

NASA'S EARTH SCIENCE AND CLIMATE CHANGE ACTIVITIES: CURRENT ROLES AND FUTURE OPPORTUNITIES

HEARING BEFORE THE SUBCOMMITTEE ON SPACE AND AERONAUTICS OF THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY HOUSE OF REPRESENTATIVES ONE HUNDRED SEVENTEENTH CONGRESS

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**NASA'S EARTH SCIENCE
AND CLIMATE CHANGE
ACTIVITIES: CURRENT ROLES
AND FUTURE OPPORTUNITIES**

TUESDAY, MAY 18, 2021

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 11:01 a.m., via Zoom, Hon. Don Beyer [Chairman of the Subcommittee] presiding.

**SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES**

HEARING CHARTER

***NASA's Earth Science and Climate Change Activities: Current Roles and
Future Opportunities***

Tuesday, May 18, 2021

11:00 a.m.

Zoom

PURPOSE

The hearing will examine the National Aeronautics and Space Administration's Earth science and climate change activities and plans, including the role of space-based observations, partnerships, and other issues.

WITNESSES

- **Dr. Karen M. St. Germain**, Division Director, Earth Sciences Division, Science Mission Directorate, NASA
- **Dr. Gavin Schmidt**, Senior Climate Advisor (Acting) and Director of Goddard Institute for Space Studies, NASA
- **Mr. Riley Duren**, Research Scientist, Office of Research, Innovation, and Impact, University of Arizona; Chief Executive Officer, Carbon Mapper, Inc.
- **Mr. Robbie Schingler**, Co-Founder and Chief Strategy Officer, Planet

OVERARCHING QUESTIONS

- *What is the role of satellite observations in measuring, monitoring, and contributing to our scientific understanding of climate change and its impacts to Earth systems?*
- *Are there gaps or opportunities where NASA could or should be doing more to contribute to climate change activities and a science-based approach to mitigation?*
- *How should NASA partner with and coordinate on the space and airborne measurement contributions of non-federal entities to climate change efforts?*

BACKGROUND

To study and monitor climate change—the long-term changes in weather patterns and the range of observed effects of those changes on land, seas, ice, air, and life—scientists use measurements and data from instruments and platforms on the ground, in the air, and in space.¹ Scientists also

¹ NASA, "Overview: Weather, Global Warming, and Climate Change." Available at: <https://climate.nasa.gov/resources/global-warming-vs-climate-change/>.

use numerical and analytical models to better understand past climate change and forecast it into the future, and the measurements and data are also used to inform and improve those models.

NASA launched its first Earth-observing satellites more than seventy years ago; over the ensuing decades, space-based Earth observations have “transformed our ‘scientific understanding’ of the planet, revealing it to be an integrated system of dynamic interactions between the atmosphere, ocean, land, ice, and human society across a range of spatial and temporal scales irrespective of geographic, political, or disciplinary boundaries.”² NASA is a leading federal agency in observing and understanding environmental changes on Earth; today, the agency operates more than two dozen space-based Earth observing missions, including six instruments aboard the International Space Station (ISS), and NASA also conducts airborne and terrestrial field campaigns to support Earth Science research and related technology development.³ NASA data and research are significant pieces of the scientific basis that underlies national and international assessments of the indications, effects, and forecasting of climate change.

NASA’s Earth Science Division

Within NASA’s Science Mission Directorate, the Earth Science Division (ESD) supports activities to advance basic and applied research related to the nature of Earth’s dynamics and phenomena at local, regional, and global scales. The division follows an interdisciplinary, Earth Systems approach by studying the nature of and interactions between the Earth’s atmosphere, lithosphere (land, specifically the crust and upper mantle), hydrosphere (oceans and liquid waterways), cryosphere (ice), and biosphere (life). The strategic objective of the Earth Science Division is to “advance knowledge and prediction of the whole Earth system to meet the urgent demands of climate change.”⁴

Program Elements

The Earth Science Division portfolio has six program elements (see Table 1 for budget allocations):

The *Research* program supports research investigations in Earth Science, including modeling work and analysis of observational data, by civil servant scientists at NASA centers and non-NASA scientists at universities and research institutes. Activities related to contributions to the national and international climate change assessments (e.g., the National Climate Assessment) are conducted within the Research program.

² National Academies of Sciences, Engineering, and Medicine. 2018. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/24938>.

³ Additionally, NASA manages the development and launch of many of the Nation’s weather satellites on a reimbursable basis for the National Oceanic and Atmospheric Administration (NOAA).

⁴ Presentation by Karen St. Germain at the Spring 2021 Meeting of the National Academies of Sciences, Engineering, and Medicine’s Committee on Earth Science and Applications from Space, March 23, 2021. Available at: <https://www.nationalacademies.org/event/03-23-2021/docs/DEDFDD99FD02696E317242BC6B881F62C01996942915>.

Table 1: NASA Earth Science Division FY2021 Budget

Account	FY2021 Spend Plan
Earth Science Division	\$2 billion
Research	\$480 million
Systematic Missions	\$781 million
Earth System Science Pathfinder	\$344 million
Data Systems	\$251 million
Technology	\$82 million
Applied Sciences	\$63 million

Source: NASA⁵

The *Systematic Missions* program develops NASA-led Earth-observing satellite missions, operates missions in orbit, and produces mission data products. Systematic Missions in operation include Landsats 7 and 8, in partnership with the U.S. Geological Survey, and the recently-launched Sentinel 6

Michael Freilich, a mission in partnership with the European Space Agency (ESA) to measure ocean heights at high precision. Systematic Missions in development include the Surface Water and Ocean Topography (SWOT) Mission, the Plankton, Aerosols, Clouds, Ocean, Ecosystem (PACE) mission, and the NASA/Indian Space Research Organization Synthetic Aperture Radar (NISAR) mission, which will make the first-ever global survey of Earth's surface water.

The *Earth System Science Pathfinder* program supports competed, principal-investigator-led projects with schedule and budget constraints, including small- and medium-class satellite missions or space-based instruments, extended airborne science campaigns, and related scientific investigations. The scientific scope focuses on emerging areas of research or technology. Space-based Pathfinder elements are competed through Earth Venture missions and instruments.

The *Data Systems* program acquires, processes, preserves, and distributes observational Earth science data from all sources that support ESD research. The data are primarily archived and accessed through the Earth Observing System Data and Information System (EOSDIS), which has provided all Earth Science data freely to the public since 1994. In Fiscal Year 2020 alone, the archive grew by 12 petabytes (PB) and received three million site visits; the current archive total volume is approximately 42 PB, and the annual growth of the archive is expected to accelerate.⁶ Most of the data are stored across twelve Distributed Active Archive Centers (DAACs) across the country, which are located at NASA Centers, universities, and other federal agencies. ESD assigns data to individual DAACs based on scientific discipline, application, data type, and/or mission. DAACs are responsible for processing, archiving, and distributing data and ultimately making the data publicly available to end users.⁷

The *Earth Science Technology Office (ESTO)* supports technology development, primarily through competed investigations, that advances capabilities with application to Earth Science research needs.

The *Applied Sciences* program leverages the observational data and scientific findings of ESD activities to enable near-term uses by non-NASA organizations in the public and private sector.

⁵ NASA, FY2021 Spend Plan. Available at:

https://www.nasa.gov/sites/default/files/atoms/files/fy_2021_spend_plan_march_2021.pdf.

⁶ NASA EOSDIS Metrics, FY2020 (Oct 1, 2019 to Sept 30, 2020). Available at:

<https://earthdata.nasa.gov/cosdis/system-performance>.

⁷ <https://oig.nasa.gov/docs/IG-20-011.pdf>.

Applied Sciences projects support decision-making and communities with capacity building, disaster response, ecological forecasting for conservation and resource management, food security and agriculture, health and air quality, and water management. Applied Sciences projects include the Cyanobacteria Assessment Network (CyAN), which recently contributed to global standards for monitoring harmful algal blooms;⁸ the Disasters Mapping Portal, which serves as the entry point and hub for near real-time and event-specific data products for natural disasters such as hurricanes;⁹ and the NASA Harvest Consortium, made up of over 40 partners, which connects researchers, humanitarian aid organizations, economists, policymakers, and other leaders to information they need to prepare for and respond to spikes in food prices or weather-related food shortages.

Measuring and Forecasting Indicators of Climate Change

The data and research investigations within ESD contribute to measurements of the key indicators of climate change, including on surface and ocean temperatures, sea level height, and ice sheet size and distribution. As an example, NASA and NOAA conduct independent analyses of Earth's global surface temperature and release their findings concurrently every year; NASA recently reported 2020 to be tied for the warmest year on record, continuing the trend of warming surface temperatures.¹⁰

NASA is one of thirteen federal agencies that participate in the U.S. Global Change Research Program (USGCRP);¹¹ NASA contributions make up sixty percent of the total USGCRP agency budget contributions to the National Climate Assessment and other USCRP activities. On an international level, ESD also contributes to the work of the Intergovernmental Panel on Climate Change (IPCC) and the World Climate Research Programme.

NASA's Goddard Institute for Space Studies (GISS), an ESD laboratory of Goddard Space Flight Center (GSFC), leads much of the agency's work in assimilating measurements of climate indicators into numerical models to aid in study of past climate change and improve our ability to forecast future climate change.

Measuring Greenhouse Gas Emissions

A considerable focus of climate change research is the role of atmospheric greenhouse gases driving warming. Greenhouse gases, such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), absorb and then re-radiate heat in Earth's atmosphere, which causes warming, a method of "climate forcing," or initial driving of climate change. NASA's ESD uses sensors on

⁸ NASA, "Setting New Global Standards for Monitoring Algal Blooms," April 2, 2021. Available at: <https://appliedsciences.nasa.gov/our-impact/news/setting-new-global-standards-monitoring-algal-blooms>.

⁹ NASA, "NASA Helps the World Weather the 2020 Hurricane Season," February 25, 2021. Available at: <https://appliedsciences.nasa.gov/our-impact/story/nasa-helps-world-weather-2020-hurricane-season>.

¹⁰ <https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows>.

¹¹ The USGCRP is mandated by Congress in the Global Change Research Act (GCRA) of 1990 (Title 15 of U.S. Code, Chapter 56A) to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The Fourth National Climate Assessment is available at: <https://nca2018.globalchange.gov/>.

the ground, on aircraft, and in space to monitor greenhouse gases to better understand their origins and lifetimes, how they interact with Earth systems, and to inform climate change predictions, and study the human and natural processes that create and destroy greenhouse gases. On the ground, for example, the Advanced Global Atmospheric Gases Experiment (AGAGE) is a network of 15 ground sensors supported by NASA, NOAA, and agencies in Europe and Asia that have measured greenhouse gases and other trace gases, like the kinds that contribute to ozone depletion, continuously since 1978. NASA's space-based Orbital Carbon Observatories, OCO-2 in low Earth orbit and OCO-3 mounted on the ISS, measure carbon dioxide in the atmosphere on regional scales, and can, when used jointly, measure CO₂ over city-scale regions. In addition, NASA is currently developing the GeoCarb, a PI-led mission due to launch in the early 2020s and continuously monitor carbon emissions of the entire U.S. from a geostationary orbit, with a spatial resolution of 3-6 miles.

NASA's Carbon Monitoring System (CMS) is a program that offers competitive grants to support development of prototype observational and analysis capabilities that can support monitoring, reporting, and verification of carbon stocks and fluxes.

Non-Federal Space-based Measurements and NASA Partnerships

Several non-Federal entities are obtaining space-based and airborne measurements to address key climate change challenges. For example, the nonprofit Environmental Defense Fund is developing MethaneSat, an Earth-observing satellite that will carry an imaging spectrometer to measure methane emissions from specific regions around the Earth with significant oil- and gas-producing operations, known to be significant contributors to overall global methane levels. GHGSat is a commercial venture, based in Canada, working toward a constellation of hyperspectral imaging satellites that can provide greenhouse gas measurements and monitoring for commercial customers.

NASA partners, as appropriate, with non-governmental entities to enhance or complement its wide portfolio of Earth Science data. NASA established the Commercial Smallsat Data Acquisition Program to "identify, evaluate, and acquire data from commercial sources that support NASA's Earth science research and application goals."¹² NASA and its Jet Propulsion Laboratory are partnering with the nonprofit organization, Carbon Mapper, by providing an instrument that will enable Carbon Mapper's satellites to pinpoint and measure methane and carbon dioxide point-sources from space.¹³

Decadal Survey for Earth Observations in Space

NASA's ESD program is guided by the priorities and recommendations of the National Academies decadal surveys. The most recent, 2018 *Thriving On Our Changing Planet: A*

¹² <https://earthdata.nasa.gov/csds/csdp>.

¹³ <https://www.nasa.gov/feature/jpl/nasa-built-instrument-will-help-to-spot-greenhouse-gas-super-emitters>.

*Decadal Strategy for Earth Observation in Space*¹⁴ identified 35 key science and applications questions for the next decade spanning the following six areas:

- Coupling of the water and energy cycles
- Ecosystem change
- Extending and improving weather and air quality forecasts
- Reducing climate uncertainty and informing societal response
- Sea-level rise
- Surface dynamics, geological hazards, and disasters

To measure and observe these key science and applications questions, the decadal survey recommended that NASA establish a range of small-, medium-, and large-size satellite mission and technology development lines that would focus on identified priority measurements or “targeted observables” (Table 2).

Table 1: Earth Science Decadal Priorities for NASA Observation Capabilities	
Program	Notes
1. Program of Record	The series of existing or previously planned observations, which must be completed as planned.
2. Designated	A program element for cost-capped, competed or directed, medium- and large-size missions to address observables essential to the overall program: aerosols; clouds, convection, and precipitation; mass change; surface biology and geology; and surface deformation and change.
3. Earth System Explorer	A new program element for competitive, cost-capped medium-size instruments and missions targeting: Greenhouse gases, Ice elevation, Ocean surface winds and currents, ozone and trace gases, snow depth and snow water equivalent; and terrestrial ecosystem structure.
4. Incubation	A new program element focused on investment for capabilities for priority observations: atmospheric winds, planetary boundary layer, and surface topography and vegetation, with an innovation fund to respond to emerging needs.
5. Earth Venture	Add new “Venture-continuity” component to existing Earth Venture program element.

Sustained, Long Time-Series Research Measurements

Long-term (multi-year or, in many cases, multi-decade) measurements are necessary for climate change research. In 2000, a National Academies of Sciences study noted this, saying that “long-term, consistent time series are essential for the study of many critical climate processes, which vary over inherently long time scales.”¹⁵ Therefore, “both climate research and climate monitoring require a long-term commitment to consistent data sets and short-term flexibility to pursue new science and technology directions.”¹⁶

¹⁴ National Academies of Sciences, Engineering, and Medicine. 2018. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/24938>.

¹⁵ National Research Council. 2000. *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Part II. Implementation*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/9966>.

¹⁶ *Ibid.*

In a 2015 report, another National Academies committee reiterated the critical need for sustained, or continuous, observations for climate change research, finding that “detection and attribution of climatic changes and long-term trends in the Earth system—addressing, for example, land cover and land use, storm intensity, ground water change, aerosols, ozone pollution and recovery, ice mass loss, and sea level change—require sustained measurements. Such measurements are also necessary to understand climate processes characterized by low-frequency variability.”¹⁷ The report went on to recommend a quantitative, value framework that could assist NASA's ESD in determining when a measurement or dataset should be collected for durations longer than the typical lifetimes of single satellite missions.

The Decadal Survey also described, as part of a strategic framework to implement the decadal, the need to commit to sustained science and applications enabled by continuous observing for timespans that require multiple generations of spacecraft. Additional, unique scientific return comes from continuous, sustained observations, and they are particularly important for studying and understanding climate change. The decadal finds sustained observations as “central to the progress of Earth science, and integral to the long-term achievement of societal benefits.”¹⁸

¹⁷ National Academies of Sciences, Engineering, and Medicine. 2015. *Continuity of NASA Earth Observations from Space: A Value Framework*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/21789>.

¹⁸ National Academies of Sciences, Engineering, and Medicine. 2018. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/24938>.

Chairman BEYER. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time.

And before delivering my opening remarks, I wanted to note that, today, the Committee is meeting virtually. I want to announce a couple reminders to the Members about the conduct of this meeting. First, Members should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones, and also please keep your microphone muted unless you are speaking. And finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the hearing.

So good morning, and welcome today's hearing on "NASA's Earth Science and Climate Change Activities: Current Roles and Future Opportunities."

But first, I want to thank our panel of expert witnesses for being here. There's no more important time for addressing climate change and the health of our planet. Delaying action risks everything—from increased exposure to heat waves, spread of vector-borne diseases, drought, crop failures, and severe weather. Actions taken and policies developed to respond to the climate crisis must be informed by peer-reviewed science, and that science starts with measurements, observations, and research that leads to understanding.

That's where NASA (National Aeronautics and Space Administration) comes in. For studying the Earth, space is the ultimate vantage point. And thanks to NASA's fleet of space-based science observations and measurements, we have long-term research data sets that show the scientific signals of climate change. Those signals, unlike short-term variations in terrestrial weather, change over longer periods of time. NASA Earth observation measurements also provide important inputs to models that enable our ability to predict and forecast climate change. And NASA satellite measurements contribute to studies such as the National Climate Assessment, a scientific assessment of climate change and its impacts across the United States.

Beyond the data, satellite observations have the ability to tell a compelling visual story such as the significant loss of sea ice and glacier melt in the Arctic. Several astronauts have remarked on their experiences of viewing the Earth from space. In a *Scientific American* article issued just a few days ago, former NASA astronaut Scott Kelly said, quote, "During my first mission in 1999 to fix the Hubble Space Telescope, I remember passing over South America and being awed by the sheer size of the Amazon rainforest. But on my last mission in 2016, only 17 years later, burning and clearcutting were clearly evident. After seeing the Earth dramatically change from this unique perspective, I firmly believe that solving climate change is the moonshot of the 21st century," end quote.

Closer to home, NASA satellite data are helping identify algal blooms, and NASA and NOAA (National Oceanic and Atmospheric Administration) satellite data are helping farmers increase their efficient use of water resources for irrigation, saving money and increasing profitability. These are just a few examples that illustrate

the value of NASA's Earth science research to business, local resource managers, and environmental decisionmakers.

NASA once referred to its Earth science activities as "Mission to Planet Earth." In the midst of economic, property, health, and environmental impacts from climate change, it's clear we have an urgent mission before us. We need to look at every opportunity to act now. Is there more than NASA could and should do? Are there gaps in our scientific understanding of the Earth system that need to be addressed? Are there opportunities to expand the transition of research into information tools?

And, of course, it's not just NASA. Other Federal research agencies are working on climate change research and mitigation efforts. Commercial satellite imaging companies, philanthropists, and not-for-profit entities are ready and willing to contribute to the climate challenge. And we need them all. Where and how do they fit into an overall climate strategy? How should NASA effectively partner with non-Federal entities and also maintain free and open data?

In closing, the Nation is planning aggressive efforts to mitigate the climate crisis, and we'll need to check our progress. While NASA is not a regulatory agency and certainly not the carbon police, how can space-based measurements validate or check the effectiveness of mitigation strategies? Where does NASA play a role?

Today's hearing is an important opportunity to consider these and other questions, and I really look forward to hearing from our distinguished witnesses.

[The prepared statement of Chairman Beyer follows:]

Good morning and welcome to today's hearing on "NASA's Earth Science and Climate Change Activities: Current Roles and Future Opportunities". First, I want to thank our panel of expert witnesses for being here.

There is no more important time for addressing climate change and the health of our planet. Delaying action risks everything from increased exposure to heatwaves, spread of vector-borne diseases, drought, crop failures, and severe weather.

Actions taken and policies developed to respond to the climate crisis must be informed by peer-reviewed science, and that science starts with measurements, observations, and research that leads to understanding.

That's where NASA comes in.

When studying the Earth, space is the ultimate vantage point. Thanks to NASA's fleet of space-based science observations and measurements, we have long-term research data sets that show the scientific signals of climate change.

Those signals, unlike short-term variations in terrestrial weather, change over longer time periods.

NASA Earth observation measurements also provide important inputs to models that enable our ability to predict and forecast climate change.

And NASA satellite measurements contribute to studies such as the National Climate Assessment—a scientific assessment of climate change and its impacts across the United States.

Beyond the data, satellite observations have the ability to tell a compelling visual story, such as the significant loss of sea ice and glacier melt in the Arctic.

Several astronauts have remarked on their experiences of viewing the Earth from space. In a *Scientific American* article issued just a few days ago, former NASA astronaut Scott Kelly said, "During my first mission, in 1999, to fix the Hubble Space Telescope, I remember passing over South America and being awed by the sheer size of the Amazon rainforest. On my last mission in 2016, only 17 years later, burning and clear-cutting were clearly evident. After seeing the Earth dramatically change from this unique perspective, I firmly believe that solving climate change is the moonshot of the 21st century."

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NASA once referred to its Earth science activities as "Mission to Planet Earth". In the midst of economic, property, health, and environmental impacts from climate change, it's clear we have an urgent mission before us.

We need to look at every opportunity to act now.

Is there more that NASA could and should do?

- Are there gaps in our scientific understanding of the Earth system that need to be addressed?

- Are there opportunities to expand the transition of research into information tools?

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Other Federal research agencies are working on climate change research and mitigation efforts.

Commercial satellite imaging companies, philanthropists, and not-for-profit entities are ready and willing to contribute to the climate challenge.

We need them all.

Where and how do they fit into to an overall climate strategy? How should NASA effectively partner with non-Federal entities, and also maintain free and open data?

In closing, the nation is planning aggressive efforts to mitigate the climate crisis, and we'll need to check our progress.

While NASA is not a regulatory agency or a carbon police, how can space-based measurements validate or check the effectiveness of mitigation strategies? Should NASA play a role?

Today's hearing is an important opportunity to consider these and other questions, and I look forward to hearing from our witnesses.

And now I'd like to turn to the Ranking Member, the gentleman from Texas, Dr. Brian Babin for his opening statement.

Chairman BEYER. So let me—talking about distinguished, let me turn to our Ranking Member, the gentleman from Texas, my friend, Dr. Brian Babin, for his opening statement. Dr. Babin?

And, Brian, you are still muted for the moment.

Mr. BABIN. How about now, Mr. Chairman? Can you hear me?

Chairman BEYER. You're good. Thank you.

Mr. BABIN. OK. Yes, thank you very much. Great to be with you. Looking forward to this hearing. It's particularly timely.

The Biden Administration has proposed increasing NASA's Earth science budget by \$300 million, which is a 12.5 percent increase above fiscal year 2021-enacted levels. Since we don't have other details about the proposed budget yet, we do not know what impact this proposal will have on other aspects of the agency or how the agency is proposing to spend this increase.

While those details may be lacking at this moment, there are a number of other initiatives currently underway at NASA that we can certainly explore. For example, NASA received the second Earth science decadal review from the National Academies in 2018. This hearing is a great opportunity to understand how NASA is responding to that report. Previous decadal surveys highlighted NASA's unique role of developing first-of-a-kind instruments that could then be transitioned to operational agencies like NOAA and USGS (United States Geological Survey).

As NASA seeks to take on a more operational role in maintaining observational data sets, it will be important for Congress to understand the long-term impacts of this evolution on other Earth science missions, on other science divisions, on other elements of the agency like human exploration, as well as the effects on the government and society as a whole. Maintaining a balanced and sustainable portfolio of programs that NASA could insulate specific

programs from wild swings and funding that complicate planning and operations.

One way that NASA can take on these new operational roles without breaking the bank or impacting other programs is to leverage the existing commercial remote-sensing industry. Previous attempts to incorporate commercial data were met with resistance from the government, and the industry was still in its infancy at that time. The commercial remote industry is much more robust today, and agencies are much more receptive to incorporating data from novel sources. NASA initiated a data buy pilot project in 2017 and, more recently, stood up a formal data acquisition program.

One near-term decision related to leveraging the commercial remote-sensing industry is Landsat. The Landsat program has provided world-class multi-decade 30 meter resolution of Earth's surface. Last year, the Administration announced that it was undertaking a Landsat architecture study to explore novel ways to maintain the Landsat data set. As the former Director of USGS stated at the time, quote, "Rather than one single large satellite bus, which is what Landsat has been historically, we've looked at other options. The revolution in space is underway, and we'll want to capitalize on that as much as we possibly can," unquote.

Despite progress made toward this effort over the last several years, NASA issued a request for information, an RFI, for a Landsat Next instrument studies that may deviate from this plan and return a business-as-usual approach. U.S. law and national policy directs NASA to advance the commercial space sector. Title 51 of the U.S. code directs NASA to "seek and encourage to the maximum extent possible the fullest commercial use of space." NASA is also directed to "acquire, where cost-effective, space-based and airborne Earth remote-sensing data, services, distribution, and applications from a commercial provider."

Both the 2014 National Plan for Civil Earth Observations and the 2015 National Space Weather Action Plan direct Federal agencies to identify and pursue commercial solutions. More recently, the 2019 National Plan for Civil Earth Observations directed agencies to strive to engage with the full Earth observations enterprise to determine whether there is a commercial solution available or end process that might be more appropriate than creation of a new Federal observing asset. These policies were also reinforced in the most recent decadal survey for Earth science.

I look very much forward to discussing how NASA plans to incorporate commercial remote-sensing data to maximize taxpayer dollars spent on Earth science. So thank you, and I yield back the balance of my time. Thank you, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]

Today's hearing is particularly timely. The Biden Administration proposed increasing NASA's Earth Science budget by \$300 million—a 12.5 percent increase above FY21 enacted levels. Since we don't have other details about the proposed budget yet, we do not know what impact this proposal will have on other aspects of the agency, or how the agency is proposing to spend this increase. While those details may be lacking at this moment, there are a number of other initiatives currently underway at NASA that we can explore.

For example, NASA received the second Earth science decadal review from the National Academies in 2018. This hearing is a great opportunity to understanding how NASA is responding to that report. Previous decadal surveys highlighted NASA's unique role of developing first-of-a-kind instruments that could then be

transitioned to operational agencies like NOAA and USGS. As NASA seeks to take on a more operational role in maintaining observational datasets, it will be important for Congress to understand the long-term impacts of this evolution on other Earth science missions, on other science divisions, on other elements of the agency like human exploration, as well as the effects on the government and society as a whole. Maintaining a balanced and sustainable portfolio of programs at NASA could insulate specific programs from wild swings in funding that complicate planning and operations.

One way NASA can take on these new operational roles without breaking the bank or impacting other programs is to leverage the existing commercial remote sensing industry. Previous attempts to incorporate commercial data were met with resistance from the government, and the industry was still in its infancy at the time. The commercial remote industry is much more robust today, and agencies are much more receptive to incorporating data from novel sources. NASA initiated a data buy pilot project in 2017, and more recently stood up a formal Data Acquisition Program.

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I look forward to discussing how NASA plans to incorporate commercial remote sensing data to maximize taxpayer dollars spent on Earth science. Thank you, and I yield back the balance of my time.

Chairman BEYER. Dr. Babin, thank you very much. I really appreciate your insights.

Mr. BABIN. Yes, sir.

Chairman BEYER. And now let me recognize the Ranking Member of the Full Science Committee, its Chairman Emeritus, Mr. Lucas from Oklahoma.

Mr. LUCAS. Thank you for holding this hearing, Mr. Chairman.

Today's hearing is an important opportunity for the Committee to engage in oversight of NASA's current and future Earth science and climate activities. I'm looking forward to discussing how the agency can best utilize resources within existing budgets and how it can use additional resources. NASA's mandate to research Earth's atmosphere dates back to the passage of NASA's *Organic Act* in 1958, which stated, "NASA shall seek the expansion of human knowledge of phenomena in the atmosphere and space." That mission has evolved through the decades as our technical capacity and scientific knowledge have increased.

Today, the Earth Science Division of NASA oversees a broad range of activities and missions, including managing a variety of ongoing Earth observation missions, planning future missions, and

sharing the data collected from these missions with the scientific community and the public. NASA is currently operating more than a dozen Earth science missions in tandem with international partners and other Federal agencies and has a dozen more missions slated to launch in the decade ahead. These missions provide a new generation of satellites and instruments to monitor and provide data about Earth's changing climate and the scientific community.

Today's hearing represents an opportunity to evaluate NASA's Earth science and climate partnerships within the Federal Government with international partners and with the private sector. This Committee has an opportunity and an obligation to consider whether these partnerships work in the most effective manner and if the agency would benefit from new approaches to these partnerships.

Our panel represents a cross-section of government, the nonprofit sector, and industry, and that is appropriate as all three sectors must work together to provide the best knowledge to the scientific community.

Today's hearing is timely. The commercial remote-sensing industry has come a long way in a very short period of time. New remote-sensing technologies have made images of Earth more accessible. The images and data made available by commercial providers are of great value to any number of consumers, whether it's in the public safety officials, in the West managing forest, or farmers in Oklahoma growing crops.

As the author of NOAA's Commercial Weather Data Buy program and the Commercial Data Buy program in the space weather legislation passed last Congress, I have long championed the ability of commercial remote-sensing industry to fill gaps in the Federal Earth observation abilities. To be clear, this does not mean that the commercial sector would replace the government's role but instead complement it and provide more cost-effective and novel solutions.

We'll hear testimony today about how the commercial sector is helping fill this need, as well as how NASA could increase its utilization.

I look forward and thank our witnesses today for sharing their perspectives on this topic, and I expect a productive discussion about how this community can insure NASA's Earth science and climate activities can be made even more efficient and cost-effective moving forward.

Again, Mr. Chairman, I thank you for the hearing, and I yield back the balance of my time.

[The prepared statement of Mr. Lucas follows:]

Thank you for holding this hearing, Mr. Chairman. Today's hearing is an important opportunity for the Committee to engage in oversight of NASA's current and future earth science and climate activities. I'm looking forward to discussing how the agency can best utilize resources within existing budgets and how it would use additional resources.

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Today's hearing represents an opportunity to evaluate NASA's Earth science and climate partnerships within the federal government, with international partners, and with the private sector. This Committee has an obligation to consider whether these partnerships work in the most effective manner and if the agency would benefit from new approaches to these partnerships. Our panel represents a cross-section of government, the non-profit sector, and industry. And that is appropriate as all three sectors must work together to provide the best knowledge to the scientific community.

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I want to thank our witnesses today for sharing their perspectives on this topic. I look forward to a productive discussion about how this Committee can ensure NASA's Earth Science and climate activities can be made more efficient and cost-effective moving forward.

I yield back the balance of my time.

Chairman BEYER. Thank you, Ranking Member Lucas, very much.

[The prepared statement of Chairwoman Johnson follows:]

Thank you Chairman Beyer for holding today's hearing on NASA's climate change activities. I'm pleased that the Space and Aeronautics Subcommittee is taking a close look at NASA's Earth science and climate change work. Because from the agency's first Earth observing satellites over 60 years ago, NASA has been a cornerstone of the nation's Earth science and climate research activities.

The Committee on Science, Space, and Technology initiated the *Global Change Research Act* in 1990, over 30 years ago. NASA is just one of thirteen agencies involved, but its Earth science and climate research efforts have been a major contributor to the US Global Change Research Program developed in response to the 1990 Act.

A lot has happened since 1990. Based on the research and observations of our agencies over these last decades, climate change has gone from study to crisis. The work of the Committee on Science, Space, and Technology is now considering how our Nation's research and development efforts can address this crisis. Science must remain at the center, both in our continuing work to understand climate change, but also in our efforts to mitigate it and help communities respond to it.

NASA also has a role in advancing innovative technologies and approaches to sustainable aviation. I'm pleased that the Biden Administration is taking aggressive steps to address the climate crisis. This challenge requires that we examine every opportunity to leverage capabilities, partnerships, and consider potential options for further contributions. Today's hearing will take an important step toward that end, and I look forward to our witness' testimony.

Thank you and I yield back.

Chairman BEYER. At this time, I'd like to introduce our witnesses. Our first witness is Dr. Karen St. Germain. Dr. St. Germain is the Division Director for NASA's Earth Science Division within the Science Mission Directorate. Dr. St. Germain received a bachelor of science degree in electrical engineering from Union College, a doctor of philosophy degree in electrical engineering from the University of Massachusetts. So welcome, Dr. St. Germain.

Our second witness is Dr. Gavin Schmidt, Acting Senior Advisor in Climate Science to the NASA Administrator and the Director of the Goddard Institute for Space Studies. Dr. Schmidt received a first-class bachelor of arts degree in mathematics from Oxford University and a doctorate on the calculation scattering and stability of topographic Rossby waves from University College London. I hope you're going to talk about those scatterings. So welcome, Dr. Schmidt.

Our third witness is Mr. Riley Duren, a Research Scientist at the University of Arizona and Chief Executive Officer (CEO) of the Carbon Mapper, a nonprofit organization. He also maintains part-time employment as an Engineering Fellow at NASA's Jet Propulsion Laboratory (JPL). Mr. Duren received a bachelor of science in electrical engineering from Auburn University. Welcome, Mr. Duren.

And our final witness is Mr. Robbie Schingler, an entrepreneur, cofounder of Planet labs, and a former NASA Engineer and Program Manager with more than 20 years of experience building satellite projects. Mr. Schingler received a bachelor of science in engineering physics from Santa Clara University, a bachelor of science in space studies from International Space University, and a master of business administration from Georgetown University. Welcome, Mr. Schingler.

So we will start in the order just introduced. Dr. St. Germain, the floor is yours for your opening statement.

**TESTIMONY OF DR. KAREN M. ST. GERMAIN,
DIVISION DIRECTOR, EARTH SCIENCES DIVISION,
SCIENCE MISSION DIRECTORATE, NASA**

Dr. ST. GERMAIN. Chairman Beyer, Ranking Member Babin, Members of the Subcommittee, thank you so much for the opportunity to speak today on NASA's contributions as a global leader in Earth science.

NASA holds a unique position as the only space agency with integrated end-to-end Earth observing capability from building and flying satellites to research, data systems, and delivery of science applications. Today, I'll testify on how NASA's Earth science expertise advances our understanding of how to adapt to and ultimately thrive on our changing planet.

The science of the last 20 years has settled the question of whether our planet's climate is changing. What we must do over the coming 20 years is to better understand Earth systems, those interactions between land, ocean, air and ice, and human communities so we can improve our predictions of how our environment might change. Those predictions are essential for policymakers such as this Committee to make decisions on mitigation, adaption, and resilience.

There is no better vantage point than space to collect the Earth data that is the foundation of our science, our models, and our predictive capability. Today, NASA flies 23 space-based observing systems in addition to the satellites we build for our partner agencies, USGS and NOAA.

NASA systems measure greenhouse gases and sea level rise. They monitor fire weather and detect soil moisture and crop stress,

just to name a few. We combine our observations with data from our strategic partners and commercial Earth observation companies to investigate complex questions that lay the foundation for modeling prediction and scientifically sound information. This is important because these are the models and information products that inform decisionmakers at every level on imperatives like ensuring a safe and ample supply of drinking water, maintaining our Nation's ability to feed itself, and building community resilience and safety from extreme weather events.

To meet this demand for information, NASA Earth science is accelerating work in three key areas: observations, modeling and informatics, and applications and dissemination. I'm going to touch on each of these areas briefly.

NASA is observing—advancing observations capabilities by investing in technology innovation, exploring alternative observation platforms, new approaches to industry partnership and commercial services, and expanding collaboration with our international partners. And I'll say more about those specific plans in just a moment.

Modeling and informatics further our understanding and prediction of the whole-Earth system by extracting scientific understanding from the measurements and capturing that understanding in models and frameworks that span timescales from minutes to decades and spatial scales ranging from continents to individual agricultural fields.

Finally, in applications and dissemination, we're dramatically accelerating the delivery and use of scientific understanding. We're working through open science and accessibility principles to ensure our data and information are within reach, especially to previously underserved communities. And we are creating scalable science applications to meet the needs at every level of decisionmaking.

Returning to the topic of NASA space-based observation capability, the National Academies of Science laid out an ambitious but critical observation objectives in its 2017 Earth science decadal survey. NASA intends to meet those objectives through an array of space-based satellites, instruments, and missions that we're calling the Earth system observatory. These measurements will help us answer critical open questions about the Earth system. We'll observe aerosols in our atmosphere and how they interact with clouds, convection, and precipitation to tackle the largest natural uncertainty in predicting climate change while improving severe weather and air quality forecasting. We'll track minute local changes in our Earth's mass, which will inform drought predictions and help local water managers make decisions about agricultural and municipal water supplies. And our surface biology and geology observations will improve our understanding of how climate change affects food production and ecosystems.

Finally, by monitoring changes in our Earth's surface, we'll be better—we will better predict sea level rise in events such as earthquakes, volcanoes, and landslides. Together, these observations will capture a three-dimensional view of our Earth from atmosphere to bedrock, and we're now starting the first phase of mission planning.

NASA is advancing not just what we're doing but how we're doing it. We're dedicated to open science and diversity, more part-

nership with the commercial sector, and new business models to rapidly onboard advances in technology.

Around the end of this decade, almost another billion people will live on our planet, putting more pressure on Earth's resources and increasing demand for actionable information. Climate change demands science equal to the challenge it presents. NASA is moving to meet this challenge, accelerating our science, our international and interagency partnerships, and exploring new ways to do business.

Thank you for the opportunity to discuss NASA's Earth science program, and I'd be pleased to respond any questions you might have.

[The prepared statement of Dr. St. Germain follows:]



National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

May 18, 2021

**Subcommittee on Space and Aeronautics
Committee on Science, Space,
and Technology**

U.S. House of Representatives

Statement by:
Dr. Karen St. Germain
Director, Earth Science Division
Science Mission Directorate

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Dr. Karen St. Germain
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before the

Subcommittee on Space and Aeronautics
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Chairman Beyer, Ranking Member Babin, Members of the Subcommittee and Committee,

While NASA may be best known for space exploration, we are also a global leader in Earth system science, with our first space-based observations of the Earth going back to the 1960s. Over the last three decades, much of what scientists have learned about our changing climate is built on NASA's satellite observations and research in collaboration with other agencies. The vantage point of space turns out to be ideal for observing the Earth as a system, and NASA is the agency that builds the U.S.' civilian space-based observing systems. Today, NASA's Earth Science expertise prioritizes and fields the leading-edge space-based observations that help us understand and adapt to our changing planet. And our Earth science applications directly benefit people across the country and the world. NASA is the only space agency with an integrated, end-to-end program in Earth observing mission development, operations, technology, research, data systems, and applications.

We use these space-based measurements to understand Earth's systems and processes — the interactions between land, ocean, atmosphere, and ice. That understanding is the foundation of our collective ability to see climate changes and predict how our environment might evolve. We provide that data and analysis to policymakers, from Congress to counties and cities, who use it to mitigate and adapt to the changing climate, which is essential to improving our lives and protecting our future.

Over the past 20 years, much of the Earth science community has focused on fundamental observations and modeling to understand climate change and the systemic human-induced and natural influences driving it. Now we are at an inflection point. Changing temperatures are impacting agriculture, transportation, plants, and human disease vectors. Severe weather in the form of droughts, wildfires, hurricanes, hailstorms, tornados, and thunderstorms is taking an increasing number of lives and causing record-breaking economic damage. The U.S. experienced 22 separate billion-dollar weather and climate disaster events in 2020 alone, shattering the previous record of 16 such events in both 2017 and 2011. The total 2020 costs, more than \$95 billion, were the fourth-highest since 1980. Climate challenges are also playing out around the world, and were identified by the World Economic Forum as among the greatest risks to global well-being.

The changing climate brings opportunities as well. Growing seasons are increasing in what have historically been cooler areas. Previously frozen rivers and plains are becoming more usable and habitable. With diminishing Arctic sea ice, more efficient shipping routes and greater access to ocean floor resources are likely.

Whether to develop climate change mitigation strategies, plan for coming changes, or manage the climate-induced events that are already happening, decision makers are demanding information that is trusted, scientifically sound, and easily accessible. In the years ahead, the widespread and localized impact of the changing climate will drive increasing demand for data, analysis, and tools to support science-informed decisions that will help us continue to thrive on our changing planet.

NASA Earth Science Today

Today, NASA is flying 23 observing systems in space, including six on the International Space Station. These systems are measuring greenhouse gases in the atmosphere, quantifying the rates of sea level rise and glacial ice melt, watching for the conditions that can lead to wildfires and their cascading effects, and monitoring soil moisture and crop stress, just to name a few of the things we do.

We are even making measurements that can tell us whether our underground aquifers – so critical in times of drought – are either full or depleted. Within the next two years, we will begin the first ever global inventory of fresh surface water, commence with hourly observations of atmospheric pollutants that contribute to greenhouse gas formation; and undertake targeted observations of aerosols in the atmosphere to characterize their type, and their role in warming or cooling of the atmosphere, and their linkages to human health.

While observations are fundamental to our understanding of our planet, they are just the first step in obtaining actionable information. NASA's research and analysis activities advance our comprehensive scientific understanding of Earth's processes and their interactions. Using data from all available sources (including domestic, private-sector, and international partner satellites; data from airborne, ship-based, and ground network instrumentation; and outputs from operational weather models), NASA's Earth Science research program enables scientists to investigate and solve complex scientific questions that cannot be addressed using data from only a single mission or instrument. We infuse the quantitative knowledge we gain into numerical models, which can then be used to predict future conditions and anticipate the effects of different scenarios and approaches on all scales, including global climate change.

Through our observations and our research and analysis program, we advance our understanding of how our home planet is changing, and how those changes will impact everything from our underground aquifers, to the health of our surface vegetation, to the mechanics behind weather dynamics, to air quality, and more. This knowledge underpins cross-agency work undertaken to understand our climate and the entire Earth system, such as the National Climate Assessment developed by U.S. Global Change Research Program (USGCRP). The nation recoups its investment in NASA Earth Science when we make this information available to those who need it, when they need it, and in a form they can use.

Here are just a few examples of how NASA information is already at work, with and through partners, helping our nation's decision makers at every level:

Safe and ample drinking water. Increasing droughts threaten the extent of regional snowpack, water reservoir levels, and groundwater availability for all Americans, especially communities of color, sovereign tribes, and low-income communities. This year, NASA Earth Science will launch OpenET, a partnership between NASA, the Environmental Defense Fund, Desert Research Institute, and Google Earth Engine. Leveraging data from NASA, National Oceanic and Atmospheric Administration (NOAA) and U.S. Geologic Survey (USGS)-operated satellites, this will be the first operational system for measuring freshwater data, scalable down to individual farm fields. Completely accessible and free to the public and covering 17 Western states, OpenET will be a valuable resource to water managers and agricultural producers.

For a broader view, NASA is also launching the Surface Water and Ocean Topography (SWOT) mission in early 2022. A joint partnership with France, with contributions from Canada and the United Kingdom, SWOT will provide the first global survey of Earth's surface water, including detailed observations of the ocean's surface topography, and measurements of how water bodies are changing over time.

Our nation's ability to feed itself. As farmers and livestock producers struggle to adjust to hotter temperatures, more frequent droughts, and rapidly changing flood and storm patterns, we must find more sustainable food-production practices. Since its launch in 2015, the NASA Soil Moisture Active Passive (SMAP) satellite mission has collected soil moisture measurements around the globe with impressive accuracy. Because of the value of this information to farmers, we have made this information freely available to the public through a portal created in partnership with the U.S. Department of Agriculture (USDA) and George Mason University and offering it along with many other NASA datasets through Google Earth.

Safety from extreme weather events. Low-lying homes, businesses, and critical infrastructure, such as military installations and our nation's launch infrastructure, are increasingly at risk from sea-level rise, increased flooding and hurricane-force winds. With the November 2020 launch of the Sentinel-6 Michael Freilich satellite, a joint U.S.-European effort, we are collecting the most accurate data yet on sea level and how it changes over time.

Better sea level measurements add to advances in our knowledge of the entire Earth system and will help decisionmakers in regions throughout our country suffering from the impacts of sea level rise develop flood-risk resilience and disaster response plans. These regions include Virginia's Hampton Roads, home to 1.7 million people, as well as both NASA's Langley Research Center and the world's largest naval facility, Naval Station Norfolk. The only part of our country that has seen more of the impact of sea level rise is the New Orleans region, home to more than a million Americans and NASA's Michoud Assembly Facility. NASA and Americans stand to benefit from these increased capabilities.

Informed policy decisions. NASA measurements provide information for policymakers, including information regarding the efficacy of environmental policies and decisions. NASA provides cutting edge greenhouse gas observations from space. Our Carbon Monitoring System offers a product-oriented overlay that provides actionable results with quantified uncertainty for monitoring, reporting, and verification of carbon stocks and fluxes.

As the nation's civil space agency and with substantial Earth science and applications research programs, NASA-funded research results and NASA personnel were foundational contributors to the fourth National Climate Assessment (NCA4). NASA's observations, advanced Earth system models, and scientific analyses underpinned virtually all of the scientific findings in NCA4 Volume I: Climate Science Special Report, which details how climate change is affecting the physical Earth system and documents the status and current knowledge of physical climate science. NASA also made substantial contributions to the NCA4 Volume II, which focuses on observed and projected impacts, risks, and risk reduction approaches for the United States, and implications of climate change impacts under a variety of mitigation approaches.

The Next Two Decades

Looking further into this decade and beyond, NASA Earth Science is accelerating work in three key areas to advance our understanding of the Earth system processes that influence how and when the specific impacts of climate change are likely to play out, and to rapidly make this information available and usable to those who need it:

- **Space-based Observations:** Increasing our ability to "see" Earth systems by investing in innovative technologies, exploring alternative observation platforms, experimenting with new approaches to industry partnership and commercial services, and continuing to expand international collaboration.
- **Modeling & Informatics:** Integrating these observations and advanced models through frameworks that span timescales from minutes to decades, to further our understanding and prediction of the whole Earth system.
- **Applications & Dissemination:** Dramatically accelerating the uptake of scientific understanding and delivery of information in scalable ways to inform policymakers, managers and the public, aiding decisionmakers at every level, every day.

The 2017 Earth Science Decadal Survey by the National Academies of Science, Engineering, and Medicine laid out ambitious, but critically necessary, research and observation guidance for the work NASA should undertake by 2028. NASA is developing the mission concept for an Earth System Observatory consisting of an array of

space-based satellites, instruments, and missions that will deliver the highest priority data identified in the Decadal Survey, including data to improve scientific understanding in the following areas:

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

Together, these observations will create a 3D view of our Earth, from atmosphere to bedrock. Change is coming not just in what we are doing, but also in how we are doing it. NASA Earth Science is approaching the development of observing systems with new principles, including:

- **Open science and diversity:** A more diverse workforce, conducting science that is open and accessible to all, creates a stronger end result. This will also help NASA make our science and data more accessible at regional and local scales, as a way of reaching communities that often have fewer means to mitigate environmental degradation, such as low-income neighborhoods and tribal nations.
- **Partnership with commercial companies:** The precision manufacturing and digital technology enabled by commercial forces and private investment opens pathways to miniaturization and modularization of instruments and spacecraft, as well as advances in quantum computing and artificial intelligence.
- **New business models:** Focusing on innovation to increase opportunities for access to space, and leveraging ideas and talent at companies, universities, and other research institutions will augment and enable our core observation capabilities through competed tech demonstrations.

NASA's partnership with the Indian Space Research Organisation (ISRO) to deploy synthetic aperture radar is a good example of how we are tying these principles together. Called NISAR (NASA-ISRO Synthetic Aperture Radar), this mission will exploit new innovations in radar to gather an unprecedented, detailed view of Earth, measuring some of our planet's most complex processes. Data from NISAR on ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides, will assist how we manage both hazards and natural resources in the future. The data will be open and accessible to the public. The science from NISAR will inform us on the evolution and state of Earth's crust, helping us better understand our planet's processes and changing climate. This three-year mission is planned for launch in 2023.

Just as a rapidly changing environment presents challenges, the rapid pace of innovation and private sector investments presents opportunities to enable science-informed decisions throughout the public and private sector. Dramatic advances in precision manufacturing and digital technology, driven largely by industry, have enabled miniaturization and modularization of instruments and spacecraft, in some cases lowering launch costs. Together, these innovations are creating new ways to observe Earth at the time and spatial scales the nation will need to build resilient communities, support sustainable agriculture, assess air quality and biodiversity, and manage water resources.

More observations and commercially available computing power are unleashing advances in modeling, machine learning, and informatics, which accelerate our predictive capability. NASA is improving our predictive models for the ocean, land, atmosphere, and cryosphere processes, as well as for the interactions between them – which is the key to improving longer-range forecasting. Technology-based efforts like these enable *open science*, which will provide the immediate access and transparency necessary to inform policy development and management approaches, especially in communities most impacted by climate change.

NASA is planning to undertake these new observations as aggressively as we can, leveraging our resources as well the capabilities of our commercial, academic, interagency, and international partners. We are modernizing our data systems in partnership with the private sector to dramatically increase access to data and foster an open science ecosystem where we can quickly learn from these observations and make them readily available to decision-makers at every level.

NASA is leveraging the growing private sector investments in Earth science, including new constellations of commercial small satellites that gather Earth imagery, radio occultation measurements, and other environmental data. And we are investing in innovative observing system technologies and mission concepts. The Earth Science Technology program competitively awards targeted technology development and demonstration grants that will enable future observations, while the Earth Venture Program funds competitively-selected, cost-capped instruments and missions led by our academic research partners around the country. Future missions will also open many of the instruments and spacecraft for competitive selection.

Conclusion

The unique vantage point of sustained, trusted, space-based observations provides critical information to advance our understanding of Earth systems, addressing the multitude of components that interact to shape our present and future environment. Through strong collaboration with NOAA, USGS, USDA, and commercial and international partners, we deliver the benefits of our technology, observations, research, and applications to enable humanity to thrive.

At the end of this decade, another billion people will be living on our planet, putting more pressure on our Earth's systems. NASA is moving with urgency, focus, and in concert with the science community, our sister agencies in the federal government, our international partners, the private sector, our research associates in academia, and, of course, at the direction of Congress and the Administration, to meet the unrelenting challenge of a changing climate.

But know that we at NASA are relentless as well. We are accelerating our science, our partnerships, and new ways to do business. We are doing this because it is our mission, a mission we take to heart. Climate change demands science equal to the challenge it presents, and NASA will provide the space-based data needed to understand, mitigate, and adapt to our changing planet.

Thank you for the opportunity to discuss NASA's Earth Science program; I would be pleased to respond to any questions you might have.

Karen M. St. Germain, PhD

Deputy Assistant Administrator, Systems



Dr. Karen St. Germain is the Deputy Assistant Administrator, Systems (DAAS), for NOAA's Satellite and Information Service. She guides the ongoing development and deployment of NOAA's two major satellite programs (the Joint Polar Satellite System and Geostationary Operational Environment Satellite – R series), the COSMIC-2 mission, and the Space Weather Follow-On. She also leads the development of the next-generation capabilities that will replenish and augment these systems in the future.

Prior to becoming the DAAS, Dr. St. Germain served as the Director of the Office of Systems Architecture and Advanced Planning (OSAAP) where she led enterprise-level mission architecture development and systems engineering to enable NESDIS to become a flexible, stable and responsive civil space agency in support of NOAA's mission. Dr. St. Germain is a leader in enterprise-level planning and multi-organizational programs of national significance. She is also an expert in major systems acquisition, with particular proficiency in transitioning new technology into operational systems.

Dr. St. Germain developed a deep understanding of the NESDIS mission as NOAA's lead for all aspects of system performance during the development of the successful Suomi-NPP system, from 2006 to 2011. In 2011, Dr. St. Germain accepted a position in the Space, Strategic and Intelligence Systems (SSI) Office, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD AT&L). There, she led the DoD 2014 Strategic Portfolio Review for Space, a special assignment task for the Deputy Secretary of Defense to develop a strategy and implementation plan for adapting to evolving challenges in the space domain. Dr. St. Germain also led the Remote Sensing and Prompt Strike Division within SSI, where she was responsible for acquisition shaping and oversight of DoD strategic missile warning and space-based environmental monitoring portfolio, and the Program Director of the Conventional Prompt Global Strike Program.

Before joining NOAA, Dr. St. Germain had a successful research career at the University of Massachusetts, the University of Nebraska, and the Naval Research Laboratory. She has performed research aboard ice-breakers in the Arctic and Antarctic, flown through hurricanes and tropical storms on NOAA's P-3 airplanes and measured glacial ice on a snowmobile traverse of the Greenland ice sheet. She also led the modeling and calibration of the WindSat Coriolis mission, the first space-borne radiometer to measure ocean surface wind direction.

Dr. St. Germain holds a Bachelor of Science degree in electrical engineering from Union College (1987) and a Doctor of Philosophy degree in Electrical Engineering from the University of Massachusetts (1993). She is also a Distinguished Graduate of the National War College, National Defense University where she earned a Master of Science degree in National Security Strategy in 2013.

Chairman BEYER. Thank you very much, Dr. St. Germain. We'll have plenty of questions for you, I'm sure.

Now, let me recognize Dr. Gavin Schmidt for his testimony.

**TESTIMONY OF DR. GAVIN SCHMIDT,
SENIOR CLIMATE ADVISOR (ACTING)
AND DIRECTOR OF GODDARD INSTITUTE
FOR SPACE STUDIES, NASA**

Dr. SCHMIDT. Chairman Beyer, Ranking Member Babin, Members of the Subcommittee, my name is Gavin Schmidt, and I'm the director of the NASA Goddard Institute for Space Studies and the Acting Senior Advisor on Climate to the NASA Administrator.

Today, I would like to share with you the breadth and depth of NASA's work on climate, covering pure scientific research, technology development, applied science, education, as well as the efforts to reduce the agency's own emissions and build greater resilience.

NASA is the lead agency for civil aeronautics research and for scientific research that can be productively studied from space, acknowledging that practical benefits for society are always an important measure of success. NASA is specifically tasked with ensuring public access to accurate data on global warming.

Since the late 19th century, global surface temperatures have risen more than 1 degree Celsius, 2 degrees Fahrenheit. Sea level has risen by about 12 inches since 1900 and 3 millimeters per year right now. These broad changes are already having a direct impact on communities in the United States and internationally.

We track most of the factors driving climate change and investigate the processes that underlie the emergent patterns of climate variability. My colleague Dr. Karen St. Germain has already expanded on these topics in her testimony today.

Research connections on climate also include NASA's Heliophysics Division and the Planetary Science Division under the broad umbrella of Astrobiology. NASA's climate portfolio also encompasses research into sustainable aviation and space technology transfer focused on clean energy and environmental modeling—monitoring.

NASA is investing in industry partnerships that will develop the next generation of single-aisle aircraft that will be at least 25 percent more fuel-efficient by the early 2030's. We will award contracts for the first-ever high-powered hybrid electric propulsion system for large transport aircraft by the end of summer 2021 with flight demonstrations of an electrified powertrain expected as early as 2023.

NASA is also providing solutions to the challenge of all electric flight through development and flight tests of the X-57 airplane. A 2018 competition developed in partnership with the Robert Wood Johnson Foundation, focused on an aerosol monitor that could be used both on the International Space Station and in urban polluted environments. Another NASA prize competition, the CO₂ Conversion Challenge, seeks to create a carbon-neutral manufacturing system that can be used in space, as well as on Earth.

NASA has partnered with local government entities. For instance in New York, NASA input into the city's climate change panel has

been important in helping set new standards and planning guidelines.

NASA also partners with other agencies such as the Department of Energy and NOAA and through the USGCRP (U.S. Global Change Research Program) to help coordinate global change research across the Federal Government. NASA is participating in the White House's National Climate Task Force and the Climate Innovation Working Group.

Internationally, NASA has partnerships with space agencies across the world to develop, launch, and maintain platforms and instruments for long-term climate data. NASA's GLOBE (Global Learning and Observation to Benefit the Environment) and AERONET (Aerosol Robotic Network) programs and SERVIR, a joint NASA and USAID (United States Agency for International Development) initiative, collectively have a presence in nearly 125 countries.

NASA recognizes that rising sea levels and increasing hurricane activity along the Gulf Coast will have significant impacts on our ability to fulfill our mission and that we must implement protective measures in order to reduce our risks. Center master plans now include sustainability as a key goal. And, since 2008, NASA has seen a consistent downward trend in its own greenhouse gas emissions.

For education and outreach, NASA's Science Activation program enables NASA science and experts to—and content to engage learners of all ages. NASA reaches upper elementary-aged children through ClimateKids.NASA.gov while Climate.NASA.gov is a top public website with almost 10 million annual visitors.

Recently, NASA has convened the Climate Strategy Working Group to develop a more integrated approach to the agency's climate portfolio and to address the Administration's priority for a governmentwide approach in response to the climate crisis. Additionally, we are creating a climate action plan to further build resilience and educate management on the need to embed climate change mitigation and adaptation into our decisionmaking procedures.

NASA has long recognized that climate science is a fundamental part of our mandate. With the increasing evidence for serious impacts and the elevation of this topic by the Administration, it is time for a renewed focus on all aspects of climate change and a commitment to ensure that this data and understanding will continue to accumulate and be used for the benefit of society. Thank you very much.

[The prepared statement of Dr. Schmidt follows:]



National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

May 18, 2021

**Subcommittee on Space and Aeronautics
Committee on Science, Space,
and Technology**

U.S. House of Representatives

Statement by:
Dr. Gavin A. Schmidt
Senior Advisor on Climate to the Administrator (Acting)
National Aeronautics and Space Administration

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before the

**Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives**

Chairman Beyer, Ranking Member Babin, Members of the Subcommittee and Committee,

My name is Gavin Schmidt, and I am the Director of the NASA Goddard Institute for Space Studies (GISS) in New York and, since February, the acting Senior Advisor on Climate to the NASA Administrator. I have been a climate scientist for almost three decades, and since 2004, I have worked for NASA at GISS, where I am the Principal Investigator for the GISS ModelE Earth System Model.

My scientific work has mainly focused on the development, evaluation, and application of climate models to issues of the detection and attribution of climate change both in the past and in the present. During the past decades, we have learned that space provides a unique vantage point to learn about our planet and to understand it as a system. As the preeminent civilian agency that develops U.S. systems to provide space data, much of what we know today about the long-term changes in our Earth system comes from NASA-built systems going back to the 1960s. We recognize that this role in understanding our Earth system is important for the future and can help inform how we can thrive on our changing planet.

As part of my current role, I have been tasked with developing a renewed climate strategy for the whole of NASA. Today, I would like to share with you the breadth and depth of NASA's work on climate from across the whole agency, covering pure scientific research, technology development, applied science, and education as well as the agency's own emissions and efforts to build greater resilience to climate change. NASA's work on climate is one of the key overarching elements in how the agency is responding to the Administration's priorities.

NASA is legislatively mandated to perform climate-related research and development

By statute, NASA is the lead agency for civil aeronautics research and conducts aeronautics research and development. We fill this role as part of the U.S. Government's responsibility to "increase the efficiency of the Nation's air transportation system" and "protect the environment" (51 U.S.C. § 40102).

NASA has also been tasked with scientific research that can be productively studied from space, including Earth science and Sun-Earth connections (51 U.S.C. § 20301). Specifically, NASA shall

...pursue a program of Earth observations, research, and applications activities to better understand the Earth, how it supports life, and how human activities affect its ability to do so in the future. (51 U.S.C. § 60501)

Additionally, the law acknowledges that practical benefits for society will be an important measure of the success of these programs in addition to securing new knowledge about the Earth system and climate change. NASA is also tasked with ensuring our policies on climate related data facilitate their availability and widest possible use to ensure public access to accurate and current data on global warming (51 U.S.C. § 60506).

NASA takes all of these responsibilities very seriously.

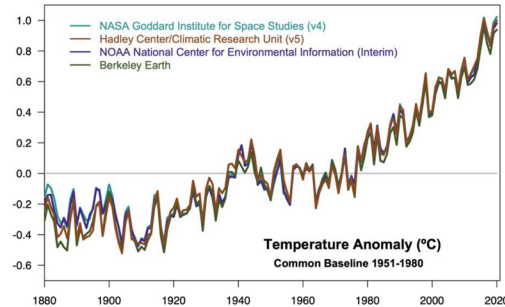


Figure 1: Global surface temperature anomalies since 1880 from four independent methodologies.

Human-caused climate change is already having impacts

Since the late 19th Century, global surface temperatures have risen more than 1.2°C/2.2°F according to analyses from NASA GISS (Figure 1), with greater trends on land than over the ocean, and with recent warming rates in the Arctic that are more than three times the global mean. Sea level determined from tide gauges has risen an average of 10 to 12 inches since 1900, and since 1993 is rising at more than 3 mm/year and accelerating according to satellite altimeter data (Figure 2). Since the beginning of comprehensive satellite observations in 1979, summer sea ice in the Arctic has decreased by more than 40%. Water vapor in the atmosphere has increased, and ocean heat content has increased by more than 30×10^{22} joules since 1970. These changes were all predicted to arise as a consequence of increases in greenhouse gas emissions, notably carbon dioxide. Climate models from 1970 onwards have, with few exceptions, been successful in predicting the subsequent changes in climate to 2020.

These broad changes in turn are having direct impact on communities in the United States and internationally. Sea level rise, particularly along the U.S. East Coast is leading to a large increase in coastal flood events. Greater intensity of precipitation is contributing to flooding, notably in response to Hurricane Harvey in 2017, but also more generally. Warming is making the ongoing drought in the U.S. Southwest more intense because of the greater evaporative demand from the soil. It is also adding to the intensity of wildfires, the prevalence of pine bark beetles, and poleward shifts of invasive plants and some diseases, like the tick-spread Lyme disease found here in the Northeast United States.

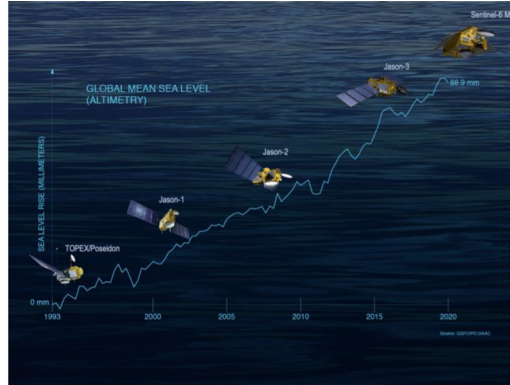


Figure 2: Global sea level changes from satellite altimeters since 1993.

NASA's research portfolio in climate

The backbone of NASA's climate research is the observations that have been made from space since the 1960s, and particularly since 1979. These long-term observations have provided dramatic evidence of climate change; for instance, the continuing loss of mountain glaciers from four decades of Landsat imagery, the mass imbalance of both Greenland and Antarctic ice sheets from the Gravity Recovery and Climate Experiment (GRACE) & GRACE-Follow On gravity measurements, and the rise of global sea level from satellite altimetry missions (see Figure 2). In collaboration with the National Oceanic and Atmospheric Administration (NOAA), Department of Defense (DoD), international partners, and other agencies, we have documented changes in temperatures from the ocean depths to the mesosphere 80 kilometers high in the atmosphere, seen the dramatic collapse of sea ice in the Arctic, and documented the history of the ozone hole and its impact on atmosphere and ocean circulation.

We have tracked most of the factors driving climate from greenhouse gas concentrations, deforestation, and air pollution to solar and volcanic activity. Beyond the trends, NASA research has investigated all manner of climate processes that underlie the emergent patterns of climate variability and change. This includes everything from elucidating the processes of cloud formation, the vertical distribution of rainfall, the phase of cloud condensate, the direct and indirect impacts of aerosols, the mechanisms changing the reflectivity of ice and snow, the impact of atmospheric chemistry, to the spatial and temporal variation of important climate drivers such as carbon dioxide, methane, and nitrous oxides.

In collaboration with multiple agencies, including NOAA, the National Science Foundation, and the Department of Energy (DOE), the observations of these processes combined with fundamental research on geophysical fluid dynamics have informed and improved the development of modeling systems on weather to climate that have then allowed for the attribution of the trends we are seeing and the prospects for the future. Much of this work led by NASA and our interagency partners informs the National Climate Assessments developed by the U.S. Global Change Research Program (USGCRP) and the Assessment Reports developed by the UN Intergovernmental Panel on Climate Change (IPCC). My colleague, Dr. Karen St. Germain, the Director of NASA's Earth Science Division (ESD), will expand on these topics in her testimony today.

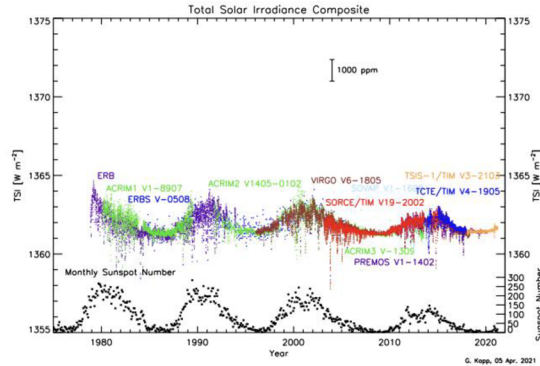


Figure 3. Multi-instrument, multi-agency composite record of total solar irradiance since 1979 encompassing three and a half solar cycles, cross-calibrated to produce a climate quality record.

However, research connections on climate go well beyond ESD. For instance, NASA's Heliophysics Division continues to support investigations on the impacts of variability of solar activity on Earth's climate across all timescales through its Living With a Star (LWS) program. Additionally, work in NASA's Planetary Science Division, under the broad umbrella of astrobiology, investigates habitability both on Earth across 4.5 billion years, on other solar system bodies (such as Venus, Mars and Europa), and on newly characterized exoplanets, often using climate models that were initially developed for modern Earth conditions and expanded to encompass this increasingly broad range of possibilities.

Beyond the Science Mission Directorate, NASA's climate portfolio encompasses research in aeronautics and space technology, focused on clean energy, environmental monitoring, sustainable aviation, and remediation.

NASA Technology can play a key role in climate mitigation

Since its inception, NASA has developed or enabled the development of technologies essential for our core missions in space and planetary exploration, study of our home planet, and commercial flight. Through our technology transfer programs, many of these innovations have been repurposed for use here on Earth. For example, a methane-detection sensor technology for Martian exploration was licensed by JPL to California-based company SeekOps, who both sells these sensors and uses the technology to precisely detect emissions and leaks on well pads across California, North Dakota, Ohio, Colorado, and Texas. This technology transfer opportunity now enables SeekOps to deliver value to improving climate outcomes in two main ways: (1) by improving safety for those on or near the well pads by ensuring better detection of dangerous leaks; and (2) by inspecting the infrastructure and highlighting any unknown hot spots or emissions that could turn into danger zones in the future.

NASA has developed or fostered the development of many technologies that can play a key role in climate mitigation. NASA research and development of advanced vehicle technologies and operational concepts have directly contributed to the dramatic improvement in fuel efficiency of the global civil aviation fleet over the last fifty years. Although aviation only represents 2.1% of global carbon dioxide emissions, it plays a growing role as other sectors turn to low- or no-carbon energy sources. The global aviation industry has coalesced around decarbonization goals for civil aviation, stating a commitment to reduce carbon emissions from aviation by half by 2050, compared to 2005.

NASA plays a critical role in the U.S. contribution to achieving these goals. NASA is investing in cost-sharing partnerships with U.S. industry to research and demonstrate high risk, high payoff technology advancements that will enable entry into service by the early 2030s of next generation single-aisle aircraft which are at least 25% more fuel-efficient than today. NASA and industry will demonstrate first ever high-power hybrid electric propulsion for large transport aircraft, ultra-high efficiency long and slender wings, advanced composite materials

and manufacturing processes, and advanced engine technologies, all based on breakthrough NASA innovation and industry collaboration. The first of these advances – NASA contract awards for flight demonstrations of an electrified powertrain, the heart of the hybrid-electric propulsion system – are expected by the end of summer 2021, with a first demonstration flight occurring as early as 2023.

A key tenet of NASA’s focus to improve aircraft fuel efficiency and reduce carbon as well as other harmful aircraft emissions is through improved airspace management and aircraft operations. NASA has collaborated with the FAA and U.S. airlines to reduce carbon emissions through development and demonstration of advanced airspace tools and concepts. In fact, this summer NASA, FAA and industry partners are concluding a five-year collaboration by demonstrating these tools at airports in the Dallas, Fort Worth area. Looking ahead, NASA will advance integrated ground and flight-based technologies for trajectory optimization through every phase of flight, reducing fuel burn, CO₂ emissions, contrail formation and ozone impact.

At a smaller scale, NASA is providing solutions to the challenge of all electric flight through development and flight tests of the X-57 all-electric general aviation-sized airplane, in the grand tradition of NASA “X” experimental aircraft. In a joint effort between Armstrong Flight Research Center at Edwards Air Force Base in California, Langley Research Center in Hampton, Virginia, and Glenn Research Center in Cleveland, Ohio, the X-57 will fly for the first time in late 2021 to test and determine the airworthiness of electrified aircraft technologies, such as batteries and electric motors, with applicability to a broad range of electric aircraft configurations and missions. Data from development of the X-57 is being shared with industry and academia to support new industry standards and development of certification pathways for electric aircraft.

As an example of how NASA research can spark commercial innovation, NASA worked with Electric Power Systems, an Industry, California based company, to design and develop the batteries for the X-57. The resulting technology has been licensed to the company for use in other commercially available electric planes, including in Colorado-based Bye Aerospace’s Sun Flyer Trainer. The primary use of these batteries are for short duration (approximately 1 hour) flights and could enable the creation or expansion of zero-emissions aviation business models, such as short travel between small airports and vertical take off and landing vehicles for transportation within cities. This Advanced Air Mobility Market is envisioned to blossom to an annual estimated value of \$115 billion by 2035.



Figure 4. New aircraft concepts from the ULI (from University of Illinois Urbana-Champaign) using hydrogen fuel cells, and a NASA Turbo-Electric aircraft concept with a superconducting electric drivetrain.

Additionally, NASA’s University Leadership Initiative (ULI) supports universities pioneering next-generation technologies for a net-zero carbon emissions aviation future. The most promising ULI concepts will be matured to ground tests in larger facilities or actual flight testing with the goal to position them for commercialization before 2050. Examples of awards include the development of a real-time weather forecasting tool to improve the safety and efficiency of low altitude aircraft operations, led by Oklahoma State University researchers; an assessment of the challenges and opportunities of electric propulsion led by Ohio State University; advanced aircraft concepts with key innovations from the University of Illinois Urbana-Champaign; and an advanced turbine research for hybrid electric propulsion systems led by Pennsylvania State University.

The Space Technology Research Grants (STRG) Program is another grant program that focuses on the development of space technology and applications. For example, STRG is currently funding the Center for the

Utilization of Biological Engineering in Space (CUBES), a consortium of five universities, led by the University of California, Berkeley, and including Stanford University, the University of California, Davis, Utah State University, and the University of Florida. CUBES is the first coordinated and large-scale effort to enable in situ biomanufacturing of crucial mission products to enable sustainable human space exploration, and is currently developing new biomanufacturing technologies that primarily use carbon dioxide, water, and sunlight to make a wide range of products including food, polymers, and pharmaceuticals for future space missions.

Notable CUBES results include the development of a novel solar-powered biohybrid system that uses an electrochemical cell and unique microbes to absorb carbon dioxide and transform it into organic feedstocks to supply chemical and biological manufacturing systems. Other team members have generated additional significant advances in plant and algae-based production of pharmaceuticals, increasing photosynthetic efficiency and light utilization for improved crop production, novel methods of biomanufacturing nitrogen fertilizers, and the production of high-strength bioplastics. These innovations are not only pioneering new ways to sustain humans in space, but also are generating technologies that can help secure a sustainable future here on Earth.

Prizes and competitions are an innovative mechanism to engage the public in solving tough challenges related to NASA's mission. A 2018 competition that was developed in partnership with the Robert Wood Johnson Foundation focused on an aerosol monitor that could be used both on the International Space Station and in urban polluted environments. Two winning designs are currently being refined for flight readiness and integration, one from Applied Particle Technologies of St. Louis, Missouri, and the other from Access Sensor Technology of Fort Collins, Colorado, while both companies are also using their technology in terrestrial applications as well.

Today, another NASA prize competition, the CO₂ Conversion Challenge, seeks to create a carbon neutral manufacturing system that can be used in space, as well as on Earth. This type of system will allow NASA to send humans on long duration space missions using readily available resources. It could also be useful for Earth applications allowing the planet to break free from the reliance on natural resources such as oil, natural gas, and coal. The Challenge received over 20 entries in the initial phase, with the top three teams set to receive \$350,000; \$200,000; and \$100,000 for first, second, and third place respectively. These three teams hail from California and New York and their proposals are currently being evaluated with an anticipated award date in June of this year.

NASA's climate research has a broad range of stakeholders

NASA partners with American companies and universities to develop and demonstrate technologies that advance sustainability across a variety of sectors. One mechanism used to advance technology for NASA and space applications is the Small Business Innovation Research (SBIR) program. NASA has awarded contracts to a number of commercial entities to further the agency's climate-related research and analysis. Virginia Diodes, headquartered in Charlottesville, Virginia, for example, has received several awards from the NASA SBIR Program, including one to supply a receiver for a CubeSat deployed from the International Space Station in May 2017. Called IceCube, this bread-loaf-sized satellite measured ice clouds in low Earth orbit until October 2018. These measurements produced the world's first map of the global distribution of atmospheric ice, which have an important effect on Earth's energy budget and therefore our climate.

Applied Geosolutions, a New Hampshire-based small business, has also received SBIR funding for its Rice Decision Support System (RiceDSS). RiceDSS improves real-time rice production forecasting and assessments of growing conditions. According to Applied Geosolutions President Willian Salas, the funding provided the company with a unique opportunity to help promote economic stability while addressing key humanitarian issues associated with climate change and the global food supply system. The company is planning to provide consulting services, leveraging the use of forecasts to optimize efficiency and support adaptation and mitigation strategies.

Extremes that are being increasingly influenced by climate change can often require a rapid turnaround emergency response, and we are partnering with a number of state and local agencies in responses to disasters from wildfires to hurricanes. NASA has also partnered with local government entities to help plan for climate

change and sea level rise in urban environments. For instance, NASA input into the New York City Climate Change Panel has been important in helping the city set new standards and planning guidelines.

NASA also partners with members of the interagency community, through agreements with specific agencies, as well as in the agency's participation in interagency working groups. For example, building upon a number of years of collaboration, NASA also signed a Memorandum of Understanding with DOE in October 2020 to further potential collaboration in a number of key areas, including space nuclear power and propulsion, lunar surface infrastructure, and science and innovation. In 2018, NASA and DOE jointly conducted a successful test of an integrated 1kW nuclear fission power system in the Nevada National Security Test Site that was a precursor to demonstrate a fission surface power system on the Moon, an effort that is currently underway through a collaboration between NASA, DOE, and industry. The technology developed through these efforts could have potential applications to furthering Earth-based low carbon energy.

NASA actively participates in the USGCRP to help coordinate the global change research activities of 13 U.S. agencies. NASA also is a member of the White House's National Climate Task Force (NCTF), as well as the NCTF's Climate Innovation Working Group. In addition, NASA participates in a variety of subject matter specific working groups both within the U.S. Government and with international organizations, such as the International Civil Aviation Organization (ICAO) and the UN.

Likewise, the Agency is also participating as subject matter experts in ICAO's Committee on Aviation Environmental Protection (CAEP) Long-Term Aspirational Goal Task Group. The activity was chartered by the ICAO 40th Assembly in 2019 to explore the feasibility of a long-term global aspirational goal for international civil aviation CO₂ emissions reductions, including options and roadmaps for their realization. The Task Group will provide results to the 41st ICAO Assembly in 2022.

Internationally, NASA also has partnerships with space agencies across the world to develop, build, launch and maintain platforms and instruments for long-term climate data, including satellite altimetry missions (see Figure 2) through partnerships with the National Centre for Space Studies, European Space Agency, and the European Organisation for the Exploitation of Meteorological Satellites. NASA's Global Learning and Observations to Benefit the Environment (GLOBE) Program and Aerosol Robotic Network (AERONET) have a presence in nearly 125 countries, helping to promote international collaboration and citizen science across the world.

Particularly notable is SERVIR, a joint NASA and USAID initiative in place since 2005, which works in partnership with leading regional organizations worldwide to help over 50 developing countries in Asia, Africa, and the Americas use information provided by Earth observing satellites and geospatial technologies to support sustainable, climate-resilient decision-making. Current climate-related efforts include: the promotion of adaptation and resilient development informed through the use of geospatial information and data to provide critical early warning forecasting systems and help strengthen disaster risk reduction and response; the support of food security decision-making through forecasts and modeling, helping countries anticipate and take action on agricultural conditions in response to drought and other climate shocks; and using data on land use and land cover to help inform and demonstrate improved land management to reduce emissions and conserve biodiversity. NASA and USAID also support the Multi-Angle Imager for Aerosols (MAIA) mission, which studies how human health is affected by different types of particulate matter, the impacts of which are expected to intensify with climate change.

Other international partnerships are being formed with the C40 global cities organization to ensure that these municipalities have access to the relevant data for their unique challenges.

NASA is building resilience for its facilities

NASA recognizes that climate change will have significant impacts on our ability to fulfill our mission. For examples, rising sea levels have the potential to impact our coastal launch infrastructure at both the Kennedy Space Center in Florida and the Wallops Flight Facility in Virginia, as well as the Langley Research Center in

Hampton Roads, Virginia. Moreover, the increase in hurricane activity along the Gulf Coast increases the threat of disruptions to our Mission Operations and training facilities at Johnson Space Center in Texas each year.

In 2010, NASA initiated the Climate Adaptation Science Investigator Work Group (CASI) to expand collaboration among its Earth scientists, applications researchers, and institutional stewards in order to help manage climate change risks at each of its Centers and facilities. This led to multiple workshops and Center-specific adaptation plans identifying local vulnerabilities and determining their associated risks to operations and missions.

The Agency recognizes that in order to mitigate impacts, we must implement proactive measures to reduce our environmental, institutional, programmatic, and operational risks. This includes integrating our climate data and modeling into the Agency's decision and policymaking processes, as well as identifying and implementing adaptation strategies to address potential mission impacts. Center master plans now include sustainability as a key goal in facility development.

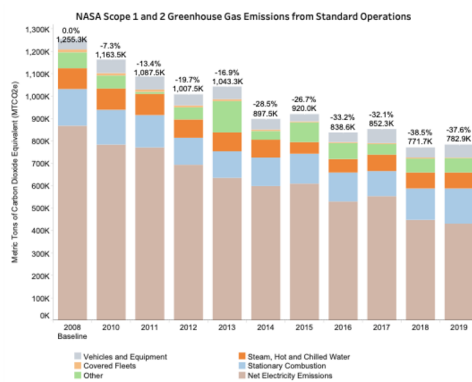


Figure 6. Greenhouse gas emissions from 2008 to 2019 from NASA Standard Operations.

NASA's institutional greenhouse gas emissions from standard operations are falling

Since the inception of the U.S. Government's Annual Energy Data Report in 2008, NASA has seen a consistent downward trend in greenhouse gas emissions. These trends have been driven mainly by reduced electricity use that have arisen from modernization of facilities, including switches to more energy efficient lighting, better insulated buildings, and more efficient HVAC systems. Further progress will require a greater focus on emission cuts specifically.

As part of the NASA response to Executive Order 14008, the Agency is creating a Climate Action Plan to include specific activities to further resilience and educate management, including procurement, finance, and facilities, on the need to embed climate change mitigation and adaptation into our decision-making procedures. This effort builds on the foundation of previous efforts.

NASA is contributing to STEM engagement and education around climate

One of NASA's most accessible websites targeted to children is <https://climatekids.nasa.gov>, which covers the science and observations of climate change. Targeted to upper-elementary-aged children, the site is full of games, activities, and articles that make climate science accessible and engaging.

For a broader audience, NASA's Global Climate Change website, <https://climate.nasa.gov>, is the leading source of up-to-date climate change data and information for the public. Today, the website is a top-three NASA website, with almost 10 million annual visitors and 23 million pageviews.

More broadly, NASA's Science Activation Program, a collaborative model leveraging partnerships through a network of science and community-based institutions, enables NASA science experts and content to engage learners of all ages across. Currently, our Science Activation Program includes eight climate-related projects reaching K-12 and undergraduate students, and communities across the country.

Among other efforts, the Arctic and Earth STEM Integrating GLOBE and NASA (SIGN) trains teachers, 4-H leaders, and community members on climate change concepts, culturally responsive curricula, and environmental observing protocols relevant to Alaskan climate change issues in face-to-face and online courses. In Maine, the Real World, Real Science project, led by the Gulf of Maine Research Institute, uses NASA's rich array of data assets to engage middle school learners in explorations of weather and climate, ecosystem change, and stability, and the ways that human and natural systems intersect.

More directly, the NASA GISS Climate Change Research Initiative is a year-long STEM engagement opportunity for New York metropolitan area educators and graduate students to work directly with NASA scientists and lead research teams in a NASA research project. Outputs include peer-reviewed in-depth lesson plans using NASA data and analysis that are aligned with the Next Generation Science Standards.

Further development of NASA's Climate Strategy

In recent months, NASA has convened a Climate Strategy Working Group (CSWG) with representatives from all the Agency's Mission Directorates and from multiple NASA Centers to develop an Agency climate strategy that will provide an integrated approach to the Agency's climate portfolio and will address the Administration's priority for a government-wide approach in response to the climate crisis. NASA recognizes that while its climate portfolio is broad and deep, the Agency can be more integrated across programs, Directorates, and Centers, as well as connected to our interagency and other partners. Additionally, the Agency lacks a single "point of entry" to learn more about the entirety of NASA's climate portfolio, how research and applications have been successful, and the opportunities for potential new partnerships.

For instance, although many Earth Science Division's Applied Sciences programs involve climate change, climate is not a central focus for any one of the programs. Conversely, much of the science applied to climate change issues at NASA does not reside within the Applied Sciences programs at all. This has led to a patchwork of climate-related partnerships that have been successful but narrowly tailored and somewhat haphazard. For instance, while New York City has benefitted greatly from NASA input into its decision-making progress, neighboring towns in New Jersey or Connecticut have not. One question will be how more targeted outreach, training, and partnership-building can further the aims of environmental justice. Many communities that are being or will be affected by climate change might not have the resources or tradition of partnering with NASA.

The CSWG is currently working on a white paper to address these and other challenges for presentation to NASA leadership.

Summary

NASA has long recognized that climate science and climate change are fundamental parts of our mandate, and for decades we have worked on fundamental and applied research in these areas. With the increasing evidence for serious impacts and the elevation of this topic by the Administration, it is time for a renewed focus on all the aspects of climate change that NASA works on and a commitment to ensure that the data and understanding that NASA has and will continue to accumulate will be used for the benefit of society.

GAVIN A. SCHMIDT

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RESEARCH POSTS:

	NASA Goddard Institute for Space Studies
Feb 2021 to date	Sr. Advisor on Climate Science to the NASA Administrator
May 2014 to date	Chief
2012–2014	Deputy Chief
2004 to date	Physical Scientist
	Center for Climate Systems Research, Columbia University
2014 to date	Adjunct Senior Research Scientist
2004–2014	Adjunct Research Scientist
2002–2004	Research Scientist
1998–2002	Associate Research Scientist
1996–1998	NOAA Postdoctoral Fellow in Climate and Global Change
1994–1996	Centre for Climate and Global Change Research McGill University, Montreal. Postdoc.

EDUCATION:

1990–1993	University College London PhD (with E.R. Johnson). “The calculation, scattering and stability of topographic Rossby waves”
1985–1988	Jesus College, Oxford University First Class B.A. (Hons) in Mathematics

AWARDS AND RECOGNITION:

- Robert H. Goddard Honor Award (2020)
- Honorary Doctor of Science, Bristol University, UK (2018)
- Honorary Doctor of Science, Williams College, MA (2017)
- AAAS Fellow (2017), AGU Fellow (2018)
- Outstanding Leadership Medal (GSFC, 2017)
- AGU Stephen Schneider Lecturer (2013)
- AGU Inaugural Climate Communication Prize (2011)
- EarthSky Science Communicator of the Year (2011)
- AGU Citation for Excellence in Refereeing: JGR (2010), Paleoceanography (2004)
- NASA Special Act Award (2010), Performance Award (2007)
- Scientific American 50 “Research Leader” (2004)
- University College London: Andrew Rosen Prize (1991)
- Jesus College: Progress Prize (1986), Collection Prize (1987), Exhibitioner (1987–8)
- h-index (May 2021): 59 (Web of Science); 71 (Google Scholar)

REFEREED PUBLICATIONS:

- O'Connor, G. K., K. M. Cobb, H. R. Sayani, A. R. Atwood, P. R. Grothe, S. Stevenson, J. K. Baum, T. Chen, D. Claar, N. Hitt, J. Lynch-Stieglitz, **G. A. Schmidt**, and R. M. Walter, 2021: Coral oxygen isotope and in situ records capture the 2015/2016 El Niño event in the central equatorial Pacific. *Geophys. Res. Lett.*, submitted
- Zhou, T., K. DallaSanta, L. Nazarenko, and **G. A. Schmidt**, 2020: The impact of increasing stratospheric radiative damping on the QBO period. *Atmos. Chem. Phys.*, in press
- Lunt, D. J., D. Chandan, H. J. Dowsett, A. M. Haywood, G. M. Lunt, J. C. Rougier, U. Salzmann, **G. A. Schmidt**, and P. J. Valdes, 2020: Multi-variate factorisation of numerical simulations. *Geosci. Model Dev.*, submitted
- Miller, R. L., **G. A. Schmidt**, L. Nazarenko, S. E. Bauer, M. Kelley, R. Ruedy, G. L. Russell, A. Ackerman, I. Aleinov, M. Bauer, R. Bleck, V. Canuto, Y. Cheng, T.L. Clune, A. D. Del Genio, G. S. Elsaesser, G. Faluvegi, N. Y. Kiang, D. Kim, A. A. Lacis, A. Leboissetier, A. N. LeGrande, K.K. Lo, J. Marshall, E. E. Matthews, S. McDermid, K. Mezuman, L. T. Murray, V. Oinas, C. Orbe, C. Pérez García-Pando, J. P. Perlwitz, M. J. Puma, D. Rind, A. Romanou, D. T. Shindell, S. Sun, N. Tausnev, K. Tsigaridis, G. Tselioudis, E. Weng, J. Wu, and M.-S. Yao, 2021: CMIP6 historical simulations (1850–2014) with GISS ModelE2.1.1. *J. Adv. Model. Earth Syst.*, 13, no. 1, e2019MS002034
- Bush, R., A. Dutton, M. Evans, R. Loft, and **G. A. Schmidt**, 2020: Perspectives on data reproducibility and replicability in paleoclimate and climate science. *Harvard Data Sci. Rev.*, 2, no. 4
- Dunne, J. P., M. Winton, J. Bacmeister, G. Danabasoglu, A. Gettelman, J.-C. Golaz, C. Hannay, **G. A. Schmidt**, J. P. Krasting, L. R. Leung, L. Nazarenko, L. T. Sentman, R. J. Stouffer and J. D. Wolfe, 2020, Comparison of equilibrium climate sensitivity estimates from slab ocean, 150-year and longer simulations, *Geophys. Res. Lett.*, 47, no. 16, e2020GL088852
- Orbe, C., D. Rind, J. Jonas, L. Nazarenko, G. Faluvegi, L.T. Murray, D.T. Shindell, K. Tsigaridis, T. Zhou, M. Kelley, and G. Schmidt, 2020: GISS Model E2.2: A climate model optimized for the middle atmosphere. Part 2: Validation of large-scale transport and evaluation of climate response. *J. Geophys. Res. Atmos.*, 125, no. 24, e2020JD033151
- Sherwood, S., M. J. Webb, J. D. Annan, K. C. Armour, P. M. Forster, J.C. Hargreaves, G. Hegerl, S. A. Klein, K. D. Marvel, E. J. Rohling, M. Watanabe, T. Andrews, P. Braconnot, C. S. Bretherton, G. L. Foster, Z. Hausfather, A. S. von der Heydt, R. Knutti, T. Mauritsen, J. R. Norris, C. Proistosescu, M. Rugenstein, **G. A. Schmidt**, K. B. Tokarska and M. D. Zelinka, 2020, A combined assessment of Earth's climate sensitivity, *Revs. Geophys.*, 58, no. 4, e2019RG000678
- Kelley, M., **G. A. Schmidt**, L. Nazarenko, R. L. Miller, S. E. Bauer, R. Ruedy, G. L. Russell, I. Aleinov, M. Bauer, R. Bleck, V. Canuto, G. Cesana, Y. Cheng, T.L. Clune, B. Cook, C. A. Cruz, A. D. Del Genio, G. S. Elsaesser, G. Faluvegi, N. Y. Kiang, D. Kim, A. A. Lacis, A. Leboissetier, A. N. LeGrande, K. K. Lo, J. C. Marshall, S. McDermid, E. E. Matthews, K. Mezuman, L. T. Murray, V. Oinas, C. Orbe, C. Pérez García-Pando, J. P. Perlwitz, M. J. Puma, D. Rind, A. Romanou, D. T. Shindell, S. Sun, N. Tausnev, K. Tsigaridis, G. Tselioudis, E. Weng, J. Wu, and M.-S. Yao,

- 2019: GISS-E2.1: Configurations and climatology. *J. Adv. Model. Earth Syst.*, 12, no. 8, e2019MS002025
- Bauer, S.E., K. Tsigaridis, G. Faluvegi, M. Kelley, K.K. Lo, R.L. Miller, L. Nazarenko, **G.A. Schmidt**, and J. Wu, 2020: Historical (1850–2014) aerosol evolution and role on climate forcing using the GISS ModelE2.1 contribution to CMIP6. *J. Adv. Model. Earth Syst.*, 12, no. 8, e2019MS001978
- Cheng, Y., V. M. Canuto, A. M. Howard, A. S. Ackerman, M. Kelley, A. M. Fridlind, **G. A. Schmidt**, M. S. Yao, A. Del Genio, and G. S. Elsaesser, 2020: A second-order closure turbulence model: New heat flux equations and no critical Richardson number. *J. Atmos. Sci.*, 77, no. 8, 2743–2759
- Orbe, C., L. Van Roekel, Á. Adames, G. Danabasoglu, A. Dezfili, J. Fasullo, P. J. Gleckler, J. Lee, W. Li, L. Nazarenko, **G. A. Schmidt**, K. Sperber, and M. Zhao, 2020: Representation of modes of variability in 6 U.S. climate models. *J. Climate*, 33, 7591–7617
- Hausfather, Z., H. F. Drake, T. Abbott, and **G. A. Schmidt**, 2020: Evaluating the performance of past climate model projections. *Geophys. Res. Lett.*, 47, no. 1, e2019GL085378
- Rind, D., C. Orbe, J. Jonas, L. Nazarenko, T. Zhou, M. Kelley, A. Lacis, D. Shindell, G. Faluvegi, G. Russell, M. Bauer, **G. A. Schmidt**, A. Romanou, and N. Tausnev, 2020: GISS Model E2.2: A climate model optimized for the middle atmosphere — Model structure, climatology, variability and climate sensitivity. *Geophys. Res. Atmos.*, 125, no. 10, e2019JD032204
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- Schmidt, G. A.**, *et al.*, 2014. Configuration and assessment of the GISS ModelE2 contributions to the CMIP5 archive, *J. Adv. Model. Earth Sys.*, **6**, 141–184
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GRADUATE STUDENT SUPERVISION:

- Nathan Lenssen (Columbia). PhD Topic: *Detection and Attribution of decadal climate change* (joint with L. Goddard)
- Keren Mezuman (Columbia). PhD Topic: *Impacts of agriculture on nitrate aerosols and climate* (joint with A. Fiore and S. E. Bauer)
- Marion Benetti (LOCEAN, France). External examiner, (supervisor G. Revedrin)
- Christy Field (Columbia). PhD Topic: *Modeling the impacts of production and climate on ^{10}Be in ice cores* (joint with D. Rind, S. Hemming)
- Allegra LeGrande (Columbia). PhD Topic: *The climate imprint on the oxygen isotopic composition of water: Observations, proxies, and coupled isotopic model simulations* (joint with W. Broecker)
- Jiping Liu (Columbia). PhD Topic: *Sea ice influence on climate change* (joint with David Rind)
- Duane Thresher (Columbia). PhD Topic: *Using Tracers in a GCM in Comparison with Proxy Records to Determine Ocean Conditions During the LGM and Subsequent Deglaciation* (joint with David Rind)
- Gilles Delaygue (LMCE, France). External examiner, (supervisor J. Jouzel)

CHAired WORKSHOPS AND SYMPOSIA:

- 6th US Climate Model Summit, June 2020 (Chair)
- 5th US Climate Model Summit, April 2019 (Co-Chair)
- “Using paleoclimate modelling to constrain future climate projections”, Co-Convenor, AGU Joint Assembly, May 2015
- “Using paleoclimate modelling and data to learn about the future”, Co-Convenor, EGU, March 2013 and April 2015.
- “Using paleo-climate model/data comparisons to constrain future projections” (workshop organiser), March 2012, Bishop Museum, Honolulu
- “Using Paleoclimate Observations and Analysis for Improving Earth System Prediction”, Co-Convenor, Oct 2011, WCRP Open Science Meeting, Denver
- “First International workshop on Climate Informatics” (workshop organiser), August 2011, New York Academy of Sciences
- “AR5 Science Workshop” (workshop organiser), November 2008, Columbia University, New York
- “The Arctic and Antarctic Oscillations: Feedbacks and Connections With the Climate System”, Co-Convenor, AGU, December 2000

COMMUNITY SERVICE:

- AGU Climate Communications Prize Committee (2013–2016), Chair (2015–2016)
- Associate Editor *J. Climate* (2005–2016)
- NCAR Community Climate System Model Advisory Board (2009–2015)
- CLIVAR/PAGES Intersection Panel (2004–2013). Co-chair (2006–2013)
- ESMF Advisory Panel (2002–2007), CLIVAR PPAI Panel (2005–2007)
- Popular Mechanics, Advisory Board (2007–2014)
- Member American Geophysical Union

Chairman BEYER. Dr. Schmidt, thank you very much.
Now, I would recognize Mr. Riley Duren for your testimony.

**TESTIMONY OF MR. RILEY DUREN, RESEARCH SCIENTIST,
OFFICE OF RESEARCH, INNOVATION, AND IMPACT,
UNIVERSITY OF ARIZONA;
CHIEF EXECUTIVE OFFICER, CARBON MAPPER, INC.**

Mr. DUREN. Thank you, Chair Beyer, Ranking Member Babin, Members of the Subcommittee. I appreciate the opportunity to contribute today. This is really an important discussion. And I'll start by saying that simply by convening this hearing, you're already taking, I think, an important step in highlighting a persistent gap in U.S. climate policy discussions.

Satellite observations and data in general are critical not only for basic climate research but also enabling science-based decision-making by a broad cross-section of society. So NASA and its partners absolutely belong in these discussions, and thank you for highlighting this topic.

As lawmakers consider investments in the Nation's physical infrastructure, it's also important to recognize the urgent need to address gaps in critical data infrastructure that can inform efforts to minimize climate impacts and improve overall environmental resiliency in United States and the world. As an example of data gaps and opportunities for improvement, I'd like to describe a new public-private partnership that's leveraging NASA science and technology to deploy a global decision support system for quantifying, tracking, and supporting mitigation of greenhouse gas emissions.

In recent years, there has been a growing number of public and private sector actors that have signaled an interest in reducing their methane and carbon dioxide emissions, including ambitious decarbonization targets by some of the world's leading economies and major oil and gas companies. Notable field studies over the years by many groups have conclusively identified the existence of so-called methane super-emitters where a relatively small fraction of infrastructure is responsible for a disproportionate amount of emissions.

My own NASA-funded research team used advanced remote sensing aircraft to conduct the first comprehensive economywide survey of methane emissions in California. We found that less than .2 percent of the infrastructure in the State is responsible for over 1/3 of California's entire methane inventory. Many of these super-emitters are highly intermittent, they're widely dispersed over the landscape and they're difficult to find typically with conventional surface measurements.

If you can cue the movie, please. Great, thanks.

[Video shown.]

Mr. DUREN. So our recent airborne surveys with NASA aircraft over the Permian oil and gas basin and other regions around the United States add to this body of evidence. What you're seeing here is a false color movie taken from a NASA aircraft at 18,000 feet looking at methane plumes. And this offers a vivid illustration that these super-emitters are broadly distributed across the landscape almost like invisible wildfires, and they mostly go unseen even by

operators who are otherwise motivated to fix leaks to avoid product loss.

So oil and gas companies that have reviewed our data indicate that at least half of the methane super-emitters were detected are the result of leaks and malfunctions that were previously unknown. So this suggests low-hanging fruit if you will for near-term progress. The idea here is that a high-fidelity constellation of satellites could offer daily facility-scale methane monitoring over key regions globally to alert operators and regulators of leaks for more timely and cost-effective repairs.

However, in practice, this means confronting both technical and institutional barriers. No single organization today has the mandate, resources, or even the culture to field this kind of decision support system, at least not quickly or affordably at scale. In this case, the challenges are the necessary remote-sensing technology is currently unavailable outside of NASA. NASA itself lacks the capacity to launch large constellations of satellites. There's no existing government program to finance the buildout of such a system. Sustaining these systems once you establish them is difficult, given shifting Federal priorities. And purely commercial services may lack the transparency needed for global public trust and adoption.

So to confront these challenges, we've established a new non-profit organization called Carbon Mapper and a public-private partnership that includes remote-sensing technology transfer from NASA's Jet Propulsion Lab, Planet's agile aerospace approach to deploying constellation, science leadership from the University of Arizona and ASU (Arizona State University), policy expertise and data transparency enabled through California and our nonprofit partners, all powered by philanthropy. Philanthropy is paying for the startup of this program.

I know speak for other partners in thanking Dr. St. Germain from NASA and Mr. Schingler from Planet and their teams for their vision and support in establishing this program.

And in closing, effective responses to climate change and other environmental challenges require action by a cross-section of society, including governments, businesses and private citizens. And the same applies to generating robust data and shared awareness to inform those actions. We don't have time as a species for delayed action or false starts because of incomplete data or monolithic approaches. We need the best possible science and systems engineering creativity of organizations like NASA to enable new innovative efforts to deliver action climate data. And we need the help of Congress in helping us support and recognize these efforts. Thank you very much.

[The prepared statement of Mr. Duren follows:]

Riley Duren testimony
House Science, Space & Technology Committee
Space & Aeronautics Subcommittee
*NASA's Earth Science and Climate Change Activities:
Current Roles and Future Opportunities*

May 18, 2021

Statement

Thank you, Chair Beyer, Ranking Member Babin, and Members of the Subcommittee for the opportunity to contribute today. In convening this hearing you've already taken an important step in highlighting a persistent gap in ongoing US climate policy discussions. Satellite observations and data in general are critical not only for basic climate research but also in enabling science-based decision making by a broad cross section of our society. NASA and its partners absolutely belong in these discussions. As lawmakers consider investments in the nation's physical infrastructure it's also important to recognize the urgent need to address gaps in critical **data** infrastructure that can inform efforts to minimize climate impacts and improve environmental resiliency.

As an example of data gaps and opportunities for improvement I'd like to describe a new public-private partnership that is leveraging NASA science and technology to deploy a global decision support system for tracking and mitigating greenhouse gas emissions. In recent years, a growing number of public- and private-sector actors have signaled an interest in reducing their methane and CO₂ emissions including ambitious decarbonization targets by some of the world's largest economies and major oil and gas companies. Multiple field studies have conclusively identified the existence of methane "super-emitters" where a relatively small fraction of infrastructure is responsible for a disproportionate amount of emissions. My own NASA funded research team used advanced remote-sensing aircraft to conduct the first comprehensive, economy wide survey of methane emitters in California and found that less than 0.2% of the infrastructure is responsible for over a third of the state's entire methane inventory. Many of these super-emitters are highly intermittent, widely dispersed and difficult to find with conventional surface measurements. Our recent airborne surveys of the Permian basin and other regions add to this body of evidence. This false-color movie of methane plumes observed by NASA aircraft offers a vivid illustration: these super-emitters are broadly distributed across the landscape like invisible wildfires and they mostly go unseen even by operators who are motivated to find leaks to avoid product loss. Oil and gas companies that have reviewed our data indicate that at least a half of the methane super-emitters we're detecting are the result of leaks and malfunctions that were previously unknown.

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However, in practice this means confronting both technical and institutional barriers. No single organization today has the mandate, resources or culture to field this kind of decision support system – at least not quickly or affordably. In this case,

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I know I speak for our other partners in thanking Dr. St Germain from NASA and Mr. Schingler from Planet and their teams for their vision and support. In closing: effective response to climate change and other environmental challenges requires action by a cross-section of society including governments, businesses and private citizens. The same applies to generating robust data and shared awareness to inform those actions. We don't have time for delayed action or false starts because of incomplete data or monolithic approaches. Our society needs the best possible science and systems engineering creativity of organizations like NASA to enable new innovative efforts to deliver actionable climate data. And we need the help of Congress in recognizing and supporting these kinds of efforts by NASA and its partners both domestically and globally.

Thank you.

Prepared Statement

Introduction

Thank you, Chair Beyer, Ranking Member Babin, and Members of the Subcommittee for the opportunity to contribute today. In convening this hearing you've already taken an important step in highlighting a persistent gap in ongoing US climate policy discussions. Satellite observations and data in general are critical not only for basic climate research but also in enabling science-based decision making by a broad cross section of our society. NASA and its partners absolutely belong in these discussions. As lawmakers consider investments in the

nation's physical infrastructure it's also important to recognize the urgent need to address gaps in critical data infrastructure that can inform efforts to minimize climate impacts and improve environmental resiliency.

Today I'd like to share some thoughts about needs and gaps for satellites (and other) observing systems that can help support and accelerate efforts to mitigate greenhouse gas (GHG) emissions in the US and globally along with some specific recommendations for this committee. Additionally, as an example of potential new approaches for addressing observational gaps, I'll describe a new public-private partnership that is leveraging NASA science and technology to deploy a global decision support system designed to track and help mitigate GHG emissions. This example addresses one of many facets of this challenging topic and should be considered representative rather than comprehensive

Methane and carbon dioxide (CO₂) are the two dominant anthropogenic climate-forcing agents. Methane in particular packs a powerful climate punch, with a global warming potential that's nearly 90 times greater than CO₂ on 20 year time-scales. Methane is also relevant to air-quality given its role as an ozone precursor and the tendency for co-emitted reactive trace gases that can impact human health. While atmospheric levels of methane and CO₂ at global scale are very well known thanks to decades of accurate surface observations, they are driven by activity at millions of facilities across the planet whose individual emissions are not directly measured in most cases – in part due to the high cost of deploying localized sensors everywhere. These uncertainties are serious impediments to efforts by businesses to reduce product loss while remaining competitive in global markets and also threaten the accuracy of greenhouse emission inventories compiled by national, state and local governments. Efforts to mitigate (reduce) methane and CO₂ emissions are complicated by inconsistencies between estimates derived from atmospheric measurements, greenhouse gas inventories, and self-reporting programs. Contributing to these discrepancies are a population of facilities that emit anomalously high amounts of greenhouse gases, often in an unpredictable and intermittent fashion. Multiple field studies have conclusively identified the existence of methane “super-emitters” where a relatively small fraction of infrastructure is responsible for a disproportionate amount of emissions.

Starting in 2016, my own research team, jointly funded by NASA and California's Air Resources Board and Energy Commission, used advanced remote-sensing aircraft to conduct the first comprehensive, economy wide survey of methane emitters in California and found that less than 0.2% of the infrastructure there is responsible for over a third of the state's entire methane inventory (Duren *et al.*, 2019). Figure 1 illustrates examples spanning the oil and gas, waste management and agriculture sectors. Many of these super-emitters are highly intermittent, widely dispersed and difficult to find with conventional surface measurements. With the support of NASA and other sponsors we have since expanded our airborne studies to other key US regions where we're finding additional evidence that strong methane point sources (concentrated plumes released from infrastructure typically <10 meters across) can contribute up to 20-50% of a region's total emissions and are highly intermittent in some sectors – particularly for oil and gas production, where half of the high emitting point sources

are often active less than 25% of the time. We also seeing methane super-emitter activity at natural gas infrastructure, refineries, landfills, waste-water treatment plants, large dairies, etc.

Our recent airborne remote sensing surveys of the Permian basin and other regions add to this body of evidence (Cusworth *et al.*, 2021a). Figure 2 offers a vivid illustration of typical methane plumes in the Permian observed by remote sensing aircraft: these super-emitters are broadly distributed across the landscape like invisible wildfires and they mostly go unseen even by operators who are motivated to find leaks to avoid product loss. Additionally, oil and gas companies that have reviewed our data in California, Texas and New Mexico indicate that at least a half of the methane super-emitters we're detecting are the result of leaks and malfunctions that were previously unknown. We are currently working to verify this with independent follow-up observations and planning future collaborative field studies with our research partners and industry participation to further explore and confirm mitigation potential.

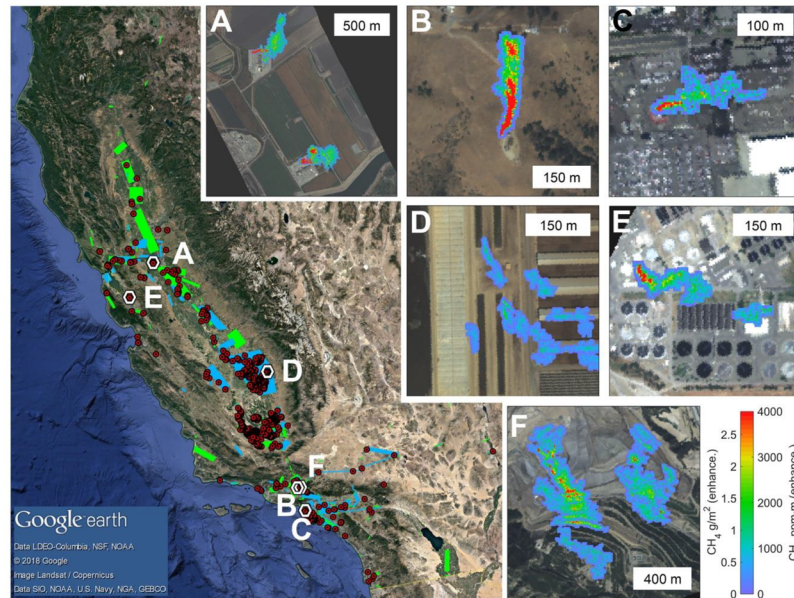


Figure 1: Methane super-emitters detected with NASA remote sensing aircraft during the California Methane Survey. Main figure shows 2,000 individual flight lines from 2016 (blue) and 2017 (green) that covered more than 272,000 individual facilities and infrastructure elements. Detected methane sources are indicated by red points, with the densest clusters seen in the San Joaquin Valley (dairies and oil fields). The inset images show examples of representative methane plumes from different sectors: a, compressor stations at a natural gas storage facility; b, oil well; c, tank of liquefied natural gas; d, dairy manure management; e, wastewater-treatment plant; f, landfill. The color scales indicate the methane concentration enhancement (the mass of methane in a plume relative to background air) in each pixel in units of parts per million-meter (ppm-m). [source: Duren *et al.* 2019]



Figure 2 This false color scene shows a typical collection of methane plumes detected by the Global Airborne Observatory (overlaid on Google Earth imagery) from an altitude of 17,500 ft (~5.3 km) in Fall 2019 over the Permian oil and gas basin. The red plumes indicate methane emissions from oil & gas infrastructure: wells, tank batteries, compressor stations, gathering lines, etc. The plumes are all aligned with the prevailing wind. We have detected over 3,000 such plumes so far in the Permian basin with our airborne surveys. The area shown here is a small fraction of a single Carbon Mapper satellite observation. [source: Carbon Mapper, University of Arizona, NASA Jet Propulsion Laboratory, Arizona State University; Cusworth *et al.*, 2021a]

Meanwhile, nearly 60% of global CO₂ emissions from coal power plants occur in regions that lack facility level emissions monitoring and reporting programs. We are now demonstrating with aircraft and satellite observations the ability to independently detect, pinpoint, and quantify CO₂ emissions from large coal and gas fired power plants (Cusworth *et al.*, 2021a). High costs of monitoring systems and incomplete data accessibility and transparency are barriers to diagnosing and mitigating anomalous point sources for geographically dispersed infrastructure.

Remote sensing, in principle, is capable of contributing data that can help fill gaps in current methane and CO₂ accounting systems and even enable direct action by facility operators and regulators. In practice, the ultimate mitigation impact of such data depends on the degree of completeness (or what fraction of emissions can be identified and quantified) which is a function of detection limit, spatial coverage and sample frequency. The latter is particularly critical given the intrinsic variability in many methane and CO₂ point source emissions.

Carbon Mapper: a Public-Private Partnership for Operational GHG Monitoring

In recent years, a growing number of public- and private-sector actors have signaled an interest in reducing their methane and CO₂ emissions including ambitious decarbonization targets by some of the world's largest economies and major oil and gas companies (e.g., [Oil and Gas Methane Partnership](#)). This, when combined with the aforementioned summary of methane

super-emitter activity, suggests potential “low hanging fruit” for near-term mitigation progress. A high-fidelity constellation of satellites could offer daily, facility scale methane monitoring over key regions globally to alert operators and regulators of leaks for more timely and cost-effective repairs.

However, deploying such an observing system means confronting both technical and institutional barriers. No single organization today has the mandate, resources or culture to field this kind of decision support system – at least not quickly or affordably. In this case,

- The necessary remote-sensing technology is unavailable outside NASA
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We plan to launch the first two Carbon Mapper satellites in 2023 followed by a larger constellation starting in 2025 by our commercial partner Planet that will offer daily to weekly monitoring of methane and CO₂ point source emissions at facility-scale in key regions globally. Teaming JPL and Planet together created a unique solution: a high sensitivity, moderate resolution payload and agile satellite platform that can deliver the required precision (detection limit), spatial coverage, and temporal sampling. By persistently tracking and pinpointing point source emissions at individual facilities, Carbon Mapper is designed to complement other observing systems that are capable of quantifying net regional emissions and the largest point sources. We will accomplish this observing strategy by tasking our satellites to acquire data over priority areas based on a combination of prior knowledge of infrastructure locations and follow-up based on “tips” from other satellites designed for wider area monitoring (for example the Sentinel-5P, EDF’s MethaneSAT or NASA’s OCO-2 and OCO-3 missions). Figure 3 provides a notional map of Carbon Mapper sampling areas in the US and Canada; there are similar patterns in other parts of the world. This is similar to the existing tasking approach used by Planet’s constellation of Skysat satellites and is enabled by the moderate field of view provided by NASA JPL’s spectrometer technology. The system includes other observing modes: glint mode for tracking methane emissions from offshore oil and gas platforms and pushbroom mapping for larger area coverage on land.

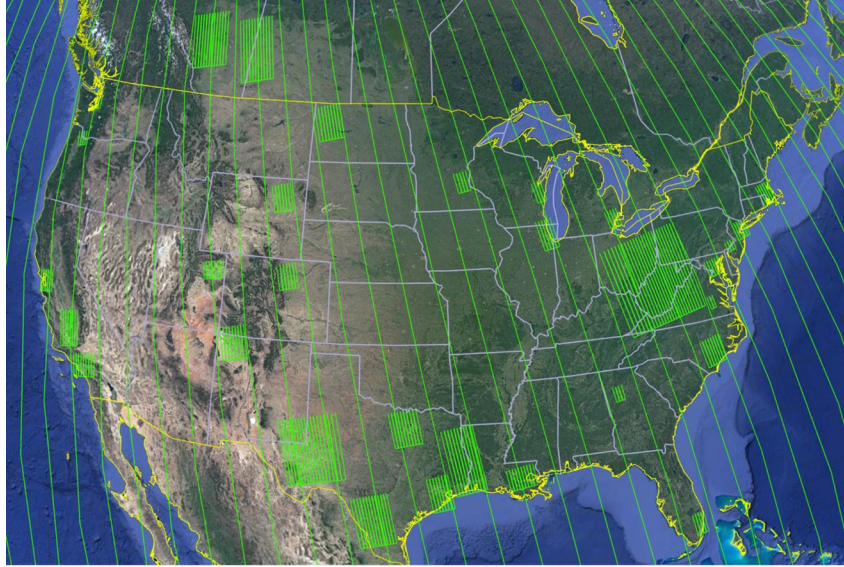


Figure 3: Green boxes indicating notional priority regions for persistent Carbon Mapper observations of methane and CO₂ point source emissions in the US and Canada. The system will likely have similar sampling patterns in other regions and has the flexibility to sample the entire landmass with slower reduced revisit time. [Source: Carbon Mapper]

A unique aspect of this program is the role of Planet's commercial space operation in offering sustained data delivery in support of Carbon Mapper's public good mission beyond the time horizon of traditional research driven satellites. This dual-use potential is enabled by the NASA imaging spectrometer technology which spans the visible to shortwave infrared wavelengths (380-2510 nm) which in addition to Carbon Mapper's focus on methane and CO₂, offers 25 other land and ocean environmental indicators that can generate commercial revenue to sustain our public-good mission. This provides a degree of continuity and stability that is often difficult to attain with federal research satellites.

Meanwhile, we're using research aircraft to expand regional methane surveys over more US states and working with facility operators, state and local agencies and other early adopters to ensure maximum impact when the data starts flowing from the satellite constellation. Carbon Mapper will have transparent, open policies for releasing emissions data to expand accessibility and trust for widest possible adoption and impact by governments, businesses, and the general public. This will be further strengthened by the California Air Resources Board that will provide independent ground-truth measurements across the state for comparison with Carbon Mapper data towards increasing confidence in the data in other jurisdictions around the world. By

combining the strengths of diverse institutions Carbon Mapper may suggest a broader model for additional, expanded collaborations between NASA and other non-governmental actors to move quickly to deploy the critical data infrastructure needed to address the diverse environmental challenges confronting our society.

Progress and Gaps in GHG Monitoring

Stakeholder needs for GHG data varies widely which translates to differing requirements on the supporting observations, analysis and estimation frameworks. For example, most countries deliver national GHG inventories that represent their primary method for reporting and tracking emissions. These so-called “bottom-up” inventories apply well-established accounting methods to combine activity data and standard emission factors to estimate annual aggregate emissions for the country organized by gas and economic sector. Some sub-national governments use the same approach to produce inventories for their jurisdiction although regular updates are not universal. The accuracy of these inventories can vary significantly by region (e.g., due to varying availability of activity data) as well as by gas and sector (e.g., methane emission estimates tend to be highly uncertain in most jurisdictions because of emission factors that don’t capture skewed behavior such as the previously described super-emitters).

Over the past decade, scientists have developed methods for independently evaluating GHG emissions including the use of atmospheric measurements that can directly constrain emissions from a given region. Those so-called “top-down” atmospheric methods have historically been limited to continental scale emissions estimates motivated by carbon cycle research however there have been recent strides in resolving country-level emissions, including the use of satellite data (Maasaakkers, *et al.*, 2019). Other teams are using similar methods to detect trends in urban scale emissions with surface measurement networks, although those remain quite sparse and limited to a handful of testbed projects (Yadav *et al.*, 2021). Meanwhile, other scientists have successfully developed space-time resolved fossil fuel CO₂ emission maps using available activity data at sufficiently fine scale to enable independent assessment of fossil fuel CO₂ emissions from individual cities (Gurney *et al.*, 2020). A common feature of all these examples is the current state of the art involves significant latency in publishing data: time lags of 1-3 years are not unusual. ***Data latency remains a core challenge and is a major reason for why more operational, streamlined frameworks are needed to effectively support decision making in the face of rapidly changing economic, political and environmental conditions.***

At the finer scale end of the GHG data spectrum are the needs of facility operators and local regulators to detect, pinpoint and quantify methane leaks from individual facilities and equipment. Building on the Carbon Mapper example described above, there are many technologies available for providing actionable emissions data at facility scale including satellites, aircraft, drones, and surface measurements in cars, handheld sensors or fence-line monitoring systems within or adjacent to facilities. These technologies have widely varying degrees of sensitivity, spatial resolution, area coverage, sample frequency, reliability and cost.

Except for some isolated applications, there is generally no single one-size-fits-all GHG measurement and estimation technique. A system of systems or “tiered observing system” will likely provide the most optimal performance through thoughtful combination of different methods (see Figure 4). For the methane leak detection example, appropriately equipped satellites and remote-sensing aircraft have the advantage of wide-area coverage and for high emission sources can alert technicians or inspectors on the ground to visit specific sites with surface instruments or drones offering lower detection limits and more precise geolocation – ultimately translating to more efficient location of leaks and potentially, repairs. Another emerging application is the potential adoption of low methane intensity standards for natural gas (e.g., the [MiQ initiative](#)) where independent measurements across global supply chains could help provide certification for suppliers and consumers. Such frameworks will require a combination of measurement techniques including point source tracking and quantification of wider area (e.g., oil and gas production basin) emissions; again, a system of systems. Additionally, for the national and sub-national GHG emission reporting and tracking application, the most accurate and timely estimates will likely involve the integration of top-down and bottom-up methods rather than relying on a single approach. For all of the above cases, ***cooperative systems of systems likely offer more effective, affordable, and timely guidance than monolithic GHG quantification and tracking methods.***

With regards to space based GHG observations, the US, Japan and EU continue to operate research satellites that are providing critical insights into carbon cycle processes at continental to global scales as well as some experimental efforts to estimate regional scale CO₂ and methane emissions (e.g., NASA’s OCO 2 and OCO-3 missions, JAXA’s GOSAT series, and the EU’s Sentinel-5P, respectively). Meanwhile, the Italian and Chinese space agencies have both launched satellites (PRISMA and Gaofen-5, respectively) that have demonstrated the ability to detect and quantify methane and CO₂ emissions at the scale of individual facilities including US power plants and oil & gas infrastructure. The European Commission has signaled an intention to use existing and future satellites in its Copernicus program capable of providing operational methane monitoring ([EU Methane Strategy](#), 2020) as well as CO₂ emissions from cities and large power plants (Kuhlmann *et al.*, 2020). Our own team has used PRISMA and airborne remote-sensing observations to pinpoint and quantify CO₂ emissions from coal power plants in the US and other countries (see Figure 5; Cusworth *et al.*, 2021b).

These developments, along with philanthropically funded programs such Carbon Mapper and our partner mission, EDF’s [MethaneSAT](#), offer promising signs of an emerging global system of systems for monitoring methane and CO₂ emissions relevant to mitigation action. However, they are mostly being deployed independently and so continued efforts to coordinate between the programs as well as integrated analysis of the diverse data sets will be key for success. I’m unaware of any plans by the US government to launch similar satellites like the ones described here with sensitivity to methane or CO₂ emissions from individual facilities. Given US ambitions to provide climate leadership on the global stage, this subcommittee may wish to give some consideration to how the nation’s interests and capabilities align with regards to emissions estimates generated by satellites for industrial facilities around the world.



Figure 4 Conceptual view of a “tiered observing system” (system of systems) for methane monitoring including satellites and aircraft that routinely survey large regions and alert teams on the ground to deploy follow-up surface measurements to high emitting facilities for more cost effective and rapid leak detection and repair. [Source: NASA/JPL-Caltech]

Recommendations for Congress

The recent commitment by President Biden’s administration to reduce US greenhouse gas emissions by 50% by 2030 suggests the need for a whole-of-society approach that is underpinned and guided by the best available US science and technology. The credibility of the expanded US Nationally Determined Contribution could be dramatically strengthened by a bold commitment to operationalizing advanced science-based methods for quantifying and locating greenhouse gas emissions that increases the likelihood that US domestic mitigation policies are successful while enhancing credibility with and galvanizing progress in other countries. In particular, the success of these efforts will critically depend on immediate, focused mitigation of methane and other short-lived climate pollutants (including methane, HFCs, and black carbon) in addition to longer-term decarbonization initiatives. ***The US has developed advanced science-based methods capable of targeting expedited mitigation opportunities and authenticating reported baseline emissions and future reductions for all greenhouse gases,***

including methane and other short-lived climate pollutants, and it should invest in further operationalizing those methods.

Congress should consider steps to resolve critical data infrastructure gaps and direct federal efforts (with appropriate support from other sectors and partners) to deploy and sustain advanced, science-based quantification and tracking of emissions for all greenhouse gas in the US. In doing so it is recommended that Congress:

- Recognize the limitations of existing federal GHG monitoring programs particularly with regards to measurement continuity given that many of the research driven programs are limited to infrequent or short-duration pilot efforts.
- Leverage established relevant federal pilot programs (e.g., NASA's [Carbon Monitoring System](#) program, [NIST GHG Measurement Program](#), etc.) and emerging nongovernmental programs to build-out and operationalize research-grade observations and analysis frameworks for decision support.
- Explore leveraging other capabilities of federal agencies that traditionally have not been applied to research driven monitoring programs (e.g., systems engineering at NASA) to help provide the necessary system-of-systems design and program management required for truly operational GHG monitoring
- Consider establishing a new interagency program as a companion to the USGCRP but with a mission and resources to deliver operational GHG monitoring and decision support for US federal, state, and local governments, businesses, and civil society
- Expand US agency support for and participation in international and intergovernmental initiatives such as the World Meteorological Organization (WMO)'s [Integrated Global Greenhouse Gas Information System](#) (IG3IS)
- Explore options to support, match and build on the contributions by non-governmental actors including philanthropy and private sector
- Consider establishing a sub-national climate action partnership between the federal government and state and local agencies to facilitate more widespread and actionable GHG monitoring, potentially including federal resources to help build scientific and technical capacity in those sub-national agencies.

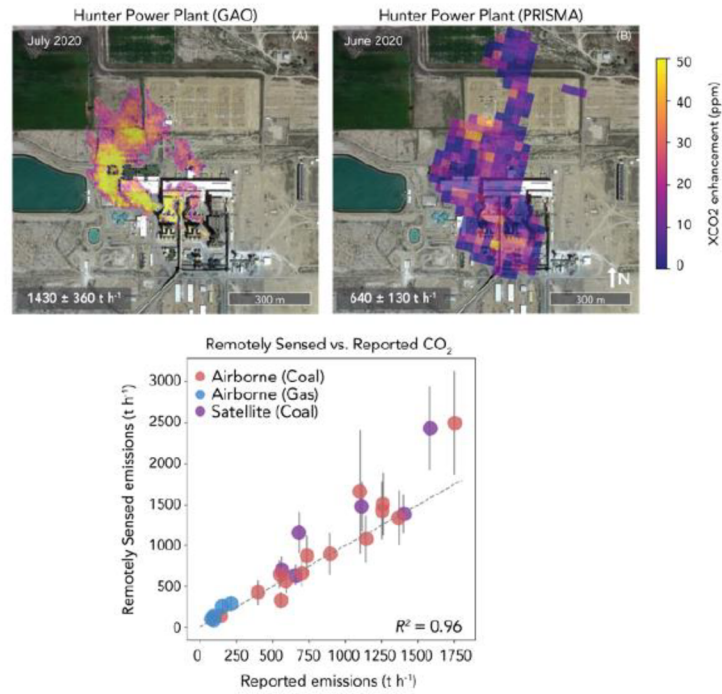
Comparison between retrieved and reported CO₂ emission rates

Figure 5. Examples of using satellite and airborne remote sensing to pinpoint and quantify CO₂ emissions from coal and gas fired power plants. Note the variability in emissions in the top panels indicating the need for frequent sampling for accurate estimation. The bottom plot shows mostly good agreement between the remotely sensed emissions in the US and those reported to the Environmental Protection Agency by those facilities using stack monitoring but with some notable outliers. [source: Cusworth *et al.*, 2021b]

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Biography

Riley Duren is a Research Scientist at the University of Arizona and Chief Executive Officer of the Carbon Mapper non-profit organization. He also maintains a part-time appointment as Engineering Fellow at NASA's Jet Propulsion Laboratory, although that work is outside the scope of today's testimony. His career at NASA began with launching space shuttle science payloads from the Kennedy Space Center (1988-1995). He joined JPL in 1996 where he worked at the intersection of science and engineering to deliver earth observing systems and deep space telescopes including the Kepler mission for which he served as Chief Engineer. From 2008-2019 he was the Chief Systems Engineer for JPL's Earth Science and Technology Directorate, with a broad portfolio of satellite and aircraft instruments and missions, research

and analysis, applied science, and technology projects spanning NASA's earth science enterprise.

In 2008 he established a research program that extends the discipline of systems engineering to the challenge of climate change decision support. He has served as Principal Investigator for 10 research projects involving greenhouse gas observing systems and data analysis frameworks. His team combines atmospheric measurements from satellites, aircraft and surface-based observing systems, tracer transport modeling, machine learning, and big data methods to detect, quantify and attribute methane and carbon dioxide emissions. The team also applies considerable energy to engaging with and entraining end users of the data sets produced by these programs towards increasing the data's relevance, adoption and impact. His work has supported programs at NASA, the National Institute of Standards and Technology, the National Oceanographic and Atmospheric Administration, the California Air Resources Board, and California Energy Commission, and multiple non-governmental organizations. In 2020, Mr. Duren co-founded Carbon Mapper, a new non-profit organization and public-private partnership involving leading philanthropists, the commercial satellite imaging company Planet, JPL, the State of California and two universities, with a public good mission to deploy a constellation of small satellites that will provide globally operational monitoring of methane and carbon dioxide point source emissions at facility scale to help accelerate climate mitigation action. The program also includes expanding airborne methane surveys of key regions to help prepare for and complement the satellites.

Mr. Duren's honors include two NASA Exceptional Achievement Medals, the agency's Systems Engineering Excellence Award, and seven Group Achievement awards. He has served on National Academy of Science and California Council of Science and Technology committees and was a contributing author to the Second State of the Carbon Cycle Report for the US Global Change Research Program. He received a BS degree in Electrical Engineering from Auburn University in 1991. His professional work is partially motivated and inspired by his personal interests in forest conservation and wildlife photography.

Riley Duren Biography
House Science, Space & Technology Committee
Space & Aeronautics Subcommittee
*NASA's Earth Science and Climate Change Activities:
Current Roles and Future Opportunities*

May 18, 2021

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Chairman BEYER. Mr. Duren, thank you very much. We really appreciate that fascinating overflight.

And now let me recognize our final witness, Mr. Schingler, for your testimony.

**TESTIMONY OF MR. ROBBIE SCHINGLER,
CO-FOUNDER AND CHIEF STRATEGY OFFICER, PLANET**

Mr. SCHINGLER. Chairman Beyer, Ranking Member Babin, Chairwoman Johnson, Ranking Member Lucas, and Members of the Subcommittee, I'm honored to appear before you today to discuss the important role that commercial companies are playing in supporting NASA's Earth science and climate change mission and the opportunities NASA has to better leverage the commercial enterprise to meet their scientific and climate goals.

I had the privilege to join NASA during my undergraduate studies. It forged my professional life with 9 years of service that set the conditions for my founding role at Planet. I'm proud to be inspired, trained, and influenced by NASA.

Now, everyone knows the big new rockets being developed today, but few people are aware of the renaissance occurring in satellites that orbit our planet. It's a bit like the transition from the main-frame computer to the desktop computer, putting the power of knowledge about the Earth into the hands of more of society. And over the last decade, this has resulted in a 1,000-fold increase in capability per dollar.

This dramatic improvement means more data for more applications. For example, Planet captures an image of the entire landmass of the Earth every day, powered by the world's largest constellation of Earth observation satellites in history. This data set accelerates our understanding of land-use change, biodiversity, and climate science, while also helping farmers increase agricultural yield, companies monitor supply chains, and governments prepare for and respond to natural disasters.

I'm convinced that only the American market-based risk capital ecosystem could create Planet 10 years ago. Congress and this Committee has been instrumental in that proud history. Given the urgency to make strides in climate science, the benefit of massive investment from capital markets in the satellite industry, combined with innovation and a lasting foundation of U.S. Government systems, I'm confident we can work together to make an even brighter future.

To that end, I respectfully offer a few recommendations for your consideration. This Committee can support NASA and the commercial U.S. remote-sensing sector by bringing the Commercial Smallsat Data Acquisition Program into statute in the next NASA authorization bill.

In 2017, under the leadership of Thomas Zurbuchen, NASA, OMB (Office of Management and Budget), and Congress saw the potential of value that U.S. commercial remote-sensing companies could bring to Earth and climate scientists. They set out to understand the scientific viability of these new data sets, and it led to the Commercial Smallsat Data Acquisition Program. This is a huge success from my perspective, and NASA is actively bringing on new

commercial companies and expanding the scientific user community with Federal civilian agencies.

Investments in commercial remote-sensing capabilities fused with government-operated sensors drive innovation, power job creation, and lead U.S. universities and researchers—research centers on a path to excellence. I urge this Committee to bring in the Commercial Smallsat Data Acquisition Program into statute in the next NASA authorization bill and robustly fund the program to reflect the growth and value it is demonstrating in the scientific community.

As NASA is creating their next flagship missions, including the Landsat Next program, NASA should incorporate the planned viable commercial capabilities into their procurement strategies and see commercial capabilities as a forethought rather than an afterthought.

Now, let me be clear. Commercial constellations do not replace national systems. They complement, improve, and enable national systems to more affordably push the scientific frontiers. When there are reliable commercial Earth observation systems, the national systems can stretch even further to enhance our understanding of the planet.

Finally, we advocate for a whole-of-civil-government approach to commercial data buys. Embrace a whole-of-civil-government approach to making scientifically accurate and factual Earth observation data available. Put another way, you can't manage what you can't measure, and this community has the information to bring us to a common operating picture to better manage our society. These efforts to purchase commercial data for both scientific and operational use cases across all civilian agencies could be led by NASA in partnership with NOAA and USGS.

So as I conclude, allow me to thank the Committee for including a voice from the U.S. commercial sector in this important hearing. As Congress and the Biden Administration look to focus on climate programs, this conversation is well-timed to highlight the important role that remote-sensing satellites, both national assets and commercial constellations, have in providing the data needed to empower better decisions by Federal agencies, State and local governments, communities, companies, and individuals.

Planet is a committed partner to NASA and will provide innovative commercial services to equip America's Earth-observing community with the tools to lead in this increasingly competitive international landscape. You can be confident, as I am, that U.S. remote-sensing companies deliver new data sets and novel tools to enable governments, societies, and businesses to make better decisions and guide humanity toward a more secure and sustainable future.

Thank you, and I look forward to your questions and our exciting future ahead.

[The prepared statement of Mr. Schingler follows:]

**Statement of
Mr. Robbie Schingler
Co-Founder and Chief Strategy Officer
Planet Labs Inc.**

before the

**Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives
on**

“NASA’s Earth Science and Climate Change Activities: Current Roles and Future Opportunities”

May 18, 2021

Chairman Beyer, Ranking Member Babin, Chairwoman Johnson, Ranking Member Lucas and members of the Subcommittee, I am honored to appear before this Subcommittee to discuss NASA's Earth Science and climate change mission, the important role that commercial companies are playing today in support of that mission, and the opportunities that NASA has to better leverage commercial enterprise to meet their scientific and climate goals. As Congress and the Biden Administration look to focus on climate programs, this conversation is particularly well-timed to highlight the important role that space-based remote sensing satellites (both national assets and commercial constellations) have in providing the data needed to understand our changing world and empower better decisions by federal agencies, state and local governments, communities, companies, and individuals.

Planet Overview

Inspired by the idea that commercial components and an iterative Silicon Valley approach to satellite design could dramatically reduce the cost of satellites, Will Marshall, Chris Boshuizen, and I left NASA Ames and founded Planet 10 years ago. Today, Planet, based in San Francisco, CA, builds and operates the largest constellation of Earth-imaging satellites in history and enables, for the first time ever, the ability to capture daily changes to the entire Earth's landmass. Planet serves the medium- and high-resolution optical and near-infrared imagery needs of over 600 customers in 65 countries including commercial businesses, scientists, students, journalists, federal and local governments, and analysts. With 200 satellites in orbit, Planet provides global daily coverage to more than 20,000 users. Our ability to rapidly design, build, launch, and maintain a large, resilient satellite network provides greater understanding of our ever-changing planet. We continually refresh and upgrade our fleet of compact small satellites to monitor the changing globe daily for a range of humanitarian, scientific, commercial, and government applications.

We founded Planet with the mission of making geospatial information more available - to make change visible, accessible, and actionable. In the last decade, other U.S. entrepreneurs have joined Planet and pioneered novel, commercial remote sensing capabilities that operate at the speed of business and play a key role today in measuring and monitoring changes to our planet. These commercial data are enabling governments, a wide range of industries, leading scientific researchers, state and local communities, and individuals around the world to make better decisions.

NASA leads the way in utilizing commercial capabilities and creating programs to complement scientists' use of national assets. But more can (and should) be done. There is an opportunity to fully leverage the

unique capabilities of U.S. commercial space-based potential in tandem with national remote sensing programs. This unprecedented and unparalleled data access would serve to enable fast-track efforts to confront the impact of environment and climate change, facilitate transparency and global understanding, and further accelerate America's leadership to solve global issues.

Current NASA Earth Science Partnerships with Commercial Remote Sensing Companies

The last decade has seen rapid growth in the number of companies building, launching, and operating Earth observing satellites that provide data and analytical tools to an expanding base of public and private sector users. Over 400 small satellites (SmallSats) were launched in 2019 and 2020 alone. As the largest Earth observing company, Planet has built and operated more than 450 SmallSats that provide over 15 Terabytes of high-resolution data to scientists, policymakers, and industry every day. NASA's Science Mission Directorate has leaned forward and fostered a program within the Earth Science Division to leverage these commercially available datasets to support NASA's Earth Science research and application goals.

In FY2018, NASA's Earth Science Division (ESD) launched the Private-Sector Small Constellation Satellite Data Product Pilot to identify, evaluate, and acquire remote sensing imagery and data from commercial sources that support NASA's Earth Science research and application goals. Under the Pilot program, NASA awarded contracts to three Earth observing satellite companies (including Planet). NASA's conclusion – informed by evaluations and input by individual Earth scientists – was positive and informative. Specifically, NASA's "Commercial SmallSat Data Acquisition Program Pilot Evaluation Report"¹ (April 2020) stated the pilot "demonstrated the usefulness of commercial data and imagery for advancing scientific research and applications". The NASA report highlighted areas of improvement for the commercial partners and Planet has taken that feedback and incorporated it into product investments to increase the quality of our products to better serve NASA's needs. This is the sort of commercial-government partnership that allows for U.S. industry to continue to innovate in the global market.

Following the successful pilot, NASA established the Commercial SmallSat Data Acquisition (CSDA) Program² and contracted with the three companies from the pilot program to provide NASA-funded researchers with access to their Earth observation data. Since its inception, NASA has released subsequent RFI's to onramp new commercial data vendors and evaluate data for its potential to advance NASA's Earth Science research and applications activities. Additionally, to support the further utilization of this commercial remote sensing data, NASA released the Commercial SmallSat Data Analysis solicitation (ROSES A.42) in 2020.

In order to continue the success of NASA's CSDA program and build a community of researchers that utilize commercial remote sensing data along with national assets, NASA's Science Mission Directorate is expanding the program's user community beyond NASA-funded researchers to include scientific researchers from Federal civilian agencies. This is part of an effort to standardize the End User License Agreements (EULAs) and to increase the scientific collaboration and information sharing across the US research community. This represents a much needed step and is a strong sign that commercial remote sensing data is valuable for researchers across a variety of disciplines within the government. Inspired by NASA's Landsat program to spur scientific and technical innovation, Planet launched its Education and Research program on Earth Day four years ago with a license to stimulate scientific innovation on high

¹ https://cdn.earthdata.nasa.gov/conduit/upload/14180/CSDAPEvaluationReport_Apr20.pdf

² <https://earthdata.nasa.gov/esds/csdap>

cadence land monitoring applications. Today, there are now over 1,000 peer-reviewed publications and conference papers that have used Planet's data for their research. A year ago we had just over 600 publications and now this ongoing contribution to the global knowledge base of our world is accelerating at a rate of new paper every 24 hours.

Beyond the pure research side, NASA is using commercial remote sensing data in their programs to address international food insecurity and provide information on the COVID pandemic. COVID-19 has severely impacted the global food system, requiring rapid response in affected countries to design and enact aid programs. In spring 2020, the Government of Togo approached NASA Harvest to create a country-wide map of cropland as part of an effort to distribute aid to farmers to boost food production. Working with Planet, NASA Harvest was able to create this map and deliver it to the Togolese government in only 10 days. NASA's COVID-19 Dashboard features data collected by both public and commercial satellites, as well as instruments aboard the International Space Station and ground-based networks. Comparing complementary datasets on the dashboard helps reveal a deeper story of how society and the environment have changed due to COVID-related shutdowns. Commercial imagery was ingested into the dashboard for major cities like San Francisco to monitor changes in surface transportation and air travel.

Commercial Remote Sensing Data Enables Climate Action and Better Decisions

Planet's daily global imagery, along with data from other commercial providers, enable scientists, governments, corporations, and more, to formulate effective data-based solutions to monitor, measure, and anticipate the effects of climate change. These datasets complement government-operated space and ground-based sensors, and dramatically improve the spatial, temporal, and spectral resolution available to government scientists and decision makers. From monitoring real-time changes in wildfire spread in California, to recording daily changes in Arctic ice, to better understanding crop production and food security around the world, Planet and commercial imagery is empowering governments, companies, and individuals with the daily data they need to address the challenges of climate change.

To demonstrate the diversity of use-cases for this commercial data, below are a few programs that highlight work that is being done in the Earth Science and climate fields with private companies, universities, non-governmental organizations (NGOs), and international government partnerships.

- [Education and Research](#) - Planet has provided access to more than 10,000 students and researchers at more than 1,000 universities throughout the world, and empowered more than 50 universities with increased access that has fostered classroom education and research programs.
- [California Forest Observatory](#) is a data-driven forest monitoring system that leverages Planet satellite data and artificial intelligence to map drivers of wildfire behavior across California – including vegetation fuels, weather, topography, and infrastructure.
- [Cloud to Street](#) combine's Planet's high-resolution Basemaps and building analytics with flood risk models to inform development planning and preparedness in communities.
- In response to hurricane's Michael and Florence, [FEMA](#) used Planet's imagery for situational assessment of impacts upon citizens, communities and infrastructure. Planet's extensive archive was used for preliminary assessment and Planet's daily monitoring provided images on the first clear days and was used to cue higher resolution assets.
- [Norway's International Climate and Forests Initiative \(NICFI\)](#), a pioneering program to stop global deforestation, procured Planet data across 64 tropical countries to support the prevention of deforestation and help save the world's tropical forests, providing that data to the UN Food and Agriculture Organization (FAO), the 64 nations Ministries of Forestry, researchers and NGOs, and some of the data is made universally open as a digital public good.

- Allen Coral Atlas leverages Planet data to map the entirety of the world's shallow-water coral reefs in unprecedented detail, and monitor them for change. The program combines machine learning, field data, and Planet satellite imagery to generate habitat maps that are made publicly available to scientists, academics, policymakers, and protected area managers to more effectively target conservation and restoration interventions.
- Tropical forests absorb and store carbon dioxide from the atmosphere and are one of our best defenses against the threat of climate change. Researchers from Arizona State University used machine learning to combine airborne LiDAR data with Planet's high-spatial and temporal resolution satellite imagery to comprehensively measure above ground carbon stocks and emissions of every hectare in Peru. This technique can be expanded to all tropical forests and can play an important role in setting precedent for sustainable management of these vital ecosystems and can serve as a transformative tool to quantify the climate change mitigation benefits they provide.
- Carbon Tracker uses Planet data to track greenhouse gas emissions with unprecedented detail and speed. Such capabilities can be used to verify progress toward climate commitments such as global coal power plant decommissioning.
- Carbon Mapper, a new nonprofit organization, and its partners (Planet, the State of California, NASA's Jet Propulsion Laboratory, the University of Arizona, Arizona State University, High Tide Foundation and RMI) announced recently a pioneering program to help improve understanding of and accelerate reductions in global methane and carbon dioxide emissions. The consortium will deploy a ground-breaking hyperspectral satellite constellation with the ability to pinpoint, quantify and track methane and carbon dioxide emissions with the first satellites launching in 2023.
- Commercial agricultural customers use Planet imagery in their farm management platforms allowing farmers to make more informed decisions around ideal investments in seed and crop protection products and when to plant and harvest. Satellite imagery provides the almost daily coverage necessary to conduct crop yield analysis, land use change and monitor additional impacts to farms.
- Researchers at DOE's Lawrence Berkeley National Lab leverage Planet's daily monitoring to produce statistically reliable indicators including: earlier detection of crop health including disease detection, crop discrimination, drought tolerance, nitrogen efficiency, better data on infection from disease, responses to drought and heat, grain yield and quality, and automated measurements like phenotyping to save costs and time for farmers.
- The United States Forest Service and forest managers internationally use Planet data to monitor and forecast bark beetle disease spread. The daily imagery is used to determine the latest dead forest stand to make derivative products available to the public to enable prompt removal of dead and infected trees to mitigate spread.
- San Francisco International Airport (SFO) - Airports undergo major infrastructure upgrades and maintenance and require high frequency and high resolution imagery that is cost effective to monitor these developments. SFO uses Planet's biweekly Basemaps to perform more efficient reviews of airport plan updates in collaboration with the FAA around airport planning, design, operations and maintenance decisions.
- State of New Mexico Land Office - The Land Office leases 9 million acres of surface land across the state. Entities can be difficult to regulate, especially given that they operate in highly remote areas and/or are undeterred by fines. Lack of visibility into these areas prohibits the Land Office from uncovering infractions, recovering fines, and bringing people into compliance. The Land Office uses Planet imagery to monitor leased and to-be leased land in the state. Planet imagery helps ensure that their lessee and other related parties are compliant with permits and guidelines.
- San Luis Obispo County, CA - Planet imagery is used to monitor the county for building code and water usage infractions. The county is now proactively searching for violation and seeking

compliance at a much greater rate than previously - when suspected infractions needed to be actively reported by citizens or discovered by inspections.

Opportunities/Recommendations

NASA is leading the way among civil agencies to realize the value of commercial remote sensing data to help them achieve their scientific and climate goals. Credit goes to leadership at NASA's Science Mission Directorate, the Earth Science Division, and the Office of Management and Budget for leaning forward to leverage this new capability. But challenges remain and opportunities exist for better utilization of the commercial capabilities and to stimulate additional industrial investments to serve growing science and climate needs. To that end, here are a few opportunities to expand upon NASA's successes and embrace the advantages of the commercial remote sensing ecosystem:

1. Commercial Capabilities as an Enhancement to NASA Earth Science Missions

Consistent with the 2017-2027 Decadal Survey for Earth Science and Applications from Space³, NASA is encouraged to seek commercial or international partnership opportunities with the goal of reducing implementation costs and enabling overlapping mission capabilities. NASA Earth Science and climate missions should consider commercial remote sensing capabilities during the initial architecture designs and systems should be designed to focus on interoperability between commercial, international, and national programs. This is a change in paradigm of how commercial capabilities are often considered by Earth Science missions. Instead of thinking of commercial companies as a supplement that can be added on to missions as a bonus, NASA would benefit from first asking "what can I acquire from commercial companies today to meet my mission needs" with a risk adjusted forecast of viable commercial services and then develop the NASA run missions around the cutting edge capabilities that currently are not likely to be available commercially, or do not have a robust commercial market. Thinking about missions in this way will enable NASA to focus on the cutting edge capabilities, it will reduce mission development and operation costs (allowing NASA to invest in more high priority missions); it will prevent NASA from developing duplicative capabilities as the commercial sector; and it will support a domestic industry (instead of compete with it). Commercial companies design and develop their next generation capabilities based on the market signals sent by customers. NASA can send strong signals into the market and shape a commercial industry where commercial constellations are designed in tandem with NASA missions with interoperability built in from the beginning.

2. Landsat Next Leveraging Commercial Capabilities

Commercial companies have created datasets that are complementary to the Landsat and Sentinel-2 constellations, providing increased temporal and spatial resolution to users of the public datasets. Planet's SuperDove bands are specifically designed to be interoperable with public Earth Observation datasets. This alignment allows for the fusion of higher spatial resolution and improved temporal resolution from Planet imagery with exquisite instrumentation calibration provided by Landsat and Sentinel. Many studies today utilize Planet's high spatial and temporal resolution – augmented by the capabilities of Landsat and/or Sentinel-2 – to capture dynamic processes that would be impossible to observe with any one sensor in isolation. With today's focus on sustainability and an increased maturity of Earth Observation applications powered by cloud-native geospatial protocols and machine learning technologies, demand for higher spatial and temporal resolution has widely emerged allowing for users to monitor for change and make data-driven decisions. By combining these commercial and national datasets together, scientists and agency users are able to dramatically improve the sensitivity and

³ <https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth>

robustness of their monitoring of Earth with a monitoring service at the temporal rate of human activities.

Across the public and commercial remote sensing sectors, there is increasing investment in data fusion to improve interoperability and agency response. These initiatives include the Harmonized Landsat-Sentinel effort, ESA's 'Sen2Like', and Planet's own Fusion product development. Planet is supporting cross-agency efforts toward data fusion that ensure that decision makers and scientists are able to access fully resolved datasets that exceed the performance of any one sensor in isolation. Planet's dense time series data has proven indispensable in these efforts.

Unfortunately, the commercial community is receiving mixed messages from the Landsat Next program at NASA and USGS. Recently, material and unexplained changes and inconsistencies between the Landsat Next Instrument Study Presolicitation published on February 18, 2021 and the Landsat Next RFI published on October 13, 2020 suggest that rather than looking for novel new approaches to meet and exceed the Landsat mission requirements, the NASA Landsat Next team has predetermined the constellation and instrument structure for Landsat Next. In the most recent instrument study, NASA included requirements that respondents to the study assume prescribed and specific orbital altitude and minimum swath width that favor a more traditional and expensive architecture toward large satellite designs. Such prescriptive requirements (particularly in an early study) will limit innovation in the Landsat Next architecture, constrain what NASA may learn from the Instrument Study, and may ultimately restrict the Landsat Next mission to coarser spatial resolution and lower revisit rate. These outcomes are likely to negatively impact the Landsat user community and result in an inefficient use of U.S. taxpayer resources. The effect of such requirements during an instrument study could be to limit the possible responses/offers and predetermine the instruments and architecture for the Landsat Next system.

Commercial companies do not replace national systems - they complement, improve, and enable National systems to more affordably push the scientific frontiers. Like other Earth Science missions, Landsat Next should be open and receptive to commercial capabilities and consider how novel solutions can be leveraged by Landsat Next to help meet and exceed the science mission objectives for Landsat.

3. Support NASA's Commercial Smallsat Data Acquisition Program

Through direction and support of leadership at NASA's Science Mission Directorate and the Earth Science Division, the CSDA Program currently provides all NASA-funded researchers with access to commercial remote sensing data including Planet's daily, global imagery. This NASA program is actively moving to include more commercial datasets that are relevant for NASA researchers as well as expand the potential science user community. This program is a model program that other civil agencies can follow to integrate commercial data into their existing pipelines and use-cases. Despite these successes and the demonstrated desire by NASA to grow the program both in terms of user community and in terms of onramping new commercial providers, the program does not exist in statute and its funding has been flat since the initial pilot in FY2018. Congress can show support to this program and similar endeavors to leverage commercial data by putting the CSDA Program into statute in the next NASA Authorization Bill and by robustly funding the program to reflect the growth and value it is demonstrating.

4. Whole-of-Civil-Government Approach to Commercial Databuys

There is an opportunity to empower federal civilian agencies, scientists, and climate action decision-makers with access to daily global commercial imagery, of the entire United States and global land mass – an unprecedented new capability enabled by U.S. commercial services leveraging small satellites – to advance America's climate, infrastructure, environmental justice,

commercial, and global innovation competitiveness priorities. Through a whole-of-civil-government approach, Congress and the Administration can facilitate federal agencies to fully leverage the unique capabilities of U.S. commercial space-based observatories in tandem with existing national remote sensing programs. These combined data products create unprecedented and globally unparalleled services that can be an enabling tool that fasttracks efforts to confront the impact of environment and climate change, facilitate transparency and global understanding, and further accelerate America's leadership in deploying domestic innovation and technology to solve global issues. Congress and the Administration can accelerate adoption of these imagery and analytics sources by embracing a whole-of-civil-government approach to making scientifically accurate and factual earth observation data available to all federal civilian agencies, scientists, and climate action decision-makers. These efforts to purchase commercial data for both scientific and operational uses across all civilian agencies could be led by NASA in partnership with NOAA and USGS.

5. Regulations and Demand Signals to Enable International Competition

Recent years have seen an increased investment by international companies and nations in the fields of remote sensing and geospatial analytics. This increased international interest is motivated both by scientific and climate priorities as well as by national security and power projection aspirations. These, often government backed, entities are competing with U.S. companies in the growing international commercial market for geospatial imagery and analytics. In order to support U.S. enterprise and maintain our leadership position in this technology field, we need regulatory policies that enable U.S. companies to compete internationally and we need U.S. federal agencies to directly support national capabilities by prioritizing commercial databuys and programs that leverage commercial services. NASA should work with relevant partner agencies (including NOAA, USGS, FAA, FCC, and State Department) to ensure that regulatory policies not only foster a safe environment for space operations, but also support American enterprise. Remote sensing regulations, launch payload regulations, orbital debris regulations, and spectrum regulations all play a critical role in allowing U.S. companies to successfully compete internationally. Similarly, the demand signals sent by federal agencies prioritizing leveraging commercial capabilities (rather than developing competing national systems) greatly impacts the health of the broader U.S. commercial remote sensing market.

Summary

Space-based remote sensing by national missions led by NASA's Earth Science Division and by commercial constellations (such as Planet's) play a key role in providing the data needed to understand our changing world and empower better decisions. U.S. entrepreneurs have built upon the legacy of NASA Earth Science missions and pioneered novel commercial remote sensing capabilities that complement national assets and today play a key role in measuring and monitoring changes to our planet. The commercial remote sensing community is vibrant and provides data and analytics tools used by scientists, researchers, companies, communities, federal agencies, climate action decision-makers, and individuals to make better data-based decisions.

NASA's Science Mission Directorate is a leader among civilian federal agencies at leveraging these commercial capabilities and purchasing data for their scientific user community. Moving forward, NASA and the federal government should prioritize leveraging commercial remote sensing capabilities as it designs the next generation of national remote sensing assets. An investment in making commercial data available across federal civilian agencies, scientists, and climate action decision-makers will take advantage of space-based remote sensing innovation founded and built in the U.S. and advance the Nation's climate priorities.

Robert H. (Robbie) Schingler, Jr.

PROFILE

Robbie Schingler is an entrepreneur, co-founder of Planet Labs, and a former NASA engineer and program manager with more than 20 years of building satellite projects. As the co-founder of the world's largest Earth Observation satellite company, Robbie is a leader in the commercial remote sensing sector serving the rapidly expanding and diversifying user community across commercial businesses, government users, scientists, developers, and journalists. Robbie writes and speaks frequently about the 21st century aerospace industry and the space renaissance and is an advocate to encourage intentional, entrepreneurial efforts in aerospace.

EDUCATION

Georgetown University – <i>Master of Business Administration</i>	2003-2005
International Space University – <i>Master of Science, Space Studies</i>	2000-2001
Santa Clara University – <i>Bachelor of Science, Engineering Physics</i>	1996-2000

RELEVANT WORK EXPERIENCE

PLANET LABS INC.	San Francisco, CA
<i>Co-Founder, Chief Strategy Officer</i>	2011 - Present

Robbie Co-founded Planet and has raised over \$500M, employees 500 people, launched over 450 satellites, and has more than 35,000 users across 600 customers in 65 countries. Planet is redefining the geospatial industry with novel, web-based products and subscriptions to bring geospatial data to government, businesses, and civil society. Robbie is currently responsible for incubating new missions and lines of business, corporate development, policy efforts, and Planet's impact initiatives and serves on it's Board of Directors. Planet has a complete end-to-end, in-house aerospace capability with the proven the ability to develop and deploy very compact, high performing satellites quickly (aka "agile aerospace"), mass manufacture of satellites (can build and deliver 40 satellites in one week), and autonomously operate a disaggregated and diversified satellite network (currently operated the largest constellation of satellites in history).

NASA HEADQUARTERS	Washington, DC
<i>Chief of Staff, Office of the Chief Technologist</i>	2009 - 2011

Chief of Staff of the Office of the Chief Technologist responsible for program formulation and policy for technology within NASA, resulting in the establishment of the Space Technology Mission Directorate and associated NASA directives with congressional authorization and appropriation.

NASA AMES RESEARCH CENTER (ARC)	Moffett Field, CA
<i>Research Engineer & Technical Project Manager</i>	2006 - 2009

Development of the ARC mission design center and small spacecraft office and incubated the Transiting Exoplanet Survey Satellite (TESS) mission. Director of partnerships at ARC, with emphasis on small spacecraft including the development of three Space Act Agreements.

OTHER RELEVANT EXPERIENCE AND ACCOMPLISHMENTS

Robbie is an active member of the National Geospatial Advisory Committee's (NGAC) Landsat Advisory Group (LAG) and a member of the Advisory Committee for Commercial Remote Sensing (ACCRES), has testified to Congress on the role of Public Private Partnerships for Earth Observation, recipient of numerous NASA awards including leading the 2010 response to the Presidential Directive on Open Government for NASA, co-founder of the US Space Generation Advisory Council (SGAC), a 2005 recipient of the Landegger International Business Diplomacy Honors, and a 2005 Presidential Management Fellow.

Chairman BEYER. Mr. Schingler, thank you very much, all fascinating. And now we'll begin our round of questions. I get to go first by virtue of this Chairmanship, so let me begin with Dr. St. Germain.

We just heard from both Mr. Duren and Mr. Schingler about all that is happening on the commercial side in terms of data, Planet having more satellites tracking what's going on Earth than anyone else. How do you feel about and what are your thoughts about this ever-growing possible partnership between our public NASA and our commercial companies?

Dr. ST. GERMAIN. Thank you for the question. I couldn't be more excited—I just muted. There we go. I think we're back. I couldn't be more excited about the possibilities enabled by all of the growth in commercial Earth observation in both directions. I think, as Robbie said, the capabilities that the commercial sector is bringing to science are very exciting. They absolutely complement our government systems, and they expand the scope of the science we can do. And in the other direction, Riley talked about bringing NASA technology out into the commercial sector to enable future commercial capabilities, and I think that is just as exciting. So I am thrilled and really looking forward in this position to exploring new ways of partnering with the commercial sector. Thank you.

Chairman BEYER. Great, thank you. And, Riley, you talked about, you know, the super-emitters, the methane with that great flyover and that only 1/3 of the—2/10 of 1 percent of the infrastructures were responsible for 1/3 of the State's methane emission. How does that compare to the other greenhouse gas emissions from transportation, from buildings, from manufacturing? Is methane just a tiny piece of this or if you can fix those flares, can you make a significant difference?

Mr. DUREN. Yes, great question. What I like to say about greenhouse gases, like many things on the planet, is it's a mixed bag. Methane tends to be leaky in the way it manifests, and the best way I can describe it as if you have a sprinkler system in your yard, you're eventually going to have a leak. That doesn't mean that the sprinklers are necessarily spraying water all over the place, but when it happens, you know, you find out when you look your water bill. If you're lucky, you see the geyser shooting up, you know, in the front yard. So that tends to be the nature of methane associated with human activity, whether it's the energy sector, the waste management sector, or even agriculture. It's very—it tends to be very leaky, and therefore, it can occur randomly and it's difficult to predict.

That's different generally speaking than some of the other greenhouse gas emissions but in particular CO₂ emissions from the transportation sector. Imagine that being spread out over freeway systems or through other transportation vehicles.

And so I guess what I would say is your mileage varies so to speak, and it is—it's very different by sector. And the technology I talked about addresses one part of the greenhouse gas monitoring challenge. It really focuses on these leaky point sources for methane and CO₂, for example, stationary power plants. We need a broader constellation of systems or system of systems as we like to say in NASA system engineering world, to address the full land-

scape, and that's part of what we have between what we talked about with Carbon Mapper, NASA's existing program, and programs with other international space agencies, as well as commercial actors with instruments on the ground, not just space.

Chairman BEYER. Cool, very cool, thanks. Mr. Schingler, you talked about NASA's Commercial Smallsat Data Acquisition Program. As you probably know, the Senate folded NASA's reauthorization into its *Endless Frontiers Act* last week. Did that include the Small Data—Smallsat Data Acquisition Program?

Mr. SCHINGLER. To my knowledge, Chairman, that does not include this—the NASA Smallsat Data Acquisition Program in its current form.

Chairman BEYER. So we still have a ways to go, OK, great, because we're about—hopefully later this year we will take up NASA reauthorization.

And then, Dr. Schmidt, one of the things you talked about was the many, many different players you have, and in your new role on the Climate Task Force, how do you coordinate all these people that want to be part of providing information on climate change?

Mr. SCHMIDT. Thank you very much for the question. Yes, no, that's a real challenge, and as I've stepped into this new role, that has really been the dominant theme of what we've been doing. We've been bringing together all of the people who are working with external partners, and we're trying to collate that information and we're going to make that more visible and then we'll be able to see I think where the gaps are, where the successes are, and where we may be able to roll out a broader use of the information and data that NASA provides.

Chairman BEYER. It sounds like the invasion of Normandy, but good luck, so—

Mr. SCHMIDT. Thank you.

Chairman BEYER. Well, my time is up. Let me now recognize our Ranking Member, Dr. Brian Babin.

Mr. BABIN. OK, thank you very much, Chairman Beyer. I want to say thank you to our witnesses as well. I appreciate you being here.

Mr. Schingler, your testimony highlights issues with the Landsat architecture in a recent instrument study pre-solicitation. Please allow me to read from your testimony. "Unfortunately, the commercial community is receiving mixed messages from the Landsat Next program at NASA and USGS. Recently, material and unexplained changes and inconsistencies between the Landsat Next instrument study pre-solicitation published on February the 18th, 2021, and the Landsat Next RFI published on October 13 of 2020 suggests that rather than looking for novel new approaches to meet and exceed the Landsat Next mission requirements, the NASA Landsat Next team has predetermined the constellation and instrument structure for Landsat Next. In the most recent instrument study, NASA included requirements that respondents to the study assumed prescribed and specific orbital attitude and minimum swath width that favor a more traditional and expensive architecture toward large satellite designs. Such prescriptive requirements, particularly in the early study, will limit innovation in the Landsat Next architecture, constraining what NASA may learn from the in-

strument study and may ultimately restrict the Landsat Next mission to coarser spatial resolution and lower revisit rate. These outcomes are likely to negatively impact the Landsat user community and result in an inefficient use of U.S. taxpayer resources. The effect of such requirements during an instrument study could be to limit the possible responses or offerors and predetermine the instruments and architecture for the Landsat Next system,” unquote. Can anything be done, Mr. Schingler, to ensure an unbiased solicitation, or will it require legislative action? Thank you.

Mr. SCHINGLER. Thank you for the question, and I think by highlighting the benefits of what has already happened with NASA on the commercial side with the Commercial Smallsat Data Program and the scientific utility that’s coming out of that, I think it can better inform the program office in how they come about procuring the next generation of systems for Landsat. And for the Committee to recognize, this is something to be launched later on this decade. We do need to think about 5 years ago what was available and what can be available 5 years from now.

As we are seeing also with the European Union Copernicus program and their planned upcoming constellations, we should be thinking about these, as Riley was saying, as a system of systems, which is what are the needed data gaps that allow for these free and open data sources provided by governments to be interoperable with one another. It is no one sensor that is necessary for us to have the data necessary for climate action, but it—instead, it is something that is about interoperability and looking for reference data sets that other data sources can be available for.

And so at this early stage of a procurement strategy, we do urge this Committee and NASA and USGS to open up the aperture and to consider more novel and innovative approaches toward the next-generation Landsat Next program.

Mr. BABIN. OK. One more question for you, Mr. Schingler. Your testimony also mentions the commercial remote-sensing regulatory process. Since you also sit on the advisory committee for commercial remote-sensing, what can NASA do to aid the Department of Commerce in the interagency process that reviews new remote-sensing technologies?

As noted in the last advisory committee meeting, despite the new streamlined regulations, American companies are still forced to be second place in many areas of commercial remote-sensing and prohibited from offering anything not on the market without significant, often crippling conditions being placed on their operations, real quickly, please.

Mr. SCHINGLER. Yes, the advisory committee for commercial remote-sensing met a couple of weeks ago, and there was an excellent briefing from a national geospatial intelligence agency colleague who articulated a leaderboard across all the remote-sensing capabilities globally. And if you play it back over time, you could see how other nations are accelerating in taking over leadership for commercial remote-sensing capabilities.

Last year, NOAA did a great job in shifting a bit of the approach toward regulatory process. There’s still more to be done. It should be more than just what is commercially available today but fore-

casting where things are going so that American competitiveness can continue to excel in the global marketplace.

Mr. BABIN. OK. I see my time's expired. I had one for Dr. St. Germain, but we will submit it in writing then. So with that, Mr. Chairman, we will yield back. Thank you.

Chairman BEYER. Dr. Babin, thank you very much.

Mr. BABIN. Yes, sir.

Chairman BEYER. I now recognize the Chair of the House Administration Committee, Ms. Lofgren from California.

Ms. LOFGREN. Thank you, Mr. Chairman, and thanks for this wonderful hearing, which I think is instructive to all of us.

Dr. St. Germain, it's my understanding that the Earth Science Divisions Applied Sciences Program used to have a dedicated wild-fire program, wildland fires program, and that had been created because of an identified need, but it was concluded in 2017 because it didn't have enough money to keep going. Now, we have an increasingly prolonged wildfire season in the United States, certainly in my State of California, but not just in California, all over the United States. And we've got devastating wildfires that are being experienced. Is it important or valuable to have dedicated programs to tackle some of our biggest climate challenges and targeted appropriations to support this work in your judgment?

Dr. ST. GERMAIN. Thank you for the question. Today, we provide a lot of support for wildfire, both prediction and disaster response. We support that through two of our programs. One—both out of our Applied Sciences Program. One is the Ecological Forecasting Program, and the other is the Disasters Program. And just to give you a sense, in 2020 we supported six Disasters activations in support of wildfires in the Western United States.

I think there are a number of ways that we can manage these things, and there are always choices, right, and those choices have an impact on the synergies we can take advantage of. I'm always open to looking at alternative ways of managing the—our programs and continually reevaluating them in the context of their effectiveness.

Ms. LOFGREN. Well, you are all the scientists, not us, but I'm interested in making sure that we are making the appropriate investments in wildfire R&D (research and development) work. And if it's not a specialized division, then, you know, what other portfolios need to be enhanced? You know, right now, there are people being evacuated down in the Los Angeles basin. We had—you know, a number of people lost their lives in Paradise, California, in Doug LaMalfa's district last year, so I'm just interested in what needs to be enhanced in terms of prediction. And also, as you probably know, the Governor of California just announced a big investment in fuel reduction, but it seems to me that the preventative efforts could be greatly enhanced through this whole observation program. What are your thoughts on that?

Dr. ST. GERMAIN. The—let's see. Today, we work—when—in our wildfires work, we work very closely with our interagency partners, NOAA, for example, as well as responders on the ground. We had—as I said, we can always look at ways to do that better, and I'd like to actually give that some thought and take the question for the record and come back to you with some ideas.

Ms. LOFGREN. I would appreciate that very much because obviously there's fighting the fires, but this is not—this drought that we have is not going to—it's not a temporary situation. This is a permanent situation, and the steps that we're going to need to take to prevent the catastrophic spread of fires is something that needs to get our attention not only at a State and county level but at a Federal level, so I would appreciate that advice.

And, Mr. Chairman, I yield back.

Mr. SCHINGLER. Congressman—woman, may I respond to that?

Ms. LOFGREN. Oh, that would be lovely, thank you.

Mr. SCHINGLER. Excellent. Yes, so there is a fantastic program that's called the California Forest Observatory that was launched last year, and it is a combination of aerial lidar data with Earth observation data from—

Ms. LOFGREN. Yeah.

Mr. SCHINGLER [continuing]. Space to quantify—and weather data to then understand wind patterns and quantify the fuel load. What this does is it allows for Cal Fire (California Department of Forestry and Fire Protection) to be able to understand where the risk is and forecast where things can go. This is just a pilot project, as it is right now. It is working and operational, but it is—the technology behind it is scalable to the rest of the country.

In addition to that, there are some other government sensors that detect infrared signatures that are extremely useful not just for national security, which is its primary purpose, but also for understanding fire, fire spread, and hotspots. And being able to have that data more easily accessible to our firefighters on the ground is something that would be really welcome.

Ms. LOFGREN. That's great information. Maybe the two of you can talk after this hearing, and I'm—I don't want to abuse my time, Mr. Chairman, so I yield back.

Chairman BEYER. Thank you, Ms. Lofgren, very much.

I now recognize the Ranking Chairman of the Full Committee, Mr. Lucas.

Mr. LUCAS. Thank you, Mr. Chairman.

Mr. Schingler, your company has been around for a decade, and you've partnered with NASA and other Federal agencies during that period. How has NASA's approach to commercial providers changed over that time or has it?

Mr. SCHINGLER. Thanks for the question. Yes, thank you for the question. And honestly, it might be a bit of my heritage, but NASA is the most forward leaning of all the government agencies in partnering with commercial companies.

You can see this picture behind me is actually taken from an astronaut from the International Space Station in 2014 when we first launched our first fleet of 28 satellites. And over time, as we mentioned with the Commercial Smallsat Data Pilot Program now hopefully an upcoming operational capability is extremely promising.

And then also, as Riley was mentioning with the Carbon Mapper program, we are at the scale and support right now that we are looking to transfer some of the cutting-edge technology from NASA that can then be applied for an operational capability, and that's what Carbon Mapper is all about.

So NASA is only accelerating with its adoption and partnership with all that America has to provide in not only solving additional climate change challenges but then also bringing it to the rest of society.

Mr. LUCAS. Well, continuing down this vein, how can the Committee help spur increased partnerships between NASA and the commercial data providers in the future?

Mr. SCHINGLER. Well, my main recommendation is to—for this Committee in particular is to put into statute for the Commercial Smallsat Data Acquisition Program and to robustly fund it. There are many companies just like Planet. There are about a half-dozen or so that are operational and about two dozen or so that are coming up. The more that governments can partner with emerging commercial players, they—those commercial players, if they have a customer, they listen to them. They want to please them, and they will upgrade their services to meet their needs. And so I think by creating that program and then opening up the aperture to allow for NASA scientists to find scientific utility rather than to prove it from a procurement strategy is part of how we can think through creating new program offices.

Mr. LUCAS. Continuing with you, Mr. Schingler, NASA has for years partnered with other agencies. I think of USGS and NOAA on Earth observation activities. Currently, those partnerships consist of NASA developing new satellites and instruments, which are then operated by the other agencies. Do you still view this as the most productive and cost-effective model?

Mr. SCHINGLER. I think there are definitely scientific signatures that need to be collected that can only be done by national labs and that are necessary not just for science but also for commercial. You know, we use some of the signatures that we get from NASA and NOAA satellites for interoperability for our data sources. However, many of our legacy programs can be upgraded to go further out and to do the harder thing and to allow for operational services to then be provided by commercial players such as Planet and others. So I do think that there's a great opportunity to look at program offices not just for the specific data that they're trying to do but what is that signal that they're actually sending to the market in order to stimulate innovation and to think about it across industry, academia, and government programs together.

Mr. LUCAS. Well, along that line, from your perspective, what kind of adjustments in the model that we're using now—mechanically, what do we need to look at on this Committee to improve that model along the lines of what you were discussing?

Mr. SCHINGLER. Well, I have two suggestions. One—besides putting into statute the Commercial Smallsat Data Program, one suggestion is to have a portion of that that allows for a NASA scientist to innovate with whatever is out there. And so that is one way to accelerate that. And the second is to partner with prototypes. Instead of doing operational missions and science-grade PI- (principal investigator-) led programs, to think through and expand the in particular Earth Science Venture program to allow for there to be public-private partnerships that then allow for much more of these hosted payloads to happen on the—not just about once every 2 years and a new mission once every 2 years but to allow for that

happened on the order of 6 months. The industry is there to ready to partner with NASA on this, and this is something that NASA and this Committee should consider.

Mr. LUCAS. Thank you very much. Mr. Chairman, my time is about to expire. I yield back.

Chairman BEYER. Thank you, Mr. Lucas, very much.

I now recognize the gentleman from Florida, Governor Charlie Crist.

Mr. CRIST. Thank you, Mr. Chairman, and thank you to the witnesses for being with us today.

Under the Biden Administration, NASA's science missions will play a critical role in informing the Federal Government's efforts to combat climate change. One of the most significant climate change impacts that Florida faces is the increasing frequency of severe weather, specifically, hurricanes and as well as other tropical storms.

Dr. St. Germain, could you discuss the role that NASA's Earth observations play in weather forecasting, and could the prediction of these observations be used to improve weather prediction on capabilities?

Dr. ST. GERMAIN. Thank you so much for the question. So of course, as you know, NASA partners with NOAA to build NOAA's operational weather satellites, and we also partner with NOAA and other agencies to advance modeling and data assimilation. That happens primarily through the Joint Center for Satellite Data Assimilation. We augment those observations and capabilities with smallsat technologies like CYGNSS (Cyclone Global Navigation Satellite System), RainCube, TEMPEST-D (Temporal Experiment for Storms and Tropical Systems—Demonstration). These are all small demonstration missions that brought additional data to bear and are particularly interesting for tropical cyclones and point to a path of more affordable observations.

In addition to that, about 1/3 of our 45 disaster activations last year were associated with weather and in particular tropical cyclones. So—and then all of that of course is underpinned by our Research and Analysis Program in weather and atmospheric dynamics. So across our whole Earth Science Division from technology to science to exploratory science to applied science, we are supporting the advancement of weather prediction and warning capability.

Mr. CRIST. Thank you. The 2020 Atlantic hurricane season was the most active and the fifth-costliest Atlantic hurricane season on record. Again to you, Dr. St. Germain, given the increase in frequency of severe weather events and the resulting risk to human life and infrastructure, can you discuss what the next generation of sensing and imaging capabilities looks like, especially as they relate to weather prediction?

Dr. ST. GERMAIN. Yes. So, of course, as you know, NOAA is formulating its next generation of weather observation capabilities, particularly in geostationary orbit, and NASA's future observing systems will be aligned with the recommendations from our decadal survey, which of course characterize the most important observations to make to achieve both climate change—advance climate change understanding, as well as weather-related understanding. So the primary missions associated with the decadal sur-

vey are, of course, the aerosols convection—clouds convection and precipitation observations. Those will be looking to move forward on to answer some of those really fundamental questions. And actually I think probably Dr. Schmidt may have something to say on this topic as well.

Mr. CRIST. Doctor?

Mr. SCHMIDT. No, I think you actually covered it pretty well—

Dr. ST. GERMAIN. OK.

Dr. SCHMIDT [continuing]. Sorry.

Dr. ST. GERMAIN. OK.

Mr. CRIST. Would any of the other panelists like to comment on this?

Mr. SCHINGLER. When it does come to increasing our understanding of extreme weather, it is a combination of a variety of data sets. Different types of microwave sounders from space, also ground-based and in addition to land monitoring systems, so Landsat models are included in that, and that is something that NOAA should look at, which is including in other types of land monitoring data sensors to allow for us to have better models.

The other thing that is extremely promising about this is the power of cloud computing and machine learning on top of these aggregate disparate data sets together that allow for us to have a better understanding for what's about to happen. So as these data are all activated and interoperable with one another, we will be able to better anticipate what's about to happen not just for weather but also for other types of land-use change.

Mr. CRIST. Great, thank you very much. I appreciate that. I see my time is about to expire, Mr. Chairman. Thank you. I yield back.

Chairman BEYER. Thank you, Congressman Crist.

And now let me recognize the Congressman from Cape Canaveral, Mr. Posey.

Mr. POSEY. Thank you very much, Chairman Beyer, and I appreciate you holding this hearing on the current roles and future opportunities for NASA's Earth science.

Mr. Schingler, China is aggressively pursuing remote-sensing capabilities and offering them on the commercial market. I'm just wondering what we can do to ensure that we remain the leader in commercial remote sensing.

Mr. SCHINGLER. Thank you for the question. Over the last 5 years, as I've mentioned in my testimony and my verbal statement, there is a renaissance that's happening in Earth observation, and it has been led by U.S. companies and companies across Europe. Over the last 4 years, that has been eclipsed by a number of Chinese companies that are very well-funded and very well-supported across academia and the Chinese Government.

We are competing in a global marketplace, and what makes American entrepreneurship great is that we look for global products in market-making industries, bring them to society, and then we upgrade them. And it's trusted. So I do think that the foundation that we have inside American industry will thrive and grow this new frontier economy, but it definitely is a challenge.

Some of the things that are being brought up right now is to really embrace U.S. commercial industry and purchasing the services that exist today, knowing that there's a partnership for it to

be upgraded over time. And this is something that that we have not seen fully embraced inside the DOD (Department of Defense) and the IC (intelligence community) community.

And I can say again that NASA has been an early adopter into this, and we look forward for this to expand, but that's the main thing is to partner, is to be a lighthouse customer, not the only customer, but to be a customer of U.S. commercial industry, and they will rise up, and they will solve the needs of tomorrow.

Mr. POSEY. Thank you. Thank you very much, Mr. Schingler.

Dr. St. Germain, I'm particularly worried about China, as many of us are, through state-owned enterprises investing in new private climate satellite companies in order to influence the information they receive. Can you tell us how NASA might not only validate the new data coming from these nongovernment satellites but also any intentional or unintentional biases that can emerge from it?

Dr. St. GERMAIN. Thank you for the question. So NASA doesn't have any direct bilateral collaboration or work underway with China, but we do have a lot of multinational partnership work underway and in fact we lead multinational organizations such as the Committee on Earth Observations, and our primary focus in those leadership roles is to expand and really underscore open science and the trust and transparency that goes into the—understanding those measurements and their scientific integrity.

And so I think where we can really contribute here is leading in that international arena, along with our commercial partners, to underscore the importance of transparency and trust in the data that we're using and create that expectation internationally.

Mr. SCHMIDT. Might I add something to that answer?

Mr. POSEY. Absolutely.

Mr. SCHMIDT. One of the key issues with any new source of data is that every new source of data has its own special characteristics. One might call it bias, but they all have special characteristics as a function of their orbits, their instruments, and how often they're reported. When you put that into a data assimilation system, the physics that's been embedded within that system tells us whether things are consistent, whether things are coherent. And so these systems will tend to reject data that is too biased, that doesn't fit into how the estimations is thinking that things should work, and we can—we are able to detect instruments that are malfunctioning. We are able to detect instruments that are not properly calibrated by embedding them within a larger data assimilation system. And that would be true for data from any source.

Mr. POSEY. Thank you very much. I see my time is expired. I appreciate it, Mr. Chairman. I yield back.

Chairman BEYER. Thank you, Mr. Posey. And, Mr. Posey, I'm going to ask a second round of questions if you care to hang in for that, so you're most welcome to.

Mr. POSEY. OK.

Chairman BEYER. So let me—Mr. Duren, you wrote that there's a real problem in data latency, that you have these wonderful people collecting data, and it takes one to three years until it's delivered and published in time. How do we get over that? You say we need more streamlined frameworks to effectively support decision-making but that data latency is an obstacle.

Mr. DUREN. Yes, sir. Of course, you know, things vary, but it's generally the case that when it comes to greenhouse gas emission estimation in general, that current frameworks fall into one of two buckets. Bucket one is conventional greenhouse gas inventories that are compiled by—typically by nation states but increasingly some subnational jurisdictions, and those methods use fairly tried and true publicly available data that we call activity data, things like how many vehicle miles traveled, how many cows, how much coal is bought and sold, and then these regulatory agencies like the Environmental Protection Agency, apply emission factors that generate an annually aggregated, nationally aggregated accounting of all greenhouse gas emissions by sector and by gas. As you can imagine, that process takes time. In many cases those inventories lag by a couple of years, and so they're trying to get it right but they're not necessarily fast.

And the other bucket are experimental advanced science-based measurements using atmospheric measurements from a variety of techniques, not just satellites but surface measurements. And NASA and many other agencies, NOAA, and experts from around the world in academia are advancing that. NASA's own carbon monitoring system is pioneering that, many projects that are advancing that, but these are experimental in nature, and to the extent that they do produce data more quickly, they don't do it for very long. They typically last about 3 years, these pilot projects. And they also tend to be very focused in individual areas. So the need to operationalize climate data, in particular greenhouse gas data, means also addressing this latency problem. And there are ways to accelerate it mainly by providing some engineering and machine learning and automation and software engineering to speed these processes up and, most importantly, sustain them so they're not just one-off research programs. So we need to expand the research to operations gap.

Chairman BEYER. Thank you very much.

Mr. SCHINGLER. Chairman—

Chairman BEYER. Mr. Schingler—

Mr. SCHINGLER. Yes, please.

Chairman BEYER. Yes, go ahead, please.

Mr. SCHINGLER. May I comment on this?

Chairman BEYER. Yes.

Mr. SCHINGLER. So the latency is really all about speed to information, helping people make better decisions. And, I mean, we are so connected here and we get pushed information constantly. And really if you unpack that infrastructure that's put in place across cell towers and so forth, that infrastructure is now going up into space, right? So we will have over the next few years real-time connectivity via space-based orbiting assets. We will have satellites that then in space take pictures of the Earth and tap into that so that you have a real-time understanding of what's happening.

The other major trend that's happening is something that is in the Internet of Things world or edge computing, which is where you collect information you do some compute right where it is so for things that happen that have some public interest, so, for instance, in Riley's program at Carbon Mapper, if there is a methane

leak, which is really toxic for public health, that could be detected on board and immediately informed to first responders.

And so these are some of the things that are happening today across infrastructure that's going into space that allows for real-time understanding of the planet at the speed of decisionmaking for public health but then also for commerce.

Chairman BEYER. Thank you very much. And, Dr. St. Germain, lots of talk about all the different data. What's NASA's policy on NASA-supported Earth science data in terms of archiving, in terms of free and open access, and availability to the public, including raw data? And how do you maintain that policy, including conformance to the World Meteorological Organization data policies with our non-Federal partners?

Dr. ST. GERMAIN. Thank you for the question. Yes, NASA has a full and open science data policy. All of our data are freely available, and we are really pushing to advance that with not just availability but real discoverability and putting the data in the same ecosystem as the computation capability and the models and the applications. So that's all part of our plan to accelerate our delivery of actionable information.

In the context of commercial data, of course, we negotiate with the commercial data provider on the terms of a user license, and that can—in the early going, in the NASA Commercial Data Pilot Program, that was limited to NASA users only. But of course when we're talking about open science, we want to make sure that other non-NASA-funded scientists and other agencies have access, so we're working to standardize a set of options for user licenses that can allow us to distribute that data more broadly.

Chairman BEYER. Great, thank you very much.

Mr. Posey, the floor is again yours for questions.

Mr. POSEY. Thank you. Thank you very much, Mr. Chairman. I appreciate a second round.

Dr. St. Germain, a real fear is I believe that private satellite companies could possibly target facilities, industries, competitors, whatever, while ignoring other areas and then selectively release information. What would prevent these companies from cherry-picking observations to gain an upper leg over others that puts their interests first and skewing the data that decisionmakers receive and the public receives?

Dr. ST. GERMAIN. Let's see. So for the data that NASA acquires and—

Mr. POSEY. No, we're going back to China, back to the China [inaudible]. I'm sorry.

Dr. ST. GERMAIN. OK. So I think that is a question that is probably more—would be more important for operational agencies that are—that could make use of Chinese data, but as I said earlier, we at NASA don't have—we don't buy Chinese data, and we don't have any ongoing bilateral arrangements to use Chinese data.

Mr. SCHINGLER. Representative Posey, it is—

Mr. POSEY. Do others want to weigh in here?

Mr. DUREN. Can I answer that? So I think—yes, Congressman, I think this is why Robbie and I and others and I know our NASA colleagues would agree that it's important to have a global system of systems that's not limited to a unilateral actor. Environmental

data from Earth observations is too important [inaudible] wrong either intentionally through bias or by getting it wrong because the science or the technology is wrong.

So I think we are on the verge of seeing an emergent global observing system of systems that includes observations not just by NASA but also of their international partner agencies in Europe and Japan and not just China and also in commercial space.

And so I think the best way to tackle the question you're raising is really for an open-skies policy with multiple independent observations that can crosscheck and validate each other and build public confidence that no single system is introducing bias either intentionally or otherwise. And I think a good question for this Subcommittee is what's the right role of NASA and Federal agencies to help enable that to make it work?

Mr. POSEY. Well, listen, I appreciate the good answers. Dr. Schmidt, do you want to weigh in?

Mr. SCHMIDT. I think that that's very—I mean, what Riley said was good. Multiple use of the same place and time from multiple instruments gives us a coherent and consistent story about what's happening, and that needs to be multi-instrument, multi-platform, and multi-companies and multi-sources of that data. And I think that the more that we build an infrastructure that allows that data to all be kind of part of one thing, then we will be able to see things in real time that are anomalous or not.

Mr. SCHINGLER. And, Congressman, to—the commercial systems out there are also critically important for that overall multi-data source observation that is secure. So, for instance, GeoAssurance, what this is called inside of the geospatial intelligence community, and if you have problems of how you built your satellite and putting it up into space, you know that it's quite secure, that connection can also be secure. And to have pixel-level providence builds trust that what you're capturing is truth.

And as a commercial company that abides by jurisprudence and the rule of law, getting all of society on a common operating picture so that bad actors can be seen and light can be shown, it allows for the fourth estate, media, think tanks, and science organizations to actually validate and hold truth to power for those who are doing things that are different from what they're saying.

So there is something that is really, really powerful about our sector in remote sensing to provide that level of transparency to allow for us to have a more secure and sustainable world.

Mr. POSEY. Like the news really, we want it to be as accurate as possible, and that's not always the case.

Mr. Chairman, I want to thank you for holding this hearing, very interesting, good information. Thank you, witnesses, for your input. We really do appreciate it. Thank you.

Chairman BEYER. And thank you, Congressman Posey.

I'm going to—since we have these wonderful people and we don't want them to go to lunch, I'm going to fire one more set of questions at them, which you are welcome to stay if you'd like, but I understand you have other meetings, too.

So, Dr.—to Robbie Schingler, you spoke specifically about U.S. Federal agencies prioritizing commercial data buys, and I guess frustrated with DOD and the IC, but you also talked about remote-

sensing regulations, launch payload regulations, orbital regulations, spectrum regulations all play a critical role in our commercial sector's ability to participate internationally. Do you think those—that we are overregulated, the regulations have gone too far, the commercial industry does not have sufficient input in the development of those regulations? Have we right-sized it yet?

Mr. SCHINGLER. Thank you, Chairman Beyer. There are two questions in there, the first one around the U.S. Defense Department and the intelligence community. I think it's important to note that the National Reconnaissance Office more or less created Earth observation, and they created extraordinary technologies in space that allowed for our Nation to understand what's happening in an offset that other people did not know how they actually did it, just extraordinary stuff, so I do not want to state anything otherwise.

However, what has happened is that when you have a disruptive capability, which Planet and others are a part of, it isn't the way in which people are used to the performance of the system but a new axes can come out, so, for example, timeliness, looking for the unknown unknowns, and those types of activities is just not the way that it's been tooled up.

So there—yes, there has been some frustration on our part because we want the government to lean in and find mission utility and to actually be a partner for us to upgrade those services to support them.

So I just want to more or less state is that we're doing the best that we can as a commercial partner. And also I do believe that the government program offices are also doing the best they can within their constraints. And that's where oversight can come in, to really help see are there any blind spots that we have in our overall strategies? So that's No. 1.

No. 2 about regulation, regulation is—I actually said this at a conference a couple of years ago, but it's actually like a really hot place to be in because you're shaping markets. You don't want to go too far out in front, but you also don't want to hold back innovation. And so it's something that allows—that is a constant dialog, so having these advisory committees really does support and help.

But of the biggest challenges that we have today, it is going to be RF, remote frequency challenges, sharing of that, as well as orbital debris. And we do need, as a global community—and it could be led by the United States—a space traffic management capability that allows for freedom to operate and space security. This is going to be a challenge over the coming decades, and it's something that we should not wait in order to come up with, with a good solution.

So I would say in some cases there are some constraints around industry, probably for some very good reasons, but some might be for legacy reasons, and so that's where the advisory committees can come in to try to show those blind spots to the regulators.

Chairman BEYER. Great, thank you very much. Mr. Duren and Mr. Schingler, the importance of free, unrestricted, and open data sharing as part of the Federal Government's research and development activities is paramount, so is your data, the raw data in your agreements, in contracts with NASA either through the Commercial Small Data—Smallsat Data Acquisition Program or arrange-

ments for Carbon Mapper available to the public freely, openly, no restrictions?

Mr. DUREN. Yes, I'll start and then I'm sure Robbie can chime in. So Carbon Mapper is a nonprofit, and we have a public good mission to make methane and CO₂ data freely and publicly available globally. And so the approach that we've established is that Carbon Mapper will stand up a global data portal that maintains a running stream of methane and CO₂ data to the public that includes the best possible quality control and uncertainty quantification that is also underpinned by independent validation by the California Air Resources Board.

We didn't talk about it in detail, but California's role in our public-private partnership is they will get access to all of the methane CO₂ data collected over California immediately, and they'll send people out in the field to do ground-based follow-up on it if you will to help certify it and validate it so that it has broader trust globally and ideally adoption.

The other thing to understand about the public-private partnership and the way that our vision of how to monetize the buildout and sustainment of the system is that it is dual use, so there is a commercial arm to this, and it's enabled by the NASA technology. The imaging spectrometers that were designed by NASA JPL actually cover the full spectral range from the visible wavelengths through the shortwave infrared, and that allows us not just to detect and quantify methane CO₂ emissions, there are dozens of other environmental indicators on the land and in the oceans that Planet is free to commercialize. And so it's this dual-use program where Planet can commercialize other applications while serving Carbon Mapper's public good mission and actually sustain the program through a revenue share back to the nonprofit is part of what's innovative about this, and we think it will help address one of the challenges we face with Federal programs, and that is continuity. How do you keep these observations going once you start them?

I guess I'll now hand it over to Robbie and maybe you can add.

Mr. SCHINGLER. Yes, I'm super excited about this program. It is a really unique public-private partnership, and so hats off to Riley and to Karen for actually pulling this together.

It's not just continuity, but it's upgradability, right? It's collecting the needed information that's needed not just for today and that we know of but also where things are actually going. An example of this around open data versus commercializable data are a couple of programs that we've pioneered in the last couple of years, and it's under a broad rubric that we called digital public goods.

And so one example is what we've done with Norway. So Norway has been a longtime supporter of a U.N. program to reduce submissions of deforestation. And we entered into a project with them after 4 years of validation that opens up a monthly cloud freebase map of 64 tropical countries around the world that's available to the forest reprograms inside all of those countries to allow for people to be on a common operating picture to curb deforestation and, importantly, it allows for those nations to get access to payments from the World Bank for not chopping down their forests. And so this is a good example of—it's all based on our commercial data. We created a higher-order data product and then a specific license

to allow for public benefit to happen while we also still had the ability to sell similar types of data, put it into a different format, then to serve those to our over 600 enterprise customers that we have around the world.

So that's one specific example that we have done successfully, and that model came into the formulation of Carbon Mapper as a nonprofit where we deliver the data to Carbon Mapper, and then they deliver a higher-order data product, almost like a weather service for methane and CO₂ emissions to the public as a digital public good.

Chairman BEYER. Thank you very much, very, very encouraging.

So let me wrap up with one last question for Dr. Schmidt, although you're welcome to add to that, too. You are the supervisor on climate for the NASA Administrator, the very pinnacle of our climate change efforts. Is there any hope? Do you have any shot at keeping at 1.5 percent centigrade by 2050 or the end of the century?

Mr. SCHMIDT. One and a half degrees centigrade, that's a very hard question. There are pathways that would keep us below that by the end of the century. There aren't that many pathways that prevent us from going above that in the short term because of the inertia in the—both the climate system, the oceans, and in our societal responses.

But, you know, there are a lot of activities going on, and there are a lot of very, very promising activities at all levels, the Federal, regional, local, and international level that are pushing us in that direction. The targets and the plans that people have put in through the Paris Agreements for their nationally determined contributions to cutting emissions are getting closer to the 2 degrees target, and the ratchet mechanism that was built into the Paris Agreement seems to be working. People are seeing what can be achieved and then trying to look into doing better.

And so I don't think it's totally hopeless, but I think it is clear that we do need to prepare for more climate change to come. The exact number, speaking personally, the exact number that we end up with is not—you know, nothing particularly terrible happens if you go from 1.5 to 1.55 or 1.6, but what we know is that the impacts are ratcheting up, and they are increasing exponentially as we continue to warm the planet. And so we're always going to be in a situation where we could be doing better, but it's never the case that we should be giving up on making better decisions.

Chairman BEYER. Mr. Duren?

Mr. DUREN. I just wanted to chime in quickly. We get this question a lot, especially on the greenhouse gas mitigation topic, you know, is it too late. What I would say is there is still time and an urgent need to act quickly. The window is closing, and you can look at the Biden Administration's recent commitment to cut, you know, U.S. greenhouse gas emissions by 50 percent by the end of this decade. We're well into this decade already.

I do think that it is an all-hands-on-deck moment for not just the Federal Government but all government branches, private sector, and civil society. And it's not too late to act, but I think we could do a lot more as a society to take advantage of all the resources at our disposal.

And I know we've been talking in this hearing mainly about our Earth observations and NASA data, but I want to add another aspect of NASA that is part of the Federal capability, and that is NASA's engineering and program management capability. You mentioned in your opening statement moonshot. That's brought up frequently in regards to the climate response of this country and others, and I think that that is a minimum an analogy of what kind of effort mobilization is needed. And I think there's that can and should be done in engaging all of the resources of the Federal Government that right now are constrained by institutional limitations. NASA fits over here in this part of the ecosystem and the other agencies do that. And I realize that it's unrealistic to call for a whole-scale reorganization of government, but I think there is creativity needed and resources that are still untapped within agencies like NASA that can do more than deliver satellites. And so I—that's something probably beyond the scope of this hearing, but I just want to throw that out there is there's more we could and should be doing.

Mr. SCHINGLER. And to echo on that, Chairman Beyer, this is an opportunity for the U.S. Government to provide leadership across the entire Federal Government, just like what Riley is saying. We have the National Space Council. That should have a strong voice for climate. It should encourage the Office of Space Commerce within the Department of Commerce, the climate envoy, and commercial players to be part of this overall solution. It is a system of systems. NASA has a systems engineering approach to it. NASA has been playing with this data, understanding climate as it has happened, and that technology can really be useful for us to understand what we can do about it.

The most encouraging thing I see in tackling the problems of today is the fact that Larry Fink, who is the CEO of BlackRock, who has over \$6 trillion under management in his last three statements have said that climate risk is investment risk. If we take a look at the global markets and the amount of money that is going toward so-called ESG funds or environmental, social, and governance funds, the market is shifting. We do—and we need to ride that wave and shift it in order for us to live sustainably on this planet.

So this is an all hands on deck, and it's not just government. It is industry. That—those are the incentives that will actually drive consumer behavior and corporate behavior. So I'm encouraged by it, but we do need to accelerate our activities.

Chairman BEYER. I think for anyone who's listened to the last hour and a half plus, they have to be encouraged by the capabilities of our four witnesses today and all the things that you're doing, so thank you very, very much for being here. Thank you for your good work on behalf of all of humanity, and we hope you will come back to talk with us often.

So let me just say that the record will remain open for two weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

So if there is no objection, the witnesses are excused, and this hearing is now adjourned. Thank you, and have a great day. We'll see you soon.

[Whereupon, at 12:36 p.m., the Subcommittee was adjourned.]

Appendix

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Karen M. St. Germain

1

Questions for the Record to: Dr. Karen St. Germain
Submitted by Chairman Beyer

1. What are the currently defined roles and responsibilities for NASA in sustaining long-term space-based Earth science observations in the federal government?

Most of what we know about changes in the Earth system comes from satellite data, specifically the long-term records of changes over time provided by decades of continuous satellite data sets. NASA works with both domestic and international partners toward sustained observations to provide ongoing situational awareness of the changing climate and earth system, to support climate change prediction and implementation of adaption and mitigation measures. In some cases, observables identified in Decadal Surveys achieve both new science and support sustained observations. NASA also partners with the European Copernicus program to share the cost of sustained observations, and the FY23 President's Budget Request supports this as a cost-effective approach. NASA has also implemented the 2017 Earth Science Decadal Survey recommendation to implement an Earth Venture Continuity (EVC) line of competed missions within the broader Earth Venture program. The first EVC mission, Libera, will contribute to maintaining the 40-year data record of the balance between the solar radiation entering Earth's atmosphere and the amount absorbed, reflected, and emitted. The NASA Earth Science Technology Office develops new technologies to make sustained observations more affordable, and these technologies routinely transition to NASA missions, other US agency missions, and/or the commercial sector. The international ecosystem is dynamic, and NASA assesses the state of available observations annually.

NASA also develops satellites for the National Oceanic and Atmospheric Administration and the US Geological Survey, which provide long-term Earth observation data sets.

2. To what extent is NASA climate science and climate change research contributing to mitigation efforts?

a. How is NASA measuring the effectiveness of transitioning its research to applications and operations so that decision-makers in communities can fully leverage the scientific data and knowledge gained through NASA research?

Most of the Agency's climate-relevant work is more closely tied to climate adaptation than it is to resilience and mitigation. Developing applications to inform climate mitigation decisions is an area in which NASA has not been traditionally as active. We are in the planning stages to do more work in this area, through the Greenhouse Gas Monitoring and Measurement Interagency Working Group, consistent with the Agency's appropriations for FY22 and the President's 2023 budget submission.

Effective mitigation requires a full understanding of the consequences of policies across a wide range of impacts – including climate, but also air quality, public health, economic costs, and crop yields. NASA models are informing international assessments of mitigation strategies through Shared Socio-economic Pathway (SSP) simulations done as part of the Coupled Model Intercomparison Project (CMIP). Models are also being used for policy-specific impact modeling for scenarios developed by, for instance, the Environmental Protection Agency (EPA), the Department of Transportation, and the United Nations Environmental Program (UNEP). These latter simulations can provide actionable information to policy makers faced with specific decisions that have wide-ranging implications beyond carbon dioxide emissions.

NASA's Applied Sciences Program largely measures the progress of our applications using "Application Readiness Levels," a metric that tracks progress from a phase of discovery and feasibility to integration in a partner's decision-making system. More information can be found here:

<https://www.nasa.gov/sites/default/files/files/ExpandedARLDefinitions4813.pdf>

3. What are the deliverables of NASA's Carbon Monitoring System program, and what are its metrics for success?

a. In response to one of my questions during the hearing, Mr. Duren noted that NASA's Carbon Monitoring System was pioneering approaches to more timely measurements of greenhouse gas emissions using remote sensing, but that such experimental pilots are, by definition, relatively short-lived and narrowly focused. What would be needed, from a research and development perspective, to mature the prototype capabilities in carbon monitoring, reporting, and verification developed by the Carbon Monitoring System and to implement those capabilities more broadly?

Key deliverables include products describing the distribution and evolution of biomass and of the exchange of carbon between the surface biosphere and atmosphere, taking advantage of the full suite of data available from NASA's satellite missions, as well as related data. A metric of success is the use of data by stakeholders for their purposes associated with understanding how carbon is distributed and transformed within the Earth system.

The CMS products are designed to make maximal use of presently available NASA (or other freely available) satellite and related data, as well as to prepare for data that will become available in the future as new satellite missions are launched. NASA will continue to advance the science and look to demonstrate utilization of data by stakeholders based on proposals competitively submitted and reviewed within the CMS program. The long-term usefulness of these products will be entirely dependent on the existence of long-term data to feed into the CMS products. Engagement with "boundary organizations" can help facilitate use of CMS-produced products with multiple users (e.g., state/local/national governments), as well as increased engagement with other Federal agencies that have interests and equities in the use of these products. NASA is planning an Earth Information Center with an initial focus on prototyping capabilities for a GHG monitoring and information system. This effort will include interagency collaboration and leverage already demonstrated capabilities for a future GHG monitoring, reporting and verification system. The framing of this work is informed by groups such as the Greenhouse Gas Monitoring and Measurement Interagency Working Group and Carbon Cycle Interagency Working Group of the US Global Change Research Program.

4. In response to one of my questions during the hearing, Mr. Duren noted the need for "a broader constellation of systems, or system of systems...to address the full landscape" of greenhouse gas monitoring. To what extent is NASA involved in agency and/or interagency discussions on the concept of a greenhouse gas monitoring system, including any space-based element such a concept might include?

- The FY 2023 Budget supports NASA and EPA efforts, in coordination with other agencies, to prototype capabilities for a greenhouse gas monitoring and information system that will integrate

data from a variety of sources with a goal of making data more accessible and usable to Federal, State, tribal and local governments, researchers, the public, and other users. Additionally, agencies are working through the Greenhouse Gas Monitoring & Measurement Interagency Working Group to coordinate on existing capabilities and opportunities for enhancing measurement and quantification of GHG emissions and removals, with a goal of developing an operational GHG monitoring system that informs local to national-scale GHG emission mitigation efforts and assesses the effectiveness of GHG reduction policies. As part of this effort, NASA plans to initiate an architecture analysis in FY2023 to assess future observation needs and solutions.

- NASA is also engaged in international discussions on carbon measurement, especially through the Committee on Earth Observing Satellites (CEOS) and Coordinating Group on Meteorological Satellites (CGMS). Since satellite-Earth observations of carbon are critical for effective carbon monitoring, CEOS is the primary international forum for coordination of space-based Earth observations. NASA is also a prime supporter of the science effort behind the World Meteorological Organization's International Global Greenhouse Gas Information System (IG3IS), co-funded with the National Institute of Standards and Technology (this effort was included as a highlight in the FY21 edition of the US Global Change Research Program's annual report – Our Changing Planet).

Each satellite for monitoring greenhouse gases (GHGs) provides unique observations that provide information sensitive to fluxes (emissions and uptake combined) on different spatial and temporal scales. The data that exist so far (primarily from OCO-2 and GOSAT) have focused more on the global scale, getting fluxes pertinent to more regional scales (~1000 km). OCO-3 and TropOMI are now also looking at regions with emission sources on the order of 10-20 km. Newer systems being developed by the private sector are predicted to have viewing strategies sensitive to sources at scales of less than 1 km, at the expense of sensitivity to regional and global fluxes. Using a variety of sensors can provide a more holistic picture to the emissions and uptake of GHGs.

a. What are the opportunities and barriers to increasing NASA's contributions to greenhouse gas measurements and modeling?

There are significant opportunities to increase NASA's contributions and the President's FY23 Budget request for NASA includes targeted investments in research, applications, and technology development. NASA continues to advance technology for new measurement capabilities that can advance future generations of airborne and satellite-based measurements of greenhouse gases. The High Altitude LIDAR Observatory (HALO) instrument is an example of a technology already in development that uses active remote sensing/light detection and ranging (LIDAR) that can allow NASA airborne campaigns to detect methane enhancements up to 20 kilometers downwind of a point source. NASA also looks forward to new greenhouse gas data providers like GHGSat of Canada and the public-private partnership Carbon Mapper from California, expected to launch in 2023. The quality of the current data and tools used to analyze the data (including models) are also on the upward trajectory as well, through NASA's Carbon Monitoring System and other efforts, allowing for improved understanding of GHGs as we move forward. NASA's data assimilation capability (implemented through the Global Modeling and Assimilation Office at the Goddard Space Flight Center) is well positioned to support carbon data assimilation that can inform carbon-related efforts, especially the "top-down" assessment that complements the "bottoms-up" assessments made based on information on surface sources.

NASA's space based GHG observing systems, such as the Orbiting Carbon Observatories, are research satellites and not intended as sources of long-term operational measurements. NASA is part of interagency and international discussions on a longer-term GHG monitoring plan that could include future operational measurements.

5. **While methane dissipates more quickly than carbon dioxide, it exerts a far more powerful warming effect for the duration of its life in the atmosphere, and the recent United Nations report, "Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions," released in May 2021, found that cutting methane emissions could be the strongest way to meaningfully slow near-term warming. What, if any, plans does NASA have to improve our monitoring and understanding of domestic methane emissions?**

- a. **What tools and resources would NASA require to augment its capabilities in this area?**

NASA has made significant contributions to studies of methane emissions and concentrations, especially with airborne observations using the AVIRIS-ng and HyTES instruments. These have helped to characterize emissions in a variety of human-induced areas, as well as some natural sources (Arctic permafrost). Continued use of these instruments will help provide additional information. The airborne observations were particularly important in demonstrating the capabilities for airborne methane detection, and there is now a vigorous private sector/non-profit effort to use/develop space-based instruments for methane detection (the forthcoming CarbonMapper draws significantly on NASA heritage). NASA is looking to enhance the focus on methane within its Carbon Monitoring System activity as part of its next solicitation. NASA is also currently engaged in a cooperative activity with the European Space Agency on an Arctic Methane Permafrost Challenge to bring together US and European investigators to assess what can be said about our knowledge of emissions of methane from Arctic permafrost, which have the potential to increase significantly in a future warmer climate.

6. **The Subcommittee on Space and Aeronautics held a hearing on March 24, 2021 on sustainable aviation, and witness testimony noted that aviation emissions can have an outsized impact on climate change because they occur primarily at cruising altitudes, reaching different layers of the atmosphere than surface transportation emissions. What is known about the interaction between the atmosphere at aircraft cruising altitudes and the products of jet fuel combustion, including carbon, methane, water vapor, nitrous oxide, and particulate matter, and what are the open questions about how that interaction contributes to climate change?**

- a. **Does the Earth Science Division collaborate with NASA's Aeronautics Research Mission Directorate on this area of research?**

Significant studies were done in prior decades through the Atmospheric Effects of Aviation Project (AEAP) and its Subsonic Assessment Program, which was funded by the former Office of Aeronautics but implemented largely by the former Office of Mission to Planet Earth in close consultation. A variety of field campaigns, modeling studies, and investments of fundamental processes were carried out in order to obtain this information, which has been documented in numerous NASA and other reports, most notably one done under the auspices of the Intergovernmental Panel on Climate Change (IPCC)

(<https://www.ipcc.ch/site/assets/uploads/2018/03/av-en-1.pdf>,
<https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/>). Impacts of aviation-induced contrails are also included in the recent 6th IPCC Assessment Report
(https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf).

In recent years, ESD and Aeronautics collaborations has been limited, but efforts are underway to increase collaborations. ARMD does periodically use some of the Earth Science Division's aircraft (notably the DC-8) in its field campaigns, and there is some common use and support for in situ monitoring instruments, most notably at the Langley Research Center.

7. During the hearing, I noted the importance of free, unrestricted, and open data sharing as part of the Federal government's research and development activities and asked about NASA's data policies with respect to the purchase of commercial remote sensing data to support Federally-funded scientific research. Please provide additional information on the following:

a) NASA's policy on NASA-supported Earth science data in terms of archiving, free and open access, and availability to the public, including raw data;

NASA's Earth Science program uses the Agency's advanced technology to view the Earth from the vantage point of space to understand and protect the planet, study the Earth system, and improve prediction of Earth system change. To meet this challenge, NASA promotes the full and open sharing of all data with the research and applications communities, private industry, academia, and the public. The greater the availability of the data, the more quickly and effectively the user communities can utilize the information to address basic Earth science questions and provide the basis for developing innovative practical applications to benefit the public.

All NASA data products are available to the public. The most requested products are available for immediate download from the Earthdata website and from NASA's Distributed Active Archive Centers (DAACs). Rarely requested products are typically not available online because of cost and must be requested directly from the DAACs; there are no restrictions on who can make such requests.

b) Copies of NASA's policies for its contracts under the Commercial Smallsat Data Acquisition Program and other public-private Earth science activities on the availability of the data, including raw data, to the public, free of restrictions, and archiving of the data for public use; and

All new commercial data contracts include the following data licenses, which provide for scientific non-commercial use for NASA commercial data acquisitions:

- End User License Agreement (EULA) Tiers:
 - US Government - US Government; State, Local, and Tribal Governments within the U.S.; Academia; and Non-Governmental Organizations and/or Non-Profit Organizations
 - US Government Plus - US Government; State, Local, and Tribal Governments within the U.S.; Academia; Non-Governmental Organizations and/or Non-Profit Organizations; Foreign Government and International Space Agencies
 - Public – publicly open with no restrictions.

Data Management / Access:

- A web-based Smallsat Data Explorer (SDX) tool is in place to enable users to search, discover, and access NASA's commercial smallsat data holdings. Planet and Spire data currently are mirrored in SDX, and the tool is being further enhanced to support data from Maxar and Teledyne Brown Engineering, Inc., and to improve the user experience.
- In early FY2022, ingest, archive, catalog, and distribution of the purchased commercial data will be transitioned to the NASA's Earth Observing System Data and Information System (EOSDIS) Earthdata Cloud system allowing users to have a one-stop-shop to search both NASA data and commercial data purchased by NASA.

c) How NASA's contracts and agreements with non-Federal partners, including commercial entities, conform to World Meteorological Organization data policies.

NASA's Earth data are available without restrictions to all users. In the context of contractual agreements with external entities, NASA obtains the most open license possible for data governed by a contract within budget constraints. This policy attempts to balance access rights with scientific utility. The World Meteorological Organization (WMO) data policy requires free and unrestricted sharing of "core" data used for the protection of life and property. Additionally, the WMO data policy strongly encourages the sharing of other data used in Earth system monitoring. NASA participated in WMO's development of its new data policy, as a part of the Standing Group on Data Information and Products. Broadly, the NASA and the WMO policies are consistent in their aim to make data sharing as open as possible.

NASA Open Data, Services and Software Policies:

<https://earthdata.nasa.gov/collaborate/open-data-services-and-software>

- 8. The NASA Earth Science data archive contains more than 42 petabytes (PB) of data, and it was growing at a rate of 32 terabytes (TB) a day at the end of the last fiscal year, a rate that is only expected to increase. Are there metrics—for example, I know that the Hubble Space Telescope now sees more scientific papers written each year based on archival data than using only its newest data—that tell you to what extent the archive is being used to support scientific research?**

a. How does NASA enable the use of archival data by the scientific community, and what are the opportunities and challenges to increasing the accessibility and usability of the data archives by the science and user communities?

Earth and climate research requires data from the longest possible time series, often spanning multiple missions. NASA's data holdings enable significant numbers of scientific studies and findings across all the Earth science domains, and will continue to do so. The Earth Science Division has kept metrics about the archives and distribution of data since the 1990s. For example, in 2020, there were over 600 citations of NASA Earth science oceanography data in publications, while NASA's socioeconomic data was likewise cited in over 700 science publications. Moreover, in FY2020, nearly 2 billion products, totaling some 44 PB of data, were distributed to NASA's science user community, and of this over 7 PB went directly to academic institutions. Archived data is critical to all this research.

NASA has a dedicated Earth Science Data Systems (ESDS) Program that enables the discoverability and accessibility of data through standard search engines and user interfaces, including commercial (e.g. Google) and other partner catalogs (foreign and domestic).

The ESDS Program supports rigorous science investigations and interdisciplinary research and enforces NASA's policy of full and open sharing of all data, tools, and ancillary information for all users. The program also uses community accepted standards to broaden data discovery, access and use, and actively engages members of the Earth science community in the evolution of data systems. The program also conducts an annual user survey to assess the user satisfaction with the accessibility of data from ESDS.

Challenges

- The increased volume, variety, complexity, and velocity of Earth science data require new approaches for both scientific data management, as well as supporting science at global scales.
- Evolving both science data systems and workforce skill sets to meet the ever-changing technology landscape.
- Users of Earth science data span many science disciplines, organizations, and industries. These communities use different tools and standards, and have different expectations for data products. Efficiently balancing competing needs takes considerable effort.

Opportunities

- Migrate data to the commercial cloud to co-locate data with scalable computing, and invest in tools to transform data from archival formats to community/tools specific formats.
- Collaborate with other agencies to co-locate Earth observation data and models in common locations to support cross-agency collaboration and science.
- Develop new data management and analysis technologies that enable "Big Science" or science at scale including modeling.
- Increase interoperability of our data and information systems with other agencies and partners.
- Develop open source software, tools, algorithms, and documentation to allow for broader participation in the scientific process and accelerate transition of scientific understanding to decision making.

**Questions for the Record to: Dr. Karen St. Germain
Submitted by Rep. Sherman**

1. **How does a model like Carbon Mapper constellation sustain itself long term? How can we ensure continuity of this program seeded by philanthropic funding?**

NASA defers to Carbon Mapper, Inc. regarding its long-term business plan, and recommends contacting them for further details.

2. **Innovative partnerships like Carbon Mapper offer a means to accelerate climate action by combining the strengths of some of our top institutions in the US – NASA/JPL, the state of California, commercial space companies, major universities, and philanthropy – all united under a common mission. These programs offer a way to move more nimbly than traditional institutions in addressing critical data gaps and providing operational decision support across the US and globally. Carbon Mapper, which was developed in CA at the Jet Propulsion Laboratory, took over a decade to get it into the hands of the private sector. How can Congress help NASA and other federal agencies to transition these activities quicker into the hands of State government and private sector?**

NASA engages with private entities and international partners to meet various objectives, including: facilitating collaborative opportunities domestically and internationally; helping NASA resolve gaps in technical capabilities that are important to meeting our mission objectives; supporting U.S. economic innovation and industrial competitiveness; serving as a tool for meeting NASA's mandate under the Space Act of encouraging the "fullest commercial use of space"; helping maintain essential NASA expertise and facilities; and facilitating NASA's education and outreach goals. These collaborations provide the Agency with a variety of means for accomplishing its missions, and NASA planners take these options into consideration when formulating missions.

NASA supports the transition of NASA-developed technologies and techniques to the private sector when there are interested partners. In general, this landscape is changing rapidly and NASA is pioneering new types of public private partnerships. NASA is beginning to see more interest than ever before from philanthropies seeking to assist in these transitions. These new partnership models require working through new types of partnership agreements and occasionally making adjustments to NASA's traditional management practices.

Responses by Dr. Gavin Schmidt

Questions for the Record to: Dr. Gavin Schmidt

Submitted by Chairman Beyer

1. **In your written remarks, you stated that NASA is working toward a new agency-wide integrated strategy on climate change. How is NASA developing this strategy?**

NASA convened an Agency-wide Climate Strategy Working Group, comprised of representatives from across the Agency and multiple NASA centers. Over several months, this team assessed the work NASA does on climate science and relevant technologies, examining the partnerships the Agency has successfully formed to utilize this work, and identifying strengths and opportunities of this portfolio. NASA's current Chief Scientist Kate Calvin is now chairing the Working Group as their work continues.

2. **What are the objectives of the White House's National Climate Task Force?**

- a. **Is the task force defining federal agency roles and responsibilities in addressing the climate crisis? If so, do you anticipate any potential changes for NASA's role in addressing the climate crisis?**

The National Climate Task Force (NCTF) is charged with facilitating the organization and deployment of a Government-wide approach to combat the climate crisis. Specifically, the NCTF will facilitate planning and implementation of key Federal actions to reduce climate pollution; increase resilience to the impacts of climate change; protect public health; conserve our lands, waters, oceans, and biodiversity; deliver environmental justice; and spur well-paying jobs and economic growth.

NASA provides accurate and actionable information about climate changes. The agency sees participation within the NCTF as an opportunity to enhance these goals by providing access to the key data and science that will underpin wider government actions, further develop and strengthen interagency partnerships, and better align the Agency's own efforts on vulnerability, resilience, and emissions with best practices from rest of the Executive Branch.

3. **Why are NASA's climate models important for the scientific understanding and forecasting of climate change, and how do NASA's models and their applications compare to the models of other federal research agencies, such as the National Oceanic and Atmospheric Administration or the Department of Energy?**

NASA's climate modeling is at the cutting edge of current research and is focused on the use of remote sensing data in the development, calibration, and evaluation of these models and their projections. NASA's models are widely used, most recently in the United Nations Environment Programme's (UNEP) report on methane emissions and their impacts and solution, as well as the Intergovernmental Panel on Climate Change's (IPCC) 6th Assessment Report. Because of its focus on use of remote sensing data, the Agency's models are complementary to those developed by the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy (DOE), or the National Science Foundation (NSF). Models continue to improve with new data provided by NASA's fleet of satellites, that of its partners and each generation of models.

4. **How would you describe the current maturity of climate forecasting? Are we at the point where climate models can produce mid-term forecasts at a level of both precision and accuracy to be useful for practical, community decision-making?**

a. If so, to what extent are climate forecasts being used in decision-making, and how can NASA better support the transfer of such capabilities and information to decision-makers?

When it comes to long term projections of climate, the science backing these projections is mature. NASA has high confidence in the results from global climate model ensembles that identify future global mean conditions on a decadal to century level timescale, including for temperature and precipitation. For subseasonal to seasonal (S2S) prediction, the field is evolving and the science and practical skill at employing these models for the S2S specific questions is still immature. NASA plays an important role in providing initial conditions for S2S models by introducing new technologies bringing about new observations. NASA also develops data assimilation methods that combine these models and observations resulting in improved model forecast and projections precision and accuracy. Earth observation data is also critical to provide a baseline for evaluating model prediction skill. Improvements in a range of these capabilities including Earth observations, modeling development, and research to operations is critical to a future when this information is more useful for local and regional decision making.

Some decision-makers are already embedding such information into planning decisions (for instance, in New York City, or water resource managers in Nevada and California), and NASA has targeted a wide range of these types of users through the work undertaken by the Earth Science Division in the Science Mission Directorate. For example, NASA has partnered with Microsoft to generate city-specific climate projections by downscaling NASA's global climate model datasets and developing a tool to visualize future temperature and precipitation conditions in understandable and/or related ways to today's decision makers. The City of Chicago is using these urban heat related products for their planning and heat mitigation purposes.

Similarly, the NASA Sea Level Change Team is working directly with coastal interest groups to help refine and localize risks associated with global sea level and its regional variations. NASA is working to make projections and risk assessments more widely accessible, for example, through the sea level portal (<https://sealevel.nasa.gov>), or through the Socio-Economic Data and Applications Center (SEDAC), and with other agencies, either through interagency committees and subcommittees (notably the Subcommittee on Global Change Research) or through partnerships (such as with NOAA and EPA). More generally, NASA Earth Science has initiated a Climate and Resilience program to further enhance efforts to make climate model information usable in public and private sector climate-related decision making, in ways that span the breadth of NASA's applications in agriculture, water resources, ecological forecasting, air quality, public health, and disasters.

- 5. You briefly mentioned in your written testimony the question of how “more targeted outreach, training, and partnership-building can further the aims of environmental justice.” Could you elaborate on what trainings and partnerships are being planned? What, if any, other research or activities is NASA carrying out to contribute to the Administration's environmental justice goals?**

NASA-funded researchers are already demonstrating that satellite data from NASA and its international partners, as well as airborne data and knowledge about the characteristics of populations and economic activities at the surface, can be used to demonstrate the connection between harmful environmental exposure (poor air quality) and the demographic and economic status within metropolitan areas. In addition, NASA is actively examining new modes of engagement and enhancement of existing efforts targeting underserved localities and sectors.

NASA's long experience in developing Earth science applications has shown that a 'loading dock' model for the practical use of scientific data (where the data is just made available on a website and people are expected to find and use it on their own) does not result in broad uptake. Instead, support for data use is required, ranging from increasing awareness that useful data exists, to training in how to apply it within any specific application, to the co-creation of new metrics and applications with engaged partnerships. The uptake of such support efforts is varied, favoring the larger and more well-funded jurisdictions or enterprises over small to medium-sized efforts. This situation projects onto existing inequalities in both provision and capacity.

NASA is in the early stages of creating the Transform to Open Science (TOPS) initiative. This five-year effort is focused on capacity building, partner engagement, and incentives to help accelerate scientific discovery through open science. By creating a collaborative culture empowered by the open sharing of data, information, and knowledge, NASA will broaden the scope of people from all backgrounds and experience levels who can contribute to, and benefit from, NASA observations and science.

6. **As you noted in your testimony, much of NASA's critical space infrastructure is located in coastal regions, many of which are vulnerable to climate change impacts, including rising sea levels and more frequent and severe hurricane and flood events. Threats from five different hurricanes in 2020 forced work stoppages at Stennis Space Center, most notably on the Green Run test of the Space Launch System, to secure the facility and ensure the staff was safe. What are the current projections for when and how rising sea levels could impact operations?**

a. What are NASA's plans to address infrastructure vulnerabilities to climate change?

In 2011, NASA initiated the Climate Adaptation Science Investigator (CASI) work group to build center-by-center assessments of vulnerability to sea level rise and storm surge and to inform resilience efforts. These were made available to NASA Centers and were published in the 2014 [Rosenzweig, C., et al., 2014. Enhancing Climate Resilience at NASA Centers: A Collaboration between Science and Stewardship, Bulletin of the American Meteorological Society, 95(9), 1351-1363.]. Updated projections were made in 2015. As part of the Agency's proposed Climate Action Plan (in response to Executive Order 14008), these qualitative and quantitative assessments will be updated, including a "restart" of the CASI effort through a partnership between Earth Science and NASA's Office of Strategic Infrastructure.

Questions for the Record to: Dr. Gavin Schmidt
Submitted by Mr. Perlmutter

1. I'd like to understand the NASA approach and the industry approach to how we leverage existing climate data and improve analytics around past data that's been collected. What steps are NASA and commercial industry taking to create new analytics for existing data and how can Congress better support those efforts? What opportunities are on the horizon with new artificial intelligence capabilities?

NASA has long recognized the unique benefit of long-term time-series of climate variables, from multiple missions and data sources, over many decades. Constructing such time-series is complicated by changing technology, algorithm development, insufficient or missing overlaps, mission or instrument-specific biases, varying spatial coverage and ground footprints, thus requiring dedicated research projects. Among other Agency activities, one specific competitive program for this is the Making Earth System Data Records for Use in Research Environments (MEaSUREs) program which provides the opportunity to the research community to augment NASA's high-level products.

Peer-reviewed projects develop and generate products making use of multi-source information (satellite, in situ, airborne) which are unified and coherent sets of observations of a given parameter of the Earth system, optimized to meet specific requirements in addressing science questions, and are made openly available to all stakeholders via the NASA Distributed Active Archive Centers (DAACs). Notable examples of critical multi-decadal data sets provided by this program include: Ice Motion and Bed Topography in Antarctica; Greenland Ice Mapping & Measuring change in rapid flow; Freeze/Thaw Earth System Data Record; A Climate Data Record of Altimetric Sea Level Change and its Mass and Steric Components; and Long-term Precipitation Products. In addition, the program enables the investigators to implement artificial intelligence methods, in particular a 30-year data set of marine low clouds is developed by utilizing a neural network-based analysis of the morphology of marine low clouds to identify types of mesoscale organization and classification. These data aim at improving the understanding of cloud formation, cloud radiative effects and cloud feedbacks as well as extreme events studies.

Other efforts to combine multiple sources of data are accomplished within the projects of operating missions, for example missions that have had follow-ons, such as the Gravity Recovery and Climate Experiment (GRACE) and GRACE-Follow On data on changes in Earth's gravity field and mass redistribution, the calibration of the long-term record of Total Solar Irradiance (TSI), Earth Radiation Budget, and the ICESat, ICESat-2 and Operation IceBridge (airborne) missions to build a record of ice sheet topography over time.

Responses by Mr. Riley Duren

Questions for the Record to:

Mr. Riley Duren

Submitted by Chairman Beyer

1. Your testimony emphasized the power of leveraging NASA's engineering and program management capabilities, and particularly its systems engineering capability, to help the United States meet the challenge of climate change. How would you envision these agency-wide capabilities of NASA, as an R&D agency, being leveraged?

The US response to climate change, biodiversity threats, and related environmental challenges suggests a whole-government mission focus analogous to a "climate moonshot". The scope, complexity and cross-coupling of these threats and the response-space presents an unprecedented engineering and management challenge. NASA has a unique combination of system engineering, project management, and science skills, developed over decades of implementing large and complex national and international programs that could potentially be applied to this challenge. For example, in addition to continuing to develop critical earth observing satellites, NASA could contribute systems engineering more broadly – in coordination with other agencies – to design, develop and commission climate information systems that offer improved decision support and "climate intelligence" in key domains such as greenhouse gas and air quality mitigation, sea level rise adaptation, water and food security, ecosystem management, and natural hazard responses. Additionally, NASA could contribute systems engineering expertise to another grand challenge: supporting efforts by other agencies, companies, land-owners, and non-governmental organizations to scale-up, deploy and monitor negative emissions technology.

2. NASA has had a long-standing Applied Sciences program under its Earth Science Division. To what extent, in your view, is the Applied Sciences program contributing to the use of Earth science data to support climate-related decision-making? In your view, are there changes that would enable Applied Sciences to further support to climate mitigation and decision-making?

NASA's Applied Science Program has been advancing the use of earth observations for climate-related decision-making for some years now, particularly in key societal benefit areas such as water resources, agriculture, health and air quality, and disaster response. With regards to decision-support for carbon/greenhouse gas emissions mitigation, NASA's Carbon Monitoring System (CMS) program - within the Research and Analysis program - is currently one of the broadest and most integrative such programs on the planet. While NASA's CMS program is currently administered as a portfolio of research solicitation-driven, investigator-managed projects it could be expanded to include a more mission-driven objective to help establish a coordinated multi-agency US Carbon Monitoring System. An expansion along those lines could apply the unique combination of NASA's research, program management and systems engineering expertise – in concert with other key agencies – to help deliver a cohesive US carbon monitoring capability to match and/or contribute to emerging international programs such as the Integrated Global Greenhouse Gas Information System (IG³IS) or the International Methane Emissions Observatory (IMEO).

Submitted by Mr. Sherman

1. How does a model like the Carbon Mapper constellation sustain itself long term? How can we ensure continuity of this program seeded by philanthropic funding?

The ability of Carbon Mapper to deliver operational, open-source methane and carbon dioxide emissions data on a daily basis at the scale of individual facilities around the globe depends on the successful build-out and continuity of a constellation of satellites (provisionally, 20 or more). Long term success will hinge on our partner Planet's ability to commercialize multiple data products from the satellites to support that build-out and continuity. Data acquisition programs at federal and state agencies and private sector companies can help ensure the success of Carbon Mapper and future public-private partnerships that contribute climate data for societal benefit.

2. Innovative partnerships like Carbon Mapper offer a means to accelerate climate action by combining the strengths of some of our top institutions in the US — NASA/JPL, the state of California, commercial space companies, major universities, and philanthropy — all united under a common mission. These programs offer a way to move more nimbly than traditional institutions in addressing critical data gaps and providing operational decision support across the US and globally. Carbon Mapper, which was developed in CA at the Jet Propulsion Laboratory, took over a decade to get it into the hands of the private sector. How can Congress help NASA and other federal agencies to transition these activities quicker into the hands of State government and private sector?

The Carbon Mapper program builds on several years of NASA-funded research and airborne prototyping including JPL's imaging spectroscopy technology and related data analysis tools that fully demonstrated the utility for actionable greenhouse gas measurement. As soon as the latter was established, efforts were initiated to transfer that technology to the Carbon Mapper program through an innovative public-private partnership that itself required 2 years to form. A key factor is the ability to establish the commercial value of the data. Improved information about the value of the data and support from Carbon Mapper's philanthropic donors have both helped make the case for private sector investments in the technology transfer at this time. Congress and NASA can help ensure the success of the full Carbon Mapper constellation and other innovative public-private programs by prioritizing and accelerating prototyping efforts and early and sustained partner-building.

Responses by Mr. Robbie Schingler

Questions for the Record to:

Mr. Robbie Schingler
Co-Founder and Chief Strategy Officer
Planet Labs Inc.

before the

Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives
on

“NASA’s Earth Science and Climate Change Activities: Current Roles and Future Opportunities”

May 18, 2021

Submitted by Chairman Beyer

1. Under Planet’s current contract agreement through NASA’s Commercial Smallsat Data Acquisition (CSDA) program, what level data products is Planet required to make available to NASA users, and does that include the raw, unprocessed and/or uncalibrated Data?

Under the CSDA program, NASA users have access to all data product levels for PlanetScope and RapidEye satellites, with the exception of the fundamental raw frames acquired by the satellites. Planet additionally does offer basic imagery without rectification and minimal correction for download to NASA users.

a. Under Planet’s current contract agreement through the CSDA program, what are the requirements for the maintenance and archiving of data?

All Planet data downloaded by registered users is aggregated and recorded monthly to then be downloaded by an internal NASA team to NASA’s archive for future data search capabilities. This data includes the data scene IDs, asset types, user information, and area of interest geometry. This NASA archiving of data is done by NASA internally and Planet supports NASA’s archiving process. In addition, all Planet imagery (including imagery not downloaded by NASA users) is stored permanently by Planet in the cloud and is accessible to all users.

b. Are any Planet data archived in a public data system, such as the Earth Observing System Data and Information System, and/or accessible through a public interface beyond Planet’s own website(s) and databases?

All data downloaded by NASA researchers is available through NASA's SmallSat Data Explorer: <https://earthdata.nasa.gov/esds/csdsap/smallsat-data-explorer>. Additionally, NASA is working to establish the EarthData Cloud as a repository for Planet and other data acquired through CSDA. External to NASA, all Planet imagery (including imagery not downloaded by NASA users) is stored permanently by Planet in the cloud and is accessible to all users.

c. When NASA-funded researchers publish, in a scientific journal, papers that describe research that uses Planet data accessed through contractual agreements through NASA's CSDA program, is Planet required to allow the researcher to make the underlying data supporting the work freely and publicly available, through the journal's data-hosting mechanisms or another venue?

Planet's Scientific Use License does not permit data sharing to anyone without an appropriate Planet user account. From a data reproducibility standpoint, we would encourage researchers to include either a list of image IDs or code that a user with a Planet account can use to download the images used in the publication via our Command Line Interface. However, any derived data products such as maps, generated indices, and annotated figures, can be included in publications.

Submitted by Mr. Perlmutter

1. I'd like to understand the NASA approach and the industry approach to how we leverage existing climate data and improve analytics around past data that's been collected. What steps are NASA and commercial industry taking to create new analytics for existing data and how can Congress better support those efforts? What opportunities are on the horizon with new artificial intelligence capabilities?

Planet downloads more than 30 terabytes of data every day from our satellites and we have an archive of an average of 2,000 images for every point on the Earth's landmass. This necessitates automation and using machine learning and artificial intelligence to fully realize the scientific possibilities of our data sets. Planet is building a software stack on top of our data to enable partners and customers to easily extract information and create applications that power decisions and action. We plan to leverage the tremendous developments in machine learning – especially in computer vision and predictive analytics – as well as traditional data science, enabling an ecosystem of users to build value on top of Planet's products. Developing these analytics tools to derive value from imagery is being done internally at Planet as well as by an ecosystem of analytics companies and the user community. These analytics tools extend beyond usage by scientists and are also being developed in a wide range of sectors, including: national security, agriculture, natural disaster, climate monitoring, insurance, supply chain, mapping, regulatory/management, forestry, human rights, and climate justice.