WRITTEN STATEMENT BY
STEPHEN M. VOLZ
ASSISTANT ADMINISTRATOR
NATIONAL ENVIRONMENTAL SATELLITE, DATA,
AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

HEARING TITLED
"CELEBRATING 50 YEARS OF THE LANDSAT PROGRAM"

SUBCOMMITTEE ON SPACE AND SCIENCE
COMMITTEE ON COMMERCE, SCIENCE & TRANSPORTATION
U.S. SENATE

December 1, 2022

Chairman Hickenlooper, Ranking Member Lummis, and Members of the Subcommittee, I am Dr. Stephen Volz, the Assistant Administrator of the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS). Thank you for the opportunity to participate in today's hearing. I am pleased to join the other witnesses, Kate Calvin of NASA, Kevin Gallagher of the U.S. Department of the Interior, Waleed Abladati of the Cooperative Institute for Research in Environmental Sciences, and Daniel Jablonsky of Maxar Technologies, to discuss the 50th anniversary of the Landsat Program, the 62nd anniversary of the launch of TIROS-1 and the beginning of NOAA's environmental satellite program, and the 64th anniversary of the creation of NASA.

All three of our agencies provide important and complementary support to the wellbeing and economic vitality of our nation and can trace our roots back in part to the International Geophysical Year (IGY), 1957-1958.[1] The scope of the IGY included global collaboration in 11 different Earth sciences: aurora and airglow, cosmic rays, geomagnetism, glaciology, gravity, ionospheric physics, precision mapping, meteorology and radiation, oceanography, seismology, and solar activity. The IGY also sparked the monitoring of several key atmospheric variables including the atmospheric carbon dioxide concentration at Mauna Loa in Hawaii and the total amount of ozone above Halley Bay in Antarctica. These activities spurred the development of rockets and satellites, highlighted the importance of regular and synchronized global observations, and established collective activities to provide access to and archive of the tremendous data and information through the establishment of World Data Centers.

In 1960, NASA and the Department of Defense launched the TIROS-1 satellite, the world's first dedicated weather satellite and the predecessor for our Polar Operational Environmental Satellites and Joint Polar Satellite System (JPSS). This was followed by the development and launch of our early Geostationary Operational Environmental Satellites (GOES). The Department of the Interior's U.S. Geological Survey (USGS) and NASA developed the Landsat series, which is the longest continuous, space-based record of Earth's land in existence. With

[1] www.nasa.gov/feature/70-years-ago-scientists-establish-the-international-geophysical-year

respect to the immense amount of data our agencies have gathered, we each operate globally recognized world data centers that the international community relies upon and provides US leadership in these areas. At NOAA, the National Centers for Environmental Information continues to be a national and international repository of space-based and *in situ* weather and climate, space physics, and geomagnetic data and the World Magnetic Model, and also houses the World Ocean Database. USGS is a leader in land use/land change data, and NASA is a leader in a wide range of space-based data and research.

Partnerships among the agencies remain strong with interdependence at the operations level, co-dependence in the maintenance of long-term environmental data records, regular consultations through the National Academy of Sciences Decadal Surveys, and U.S. leadership in multilateral organizations. The participation of Dr. Waleed Abdalati highlights the essential value of the research and academic community in the continuing efforts to improve our understanding of the complex earth environmental systems which in turn lead to improved information products and services.

The participation of Mr. Jablonsky demonstrates that the aerospace industry plays an important role in maintaining U.S. leadership in space-based Earth observation. With successes over the past 10 years, the U.S. Government will increasingly seek ways to incorporate the commercial sector in our long-term plans and activities.

NOAA Builds on the Legacy of the International Geophysical Year

NOAA has a unique mission to understand, predict, and support the health of our oceans and atmosphere. From daily weather forecasts and severe storm warnings to fisheries management, coastal restoration, and data to enhance marine commerce, NOAA’s products and services promote economic vitality, affecting more than one-third of America’s gross domestic product. We work to save lives, protect property, and enhance the American economy through the timely delivery of trusted weather, water, and climate forecasts, analyses, and information.

For decades, NOAA has been at the forefront of the world’s weather and climate enterprise. We are the global leader in observing the Earth to understand its interconnected physical and biological systems, and in disseminating knowledge from that understanding to people, communities, and industry every day and into the future. Our observation and information systems drive NOAA’s weather, water, and climate products and services, which afford vital industries – shipping, fishing, agriculture, construction, energy and water resources, and more – the ability to predict and plan for the future. As a leading federal source for operational weather, water, and space weather forecasts, and warnings, and climate assessments, we provide critical predictions and decision support tools by developing unique products that merge a variety of satellite and *in situ* data to address complex societal needs. In many cases our partner agencies (NASA, USGS, DoD) provide complementary and supplementary roles.

Satellite datasets, collected by NOAA, and our research and international partner agencies, are essential for NOAA predictions and monitoring across all scales and times, and account for around 90 percent of all data that is used by NOAA’s operational forecast models. NOAA has the distinct and important role of planning for, jointly acquiring, and operating the Nation's operational environmental satellites, and working with our global partners to ensure our systems work together. Our satellites are relied upon 24 hours a day, seven days a week for weather, ocean, climate, and space weather data by NOAA, as well as individuals, businesses, and all levels of government to protect lives and property within the U.S. and around the world.

NOAA accomplishes this environmental satellite and data mission through strategic partnerships and operational cooperation with a number of federal, private, and international space organizations and academia. Our longest-standing and closest strategic partner in Earth observations from space is NASA. NOAA's Mission is "science, service, and stewardship to understand and predict changes in climate, weather, ocean and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources."[2] NASA seeks "new knowledge and understanding of our planet Earth, our Sun and solar system," and "to understand how biological and physical systems work at a fundamental level," with the intent to understand "how and why Earth's climate and environment (are) changing."[3] These complementary missions enable NOAA to address the observation and information needs to meet the operational service delivery demands of the Nation, including, among other services, environmental and climate predictions and analysis, and weather and water forecasts, warnings, and information.

NOAA and USGS Collaboration

NOAA has a long history of collaboration as well with the USGS, as both agencies share unique but complementary responsibilities to protect lives and property. One of the areas of longstanding collaboration is USGS's use of the NOAA GOES-Data Collection System (GOES DCS). USGS has deployed over 12,200 ground-based Data Collection Platforms (DCPs) to support its Water Resources Mission to collect and disseminate reliable, impartial, and timely data that are needed to understand the Nation's water resources. The majority of USGS water data is sent from remote DCPs to the NOAA GOES spacecraft, and is then received directly by USGS as a direct broadcast from the GOES spacecraft. This GOES DCS system is relied upon by USGS, the US Army Corps of Engineers to monitor and transmit information on rivers, reservoir levels, and snowpacks in the American West. Much of this work is overlaid on Landsat images to depict the extent of floods.

Similarly, scientists at NOAA's Great Lakes Environmental Research Laboratory use satellites, remote sensing, buoys, and autonomous platforms to gather information on the Great Lakes to monitor and forecast the extent of harmful algal blooms. This includes the use of images from USGS's Landsat-8 to evaluate bloom location at a resolution of about 30 meters.[4] The Minnesota Sea Grant Program has developed remote sensing methods that can use both Landsat and Sentinel satellite imagery to provide census-level colored dissolved organic matter measurements across the state of Minnesota, providing essential information for the understanding and

---

[2] NOAA's Mission and Vision : https://www.noaa.gov/our-mission-and-vision

[3] https://science.nasa.gov/about-us/smd-vision

[4] How NOAA tracks harmful algal blooms. research.noaa.gov/article/ArtMID/587/ArticleID/2469/A-Look-Inside-How-NOAA-Tracks-Harmful-Algal-Blooms

management of lakes.[5] Researchers with the Maine Sea Grant Program have also used USGS Landsat data to analyze the suitability of satellite data for use in site selection for oyster aquaculture.[6]

In addition to its work with NASA and USGS, NOAA also has strategic partnerships with the Department of Defense, the U.S. aerospace industry, and the international satellite Earth observation community. NOAA benefits from and leverages its partnerships with Cooperative Institutes and Minority Serving Institute Cooperative Science Centers for research to operations to research (R2O2R) and algorithm development to increase the value of NOAA's satellite data in addressing societal challenges, such as air quality in urban areas, monitoring change in the urbanized coastal environment (land and water), and weather forecasting in complex urban areas.

NOAA has provided essential environmental satellite data since the 1960s and we plan to do indefinitely. We are currently actively planning for the next generation of satellite constellations that will extend into the 2050s, equipping the Nation with a high-performing and reliable baseline of environmental satellite information. NOAA has benefited from the longstanding support of the U.S. Congress to provide oversight and appropriations for our satellite programs. I am pleased to join you to discuss the importance of our next-generation satellites and future environmental data for our Nation.

Meeting Shared and Complementary User Needs

At NOAA, we are continuously improving our satellite data and information to create products and services that meet evolving national and local needs and requirements. Over the past five years, even through the COVID-19 pandemic, NOAA has sustained meaningful interactions with numerous stakeholders to ensure that we understand the requirements of our primary users of our data services. We have also met with the customers of those users to understand their working conditions and to ensure that we provide the data in ways that address their downstream current and future needs.

Every day, we see communities grappling with environmental challenges due to unusual or extreme events that affect their health, security, and economic well being. Below are some examples of regions and populations that benefit from observations from NOAA satellites, as well as severe events that are characterized by NOAA satellite observations. These data and information additionally benefit USGS in meeting its user needs. Our partnership with the academic community provides critical support to address emerging areas that require targeted and dedicated research.

Coastal Populations. In 2020, the marine economy accounted for $361.4 billion, or 1.7 percent of current-dollar U.S. gross domestic product.[7] The concentration of people and economic activity at the coasts places pressures on ecologically sensitive coastal ecosystems and leaves

[5] Regional measurements of Minnesota's lakes using Landsat 8 imagery. 2020. repository.library.noaa.gov/view/noaa/34252
[6] Oyster aquaculture site selection using Landsat 8 derived seas surface temperature, turbidity, and chlorophyll-a repository.library.noaa.gov/view/noaa/40053
[7] Marine Economy Satellite Account, 2014-2020. Bureau of Economic Analysis. 2022

residents and visitors vulnerable to coastal hazards such as hurricanes, erosion, sea level rise, and harmful algal blooms. To better understand these threats, the NOAA Ocean Service, NESDIS, USGS, NASA, and other federal and state partners are involved in joint projects that use digital elevation models to better protect coastal communities from coastal inundation and coastal flooding.

Underserved Communities. The most severe harm from climate change falls disproportionately upon underserved communities - those who are least able to prepare for and recover from heat waves, poor air quality, flooding, coastal erosion, and other impacts. For example, through mapping of climate changes using satellite and *in situ* data, we know that African American individuals are more likely to live in areas with the largest projected increases in childhood asthma diagnoses and extreme temperature-related deaths[8]. NOAA, USGS, NASA, the Environmental Protection Agency, and others work collaboratively to ensure that forecasts and warnings reach and are understood by the most vulnerable citizens and communities, protecting human health. As a specific response to this need, we are committed to ensuring our websites are compliant with Section 508 of the 1973 Rehabilitation Act, including ensuring our information is accessible to visually and hearing impaired individuals.
Farmers. Key production regions for food grains in central California and the central U.S. are experiencing severe drought this year. According to the U.S. Department of Agriculture, as of August 2, 2022, drought affected at least 45 percent of the production acreage for barley, cotton, rice, sorghum, winter wheat, and hay.[9] NOAA and USGS, through programs such as the National Integrated Drought Information System, play important roles in ensuring that the agricultural communities have access to its Earth observed and *in situ* data to mitigate or minimize the effects of drought and aridification that is ongoing across the Western U.S.

Arctic. The warming in the Arctic is occurring at two to three times the global average rate and is projected to continue. Older, thicker sea ice that once covered the central Arctic ocean is now almost entirely gone.[10] Extreme events and increasing variability throughout the Arctic impact the safety and wellbeing of communities within and far away from the Arctic and carry implications for U.S. national security interests.[11] Using Landsat data, NOAA, NASA, and USGS scientists actively collaborate in Alaska and the Arctic region to better understand the climate processes that are underway and how those relate to changes in global weather patterns, the existence of a persistent ice-free Arctic, and to national security. The National Weather Service (NWS) uses Landsat imagery to supplement other satellite sources to map river ice hazards which can be responsible for severe flooding.

Wildfires. Drought and persistent heat set the stage for extraordinary wildfire seasons from 2020 to 2022 across many western states.[12] Such a rapid increase in the number and intensity of wildfires has become a major threat to lives, property, public health, electricity supply, water resource quality, and local and regional economies in the western U.S. and beyond. NOAA,

---

[8] Climate Change and Social Vulnerability in the United States: A Focus on Six Impact Sectors. Environmental Protection Agency.
[9] USDA summary of agricultural products affected by drought. USDA. August 2022.
[10] Arctic Report Card: Update for 2021. NOAA. 2021.
[11] Department of Defense Arctic Strategy. DOD. 2019.
[12] Wildfire Climate Connection. Noaa.gov. August 2022.

NASA, USGS, and other Federal agencies are important partners in supplying actionable information from our space-based assets to the wildland community to support the time-critical detection and active management of wildfires.

Floods. Floods are the most common and widespread of all weather-related natural disasters.[13] In just the three months of June through August 2022, major flooding or flash floods occurred in six states, including in Death Valley National Park and Yellowstone National Park. Before, during, and after flooding events, NOAA, USGS, NASA, and the U.S. Army Corps of Engineers work in close partnership with vulnerable communities to address flooding and make use of digital elevation models to better protect communities, informing vulnerable populations about potential inundation. NOAA's NWS also routinely uses Landsat imagery to map the extent of flooding.

Heat. Heat is the leading cause of all weather-related deaths in the United States.[14] In the summer of 2022, more than 150 million people were placed under heat warnings and advisories. As part of the National Integrated Heat Health Information System, NOAA launched Heat.gov in July 2022 to provide decision-makers and the public with clear, timely, and science-based information to reduce the health risks of extreme heat. NOAA, NASA, and USGS work closely together with partners at Federal, State, and local levels to support affected populations prepare for, endure, and recover from extreme heat events.

Harmful Algal Blooms. Harmful algal blooms (HABs) occur when algae grow out of control in marine, Great Lakes, and freshwater environments. These HABs may produce toxic or harmful effects on people, infrastructure, fish, shellfish, marine mammals, and birds, and threaten access safe drinking water supplies. HABs have been reported in every U.S. coastal state, and their occurrences are on the rise, increasingly affecting the health of marine ecosystems and people. Resource managers at Federal, State, local, and Tribal levels share responsibilities to protect these resources and people from HAB hazards; data from EO satellites provides foundational data to detect and monitor HAB outbreaks.

Space Weather. According to the National Research Council, disabled electric power grids and collateral impacts from geomagnetic storms could result in economic and societal costs of up to $2 trillion per large storm, and it could take four to ten years for full recovery of grids.[15] By monitoring space weather from space using NOAA and NASA satellites, and USGS and National Science Foundation (NSF) ground assets the NWS Space Weather Prediction Center is able to warn users and commercial partners to safeguard these national assets from space weather events.

Orbital Debris. A hazard that all members of this panel face is the exponential rise in the amount of orbital debris that pose threats to orbiting spacecraft. The NOAA Office of Space Commerce is working with the Department of Defense, NASA, and commercial companies to stand up a

---

[13] Severe Weather 101. NOAA National Severe Storms Laboratory.
[14] Weather Related Fatality and Injury Statistics. National Weather Service.
[15] National Research Council 2009. Severe Space Weather Events Understanding Societal and Economic Impacts: A Workshop Report: Extended Summary. Washington, DC: The National Academies Press. https://doi.org/10.17226/12643.

cloud-based Open Architecture Data Repository where debris can be tracked and shared with all space operators.

NOAA is helping to meet these challenges through the provision of trusted and validated data and information as well as user-ready products and services. The scope of the challenge is enormous, and NOAA must innovate to meet the need, leverage new technological solutions, develop broader business models and partnerships with public and private sectors, and demonstrate organizational agility to adjust to changing needs, opportunities, and risks. We must do this all while meeting our critical mission to deliver environmental observations without interruption.

The increasing number of extreme events and increasing risks of harm to communities from those events necessitates enhanced information to meet this challenge. We need to monitor fire events with better resolution and more rapid response, to observe and forecast water quality and HABs with better resolution and forecasting, and to monitor and predict the intensification and trajectory of hurricanes, tornadoes, and derechos better and faster. Our communities need better information that is designed and scaled to meet their local and specific needs in light of increased extreme weather events and environmental changes. New technologies, developed by the commercial sector and often demonstrated by NASA research satellites through direct cooperation with NOAA, must be integrated into NOAA's next-generation satellite architecture to enable us to more completely deliver to users the most impactful observations and data.

NOAA's Next-Generation Satellite Architecture

NOAA's next-generation satellite programs will provide enhanced observations into the 2050s to meet increasing and evolving needs, contributing both continuous and innovative environmental information to diverse end users. NOAA will also modernize its information systems architecture by including seamless integration of NOAA and partner satellite data and *in situ*, ship, plane, and drone observations from our internal NOAA partners, and from a growing community of commercial providers. Developing these next-generation satellites takes a decade or longer from concept to launch and full deployment, but we are committed to and excited about this work.

In recognition of societal needs to adapt to and mitigate the effects of extreme weather and various hazards, NOAA's next-generation satellites will include advanced imagers that are relied upon to detect a wide range of hazards such as hurricanes, floods, and wildland fires. Harnessing the advances in high performance computing, artificial intelligence/machine learning, and the cloud, NOAA will provide additional capabilities to process and deliver data and information to users such as communities, emergency managers, and city planners to inform their activities and actions.

The requirement to sense the atmosphere for temperature, pressure, and water vapor input for weather and environmental numerical models remains one of NOAA's top priorities for its next-generation systems. To provide needed protections to coastal communities, NOAA plans to add an ocean color imager in geostationary orbit that will complement and vastly augment capabilities in the polar orbit to detect harmful algal blooms. The capabilities from NOAA's satellites are relied upon by NASA, USGS, many other Federal and state agencies, and the commercial sector.

Definition of the next-generation satellite programs is underway, and definitive life cycle costs have not been finalized. Arriving at approved program scopes and final life cycle costs, along with the relevant technological review assessments, will be done in close coordination and consultation with NASA and the Department of Commerce's Office of Acquisition Management.

NOAA's 2014-2017 Satellite Observing System Architecture study evaluated alternative architectures for its next-generation missions. The study indicated key takeaways for consideration in NOAA's next-generation satellite constellation plans including an integrated system of observations from NOAA and international and commercial partners. NOAA is using this comprehensive assessment to guide the design and development framework for the future architecture, and continues to develop NOAA's next-generation plans based on new information and resource constraints.

Our next-generation plans are also informed by our space engineering experience over past decades, such as the successes of the GOES-R Series and JPSS programs, the experiences of our domestic and international partners, and the U.S. commercial space sector. These lessons learned and coordination activities are focused on delivering reliable and continuous data and information for users.

NOAA relies on the U.S. aerospace industry for support throughout the lifecycle of satellite acquisition–from instrument and spacecraft bus development to launch vehicle and services to development and deployment of the antennas and ground systems. As NOAA works with industry, it is increasingly assessing the ability of commercially provided data to fill specific mission requirements. Through the Commercial Data Program, NOAA has purchased radio occultation data that are currently being integrated into its weather forecast models. As the commercial sector demonstrates the ability to deliver data that meet NOAA mission requirements, we will continue to engage and acquire these commercially-based data as part of our overall next generation satellite architecture plans.

Implementing NOAA's Next-Generation Satellite Architecture

To best facilitate user needs across orbits and observations, NOAA's next-generation satellite architecture includes three portfolios: geostationary observations, low Earth orbit, and space weather observations (see Figure 1).

The next-generation architecture also includes an evolved support system to operate the satellites and use the data. This includes supporting our satellite operators while integrating more and varied observing system elements. It also involves evolving the ground infrastructure into a system that supports all satellites and ensures the data are reliable and shareable. We will transform the "bits and bytes" received from around the world into timely, actionable, and reliable environmental information and create new data products and services. NOAA's future architecture will also ensure the quality, accuracy, and preservation of the Nation's historical environmental data archives while augmenting this vast repository with new datasets, merged products, and integrated observations from NOAA, U.S., and global observing systems.

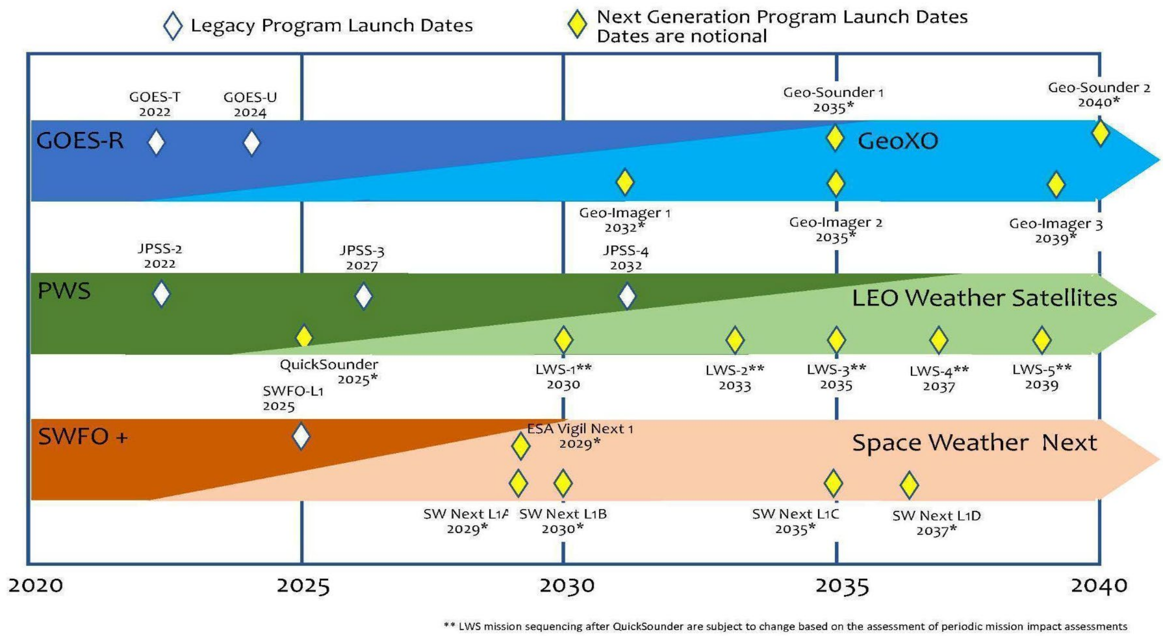

Figure 1: Notional Flyout of NOAA's Next-Generation Satellites

Geostationary Observations. NOAA's geostationary Earth orbiting (GEO) satellites provide the only continuous observations of weather and hazardous environmental conditions over the Western Hemisphere - from the eastern Atlantic to the western Pacific and from the Arctic Circle to the southern tip of South America. Information generated from our GOES system helps protect the lives and property of the one billion people who live and work in the Western Hemisphere with continuous, near-real-time observations and warnings.

NOAA's Geostationary Extended Observations (GeoXO) program is the next generation of GEO capabilities that will enable the continuous improvement of terrestrial weather prediction and warning, and will provide information enabling better climate adaptation and mitigation, healthy oceans, and resilient coastal communities and economies. As the follow-on program to the current GOES-R Series, GeoXO will provide continuity of critical geostationary data with its first launch in 2032 and planned observations through 2055. Due to the significant capabilities proposed, GeoXO is our largest investment through the 2030s, and due to the criticality of providing continuous observations, GeoXO has an aggressive 11-year development schedule.

The GeoXO pre-formulation phase included extensive, direct outreach to thousands of end users in many dozens of organizations as well as observation value assessments. It also included Observational System Simulation Experiments, an analysis of observations relative to the NOAA mission service areas, and consultation with the NOAA Observing System Council to define future observational needs and select the recommended payload instruments for GeoXO. End users require continuity of existing observations for short-term forecasting, severe weather watches and warnings, and monitoring of a range of hazardous environmental conditions such as tropical storms, lightning and winds, flooding, snow, wildfires, volcanic ash, and others. Current and future instruments in NOAA's GEO support NOAA's weather mission with essential information to notify and protect people and property across the country. These observations, together with the 50-year record of GOES observations, also provide an essential climatological data record supporting NOAA and national climate analyses and a range of climate products and services.

Following outreach to users on their satellite data needs, NOAA is now conducting industry studies to evaluate the technology readiness and costs of potential new instruments.

- A hyperspectral infrared sounder promises to improve localized forecasts and nowcasting by enhancing weather forecasting models,[16] which is critical as extreme weather events including storms, tornados, and hurricanes become more frequent and more severe.

- An atmospheric composition instrument could provide a new platform to monitor air quality, track transport and dispersion of hazardous emissions (volcanic, smoke, chemical, and radioactive), and monitor greenhouse gasses.[17] Air pollution results in at least 100,000 premature deaths and nearly $1 Trillion in damages each year in our nation.[18] GeoXO's atmospheric composition capabilities could improve the guidance that NOAA provides every day to national, state, and local environmental authorities who issue pollution alerts.

- A geostationary ocean color instrument could complement instruments in low Earth orbit to expand NOAA's ocean observing system to support the blue economy, increase coastal resilience, and help enable NOAA's oceans, coastal, and fisheries services. This information is also valuable to other non-federal users to better assess ocean productivity and health, ecosystem change, aquaculture and fisheries management, coastal and inland water quality, seafood safety, and hazards such as harmful algal blooms. Economic analyses estimate the health effects of HABs at over $1 billion per year and that more timely and precise forecasts have potential to reduce the duration fisheries must be closed to avoid seafood poisoning.[19]

GEO satellites allow near real time data sharing partnerships that provide global benefit for weather forecasting and environmental monitoring activities. GEO data will be leveraged in innovative global inputs that supplement low Earth orbiting (LEO) observations. NOAA observations will be matched with similar satellite missions deployed in the same period by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) over Europe and by the Japanese Meteorological Agency and Korean Meteorological Agency over the western Pacific and Asia, to create a GEO ring of observations. These combined observations will provide global data sets for use by NOAA and our international partners to meet global modeling system and mission service needs. NOAA has previously benefited from acquisition

---

[16] Geostationary Extended Observations (GeoXO) Hyperspectral InfraRed Sounder Value Assessment Report. 2021. repository.library.noaa.gov/view/noaa/32921

[17] A Value Assessment of an Atmospheric Composition Capability on the NOAA Next-Generation Geostationary and Extended Orbits (GEO-XO) Missions. 2020. repository.library.noaa.gov/view/noaa/27224

[18] Goodkind, A. L., Tessum, C. W., Coggins, J. S., Hill, J. D., Marshall, J. D. (2019) Fine-scale damage estimates of particulate matter air pollution reveal opportunities for location-specific mitigation of emissions. Proc. Natl. Acad. Sci., 116(18), 8775-8780.

[19] The Value of Geostationary Ocean Color. 2021. repository.library.noaa.gov/view/noaa/33278

efficiencies, just as other partners have utilized U.S. instrument vendors to meet their own mission needs.

Low Earth Orbit. LEO satellites from NOAA, NASA, and international partners provide a half century of unbroken climate data records and are the backbone of global weather forecasting models. These satellites detect and monitor hazards such as fires, droughts, floods, poor air quality, coral bleaching events, unhealthy coastal waters, and others. NOAA itself collects about half of the LEO data we use every day to meet our ongoing mission needs with the balance provided by our interagency and international partners. NOAA satellites in the LEO portfolio will supplement, and eventually replace, the current JPSS satellites.

The next generation of NOAA LEO satellites will leverage commercial space capabilities for increased flexibility. Together with NOAA's fleet and aircraft observations, NOAA's LEO satellite data will support the missions of all NOAA services including weather forecasting, fisheries management, ocean and coastal monitoring, and the research that supports these activities.

For accurate forecasts, weather models integrate measurements from microwave (MW), infrared (IR), and radio occultation (RO) sounders on polar satellites. These observations are especially important in polar regions where geostationary and in situ observational data are sparse. For example, JPSS provides critical data for nearly all weather forecasting in Alaska, and this is critical for aviation and the maritime industry. Ozone measurements also track the contours of the ozone layer and the extent of stratospheric ozone. Improved MW, IR, and RO soundings with more frequent observations and better spatial and vertical resolution have the potential to improve modeling and allow for higher-resolution short- and long-term weather forecasts.

A distributed constellation of satellites will provide greater diversity in data needed by the weather forecast models to cover all facets of the event under investigation, a resilient system less susceptible to individual satellite failures, and a higher refresh rate for measurements, which enables higher-accuracy weather forecasts and improvements in other key applications.

NOAA's next-generation LEO satellites would also provide vital data for wind speed, sea surface temperature, and ocean color. Hyperspectral ocean color imagery at improved spatial resolution would improve our understanding of harmful algal blooms and phytoplankton dynamics to give managers tools to mitigate economic impacts. The LEO observations would complement similar ocean color observations from geostationary orbit. NOAA is working with NASA to assess and integrate the upcoming Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission observations into our mission services, an example of research for operational use. Enhanced atmospheric composition sensors for methane, carbon dioxide, sulfur dioxide, ozone, nitrogen dioxide, carbon monoxide, and other pollutants will enable more timely and accurate forecasts of air quality hazards and allow NOAA to assess climate change both granularly and holistically. It is important to note that this increased amount and diversity of data going into forecast models may also require the models using the data to adapt and increase their computing power.

NOAA's next-generation satellite architecture for the LEO program serves users by collecting and delivering the following global observations: MW soundings and imagery, hyperspectral IR soundings, RO soundings, visible-IR imaging including day-night band imagery, measurements of atmospheric composition including ozone, ocean surface winds, ocean color, radio detection and ranging imagery, 3D winds, and ocean surface height. NOAA will continue to evaluate and prioritize these data demands as we scope the program.

Space Weather Observations. Space weather observations aid in safeguarding fundamental power grid infrastructure, civil aviation, and on-orbit assets and astronauts. Building on the Space Weather Follow-On program, the Space Weather Next (SW Next) program will reliably provide critical space weather products and services to observe and identify this hazard and support the needs of diverse users across the U.S. and around the globe. These users will include the electric power and airline industries, utility and telecommunications companies, commercial and government satellite operators, U.S. and foreign governments, and the space weather research and academic communities.

Observations from NOAA's SW Next program will be combined with complementary data collected by federal and international partners and will be processed through NOAA's Office of Satellite Ground Services to provide the necessary information flow for space weather forecasts. This data and information flow will enable NOAA's Space Weather Prediction Center (SWPC), the Office of Space Commerce, and other operational users to deliver actionable information that protects critical power grid infrastructure and civil aviation, and provides essential space situational awareness.

SW Next will maintain and extend space weather observations from a range of different observing points, selected to most efficiently provide the comprehensive knowledge of the sun and the near-earth space environment. These observation points could include LEO, GEO, highly elliptical orbit, and Lagrange Point 1 (L1) and Lagrange Point 5 (L5) orbits. As an initial step, NOAA has signed an agreement with the European Space Agency (ESA) to collaborate on a space weather mission flying at L5. NOAA will provide a coronagraph, ESA will provide the spacecraft, other instruments, and operations, and both Agencies will exploit the observations for science and operations. These observations will provide near-real-time coronal mass ejection imagery, solar wind, solar imaging, coronal imagery, solar wind parameters, magnetospheric particles, and ionosphere parameters, and other relevant observations required to support space weather forecasts provided by SWPC.

This work supports space weather forecasts as authorized by the *Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act* (P.L. 116-181), with the leadership and support of this Committee, and as driven by the National Space Weather Strategy and Action Plan (March 2019). Several complementary projects within SW Next will provide continuity and resiliency of space weather observations from multiple orbits with launches in the 2020s, early 2030s, and onward. Just as with our LEO portfolio, it is important to note that this increase in the amount and diversity of the data must be accompanied by improvements in our space environment and weather models, requiring the models to adapt and increase their resolution and available computing power.

Space weather observations are needed from a multitude of orbit views, so NOAA is pursuing partnerships to augment the SW Next architecture. This year for the first time, NOAA is working with NASA and the NSF to engage the National Academy of Science, Engineering and Medicine (NASEM) to complete the Decadal Survey for Solar and Space Physics 2024-2033. NOAA will use the NASEM recommendations to inform its observing system decisions, and to improve coordination with NASA and the NSF while addressing combined observational objectives. In addition, SW Next is developing a methodology to understand the impacts of observational capabilities on user needs such as alerts, watches, and warnings. We are engaging with users to better understand how our products and services support end-user decision-making. This process will aid in prioritizing NOAA program requirements and in assessing potential economic and societal benefits. The SW Next program is evaluating its alternatives to determine the most cost-effective architecture to meet user needs and will continue to leverage user engagement to identify and prioritize user needs across the enterprise.

Conclusion

NOAA's next-generation satellite architecture provides the environmental space-based observations needed for critical weather forecasts and to meet the growing needs of the Nation in a changing environment. NOAA's integrated next-generation observing system will leverage new and existing technologies and partnerships at all levels, and will combine data from various sources, allowing us to deliver significantly improved products and services to our users. The urgency of our changing environment requires action now to better fulfill NOAA's essential mission to protect lives, property, critical infrastructure, and our economy.

The challenges our nation and planet face demand the continued partnership of federal agencies, each of which brings longstanding expertise in our respective areas. Alongside and in cooperation with the commercial sector's activities, academia, international partners, and investments in NASA, USGS, and NOAA's next-generation satellites will allow us all to better serve the Nation.