National Aeronautics and Space Administration

Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

November 30, 2022

Reply to Attn of: Science Mission Directorate

Summary of NASA Responses to Earth System Observatory Independent Review Board Recommendations

The Earth System Observatory (ESO) is a complex and ambitious program of national and international importance. As noted by the Independent Review Board (IRB), its success would result in significant science and applications advances. The ESO's IRB non-consensus report highlights this complexity and importance in laying out their observations, findings, and recommendations. The IRB recommends that NASA proceed with this important program and their detailed recommendations will inform the decisions we make moving forward to maximize the success of the ESO.

The IRB fully met the scope of its review as laid out in the Terms of Reference, identifying a variety of critical cross-cutting factors across ESO's organization and management, science priorities and integrated operations, technical approach, and schedule and cost. NASA accepts the intent of all the IRB's recommendations. The ESO IRB final report and NASA's response are enclosed.

Our responses indicate the steps SMD has already begun taking to coordinate with our internal and external stakeholders, including our international partners, to implement the IRB's recommendations.

I want to thank the IRB Co-Chairs, Dr. Waleed Abdalati and Mr. Geoff Yoder, as well as the experienced board they pulled together for their work to produce this comprehensive and rigorous review while meeting the constraints of a challenging eight-week timeframe. The IRB's independent analysis provides us with valuable, thought-provoking insights as we take the necessary steps to realize this ambitious collection of missions that is a hallmark of the groundbreaking work we do at NASA.

Sandra Connelly for
Thomas H. Zurbuchen, Ph.D.
Associate Administrator,
Science Mission Directorate

Enclosure
NASA Response to the ESO IRB Final Report
ESO IRB Final Report

cc:
Earth Science Division/Dr. St. Germain

NASA's Response to ESO IRB Recommendations

In July 2022, NASA established an Independent Review Board (IRB) to proactively assist with assessment of current plans and goals for the next generation of Earth-observing satellites, designed to propel us forward in understanding our changing planet: NASA's Earth System Observatory (ESO).

The new set of Earth-focused missions will provide key information to guide efforts related to climate change, disaster mitigation, fighting forest fires, improving weather and air quality forecasts, and improving real-time agricultural processes. Within the ESO, each satellite will be uniquely designed to complement the others, providing a 3D, holistic view of Earth, from bedrock to atmosphere.

The IRB has helped NASA review the technical concepts developed during preliminary formulation to date for robustness and the ability to satisfy the mission's essential requirements. It will help ensure NASA is adopting lessons learned from experience with previous large, strategic science missions.

Within their ESO recommendations, the IRB identified both mission-specific and cross-cutting considerations in ESO organization and management, science priorities and integrated operations, technical approach, and schedule and cost. The IRB made 33 recommendations in total. This document provides NASA's response to the recommendations.

1. NASA should work with international partners to establish a 10-15 year international plan for sustained gravimetry observations beyond Mass Change (MC) and determine how best to execute the current MC concept in the context of that plan.

NASA Response: Concur; NASA has been collaborating with partners like ESA, DLR, and CNES since the study phase of MC and is actively discussing the continuity of this measurement.

2. Closer synergy is needed to connect the needs of the science teams, Distributed Active Archive Centers (DAACs), and user community to make ESO data scientifically useful for interdisciplinary science and a mechanism to adequately fund these activities is needed. IRB recommends an ESO-wide effort to define data system and software requirements for integrated cross-mission science and applications that will help guide design of the pre-launch analytics environment.

NASA Response: Concur; NASA is in the process of establishing system and software requirements for integrated cross-mission data, science and applications.

3. Individual project teams (Atmospheric Observing System (AOS), MC, Surface Biology and Geology (SBG)) should interact more with the Earth Science Data Systems (ESDS) group to gain visibility into data system plans even before science teams are formed.

NASA Response: Concur; the SMD Chief Science Data Officer's team is increasing engagement with all ESO missions to ensure data system plans are integrated during formulation.

4. Determine the optimum solution for integrating the missions into a coherent ESD observatory structure. Clearly define roles of each step to avoid issues as identified in the WFIRST lessons learned.

NASA Response: Concur; NASA is considering multiple organizational options for the overall management of the ESO to ensure mission success.

5. Investigate opportunities for aligning launch dates such that complementarity of observations is optimized, e.g., maximizing overlap of visible to shortwave infrared (VSWIR) and thermal infrared (TIR) on SBG, and overlap of AOS-Polar (AOS-P) and AOS-Inclined (AOS-I).

NASA Response: Concur; SBG and AOS will study this during Phase A.

6. Consider descopes on AOS-P to bring costs in better alignment with agency resources and expected margins.

NASA Response: Concur; NASA will study content changes to better align cost and risk with resources and address with SMD leadership at KDP-A for AOS.

7. Identify a person to oversee the full ESO portfolio, such that it is viewed as a complete observatory.

NASA Response: Partial concur; the Earth Science Division (ESD) is considering multiple organizational options for the overall management of the ESO to ensure mission success. Integration of the observatory across disciplines of project management, engineering, science, applications, and data, may require more than designation of a single person for oversight.

8. SBG: Increase engagement with NASA DAACs; Continue early acquisition of long-lead electronic components.

NASA Response: Concur; the SMD Chief Science Data Officer's team is increasing engagement with all ESO missions to ensure data system plans are integrated during formulation; ESD will continue to approve appropriate long-lead procurements.

9. SBG-VSWIR: Expand validation efforts with other ESO programs under ground campaign.

NASA Response: Concur; SBG will study this during Phase A.

10. SBG-TIR: Establish JPL-Italian Space Agency (ASI) exchange of on-site liaisons to ensure interface issues and communication challenges are addressed rapidly and effectively. Procure long-lead electronic parts and investigate field programmable gate array (FPGA) solutions if application-specific integrated circuit (ASIC) spin is not successful; i.e., provide a backup for the Falcon ASIC. Evaluate non-adiabatic interfaces of Payload to Bus and over-design thermal management system given more capable bus provided from ASI.

NASA Response: Concur; NASA ESD has already approved procurement of long-lead electronic parts on all ESO missions. SBG will investigate FPGA solutions, as well as options for payload bus interfaces and thermal management during Phase A. NASA will work with ASI to develop a shared approach to address interface and communication challenges, leveraging lessons learned from the NASA-ASI partnership on MAIA.

11. Explore opportunities with the European Space Agency (ESA) or other partners to develop more sustainable program and assess associated implications.

NASA Response: Concur; NASA will study whether additional domestic and international partnerships beyond those already planned can feasibly be implemented in the future.

12. Project should consider very low size, weight, power, and cost (SWAP-C) PIC (Photonic Integrated Circuit) technology demonstration on MC mission both as a possible backup-system for the Laser Ranging Interferometer (LRI) and as a tech push for future missions.

NASA Response: Concur; MC will study this during Phase A.

13. Project should continue risk-reduction efforts with universities on future ACC (accelerometer). If feasible, provide opportunity to fly technology on mission (even if not at satellite center of gravity (CG)) to characterize for future missions funded in the Tech maturation program.

NASA Response: Concur; MC will study this during Phase A.

14. Review the work assignments to the technology-oriented NASA Research Centers related to delivery of flight hardware to ensure compatibility with capabilities.

NASA Response: Concur; NASA will review center work assignments while considering how best to align mission content with Center capabilities.

15. Explore partnerships both domestic and internationally for potential non-traditional partnerships such as but not limited to ground system operations, spacecraft operations, etc. with a focus on future sustainability in mission implementations.

NASA Response: Concur; NASA will study whether additional domestic and international partnerships beyond those already planned can feasibly be implemented in the future.

16. The IRB recommends an ESD study focusing on clarifying lines of authority and communication, integration function at the ESD ESO level including consideration for an ESO Program Scientist, Program Executive, data czar to help surface application requirements, function that connects the dots between science teams and specific ROSES and Technology offices, etc. The study should also consider if someone should be designated within ESD to review plans, descopes, launch schedules, etc. from a systems level perspective for the overall observatory. The data system is where most users will interact with the program as a system and this is where the scope, schedule and timing of these platforms will determine how well the data can be used and by whom.

NASA Response: Concur; ESD is considering multiple organizational options for the overall management of the ESO to ensure mission success.

17. Combine AOS-P and AOS-I into an integrated project for more effective cost, schedule, and performance management.

NASA Response: Non-Concur; While NASA agrees that effective cost, schedule and performance management are essential for AOS success, NASA believes that development of seven instruments and two spacecraft in different orbits, while interfacing with four international partners, is too complex for effective management under a single project. NASA recognizes that this integration will require special attention to the AOS constellation in the context of the overall ESO integration.

18. Charter review of past Lessons Learned with recommendations for how to best implement appropriate Lessons Learned in ESD and the ESO.

NASA Response: Concur; the NASA ESO team will review Lessons Learned in the NASA databases with an eye to implementation of the ESO.

19. Ensure that an overarching ESD Program Office oversees, supports, and coordinates science data utilization in the applications domain (See Q4).

NASA Response: Concur; ESD is considering multiple organizational options for the overall management of the ESO to ensure mission success.

20. Determine the optimum solution for integrating the ESO missions into a higher level ESD integrated structure. Focus areas should include HQ, Center, and project management and how these projects leverage the rest of the ESD portfolio. Clearly define roles of each step to avoid issues as identified by the WFIRST lessons learned.

NASA Response: Concur; ESD is considering multiple organizational options for the overall management of the ESO to ensure mission success. Considerations will include the connections between the ESO structure and the higher level ESD integrated structure.

21. Centers should conduct an independent assessment of workforce availability and not rely solely on workforce planning tools. Includes skills and training assessment to achieve the best balance of technical capabilities with institutional capabilities.

NASA Response: Concur; NASA is evaluating and closely monitoring center workforce planning approaches in response to findings from several different IRBs.

22. Review strategies for improving team morale such as periodic science lectures, etc.

NASA Response: Concur.

23. Deviations from decadal survey (DS) recommendations should use the Committee on Earth Science and Applications from Space (CESAS) as the community input for recommended changes. An example could include assessing a continuity gap with Mass Change (MC) or applicability of short duration missions.

NASA Response: Concur; NASA will ask CESAS to review the current status of mission plans compared to DS recommendations as part of the upcoming midterm review.

24. Assign a Standing Review Board (SRB) chair for each mission during pre-formulation to start working with the IRB for a successful handover of information.

NASA Response: Concur; ESD is in the process of establishing SRBs for the ESO missions, starting with appointment of SRB chairs.

25. Develop a common understanding of SRB engagement in addition to formal Key Decision Points (KDPs).

NASA Response: Concur; ESD is in the process of establishing SRBs for the ESO missions.

26. Start the communications plan now with emphasis on the observatory philosophy to help with sustainability.

NASA Response: Concur; ESD's communications team will establish an ESO-level communications plan.

27. AOS: AOS-I and AOS-P projects should be integrated.

NASA Response: Partial Concur; NASA agrees that additional emphasis on AOS-I and AOS-P integration is necessary; however, NASA does not believe this integration is best accomplished by combining into a single, large and complex project. See response to #17.

28. AOS: A single spacecraft (s/c) contractor should be considered for both missions.

NASA Response: Concur; AOS will study this during Phase A.

29. AOS: An assessment to better balance AOS-P and AOS-I payloads to enable use of a common s/c could be explored.

NASA Response: Concur; AOS will study this during Phase A.

30. SBG: Re-evaluate costs allocated to PM/SE/MA (project management/systems engineering/mission assurance) to ensure they capture complexities associated with International Partner interfaces (I/F's) and support to 2 missions (SBG-VSWIR and SBG-TIR).

NASA Response: Concur; SBG will address this during Phase A.

31. MC: An improved implementation approach for the Accelerometers is needed.

NASA Response: Concur; MC will address this during Phase A.

32. MC: Further exploration of options to improve redundancy is needed to reduce risk.

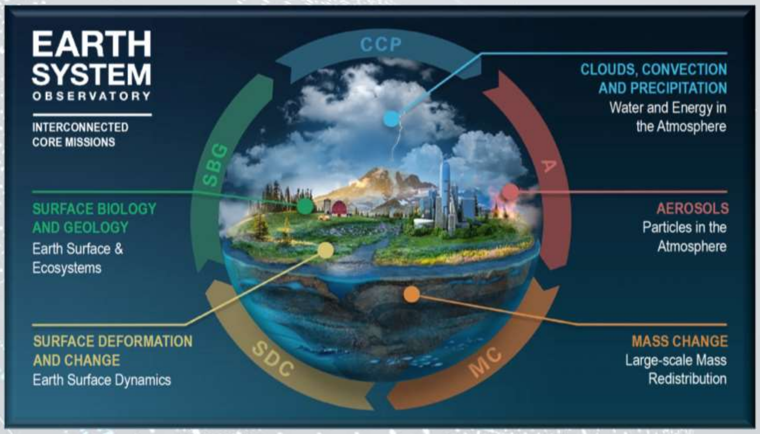
NASA Response: Concur; MC will address this during Phase A.

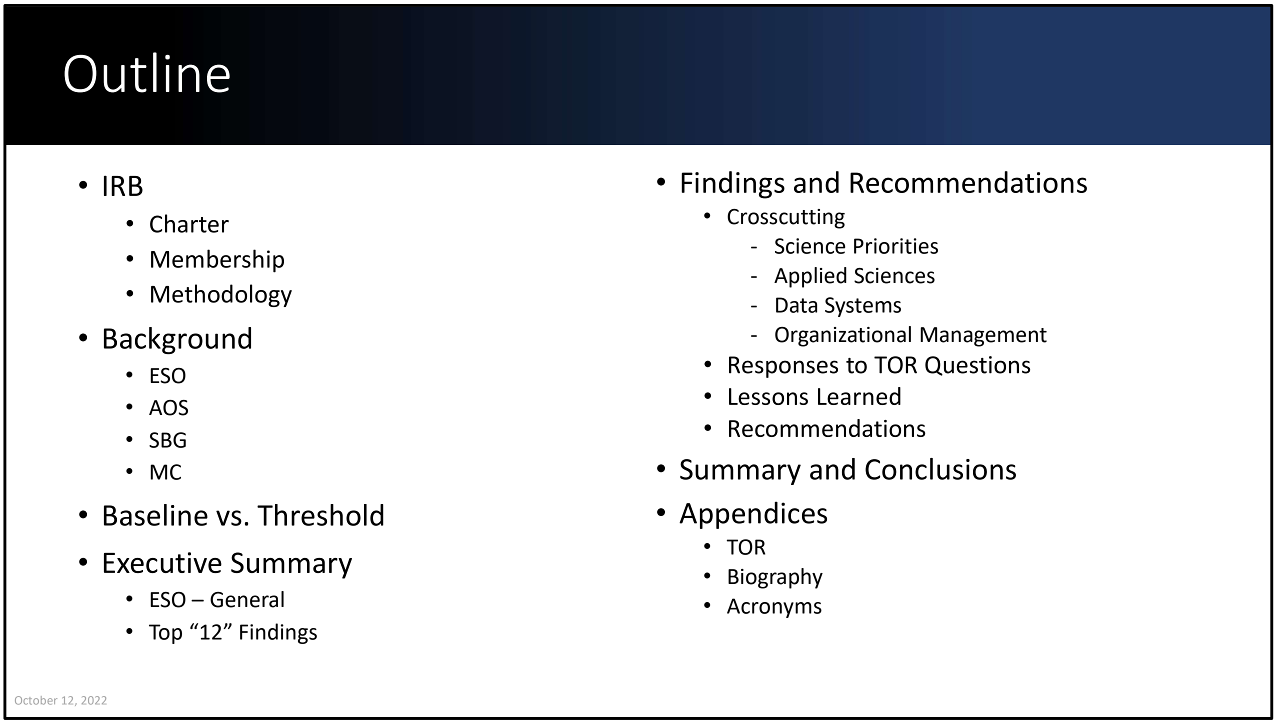
33. MC: A long-term solution to achieve MC science should be pursued in parallel with the MC approach leveraging Grace Follow-On (GFO).

NASA Response: Concur; In addition to the planning described in the response to #1, ESTO is investing in quantum gravimetry technologies in partnership with STMD for a potential demonstration mission that could provide more affordable options in the future.

Earth System Observatory (ESO) Independent Review Board (IRB) Final Report

October 12, 2022





Outline

- IRB
  - Charter
  - Membership
  - Methodology
- Background
  - ESO
  - AOS
  - SBG
  - MC
- Baseline vs. Threshold
- Executive Summary
  - ESO – General
  - Top “12” Findings
- Findings and Recommendations
  - Crosscutting
    - Science Priorities
    - Applied Sciences
    - Data Systems
    - Organizational Management
  - Responses to TOR Questions
  - Lessons Learned
  - Recommendations
- Summary and Conclusions
- Appendices
  - TOR
  - Biography
  - Acronyms

October 12, 2022

The IRB is pleased to present our report and offer our special thanks to Dr. Thomas Zurbuchen, Dr. Karen St Germain, and Kathleen Gallagher Boggs at NASA HQ for their support for our work. We also want to commend the ESD staff, Program Offices and project offices for their support and responses to the IRB requests for meetings and information. The teams have formulated a comprehensive plan for carrying out the ESO missions per the 2017 Earth Science Decadal Report.

The IRB submits the results of our work in the form of 54 findings and 40 recommendations, all with the overriding goal of maximizing the probability of ESO mission success.

Independent Review Board Background

October 12, 2022

IRB Background

- The NASA Science Mission Directorate Associate Administrator established an Independent Review Board (IRB) to proactively assist with assessment of plans and goals for the ESO.
- The IRB is chartered to:
  - Review the technical concepts developed during preliminary formulation to date for robustness
  - Review the ESO’s ability to satisfy the mission’s essential requirements
  - Ensure NASA is adopting lessons learned from experience with previous large, strategic science missions

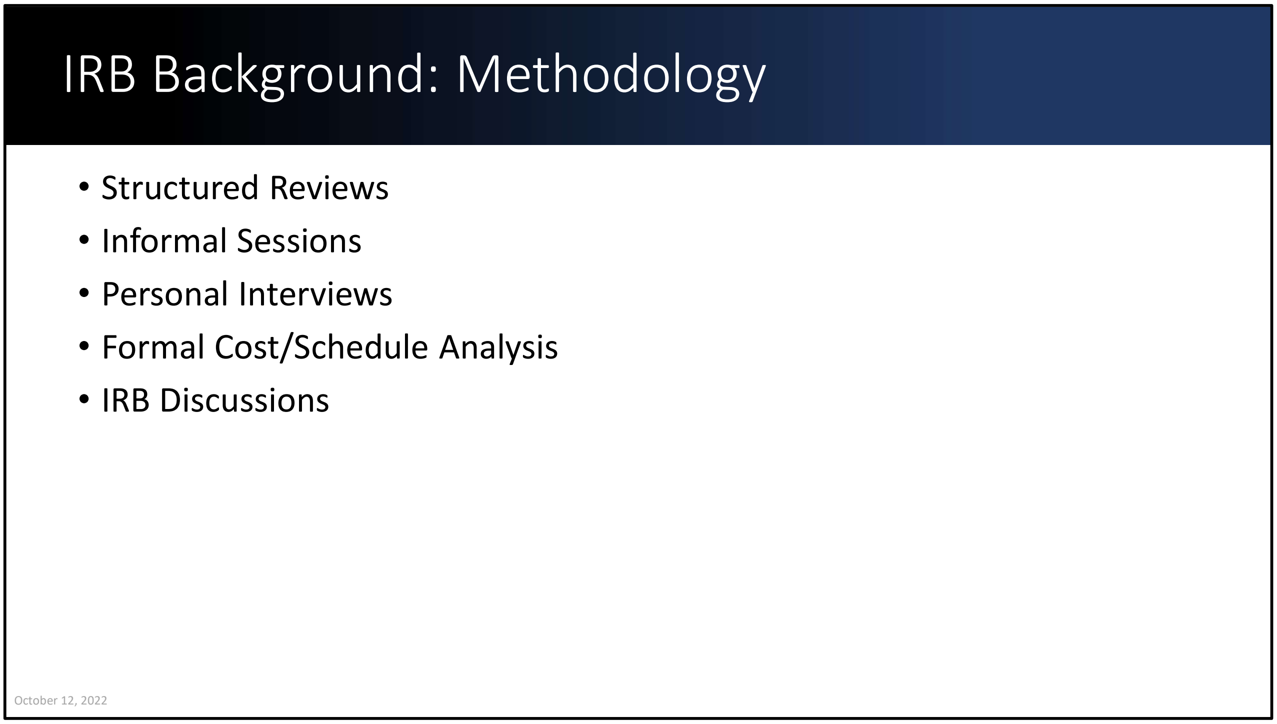
IRB Background: Scope

The ESO IRB will review the overall architecture and individual technical concepts developed during Pre-Phase A for robustness and the ability to satisfy preliminary Level 1 Requirements, including addressing the following questions:

1. Does the proposed architecture meet the intent of the Decadal Survey and alignment with Agency need and the ESO?
2. Are the scope and cost/schedule understood and aligned?
   a. Do the mission concepts fit within the cost estimates developed by the National Academies in the 2018 Earth Science Decadal Survey?
   b. What is the likely range of probable cost and schedule for the overall architecture and the individual mission concepts, and what are the drivers?
   c. How do non-optimal funding profiles affect the cost/schedule of the missions?
   d. Are there any (obvious) make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?
   e. Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?

IRB Background: Scope (cont.)

3. Does the current partitioning of work across NASA centers and our external partners best position the program for cost/schedule/technical success?
4. Is the management approach and structure adequate for a program of this scope and complexity? Are lessons learned from the Large Mission Study and previous IRBs (e.g., JWST, Mars 2020, Mars Sample Return) being implemented?
5. What is the current readiness of critical technologies? What technology investments are needed to best position the program for success?
6. What is the current applications readiness of the mission concepts and associated applied sciences planning? What applied science/applications investments are needed to best position the program for success?



IRB Background: Methodology

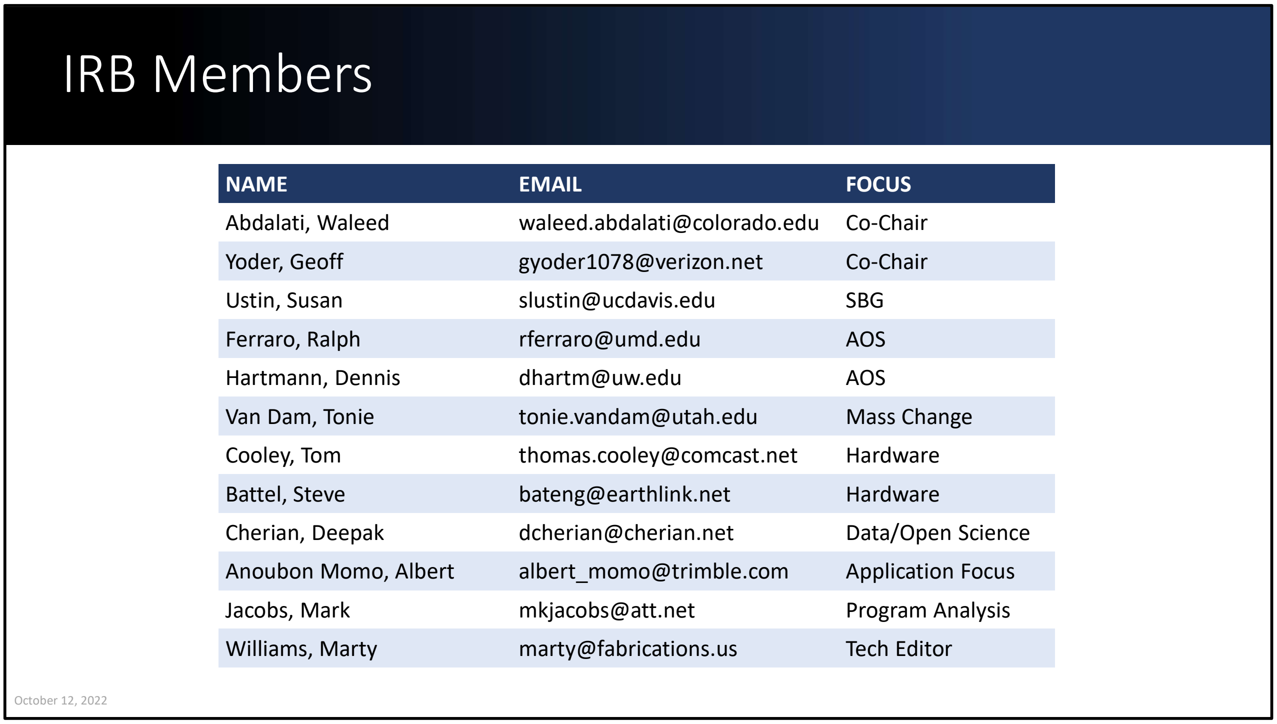
- Structured Reviews
- Informal Sessions
- Personal Interviews
- Formal Cost/Schedule Analysis
- IRB Discussions

October 12, 2022

The IRB met in virtual plenary sessions on twenty-one occasions over a ten-week period. Our meetings included thirteen formal presentations by ESD, Program and project personnel covering scientific, technical, and programmatic data. In addition, we conducted approximately eleven informal “splinter” sessions and expert interviews. We also reviewed project Mission Concept Review concepts, schedules, and cost analyses that helped inform our findings and recommendations. Specifically, the IRB reviewed the TOR requirements, Project specific MCR and IRB meeting presentations, Lessons Learned from 10 previous Lessons Learned reports, and funding clarifications.

The IRB approach followed a traditional systems engineering process by first understanding the high-level requirements from the Project Authorization Letters (PALs), talking with ESD and Program Office personnel, conducting deep dive discussions with project personnel to understand the requirements decomposition, and reengaging with ESD and the Program Office to address any issues identified during the deep dive sessions. Parallel splinter sessions were held for topics such as data and applications, design and science focused clarifications, and cost assumptions.

Many of the detailed observations, findings, and recommendations were drafted by a subset of IRB members then discussed and finalized by the entire group.



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October 12, 2022

The 12 members of the IRB spent a combined total of approximately 800 person-hours on the review, which was conducted between late July and late September 2022. All members of the board participated fully, engaging in discussions that were thorough and spirited. The support provided by Elaine Denning, Mike Egan, and Tahani Amer from NASA HQ was greatly appreciated.

ESO Background

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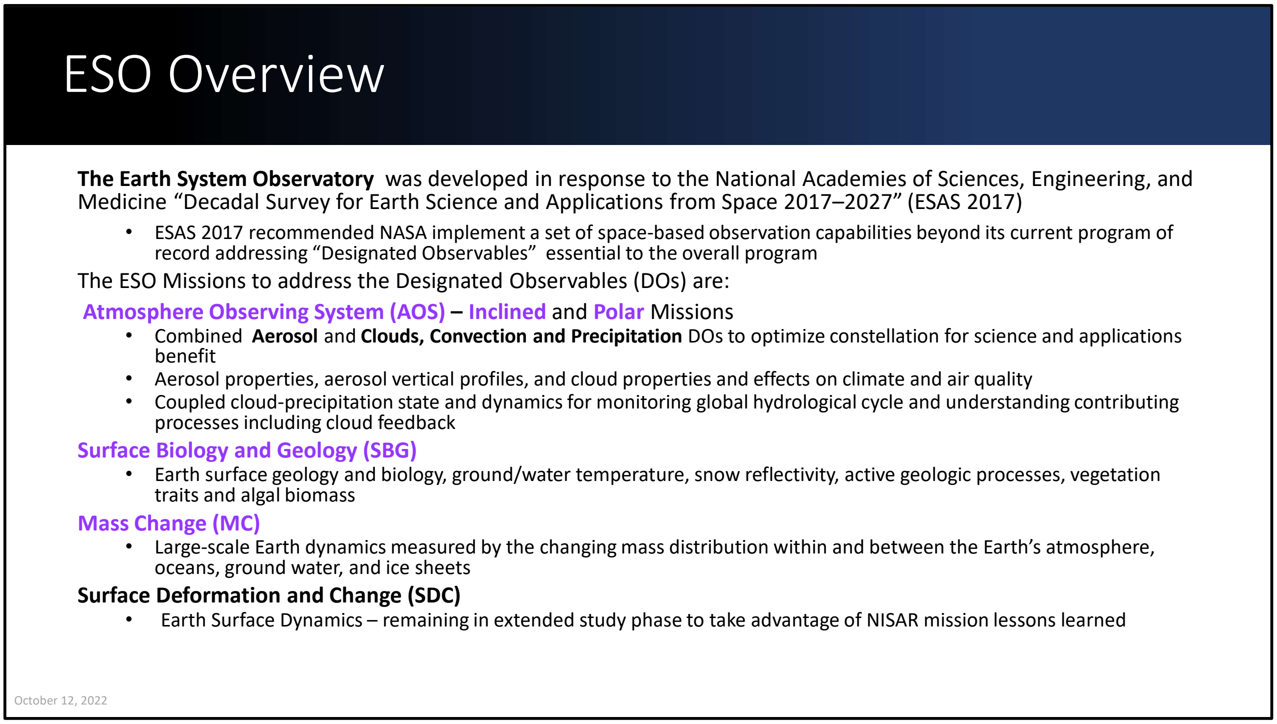


ESO Overview

The Earth System Observatory was developed in response to the National Academies of Sciences, Engineering, and Medicine “Decadal Survey for Earth Science and Applications from Space 2017–2027” (ESAS 2017)

- ESAS 2017 recommended NASA implement a set of space-based observation capabilities beyond its current program of record addressing “Designated Observables” essential to the overall program

The ESO Missions to address the Designated Observables (DOs) are:

Atmosphere Observing System (AOS) – **Inclined** and **Polar** Missions

- Combined **Aerosol** and **Clouds, Convection and Precipitation** DOs to optimize constellation for science and applications benefit
- Aerosol properties, aerosol vertical profiles, and cloud properties and effects on climate and air quality
- Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback

Surface Biology and Geology (SBG)

- Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass

Mass Change (MC)

- Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth’s atmosphere, oceans, ground water, and ice sheets

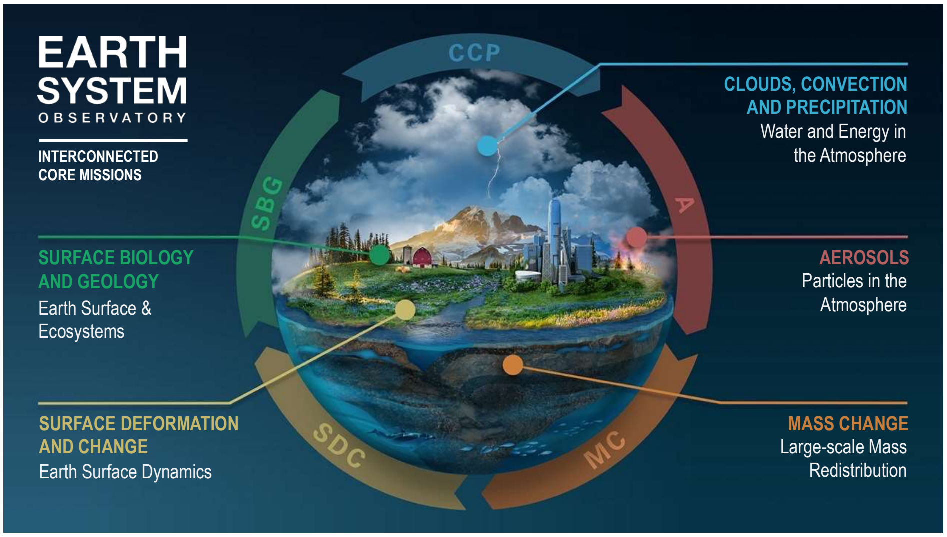
Surface Deformation and Change (SDC)

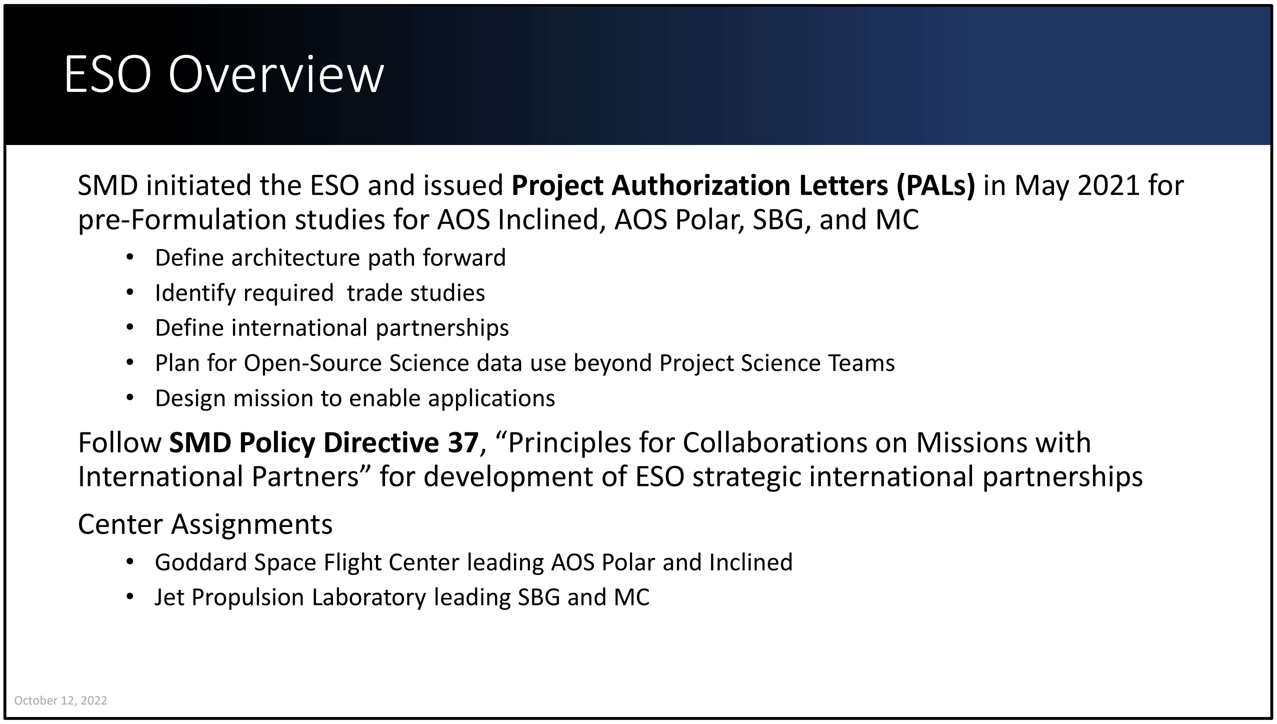
- Earth Surface Dynamics – remaining in extended study phase to take advantage of NISAR mission lessons learned

October 12, 2022

For AOS-P and I NASA is providing both s/c; For SBG TIR, only the instrument is provided, so we treat SBG (TIR and VSWIR) as one NASA mission, but AOS as 2.

ESO Overview





ESO Overview

SMD initiated the ESO and issued **Project Authorization Letters (PALs)** in May 2021 for pre-Formulation studies for AOS Inclined, AOS Polar, SBG, and MC

- Define architecture path forward
- Identify required trade studies
- Define international partnerships
- Plan for Open-Source Science data use beyond Project Science Teams
- Design mission to enable applications

Follow **SMD Policy Directive 37**, “Principles for Collaborations on Missions with International Partners” for development of ESO strategic international partnerships

Center Assignments

- Goddard Space Flight Center leading AOS Polar and Inclined
- Jet Propulsion Laboratory leading SBG and MC

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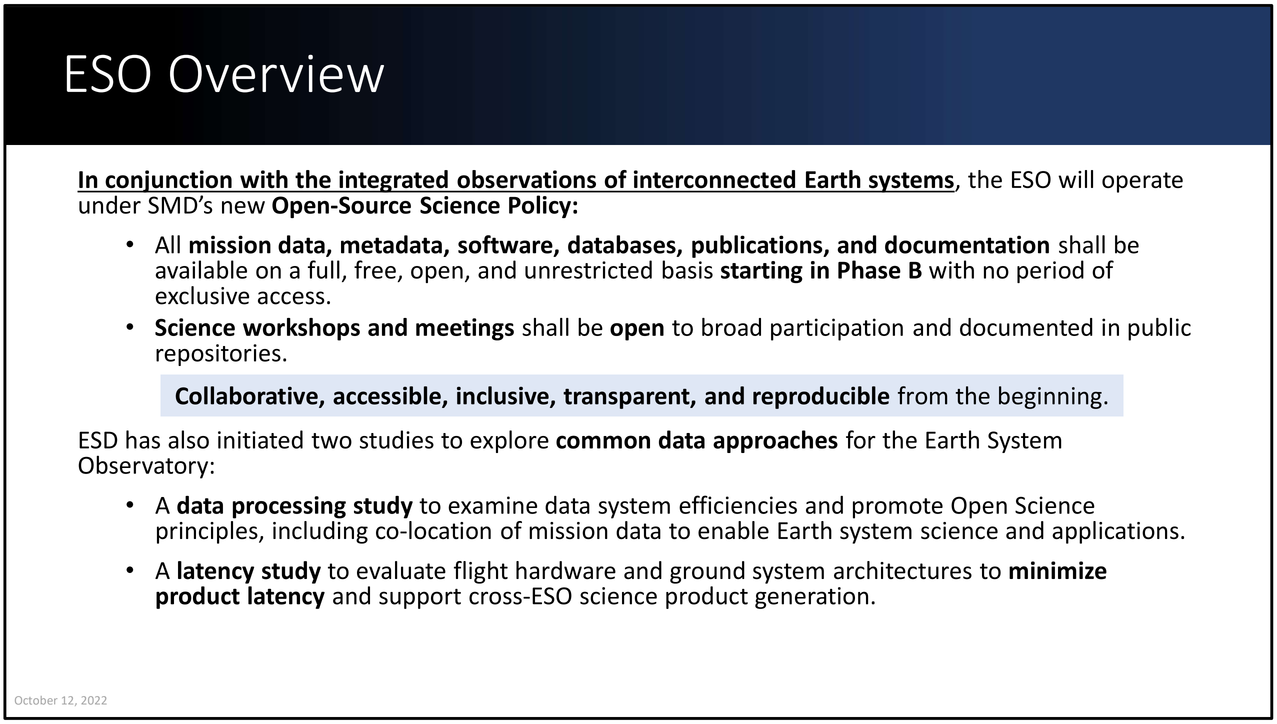
Further direction to the PAL was provided by the ESD Director via email for Mass Change to only include Phase A-D within the cost cap.



ESO Overview

In conjunction with the integrated observations of interconnected Earth systems, the ESO will operate under SMD's new **Open-Source Science Policy:**

- All **mission data, metadata, software, databases, publications, and documentation** shall be available on a full, free, open, and unrestricted basis **starting in Phase B** with no period of exclusive access.
- **Science workshops and meetings** shall be **open** to broad participation and documented in public repositories.

Collaborative, accessible, inclusive, transparent, and reproducible from the beginning.

ESD has also initiated two studies to explore **common data approaches** for the Earth System Observatory:

- A **data processing study** to examine data system efficiencies and promote Open Science principles, including co-location of mission data to enable Earth system science and applications.
- A **latency study** to evaluate flight hardware and ground system architectures to **minimize product latency** and support cross-ESO science product generation.

October 12, 2022

Underlined text is intended to highlight that ESO is part of a larger integrated set of observations.

AOS Science

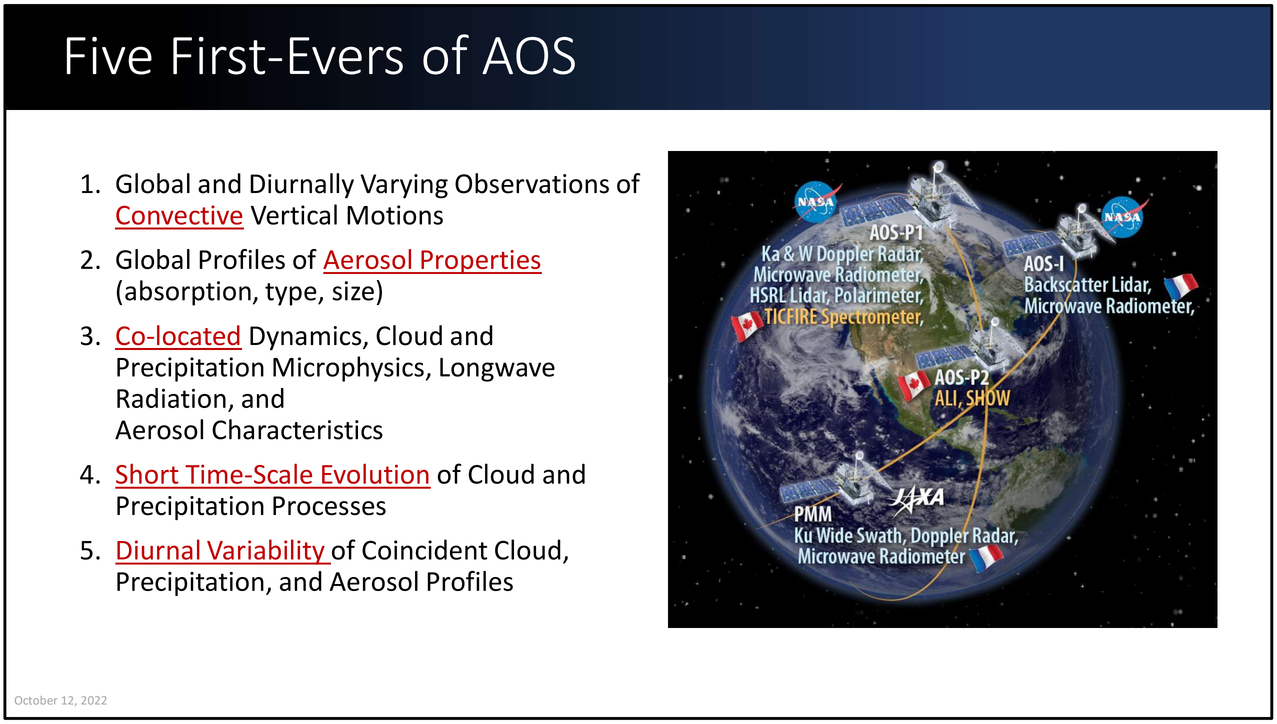
October 12, 2022

Concepts and Capabilities Mapped to DS

The proposed architecture for AOS P and I projects directly advances the DS goals:

1. Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do?
2. What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impacts on human health, agriculture, and ecosystems?
3. How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies?

- Several proposed sensors build upon successful heritage instruments (e.g., GPM DPR, Cloudsat radar, etc.) and partnerships (e.g., JAXA/TRMM, GPM, etc.)



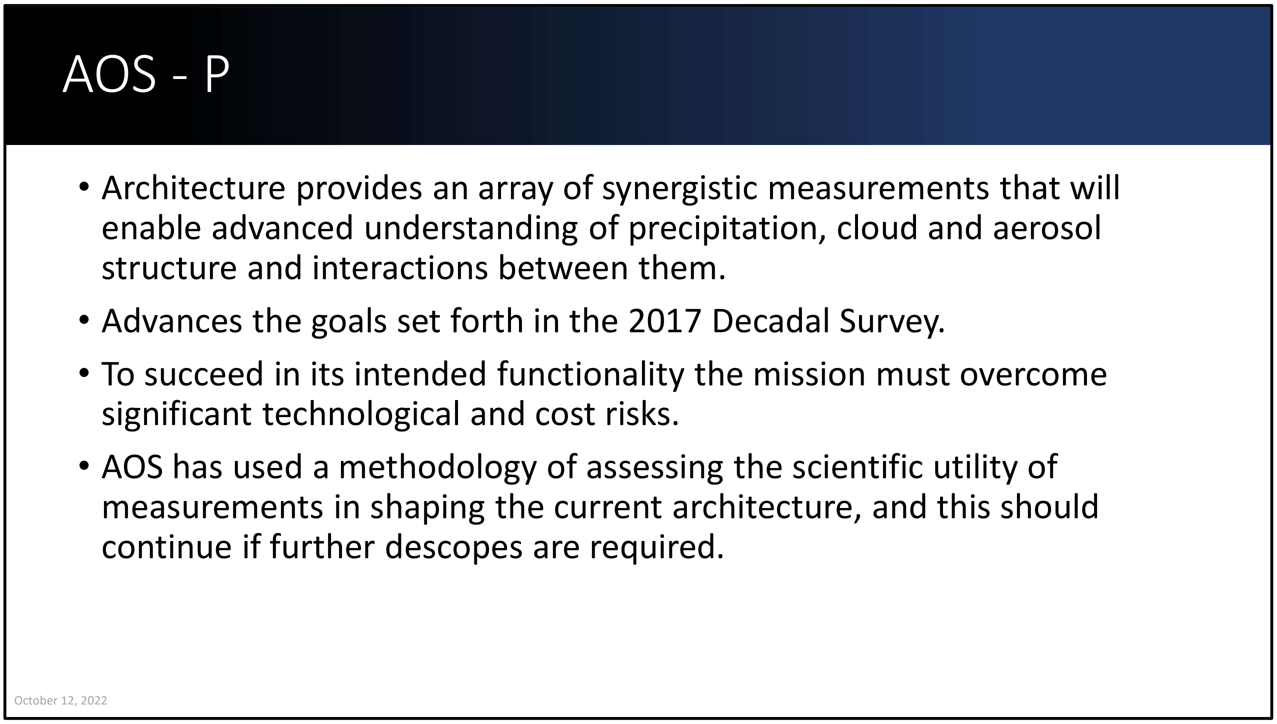
Five First-Evers of AOS

1. Global and Diurnally Varying Observations of Convective Vertical Motions
2. Global Profiles of Aerosol Properties (absorption, type, size)
3. Co-located Dynamics, Cloud and Precipitation Microphysics, Longwave Radiation, and Aerosol Characteristics
4. Short Time-Scale Evolution of Cloud and Precipitation Processes
5. Diurnal Variability of Coincident Cloud, Precipitation, and Aerosol Profiles

October 12, 2022

AOS provides some degree of continuity of past missions like TRMM and GPM and CloudSat and CALIPSO while at the same time accomplishing several key first-ever capabilities as listed here. One first-ever that warrants further highlighting is #3, which speaks to the highly synergistic nature of the measurements, particularly in the polar orbit, that makes the scientific benefit of the whole much greater than the sum of its parts.

The AOS projects provided a sixth “first” which was the first-ever integrated sub-orbital science program that is more robust and structured set of activities than we are currently aware of. The IRB is not certain that this is a “first.” Costs captured in the AOS-I budget.



AOS - P

- Architecture provides an array of synergistic measurements that will enable advanced understanding of precipitation, cloud and aerosol structure and interactions between them.
- Advances the goals set forth in the 2017 Decadal Survey.
- To succeed in its intended functionality the mission must overcome significant technological and cost risks.
- AOS has used a methodology of assessing the scientific utility of measurements in shaping the current architecture, and this should continue if further descopes are required.

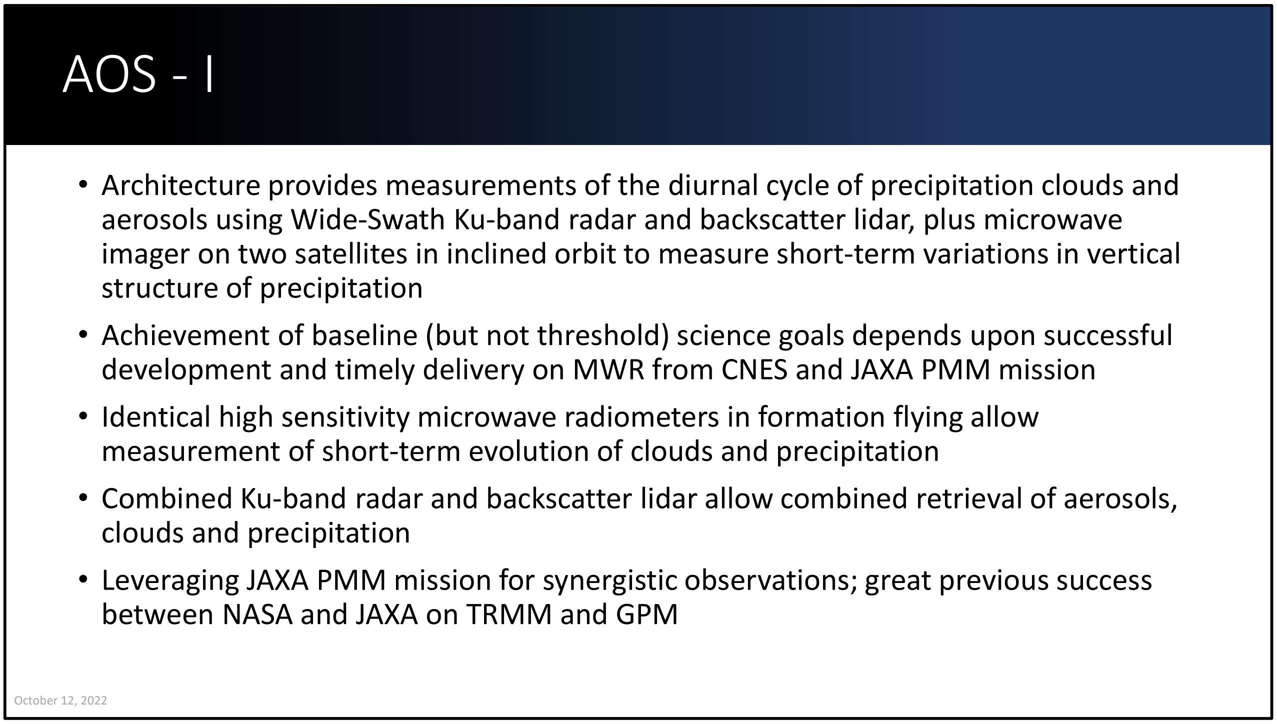
October 12, 2022

AOS, as designed, will provide:

- Significant advances in observation of precipitation and clouds through the synergistic observations from Ka and W Doppler radar, combined with microwave radiometer, HSRL Lidar and Polarimeter.
- Significant advances in observation of aerosol cloud interactions through synergistic observations from HSRL Lidar and Polarimeter.
- New measurements of thin ice clouds and water vapor in cold environments from TICFIRE and SHOW
- New measurements of stratospheric aerosols and water vapor ALI and SHOW.

Dual orbiters are needed to ensure wide array of measurements needed to meet DS objectives

TICFIRE and SHOW are not in the critical path for AOS-P, but will add significant capability at minimal cost to NASA (SHOW is on CSA mission)



AOS - I

- Architecture provides measurements of the diurnal cycle of precipitation clouds and aerosols using Wide-Swath Ku-band radar and backscatter lidar, plus microwave imager on two satellites in inclined orbit to measure short-term variations in vertical structure of precipitation
- Achievement of baseline (but not threshold) science goals depends upon successful development and timely delivery on MWR from CNES and JAXA PMM mission
- Identical high sensitivity microwave radiometers in formation flying allow measurement of short-term evolution of clouds and precipitation
- Combined Ku-band radar and backscatter lidar allow combined retrieval of aerosols, clouds and precipitation
- Leveraging JAXA PMM mission for synergistic observations; great previous success between NASA and JAXA on TRMM and GPM

October 12, 2022

AOS relies on and benefits from numerous international partnerships for some of its key measurements

The science priority employed in the selection of descopes is well-considered.

Lack of details on sub-orbital segment of AOS presents an unclear risk, especially if further descopes are required.

Intersections with AOS-P measurements are also beneficial to enhancing DS science objectives

Such overlap is costed in the budget; the IRB assumes that the project is counting on funding for a more robust overlap with extended missions funding

Program indicated that threshold requirements were fulfilled by the JAXA contribution, but MWR adds important complementary information

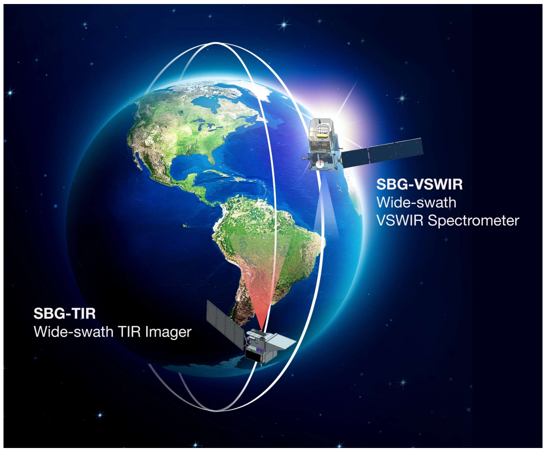
Overlap with PMM is essential (simultaneity of microwave and lidar measurement)

SBG Science

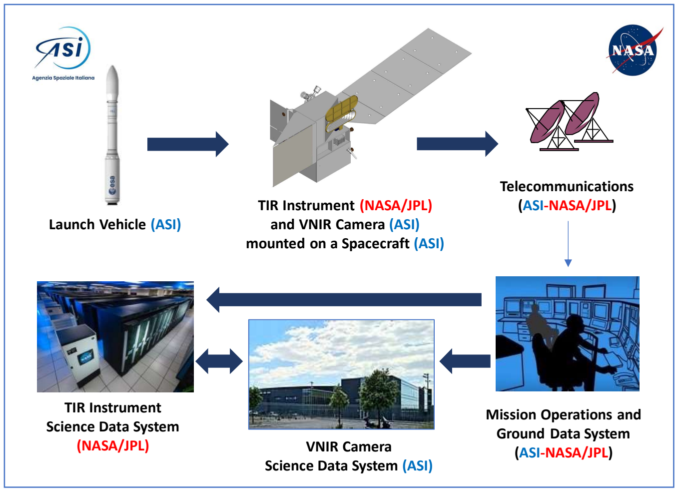
October 12, 2022

Concepts and Capabilities Mapped to DS

- Surface Biology and Geology (SBG) will help answer climate, ecosystems and natural resources, hydrology, solid Earth, and weather-related questions
- Wide-swath Thermal Infrared (TIR) Imager platform, launch in 2027
- Wide-Swath Visible and Short-Wave Infrared (VSWIR) Spectrometer platform, launch in 2028
- Three-year prime mission for each
- Partnership with the Agenzia Spaziale Italiana (ASI) for TIR



SBG TIR Architecture



Launch Vehicle (ASI)

TIR Instrument (NASA/JPL) and VNIR Camera (ASI) mounted on a Spacecraft (ASI)

Telecommunications (ASI-NASA/JPL)

Mission Operations and Ground Data System (ASI-NASA/JPL)

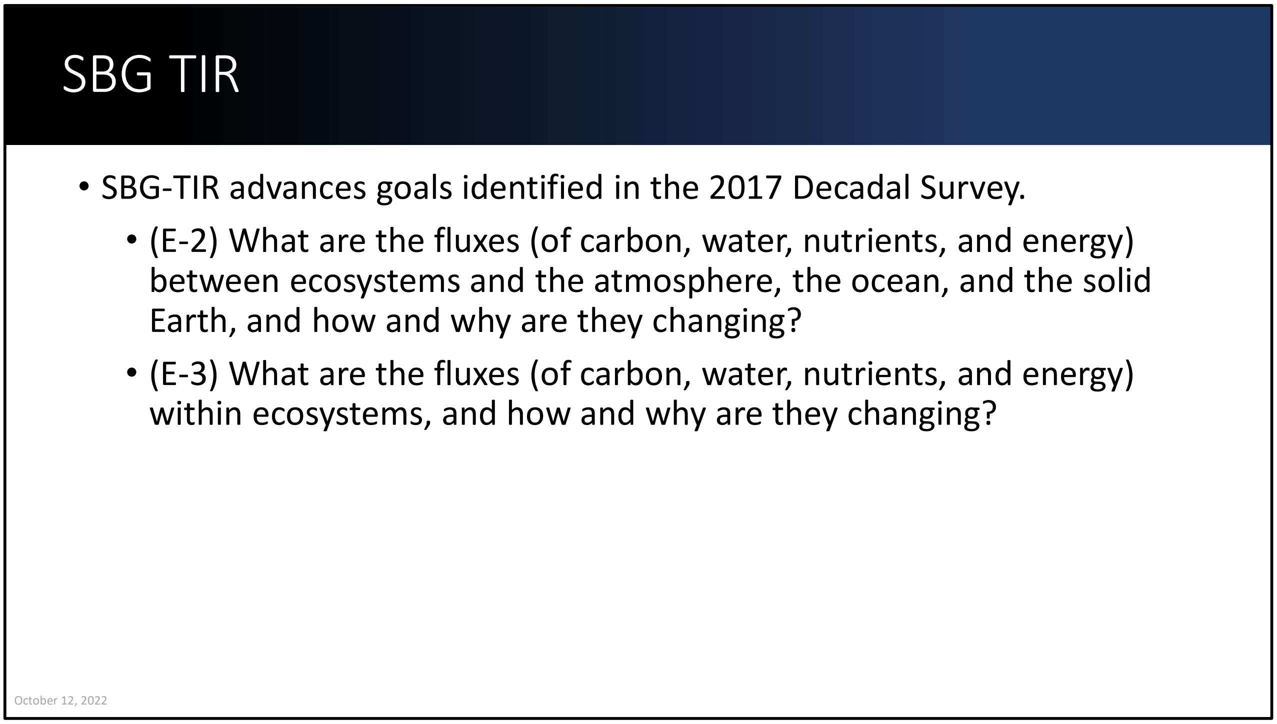
VNIR Camera Science Data System (ASI)

TIR Instrument Science Data System (NASA/JPL)

Legend: 🟥 NASA/JPL 🟦 ASI

Responsibilities/Contributions

- NASA/JPL
  - TIR Instrument
  - Mission System Elements, as appropriate
- ASI
  - Visible and Near-Infrared (VNIR) Camera
  - Spacecraft
  - Launch Vehicle
  - Mission System Elements, as appropriate



SBG TIR

- SBG-TIR advances goals identified in the 2017 Decadal Survey.
  - (E-2) What are the fluxes (of carbon, water, nutrients, and energy) between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?
  - (E-3) What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing?

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The SBG-TIR Architecture provides thermal measurements in sufficient bands and at high spatial resolution to enable greater understanding of the patterns of kinetic temperature and emissivity of the Earth's surface over space and time. SBG-TIR will provide detailed cold temperature data for surface ice and snow in boreal and high elevation regions.

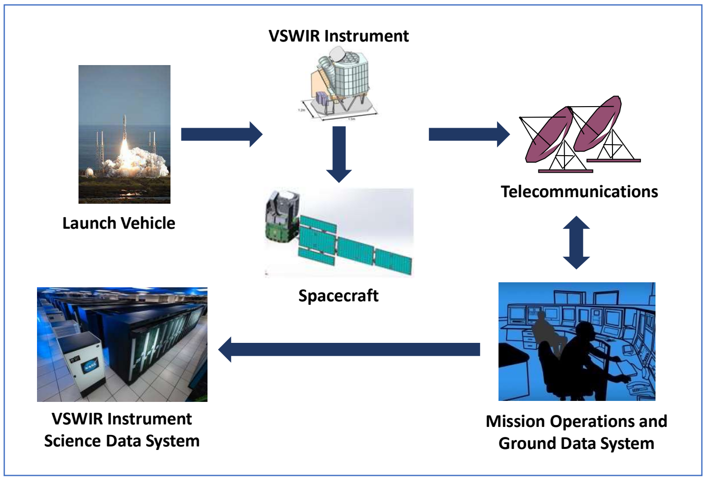
SBG-TIR will collect global information about global patterns of evapotranspiration that will bring greater understanding of the health of the Earth's ecosystem and promote more efficient agriculture while using less water. These data will be synergistic with the AOS-P precipitation data and the MC measurements of changes in deep water storage.

The addition of a MWIR wavelength band will greatly increase accuracy and detection of peak temperature measurements typical of wildfires.

Accurate measurements of evapotranspiration are an important contribution to climate research since a large fraction of terrestrial precipitation returns to the atmosphere through this process.

Accurate temperatures are important for many environmental and societal applications including extreme hot/cold weather, drought, floods and rain on snow events, urban heat islands, water temperature, and temperature ranges for optimal crop production.

SBG VSWIR Architecture



VSWIR Instrument

Launch Vehicle

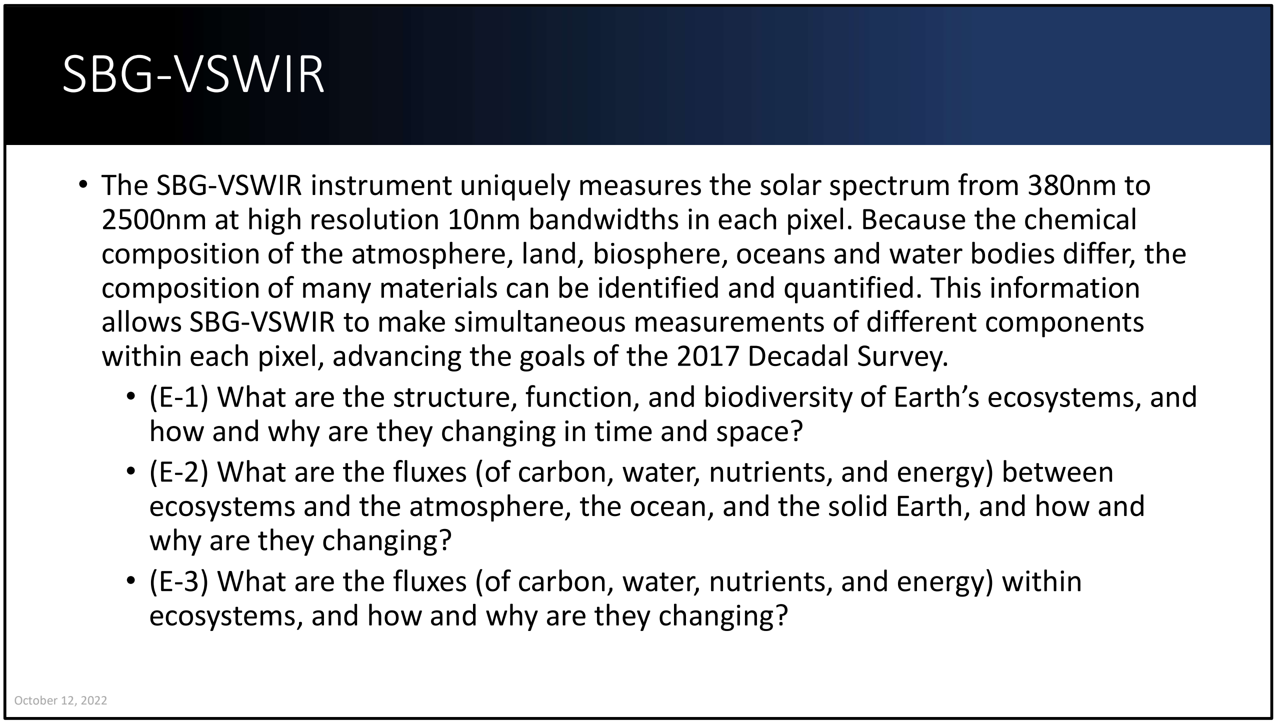
Telecommunications

Spacecraft

VSWIR Instrument
Science Data System

Mission Operations and
Ground Data System

- SBG-VSWIR will be a partnership between NASA and Industry
- >200 spectral bands, 10nm bandwidths, from 380nm-2500nm wavelength interval
- SnR 400 VNIR, 250 SWIR
- 30m spatial resolution, 185 km swath



SBG-VSWIR

- The SBG-VSWIR instrument uniquely measures the solar spectrum from 380nm to 2500nm at high resolution 10nm bandwidths in each pixel. Because the chemical composition of the atmosphere, land, biosphere, oceans and water bodies differ, the composition of many materials can be identified and quantified. This information allows SBG-VSWIR to make simultaneous measurements of different components within each pixel, advancing the goals of the 2017 Decadal Survey.
    - (E-1) What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space?
    - (E-2) What are the fluxes (of carbon, water, nutrients, and energy) between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?
    - (E-3) What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing?

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Mission leverages planning for and coordination with the European Union's CHIME mission of two hyperspectral imaging satellite. Discussing collaboration with AOS for access to aerosol data and possibly use SBG to provide the AOS team with information on surface conditions.

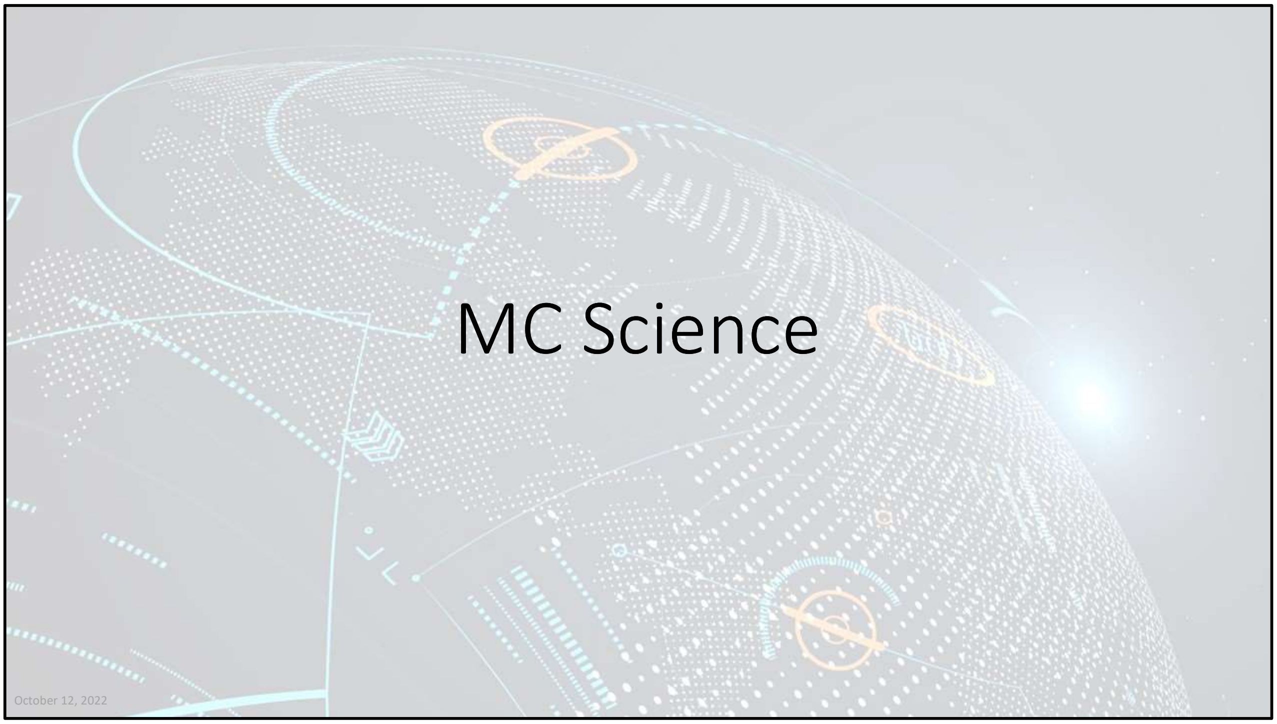
Provides a basis for a wider range of terrestrial plant species and plant communities, wildlife habitats, shallow water algae, and macrophytes to be identified and mapped.

Plant biochemical traits can be quantified and monitored over time, including foliar chlorophyll, nitrogen and water and carbon contents. Measurements of photosynthetic pigments can improve estimates of gross and net photosynthesis.

Accurate measurements of carbon sequestration and respiration are needed to improve global biogeochemical models.

Data can be analyzed using correlative spectral ratio methods to methods driven by the optical properties of the materials, to deep learning statistical methods.

Spectral reflectance is derived from the radiance data using physically based models and the VSWIR data itself, producing more accurate retrieval of spectral reflectance than other methods.



MC Science

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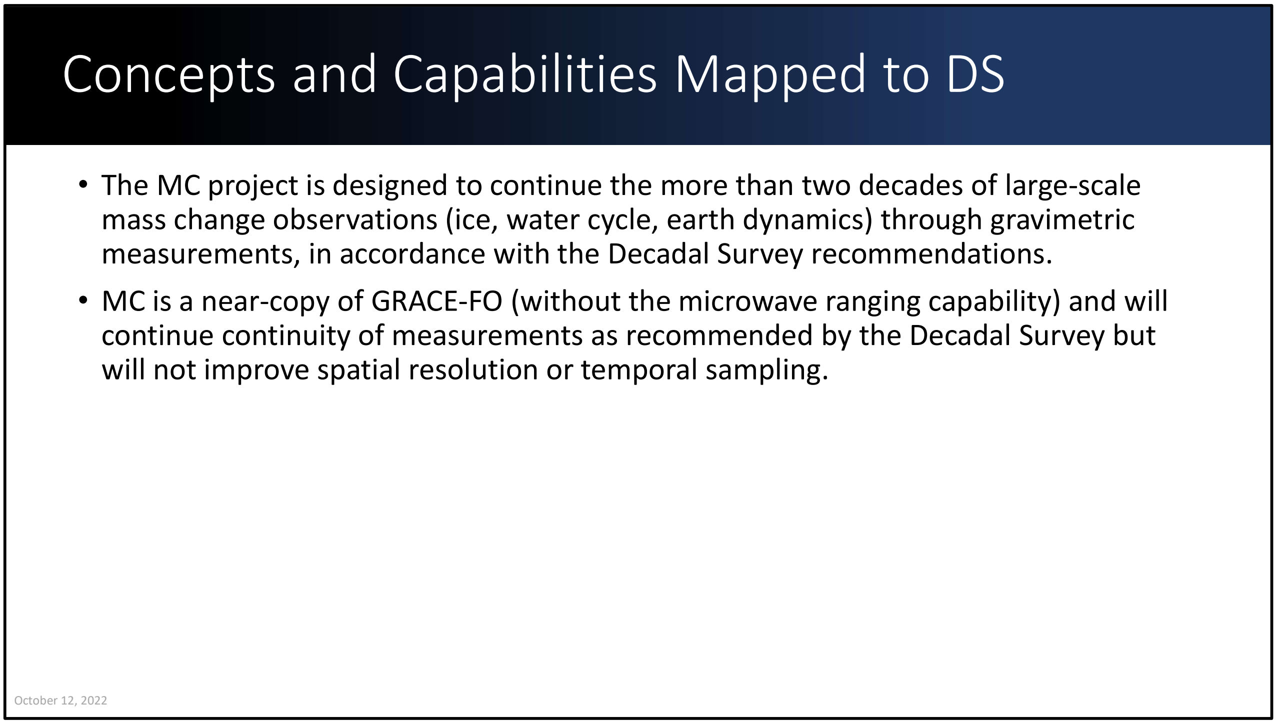

Concepts and Capabilities Mapped to DS

- The MC project is designed to continue the more than two decades of large-scale mass change observations (ice, water cycle, earth dynamics) through gravimetric measurements, in accordance with the Decadal Survey recommendations.
- MC is a near-copy of GRACE-FO (without the microwave ranging capability) and will continue continuity of measurements as recommended by the Decadal Survey but will not improve spatial resolution or temporal sampling.

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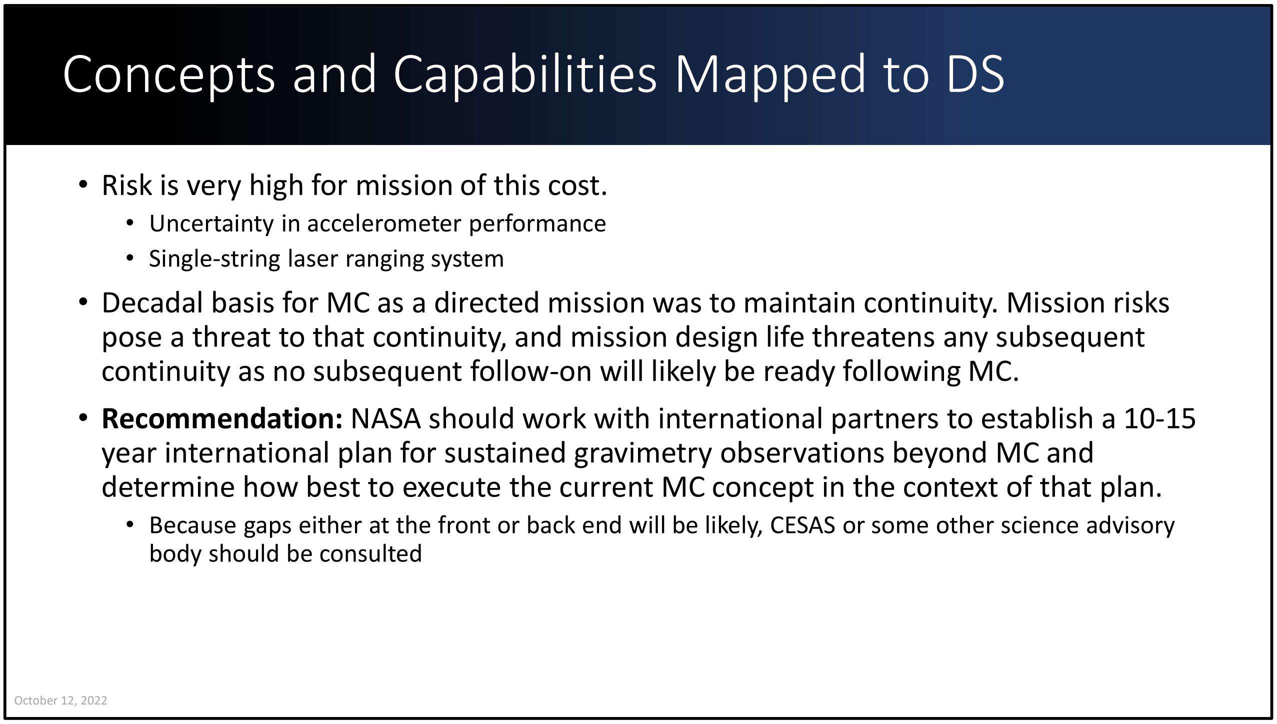
Decadal Survey made clear importance of improved resolution and sampling as a goal of gravimetric measurements from space. MC is regarded as a temporary bridge to that future capability.



Concepts and Capabilities Mapped to DS

- Risk is very high for mission of this cost.
  - Uncertainty in accelerometer performance
  - Single-string laser ranging system
- Decadal basis for MC as a directed mission was to maintain continuity. Mission risks pose a threat to that continuity, and mission design life threatens any subsequent continuity as no subsequent follow-on will likely be ready following MC.
- **Recommendation:** NASA should work with international partners to establish a 10-15 year international plan for sustained gravimetry observations beyond MC and determine how best to execute the current MC concept in the context of that plan.
  - Because gaps either at the front or back end will be likely, CESAS or some other science advisory body should be consulted

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MC should maintain and build relations with ESA for a more integrated, longer-term approach to avoid a gap in the observation.

JPL and Goddard share work-load for the MC; this partitioning is what existed for GRACE-FO.

Being a near copy of GRACE-FO, MC has high TRLS (6-7).

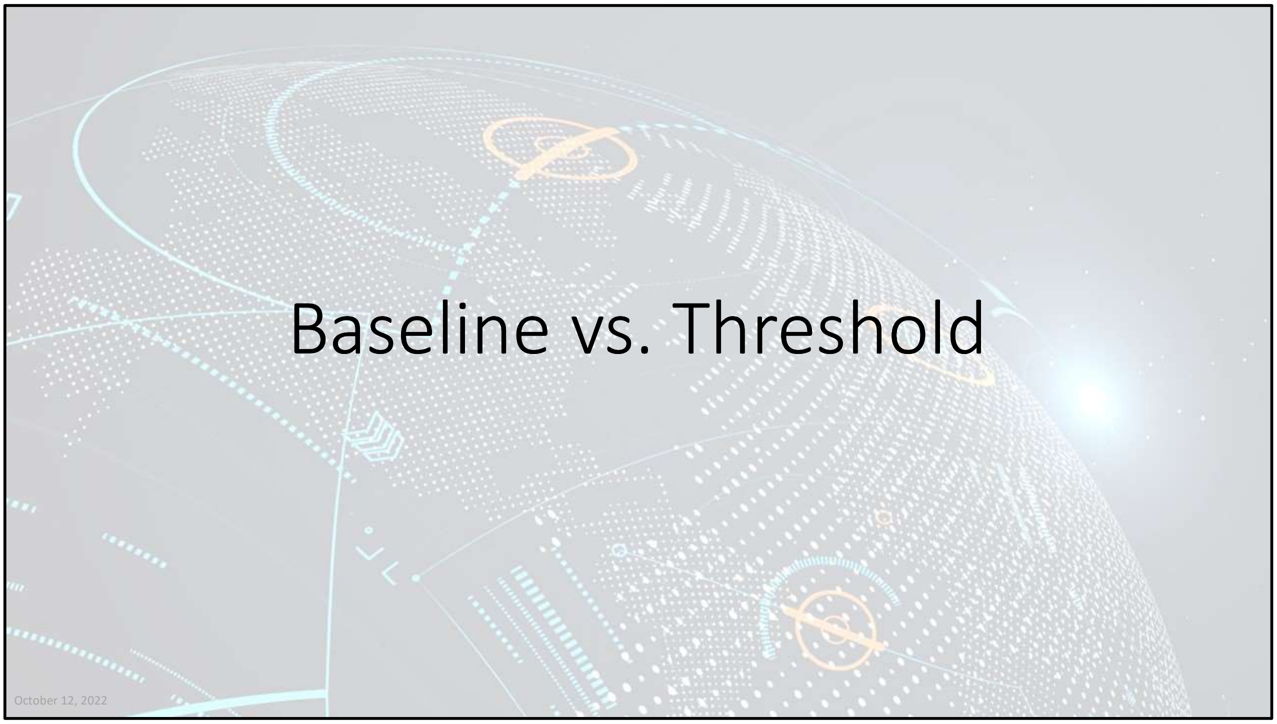
Extensive user community from GRACE and GRACE-FO; community is highly engaged in defining the science requirements.

MC has been given a budget of $368M in FY18 for Phase A-D

It is unlikely that any cost savings can be made via descopes; redundant parts from GRACE-FO are already included

This non-optimal funding significantly increases the risk of failure

A major concern is what happens to gravimetry measurements after MC, if launched ASAP, reaches end of life. Without up-front planning and investment, there will likely be a significant gap following MC, and continuity will be disrupted (or ended). By working with international partners now on a longer-term plan for gravimetry measurements, a longer-term strategy can and should be developed which can allow for an assessment as to whether a near-term gap that leads a more robust sustained program ultimately provides greater benefit and more “continuity” than a near-term launch of the high-risk concept currently under consideration.



Baseline vs. Threshold

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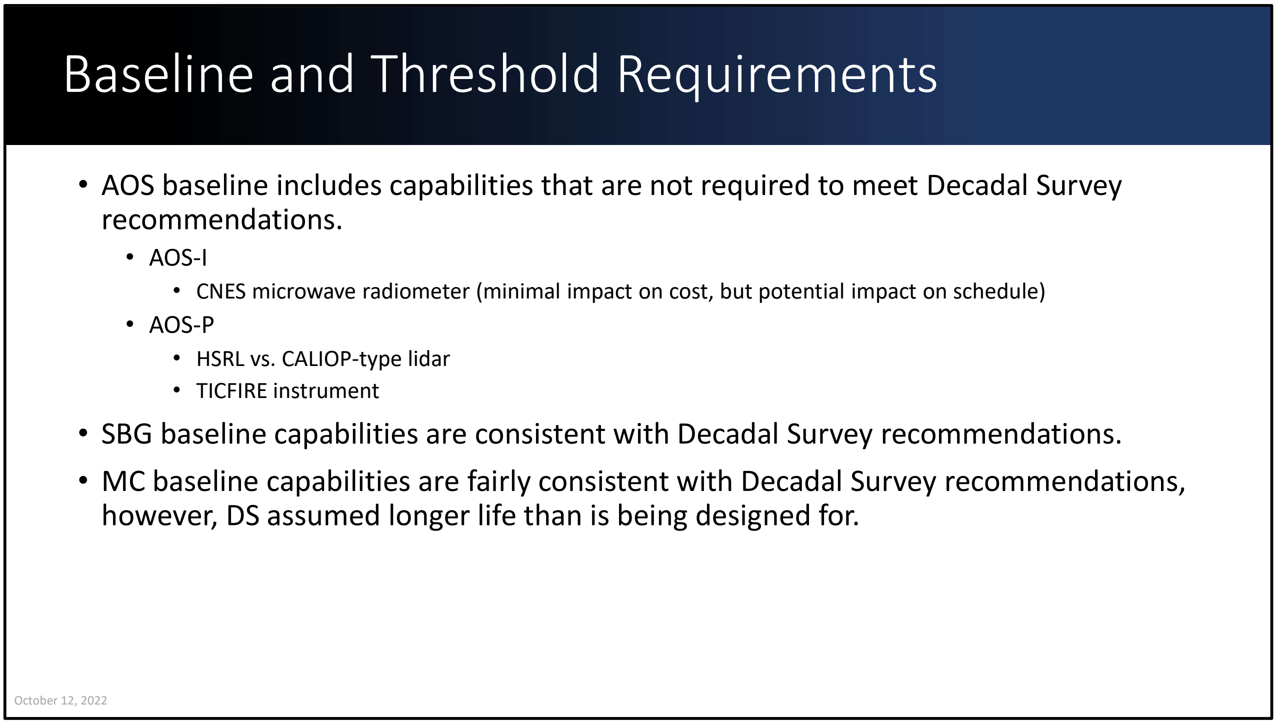
Baseline and Threshold Requirements

- Baseline requirements are those that seek to deliver the desired science objectives and drive the baseline mission design.
- Threshold requirements are those which, if not met, a mission is considered unsuccessful in achieving its objectives, and underly the descoping strategies.
- ESO PALs allowed for establishment of baseline requirements in excess of Decadal Survey minimum requirements, as long as mission costs could be within established caps.
    - Enhanced baseline capabilities allow for more science to be addressed and more of the Decadal Survey's priorities to be addressed.
- SBG and MC baselines align with DS minimum recommendations, while AOS exceeds them.
- Descope options are the reduction from baseline to threshold.
- Finding: Baseline mapping to DS is inconsistent among missions, and threshold mapping to DS is unclear.



Baseline and Threshold Requirements

- AOS baseline includes capabilities that are not required to meet Decadal Survey recommendations.
  - AOS-I
    - CNES microwave radiometer (minimal impact on cost, but potential impact on schedule)
  - AOS-P
    - HSRL vs. CALIOP-type lidar
    - TICFIRE instrument
- SBG baseline capabilities are consistent with Decadal Survey recommendations.
- MC baseline capabilities are fairly consistent with Decadal Survey recommendations, however, DS assumed longer life than is being designed for.

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MWI would likely last longer than LRI

Program Mitigation and Guidance

Some budget mitigation approaches recommended by Decadal Survey are appropriate to employ and have been.

1. First delay large missions: ***delays have already occurred.***
2. Second delay medium-sized Designated missions, unless these delays threaten critical continuity measurements:
   a. ***Surface Deformation and Change (large? medium?)***
   b. ***the Mass Change question about critical continuity***
3. Should continuity be threatened, the cadence of medium-sized competitive missions should be reduced but not to fewer than two competitions in the decade: ***already down to three from the envisioned four***
4. The budgets for Ventures and research and applications should not be reduced by more than 5% from their historical averages: ***not much in relative dollars to capture here***
5. For budget challenges that exceed this capacity, consultation with CESAS is required

Program Mitigation and Guidance

- Even with these measures, there is more than can fit into the Decadal cost box.
  - Should costs be allowed to grow?
    - Decadal says no, but…
    - Cost of doing business is much higher, but…
    - Cost mitigation strategies have already been employed
  - Should we revert to minimum science?
- Is it time to go to CESAS?

Top Findings

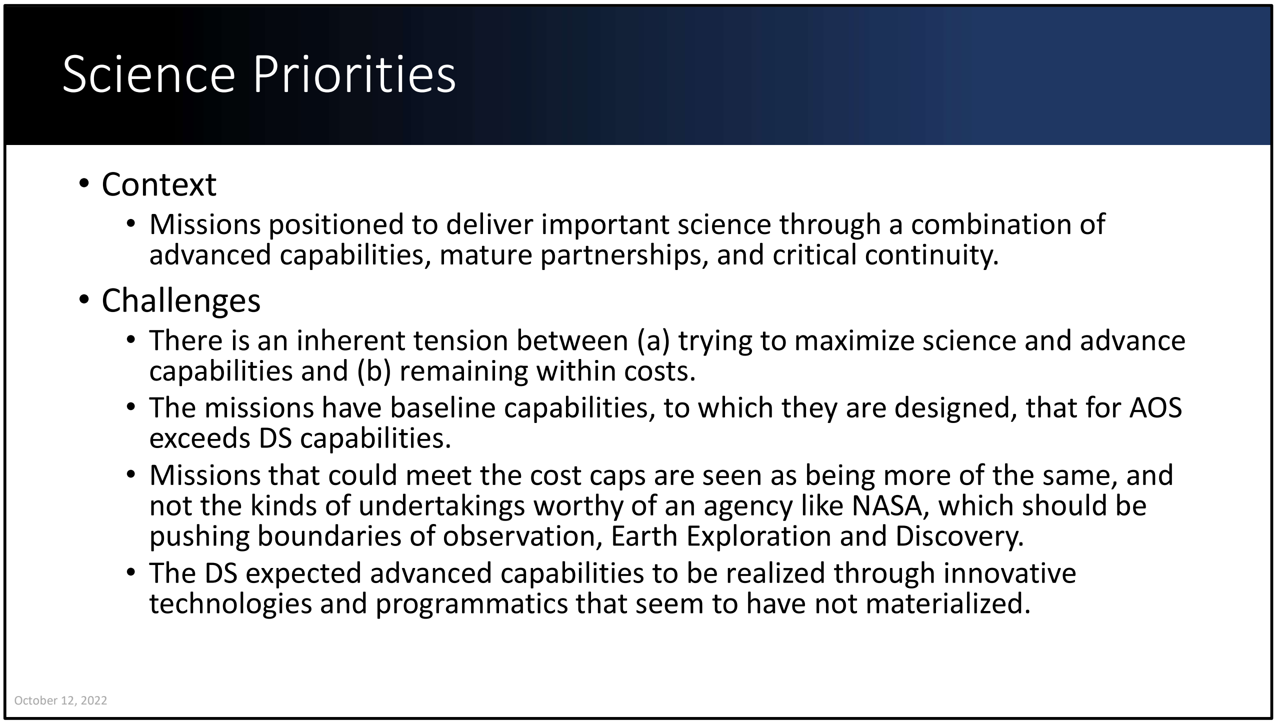
Strengths

- Missions as laid out follow the DS science recommendations and would result in significant science and applications advances
- Data Systems study is focused on the right areas
- The Applied Sciences Program personnel (Program Applications Leads) are actively engaged throughout mission planning

Issues

- ESD management is not structured to support the observatory approach
- Design-to-cost approach challenges programmatics and science capabilities
- Collective IRB cost estimate for AOS, SBG, and MC exceeds the project and DS estimate
- MC approach is a high-risk, single-string, 3-year design life concept with 5-year mission requirement
- Baseline mapping to DS is inconsistent among missions, and threshold mapping to DS is unclear
- AOS-I and –P are not structured for success and should be treated as a single combined mission
- Closer synergy is needed to connect the needs of the science teams, DAACs, and the user community to make ESO data scientifically useful for interdisciplinary science
- Exploring partnership opportunities beyond traditional approaches for sustainability
- Lessons Learned have not been incorporated

Findings and Recommendations – Cross Cutting



Science Priorities

- Context
  - Missions positioned to deliver important science through a combination of advanced capabilities, mature partnerships, and critical continuity.
- Challenges
  - There is an inherent tension between (a) trying to maximize science and advance capabilities and (b) remaining within costs.
  - The missions have baseline capabilities, to which they are designed, that for AOS exceeds DS capabilities.
  - Missions that could meet the cost caps are seen as being more of the same, and not the kinds of undertakings worthy of an agency like NASA, which should be pushing boundaries of observation, Earth Exploration and Discovery.
  - The DS expected advanced capabilities to be realized through innovative technologies and programmatics that seem to have not materialized.

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Science Priorities (cont.)

Implications

- Appear to be presented with one of two choices:
  - Fly more of the same
    - Not innovative but allows the science to be achieved
    - Can bring to bear needed observations in a more timely manner
  - Exceed cost caps
    - Would be acceptable, given that the programmatic landscape is not what it was during ESAS2017
    - Nearly all DS-recommended cost mitigation options have been exercised

Applied Sciences

Context

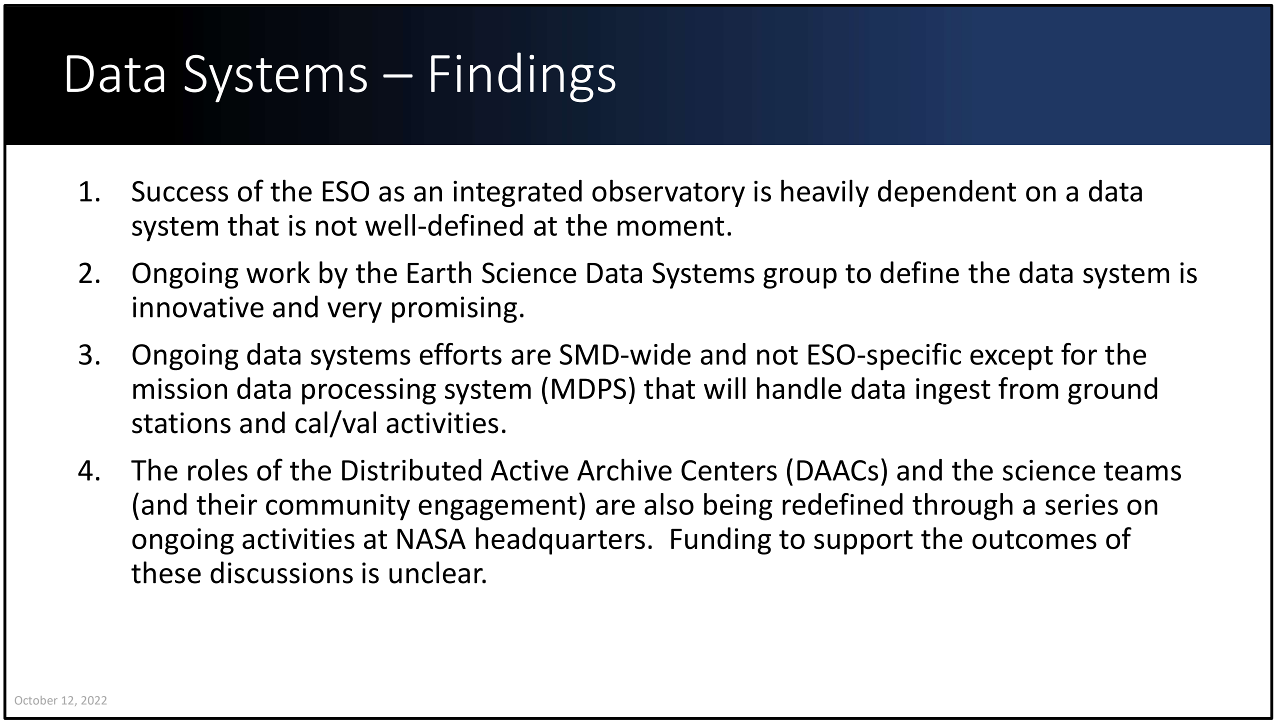
- ESD has entered a new era in which Applied Sciences is robust and a core consideration of mission implementation

Challenges

- Delivering on the full potential of the spectrum of operations opportunities
- Producing data products in forms usable to non-traditional users
- Effective balancing of science needs/interests and applications needs/interests

Implications

- Robust and adaptable data systems and processes needed
- Coordination among missions, science, and products is needed



Data Systems – Findings

1. Success of the ESO as an integrated observatory is heavily dependent on a data system that is not well-defined at the moment.
2. Ongoing work by the Earth Science Data Systems group to define the data system is innovative and very promising.
3. Ongoing data systems efforts are SMD-wide and not ESO-specific except for the mission data processing system (MDPS) that will handle data ingest from ground stations and cal/val activities.
4. The roles of the Distributed Active Archive Centers (DAACs) and the science teams (and their community engagement) are also being redefined through a series on ongoing activities at NASA headquarters. Funding to support the outcomes of these discussions is unclear.

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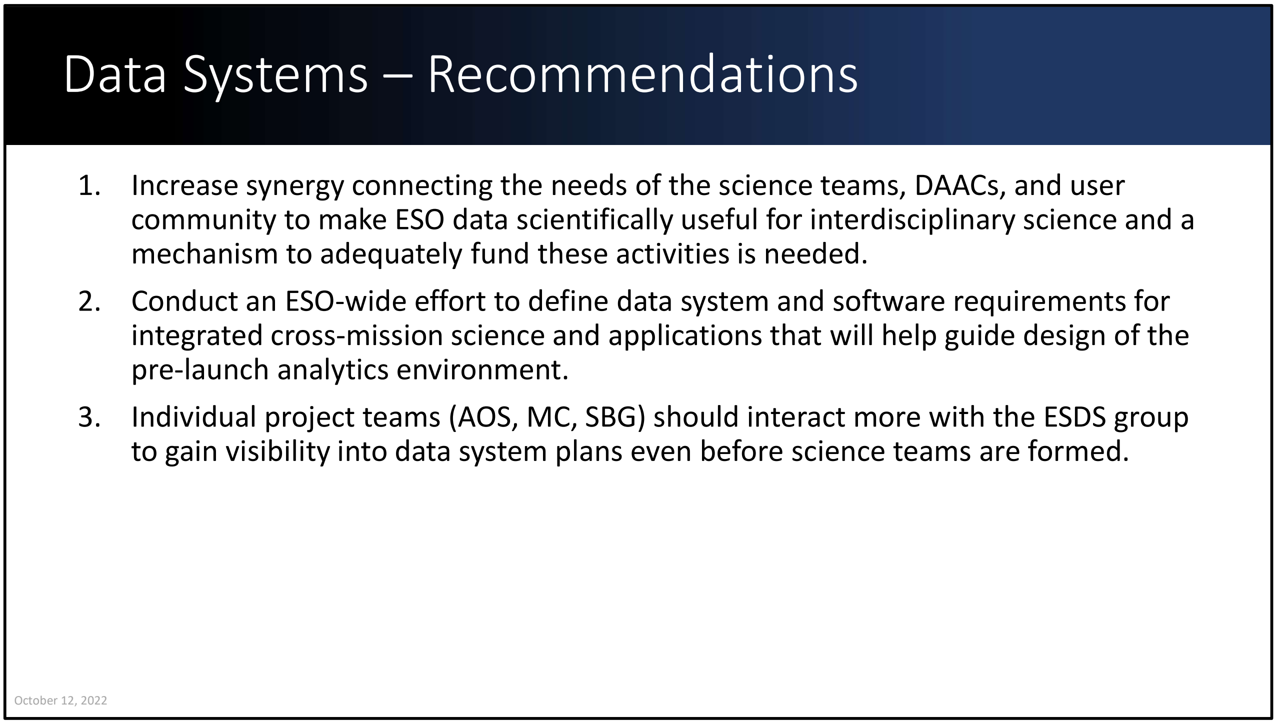
Further ESO-specific data system work is expected at Phase B when science teams are created after an ongoing study to redefine science teams (FESTive) has completed.

The board commends ESDS group on their ongoing efforts to engage the broad community for design inputs, to define a common data processing system for all missions, support of open-source scientific software, community training programs, and work to reimagine how DAACs and science team’s work.



Data Systems – Recommendations

1. Increase synergy connecting the needs of the science teams, DAACs, and user community to make ESO data scientifically useful for interdisciplinary science and a mechanism to adequately fund these activities is needed.
2. Conduct an ESO-wide effort to define data system and software requirements for integrated cross-mission science and applications that will help guide design of the pre-launch analytics environment.
3. Individual project teams (AOS, MC, SBG) should interact more with the ESDS group to gain visibility into data system plans even before science teams are formed.

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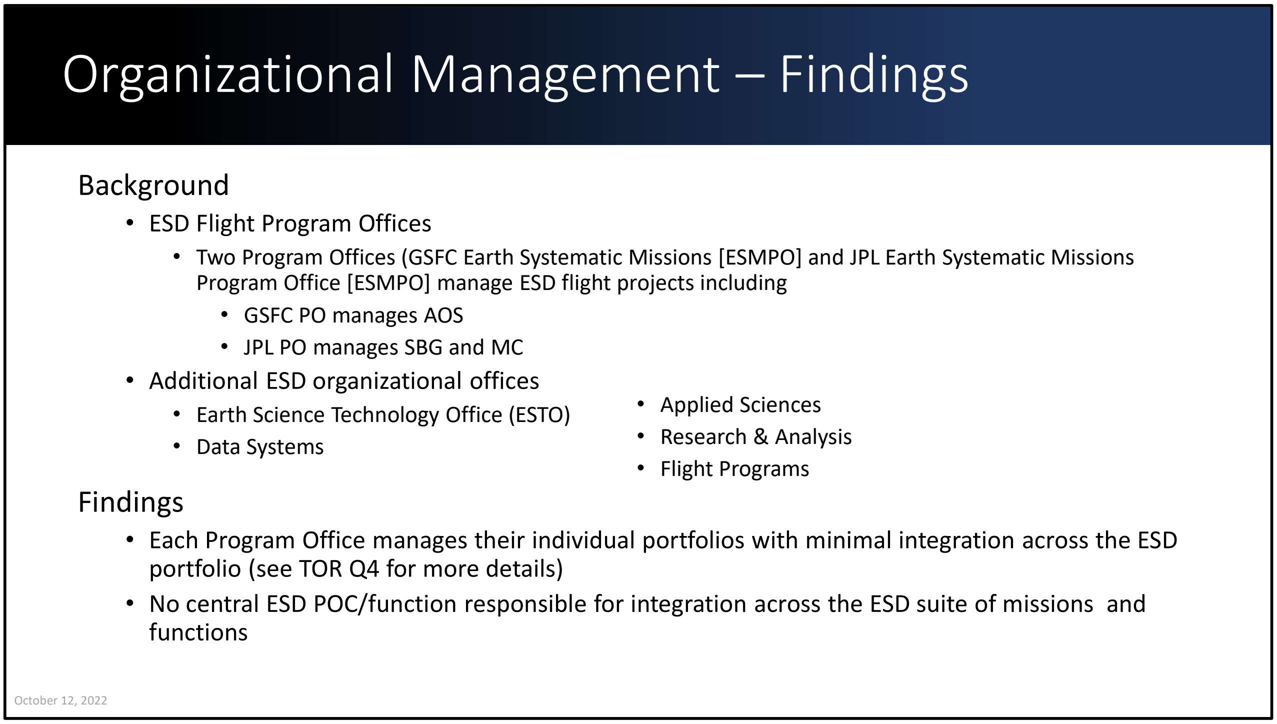

Organizational Management – Findings

Background

- ESD Flight Program Offices
    - Two Program Offices (GSFC Earth Systematic Missions [ESMPO] and JPL Earth Systematic Missions Program Office [ESMPO] manage ESD flight projects including
        - GSFC PO manages AOS
        - JPL PO manages SBG and MC
- Additional ESD organizational offices
    - Earth Science Technology Office (ESTO)
    - Data Systems
    - Applied Sciences
    - Research & Analysis
    - Flight Programs

Findings

- Each Program Office manages their individual portfolios with minimal integration across the ESD portfolio (see TOR Q4 for more details)
- No central ESD POC/function responsible for integration across the ESD suite of missions and functions

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The IRB recommends clarifying lines of authority, communication, integration, and function within ESD including consideration of an ESD Program Scientist/Program Executive/Data Czar to help surface application requirements, functions that connects the dots between science teams and specific ROSES and Technology offices, etc. The consideration should also include someone designated within ESD to review plans, descopes, launch schedules, etc. from a systems level perspective for the overall observatory.

The data system is where most users will interact with the program as a system and this is where the scope, schedule, and timing of these platforms will determine how well the data can be used and by whom.

Organizational Management – Recommendations

Recommendations

- Perform an assessment to determine the optimum solution for integrating the missions into a coherent ESD observatory structure. Clearly define roles of each step to avoid issues as identified in the WFIRST lessons learned.
  - Considerations include:
    - POC(s) (possibly a PS and PE, Czar) looking across the entire ESD flight portfolio
    - Establishment of a Directors Of forum: Data systems, Flight Programs, Research and Analysis, Applied Sciences (ESTO) and the two Program Office Managers (GSFC and JPL) to form an ESD Integration panel (name and scope TBD) which meets, at a minimum, quarterly for cross discipline discussions including vision planning

Findings and Recommendations – Funding

Findings

- ESO Project estimates for AOS, SBG, and MC match their required totals and funding profile, but IRB analysis shows some areas of concern
    - High risk in the selected MC implementation (residual GFO ACCs, single string)
    - AOS costs may be too low for PM/SE/MA, System I&T, and Phase E
    - IRB estimates exceed planned funding levels by $31M in FY26 growing to $508M by FY34
- Current budget does not support the additional funding necessary to improve the solution for the MC Accelerometers and adding some redundancy

Recommendations

- Options to reduce funding requirements include
    - Potential contracting efficiencies between AOS-I and AOS-P
    - Modifications to enable/enhance AOS s/c commonality
    - Additional partnerships; larger international partner role
    - Use descopes; however, these options appear very limited

Findings and Recommendations
Responses to TOR Questions

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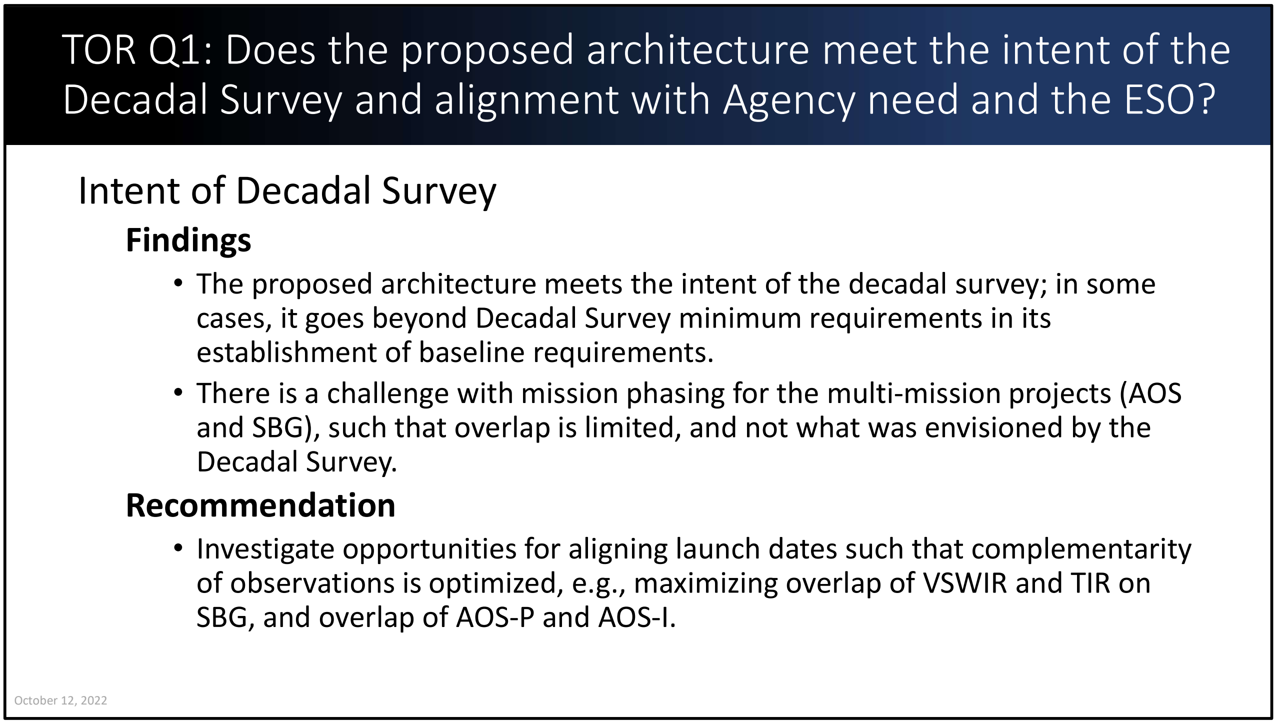

TOR Q1: Does the proposed architecture meet the intent of the Decadal Survey and alignment with Agency need and the ESO?

Intent of Decadal Survey

Findings

- The proposed architecture meets the intent of the decadal survey; in some cases, it goes beyond Decadal Survey minimum requirements in its establishment of baseline requirements.
- There is a challenge with mission phasing for the multi-mission projects (AOS and SBG), such that overlap is limited, and not what was envisioned by the Decadal Survey.

Recommendation

- Investigate opportunities for aligning launch dates such that complementarity of observations is optimized, e.g., maximizing overlap of VSWIR and TIR on SBG, and overlap of AOS-P and AOS-I.

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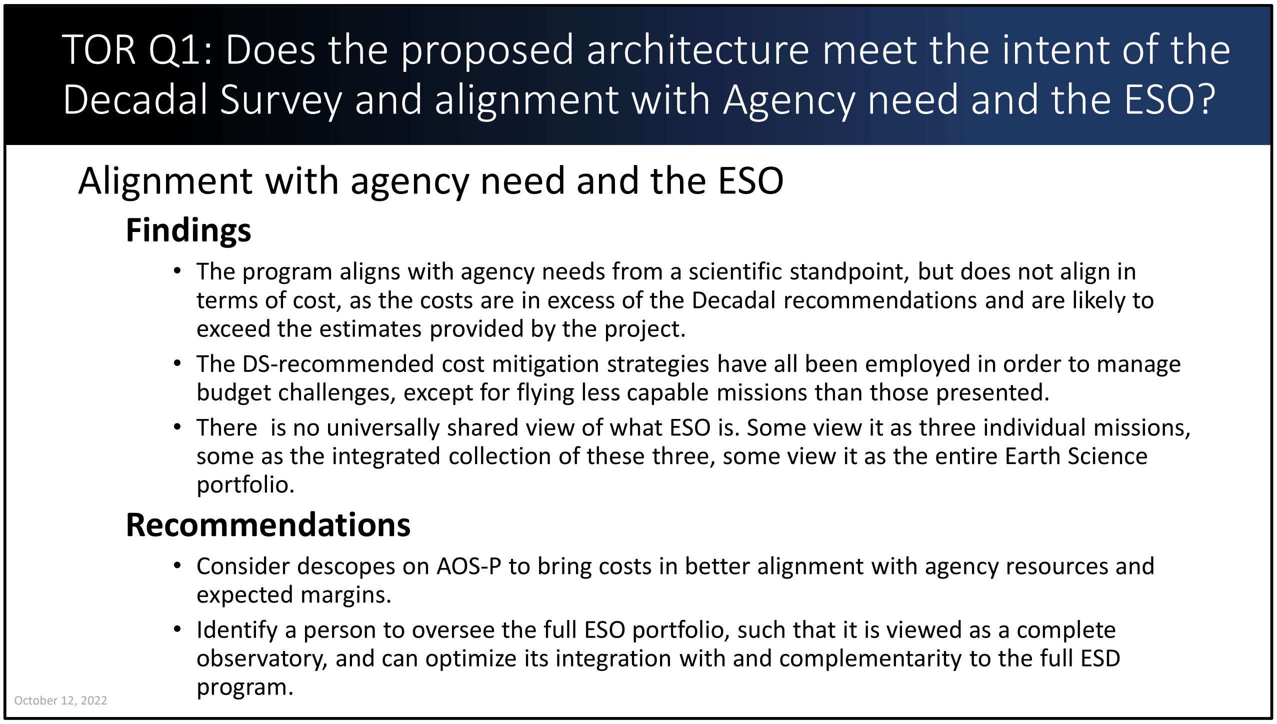
There was shared agreement that the architecture will meet the DS recommendations, and in some cases exceed them, but the cost challenges and optimism are such that the ability to execute at cost and on schedule are significantly unlikely. The design-to-cost approach used by the projects to include as much as possible within cost cap (by some estimates) has AOS designed to exceed the threshold missions and there are opportunities for descoping AOS-P. These are presented in response to question 2e.



TOR Q1: Does the proposed architecture meet the intent of the Decadal Survey and alignment with Agency need and the ESO?

Alignment with agency need and the ESO

Findings

- The program aligns with agency needs from a scientific standpoint, but does not align in terms of cost, as the costs are in excess of the Decadal recommendations and are likely to exceed the estimates provided by the project.
- The DS-recommended cost mitigation strategies have all been employed in order to manage budget challenges, except for flying less capable missions than those presented.
- There is no universally shared view of what ESO is. Some view it as three individual missions, some as the integrated collection of these three, some view it as the entire Earth Science portfolio.

Recommendations

- Consider descopes on AOS-P to bring costs in better alignment with agency resources and expected margins.
- Identify a person to oversee the full ESO portfolio, such that it is viewed as a complete observatory, and can optimize its integration with and complementarity to the full ESD program.

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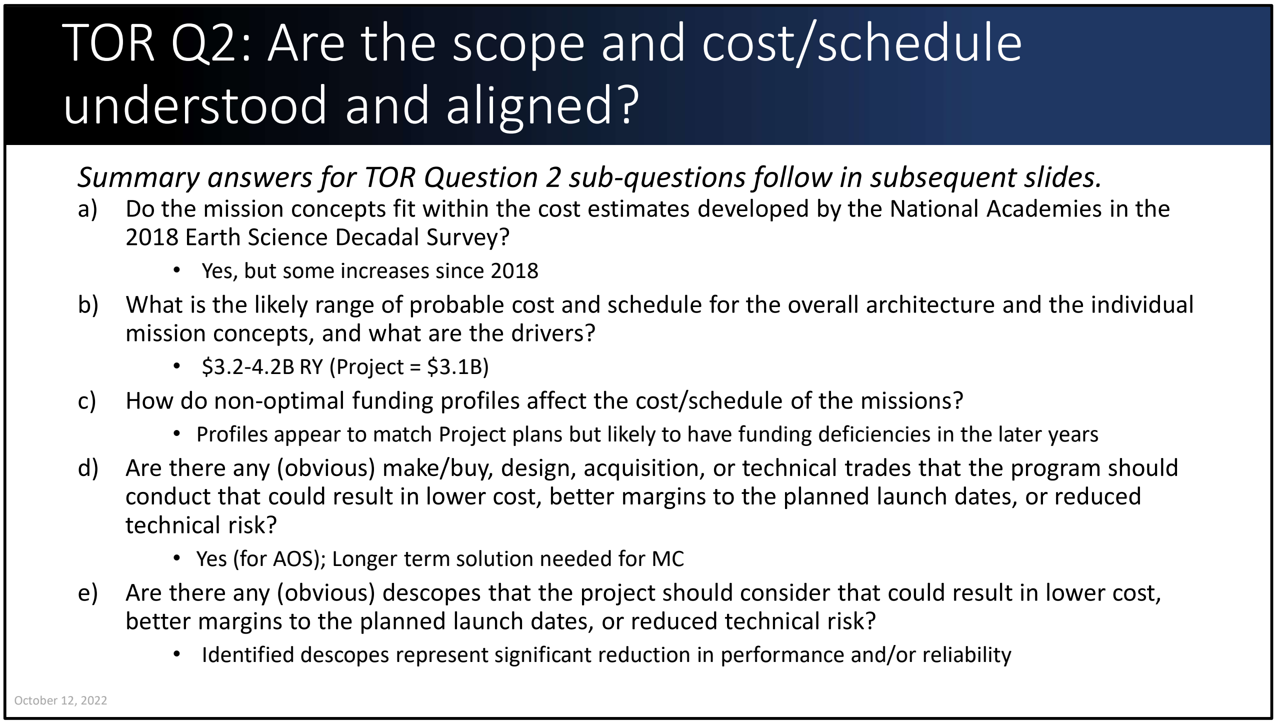
Cost issues are discussed in more detail in response to Question 2. There have been pressures leading to this, e.g., COVID and supply-chain issues, but the fact is that costs are higher than envisioned and will likely not be met.



TOR Q2: Are the scope and cost/schedule understood and aligned?

Summary answers for TOR Question 2 sub-questions follow in subsequent slides.

a) Do the mission concepts fit within the cost estimates developed by the National Academies in the 2018 Earth Science Decadal Survey?
   - Yes, but some increases since 2018

b) What is the likely range of probable cost and schedule for the overall architecture and the individual mission concepts, and what are the drivers?
   - $3.2-4.2B RY (Project = $3.1B)

c) How do non-optimal funding profiles affect the cost/schedule of the missions?
   - Profiles appear to match Project plans but likely to have funding deficiencies in the later years

d) Are there any (obvious) make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?
   - Yes (for AOS); Longer term solution needed for MC

e) Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?
   - Identified descopes represent significant reduction in performance and/or reliability

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For a) Yes, but at high risk

Underlying reasons for answers on previous slide.

a. Impacts from COVID, supply chain disruptions, and inflation were not included in the somewhat lower 2018 Earth Science Decadal Survey estimates

b. Combined costs for AOS, SBG, and MC likely 10-30% higher than current Project estimates

Combined Project Total = $3.1B; IRB Estimate = $3.6B

Difference mostly from AOS

c. Requested funding profiles appear reasonable through FY25, but efforts supporting System I&T and Phase E costs are likely to not ramp-down as far as Project estimates reflect

d. Concerns with current plans include:

Lost efficiencies from having two separate s/c procurements for AOS-I and AOS-P

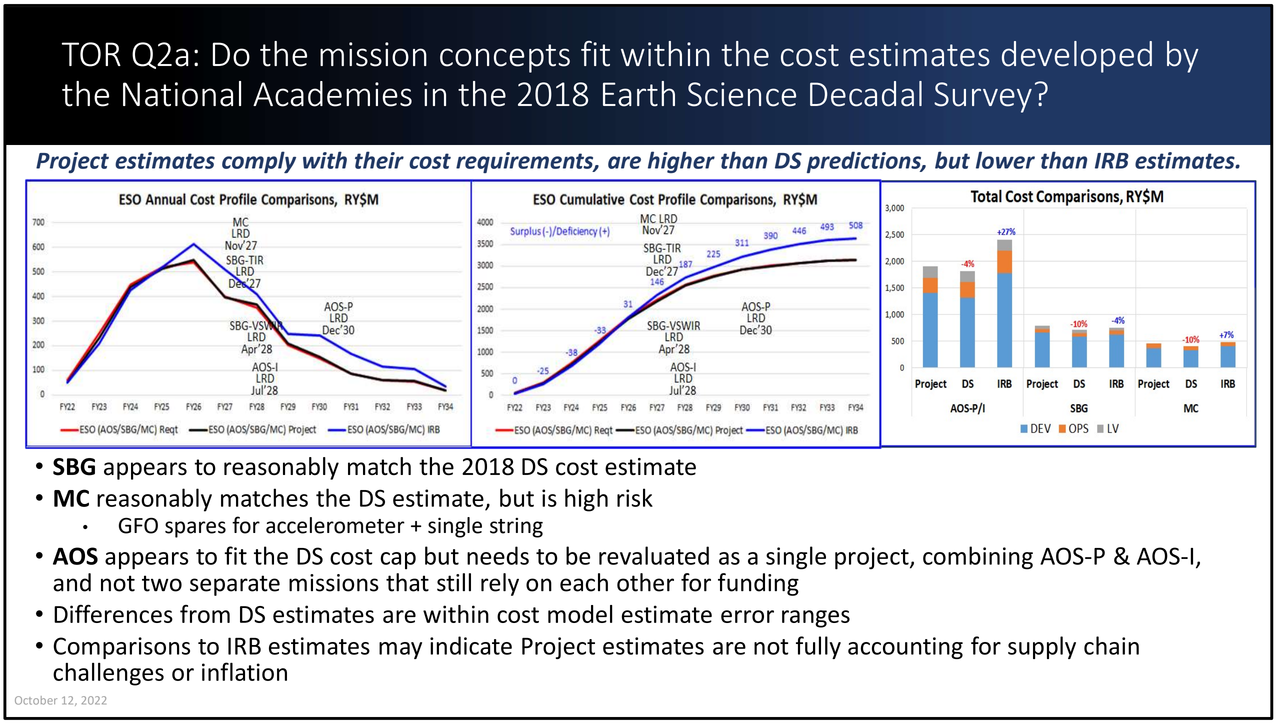
MC should reengage with ESA for a more integrated longer-term approach to avoiding a gap in the future

Planned LRDs seem reasonable; however, any changes are likely to move LRDs out

e. Limited options for descoping exist in current plans

Relatively short Phase E durations for Primary Missions (2-3 years except 5 years for MC)

Many elements are single-string



TOR Q2a: Do the mission concepts fit within the cost estimates developed by the National Academies in the 2018 Earth Science Decadal Survey?

Project estimates comply with their cost requirements, are higher than DS predictions, but lower than IRB estimates.

- **SBG** appears to reasonably match the 2018 DS cost estimate
- **MC** reasonably matches the DS estimate, but is high risk
  - GFO spares for accelerometer + single string
- **AOS** appears to fit the DS cost cap but needs to be revaluated as a single project, combining AOS-P & AOS-I, and not two separate missions that still rely on each other for funding
- Differences from DS estimates are within cost model estimate error ranges
- Comparisons to IRB estimates may indicate Project estimates are not fully accounting for supply chain challenges or inflation

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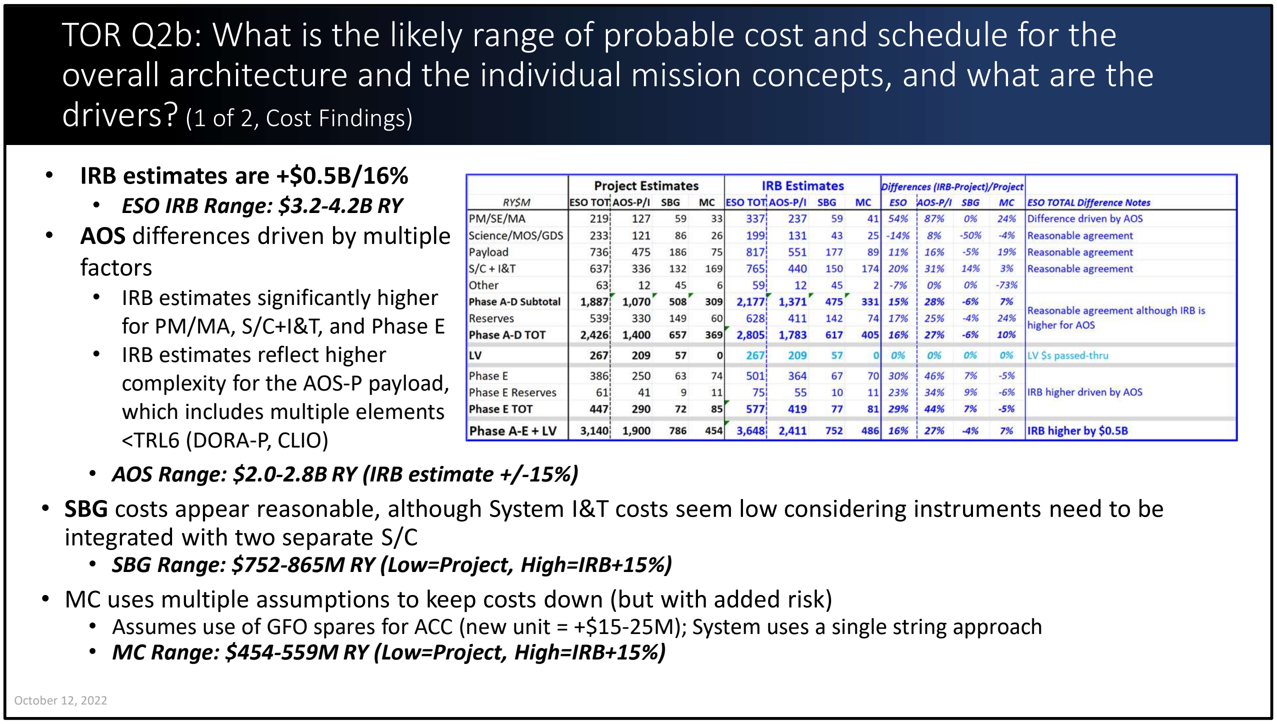
Decadal Survey cost was for Phase A-D; Above graphs assume Phase E is as the projects identified – the Projects' Phase E was added to the Decadal Survey's A-D.

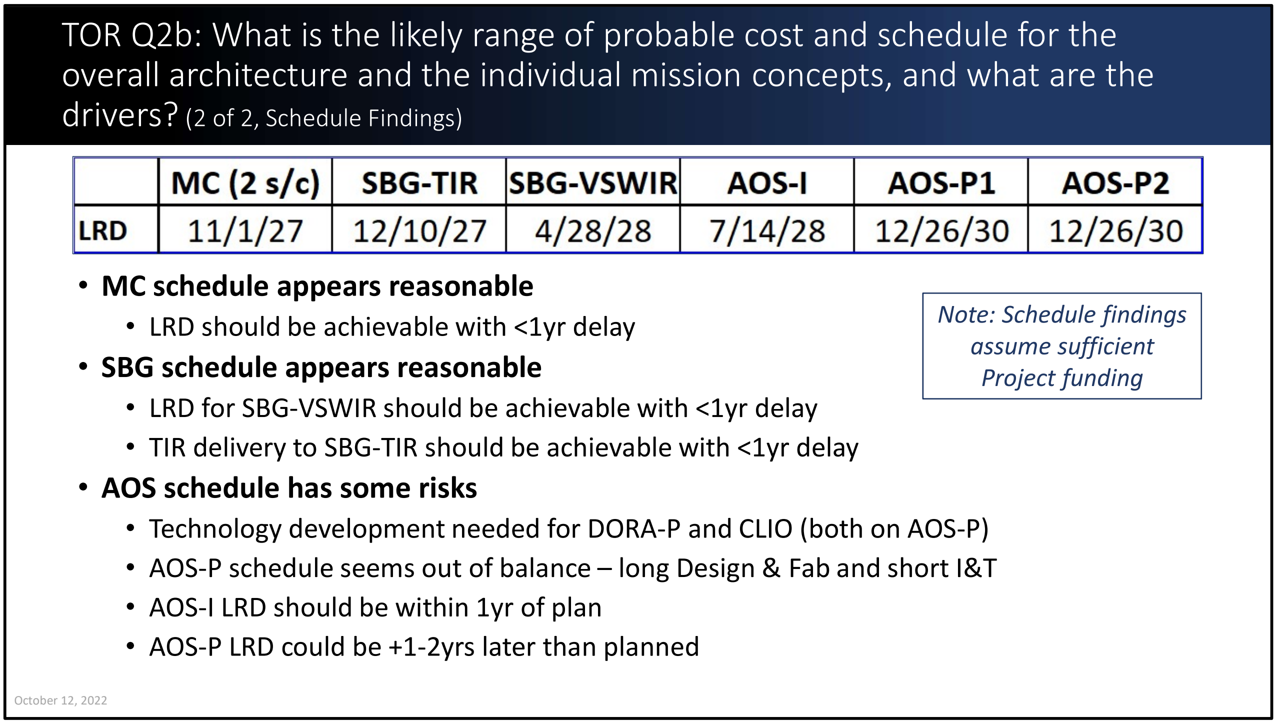


TOR Q2b: What is the likely range of probable cost and schedule for the overall architecture and the individual mission concepts, and what are the drivers? (1 of 2, Cost Findings)

- **IRB estimates are +$0.5B/16%**
  - ***ESO IRB Range: $3.2-4.2B RY***
- **AOS** differences driven by multiple factors
  - IRB estimates significantly higher for PM/MA, S/C+I&T, and Phase E
  - IRB estimates reflect higher complexity for the AOS-P payload, which includes multiple elements <TRL6 (DORA-P, CLIO)
  - ***AOS Range: $2.0-2.8B RY (IRB estimate +/-15%)***

	Project Estimates				IRB Estimates				*Differences (IRB-Project)/Project*				
RY$M	ESO TOT	AOS-P/I	SBG	MC	ESO TOT	AOS-P/I	SBG	MC	*ESO*	*AOS-P/I*	*SBG*	*MC*	*ESO TOTAL Difference Notes*
PM/SE/MA	219	127	59	33	337	237	59	41	*54%*	*87%*	*0%*	*24%*	Difference driven by AOS
Science/MOS/GDS	233	121	86	26	199	131	43	25	*-14%*	*8%*	*-50%*	*-4%*	Reasonable agreement
Payload	736	475	186	75	817	551	177	89	*11%*	*16%*	*-5%*	*19%*	Reasonable agreement
S/C + I&T	637	336	132	169	765	440	150	174	*20%*	*31%*	*14%*	*3%*	Reasonable agreement
Other	63	12	45	6	59	12	45	2	*-7%*	*0%*	*0%*	*-73%*	
Phase A-D Subtotal	**1,887**	**1,070**	**508**	**309**	**2,177**	**1,371**	**475**	**331**	***15%***	***28%***	***-6%***	***7%***	Reasonable agreement although IRB is higher for AOS
Reserves	539	330	149	60	628	411	142	74	*17%*	*25%*	*-4%*	*24%*	
Phase A-D TOT	**2,426**	**1,400**	**657**	**369**	**2,805**	**1,783**	**617**	**405**	***16%***	***27%***	***-6%***	***10%***	
LV	**267**	**209**	**57**	**0**	267	209	57	0	*0%*	*0%*	*0%*	*0%*	LV $s passed-thru
Phase E	386	250	63	74	501	364	67	70	*30%*	*46%*	*7%*	*-5%*	IRB higher driven by AOS
Phase E Reserves	61	41	9	11	75	55	10	11	*23%*	*34%*	*9%*	*-6%*	
Phase E TOT	**447**	**290**	**72**	**85**	**577**	**419**	**77**	**81**	***29%***	***44%***	***7%***	***-5%***	
Phase A-E + LV	**3,140**	**1,900**	**786**	**454**	**3,648**	**2,411**	**752**	**486**	***16%***	***27%***	***-4%***	***7%***	**IRB higher by $0.5B**

- **SBG** costs appear reasonable, although System I&T costs seem low considering instruments need to be integrated with two separate S/C
  - ***SBG Range: $752-865M RY (Low=Project, High=IRB+15%)***
- MC uses multiple assumptions to keep costs down (but with added risk)
  - Assumes use of GFO spares for ACC (new unit = +$15-25M); System uses a single string approach
  - ***MC Range: $454-559M RY (Low=Project, High=IRB+15%)***



TOR Q2b: What is the likely range of probable cost and schedule for the overall architecture and the individual mission concepts, and what are the drivers? (2 of 2, Schedule Findings)

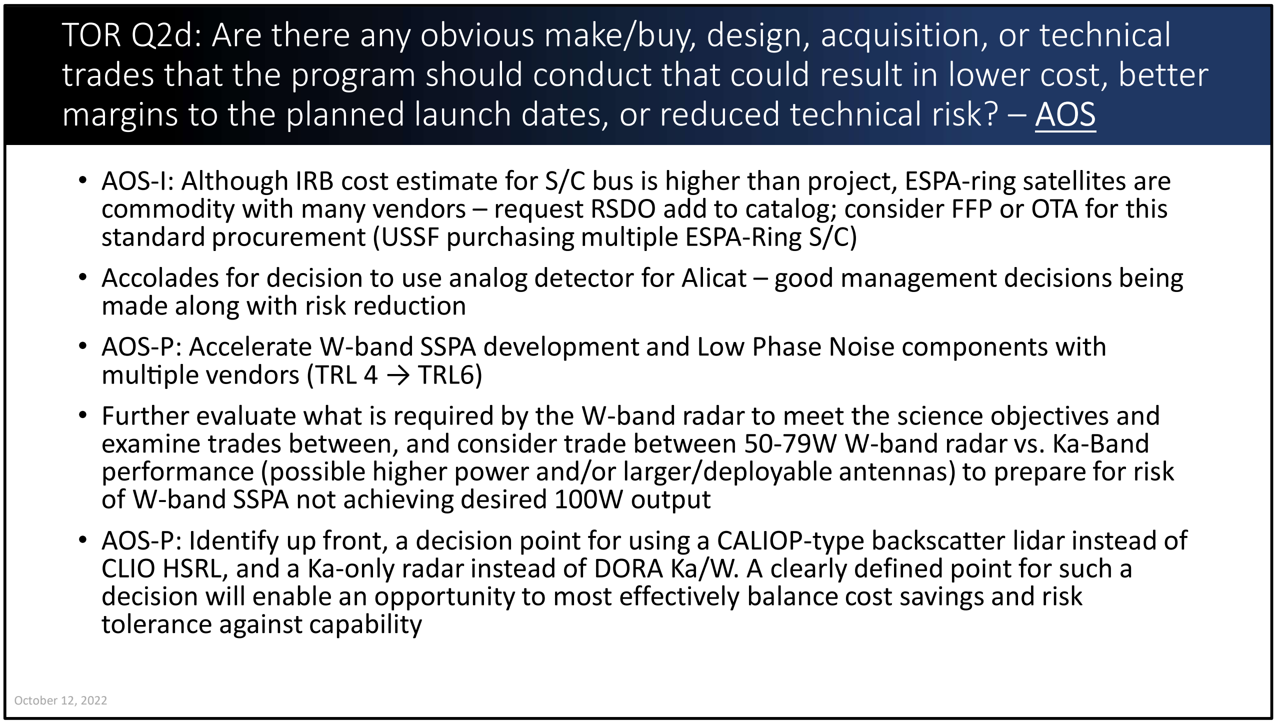
	MC (2 s/c)	SBG-TIR	SBG-VSWIR	AOS-I	AOS-P1	AOS-P2
LRD	11/1/27	12/10/27	4/28/28	7/14/28	12/26/30	12/26/30

Note: Schedule findings assume sufficient Project funding

- **MC schedule appears reasonable**
  - LRD should be achievable with <1yr delay
- **SBG schedule appears reasonable**
  - LRD for SBG-VSWIR should be achievable with <1yr delay
  - TIR delivery to SBG-TIR should be achievable with <1yr delay
- **AOS schedule has some risks**
  - Technology development needed for DORA-P and CLIO (both on AOS-P)
  - AOS-P schedule seems out of balance – long Design & Fab and short I&T
  - AOS-I LRD should be within 1yr of plan
  - AOS-P LRD could be +1-2yrs later than planned

TOR Q2c: How do non-optimum funding profiles affect the cost/schedule of the missions?

- The overall work alignment is properly phased when each element of the program is treated as an individual project without constraints that naturally arise due to either technical or programmatic interaction.
- The funding peak in FY25 and FY26 due to parallel workflow and phasing is probably not possible given supply chain issues and staffing shortages.
- The most likely scenario due to the planned peak in FY25 and FY26 will be a slip to the right that will impact both work efficiency and cost.
- The slip discussed above will almost certainly affect more than one mission with a resulting ripple effect that could cost more than following a less aggressive strategy that addresses the parallel phasing issue.
- An additional outcome of the aggressive strategy will be a need for larger UFE in the peak years since all projects will likely have large parallel demands rather than distributed phased demands on reserve funding.
- Given their impact on the near-term funding profile and on the funding tail in the out years, the AOS-I and AOS-P projects could potentially benefit by organizing and aligning development as an integrated project rather than as independent projects.



TOR Q2d: Are there any obvious make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – AOS

- AOS-I: Although IRB cost estimate for S/C bus is higher than project, ESPA-ring satellites are commodity with many vendors – request RSDO add to catalog; consider FFP or OTA for this standard procurement (USSF purchasing multiple ESPA-Ring S/C)
- Accolades for decision to use analog detector for Alicat – good management decisions being made along with risk reduction
- AOS-P: Accelerate W-band SSPA development and Low Phase Noise components with multiple vendors (TRL 4 → TRL6)
- Further evaluate what is required by the W-band radar to meet the science objectives and examine trades between, and consider trade between 50-79W W-band radar vs. Ka-Band performance (possible higher power and/or larger/deployable antennas) to prepare for risk of W-band SSPA not achieving desired 100W output
- AOS-P: Identify up front, a decision point for using a CALIOP-type backscatter lidar instead of CLIO HSRL, and a Ka-only radar instead of DORA Ka/W. A clearly defined point for such a decision will enable an opportunity to most effectively balance cost savings and risk tolerance against capability

October 12, 2022

Other possibilities: Consider procuring both I and P s/c from RSDO or other competitions using a single contractor (one vendor and economies of building 2 s/c)

Explore possibility of a common s/c design between I and P (balancing payloads).

TOR Q2d: Are there any obvious make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – SBG

- **SBG-VSWIR**
  - Project is well thought out and acquisition plan is supportable. High heritage previous sensors makes the design/build of this sensor moderate to low risk.
- **SBG-TIR**
  - The Falcon digitizer for the detectors is a new ASIC design undergoing tech maturation. The project should consider alternative FPGA (Field Programmable Gate Array) based approaches in parallel with the high data-rate if the ASIC (Application-Specific Integrated Circuit) design fails to meet all the specified requirements.
  - The project is engaging with the Italian Space Agency (ASI) and should consider the use of on-site liaison engineers with ASI in order to ensure rapid resolution of interface issues between JPL and ASI. Overall, project has well conceived risk/schedule posture.
- **SBG**
  - Ground/science/operations planning should continue and increase involvement with multi-disciplinary science campaigns while increasing the accessibility of data the broader community. Project should increase coordination with NASA DAC program.

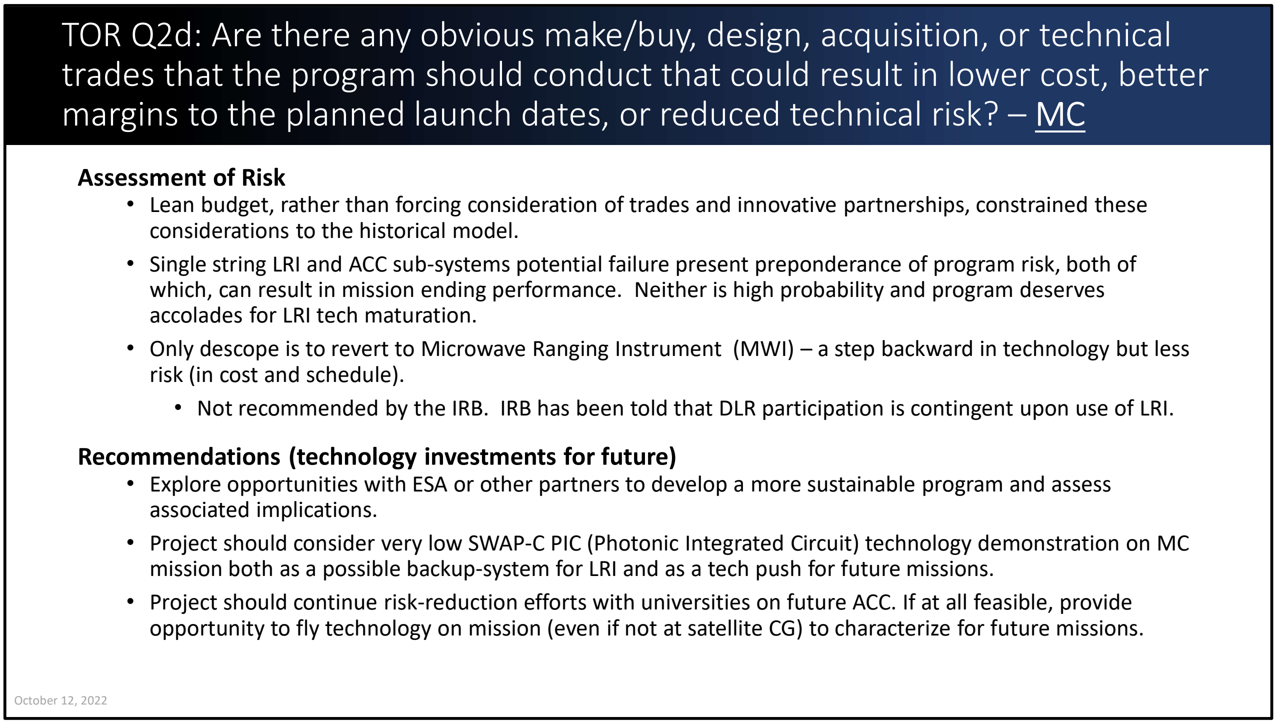
TOR Q2d: Are there any obvious make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – SBG

Assessment of Risk

- SBG-VSWIR: Moderate risks being managed – none are critical to meeting DS Science thresholds.
- SBG-TIR: One high risk payload/component-FPA (Focal Plane Array) electronics for payload.
  - International interfaces are high risk and should continue to have elevated attention by project leadership. ESO should continue to allocate additional early funding for risk mitigation.

Recommendations

- SBG: Increase engagement with NASA DAACs; Continue early acquisition of long-lead electronic components
- SBG-VSWIR: Expand validation efforts with other ESO programs under ground campaign.
- SBG-TIR:
  - Establish JPL-ASI exchange of on-site liaisons to ensure interface issues and communication challenges are addressed rapidly and effectively.
  - Procure long-lead electronic parts and investigate FPGA solutions if ASIC spin is not successful; i.e., provide a backup for the Falcon ASIC. Evaluate non-adiabatic interfaces of Payload to Bus and over-design thermal management system given more capable bus provided from ASI.
- Consider extending the EMIT mission to increase maturity of SBG VSWIR algorithms before launch.



TOR Q2d: Are there any obvious make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – MC

Assessment of Risk

- Lean budget, rather than forcing consideration of trades and innovative partnerships, constrained these considerations to the historical model.
- Single string LRI and ACC sub-systems potential failure present preponderance of program risk, both of which, can result in mission ending performance. Neither is high probability and program deserves accolades for LRI tech maturation.
- Only descope is to revert to Microwave Ranging Instrument (MWI) – a step backward in technology but less risk (in cost and schedule).
  - Not recommended by the IRB. IRB has been told that DLR participation is contingent upon use of LRI.

Recommendations (technology investments for future)

- Explore opportunities with ESA or other partners to develop a more sustainable program and assess associated implications.
- Project should consider very low SWAP-C PIC (Photonic Integrated Circuit) technology demonstration on MC mission both as a possible backup-system for LRI and as a tech push for future missions.
- Project should continue risk-reduction efforts with universities on future ACC. If at all feasible, provide opportunity to fly technology on mission (even if not at satellite CG) to characterize for future missions.

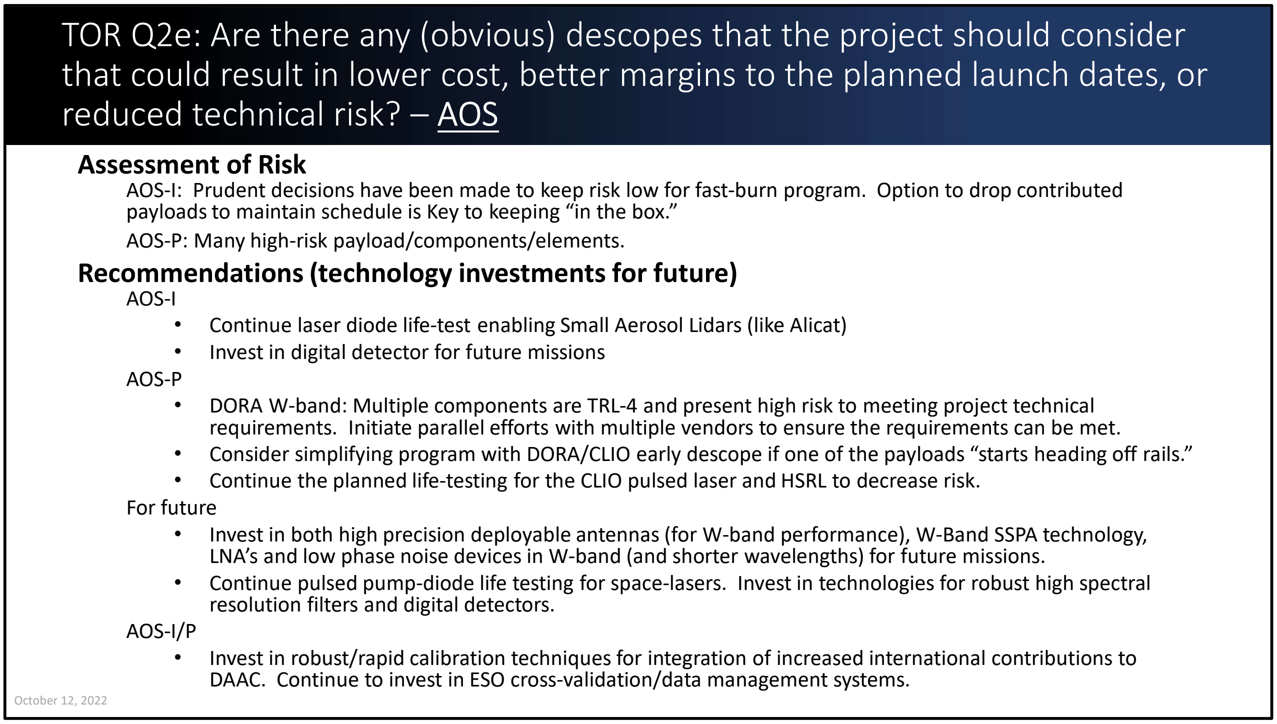
October 12, 2022

Project should continue risk-reduction efforts with universities on future ACC. If at all feasible, provide opportunity to fly technology on mission (even if not at satellite CG) to characterize for future missions.

This should be funded out of separate Tech maturation program.

TOR Q2e: Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – AOS

- AOS-I
  - Alicat is simple backscatter lidar based on heritage programs and core to AOS-I mission – descopes include dropping JAXA/CNES instruments if schedule gets out of box (cost not a major factor for these payloads).
- AOS-P
  - Program has identified appropriate descopes: CALIOP-type lidar, rather than HSRL) and Ka-band radar only (no W-band). Both are appropriate descopes.
    - Science capability would be significantly reduced, but not below Decadal Survey threshold capability
- AOS-P
  - De-manifest TICFIRE if CSA delays delivery.
    - Time-driven, not cost-driven



TOR Q2e: Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – AOS

Assessment of Risk

AOS-I: Prudent decisions have been made to keep risk low for fast-burn program. Option to drop contributed payloads to maintain schedule is Key to keeping "in the box."

AOS-P: Many high-risk payload/components/elements.

Recommendations (technology investments for future)

AOS-I
- Continue laser diode life-test enabling Small Aerosol Lidars (like Alicat)
- Invest in digital detector for future missions

AOS-P
- DORA W-band: Multiple components are TRL-4 and present high risk to meeting project technical requirements. Initiate parallel efforts with multiple vendors to ensure the requirements can be met.
- Consider simplifying program with DORA/CLIO early descope if one of the payloads "starts heading off rails."
- Continue the planned life-testing for the CLIO pulsed laser and HSRL to decrease risk.

For future
- Invest in both high precision deployable antennas (for W-band performance), W-Band SSPA technology, LNA's and low phase noise devices in W-band (and shorter wavelengths) for future missions.
- Continue pulsed pump-diode life testing for space-lasers. Invest in technologies for robust high spectral resolution filters and digital detectors.

AOS-I/P
- Invest in robust/rapid calibration techniques for integration of increased international contributions to DAAC. Continue to invest in ESO cross-validation/data management systems.

October 12, 2022

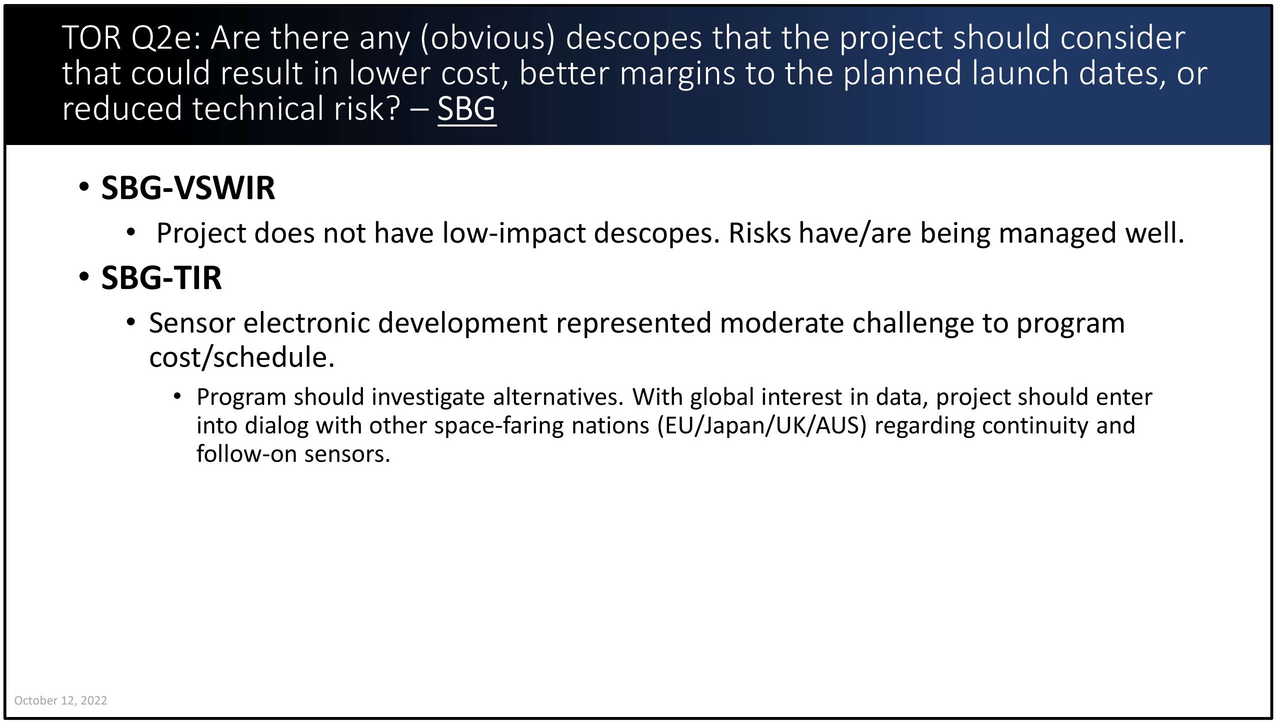
AOS-P: ESD should allocate additional early funding for risk mitigation on CLIO HSRL and DORA-W/Ka. DORA W-band has multiple components that are TRL-4 and present high risk to meeting project technical requirements. Immediate and parallel efforts with multiple vendors should be initiated to ensure the requirements can be met. Consider simplifying program with DORA/CLIO early descope, if one of these complex payloads "starts heading off rails."

Each payload faces major challenges in meeting desired requirements, and stacking those challenges greatly increases programmatic risk. Consider simplifying program with DORA/CLIO early descope, if one of these complex payloads "starts heading off rails." LIO pulsed laser and HSRL filter require tech maturation to decrease risk. Program is currently pursuing laser life-testing which it should continue (even past PDR/CDR to establish multi-year baseline). Continued planned risk reduction program.

AOS-I: Stay the course for AOS-I. Continue laser diode life-test enabling Small Aerosol Lidars (like Alicat) can be developed for multiple manifesting on future S/C (small package/ESPA ring compatible). Invest in digital detector for future missions.

For future: Invest in both high precision deployable antennas (for W-band performance), W-Band SSPA technology, LNA's and low phase noise devices in W-band (and shorter wavelengths) for future missions. Continue pulsed pump-diode life testing for space-lasers. Invest in technologies for robust high spectral resolution filters and digital detectors.

AOS-I/P: invest in robust/rapid calibration techniques for integration of increased international contributions to DAAC. Continue to invest in ESO cross-validation/data management systems.



TOR Q2e: Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – SBG

- **SBG-VSWIR**
  - Project does not have low-impact descopes. Risks have/are being managed well.
- **SBG-TIR**
  - Sensor electronic development represented moderate challenge to program cost/schedule.
    - Program should investigate alternatives. With global interest in data, project should enter into dialog with other space-faring nations (EU/Japan/UK/AUS) regarding continuity and follow-on sensors.

October 12, 2022

Assessment of Risk

SBG-VSWIR: Moderate risks are being managed – none are critical to meeting DS Science thresholds.

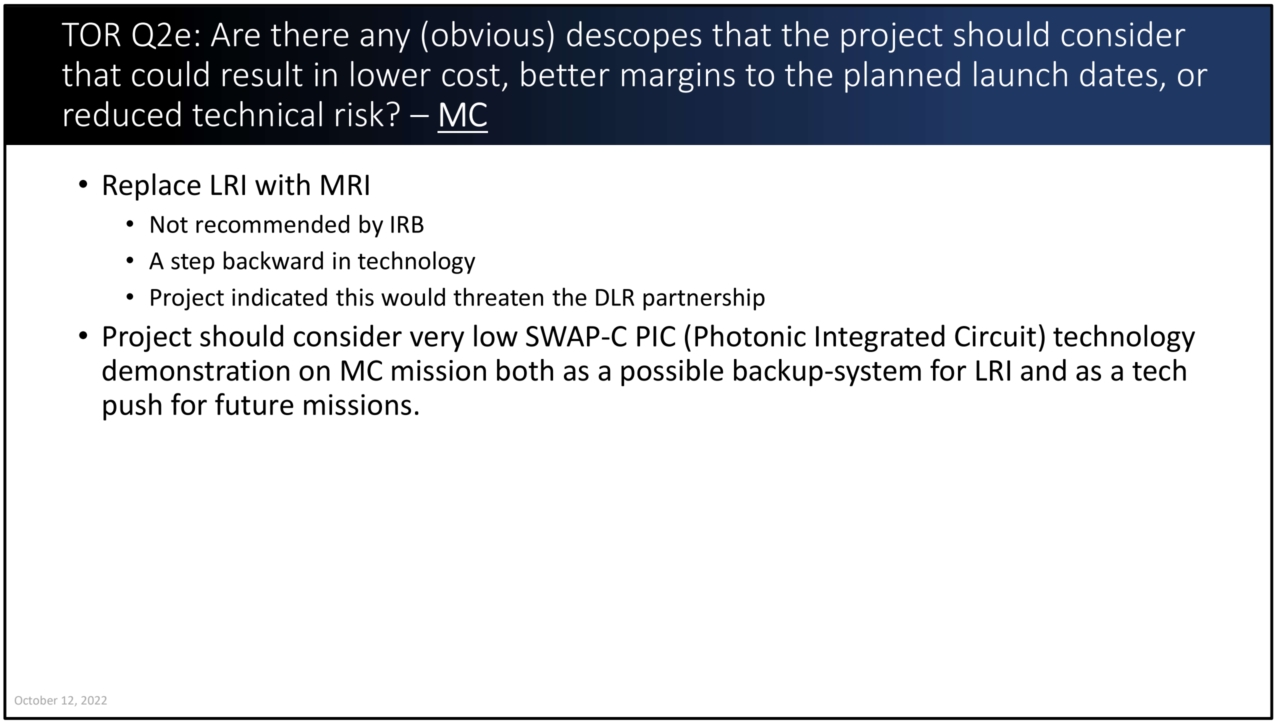
SBG-TIR: One high risk payload/component-FPA (Focal Plane Array) electronics for payload. International interfaces are high risk and should continue to have elevated attention by project leadership. ESD should continue to allocate additional early funding for risk mitigation.

Recommendations (technology investments for future):

SBG: Increase engagement with NASA DAACs; Continue early acquisition of long-lead electronic components;

SBG-VSWIR: Expand validation efforts with other ESO programs under ground campaign.

SBG-TIR: Establish JPL-ASI exchange of on-site liasons to ensure interface issues and communication challenges are addressed rapidly and effectively. Procure long-lead electronic parts and investigate FPGA solutions if ASIC spin is not successful; i.e., - Provide a backup for the Falcon ASIC. Evaluate non-adiabatic interfaces of Payload to Bus and over-design thermal management system given more capable bus provided from ASI.



TOR Q2e: Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk? – MC

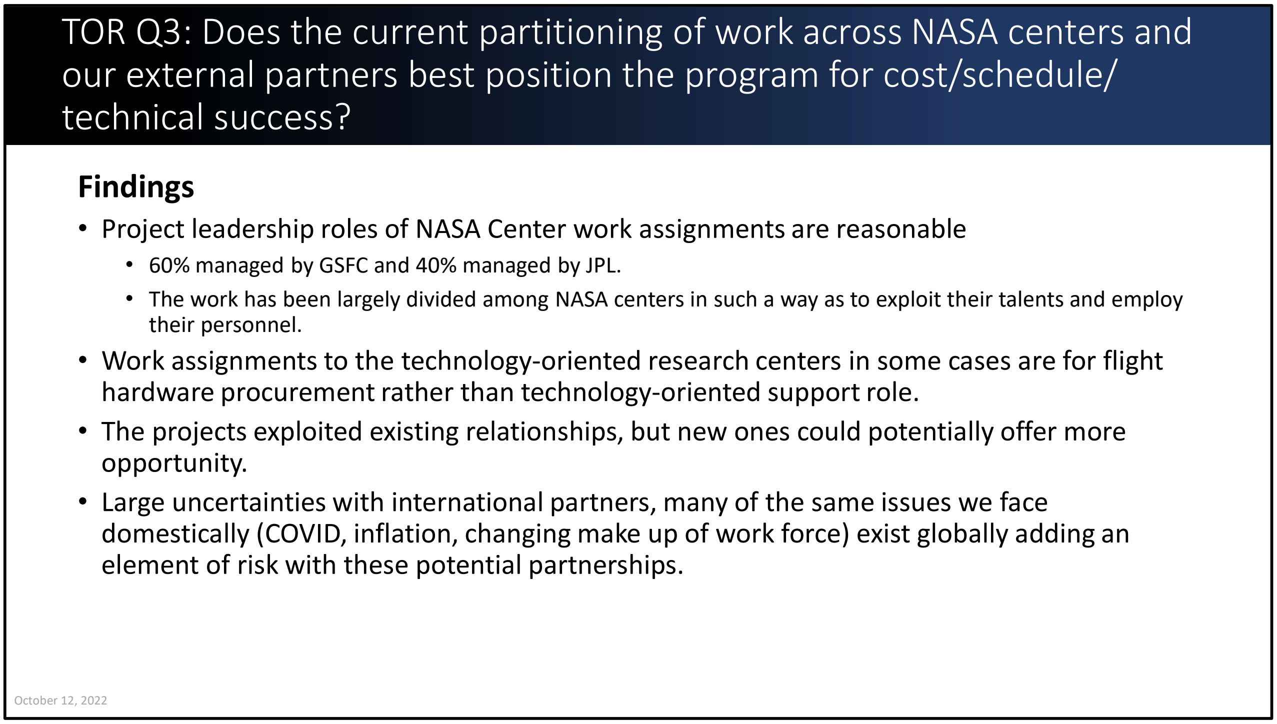
- Replace LRI with MRI
  - Not recommended by IRB
  - A step backward in technology
  - Project indicated this would threaten the DLR partnership
- Project should consider very low SWAP-C PIC (Photonic Integrated Circuit) technology demonstration on MC mission both as a possible backup-system for LRI and as a tech push for future missions.

October 12, 2022

Single string LRI and ACC sub-systems potential failures represent the preponderance of program risk, both of which, can result in mission ending performance. Neither is high probability and program deserves accolades for LRI tech maturation.

Project should continue risk-reduction efforts with universities on future ACC. If at all feasible, provide opportunity to fly technology on mission (even if not at satellite CG) to characterize for future missions. This should be funded out of tech maturation program.

Although diode life-testing is suggesting long life (and graceful degradation), project should consider very low SWAP-C PIC (Photonic Integrated Circuit) technology demonstration on MC mission both as a possible backup-system and as a tech push for future missions. Support for such an implementation would appropriately be an ESTO expense.



TOR Q3: Does the current partitioning of work across NASA centers and our external partners best position the program for cost/schedule/ technical success?

Findings

- Project leadership roles of NASA Center work assignments are reasonable
  - 60% managed by GSFC and 40% managed by JPL.
  - The work has been largely divided among NASA centers in such a way as to exploit their talents and employ their personnel.
- Work assignments to the technology-oriented research centers in some cases are for flight hardware procurement rather than technology-oriented support role.
- The projects exploited existing relationships, but new ones could potentially offer more opportunity.
- Large uncertainties with international partners, many of the same issues we face domestically (COVID, inflation, changing make up of work force) exist globally adding an element of risk with these potential partnerships.

October 12, 2022

One of the IRB’s initial reactions to the work assignment and distribution of work was that GSFC and JPL were the right Centers to lead the projects but that some of the Center work assignments, International Partnerships, and industry partnerships should be further reviewed. The AOS project approached a high-volume commercial satellite company with a goal of procuring and modifying one of the spacecraft for the AOS mission. However, the company declined to disrupt their established flow to modify one or two spacecraft for NASA.

The MSR IRB also stated that the roles of the Technology focused NASA Research Centers should be confined to research and support and not provide flight hardware that may be outside the Centers experience. While the IRB applauds the projects reaching out to the various NASA Centers for partnerships, the roles assigned to the research centers should be reviewed to ensure they are consistent with the Centers’ expertise.

Alternative arrangements, such as industry partners, or other international partners, were sought, which may have better positioned NASA to deliver on cost, but with limited success. Given the schedule and plan that was shown the viable options were somewhat limited, posing some risk to the success of the program.

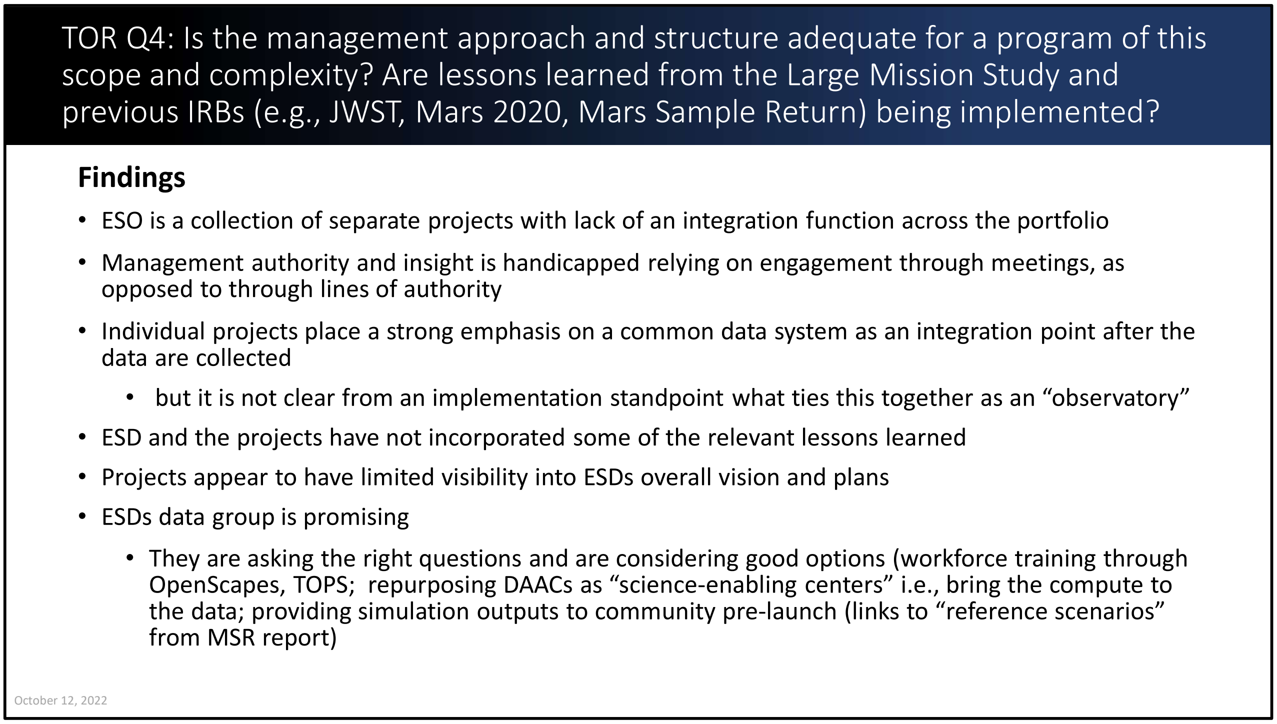
MC is a third instrument in a series and the project is primarily focused on collaborating with groups from the first and second mission.

AOS and SBG have some room to modify budgets and work with new partners and appears to have more international collaboration than internal NASA cross-center collaboration.

TOR Q3: Does the current partitioning of work across NASA centers and our external partners best position the program for cost/schedule/technical success?

Recommendations

1. Review the work assignments to the technology-oriented NASA Research Centers related to delivery of flight hardware to ensure compatibility with capabilities.
2. Explore partnerships both domestic and internationally for potential non-traditional partnerships such as, but not limited to, ground system operations, spacecraft operations, etc. with a focus on future sustainability in mission implementations.



TOR Q4: Is the management approach and structure adequate for a program of this scope and complexity? Are lessons learned from the Large Mission Study and previous IRBs (e.g., JWST, Mars 2020, Mars Sample Return) being implemented?

Findings

- ESO is a collection of separate projects with lack of an integration function across the portfolio
- Management authority and insight is handicapped relying on engagement through meetings, as opposed to through lines of authority
- Individual projects place a strong emphasis on a common data system as an integration point after the data are collected
  - but it is not clear from an implementation standpoint what ties this together as an "observatory"
- ESD and the projects have not incorporated some of the relevant lessons learned
- Projects appear to have limited visibility into ESDs overall vision and plans
- ESDs data group is promising
  - They are asking the right questions and are considering good options (workforce training through OpenScapes, TOPS; repurposing DAACs as "science-enabling centers" i.e., bring the compute to the data; providing simulation outputs to community pre-launch (links to "reference scenarios" from MSR report)

October 12, 2022

The IRB believes the projects are well-focused on their specific missions, but integration with other projects is ad-hoc. Projects commented that the science teams create the integration meetings limited HQ guidance or support.

The IRB did not see evidence of an integrated Observatory, rather projects largely functioned as stove pipes, with integration being somewhat ad-hoc, as opposed to built into the structure. The Two Program Offices casually talk to each other for items such as lessons learned but not Observatory level integration. HQ Program Scientists and Program Executives focus on their specific projects but there is no formal Observatory integration activity. The IRB did not identify a Program Scientist or Program Executive or a position within ESD responsible for looking across the ESO portfolio not only for integration functions but also applicability to other funding sources such as ROSES. The data system is where most users will interact with the program as a system and this is where the scope, schedule and timing of these platforms will determine how well the data can be used and by whom.

ESDs data group is promising. Concern is that the only ESO-specific work at the moment is the ground system → cal-val piece. Final analytics framework choices is being left to Science Teams which in turn will be constituted after a SMD-wide science team study that is getting underway (festive). This timeline and SMD-wide focus seems risky (to an ESO review board) given how much is expected from this data system.

ESD and the projects have not incorporated some of the relevant lessons learned. There is reasonable NASA oversight of the programs for smaller details but the vision of how these programs should operate as an observatory isn't clear.
Projects appear to have limited visibility into ESDs overall vision and plans (It took a while for us to understand the data side despite all the project-level meetings). Formal interaction is only expected at Phase B ("when the DAACs meet the projects to set up data products").

TOR Q4: Is the management approach and structure adequate for a program of this scope and complexity? Are lessons learned from the Large Mission Study and previous IRBs (e.g., JWST, Mars 2020, Mars Sample Return) being implemented? (cont.)

Recommendations

1. The IRB recommends ESD identify and implement ways to clarify lines of authority, communication, and integration possibly though an integration function at the ESD ESO level.
2. Consider designating an ESO Program Scientist, Program Executive, or data czar to help surface application requirements, and connects the dots between science teams and specific ROSES and Technology offices, etc.
3. Combine AOS-P and AOS-I into an integrated project for more effective cost, schedule, and performance management.
4. Charter review of past Lessons Learned with recommendations for how to best implement appropriate Lessons Learned in ESD and the ESO.

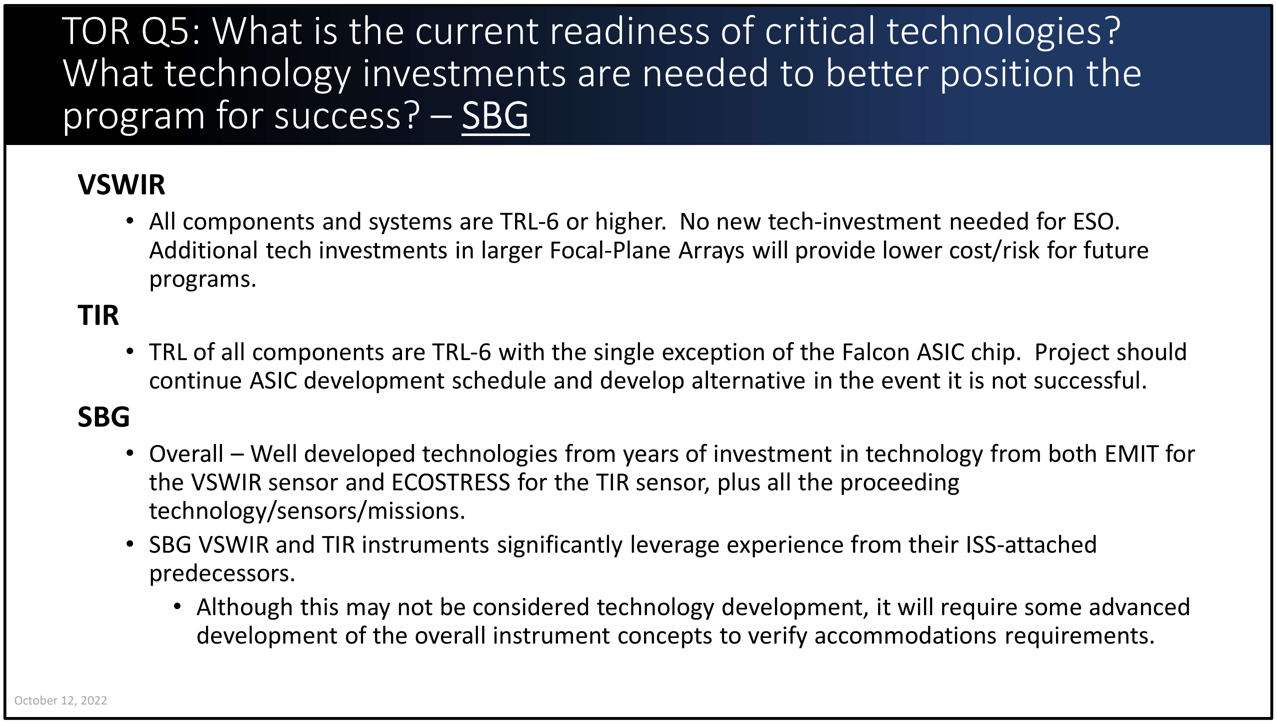
TOR Q5: What is the current readiness of critical technologies? What technology investments are needed to better position the program for success? – AOS

AOS-P

- High-risk payload/components are a high risk to the project in ESO additional early funding should be considered for risk mitigation on CLIO HSRL (TRL-4) and DORA-W/Ka (TRL-4).
  - DORA W-band has multiple components that are TRL-4 and present high risk to meeting project technical requirements.
    - Immediate and parallel efforts with multiple vendors should be initiated to ensure the requirements can be met.
  - CLIO pulsed laser and HSRL filter require tech maturation to decrease risk.
    - Program is currently pursuing life-testing which should continue (even past PDR/CDR to establish multi-year baseline).

AOS-I

- Risk reduction program for data system upgrade is appropriately addressing TRL-5 maturation needs.
- Life testing of laser diodes and investments in digital detector should be considered for future follow-on program.



TOR Q5: What is the current readiness of critical technologies? What technology investments are needed to better position the program for success? – SBG

VSWIR

- All components and systems are TRL-6 or higher. No new tech-investment needed for ESO. Additional tech investments in larger Focal-Plane Arrays will provide lower cost/risk for future programs.

TIR

- TRL of all components are TRL-6 with the single exception of the Falcon ASIC chip. Project should continue ASIC development schedule and develop alternative in the event it is not successful.

SBG

- Overall – Well developed technologies from years of investment in technology from both EMIT for the VSWIR sensor and ECOSTRESS for the TIR sensor, plus all the proceeding technology/sensors/missions.
- SBG VSWIR and TIR instruments significantly leverage experience from their ISS-attached predecessors.
    - Although this may not be considered technology development, it will require some advanced development of the overall instrument concepts to verify accommodations requirements.

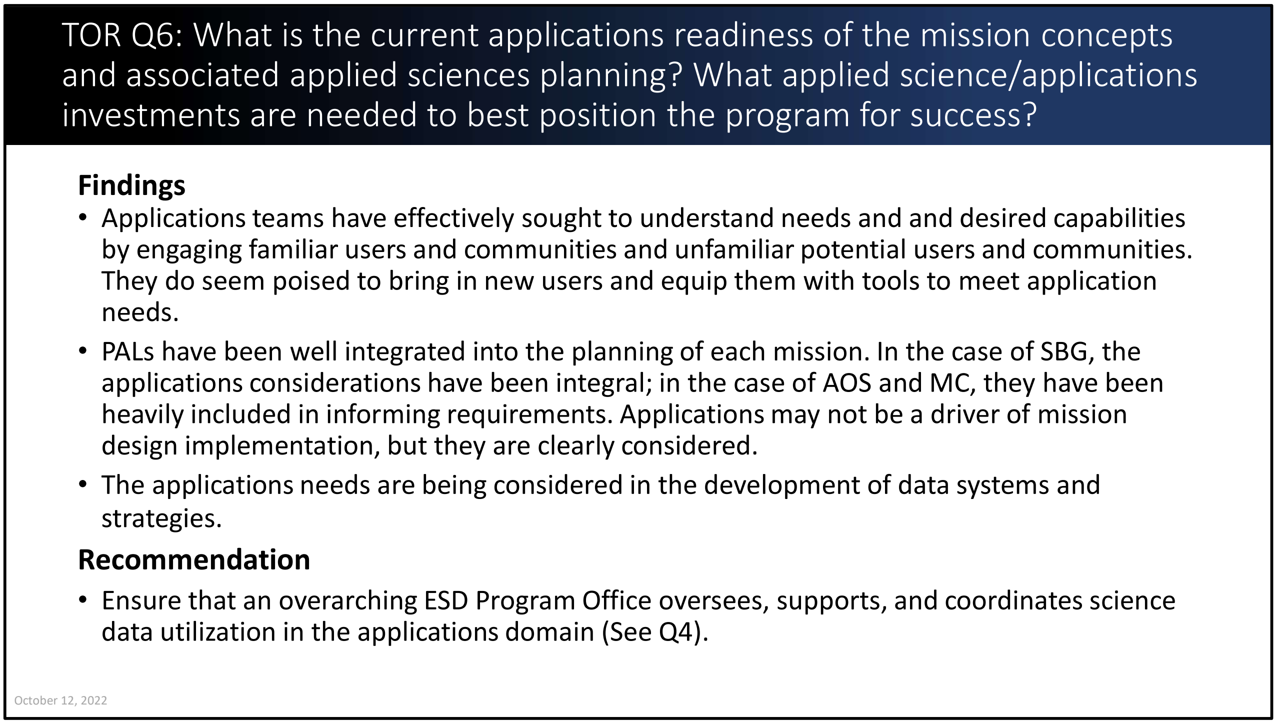
October 12, 2022

SBG VSWIR and TIR instruments significantly leverage experience from their ISS-attached predecessors.

Adapting these instruments to a spacecraft-based platform will likely encounter challenges with accommodations that could impact costs and schedule. Although this may not be considered technology development, it will require some advanced development of the overall instrument concepts to verify accommodations requirements.

TOR Q5: What is the current readiness of critical technologies? What technology investments are needed to better position the program for success? – MC

- All components and systems are TRL-6 or higher (many TRL-9).
  - One of four flown accelerometers (ACCs) have failed.
- Additional high-TRL options for ACC are desired; project should continue risk-reduction efforts with universities on future ACC.
  - If at all feasible, provide opportunity to fly technology on mission (even if not at satellite CG) to characterize for future missions.



TOR Q6: What is the current applications readiness of the mission concepts and associated applied sciences planning? What applied science/applications investments are needed to best position the program for success?

Findings

- Applications teams have effectively sought to understand needs and and desired capabilities by engaging familiar users and communities and unfamiliar potential users and communities. They do seem poised to bring in new users and equip them with tools to meet application needs.
- PALs have been well integrated into the planning of each mission. In the case of SBG, the applications considerations have been integral; in the case of AOS and MC, they have been heavily included in informing requirements. Applications may not be a driver of mission design implementation, but they are clearly considered.
- The applications needs are being considered in the development of data systems and strategies.

Recommendation

- Ensure that an overarching ESD Program Office oversees, supports, and coordinates science data utilization in the applications domain (See Q4).

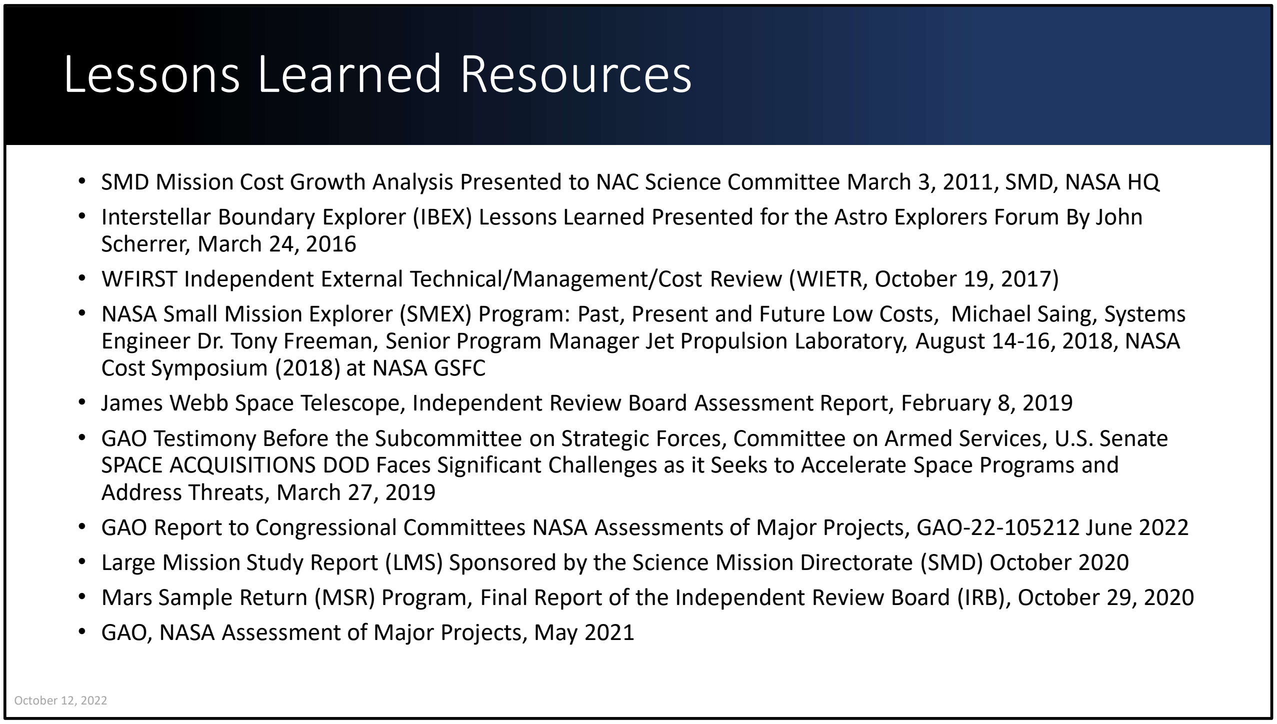
October 12, 2022

SBG has the strongest and broadest applications component of the ESO instruments, with applications from agricultural water management and crop ET, to wildfire risk, fire spread, toxic algae, smoke plumes, etc., information relevant to agencies that manage coastal and inland water quality, Forest service (US and State), climate change carbon sequestration, Changes in land cover as the earth's climate changes, invasive species and threatened and loss of endangered species. The smoke and aerosol sensor on AOS has attracted interest for contributing information about health risks. Precipitation information would be key for severe weather safety (floods/snow/ice/droughts, etc.) these are relevant to the many weather services, but also transportation, evacuation, first responders, health advisories, etc. Appears more challenging for applications users to directly use the MC data as acknowledged by the team who thought that higher level products were needed to ensure use by applications groups.

The program would benefit from central focal point(s) (a scientist or data specialist) to integrate the information. Examples: Tie together field campaigns and mission needs (measure specific parameters needed for algorithms, rather than trying to infer them. An example of such a structure is GPM. Data integration across the ESO sensors (and other programs like Earth Ventures, etc.) needs to be done with total buy in from ESO scientists, not just rely on the DAAC's. Program investment must reflect this priority and these considerations so that broad use of these data lend themselves to making more precise assessments of different algorithms.

Findings and Recommendations – Lessons Learned

October 12, 2022

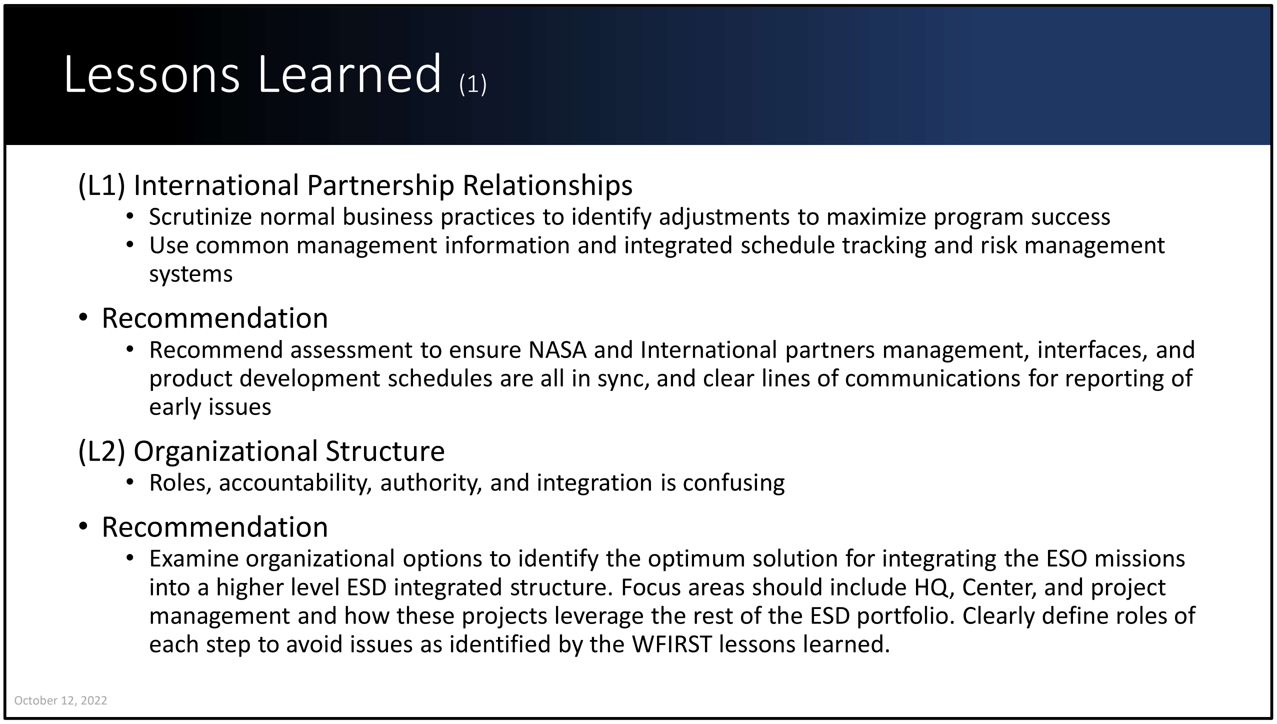


Lessons Learned Resources

- SMD Mission Cost Growth Analysis Presented to NAC Science Committee March 3, 2011, SMD, NASA HQ
- Interstellar Boundary Explorer (IBEX) Lessons Learned Presented for the Astro Explorers Forum By John Scherrer, March 24, 2016
- WFIRST Independent External Technical/Management/Cost Review (WIETR, October 19, 2017)
- NASA Small Mission Explorer (SMEX) Program: Past, Present and Future Low Costs, Michael Saing, Systems Engineer Dr. Tony Freeman, Senior Program Manager Jet Propulsion Laboratory, August 14-16, 2018, NASA Cost Symposium (2018) at NASA GSFC
- James Webb Space Telescope, Independent Review Board Assessment Report, February 8, 2019
- GAO Testimony Before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate SPACE ACQUISITIONS DOD Faces Significant Challenges as it Seeks to Accelerate Space Programs and Address Threats, March 27, 2019
- GAO Report to Congressional Committees NASA Assessments of Major Projects, GAO-22-105212 June 2022
- Large Mission Study Report (LMS) Sponsored by the Science Mission Directorate (SMD) October 2020
- Mars Sample Return (MSR) Program, Final Report of the Independent Review Board (IRB), October 29, 2020
- GAO, NASA Assessment of Major Projects, May 2021

October 12, 2022

Ten lessons learned were reviewed for applicability to the IRB review. Common themes are captured in this report along with recommendations.



Lessons Learned (1)

(L1) International Partnership Relationships
  - Scrutinize normal business practices to identify adjustments to maximize program success
  - Use common management information and integrated schedule tracking and risk management systems
- Recommendation
  - Recommend assessment to ensure NASA and International partners management, interfaces, and product development schedules are all in sync, and clear lines of communications for reporting of early issues

(L2) Organizational Structure
  - Roles, accountability, authority, and integration is confusing
- Recommendation
  - Examine organizational options to identify the optimum solution for integrating the ESO missions into a higher level ESD integrated structure. Focus areas should include HQ, Center, and project management and how these projects leverage the rest of the ESD portfolio. Clearly define roles of each step to avoid issues as identified by the WFIRST lessons learned.

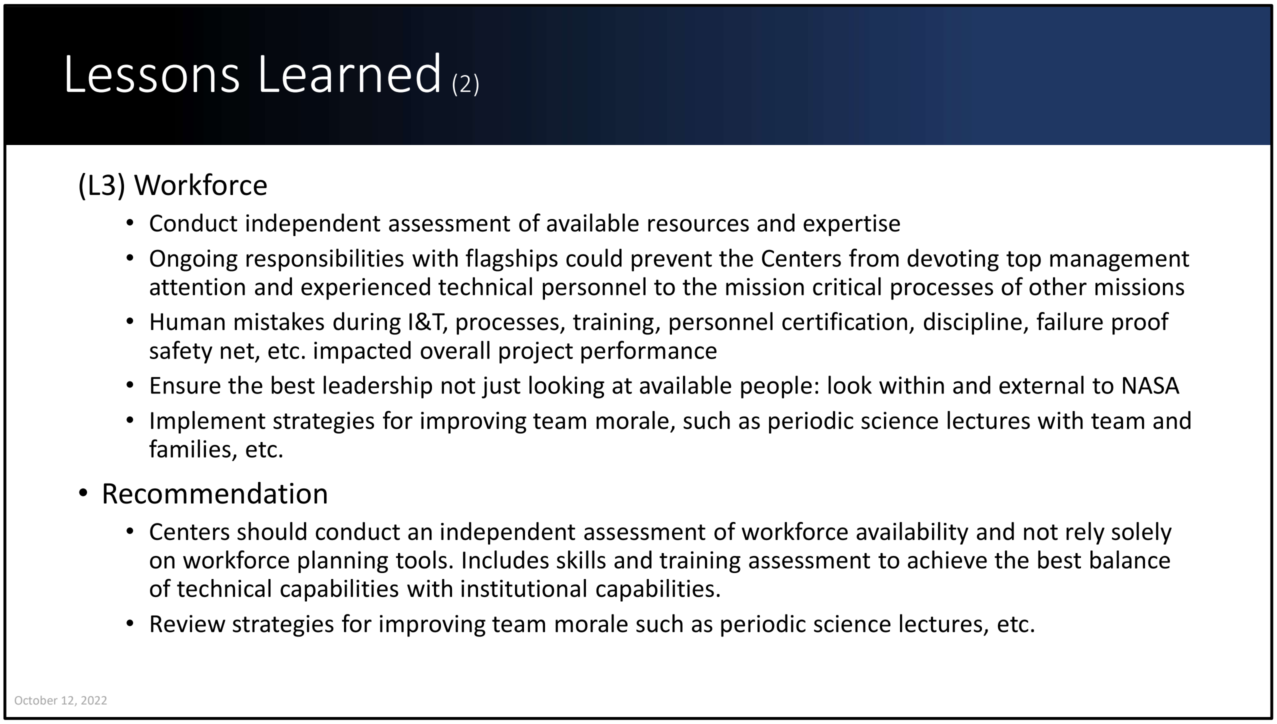
October 12, 2022

International Partnerships

Mars Sample Return (MSR) report stated that significant mismatches existed between NASA and ESA causing potential cost and schedule issues. The three projects reviewed have international components and should be reviewed to ensure processes and communications are clear between the projects and partners.

Organizational Structure

ESO is operated as a set of independent projects focusing on individual Decadal Survey guidance. While the data structure study is the common integration function, AOS is operating as two separate projects but rely on each other for funding and resources. The IRB was unable to identify a focal point within the Earth Science Division that focuses on integration across the various ESD Programs and Projects. The MSR IRB report states that organizational roles should be clarified to the maximum extent possible. More specifically, the MSR IRB recommended conducting an independent assessment of all available Center resources at GSFC and JPL to achieve the best balance of technical capabilities with institutional capabilities. The WFIRST IRB stated that roles, accountability, and authority is confusing where expectations are set by the HQ Division leaving the Program Offices with no authority causing inefficiencies and confusion. Lessons learned from both MSR and WFIRST point to lack of clarity and integration with roles, responsibilities, and overall ESD mission integration. The ESO IRB believes that having two Program Offices (GSFC and JPL) each responsible for various ESD projects without specific ESD identified integration functions could cause missed opportunities for innovation and collaboration with each other and with other elements within ESD.



Lessons Learned (2)

(L3) Workforce

  - Conduct independent assessment of available resources and expertise
  - Ongoing responsibilities with flagships could prevent the Centers from devoting top management attention and experienced technical personnel to the mission critical processes of other missions
  - Human mistakes during I&T, processes, training, personnel certification, discipline, failure proof safety net, etc. impacted overall project performance
  - Ensure the best leadership not just looking at available people: look within and external to NASA
  - Implement strategies for improving team morale, such as periodic science lectures with team and families, etc.

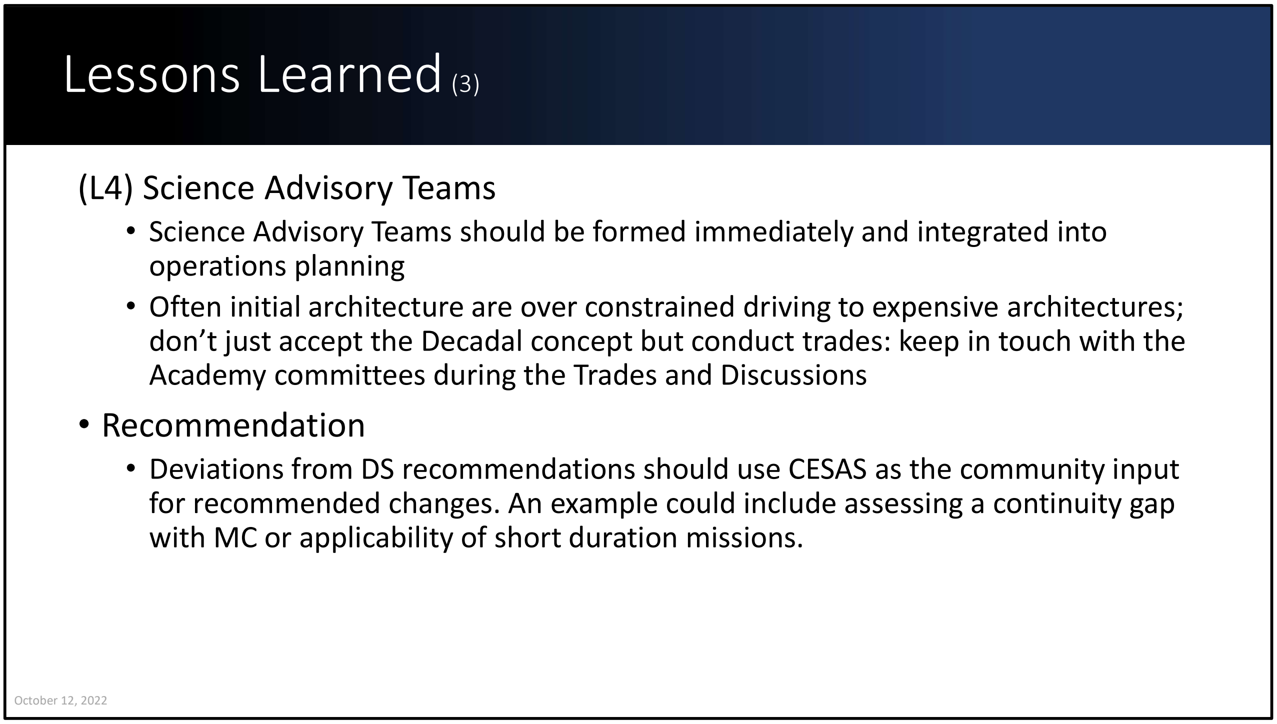
- Recommendation
  - Centers should conduct an independent assessment of workforce availability and not rely solely on workforce planning tools. Includes skills and training assessment to achieve the best balance of technical capabilities with institutional capabilities.
  - Review strategies for improving team morale such as periodic science lectures, etc.

October 12, 2022

The MSR IRB stated that workforce issues across the Agency are being taxed, in particular “issues” with workforce retention in specialty groups. The MSR IRB was concerned that GSFC and JPL ongoing responsibilities with flagships could prevent it from devoting top management attention and experienced technical personnel to the mission critical processes. The ESO IRB was told that workforce required for these projects was identified in the workforce planning tool but with the exception of SBG, the resources themselves were not identified. This could lead to the same problem identified by the MSR IRB. The JWST IRB stated that human mistakes during I&T, processes, training, personnel certification, discipline, and failure proof safety net were an issue with JWST. Training and certification should also be reviewed as part of the workforce assessment. The Large Mission Study recommended that the missions ensure the best leadership not just looking at available people and look within and external to NASA.

The MSR IRB also stated that the roles of the Technology focused NASA Research Centers should be confined to research and support and not provide flight hardware that may be outside the Centers experience. While the IRB applauds the projects reaching out to the various NASA Centers for partnerships, the roles assigned to the research centers should be reviewed to ensure they are consistent with the Centers expertise.

The JWST IRB recommended that JWST implement strategies for improving team morale, such as periodic science lectures with team and families. The ESO IRB concurs with this approach and recommends the ESD and the projects also conduct various morale strategies to increase morale within the projects.



Lessons Learned (3)

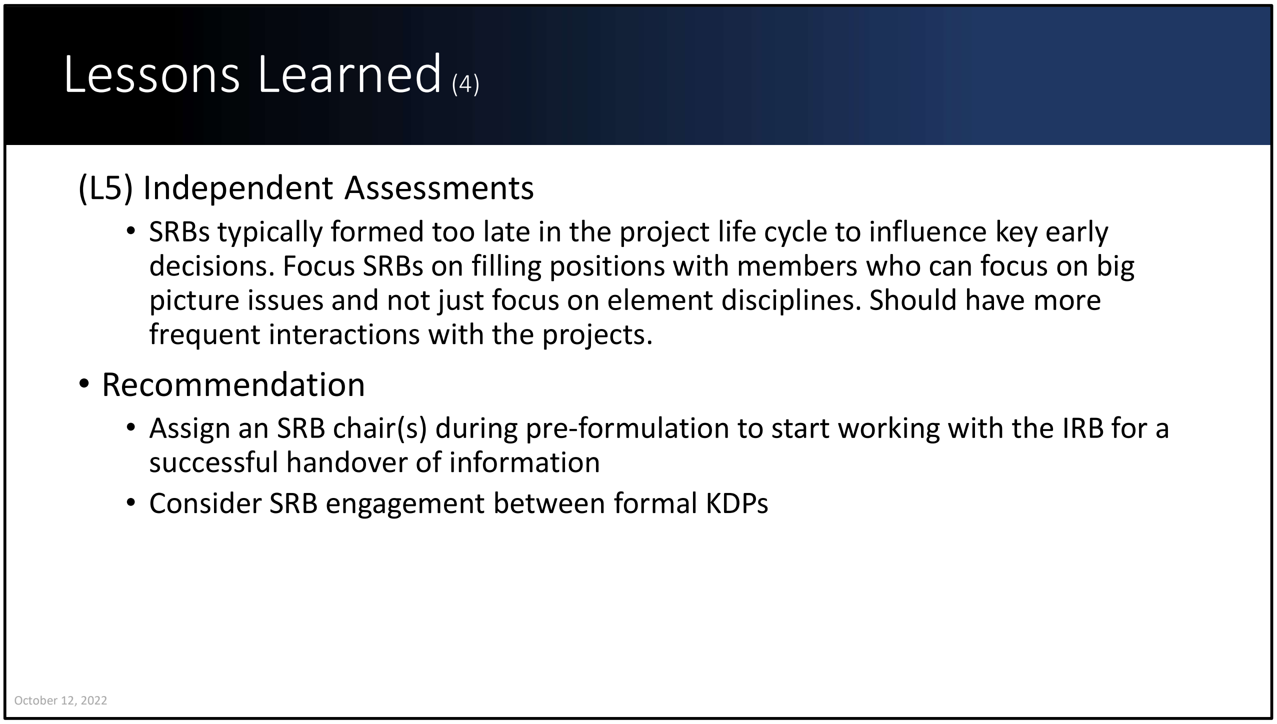
(L4) Science Advisory Teams

- Science Advisory Teams should be formed immediately and integrated into operations planning
- Often initial architecture are over constrained driving to expensive architectures; don’t just accept the Decadal concept but conduct trades: keep in touch with the Academy committees during the Trades and Discussions

- Recommendation
  - Deviations from DS recommendations should use CESAS as the community input for recommended changes. An example could include assessing a continuity gap with MC or applicability of short duration missions.

October 12, 2022

Science Advisory Teams: The MSR IRB recommended that Science Advisory teams should be formed immediately and integrated into operations planning. The Large Mission Studies also stated that often initial architectures are over constrained driving to expensive architectures. The LMS further stated that missions should not just accept the Decadal Survey concept but conduct trades while keeping in touch with the Academy committees during the trades and discussions. The ESO IRB was told that multiple options were considered (sometimes in the 100’s) in working groups narrowing down to the Mission Concept Review concepts presented to the IRB. The resultant concepts appear to rely on “what has been previously done” ultimately using a Design-to-Cost approach for what can fit within the budget. The projects have cost challenges that may require innovative concept and descope trades to be considered that may require presenting to the CECAS.



Lessons Learned (4)

(L5) Independent Assessments

  - SRBs typically formed too late in the project life cycle to influence key early decisions. Focus SRBs on filling positions with members who can focus on big picture issues and not just focus on element disciplines. Should have more frequent interactions with the projects.

- Recommendation
  - Assign an SRB chair(s) during pre-formulation to start working with the IRB for a successful handover of information
  - Consider SRB engagement between formal KDPs

October 12, 2022

Independent Assessments: The Large Mission Study stated that SRBs are typically formed too late in the project life cycle to influence key early decisions.

Consideration for SRB membership should focus on filling positions with members who can focus on big picture issues and not just focus on element disciplines.

Lessons Learned (5)

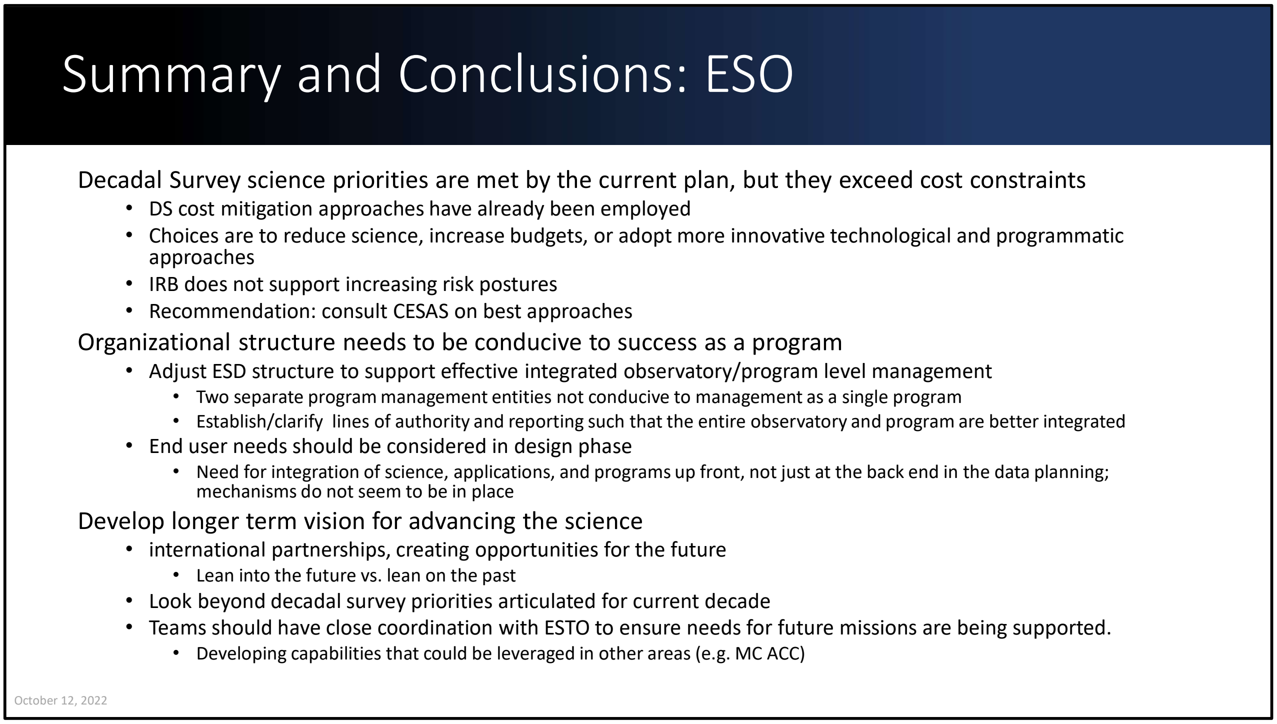
(L6) Management Processes

- Are management processes in place adequate for a project of this scope and complexity? The push for science return and design-to-cost model caused tension especially since the present scope and schedule appear to exceed the resources available
- NASA HQ should be responsible for developing an early communication plan (this could help with focusing on observatory messaging)
- GSFC monthly mission status reviews and SMD flight program reviews were combined to provide everybody the opportunity to see the same charts early on

- Recommendation
  - See TOR Q4 Recommendation
  - Start the communications plan now with emphasis on the observatory philosophy to help with sustainability

Summary and Conclusions

October 12, 2022



Summary and Conclusions: ESO

Decadal Survey science priorities are met by the current plan, but they exceed cost constraints

- DS cost mitigation approaches have already been employed
- Choices are to reduce science, increase budgets, or adopt more innovative technological and programmatic approaches
- IRB does not support increasing risk postures
- Recommendation: consult CESAS on best approaches

Organizational structure needs to be conducive to success as a program

- Adjust ESD structure to support effective integrated observatory/program level management
  - Two separate program management entities not conducive to management as a single program
  - Establish/clarify lines of authority and reporting such that the entire observatory and program are better integrated
- End user needs should be considered in design phase
  - Need for integration of science, applications, and programs up front, not just at the back end in the data planning; mechanisms do not seem to be in place

Develop longer term vision for advancing the science

- international partnerships, creating opportunities for the future
  - Lean into the future vs. lean on the past
- Look beyond decadal survey priorities articulated for current decade
- Teams should have close coordination with ESTO to ensure needs for future missions are being supported.
  - Developing capabilities that could be leveraged in other areas (e.g. MC ACC)

Summary and Conclusions: AOS

Capabilities as currently planned meet, and in the case of CLIO exceed, DS science recommendations

- IRB-projected costs exceed caps and project estimates
- Descopes are possible that will significantly reduce science capabilities. Potential options are:
  - Changing from CLIO to CALIOP-type lidar
  - Eliminate Dora's W-band radar and rely on Ka-band only
  - The earlier the decisions are made, the more savings will be realized

Programmatic efficiencies could be implemented

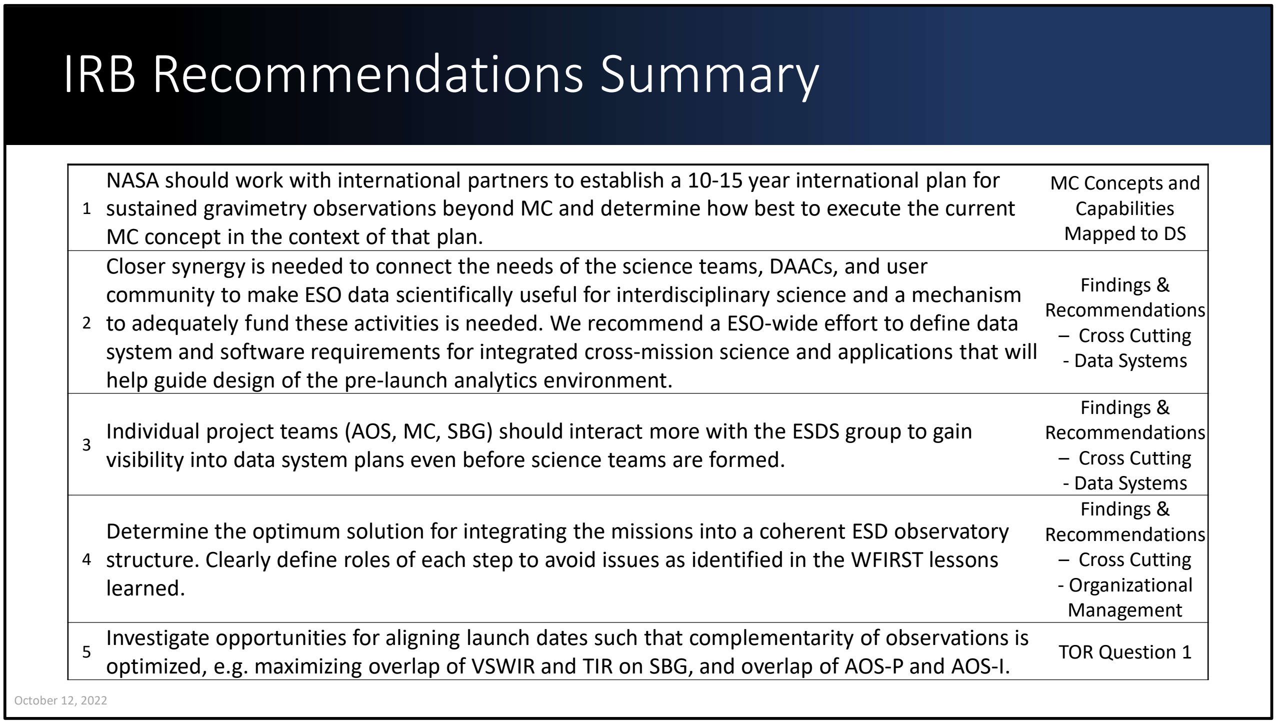
- Integrating AOS-I and AOS-P projects
- Considering a single s/c contractor for both missions
- Perform an assessment to better balance AOS-P and AOS-I payloads to enable use of a common s/c

Summary and Conclusions: SBG

- Capabilities as currently planned meets DS science recommendations
- Project costs align with IRB cost estimates
- Potential cost savings could be realized by operating in a lower orbit and/or using a smaller launch vehicle
  - Savings of up to $35M
  - Decision can be deferred to PDR
  - Increased drag and debris exposure, which could reduce mission life

Summary and Conclusions: MC

- Capabilities as currently planned meet minimal DS science recommendations at high risk
  - Long stored GFO accelerometers, with one of four having failed on orbit
  - Single-string LRI
  - Very low cost reserves
- An improved implementation approach for the Accelerometers is needed
- Further exploration of options to improve redundancy is needed to reduce risk
- A long-term solution to achieve MC science should be pursued in parallel with the MC approach leveraging GFO



IRB Recommendations Summary

1	NASA should work with international partners to establish a 10-15 year international plan for sustained gravimetry observations beyond MC and determine how best to execute the current MC concept in the context of that plan.	MC Concepts and Capabilities Mapped to DS
2	Closer synergy is needed to connect the needs of the science teams, DAACs, and user community to make ESO data scientifically useful for interdisciplinary science and a mechanism to adequately fund these activities is needed. We recommend a ESO-wide effort to define data system and software requirements for integrated cross-mission science and applications that will help guide design of the pre-launch analytics environment.	Findings & Recommendations – Cross Cutting - Data Systems
3	Individual project teams (AOS, MC, SBG) should interact more with the ESDS group to gain visibility into data system plans even before science teams are formed.	Findings & Recommendations – Cross Cutting - Data Systems
4	Determine the optimum solution for integrating the missions into a coherent ESD observatory structure. Clearly define roles of each step to avoid issues as identified in the WFIRST lessons learned.	Findings & Recommendations – Cross Cutting - Organizational Management
5	Investigate opportunities for aligning launch dates such that complementarity of observations is optimized, e.g. maximizing overlap of VSWIR and TIR on SBG, and overlap of AOS-P and AOS-I.	TOR Question 1

October 12, 2022

The table of IRB recommendations is an integrated set of recommendations combining various recommendations into groups and is not intended to be a one-for-one trace to the body of the document but rather a reference.

IRB Recommendations Summary

6	Consider descopes on AOS-P to bring costs in better alignment with agency resources and expected margins.	TOR Question 1
7	Identify a person to oversee the full ESO portfolio, such that it is viewed as a complete observatory.	TOR Question 1
8	SBG: Increase engagement with NASA DAACs; Continue early acquisition of long-lead electronic components.	TOR Question 2d
9	SBG-VSWIR: Expand validation efforts with other ESO programs under ground campaign.	TOR Question 2d
10	SBG-TIR: Establish JPL-ASI exchange of on-site liaisons to ensure interface issues and communication challenges are addressed rapidly and effectively. Procure long-lead electronic parts and investigate FPGA solutions if ASIC spin is not successful; i.e., provide a backup for the Falcon ASIC. Evaluate non-adiabatic interfaces of Payload to Bus and over-design thermal management system given more capable bus provided from ASI.	TOR Question 2d
11	Explore opportunities with ESA or other partners to develop more sustainable program and assess associated implications.	TOR Question 2d

IRB Recommendations Summary

12	Project should consider very low SWAP-C PIC (Photonic Integrated Circuit) technology demonstration on MC mission both as a possible backup-system for LRI and as a tech push for future missions.	TOR Question 2d
13	Project should continue risk-reduction efforts with universities on future ACC. If at all feasible, provide opportunity to fly technology on mission (even if not at satellite CG) to characterize for future missions. This should be funded out of separate Tech maturation program.	TOR Question 2d
14	Review the work assignments to the technology-oriented NASA Research Centers related to delivery of flight hardware to ensure compatibility with capabilities.	TOR Question 3
15	Explore partnerships both domestic and internationally for potential non-traditional partnerships such as but not limited to ground system operations, spacecraft operations, etc. with a focus on future sustainability in mission implementations.	TOR Question 3

IRB Recommendations Summary

16	The IRB recommends an ESD study focusing on clarifying lines of authority and communication, integration function at the ESD ESO level including consideration for an ESO Program Scientist, Program Executive, data czar to help surface application requirements, function that connects the dots between science teams and specific ROSES and Technology offices, etc. The study should also consider if someone should be designated within ESD to review plans, descopes, launch schedules, etc. from a systems level perspective for the overall observatory. The data system is where most users will interact with the program as a system and this is where the scope, schedule and timing of these platforms will determine how well the data can be used and by whom.	TOR Question 4
17	Combine AOS-P and AOS-I for more effective cost, schedule, and performance management.	TOR Question 4
18	Charter review of past Lessons Learned with recommendations for how to best implement appropriate Lessons Learned in ESD and the ESO.	TOR Question 4
19	Ensure that an overarching ESD Program Office oversees, supports, and coordinates science data utilization in the applications domain (See Q4).	TOR Question 6

IRB Recommendations Summary

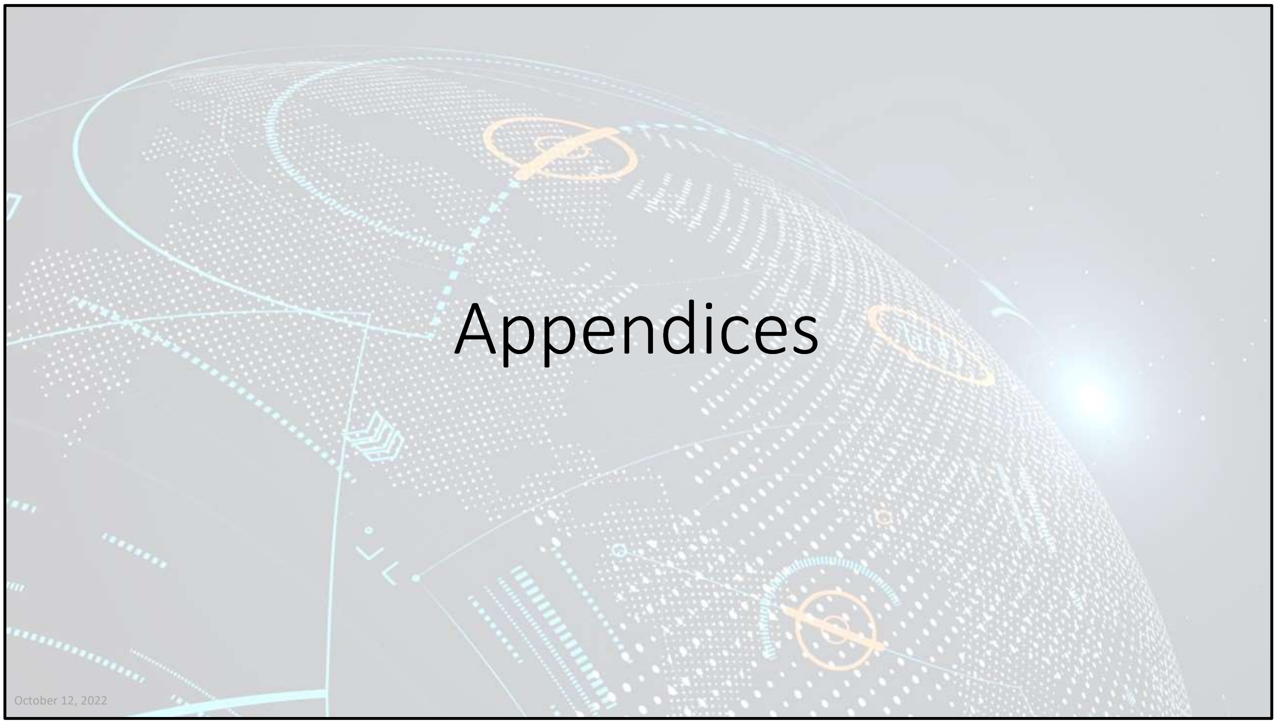
20	Determine the optimum solution for integrating the ESO missions into a higher level ESD integrated structure. Focus areas should include HQ, Center, and project management and how these projects leverage the rest of the ESD portfolio. Clearly define roles of each step to avoid issues as identified by the WFIRST lessons learned.	Findings & Recommendations – Cross Cutting - Lessons Learned
21	Centers should conduct an independent assessment of workforce availability and not rely solely on workforce planning tools. Includes skills and training assessment to achieve the best balance of technical capabilities with institutional capabilities.	Findings & Recommendations – Cross Cutting - Lessons Learned
22	Review strategies for improving team morale such as periodic science lectures, etc.	Findings & Recommendations – Cross Cutting - Lessons Learned
23	Deviations from DS recommendations should use CESAS as the community input for recommended changes. An example could include assessing a continuity gap with MC or applicability of short duration missions.	Findings & Recommendations – Cross Cutting - Lessons Learned
24	Assign an SRB chair for each mission during pre-formulation to start working with the IRB for a successful handover of information.	Findings & Recommendations – Cross Cutting - Lessons Learned

IRB Recommendations Summary

25	Develop a common understanding of SRB engagement in addition to formal KDPs.	Findings & Recommendations – Cross Cutting - Lessons Learned
26	Start the communications plan now with emphasis on the observatory philosophy to help with sustainability.	Findings & Recommendations – Cross Cutting - Lessons Learned
27	AOS: AOS-I and AOS-P projects should be integrated.	Cost & Schedule Backup
28	AOS: A single s/c contractor should be considered for both missions.	Cost & Schedule Backup
29	AOS: An assessment to better balance AOS-P and AOS-I payloads to enable use of a common s/c could be explored	Cost & Schedule Backup
30	SBG: Re-evaluate costs allocated to PM/SE/MA to ensure they capture complexities associated with International Partner I/F's and support to 2 missions (SBG-VSWIR and SBG-TIR).	Cost & Schedule Backup

IRB Recommendations Summary

31	MC: An improved implementation approach for the Accelerometers is needed.	Cost & Schedule Backup
32	MC: Further exploration of options to improve redundancy is needed to reduce risk.	Cost & Schedule Backup
33	MC: A long-term solution to achieve MC science should be pursued in parallel with the MC approach leveraging GFO.	Cost & Schedule Backup



Appendices

October 12, 2022

Appendix: Terms of Reference (1)

Earth System Observatory (ESO) Program
Independent Review Board (IRB)
Terms of Reference (TOR)

I. Background

NASA is designing a new set of Earth-focused missions, the Earth System Observatory (ESO), to respond to the 2017 Earth Science Decadal Survey, *Thriving on Our Changing Planet*, and provide key information to guide efforts related to climate change, disaster mitigation, fighting forest fires, improving weather and air quality forecasts, and improving real-time agricultural processes. Within the ESO, each satellite will be uniquely designed to complement the others, working in tandem to create a 3D, holistic view of Earth, from bedrock to atmosphere. Areas of focus for the observatory include:

- Aerosols (A): Answering the critical question of how aerosols affect the global energy balance, a key source of uncertainty in predicting climate change.
- Cloud, Convection, and Precipitation (CCP): Tackling the largest sources of uncertainty in future projections of climate change, air quality forecasting, and prediction of severe weather.
- Mass Change (MC): Providing drought assessment and forecasting, associated planning for water use for agriculture, as well as supporting natural hazard response.
- Surface Biology and Geology (SBG): Understanding climate changes that impact food and agriculture, habitation, and natural resources, by answering open questions about the fluxes of carbon, water, nutrients, and energy within and between ecosystems and the atmosphere, the ocean, and the Earth.
- Surface Deformation and Change (SDC): Quantifying models of sea-level and landscape change driven by climate change, hazard forecasts, and disaster impact assessments, including dynamics of earthquakes, volcanoes, landslides, glaciers, groundwater, and Earth's interior.

NASA is currently initiating the formulation phase for the ESO. Among its first integrated parts is NASA's partnership with the Indian Space Research Organisation (ISRO) on the NISAR (NASA-ISRO Synthetic Aperture Radar) mission, intended as a pathfinder for the ESO, and specifically SDC. The AOS, MC, and SBG missions are targeting KDP-A in CY2022, with SDC following at a later date.

Appendix: Terms of Reference (2)

II. Scope

The Earth System Observatory (ESO) Program Independent Review Board (IRB) will review the overall architecture and individual technical concepts developed during Pre-Phase A for robustness and the ability to satisfy preliminary Level 1 Requirements, including addressing the following questions:

1. Does the proposed architecture meet the intent of the decadal survey and alignment with Agency need and the ESO?
2. Are the scope and cost/schedule understood and aligned?
    a. Do the mission concepts fit within the cost estimates developed by the National Academies in the 2018 Earth Science Decadal Survey?
    b. What is the likely range of probable cost and schedule for the overall architecture and the individual mission concepts, and what are the drivers?
    c. How do non-optimal funding profiles affect the cost/schedule of the missions?
    d. Are there any (obvious) make/buy, design, acquisition, or technical trades that the program should conduct that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?
    e. Are there any (obvious) descopes that the project should consider that could result in lower cost, better margins to the planned launch dates, or reduced technical risk?
3. Does the current partitioning of work across NASA centers and our external partners best position the program for cost/schedule/technical success?
4. Is the management approach and structure adequate for a program of this scope and complexity? Are lessons learned from the Large Mission Study and previous IRBs (e.g., JWST, Mars 2020, Mars Sample Return) being implemented?
5. What is the current readiness of critical technologies? What technology investments are needed to best position the program for success?
6. What is the current applications readiness of the mission concepts and associated applied sciences planning? What applied science/applications investments are needed to best position the program for success?

Appendix: Terms of Reference (3)

III. Review Management

The convening authority for the ESO IRB is NASA's Science Mission Directorate (SMD) Associate Administrator (AA). As such, the ESO IRB will report to the SMD AA. This Independent Review will be organized by Cornell Technical Services (CTS) at LaRC and will be comprised of members with considerable current experience in program and project management, engineering, and science relevant to ESO.

The SMD AA will assure the necessary support for the ESO IRB. The ESO IRB Chair and the SMD co-Review Managers will support all activities of the ESO IRB and coordinate the production and ensure the quality of review deliverables. The co-Review Managers will ensure that the information needs of the IRB members are met, consistent with U.S. laws, policies, and regulations. The non-consensus final report will be verbally presented to the SMD AA and other NASA stakeholders, followed by the provision of a non-consensus final written report.

IV. Notional Schedule

The IRB will conduct the assessment over an approximately 11-week period from initial meeting to completion of the non-consensus final report. The final schedule will be determined following discussions between the ESO IRB Chairs, co-Review Managers and other NASA stakeholders.

Week #1 - Hold kickoff telecon to review assessment plan; following discussion with ESD leadership, determine final schedule

Weeks #2-3 - Program presents status to review board; review board sends questions and presentation request to the program

Week #4-5 - Program briefing to review board; virtual site visits

Week #6 - Optional additional reviews with projects; virtual site visits

Week #7 - Develop draft findings and questions for discussion with ESO program; develop draft report

Week #8 - Complete draft report; brief ESO program, and consider comments from the program

Week #9 - Draft semi-final report; brief SMD leadership

Weeks #10-11 - Prepare final report; print and deliver to SMD AA

Appendix: Terms of Reference (4)

V. Deliverables

- Individual Member Independent Reports (IMIRs)
- Presentation to SMD AA and other NASA stakeholders summarizing the review results.
- Non-consensus final report with observations, findings, concerns, and recommendations consistent with the Scope outlined above.

VI. Personnel

The expected membership includes:

TBC: ESO IRB Co-Chair
TBC: ESO IRB Co-Chair
TBD: Up to 5 ESO experts
TBD: Up to 2 Senior Project Managers/Technology Development
TBD: Up to 2 Programmatic Experts
TBD: 1 Data expert
TBD: 1 Applications expert

Appendix: Terms of Reference (5)

Ex Officio

Ms. Elaine Denning, NASA/HQ (co-Review Manager/Policy)
Dr. Mike Egan, NASA/HQ (co-Review Manager/ESD)
Dr. Tahani Amer, NASA/HQ (co-Review Manager/ESD)
Ms. Tylar Greene, NASA/HQ (Public Affairs Officer)

Approved:

Thomas Zurbuchen
Digitally signed by
Thomas Zurbuchen
Date: 2022.06.29
13:45:54 -04'00'

Thomas H. Zurbuchen, Ph.D.
Associate Administrator
Science Mission Directorate

Appendix: Biographies
Waleed Abdalati, Co-Chair

Waleed Abdalati is Director of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado, Boulder (CU-Boulder). Research at CIRES, which was established through a cooperative agreement with the National Oceanic and Atmospheric Administration (NOAA), focuses on understanding the physical, chemical, biological, and social aspects of the Earth's environment at time scales that range from minutes to millennia, and spatial scales that range from the microscopic to global.

Dr. Abdalati is also a Professor in CU-Boulder's Geography Department. His own research focuses on the use of satellites and aircraft to understand how Earth's glaciers, ice sheets, and sea ice are changing and the implications of those changes for the Earth System.

Dr. Abdalati spent 14 years working for NASA in various research and leadership capacities, most recently as NASA Chief Scientist. In this role, he advised the NASA Administrator on matters related to NASA's science programs and strategic planning and served as the key NASA science interface to the White House, Congress, and other federal agencies. He has served on various environment-focused National Academy of Sciences committees, most recently as co-chair of the *Earth Science and Applications from Space 2017* Decadal Survey. Currently he serves on the board of directors for the International Space Station National Laboratory.

Dr. Abdalati earned a B.S. from Syracuse University and an M.S. and Ph.D. from CU-Boulder, and prior to his scientific career, he was an engineer in the aerospace industry.

Appendix: Biographies
Geoffrey L. Yoder, Co-Chair

Mr. Yoder is currently a member of the Charles F. Bolden Group and serves on the Board of Advisors for the Telophase Corporation. He is also Chair for the Volatiles Investigation Polar Exploration Rover (VIPER) Review Team (VRT), a project that is assessing the viability of NASA's volatiles. In 2021, he served as a technical reviewer, i.e., subject matter expert, for the SLS EUS+CAPs KDP-C IRT.

Mr. Yoder retired from NASA in 2016 following a distinguished career. His most recent NASA positions include Acting NASA Associate Administrator and Deputy Associate Administrator for the NASA Science Mission Directorate (SMD). In this role, he was responsible for planning and overseeing a $5.6B annual budget with a portfolio of 114 science missions in formulation, development, and operations.

Mr. Yoder joined NASA in 2000 and was responsible for formulating the Flight Hardware Development Branch within JSC's Engineering Directorate. In 2005, he joined the Exploration Systems Mission Directorate (ESMD) at NASA Headquarters. As Director for the Directorate Integration Office, he was responsible for architecture trades and analysis, information technology architecture and IT management, risk and knowledge management, technology protection, and Constellation Program Level 1 requirements. Later, he served as Director of the Constellation Systems Division, responsible for management of the Constellation Systems and Commercial Crew and Cargo Program.

In 2010, Mr. Yoder joined the Astrophysics Division in the SMD as the Astrophysics Division Deputy Director, leading one of the world's largest space astrophysics programs. The astrophysics portfolio includes more than a dozen flight projects, e.g., Hubble Space Telescope, Chandra X-ray Observatory, Spitzer Space Telescope, and numerous research grants.

In 2012, Mr. Yoder was tasked by the NASA Administrator to plan, organize, and direct the Office of Evaluation, responsible for NASA's cost estimating policies and tools, assessing programs, projects, and institutions for cost effectiveness, quality, and performance and reviewing newly proposed and ongoing programs/projects to provide objective assessments to the Mission Directorates and Agency Program Management Councils. Later, Mr. Yoder became Program Director for NASA's $8B James Webb Space Telescope. Eventually, he became Deputy Associate Administrator for Programs in the SMD.

Prior to joining NASA, Mr. Yoder was employed by Litton Systems Inc. (1986 -2000). He was responsible for reliability assurance for various avionics suites, directing reliability and qualification test, and verification activities. He served as a scientist for the Reliability Assurance Department, participating in various product improvement initiatives, e.g., Navy Production Technology Improvement Program (PTIP). He also served as Engineering Project Manager for various commercial, military, and space projects.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Steve Battel is a graduate of the University of Michigan with 45 years of experience as a system engineer, designer, and manager for NASA and DOD space projects. He is known within the space community for his science and engineering leadership related to the development of unique electronic systems and scientific space instruments for Earth observing, planetary geochemistry, space physics, and astrophysics applications. President of Battel Engineering since 1990, Steve is also a professor in the departments of Electrical Engineering and Climate and Space Sciences and Engineering at the University of Michigan. Before 1990, Steve held design engineer, staff engineer, and project management positions at the University of Michigan, Lockheed, Berkeley, and the University of Arizona.

Steve's areas of specialization include low-noise instrumentation, electromagnetic compatibility, avionics, and power systems for space applications. He has more than 60 inventions and is internationally recognized for his expertise in the design and development of space high voltage electronics especially for systems intended for operation in challenging planetary environments and down-hole oil well environments. Steve has participated in more than 120 review and advisory boards for NASA and commercial missions. Past missions include JWST, MSL, Mars 2020, IXPE, JUNO, Deep Impact, TDRS, B612, SPIRE, SkyBox, Aquarius, GRACE, OCO, Planet, and Landsat9. Current missions include Dragonfly, Mars Sample Return, Europa Clipper, GOES, OSAM-1, Tracers, LISA, NISAR, SWOT, Lynk, and MethaneSat.

Steve is a member of the National Academy of Engineering (NAE), a Fellow of the American Institute of Aeronautics and Astronautics, a Fellow of the American Association for the Advancement of Science, a Senior Member of IEEE, and a member of Sigma Xi. He is a former member of the Space Studies Board (SSB) and the Aerospace Science and Engineering Board (ASEB) and is currently the NAE Co-Chair for the NRC Report Review Committee as well as a member of the Committee on Space and Solar Physics (CSSP). Steve has participated in four Decadal Surveys (including the Earth decadal) and seven other committees for the National Academies including Chair of the recent report entitled "Leveraging Commercial Space for Earth and Ocean Remote Sensing."

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Dr. Deepak Cherian is a physical oceanographer in the Climate and Global Dynamics Laboratory (CGD) at the National Center for Atmospheric Research (NCAR), Boulder, Colorado. He holds a Ph.D. in Physical Oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution (MIT-WHOI) Joint Program in Oceanography. His current research focuses on small-scale mixing in the ocean using both in-situ observations and ocean models. He is a recipient of multiple research grant awards from NOAA, NASA, and NSF. As an active participant in the open-source scientific Python community, he promotes open science principles by enhancing and democratizing scalable big data analytics software capabilities across many disciplines, particularly in the geosciences as an active member in the Pangeo community. He also works to increase diversity and representation in the open-source scientific software community through continued involvement in NCAR's Summer Internships in Parallel Computer Science (SIParCS) program.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Dr. Thomas Cooley, a member of the scientific and technical cadre of senior executives, is the Chief Scientist, Space Vehicles Directorate, Air Force Research Laboratory, Air Force Materiel Command, Kirtland Air Force Base, New Mexico. As Chief Scientist, Dr. Cooley is responsible for the technical quality of a $200M annual Air Force space science-and-technology investment. Additionally, Dr. Cooley coordinates these space investments with other government agencies and industry internal research and development to avoid duplication of effort and/or gaps.

Dr. Cooley began his career at NASA's Jet Propulsion Laboratory developing advanced microwave communications and remote sensing technologies while attending graduate school. After completing his doctorate, he spent one year as a Post-Doc Researcher advancing optical calibration techniques in Toulouse, France.

He joined the AFRL in 1998, and has contributed to a wide range of technologies focused on Electro-Optic sensors and imaging spectroscopy from space platforms. In 2004, Dr. Cooley became the Principal Investigator of the Advanced Responsive Tactically-Effective Military Imaging Spectrometer, a hyperspectral sensor built to demonstrate the value of phenomenology for a wide range of military applications. Prior to its launch, Dr. Cooley assumed full programmatic responsibility for the entire TacSat-3/ARTEMIS satellite program until its mission ended in April 2012. In 2015, Dr. Cooley was the AFRL Space Intelligence, Surveillance and Reconnaissance Mission Lead supporting Air Force Space Command and Air Combat Command technology and capability planning processes.

Dr. Cooley has published more than 70 papers in national and international journals or conferences. He has also served as an adviser on space and airborne sensors technology to the AFSPC, the Space and Missile Systems Center, and other organizations.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Mr. Ferraro is the Associate Director of the Earth System Science Interdisciplinary Center (ESSIC) at the University of Maryland, College Park, MD. He is responsible for overseeing the professional growth of ESSIC's scientists, developing several new strategic initiatives to monitor and enhance their performance on projects such as those at NASA. In addition, he assists the ESSIC Director on day-to-day activities at the Center, including engaging other University of Maryland departments and developing strategic growth opportunities for ESSIC.

Mr. Ferraro has more than 40 years of professional experience in the earth science, with an emphasis on remote sensing. During his previous career at NOAA/National Environmental Satellite Data and Information Service (NESDIS), he was the focal point for engagement with NASA on several earth science missions, including EOS, TRMM, and GPM. Precipitation retrieval has been his primary focus with an emphasis on both weather and climate applications. Because of this engagement, NOAA/NESDIS was able to accelerate its use NASA sensor data and products to support NOAA operations.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Dennis L. Hartmann is Professor in the Department of Atmospheric Sciences at the University of Washington, Seattle. Hartmann's scientific expertise includes atmospheric dynamics, radiative transfer and remote sensing, and applications of mathematical and statistical techniques to data analysis. He has authored a textbook on Global Physical Climatology, which is in its second edition. Hartmann was a member of the Earth Radiation Budget Experiment Science Team and was an Earth Observing System interdisciplinary investigation principal investigator and member of the Science Executive Committee of EOS. He served as Chair of the Department of Atmospheric Sciences and was interim dean during the formation of the College of the Environment at the University of Washington. Hartmann has served on numerous advisory and leadership committees for NASA, NOAA, NSF, and NAS/NRC in the US. He served on the Board of Directors of the Swiss National Center for Competence in Research – NCCR Climate, and as Chair of the Board of Trustees of the University Corporation for Atmospheric Research. He served as a coordinating lead author of the IPCC Fifth Climate Assessment Report. He chaired the NAS/NRC Committee to Assess NASA's Earth Science Program (2012), and was a member of the steering committee for the 2017-2027 NRC Decadal Survey for Earth Science and Applications from Space.

Hartmann has received several major honors for his scientific research and service. He received the NASA Distinguished Public Service Medal, the Carl Gustaf Rossby Award from the American Meteorological Society, and the Roger Revelle Medal from the American Geophysical Union. He is a Fellow of the AMS, AGU, and AAAS. He is a member of the National Academy of Sciences of the USA.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Mark K. Jacobs is a senior systems engineer with over 35 years of experience assessing advanced development requirements and life cycle costs for NASA science missions and instruments. Mr. Jacobs provides cost/schedule analysis support to the Explorer, Discovery, Mars Scout, New Frontiers, and Earth Ventures programs, and is currently supporting multiple NASA Standing Review Boards including JUICE, Europa Clipper, IXPE, SPHEREx, IMAP, and Solar Cruiser, and other HQ evaluations including Mars Sample Return. He has significant experience developing NASA cost models covering all phases of a project and with various NASA advanced technology assessments related to instruments, spacecraft, launch vehicles, and operations. He earned his B.S. in Metallurgical Engineering from the University of Wisconsin.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Albert H. Anoubon Momo is Vice President and Executive Director at Trimble (NASDAQ:TRMB), in charge of the emerging markets and funded projects.

In this role, Albert is at the forefront of Trimble's international expansion, pursuing projects financed by multilateral development banks, intergovernmental organizations, bilateral development organizations, export credit agencies, private companies, and local governments in emerging countries. Before joining Trimble, Albert worked at the United States Agency for International Development (USAID), DigitalGlobe (formerly GeoEye), Bechtel, Rockwell Collins, and the National Oceanic and Atmospheric Administration (NOAA).

Albert is a member of the Applied Sciences Advisory Committee (ASAC) of NASA. From 2020 to 2022, Albert also served as the Chair of the Trimble Foundation, which is a non-profit, donor-advised fund to support Trimble's philanthropic efforts. Albert is also a member of the Board of Directors of the Cadasta Foundation.

Albert is a board member of the World Geospatial Industry Council (WGIC) which is a registered not-for-profit trade association of commercial geospatial companies representing the entire value-chain of the geospatial ecosystem. He's a member of the Public Private Partnerships (PPP) Committee and lead the Diversity, Equity, and Inclusion (DEI) Committee.

He holds multiple higher degrees from Johns Hopkins University (USA), University of Maryland at College Park (USA), and Ecole Polytechnique de Yaoundé (Cameroon).

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Dr. Susan L. Ustin is a Distinguished Professor Emeritus in the Department of Land, Air, and Water Resources at the University of California Davis. She began her remote sensing career as a post doc analyzing data from JPL's first Airborne Infrared Imager (AIS-1). Since then she has worked with many types of remote sensing systems, but with an emphasis on imaging spectroscopy to address biochemical and biophysical traits related to physiological processes and identification of spectral species, at scales from the leaf to the globe. She was briefly a member of the EOS HIRIS science team before it was cancelled and a member of the Biosphere-Atmosphere Interactions IDS team. She is a past member of NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) Science Team, and the planned Hyperspectral Infrared Imager (HyspIRI) satellite working group. Dr. Ustin is an author or co-author of more than 250 publications, including as co author, a book on Leaf Optical Properties, and was Editor of the Manual of Remote Sensing, Volume 4. She is the recipient of an honorary doctorate from University of Zurich and the William T. Pecora Award and was elected Fellow of the American Geophysical Union, Fellow of the Ecological Society of America, Fellow of the Remote Sensing Society, and Senior Member IEEE.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Prof. Tonie van Dam received her Doctorate Degree from the University of Colorado, Boulder in 1991. She spent time as a post-doc at MIT and NASA. She then worked as a research scientist for the US National Oceanographic and Atmospheric Administration. In 2002, she moved to Luxembourg where she was a research scientist at the European Center for Geodynamics and Seismology.

In 2008, she became a member of the Faculty of Science, Technology, and Communication at the University of Luxembourg. In 2020, she moved to the University of Utah, where she became a full professor in 2021.

Prof. van Dam is responsible for a number of research projects to quantify the present-day ice mass change in Greenland, to investigate ideas for new satellite gravity observations, and using satellite gravity to investigate how the global water cycle is evolving as a result of global warming. She has recently been inducted into the Luxembourg Academy of Sciences. And in 2019, she received the Vening Meinesz Medal from the European Geosciences Union in recognition of her research.

Appendix: Biographies (Members, in Alphabetical Order by Last Name)

Ms. Marty A.C. Williams is the owner of Fabrications, a small, woman-owned company, based in Port Richey, FL. She has been providing top-quality graphic and document design for more than 20 years and has been growing Fabrications into one of the most sought out firms in the proposal arena. Helping its clients win billions in contract awards, Fabrications serves some of the largest consulting firms, federal defense contractors, global recruiting agencies, IT firms, environmental consulting firms, small, local companies, and networking groups. Ms. Williams edits, designs, and produces graphics for any type of publication or web site.

Appendix: Acronyms

AA = Associate Administrator
ACC = Accelerometers
AOS = Atmosphere Observing System
AOS-I = AOS Inclined
AOS-P = AOS Polar
ARC = Ames Research Center
ASI = Agenzia Spaziale Italiana
ASIC = Application Specific Integrated Circuit
BOE = Basis of Estimate
CALIPSO = Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CALIOP = Clout-Aerosol Lidar with Orthogonal Polarization
CDR = Critical Design Review
CESAS = Committee on Earth Science and Applications from Space
CL = Confidence Level
CLIO = Cryogenic Laser Interferometer Observatory
CNES = Centre National D’Etudes Spatiales
CSA = Canadian Space Agency
DAACs = Distributed Active Archive Centers
DLR = Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
DO = Designated Observables
DORA = Deployable Optical Receiver Aperture
DS = Decadal Survey
EMIT = Earth Surface Mineral Dust Source Investigation
ESD = Earth Science Division
ESO = Earth Science Observatory
ESMPO = Earth Systematic Missions Program Office
ESTO = Earth Science Technology Office
FPGA = Field Programmable Gate Array
GAO = Government Accounting Office
GFO = Grace Follow On
GRACE-FO = GRACE Follow On
GRC = Glenn Research Center
GSFC = Goddard Space Flight Center
HQ = Headquarters
HSRL = High Spectral Resolution Lidar
IBEX = Interstellar Boundary Explorer
ICE = Independent Cost Estimate

Appendix: Acronyms

IMS = Integrated Master Schedule
IRB = Independent Review Board
KDP = Key Decision Point
LMS = Large Mission Study
LNA = Low Noise Amplifier
LRD = Launch Readiness Date
LRI = Laser Ranging Interferometer
MA = Mission Assurance
MC = Mass Change
MCR = Mission Concept Review
MDPS = Mission Data Processing System
MSR = Mars Sample Return
MWI = Microwave Ranging Instrument
MWR = Microwave Radiometer
MWIR = Mid-Wavelength Infrared
NAC = NASA Advisory Committee
PAL = Program Applications Lead
PALs = Project Authorization Letters
PDR = Preliminary Design Review
PE = Program Executive

PIC = Photonic Integrated Circuit
PM = Program Management
POC = Point of Contact
PS = Program Scientist
RSDO = Rapid Spacecraft Development Office
SBG = Surface Biology and Geology
SDC = Surface Deformation and Change
SE = Systems Engineering
SMD = Science Mission Directorate
SMEX = Small Mission Explorer
SRB = Standing Review Board
SSPA = Solid State Power Amplifier
SWIR = Short Wavelength Infrared
TIR = Thermal Infrared Imager
TOR = Terms of Reference
TRL = Technology Readiness Level
TRMM = Tropical Rainfall Measuring Mission
VNIR = Visible and Near- Infrared
VSWIR = Visible and Short=Wave Infrared Spectrometer
WFIRST = Wide Field Infrared Survey Telescope