements including the contribution from the PoR.

The A+CCP combined DO — As noted previously, much has been learned from the A-Train observing system. These lessons suggest there are a number of ways the CCP objectives will be enhanced when combined with the aerosol DO. With the ability of lidar to profile optically thin clouds, and radar to profile optically thick clouds and precipitation, co-located radar/lidar observations provide a characterization of the vertical structure of cloud occurrence and heating. Other examples include: i) enhanced detection of thin clouds and cloud profiling, ii) understanding how aerosols impact the onset of precipitation and potentially modify the vertical structure of cloud and precipitation hydrometeor properties, and iii) combining CCP measurements to improve ways to estimate ice content of clouds. This study will identify these CCP science enhancements, identify those DS science objectives that can be addressed uniquely by the combining of A and CCP into a joint measurement concept, set the desired prioritized measurement capabilities attached to these objectives, and provide measurement approaches that address these capabilities. Specifically, the study will begin with a subset of the A and CCP measurement approaches and formulate possible implementation scenarios: i) in the form of a train of satellites, ii) involve contributions by partners (see **Section 6**), and iii) examine alternative approaches and technologies.

1.2 Assessing the Science Value and Application Potential of Measurement Architectures

Development of a set of prioritized science objectives to be addressed by the A, CCP, and A+CCP DOs will be accomplished early in the proposed study by the A-CCP science team depicted in **Figure 1-1**. The science objectives, closely aligned with the imperatives of the DS, will result in a set of quantifiable capabilities on sets of geophysical parameters that are needed to address the science questions. It will be the charge of the Science Impact Team (SIT) and the Applications Impact Team (AIT), interacting with the ESD Program Scientist (PS) and Program Applications Lead (PAL), to evaluate the extent to which various measurements architectures (i.e. sets of measurables with specified characteristics) provide the geophysical parameters required to meet the science objectives and contribute to application objectives. The SIT roster includes polarimetry expertise across several areas. Baastian van Diedenhoven is a member of the GISS polarimetry group. Olga Kalashnikov is a member of the A-CCP science team and brings a solid polarimetry background from JPL's MAIA and MSPI group. Likewise, Sharon Burton and Snorre Stammes from LaRC have been involved in joint lidar-polarimeter algorithm development, in close collaboration with Brian Cairn's group at GISS. Furthermore, Pete Colarco leads an internal GSFC effort for the development of algorithms for the HARP polarimeter. We have identified multiple AIT team members (*e.g.*, Omar, Zavdoski, Duncan, Soja, Al-Saadi, Chatfield) with extensive air quality experience and liaison to relevant Applied Sciences teams. These teams will be composed of individuals who are reasonably well versed in the capacity for measurements to characterize desired geophysical

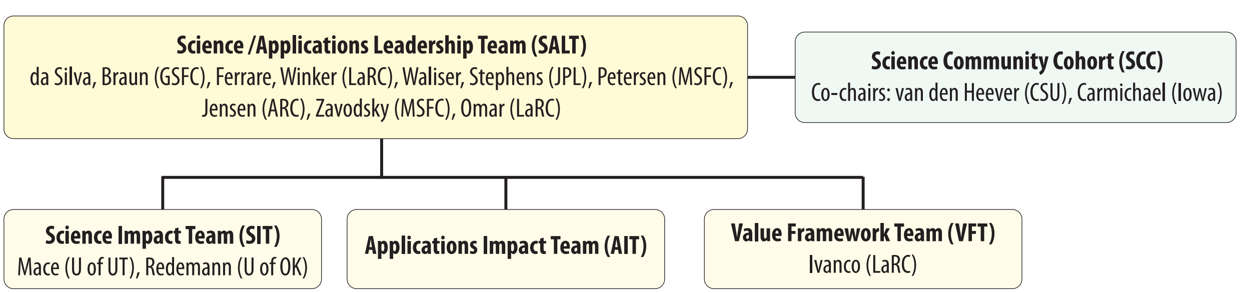


Figure 1-1: The A-CCP team will be involved in defining prioritized science objectives and science/applications assessment activities.

quantities and applications, but who are not deeply involved with specific instrument concepts or designs and can provide objective input to this assessment activity.

1.2.1 Modeling, OSSEs, and Field Campaign Data for Science Assessment

The objective of the SIT will be to provide information from the science community to the Value Framework Assessment discussed below, supporting the SALT, SET, and SMT in arriving at objective decisions regarding mission architecture trades. The SIT inputs will help the A-CCP team quantifiably measure the information or constraints that measurement architectures provide for specific science questions or geophysical parameters. The SIT inputs will assist in the A-CCP team's measurement of the contribution that a particular observing system configuration provides to a science question, either via the geophysical parameters required to address it, or more indirectly when these observables are assimilated in earth system models. The recent work of Mace and Benson (2017) provides a pertinent example where 6 single- and dual-frequency radar concepts were evaluated for their ability to constrain ice precipitation processes in tropical anvils sampled during TC4.

The SIT provided science community perspective will support the A-CCP team's quantification of the capacity for various measurement architectures to inform science objectives using measurements collected in field campaigns, modeling activities, and observing system simulation experiments (OSSEs). No new field work is being proposed for this study. However, our intention is to use data from past field programs in a focused manner to address the applicability of measurement combinations of specified characteristics to constrain geophysical parameters and physical tendencies. The SIT will assist NASA Headquarters (HQ), namely Hal Maring (A-CCP PS), Barry Lefer, Ken Jucks and Gail Skofronic-Jackson to leverage past and future field campaign investments that focus on aerosol, clouds, and precipitation. The SIT will also provide the science community's perspective regarding other non-NASA data sources, as well as the 2018 National Science Foundation-sponsored Southern Ocean Clouds, Radiation, and Aerosol Transport Study (SOCRATES), that occur in uniquely important environments or document specific processes of interest. Campaigns that include representative measurement sets such as multi-frequency radar, lidar, and polarimeter, especially when combined with ground truth validation, will be considered. Examples include the previous ACE and GPM field campaigns such as the 2013 PODEX, the 2014 IPHEX and RADEX1, the 2015 OLYMPEX and RADEX2, and the 2017 ACEPOL campaigns.

In addition, the SIT will also bring to bear the science community's experience with data from past EV-S campaigns such as ATTREX, DISCOVER-AQ, NAAMES, and ORACLES.

Given the constraints on time and resources, the SIT will initially identify a limited number of cases, both real and simulated, that represent processes and situations of interest that would contribute useful information to the value assessment applied to specific mission architectures. From past campaign data sets, the SIT will provide sets of case studies that are uniquely representative of the required processes and geophysical parameters from A, CCP, and A+CCP, and that are well supported observationally.

The SIT will also support the SALT in the coordination of OSSE activities to assess the ability of specific architectures to address the A-CCP science objectives. OSSE figures of merit will include the quality of retrievals, sampling adequacy, and impact on meteorological/aerosol analysis and forecasts. For Aerosols, OSSE studies will likely leverage global mesoscale Nature Runs already existing at GMAO to simulate lidar and polarimeter measurements on specified orbits, and the execution of established retrieval and data assimilation algorithms to assess the impact of the synthetic observations. For CCP-related OSSE studies where regional cloud-resolving models are required, the working with the SALT, the SIT will provide science community inputs relevant to establishing a library of simulation data sets that address specific science objectives identified for CCP and A+CCP. The case studies will be coupled with libraries of forward measurement simulators to allow us to link modeled microphysics and dynamics with specific processes, and to the extent to which simulated measurements convey information about those processes.

The inputs from the SIT will occur in two phases. Early in the study process, during the SITM refinement where sets of observables are defined for formal mission architecture studies, the team will provide input to the definition teams regarding the information that certain measurements and measurement combinations contribute in a general sense. In the second and more complex phase of the study, the SIT will provide science community perspective to aid the SALT's evaluation of specific mission architectures for their capacity to quantify geophysical variables and contribute more broadly to science questions. The information provided by the SIT will ultimately be used as input to a value assessment described below. This second phase will be necessarily iterative as instrument concepts are refined in collaboration with engineering to meet the stated desired capabilities of science while remaining within reasonable cost constraints.

1.2.2 Assessing the Application Potential of Architectures

The Application Assessment Team (AIT) is tasked with working with the A-CCP PAL (John Haynes) to assess the potential of specific architecture options to contribute to DS application objectives. Such assessment will provide input to the Value Framework described below by scoring application-related figures of merit for each architecture being considered. Earlier on in the study, the AIT will work with the Value Framework Team (VFT) to define application-relevant figures of merit. While the specific criteria for scoring the application figure of merit will be developed in the early stages of the A-CCP study, it is anticipated that consultation with end users and several stakeholders will factor in the analysis.

The AIT will consult with the end users to assess factors that will increase the applications value of measurements so that mission architecture trades can be simulated to achieve maximum benefit for society. The AIT will engage a number of key users to provide assessments of applications relevant mission architectures from which the team can generate figures of merit for the value frame work. The AIT will leverage the modeling, OSSEs, and field campaign data provided by the SIT to determine the suitability of measurement combinations and architectures to address applications questions and objectives and provide. In particular, the AIT will use the measure of information or constraints developed from measurement architectures for geophysical parameters in **Section 1.2.1**. These will be related to applications questions to quantify the utility and quality scores for benefit analyses.

The overarching objective of the AIT is to ensure that applications considerations are taken into account as much as possible within mission design parameters. As such, it is expected the AIT will participate in meetings to define the key applications criteria to be considered in the final mission concept. The AIT will identify applications and their readiness levels relevant to the A-CCP mission early in its lifecycle (Pre-Phase A) and the feasibility of integrating end-user needs in mission design and development. The AIT will assess the membership of the Early Adopters Program (EAP) and aid in recruiting users from their networks to increase the visibility and application of the A-CCP mission concept. To achieve these objectives the members of the AIT are well versed in the capacity for measurements to characterize desired geophysical quantities, associated uncertainties and limitations, derived applications, and relevant end user communities, especially the EAP.

Applications activities will be planned and conducted in accordance with the ESD Directive on Project Applications Program (https://science.gsfc.nasa.gov/610/applied-sciences/mission_applications_materials/FAS%20Directive_signed.pdf). By the end of the Pre-Phase A period, the applications team will deliver a Community Assessment Report as part of the final report and presentation to ESD. The report will define what products are useful to the user community and will include such descriptors as spatio-temporal resolutions and factors that may increase the applications value of planned A-CCP products.

1.3 A Value Framework for Assessing Mission Architectures

To inform mission architecture down-select decisions, the A-CCP team will develop and adopt a framework to characterize the value of each mission architecture, with the value of a mission architecture defined by its science, application, and programmatic benefits relative to its associated cost and risk. Leading into and during those decision processes, this Value Framework will provide a consistent and structured format that captures the key parameters for each mission architecture that will drive the down-select decision, supporting the facilitation of the discussions across this multi-center team and with Earth Science Division leadership. After the decisions are made, the framework can then be used to provide transparency into the analysis and factors that resulted in the decision, informing subsequent mission formulation and advocacy efforts.

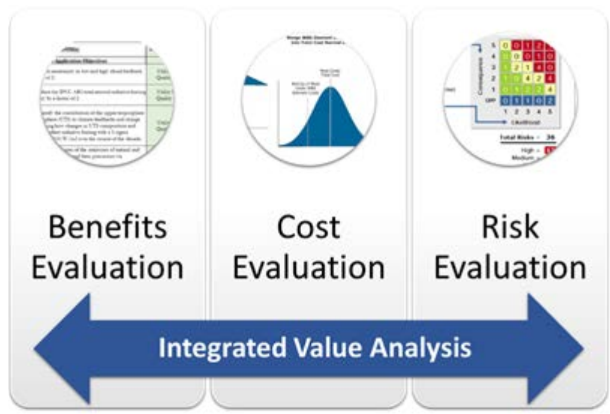


Figure 1-2: Illustration of the integrated value analysis

The framework will consist of four major elements used to assess the value of the mission architectures (Science and Application Benefits, Programmatic Benefit, Cost, and Risk), as illustrated in **Figures 1-2** and **1-3**. Benefits will first be assessed with the use of Multi-Attribute Decision Analysis strategies (**Figure 1-3**). Science Benefits will be represented by science objectives

	Aerosols Mission Concepts			CCP Mission Concepts			A&CCP Mission Concepts		
Figures of Merit (FOMs)	Mission Concept 1	Mission Concept 2	Mission Concept 3	Mission Concept 1	Mission Concept 2	Mission Concept 3	Mission Concept 1	Mission Concept 2	Mission Concept 3
Earth Science Application Objectives									
C-2a. Reduce uncertainty in low and high cloud feedback by a factor of 2.	Utility Score Quality score	...							
C-2h. Reduce the IPCC AR5 total aerosol radiative forcing uncertainty by a factor of 2.	Utility Score Quality score	...							
C-2g. Quantify the contribution of the upper troposphere and stratosphere (UTS) to climate feedbacks and change by determining how changes in UTS composition and temperature affect radiative forcing with a 1-sigma uncertainty of 0.05 W/m2 over the course of the decade.	Utility Score Quality score	...							
C-5a. Improve estimates of the emissions of natural and anthropogenic aerosols and their precursors via observational constraints	Utility Score Quality score	...							
...	...								
Programmatic FOMs									
Derived from the Decadal Strategic Framwork (Table 2.4 ESAS 2017)									
Additional FOMs tailored to NASA Strategic objectives									

Scores are either obtained from science studies or from qualitative assessments

Scoring across multiple science objectives will be reflected in the framework

Notional Example

Figure 1-3: Notional value matrix to assess benefits of mission architectures.

identified in the Decadal Survey, with each mission architecture being assessed in a manner similar to that identified in the *Continuity of NASA Earth Observations from Space* report (NAS 2015), under which mission concepts are evaluated on utility (the degree to which the concept addresses the objectives if all the target geophysical variables were measured perfectly) and Quality (the degree to which measurements provide the required geophysical variable). It is assumed that the importance of each science objective has already been established by the DS in the form of a cardinal scale (Important, Very Important, Most Important).

The Science and Application Leadership Team (SALT), the SMT, SIT and the AIT, working with the A-CCP PS and PAL, will identify the schemes for quantifying the utility and quality scores, and the studies (*e.g.*, OSSEs, modeling, etc.) required to quantify them. Programmatic benefits (*e.g.* international cooperation, innovative technologies) will be represented by programmatic objectives defined in consultation with ESD leadership, drawing from content available in the Decadal Survey and the Designated Observables Guidance letter, and evaluated quantitatively using criteria approved by the SALT. Qualitative assessments will be used as necessary for programmatic and science/applications objectives which prove difficult to score quantitatively. The results of these assessments, along with the Decadal Survey's prioritization, provide the overall benefit produced by each mission architecture. These benefits will then be evaluated within the context of costs of the mission architectures — obtained from cost estimates using component-level parametric cost models — and risk assessments. To provide insight into the key discriminators across mission architectures, the scores against each science objective and programmatic figure of merit will be reported in combination with the integrated cost and risk scores, rather than rolled up. This analysis will be included in the study team's final report to provide a value-driven basis for the down-select decisions made during the study's execution.

The Systems Analysis and Concepts Directorate (SACD) at the Langley Research Center (LaRC) will lead the VFT, coordinating with Goddard Space Flight Center (GSFC) Study Coordinator and the LaRC, and Jet Propulsion Laboratory (JPL) Deputy Study Coordinators to define, implement, and facilitate the value framework. The specific scientific criteria for the VF will be defined as part of the Study, with the LaRC SACD playing a leading role in the analysis and the SALT/SCC/SMT/SET providing input regarding qualitative and quantitative assessment measures. SACD supports the Office of the Administrator and each of the NASA mission directorates, performing strategic planning, technology assessment and gap analysis, and concept development, analysis, and integration of complex aerospace systems. The SACD supports the Science and Mission Directorate (SMD) by functioning as an independent assessment arm, with appropriate firewalls, for the Science Office for Mission Assessment (SOMA), as well as for select Earth System Science Pathfinder (ESSP) Program Office and Committee on Earth Observation Satellites (CEOS) projects. SACD analysts will develop the framework in concert with the study team and will facilitate the integration of the utility and quality scores determined by the science team into the framework.

The planned key activites and deliverables for FY19 and FY20 are shown in **Figures 1-4** and **1-5**.

1.4 Engaging the Wider Science Community

The primary connection of the A-CCP study to the wider science community is realized through the Science Community Cohort (SCC). The SCC is an external group consisting of leading national and international scientists (and application practitioners) in the Aerosols and CCP communities. The SCC provides general advice on matters relating to science directions of the A-CCP study. The SCC will be provided full access to the science outputs of the study, the Value Framework Plan, and offer community input to the SALT on activities needed to strengthen the overall A-CCP study. In addition to members of academia, the SCC will also include relevant industry/OGA liaisons in the area of air quality. In addition, the SALT may organize town hall style meetings at the AGU, EGU, and AMS annual meetings to brief the broader scientific community on the status of the A-CCP study, and to engage in discussions with potential national and international partners.

For air quality applications there are a number of stakeholders that we intend to engage during the A-CCP study. AQ Managers (*e.g.*, EPA, state agencies) require accurate surface concentrations of PM2.5 if this data is to be used for regulatory purposes (meeting national standards such as NAAQS). AQ forecasters (*e.g.*, NOAA) require satellite derived PM2.5 for evaluation of their AQ forecasts; although accuracy may be less important for these users, temporal and spatial resolution are critical (*e.g.*, tracking forest fire plumes). Improving the accuracy of air pollution forecasts is very important to provide at risk populations with improved information for behavioral modification decisions since the majority of air pollution-related health impacts occur on "good" or "moderate" days. By leveraging efforts by the MAIA mission, we hope to actively engage Health Professionals (*e.g.*, epidemiologists) and further capture the requirements of that community.

Key Activities	Deliverable	Completion Date
Continue collaboration with Systems Engineering Team to ensure generation of key mission parameters.	Documentation during architecture studies.	January 2020
Facilitate risk assessment activities.	Documentation of risk assessment for each mission concept.	February 2020
Support cost activities as requested.	Documentation of cost assessment for each mission concept.	February 2020
Coordinate and document the generation of benefit scores. Design and facilitate Expert Judgment Elicitation when needed.	Documentation of benefit scores and their sources.	May 2020
Produce visualization and analysis.	VF report.	July 2020

Figure 1-4: FY19 VF Key Activities

VF Key Activities	VF Team Deliverables	Completion Date
Value Framework Design: • Define value and identify its components • Define methods and processes to assess benefits, cost, and risk • Obtain study team concurrence through frequent interactions • Peer-review by Decision Science practitioners	Complete, documented Value Framework ready for implementation. Methods and processes are identified, peer-reviewed, and agreed upon.	May 2019
Support definition of science and applications objectives, and preliminary identification of programmatic factors.	Facilitation throughout development of prioritized SATM(s), as well as during preliminary identification of programmatic factors.	May 2019
Collaborate with Systems Engineering Team to identify key mission parameters to enable VF evaluation and ensure their generation.	List of key mission parameters, documentation during architecture studies.	March 2019, then throughout studies
Support definition of benefit scoring methods and processes.	Scoring plan.	May 2019
Support definition of risk assessment methods and processes.	Risk assessment plan.	September 2019
Develop tools and visualization for documenting and collating VF inputs; test and validate.	Visualization tools, documentation scheme.	September 2019

Figure 1-5: FY20 VF Key Activities

2.0 - ARCHITECTURAL APPROACHES FOR DESIGNATED OBSERVABLES

We will use an integrated system architecture approach to map the performance-cost-risk trade space of the A-CCP DOs. This approach requires the use of prioritized science traceability matrices (SITMs), with varying levels of performance capabilities, along with matching libraries (**Section 2.2**) of varying technical capability and technology readiness, and consideration of PoR capabilities and those of potential extended field campaigns. The use of design centers at GSFC, LaRC, JPL, MSFC, and GRC will stretch across fiscal years 2019 and 2020. Architecture studies in fiscal year 2019 will address aerosol science achieved via (a) single spacecraft and (b) a distributed constellation of smallsats; CCP science via (a) single spacecraft and (b) a distributed constellation of smallsats; A+CCP science via (a) a distributed constellation of smallsats and (b) a combination of a single spacecraft and a constellation of smallsats (hybrid). Based on prior experience and design center availability, the fiscal year studies will be performed as follows: (a) Aerosol single spacecraft - LaRC, (b) Aerosol distributed smallsats, CCP single spacecraft, A+CCP hybrid - GSFC; (c) CCP distributed smallsats, A+CCP distributed smallsats - JPL. With the full involvement of the NASA ESD's A-CCP PS, PE, and PAL over the course of the fiscal year 2019 study activities, the A-CCP team will conduct comprehensive discussions involving all stakeholders prior to determining the scope and content of design center efforts in fiscal year 2020.

2.1 Integration of Science, Applications, and Engineering

Essential to a successful observation system architecture activity is the integration of science, applications, and engineering throughout the process. Maintaining this integrated approach during the A-CCP study will maximize the potential for end results that reflect an optimal balance between science and applications needs and technical capabilities. To this end, the A-CCP study contains multiple check points where the science leadership team, science and applications assessment teams, and the independent science panel meet with the PS, the PAL, the systems engineering team and the independent engineering panel to review aspects of the study.

The architecture formulation phase of the A-CCP study will begin with a joint review of the prioritized SITMs by the science leadership team, science and applications assessment teams, and, A-CCP PS and PAL, independent science panel, systems engineering team (made up of a single Study Plan Systems Engineer from each of the partner Centers, as applicable), and an independent engineering panel from each partner NASA Center and the Aerospace Corporation — as applicable). The intent of this joint review is to ensure there is a shared understanding of the science objectives and related prioritized desired measurement capabilities, as well as any sensitivities and interdependencies inherent to the measurements. This face-to-face review will be by invitation only and focus on the programmatic constraints/assumptions inherent to the work to go.

2.2 Identification of Technology/Technical Readiness (Govt., Academia, Industry, Foreign)

To conduct assessments of a comprehensive set of observation systems architectures, technical capability and technology readiness libraries for the instruments, spacecraft, access-to-space, and field campaigns (airborne/ground instruments) providers will be created. The instrument library will be developed by a multi-center team and contain entries of different instrument types (*e.g.*, radar, polarimeter, lidar) at varying levels of performance (*e.g.*, threshold and objective), maturity (no less than TRL 6 by the A-CCP system level Preliminary Design Review (PDR)), and cost. Instrument concept specifics will be solicited from a wide array of providers, including NASA Centers and JPL, industry, and academia through the use of a Request For Information (RFI). The RFI responses, combined with the knowledge inherent to the team partners, will be used to develop the instrument library. The Aerospace Corporation will participate in the formulation of the instrument library and also be tasked to formulate an instrument "classified annex" (at the Top Secret/Sensitive Compartmented Information (TS-SCI) level) that could be made available to members of the A-CCP management, science, and systems engineering teams who have the required clearance. Over the course of the study, the instrument library will be re-visited, as appropriate, to reflect technology maturation (*e.g.*, life testing) consistent with technology maturation plans already present in the library. Normalized costing will be performed using NASA and Aerospace instrument cost models with cost drivers identified.

The RFI will be released and followed up by an Industry/Academia Q&A day held at the GSFC within approximately two months of receiving a study authority to proceed (ATP) from ESD. The A-CCP Science Leadership and Systems Engineering teams will create a standardized input form for the RFI. The form will contain essential aspects of instruments such as:

- Measurement performance information
- Master Equipment List (MEL)
- Mass, power, volume, and data rate
- Thermal, mechanical, and electrical spacecraft interfaces
- Technology readiness assessments
- Maturation roadmaps (as applicable to reach TRL 6 by A-CCP observation system PDR)

Following receipt of RFI responses, an invitation will be extended to any responder to provide the government a proprietary briefing. **Table 2-1** contains a preliminary listing of the Center partners' contributions and potential industry contributions to the instrument library.

Similar catalogs for spacecraft, launch vehicle and rideshare opportunities will be generated, largely from existing databases. A library of field campaigns (airborne/ground instruments ala Operation IceBridge) will be created, post finalization of SITMs, as a direct result of the planned Blue Sky Innovation Workshop. The intent of the Blue Sky workshop is to creatively explore many architecture possibilities before launching into architecture design activities. Top level advantages: (1) assure that we aren't rushing to narrow design solutions, (2) provide transparency and clarity of how each future design activity maps into the big picture. A successful Blue Sky activity will influence the architecture studies by capturing creative ideas at the beginning of the design process. The SITMs will be examined for desired capabilities that are directly applicable to existing airborne and ground instruments, applied as part of regional/global extended field campaigns. The logistics and costs associated with these field campaigns will be refined, post workshop, with their specifics included in a field campaign library for use in the planned architecture design center efforts.

In all cases, the content of the libraries will be limited to those hardware whose technology readiness level (TRL) is either TRL 6+ at the time of study completion (mature) or projected to be TRL 6 by A-CCP's notional system level PDR date (emerging). The description of each mature system will include discussion of such aspects as measurement capabilities, flight worthiness, and accommodation requirements. The description of each emerging system will include discussion of projected measurement capabilities, technology maturation roadmaps, subsystem space qualification, and accommodation requirements. To the extent that new technology is inherent to technology maturation roadmaps, it will be evaluated over the course of the design center efforts.

Table 2-1: Potential instrument providers and library entries.

Center/ Partner	Instrument Name/Type	Spaceborne Heritage	P.O.C.
Ball Aerospace	Lidar, microwave radiometer/GMI	GPM	Pett
LaRC	CALIOP-like Low rep-rate backscatter lidar and HSRL	CALIPSO and airborne HSRL; EarthCARE will deploy an ESA UV HSRL and Aeolus deploys a UV wind lidar based on similar technology	Hostetler
GSFC	CATS/ High rep rate backscatter lidar	ISS	McGill
	APS Polarimeter	Glory	Cairns
	Single (X or Ku band), Dual- (Ka, W) and tri- (Ku, Ka, W) band radars	Airborne subscale demo for ACE, CloudSat, NG space heritage.	Heymsfield, Lihua Li
JPL	W band radar - nadir	Cloudsat	Tanelli/Durden
	W band radar – scanning	IIP	Sadowy
	C to Ka band single frequency radars	Various forms including scatterometers, altimeters, Rain-Cube –Invest, SWOT, GLISTIN	Tanelli/Peral
	Multi-frequency (any combination of Ku, Ka and W band) radar (MASTR – IIP, APR-3 – AITT)	Raincube, CloudSat, and PR-2 heritage (MASTR first complete prototype airborne Test flights and critical subsystem TVAC/Vibe planned in 2019)	Tanelli/Sanchez-Barbetty
	VIPR (G-band IIP, water vapor profiler in cloud)	first complete prototype airborne Test flights planned for 2020	Lebsock/Cooper
	MSPI/imaging polarimeter, MAIA	MAIA EVI-3 (launch 2021)	Diner
	EMIT/spectrometer	M3, EMIT EVI-4 (launch 2022)	Green
	Microwave radiometer/miniaturized	MASC-TEMPEST (INVEST), ENTICE – derived of MASC, not yet flown in pace	Padmanabhan Lim
	Microwave, lower frequency	COWVR, waiting launch as part of airforce demonstration	Brown
Northrop-Grumman	X- or Ku-band radar	NG space demo of X-band antenna in 2018	Michael Cooley
SRON	SPEX Polarimeter	Airborne, planned for PACE	Otto Hasekamp
UMBC	HARP/polarimeter	InVEST (launch 2018) PACE (launch 2022)	Martins

An appendix containing technologies that are attractive, but are not expected to be ready to support the implementation of the A-CCP observing system will be included in a separate appendix in the final study report.

Commercial data buys in lieu of conventional instrument deployment will also be considered, as will the data available from Other Government Agencies (OGAs) and foreign space agencies according to existing PoRs. Consistent with the study's approach to TRL, the discussion of commercial data buys and data available from OGAs and foreign space agencies will focus on existing offerings and projected offerings expected to be mature (TRL equal to or greater than 6) at the time of the A-CCP's observation system PDR. Risks associated with these alternative approaches will be identified and assessed vis-à-vis using NASA dedicated capability.

The final step in the technical/technology library phase of this study will be to reconcile and normalize assessment of measurement performance, technology readiness, and technical risk. The Science Leadership and Systems Engineering teams will examine the libraries for completeness, and resolve any problems identified. An independent panel of scientists and engineers will then perform a systematic assessment of each library versus the prioritized desired measurement capabilitiess included in the finalized

SITMs. In the case of the instrument library, the panels will have access to the instrument design centers at GSFC and the Aerospace Corporation in the event that more in-depth assessments are required. This reconciliation will ensure that the content of each library used in the architecture study is consistent with the study's TRL guidance and fully capable of meeting the desired prioritized science measurement capabilities stated in the SITMs.

2.3 General Approach for Defining and Assessing Observing System Architectures

Consistent with the intent to provide the most comprehensive assessment of observing system architectures to ESD, single spacecraft, multiple small satellites, and hybrid architectures will be evaluated for each potential science observable option (Aerosols as a single observing system, CCP as a single observing system, and a Combined Aerosol and CCP observing system). An architecture type can satisfy the SITMs at varying levels of value determined by the composition of a constellation. A constellation consists of a selection of one or more instrument(s) placed on one or more spacecraft flying in one or more orbit(s). Inherent to each architecture examined is appropriate launch and ground system capabilities. Phase E operation concepts could consider government and commercial solutions for communications, data processing, and storage.

Each architecture assessed will draw from the libraries of instrument, spacecraft, and access-to-space capabilities described above. The technical performance, cost, and schedule of each architecture will be assessed by the multi-center engineering team. Scientific value relative to the SITMs will be determined by an objective function developed by the science team in consultation with the systems engineering team. Thus, each architecture will provide a specific scientific value at an associated cost and technical risk.

Finally, after thorough and extensive discussions with the A-CCP PE, PS, and PAL, a subset of architectures will be chosen for more detailed study. To ensure transparency and unbiased results, the studies will be conducted at design centers located at GSFC, LaRC, JPL, Glenn Research Center (GRC), Marshall Space Flight Center (MSFC), and the Aerospace Corporation. Each design center will be provided with the same set of technical/technology libraries to ensure uniformity of inputs for the respective studies, along with access to the Science Leadership Team in the event that science-related questions arise. The design centers at MSFC, GRC, and the Aerospace Corporation will provide results independent of any perceived organizational bias tied to the use of instruments associated with a given Center. The A-CCP will work closely with the A-CCP PE, PS, and PAL to ensure a uniform understanding of the results - format and content - that will be delivered by each design center. The A-CCP team will also ensure that the ESD PE, PS, and PAL are kept informed as to the final schedule of design center studies and their location.

2.3.1 Definition of System Level Capabilities and Current/Projected Capabilities

Working only from the SITMs codified earlier in the study and the technical/technology libraries provided, system-level implementation capabilities will be defined. The system-level capabilities will reflect the temporal and spatial resolutions required by the SITM(s), as well as data flow, data archiving, communications, and ground system capabilities. Those capabilities will include traditional government-unique approaches, as well as commercial communications, cloud storage and computing for archiving and data processing, commercial ground systems, commercial launch services (including rideshare), and contributions from international partners for any or all aspects noted.

2.3.2 Spacecraft

Per the study definition received from ESD, the spacecraft aspect of all architectures will be based on a commercial procurement managed by the observing system management Center tasked by ESD.

Using the spacecraft technical/technology library, each architecture study will look at classes of spacecraft that will provide the required performance for the type of instrument(s) being accommodated (provided via the instrument technical/technology library) in concert with associated spacecraft cost and delivery schedule. The use of GSFC's Rapid Spacecraft Development Office (RSDO) catalog and a conventional Request For Proposal (RFP)-based procurement approach will be factored into notional observing system master schedules.

2.3.3 Airborne and Ground-based DO Measurements

Recognizing the continuing pressure to control costs at the observing system level, each architecture study will include the use of the field campaign library (formulated post Blue Sky Innovation session) to ensure the cost effective the use of existing ground-based instruments and extended field campaigns (*i.e.,* airborne instruments used in conjunction with ground- and space-based assets, *e.g,* Operation IceBridge).

2.3.4 Commercial Data Buys

The A-CCP architecture teams will leverage the results from NASA's first pilot data ($NNH_18ES0001$) buy to inform options for potential data buys related to A-CCP measurement objectives.

2.3.5 Calibration and Validation

Each architecture team will work with both science and systems engineering SMEs to develop a ground and airborne calibration validation strategy. Input will be solicited from Centers, industry, and academia for potential instruments that could provide the required calibration validation measurements. To the extent practical, the emphasis will be on the use of existing NASA-owned or commercially-available instruments to provide these data sets. All options will be considered for platforms, including piloted and remotely-piloted NASA aircraft and commercially-available aircraft.

2.3.6 OSSEs to assess abilities of specific observing system concept architectures to address DO priorities

In cases where architectures developed reflect new or unique approaches with potentially expanded scientific value, the A-CCP science team will perform a limited number of detailed OSSE's to further understand the scientific value of the architecture.

2.3.7 Assessment of Algorithm Requirements

Historically overlooked during architecture studies, the algorithm requirements inherent to each observing system architecture will be assessed by the A-CCP science team. The cost and schedule associated with the development of any modified or new algorithms will be included in the results submitted to ESD.

2.4 Architecture Options

Three architectures will be considered for satisfying the SITMs: Distributed SmallSats, Single Observatory, and Hybrid Approach. After discussions with the A-CCP PE and PS, the studies shown in

Table 2-2 were modified such that architecture studies in fiscal year 2019 will address aerosol science achieved via (a) single spacecraft and (b) a distributed constellation of smallsats; CCP science via (a) single spacecraft and (b) a distributed constellation of smallsats; A+CCP science via (a) a distributed constellation of smallsats and (b) a combination of a single spacecraft and a constellation of smallsats (hybrid). Based on prior experience and design center availability, the fiscal year 2019 studies will be performed as follows: (a) Aerosol single spacecraft - LaRC, (b) Aerosol distributed smallsats, CCP single spacecraft, A+CCP hybrid - GSFC; (c) CCP distributed smallsats, A+CCP distributed smallsats - JPL. The balance of studies shown in **Table 2-2** for fiscal year 2019 will be considered for fiscal year 2020 with the understanding that the original redundancy of studies across design centers has now been eliminated. The intent of the redundancy has been retained by adding the inclusion of design center personnel from all partner centers to the efforts now called out in **Table 2-2**.

Inherent to the Center-inclusive nature of the A-CCP study is the use of the design centers located at GSFC, LaRC, JPL, MSFC, and GRC. The inclusion of the Aerospace Corporation's design center will provide a more balanced, comprehensive study results. The full inclusion of the A-CCP PE, PS, and PAL serves to provide the final piece of the A-CCP team's balanced approach to the architecture studies.

During the initial A-CCP draft study planning phase, the GSFC Study Coordinator sent out a request to each Center's upper management to submit its desired involvement in the overall A-CCP study. To the extent that each Center's resource availability aligned with the overall proposed A-CCP study budget and schedule, all desired involvement activities have been included and are described in the following sections. The planned cadence of the design center efforts allows for results to be discussed by the larger A-CCP team and used to inform subsequent design center efforts. A number of representatives from each Center's design center will be invited to participate in each of the architecture study assessments at GSFC, LaRC, MSFC, GRC, and JPL to serve as SMEs.

The GRC Compass and Aerospace Corporation design centers will provide initial architectures as noted and additional architecture efforts, as required, to be determined at approximately the midpoint of the overall architecture effort. The proposed A-CCP budget contains funding in fiscal year 2021 (FY21) for one Aerospace study and two GRC studies.

In the event that results from individual observing system architectures delivered by the Center and JPL design centers diverge due to significant differences in the interpretation of the supplied libraries, a separate 30-day reconciliation period will be entered into for each instance to ensure all issues are addressed in a transparent manner and additional architecture work is conducted, if deemed necessary.

Table 2-2: The A-CCP study's combination of a science center-based design lab and independent design lab efforts will ensure final observing systems architectures are free of any inherent bias.

Architecture	Design Center	Notes
DSS/Aerosols	GSFC, LaRC	
DSS/CCP	GRC, JPL	
DSS/A-CCP	JPL, Aerospace	GRC and Aerospace will be funded to perform additional architecture work on an as-needed basis
SO/Aerosols	GSFC, LaRC	
SO/CCP	GSFC, MSFC	
SO/A-CCP	MSFC, Aerospace	
H/Aerosols	GRC, LaRC	
H/CCP	GRC, JPL	
H/A-CCP	GSFC, JPL, Aerospace	

2.4.1 Distributed SmallSats

The GSFC, LaRC, GRC, JPL, and Aerospace design centers will each perform single architecture studies as noted in **Table 2-2**.

2.4.2 Single Observatory

The GSFC, LaRC, MSFC, and Aerospace design centers will each perform single architecture studies as noted in **Table 2-2**.

2.4.3 Hybrid Observing Systems

The GSFC, LaRC, GRC, JPL, and Aerospace design centers will each perform hybrid architecture studies as noted in **Table 2-2**. These studies will occur in FY20 so as to maximize the benefits gleaned from the distributed SmallSat and single observatory architecture studies.

2.4.4 Gap-filling Airborne and Ground-based Observations

The Science Leadership team will draw upon NASA scientists and engineers with extensive research and analysis (R&A) field campaign experience to define potential gap-filling airborne and ground-based campaigns that could complement A-CCP spaceborne assets toward addressing key science objectives. The Blue Sky Innovation session held post SITM finalization will contain a session in which the SITM will be closely examined to determine what desired capabilities are easily met through the use of extended field campaigns involving mature airborne and ground instruments (note that the SITM will have already been "filtered" using the PoR capabilities). All candidate campaigns will have associated top level airborne and ground-based instrument capabilites, seasonal requirements, durations, and global coverage capabilites, along with rough order of magnitude (ROM) cost estimates. The campaigns will be included in the field campaign library for application during the design center architecture efforts.

2.5 Pivot Point and Summary Reports

The A-CCP Study Coordinator and study management team will work closely with ESD over the course of the study to define the summary report format that best serves ESD's needs. A baseline format will be defined prior to the kickoff of the individual architecture studies, with any subsequent revisions being mutually agreed upon by ESD and the Study Coordinator.

2.6 Creation of data sheets for use in independent cost/schedule assessments

The A-CCP Study Coordinator will work closely with the study management team to formulate standardized data sheets that will contain the results from the individual architecture studies needed to perform independent cost/schedule/technical risk assessments. These independent assessments will be performed by Technomics.

3.0 - INDEPENDENT SCIENCE/COST/SCHEDULE ASSESSMENT

3.1 Independent Assessment by Community Panel using Value Framework

The study team will perform a comprehensive assessment of the observing systems architectures, applying a comprehensive framework to analyze the value of each architecture as defined by its provided benefits relative to its associated cost and risk (schedule and technical). The team will execute a series of analyses that each produce valuable, timely products and findings. This effort will begin with an initial coordination meeting with the PE/PS/PAL in September 2018, followed by a larger kickoff meeting in October 2018. Progress will be briefed at the A-CCP team kickoff meeting in January/February 2019.

As discussed in **Section 1.3**, benefits will first be assessed within the Value Framework employing a Multi-Attribute Decision Analysis approach. Working in concert with the SMT, SALT, Systems Engineering Team, SCC, and PE/PS/PAL, figures of merit (cf. **Section 2.3**, paragraph 2) will be defined that encompass science and application objectives (traceable to the Decadal Survey) and programmatic objectives identified by the study team. Quantitative utility and quality scores (ref Continuity Report) will be determined by the science leadership team and reviewed by the independent science panel during a week-long workshop. It will be used together with qualitative assessments to complete the scoring matrix. Benefits will be evaluated against independent cost/schedule/technical risk estimates (**Section 3.2**). Poorly performing options (*e.g.* low benefit gained for large increases in cost and risk) will be documented and removed from further consideration. LaRC's SACD, which has developed similar frameworks for supporting mission analysis efforts for other NASA mission directorates, will take the lead in setting up the structure for quantitatively and qualitatively assessing the value of the mission architectures, including science and programmatic figures of merit. Study team members from SACD will also facilitate the completion of the Value Framework by the broader science/engineering/project team, whose expertise is required to develop quantitative formulations for scoring each figure of merit being evaluated. SACD personnel will also aid in the interpretation and presentation of results from Value Framework.

Completion of this phase of the study will provide a comprehensive, documented, and transparent analysis of the value that the architectures put forward. This analysis will be included in the study team's final report to provide a value-driven basis for assessing the observing systems architectures.

3.2 Independent Cost/Schedule/Technical Risk Assessments

As noted in **Section 2.6**, the A-CCP Study Coordinator will work closely with the study management team to formulate standardized data sheets that will contain the results from the individual architecture studies needed to perform independent cost/schedule/technical risk assessments. These independent assessments will be performed by Technomics. The Study Coordinator will ensure that the ESD PE and PS are kept up-to-date on the progress and results of this effort.

3.2.1 Process

A systematic process that ensures development and documentation of credible, defensible cost estimates is essential. The process employed in this study will reflect features that are consistent with best practices, specifically the Government Accounting Office's (GAO's) prescribed "12 Steps of a High-Quality Cost Estimating Process." Though displayed as a sequential process in **Figure 3-1**, feedback loops exist in order to improve estimating approaches as additional information is compiled and results are analyzed.

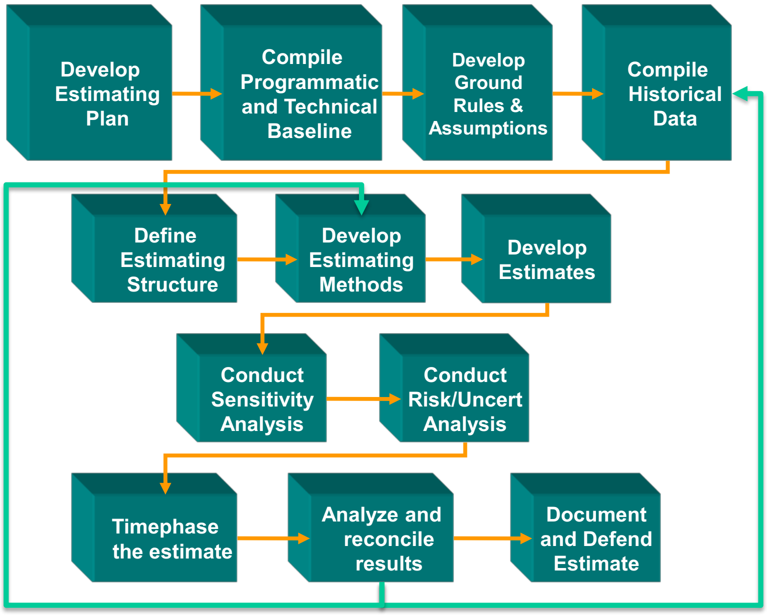


Figure 3-1: Cost estimation process from GAO's "12 Steps."

The "Compiling the Baseline" step involves understanding the salient technical and programmatic features of each alternative to be evaluated and placing them in standardized data input sheets. The architectural studies represent the principle source of the required technical (*i.e.,* physical and performance parameters) and programmatic (*e.g.*, key decision points, etc) information. Given the foundational nature of this baseline information, this step also includes ensuring the completeness of each architecture (*i.e.,* relative to hardware definition) and realism of key technical values associated with each architecture (*e.g.*, mass, power, etc.). Validation will be accomplished via collection/review of Cost Analysis Data Requirement (CADRe) information (*i.e.,* Part B) for relevant projects/subsystems/components and Master Equipment List (MEL) information not addressed in the CADRes. The "Ground Rules & Assumptions" step involves creating general and specific estimating ground rules and assumptions that represent agreed-upon (by study partners and ESD) boundary conditions for the cost/schedule estimates.

The "Historical Data" step will begin early in the overall study, as it involves the collection, organization, and normalization of historical (*i.e.,* actual) cost, and technical and schedule data for as many relevant projects as possible. Specific to this study, data from missions with primary and secondary scientific objectives regarding the examination of aerosols, clouds, convection, and precipitation are imperative to creating informed estimates. **Table 3-1** is an example of such data that will be collected.

Additional information that will affect the cost of the observing system architectures will be the heritage and technological readiness of the instrumentation and spacecraft derived from the libraries created in the A-CCP study. The data will be normalized for a variety of factors (*e.g.*, inflation) to ensure comparability across projects, and all normalization procedures will be documented to provide traceability to the source data. Utilizing systems like the One NASA Cost Engineering (ONCE), NASA Business Objects (BOBJ), and additional databases will assist in organizing and normalizing historical cost data.

Central to the "Estimating Structure" step is the creation of NASA-compliant work breakdown structures (WBS) that include all relevant elements of cost, thereby ensuring that: a) each estimate

Table 3-1: Example collection of historical data sources and applicability to the study.

Name of Mission	Acronym	Type of Mission			Science Objective		Additional Notes
		Single Observatory	Distributed SmallSat	Hybrid	Aerosol	CCP	
Glory	—	X			X		
Earth Cloud Aerosol and Radiation Explorer	EarthCARE	X			X		International Partnership, internationally managed
Polarization & Anisotropy of Relfectances for Atmospheric Sciences Coupled with Observations from a Lidar	PARASOL	X		X	X		Single small sat, part of A-train missions
Earth Radiation Budget Satellite	—	X			X		Launched in 1984, will not use for reference
Terra	—	X			X		Launched in 1999, will not use for reference
Global Precipitation Measurement	GPM	X				X	International partnership, NASA managed
Tropical Rainfall Measuring Mission	TRMM	X				X	
Aura	—	X		X	X	X	Part of A-Train missions
Environmental Satellite	EnviSat	X				X	International partnership, internationally managed
Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats	Tropics		X			X	
Surface Water and Ocean Topography	SWOT	X				X	International partnership, NASA managed
Aerosols Clouds Ecosystems	ACE	X	X	X	X	X	Multiple architectures studied, currently in dev
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations	CALIPSO	X		X	X	X	Part of A-Train missions
Cloud Satellite	CloudSat	X		X	X	X	Part of A-Train missions
Acqua	—	X		X	X	X	Part of A-Train missions
Land Satellite	LandSat	X		X	X	X	Multiple satellites in constellation part of the same mission
Geostationary Operational Environmental Satellite System	GOES	X		X	X	X	Multiple satellites in constellation part of the same mission

for a given alternative is complete, b) cost driving elements are readily visible, and c) estimates can be compared across alternatives with the appropriate degree of cost driver discrimination.

The "Estimating Methods" step involves development of the 'best' estimating approach (*e.g.*, parametric, analogy, engineering build-up or extrapolation) for a given observing system architecture cost element. The 'best' approach for estimating each element cannot be predetermined, since that selection is driven by the type, quantity, quality, and detail of historical project data available. The effort applied to developing methodology for a given cost element will be consistent with the magnitude of that element's expected costs, risks, and uncertainties. To ensure completeness, existing methods deemed credible and acceptable (*e.g.*, the NASA Instrument Cost Model (NICM), PRICE, and SEER models), provided they are calibrated with relevant historical actuals, will also be used.

The "Develop Estimates" step involves application of the various methodologies to develop cost and schedule estimates. The "Sensitivity Analysis" step involves analysis of how the estimates vary in response to changes in key programmatic ground rules and assumptions, technical parameters, or estimating methodology. Meanwhile, the "Risk and Uncertainty Analysis" step involves generating statistical uncertainty bounds about all point estimates based on the variability associated with the various cost estimating methodology employed. It also involves generating reasonable bounds for methodology input parameters by cost element and quantifying the impact of those input parameter variances on the resulting estimate. The "Time Phase" step provides uniformity of cost by time-phasing the constant year estimates developed (*i.e.,* the output of the various estimating methodology employed) using techniques and assumptions appropriate for a given phase (*e.g.*, a Rayleigh distribution for development estimates) and then converting the time-phased constant year dollar estimates to then-year dollar (*i.e.,* inflation-adjusted) estimates using appropriate inflation indices.

3.2.2 Uniform Delivery of Results

The "Reconciliation" step's focus for the A-CCP study will be the comparison of Center design center-developed and Technomic cost estimates, followed by assessing the magnitude of cost differences and investigating the underlying assumptions, data, and methodologies driving those differences. The thorough application of all aspects of this step will ensure uniformity of the formatting of final results (*e.g.*, the estimates will be presented in tabular and graphical formats to ensure the results are easily interpreted), thus enabling the efficient application of results by ESD.

3.2.3 Risk Assessments Results

The "Document and Defend Analysis and Results" step will ensure that results are documented in a manner that enables an experienced analyst at NASA HQ to replicate the results. The documentation will include both a technical report and a presentation, each of which describes the results/products of every step in the process.

4.0 - CONTRIBUTIONS AND SYNERGIES

4.1 A-CCP synergies with the PoR and commercial missions

The DS identified the important role that PoR measurements can make in addressing the science objectives, with the potential to substantially reduce the cost or enhance the benefit of A-CCP. The A-CCP team will thoroughly evaluate the relevance of PoR missions (**Appendix A** of the DS) to the A-CCP objectives, particularly in terms of existing and planned U.S. and international missions that will be potentially well-suited to providing close-in-time (A-Train-like) measurements fulfilling one or more of the A-CCP desired measurement capabilities and perhaps impacting subsequent architecture designs. Other missions in the PoR may be able to provide additional valuable measurements, but perhaps with less accuracy, quality, or synchronization in time. Where applicable, the A-CCP study report will identify potential partner missions within the PoR.

Active sensors like CloudSat and CALIPSO are not expected to still be in operation by the time of an A-CCP mission. EarthCare may also be very relevant, but may be beyond its mission lifetime by the launch of A-CCP. We will carefully examine how potential A-CCP lidar measurements would address stratospheric aerosol measurements and complement the OMPS and SCCE-III measurements. While it is unlikely that sensors such as the Moderate resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging SpectroRadiometer (MISR) will be operating during A-CCP, measurements from similar multiwavelength imaging VIS/IR radiometers [*e.g.* the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) and the Joint Polar Satellite System (JPSS)] and the Ocean Color Instrument (OCI) on the Plankton, Aerosol, Cloud, ocean Ecoystem (PACE) are expected to play important roles for providing large and frequent coverage of estimates of cloud and aerosol properties. Narrow and broadband radiometers for cloud properties, aerosols, and radiative fluxes are expected to be present within the PoR, but their utility to A-CCP will need to be examined.

GPM can provide active radar and passive microwave observations relevant to A-CCP, and will be important to continued global mapping of precipitation. The Tropical Rainfall Measuring Mission (TRMM), the predecessor to GPM, lasted more than 17 years before running out of fuel. GPM's longevity will depend on the health of the instruments and spacecraft, not fuel most likely (fuel will last into the 2030s). Therefore, GPM may play an important role in A-CCP objectives, although its inclined orbit makes it unsuitable for studying polar A-CCP processes.

New capabilities of operational satellites provide aerosol and cloud data that can contribute to A-CCP science. The Advanced Baseline Imager (ABI) and Advanced Himawari Imager (AHI) on the Geostationary Operational Environmental Satellite R series (GOES-R) and Himawari geosynchronous satellites, respectively, provide 16 frequencies spanning visible and shortwave, near-, and long-wave infrared wavelengths at spatial resolutions of 0.5 to 2 km and temporal resolution of 10-15 minutes (full disk). These frequencies allow detection of aerosols and measurements of aerosol optical depth; cloud-top temperature, height, and phase; cloud optical depth and effective size; and TOA reflected shortwave radiation. Beginning in 2021, Meteosat's Third Generation (MTG) satellites will carry the Flexible Combined Imager (FCI) with comparable frequencies and level-2 products with spatial resolution from 0.5 to 2 km and temporal resolution of 10 minutes. These measurements will be especially important for investigating the evolution of cloud systems and aerosol regions, as well as the impacts of aerosols on air quality and weather.

The GOES-R series also includes the Geostationary Lightning Mapper (GLM), while the MTG series will include the Lightning Imager (LI), providing broad coverage of continuous lightning measurements. These new capabilities will allow connection of lightning occurrence and flash density to CCP-derived convective system properties and potential aerosol impacts on these systems.

The geosynchronous data will provide coverage of lower to middle latitudes, but will be of more limited utility at higher latitudes. The operational suite of polar-orbiting satellites will therefore play a more critical role in high-latitude aerosol and cloud measurements. Important sensors include VIIRS on the JPSS series of satellites; and the Meteorological Imager (METimage), the Ultraviolet/Visible/Near-Infrared/Shortwave-infrared spectrometer (UVNS), the Ice and Cloud Imager (ICI), and the Multi-viewing/Multi-Channel/Multi-polarization Imager (3MI) instruments on the Metop-SG A-series of satellites.

The use of operational and research missions from the PoR can help to either fulfill observable requirements, thereby reducing mission costs, or enhance the mission science outcomes. However, such datasets may require investments in data processing and algorithms at Levels 0, 1, and 2. For example, the ABI and AHI can provide MODIS- and VIIRS-like products for cloud and aerosol properties. However, derivation of climate quality products requires storage of L0 and/or L1 products, consistent calibration of and intercalibration between sensors, L2 product algorithms to derive cloud and aerosol optical depth, cloud effective radius, and cloud top phase and height, and the ability to reprocess as algorithms evolve. As part of the analysis of the PoR, we will assess data processing requirements and costs, including storage, algorithm development, and infrastructure requirements.

4.2 The A-CCP study's relation to other Designated Observable (DO) studies

There area number of ways the A-CCP study relates to the other DOs. Preliminary engagement with a number of studies that are under development has already begun and both the SALT and SCC members will maintain this engagement. The study strategy is to include members on the A-CCP teams who are directly involved in these other studies as called out below.

4.2.1 Surface Biology and Geology

The study will further explore obvious connections between the SBG and A-CCP. The VIS-NIR spectral measurements of SBG in particular have the potential to provide important cloud and aerosol information and this potential will be explored as part of the study. Aerosol information derived from A offers a potential improvement to atmospheric corrections employed in the SBG measurement approach. Other potential connections exist and these will be explored during the study and in consultation with the SBG study. These connections have already begun, and we plan to invite SBG representatives to A-CCP meetings and attend selected SBG meetings.

4.2.2 Mass Continuity

Several studies have recently demonstrated the importance of surface mass balance changes to total ice mass change of the major ice sheets. As snowfall is a critical component of the surface mass balance, better measures of snowfall over the major polar ice masses in conjunction with the ice mass changes potentially provide a broader understanding of how ice changes. The study will quantify the expected improvement of polar snowfall over past CloudSat observations. Studies have also shown the value of ice mass loss information from gravimetric observations as a way of calibrating snowfall in polar regions. Membership of the SIT will include precipitation experts who have engaged in the use of GRACE data and who thus understand the relation between the mass continuity DO and CCP.

4.3 A and CCP potential contributions to Earth Science Explorers (ESEs), Incubation and other DS TOs

4.3.1 Snow Depth/Cover

CCP would contribute to this observable objective with an altimetric mode on a Ka- (and perhaps W-) band radar as noted in the CCP description. Preliminary discussion with the snow community has begun in order to understand requirements and assess whether CCP capabilities have the potential to contribute. Since the measurements of CCP are relevant to this community, participation in the A-CCP meetings will be extended to representatives of this community. SALT proposes to form a separate category of participants/consultants who are not directly connected to the measurement objectives of A-CCP but whose own science objectives might benefit from A-CCP. The snow community is one such community. Others will include all other ESE activities described below.

4.3.2 Greenhouse Gases

Convective transport is fundamental to the transport of trace gases within the atmosphere. Further, CO_2 retrievals from sensors such as OCO-2 and GeoCARB can be biased by the scattering influences of subvisible cirrus and stratospheric aerosol. Constraining prior estimates of the aerosol and clouds with lidar observations can improve CO_2 retrievals. The relevance of and links to the trace gas/greenhouse gas community will be explored.

4.3.3 Ocean Surface Winds and Currents

Lidar can provide estimates of ocean surface winds at the spatial scale of the lidar footprint, demonstrated by CALIPSO. These high-resolution measurements capture the small-scale variability of surface winds, which may be important to air-sea exchanges and can inform the interpretation of surface winds from scatterometers having much larger footprints. Microwave radiometry is also a standard tool used to deduce ocean winds, thus any microwave observations that might be considered for A-CCP will be reviewed with this application in mind.

4.3.4 Ozone and Trace Gases

UV-Vis retrievals of tropospheric trace gases can be impacted by aerosols, with effects dependent on aerosol vertical distribution. Lidar profile data can provide constraints and improve retrievals. The study team will reach out to the Ozone and Trace Gases study team to explore potential linkages.

4.3.5 A and CCP potential contributions to the Planetary Boundary Layer (PBL) Incubator

Boundary layer cloud, central to low cloud feedbacks, represents an important element of the CCP measurement objective and thus CCP offers observations relevant to PBL objectives. Furthermore, PBL height from lidar is also a potential contribution to PBL science. A-CCP would also benefit from any connected PBL measurements of thermodynamics and wind. The study team will formally link to the PBL study team and include members of the latter on the SCC.

4.3.6 A potential contribution to Ocean Ecosystem structure

Spaceborne lidar also provides valuable information for study of the global ocean ecosystem. CALIOP has demonstrated that ocean ecosystems' properties can be measured with a satellite lidar, but its coarse vertical resolution is incapable of charactering water column structures that are essential for reducing uncertainty in key global ocean science objectives. The addition of ocean profiling capability to the lidar anticipated for the A and A+CCP architectures will be explored under this study, cost impacts on the aerosol lidar will be defined and synergies with PACE explored.

4.3.7 Atmospheric Winds

A doppler capability for measuring vertical motion within clouds and precipitating systems for CCP would complement the measurements of vertical profiles of horizontal winds, providing information on the three-dimensional dynamic structure of storms systems, and the coupled behavior between winds and precipitation/latent heating. In the case that vertical motion is determined by changes in the structure of the vertical profile of reflectivity based on measurements from a sequence of closely spaced cloud/precipitation radars on small/CubeSats, rather than doppler on one spacecraft/ instrument, the time lapse information from such a system may also provide information on horizontal winds as well. The atmospheric wind ESE will be represented on the A-CCP study through the SIT.

5.0 - THE ROLE OF TECHNOLOGY INNOVATION

The flexibility and responsiveness needed to leverage new opportunities and technological advances are hallmarks of the Earth Science and Applications from Space (ESAS) 2017 recommended program. With an influx of ideas and flight demonstrations of disaggregation into small spacecraft and constellations, multiple viable approaches to accomplishing many Earth science measurement objectives now exist. In addition to spacecraft and sensor technology, significant advances in data analytics, advanced computational techniques, and in modeling and analysis offer the potential of extracting new knowledge and additional accuracy from space-based measurements of the Earth.

Advances in integrated model analysis systems, technology investment in sensors, low size, mass and power electronics, small satellites, and secondary payload and rideshare transportation elements are all potential elements relevant to the implementation of A-CCP. The study will review these elements as they apply to the A-CCP objectives. Specifically, the study will:

- Examine the information in air quality analyses to constrain aerosol speciation,
- investigate mature and emerging sensor advances relevant to A and CCP and identify the steps necessary to mature emerging technologies, and
- examine the trade space between constellations of small, distributed sensors versus single, larger, more capable platforms for addressing the objectives of A-CCP.

6.0 - APPROACH FOR IDENTIFYING PARTNERSHIPS

This study plan will explore partnerships principally on two different levels. One level of effort will focus on potential international contributions to the TOs, specifically building on past and ongoing discussions with the potential partners identified below. We propose to engage the agencies identified below via the individuals who have been central to these discussions to date. The second effort seeks to explore specific connections with other TOs relevant to A and CCP that are, or may be, in play in the time frame of A and CCP. The most apparent evidence of partner involvement in the A-CCP study will be the inclusion in the design architecture libraries of what they propose to contribute (ex. instrument(s), access-to-space, spacecraft) along with supporting the quantification of aspects of the PoR. Once the libraries contain this information, the partner(s) involvement will be limited to responding to any clarification questions brought up by the A-CCP team. The study will explicitly explore relationships with the SBG DO in ways described below.

6.1 International Partnerships

Our approach to international partnership focuses on the specific engagement of potential partners that have expressed genuine interest and exhibit real potential for making contributions to A-CCP. Potential partners are listed below.

6.1.1 Japanese Aerospace Exploration Agency (JAXA)

There are three Earth Observation missions being considered or are under development by JAXA that are relevant to CCP. The two most relevant under consideration are the third-generation AMSR and a potential mission involving a third incarnation of the precipitation radar first conceived for TRMM and now implemented as part of GPM. On the latter, several options are currently being considered for the radar, including incorporating Doppler capability and new scanning approaches to produce enhanced observations of cloud and precipitation processes. The third JAXA effort revolves around EarthCare and the science community developed within Japan to support EarthCare. Joint analyses involving the A-CCP study team and JAXA are proposed to identify the specific contributions by EarthCare to A-CCP science traceability. Key JAXA and Japanese scientists include Riko Oki from JAXA and Yukari Takayabu and Kentaroh Suzuki from the University of Tokyo.

6.1.2 Indian Space Research Organization (ISRO)

Discussions with the director of the ISRO Space Applications Center, and his deputies for the Microwave Remote Sensors Area (MRSA) and for Earth, Ocean, Atmosphere, Planetary Science and Applications Area (EPSA), has confirmed the keen interest to consider low-inclination individual and convoy active and passive microwave sensors to measure different aspects of cloud states, convective dynamics, and their evolution, primarily in the tropics and subtropics. In the microwave spectrum, possible contributions range from X-band nadir-pointing radars that resolve vertical cloud structure and convective-scale evolution, up to millimeter-wavelength radiometers with a wide swath capable of sampling the diurnal-cycle scales of clouds and environmental moisture. Collaborative analyses with ISRO will consider quantifying the benefits of flying a profiling radar in formation with ISRO's program-of-record radiometers (including the Humidity Sounding Unit on ATMSIT-2). Key ISRO and Indian scientists include Baby Simon from ISRO and Prof. G. S. Bhat from the Indian Institute of Science.

6.1.3 Centre National D'Études Spatiales (CNES)

Discussions with CNES on engagement with Aerosols and Cloud/Convection/Precipitation have developed on two fronts — mainly through the program manager for atmosphere, meteorology, and climate. The first has revolved around a proposed contribution of a cloud/aerosol lidar instrument, the concept of which is being studied since 2014 in the frame of a joint CNES and NASA/LaRC phase 0 study (a CNES-NASA Implementing Arrangement was signed in 2017). A secondary area of possible contribution concerns the CNES's interest in developing a next-generation millimeter-wave sounder, whose capabilities could be optimized for a concerted observation strategy with CCP radars and could be an important radiometric contribution to CCP radiometers. We propose to include key scientists from France in the study and work with them to provide joint analyses of radiometer capabilities to quantify the enhancement to the science requirements of CCP. A key CNES contact is Pierre Tabary, CNES Program Manager for Atmospheric Physics, Meteorology, and Climate.

6.1.4 European Organisation for the Exploitation of Meteorological Satellites/European Space Agency (EUMETSIT/ESA)

There have been preliminary discussions about flying the EUMETSIT/ESA 3MI polarimeter as part of a new train that possibly includes a lidar. While the virtues of tying 3MI to a lidar is obvious, discussions and planning are preliminary/tentative. Key individuals include Jerome Reidi, U. of Lille, and Thierry Marbach, EUMETSIT.

6.1.5 Canadian Space Agency (CSA)

The CSA was a partner of the CloudSat mission and provided specific contributions to the radar and to product validation through support of the science community within Canada. They have had a continuing desire to explore partnerships on a next generation version of CloudSat. We propose to include CSA representatives on our study to engage them throughout the definition stages of the study.

6.1.6 Netherlands Institute for Space Research (SRON)

SRON has collaborated with the precursor ACE Study, having participated in the ACEPOL field campaign with their Spectropolarimeter for Planetary Exploration (SPEX) airborne polarimeter. SRON will contribute the SPEX One polarimeter to PACE. We propose to engage SRON representatives early in the study's measurement definition stages, and continue the dialogue to explore possibilities for further partnership in polarimetry. Key SRON individuals include Otto Hasekamp.

6.2 Potential partnerships and relations with other DOs

We plan to connect to the SBG mission study and have already had discussion with team leads to build these connections. The Visible-SWIR measurements being proposed for SBG have considerable cloud and aerosol capabilities and the observations proposed for a A+CCP mission have reciprocal value to SBG. The spectral, spatial, and temporal coverages of the proposed SBG observations will be a topic to be examined in both studies and the potential of a lower cost spatially coarser resolving Vis-SWIR spectrometer to support A+CCP objectives will be examined.

7.0 - END USERS AND SOCIETAL IMPACTS

The NASA Headquarters Directive on Project Applications Program (2016, NASA Headquarters, Science Mission Directorate, Earth Science Division) provides the backdrop for identifying end-users, stakeholders, and societal impacts in the context of developing a Project Applications Plan (PAP) to support the A-CCP mission study. As such, the AIT will concurrently engage the A-CCP PAL and the user community to identify specific A-CCP dataset applications and impacts relevant to decision makers in areas such as air quality, wildland fire, weather, water, short-term climate, and disasters management fields. While it is recognized that end-user requirements should not specifically drive the science questions and design requirements, they are an integral piece in the overall potential return on investment for a mission. We are poised to initiate and develop a team for the integration and inclusion of applications to support the Mission Concept Review (MCR) by providing enhanced information to inform the Formulation Authorization Direction (FAD) and the Program Level Requirements **Appendix (PLRA**). Subsequent PAP phases of the mission are expected to include workshops (set up to ensure remote attendance for those who can not attend in person) and case studies, writing of a PAP, an Early Adopters (EA) program, and an Applications Traceability Matrix (ATM) to support Systems Requirements Reviews (SRR). This ATM will include all the applications developed in consultation with the A-CCP SALT and EAs. The PAP will also include plans to generate synthetic, proxy datasets prior to launch to train and familiarize the end users with the instrumentation and products of A-CCP relevant to the application areas outlined above. Because of the number of products with potential societal benefits, A-CCP is highly pertinent to NASA's Applied Science Program's (ASP) efforts.

As part of the DO study, the AIT will develop, characterize, and articulate the applied value of the mission, working with the A-CCP PAL and with multiple NASA centers and a developed stakeholder community to maximize NASA science for overall societal value—all of which will feed into the deliverables for subsequent mission phases. Specifically, the AIT will develop plans for newsletters, articles, and other communication strategies and participate in applied science teams [*e.g.*, Health and Air Quality Applications Science Team (HAQAST), Disasters Team, etc.] to expand communication of mission details. The team will also conduct surveys and host an applications workshops (set up to ensure remote attendance for those who can not attend in person) that leverages pre-existing communities in the aforementioned applications areas to establish a Community of Practice and Potential and to generate inputs to contribute to the MCR.

Members of the AIT have extensive experience in ASP management (*e.g.*, Soja, Omar, Al-Saadi), Disasters coordination (*e.g.*, Kirschbaum, Soja) and specific remote sensing instrumentation (*e.g.*, lidar, polarimetry, and passive microwave radiometry) to be able to effectively bridge the science team and applications communities. Previous experience includes leading a constellation of satellites for pollution monitoring through:

- CEOS — Al-Saadi
  - Geostationary Environment Monitoring Spectrometer (GEMS)
  - Tropospheric Emissions: Monitoring Pollution (TEMPO)
- CALIPSO — Omar, Soja
- Coordination of applications programs for GPM — Kirschbaum
- Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) — Zavodsky

- PACE missions — Omar
- AURA mission — Bryan Duncan
- MAIA Mission — Abigail Nastan

This experience includes scientific remote sensing understanding of the various instrument concepts. The team will leverage their experience and work with the Soil Moisture Active Passive (SMAP) and Ice, Cloud, and land Elevation Satellite (ICESIT) application teams to develop effective strategies for establishing an advanced EA program. The SCC membership is designed to include scientists with extensive applications experience and members of the application community at large as to permit constructive inputs to the deliverables provided by the AIT.

8.0 - DATA PRODUCTS AND CAL/VAL

Initial templates for data products that can serve as a reference exist and are well-described [*e.g.*, Earth Observing System Data and Information System (EOSDIS) data level standard for processing]. Such products can be generally defined as:

- Level 0 — raw and unprocessed instrument data
- Level 1(A) — time and geo-referenced data at instrument resolution with all calibration and radiometric transfer coefficients available
- Level 1(B) — data at instrument resolution converted to common sensor units (*e.g.*, a common radar unit is “reflectivity” in units of dBZ)
- Level 2 — processed into corrected geophysical parameters at instrument resolution
- Level 3 — data produced by averaging and/or merging data to a common grid
- Level 4 — data are typically considered as hybrid analysis datasets produced, for example, by assimilating lower-level instrument data into model analyses

The creation of multi-sensor Level (4) data produced using model-assimilation will be especially important in the A-CCP era.

The study approach to developing calibration and validation (cal/val) requirements and costs will maintain a tight coupling to mission science and architecture. The approach will consider those used in previous missions (CloudSat, Calipso, GPM, etc), recognizing the limitations of the mission cost cap(s). Broadly speaking, an initial template cal/val can be explored and refined in the context of three established and complementary approaches including:

- *Direct statistical validation* of satellite data products and diagnosis of product uncertainties against carefully selected references (ground or airborne)
- *Physical validation* supported by robust field-measurements/datasets targeting the development, testing, and refinement of physical assumptions made in retrieval algorithms, often guided by patterns of uncertainty discovered using direct validation
- *Integrated validation,* which tests the utility and value of data products with known uncertainties in relevant science and/or societal applications

In considering the approaches to direct cal/val, we will reach out to existing national and international partners to identify and assess relevant “reference” datasets at regional and national scales, assess dataset gaps for specific “regimes” of interest, and identify new partners and associated datasets to address cal/val in those regimes. Fortunately, numerous agency, interagency, and international partners provide robust resources for identifying such datasets across the A-CCP spectrum and for determining and minimizing costs associated with obtaining/processing the data. Note that these datasets can also be used to inform mission science as it pertains to the determination of verifiable level-1 science requirements (cf. Architecture studies section above). Concerning physical validation, our approach will concurrently draw on mission architecture studies in terms of understanding measurements, retrieval algorithms, and sampling constraints relative to identifying existing cal/val datasets and data gaps (*e.g.*, field campaign data) necessary for testing and referencing the retrieval algorithms. Identifying data gaps for physical validation must occur in concert with efforts outlined in Sec. 1.2.1, as this will enable the determination of field campaign measurement types, regimes, and the approximate cost required to validate algorithm physics and/or construction of DO sub-orbital campaigns as part of the mission architecture. Field campaign costs can be reasonably estimated from a wide variety of mission-relevant airborne field campaigns completed in support of recent A-CCP-relevant satellite missions and/or Earth Venture Suborbital (EVS — cf., 1.2.1). Finally, the integrated validation approach relies on tests and assessments typically conducted by end users. Hence, developing the integrated portion of the cal/val strategy will require interfacing with the AIT in terms of determining priority avenues to pursue.

We will apply "lessons learned," either documented directly or from cal/val leads in the community, to develop the cal/val plan. An outcome of the cal/val portion of the study will be a set of requirements for cal/val and an associated set of costs to achieve the cal/val requirements.

9.0 - DATA ACCESS AND DATA MANAGEMENT

Currently, EOSDIS is examining the feasibility of using a commercial cloud such as Amazon Web Services (AWS) to ingest, archive, process, distribute, and manage the anticipated large volumes of new mission data such as those expected from A-CCP. One of the main advantages of placing the A-CCP archive in the cloud is that it would place mission data "close to compute" and improve management and accessibility of these data while also expediting science discovery by the end users.

As of this writing, EOSDIS and the Distributed Active Archive Centers (DAACs) are building and testing prototypes to ensure that EOSDIS data and services will work successfully on the AWS cloud platform. Such a cloud-based approach for mission data management is currently being adopted by: 1) the joint NASA/ISRO Synthetic Aperture Radar (NISAR) mission, currently scheduled for late launch in late 2021, and 2) the Surface Water and Ocean Topography (SWOT) mission scheduled for launch in 2021.

NASA's Office of the Chief Information Officer (OCIO) has chosen AWS as the source of general-purpose cloud services for NASA. During the A-CCP Study, we propose to leverage the efforts by EOSDIS and the NISAR and SWOT missions to develop a Data Management Plan for A-CCP that will rely on the AWS for data processing, data access, and eventual long-term archival by the DAAC. Such an approach will bring numerous benefits for the A-CCP mission and its data users, including:

- *Easy access:* Data users will be able to access data directly in the cloud, removing the need to download volumes of data for use
- *Rapid deployment:* With an established cloud platform, data users will be able to bring their algorithms and processing software to the cloud and work directly with the data in the cloud, simplifying procurement and hardware support while expediting science discovery
- *Scalability:* The size and use of the archive will be able to expand easily and rapidly, as needed
- *Flexibility:* The A-CCP Mission needs will dictate options for selecting operating systems, programming languages, databases, and other criteria to enable the best use of mission data
- *Cost effectiveness:* NASA will pay only for the storage and services actually used; along with scalability benefits, this allows the amount of storage or services to be continually adjusted to ensure that data and services are effectively provided at the lowest possible cost to NASA and the A-CCP mission

10.0 - STUDY MANAGEMENT

The A-CCP team, led by Study Coordinator Mr. William Cutlip, is a truly multi-Center team grounded in management best practices reflective of over 40 years of successfully managing both large and small missions for NASA's Science and Mission Directorate (SMD). Key to the A-CCP team's management philosophy is an emphasis on open communication and acceptance of varying opinions in its decision-making process.

10.1 Organization

10.1.1 Structure

Overall study management is provided by NASA's GSFC, which brings a proven record of successfully managing mission architecture studies for SMD's Earth Sciences, Astrophysics, and Heliophysics divisions. The A-CCP team considers the A-CCP Program Executive (PE), Program Scientist (PS), and Program Applications Lead (PAL) as part of the overall team and has constructed the overall study

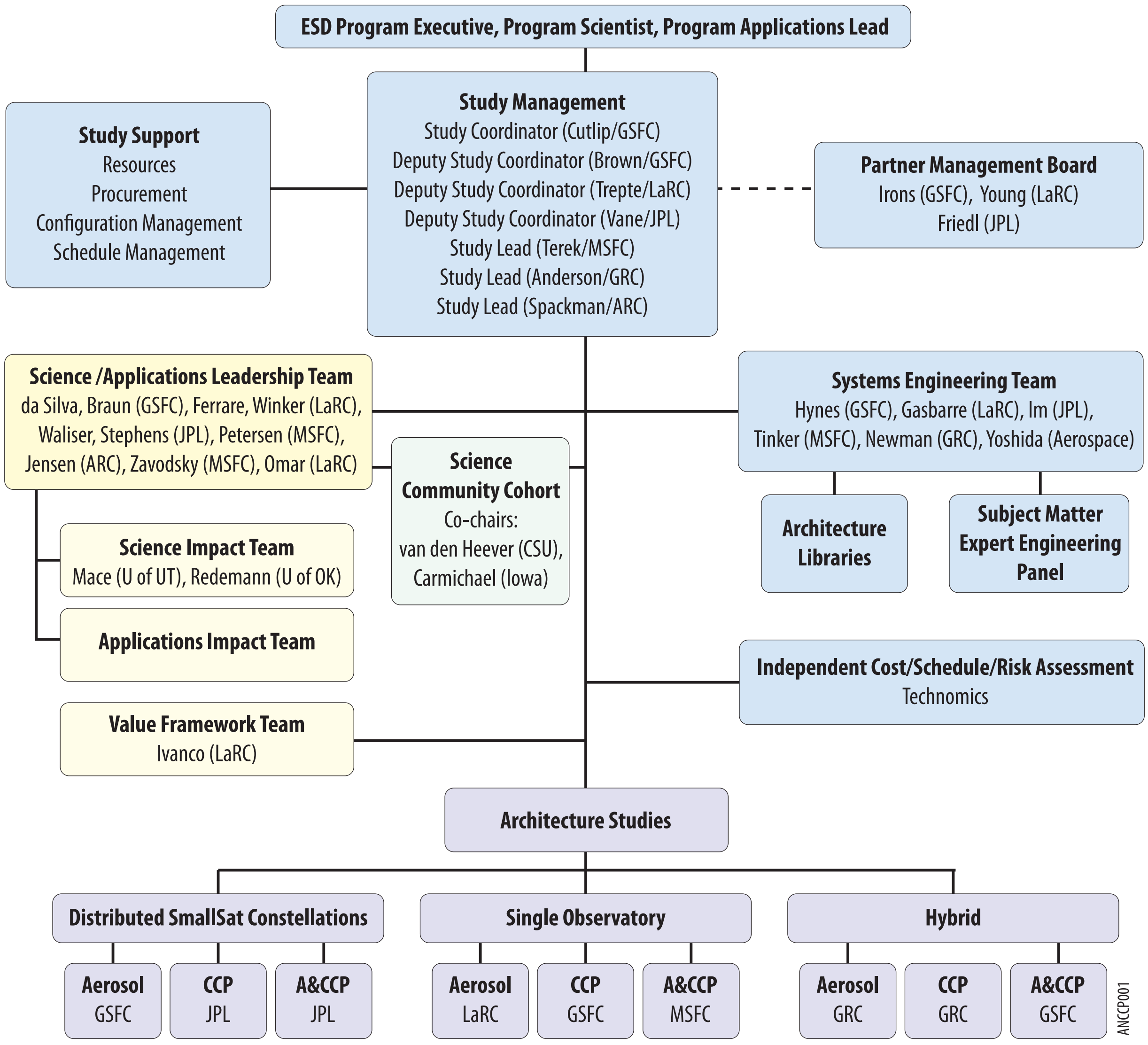


Figure 10-1: The A-CCP Study organization is designed for optimal communications between very experienced team members.

plan to maximize their involvement in science and management discussions and all decisions associated with the results delivered to ESD. The multi-Center aspect of the team is reflected in the essential use of Deputy Study Coordinators at LaRC and JPL, as well as Center Study Leads at MSFC, ARC, and GRC, as shown in **Figure 10-1**.

10.1.2 Study Management Team

Mr. William Cutlip will serve as the Study Coordinator and be responsible for day-to-day coordination of the Study as well as reporting progress and delivering study products to the NASA ESD A-CCP PE, PS, PAL, and A-CCP Study Partner Management Board. The LaRC and JPL Deputy Study Coordinators work in coordination with the GSFC Study Coordinator to lead, execute, and monitor all study-related activities, while emphasizing insight/oversight of the tasks conducted at their respective Centers. The ARC, MSFC, and GRC Center Study Leads provide insight/oversight of the tasks conducted at their respective Centers, as well, but are responsible for a smaller percentage of the overall A-CCP effort. The GSFC Deputy Study Coordinator will manage the day-to-day interactions between the architecture design center leads and the A-CCP Study Management Team (SMT).

All the members of the SMT participate in weekly review meetings and discussions. The SMT coordinates priorities and resources across the planned study activities, communicating with and managing changes in scope, as appropriate, with the NASA Program Scientists and Program Applications Leads. In addition, the SMT leads cross-functional meetings of the Science Leadership and System Engineering teams to prioritize and facilitate objective comparisons of alternative architectures with respect to performance, cost, schedule, risk, etc. The SMT develops ground rules and assumptions for independent cost estimates of the viable architectures (*e.g.*, exceed the minimum science threshold) to assess relative performance versus cost. The SMT compares the results of the architecture assessment and recommends options for further consideration by ESD senior management. Finally, the SMT documents the study process and its results.

10.1.3 Science and Applications Leadership Team

The Science and Applications Leadership Team (SALT) brings together experts from across the aerosols, clouds, convection, and precipitation satellite remote sensing community with broad experience in satellite instrumentation, airborne validation, algorithm development, scientific analysis, and applications. This team was brought together by GSFC to enable a broad exploration of the available architecture trade space. The SALT, informed by the SCC, defines the priority mission science objectives and related measurements (consistent with the 2017 Decadal Survey). The SCC consists of external SMEs that provide analyses to corroborate (or challenge) the A-CCP science strategy and priorities. The SCC is also our connection to the academic community. The SCC is co-chaired by Dr. Gregory Carmichael of the University of Iowa and Dr. Susan van den Heever of Colorado State University with Dr. Carmichael leading discussions in aerosol sciences and Dr. van den Heever leading discussions in the CCP sciences. In consultation with ESD, it is one of our priorities to identify members of the SCC early in the study.

The SALT works to develop a framework (*i.e.,* qualitative and quantitative measures of merit, relative importance, etc.) to use in evaluating alternative observing systems architectures. They investigate synergies of proposed architectures with other DOs and recommend candidate architectures for independent cost/schedule/risk assessment. The SALT hosts community workshops to status progress on A-CCP and solicit feedback. The SALT also has responsibility to the SMT for delivering STMs/ATMs for Aerosols, CCP, and A+CCP. The SCC, SIT and AIT report into the SALT, with the SIT including scientists from academia.

10.1.4 Systems Engineering Team

The Systems Engineering Team (SET) team provides requirements flow-down and traceability, leads and participates in the population of the architecture libraries, conducts trade studies including system modeling and analyses for the most promising architectures, and generates documents for reviews, including draft packages for the MCR. The SET will use SMEs from the Subject Matter Expert Engineering Team on an as-needed basis. The SET coordinates with the SALT to determine measures of effectiveness for the study (*e.g.*, technology readiness, life cycle cost, schedule or development time) to score the mission architectures.

10.1.5 Key Personnel

The A-CCP study will benefit from the experienced team members performing the key study management roles (**Table 10-1**) who will be applying lessons learned from prior study efforts, such as the need for transparency along with frequent and effective communication between study partners and our ESD sponsor, and the benefit of incremental deliverables to our ESD sponsor over the course of the study.

Table 10-1: A-CCP Study key personnel provide the depth and breadth of experience necessary to successfully deliver comprehensive and implementable observable systems architectures.

Position/Name	Role and Responsibility	Relevant Experience
Study Management		
Study Coordinator W. Cutlip (GSFC)	Overall responsibility for the success of the A-CCP study, working closely with the Deputy Study Coordinators and Study Leads	As the Senior Business Development Manager and Manager of the Earth Sciences Line of Business at the GSFC, Mr. Cutlip has over 15 years of experience building and implementing NASA mission concepts both large – MAVEN and OSIRIS-REx – and small – EV-I/EV-M/EV-S. Mr. Cutlip also served as a study lead during the ESD-sponsored concept studies associated with the 2007 Decadal Report.
Deputy Study Coordinator T. Brown (GSFC)	Responsible for the day-to-day management of A-CCP activities being conducted at GSFC. Will represent the GSFC Study Coordinator on an as-needed basis	Served >10 years as the Head of GSFC's Instrument Development Lab (IDL).
Deputy Study Coordinator C. Trepte (LaRC)	LaRC A-CCP Team Management; delivery of assigned tasks on schedule and on budget; coordination of activities with the GSFC Study Coordinator	Served >13 years as Project Scientist/Deputy PI for CALIPSO mission; Deputy PI for NASA/Russian SAGE III/Meteor 3m mission; Science investigator with several airborne field campaigns
Deputy Study Coordinator D. Vane (JPL)	JPL A-CCP Team Management; delivery of assigned tasks on schedule and on budget; coordination of activities with the GSFC Study Coordinator	Served as JPL lead for ACE Decadal Mission study; Deputy Manager of JPL Earth Science (Operating) Missions Office; CloudSat Project Manager
GRC Study Lead David Anderson	Will ensure that GRC's assigned tasks are delivered on schedule and on budget; coordination of activities with the GSFC Study Coordinator	Has served as the Project Manager of several PSD space propulsion and power technology development projects for 11 years where his projects conducted over 15 systems/mission analysis studies, including several supporting the Planetary Decadal Survey. Has also served as the SBIR topic manager for SMD's Spacecraft and Platform topic for 7 years and spent 5 years in GRC's Systems Management Office.

Position/Name	Role and Responsibility	Relevant Experience
MSFC Study Lead J. Terek	Will ensure that MSFC's assigned tasks are delivered on schedule and on budget; coordination of activities with the GSFC Study Coordinator	Manager of the MSFC Science Research and Projects Division, which includes the Earth Science, Planetary Science, Heliophysics, Astrophysics Branches, Science Projects, and Test, Branches, and the Chandra Program Office. Science and engineering expertise includes chemistry, materials engineering, and space systems.
ARC Study Lead R. Spackman	Will ensure that ARC's assigned tasks are delivered on schedule and on budget; coordination of activities with the GSFC Study Coordinator	
Systems Engineering Team (SET) The SET provides over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. The Systems Engineering Team members will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.		
Marie Ivanco (LaRC)	Will provide overall leadership of the A-CCP Value Framework. Will coordinate the definition, implementation, and facilitation of the Value Framework, coordinating with all relevant study team members.	Systems Analyst within LaRC's Systems Analysis and Concepts Directorate. Lead for decision support and mission analysis activities for multiple projects. Expertise in decision science, to include multi-objective decision making and cost-benefit analysis.
Shane Hynes (GSFC)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Mr. Hynes has been both the Mission Systems Engineer (MSE) for the Transiting Exoplanet Survey Satellite (TESS) mission and the Program MSE for 410/430/460: Astrophysics, Heliophysics and Explorers missions. He launched TESS in April 2018. He is also currently the MSE for the Ionospheric Connection Explorer (ICON) mission. Prior to this, he was the MSE for ICESat-2, Deputy MSE for Magnetospheric Multiscale (MMS), and led the technical teams for Solar TErrestrial RElations Observatory (STEREO). He has led the architectural studies for the MMS and ICESat-2 missions in collaboration with the Science Definition Teams.
Joseph Gasbarre (LaRC)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Over 18 years of experience specializing in flight and concept systems development for space-based missions and atmospheric flight vehicles. Is currently assigned to NASA's Office of Chief Engineer (OCE) where he is the Acting Chief Engineer for SMD. Prior to being named Acting SMD Chief Engineer in April 2018, Mr. Gasbarre served as the Deputy Chief Engineer for SMD since October 2017.
Eastwood Im (JPL)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Manager, JPL Earth Science Technology Research and Concept Development Office and Manager, JPL Instrument Technology and Testbeds Office. Previously, Manager, CloudSat Cloud Profiling Radar Development Team.
Newman (GRC)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Began his career at the NASA Johnson Space Center in Flight Design and Dynamics on the Space Shuttle Program, and transitioned to working on Systems Engineering for Orion (Constellation period). He performed Research and Project Management at Honda Research and Development, was a Technical Lead for Hypersonics Propulsion Systems Analysis at NASA GRC, and is currently serving as the Lead Systems Engineer for the NASA GRC Compass concurrent engineering design team.

Position/Name	Role and Responsibility	Relevant Experience
Tinker (MSFC)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Mr. Tinker is the Technical Assistant for the Systems Engineering and Integration Division in the Space Systems Department at MSFC. He has more than 20 years of experience of developing and evaluating flight systems and technology. He was recently the MSFC Chief Technologist, which leads the development and evaluation of technologies for the center and the agency. He has also served as the Assistant Manager of the Systems Development, Integration and Test Division, which develops and integrates flight and ground projects including Earth Science projects and instruments.
Yoshida (Aerospace)	Provide over-arching systems engineering perspective to the A-CCP study management team and Science Leadership Team. Along with the rest of the Systems Engineering Team members, will play a major role in the evaluation of SATMs and Libraries supporting the Architecture studies, as well as the subsequent results.	Is a Senior Project Engineer in the Strategic Studies and Assessments Division within the Civil Systems Group. Justin has over 15-years experience in space flight hardware development, propulsion and laser diagnostics system research, space system architecture design and evaluation, and programmatic assessments for numerous NASA and civil projects.
Science/Application Leadership Team (SALT) The SALT provides over-arching science perspective to the A-CCP study. The SALT will play a major role in defining the SATMs, the science elements of the Value Framework, and the scientific assessment of the architecture options.		
Arlindo da Silva (GSFC)	Will be involved in most SALT activities with focus on the Aerosols and A+CCP parts of the Study. Will lead the aerosol OSSE efforts providing a liaison to modeling and data assimilation resources at GMAO. Together with S. Braun will organize regular science related telecons and workshops, and coordinate any necessary external grants to Universities and/or private sector.	Currently ACE Science Study Lead. Principle Investigator for the Earth System Modeling Framework (ESMF). Expertise in atmospheric modeling and data assimilation, atmospheric dynamics, aerosols; leads aerosol group at GMAO.
Scott Braun (GSFC)	Will be involved in most SALT activities with focus on the CCP and A+CCP parts of the Study. Together with A. da Silva will organize regular science related telecons and workshops, and coordinate any necessary external grants to Universities and/or private sector.	Currently GPM and TROPICS Project Scientist (PS). Served 10 years as TRMM PS, two years combined as GOES-R deputy PS and PS. Principle Investigator for EVS-1 HS3 experiment. Expertise in precipitations systems, including convective storms and hurricanes.
Graeme Stephens (JPL)	Will be involved in most SALT activities with focus on the CCP and A+CCP parts of the Study but will be engaged in A in a more support role. Will be a lead in developing relationship with other DO studies, with the international science group and international agencies. Will also be heavily involved in connecting the science objectives of A, CCP and A+CCP to the architecture studies.	Principal Investigator of CloudSat. Director, Center for Climate Sciences at JPL. Co-Chair, Scientific Steering Group for Global Energy and Water Exchanges (GEWEX) project. Expertise in atmospheric radiative transfer, remote sensing, cloud-climate feedbacks, cloud-aerosol interactions, the hydrological cycle and its relevance to climate.
D. Waliser (JPL)	Will be involved in most SALT activities with focus on the CCP and A+CCP parts of the Study. Will engage in the development and evaluation of OSSE activities and in the development and application of the Value Framework.	Chief Scientist, Earth Science and Technology Directorate, JPL. Expertise in climate dynamics and global ocean-atmosphere modeling, prediction, and predictability.

Position/Name	Role and Responsibility	Relevant Experience
Rich Ferrare (LaRC)	Will be involved in most SALT activities with focus on the Aerosols and A+CCP parts of the Study. Will also be involved in determining suborbital measurements/field missions for A-CCP objectives and validation.	Currently ACE Aerosol Working Group Chairperson. Lead flight scientist in several NASA and DOE airborne field missions. Expertise in lidar atmospheric remote sensing of aerosols and trace gases.
David Winker (LaRC)	Will be involved in most SALT activities with focus on the Aerosols and A+CCP parts of the Study. Will also be involved in defining specific metrics for science aspects of the Value Framework.	Principal Investigator of CALIPSO. Expertise in active remote sensing of aerosols and clouds, aerosol forcing, cloud feedbacks.
Ali Omar (LaRC)	Will be involved in SALT activities with focus on air-quality and other aerosol related applications. Together with B. Zavodsky will co-lead the Applications Impact Team (AIT). Will Develop the A-CCP Applications plan and Applications Traceability elements for the SATM relevant to aerosol observations of the mission.	CALIPSO Science Team - lead algorithm developer for aerosol classification. Science team member of PACE and Applications Lead for PACE Atmospheric Products.
W. Petersen (MSFC)	Will be involved in all SALT activities with focus on assessment of measurement requirements, architectures, and field studies (airborne and ground-based) addressing liquid and frozen precipitation, moist convection, and CCP cal/val.	Deputy Project Scientist, Ground Validation, GPM. Lead for all GPM multi-aircraft and ground-based field campaigns. Science lead for GPM ground-validation multi-frequency polarimetric radar and supporting instrumentation. Science expertise in cloud and precipitation physics, radar remote sensing.
Brad Zavodsky (MSFC)	Will be involved in SALT activities with focus on CCP related applications. Together with A. Omar will co-lead the Applications Assessment Team (AIT).	Project Manager for Short-term Prediction Research and Transition (SPoRT) Center at MSFC focused on transition of satellite observations to operational end-users. Deputy Program Applications (DPA) Lead for TROPICS focused on identifying and fostering a community of users to accelerate the use of data from this mission in decision-maker applications. Science expertise in numerical modeling and data assimilation.
E. Jensen (ARC)	Will be involved in most SALT activities with focus on the CCP and A+CCP parts of the Study. Will lead cloud process modeling studies to help define the SATMs and assessment of architectures.	Principal Investigator of ATTREX. Project Scientist for numerous airborne field experiments. Expertise in using satellite and airborne measurements to constrain numerical models of cloud systems.
Science/Application Leadership Team (SALT) Ex-officio Members		
Jay Mace (U. Utah)	Together with J. Redemann will co-load the Science Impact Team (SIT). SIT will provide science community perspective relative to the appropriateness of aerosol and cloud observations to science objectives of A-CCP	Acted as lead of ACE cloud study team. Directed ACE-related field campaigns RADEX. Expertise in interpretation of combined active and passive remote sensing for cloud and precipitation property retrievals.
Jens Redemann (U. Oklahoma)	Together with J. Mace will co-load the Science Impact Team (SIT). Will provide science community perspective relative to the appropriateness of aerosol and cloud observations to address aerosol-cloud-radiation interactions and air quality objectives.	Principal Investigator of ORACLES (EVS-2 mission). Director, School of Meteorology (University of Oklahoma). Former member of MODIS, CALIPSO and ACE formulation science teams. Co-chair of AMS radiation science committee. Expertise in atmospheric radiative transfer, remote sensing, aerosol-cloud-climate interactions.

10.1.6 Communication Approach

The A-CCP team will operate as "one team," with the GSFC Study Coordinator emphasizing open and honest communications among all team members – the ESD PE, PS, and PAL all being included as part of the team! This philosophy is an essential aspect of the team's overall management approach, and a key tool used in controlling costs and maintaining schedule.

The A-CCP management team, systems engineering support, and science leadership team meets weekly on an in-person/virtual basis. The group discusses progress and issues, resolves problems, and plans for the coming week. Given the team's geographical separation, web-based management tools will be put to use during the study as well as telecons and WebEx. A SharePoint-based Management Information System (MIS) will provides all team members with password-protected internet access to current schedules, study documentation, issues/resolutions, presentations, and action items.

10.1.7 Decision Making Approach

Key study decisions are based on interactive discussions within and across the Study Management, Science Leadership, ESD PE/PS/PAL, and System Engineering Teams, as appropriate, and in the best interests of the ESD-desired study results, versus the particular interests of any individuals or institution. Science related decisions are facilitated by the SALT and its subgroups (VFT, SIT, AIT). The science team is responsible for defining SITMs, Value Framework criteria and evaluating the architectures – working in conjunction with the Systems Engineering Team and the SMT.

The SMT has the overall decision authority of the study, with the SALT reporting in to the SMT and the PMT providing guidance.

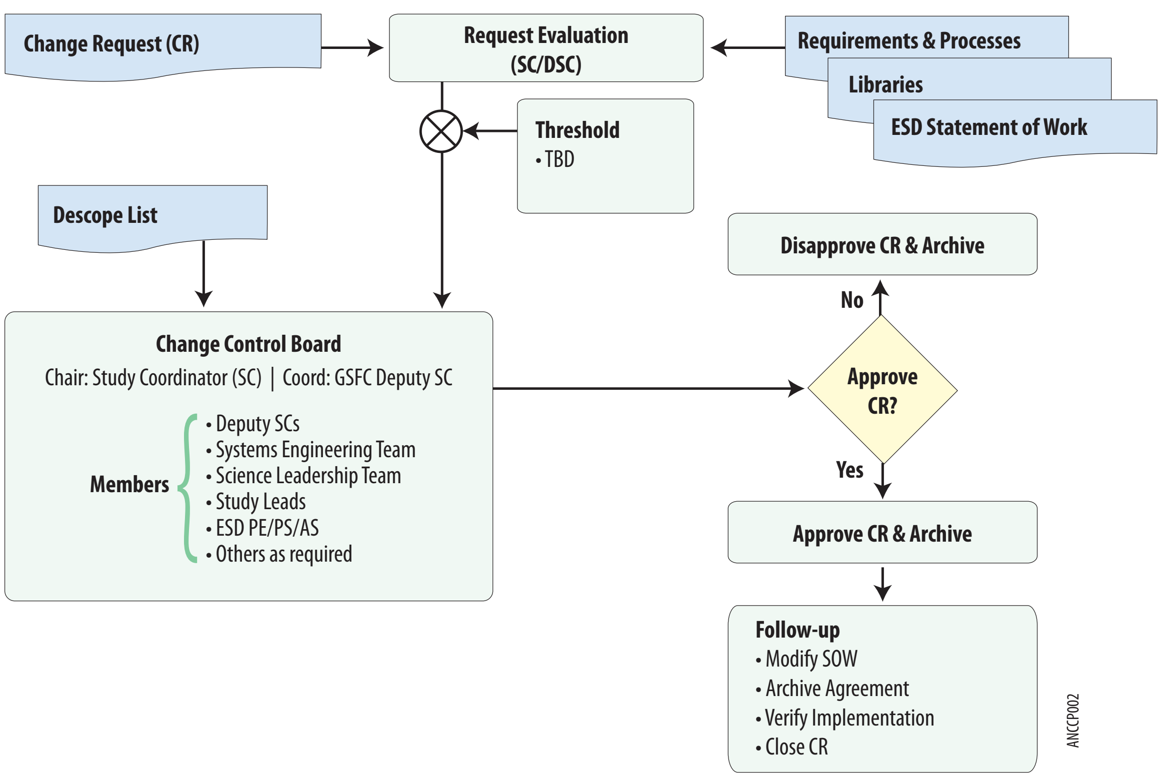


Figure 10-2: Change Control Process governs all changes that impact cost, schedule, and technical performance.

All decisions affecting ESD's stated objectives for the A-CCP study are based on a fully integrated assessment of the science requirements, risk, performance, budget, and schedule. Unresolved issues will be elevated to the Project Management Board (PMB).

Decisions will be comprehensive in nature, drawing information, analysis, and recommendations from the Science leadership team, Lead Systems Engineers, SMEs, the management team, ESD PE/PS/PAL, and independent science, technical, cost, and schedule panels.

Decisions that impact study cost, schedule, or technical deliverables are addressed via a Study Change Control Board (CCB) process (**Figure 10-2**), led by the GSFC Study Coordinator.

10.1.8 Partner Management Board (PMB)

The A-CCP study's management approach includes a PMB. The PMB provides expert advice, consultation, and facilitates effective coordination between the teaming Centers. The PMB consists of Dr. James Irons (GSFC), Dr. David Young (LaRC), and Dr. Randall Friedl (JPL). The PMB addresses issues of institutional support and makes high-level interventions as required prior to an issue becoming critical.

10.2 Reporting

The A-CCP team's organizational structure enables rapid communication and effective reporting.

10.2.1 Internal Reporting

Internal study team reporting follows an adaptive approach, with frequent informal technical and schedule progress communiqués, weekly Study Management status tag ups (GSFC Study Coordinator, Deputy Study Coordinators, Center Study Leads, and Systems Engineers – ESD PE/PS/PAL having a option invitation to support via telecon or in person), and monthly formal reporting for technical, financial, and schedule. Each study element lead is accountable for presenting progress, issues and concerns, assessing trends, and future performance. Special topic reporting is scheduled as needed. Each member of the Study Management team provides status briefings to their respective organization via existing reporting channels.

10.2.2 External Reporting

The GSFC Study Coordinator — supported by the Deputy Study Coordinators, Center Study Leads, and others, as required, will provide ESD with quarterly status briefings; these briefings will include budget, schedule, and technical status in accordance with a reporting template provided by the ESD PE. ESD management will be invited to attend the study team's monthly status meetings to facilitate open communications when key study deliverables are discussed.

Yearly status presentations will be given at NASA HQ in which collaborative discussions will drive potential ESD-directed "pivots" in the focus of the design center efforts, with agreed upon revisions to study cost and schedule.

As shown in **Foldout One**, the A-CCP team plans to hold a series of meetings/reviews in MArch of CY20 to review the Phase I design center results with the A-CCP PE/PS/PAL and other ESD senior management, and receive ESD concurrence on Phase II design center efforts.

Similar meetings/reviews are scheduled at the completion of the independent cost/schedule evaluation in early FY21, prior to submittal of the final study report.

10.3 Schedule

Schedule details are shown in **Foldout One**. Overall, the study schedule is 40 months from ESD issuance of Authority To Proceed (ATP) to submittal of the final study report, which allows sufficient time for ESD's requested study deliverables. As noted in the schedule, the A-CCP team has organized the study to support independent science and technical, as well as industry involvement. Workshops are planned in support of finalizing the SITMs and leveling of Observing System architectures. Deliverables and related reconciliation periods are scheduled in support of transparency with ESD and to support the ultimate implementation of A-CCP observing systems by ESD.

Phase I design center studies will begin in May 2019 and consist of the following architectures/ design centers in FY19:

1. Aerosol
   - Single spacecraft (LaRC)
2. Distributed smallsats (GSFC)
3. CCP
   - Single spacecraft (GSFC)

10.3.1 NASA Procedural Requirement (NPR) 7123.1B and NPR 7120.5E Compliance

For completeness, the A-CCP study schedule presented includes activities that will support the readiness for an MCR (**Table 10-2** and the transition into Phase A (**Figure 10-3**)). The formal presentation of an MCR is outside of the ESD-defined scope of this study.

Table 10-2: The results of the A-CCP study will serve as a solid foundation for comprehensive documentation and reviews in Phases A through F.

Mission Phase	Products and Results
A	**Documents:** Concept Study Report, Level 1 requirements, Mission Requirements Document (Level 2 requirements), Level 3 Requirements Document (drafts), SEMP (draft), MAR (draft), risk Management Plan (draft), Data Management Plan (draft), CM Plan (draft), Preliminary ICDs (drafts)
B-Bridge and B	Initiate contracts; procure limited long-lead items; trade studies completed; preliminary designs/documentation complete **Documents:** Project Plan, baselined requirements and ICDs; management control plans; final phase C/D plans **E/PO:** Fund partners, refine evaluation plans, reporting system **Major Reviews:** MDR, PDR/NAR, CR
C/D	System level I&T complete (hardware and software); spacecraft launched and initial checkout complete; all pre-launch Level-3 and -4 documents baselined, mission operations plans complete; GDS operational **E/PO:** Web dev, teacher workshops, planning and dev **Major Reviews:** CDR, SIR/PER, PSR, ORR, SMSR, FRR, LRR, MOR, FOR, MRR, IBR
E	Science data collection and characterization of RQ36; successfully obtain sample and deliver to Curation facility, data transfer, verification, analysis, and archiving in PDS; disseminate science data and results **E/PO:** Implementation of activities **Major Reviews:** PLAR, CERRs including Earth Return CERR
F	**Major Reviews:** Decommissioning Rev., Sample Science Rev.

Mission Concept Review	
Entrance Criteria	**Success Criteria**
1. The following primary products are ready for review: a. Stakeholders have been identified and stakeholder expectations have been defined and are ready to be baselined after review comments are incorporated. b. The concept has been developed to a sufficient level of detail to demonstrate a technically feasible solution to the mission/project needs and is ready to be baselined after review comments are incorporated. c. MOEs and any other mission success criteria have been defined and are ready to be approved. 2 Programmatic products are ready for review at the maturity levels stated in the governing program/project management NPR. 3. Other technical products (as applicable) for hardware, software, and human system elements have been made available to the cognizant participants prior to the review: a. Mission/project goals and objectives that are ready to be baselined after review comments are incorporated. b. Alternative concepts that have been analyzed and are ready to be reviewed. c. Initial risk-informed cost and schedule estimates for implementation. d. Preliminary mission descope options. e. A preliminary assessment performed by the team of top technical, cost, schedule, and safety risks with developed associated risk management and mitigation strategies and options. f. Preliminary approach to verification and validation for the selected concept(s). g. A preliminary SEMP, including technical plans. h. Technology Development Plan that is ready to be baselined after review comments are incorporated. i. Initial technology readiness that has been assessed and documented with technology assets, heritage products, and gaps identified. j. Preliminary engineering development assessment and technical plans to achieve what needs to be accomplished in the next phase. (logistics, manufacturing, and operation). l. Software criteria and products, per NASA-HDBK-2203, NASA Software Engineering Handbook. m. Preliminary assessment of RF spectrum needs.	1. Mission objectives are clearly defined and stated and are unambiguous and internally consistent. 2. The selected concept(s) satisfactorily meets the stakeholder expectations. 3. The mission is feasible. A concept has been identified that is technically feasible. A rough cost estimate is within an acceptable cost range. 4. The concept evaluation criteria to be used in candidate systems evaluation have been identified and prioritized. 5. The need for the mission has been clearly identified. 6. The cost and schedule estimates are credible and sufficient resources are available for project formulation. 7. The program/project has demonstrated compliance with applicable NASA and implementing Center requirements, standards, processes, and procedures. 8. TBD and TBR items are clearly identified with acceptable plans and schedule for their disposition. 9. Alternative concepts have adequately considered the use of existing assets or products that could satisfy the mission or parts of the mission. 10. Technical planning is sufficient to proceed to the next phase. 11. Risk and mitigation strategies have been identified and are acceptable based on technical risk assessments. 12. Software components meet the exit criteria defined in the NASA-HDBK-2203, NASA Software Engineering Handbook. Concurrence by the responsible Center spectrum manager that RF needs have been properly identified and addressed.

Figure 10-3: The A-CCP team will deliver all documentation necessary for a successful, post study completion, MCR.

11.0 - SCHEDULE AND PROPOSAL COST PLAN

11.1 Schedule

The A-CCP schedule provides a firm basis for the study cost estimates. The schedule (**Foldout One**) covers all phases of the A-CCP study and reflects the inputs and review by all study partners.

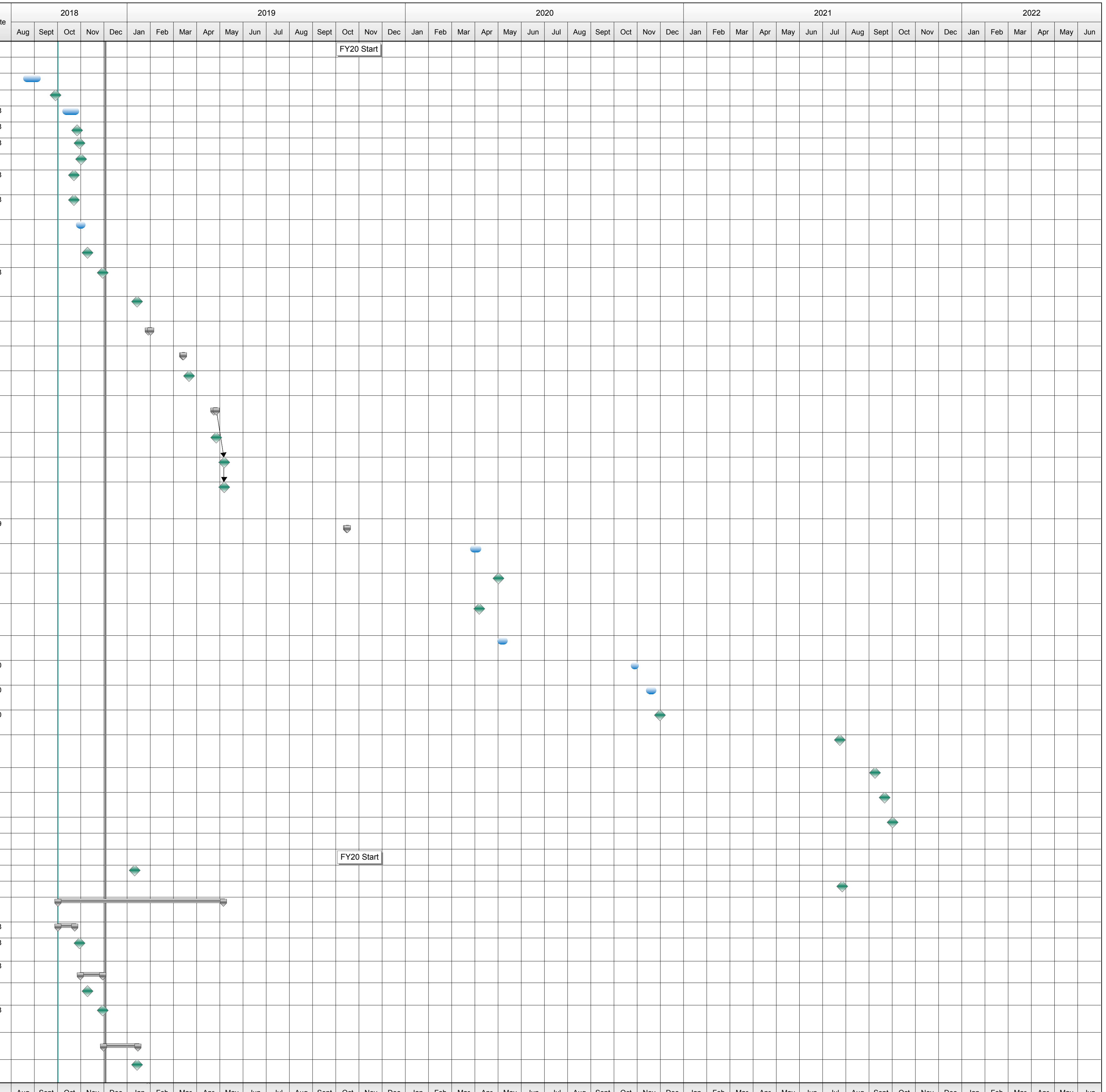
11.1.1 Key Milestones Leading to KDP-A

Consistent with the A-CCP team operation as "one team," founded on open and honest communications among all team participants, all key milestones were discussed and agreed upon before inclusion in the schedule. The milestones serve as driving foci for the team during the implementation of the study, ensuring transparency and the engagement of ESD and the science community.

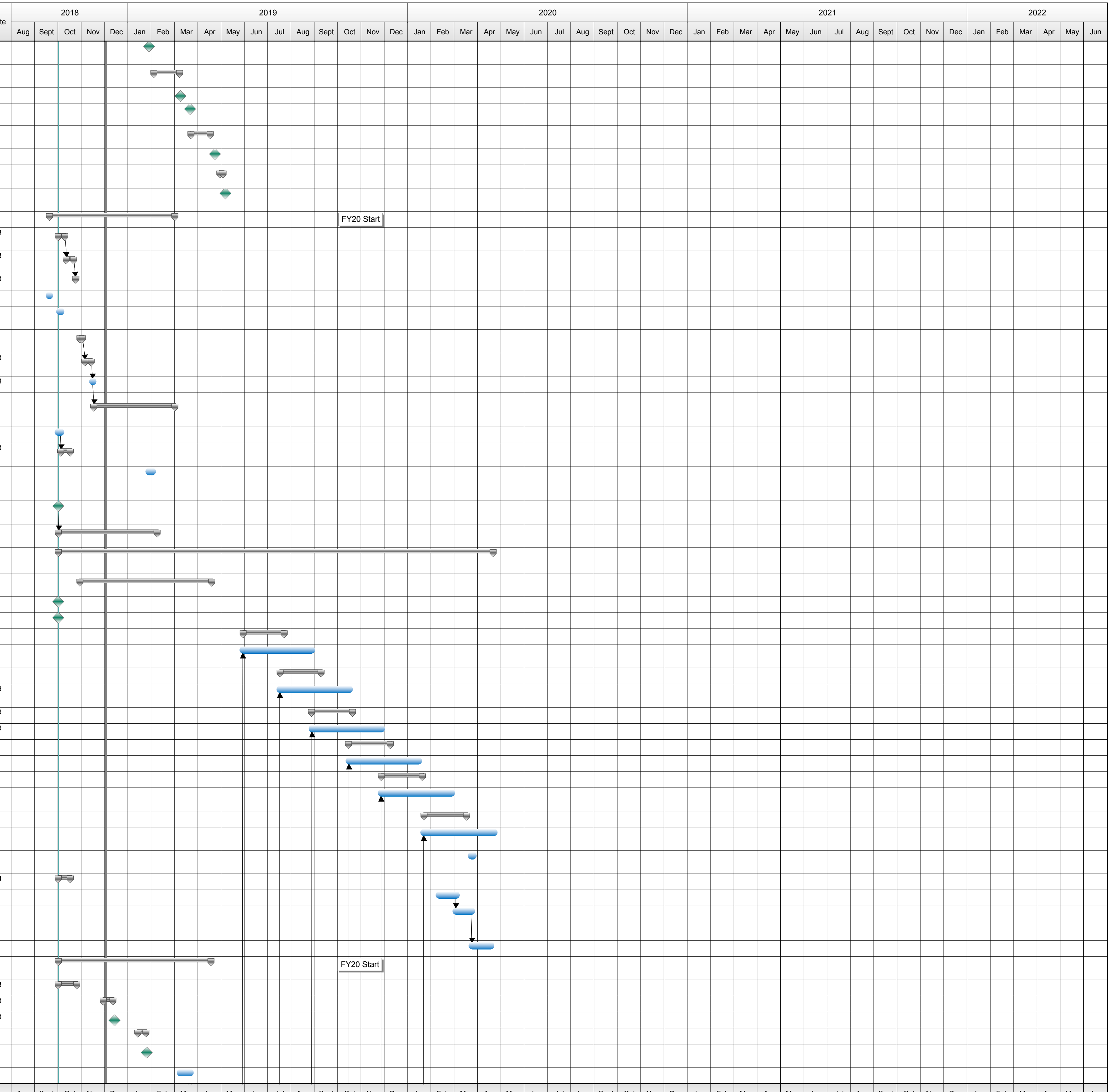
11.1.2 Deliverables

After close examination of the Table Of Content (TOC) provided by ESD, the A-CCP team formulated a phased approach to providing deliverables to ESD and independent science, engineering, and cost/schedule review panels. The planned deliverables and their due dates are included in **Foldout One**.

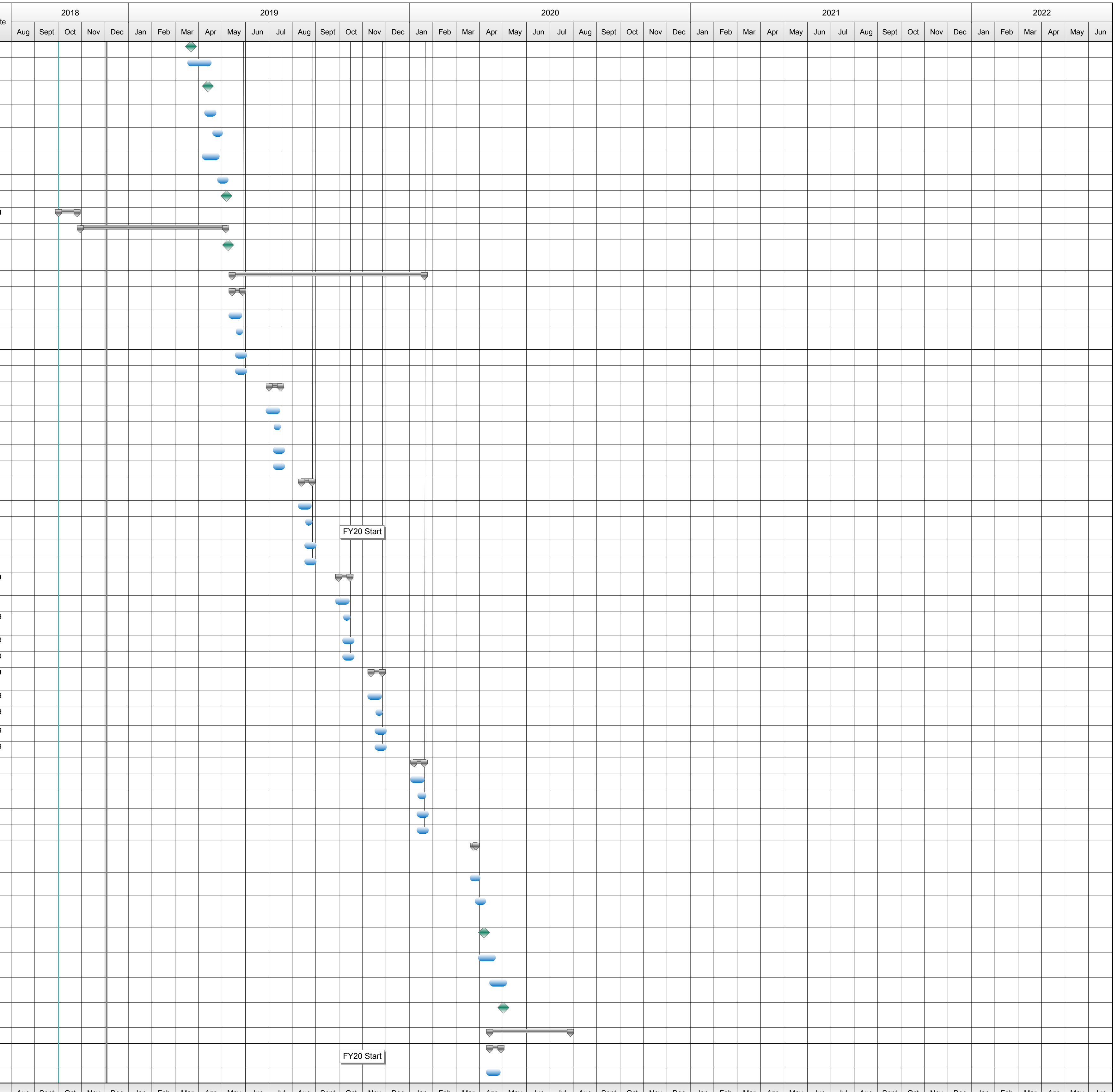
	Activity Name	Duration (Days)	Start Date	Finish Date
1				
2	**A-CCP Study Milestones**			
3	Review of HQ feedback on draft plan	10.00	8/21/18	9/3/18
4	Submit revised study plan	0.00	9/28/18	9/28/18
5	Review of HQ feedback on revised study plan	10.00	10/11/18	10/24/18
6	Submit final study plan	0.00	10/26/18	10/26/18
7	Authority To Proceed	0.00	10/29/18	10/29/18
8	Initial draft SATM	0.00	11/1/18	11/1/18
9	Draft Library Input Templates Completed	0.00	10/22/18	10/22/18
10	VF roll out to SALT @ NASA HQ	0.00	10/22/18	10/22/18
11	**Science Planning Workshop @ LaRC**	4.00	10/29/18	11/1/18
12	Post Science Planning Workshop Version of A+CCP SATM	0.00	11/9/18	11/9/18
13	Present Refined SATM and draft threshold science objectives/measurements to A-CCP PS	0.00	11/29/18	11/29/18
14	Refined SATM and Refined Threshold science objectives	0.00	1/14/19	1/14/19
15	**Kick-Off Meeting With Community @ Pasadena, CA**	5.00	1/28/19	2/1/19
16	**Blue Sky Innovation Session @ JPL**	3.00	3/12/19	3/14/19
17	Present Refined SATM and Threshold Science Objectives to A-CCP PS	0.00	3/21/19	3/21/19
18	**Science Workshop @ US Fisheries Training Facility, Shepherdstown, WV**	5.00	4/22/19	4/26/19
19	**Design Center Libraries are defined and locked down**	0.00	4/26/19	4/26/19
20	**Delivery of Prioritized SATMs to ESD Program Scientist**	0.00	5/6/19	5/6/19
21	**Study Team Concurrence On Ready to Proceed Into Phase I Architecture Study Phase**	0.00	5/6/19	5/6/19
22	Annual 2 Day Meeting with ESD	2.00	10/15/19	10/16/19
23	**Science Workshop and Study Team Meeting @GSFC To Discuss Phase Architecture Results**	5.00	3/30/20	4/3/20
24	Summary Report to ESD Program Executive and Program Scientist on Phase I Architecture Studies	0.00	5/1/20	5/1/20
25	**Study Team Concurrence On Ready to Proceed into Phase II Architecture Study**	0.00	4/6/20	4/6/20
26	Science/Systems Engineering Team Workshop	5.00	5/4/20	5/8/20
27	Annual 2 Day Meeting with ESD	2.00	10/27/20	10/28/20
28	Science/Systems Engineering Team Workshop	5.00	11/16/20	11/20/20
29	Independent Cost/Schedule/Risk Report	0.00	11/30/20	11/30/20
30	Draft Study Report Delivery To ESD Program Executive and Program Scientist For Comments	0.00	7/23/21	7/23/21
31	Preliminary Study Completion Presentation to ESD	0.00	9/8/21	9/8/21
32	Study Completion Presentation to ESD @ HQ	0.00	9/20/21	9/20/21
33	**Final Report Delivered to HQ**	0.00	9/30/21	9/30/21
34				
35	Quarterly Team Status Reviews			
36	#1	0.00	1/10/19	1/10/19
44	#11	0.00	7/26/21	7/26/21
45	**Objectives & Measurement Definition**	**155.00**	**10/1/18**	**5/6/19**
46	First Draft SATM	18.00	10/1/18	10/24/18
47	Present at Science Planning Workshop@LaRC	0.00	10/29/18	10/29/18
48	Refine SATM and draft threshold science objectives/measurements	22.00	10/31/18	11/29/18
49	Post Science Planning Workshop Version of A+CCP SATM	0.00	11/9/18	11/9/18
50	Present Refined SATM and draft threshold science objectives/measurements to A-CCP PS	0.00	11/29/18	11/29/18
51	Refine SATM and refined threshold science objectives/measurements	33.00	11/30/18	1/15/19
52	Refined SATM and Refined Threshold science objectives	0.00	1/14/19	1/14/19



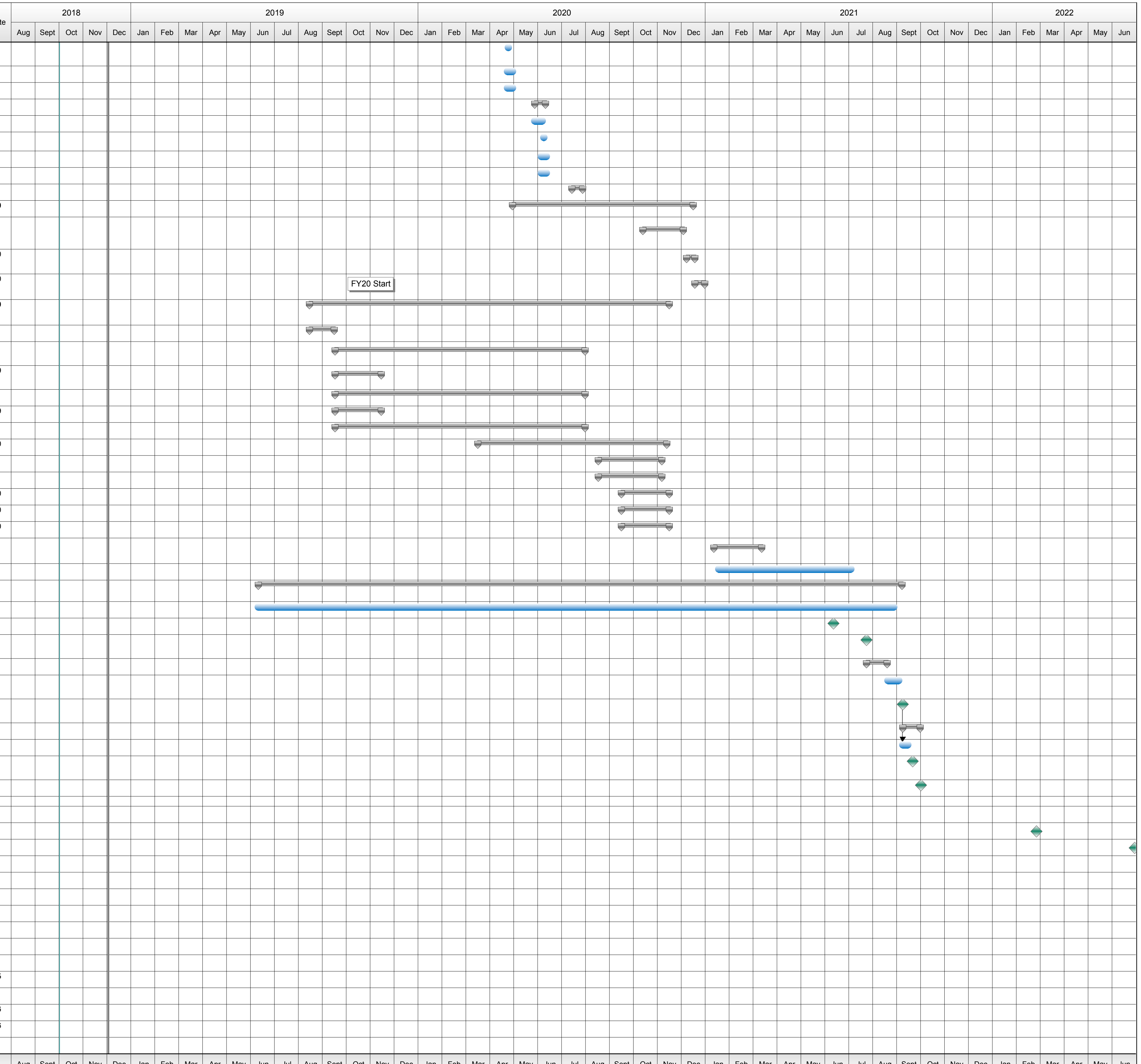
	Activity Name	Duration (Days)	Start Date	Finish Date
53	Present at Kick-Off Meeting With Community @ Pasadena, CA	0.00	1/28/19	1/28/19
54	Refine SATM and Threshold Science Objectives	25.00	2/4/19	3/8/19
55	Deliver refined SATM and Threshold Science Objectives to SCC	0.00	3/8/19	3/8/19
56	Present Refined SATM and Threshold Science Objectives to A-CCP PS	0.00	3/21/19	3/21/19
57	Refined SATM and Threshold Science Objective	19.00	3/22/19	4/17/19
58	Present at Science Workshop @ Location TBD near GSFC	0.00	4/22/19	4/22/19
59	Final Refinement of SATM and Threshold Science Objectives	5.00	4/29/19	5/3/19
60	Present Final SATM and Threshold Science to PS	0.00	5/6/19	5/6/19
61	**Value Framework Design**	**118.00**	**9/19/18**	**3/1/19**
62	Identify framework elements necessary to define value	8.00	10/1/18	10/10/18
63	Define cost and risk assessment methods and processes	8.00	10/11/18	10/22/18
64	Define tasks and schedule	3.00	10/23/18	10/25/18
65	Consult with SMT	1.00	9/19/18	9/19/18
66	Consult with SALT Face-to-Face 1	1.00	10/3/18	10/3/18
67	Consult with SALT Face-to-Face 2	5.00	10/29/18	11/2/18
68	Adjustment to VF based on SMT/SALT feedback	8.00	11/5/18	11/14/18
69	Consult with SET	1.00	11/15/18	11/15/18
70	Define key mission concept parameters required to enable scoring	76.00	11/16/18	3/1/19
71	SACD Peer Review	3.00	10/1/18	10/3/18
72	Adjustements to VF based on SACD feedback	10.00	10/4/18	10/17/18
73	Socialize VF @ Kick-Off Meeting With Community @ Pasadena, CA	5.00	1/28/19	2/1/19
74	Documented VF ready for implementation	0.00	10/1/18	10/1/18
75	Produce visualization tools and documentation scheme	95.00	10/1/18	2/8/19
76	Value Framework Definition and Evaluation of Mission Concepts	**407.00**	**10/1/18**	**4/21/20**
77	Determine scoring methods and processes	125.00	10/29/18	4/19/19
78	Benefits Scoring Plan	0.00	10/1/18	10/1/18
79	Risk Assessment Plan	0.00	10/1/18	10/1/18
80	Science Team Assessment of Aerosol with single spacecraft	40.00	5/29/19	7/23/19
81	Benefits Scores for Aerosol with single spacecraft	65.00	5/29/19	8/27/19
82	Science Team Assessment of Aerosol with distributed spacecraft	40.00	7/17/19	9/10/19
83	Benefits Scores for Aerosol with distributed spacecraft	65.00	7/17/19	10/15/19
84	Science Team Assessment of CCP with single spacecraft	40.00	8/27/19	10/21/19
85	Benefits Scores for CCP with single spacecraft	65.00	8/28/19	11/26/19
86	Science Team Assessment of CCP with distributed spacecraft	40.00	10/15/19	12/9/19
87	Benefits Scores for CCP with distributed spacecraft	65.00	10/16/19	1/14/20
88	Science Team Assessment of A+CCP with distributed spacecraft	40.00	11/27/19	1/21/20
89	Benefits Scores for A+CCP with distributed spacecraft	65.00	11/27/19	2/25/20
90	Science Team Assessment of A+CCP with hybrid	40.00	1/22/20	3/17/20
91	Benefits Scores for A+CCP with hybrid	65.00	1/22/20	4/21/20
92	Science Assessment Reconcilation	3.00	3/23/20	3/25/20
93	Risk Assessment...	**13.00**	**10/1/18**	**10/17/18**
98	Produce visualization of benefits	15.00	2/11/20	3/2/20
99	Produce visualization of total value (benefits for first 5 concepts and risk)	15.00	3/3/20	3/23/20
100	Report writing	19.00	3/24/20	4/17/20
101	Science Community Cohort (SCC) and Systems Engineering Team (SET) Review/Feedback on SATM	**144.00**	**10/1/18**	**4/18/19**
102	*Workshop Planning*	20.00	10/1/18	10/26/18
103	*SCC Independent feedback on 11/29 SATM delivery*	10.00	11/29/18	12/12/18
104	*SCC Independent feedback to SALT and SMT*	0.00	12/13/18	12/13/18
105	*SCC Independent feedback on 1/14 SATM delivery*	10.00	1/14/19	1/25/19
106	*SCC Independent feedback to SALT and SMT (will inform agenda for day 3 of kickoff meeting in Pasadena)*	0.00	1/25/19	1/25/19
107	*SCC Independent feedback on SATM*	10.00	3/8/19	3/21/19



	Activity Name	Duration (Days)	Start Date	Finish Date
108	*SCC Independent feedback to SALT and SMT*	0.00	3/21/19	3/21/19
109	*SET and SME Review of SATM*	17.00	3/21/19	4/12/19
110	*Refined SATM and refined threshold requirements*	0.00	4/12/19	4/12/19
111	*SCC Independent feedback on SATM and threshold for independent prioritization review*	5.00	4/12/19	4/18/19
112	Review of prioritized SATM and threshold requirements with PE, PS, SMT, et al at Science Workshop @ TBD facility near GSFC	5.00	4/22/19	4/26/19
113	Prepare presentation packages for Science Workshop	10.00	4/9/19	4/22/19
114	Summary Report	5.00	4/29/19	5/3/19
115	Prioritized SATM and threshold requirements delivered to PE/PS	0.00	5/6/19	5/6/19
116	**Architecture Libraries...**	**20.00**	**10/1/18**	**10/26/18**
118	...	**136.00**	**10/29/18**	**5/6/19**
137	Lock down of Libraries for Design Center Activities & submit to PE and PS	0.00	5/8/19	5/8/19
138	**Phase I Architecture Studies**	**182.00**	**5/13/19**	**1/21/20**
139	Aerosol with single spacecraft @ LaRC	**12.00**	**5/13/19**	**5/28/19**
140	*Design Center Activity*	8.00	5/13/19	5/22/19
141	*Team review of results with PS*	1.00	5/23/19	5/23/19
142	*Lessons Learned Documented*	5.00	5/22/19	5/28/19
143	*Libraries Updated, as required*	5.00	5/22/19	5/28/19
144	Aerosol with distributed spacecraft @ GSFC	**12.00**	**7/1/19**	**7/16/19**
145	*Design Center Activity*	8.00	7/1/19	7/10/19
146	*Team review of results with PS*	1.00	7/11/19	7/11/19
147	*Lessons Learned Documented*	5.00	7/10/19	7/16/19
148	*Libraries Updated, as required*	5.00	7/10/19	7/16/19
149	CCP with single spacecraft @ GSFC	**12.00**	**8/12/19**	**8/27/19**
150	*Design Center Activity*	8.00	8/12/19	8/21/19
151	*Team review of results with PS*	1.00	8/22/19	8/22/19
152	*Lessons Learned Documented*	5.00	8/21/19	8/27/19
153	*Libraries Updated, as required*	5.00	8/21/19	8/27/19
154	CCP with distributed spacecraft @ JPL	**12.00**	**9/30/19**	**10/15/19**
155	*Design Center Activity*	8.00	9/30/19	10/9/19
156	*Team review of results with PS*	1.00	10/10/19	10/10/19
157	*Lessons Learned Documented*	5.00	10/9/19	10/15/19
158	*Libraries Updated, as required*	5.00	10/9/19	10/15/19
159	A+CCP with distributed spacecraft @ JPL	**12.00**	**11/11/19**	**11/26/19**
160	*Design Center Activity*	8.00	11/11/19	11/20/19
161	*Team review of results with PS*	1.00	11/21/19	11/21/19
162	*Lessons Learned Documented*	5.00	11/20/19	11/26/19
163	*Libraries Updated, as required*	5.00	11/20/19	11/26/19
164	A+CCP with hybrid @ GSFC	**12.00**	**1/6/20**	**1/21/20**
165	*Design Center Activity*	8.00	1/6/20	1/15/20
166	*Team review of results with PS*	2.00	1/16/20	1/17/20
167	*Lessons Learned Documented*	5.00	1/15/20	1/21/20
168	*Libraries Updated, as required*	5.00	1/15/20	1/21/20
169	Study Team Review Of Phase I Architecture Study Results Prior To Proceeding With Phase II Studies	**5.00**	**3/23/20**	**3/27/20**
170	Team review of design center and VF results	5.00	3/23/20	3/27/20
171	Science Workshop and Study Team Meeting @GSFC To Discuss Phase I Architecture Results	5.00	3/30/20	4/3/20
172	Study Team Concurrence to Proceed To Phase II	0.00	4/6/20	4/6/20
173	Summary Report to PE and PS on Phase I Architecture Studies	10.00	4/3/20	4/16/20
174	HQ review/concurrence of summary report	10.00	4/17/20	4/30/20
175	Submit Final Phase I Summary Report to PE and PS	0.00	5/1/20	5/1/20
176	**Phase II Architecture Study**	**77.00**	**4/13/20**	**7/28/20**
177	A+CCP with Single Spacecraft @ MSFC	**12.00**	**4/13/20**	**4/28/20**
178	*Design Center Activity*	8.00	4/13/20	4/22/20



	Activity Name	Duration (Days)	Start Date	Finish Date
179	*Team review of results with PS*	1.00	4/23/20	4/23/20
180	*Lessons Learned Documented*	5.00	4/22/20	4/28/20
181	*Libraries Updated, as required*	5.00	4/22/20	4/28/20
182	Aerosol with hybrid @ GRC	**12.00**	**5/27/20**	**6/11/20**
183	*Design Center Activity*	8.00	5/27/20	6/5/20
184	*Team review of results with PS*	1.00	6/8/20	6/8/20
185	*Lessons Learned Documented*	5.00	6/5/20	6/11/20
186	*Libraries Updated, as required*	5.00	6/5/20	6/11/20
187	CCP with hybrid @ GRC...	**12.00**	**7/13/20**	**7/28/20**
192	**Value Framework Evaluation of Phase II Concepts...**	**166.00**	**4/29/20**	**12/16/20**
204	Study Team Review Of Phase II Architecture Study Results Prior To Proceeding With Phase III Studies	40.00	10/12/20	12/4/20
205	Summary Report to PE and PS on Phase II Architecture Studies	10.00	12/7/20	12/18/20
206	HQ review/concurrence of summary report	10.00	12/18/20	12/31/20
207	**Independent Cost/Schedule Evaluation**	**328.00**	**8/15/19**	**11/16/20**
208	Develop Estimating Plan	23.00	8/15/19	9/16/19
209	Compile Programmatic and Technical Baseline	230.00	9/16/19	7/31/20
210	Develop Ground Rules and Assumptions	45.00	9/16/19	11/15/19
211	Compile Historical Data	230.00	9/16/19	7/31/20
212	Define Estimating Structure	45.00	9/16/19	11/15/19
213	Define Estimating Methods	230.00	9/16/19	7/31/20
214	Develop Estimates	175.00	3/16/20	11/13/20
215	Conduct Sensitivity Analysis	60.00	8/17/20	11/6/20
216	Conduct Risk/Uncert Analysis	60.00	8/17/20	11/6/20
217	Timephase Estimates	45.00	9/15/20	11/16/20
218	Analyze and Reconcile Results	45.00	9/15/20	11/16/20
219	Document/Present Results	45.00	9/15/20	11/16/20
220	**Phase III Architecture Study Phase (Fine Tune)**	45.00	1/11/21	3/12/21
221	Prepare MCR Deliverables	120.00	1/18/21	7/2/21
222	**Final Report & Presentation to ESD@HQ**	**587.00**	**6/10/19**	**9/8/21**
223	Continuous Report Writing	580.00	6/10/19	8/27/21
224	First Draft of Final Report	0.00	6/11/21	6/11/21
225	Draft Final Report to PE and PS for Comments	0.00	7/23/21	7/23/21
226	HQ Review/Comments	20.00	7/23/21	8/19/21
227	Incorporate HQ Recommendations	10.00	8/20/21	9/2/21
228	Preliminary Study Completion Presentation to ESD	0.00	9/8/21	9/8/21
229		**17.00**	**9/8/21**	**9/30/21**
230	Revise Final Report	5.00	9/8/21	9/14/21
231	Study Completion Presentation to ESD	0.00	9/20/21	9/20/21
232	Final Report Delivered to HQ	0.00	9/30/21	9/30/21
233				
234	Post Report Submittal			
235	Acquisition Strategy Meeting (ASM)	0.00	2/24/22	2/24/22
236	MIssion Concept Review (MCR)	0.00	6/29/22	6/29/22
237	KDP-A (notional)	0.00	9/28/22	9/28/22
238	Phase A (9 months)			
239	KDP-8 (MDR) (notional)	0.00	6/28/23	6/28/23
240	Phase B			
241	KDP-C (PDR) (Confirmation Review) (notional)	0.00	6/26/24	6/26/24
242	Phase C			
243	CDR (notional)	0.00	6/26/25	6/26/25
244	KDP-D (SIR) (notional)	0.00	11/19/25	11/19/25
245	Phase D			
246	KDP-E (FRR, MRR, LRR) (notional)	0.00	11/16/26	11/16/26
247	Launch (notional)	0.00	11/20/26	11/20/26
248	Phase E			



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Acronyms

Acronym	Definition
3MI	Multi-viewing/Multi-Channel/Multi-polarization Imager
A	Aerosol
ABI	Advanced Baseline Imager
A-CCP	Aerosols-Clouds, Convection, and Precipitation
ACE	Aerosol-Clouds-Ecosystem
ACEPOL	Aerosol Characterization from Polarimeter and Lidar
AERONET	Aerosol Robotic Network
AHI	Advanced Himawari Imager
AIT	Applications Impact Team
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AO	Announcement of Opportunity
AR5	Fifth Assessment Report
ARC	Ames Research Center
ASP	Applied Science Program
ATM	Applications Traceability Matrix
ATP	Authority to Proceed
ATTREX	Airborne Tropical TRopopause EXperiment
AWS	Amazon Web Services
BOBJ	Business Objects
BPA	Blanket Purchase Agreement
Cal/Val	Calibration and Validation
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CATS	Cloud-Aerosol Transport System
CCB	Change Control Board
CCP	Clouds, Convection, and Precipitation
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System
CloudSat	Cloud Satellite
CNES	Centre National d'Etudes Spatiales
COMPASS	Collaborative Modeling for the Parametric Assessment of Space Systems
CSA	Canadian Space Agency
DAAC	Distributed Active Archive Centers
DISCOVER-AQ	Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DO	Designated Observable
DS	Decadal Survey
DSM	Decadal Survey Mission
EA	Early Adopter
EarthCARE	Earth Cloud Aerosol and Radiation Explorer
EDS	Engineering Design Studio
EMIT	Earth Surface Mineral Dust Source Investigation
EO	Earth Observing
EOSDIS	Earth Observing System Data and Information System
EPSA	Earth, Ocean, Atmosphere, Planetary Science, and Applications Area

Acronym	Definition
ESA	European Space Agency
ESAS	Earth Science and Applications from Space
ESE	Earth Science Explorer
ESD	Earth Science Division
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
EUMETSIT	European Organisation for the Exploitation of Meteorological Satellites
EVI-4	Earth Surface Mineral Dust Source Investigation
EVS	Earth Venture Suborbital
FAD	Formulation Authorization Direction
FCI	Flexible Combined Imager
FOM	Figure of Merit
GAO	Government Accounting Office
GEMS	Global Environment Monitoring System
GLM	Geostationary Lightning Mapper
GMAO	Global Modeling and Assimilation
GOES	Geostationary Operational Environmental Satellite System
GPM	Global Precipitation Mission
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HAQAST	Health and Air Quality Applications Science Team
HARP	HyperAngular Rainbow Polarimeter
HQ	Headquarters
HSRL	High Spectral Resolution Lidar
ICESIT	Ice, Cloud, and land Elevation Satellite
ICI	Ice and Cloud Imager
ICON	Ionospheric Connection Explorer
IET	Independent Engineering Team
IMS	Integrated Master Schedule
INVEST	In-space Validation of Earth Science Technology
IPCC	Intergovernmental Panel on Climate Change
IPHEX	Integrated Precipitation and Hydrology Experiment
ISRO	Indian Space Research Organization
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
KDP	Key Decision Point
LaRC	Langley Research Center
LI	Lightning Imager
MCR	Mission Concept Review
MEL	Master Equipment List
MESCAL	Monitoring the Evolutionary State of Clouds and Aerosol Layers
METimage	Meteorological Imager
MI	Most Important
MIS	Management Information System
MISR	Multi-angle Imaging SpectroRadiometer
MMS	Magnetospheric Multiscale

Acronym	Definition
MODIS	Moderate-Resolution Imaging Spectroradiometer
MPLNET	Micro-Pulse Lidar Network
MRSA	Microwave Remote Sensors Area
MSE	Mission Systems Engineer
MSFC	Marshall Space Flight Center
MTG	Meteosat's Third Generation
NAAMES	North Atlantic Aerosol and Marine Ecosystem Study
NAS	National Academy of Sciences
NICM	NASA Instrument Cost Model
NISAR	NASA/ISRO Synthetic Aperture Radar
NPP	Suomi National Polar-orbiting Partnership
NPR	NASA Procedural Requirement
NSF	National Science Foundation
OCE	Office of Chief Engineer
OCI	Ocean Color Instrument
OCIO	Office of the Chief Information Officer
OGA	Other Government Agency
OLYMPEX	Olympic Mountains Experiment
ONCE	One NASA Cost Engineering
ORACLES	ObseRvations of Aerosols above Clouds and their intEractionS
OSSE	Observing System Simulation Experiment
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PAL	Program Applications Lead
PAP	Project Applications Plan
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PBL	Problem-Based Learning
PDR	Preliminary Design Review
PE	Program Executive
PLRA	Program Level Requirements Appendix
PMB	Partner Management Board
PODEX	POlarization Definition EXperiment
PoR	Program of Record
R&A	Research and Analysis
RADEX	Radar Definition Experiment
RDSO	Rapid Spacecraft Development Office
RFI	Request for Information
RFP	Request For Proposal
ROM	Rough Order of Magnitude
SAC	Systems Analysis and Concepts
SACD	Systems Analysis and Concepts Directorate
SATM	Science/Applications Traceability Matrix
SBG	Surface Biology and Geology
SC	Study Coordinator
SCC	Science Community Cohort
SDT	Science Definition Team
SIT	Science Impact Team
SLT	Science Leadership Team

Acronym	Definition
SM	Study Management
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SME	Subject Matter Expert
SOCRATES	Southern Ocean Clouds, Radiation, and Aerosol Transport Study
SODA	Synergized Optical Depth of Aerosols
SOMA	Science Office for Mission Assessment
SPEX	Spectropolarimeter for Planetary Exploration
SRON	Space Research Organisation Netherlands
ST	Science Team
STEREO	Solar TErrestrial RElations Observatory
SWIR	Short-Wave Infrared
SWIS	Snow and Water Imaging Spectrometer
SWOT	Surface Water and Ocean Topography
TBD	To Be Determined
TBN	To Be Named
TEMPO	Tropospheric Emissions: Monitoring Pollution
TESS	Transiting Exoplanet Survey Satellite
TO	Targeted observable
TOA	Top-of-the-Atmosphere
TOC	Table of Contents
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TROPICS	Time-Resolved Observations of a Precipitation Structure and Storm Intensity with a Constellation of Smallsats
TS-SCI	Top Secret-Sensitive Compartmentalized Information
UMBC	University of Maryland, Baltimore County
UTS	Upper Troposphere and Stratosphere
UVNS	Ultraviolet/Visible/Near-Infrared/Shortwave-infrared spectrometer
VF	Value Framework
VIIRS	Visible Infrared Imaging Radiometer Suite
VIS-NIR	Visible/Near-Infrared
WBS	Work Breakdown Structure