National Aeronautics and Space Administration

EARTH SCIENCE TO ACTION STRATEGY 2024-2034

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Note From the Director

The climate and our environment are changing at an accelerating rate. Anthropogenic activities and natural processes are driving and being driven by this change. These result in both steady (e.g., gradual rise in global temperature) and abrupt effects (e.g., extreme events increasing in frequency and intensity). These global changes are having dramatic and interconnected impacts on the quality of life on Earth: quality of the air, availability and quality of water and food resources, droughts, wildfires, extreme heat waves, viability of coastal lands, loss of arable land, loss of biodiversity, all so critical to humans.

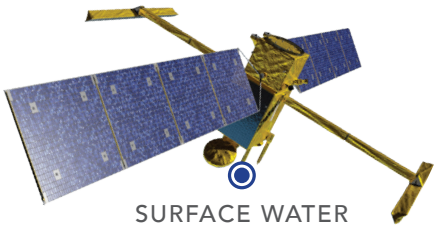
Dr Karen St. Germain,
Director, NASA Earth Science Division

This makes our current time a particularly unique moment. Advances in technology, transportation, agriculture, energy and global trade have lifted more people from poverty than any other time in history. Yet, the very same infrastructure and economics that have been optimized to deliver are now vulnerable to disruption. Changes in our environment are currently outpacing our ability to mitigate and adapt, which we must do to continue to thrive. Leaders at all levels from neighborhoods to nations, from family businesses to global suppliers, must have the best scientific insight and knowledge to inform their actions. And it is their actions that this strategy is seeking to enable.

To analyze, understand, and predict these global changes, society demands diverse and trustworthy data sources and tools to inform critical decisions and support strategies to mitigate these changes and adapt to them. As a NASA Earth science team, we recognize these needs will increasingly affect how we advance necessary technology; how we prioritize, design, and deploy future observing systems; how we design the structure and capabilities of our information systems; how we tackle research and analysis challenges; and how we approach the ways we interact with stakeholders in developing applications and tailored solutions for a positive impact on society and the economy. The urgency of this demand requires an ambitious and transformative strategy and implementation approach to align NASA Earth science and the efforts of our science and technology communities to respond to these challenges with the appropriate accuracy and at a pace consistent with the change we are seeing.

These challenges are global in nature, interconnected, and therefore are best addressed through collaborations, partnerships and by joining forces.

Over more than 50 years, NASA missions and science have built the foundational understanding of how our home planet works and changes. This Earth Science to Action strategy leverages this foundation and NASA's unique end-to-end capability as a space and science agency to enable society and decision-makers everywhere to address the most pressing challenges posed by the changing environment. My team and I will build on NASA's distinguished heritage of leading innovation and discovery, continue working with the broader Earth science community, strengthen our role as an enabling force, and collectively develop the scientific tools, models, and information systems needed to achieve the goals and objectives of this strategy. We undertake this challenge and opportunity with a sense of urgency and responsibility. I invite you to join us.



SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

Executive Summary

This NASA Earth Science to Action strategy is in response to this particular moment in the state of our Earth environment. While the increasingly frequent and intense impacts of a changing global environment are being felt more widely, these changes are harder to predict than in previous decades. Simultaneously, the reliance of governments, society and the economy on environmental information has increased significantly, which translates into demand for more sophisticated, more accurate, more trustworthy, and more actionable information at the fingertips of decision-makers, policymakers, and action takers. This also requires more complex science questions to be addressed, to better understand the Earth-human system. This strategy is intended to provide the best possible support to meet these needs today and to allow us to be agile to meet future demands.

NASA's Earth Science to Action strategy aligns our assets to provide actionable information for a wide range of actors and decision-makers, and to do so for a variety of impactful areas identified for their strategic importance to national and international priorities.

NASA is in a unique position to lead an ambitious and transformative effort, grounded in the most advanced Earth system science, to support major national and international strategies to limit or mitigate the effects of, and adapt to, the impacts of the global change affecting our planet. By providing the mechanisms to leverage existing and upcoming space missions and vast amounts of scientific data, knowledge, and modeling capabilities, NASA can create end-to-end linkages to generate information and tools that support policy and decision-making for society's well-being. NASA will work ever more closely with our partners to further understand how the Earth

system works and transform this knowledge into actionable information to respond to challenges from changing climate natural hazards and risks.

The strategy is built around two main objectives for the next ten years: (1) integrating and advancing our scientific knowledge and (2) delivering trusted information based on that knowledge. These objectives are supported by eight measurable key results to be able to assess progress toward the strategic goal. When executed, through five core values and five implementation guiding principles, NASA's strategy will generate science-based information that will also create significant opportunities for society and the economy (e.g., to support public health enhancement, intelligent agriculture, renewable and lower-cost energy, spatial optimization of urban planning, identification of local areas with exposure/vulnerability to environmental risks, etc.). This will allow us to extend NASA's capability to provide unique, trustworthy, accurate and validated information that enhances knowledge and directly supports a wide range of actions, decisions, and policymaking across sectors at global, national, regional, and local scales. Implementation of this strategy is possible because of the NASA expertise, missions, and research assets that already exist and continue to be forthcoming, as well as the long-standing, extensive partnerships our agency relies on for the successful execution of our mission. We will build on these assets and when appropriate, expand them to achieve the objectives of this strategy.

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Background and Gaps

The rapidly changing environment of planet Earth and the impacts of that change on the close relationship between our environment and our ability to thrive, pose challenges to our future. Scientific discovery provides the factual, unbiased, and trusted means to document, understand, and forecast these changes in the Earth system.

A growing body of studies warn that impacts on the human species will increase dramatically if no decisive action is taken. The magnitude of these impacts points to the necessity of urgent action to mitigate them and empower humanity's path to a thriving future. Decision-makers around the globe, including in the United States, are responding by developing mitigation and adaptation strategies at the international, national, interagency, and local levels.

NASA has long contributed to the efforts to measure, monitor, understand, and predict the Earth environment including its climate trends and global changes. The agency's constellation of space-based global observing platforms has increased in capability in the recent decade due to advancing technology and the increasing number of national and international partners now active in the Earth science enterprise. These assets allow us to take a regular pulse of the Earth's state, by measuring key parameters of the atmosphere including aerosols, clouds, precipitation, greenhouse gases, as well as parameters related to oceans, rivers, and land, including vegetation, sea surface temperature and salinity, hydrology, volcanic eruptions, forestation extent, various surface types including deserts, ice, and snow. NASA has also developed many of the high-value tools and applications linking Earth observations to societal benefits, and these are yielding positive results. However, more is urgently needed at local, regional, national, and global scales, as a significant gap remains between accelerating science and technology, and the capability of society to exploit those advances.

We can close that gap by translating and transforming our Earth science into actionable information that people can understand and use quickly and easily.

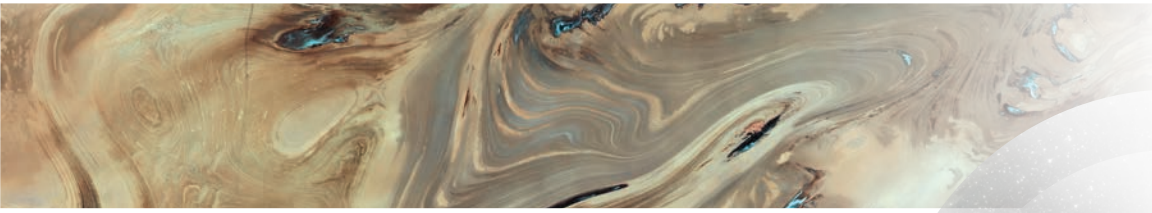
Some examples of such existing gaps include:

1. Some of the current Earth science tools and applications need significant scaling to enable application in other regions and to relevant stakeholders.
2. Some of the needed Earth observations require increases in temporal and spatial sampling to be actionable.
3. Some of the information needs to be integrated from multiple sources and curated for specific purposes.
4. There are many Earth science questions that remain to be addressed through research to enhance our understanding, and therefore our capacity to predict.
5. There is a need for better understanding of the mechanisms that interconnect the different components of the Earth system, including human and socio-economic ones and their feedback mechanisms and, in some cases, better appreciation for the cascading effects of interconnected processes.
6. There is a need to coalesce the vast amount of existing knowledge and more readily reflect it into end-to-end tools and systems that efficiently support decision and policy-making strategies.

Complexity and Urgency

NASA Earth scientists are not alone in highlighting the urgent need to provide trusted information and tools to support effective, science-based responses to our planet's changes. Many national and international bodies highlight this urgency and point to the increasing complexity of the problem. Some of the most relevant findings, recommendations, and priorities are listed below. They form the basis for a renewed emphasis and comprehensive strategy for NASA Earth science.

- **The National Academies Decadal Challenge to Increasingly Ambitious Science/Applications:** The most recent U.S. National Academy of Science, Engineering, and Medicine (NASEM) Decadal Survey (2018) for Earth Science and Applications from Space, "*Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space,*" provided several recommendations for the next decade (2018 - 2027) and serves as critical guidance for NASA in its planning for technology development,



missions, and science endeavors. One of that survey's most important statements captured recommendations to the community at large in the form of a central community decadal challenge: "*Pursue increasingly ambitious objectives and innovative solutions that enhance and accelerate the science/applications value of space-based Earth observations and analysis to the nation and to the world in a way that delivers great value ….*". The Earth Science to Action strategy allows us to take on that challenge holistically across the Earth science enterprise and engage help from the wider Earth science community, to bridge the gap between what is currently available and what is needed.

- **U.S. Global Change Research Program Points to Growth in Demand for Authoritative Information:** The most recent interagency USGCRP Strategic Plan (2022-2031) lists some of the incentives that should drive global change research and lays goals and priorities for federal global change research. For instance, it references changes that are "*increasing the risk of infrastructure failure; disruption to vital public services; threats to ecosystems and species that provide benefits to people; harms to workers, industries, and the economy; and heat-related illness and death and other health impacts… causing severe disruption to essential systems—including food, water, health, energy, transportation, and natural and managed ecosystems—that help keep people safe and healthy…—including biodiversity loss; urbanization and deforestation; and ocean acidification, deoxygenation, and other profound changes—compound risks to people and ecosystems.*" Referring to climate change itself, the USGCRP report notes the complexity of its interaction with other global changes, creating "*multiple cascading risks that can amplify harmful impacts." The strategy then highlights that "... climate and global change-related impacts have accelerated*" before noting that "*demand for authoritative information to support decision-making at local to global scales is growing, and needs are becoming more specific and complex.*" This factor is a direct driver in developing this NASA Earth Science to Action strategy. The 2022-2031 USGCRP Strategic Plan then lays out four pillars to respond to change and manage critical risks. These are: (1) Advancing Science, (2) Engaging the Nation, (3) Informing Decisions, and (4) Collaborating Internationally. These are all essential and have been adopted as important guiding principles in this NASA Earth Science to Action strategy. In addition, a key message from the most recent U.S. National Climate Assessment (NCA5) was that human

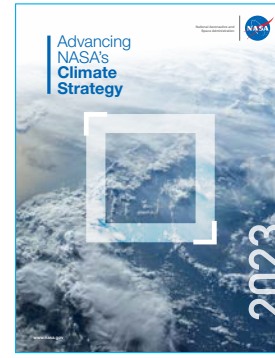
Credit: photo courtesy of the 1-184 Infantry Regiment, California National Guard)

activities are causing changes to the Earth system processes: "*Human activities cause changes throughout the Earth system, including the land surface, cryosphere, ocean and atmosphere, and carbon and water cycles. The magnitude, and for some processes the direction, of these changes can vary across regions, including within the US. These changes also occur against a background of substantial natural climate variability.*" This points to the need to account for both natural and anthropogenic aspects and their interdependence in our holistic strategy of observing, modeling, understanding, and predicting the Earth system.

- **Enhancing the Capacity to Deliver Climate Services:** The National Science and Technology (NSTC) Fast Track Action Committee (FTAC) on Climate Services issued a March 2023 report highlighting the critical need of enabling effective climate action through the provision of climate services to the public. These climate services are defined in the report as "*scientifically based, usable information and products that enhance knowledge and understanding about the impacts of climate change on potential decisions and actions.*" The report notes: "*The need for a more coherent strategy for climate services has long been recognized but is becoming more urgent as demand for more useful climate services increases substantially.*" The report makes a series of recommendations to federal agencies, including: "*Enhance the Capacity of the Federal Government and Non-federal Partners to Develop and Deliver Climate Services.*" NASA's Earth Science to Action strategy aligns with these findings and is a contributing response to these recommendations.

- **Urgency of Decisive Actions in this Decade for Mitigation and Adaptation:** The United Nations Intergovernmental Panel on Climate Change (IPCC) included several warning statements in its 2023 synthesis report regarding the impacts of taking (or failing to take) decisive actions in the near term and the importance of adaptation in the long term. Of note from that report: "*Deep, rapid and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce projected losses and damages for humans and ecosystems (very high confidence), and deliver many co-benefits, especially for air quality and health (high confidence).*" Importantly, the report also "*…recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate change adaptation, mitigation, ecosystem health, human well-being and sustainable development, and reflects the increasing diversity of actors involved in climate action.*" The NASA Earth Science to Action strategy will maximize the value of NASA assets, and to inform those who need the complex knowledge required to take actions so essential to mitigating and adapting to the effects of a changing planet.

- **Informing the Public and Decision-makers Around the World:** NASA is responding to these needs with added focus on informing the public and decision-makers about global change. In March 2023, NASA issued the "*Advancing NASA's Climate Strategy,*" in which the agency recognized that our planet is an interconnected system and that local events can have global impacts and global events impact local communities. NASA's climate strategy lays out four priorities for the agency to help with integration of climate across NASA: innovate, inform, inspire, and partner. These serve as guiding principles in this Earth Science to Action strategy, which also takes on the task laid out in the NASA Climate Strategy of ensuring: "*commitment to inform the public and decision-makers around the world by improving the accessibility and usability of climate and Earth science information. From seaside towns who wish to know more about their changing coastlines, to those in wildfire-vulnerable areas, to city-dwellers looking to track smog in their neighborhoods, communities around the world can benefit from NASA's observations and models to help plan for the future.*" In the same vein, the NASA Strategic Plan (2022) lists *Understanding the Earth System and its Climate* as a strategic objective. Specifically, it highlights: "*Studying Earth as an integrated, complex system is essential to understanding the causes and consequences*



of climate change and other global environmental concerns… Climate adaptation and mitigation efforts cannot succeed without these robust climate observations and research." The Earth Science to Action strategy is how NASA's Earth Science Division intends to lead the Earth science enterprise in achieving NASA's overarching strategic objective.

Vision and Mission Statement

Through this strategy, NASA Earth science will achieve its vision.

NASA EARTH SCIENCE VISION:

A thriving world driven by trusted, actionable Earth science.

Use of the word *thriving* in this vision was chosen carefully and to be consistent with how it is defined in the National Academies of Science, Engineering, and Medicine report [1]. "*It encompasses economic success, intellectual progress, societal prosperity, personal well-being, scientific exploration, and much more.*" The trusted, actionable Earth science will focus on resilience and critical systems that enable humanity to prosper. We believe that scientifically validated, trusted information, as well as tailored, solutions-oriented tools, are key ingredients that will make it easier for communities and institutions to take the appropriate actions and inspire current and future generations to ensure a thriving world for all.

The trusted, actionable Earth science will focus on resilience and critical systems that enable humanity to prosper. These include:

- Agriculture production
- Water and food resources management
- Wildfire response and recovery
- Sea level change and coastal risk and resilience
- Air quality
- Environmental health, water quality, and infectious disease
- Energy and sustainable infrastructure
- Disasters and extreme events
- Greenhouse gas measurement and monitoring
- Biodiversity and ecological conservation
- National security
- Terrestrial carbon accounting
- Human-ocean interactions
- Stratospheric ozone monitoring
- Society and economic sectors (insurance, real estate, infrastructure, transportation, services, etc.)
- Policy- and decision-making support at the local, state, tribal, federal government, and international levels

To achieve this vision, NASA Earth science has adopted the following mission statement, reiterated as part of this Earth Science to Action strategy.

NASA EARTH SCIENCE MISSION STATEMENT:

Compelled by our planet's rapid change, we innovate and collaborate to explore and understand the Earth system, make new discoveries, and enable solutions for the benefit of all.

Core Values

In our day-to-day activities, NASA Earth science shares a set of core values. They are evident in everything we do and represent the NASA Earth science way.

As part of our NASA Earth science enterprise, we adopt and adhere to the fundamental five NASA core values, with an emphasis on several aspects critical for our mission:

Safety: NASA's constant attention to safety is the cornerstone upon which we build mission success.

Integrity: NASA is committed to maintaining an environment of trust, built upon honesty, ethical behavior, respect, and candor.

- **Trustworthiness:** Our work is undertaken with transparency and attention to detail and with quality-control processes in place to ensure a high level of credibility and quality. We engage with our partners, users, and stakeholders, as well as the public, with a sense of responsibility, truthfulness, and humility to establish and maintain social trust. We share all aspects of what we do (data, science, knowledge, methodologies) to the maximum extent possible to ensure high confidence in our findings.

Inclusion: NASA is committed to a culture of diversity, inclusion, and equity, where all employees feel welcome, respected, and engaged.

Teamwork: NASA's most powerful asset for achieving mission success is a multidisciplinary team of diverse, talented people across all NASA centers.

- **Collaboration:** We work collaboratively, we co-develop with our partners and users, and reach out across agencies, across sectors, nationally and internationally, to achieve maximum value and build added-value partnerships.

Excellence: To achieve the highest standards in engineering, research, operations, and management in support of mission success, NASA is committed to nurturing an organizational culture in which individuals make full use of their time, talent, and opportunities to pursue excellence in conducting all agency efforts.

- **Innovation:** We initiate and encourage activities with a potential to improve our mission, even if the end result is uncertain. We take thought-out risks to ensure we can explore bold and innovative ideas, keep us at the edge of science and technology, and allow us to advance the state of the art and remain an innovation hub for Earth science.

Strategic Goal

To achieve our vision and mission with a sense of urgency, while tackling the complexities associated with the global challenges of our changing planet, we have adopted a single strategic goal:

> NASA EARTH SCIENCE STRATEGIC GOAL:
>
> **Within a decade, we will advance and integrate Earth science knowledge to empower humanity to create a more resilient world.**

This strategic goal will focus our activities in the coming decade to integrate our science assets to more comprehensively meet the various needs, address the gaps, advance knowledge, leverage the opportunities made available through technology advances and partnerships, and to provide humanity with the information it needs to take action. This will simultaneously build the necessary capacity and lay the groundwork for helping society be ready to confront the growing demands and the evolving needs of the decade(s) to follow. This will result in a more agile and responsive NASA Earth science enterprise, positioning us to address future questions and needs that we cannot foresee today.

Objectives

This strategic goal will be accomplished by focusing on two major objectives, described below. These objectives are associated with specific Key Results (KRs) to effectively assess progress toward their achievement.

Objective 1:

Holistically Observe, Monitor, and Understand the Earth System

Using the power of science, cutting edge technology, engineering, modern tools and infrastructure, partnerships, and space-based observations, NASA will build a global framework that will allow constructing a comprehensive digital description of the Earth system. This approach will include the Earth environment's physical and geological systems, including surface and interior, biologic, and chemical components, as well as human and other relevant systems. The outcome will help answer challenging science questions posed by the community and allow a thorough understanding and monitoring of the Earth system and its interconnected nature. It will also allow the emergence of new applications and discoveries to benefit society.

We will assess the progress toward achieving this objective by assessing four key results (KR):

Key Result 1.1 | **The most advanced Earth observing system in the world:** We will develop a holistic and integrated system of observing systems. Working with partners nationally and internationally in a variety of areas, we will develop and sustain a comprehensive global Earth System Observatory to provide critical parameters for probing Earth processes, their monitoring, and understanding their changes. We will increase capability, enhance performances, and retain world leadership in advancing state-of-the-art Earth system sensing, while ensuring continuity of critical environmental records.

Key Result 1.2 | **Cutting-edge technology:** We will pursue a set of innovative technology demonstrations and continuously modernize our assets. We will test and mature new technologies, data systems, and innovative techniques to enable new, cost-effective, and better science or more efficient processing, as well as more advanced observing systems and infrastructure. We will create a mechanism to support ideas to promote innovation to explore, discover, and break barriers.

Key Result 1.3

Integrated and trusted Earth system data: Working with partners nationally and internationally, we will integrate data from various sources and calibrate and validate them to provide a reliable source of consistent and trusted Earth system data and to simultaneously facilitate a seamless continuity of critical observations. For this purpose, we will build an agile infrastructure – IT and science – to allow various sources of data and observations to be combined and curated. This will contribute to building a representation of the Earth system with all its components that will satisfy the needs of a broad user base and encompass a range of disciplines. When appropriate, this consolidation and fusion of various parameters will employ modern and innovative approaches (such as Artificial Intelligence/Machine Learning) and will enable new applications and generate added-value information to benefit society and the economy. To increase efficiency and cost effectiveness, we will also consolidate, when feasible, the ground processing and dissemination mechanisms of the different missions, simultaneously ensuring free and open access and wide availability of the data.

Key Result 1.4

Scientific breakthroughs to better understand Earth: We will advance Earth science knowledge by addressing the various science questions posed by the science community, through formalized and structured processes, such as the decadal surveys and other community efforts. Similarly, we will address new and emerging science questions that are responsive to the needs of stakeholders and users, and those resulting from co-developing applications with stakeholders in different disciplines. We will reflect this acquired knowledge in consolidated models and tools to accelerate its use in various areas. This advanced knowledge includes the need to understand the complex interconnectedness of the various Earth system components, including human and other relevant systems, and their complex feedback mechanisms. It also includes seeking understanding of specific environmental phenomenology (such as cloud convection, air composition and chemistry, water cycle, energy cycle, etc.), as well as interdisciplinary topics, and understanding causative linkages and cascading effects of different processes in various thematic areas.

Objective 2:

Deliver Trusted Information to Drive Earth Resilience Activities

Based on our history of understanding Earth as a system and its various applications, we will coalesce and cultivate the diverse communities of Earth science, including working across sectors and across agencies, to generate the science-based decision support information needed by users. When appropriate, we will build efficient and interactive end-to-end tools, models, and assessment systems with the needed latencies, at the appropriate temporal and spatial scales, and with the appropriate uncertainty quantification to serve people, communities, decision-makers and policymakers, enabling them to take science-based actions. These activities will support efforts to build Earth resilience, including the development of strategies for mitigation, adaptation, and the assessment of various risks and contingencies associated with global change and its impacts. This approach will also include the investigation of potential risks due to crossing thresholds for climate tipping points and the possibilities for cascading environmental and societal impacts.

We will assess progress toward achieving this objective by assessing four key results:

Key Result 2.1

Models that capture the intricacies of the Earth system: We will develop an advanced and integrated end-to-end Earth system modeling capability. We will maintain, enhance, and develop the necessary models with expanded scope to provide the information needed to support Earth resilience activities. We will leverage modern observing, computing, modeling, and information system infrastructure and techniques to achieve efficiency and enhance resolutions, without degradation to scientific value. These models will serve as a mechanism to leverage the vast scientific knowledge, such as mentioned in Key Result 1.4 and acquired from observations and research, including about the complex interconnectedness of different Earth system components. We will work with partners nationally and internationally to jointly leverage resources, science assets, and expertise and will particularly use satellite and other observations, such as those developed as part of KR1.3, to initiate, validate, adjust, and overall improve the quality of the modeling enterprise. We will build and apply these end-to-end models of the Earth system

to predict future changes and flexibly answer what if scenarios, and therefore develop the capability to support the scientific evaluation of mitigation and adaptation activities and help with risk assessment and other climate resilience frameworks.

Key Result 2.2

Co-designed solutions and tools to support users: We will co-develop user-centered solutions options and solutions-oriented applications and support tools with various partners and stakeholders. This will encompass providing science-based information and designing solutions options, as well as easy-to-use, interactive, and solutions-oriented tools to support decision- and policy-making. We will develop and demonstrate applications with benefits in various thematic areas. We will build these tools based on modern efficient techniques, leveraging, when appropriate, the advanced modeling capabilities in KR2.1, and with the aim of enhancing scale and speed of execution. We will construct and demonstrate these realistic science-based systems to provide the foundation for actionable information in critical environmental areas. These tools and solutions will be tailored to specific needs and are also expected to support the economy and its infrastructure.

Key Result 2.3

Science-based information we can trust and act on: We will provide trusted, actionable, and science-based information. Engaging and working jointly with various partners, nationally and internationally, we will generate fit-for-purpose, trusted information combining environmental observations, past and current, with other datasets and with model projections generated from various sources, including from space, airborne platforms, or ground-based systems. To build this information, we will use integrated data from multiple sources, as referred to in KR 1.3, and will use models, tools, and co-developed solutions, as referred to in KR2.1 and KR2.2. As part of our engagement with various partners, we will conduct efforts, when necessary, to transition mature products and services into appropriate routine environments. The information will be provided at the relevant temporal and spatial scales and with the needed latency to be useful for different stakeholders and to make it readily available to people, communities, and decision- and policymakers, where and when they need it, to enable them to take action.

Key Result 2.4

Promotion of Earth information as a national asset: We will scale up information sharing, dissemination, and outreach to enhance awareness. We will establish and expand the Earth Information Center (EIC) and will gradually enhance its capabilities and benefits. In this context, we will, for example, increase the topics covered and highlighted by EIC (including the water cycle, biodiversity, greenhouse gases, etc.). EIC will allow increased data accessibility and a centralized, smoother interface with a wide range of users, stakeholders, and decision- and policymakers, as well as the public. EIC will serve as one centralized gateway to providing access to data, information, tools, and solutions. It will serve to collect, and then highlight, test cases and success stories, which in turn will help illustrate the value of Earth science and expand outreach.

Strategy Implementation

For a successful implementation of the Earth Science to Action strategy, NASA will employ several principles, used to help guide the implementation planning, and will align its assets to ensure a smooth and efficient execution.

Implementation Guiding Principles

Amplify Impact and Augment our Capabilities through Enhanced Partnerships:

- To increase the value of Earth observations overall, and to amplify the benefit to humanity of the Earth science and actions developed in NASA, we will build capacity through an extensive and diverse set of partnerships, both traditional and new. We will scale up, build strong partnerships, and be user-centered when developing solutions and actions.

- Our partners will include national and international governmental agencies, academia, non-governmental and international organizations, the private sector, and philanthropies. We will reinforce our existing partnerships and align them with the strategic objectives, and seek new ones, including with emerging space-faring nations and institutions seeking to be active in Earth science.

- When appropriate and cost-effective, we will leverage existing value-amplifying initiatives or establish new initiatives if necessary. These initiatives could be national or international.

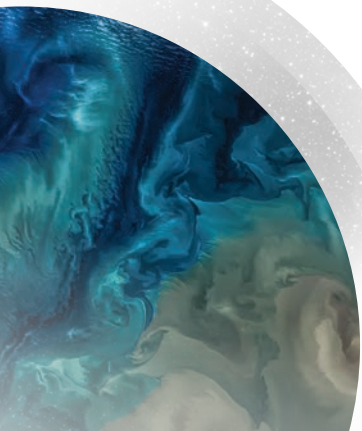
- We will use this multivariate partnership approach to achieve both depth and wide breadth in our impact and support to humanity while being cost effective.

- NASA Earth science will maintain its role as a strong participant in interagency, international community and a major player at high-level organizations and high-impact initiatives.

Engage a Diverse Workforce and the Wider Earth Science Community:

- Enable an inclusive Earth science community that attracts and retains top talent and positions NASA to address the challenges and leverage the opportunities of the future.

- Implement approaches to coalesce various Earth science communities across disciplines and across academia and the private sector to achieve the strategic goal and objectives of this strategy.



- Amplify the value of Earth science through global-reaching training, education, outreach, and capacity building.
- Nurture and continue to rely on a vibrant research community, leveraging its expertise and dynamism.

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Use a Balanced Approach when Faced with Competing Factors:

- Balance investments between innovation and sustainability/continuity of critical records.
- Support both open and fair competition and the need to promote a collaborative environment.
- Balance the pursuit of and investment in new developments, when necessary, with leveraging what already exists through collaborations and cooperation with partners, to achieve maximum value and avoid redundancy of investments across the global Earth science enterprise.
- Keep a broad view of the various Earth system components and their interconnected nature, their feedback mechanisms, and their cascading impacts. This is an area where many questions remain.
- Incentivize collaboration across disciplines to address urgent science questions. Balance and enable activities across the spectrum of science, applications, and translational research.
- Consider end-to-end approaches that cross boundaries (disciplines, sectors, themes, etc.).

Encourage Innovation to Maintain Cutting-Edge Capabilities:

- Regularly review, assess, and modernize infrastructure and science assets via transition/upgrade processes.
- Develop tools and information with cross-cutting applicability and scalability to ensure maximal value.
- Promote open data and open-source science to leverage/enable the community's creativity and innovation.
- Maintain NASA leadership in science and technology excellence by building on our agency heritage in understanding the Earth system, and striving for excellence in technology, sensors, and satellite design; research; understanding science and applications; and developing new and emerging capabilities.

Ensure Robustness and Resilience in our Processes:

- Commit to delivering missions and flight projects on time and on budget through sound planning and management.
- Account for the rapidly changing landscape in the Earth science enterprise by implementing processes that ensure agility, innovation, and cost-effectiveness.
- Implement strategies to make balanced, nimble decisions. This includes mechanisms for regularly assessing return on investment and potential new opportunities through active engagement with NASA centers and U.S. government agencies, and in consultation with partners, stakeholders, and the broader Earth science community.

Implementation Structure and Alignment of Assets

To achieve the vision laid out in this strategy over the next decade, NASA will employ our satellites and technology expertise, our science knowledge, and our data infrastructure to address the existing and foreseen challenges of a changing planet Earth. We will infuse agility and creativity in our overall structure and planning processes, to tackle unforeseen questions, adapt to emerging needs and evolving priorities and to leverage new opportunities. The essential building blocks of the end-to-end value chain of the NASA Earth science mission are illustrated below, from technology development to providing actionable information to the public. Execution of the strategy requires a focused alignment of these assets to provide knowledge and to scale that knowledge for use by a wide range of actors and decision-makers. The enterprise assets upon which the strategy implementation is founded are represented in the lower part of the pyramid, while the top layer of the Earth Science to Action pyramid represents effective mechanisms through which information is efficiently shared with decision-makers and the public. The feedback loop in the background ensures the needs of NASA data users can inspire and influence internal NASA decision mechanisms for innovation, technology, and science development. The first foundational asset consists of the elements leading to a diverse set of Earth observations: technology development, long-term sustainment, and development of new observing systems and their deployment, including satellites and data infrastructure. The second foundational asset consists of advancing NASA's scientific understanding and sustaining our expertise to analyze, understand, monitor, and predict the interconnected Earth system of systems for application as innovative and useful solutions for society. In the third asset, these actionable solutions will be developed, disseminated, and visualized in a comprehensive Earth system framework enabled by

Open Science and cutting-edge data science technologies. Finally, a variety of channels will provide public visibility, such as the Earth Information Center, a physical and virtual space that provides easily accessible, readily usable, and scalable Earth information – enabling global public understanding of the Earth system as uniquely observed and understood by NASA and our key federal partners. One of the most important pillars to sustaining this strategy is NASA's tremendous human capital, as well as the world-class science and engineering communities that power and sustain the unique innovation NASA delivers.

Virtuous Cycle
- User needs inform next iteration of programs, missions and initiatives

Public Understanding & Exchange
- Put more scientific understanding into public sphere
- Deliver applied science to users
- Participate in multi-way info exchange
- Use input to inform subsequent work

Solutions & Societal Value
- Offer models, scientific findings and info through Open-Source Science principles
- Support climate services
- Provide science applications and tools to inform decisions

Earth System Science & Applied Research
- Grow scientific understanding of Earth's systems
- Develop predictive modeling for science applications and tools to mitigate, adapt and respond to climate change

Foundational Knowledge, Technology, Missions & Data
- Technology innovation
- Earth observations missions
- Data collected from space, air and ground

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