REPORT TO CONGRESS

REPORT ON REQUIREMENTS OF NOAA'S NEXT-GENERATION SATELLITES

Developed pursuant to: Joint Explanatory Statement accompanying the Commerce, Justice, Science, and Related Agencies Appropriations Act, 2022 (Public Law 117-103)

Stephen M. Volz, Ph.D.
Assistant Administrator for Satellite and Information Services
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration

Dr. Richard W. Spinrad
Under Secretary of Commerce for Oceans and Atmosphere
and NOAA Administrator

THE JOINT EXPLANATORY STATEMENT ACCOMPANYING THE COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES APPROPRIATIONS ACT, 2022 (PUBLIC LAW 117-103) INCLUDED THE FOLLOWING LANGUAGE

No later than 180 days after enactment of this Act, NESDIS shall provide the Committees with a report about the user needs and requirements and estimated lifecycle costs of the next generation of NOAA flagship weather satellites, including GeoXO, LEO Weather Satellites, and SW Next.

THIS REPORT RESPONDS TO THE COMMITTEES' REQUEST.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

This report provides information on the user needs, requirements, and estimated lifecycle costs of the National Oceanic and Atmospheric Administration's (NOAA) next-generation satellites, including GeoXO, NEON (formerly known as LEO Weather Satellites), and SW Next.

II. INTRODUCTION: NOAA SATELLITE PROGRAM

NOAA is an international leader of the operational satellite agencies in terms of size and scale of our constellation. We have been monitoring the Earth from space since the beginning of the Space Age, with a first launch in the early 1960s as the Environmental Science Services Administration working with the National Aeronautics and Space Administration (NASA), before NOAA was established. From the vantage point of space, our satellites allow us to study Earth as a holistic system and provide a historical record of environmental change going back 60 years and continuing forward.

The NOAA National Environmental Satellite, Data, and Information Service (NESDIS) develops and deploys satellite observing systems to meet the complex needs of our Nation and international partners with critical data, products, and services. NESDIS maintains, within the National Centers for Environmental Information (NCEI) one of the world's largest environmental data archives, including data from all NOAA satellite observations and from some partner satellites, as well as other NOAA ground and in situ observing systems. Our close connections with our partners and with users from end to end are integral to all of our system development activities.

NESDIS' satellite data and information have provided an essential basis for NOAA's weather forecasting mission to provide forecasts, watches, and warnings for the protection of life and property. Our overall satellite observing system is managed as a mosaic of interconnected portfolios, each of which is essential for meeting our overall NOAA mission, extending well beyond weather forecasting to include all elements of NOAA. The broad NOAA mission continues to evolve in order to help the Nation monitor, respond to, and plan for atmospheric weather and related extreme events, climate change, ocean variability, and space weather.

Improvements to satellite data and information are focused on meeting the evolving needs for end-use products and services that are provided reliably. Over the past five years, even through the COVID-19 pandemic, NOAA has had meaningful interactions with numerous stakeholders to ensure that we understand the requirements of our primary customers and downstream users.

NESDIS' next-generation satellite programs will provide enhanced observations through the 2050s to meet growing needs, contributing both continuous and innovative environmental information to diverse end users. 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, protecting the lives and property of the one billion people who live and work in the Americas with continuous, near real-time observations and warnings. Low Earth orbiting (LEO) satellite data, from NESDIS and our partners, are the backbone of global numerical weather prediction (NWP) models and provide detailed observations that range from phytoplankton dynamics to sea level rise to air quality and volcanic eruptions. Space weather observations aid in safeguarding fundamental power grid infrastructure, civil aviation, and on-orbit assets and astronauts.

NESDIS conducted the NOAA Satellite Observing System Architecture (NSOSA) study from 2014 to 2017 to evaluate alternative architectures for its next-generation missions. The study team developed and evaluated over 100 alternatives of complete satellite architectures, including potential and likely partner and commercial contributions. The most promising architectures from the NSOSA study indicated a mixed constellation integrating NOAA, partner, and commercial assets. NESDIS used this high-level information to guide the design and development framework for the future architecture, and its specific prioritization findings continue to develop based on new information and resource constraints.

NOAA’s environmental satellite observations are complementary to partner assets in the global meteorological community, allowing us to share domestic and international partner assets for NWP models and other environmental applications. This effectively doubles or triples the quantity of available observations, improving the quality of our products and the impact of observations on user communities. NESDIS leads in international organizations and promotes data sharing and international collaboration across the Group on Earth Observations, the World Meteorological Organization, and others. NESDIS also forms bilateral partnerships with international groups such as the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) in Europe and the Japan Meteorological Agency, among others. The exploitation of data from NASA science satellites provides early access to improved observations and helps prepare our systems and users for our next-gen observatories.

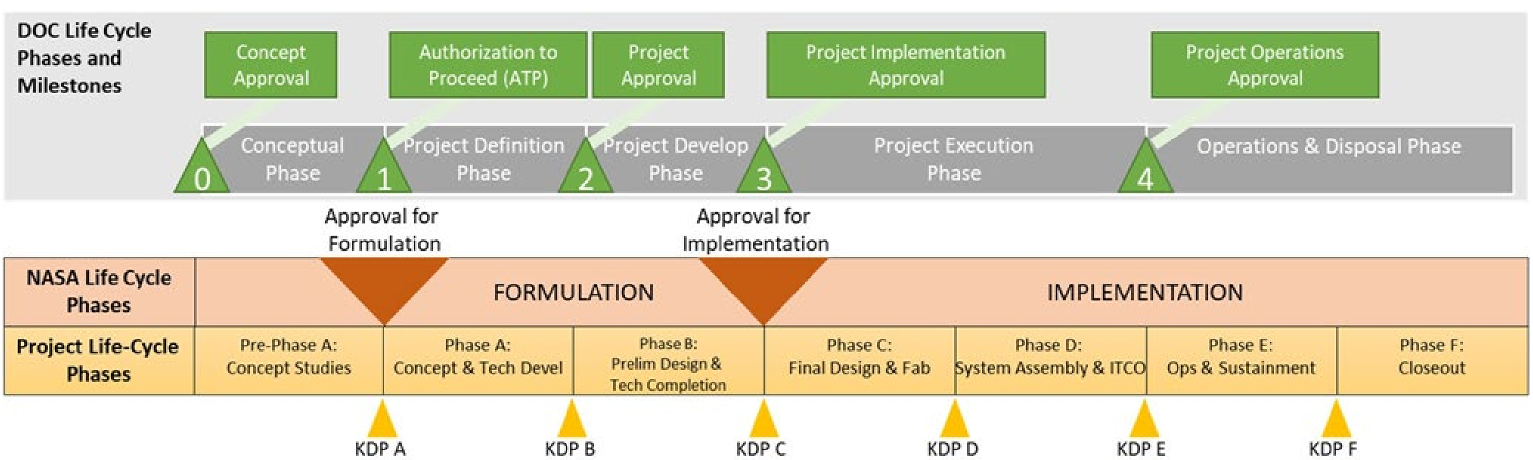
Today, more than ever, NOAA relies on satellites to monitor and forecast changes in terrestrial and space weather, the state of the oceans and coastlines, and the regional and global climate. For the U.S. to remain a world leader, NOAA must be innovative, leveraging new technological solutions, developing broader business models and partnerships with public and private sectors, and demonstrating organizational agility adjusting to changing needs, opportunities, and risks, all while meeting without interruption our critical environmental observations mission. In deciding on the future architecture, NOAA balances opportunities for innovation in the observing system against risks to mission and service continuity, ensuring that we continue to provide the highest-value observations necessary to protect life and property and safeguard our economic livelihood. NOAA, working with its partner the National Aeronautics and Space Administration (NASA), has a long history of developing, testing and then transitioning satellite observing systems into operations.

III. LIFECYCLE COSTS

NOAA is considering a broad trade space for instruments and orbits as well as innovative acquisition strategies and the use of partner and commercial data. Plans for the future GEO, LEO and Space Weather Observations (SWO) architectures are at varying degrees of development and we are working transparently with our partners and customers in defining, developing, deploying, and operating the most cost-effective satellite architecture to accomplish the NOAA weather, space weather, and environmental remote sensing missions. This includes sharing regular updates on the cost estimates for planned mission lifecycles.

The lifecycle cost (LCC) of a satellite program and/or project is defined as the total of the direct, indirect, recurring, and nonrecurring costs, including the construction of facilities, civil servant costs, and other related expenses incurred in the design, development, verification, production, launch/deployment, operation, maintenance, support, and retirement of a program/project over its planned lifespan.[1] Scoping of the next-generation satellite programs is underway and definitive LCCs have not been finalized. Arriving at approved program scopes and final LCCs, along with the relevant technological review assessments, will be developed in close coordination and consultation with NASA and the Department of Commerce's Office of Acquisition Management.

NOAA and NASA follow an integrated program management framework that employs rigorous reviews and checkpoints of programs over the course of their lifecycle, from formulation to retirement (see NESDIS Project Milestones Procedural Requirements and NASA Space Flight Program and Project Management Requirements). As the programs move from initial concepts through formulation, cost, schedule, and technical performance, parameters are refined along with the architecture and reviewed at DOC Milestone (MS) and NOAA/NASA Key Decision Point (KDP) reviews. The figure below shows an example of DOC and NOAA/NASA reviews for a single-project program. At each MS/KDP, the program and projects are assessed prior to being authorized to move to the next phase. Please note that each program is unique, with single-project programs (GeoXO) and loosely coupled programs with multiple projects (SW Next and NEON). Each review structure is tailored to best match decisions required at major acquisition and design points.



- Concept Phase: Determines the feasibility of the proposed concept and its fulfillment of needs and objectives. A review and decision point at the end of this phase determine

[1] 33 U.S.C. § 878a. Contract for development of a major program; costs; Major Program Annual Report for satellite development program.

whether the concept can likely be achieved as conceived and that associated planning is sufficiently mature to begin formulation.

- Definition Phase: During this phase, analyses of alternatives are completed and constellation architecture finalized. The proposed architecture and management plans are reviewed to ensure that the proposed architecture is credible and responsive to program requirements. Validation of completion of definition phase, including an independent assessment of the program acquisition plans, scope, and resources occur at DOC MS2. At this point, the design concepts, cost, and schedule are reasonably understood, with margins included to reflect variables to be resolved in the upcoming preliminary design phase. Successful completion results in authority to proceed to development/preliminary design phase and implementation of acquisition plan. Actions may also be directed at this point to modify or refine concepts before continuing.
- Development Phase: With the architecture defined, preliminary design and technology development can begin. At the end of this phase, the program is reviewed to ensure that management planning, technical design, cost, and schedule baselines are completed and the resources and program are considered sufficiently mature to begin execution. Final commitment to technical, schedule, and cost baselines occurs at the end of this phase.
- Implementation Phase: Final design, integration, and testing. Execution of the program/project is assessed against the baseline plan while maintaining acceptable technical and resource risk level. This oversight continues to the end of the lifecycle.

Before the development phase begins, cost estimates include larger but still quantified uncertainties because some elements of the program are yet to be defined. As the concepts and designs mature and system contractors complete the development phase, the cost and schedules for the efforts become more refined, with higher confidence of successful execution.

At the end of the development phase, an independent cost/schedule estimate is made, to be compared with the program's cost estimate. The independent and program estimates are assessed and reconciled, and a commitment to cost, schedule, and performance is set. Program commitment occurs before the program is given authority to proceed to the implementation phase. At the program commitment point, the program/project is officially baselined with cost, schedule, and technical performance tracked via established NOAA/NASA oversight structures through the remainder of the program lifecycle. Major acquisition programs that have an estimated LCC of more than $250 million are required, pursuant to annual appropriations law, to publish a Baseline Report. Changes to baselines are then provided on an annual basis to Congress via subsequent Major Program Annual Reports. The President's Budget request is also updated annually to reflect the current best estimates or official baseline.

This overall process of mission definition for satellite systems has been developed over the past 50 years by NASA, working closely with the aerospace industry. The programmatic approach has been further refined with NOAA over the past 25 years, enabling us to execute a reliable development and procurement approach for NOAA's operational satellite systems. The budget and schedule estimates developed through the sequential phases of maturity described above have been validated through this process, and allow us to define, with confidence, the critical parameters of these long-lasting and complex systems, including the LCC, launch schedules, technical risks, and expected overall mission performance.

Changes to the total LCC are rare. Since 2013, there have been three LCC changes for the GOES-R Series, with only one since 2016. In 2020, an increase was made due to an unexpected server replacement and sustainment scope changes. Since 2016 there has been one LCC change to the PWS (JPSS plus PFO) program. In 2020, a decrease of $735M was made to accommodate improved efficiencies in program management and systems engineering and reduced costs in hardware elements of the program.

To date, none of our next-generation programs has been officially baselined. This report is centered on user requirements, and outlined programs do not represent approved program scopes. Approved program scopes will be developed as part of the Department's MS2 process, which will culminate in a Milestone Decision Memorandum signed by the Deputy Secretary. Of the programs discussed in this report, only GeoXO is at the stage in program development where it is nearing a MS2 decision, currently scheduled for December 2022.[2] Although space-based commercial data buys are a component of NOAA's next-generation satellite architecture, funding for these purchases is reflected in the NESDIS Systems/Services Architecture & Engineering budget line and is not included in these program life cycle cost estimates or budgets.

Maintaining current satellite performance and capabilities alone will not allow us to provide more accurate and more timely weather forecasts. With current capabilities alone, we will also not meet the growing demand of observations needed to monitor global climate change and its impacts throughout the Earth system and ocean, coastal, and fisheries habitats. New technologies, developed by the commercial sector and fully integrated into an Earth system observing constellation, and new partner observations, will unlock our ability to provide expanded geographical coverage, higher-quality products, and improved delivery of observations and data in support of the NOAA mission. This document lays out the requirements to meet NOAA's satellite observation needs across weather, climate, oceans, and fisheries.

Table 1 (below) outlines the 10-year funding estimates for NESDIS.

[2] By the time of release of this report, the GeoXO MS2/3 has been completed (December 2022), and the GeoXO program baselined.

Table 1. NESDIS 10-year Funding Estimates †

PPA ($, millions)	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	Total
ORF^	$394.4	$402.3	$410.3	$418.5	$426.9	$435.4	$444.1	$453.0	$462.1	$471.3	**$4,318.5**
CGS	$120.9	$120.9	$120.9	$120.9	$120.9	$100.0	$100.0	$100.0	$100.0	$100.0	**$1,104.5**
SAE	$74.5	$54.5	$54.5	$54.5	$54.5	$54.5	$54.5	$54.5	$54.5	$54.5	**$565.0**
PWS	$342.4	$342.4	$342.4	$342.4	$342.4	$292.4	$292.4	$267.4	$267.4	$267.4	**$3,099.0**
LEO^^	$123.6	$200.0	$200.0	$200.0	$200.0	$187.0	$187.0	$187.0	$187.0	$187.0	**$1,858.6**
GOES-R	$276.0	$100.0	$96.0	$96.0	$96.0	$96.0	$96.0	$52.5	$52.5	$52.5	**$1,013.5**
GeoXO*	$417.4	$671.0	$691.5	$1,320.0	$1,320.0	$1,250.0	$1,250.0	$1,250.0	$1,250.0	$1,250.0	**$10,669.9**
SWFO	$97.2	$41.2	$22.3	$21.8	$13.6	$0.0	$0.0	$0.0	$0.0	$0.0	**$196.1**
SW Next**	$225.0	$231.2	$231.2	$231.2	$231.2	$200.0	$200.0	$200.0	$200.0	$200.0	**$2,149.8**
CDA	$2.5	$2.5	$2.5	$2.5	$2.5	$2.5	$2.5	$2.5	$2.5	$2.5	**$25.0**
NESDIS Total	**$2,073.9**	**$2,166.0**	**$2,171.6**	**$2,807.8**	**$2,808.0**	**$2,617.8**	**$2,626.5**	**$2,566.9**	**$2,576.0**	**$2,585.2**	**$24,999.9**

† All future year numbers in the table are subject to change and refinement through the annual President's Budget process. The FY 2024 President's Budget policy proposed a planning level of $25 billion over a ten-year horizon. The numbers in this table represent NESDIS's current plan to maximize the suite of satellite observations within that overall level.

^The NESDIS ORF account consists of four PPAs: Office of Satellite and Product Operations; Product Development, Readiness, and Application; U.S. Group on Earth Observations; and National Centers for Environmental Information.

^^The Near Earth Orbit Network (NEON) is early in its formulation phase. NEON is the follow-on program to the Polar Weather Satellites (PWS). The funding profile relative to program scope and schedule will be continuously evaluated as the program progresses through future milestone reviews.

*The funding profile maintains the approved GeoXO constellation and life cycle cost of $19.6 billion. However, the funding profile is reduced relative to the GeoXO Milestone 2 baseline (by $350M over FY 2029-2033, with payback in out years): this update was made to better align the NESDIS funding profile with overall NOAA and DOC funding priorities. The funding profile relative to program scope and schedule will be continuously evaluated as the program progresses through future milestone reviews.

**The SW Next program is early in its formulation phase. SW Next will sustain, improve, extend, and mitigate potential gaps in observations to support NOAA's space weather forecast operations. The funding profile allows NOAA to continue formulation and development phases for the Lagrange Point 1 (L1) mission, Lagrange Point 5 (L5) partner mission with the European Space Agency. The funding profile relative to program scope and schedule will be continuously evaluated as the program progresses through future milestone reviews

IV. GEOSTATIONARY EARTH ORBIT PORTFOLIO

In 2021, the United States experienced 20 separate billion-dollar weather and climate disasters, putting the year in second place for the most disasters in a calendar year, behind the record 22 events in 2020.[3] The annual average number and the combined cost of billion-dollar disasters have both quadrupled when comparing the 1980s to the 2010s, with annual adjustments to address inflation using the Consumer Price Index. Geostationary satellite observations, provided in near real-time to users, inform the public about these extreme weather events, provide critical information for ocean and coastal resource management and weather-vulnerable industries, and ultimately help protect the Nation's communities and economy.

The Geostationary Extended Observations (GeoXO) program is the next generation of GEO capabilities that will support strategic objectives involving terrestrial weather prediction and warning, climate adaptation and mitigation, healthy oceans, and resilient coastal communities and economies. As the follow-on program to the Geostationary Operational Environmental Satellite-R (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 and the high mission return, GeoXO is our largest investment through the early 2030s and has an aggressive 11-year development schedule.

Among a wide range of potential alternatives, NSOSA narrowed the trade space for geostationary observations to the highest-value architectures and recommended that NESDIS further evaluate three options: a constellation that occupied both GEO and tundra orbits and included Earth and space weather observations; a GEO-only constellation with Earth and space weather observations; and a disaggregation of the Earth and space weather capabilities. NSOSA also recommended that NESDIS evaluate options for use of commercial services, specifically commercial communications services for all rebroadcast services and payload hosting. In its pre-formulation phase between 2019 and 2021, NESDIS evaluated these NSOSA recommendations and further refined the trade space, ultimately selecting a GEO architecture that makes selective use of commercial services as the program baseline, and which moves the space weather observations to a stand-alone NESDIS program element, in the SWO portfolio. We further concluded that the tundra orbiting observations should not be included in the baseline GEO plan, both because of cost and the limited additional operational impact of the observations to meet NOAA's mission. The GeoXO pre-formulation phase included extensive user outreach – to thousands of end users in dozens of organizations – 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 a range of hazardous environmental conditions, such as tropical storms, lightning and winds, flooding, snow, wildfires, volcanic ash, and others. Imagers and lightning mappers in NESDIS' geostationary observing system support NOAA's National Weather Service (NWS) with essential information to inform and protect people and property

---

[3] National Centers for Environmental Information: www.ncei.noaa.gov/access/monitoring/billions/#:~:text=In%202021%2C%20there%20were%2020,and%201%20winter%20storm%20event

across the country. Our analyses also indicated that imagers and lightning mappers, even with performance improvements, would not address the growing need for improved forecasts and services. New observations were needed to meet their evolving weather and environmental monitoring needs as the global climate continues to change.

A hyperspectral infrared sounder would improve localized forecasts and nowcasting – critical as weather disasters including severe storms, tornados, and hurricanes continue to worsen – by enhancing NWP models. Simulations show that a GEO Sounder has potential to provide the largest 24-hr forecast error reduction for the U.S. among all other LEO/GEO instruments, improving regional forecasting up to 40 percent. For severe weather, a sounder will provide increased atmospheric condition data in real time for nowcasting, localized forecasts, and Warn-on-Forecast.

In addition, the Imager has improved spatial resolution in multiple channels for more precise warning and watch areas, improved forecasting, and earlier wildfire detection. It also has two new channels which improve measurement of low-level water vapor, which is key for severe weather and is a region where numerical models often struggle. An atmospheric composition instrument would meet users' needs to monitor air quality, track dispersion of hazardous emissions (volcanic, chemical, and radioactive), and monitor greenhouse gases for climate forecasting.

Observations of ocean biology, chemistry, and ecology by a geostationary ocean color instrument would enable NOAA's National Ocean Service (NOS) and National Marine Fisheries Service (NMFS) to 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, all key requirements of NOAA's mission. The ocean color instrument would gather data from the ultraviolet through near-infrared spectrum, expanding upon NOAA's ocean observing system that supports the blue economy and increases coastal community resilience in the wake of sea level rise and coastal flooding. The geostationary observing location will reveal important diurnal variations in harmful algal bloom evolution and propagation and will ensure persistent cloudy regions common in coastal zones will be tracked effectively.

The international partnership of GEO satellites provides potential to leverage GEO data into innovative global inputs that supplement LEO observations. NESDIS already benefits from acquisition efficiencies as other partners share U.S. instrument vendors.

NESDIS has determined that the requirements for the GeoXO program are to collect and deliver these observations:

- High-resolution imagery;
- Lightning mapping;
- Day/night imagery;
- Hyperspectral infrared sounding
- Atmospheric composition measurement; and
- Ocean color imagery.

These observations will be matched with similar satellite missions deployed by our international meteorological agency partners in the same period, deployed by EUMETSAT over Europe and the Japanese Meteorological Agency and Korean Meteorological Agency over the western Pacific and Asia. The combined effect of these observations will provide global data sets for use by NOAA to meet its global modeling system and mission service needs.

The GeoXO program will include satellites that host five high-priority Earth-observing instruments – Imager, Sounder, Lightning Mapper, Ocean Color, and Atmospheric Composition – and a Data Collection System (DCS) signal relay service. The program scope also includes ground segment command and control, and data product development, processing and distribution. Ground capabilities will be implemented through an architecture of program-developed, mission-unique capabilities, as well as NESDIS-developed enterprise ground system capabilities featuring cloud-based product generation and delivery. Data distribution for users that need radio frequency broadcast will be provided by commercial services funded through GeoXO. Over the program's operational lifetime, program scope also includes operations, maintenance, and sustainment.

To meet these requirements, GeoXO is a series with six geostationary satellites operated in a constellation of three (East & West satellites with Imager, Lightning Mapper, and Ocean Color instrument, plus Central satellite with Sounder and Atmospheric Composition instrument), as illustrated in the figure below. As has been the case for the previous GOES programs, GeoXO will also plan to maintain an on-orbit spare for the East/West satellites in order to have a backup ready to go quickly into service in case of a problem with an operational Imager.

GeoXO activities and assets include development and delivery of six spacecraft and instruments, an on-orbit Imager satellite spare, partner data, science efforts to develop and maintain the data algorithms for the products, and operations of all the satellites through 2055. GeoXO is scheduled to have a DOC baseline and an independent assessment of resource and acquisition plans at DOC MS2, which is targeted for December 2022.[4] Engineering design studies will then continue with contractors on-board to develop the final architecture and detailed design. At the conclusion of the formulation phase, another set of independent assessments will validate final scope, cost, and schedule prior to the KDP-C for baseline commitment. At this program commitment point, the baseline will be formalized, and the program will be given authority to begin the execution and build phase. NOAA-NASA program commitment is planned for 2026. The program development table (with upcoming steps highlighted) and 5-year profile for GeoXO are included below.

Table 2. Program development timeline for GeoXO. Dates are notional.

DOC Acquisition Milestones		**Program Key Decision Points**	
MS1	Q1 FY 2022	KDP-A	Q4 FY 2021
MS2	Q1 FY 2023	KDP-B	Q1 FY 2025
MS3	Q1 FY 2026	KDP-C	Q4 FY 2025
MS4	Q3 FY 2032	KDP-D	Q1 FY 2031
Project Launch Readiness Dates		KDP-E	Q3 FY 2032
Imager-1	Q1 FY 2033		
Imager-2	Q3 FY 2035		
Sounder-1	Q1 FY 2036		
Imager-3	Q3 FY 2039		
Sounder-2	Q1 FY 2041		
Imager-4	Q1 FY 2043		

[4] The Milestone 2/3 review was successfully completed December 12, 2022.

Table 3. Five-year profile for GeoXO

GeoXO Funding Profile (Budget Authority in $K)	
FY 2023	$285,000
FY 2024	$417,429
FY 2025	$671,000
FY 2026	$691,500
FY 2027	$1,320,000

V. LOW EARTH ORBIT PORTFOLIO

Earth-observing satellites provide over 90 percent of the data routinely assimilated into NWS NWP models, and low Earth orbiting (also known as polar-orbiting) satellites are the backbone of global NWP models.[5] These satellites detect and monitor hazards such as fires, droughts, floods, poor air quality, coral bleaching events, harmful coastal waters, and others, complementing observations and expanding the geographic coverage provided by the GeoXO suite. NESDIS collects about 50 percent of required LEO data from our operational and research partners to meet our ongoing mission needs, with the balance provided by our partner Agencies such as EUMETSAT, Japanese Aerospace Exploration Agency, and Indian Space Research Organisation.[6] NOAA's NEON will provide continuity of our polar weather satellites and data; feature a disaggregated, agile approach to leverage commercial space capabilities; and serve all NOAA Line Offices, including NWS, NOS, NMFS, and the Office of Oceanic and Atmospheric Research. With multiple orbits, this distributed constellation of satellites will provide greater data diversity needed by the NWP models, 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. Over 40 years of LEO measurements from NOAA satellites also provide critical climate data records; NEON will ensure these data records remain unbroken.

The NSOSA study indicated that the LEO constellation would include a mixture of satellite types, potentially including smaller satellites, flying more frequently in more diverse orbits, and having a greater variety of instruments. The study recommended a number of attributes for the mature constellation:

- Feature infrared (IR), microwave (MW), and radio occultation (RO) sounders
- Fly in as many as four sun-synchronous orbits with different equator crossing times

[5] National Weather Service: www.nco.ncep.noaa.gov/sib/counts/March_2022.html

[6] National Environmental Satellite, Data, and Information Service: www.nesdis.noaa.gov/s3/2022-05/NESDIS-REQ-1002-1.pdf .

- Have different measurement types supported on separate satellites, supporting a more directed replenishment approach
- Include lightweight ocean surface vector wind sensors and enhanced day-night-band imaging capability (smallsat family)
- Fly in additional orbits beyond a single sun-synchronous orbit (smallsat family)
- Feature smallsat instrument performance that is similar to, but not necessarily identical to, that of current systems such as JPSS
- Support, if needed, additional selective capabilities requiring a larger, dedicated satellite, with operational Doppler wind Light Detection and Ranging as the leading candidate (depending on results from current demonstration missions, technology developments, and forecast impact studies)

A variety of instruments (with size and cost profiles that are compatible with smaller LEO satellites) are feasible and will be evaluated in future acquisition studies. During the formulation period, the program will continue to participate in NESDIS user engagement activities to identify and prioritize user needs that require support from LEO observational platforms. Capability gaps are defined and prioritized based on relative user impact and assessment of societal and economic benefits.

Users require continuity of critical existing observations provided by JPSS. For accurate forecasts, NWP models integrate measurements from MW, IR, and RO sounders on polar satellites. These observations are especially important in polar regions where other observational data are sparse; for example, JPSS provides critical data for nearly all weather forecasting in Alaska for aviation and the maritime industry. Ozone measurements track the health of the ozone layer. JPSS also provides vital data for wind speed, sea surface temperature, and ocean color for NOS and NMFS.

End users have indicated a desire for enhanced observations and forecasts to meet evolving needs such as higher-resolution short- and long-term weather forecasts, improved information about ocean ecology, accurate forecasts of air quality hazards, and others. For example, improved MW, IR, and RO soundings with more frequent observations and better spatial and vertical resolution would improve modeling to allow for higher-resolution short- and long-term weather forecasts.

NESDIS has studied and evaluated the relative importance and contribution to weather models of the following global observations:

- Microwave soundings and imagery;
- Hyperspectral infrared soundings;
- Radio occultation soundings;
- Visible-infrared imaging, including day-night band imagery;
- Measurements of atmospheric chemistry, including ozone;
- Ocean surface winds;
- Ocean color;
- Radio detection and ranging (RADAR) imagery;
- 3D winds; and

- Ocean surface height.

The NEON program is established as loosely coupled projects to pursue broad trade-space regarding instruments, platforms, launch policy, orbits, and resourcing other sources of data. NEON has started their formulation efforts to assess technical alternatives, define constellation architecture, and assess costs for individual projects. Following the NESDIS Program Milestone Procedural Requirements, the program is planning and designing the proposed concept. Once the concept definition and design are approved through the established processes noted above to build the architecture and cost estimates, the Program will seek approval for implementation with a proposed LCC. Following the launch of the QuickSounder mission in Q1 of FY 2026, the next NEON mission is notionally planned for the early 2030s. Contract information from the QuickSounder mission and data from the Phase A studies that will be funded in FY 2023 will refine the cost estimates. For now, the five-year profile below for NEON supports the development and launch of the QuickSounder mission, which will inform the initial development for future NEON missions, and broader NEON program formulation activities. The program development table below shows the QuickSounder schedule, which will inform proceeding schedules, and the budget authority for the NEON program, which encompasses QuickSounder.

Table 4. Program development timeline for QuickSounder. Dates are notional.

DOC Acquisition Milestones		**Program Key Decision Points**	
MS1	Q4 FY 2022	KDP-A	N/A*
MS2	Q1 FY 2023	KDP-B	N/A*
MS3	Q3 FY 2024	KDP-C	Q3 FY 2024
MS4	N/A*	KDP-D	N/A*
Project Launch Readiness Dates		KDP-E	Q1 FY 2026
QuickSounder	Q1 FY 2026		

*Certain Key Decision Points and Milestones are not applicable (N/A), as QuickSounder is classified as a streamlined mission with fewer documentation requirements and process reviews.

Table 5. Five-year profile for NEON, which includes QuickSounder.

NEON **Funding Profile (Budget Authority in $K)**	
FY 2023	$78,330
FY 2024	$123,590
FY 2025	$200,000
FY 2026	$200,000
FY 2027	$200,000

The first NEON mission, QuickSounder, is an early risk reduction and demonstration mission that will allow NOAA to gain experience with new commercial business models, acquisition strategies, and programmatic review and approval processes that the NEON program might later leverage. The program is in the process of further refining and validating assessments for the design and schedule of the project. The QuickSounder project completed DOC MS1 in August 2022, which validated the mission need and acceptable mission risk. The current estimate for the total system cost of QuickSounder is less than $250 million; this includes flight hardware, ground systems and operations, and science product development. The estimate was validated during MS2 in December 2022. The targeted launch date for QuickSounder is in late 2025. Simultaneously, the NEON program will be working on the initial project concepts and design for subsequent NEON missions. The balance of NEON funding will be used to explore advancements in the commercial aerospace industry while evaluating trade-space between architecture, density, instruments and value, to help define and begin to build the next generation of polar orbiting satellites. This includes the formulation studies and development contracts for NEON series 1 (microwave and infrared sounders).

VI. SPACE WEATHER OBSERVATIONS PORTFOLIO

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 4 to 10 years for full recovery.[7] The Space Weather Next (SW Next) program will provide critical space weather products and services to mitigate this hazard and support the needs of diverse users across the United States and internationally, including 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 and measurements from NESDIS' SW Next program will be combined with complementary data collected by NOAA's research and operational partners and processed through NESDIS' Office of Satellite Ground Services, to provide the necessary information flow for space weather forecasts. This data and information flow will enable the Space Weather Prediction Center (SWPC) at NWS, 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 will include LEO, GEO, highly elliptical orbit, Lagrange Point 1 (L1) orbit, and extended orbits for near real-time coronal mass ejection imagery, solar wind, solar imaging, coronal imagery, solar wind parameters, solar imaging, magnetospheric particles, and ionosphere parameters, and other relevant observations required to support space weather forecasts provided by NWS SWPC. The program supports space weather forecasts as authorized by the *Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act* (Public Law 116-181) 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.

NSOSA provided the basis for architectural frameworks for the future to allow for resilience, flexibility, and cost-effective implementations. These included the use of small and medium satellite platforms, evolving and integrating partner observations, new and more observations needed by models to increase capability, and providing onramps for new technologies. For space weather, NSOSA identified the need to continue the program of record that included the upstream solar wind observations, coronal and solar imagery along the Sun-Earth Line (SEL), and magnetospheric and ionospheric observations (e.g., GOES-R series, COSMIC-2, LEO satellites, SWFO). NSOSA also provided an initial list of high-value, prioritized new capabilities beyond the program of record for NOAA to consider, including off-SEL coronal and solar imagery, heliospheric imagery and solar wind parameters, auroral imagery, thermospheric density, and photospheric magnetograph imagery on the SEL. The NSOSA recommendations are central for the SW Next program along with needs defined in the NOAA Consolidated User

[7] National Research Council: https://nap.nationalacademies.org/read/12643/chapter/1

Observational Requirements, the National Academies of Science Decadal Survey in Solar and Space Physics, and reports from the White House Office of Science and Technology Policy, Space Weather Operations, Research, and Mitigation subcommittee.

Space weather observations are needed from a multitude of orbit views, requiring multiple program capabilities to fulfill the necessary architecture. SW Next is therefore pursuing viable partnerships to augment the SW Next objective architecture. In addition, SW Next is developing a methodology to understand the impacts of observational capabilities on user needs such as alerts, watches, and warnings. In addition, we are leveraging user engagements to understand the impacts of predictive product use on end-user decision-making and how those decisions impact systems and services. This process will aid in prioritizing NOAA program requirements and in assessing potential economic/societal benefits. The SW Next program is evaluating cost-to-benefits of architectural implementation options in its analysis of alternatives to determine the most cost-effective architecture to meet user needs. The program will continue to participate in and be supported by NESDIS user engagement activities that identify and prioritize user needs across the enterprise.

NESDIS has studied and evaluated the relative importance to the space weather program of the following observations:

- Coronal imagery;
- Solar imagery;
- Solar wind parameters;
- Heliospheric imagery;
- Magnetospheric parameters;
- Ionospheric parameters;
- Thermospheric parameters; and
- Photospheric magnetograph imagery.

SW Next will provide continuity of highest priority space weather observatories from NOAA and agency partner missions, and it may evolve to provide observations for additional products or enhanced performance of current measurements as informed by continuing and emerging needs of NWS SWPC and its operational partners in the U.S. Air Force and Space Force, to enable generation and improvement of space weather products and services. These users require continuity of coronal and solar imagery for early warnings of space weather events, and ionospheric and magnetospheric observations for disturbances from solar and geomagnetic activity. The most critical of these observations are required along the SEL, including Earth-impacting coronal mass ejections and the magnetic and particle disturbances they can carry. For resilience and critical data continuity for at least the SWFO-L1 mission, the SW Next L1-series project needs to launch its first system in 2028. Users also require new observations to enable longer lead time and more accurate solar storm warnings through operational off-SEL, or Lagrange Point 5 (L5), observations through a partnership with the European Space Agency (ESA) L5 “Vigil” mission. Aviation, energy, and defense sectors use forecasts of auroral oval location and probability. In addition, aviation, space commerce, energy, and defense sectors require enhanced thermosphere imagery and upper atmospheric weather and satellite drag forecasting.

As with NEON, SW Next is very early in formulation efforts with significant work to go toward assessing technical alternatives, defining constellation architecture, and assessing cost for the full program. The SW Next program as a whole is far from completing the necessary activities to provide an LCC estimate with an associated specific mission content with confidence. In the next few years, the program will undergo the established processes noted above to build the architecture and cost estimates. The first mission of the program can be established, however; it will be the L1 mission, which is in formulation and in preparation for MS2 in Q2 of FY 2023. As the L1 Series completes the milestones for authority to proceed, the LCC will be baselined, refined, and formally reported. For now, the 5-year profile below for SW Next supports program and initial project formulation activities, as well as design and development activities for the first L1 mission and hosted compact coronagraph on an ESA Vigil L5 mission. The program development table is also included below.

Table 6. Program development timeline for SW Next program. Dates are notional.

DOC Acquisition Milestones		**Program Key Decision Points**	
MS1	Q4 FY 2022	KDP-0	Q4 FY 2022
Project Launch Readiness Dates		KDP-1	Q3 FY 2023
L1	Q1 FY 2029		
L5 ESA Vigil	Q1 FY 2029		

Table 7. Five-year profile for SW Next.

SW Next Funding Profile (Budget Authority in $K)	
FY 2023	151,606
FY 2024	$225,000
FY 2025	$231,200
FY 2026	$231,200
FY 2027	$231,200

VII. CONCLUSION

To ensure that the Nation has the essential observations needed to deliver accurate weather forecasts, and to provide new and enhanced products and services to address the global climate crisis, NOAA’s satellite budget must proactively support both current and next-generation satellite programs. Taken together, the GeoXO, NEON, and SW Next programs continue the long legacy of reliable delivery from NESDIS, advancing the NESDIS strategic principles of commitment through continuity of products and services; of community through the combination of internal strengths and contributions from partners; and of capabilities through integrated architecture and use-inspired science.

The GEO portfolio of satellites provides the only persistent coverage of weather and dangerous environmental conditions in the Western Hemisphere, protecting the lives and property of the 1 billion people who live and work in the Americas. NOAA established the GeoXO program to continue the critical imagery and lightning observations currently provided by the GOES-R Series and to expand the NOAA’s geostationary observations to meet growing user needs for improved weather prediction, ocean monitoring, and air quality measurements. GeoXO will provide essential information for disaster preparation and prevention, meet international expectations, and support the Biden-Harris Administration’s climate change and environmental justice objectives.

The LEO portfolio of satellites circles the Earth from pole to pole and is the backbone of the global observing system critical for weather forecasting, environmental monitoring, and provides critical elements to inform public warnings associated with severe weather events. It is particularly important for monitoring polar regions where other observational data are sparse. The LEO program’s architectural shift from large, multi-instrument satellites to a mixture of smaller satellites and rapid responses to changes in observational needs will increase the accuracy of our NWP models and other critical products and services.

The SWO portfolio provides critical operational, satellite-based, space weather observations and measurements necessary to generate and improve space weather products and services. Space weather is a high-consequence natural hazard, capable of damaging electric utility grids, interrupting navigation and communications, harming astronaut health and safety, and disabling key national security assets in space and on the ground. Space weather observations mitigate this hazard and support the growing commercial space sector by enabling SWO’s users, such as NOAA’s Space Weather Prediction Center, to issue timely and accurate forecasts, warnings, and alerts that protect life on earth and in orbit. NOAA established the SW Next program to provide space weather measurements, including remote observations of the Sun and space-based in situ measurements, to support space weather forecasting requirements through a comprehensive, multi-orbit regime. SW Next will also develop ground services and partner arrangements to support NOAA space weather assets and to acquire and ingest space weather data from NOAA and partner space weather observatories.

Today’s investments in NOAA’s next-generation satellite architecture will allow us to make the observations needed to improve weather forecasts and monitor global climate change and its impacts throughout the Earth system, and ocean, coastal, and fisheries habitats. By leveraging new technologies, a fully integrated system observing constellation, and partnerships across scales, we will more completely deliver the NOAA mission.