# NASA ADVISORY COUNCIL

# EARTH SCIENCES SUBCOMMITTEE

Kennedy Space Center

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## MEETING REPORT

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Steve Running, Chair

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Lucia Tsaoussi, Executive Secretary

*Table of Contents*



***Prepared by Joan M. Zimmermann***
***Ingenicomm, Inc.***

January 10, 2017

Introduction and Announcements

Dr. Lucia Tsaoussi, Executive Secretary of the Earth Science Subcommittee (ESS), opened the meeting and made administrative announcements. Members introduced themselves around the table. Dr. Steve Running, Chair of the ESS, was unable to attend the first day of the meeting due to travel woes, thus ESS Vice Chair Dr. Anne Nolin took his place as Chair. Dr. Tsaoussi noted that ESS is in the process of being re-tooled as part of the new advisory structure, and will soon be known as the Earth Science Advisory Committee (ESAC). The Science Committee, of which ESS was a part, now presides over only the Planetary Protection Subcommittee (PPS) and the Big Data Task Force (BDTF). Advisory committees for NASA's Science Mission Directorate (SMD) have been separated from the NASA Advisory Council (NAC) and will be referred to as "chartered division committees" in the near future. They will function solely as advisory committees, and are envisioned to be chartered every two years. The members of ESS will have to be officially reappointed to the new committee; members will continue to be special government employees (SGEs). The Senior Reviews and Science Definition Teams (SDTs) will also report to the newly structured Earth Science committee. The contents of the charter are effectively the same. Administrator Charles Bolden will sign the new committee charter on 11 January.

Earth Science Division (ESD) Overview

Dr. Michael Freilich, Director of the Earth Science Division (ESD), presented an update of division activities. He briefly took pains to clarify the NAC's new organizational structure as being advantageous for the community, as it enables members to report directly to the division directors; there is no longer a need to "go up the chain" to the NAC in order to deliver advice. Dr. Freilich said he would be soliciting specific advice from the community as NASA enters a period of transition, with its potential challenges. Small satellites (SmallSats, CubeSats, MicroSats) and SmallSat constellations have begun to make up a growing portion of the program. It is an area of growing interest both inside and outside the Agency, but for ESD, NASA must approach the issue from a standpoint of science. The tools required to get the science and needed measurements are not new to ESD, however. NASA is really interested in the scientific utility of small satellites, as well as the socioeconomic value of ESD, and how Earth Science tells its story going forward. ESD touches a huge swath of humanity with its work.

The Cyclone Global Navigation Satellite System (CYGNSS) launched from an L-1011 jet on 2016 December 15. It is constellation of eight small satellites, the first of the Earth Venture Orbital (EV-O) missions, and it is doing very well. The four programs under ESD are Research, Applied Sciences, Flight, and Technology, all of which seek to provide data that allows us to understand the Earth as an integrated system. ESD is also a developer of applications that deliver a direct benefit to everyone on the planet, through tailored information products. About 60-62% of the ES budget goes to the Flight element. The bulk of the 38% remainder is in Research, or the "redeeming of the investment" in Flight. Research is essentially the integrative part of the program. The Research and Analysis (R&A) program takes the measurements from spaceborne, airborne, and *in situ* instruments maintained by NASA, other agencies, and international partners, and turns them into understanding. The Applied Sciences Program (ASP), headed by Associate Director Dr. Lawrence Friedl, receives about $60M a year. ASP identifies, develops,

and tests tailored information products to the nontechnical user community; it functions as the flexible bridge between the user communities and the science community. Earth Science Applications constitute an increasingly high-visibility task. The Earth Science Technology Office (ESTO) invests in maturing technologies for the missions of the future. ESTO is a little different from other divisions in the Science Mission Directorate (SMD), as Earth Science is a little broader than Planetary, Heliophysics, and Astrophysics. ESD has done an excellent job in investing in a broad range of technology. The real metric of success in ESD is how many of the new missions use, in a critical way, something that came out of ESTO. The proportion is pretty close to 100%, and the investments can be easily traced. The ESS can function as a key amplifier to communicate these accomplishments to the community.

ESD works with other divisions in SMD and other agencies. Dr. William Large asked how ESD makes up the "shortfall" of 38% of the budget, when 62% is spent for Flight in a program that should ideally be 50-50 non-Flight activities. Dr. Freilich pointed out that in part, NASA is responding to clear recommendations from the Earth Science community; everyone agreed, for instance, that the Earth-observing constellations were near to collapse. ESD responded to this situation very well without losing sight of the ultimate goal of 50-50 concentrations in Flight vs. Research. The split is much more balanced between Flight and non-Flight, but ESD must be careful as to how precisely it justifies each dollar. The division seeks to keep the balance in the current range, despite budget fluctuations. The temptation is always to cut the non-Flight program because there is no "aggrieved party." But ESD tries hard to preserve the balance with a focus on missions. Dr. Nolin asked if there had ever been a time when ESD had a substantial budget that could illustrates how to better justify a larger portion devoted to non-Flight. Dr. Freilich replied that during decade-plus his tenure, ESD has never had a 50-50 split. But he still felt it was a realistic goal. The point to make was that the non-Flight portion exists to redeem the hardware investment, in knowledge. Dr. Efi Foufoula-Georgiou suggesting presenting the relationship as flight to knowledge, flight to society, and flight to future innovation. Dr. Freilich felt that depicting the program in terms of three bilateral relationships would be less powerful than saying that all portions of ESD's investments inform each other in an integrative sense, for the integrated Earth system. Both measurements and understanding go hand in hand; it is essential to understand the science in order to develop new instruments for new measurements; research redeems investment in flight, and vice versa. ESD has a uniquely funded program; it is not just an engineering program. Dr. Anna Michalak wondered whether there was a similar risk in targeting a quantitative goal, begging the question of why the ESD portfolio is not 40-60, 30-70, etc. Dr. Freilich noted he had never gotten that level of pushback, and that he was usually queried about the budget split on the assumption that NASA doesn't know the ratio. The question is typically more of an accounting issue. Dr. Michalak suggested that ESS might state that it would be catastrophic to drop below a certain level, because Earth Science is fundamentally different from other NASA programs. Dr. Freilich said that NASA typically says that ESD should be covering all aspects of the integrated Bretherton diagram, otherwise the program will be qualitatively different. In the future, when there may be more of a focus on business and return on investment (ROI), it might be better to say of non-Flight and Research that one can buy ROI by the yard, as a more efficient way of using resources. Dr. Thomas Herring asked how much extra funding is leveraged from international partners and other Federal agencies in non-Flight areas. Dr. Freilich said there are some missions that would not exist without some collaborations, and he didn't know how to calculate that value. Often, partnerships do not

save money *per se*, but partnerships can make missions far more robust. Dr. Freilich added that partnerships also provide "soft diplomacy" whose value cannot be calculated, as are the benefits from data exchanges, and relationships, with other nations. Dr. Mahta Moghaddam contended that, assuming that flight systems will continue to cost a lot of money, and assuming the budget will not increase, it looks like Technology could benefit from more investment for future flights, to fix the balance. Dr. Freilich noted that the other value of Technology is to increase ESD's ability to support science. Dr. David Siegel felt that Education and workforce issues seem to be missing from the agenda. Dr. Freilich noted that ESD no longer hosts an Education element (this is true of SMD as well), but that it does support the international Global Learning and Observations to Benefit the Environment (GLOBE) program, new investigator programs, and young scientists. In the last several years, there have also been thrusts at the National Science Foundation (NSF), the Department of Energy (DOE), etc., to more centrally locate Education in the Federal agencies. ESD has the benefit of being a more practical division, as everyone has an interest in the planetary forces that affect them. Dr. Large felt that a nimble workforce will be needed to support new initiatives, such as SmallSats, and as such should be part of the discussion. Dr. Christian Kummerow commented that the community always has an issue with Applied Sciences, and that the community needs to recognize that ASP feeds back to science. Dr. Tsaoussi pointed out that there is an advisory group for ASP (Applied Sciences Advisory Committee; ASAC), and that perhaps ESS would benefit from an ASAC briefing. Dr. Ian Joughlin asked if the committee could weigh in on risk postures vs. reduced costs for the Flight program. Dr. Freilich felt that the community's basic conservatism and focus on capability are really important. Everybody else is flying synthetic aperture radars (SARs) as free-flyers in space: Vietnam, Israel, India, etc. The last one NASA flew was in 1979. It's not for lack of trying. The reach is so large and the benefits so great. If a satellite doesn't advance the field in a unique way, however, ESD doesn't fly it.

Dr. Freilich reviewed the ESD budget for FY17: $1,927M. The runout to 2020 is stable ($2,027M in 2020). Congress has generally appropriated the Administration's requests over the last few years. While NASA is operating under a Continuing Resolution (CR), it is being funded at the FY16 level, which enables NASA as a whole to carry out its Operating Plan. The CR lasts thru 28 April 2017. Dr. Freilich felt that NASA would get through 2017 pretty well; ESD has a plan, and it has funding. The best thing to do is use the funding and present condition of stability to amass more accomplishments.

Dr. Freilich addressed how the Decadal Survey has influenced the ESD as a function of the whole agency. The bottom line is that ESD consumes about 10% of the NASA budget and has been doing so for a relatively long time. The Decadal Survey helped NASA to recover its investment in the Earth-observing satellite (EOS) system in roughly 2006. Dr. Large commented that what ESD does with its budget has also changed over time, and that the community should understand that we're getting more for our dollar than we used to. Dr. Freilich agreed, but felt that was a secondary argument. The National Oceanic and Atmospheric Administration (NOAA) Earth-observing budget is about $2.5B per year, which just shows how much NASA/ESD does with its investment. He didn't feel that the works of other agencies help the NASA story; rather they detract from the clarity of the NASA program.

***Flight***

ESD is flying 19 missions/instruments at present, in a combination of primary and extended missions, and has roughly 20 missions queued up in formulation and development. The Earth-Observing One (EO-1) mission ends this year, and Gravity Recovery and Climate Experiment (GRACE) will likely end this year. Earth Science has become and remains a vigorous program that spans all the disciplines. The Sentinel-6 A and B instruments are NASA contributions to the European Space Agency's (ESA) Copernicus program, and are the only significant, non-European hardware contribution to nadir altimetry. It's a mutually beneficial program; ESD negotiated for the contribution, and plans to leverage this European investment in sustained measurements in space. NASA is also working with the US Geological Survey (USGS) to launch LandSat 8 in 2022. ESD also has a set of CubeSat missions launching in November 2017, as well as technology demonstrations.

***Earth Venture Overview***

Dr. Freilich reviewed ESD's Venture-class solicitations, all of which have been solicited and selected on time, and fully funded. The classes are Suborbital, (EVS), Mission (EVM; complete self-contained small missions, such as CYGNSS, capped at $100M), and Instruments (EVI.) EVS and EVM projects are solicited every 4 years, and EVI every 18 months. ESD is currently evaluating its fourth EVI call. The total costs of Venture-class program are about 11% of the ESD budget. The orbital missions of EV are funded under Flight, and the Suborbital missions of EV are funded under the non-Flight budget. This compartmentalization illustrates the arbitrary nature of the budget when describing Flight vs. non-Flight projects. In the future, ESD will be moving more to targeted solicitations. Asked how the targets would be chosen, Dr. Freilich said he hoped to find guidance for decisions in the Decadal Survey, and from community feedback through Town Hall meetings. He stressed that NASA wants to know what the community wants for Venture. Are the cost caps right? Should ESD put in an additional line? Dr. Freilich was pleased that the Venture Class is governed by very few principles; its overriding principle, however, is to have stable funding and schedule. "Don't fall in love with your mission" is its catchphrase; terminating a mission in Venture Class is not viewed as a bad thing. He was pleased to say that termination has not been necessary thus far. Dr. Joughlin asked about the timing of a wedge for new missions. Dr. Freilich replied that the wedge for new missions opens up in 2021, as ESD finishes out the recommendations from the previous Decadal Survey.

***Cyclone Global Navigation Satellite System (CYGNSS)***

Dr. Chris Ruf is the principal investigator (PI) for CYGNSS. The mission objective is to fly a homogeneous, SmallSat constellation to measure winds and air-sea interactions, collect reflection data in the L-band from the sea surface, to see the developing eye walls of developing hurricanes and tropical storms. Measurements are to be taken every 7 hours over the entirety of the tropics. First-light operations began on 4 January. All eight spacecraft are in the middle of a 60-day commissioning phase. The noteworthy features of the first light measurements are that the instruments' specular points are well-centered, and the spacecrafts are demonstrating good receiver performance. Dr. Large asked how CYGNSS would be useful. Dr. Freilich noted that the understanding of bistatic scatterometry is straightforward, and that the utility of the shape and magnitude of delayed Doppler measurements has been established in modeling exercises. CYGNSS may also have operational potential; as such, its

baseline science mission is to demonstrate approach and to provide measurements that could be useful to NOAA. Dr. Jack Kaye noted that additional investments have been made in the competitive research program to do a little more with CYGNSS. A competitive science team will kick in the year after launch; at some time in 2017 there will be an opportunity to exploit CYGNSS data, which begins operations in 2018. This competition is part of the Research program for all flight missions.

EVM-2 is a demonstration mission called geoCARB, which will provide geostationary measurements of CO, $CO_2$, $CH_4$ and solar-induced fluorescence (SIF) to see if they work. The project cements ESD's commitment to flying earth-observing missions on geostationary satellites. Venture Class Launch Services (VCLS) is a joint ESD/NASA launch services program initiative to purchase vehicles that are massively SmallSat capable, to deliver them to low-Earth orbit (LEO). Total NASA costs per selectee/launch are to be under $15M. Virgin Galactic LLC, and Rocket Lab USA, are two potential contractors.

***Satellite Needs Process***

The Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) have established a Satellite Needs Working Group (SNWG) to enable Federal departments and agencies to annually communicate their Earth-observing satellite measurement or product needs to NASA. NASA is conducting an assessment of these needs. NASA will consider these needs, which will then be tracked and attributed, with information on both met and unmet needs, in each NASA submission to OMB. There is no expectation, however, that NASA will be required to meet any of these needs. It takes NASA about 6-8 months to adjudicate the sum of met and unmet needs. Dr. Joughlin asked if there were any value in NASA making other agencies aware of its satellite capabilities. Dr. Freilich said he usually relied on the Senior Review process for this determination. He noted that ESS could, however, make a recommendation along those lines. Dr. Foufoula-Georgiou asked if the SNWG could be used to leverage needs at the research level. Dr. Freilich said he did not see too many forums for such a use, but felt this process was a good way to illuminate NASA's integral use to federal agencies. Dr. Large noted that it would be good to for the community to know who is who in this the SNWG, to use as points of contact. Dr. Joughlin asked if there were a way to back up any of these unmet needs with resources. Dr. Freilich noted that the question that SNWG puts forward is how NASA can best spend its money to help other agencies. Seventy-seven products have been adjudicated thus far, from USGS, DOE, USDA, etc. Submission categories are Continuity, Continuity with Improvements, and Unmet Needs; one need submission can include all three categories, addressing subjects in the categories of Land, Cryosphere, Water, and Atmosphere.

***R&A Selected Upcoming Highlights***

The Arctic-Boreal Vulnerability Experiment (ABoVE) and FLARE are the new, most recently completed science programs. ESD is also pursuing the purchase of a new Gulfstream-V aircraft (in conjunction with the Human Exploration and Operations Mission Directorate; HEOMD). In the Applied Sciences Program, there are new initiatives in Food Security, and a new ROSES call for apps focused on a few disaster types. Dr. Friedl added that NASA has integral ties with the Federal Emergency Management Agency (FEMA), and many non-government organizations (NGOs) that support disaster response in other countries.

ESD continues to abide by its guidance from the 2007 Decadal Survey, the 2010 NASA Response to Climate report, and the largely positive 2012 Decadal mid-term report, Earth Science and Applications from Space. The next Decadal Survey is due December 2017.

Small satellites/Constellations

Dr. Freilich gave an overview on the various perceptions of the utility of small satellite (SmallSat) capabilities for NASA. NASA is focused on science, applications, and societal benefit of SmallSats. Recently, the systems engineering (SE) community has begun to look more closely at SmallSats. ESD has been flying constellations for years, i.e. the well-known A-train formation. A well-thought out formation in space can comprise a super-observatory made of heterogeneous components. ESD also flies a loose constellation (TERRA) and the LandSats in the same vein. There is also a new emphasis on homogeneous constellations, multiple copies of the same satellite spaced out in an orbit; one of these is the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS) mission. TROPICS is a 12-satellite CubeSat constellation distributed across three different orbital planes, while CYGNSS is an eight-microsatellite constellation. TROPICS is the first science-focused CubeSat constellation.

The FY17 Budget augmentation to ESD includes a Small Satellite Constellation Initiative. NASA put out a Request for Information (RFI) about the feasibility of purchasing SmallSats from the private sector. ESD will likely proceed with a Request for Proposals (RFP) if Congress appropriates the FY17 budget for ESD. Industry has responded very positively to the RFI. NASA will use this information/proposals to advance Earth system science, specifically in multispectral land imaging, and radio occultation measurements, if the products of are appropriate quality. NASA is also looking also for ideas on data availability and NASA's ability to distribute the data; this is a potential way for NASA to use measurements being made by others. The RFI also noted that NASA may invest up to $25M on two data purchases in 2017. Near-term evaluation pilot activities will likely be confined to NASA-funded, non-real-time research. Asked about coordination with NOAA needs, Dr. Freilich noted that he speaks to NOAA weekly, and enjoys very close communications. NOAA has much less money for data buys. NASA is not duplicating efforts or competing through the RFI; it is just exploring the "art of the possible." That said, Dr. Freilich requested ESS perspectives on how ESD should approach the program in terms of balance, science focus, etc.

Discussion

Dr. Foufoula-Georgiou asked for Dr. Freilich's reaction to new product development in Google Earth. Dr. Freilich noted that Geoscience Australia has also been putting together new products based on newer data. NASA has been investing in NASA Earth Exchange (NEX) at Ames Research Center to make it easier to access huge quantities of moderate-resolution images, to take advantage of the long-term Earth imagery collection. NASA is also looking at processing-in-place techniques and use of the Cloud for processing and storage. Dr. Nolin noted that this is a new paradigm: programs are now allowing the user to choose spatial and temporal resolutions. Dr. Schmitt asked if there was a downside/risk to ESD's unique position, in terms of maintaining future budgets. Dr. Freilich conceded that risk was unavoidable, and if one were to prevent ESD from producing science for societal benefit, it would be tantamount to preventing knowledge accumulation. ESD will continue to support basic research that has applications, versus research solely for applications. Dr. Friedl noted that part of NASA's mission is to deliver applications; and the Agency is also working with other agencies and NGOs. He was always careful to state that NASA is extending the use of its science to enable what other agencies are doing. Having Earth Science within NASA allows the systems engineering expertise at NASA to provide further benefits. Dr. Large thought it was unclear at present whether collaboration or competition with other agencies will be helpful, but that NASA is well-positioned to go either way. Dr. Kaye felt it important to note that Earth Science is both good and useful, and would do well to remain policy-neutral. ESD does not manage, regulate or make policy; it simply carries out the science to understand how the Earth works. Science can't be used to support an agenda. The Global Change Research Program (GCRP) advances the science; it is not doing science to further the aims of the Climate Action Plan. Dr. Kummerow felt that Applications should be more clearly framed in this light. Dr. Friedl agreed that there has been an evolution in thinking about how Applications requirements are aligned with missions; NASA is now bringing Applications people into the formulation and development phase of Earth Science missions, while the mission itself retains the focus on the research activity. In the G-20 and G-7 meetings, Earth observation science has often been called in to help support transparency and sustainable development goals. Applications can also bring societal applications to the fore, to help policy makers in their decision-making. Dr. Large felt that it's not clear how much Applications work is done solely by NASA versus through partnerships. Dr. Freilich noted that ESD will be getting more advice on Applications from the next Decadal Survey.

Dr. Moghaddam asked if proposed data buys from small satellites would be limited to US companies. Dr. Freilich replied in the affirmative, but he did note that one of the small launch vehicle vendors was a New Zealand company that opened a US subsidiary to meet requirements. He added that NASA, notably, is not opening up the SmallSat initiative to ideas from the NASA centers. Dr. Siegel raised a caution for to ensure that Google Earth engine standards be used for reproducibility of results. Dr. Freilich noted that with regard to transparency, there is a great emphasis on open source code today, which will probably continue. How the research community will handle this, however, is not obvious. There are some pilot programs in the NASA data system that are dealing with this issue. Dr. Kaye added that it is also not clear where links to data, algorithms, etc., were to be stored for the National Climate Assessment; this remains a work in progress. Dr. Friedl suggested that data standards could be a topic for a future meeting. Dr. Large said NASA might consider having a standard data management policy, standardizing code, data,

etc. Dr. Tsaoussi noted that some Earth Science ROSES calls are employing this approach and have begun to get some feedback on data management plans. Dr. Nolin noted that there are data management standards extant at different levels of complexity; at an absolute minimum, one could have a DOI for a metadata requirement, e.g.

Dr. Moghaddam asked how ESTO investments be fast-tracked into Decadal Survey missions, and ESTO work might be phased better to gain a more immediate benefit in new missions? Dr. Komar noted that prior to the issuance of the last Decadal Survey, ESTO was science-driven and competed, and lined up very well with the 2007 Decadal Survey. From an instrument perspective, all 5 EVI selections, and both EVMs, have ESTO investments. Dr. Moghaddam asked more about the lag between ESTO work and infusing new technologies into missions. Dr. Komar said there was about a 6-to-7 year lag, typically, with respect to the Decadal Survey. Dr. Freilich suggested that getting papers out more quickly from field campaigns might help, and asked whether ESD should take money from Research and funnel it into ESTO; this is the balance that the community needs to be aware of. Technology must be mature before it is infused into major missions. He pointed out that ESTO went through a very formal process mapping Decadal Survey needs against ESTO planning. Dr. Komar noted that ESTO is accelerating its calls to produce instruments more quickly, as a result of Lessons Learned activities.

InVEST Program

Dr. Komar, Associate Director of ESTO, gave an overview of the In-Space Validation of Earth Science Technologies (InVEST) program, which has about 117 active technology development projects. It is a science-driven, peer-reviewed competitive program. Each grant is managed throughout its lifetime. ESTO manages some R&A activities as well, and also manages the technology program for the LandSat program (SLI-T). ESTO also oversees Earth Venture Instruments, Technology, and Airborne Instrument Technology Transition. ESTO has validated three U-Class satellites (CubeSats), polarimetry processing for ACE, Autonomy Technology for HyspIRI, and readout integrated circuit (ROIC) technology for GEO-CAPE.

The ESTO InVEST 2012 program produced five individual CubeSat demonstrations: MiRaTA, RAVAN, IceCube, HARP, and LMPC. MiRaTA is scheduled to launch in late 2017, and will validate new microwave radiometry. RAVAN (a radiometer based on nanotubes) was launched on a National Reconnaissance Organization (NRO) satellite in late 2016. IceCube is a high-frequency radiometer, built at Goddard Space Flight Center, which will launch to the International Space Station (ISS) in March 2017, to perform spaceborne cloud ice remote sensing. HARP will launch tentatively in 2017, and will demonstrate a 2-4km field-of-view hyperangular polarimeter for cloud and aerosol characterization. LMPC, its launch to be determined, will demonstrate a linear-mode, single photon detector in a space environment. This latter project may not go due to some Aerospace issues. U-Class satellite candidate development, resulting from the InVEST 2015 program, includes five projects slated to fly in 2018, including TEMPEST-D, a technology demonstration of a $K_a$-band, active sensor for measuring the transition of clouds to precipitation. RainCube will validate a new $K_a$-band sensor architecture and ultracompact $K_a$ antenna. CIRiS will validate an uncooled infrared radiometer designed for high radiometric performance for LEO. CIRAS is an infrared atmospheric sounder. Cube RRT will

demonstrate wideband RFI-mitigating backend technologies vital to future spaceborne microwave radiometers.
CYGNSS has much provenance in ESTO, and represents the start of a future, distributed architecture scheme. Looking ahead, ESTO is targeting smaller instruments that are lighter and consume less power; high-resolution optical and infrared sensors; next-generation lidar and radar; formation-flying; nanosatellites and CubeSats; fractionated spacecraft/distributed architecture; autonomous operations; high-resolution ensemble modes; and rapid, error-free data transfer. One can envision continuity measurements with SmallSats, eventually.

Dr. Kummerow asked whether ESTO was considering satellite-to-satellite data transfer. Dr. Komar said he knew of some non-NASA laser communication demonstration projects for data relay, but felt that $K_a$ band would be relay-capable one day. There is one ESTO CubeSat in development that is carrying a $K_a$-band reflector. The SmallSat program is meant to qualify instruments for space, and is not meant to replace larger missions, but to complement them. ESTO is also looking for new capabilities and measurements, or smaller-scale versions that in some cases could theoretically overlap with the capabilities of larger missions, such as demonstrating a $CO_2$ lidar in space. There is some limited collaboration possible with HEOMD via the use of ESPA (launch vehicle adaptor) rings. Dr. Freilich reminded members that part of the discussion is to elicit feedback from ESS. Dr. Moghaddam commented that active sensors, which are difficult to miniaturize and which have inherently high power needs, would be worth an investment here. Dr. Kummerow asked what fraction of very good proposals are left on the table. Dr. Komar said there are typically some proposals that fall in a gray area, and sometimes decisions are made programmatically; a proposal has to be justifiable. For example, a highly ranked SLI-T proposal was passed over because a similar project was already being done in InVEST. Historically, ESTO has about an 18-20-% selection rate. The program is also trying to get some collaboration with the Space Technology Mission Directorate (STMD). Asked if ESTO had any interactions with SMD divisions, or Education, Dr. Komar described some interaction with PSD, where there are common interests. PICASSO and MATISSE are the planetary programs for instruments, which came about through discussions with ESTO. ESTO also shares synergies with Astrophysics and Heliophysics divisions of SMD, and with the National Reconnaissance Organization (NRO). There is ongoing communication between ESTO and the science directors at Headquarters.

Discussion

Dr. Nolin raised some possible topics for a letter: workforce development for Applied Sciences, Venture class missions, and SmallSat constellations. Dr. Freilich recommended that committee members consider the potential use of SmallSat constellations to advance science; i.e. given the science and Applied Sciences needs within ESD, and given the successes in building credibility, should ESD be increasing investment in these SmallSat solutions, possibly to the detriment to some future Decadal Survey missions? Dr. Marshall Shepherd noted that the University of Georgia hosts a small CubeSat program, and was also concerned as to whether SmallSats are a fad; he asked if other parts of NASA are heavily investing in CubeSats. Dr. Freilich answered that in general, the answer is no, but there are some exceptions. Planetary science has some SmallSats accompanying the Mars 2020 mission. STMD is always interested in miniaturization approaches but without a sustained model. In the private sector, there

is plenty of interest, however, such as Spire's efforts in radio occultation. Dr. Thomas Zurbuchen, the new SMD Associate Administrator, also has a heavy interest in CubeSats. He really wants everyone in SMD to look at SmallSats, and to rule them out if they are not appropriate to the task. Dr. Nolin commented that one of the biggest challenges is to capture spatial and temporal variability; a satellite constellation would ideal to address some of this challenge. From a more integrated perspective, SmallSats could be more useful when integrated with ground-based and airborne sensors. Such a scheme could answer some larger-scale questions for societal benefit. Dr. Kummerow felt that there was always a fight in Earth Science between developing new processes vs. monitoring; CubeSats may be one way to do the monitoring. Dr. Michalak noted the natural evolution for instrumentation, and that the best place for SmallSats may be for maturing instruments, instead of putting up large instruments that are not well understood. Dr. Freilich felt Dr. Michalak's statement was especially relevant for LandSat, and that the key question is whether one is looking for more or better measurements. Dr. Moghaddam noted that adding CubeSats provides another layer between airborne and spaceborne, a mesoscale of time and space. Dr. Freilich said that ESD is also exploring atmospheric sounding properties, and NOAA has a similar vision for a 6-12 satellite "U-sat" mission. After the Microwave Radiometer Technology Acceleration (MiRaTA) and TROPICS missions, it might be worthwhile to consider whether NASA should move forward with a full-up constellation development to support a future NOAA mission. Dr. Large was nervous about recommending that ESTO do more with an already full portfolio. Dr. Komar said he could easily envision flying SmallSats as scientific instruments. Dr. Kaye felt that SmallSats for temporal sampling should be considered in light of the scientific and/or societal benefit of additional observations, especially in the context of what current technologies are able to provide. Dr. Michalak noted there are two aspects to extra temporal coverage: the value of the extra informational content, and process-based models. Dr. Foufoula-Georgiou thought that CubeSats could help larger missions reach their potentials, by doing some things the larger mission can't do well. CubeSats could also provide more precise real-time interrogation of small, short-lived events, and multi-sensor understanding, as well as new and exciting measurements. Dr. Herring asked about the prospects of miniaturizing active sensors. Dr. Komar felt that at present, lasers are too tough, although ESTO is trying to solve that issue for $CO_2$. A small communications laser may be possible, but not science lasers. With radars, the $K_u$ band is a real problem. SAR can be done with precisely located CubeSats, but is still a vision. It would be possible to get a laser into an ESPA ring for a technology demonstration, but you still can't get L-band radar onto a CubeSat. Dr. Siegel felt that any effort to miniaturize and reduce power would a win. Dr. Freilich asked the committee to consider how small and large missions might be weighted in a Flight program that may have fewer resources in the next 5-15 years.

Small Satellites Constellation Partnerships

Ms. Christina Moats-Xavier, Deputy Program Manager, for the ESD Science Pathfinder Program, presented a briefing on small satellite partnerships at NASA. NASA is pursuing a rich program of Earth Science system, spaceborne missions using small satellites (e.g., CYGNSS, TROPICS, InVEST, VCLS). ESD needs reliable options for persistent, high-quality measurements. SmallSats have become more capable, miniaturization is improving, and are heavily supported by expanding low-cost launch options. There is currently political support for alternative approaches to acquiring Earth-observation data. As related earlier, if ESD receives Congressional appropriation, it will invest up to $25M in two or more data

purchases in 2018. Data purchase objectives are to explore strategic approaches for acquisition of measurements, and to examine the real utility of commercial data for NASA research. If successful, future data buys may augment or replace NASA-collected data. NASA is participating in this exercise as an "interested consumer."

The data-buy RFI was released in July and centered on GPS radio occultation and land imaging data, although all types of data were considered. The RFI also requested that responders address any data constraints considered for their commercial customers, and that they share present and near-term business forecasts (3-5 year horizon) for planned availability of data. As a result, NASA concluded that there is a pool of commercial vendors, with customers in place, that are operating SmallSats collecting data relevant to Earth Science. There are also some new entrants ready to join commercial space, therefore it is a good time for NASA to investigate a pilot purchase.

Next steps will involve working with Procurement to prepare the solicitation, collect additional feedback from the commercial vendors on the benefits and challenges of their plans, and identify opportunities to expand data purchases into future years. Ms. Moats-Xavier requested committee feedback on this pilot program. Dr. Large asked who would evaluate the data and how is it paid for. Ms. Moats-Xavier said she had heard a suggestion at a recent Town Hall meeting on the subject, which was to hold a small ROSES call to help validate the data. Dr. Large felt this suggestion made sense. Dr. Freilich related that the $25M wedge is targeted solely to the data purchase. Dr. Kummerow seconded a concern that the commercial vendor would not have the same standards on scientific data. Ms. Moats-Xavier noted that the National Geospatial Intelligence Agency also interested in commercial data purchases.

Venture Class Launch Services (VCLS)

Ms. Ana Stark, VCLS Program Manager, presented a briefing on the Launch Services Program (LSP), which acts as a "smart broker" to procure launch services for missions. In traditional launch services, LSP typically works with customers 3-5 years before launch, and also provides advisory services. LSP holds agreements with ISS for such items as Commercial Crew launches, and tailors services to customer requirements. LSP, however, does not provide go/no-go decisions on launch dates. LSP first enabled flight opportunities for CubeSats through NASA's CubeSat Launch Initiative; these launches were typically characterized by limited requirements and high-risk tolerance. In September 2015, VCLS awarded contracts to Firefly, Rocket Lab USA, and Virgin Atlantic for Earth Science Venture Class missions. VCLS significantly streamlines insight and oversight while still protecting its investment and allowing LSP to influence best practices (through the use of milestones). The pricing for these vehicles ranges from $4.7 to $6.95M.

Firefly's VCLS launch in March 2018, may not go as planned, because Firefly is having financial difficulties. Rocket Lab USA's launch vehicle is the Electron rocket, whose first launch is scheduled at the end of January 2017; NASA's launch will be their sixth launch. Virgin Galactic's vehicle is Launcher I; its first NASA launch will be their third launch. The hope is that VCLS will enable the market for the low-end performance range. Asked if SpaceX was too large for VCLS, Ms. Stark answered that while their bid was competitive, it may not have been financially beneficial to SpaceX.

CubeSat Launch Initiative

Mr. Garrett Skrobot presented a briefing on the CubeSat Launch Initiative (CSLI), which began as the Educational Launch of NASA Satellites in 2007. CSLI provides launch opportunities to educational institutions in the US, and is committed to broadening access to space, using ride shares at the beginning of the effort. CSLI provides benefits to education and to NASA, in term of both center management experience and support for the future STEM workforce. Proposals to CSLI are submitted in an annual call, and are selected through a Headquarters committee that includes representation from HEOMD, STMD, SMD, and Education. Proposals undergo technical merit and feasibility reviews. The selectee builds the satellite, raises all funds necessary for construction, and provides NASA the completed satellite for launch. NASA manifests CubeSats on a variety of flights. Students or centers "ride along" on in the post-selection process, and track and operate the CubeSat from ground stations. Students analyze data, write technical papers, and provide the results and data analyses to NASA. CSLI has strong partnerships with NRO and the US Air Force for CubeSat integration onto non-NASA launches. Thus far, 119 proposals have been selected, representing 66 organizations and 32 states. Seventy-two percent of the involved organizations are in higher education, and 19% are in NASA. Launch vehicles range from the very small Super Strypi to the Atlas V rocket. CSLI has manifested 52 and launched 46 projects. Of the 46 launches, 87% have been successful. The program currently has a healthy manifest of 53 through March 2018, including launches to ISS. Thirteen CubeSats are due to fly on Exploration Mission One (EM-1), the first test flight of the Space Launch System (SLS). In response to a question, Mr. Skrobot said that CubeSats launched from ISS will typically fly for 8-10 months. Dr. Nolin asked if CSL provided guidance and training for nontraditional universities. Mr. Skrobot replied that the program had very diverse selectees. There is also a document entitled "CubeSat 101" that is currently being reviewed, for imminent publication. It covers everything from A-to-Z on building satellites, the licensing process, etc. Dr. Shepherd was glad to hear there would be documentation, and related that his university group had only gotten limited information thanks to a call from Mary Cleave at SMD. Mr. Skrobot noted that there is also an annual three-day CubeSat workshop at California Polytechnic University.

Discussion

Dr. Moghaddam suggested the committee consider a possible need to extend technology demonstrations to include more on-orbit flights outside the SmallSat area, such as an ISS demonstration for free flyers (carrying, for example, 30% smaller radars and lidars). Dr. Freilich pointed out that ESD has indeed flown several similar radar and lidar instruments on ISS. Dr. Michalak recommended using a greater proportion of SmallSats when they can provide high-quality observations. Dr. Andrew Dessler cautioned against advocating for proportions, as scientific value can't be assessed before missions are identified. Dr. Joughlin felt that ESS should merely state that ESD pursue the best science it can through CubeSats. Dr. Freilich noted that the balance between small and "Flagship" missions could be changed dramatically without changing overall dollars in the program. Dr. Kummerow felt that the community was asking CubeSats to do new science, and that a recommended budget wedge should be couched in those terms. Dr. Nolin said she was hearing that CubeSats can help in many areas, including in the training of the future workforce, but that it's not a zero-sum game. Dr. Moghaddam felt there was a need for more scientific papers on CubeSat data, but that there was also commercial value to bringing in vendors. Dr. Siegel emphasized the science vision for CubeSats: can they be a low-cost alternative for filling in gaps on sustained Earth imaging? CubeSats are valuable if they can be miniaturized for LandSat 10. Dr. Foufoula-Georgiou suggested a multi-faceted observation: the airborne program has grown, and should continue. The Applied Science Program should emphasize more partnerships to leverage its limited resources. The Technology program will also continue to be critical. For understanding from space, a mixed portfolio of SmallSats and large missions should dominate the Flight program, and SmallSats should constitute 5-10% of the Flight program.

Dr. Large recommended that the data purchase proceed, though he expressed discomfort in recommending percentages. Dr. Kummerow supported recommending better integration of science and applications. Dr. Moghaddam recommended increasing funds for Venture Class missions if it does not harm anything else. Dr. Freilich noted that this latter question would be addressed in the Decadal Survey.

January 11, 2017

Dr. Running arrived to participate in the second day of the meeting, and Dr. Nolin continued to moderate the discussion for the sake of continuity.

Earth Science GPRA

Dr. Nolin reviewed the Government Performance and Results Act (GPRA) template, and considered tightening the language used for the reporting. Dr. Tsaoussi pointed out that a very truncated version of the report from each SMD division goes to Congress, and that she works to condense the output of the GPRA exercise. She felt therefore that the ESS could continue its current, lengthier format, which can include programmatic accomplishments, matters of interest to the community, campaigns, peer-reviewed papers, etc. She welcomed feedback on proposed changes to the template.

The committee debated various ways to make the GPRA process less cumbersome. Dr. Freilich stressed that retaining the full report was important for documenting, in detail, a written record of the Earth Science's annual research results. To streamline the process, ESS agreed to have fact-finding discussions with focus-area PMs, in which committee members could help the PMs finalize text and identify big topic areas, followed by a separate FACA telecom for purposes of assigning color grades.

Dr. Nolin summarized the observations and finding with regard to GPRA, and agreed to have ESS develop a template to facilitate smaller, focused telecoms with PMs, to produce a smaller, focused report.

Earth Science Value Framework

Dr. Freilich addressed the potential for increased attention on quantitative metrics for the overall evaluation of ESD, noting that increasingly, there have been questions about quantifying investments per their impacts on society, the economy, other agencies, etc. It is clear that the incoming administration thinks along business lines, thus ESD must articulate what it is doing through a more business-related filter. There are many commissioned studies from the European Union (EU), NASA, etc. on the socioeconomic impact of NASA's Earth Science task. Part of the difficulty with some studies is the "too many zeros" problem. If the impact is really so big, why aren't businesses investing in the same technologies as the government? Dr. Freilich asked ESS to recognize this issue, and that it was not about changing objectives and approaches. He recommended three very good reports that the committee might want to use as guides. The first is the Econometrica study, commissioned by the National Academies and focused on Earth observations and their impacts (excluding LandSat); a set of studies by the EU on the European Copernicus program, which looks at both socioeconomic and science downstream returns; and a study by NASA's Applied Sciences Program on the same issue. Dr. Foufoula-Georgiou felt these studies could be part of another good template to provide the PMs, for communicating Earth Science impact. Dr. Freilich said he was not asking the committee to produce anything; this is just a sensitization exercise. Dr. Large commented that there are opportunities for ESD to collaborate with other entities, through interagency relationships, to help translate impacts to dollars. The value of increased response times to disaster, for instance, could be quantified. However, the committee shouldn't recommend funding science proposals based on their socioeconomic impact.

Dr. Freilich reiterated that NASA is not an operational agency with a mandate to produce operational products, although it must be recognized that NASA often supports and critically enables operational agencies. However, NASA must be careful about how much contribution it claims. Dr. Siegel commented that calculating impact is very method-specific, and therefore one must be careful about setting up the problem. Dr. Dessler felt the issue was agenda-specific as well, and was skeptical that one can win these arguments. An alternative approach would be to argue the value of basic research. Dr. Freilich emphasized that it's not a "win-lose argument;" there must be a discussion to further the understanding on all sides and of all objectives, and to achieve some consensus on the value of Earth Science. Dr. Michalak suggested a middle ground between dollar value and asserting the value of basic research, such as demonstrating how the work enables things beyond basic research, which are valued; e.g. providing better maps, or lessening times for disaster response. Dr. Nolin suggested viewing the issue in terms of what would be lost if NASA stopped doing Earth Science.

Economic Value of Earth Science Information

Dr. Bruce Wielicki presented a briefing on a way to frame the economic value of Earth Science. Basic research is a vague concept and not very defensible for NASA's current budget level. As such, the program is very vulnerable to budget austerity, as the checkered past of Earth-observing systems can illustrate. Science is an economic investment by the public. At present, we have no climate-observing system—should we have one? Is it worth it? What is the economic value of an advanced climate-observing system? There are many technologies available to support such a system. Some data can be quantified: e.g., the value of accurate hurricane tracking. Statements in support of a climate-observing system must be traceable and verifiable. Rigorous analysis must take into account the uncertainties in climate science, economic impacts, and policy, and will require a combination of climate science and economics expertise. Focusing on climate sensitivity, which has some of the largest uncertainties, the Interagency Panel on Climate Change (IPCC) has concluded that there's a quadratic relationship between global warming and economic impacts (melting of ice sheets, agricultural issues) which leads to a factor-of-16 uncertainty for economic impacts. Citing a paper based on reflected solar accuracy and climate trends (Wielicki *et al*, 2013; *Bulletin of the American Meteorological Society*), Dr. Weilicki discussed a science value matrix described therein:

High accuracy is critical to more rapid understanding of climate change. A better observing system yields results in a shorter period of time and can help society make better decisions on climate issues more quickly, which in turn can be related to the economic value of science information. Some researchers feel that there should be more venues in which to disseminate this sort of information. Dr. Shepherd noted that *Weather Climate and Society* is a journal that publishes such data. Dr. Wielicki commented that NASA should also stay apprised of efforts to quantify climate variables, such as that being done in companies like IBM, which is aggressively addressing this topic from an economic standpoint. NASA needs to leverage these nimble companies.

Dr. Wielicki presented details of a Value of Investment (VOI) Estimation method, based on unchanged emissions profiles, climate sensitivity, climate change, and economic impacts. Dr. Siegel noted that these frameworks are not additive; their weights have to be determined expertly and uniformly. Dr. Wielicki asked that members consider the briefing as an overarching argument, apart from details of the methodology.

Climate change data is obscured by natural variability uncertainty and observing system uncertainty. Today's global Gross Domestic Product (GDP) is $80T US dollars. Based on data on climate damage estimated from 2050 through 2100, an up to $4T per year reduction could be expected to impact the GDP

for decades, based on a "discount rate" of 3%. Dr. Foufoula-Georgiou added that this measurement excluded impacts on the world's most vulnerable regions, and on environmental immigrants. Dr. Wielicki agreed, saying that these factors were not weighted in this argument; if they were, they would greatly expand impacts beyond just pure dollar values. Based on just GDP inputs, calculations indicate that the additional cost of an advanced climate observing system is about $10B per year, worldwide, weighed against the potential trillions of dollars lost per year in GDP, making improved climate observations valued at $3T to $17.6T, depending on the discount rate used. Even at the highest discount rate, the return on investment (ROI) is very large, at $50 ROI per dollar invested. In other terms, one can say that delaying the launch of an improved climate observatory by 10 years reduces its benefit by $2.6T, with each year of delay causing a loss of $260B of world benefits.

Dr. Wielicki ended the briefing by stating that even large (factor of 5) changes in the presentation's economic analysis leave the conclusion unchanged: the ROI of an improved climate-observing system (COS) ranges from 10:1 to 250:1. A new COS would be one of the most effective investments society could make to provide a stable economic future in the face of climate change. Dr. Michalak asked if mitigation costs were included in the analysis. Dr. Wielicki stated that, yes, the costs include the benefit to society in avoiding impacts, as well as the cost of mitigation (i.e. emissions reduction costs). Moreover, the cost of the satellites is small relative to the mitigation costs. Dr. Michalak asked why it wouldn't be beneficial to simply mitigate without a new COS. Dr. Nolin felt that ESS should think more broadly beyond this example, and focus on the idea of the approach. Dr. Michalak couched an observation, finding and recommendation in the following terms: attempts are being made to put an economic value on a COS; Earth scientists are historically adept at arguing for basic research and are able to trace benefits to NASA science, but research scientists are not economists and therefore not equipped to make the economic argument; thus a recommendation might be that in the future, the committee should invite multiple experts to brief on the economic frameworks available. Dr. Foufoula-Georgiou felt that a useful analogy could look at a system within desired bounds, such as ecosystem impacts, dollars, and population impacts. Dr. Wielicki pointed out that calculations on health impacts have been done by the Environmental Protection Agency (EPA) for a long time. Dr. Raymond Schmitt noted that there are lists of central climate variables, and that an obvious next step would be to decide which one to approach next, such as sea level rise, a variable which is accurate at present. Dr. Joughlin noted that this variable may be changing, given the current acceleration. Dr. Siegel felt that from an ocean color perspective, it is hard to come up with a single objective; these analyses break down when considering multiple objectives. Dr. Freilich said that while ESD does not have the economic expertise, he asked whether ESD resources should be diverted to bringing together the appropriate bases of knowledge across the nation to cast the rationale in a reasonable way, or if ESD should stand up a program on developing this economic expertise. Dr. Friedl announced that the ASP had just selected a proposal to advance analysis techniques to quantify Earth Science data; and to inform the community of the terms and concepts, in response to resistance in the Earth Science community about learning more economics. Dr. Running felt it was high time that economic theory and modeling get some attention with respect to Earth systems; there is no recognition of catastrophic failure of the system, for instance. Dr. Michalak asked if there were a strong enough need to divert funds for complete economic analyses for these missions. She felt it made sense to more clearly articulate the benefits of NASA and the downstream impacts, rather than concentrate on the dollar value. The value of a climate-observing system is an important question, which may be more of a question for the National Academies of Science, or for an interagency task. Dr. Kummerow felt it important to have to have documentation of the analysis. Dr. Moghaddam noted that Earth Science were to go through this exercise in response to climate denial arguments, it must first address the sensitivity issue; it would be beneficial to focus on science, define objectives, methods, and uncertainty analyses, and communicate that climate sensitivity is not zero. Dr. Wielicki averred that learning the economic

framework is not difficult; AGU is planning to write a primer on the subject. Dr. Siegel felt that from an academic POV, it's important that any referenced economist should be doing top-shelf work. Dr. Freilich said that now would be the time to meld the disciplines. Dr. Nolin suggested that understanding the integrated value of the work is essential, and that ESD was already on board to do this through ASP. Dr. Schmitt noted that the Ocean Studies Board is producing a report on the sustainability of the EOS for decades. Dr. Wielicki added that there are many economists already working on the Interagency Panel on Climate Change (IPCC). Dr. Large noted that top-of-the-atmosphere radiation measurements are not adequate, and that NASA is the only agency that can improve this part of the equation, which has large effects on climate change. Dr. Dessler commented that many researchers are calculating the value of climate change, but not specifically on the effects of change in observation uncertainties. Dr. Foufoula-Georgiou felt that the use of GDP does have some value, and that she would personally support developing the framework presented by Dr. Wielicki.

Discussion

Dr. Nolin directed a discussion on observations, findings and recommendations, and the committee viewed and modified language on projected slides.

Overall, ESS discussed findings on considering a strategy to reach an optimum 50-50 budget split between Flight and non-Flight in ESD; constellations demonstrating implementation of all 4 ESD areas, and that a CubeSat constellation approach holds promise as part of a mission portfolio; support for InVEST CubeSats; data buy proposals will likely have value for Earth Science research and technology; A recommendation to continue SNWG discussions on a regular basis was proposed.

ESS discussed a finding to support the continued implementation of CubeSat program, and a recommendation to support an increase in the budget for the purposes of expanding the CubeSat program.

ESS finalized language on a GPRA finding and recommendation: GPRA is a valuable review and assessment document; ESS will consider a new GPRA template with a focus on key accomplishments, explanations, and implications of accomplishments. The committee took an action to task a subset of the ESS to revise the template for its next report, and to establish fact-finding telecoms, to be followed by review telecoms for the purposes of voting on grade colors.

ESS discussed a finding and recommendation on an economic framework for viewing impacts of climate change on society, noting that ESS is challenged by lack of economic expertise. ESS formulated a recommendation to encourage ASP proposals in this area. Dr. Kaye commented ESD could just add the socioeconomic component to existing science proposals, noting that land use proposals already require something like this. Dr. Dessler felt that economic arguments are not the strongest for science. Dr. Running found Dr. Wielicki's framework useful, as it makes a valuable point to the outside world, even if it doesn't seem rigorous enough to the science community. Dr. Foufoula-Georgiou noted that GDP is an insufficient variable, and that there are subtleties in economic values (clear-cutting lumber is considered more valuable than the ecosystem the forest provides, e.g.).

Dr. Kummerow commented that Earth Science applications may be too narrowly defined, and that NASA might consider a better integration between ASP and science in meeting societal needs going forward; he suggested that applications and science panels be formed to integrate the process at the program management level. ESS considered the wording of recommendation that ESD pursue actions to increase the understanding of the Earth as a fully integrated system, including socioeconomic implications, and to integrate science and applications more closely.

Closing Remarks
Dr. Nolin adjourned the meeting at 12:50pm.

# Appendix A
## Attendees

Earth Science Subcommittee members
**Steve Running, ESS Chair, University of Montana**
Andrew Dessler, Texas A&M
Efi Foufoula-Georgiou, University of Minnesota
Thomas Herring, Massachusetts Institute of Technology
Ian Joughin, University of Washington
Christian Kummerow, Colorado State University
William Large, National Center for Atmospheric Research
Anna Michalak, Carnegie Science
Mahta Moghaddam, University of Southern California
Anne Nolin, Oregon State University
Ray Schmitt, Woods Hole Oceanographic Institute
J. Marshall Shepherd, University of Georgia (via Webex)
David Siegel, University of California, Santa Barbara
**Lucia Tsaoussi, Executive Secretary, NASA Headquarters**

NASA Attendees
Michael Freilich, NASA HQ
Lawrence Friedl, NASA HQ
Eric Jensen, NASA HQ
Jack Kaye, NASA Headquarters
Christine Moats-Xavier, NASA KSC
Garrett Skrobot, NASA LSP/CubeSats
Ana Stark, NASA HQ

Non-NASA Attendees
Ana Wilson, Ingenicomm
Joan Zimmermann, Ingenicomm

# Appendix B
## ESS Membership

Steve Running, ESS Chair
University of Montana

Roland Burgmann
University of California, Berkeley

Greg Carmichael
University of Iowa

Andrew Dessler
Texas A&M

Efi Foufoula-Georgiou
University of Minnesota-Twin Cities

Sivaprasad Gogineni
University of Kansas

Kass Green
Kass Green and Associates

Thomas Herring
Massachusetts Institute of Technology

Ian Joughin
University of Washington

Christian Kummerow
Colorado State University

William Large
National Center for Atmospheric Research

Anna Michalak
Stanford University

Mahta Moghaddam
University of Southern California

Anne Nolin
Oregon State University

Richard Rood
University of Michigan

Raymond Schmitt
Woods Hole Oceanographic Institute

J. Marshall Shepherd
University of Georgia

Hank Shugart
University of Virginia

David Siegel
University of California, Santa Barbara

# Appendix C
## Presentations

1. Earth Science Division Update; *Michael Freilich*
2. Small Satellite Constellations; *Michael Freilich*
3. In-Space Validation of Earth Science Technologies (InVEST) Program; *George Komar*
4. Small Satellite Constellation Partnerships; *Christine Moats-Xavier*
5. Venture Class Launch Services; *Ana Stark*
6. CubeSat Launch Initiative; *Garrett Skrobot*
7. Economic Value of Earth Science Information; *Bruce Wielicki*

# Appendix D

NAC Earth Science Subcommittee

**Agenda**

Kennedy Space Center Visitor Complex

Debus Conference Facility, State Road 405

Kennedy Space Center, FL 32899

10-January-2017

| | | | |
|---|---|---|---|
| 8:30 | 8:45 | Opening remarks – new charter | L. Tsaoussi |
| 8:45 | 8:50 | Meeting charge | S. Running |
| 8:50 | 10:30 | Earth Science Division Update | M. Freilich |
| 10:30 | 10:45 | Coffee Break | |
| 10:45 | 12:00 | Small satellites/constellations | M. Freilich |
| 12:00 | 12:30 | Discussion | ESS Members |
| *12:30* | *1:30* | *Lunch* | |
| 1:30 | 2:00 | InVEST program | G. Komar |
| 2:00 | 2:45 | Discussion | ESS Members |
| 2:45 | 3:00 | Coffee Break | |
| 3:00 | 3:30 | Small satellites Constellation Partnerships | C. Moats-Xavier |
| 3:30 | 4:00 | Venture Class Launch Services | A. Stark |
| 4:00 | 4:30 | Cube Sat Launch Initiative | G. Skrobot |
| 4:30 | 5:00 | Discussion | ESS Members |
| 5:00 | 5:30 | Public Comment | |
| 5:30 | | Adjourn | |

11-January-2017

| | | | |
|---|---|---|---|
| 8:30 | 9:00 | Earth Science GPRA report template | S. Running / ESS Members |
| 9:00 | 9:30 | Earth Science Value Framework | M. Freilich |
| 9:30 | 10:00 | Economic Value of ES Information | B. Wielicki |
| 10:00 | 10:15 | Coffee Break | |
| 10:15 | 11:50 | Discussion | ESS Members |
| *11:50* | *12:45* | *Lunch* | |
| 12:45 | 1:00 | Closing Remarks | S. Running/L. Tsaoussi |
| 1:00 | | Adjourn | |