NASA Earth Science

EARTH SCIENCE ADVISORY COMMITTEE/ APPLIED SCIENCE ADVISORY COMMITTEE

APRIL 16-17, 2023

MEETING MINUTES

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Sara Tucker, Chair

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Lucia S. Tsaoussi, Executive Secretary

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Tuesday, April 16

Call to Order, Opening Remarks

Dr. Lucia Tsaoussi, Executive Secretary of the Earth Sciences Advisory Committee (ESAC), welcomed the members of the committee and the Applied Sciences Advisory Committee (ASAC) to the meeting and called the meeting to order at 8:31. Under the Federal Advisory Committee Act (FACA) rules, the meeting was open to the public and had been advertised on the Federal Register, and minutes were being taken to be posted on the NASA website. All presentations and statements would be part of the public record. The ESAC is a committee to advise the director of the Earth Science Division (ESD) on implementing all Earth Science programs, and its charter is on the NASA website. The first day of the meeting was held jointly with the Applied Sciences Advisory Committee (ASAC), a committee that advises the Earth Science Division director on Applied Sciences.

SGE Ethics Training

Mr. Griffin Farris from NASA Headquarters' ethics team presented the SGE ethics briefing for special government employees serving on NASA advisory committees.

Meeting Charge

Dr. Tsaoussi asked the Committee members to introduce themselves, then Dr. Sara Tucker, Chair, ESAC, welcomed the attendees and asked the speakers to clarify during their presentations whether they are looking for feedback. Dr. David Saah, Chair, ASAC, explained that the main goal and objective of the joint committee meeting was to try to cross the divide in their discussions, and he encouraged the group to talk with people they do not usually interact with. The two committees would determine their findings and recommendations separately.

Earth Science Division Update

Dr. Karen St. Germain gave an overview of recent activities in the ESD and highlighted several recent accomplishments, starting with the additions to the Earth Science Fleet: SWOT, TEMPO, and PACE. The heart of Earth Science to Action is the Decadal's challenge that they pursue the ambitious objective of advancing the science while using the science to make connections between learning and solutions. Partnerships are a key enabler for delivering societal value, so as part of the ES2A strategy, ESD is deeply invested in partnerships with other federal agencies; at the state, local, and tribal level; with nations around the world; and with international organizations. The strategy includes the Earth Information Center, the U.S. Greenhouse Gas Center, and the Responsive Science Initiatives, a new element established to answer research questions that emerge from users of the NASA Earth science data and information.

After reviewing the ESD president's FY25 budget request by program, as well as ESD's budget priorities and highlights, she noted that the division is working hard to prepare the community for the end of the Terra/Aqua/Aura missions. That work will be a big focus for the next few years.

Dr. Venkat Lakshmi asked if there is a way to create a consistent long-term data set for precipitation spanning from trim through GPM to AOS. Dr. St. Germain said the idea of creating long-term consistent records from sensor to sensor has been part of the NASA DNA, but they have been doing that primarily from NASA sensor to NASA sensor. With MODIS to VIIRS, they are in discussions with NOAA because it has to happen, and they need the longer-term records to enable science priorities. Dr. Belay Demoz, who had participated on a study team that looked at the issue, asked if they needed an outside agency to look at it. Dr. Tucker noted that even outside NASA and NOAA, weather observations are still made. Dr. Lakshmi stated that Earth observation agencies, as well as NASA and JAXA, have to take it on.

Dr. Dylan Millet asked about NASA's philosophy on maintaining continuity from the standpoint of research capacity and expertise for the non-NASA assets that will be a big part of the portfolio moving forward. Dr. Jack Kaye said they try to provide stability for the Competed Science Team funding, independent of whether they have a mission, so a community of investigators are positioned to work on the topic. They also try to support mutual cal/val through the European Space Agency (ESA) and the Joint Program Planning Group. They have done a variety of field campaigns to anticipate future missions, including getting precursor data sets that can be used for algorithm development. They also try to figure out how they can support cal/val. If they really want to make sure they are looking at the long-term Earth observing system evolution, they have to go back, reprocess, and maintain that capability. That will be a challenge, but it is something they recognize and try to do.

Dr. St. Germain added that, from the observation perspective, they signed a strategic partnership with ESA and JAXA. Embedded in the language of those partnerships is the idea that they will work together to establish sustained observations in the areas where they are needed. NASA cannot continue launching new observation capabilities every year and building replicas of past observatories. They are heading toward a global observatory and making sure they have the sustained observations at the global level as opposed to the agency level. However, there are examples where they are achieving sustained observations and advancement.

Earth Science to Action Strategy (ES2A)

Dr. St. Germain gave an introduction and short overview of the strategy and noted that ES2A is a whole of NASA Earth enterprise strategy. With the accelerating changes in the Earth's system and an unprecedented number of calls to NASA headquarters for actionable information, the strategy is designed to meet the moment as they look ahead over the next decade. The research they are doing today may lead to decision support tools they do not even know they need, so the strategy is about streamlining the whole process and taking advantage of everything that NASA does.

The word "action" refers to enabling people (e.g., nations to neighborhoods, individual farmers to policymakers) to act where they are when they need to take the action they need to take. NASA is not getting into the business space that is already occupied by other agencies or the private sector, and they are not repurposing the research resources to do this work. Research is the future, the heart of what they do, and they are not going to damage the research portfolio.

After reviewing the vision, mission, and the strategy goal, Dr. St. Germain gave a detailed description of the strategy's two objectives: to holistically observe, monitor, and understand the Earth's system and to deliver trusted information to drive Earth resilience activities. She stressed that understanding what is happening in the Earth system and conveying it is a national strategic asset.

In examining NASA's core values, Dr. St. Germain emphasized the importance of trustworthiness, innovation, and collaboration, and talked about the guiding principal of diversity, an important and high-profile topic across government. Propelling science forward is largely about the quality of the questions being asked, so having more eyes and brains on a problem accelerates the pace of discovery because people from different backgrounds ask different questions. Since the impact of information is different on different communities, they want a broad section of communities to participate when they focus on making the information useful and impactful.

OpenET, a solution that NASA codeveloped, is essentially an ensemble, evapotranspiration satellite product based largely on Landsat and sample data. The spatial resolution allows users to see at the field scale and gives them a best estimate of how much water a field has used, which informs the producer how much they need to apply. It is changing the way water is managed, and the understanding of what those users need came back and fed the virtuous cycle, in that case, the development of Landsat Next.

Every person in the ESD has been asked to let the strategy inform their day-to-day decisions and to see themselves as leaders in the implementation. NASA is positioned to make a difference in this space and feels a responsibility to do that.

Earth Science Decadal Survey Perspective (CESAS)

Dr. Anne Nolin gave a presentation on her personal perspective of ESD's ES2A and its relation to the Decadal Survey. Of the eight recommendations in the Decadal, she discussed two: amplify the cross-benefit of science and applications and pursue ambitious science despite constraints.

The science community knows that resources are constrained, and the broader community needs to know it as well. They hear about the ES2A, and at the same time they hear there is decoupling and delay and reduction in the Decadal satellite missions, so NASA must be clear about how it is communicated.

Implementation approaches for the ES2A are needed. It is not clear that it can be implemented without negatively impacting the science, and the community will feel that it is impossible. ESD should identify and communicate the expected impacts and potential mitigation strategies. When it is properly identified and communicated, the community will understand they may be giving up some basic science, but in return they may receive applied science and improved public support, which is very important because it leads to greater Congressional support.

It is important that they describe the partners/private sector more completely in an implementation plan and how it would work. There are different levels of validation for research products and in order to build the trustworthiness of their deliverables, they have to keep the fit for purpose aspect in mind. OpenET is a great example of that, but they need more examples.

Resources are critical but where do they come from? As ES2A is communicated to Congress and the communities, and the communities demand that Congress act on this through the ESD component of NASA's budget, they will see a return on the investment in a number of ways. Dr. Nolin walked through her take-home messages and emphasized the need to listen to the communities to understand the fit for purpose aspect of what they need for applications and the level of uncertainty that is acceptable to them.

Discussion

Ms. Rhiannan Price asked that if the ES2A strategy is more about the alignment and the decrease in friction, how can that process be measured since the indicators to measure the results are going to be longer scale. Mr. Albert Anoubon Momo also asked how they will track progress and measure success. Dr. Sid Boukabara replied that the strategy's key results are a higher level so they would be comfortable with the progress and success at the end of the timeframe they are giving themselves. There is an ongoing discussion about how to roadmap what they are doing, what they say they will do, what the timeframe will be, and what the specific actions, projects, and studies are.

Ms. Price also asked who are they actually empowering related to accessibility? Is it the farmer in the U.S. who can use the tablet, or is it the female farmer who is data illiterate in South Sudan? Dr. Thomas Wagner replied that one of the hallmarks of Applied Science is coproduction and being user-centered. Unless the user wants something, they are not going to produce it. They are grappling with bringing the latest and greatest from NASA, e.g., a new product from SWOT, into that foray, but they plan to do it.

Dr. Lisa Dilling asked about the virtual cycle and said it seems to be a fundamental change to the way NASA builds missions and satellites to be more usable from the beginning. Dr. St. Germain replied that, historically, they had science teams formed up, but for the Decadal missions they had science and applications teams formed up, which was productive and satisfying. They did not drive the missions to be

applications missions, but they had the conversations upfront and made informed decisions about how to structure the mission and how the data would be used scientifically and in terms of applications. Then they took what they learned and infused it into the guidance for the whole team. Dr. Julie Robinson added that they did some pathfinders, even in formulation of PACE and NISAR, and that informed the way they set up the science and applications teams for the Earth System Observatory missions. That now informs the way they structure their ongoing management of those missions as they come in to development. In their operating plans, it is explicit that program scientists, program applications leads, and data system leads are coequal leaders of the science teams at Headquarters. They are also being more explicit that missions need to integrate with each other, so they have teams thinking about the full spread of science to applications. The virtuous cycle touches external science teams and the way science applications teams are structured in the community, but it also touches the way they work together as people, even in NASA Headquarters, on a mission team, or a cross-mission team.

Dr. David Wilkie asked about the process used to identify the audiences and outcomes for OpenET. Dr. Wagner explained that a lot is driven by their program managers, program scientists, and the scientists at NASA centers. Some come through competitive processes. In some cases, they have a large consortium or they compete a team, and the team decides what the priorities are. Other programs are peer review and people pitch whatever ideas they want. They rely on the community of scientists to drive those needs. Dr. Nolin added that OpenET covers 17 Western states and was developed by her colleagues at the Desert Research Institute (DRI), along with NASA Applied Sciences program and private foundations. DRI and others had been working with farmers and ranchers in very dry places for many years and they listened to what those communities said they needed. Everything came together at the right time — NASA Applied Science program was there, foundation funding was available, and the Google Earth engine existed to make it user-friendly. It lives and functions in the cloud and has a great web interface. Most NASA products are not accessible by anyone who has not had a high-level course in remote sensing, imaging, analysis, digital image processing, and commercial off-the-shelf software. OpenET is only available to people who speak English as a first language, but it would be relatively straightforward to translate it into Spanish. However, the resources are not being put into it.

Dr. Emily Sylak-Glassman said they have a robust way of tracking the use of these applications, and it takes relationships, strategy, and luck. Even with a perfect solution, it is very difficult to get it to successfully transition.

Dr. Saah pointed out that it works really well within your own institution or when working between like institutions. But how do you preserve that co-development framework and approach and still have agility when you cross over to the commercial sector, a foundation, or a foreign government ministry without the same commitments to open science? Dr. Wagner suggested they look on Earth.gov at the Greenhouse Gas Center and the new observations for tracking large emission events. They have made tremendous gains across the entire program in the last decade. People can use a touch screen and scroll with their fingers to see the latest plumes around the world from the EMIT data, a very complex system on the space station. That actionable information exemplifies the strategy where they are heading.

Dr. Danielle Wood saw a need to formalize the process by which they translate the understanding of what science is available at what quality, what users' needs are, and building the systems. That will require system engineering, project management, and social sciences. If NASA takes a systems engineering approach, they will create cadres of people who are specialists in applications, not just those who have done science and been good at applications, but a formal professional toolset of being able to translate between physical science, social science, system engineering, and building the information systems.

Dr. Tucker asked if they are getting input from the larger community outside of the centers and Dr. St. Germain said they have started that process.

Dr. Robinson said conversations with users are happening through OpenET conferences and conversations with philanthropists that may have a specific goal, like reducing infectious disease. NASA can create the ecosystem to ensure the right kinds of opportunities and conversations happen, but NASA does not have to dictate how that perfect combination comes about. If they set up the engagement with the broader community, the highest priority things will have the chance to bubble up and develop in the implementation phase.

Dr. Dilling asked about handing off measurements to NOAA or other agencies for observations that need to continue even as their lifetimes end. Dr. St. Germain said sustained observations may need to be sustained for science purposes, which differs from making them for operational purposes. There is a budget line for sustained observations, and they want to use NASA's agility and resources to get as much accomplished as they can. Often that is to leverage money from other people/agencies.

Dr. Edward Kearns noted that NOAA data comes through a $10B industry that acts as a giant fund for NOAA's data. That type of opportunity is also right for NASA's information, but they need a very deliberate strategy with a forcing function, not an organic approach. However, the speed at which the commercial world works compared to the government will be a huge issue. Are incentives being built into the metrics for NASA scientists to work faster, to share their data quicker, or to get their models out in the street in an extremely timely fashion? Dr. St. Germain said the pace of decisions is the biggest challenge between the public and private sectors, and it is associated with acquisition rules, but more critically with the budget cycle. They could adjust the incentives they build into their programs, because if incentives are structured only around things like publications in particular journals, they are not going to get the enterprise to contribute as fully as they need. Dr. Wagner pointed out issues in working with the private sector, including how fast NASA can process a purchase through its system or getting observations off the sensor faster. The ways NASA serves data are changing, and they are engaged in conversations with as broad a sector of industry as they have been able to meet with.

Flight Program Update

Scott Schwinger, acting associate director for flight programs in Earth Science, updated the committees about the status of the flight program, including recent and upcoming launches and the missions in implementation. POLSIR (EVI-6) is in formulation and they are leaning into a modest cost cap for two CubeSats. The team is moving quickly through formulation and have a PDR scheduled later this summer.

He discussed NASA's legacy of partnering with USGS in the Landsat work and noted they are now in formulation with Landsat Next, an ambitious mission with three orbiting satellites that will push the number of spectral bands of the Landsat measurements. In his status update of the missions related to the Earth System Observatory, Mr. Schwinger noted that for AOS they are looking closely at the architecture and making modifications as they have encountered challenges with the current budget and budgetary outlook.

For the Earth System Explorers (ESE), the first program line that is a two-step process within Earth Science, they are on the precipice of making selections for the nine-month Phase A studies, with a downselect of up to two missions next year.

He discussed the mission cadence and noted that ESD has few options if they receive an appropriation that does not allow them to execute their full plans. Previously, when this has happened, they delayed their competed opportunities. Going forward, rather than telegraphing the type of Earth Venture instruments or missions, they are going to label them small, medium, or large, which will give ESD the ability to dial up or down the size of the opportunity depending on the available budget. The program is planning to give as much notification to the community as they can about the size of the opportunity. By

removing the labels from the ventures in terms of instruments and missions, they will establish a more regular cadence for the opportunities and then dial the value of those opportunities up or down depending on the available funding.

Dr. Tucker asked about the future for LiDAR missions, and Dr. St. Germain said that with the cadence they have of competed missions she expects to see all kinds of technologies coming through the competed door, including LiDAR. Dr. Robinson noted that JEDI has demonstrated strong stakeholder engagement, and the Forest Service would like to use it to do the next U.S. Forest Inventory update. She believes LiDAR will be able to get biodiversity, structure, and how that relates to the way to get total carbon, soft estimates, etc. They are still working on the science requirements with Italy for a multi-purpose LiDAR. Dr. Tucker added that there are LiDAR communities supporting surface observations. Mr. Mike Seablom said they are still soliciting for LiDAR technology developments and getting very strong proposals.

Dr. Jennifer Watts asked if there were any efforts on NASA's part for data sharing agreements with China or mutual parties about their satellites. Dr. St. Germain said there are very strict regulations with regard to any bilateral activity with China. Whether it is possible on a multi-level sense is a different question. Dr. Kaye said there is definitely interest, but he does not think they are actively using any of the mechanisms that might, in principle, allow then to do that, like CGMS or WMO.

Dr. Lakshmi asked how NASA sees the technological edge in LiDAR for CO_2 measurement and, for example, building sensors and missions to add that edge. Dr. St. Germain said technological leadership is, broadly speaking, one of many factors that goes into their decisions about what to do next and how to do what they need to do. NASA does not have the resources to be out on cutting edge in everything, but they also look to ESTO and competitive programs to bring in some of that innovation.

Dr. Christine Chiu asked how to help increase the temporal resolution, not just the spatial resolution. Dr. St. Germain responded that the guidance they got from the Decadal Survey talked about spatial resolution, temporal resolution, and spectral resolution of information and content. They have a mix of those things in the missions they have going forward. A fundamental requirements driver of Landsat is the longevity of the record but also improving the temporal fidelity. In the small sat fleet missions they are starting to see more spatial fidelity. Moving forward, they will have hybrid architectures, some of which will have larger, flagship-type sensors, and some will be comprised of fleets of smaller sensors that fill in the temporal. They may not be able to get improvement in all dimensions in one mission, but a combination of larger and smaller missions and things like commercial and partner data will help to get there.

Dr. Chiu asked how they will come up with a holistic or coherent plan that fills all the dimensions, and what is the timeline. Dr. St. Germain pointed out they do very few directed missions, and they are rooted in the Decadal Survey recommendations. Otherwise, they have competed missions. The NASA flight program relies on competition to bring in innovation and is enabled by the technology investments. A fundamental part of the selection process is looking at the science each mission can uniquely contribute to. Sometimes the big contribution is along temporal dimension.

Research Program Update

Dr. Jack Kaye gave an overview of the Research and Analysis (R&A) Program, beginning with staffing, the ROSES-23 selections for all of ESD, and those upcoming in 2024. It is expected that all solicitations will be dual anonymous for ROSES 2025 and forward. He quickly reviewed some highlights of the research results, and focused on CASI, the Climate Impacts Group, and their sea-level change team, which has worked with NOAA to produce a variety of useful products.

NASA's Earth Science airborne fleet includes the planes, platforms, systems, opportunities, and people that conduct an Airborne science program that supports both research and Earth action and is second to

none in the world. The Boeing 777 is currently being modified to replace the DC-8, which is being dispositioned through GSA. Dr. Kaye updated the group about the Earth Venture Suborbital (EVS-4) Solicitation Process; two potential future field campaigns, PANGEA and Arctic-Coastal Land Ocean Interactions; and NASA Surface-Based Measurement Networks.

In ROSES-22, they solicited Increasing Participation of Minority Serving Institutions (IPMSI) and some of their measurement networks. Through the program, which is only open to MSIs, they pay for the instruments, installation, and faculty to work with students and connect them to ESD science. Out of the 22 proposals submitted, 15 were chosen and most of the funded instruments have now been installed or are in the process of being installed.

The Decadal survey had a recommendation that they work on a long-term strategic plan for a sustained commitment to modeling, so they need to think not only about what they are doing globally, but how can they do things in a way that leverages the capabilities they bring. He reviewed the issues and challenges as they work to contribute to the Earth Action thrust and posed questions to consider. Observationally-driven modeling is unique to ESD so how can they make that useful? How can it inform the models, whether in initial conditions, process representation, quantitative evaluation, or assimilation and reanalysis, to get it into the models in a way that will make them useful? As they evaluate the modeling program to build off their historical strengths, there will be increasing demands on computing, especially if there is a focus on increased resolution. So ESD must pay attention to changes in the computing world, the transition from a CPU-based architecture to GPU-based architectures, AI and ML, and eventually quantum computing. The previous month, the Office of the Inspector General did an assessment of NASA's high-end computing capability, so computing is getting a lot of attention right now.

Dr. Kaye wrapped up with a quick overview of the Global Learning and Observations to Benefit the Environment (GLOBE) Program, the Early Career Investigator Program, and the Student Airborne Research Program (SARP), which now has a location on each coast. He reviewed interagency and international coordination highlights and talked about NASA-New Zealand Research Partnership, which began after the NASA administrator and deputy administrator visited New Zealand in 2023 and committed to explore potential cooperation in Earth Science.

Earth Action Program Update

Dr. Wagner, the new associate director for Earth Action, gave an update on the Earth Action program. Earth Action is generally in the top half of the pyramid, but they are also working on being the arrow by figuring out how they get that information from users and how they incorporate it back into the bottom of the pyramid. He asked ESAC and the ASAC for ideas on ways to collect information.

Earth Action focuses on being user centered, so for anything they do there has to be a user who wants it. They are building bridges to all levels and, for example, taking the latest and best from Earth Science Technology Office (ESTO) modeling and bringing that to Earth Action, where they scale it to fit the needs of the user community.

He reviewed the programs and highlighted some of the newer ones that fall under Responsive Science Initiatives (RSI): Energy and Infrastructure, Greenhouse Gas Center, Satellite Needs Working Group, Wildland Fires, Commercial SmallSat Data Acquisition, and Earth Information Center.

Dr. Wagner ended by detailing several key recent activities of the EA programs: the U.S. Greenhouse Gas Center, the SERVIR program that works with the Ecuadorian government, HARVEST provided wheat estimates for Ukraine, FireSense, a tool to help understand fire in a way that makes sense to the people who fight the fire, the commercial satellite data program, the disasters program, the Earth Information Center, and ARSET, their remote sensing user training program. At NASA, a lot of Earth Action-style

work has been going on for a long time across the organization — in R&A, flight, ESTO, and data, and they will all be working together going forward.

Discussion

Dr. Millet asked if it is correct that if a given portfolio has both applied and basic research aspects, every activity has to be both. Dr. Kaye said at the portfolio level, there will be a mix and they see almost everything they do as having the potential to be actionable because it will address important Earth system science questions. They want to make sure they do not introduce inadvertent roadblocks to people who want to make that connection. Some changes are finessed at the graduate student-led research activity to make sure that people understand that they can choose where they position themselves relative to the layers, and they should not feel constrained.

Dr. Tucker said she does not foresee a successful ES2A without the computing capabilities and asked what they need to solve that problem other than money. Dr. Kaye responded that they need a disciplined way of getting requirements established. Dr. Demoz commented on the need for digital twins and huge computer power to extrapolate on the effect of climate change on urban areas. Dr. Tucker said the need for that type of computing is all connected.
Mr. Joel Scott added that advancing the power of Earth information and Data, making it more actionable is at the heart of the ES2A strategy, but it is also about working better together internally and with their counterparts at Earth Action to understand their priorities, the decision support context they want to support, and working with them to get that information. They will leverage that computing capability where it is most cost-effective when they need to.

Dr. Saah asked if they had thought about investing in that initial build-out and then making it available to the community so they would have that compute at a much more affordable and consistent cadence. Dr. Wagner said they have thought about that, but there are multiple issues. Mr. Scott added they have already partnered with IBM Research and their Watson supercomputer. NASA is bringing the geospatial expertise and is partnering with people who have data science and AI training expertise and the big supercomputer at IBM to develop that model and do the initial lift in a cost-effective way.

Mr. Momo asked about their partnering plans for Geodesy project. Dr. Kaye said for the surface networks, they work with the obvious international counterparts. So for Geodesy, there will be a number of stations and things that they actually build, and then they will look to international partners to pay for and create other stations as part of the network. Dr. Tsaoussi said they are not privatizing, as these facilities are essentially government-owned. They are supporting the International Secretariats for the different online DAAC data distribution services, and those are part of the Space Geodesy Program. Dr. Kaye added when NASA engages internationally, they always try to lead by example and do not ask people to do anything they are not prepared to do themselves. They have to be judicious but look for the rest of the world to do their part because the terrestrial reference frame is something that benefits everyone.

Dr. Dilling gave kudos to Dr. Kaye and the program for their efforts to build diversity and inclusion and their openness to a new generation of PIs, scientists, and other users. In the future, for dual anonymous peer reviews she hoped to see a presentation about how it transformed the kinds of proposals being selected. She suggested it be disseminated broadly so other agencies and people will see it is practical.

Dr. Dilling had read a paper that claimed that with remote sensing and AI/ML, you would be better at stream flow predictions than 25 years of process modeling in the hydrology field. She asked what that might mean for the portfolio of things they are working on. Dr. Kaye said they are seeing it most in weather forecasting where some people in the private sector say they can do better forecasts with AI.

They also hear questions in the community about physics-free models, but the AI models are trained on reanalysis, so perhaps it is not possible unless you get to the point that you can train them solely on the basis of observations. But things are evolving fast and they are struggling to keep up. Recently the Administration worked with the Office of Satellite Data Processing and Distribution at NOAA to do a high-level workshop on AI/ML and numerical weather prediction.

Mr. Seablom said 75 percent of the proposals for the AIST program have some form of AI or ML. The ML is only as good as the training data set that they have. They have seen value in the replacement of parameterizations, where there are good observations to support that, but they do not yet see a replacement for physics-based models. The reanalysis data sets allow emulating the forecast, but the reanalysis data set still has to be created, which requires a physics-based model. On the instrument side, they see growth in AI-enabled instruments, and the PIs are bringing a lot of ideas to the table. Dr. Robinson said that when considering AI models, they are not always most interested in the end number but whether they can predict tipping points. Can they predict things that never happened in the past and identify when cascading effects are going to happen? Other AI/ML approaches, such as digital twinning, are some of the most interesting model spaces they are starting to talk about, and they are working to make sure they have the right breadth of modeling expertise, even in the headquarters team, so they are writing the right solicitations and offering the right opportunities. Dr. Boukabara noted they are watching explainable AI, where physical constraints are included in the training to take advantage of the observational data, as well as the model, in an efficient AI-based system.

Ms. Price asked about aggregated statistics on geographic diversity, the percentage of MSIs working with or who want to work with NASA, and if there other ways to have interdisciplinary exchanges. Dr. Kaye said much is going on with broader community engagement and they need to coordinate with them. The SMD has a Bridge program, and they have a research initiation activity they are helping to support in their Office of STEM Engagement with its Minority University Research and Education program.

ESTO Program Update

Mr. Seablom gave an overview of ESTO, which exists to enable the other four elements: the flight program, data systems, R&A, and Earth Action. He noted that the infusion of new technology is critical for scientific discovery because it enables new capabilities, lowers the risk of mission failure, and helps make complex missions affordable. Missions are becoming increasingly complex with multiple satellite platforms and cooperative with measurements directed by models. ESTO's role is to connect the science used to develop the new missions. His office uses a competitive model to acquire new ideas from the science community; they do not direct people in any specific technology or targeted science topic. They direct them at the Decadal Survey recommendations and solicit ideas, an approach that encourages innovation. Failure is an option because they cannot achieve real breakthroughs without the occasional failure.

After introducing the four core and focused technology programs, he noted that although NASA does not do operational wildland fire management, they have outstanding capabilities in Earth science. The FireSense program's goal is to look at instruments and information systems and how they could mature existing capabilities within the agency and deliver them to operational agencies such as CAL FIRE or the National Interagency Fire Center. That later became part of the integrated effort in FireSense, and the program specifically supports that Earth Action element. An infusion of technologies will result in a capstone Airborne campaign in 2028 to demonstrate the new technologies for the operational agencies. Under the FireSense technology program, they completed a minority-serving institutions prize challenge to solicit ideas for the Capstone mission and encourage entrepreneurship.

The metrics ESTO uses to gauge success include transitions from one program to another, infusions of technologies into space missions, refereed papers that have been published, patents, number of students supported, and conference papers.

The Quantum Gravity Gradiometer is a new project that plans to fly a technology demonstration mission toward the end of the decade. The manipulation of quantum states of matter through the effects of superposition entanglement could produce a paradigm shift for many types of scientific measurements in the next decade if the promise of quantum sensing comes true. These applications include light detection and imaging in low light in Planetary Science, dark matter and dark energy detection in Astrophysics, and ecosystem structures and gravitational field measurements with higher precision and sensitivity in Earth Science. An international race is now underway to develop quantum sensing, computing, and communications, and the Administration has made U.S. leadership in these areas a priority. Gravity field measurements are possibly the best opportunity for NASA to understand, develop, and demonstrate quantum sensing capabilities. The quantum gravity radiometer was considered in the mass change study, and the potential performance showed an anticipated science value. They hope the pathfinder mission can answer questions about cost savings. Mr. Seablom then demonstrated the QGG Reference Design Physics Protocol, which is the purpose of the pathfinder mission.

A study was conducted to determine the overall impact of ESTO, including advancing TRLs and where the infusions have been made and highlighted the technology on SWOT, TEMPO, PACE, and NISAR. For their strategic direction, it is important that they are mission-focused and consistent with what NASA has been doing in the last strategic technology investment plan. Their goal is 10 percent of their investment is transformational, and going forward they are pursuing several emerging technology areas, including quantum sensing, digital twin architecture, and new observing strategies.

Earth Science Data Systems (ESDS) Update

Mr. Scott updated the committees about ESDS and noted that one of ESDS's vital successes has been the Distributed Active Data Centers (DAACs), which are distributed across the country. Each DAAC has a specific focus and is centered around the user community. They not only work with the missions and science and application teams, they also work with their user working groups to find out what the user needs are in each of those communities and bring it back into the DAAC activities and at the program level. ESDS want to be responsive to their needs and support the foundational research, as well as the Earth applications and actions. ESD collects a large amount of data and elements of data systems run through the entire ES2A pyramid, so ESDS works to be good stewards of the data and make sure the data is findable, accessible, and operable, and reusable.

ESDS focuses on Open Science to accelerate discovery because the Earth is facing some big challenges and they need more minds on the problem. ESDS is facing challenges with the growing data volumes, are evolving to meet and achieve the ES2A strategy, and were involved in the architecture in migrating SWOT and PACE data at Goddard and JPL. SWOT is now end-to-end in the cloud, and PACE data is being served out of the cloud.

ESDS has high satisfaction scores, but with the large amount of data coming in, they need to create an innovative way to meet user's needs so they can access the data. For example, they are working to enable the DAAC that will be responsible for NISAR data to aggregate and subset the data users want so it has a smaller footprint, while still giving them the information they want. They are migrating to the cloud and by having data stored in one place, colocated from multiple missions next to compute, they will be able to adapt to the growing data volumes.

To understand their user needs, all of the DAACs and user working groups have program scientists from R&A and Earth Action recommend members to be on those different user working groups to be able to understand different communities' needs and scientific expertise.

AI is an emerging area and there will be a lot of disruption around it. Mr. Scott said they need to do it within a trusted framework and determine what aspects needs a subject matter expert's review. Machines are not always great at identifying things they have never seen before, so that is when a human needs to help make sure that they are deploying AI in a trusted way.

In the last few decades, data, software, and their computing frameworks have evolved, but the scientific method is still the same. The way information is shared needs to evolve, and that is where Open Science comes in to accelerate scientific discovery in a robust way. People can still put citations, licenses, or Creative Commons on it so they can be cited and credited, but then someone else can come along and build upon that work.

Mr. Scott told the group about a massive open online course (MOOC) at openscience101.org, where they learn skills related to Open Science; what it means for data, software, and publication; and how to properly site and credit others as they engage in these practices. He also recommended that the committee members sign up for the Earth Data Discovery newsletter at earthdata.nasa.gov/subscribe.

Discussion

Dr. Lakshmi organized a chapter conference on remote sensing of the traditional water cycle from sensors to science to society. The report, which talks about things that will provide background information for the next Decadal survey, will be available soon.

Ms. Plale asked if the cloud was private or commercial. Mr. Scott said it was on Amazon's Web Services. She asked if they coordinate with NOAA on some of their work. Mr. Scott said a lot of technology is shared and coordinated between the two agencies. One example is the Earth data common metadata repository. ESDS is always looking for ways to coordinate with NOAA in terms of in-region access and direct S3 access, and making sure they are operating in complementary ways.

Dr. Wright asked about an ESTO-type in the Planetary Science Division. Mr. Seablom said there is a technology "federation" in the NASA Science Mission directorate comprised of the four Division technology offices that meet monthly under the direction of the SMD chief technologist. At that meeting, the notes are compared, solicitations are discussed, and any overlap occurs (although there is not a lot of overlap). For information systems, they did an autonomy workshop in 2018, and a lot of the informatics could have great potential.

For the five million users of EOSDIS data and services, Ms. Price asked what a typical or aspirational user looks like in terms of education, access to certain infrastructure, conferences they attend? Mr. Scott pointed out the restrictions on what they are allowed to track and monitor on users. They can get information from email addresses (.gov or .edu), but it is tax payer-funded, and they try to reduce barriers and do not have a paywall. People who register for a print data login are eligible to receive the American Customer Satisfaction Index survey, which has some demographic questions about their backgrounds, expertise, and interests.

Dr. Millet said the shift to the EVS proposals where the team is identified in a subsequent step is a positive outcome in terms of flexibility and the diversity of the teams. It may also decrease the burden to entry and increase the representation of the proposal pool, since for the previous EVS's they had to be at a Center or have a very close Center affiliation. Dr. Kaye agreed and said previously a lot of people came to

the Earth Science project office at Ames for help writing the proposals. Now it is simplified and focuses on concepts for missions that makes sense.

Dr. Kearns asked what incentives they have to get NASA scientists to contribute their model output to the DAACs and get it on the cloud next to the AI applications that exist in the commercial cloud. Mr. Scott pointed to the levels of service in the ESDS program on their data website, which shows what level of service the DAAC and the archives give the different data types. The intent and purpose behind the data helps inform the level of service they give it, and they have to be judicious given budget constraints. Dr. Wagner asked if TOPS is creating an archive to support the Open Science requirement for model output. Mr. Scott noted policy SPD-41A, the SMD policy on Open Science. If people want to cite their data there options like Sonido and resources connected to the OS101 curriculum that show where to cite it and still be compliant with Open Science policy. Dr. Kearns asked if they are pursuing a strategy to identify and keep the most used data sets at the highest level, while pushing those with a limited audience down to something like Glacier storage, which saves cost. Mr. Scott said they are pursuing that type of cost-saving measure.

Dr. Wilkie asked where to find a VEDA-powered NASA site, and Mr. Scott directed him to the portal for the Earth Information Center at Earth.gov/ghgcenter.

Dr. Dilling wanted to know how ESTO improves science. Mr. Seablom said the technology Pathfinder is not a science mission but it addresses barriers to what could be the next generation mass change mission. Dr. Tsaoussi said their studies are defining the base level, which is based on 300km monthly observation of current missions. To answer hydrology questions, they look to go to 100km and observe 80 percent of the water basins in the world, as opposed to the 20 percent they fully observe now and move from monthly to weekly data. Once they prove the quantum gradiometer can make those measurements in space, the instrument needs to be further advanced to measure the gravity. Dr. St. Germain added that the gravity measurements track the movement of water around the planet. If that can be done at higher spatial and temporal scale, they can take more direct action on everything from food security to water security. Dr. Dilling said it would be helpful to have an illustration of that in the presentation rather than a chart.

Dr. Saah asked what are the biggest gaps in the program they should be thinking about. Dr. St. Germain responded that while have they great models, they have to advance the modeling strategy to get the kinds of predictive capability at the scales and parameters that people want. It is a very complex problem, and storing and stewarding that volume of data and feeding it into the models within the resources available is another challenge. Within a year or so, the data from SWOT, PACE, and NISAR will double the total data volume. Dr. Saah said they are so dependent on the data products that they may need to think about using the analytic, getting it close to the data, then getting access to augmented high-computer environments using foundation models to try to accelerate it. It would require a national effort, and it would be interesting to see where NASA fits into the conversation. Dr. Robinson is concerned about false data from AI and modified photography. NASA has a highly trusted brand, but with open data, there is an accompanying risk of false data.

Dr. Boukabara said the challenge they face is connecting the data, models, and applications to the decision-making in a comprehensive fashion so that when they give actionable information and assessments.

Dr. Tucker asked Mr. Seablom if 10 percent of the budget going to transformational technology is enough. Mr. Seablom said the 2017 science technology investment plan determined as guidance for the whole agency that technology would be focused primarily on mission-enabling work. If they did 25 percent transformational, they might lose the R&A program scientists because they were not focusing on the primary mission. Without transformational, it is not NASA anymore. Mr. Scott added there are

transformative actions in all of the elements, not just ESTO, and they used more than 10 percent to evolve the data systems and examine how to explore new technologies and AI and leverage the cloud.

Ms. Plale asked Mr. Scott about their organizing strategies, and he said the growth in the curve is largely driven by SWOT and NISAR and, to a lesser degree, PACE. The ESO missions are not in there yet, but in the next decade, it will not be that much more. They do need to think critically about the data that may not have unique information, and they may need to rely on emerging technologies like AI to figure out where the really valuable information is coming from and prioritize it.

Dr. Lakshmi said the real power of AI will not come in figuring out what happened 20 years ago or predicting the future, but in whether they get it better than a physical model. He emphasized that most people study subsets of data, so access from the cloud by a specific person or group for a specific research problem does not seem to be that large compared to NASA's problem of doubling their data holdings every year. Dr. Kearns has seen the graph of increasing data volumes his entire career, and it has never been the problem. The actual information that needs to be extracted from the data is very important, and that is where AI can come in. He noted that the people doing AI that have gotten far without SMEs on board, so bringing that technology to NASA with all of its SMEs will be transformational.

Dr. Saah believes the data is never a problem, but if the compute is next to the data, and the data is located in a place on AWS with a price block, that is trouble. In some programs where the compute is a challenge, they need to make sure each of the hubs has an integrated compute strategy so that barrier can be removed. Dr. Lakshmi is not worried about the computing, but the storage part concerns him. Dr. Jennifer Watts said her community is concerned about data being privatized.

Dr. Lisan Yu read a paper that predicted the physical oceanography field is going to disappear in 20 to 30 years. She was impressed by the power of the data and said if they have a lot of data, they do not need the physics. The future is changing, and the people in the room will not lead it because they do not control the engine of computer science. Dr. Saah pointed out that universities like Berkeley are combining the data science and physical science programs and creating a new college.

Dr. St. Germain passed out the first Earth Day posters, then Dr. Saah thanked Dr. Tucker and Dr. St. Germain for coordinating the combined meeting.

The meeting was adjourned at 5:04 p.m.

Wednesday, April 17

Call to Order
Dr. Tsaoussi welcomed the group to the second day of the meeting, and Dr. Tucker called the meeting to order at 8:42.

Public Comment
There were no public comments.

ESO Mission Update
Dr. Robinson filled in for Dr. St. Germain to update the committee on the ESO missions. There were five designated observables treated co-equally in the Decadal Survey, and seven sets of measurements for the Explorer missions that were also treated as co-equally.

Although they had a solid FY2024 budget, delays and reductions from the original Decadal survey plan required them to create a strategy to address the budget in the cost plans for the missions. Ultimately, they decided to use a decouple, partner, and compete approach to reduce costs.

Dr. Robinson discussed the IRB's concerns about coupling a partner mission and a NASA-built mission in SBG and the risk in AOS of having two major instrument developments that were proposed at the Mission Concept Review that had never flown before. The IRB also recommended they focus on how they are going to integrate the science of all the missions to accomplish the Earth System Observatory goal of advancing the understanding of the Earth's system as a whole. Several teams are working on different concepts, and they are making progress on that.

Dr. Tucker asked if they are keeping the names Storm and Sky. Dr. Robinson explained that without the backscatter LiDAR, they are not sure that AOS-Storm is the right characteristic, so they are going to let the project team come back with a recommendation. AOS-Sky does have a reduced scope from the previous Sky, but they believe the name will be retained.

Dr. Lakshmi asked about the change in the retrieval of precipitation from GPM to AOS. Dr. Robinson said it is basically equivalent.

Dr. Demoz wanted to know if they had done a risk-benefit study on having CALIGOLA decoupled as opposed to a NASA built. Dr. Robinson replied there is risk in the LiDAR no matter what they do because the LiDAR presented at the AOS MCR and the LiDAR in CALIGOLA have never been built. But by collaborating, NASA is not covering all that risk, so the decision was driven more by budget than risk assessment. In reality, the alternative was no LiDAR.

Dr. Robinson explained that they will need a delta KDPA, and they have to see if they can meet the cost targets they identified for the NASA-contributed components. A team is doing the preformulation study with ASI on CALIGOLA, so much could still change in the structure. No one else is partnering with ASI on this, but AOS remains a full integrated partnership so the contributors to the missions are a part of all the science teams. They are having conversations about what is assigned to missions, to AOS, and to ESO in a collective way. Level zero and level one products will stay with the missions. Some level two products may stay with the missions, but level twos and higher will be cross-mission.

Dr. Chiu asked about the SmallSat and the radiometer. Dr. Robinson said the CNES radiometer is the only thing flying there, so they do not need a spacecraft as big as they would for AOS-Storm. It is a microwave radiometer. It is important for the community to understand that they have found ways to

reduce costs to make it work, but they have budget constraints. If they encounter any challenges, they will start losing the ability to keep all of the mission elements.

Dr. Lakshmi noted that the GPM IMERG or the precipitation from space has revolutionized hydrology in the past 10 to 15 years. The work done by NASA, along with its partners, is immeasurable for hydrology. Dr. Robinson added that one reason they renamed that budget line PMM was to emphasize that it is precipitation continuity for the world and is incredibly important for science and applications.

Dr. Rowena Lohman asked about a NISAR follow-on like GRACE and the decision to end the SDC DO study. Dr. Robinson replied that when the Decadal Survey was authored in 2017, the expectation was that NASA would already be in extended operations with NISAR and they would be doing formulation of an SDC mission as a follow-on to NISAR to meet the recommendation of having SDC observations in this decade through the NISAR mission. But NISAR has been delayed and has not flown yet. The people who were working on the SDC pre-formulation studies are largely on the NISAR science team. The community is doing good science either way, so it does not make sense to keep doing architecture trades when they might learn a lot from the measurements taken in NISAR.

Dr. Millet asked how the data was handled for the collaborative missions with Italy and France. Dr. Robinson said there are open science principles in the implementation agreements with other space agencies. On some missions, they modified the agreement to fit various legal constraints in different countries, but they intend to have them as part of the overall NASA mission pool. NASA investigators will have access to all of the data sets and participate in the mission, AOS, and ESO-integrated science teams. It is important to their collaborators that the science community is included with competitive science teams. They all share the common purpose of open access to the data and innovation and sometimes to multinational publications and science activities.

Dr. Chiu asked Dr. Robinson how things can be done differently and reduce the uncertainty when they do observations the same way, for example, AOS-Sky. Dr. Robinson replied that the structure they have today has all the major capabilities of Sky, but it is on three spacecraft flying in formation rather than on one big spacecraft. They do not think that affects their ability to address the uncertainty aspect and is part of why they did not cancel any component. Dr. Chiu added that a new capability is probably crucial to measure something they have not previously measured or where the source of the uncertainty comes from. It could be something related to aerosols, or the clouds, which is really about the cloud structure & processes. She said they need to think about the normal way to analyze the observations to do great science. Dr. Robinson said they have kept the opportunity open for a new capability. If someone comes in to the Explorer class mission with a new capability for cloud profiling within the cost cap, they will get it. The alternative would have been to back it off to more of a copy of a previous radar. Dr. Tucker recognized Dr. Chiu's concern as valid. Not having the HSRL limits the opportunity to reduce uncertainty about aerosols. They can try to help CALIGOLA develop a mission that will do as good as possible to meet those science needs. Dr. Robinson said the Decadal Survey gave very clear guidance that if they have budget challenges, they should prioritize completed missions over directed missions, and in some cases, it was only through a major investment in a directed mission that they would have gone further. The challenge with HSRL is it was not ready based on the IRB report.

ESD Communications Strategy

Ms. Wendy Mihm, communications lead for ESD, told the Committee that in 2020 Dr. St. Germain recognized the need for a more streamlined communications machine to share ESD's stories. Based on audit results, she established a working group. Since they have built an ESD communications team with expertise in all relevant disciplines: digital expertise, best practices and analytics to make sure that web and digital content breaks through, strategic messaging and leadership support, internal communications,

written and video storytelling, public engagement and events, and visual branding and visual design capabilities.

Discussion

Dr. Watts asked how ESD is communicating with Congress. Ms. Mihm said when they go to the Hill, if they know who will be in the audience, they take very specific examples down to the imagery or science work being done in their states that benefit their constituents. Often, they are talking to staffers who are very young and may not have been exposed to the information, so the Communications team starts from the beginning and makes information bite size and has handouts in plain language that the staffers can take with them. Dr. Chiu thanked Ms. Mihm and her team for the work on this important issue.

Dr. Lakshmi asked about approaching conventional media, including a Sunday morning show. Ms. Mihm responded that whenever they can get on those shows, they try to do that. Their office takes the lead on big picture media elements like that. It is really important and effective in the world of marketing communications to take an opportunity to tell a story in an organic way that links to something happening in the real world.

Dr. Helen Pillar shared her perspective from the ECCO ocean modeling community. Working with NASA experts the past few years to improve their data visualization and storytelling, present story maps that build a coherent picture of the support they can offer for science, increase their user base in sciences, and acquire industrial partners for things like informing marine carbon dioxide removal has been so important. It would be valuable to have a training on how to communicate more clearly available to the wider NASA enterprise. The Communications team is developing a brand book with the goal of having it up and running by the first quarter of 2025. Then they would like to offer trainings, not just to the immediate Earth Center of Excellence, but to other people so they can use those guidelines and some of the best practices.

Digital Twins for Connecting Data, Models, and Decision-Making

Dr. Boukabara gave a presentation to inform the committee about discussions they are having within NASA Earth Science and the community about using digital twins to connect observations, models, and decision-making. ESTO and others in the community are already investing in digital twins for some of the 16 areas identified in the ES2A strategy that are essential to a thriving world for all. He asked for the committee's feedback about his presentation.

One objective of the ES2A 2024-2034 strategy is to holistically observe, monitor, and understand the Earth system, and he focused on the key element of a comprehensive digital replicability of the Earth, which means capturing the multidimensionality of the Earth system, including other relevant components. Some studies show that accounting for the human aspect of the societal impact in the environmental modeling is important, but not as boundary conditions for decision-making. Feedback on how humans interact with the environment and how the environment impacts humans will affect the accuracy of the forecast, so it is important to include that in the digital replica. NASA actually has those assets.

A digital twin is an integrating and connecting function to promote coordination between assets in NASA and agencies, philanthropies, the private sector, and academia. At the high level, a digital twin is a classical control system. Ms. Plale asked if he was envisioning it in logical time or real-time? Dr. Boukabara said that, in theory, it would be something you operate on a regular basis, perhaps half a year, to compare your state of the Earth and the environment in general, with the actual state you had set. In Earth Science they can think of it as the value chain of what they do. A digital twin will not replace the National Assessment or the IPCC report, but it provides one tool to see the state as a whole.

Dr. Boukabara highlighted the importance of finding a way to collaborate and coordinate among a multitude of entities. If they have this capability and combine it with open data and open science and get it out to the community, it will lead to the reproducibility, transparency, and trust they strive to achieve. It could also lead to a mechanism by which they can garner contributions and capture new knowledge and discoveries.

Discussion

Dr. Demoz asked about the risk of diffusion and the contribution of DOE. Dr. Boukabara said they are looking for a memorandum of understanding and strategic agreement with DOE, not exclusively, to leverage each other's assets, including high-end computing. They are also looking to others including IBM and Google, who are moving quickly with GraphCast and Forecast Net. As for the risk of diffusion, they should pay attention to gap identification (PPM), but they still need to look at the Earth system as a whole. They might need to focus on the PPM because there is an actual gap, but not at the expense of having the comprehensive view of the Earth system. Dr. Demoz agreed but expressed concern about the lack of funding and the large investment it would require.

Dr. Tucker asked if there is funding dedicated toward this effort. Dr. Boukabara said they had discussions outside of the budget constraint. However, if they can show the benefit of it to multiple stakeholders, it will create a positive cycle of support. Then, combining it with the ES2A strategy could create the potential for additional support.

Although Ms. Plale thought the vision that Dr. Boukabara articulated could accomplish a lot, she noted if it moves along at six-month increments, when they reach the point where things are actionable and others want to engage, they will want to go faster than real time to understand the implications of what they are doing and that will add an additional computational demand. There are two time-related aspects, Dr. Boukabara said, one for the modeling, one for the observation. The model projection is probably not something they will do every day for climate projections, but the observation needs to be kept as fresh as possible because some users need that data. They have not talked about the query aspect, but he could see it would need to be fit for purpose for different applications.

Dr. Pillar thought it is a really important work and that NASA has a need to integrate existing, valuable, well-established assets around modeling, observing, and data assimilation, and the digital twin allows for that. She asked if they had thought about the communication of uncertainty and constructing a rigorous uncertainty quantification education framework as part of the tool, not just the forward modeling capabilities and the observations. Dr. Boukabara said he agreed from a technical point of view. The uncertainty quantification is listed in the ES2A strategy as part of putting together the digital replica.

Dr. Yu gave kudos to Dr. Boukabara for including applications in the modeling systems concept and asked if they will integrate that decision-making through the application module and have it influence results. Dr. Boukabara said that assimilation is limited to MWP, so the geophysical scope is limited and goes only to the environmental prediction. It is an extension in terms of geophysical scope as well as the output. Dr. Yu noted that it is a very complicated system that will require computational skills, a geophysical background, and decision-making skills. She asked about training components in the design. Dr. Boukabara said they are not talking about training at this point. Expertise from remote sensing to modeling, communication and social science will be needed, but they want to bring together different expertise to support the initiative rather than training anyone to do everything.

Dr. Wright asked about weak links in the chain to build an effective digital twin that meets requirements. Will the system observatory provide the designated observations required to strengthen those links? And if not, what do the technologists and budget people say about the time scale for making the observations to fill the gaps? Dr. Boukabara replied that they will make do with what they have first, and that will

allow them to identify the gaps. They will address the gaps through partnerships, additional budget, and exploring various technology paths.

Mr. Seablom noted that digital twins was one of the major topics in the recent advanced information systems technology program solicitation and will allow them to prototype and learn what the architecture needs to look like and how to accommodate the data and models in a form that a digital twin can use. They will get a variety of use cases and answers about the architecture through the prototyping efforts then build the framework around proposals from universities, field centers, and other ideas.

Dr. Tucker asked about the risk of not having an observation they need to get information and the quality or efficiency of the digital twin models. Dr. Boukabara said there is probably a risk, but they are starting from the assumption that they have good enough observations. Dr. Rivero-Calle shared concerns based on her experience when satellites do not agree with each other on ocean satellite data. From a biological perspective in the ocean, there is so much variability that the scales at which they measure things change greatly and the uncertainties can be huge. Also, some of the global climate models do not agree. Dr. Boukabara shares the same concerns. Digital twins will not replace the IPCC or climate assessment, but it will give the state-of-the-Earth system with their current capabilities, flaws and uncertainty included. Dr. Rivero-Calle said it looks like a black box, and she does not see how they will get to final answers with those outcomes. Dr. Boukabara said it is about collecting the existing tools.

Dr. Lakshmi asked if they are going to put resources and focus on extreme events when they do "use case" simulations with digital twins. Dr. Boukabara said assets, such as models that have a portion of their effort on extreme weather, would be a component of the digital twin value chain. If they combine different models for all of the time scales with application models that give spread of species, biodiversity, agriculture crop yield, water resources, or energy capacity, it gives not only a risk assessment, but also the geographically distributed impact in the future or statistics with the climate extremes. It leverages what they have all the way to decision-making and solutions. Dr. David Considine added that for the digital twin construction, they have the digital replica, which is subject to the problems with current models when they cannot represent extremes as well as they would like. They have to have a system that is fit for purpose. It does not have to be an extraordinarily exact reproduction of the whole Earth system, but it needs to be able to capture the extreme situations they worry about. During construction, they will evaluate if it is fit for purpose, if it captures extremes, and what they need to do to improve it over time.

Dr. Chiu asked how NASA's work on digital twins compared to the Europeans. Dr. Boukabara said the Europeans have a lot of funding and two major models they are working on at the one-kilometer, possibly the sub-kilometer, resolution for climate and extremes. ESA is working on applications to be added, and there is a lot of value in working with them on lessons learned. If NASA combines the infrastructure to capture knowledge and contributions with open science and open data, they will be able to create an ecosystem where people can contribute commercial data and AI companies can contribute. The design has an element of infrastructure and flexibility that will allow collaborations.
Dr. Pillar asked about lessons learned from Destination Earth and predicting extremes for long-term adaptation strategies. Dr. Boukabara replied it would require discussions with people more skilled than he is to decide that, but it is something to address.

Dr. Tucker asked about Advanced Information Systems Technology (AIST) efforts and the approach being taken to tie them together. Mr. Seablom said that AIST is about $23 million a year, with much of that for digital twins. The proposals just came back and are going to be doing prototyping efforts to sketch a use case for small, focused efforts. When they look at the composite of those, they will consider what architecture can accommodate multiple use cases. There might be a coastal zone or an agricultural digital twin. The program will shepherd the prototype development, and what they learn from the prototypes will

be fed into the final architecture. But NASA AIST is not dictating how the digital twins are done; they are soliciting from the community.

Dr. Robinson pointed out they are providing opportunities to treat this as a technology development and letting the community tell them the kinds of problems they think they can solve. There is an open solicitation for proposals opportunity and some competed activities in the portfolio where they are looking at whether a digital twinning approach solves a specific problem. Also, they are strategically adding it to the set of things that Earth Science supports, because they have not traditionally supported these kinds of approaches. Dr. Boukabara laid out a framework for rolling that in to address concerns that they might be missing opportunities to have impactful conclusions unless they incorporate a new modeling methodology into the tools. It will need to be evaluated to see if it offers advantages. They are opening the aperture and allowing a new modeling approach to become part of the enterprise. He added that there is a whole spectrum of types of digital twins, so the issue is how they will leverage it into a capability that will be helpful for society, decision-making, and mitigation strategies, etc.

Dr. Tucker asked how it will pull in information from outside-funded NASA work. Dr. Boukabara said they have to be intentional about partnerships to increase the collective value, but it is a work in progress. He said feedback from the committee would be useful.

Dr. Lohman asked if there is a potential partnership with DOD. Dr. Boukabara said they are talking to DOD, but the question remains, how will they approach it in a way where everybody brings their expertise, assets, and models, and puts it together for the benefit of all? They have to find ways to coalesce the communities, as well.

Ms. Baynes pointed out that within data systems they have been working on determining what the organizational requirements of the future will be and how those requirements can be intentionally done to serve specific research and public purposes. They want to repeat the things they have done with the Earth Information Center and Greenhouse Gas Center in a more intentional, repeatable, transparent manner.

Dr. Chiu asked that they keep poorer users in mind when they design the system or data so that users with fewer resources also have a chance to explore the tools.

Ms. Plale asked if the proposals will have a commitment from the agency to help with opening up an API or a streaming interface. Do the proposals have an implied ability to work with NASA? Mr. Seablom said they intend to give them a sandbox to explore their ideas, and then NASA will look at the results from what comes out of it, and that will lead to standards. Ms. Baynes talked about OpenScapes, an organization they have been funding at a pretty low level that focuses on not only migrating users to the cloud, but also teaching user support agents and people on the ground how to support users in the cloud by developing reusable toolkits for interacting with the data. The distribution of data from the cloud has now surpassed the distribution from on premise systems. That includes people who are downloading and operating on the data in the cloud. Ms. Plale asked if they use Amazon-hosted sandboxes for these proposals, and Mr. Seablom said they are not, but they eventually could be.

Dr. Tucker asked Dr. Boukabara if he has an assessment of what will be needed to start. He said they did not get to the point of programmatic implementation, but it is part of needs assessment and then pragmatic execution solutions of partnership versus leveraging it.

Dr. Millet asked how they think about maintaining connectivity as other models are evolving while they are developing this overarching infrastructure. Dr. Boukabara said the models will continue to evolve while they continue to improve. There are a lot of ways to create that capability without impeding or slowing down the evolution of the individual components.

Dr. Tsaoussi said considering what principles, ideas, or issues they could take in consideration when developing the implementation plan would be constructive. Dr. Robinson said it would be most intentional to connect things so they develop level three or level four products that cross missions. Ideally, that would be done with the science team that identified the product, why it was needed, and how to build it. She reviewed examples of various ways things could be connected and said the key is to be science-driven or user-need-driven in the case of Earth Action-type work, and then make sure they do the most important pieces connecting those things. The overarching ESO integration questions might be something they should address at a future meeting.

Dr. Boukabara said there are scientific arguments for integration on the input and output side. On the input side, there is the importance of the interconnectedness. On the output side, the water resources application should feed the agriculture and agriculture should feed wildfires. That is how to get the cascading effect and the ability to assess tipping points. To maintain the integrity of the research, they have pieces of the puzzle, and they are all important, but it is about putting them together to get the big picture that everyone should be striving for.

ESO Integration

Dr. Wagner updated the committee on the integrated ESO project (iESO), a concept currently under consideration, and asked the committee for their advice. He reviewed the four primary objectives of the project and the two-phase process they are considering. Dr. Robinson noted that this idea was a recommendation of the independent review board for ESO, and they owe them a response. So they need input about how to do it and how to identify and message its value.

Discussion

In response to a question about digital twins, Dr. Wagner said they are going in a direction of modeling and digital twins, and they need an analysis-ready data set for people to check those models against, although there will probably be changes in resolutions and formats. Some missions are already in phase B, but they are already pretty mature and will probably not change instruments or orbits. But there might be changes to level three products and beyond.

Dr. Tsaoussi noted that there could be an unlimited number of level three and four products. Beyond level two, the community has to weigh in through competition, which causes delays. So how do they bound the ideas people have and have a sense it is done correctly and is of high value? Could there be classes of level three or four products that do not require that rigor? Dr. Tsaoussi asked the committee for principles along those lines.

Dr. Kaye noted that in principle, the mechanisms they have allow them to do cross-mission integration, but a lot of them do not kick in until after the mission launches, so the cross-mission and integration may end up competing with exploitation of data they already have. A post-launch competed science team is typically exploiting existing data, new products, and alternative algorithms, and they always encourage integrating multiple data sets. It definitely has the potential to put a lag in the system if the work on integration across missions can only start the year after the launch. There are tools to do integration across the missions, but they are slow and constrained. He asked how they get ahead of the curve and what does it mean to do that.

Mr. Seablom said the concept of SensorWeb was to use multiple satellites to perform adaptive targeting of a feature of interest. ESTO studies have done some demonstrations with the commercial satellite Capella, and they think it is a tool that could be useful for the scientists involved in iESO activities.

Ms. Plale asked if the DAAC would create these integrated products, and Ms. Baynes explained it is not the responsibility of the DAAC to generate new products. It is the responsibility of the DAAC to make sure that existing products and new products coming into the system are more usable for cross-interoperable.

Dr. Wagner explained that ESO missions are only defined as new missions from the Decadal survey: surface biology and geology, surface deformation and change, mass change, and the AOS, which combine two of the atmospheric missions. Now they need to think through all of the changes (the potential for models and AI/ML, and challenges) because the combined outcomes of it is greater than the sum of the parts. They should not think of ESO by itself because there are other kinds of satellite data that play a big role, so how do they bound the concept? Dr. Considine added that they could imagine, with the JPSS or NOAA platforms, finding synergies between measurements that are made with the cloud profiling radar and the LiDAR and the follow-on to AIRS instrument. If there is a real scientific issue to be addressed using a particular combination, then it would be silly not to consider that to be part of a combined observatory. NASA has a history of trying to use its instruments in a non-stove-type fashion, so they are trying to be more deliberate about structuring themselves so they can exploit the whole observing system.

Dr. Demoz said NASA has a role in getting to a place where it is easy for the community to use it, but they have to be careful about knowing where that limit is. As they go forward, a satellite mission train and other things have a role in getting the data to a place where it is usable. Dr. Chiu agreed the data integration involves a different level of complexity, and the bundle data is very powerful. She asked if NASA had done a survey or used AI to look at the people who download data or papers. Ms. Baynes said they have done so, but the problem is getting people to consistently cite the data properly. NASA has done surveys and tries to extract data from papers, summaries, and abstracts to map thematics. They have metrics for how much data is used, but they have not been very good at tying that to actual publications. Dr. Chiu suggested it would be better to have users log into certain machines with a code provided by NASA to get the data so they do not have to download it. Dr. Wagner noted the group seemed to agree with that idea and said perhaps people could be working in a cloud environment. How does NASA optimize that, he asked. It is almost like next generation science. Ms. Baynes mentioned that OpenScapes was working hard to provide something along those lines.

Dr. Wagner said they would like the committee to tell NASA what multi-sensor products they should produce moving forward and scope the multi-sensor products using ESA, private sector, and NASA assets. The question is how they bound it, he said. Ms. Baynes noted the committee may also have input on some process issues. Once they compete a science team and get a list and priorities, they need to think about procurement. Are they directed, competed, or just a simple implementation at the DAAC level? Dr. Millet supported thinking holistically about the global observing network because NASA is no longer providing the assets for some observables, which are crucial to include. Also, they should include a competed aspect because if it is that broad, no matter who is in the room it will be hard to cover that scope intellectually.

Dr. Yu believes that if they bring all the data together in the cloud, have an easy-to-access interface to query that data, and push it to its limits and test out synergies and data fusion approaches, NASA will hit a lot of their targets. It is also important to include all NASA data possible, along with commercial data, possibly aligned with public open access data, as well as data from NOAA and DOE. Dr. Yu noted that data is NASA's greatest asset, and if the data was packaged in a category-based integration system that is easily accessible even to those who are not experts, it would be very useful. She stressed the idea of GRACE observations and packaging data related to water, energy (solar radiation, etc.), ocean warming, and clouds in a package.

Dr. Tucker noted that ES2A is a NASA priority and asked what the outside community needs and what is going to address them. Dr. Wagner pointed to the Community Assessment Reports (CAR), where NASA surveyed early adopters on how they were going to use the mission for applications. But if they get a science team together to look at the integration, the committee would be the ones drawing on those reports and even helping to write them. Dr. Tsaoussi added that there is not a single project selected in the NASA GRACE-FO Science Team, which only uses GRACE data. A reasonable approach is to establish a process to augment or leverage that. Dr. Demoz said make it easier for the outside world to engage with it and use it.

After Dr. Yu asked about the future of the DAACs, Ms. Baynes gave an overview of the studies that are underway as they look at moving the DAACs to the cloud. They have worked on cross functional positioning and consolidating and reorganizing the functionalities of the DAACs over five years. As they move to the cloud, they are retiring the ECS system, which is one of the original EOS underpinnings from the 1990s. They do not have specific plans yet, but that change is coming.

Dr. Tucker asked about the gap assessment within the product integration side. Ms. Baynes said they have to think about who they are leaving behind as they move forward and how they can keep that continual service excellence. Dr. Wagner said they know, through work in the Applied Sciences community, that there are almost an infinite number of gaps.

Dr. Wagner talked about the proposed two-phase approach. Phase 1 is an experimental phase where they focus on existing and near-term missions. It might last 18 months and inform Phase 2. He asked the committee if that structure makes sense and looks forward to their recommendation, which they will take under advisement and let them know how it is going at the next meeting. Dr. Robinson added that it is important not to over-promise, especially in a time when budgets are tight.

Findings and Recommendations

The ESAC had a lengthy and wide-ranging discussion about the information presented at the meeting and noted several findings and recommendations.

Closing Remarks

Dr. Tucker thanked the group for attending the meeting and staying late to work through the findings and recommendations. Dr. Tsaoussi thanked the presenters and the people from NASA who attended.

Adjourn

The meeting was adjourned at 3:35 p.m.

Appendix A
Participants

ESAC members

Dr. Sara Tucker, Ball Aerospace & Technologies Corp., *Chair, Earth Science Advisory Committee*
Dr. Lucia S. Tsaoussi, NASA Science Mission Directorate, *Executive Secretary*
Dr. Jui-Yuan (Christine) Chiu, Colorado State University
Dr. Indrani Das, Lamont-Doherty Earth Observatory
Dr. Belay Demoz, University of Maryland Baltimore County
Dr. Venkat Lakshmi, University of Virginia
Dr. Jennifer Logan, Northrup Grumman
Dr. Rowena Lohman, Cornell University
Dr. Dylan Millet, University of Minnesota
Dr. Helen Pillar, University of Texas
Ms. Beth Plale, Indiana University
Ms. Melanie Preisser, York Space Systems
Dr. Sara Rivero-Calle, University of Georgia
Dr. Jennifer Watts, Woodwell Climate Research Center
Dr. Robert Wright, University of Hawaii
Dr. Lisan Yu, Woods Hole Oceanographic Institution

ASAC members

Dr. David Saah, University of San Francisco, *Chair, Applied Sciences Advisory Committee*
Ms. Christine Bognar-McMahon, NASA Science Mission Directorate, *Executive Secretary*
Mr. Albert Anoubon Momo, Trimble, Inc.
Dr. Lisa Dilling, Environmental Defense Fund
Dr. Edward J. Kearns, First Street Foundation
Ms. Rhiannan Price, DevGlobal
Mr. Ian Schuler, Development Seed
Dr. David S. Wilkie, Wildlife Conservation Society
Dr. Danielle R. Wood, Benesse Corp. Career Development

NASA
Elizabeth Anderson
Katie Baynes
Kate Becker
Sky Bischoff-Mattson
Brock Blevins
Sid Boukabara
Sara Boyer
Sarah Brennan
Jessica Burnett
John Ceballos
Peter Colarco
David Considine

Sarah Cutshall
Winfield Decker
Bradley Doorn
Richard Eckman
Mike Egan
Amber Emory
Jared Entin
Griffin Farris
Craig Ferguson
Lawrence Friedl
William Gail
Colene Haffke
Michelle Hawkins
John Haynes
Peifen Heesch
Aisha Henderson
Elizabeth Howell
Bryan Johnson
Lenai Johnson
Elizabeth Joyner
Alix Kashdan
Teresa Kauffman
Jack Kaye
Jennifer Kearns
Maudood Khan
Kim Kyu-Myong
Maya Levisohn
Robert Levy
Melissa Martin
Megan McGroddy
Wendy Mihm
Christina Moats-Xavier
Amanda Moore
Anne Nolin
Molly Olonoff
Ryan Pavlick
Susie Perez Quinn
Helen Pillar
Corena Pincham
Steve Platnick
Julie Robinson
Cecile Rousseaux
Natasha Sadoff
Karen St. Germain
Joel Scott
Mike Seablom
Nancy Searby
Antonios Seas
Stephanie Schollaert
Florian Schwandner
Scott Schwinger
Paul Speth
Emily Sylak-Glassman
Sara Tucker
Woody Turner
Sikchya Upadhayay
Thomas Wagner
Zoe Wai
Kevin Ward
Jennifer Wei
Amanda Whitehurst
Jamie Wicks
Jinwoony Yoo

Other
Francesco Bordi
Art Charo
Jeff Foust
Xianglei Huang
Tony Maranto
Gene Mikulka
Katherine Patton
Mauricio Peredo
Richard Rogers
Katie Salvaggio
Nicholas White

Appendix B

Earth Science Advisory Committee Members

Dr. Sara Tucker, Chair, Earth Science Advisory Committee
Ball Aerospace & Technologies Corp.

Dr. Lucia S. Tsaoussi, Executive Secretary
NASA SMD

Dr. Jui-Yuan (Christine) Chiu
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Dr. Venkat Lakshmi
University of Virginia

Dr. Jennifer Logan
Northrup Grumman

Dr. Rowena Lohman
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Dr. Dylan Millet
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Dr. Helen Pillar
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Ms. Beth Plale
Indiana University

Ms. Melanie Preisser
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Dr. Sara Rivero-Calle
University of Georgia

Dr. Jennifer Watts
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Dr. Robert Wright
University of Hawaii

Dr. Lisan Yu
Woods Hole Oceanographic Institution

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Ms. Christine McMahon-Bognar, Executive Secretary
NASA Science Mission Directorate

Mr. Albert Anoubon Momo
Trimble, Inc.

Dr. Lisa Dilling
Environmental Defense Fund

Dr. Edward J. Kearns
First Street Foundation

Ms. Rhiannan Price
DevGlobal

Mr. Ian Schuler
Development Seed

Dr. David S. Wilkie
Wildlife Conservation Society

Dr. Danielle R. Wood
Benesse Corp. Career Development

Appendix C
Presentations

April 16
Ethics Briefing for Special Government Employees Serving on NASA Advisory Committees, Griffin Farris
Earth Science Advisory Committee Update, Karen St. Germain
Earth Science to Action, Dr. Karen St. Germain, Julie Robinson
ESD Earth to Action Strategy and the Decadal Survey Perspective, Anne Nolin
Flight Program Update, Scott Schwinger
Research and Analysis Program Overview, Jack Kaye
Earth Action Program Update, Thomas Wagner
ESTO Program Update, Michael Seablom
Earth Science Data Systems Program Update, Joel Scott

April 17
ESO Mission Update, Karen St. Germain (presented by Julie Robinson)
ESD Communications, Wendy Mihm
Digital Twin(s) for Earth: Connecting Observations, Models, and Decision-Making, Sid Boukabara
Integrated Earth System Observatory Project (iESO), Thomas Wagner

Appendix D
Agenda

Earth Science Advisory Committee Meeting
April 16-17, 2024

Tuesday, April 16

ESAC & ASAC Joint Meeting

8:30	Call to Order, Opening Remarks	Lucia Tsaoussi/Christine McMahon-Bognar
8:40	SGE Ethics Training	Griffin Farris
9:40	Meeting Charge	Sara Tucker/David Saah
9:50	Earth Science Division Update	Karen St. Germain
10:15	Break	
10:30	Earth Science to Action Strategy (ES2A)	Karen St. Germain
11:00	Earth Science Decadal Survey Perspective (CESAS)	Anne Nolin/William Gail
11:30	Discussion	ESAC/ASAC members
12:00	Lunch	
1:00	Flight Program Update	Scott Schwinger
1:30	Research Program Update	Jack Kaye
2:00	Earth Action Program Update	Thomas Wagner
2:30	Discussion	ESAC/ASAC members
3:00	Break	
3:15	ESTO Program Update	Michael Seablom
3:45	Earth Science Data Systems Update	Joel Scott/Katie Baynes
4:15	Discussion	ESAC/ASAC members
5:00	Adjourn	

Wednesday, April 17

8:30	Call to Order	Lucia Tsaoussi
8:35	Public Comments Open	
8:45	Opening Remarks	Sara Tucker
9:00	ESO Mission Update	Julie Robinson
9:30	ESD Communications Strategy	Wendy Mihm
10:00	Discussion	ESAC members
10:15	Break	
10:30	Digital Twins for Connecting Data, Models and Decision-Making	Sid Boukabara
11:00	Discussion	ESAC members
12:00	Lunch	
1:00	ESO Integration	Thomas Wagner
1:30	Discussion	ESAC members
2:15	Findings & Recommendations	ESAC members
2:55	Closing Remarks	Sara Tucker /Lucia Tsaoussi
3:00	Adjourn	

Appendix E
WebEx Chat Transcripts

Chat, April 16

1:02 PM from Bryan Johnson to everyone:

can all hear online?

2:47 PM from Elizabeth Howell to everyone:

Hi everyone joining online - our audio is going to cut out temporarily in a few minutes as the computer is forcing a restart, we are unable to override. We will have a coffee break that begins at 3pm ET, and will reconvene at 3:15pm ET, by which time (hopefully) the restart will be complete and our audio will be back up. Apologies for the inconvenience.

2:49 PM from Helen Pillar to all panelists:

Thanks for the heads up

3:00 PM from Elizabeth Howell to everyone:

Can you hear us now?

3:01 PM from Molly Olonoff (privately):

Yes I heard a bit at the end but now you are muted.

3:02 PM from Elizabeth Howell to everyone:

Great - thank you!

Chat, April 17

8:29 AM from Molly Olonoff to everyone:

Hi everyone online! We should be starting shortly.

8:31 AM from Helen Pillar (privately):

Good morning

8:42 AM from Rowena Lohman (privately):

I have to disappear from 11:15-12:05 for class

10:08 AM from Bryan Johnson to everyone:

Hello - taking a 10 min break.

10:26 AM from Bryan Johnson to everyone:
Starting back up soon - Welcome Back

12:04 PM from Bryan Johnson to everyone:
Hi everyone online! We are taking a break from 12:00-1:00 pm ET.

1:00 PM from Bryan Johnson to everyone:
Good Afternoon

3:34 PM from Helen Pillar to all panelists:
Many thanks for accommodating virtual participation