

Advisory Committee for Geosciences (AC/GEO)

April 14-15, 2021

Meeting Held Online

Meeting Minutes

AC/GEO Attendees:

Dr. Dr. Hodges (Chair)
Dr. Lihini Aluwihare
Dr. Carol Arnosti
Dr. J. Ramón Arrowsmith
Dr. Kerry Cook
Dr. Luis Alberto González
Dr. Colette L. Heald
Dr. Kaatje Kraft
Dr. Amanda Lynch
Dr. Robyn M. Millan
Dr. Gary Mitchum
Dr. Vernon Morris
Dr. David B. Parsons
Dr. Tammi Richardson
Dr. Alan Robock
Dr. Barbara Romanowicz
Dr. Sharon Stammerjohn
Dr. Cathy Whitlock

NSF Senior Staff:

Melissa Lane

Other Meeting Participants:

Dr. Anjuli S. Bamzai, Division Director, Division of Atmospheric and Geospace Sciences (AGS)
Dr. Maggie Benoit, Program Director, Earth Sciences (EAR)
Dr. Scott Borg, Senior Advisor, GEO
Dr. Carla Cáceres, Chair, AC for the Directorate for Biological Sciences (AC/BIO)
Dr. F. Fleming Crim, Chief Operating Officer, Office of the Director (OD)
Dr. Thomas Daniel, AC/BIO
Dr. Ruth S. DeFries, Columbia University
Dr. William Easterling, Assistant Director, GEO
Dr. Michelle Elekonich, Deputy Division Director, Division of Integrative Organismal Systems (BIO/IOS)
Ms. Lauren Everett, Senior Program Officer, The National Academies of Sciences
Steven Goldstein, Division Director, EAR
Dr. Theresa Good, Division Director, Division of Molecular & Cellular Biosciences (BIO/MCB)
Dr. Stephanie Hampton, Division Director, Division of Environmental Biology (DEB)
Dr. George Hornberger, Vanderbilt University
Dr. Bauke H. Houtman, Section Head, Division of Ocean Sciences (GEO/OCE)

Dr. Alexandra Isern, Deputy Assistant Director, GEO
Dr. Brandon Jones, Program Director, GEO
Dr. Donal Manahan, Division Director, IOS
Dr. Candice Major, Section Head, OCE
Dr. C. Robertson McClung, AC/BIO
Dr. Stephen Meacham, Section Head, Office of Integrative Activities (OIA)
Dr. Madeline Midyette, Program Analyst, GEO
Dr. Brent Miller, Acting Deputy Division Director, BIO/MCB
Dr. Sethuraman “Panch” Panchanathan, NSF Director
Dr. Diane Pataki, AC/BIO
Dr. Lina Patino, Senior Program Director, GEO
Dr. Maria Pellegrini, AC/BIO
Dr. Terrence Quinn, Division Director, GEO/OCE
Dr. Smith-Nufio, Program Director, EAR
Mr. Brian Stone, Chief of Staff, Office of the Director (OD)
Dr. Alan Tessier, Deputy Assistant Director, BIO
Dr. Joanne Tornow, Assistant Director, BIO
Dr. Thomas Weingartner, Chair, AC/Office of Polar Programs (OPP)
Dr. Elizabeth Zelenski, Staff Associate, GEO

Wednesday, April 14, 2021

Welcome

Dr. Hodges welcomed everyone and after introductions he turned to Dr. Easterling for his presentation.

Update on NSF GEO

Dr. Easterling thanked the AC members for their work and provided a brief budget overview. The president’s fiscal 2022 budget request includes \$10.17 billion for NSF, a 20 percent increase to:

- enhance fundamental research and development;
- address racial equity in science and engineering;
- address climate science and sustainability research;
- strengthen U.S. leadership in emerging technologies; and,
- construct additional major research facilities.

President Biden has proposed a new NSF technology directorate, to be called the Directorate for Translation, Innovation and Partnerships (TIP) to facilitate translation innovation and the forming and maintenance of partnerships in the in the existing directorates. TIP will also have a focus on artificial intelligence, high performance computing, advanced sensor technology and simulation modeling.

Dr. Easterling also reviewed the administrations priorities—COVID-19, economic recovery, racial equality and climate change—and the NSF director’s three pillars: advancing the frontiers of research into the future; ensuring accessibility and inclusivity; and securing global leadership

in science and engineering.

He also reviewed NSF investments:

- Resilience and Broadening Participation
 - Coastlines and People (CoPe) Research Hubs
- Artificial Intelligence (AI)
 - Institute for Research on Trustworthy AI in Weather, Climate and Coastal Oceanography
- Mid-Scale Infrastructure
 - Global Ocean Biogeochemistry (GO-BGC) Array
- Convergence Research for Grand Challenges
 - Navigating the New Arctic (NNA)

Elaborating on CoPe, he highlighted the following:

- Conduct basic research focused on understanding the impacts of coastal environmental variability and hazards on populated coastal regions.
- The objective of this solicitation is to support Coastal Research Hubs, structured using a convergent science approach
- 2020 solicitation received 98 proposals
 - 55 proposals for small-scale topically-focused hubs (\$1M/yr, 5 years)
 - 43 proposals for large-scale interdisciplinary hubs (\$2-4M/yr, 5 years)
 - Awards made by end of FY 2021 (September)
 - Total Requested Dollars: \$977.8m
- Another program solicitation planned for FY 2022

Expanding on NNA he highlighted the following:

- Conduct research to understand and forecast environmental change; advance economic prosperity; promote human and ecological health; and preserve security for the United States, the circumpolar Arctic region and the globe.
- The objective is to address convergent scientific, engineering and educational challenges in, and related to, the rapidly changing Arctic.
- University of Colorado Boulder, Alaska Pacific University and University of Alaska Fairbanks awarded a five-year, almost \$5 million cooperative agreement for Navigating the New Arctic Community Office.
- 2021 Solicitation Closed on March 5
 - Planning Grants (\$300k, up to 2 years)
 - Research Grants (\$3m, up to 5 years)
 - Collaboratory Grants (No \$ Ceiling, up to 5 years) New Track in 2021
- Just launched “Arctic Community Engagement” Web page
<https://www.nsf.gov/GEO/opp/arctic/ace/index.jsp>

He also provided a major facilities update:

- Construction on NCAR’s Research Aviation Facility is on schedule and on budget, with anticipated completion in late April 2021.
- Regional Class Research Vessels (RCRV) construction experienced delays within a timeframe expected for such complicated vessels, and additional unexpected COVID-19

impacts. The delivery schedule has been replanned to account for these changes. Ships are expected to enter service in 2023 and 2024.

- Ocean Observatories Initiative (OOI) updates:
 - Community is engaged through an Innovation Lab in proposing a new location for the Pioneer Array
 - Cyberinfrastructure is transitioning to Oregon State University from Rutgers
 - South Cable of the Regional Cable Array remains offline pending repair of a fault that occurred in Aug 2020; repair anticipated this summer

Dr. Easterling next made a few comments about the ongoing the U.S. National Academy of Sciences, Engineering and Medicine (NASEM) Earth System Science Study, making the following points:

- Study on track with results expected in 2021.
- Informative workshops on computing, data and cyberinfrastructure and integration of the social sciences held in early 2020.
- Final workshop on Education and Workforce for Earth System Science on April 16.
- Detailed update from Study Chairs, George Hornberger and Ruth DeFries later in this meeting.

He also touched on recent research highlights:

- Scientists discover ancient lakebed deep beneath Greenland ice.
- Reconstructing sea-level changes over the past 2,000 years.
- Unexpected wildfire emissions impact air quality worldwide.
- Satellite imaging to map groundwater use in California's Central Valley.

Dr. Easterling focused next on the NSF Racial Equity Task Force, noting:

- Discrimination, racism, or injustice of any kind has no place in GEO, NSF or the communities we support.
- NSF Racial Equity Task Force was established to promote diversity, broadening participation and breaking down barriers to inclusion.
 - Reviewing internal and external policies and practices.
 - GEO is at the table.
 - GEO staff will have opportunities to provide input.

Turning to personnel, he reviewed GEO senior staff changes in 2021:

- Anjuli Bamzai named to Senior Advisor of Global Climate Change in Office of the Assistant Director (OAD)/GEO
- Candace Major named Division Director for AGS
- Robert Moore named Acting Section Head for Geospace Sciences/AGS
- Michael Jackson named Acting Section Head, Antarctic Section in OPP
- Jennifer Mercer named Acting Section Head, Arctic Section in OPP

Dr. Easterling noted that he will be leaving GEO at the end of May to return to his home institution. A search committee is working to fill his Assistant Director position.

Discussion:

Dr. Kraft asked about NNA and the time it takes to develop partnerships with indigenous communities. Dr. Falkner responded that there is a planning grant track in the NNA for ensuring there is that chance for the communities to take the time it requires to develop the common language and shared goals and vision. There was also a solicitation this year and the Project Officer (PO) team interfaced with the communities that had expressed concerns about timing and worked to make sure the timing did not coincide with critical subsistence harvest activities. The Arctic section also issued a Dear Colleague Letter (DCL) regarding proposals that specifically address how to cultivate these relationships.

Dr. Arnosti asked about the delay in the regional research vessels and about keeping the older ships fully operational for use until the time the original classic research vessels are brought online. Dr. Houtman said the ships are getting long in the tooth but they are being well maintained and he expressed confidence in their safety and said they are going to make it through the extended period until the new ships come online. He added that the Research Vessel (R/V) Taani is going to Oregon State University to replace the R/V Oceanus. The ship that is going to replace the R/V Endeavor will be at The University of Rhode Island (URI). The R/V Gilbert R. Mason, which will replace the R/V Pelican, will be at the Louisiana University Marine Consortium (LUMCON).

Dr. Parsons asked about computer usage, the weather climate community and its need for much more computing power and cooperation with industry, noting the Europeans are a decade ahead in skill and planning. Dr. Easterling referred to the workshops at the National Center for Atmospheric Research (NCAR) with several companies and have had a chance to get information from them on how to guide our research. Dr. Bamzai added that NSF has computing systems in the GEO Directorate for weather climate and ocean modelers. Some of the Earth Sciences also access NCAR-Wyoming high-performance computing (HPC) resources. And there are bleeding edge computing systems funded by Computer and Information Science and Engineering (CISE) or the Office of Advanced Cyberinfrastructure (OAC). Going forward, she said NSF has internal working groups like the Cyberinfrastructure Strategy Group and one of the 10 Big Ideas, Harnessing the Data Revolution.

Dr. Hodges asked how much of the administration's request will go to GEO. Dr. Easterling said he was limited in what he was allowed to say but pointed to the emphasis the Biden administration is putting on climate change science and climate research.

Dr. Aluwihare asked about the \$50 billion number Dr. Easterling used earlier. He responded that it includes funds to stand up the new Directorate.

Dr. Arnosti asked about a portion of the \$600 million NSF is supposed to get as part of the American Recovery Act. Dr. Easterling said GEO participated in the allocation, along with the other directorates. Priorities included postdocs, graduate students and early career faculty.

Dr. Kraft asked about the congressional response to the president's budget. Dr. Easterling said it would be inappropriate to comment.

Dr. Morris asked about NSF engagement with tribal nations and whether there is a strategic plan and a data sharing plan that all of the awards must conform to, noting that establishing trust can take many years. Dr. Falkner responded that all agencies are required to report on their engagement with tribal nations and so NSF has been actively collating and updating its policies and practices to strengthen them. NSH has a tribal liaison in the Office of General Counsel. And we have people from OPP coordinating with that effort, which includes not just the Alaska Native tribes, although they represent 40 percent of our native tribal organizations in the United States that are Federally recognized. At the next AC meeting it will be possible to share more specifics that give a broader picture. She agreed it takes sustained engagement over a long period of time to be sure you are developing trust, which is the key word.

Data Analysis on COVID-19 Impacts and NSF Actions

Dr. Zelenski provided examples of outreach used to keep in touch during the pandemic, including:

- Virtual Panels, Committee of Visitors (COV), AC meetings, National Science Board (NSB) meetings
- Conferences, Virtual Exhibit Booths
- Hangouts, Informal Meetings
- Website, Listserv Announcements
- Webinars, Office Hours, Listening Sessions
- DCLs, Letters to the Community
- Symposia, Workshops, Lectures

She also discussed new and renewed solicitations and DCLs:

- New/Renewed Solicitations
 - Office of Polar Programs Postdoctoral Research Fellowships (OPP- Postdoctoral Research Fellowship (PRF), NSF 21-575)
 - Ocean Sciences Postdoctoral Research Fellowships (OCE-PRF, NSF 21-538)
- Dear Colleague Letters
 - Supporting Use of Existing Data and Samples in Atmospheric Sciences Research and Education NSF 21-064
 - Opportunities for Mid-Career Scientist Support in the Atmospheric and Geospace Sciences NSF 21-018

Dr. Patino continued the presentation to discuss the impact on the productivity of scientists. Preliminary data do not show fewer proposals submitted due to the pandemic. The total number of proposals submitted to GEO was not that different from 2018. She added that the gender distribution of GEO proposals and supplements has remained steady. There is almost no difference in the gender distribution of proposals and supplements submitted in 2020 relative to the average of the previous three years. She also discussed COVID-19-related funding actions, but said the numbers are as yet incomplete and will be monitored. Also, 60 percent of the principal investigator (PI) actions related to impact on existing activities are to male PIs, but it is difficult to draw conclusions regarding the gender distribution on actions related to impacted groups. Regarding institution type, most of the funding actions are for Ph.D. granting institutions. She concluded by sharing the titles of some research projects GEO funded that related to COVID-19.

Before moving to the final part of her presentation, Dr. Patino addressed a question from Dr. Mitchum on some of the categories discussed earlier, including the research category, and her data sources. She also addressed a question from Dr. Richardson about variability in the data, a question from Dr. Morris about accounting for institutions that have closed and how NSF might respond to the multi-generational impact and a question from Dr. Hodges, who asked if the numbers captured what would seem to be a large loss in research productivity.

Dr. Midyette continued the presentation with an overview of the impacts reported by PIs through annual reports and no-cost extension (NCE) requests. She said certain themes have cropped up regarding NCEs: accessibility, career advancement and employment, spending, community, impacts on families and students and silver linings. Regarding the latter, she mentioned expanded virtual field training and a case in which a cohort of underrepresented undergraduates participated in a virtual seminar that introduced them to faculty and student research that may prove beneficial if they pursue a graduate degree. Overall, she said PI and Co-PI teams are being proactive and virtual alternatives have become an option where infrastructure and access are not an issue. But field activities are overwhelmingly being postponed and there is concern for students who depend on paid research and other professional development opportunities to meet short-term financial needs and feel confident in pursuing more education in GEO or gain other skills important in the job market. In this regard, PI and co-PI teams are sensitive to the importance of creating and nurturing a sense of community. Many feel a virtual platform is not sustainable to promote the growth of the community or the culture long term.

Discussion

Dr. Aluwihare asked about supporting more bridge programs between undergraduate and graduate school. Dr. Patino responded that some institutions did not have the resources to provide that kind of support to students.

Dr. Arnosti said NSF is not getting information from the people who need help the most. Those who are the only geoscientists in their department may not hear about opportunities, despite DCLs. Dr. Patino responded that an answer might be in supporting professional organizations or others that can build built a network for those individuals. She brought up how graduate departments are valuing applications this year or next year when student experiences may not have had the same richness as in previous years. Students presenting results at virtual professional meetings are not able to connect with PIs. Are we going to demand people have the same number of publications in 2021 as they did in 2019 and 2020? We all have to recalibrate and not just use the same metrics as we had been using in the past.

Dr. Whitlock said outreach from NSF has been really good this year and asked how much of it is going to continue. Dr. Patino responded that virtual presentation has allowed for broader engagement and NSF will continue to use hybrid interactions, both in person and using virtual interactions.

Dr. Mitchum questioned whether the data are capturing the impacts on the community. There are a lot of things people aren't able to accomplish and it doesn't show up. We're saying here that

there's been very small differences in the number of proposals, for example. He said he was not convinced that that's fair; there's still a problem to be addressed.

Dr. Falkner said that a preliminary OPP analysis suggests that for supplements it's available by established PIs. In annual reporting from newer people, they're explaining how they're coping. They're not necessarily reaching out for supplements, despite the fact that we are reaching out to all PIs. It's a mutual kind of challenge to figure out how to be sure we are encouraging the full community to take advantage of the flexibilities NSF has to offer.

Dr. Romanowicz asked about the evaluation stage of postdoc fellowships, or graduate fellowships, where people have been delayed in their productivity and how that might be taken into account in the evaluation. Dr. Patino said there may be more freedom to accept papers in preparation in place of published papers. But said she did not know if NSF will state there has to be a recalibration.

Dr. González asked if NSF is seeing a decrease in publication. He said colleagues are catching up with publications and have submitted more papers. Dr. Patino said NSF does not have that information at this point.

Report on the U.S. National Academy of Sciences, Engineering and Medicine Earth System Science Study

Dr. Hornberger provided the statement of task:

- Describe the potential value and key characteristics of a robust, integrated approach for studying the Earth system.
- Discuss emerging opportunities and barriers to progress for achieving this vision, including consideration of the interdependencies and synergies among all components.
- Identify potential synergistic opportunities within current facilities, infrastructure and coordinating mechanisms to address the overarching capabilities and recommend ways to leverage these efforts for Earth systems research.
- Discuss computational, data and analytic support for Earth systems research, including guidance on harnessing existing, planned and future NSF-supported cyberinfrastructure.
- Discuss workforce development to support the personnel needed to advance Earth systems research. This could include undergraduate and graduate education, technical training to support facilities and infrastructure and increasing diversity and inclusion in the future workforce.

He also provided the committee membership:

- Ruth DeFries, Columbia, Co-Chair
- George Hornberger, Vanderbilt, Co-Chair
- Asmeret Asefaw Berhe, University of California (UC), Merced
- Claudia Benitez-Nelson, South Carolina
- Melissa Burt, Colorado State
- James Elser, Montana
- Courtney Flint, Utah State
- Royce Francis, George Washington
- Inez Fung, UC Berkeley

- William Gropp, Illinois Urbana-Champaign
- Melissa Kenney, Minnesota
- Jerry Mitrovica, Harvard
- Constantine Samaras, Carnegie Mellon
- Kristen St. John, James Madison
- Fiamma Straneo, Scripps
- Duane Waliser, Jet Propulsion Laboratory (JPL)/Caltech

He also presented the committee's timeline:

- Jul 2020
 - Committee formation
- Aug
 - Meeting #1
- Oct
 - Meeting #2
- Nov-Apr
 - Workshops + Meeting #3
- Apr 2021
 - Meeting #4
- May
 - Meeting #5
- Jun/Jul
 - External Peer Review
- Aug
 - Report Release
- Aug 2021 – Feb 2022
 - Dissemination

Dr. Hornberger also discussed the workshops that have been held:

- Education & Workforce Framing Session
- Nov. 13, 2020
 - Explore issues associated with diversity, equity, and inclusion in the Earth systems workforce to better serve Earth and its people; creating Earth systems science learning and working environments for all; statistics and data on the geoscience workforce; and the future of Earth systems science education and training
- Engineering
- Nov. 20, 2020
 - Opportunities and challenges of work at the intersection of engineering and Earth systems science, including building effective two-way partnerships, how systems thinking approaches may vary between disciplinary areas and undertaking and operationalizing larger projects connecting Earth systems science and engineering
- Social Sciences
- Jan. 12 & 19, 2021

- Focus on the role of social science in understanding the Earth system, the value of an integrated approach at NSF and the role of social science in studying Earth system interactions, current and new exemplars of transdisciplinary research and ideas for accelerating the integration of social science in studies of Earth system interactions
- Computing & Cyberinfrastructure
- Feb. 4 & 12, 2021
 - Discussions focused on computational, data, and analytic support for Earth systems research, including guidance on harnessing existing, planned, and future NSF-supported cyberinfrastructure
- Education & Workforce Wrap-Up Session
- Apr. 16, 2021
 - Explore issues associated with education and workforce development goals, theory of change, preparing a more equitable Earth systems science workforce, and partnerships/collaborations that have been successful in bridging disciplines

The workshops are recorded and can be accessed via the study [website](#).

Discussion

In response to a question from Dr. Hodges about anything surprising learned so far, Dr. Hornberger said a lot of interesting ideas came from the workshops on computing and the workforce. Dr. DeFries said there is a real appetite in the science communities for use-inspired research while keeping the NSF basic science mission.

Dr. Lynch asked if there were areas where we hadn't made as much progress as we might have expected. Dr. Hornberger said it has to do with making connections between the engineering community and social, behavioral and economic sciences. Dr. DeFries talked about keeping facilities nimble to be able to keep up with the changes in research and the collaborations people are looking for.

Dr. Whitlock asked about connecting social science to the Earth sciences and whether the committee is thinking about more connectivity within NSF. Dr. Hornberger said the committee is discussing various approaches that might fit into an integrated program. Dr. DeFries said there will be a lot in the report about integrating social sciences, natural sciences, engineering and data science.

Dr. Easterling reviewed the impetus for the report. Over the past several years, it was noticed that a number of the grand challenges were crossing directorates. And there was a conversation about the importance of the social sciences. There are many questions about how humans interact with the physical and biological world that we don't understand and having them as part of the Earth system is necessary. But NSF is organized around the classical disciplines. And we feel we need the insights of the community to help us better deploy our research funding in a way in which we can include all aspects of the Earth system and we look to places where the community has moved on and they've embraced the notion of Earth systems. The NCAR community Earth system model used to be known as the community climate model, but most of the major advances in the architecture of the model have come from the inclusion of other parts

of the Earth system. But organizing differently to approach the problems that required a systems approach is difficult. So, NSF went to the Academy and said, help us help ourselves. This is a report for NSF, though one can't consider Earth systems fully within the bubble of NSF. We're hoping the guidance we receive from the Academy, which will go beyond just answering the specific questions that we put before them, will give us ammunition to bring together research programs.

Dr. Parsons said doing Earth System Science is very hard without The National Aeronautics and Space Administration (NASA) and The Department of Energy (DOE) and asked about the international component. Dr. Hornberger said it is part of the committee's charge to discuss collaborations, including with other Federal agencies and local agencies and that it would be international.

Dr. Stammerjohn asked if Polar Programs, which has integrated systems science programs, had a voice in the workshops. Dr. Hornberger said NNA is a poster child for Earth System Science broadly writ but he thought there were no presentations by any NSF programs. Dr. DeFries added that many examples from Polar are brought up by committee members. Dr. Lynch added that Polar Programs has been thinking this way for many decades. Dr. Stammerjohn added that there needs to be continuity over time to capture related challenges regarding integrated systems science identified years earlier.

Dr. Hodges asked how much solid science participation there has been. Dr. Hornberger said there has not been a workshop on solid Earth or atmosphere, for example. It has not been divided that way, but solid Earth is on the committee's radar. Dr. Hodges asked again if there has been participation by solid Earth sciences in the workshops.

Ms. Everett said the committee invited a broad cross section of different disciplines to all of the workshops. And staff ensure the committee is connecting with all relevant scientific disciplines that have an interest in the project. There was also an online questionnaire with responses across a large range of scientific disciplines. Dr. DeFries added in response to another question that there are strong voices on the committee for the importance of the geologic timescale. Dr. Romanowicz and Dr. Hodges asked about including the Earth's core and its influence. Dr. Hodges said it's important to not under define the Earth system.

Dr. Easterling said NSF is anticipating a big role helping the administration and GEO has embraced the concept of Earth system predictability as an initial starting point for how we might think about the opportunities to increase the amount of funding and climate change related research. We see system predictability across all the domains we've been talking about and we're going to need a guide on how to bring together all the elements necessary to advance a research agenda. It isn't exclusively focused on predictability, but that's a large part of what we're hoping to achieve at NSF. The report is going to give us a broad-brush guide.

Dr. Hornberger said predictability has been on the discussion list in every meeting. So, you will have something in the report that will be relevant. Dr. DeFries added that predictability is central, but not the total picture of the future of system science. In addition, adaptation and

biogeochemical cycles and issues that relate to Earth System Science and management of the planet are part of system science to include that as well as predictability.

In conclusion, Dr. Hodges said it's a very timely report and he thanked everyone involved for their work.

EAR Subcommittee Report on Review of the Geodesy and Seismology Instrumentation Portfolio

Dr. Arrowsmith said he was formally presenting to AC-GEO the subcommittee's report, *Recommendations for enabling Earth science through NSF's geophysical facility - A portfolio review of EAR seismology and geodesy instrumentation* and thanked the members for their work. He said the committee is asking AC-GEO to accept the report, which he distinguished from endorsing the report.

The report holds that seismic and geodetic instrumentation are essential infrastructure for the study of Earth's surface, interior, dynamics, history and hazards. They are used to elucidate the interactions between the geosphere, hydrosphere, cryosphere and atmosphere. Observations must be sensitive to displacements over orders of magnitude of spatial range (micrometer to global) and time spans (milliseconds to decades). He showed a map of geophysical networks active over the last 5 years.

The subcommittee was asked to recommend:

- Critical instrumentation and sensor network operation capabilities needed over the period from 2023-2030 that would enable progress on the science priorities articulated in *A Vision for NSF Earth Sciences 2020-2030: Earth in Time* (NASEM, 2020) and recent community consensus documents.
- A balance of investments in new and existing, but evolved, instrumentation and sensor network operation capabilities.

With the following constraints:

- Budget scenarios (reduced, modest growth, optimistic growth)
- Emphasis on EAR-supported instrumentation (no Polar and only terrestrial deployments)
- Federal Advisory Committee Act (FACA) oversight

The committee examined the integration of the *Earth in Time* report science questions with challenges identified in community report for geodesy and seismology. Dr. Arrowsmith displayed a graphic showing the alignment between the science priorities from *Earth in Time* and the Grand Challenges reports. It shows a number of areas where there's strong and broad alignment, some areas where there's less broad but deep and important alignments and a few areas where it was less significant. He emphasized that some of the emerging areas of importance are with respect to the climate system.

He listed the primary recommendations:

1. Expand resources to create large-scale, dense multi-disciplinary, multi-instrument seismic and geodetic networks and maintain and strategically expand the Global Seismic Network (GSN) and Network of the Americas (NOTA) geodetic network.
2. Support multidisciplinary rapid-deploy sensor packages for hazardous events.

3. Invest in emerging technologies.
4. Recapitalize and modernize equipment pools.
5. Push for recognition and base support for seismology and geodesy instrumentation and networks as U.S. National Infrastructure.
6. Enhance data access, exploration, utility, citability and curation as essential components of scientific infrastructure.
7. Maintain a strong and vibrant system of community governance of the facility to set high level science and instrumentation priorities and serve as a focal point, hub and springboard for community interaction, outreach, education, and collaboration.
8. Support professional facility staff.
9. Ease the deployment of geophysical networks that cross the shoreline.
10. Develop or expand partnerships to broaden the base of support.

He also showed a diagram illustrating the spectrum of priorities and frontiers for instrumentation, sensor networks and the enabling technology characterized by priority and readiness. The report contains detailed recommendations for both geodesy and seismology under different budget scenarios and he discussed tables displaying these recommendations. He also discussed the report's summary of impacts of funding scenarios compared to the current state. And he said the committee felt strongly that it needed to speak about justice, equity, diversity and inclusion. The Instrumentation Portfolio Review Committee (IPRC) advocates that the future geophysical facility embed anti-racist policy, practices and goals throughout its operations. The actions and plans include but are not limited to:

- Increasing transparency
- Providing training and resources
- Expanding selection criteria for meeting locations and field trips
- Feature indigenous knowledge of and contributions to geosciences
- Improve accountability

He noted that in the summer of 2020, both Incorporated Research Institutions for Seismology (IRIS) and UNAVCO, Inc. released statements on racism in the geosciences.

Dr. Arrowsmith also discussed the geophysical sensor networks as U.S. national infrastructure. He said geophysical networks funded by NSF are fundamental structures and facilities that are needed for modern American society and the economy to function and they should be supported as such. Essential infrastructure that is continuously and reliably present can be plugged into when needed and have a low-cost threshold for users to access, e.g., roads, railways and the Internet. He said the societal benefits include:

- Monitoring geologic hazards, including earthquakes, volcanoes and landslides
- Realtime earthquake and tsunami early warning systems
- Realtime weather forecasting
- National security, including monitoring of space weather that can interfere with power grids
- Realtime navigation.

He discussed seismogeodesy, noting that on one hand there's an interest and capability of the complementarity of the seismic and geodetic systems, broadening what is studied and working together, but also there's a gap and sensitivity.

He said one of the technologies the committee was excited about is distributed acoustic sensing (DAS), which records strain in the direction of a fiber optic cable that's comparable in signal-to-noise ratio to measurements by single component accelerometers or geophones. Opportunistic use of dark fiber along Internet corridors and ambient noise provide exciting opportunities for seismic monitoring at the urban scale. DAS can complement and supplement conventional seismic sensors and arrays already used across a wide range of disciplines.

He also highlighted applications for robotic systems in the Earth sciences, including advances in robotic systems that offer important opportunities to enhance observations of GEOlogic and geophysical processes. Applications include:

1. (semi)autonomous sensor platforms
2. Sensor deployment and retrieval
3. Data recovery and sensor health check.

He added that robotic systems represent an important Science, Technology, Engineering, and Mathematics (STEM) gateway for geophysics.

Discussion

Dr. Arrowsmith agreed with a comment from Dr. Lynch that the international connectivity of these systems is critical.

Dr. Aluwihare asked about the timeframe and the next steps. Dr. Arrowsmith said the report feeds NSF with ideas and information that they can work with and hopefully the potential for investment might be there going forward. There will be a request for proposals for the next generation of an integrated geophysical facility and the report will feed that Request for Proposals (RFP).

Dr. Whitlock asked if parts of Chapter Seven should be moved to a key message given that priorities are moving towards belonging, accessibility, justice, equity, diversity, inclusion (JEDI) and human infrastructure. Dr. Arrowsmith said the committee does not have some of those concepts as directly included in the primary recommendations due to struggling with the charge to the committee. Dr. Whitlock said she understands what Dr. Arrowsmith also said about being pretty far down the road and asked if was too late to change. Dr. Arrowsmith said he could go back to the committee and try for some better and balanced language. Dr. Hodges noted an issue with changing the document. The AC has to formally vote on whether to accept it unless NSF does not necessarily need the AC to vote on it today. Dr. Benoit said there is some time sensitivity with regard to next steps in the agency. Dr. Goldstein agree with Dr. Benoit. Ms. Lane said the AC may vote by email or accept it now pending recommendation for minor changes. Dr. Hodges said there was a recommendation to pull JEDI material and use that to write an additional recommendation.

Dr. Morris noted there wasn't a recommendation on how people might be held accountable. Dr. Arrowsmith said the report talks about providing clear timelines for improvement and regular reporting for accountability but the committee didn't have the capacity to go deeply into it.

Dr. Hodges commended the committee for talking about JEDI issues but that really wasn't their charge. He supported putting it as a recommendation but emphasized the report's original purpose and cautioned against getting bogged down over how prominent JEDI is in the report. Dr. Goldstein said specific language is being put into solicitations about JEDI.

Dr. Borg added that it isn't for the AC to do the work of the subcommittee but it could accept the report as is so it can be used to develop solicitations and pull from the report to present an AC recommendation aimed at equity, diversity and inclusion. Dr. Arrowsmith asked about Dr. Hodges writing a letter to accompany the report.

Dr. Kraft took issue with Dr. Hodges' argument that it was great the JEDI section was there at all because we need to start thinking about this as a requirement to integrate into everything we do in science and the AC should tie in what's being said within this report to the next steps of where this goes and consider the budget implications. Dr. Hodges agreed but noted there was nothing about that in the charge to the subcommittee. He proposed the AC make its own comment, as Dr. Borg suggested, and asked Dr. Whitlock to write a draft. Dr. González proposed having an additional recommendation to make sure the individual researchers are acting on it, not just the big networks. Dr. Parsons suggested the AC write a foreword in the document. Dr. Arrowsmith expressed concern that if the AC did something separately that it stay attached to the report. Dr. Isern said there is a time element to having the report approved. Dr. Whitlock said adding an 11th recommendation would be just a few sentences and would take care of the issue, adding that JEDI needs to be included. An AC letter distracts from all the good work that was done in the document. Dr. Arrowsmith said he would hate for the bureaucracy to get in the way of doing the right thing but he also wanted to make sure NSF acts on the report. Dr. Hodges asked about timing and Dr. Arrowsmith said it would take about a week. Dr. Hodges said the AC could vote the week after next. Dr. Isern said that was too late. Dr. Robin asked about a vote for contingent acceptance. Dr. Isern said the AC was highlighting an element already in the report and not making a significant change. Ms. Land said there could be a contingent acceptance and that would be part of the official record.

Dr. Hodges said that would be the quickest and best way forward and asked if there were objections from any AC members. There were no objections. He moved for a formal vote to accept the report contingent on the addition of this material talked about in the in the specific list of recommendations where Dr. Arrowsmith and the subcommittee feels appropriate. Dr. Millan asked what would happen if there was an objection. Dr. Hodges said it won't make a difference because it would just be a dissenting vote.

Dr. Hodges called the question. Dr. Robock said he did not feel competent to vote on the report and asked if he could abstain. Dr. Hodges said the vote is to endorse the existence of the subcommittee report and recommend NSF pay attention to it. It is not an endorsement of the recommendations. It is not a vote to say it is a good report, just a vote to say the AC received it.

Dr. Romanowicz asked why the report references NASA but does not reference contributions from U.S. Geological Survey (USGS) and the international community. Dr. Arrowsmith said the charge was to only do NSF-supported networks and not other government networks. The NASA Global Navigation Satellite System (GNSS) Network (GGN) is referenced because it is part of the geodetic instrumentation managed by UNESCO. Dr. Benoit added that NASA supports the infrastructure through Geodesy Advancing Geosciences and Earthscope (GAGE).

Dr. Hodges made a motion that the AC accept the subcommittee's report contingent on minor modifications and an additional recommendation that underscores the importance of issues of justice, equity, diversity and inclusion. Dr. Mitchum seconded the motion. The AC voted unanimously in favor of the motion.

Dr. Arrowsmith thanked the AC and briefly discussed version control for the document.

Preparation for Meeting with NSF Director and Chief Operating Officer

The committee developed a list of question it would pose to the NSF Director.

Meeting with NSF Director and Chief Operating Officer

Dr. Hodges thanked Dr. Panchanathan for meeting with the AC and asked if he would like to make introductory remarks.

Dr. Panchanathan thanked Dr. Hodges and the other members for their work. He began with a discussion of the President's outline for the budget. He said NSF engaged with the transition team right from day one, engaging with the administration, communicating the vibrancy of NSF, particularly the GEO Directorate. That is something the current administration deeply values. That has gotten us a 20 percent proposed increase by the president, the largest increase ever. But this is by no means done. This is the President's proposal to the Hill. Dr. Panchanathan reviewed his recent meetings and testimony on the Hill. He said NSF is starting to let people see the foundation is absolutely worthy of investment at a very high level. He also thanked Dr. Easterling for his service.

Dr. Mitchum began the questions for the director by asking about his vision for a technology directorate. Dr. Panchanathan said he wanted a directorate that is a crosscut across all NSF directorates. This technology, innovation and partnership directorate will be a horizontal that cuts through all the directorates. It will leverage the technologies that come out of the verticals, which have been overlapping. The climate problem will only be solved if all of the directorates work together. Likewise, he wants this technology directorate to energize the directorates, so they are not independent one another.

Dr. Whitlock asked how NSF would evaluate when something's transdisciplinary and how we should think about it. Dr. Panchanathan said that having served on many panels, good reviewers always pay attention and are respectful of ideas that cross that discipline to other disciplines. So, the key is to take a lot of care in assembling panels that can actually evaluate these strong ideas and at the same time ensuring you're not losing anything in the process. The Grand Challenge problems, like climate, needs very strong disciplinary work but also strong transdisciplinary inspirations to be brought together with strong disciplinary work. And with the technology

directorate, this is even more the case. We have a strong cultural Renaissance, an evolution of the culture, to embrace and recognize and reward this kind of thinking.

Dr. Cook asked how NSF is thinking about the Biden climate initiative and what might be the implications for and the role GEO could play. Dr. Panchanathan said, in one word, exciting. This is a great moment for science and for the translation of science into societally meaningful and economically vibrant outcomes. From a climate perspective, we have a \$1.2 billion number being put out there. So, we are going to have the GEO director lead. He said there's a lot of interesting things everyone is thinking about. So, The U.S. Global Change Research Program (USGCRP) efforts as well as clean energy and clean technologies will be part of the thinking. One of the seven AI institutes NSF launched last year at the University of Oklahoma is focused on weather and climate. You could arguably say that is also an effort at NSF addressing climate issues. The work we do in Arctic and Antarctic are all very important. Dr. Panchanathan said he is enthusiastic about that and excited for the GEO community. Dr. Cook asked if negotiation is required between NSF and other entities working on climate. Dr. Panchanathan said he did not consider it negotiation as much as partnership. He said he would work closely with the National Oceanic and Atmospheric Administration (NOAA), NASA, DOE and others. We need every partner we can get to the table and see how we can do some very creative things, he said.

Dr. Easterling said there will be a meeting soon led by GEO with representatives from NOAA, NASA, DOE and USGS to figure out how to work together to leverage resources in an Earth Systems sense.

Dr. Fleming said many of the agencies are interested in moving forward together. Everyone wants to protect their interests, but people want to drive the research forward. We're at a particular moment right now and the director is poised to take advantage of it.

Dr. Aluwihare asked about how long NSF will collect its own data on COVID impacts, for example in geosciences proposal submission, and how will it be used for a long-term impact on making NSF more inclusive. Dr. Panchanathan said everybody has suffered but there are certain segments who have suffered more, the disproportionately affected individuals and institutions. NSF has been working behind the scenes making the case and prevailed in terms of getting \$600 million allocated specifically for disproportionately affected individuals and institutions. These are undergraduate research students or graduate students who have been wanting to finish their doctoral degree and move on to academic positions or industry or postdoctoral positions as well as early career investigators who not been able to get their work started at speed and scale. And mid-career people are also having their share of difficulties. This can be through supplements, existing grants and grant programs that can be aligned specifically with that objective. This resource is going to be available until the end of next September. And we are going to make sure the community knows what we are trying to do.

Collecting data is important but we have to motivate people to want to submit data. The people who are affected are worried about how the data is being used. So, we have to build trust that these data are being used for the purposes of bettering the environment. You can rest assured we will be gathering a lot of data.

Dr. Hodges said there is probably not a single division within GEO not funding something to do with climate research. So, we stand ready and there's a lot of enthusiasm and ownership of the problem, including atmospheric science, polar programs and the implications for interactions with solid Earth and society.

Dr. Panchanathan said he was thrilled with the number of people committed to real progress over the next several years and they know NSF is a place that can get it done. And we will make sure they give the necessary investments to the community.

AGS and EAR Division Meeting Reports

Following a personnel update, Dr. Heald noted that the NCAR and the facilities section have been thinking about COVID affecting early career scientists and they've been working on extending the current NCAR postdocs. She said there's been a huge impact on field campaigns. They've lost at least a year of no new aircraft deployments. They've been juggling 16 campaigns and trying to put those in the queue and trying not to move deployments too far out. But they've got things going into 2022 and 2023. There have also been maintenance issues with some aircraft. And they've been trying to keep the community doing the field work everyone's committed to.

In the Atmospheric Science section, she mentioned a DCL for opportunities for mid-career scientist support and an explicit DCL about seeking submissions using previous data, reflecting the idea that with the field campaigns being challenged, people could be thinking about data mining and applying that to their science questions. They are also revising the postdoc, so the awards are supported for 24 months, but extending the award length to enable people to take leaves as postdocs or eventually have teaching time.

Dr. Heald said Geospace is working on tasking the National Academies report on solar and space physics decadal survey. She also talked about the collapse of the Arecibo radio telescope and a solicitation for feedback from the community and people in Puerto Rico about the facility's future. Also, there has been a new geophysical observatory for space physics and radio sciences established. And there is a new program solicitation on grand challenges and geospace integrative sciences. She also briefly mentioned discussions about the 21st Century report and with the community on interdisciplinary work and broader impacts.

Dr. Goldstein continued the EAR segment of the presentation. After providing a personnel update he provided "four urgent out-of-the-gate priorities":

- Address the COVID-19 Pandemic
- Racial Justice (NSF: Be A JEDI)
- Economic Recovery
- Climate Change

Turning to COVID-19, he said EAR is dedicated to providing COVID-19 support to the community and reviewed Division Director messages to the EAR community on December 4 and February 25:

- Feb. 25 letter contains guidelines for supplemental funding requests to address COVID-19 impacts (interruptions, delays, or other disruptions)

- Focus on relief for vulnerable EAR cohorts - *students, postdocs, technical staff*.

He also said that guidelines were emailed to all PIs of active awards on March 4.

Turning next to JEDI, he said EAR recognizes the overarching importance of increasing diversity in the geosciences and highlighted the following points:

- Be A JEDI is a major theme of the EAR Education and Human Resources (EHR) Program
- EAR is forming a Be A JEDI Working Group (however, until now individuals in EAR have been highly involved)
- EAR has reached out — outside of EAR and GEO — to the NSF Human Resources and Development (HRD) Program
- EAR has been standardizing JEDI emphasis in wording of ongoing solicitation preparations:
 - Project goals should “include encouraging innovative efforts to include and foster engagement with people and communities historically underrepresented in the Earth and environmental sciences that are integrated with activities including staffing, education, outreach and community activities, and considerate of needs to support belonging, accessibility, justice, equity, diversity, and inclusion (B-A-JEDI)”

Dr. Goldstein provided an example of something EAR has already done, highlighting Unlearning Racism in Geoscience (URGE), a Research Experiences for Undergraduates (REU) at Woods Hole Oceanographic Institution (WHOI) supported by EAR. He said URGE is a program to use the existing social science literature to design and implement policies that will lead to more justice, equity, diversity and inclusion in geoscience. URGE aims to help the community:

- assess where geoscience is in the fight for racial justice
- deepen its knowledge of history and policies
- develop anti-racist structures and policies
- expand local conversations to a national stage with equal access to resources and expert opinion
- develop intimate groups that will hold members accountable.

Turning next to the Biden administration’s emphasis on climate as a potential benefit to GEO and EAR, he noted that EAR covers nearly the entire solid Earth from surface to center. Nevertheless, from 2010 to 2020, each year between 20-30 percent of all EAR-awarded projects mentioned climate change. He said EAR has formed a Climate Working Group (WG) to outline climate research within EAR and identify emerging investment areas.

He turned next to the *Earth in Time* report, which has 12 priority questions. Climate is mentioned in three. In another four, climate is not mentioned, but the questions are related to climate, for example: How is the Earth’s water cycle changing? And in another three, climate is discussed in the extended writeup. He highlighted two of the report’s recommendations that are at a mature level. Subduction Zones in Four Dimensions (SZ4D), a Research Coordination Networks (RCN) that is a joint effort of EAR and the Division of Ocean Sciences (GEO/OCE). The goals are to:

- capture and model emergent phenomena

- collect datasets in 4D - in real time & through geologic time
- increase predictive understanding of tsunamis & earthquakes, eruptions and landslides

He noted a series of EAR WGs on aspects of implementing the Earth in Time recommendations:

- Climate Change
- Continental Drilling
- Critical Zone
- Cyber-Infrastructure
- Near Surface Geophysics
- Research Infrastructure
- SZ4D

And in process is: Be A JEDI/Education and Human Resources.

In conclusion, Dr. Goldstein reviewed the EAR subcommittee discussion topics:

- EAR budget – history, current state, future outlook
- COVID-19 impacts – can EAR/GEO/NSF make programs more accessible
- Importance of Be A JEDI and possible new initiatives
- EAR and climate change – continental paleoclimate (“*the past is the key to the present/future*”); Earth System Predictability: droughts, water resources, natural hazards, etc.

Dr. González emphasized that the issue of climate and paleoclimate plays a major role in understanding and enabling what we do for future programs and said it cannot be emphasized enough how EAR is impacting those.

Discussion

Dr. Hodges discussed geochronology and asked how long it will be until that idea gets mature. Dr. Goldstein said it is in the report and it has been discussed recently. We are aware of the needs of that community and will address it. Dr. Hodges said there has not been a concerted effort in EAR to bring it to the fore. Dr. Goldstein said he hoped to have something for the next AC-GEO meeting.

Discussion of Other Topics

Dr. Robock asked who will succeed Dr. Hodges as AC-GEO Chair. Dr. Hodges said he did not know, but Dr. Kraft will run the fall meeting.

Dr. Hodges also previewed the next day’s discussion of the 21st Century GEO Draft Report, including a report synopsis, with Dr. Easterling providing information on its origins and purpose.

Thursday, April 15, 2021

Discussion and Approval of 21st Century GEO Draft Report, continued

Dr. Hodges said the AC would start at the beginning of the report, discussing and reworking the wording for sections where there were differences of opinion to assure everyone was comfortable. Beginning with the introductory material, committee members proceeded to craft specific alternative wording to add or delete for each of the sections Dr. Hodges highlighted.

Following the editing, Dr. Hodges said he would finish the wordsmithing and additions the following week.

OCE Division Meeting Report & Report on Upcoming AC-OPP Meeting

Dr. Quinn said the working group is actively engaged across the Directorate. OCR was reviving the postdoc program before COVID-19 hit with a broadening participation piece being given a unique spin. This working group is exploring two separate workshops and participation in the group has expanded given the substantial interest in making progress on this topic.

He said the upcoming workshop, The Global Biogeochemical-Argo Fleet: Knowledge to Action Workshop, will join NOAA and NASA and will be international. The virtual sessions will be held in May and June. The impetus for the workshop is the G7 Future of the Seas and Oceans Initiative.

Following a staffing update from Dr. Quinn, Dr. Arnosti said there was much discussion about COVID-19 effects on ship operations and field work. About 50 percent of planned operations are taking place, though under more difficult conditions. Day rates have also increased per ship. Plans for a science cruise from Cape Town to the Canary Islands was derailed because of positive COVID-19 tests. The submersibles Jason and Century are being deployed on current cruises and Alvin is undergoing an overhaul.

Regarding proposal submission, there seems to be an increase of submissions for the August 2020 deadline and a decrease in February 2021. There was also discussion of daycare and other things junior faculty are dealing with. Also, changes to teaching remotely requires time and effort. There was also discussion about issues with project-essential support staff. Most are grant supported but can't fully carry out their jobs because they can't get access to facilities or because they can't deploy because ships aren't going out as much. Their pay continues, so grant funds get dragged down, but they need to be retained. This is a problem that is probably going to cascade in the next few years. It is helpful that NSF is looking at COVID-19 financial support into September 2022 because many people will hit the rocks in the next year or so. There was also discussion about the effects on graduate students, particularly whether the Graduate Research Fellowship Program (GRFP) grants will be extended beyond 3 years. There's no determination right now because recipients have 4 years to do the funding. There was also a discussion about potential effects of the COVID-19 vaccine and the development of guidelines for best practices with respect to vaccination and scientific parties, including legal issues and because there are going to be people who cannot or will not be vaccinated. There was also discussion about NSF responses to PIs dealing with COVID, including flexibility in scope of work and no cost extension COVID-related supplements. In some programs, this is being done on request and in others there are DCLs going out. There was also discussion about COVID impacts on GEO operations within NSF. Zoom panels have been working well and surveys have shown working from home is fairly popular. POs felt their work is getting done despite COVID. There are issues with panels in terms of people having to multitask. Having remote panels enables some people to participate who otherwise wouldn't but sometimes the panelists aren't there as much as would be desirable and you don't get the same networking effects. There was also discussion about the need for data on proposal submission, including demographic information, career stages and

relative success. It would be useful to have a survey for determining the effects of removing target dates for proposal submission.

Discussion

Dr. Hodges asked about the amount of time it takes with COVID-19 from a recommendation by a PO until the grant's office approves. Dr. Mitchum said the program managers seem to think it is working. Dr. Isern said the last data she'd reviewed showed nothing out of the norm. Dr. Hodges said he has heard the time from when something is recommended until there is a grant seems to be taking longer this year. Dr. Isern said it hasn't been any different. Dr. Quinn said he understands the sensitivity of the community and will check into it. Regarding anecdotes that COVID-19 has impacted university administration staffing, which that may be a component of processing of awards, Dr. Mitchum said that in the cases he was talking about, that wasn't the hold up.

Report on Upcoming AC-OPP Meeting

The session continued with Dr. Falkner stating that the upcoming AC-OPP meeting agenda parallels GEO in many respects. There will be an overview of COVID-19 impacts. OPP has been actively engaged in outreach with the community and there will be an update on that. AC-OPP will be meeting with the director. There will be an update on GEO. On Day 2, the AC will hear from liaisons with other committees and there will be Committee of Visitors reports. Also on the agenda are diversity and inclusion issues. A subcommittee was chartered to make recommendations. There have been learning activities in which all staff were invited. Geosciences are not diverse and polar sciences are even less diverse. Yesterday she received a set of considerations regarding vaccine use from the Joint Expert Group on Human Biology and Medicine, a group that engages in Antarctica and is between the Science Committee for Antarctic Research and the Council of Managers of National Antarctic Programs, for which she serves as chair. She also referenced a document that summarizes current advisory and Academy reports that AC-OPP put together.

Discussion

Dr. Parsons commented on the diversity challenge and said program managers (PM) have been supportive of efforts to reach out to the tribes and nations that are indigenous in the Arctic. Dr. Falkner said there is an executive order for all agencies to enhance relationships with tribal nations and the director held a Town Hall. She also referenced deliberations that experts who have familiarity with trying to oversee safe operations in remote regions put together.

Dr. Parsons also asked about OPP fitting into the rest of GEO and touching the other divisions. Dr. Falkner said leadership encouraged strong collaboration across all of NSF. It is important people collaborate and are proactive. There are many examples of things being done to improve collaboration. She also discussed the globe as an integrated system. She added that because of the cost and effort to safely operate in remote regions, OPP does not support research that could be done elsewhere but that does not mean that OPP does not support research that makes people better appreciate how the polar systems are linked to the larger globe. Dr. Quinn said he was impressed with how things get shopped around and coordinated between the divisions, even though there are cases where things fall between the cracks. Dr. Easterling said NSF is a sitting duck when it comes to dealing with interdisciplinary research because of the way NSF is

structured but the staff have done an outstanding job of working within those constructs to facilitate interdisciplinary science.

Dr. Lynch said though the Earth is a system, there is tremendous value in a geographically limited perspective that allows you to ask scientific questions in ways that are different from more disciplinary programs. We shouldn't undercut the value of having this unique structure in NSF. It's particularly obvious when thinking about socioeconomic systems and dealing with indigenous people, where the question of place is important.

Dr. Hodges previewed the upcoming joint session with AC-BIO, where there will be a discussion about how BIO and GEO researchers can productively do things in the space of climate writ large. This is partly in response to the new administration's emphasis on climate. BIO is looking for new ideas and new ways to do better at this in the realm of climate.

Dr. Easterling said that with the focus of the new administration on climate change it's a natural opportunity to reaffirm existing collaborations and to think creatively about how to do new things together. In response to a question, he said this does not necessarily involve structural changes but new programs that cross over the directorates. The participation of social, behavioral and economic sciences and engineering will also be needed.

Dr. Arrowsmith said that in reference to AC-GEO's decision yesterday to add a report recommendation on geophysical instrumentation his committee has been in discussions and has completed the work. It says the future geophysical facilities should develop a structure to embed anti-racist non-discriminatory policy practices and goals, including attention to hidden biases throughout its operations. The facility should ensure that it be equally accessible by all NSF-funded projects, regardless of institutional resources, location and demographics. We recommend the facility and NSF continue efforts to integrate justice, equity, diversity, inclusion activity and enhance community governance structures to address inequality and ensure safe and inclusive field experiences for all participants.

Joint Session with the Advisory Committee on Biological Sciences

Dr. Tornow introduced the joint session, noting that both directorates have an interest in supporting research that informs how they respond to the challenge of climate change. She referenced [*Global Change Research Needs and Opportunities for 2022-2031*](#), which recommends integrated risk framing research and an approach that couples natural and human interactions, emphasizing the connection between climate systems, ecosystems and human systems. She said this is an area where BIO and GEO already work together with colleagues in the social, behavioral and economic sciences. The report also recommended advancing our understanding of the impacts of climate change and scenario-based planning and mitigation at the local regional scale, requiring advances in regional data collection and modeling biological and physical climate interactions at that scale. She said this is a place where BIO investments are complimentary to GEO's. She said BIO makes contributions through investments in ecology, evolution and organism sciences, striving to understand how the plant biota will respond to climate change. This is critical for predicting how the biota is going to be responding in a changing climate system. And BIO is well situated to contribute through supporting functional

genomics and biotechnology to mitigate impacts of climate change on critical agricultural, aquaculture and forestry systems.

Dr. Easterling said that two years ago he and Dr. Tornow led a team of NSF colleagues in a discussion with Academy counterparts on a possible study aimed at advising NSF on how the agency can mobilize its resources to best support an Earth systems approach to facilitate NSF's ability to model and predict the individual elements of the Earth system but also to understand how they work as a whole. That is, the Earth as a system of systems that includes the physical, biological and social elements. Flash forward two years and we have a golden opportunity to leverage the new administration's interest in climate change. And this is a golden opportunity for the bioeconomy as well. There is an opportunity to tightly couple our programs with the benefit of the recommendations of the National Academy system study to help get our resources to the right places. The immediate opportunity is for our two ACs to have an open conversation on how we can work together.

Dr. Miller discussed the BIO and GEO award portfolio over the past 5 years. Fourteen hundred awards were identified and characterized and represent different facets of climate change research in GEO and BIO. Dr. Miller said he attempted to answer what scientific spaces are uniquely GEO or uniquely BIO and what scientific spaces have synergistic intersections.

The uniquely GEO investment topics were:

- Atmospheric circulation and climate variability (AGS>>OCE>OPP)*
- Hydrology, sediment, climate variability and history (EAR>>AGS>OCE)
- Ocean circulation, temperature and deep water (OCE>>OPP>AGS)
- Sea Ice, ice cover, ice sheets (OPP>>AGS>EAR>Integrative and Collaborative Education and Research (ICER)>OCE)

The uniquely BIO investment topics were:

- Plants and response to climate (DEB>>IOS)
- Population dynamics, species interactions (DEB>> IOS)
- Forests and drought (DEB>>IOS)

*Indicates rank order of divisions

Dr. Miller said these topics are strictly geophysical or biological in nature and historically they've been academically separate, where GEO seeks to understand the change that's happening and BIO seeks to understand the biotic response to the change. Over the past decade that conversation is turning more towards the role of abiotic and biotic feedbacks and climate change.

Turning to intersecting topics between GEO and BIO climate change investments for the same 2016-2020 period, Dr. Miller listed:

- Climate variability, precipitation and live on land (GEO>BIO)
- Species distributions, environmental gradients (BIO>GEO)
- Ecosystem services and biodiversity (GEO~BIO)
- Microbes and ecosystem function (BIO>GEO)
- Soil and life (GEO~BIO)
- Coral reefs (BEO>BIO)

- Organic carbon and carbon cycling (GEO~BIO)
- Food webs and ecosystem structure (GEO~BIO)
- Land management (GEO~BIO)

The intersecting topics represent areas where there is synergy, i.e., actively talking and working together to pursue mutual interest, or it is passive, i.e., when proposals come into either GEO or BIO they occupy the same conceptual space but are not guided by a joint GEO-BIO solicitation. For soil and life, GEO and BIO partnered on the Signals in the Soil (SitS) solicitation to jointly understand their interests in soil science. But that topic is bigger than SitS. Dr. Miller said neither of the lists are comprehensive. The questions to spark discussion are, for uniquely BIO or GEO topics: What research areas would benefit from more crosstalk? And, for intersecting topics: In what research areas would more “active” synergy speed discovery?

Dr. Robock said the ecologists he has been working with on the impacts of climate intervention on ecosystems have had trouble finding a place in BIO that would accept a proposal to do this research and asked how receptive BIO would be to such studies.

Dr. Cáceres said AC-BIO had been discussing where the gaps are in what NSF currently funds and where the communication gaps are where NSF wants proposals but is not receiving them because there is an impression NSF doesn't fund in that area. Dr. Tessier added that having long been in DEB, proposals on the ecological consequences of climate would fall within the domain of the ecological science. Ecology is about that interaction of organisms and their environment. He added that NSF has funded work in geoenvironment. Dr. Robock said he is getting funding for that research, but it hasn't looked at ecosystems. wants to work with biologists and submitted a proposal to the recent BIO convergence call but had to twist it to meet all the parameters. He asked if, once it's rejected, they could submit to BIO as a regular proposal. Dr. Tornow said the answer to Dr. Robock's kind of question was what was hoped for from this joint meeting about areas of opportunity where BIO and GEO together might be thinking either where BIO and or GEO can push forward and or where there's an opportunity to work together. She suggested thinking about the bigger, broader topics that may turn out to create a different sort of opportunity for specific research projects.

Dr. Pataki said climate change adaptation and mitigation options are one of the areas of intersection between BIO and GEO that could use more collaboration. When the object of your study is to test climate change adaptation mitigation options, those topics haven't fit BIO very well. The topic would have to be some biological question that is just using climate change adaptation mitigation as an experiment. They could be looking at ecological options for mitigating climate or helping people adapt to climate. Maybe the main question isn't biological but has a lot of biology in that study and that could be a collaborative topic between the directorates.

Dr. Whitlock works in paleoecology looking at how ecosystems have responded in the past, present and future. She has received funding from GEO and BIO but found a home with the Directorate for Social, Behavioral, and Economic (SBE) Sciences in the geography programs, i.e., human environment or geographical sciences. They should not be left out because they are looking at climate bio-geography and some of the same topics.

Dr. Easterling said NSF's role in geoengineering is to support research that gets at the fundamental processes at play in the way the different reservoirs of carbon, for example, exchange and can overlap the atmospheric and other physical systems as well as the biological systems and where carbon goes and where it stays and for how long and if we were to manipulate it could it possibly be a way to slow or halt warming. That is beginning to become an accepted topic. But only in engineering would we be talking about trying to make it work on a scalable level. It's really the fundamental questions that have to be answered before we can get to that point.

Dr. Hodges said identifying areas where there's enthusiasm across directorates in focus areas should be something NSF is looking for and should be creating requests for proposals in those domains. A first step is the process of looking at where climate appears in GEO and BIO, where collaborative things appear. But doing that regularly, not just on a one-off basis, and seeing where the science is leading you and letting people vote from the perspective of the kinds of proposals they are sending in; when the numbers get large enough, think about specific requests for proposals and see what happens. If you don't get a lot of proposals, you don't get a lot of proposals. And the money for that does not necessarily have to be carved out first. You can look at convergence of interest among many different groups of people and then it's up to the parties to figure out how best to support that kind of initiative.

Dr. Arrowsmith said he wanted to make paleoecology, evolution on multiple timescales, part of the conversation. The sort of geologic view of the changing Earth processes over the million-year timescale can provide useful constraints for these conversations. He's been fortunate to be funded along with paleoanthropology colleagues from SBE to look at human evolution, or the geologic context of human evolution. That has a big claim of motivation of looking at the environmental controls on human evolution in the last several million years.

Dr. Clough said if the new Directorate for Translation, Innovation and Partnership comes to pass, geoengineering impacts on biology would be a great fit for innovations in solution space.

Dr. Mitchum said that as the climate changes and habitats evolve there is worry about tropical disease outbreaks that we've never had before. We have climate change people in GEO and we have biologists who can help us with habitat evolution and with a direct tie towards how these habitats favor human disease. Dr. Pataki responded that Dr. Mitchum's recommendation is consistent with the recommendation of the Advisory Committee on Environmental Research and Education, which is publishing an advisory report to NSF about the interactions between the environment and human health and suggesting there needs to be cross cutting interdisciplinary programs to support research on how climate change is impacting human health. Dr. Pataki also said BIO is looking at new programs in infectious disease and perhaps today's conversation could link in GEO in terms of explicit linkages between climate change and health.

Dr. Hodges discussed recovery from mass extinctions and the possibility for major catastrophic global change. It is possible to look at the recovery of life after impact on timescales of tens of thousands of years. If we engage the biological community to look at the record of life after that time, we have an existence proof of how life can respond to major global catastrophic change.

Dr. Richardson said OCE has a joint program with the National Institute of Environmental Health Sciences (NIEHS) called The Oceans and Human Health. Also, biological oceanography falls within the domain of the biological oceanographers.

Dr. Robock said models are used for climate change on a 100-year timescale. NCAR has a wonderful system model that includes a biology and the land surface. It includes interactions with the carbon cycle, the roughness, reflectivity, the water, forest fires and smoke and all the interactions. There's a lot of biology in the ocean also. He asked whether BIO works with NCAR to fund development of the biological part of the model, which is crude compared to the atmospheric dynamics in the ocean dynamics in the model. He asked if BIO is trying to help them develop better ways of understanding how they work and the feedback with the biology on those scales and how important they are when climate changes. Dr. Bamzai said researchers at NCAR have been working on a data pilot with BIO. Funding has been provided to improve the land surface modeling and have it represented with more fidelity. That started about a year ago.

Dr. Morris said the atmosphere is a habitat for microbial life, which we don't know huge amounts about and don't have great information about baselines. We want to ask fundamental questions about how the evolution of that system affects the evolution of the system within it. There are many implications of that to cloud properties and cloud nucleation, especially ice nuclei, and to food security. He asked if that falls in a gap. He said the presentation did not include composition of the atmosphere and how that might feed back into the biology of the Earth system. Where do those questions find a home?

Dr. Hampton responded that this field of aero-biology is being realized as an exciting area that we know very little about. We've got a lot of contact from PIs in this area and the POs have been excited to talk to each other about it. When we start to see something like this emerging, POs can work quickly together to do co-funding and co-review of these proposals. She didn't know whether it's at that tipping point where it needs its own special attention. But POs are talking with each other about this specific topic and that's frequently how these things start.

Dr. McClung returned to Dr. Hodges' question, noting that there is another historical record that spans about 10,000 years to fairly rapid change in the domestication of crops, in particular, and very frequently that involves moving them across latitudinal climbs [?] to encounter different climatic regimes. So, there is a history of the adaptations that were necessary to accomplish that. That history is likely to prove relevant in the short timescale in which we're going to have to reverse engineer those crops to move to warmer or cooler places. Coupling that with a more refined spatial modeling of predictions of what's going to go on with climate change would allow directing this type of work. So, there's a potential synergism between the biological and the geological in areas like that. Dr. Hodges said it was a fantastic argument. In northern New Mexico it is dry as a bone in the spring and you can see the movement of species as a consequence. That would be a great thing to work on. It would be interesting to get people to think about how to interact on things like the idea of high spatial resolution climate modeling. But it's not always clear what the motivation is for people to do that. If you could get biologists and geologists who are making this kind of model to talk to each other and ask if they can make this a high priority, because it's a high priority for us. There are some wonderful things that

could happen. And a lot of that could be implemented with better computing capabilities, so there's a technological angle as well.

Dr. Cáceres referred again to research areas that could benefit from more crosstalk. In the BIO only space, DEB is much more than IOS and MCB is not shown. But looking at the interactive places, like soil microbes, which are in all of these systems, what are the spaces for more crosstalk with MCB and GEO? Dr. Good said MCB emphasizes systems in synthetic biology, for example looking at the evolutionary trajectory to plants as they adapted to one climate, how do we do it in the reverse to enable them to adapt to new climates? How do we use biology to mitigate the impacts of climate? How do we use synthetic biology and systems biology to modify plants or organisms to sequester more carbon to use less fertilizer so they're using less energy and also partner with our colleagues in engineering and the Division of Physical Sciences (PS) to think about bio-processing so instead of using fossil fuels you're using feedstocks to use biodiversity to make consumer products.

Dr. Aluwihare said decadal climate variability is a big focus of what happens in the OCE side and referenced decadal climate variability from marine systems as an area of potential overlap. It speaks to the evolution of agriculture and historical population. She also spoke about the impact of warming and increased CO₂ at the leaf level and how the physiological response is similar to some of the things we study in marine systems with algal response or co-response to CO₂ increases and warming. The physiological and biochemical level responses of eukaryotes is similar across the different terrestrial and oceanic regimes.

Regarding the modeling of the last 10,000 years, Dr. González said it was proposed quite a while ago that the domestication of animals and rice crops started the climate change and global warming is not just from the Industrial Revolution but was a result of crops in domestication. The idea was not well received, but data support that idea. It's important we start looking at records that can be analyzed to the yearly scale and in some parts of the world more than yearly. Some groups are investigating the hidden biodiversity, what is the signal of bio changes on the surface recorded by chemicals in these systems? There's room now for integrating those different data sets that will inform the modelers on how to fine tune their models for precise forecasting of the very near future.

Dr. Goldstein said that having been recently become director of the Division of Earth Sciences, he does not yet know much about whether there's a lot of synergy that can be developed, or has been developed, between BIO and EAR but he plans to look into it. EAR has seven disciplinary programs and two mention the word biology. One is geobiology and low temperature geochemistry and the other is sedimentary geology and paleobiology. Beyond that, the critical zone is a huge focus of EAR. That's the top layer of the of the continental crust, the soil layer, and the weather layer and we're involved in SitS and Origin of Life. So, there's a lot of mutual interest.

Dr. Stammerjohn said the Long-Term Ecological Research (LTER) project is a shining example of how to do integrated systems science and address climate change. She spoke of the need for long-term programs to distinguish between climate change related impacts versus natural variability. Different processes fit into different space-time categories, for example. How does

LTERR look going forward? Dr. Tornow responded that she is looking for opportunities. BIO already has a lot of programs that hit on a variety of different aspects. We can sort out what would go where and then discover we actually don't even have a thing for that other idea. And then that creates an opportunity to think about a new kind of something that's focused in that particular space, where we have an opportunity that isn't captured in the various things we have. Also, even if we have a program like LTER, for example, or the individual core programs in BIO and GEO, it's possible to refocus the portfolios or broaden what they cover. We don't need to worry much about how we're going to support them. The biggest opportunity is to understand the areas of intersection for BIO and GEO. We're looking for help clarifying those opportunities.

Dr. Easterling said much of GEO's work is enabled by investments made in high-end, large-scale, research capabilities, facilities, instrumentation and with The National Ecological Observatory Network (NEON) and the LTERs; they have to be part of a larger focus on climate change. That will be one locus of opportunity for the community to respond to solicitations that bear on climate change, he said, noting the unique capabilities on the ice and at both poles, plus the academic research fleet.

Dr. Richardson said one of the things that integrates BIO and GEO is the concept of microbial responses to climate change and the fact that microbes divide on timescales permitting evolutionary experiments. If we're thinking about how organisms adapt to changes in climate, that's a powerful tool at that scale.

Dr. Hodges said there are a lot of experimental scientific opportunities, especially the GEO biology end of the spectrum, and asked about funding for embedded sensor networks. It used to be there weren't good places to send the proposals on embedded sensor networks in coral reefs, for example.

Dr. Hampton said BIO has invested in big sensor networks. She mentioned NEON, critical zone observatories and the LTERs. For individual project-by-project sensor networks, it is more program by program collaboration on specific projects and, in particular, SitS has provided a home for a lot of where sensor development is happening alongside the scientific research the sensors enable. People are excited about sensor development as long as it is addressing some question that is of interest to that particular program.

Dr. Quinn mentioned the Global Ocean Biogeochemistry (GO-BGC) Array which will be funding 500 profiles in the ocean that take measurements of a number of ocean variables, including ones important to biology, to a depth of two kilometers. There is also OOI, where we're measuring things in real time. It is the ability of these new temporal and spatial scales of measurement and tying them in to the forcing functions and the responses to get out the mechanistic processes that we're all interested in. It's time we accelerate cooperation and interactions.

Dr. Manahan said IOS sent out the idea of organisms in a dynamic environment with a specific call to the community to think about terrestrial systems, freshwater systems and ocean systems. One can also think of organisms as sensors. That systems level thinking is what we do in IOS and a lot is co-funded with GEO. He also spoke in favor of strong cross talk between mechanistic

sub-organismal biology right down to molecular scales to genome scales and linking into huge sensing issues of a changing planet.

Dr. Hodges said that in addition to large-scale sensor networks, a lot can be done with a small group of investigators with cheap technology and asked if there is a home for those kinds of projects outside the programs mentioned. Dr. Hampton referred to cases where it's not about the development of the sensors, but about deploying and said she was seeing a lot of that in standard research proposals and particularly in macrosystems proposals where it can be a large-scale deployment with a little bit of development sprinkled in. It is a greater challenge when it involves deep sea ship time. Dr. Isern said there are proposals that utilize existing technologies to do sensor networks for appropriate scales, temporally and spatially. Our need is getting to extreme environments and being able to study bio-geological processes in extreme environments, whether polar or deep sea.

Dr. Kraft asked about taking this research and informing more of the general public and non-majors. She was impressed with some of the public facing materials and has integrated that into her community college curriculum. Students have commented on not having thought about how hard it would be for people from different domains to work together. She advocated for thinking about that public interface and how you make it accessible for non-experts, adding that it's a way to think about broader impacts.

Dr. Caceres spoke to recommendations that might be provided and breaking down silos. There were recommendations about idea labs or workshops and in planning those workshops, it is important to include a diverse group of people because every university is structured differently. She suggested recommendations be made about areas of active synergy to speed discovery and making sure we're including everybody in that conversation.

Dr. Quinn raised the public private partnership aspect. There is a solicitation now out of the NSF Convergence Accelerator (C-Accel) with interest from the private sector and GEO is working with the Subcommittee on Ocean Science and Technology in the Office of Science and Technology Policy. There's interest in land and ocean sensors and increasing the capabilities of sensors to solve long-standing problems. What new technology would you need to solve a long-standing science problem that you haven't been able to solve because you can't make the type of measurement you need? What are the impediments to making these advances?

Dr. Robin said that in addition to the critical zone observatories, we've moved to the critical zone networks with a coordinating hub. That was part of the new sets of awards. That's been effective at doing a lot of the community outreach, coordinating the data and processing and all the things that have been effective to implement to the classroom. Dr. Hodges said these issues would make a good Gordon Research Conference with an interesting, meaty, transdisciplinary idea. Dr. Richardson noted that a chat message suggested one limitation is getting seed money to figure out if the wilder ideas regarding sensors are plausible.

Dr. Quinn raised the question: What can we do to harness the power of GEO and BIO with the new administration and incoming funds at the foundation level? This is a time to think about how

we can raise the profile of these things in terms of getting people together to identify the problems that require this new technology.

Dr. Daniel said sensing can be done with communities of scientists that don't have NEON-sized operations. It is democratizing and increasing access to science from community colleges and high schools. A workshop on affordable, at-scale sensing that benefits an understanding of climate biotic interactions would be compelling.

Dr. Pellegrini said that at the intersection these different fields there are situations with little data. How is NSF going to manage that? Everybody likes to see good preliminary data and then go from there. In many cases there are also different scales of data. Will review panels be tolerant and give people a chance?

Dr. Tessier summarized the discussion so far.

- The need for BIO and GEO to think more deeply about funding areas of adaptation of organisms.
- A focus on microbes and responses in quick times and the impacts on biogeochemical cycling associated with that
- Areas between EAR and BIO regarding evolution at various timescales and lessons that can be learned from past extinction events and recoveries and the opportunity to think about speeding up adaptation. Can we mimic on faster timescales what we've seen in the past?
- How do we fund more integrative research like what we have seen at LTERs?
- New sensor needs at various scales.

Dr. Whitlock added the resilience of species and ecosystems to past climate change and how quickly they can respond, including types of adaptations, to provide information that's relevant to the future. Also, how resilient species are to things like fire and how fire is tied to climate change.

Dr. Robock said the way the biology causes climate change and feeds back with climate change is not well developed in climate models. That's the main tool used for studying global warming. He asked about NCR and biological behavior in interaction with the climate, including fires and the effects of aerosols. Dr. Whitlock said flooding and other natural disasters link GEO and BIO. Fires have a strong atmospheric link. And social programming environment (SPE) would be a partner in that area because of the human dimensions of fire and fire activity. Dr. Richardson said coastal erosion and fires can almost be linked to human behavior; it's the tendency for humans to want to return to these places of natural problems. Dr. Stammerjohn said together with climate change is the human impact. How are ecosystem services going to change because they're being impacted by human activities, general activities and climate change?

Dr. Robock asked if agriculture is part of crop atmospheric modeling. Dr. Tornow said there's research in BIO that's very much in that space. Dr. Elekonich said two programs are inspired from agriculture. The plant Genome Research Program looks at the genomic scale and everything from ecology to physiology, and tools to make things happen. She also discussed the Plant Biotic Interactions (PBI) program, a joint program with United States Department of

Agriculture (USDA). Dr. Tessier said what used to be called Coupled Natural and Human Systems (CNH) is now a program involving the human dimension within the context of agriculture and aquaculture and other aspects associated with feeding the planet. Dr. Tornow said BIO's role is complimentary to the applied aspects of agriculture, but more focus on technology and innovation at NSF offers an opportunity to work in that space. Dr. Bamzai said GEO has had interactions with the USDA's National Institute for Food and Agriculture (NIFA), which picked up projects at land grant institutions where the review process between USDA and NSF was consolidated.

Dr. Bamzai also discussed synergies between the directorates on the topic of taking from the bioinformatics at the molecular level to, e.g., interactions between infectious diseases, water and human health. Dr. Aluwihare said GEO does that well, especially in the bio-geochemical realm, though less so with the connection to human health. The joint National Institutes of Health (NIH) and NSF program on oceans in human health includes examples of this. And there's evidence for things like harmful algal blooms becoming more prominent. Dr. Mitchum said there's a connection to asthma because toxins get aerosolized, so there's a climate change and human health impact if the environment becomes more or less receptive to red tide outbreaks. Dr. Pataki said eco-hydrologists are often co-reviewed between BIO and GEO, specifically EAR and ecosystems. There are NSF programs that focus on the water cycle and look at one-way interactions between biota and the water cycle; you might be in one program or another. But with two-way interactions, it's a collaboration between BIO and GEO. Issues such as extreme drought and water security are only going to be more severe. This falls under an urgent topic in the climate change sphere. Dr. Mitchum said coastal flooding is one of the areas where it's hydrology as much as the ocean because of the increasing extreme rainfall events and the problem of ground saturation.

Dr. Manahan said issues such as COVID-bat interactions, biogeography, destruction of global habitats and human wildlife interactions are becoming issues NSF can engage in across BIO and GEO. There is a program looking at these kinds of questions, but it needs to expand into the areas of areas of BIO and GEO to have predictions because genome interactions are core to these conversations. Dr. Daniel said increased rainfall is leading to increased mosquito populations and increased malaria, so the connection with human disease is also protozoan as mediated through insect populations and insect vectors in general are increasing challenges.

Dr. Hodges said it's important to testify with respect to such human health issues. The impact on human health of glacial lake outbursts destroys freshwater availability and you get a massive bloom of disease. Dr. McClung added that one aspect of increased atmospheric carbon dioxide is increased plant biomass, decreasing the concentration of nutrients, metals and elements. There's a massive malnutrition problem as we dilute all the nutrients in our food by packing in carbon.

Dr. Easterling asked about the interaction of physical systems and biology in renewable energy systems. There's a tight climate connection for many of the renewable fuels and it invokes some of the earlier discussions on the carbon cycle.

Dr. Arnosti commented on the intersection of racism and human health and the hydrologic cycle. In many communities, those living in housing most prone to repetitive flooding are typically in the minority communities and the health effects are awful.

Dr. Good said there is discussion in biotechnology about a world without waste and how to go from a biological feedstock to consumer products and integrated bioprocessing so there would be less consumption of energy to produce things that would normally come out of fossil fuel. Also, more the photosynthesis happens in oceans than anyplace else. Dr. Easterling said there has been a lot of interest in closed system farming and those sorts of techniques where you're producing food but also fuel. Dr. Richardson mentioned the nutrient remediation with biofuel production in the micro-algae world. Dr. Hodges said there could be interesting collaborative interactions towards biological or geological sequestration tied directly into climate. Dr. González said there is a lot of research on crop waste and biofuels. Most is funded by oil companies using that as an offset for carbon dioxide emissions. But they are cognizant the future is not in the exploitation of fossil fuels.

Dr. Manahan said the ozone hole was an example of where things have been bumpy between BIO and GEO. We could look back to see what approaches we took back then that didn't work in terms of BIO-GEO crosstalk. Now biologists are doing a lot of experiments sometimes without the connections to the GEO data sets.

Dr. Hodges said today's discussion has been fruitful and should happen more often. Dr. Stammerjohn suggested holding a workshop to learn lessons from past and ongoing programs. She added that there's a lot to learn from the LTER perspective of working with systems and looking at adaptation, extinction and resilience.

Dr. Tornow thanked everyone for the conversation and spoke of the importance of joint sessions. Dr. Easterling agreed, adding that the meeting was very productive.

Wrap-Up and Action Items

Dr. Hodges reviewed action items from the AC/GEO meeting.

- Modification to the EAR Subcommittee Report on Review of the Geodesy and Seismology Instrumentation Portfolio. Dr. Hodges received permission from the AC to approve the report on its behalf when he receives the changes.
- The AC's 21st Century GEO report. Dr. Hodges will incorporate the modifications suggested and discussed earlier today. The AC voted unanimously to approve the report pending these the modifications.

Dr. Hodges reviewed the difficulties of the past year and thanked NSF GEO for a phenomenal job. He also thanked the AC/GEO members and Dr. Easterling. Dr. Easterling thanked the AC members for their work and Dr. Hodges for his leadership. Dr. Aluwihare complemented the PMs and NSF staff. Dr. Easterling also recognized the work and important role of Dr. Borg, who will be retiring. Dr. Borg thanked all the staff.

The meeting was adjourned.