National Aeronautics and Space Administration

# climate action plan

NASA research expands worldwide understanding of global climate change. The Agency applies its knowledge in taking action to ensure mission capability and protect supporting infrastructure from intensifying climate threats.

September 2021

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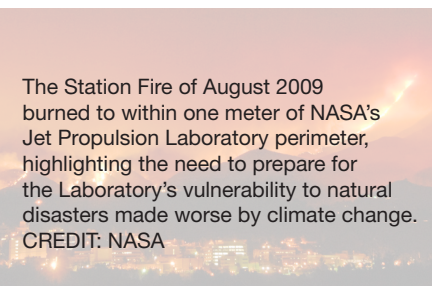
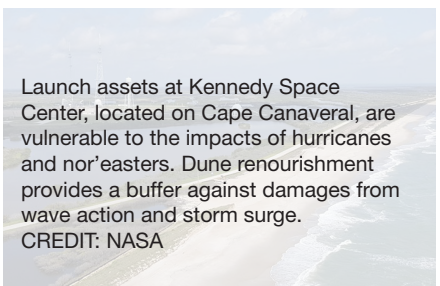
## on the cover

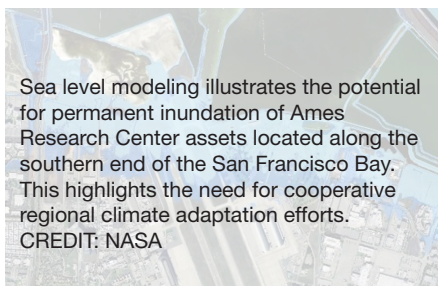
Arctic sea ice is in decline, with the melt season beginning earlier and lasting longer. NASA's ICESCAPE (Impacts of Climate on the Eco-Systems and Chemistry of the Arctic Pacific Environment) research project used an interdisciplinary approach integrating field expeditions, modeling, and satellite remote sensing to assess the impacts of changing conditions in the Arctic on ocean chemistry and ecosystems. The bulk of the research was conducted in the Beaufort and Chukchi Seas in the summer of 2010 and 2011.
CREDIT: NASA



The Station Fire of August 2009 burned to within one meter of NASA's Jet Propulsion Laboratory perimeter, highlighting the need to prepare for the Laboratory's vulnerability to natural disasters made worse by climate change.
CREDIT: NASA



Launch assets at Kennedy Space Center, located on Cape Canaveral, are vulnerable to the impacts of hurricanes and nor'easters. Dune renourishment provides a buffer against damages from wave action and storm surge.
CREDIT: NASA



Sea level modeling illustrates the potential for permanent inundation of Ames Research Center assets located along the southern end of the San Francisco Bay. This highlights the need for cooperative regional climate adaptation efforts.
CREDIT: NASA

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# NASA Climate Action Plan (September 2021)

## Table of Contents


**I. Purpose ..... 1**

**II. Agency Official Responsible for Implementation of the Plan ..... 1**

**III. Agency Policy Statement for Climate Change Adaptation and Resilience ..... 1**

**IV. NASA's Situation ..... 1**

**V. NASA Organizational Structure ..... 1**

**VI. Priority Adaptation Actions ..... 3**

Priority 1: Ensure Access to Space ..... 3

Priority 2: Integrate Climate Adaptation into Agency and Center Master Plans ..... 6

Priority 3: Integrate Climate Risks into Risk Analysis and Agency Resilience Planning ..... 9

Priority 4: Update Climate Modeling to Better Understand Agency Threats and Vulnerabilities ..... 11

Priority 5: Advance Aeronautics Research on Technologies and Processes that Reduce Contributors to Climate Change ..... 14

**VII. Special Topics ..... 17**

Special Topic 1: Update Climate Vulnerability Assessments ..... 17

Special Topic 2: Describe Agency Efforts to Enhance Climate Literacy in its Management Workforce ..... 18

Special Topic 3: Describe Agency Actions to Enhance Climate Resilience ..... 18

# I. Purpose

The National Aeronautics and Space Administration (NASA) mission is to drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth. This Climate Action Plan (CAP) provides NASA's vision for adapting to climate change effects on its mission, facilities, infrastructure, natural lands, and other assets, now and in the future. The CAP builds on the Agency's efforts, beginning in 2005, when 'regional climate variability' was identified in NASA's risk management framework as a threat to operations and missions. This CAP identifies opportunities to further incorporate consideration of climate risk into management functions and other processes to prioritize those risks and apply resources. The CAP addresses co-benefits related to climate change mitigation.

# II. Agency Official Responsible for Implementation of the Plan

The NASA senior agency official responsible for climate adaptation management activities described in this plan is Robert Gibbs, Associate Administrator for Mission Support.

# III. Agency Policy Statement for Climate Change Adaptation and Resilience

Climate variability and climate change will have important impacts on NASA's ability to fulfill its mission and thus merit a proactive and integrated response. As such, NASA will implement proactive measures to execute its mission and reduce the Agency's environmental, institutional, programmatic, and operational risks. As a global leader in the field of Earth science, NASA also recognizes that it has a unique role in monitoring, forecasting, and informing the public about climate change.

> **It is NASA policy that integrating climate considerations into the Agency's policies, strategies, master plans, and partner engagements is mandatory.**

To implement this policy, NASA commits to:

- Identify and implement adaptation strategies to avert potential mission impacts from climate change.
- Integrate climate adaptation planning and actions into the Agency Master Plans as well as Agency programs, policies, and operations.
- Minimize impacts to climate from Agency programs, policies, and operations.
- Execute priority climate scientific research, including climate observations, analysis, and modeling.
- Lead efforts and collaborate on climate change issues, sharing knowledge with a wide range of stakeholders

# IV. NASA's Situation

NASA is one of a few Federal agencies that conduct climate research and provide climate data critical for agencies and organizations worldwide to assess their climate vulnerabilities. The Agency's climate-related research encompasses solar activity, sea level rise, ocean and atmospheric temperatures, ozone layer conditions, air pollution, and changes in sea ice and land ice. Even as NASA conducts this research, it is imminently threatened by climate impacts. Many Agency assets—approximately two-thirds when measured by replacement value—are located within 16 feet of mean sea level along America's coasts. Some of these assets are located in areas experiencing impacts from sea level rise and increased frequency and intensity of high water levels. Others face long-term changes in temperature, and precipitation intensity and duration are expected to impact potable water supplies and working conditions. Many of these assets cannot be relocated since strict launch requirements, which include maintaining adequate distance from communities and other safety measures, necessitate coastal or other locations significantly impacted by climate change.

# V. NASA Organizational Structure

NASA is primarily organized into two main functional groups: mission and mission support. The mission side includes those directorates responsible for scientific research and space exploration. The mission support side includes the functions necessary to procure, house, and support mission activities, such as the NASA Shared

Services Center (NSSC). Figure 1 illustrates NASA's organization, with mission directorates shown in green and mission support shown in orange. Other NASA entities are shown in blue, including the Office of the Administrator, Inspector General (IG), and offices supporting external coordination, such as Science, Technology, Engineering, and Math (STEM) Engagement.

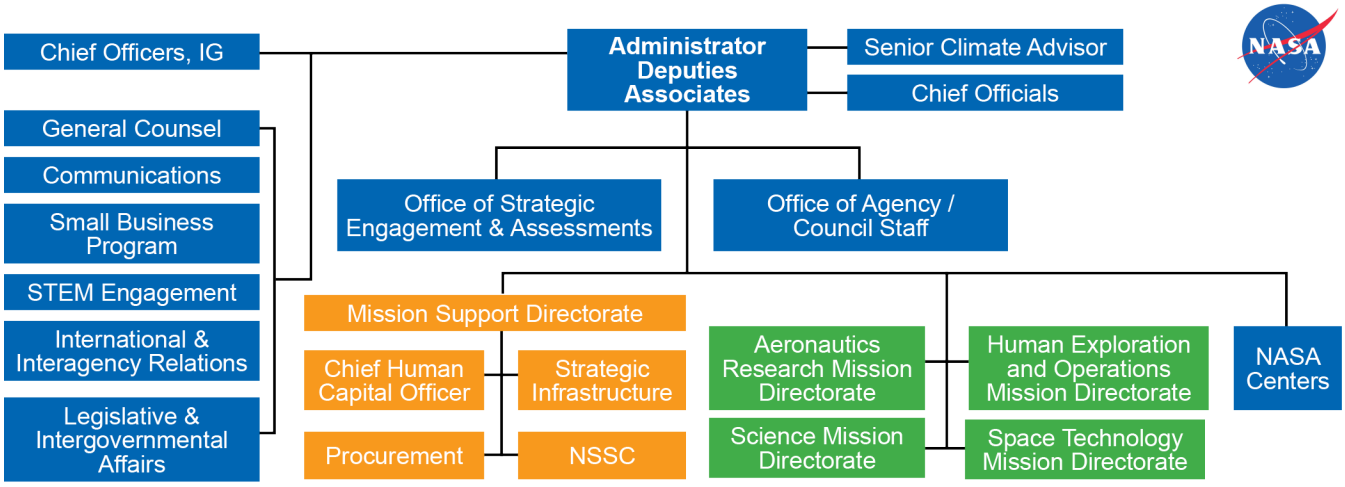


***Figure 1. NASA Organization Chart***

NASA facilities are located across the United States and around the world. Figure 2 shows the ten major NASA Centers (highlighted in blue text) in the continental United States. NASA Headquarters in Washington, D.C., provides overall guidance and political leadership to the Agency. The ten NASA field Centers provide leadership for and execution of NASA's work. All other facilities fall under the leadership of at least one of these field Centers. NASA Centers provide critical capabilities necessary for accomplishment of the mission. The Centers are optimally located for spacecraft launch, tracking, and recovery; conducting Earth science research, space technology testing, aeronautics research and testing, and human and robotic space and planetary exploration; and developing and operating sophisticated space telescopes. Historically, NASA Centers have developed and maintained their critical infrastructure to sustain flight and research operations, adapting to a variety of weather and climate risks.

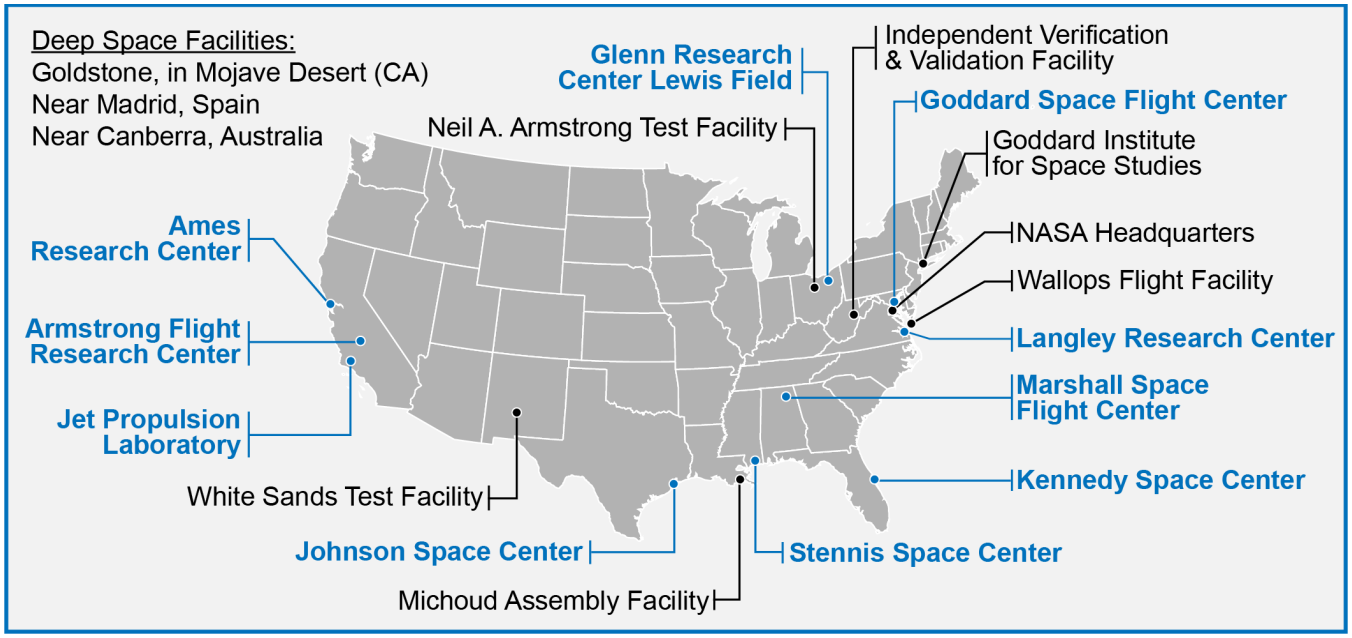


***Figure 2. NASA Centers, Component Facilities, and NASA Headquarters***

# VI. Priority Adaptation Actions

This CAP includes the following five Priority Adaptation Actions, which support the overarching commitments outlined in the Agency Policy Statement (see above):

**Priority 1: Ensure Access to Space**

**Priority 2: Integrate Climate Adaptation into Agency and Center Master Plans**

**Priority 3: Integrate Climate Risks into Agency Risk Analysis and Resilience Planning**

**Priority 4: Update Climate Modeling to Enable Better Understanding of Agency Threats and Vulnerabilities**

**Priority 5: Advance Aeronautics Research on Technologies and Processes that Reduce Contributors to Climate Change**

## **Priority 1:** Ensure Access to Space

NASA designs, manufactures, tests, and launches rockets and payloads into space as part of its core mission. Maintaining access to space is critical to the continued execution of NASA's mission. The National Oceanic and Atmospheric Administration (NOAA), international partners, and several commercial ventures rely on NASA to provide and support launch and control facilities and activities. NASA will maintain access to space by identifying and, as appropriate, managing climate-related risks to critical launch facilities, supporting infrastructure, and supply chain (see Special Topic 3B).

**Action Description:** Identify climate change-related vulnerabilities that threaten access to space, perform risk assessments, and develop risk reduction strategies to enable prioritizing adaptations.

**Goals:**

a. Comprehensive and enduring process for identification, classification, and analysis of climate change risks to NASA's infrastructure and supply chain for human exploration missions and the Launch Services Program.
b. Risk-based process for prioritizing climate adaptation strategies and initiatives for launch assets and their supply chain.
c. Prioritized list of infrastructure and supply chain risks and adaptation initiatives to manage risks to the space access mission and operations.

**Agency Leads:**

a. Deputy Associate Administrator for Systems Engineering and Integration, Human Exploration and Operations
b. Launch Services Program
c. Director, Facilities and Real Estate Division (FRED) and Director Environmental Management Division (EMD), Office of Strategic Infrastructure (OSI), Mission Support Directorate (MSD)

**Risk or Opportunity:**

a. *Risk:* A significant portion of NASA's infrastructure is in low-lying areas along coastal areas of the continental United States. Climate change is driving increased exposure to rising sea levels, and storm surge and precipitation are causing higher water levels during major storm events. The Agency conducted an initial climate vulnerability assessment in the 2010s (see Special Topic 1). Several Centers have already taken action through elevation of assets, adjusting new construction siting, and other adaptation measures. Flooding and other natural forces exacerbated by climate change continue to pose significant risk to NASA's launch infrastructure and mission. Shorelines continue to erode due to these natural forces. Table 1 lists publicly available information on hazard types and responses to disasters that have negatively impacted NASA's coastal facilities and vulnerable communities. Through requests outside of the Agency's normal budgetary cycle (e.g., appropriations from Disaster Supplemental Funding), NASA obtained funds to repair and restore facilities after each major event. Each line item in Table 1 represents an independently funded response effort, which at times included multiple events in a single annual budgetary cycle. Since 2003, total recovery expenditures have exceeded $1 billion.

b. *Risk:* Supply chain vulnerabilities related to specific events are currently identified, prioritized, and addressed through Continuity of Operations (COOP) plans, a contingency planning requirement for potential disruptions, and other standard risk management practices. Current plans and processes are event-specific and focused on short-term sustainment and recovery from the effects of the event. The plans do not consider the long-term and nonreversible effects of climate change on NASA's launch support supply chain. Associated risks—such as increased frequency of flooding events causing road closures and an inability to supply launch propellants—could impact access to space.
c. *Opportunity:* OSI and mission offices are collaborating on an enterprise geographic information system (GIS) as an improved planning, analytical, and management tool. Some Centers have implemented these capabilities to address potential flood impacts, in support of NASA and surrounding communities. The Agency's coordinated and comprehensive GIS, with improved data accuracy, completeness, and consistency, will facilitate the modeling of climate change effects and identification of critical launch support infrastructure risks.

| Center/Facility | Impact/Response Type | Year of Climate Impact/Recovery | Approximate Cost ($millions) |
|---|---|---|---|
| **Johnson Space Center** | Hurricane | 2008 | 50.0 |
| **Johnson Space Center & Kennedy Space Center** | Hurricane | 2017 | 81.3 |
| **Kennedy Space Center** | Hurricane | 2004 | 126.0 |
| | Structural Hardening | 2018 | 25.0 |
| | Hurricane | 2017 | 74.7 |
| | Dunes | 2009–2019 | 100.0 |
| | | 2012 | 18.0 |
| | | 2019 | 11.4 |
| **Kennedy Space Center & Wallops Flight Facility** | Dunes | 2012 | 4.0 |
| **Langley Research Center*** | Hurricane / Flooding | 2003 | 146.0 |
| | | 2004 | 5.0 |
| | | 2009 | 44.0 |
| **Michoud Assembly Facility** | Hurricane | 2005 | 120.0 |
| | Tornado | 2017 | 109.0 |
| | Hurricane | 2020 | 152.0 |
| **Stennis Space Center** | Hurricane | 2005 | 205.0 |
| | Hurricane | 2020 | 22.3 |
| **Wallops Flight Facility** | Dunes | 2011–2012 | 43.0 |
| | | 2012 | 11.0 |
| | Flooding | 2012 | 1.6 |
| | Shoreline Stabilization | 2020 | 23.7 |

*Includes funding for recovery at Langley Air Force Base

***Table 1. NASA Disaster Recovery Expenditures (2003–2020)***

**Scale:** Ensuring access to space involves all NASA real property, Centers, and facilities, as well as partners across the supply chain.

a. *Global:* Agencywide, including international capabilities and redundancies
b. *Local:* Center-specific, including critical launch sites (e.g., Kennedy Space Center, Wallops Flight Facility, and Vandenberg Space Force Base)

**Timeframe:**

a. Prioritized list of climate-related risks to infrastructure and mission, and adaptation initiatives. (Fiscal year [FY] 2022–FY 2023)
b. Comprehensive and sustainable processes for identification, classification, and analysis of risks to the NASA supply chain due to climate change. (Timeframe to be determined [TBD])

**Implementation Methods:**

a. Reinforce Agency policy to provide greater emphasis on climate change considerations in protecting critical launch and launch support infrastructure through hardening, relocation, and development of redundant International Space Station, launch complex, and other space exploration missions support capabilities.

b. Build from the NASA Climate Strategy Working Group and Science and Technology Forum initiatives to define and establish a community of practice to develop a comprehensive Agency process that identifies climate-related risks to mission and infrastructure, and appropriate strategic and tactical adaptive strategies.
c. Reevaluate screening-level climate exposure and assess vulnerability of critical facilities and supporting infrastructure (see Special Topic 1).
d. Enable detailed asset-level vulnerability analyses for launch support infrastructure in concert with GIS capabilities and Priority Action 4.
e. Work with partners to investigate and develop an initial Agency-wide launch support supply chain hazard exposure and vulnerability assessment that incorporates enhanced GIS capabilities.

**Performance:**

a. Track climate change risks and mitigation strategies that address critical launch infrastructure. NASA has added an Agency enterprise risk in the NASA enterprise risk management process, titled "Infrastructure Impact Due to Climate Change." The enterprise risks are reviewed quarterly at the Mission Support Council meeting as part of the Baseline Performance Review (BPR). The BPR, led by the Associate Administrator, is a bottom-up review of performance against the Agency's strategic goals and other performance metrics, such as cost, schedule, contract, and technical commitments.
b. Develop long-term Agency plans to protect critical launch support facilities through infrastructure hardening and relocation and renewal requiring new infrastructure to be built above the 500-year flood plain. For example, measure total launch facility inventory within the 500-year floodplain, and assess whether those facilities in the floodplain require additional hardening. (FY 2022–FY 2023)
c. Include climate change assessments in launch support supply chain resilience models. Identify climate-sensitive areas of the supply chain and significant threats, in order to develop appropriate metrics in accordance with the General Services Administration's Framework for Managing Climate Risks to Federal Agency Supply Chains and other supply chain resilience references. (FY 2022–FY 2023)
d. Reassess vulnerability of mission launch and operational facilities, using updated climate change projections and plans for future adaptations, to improve resilience in sustaining mission operations. Metrics and measures for resilience are under development (see Priority Action 3). (FY 2024)

**Intergovernmental Coordination:**

a. Partner with the Department of Defense (DOD), including the Department of the Air Force and Army Corps of Engineers, and other agencies to coordinate prioritized adaptation actions and avoid maladaptation for physical locations and mission support capabilities.
b. Maintain space access for launch and operations in coordination with international partners, including International Space Station partners, tracking site partners, and partners in operational missions in science and disaster response.

**Resource Implications:**

a. Climate adaptation projects are not sufficiently defined to be included in the Agency process for assigning resources for critical launch infrastructure.

**Challenges/Further Considerations:**

a. *Challenge:* The Agency must periodically perform beach renourishment at Wallops Flight Facility and Kennedy Space Center as a protective measure to ensure space access. NASA must investigate longer-term strategic adaptations.

**Highlights of Accomplishments to Date:**

a. Shoreline restoration projects have protected critical launch-related mission assets and provided a co-benefit of supporting local ecosystems and habitats, including those of endangered species. Figure 3 shows a shoreline project in which NASA relocated sand from the north end of the shore to renourish the south area of the shore that protects critical infrastructure. The breakwater system (small inset photo) reduces incoming wave energy.

b. NASA considers climate change as it relates to launch support and mission control. For example, Johnson Space Center began a review of its alarm management and alarm rationalization process to make sure alarm limits, sequence of operations, and operator response sheets take into account climate change effects.

***Figure 3. Wallops Beach Protection Project with Sand Renourishment and Breakwater System***

## **Priority 2:** Integrate Climate Adaptation into Agency and Center Master Plans

NASA's Agency Master Plan (AMP) aligns mission requirements with the Agency's real property assets, while maintaining a long-term risk mitigation strategy (AMP Goal 4) and implementing sustainability best practices (AMP Goal 5). The 2011 AMP mentions risks due to climate change but does not emphasize or provide specific guidance on how this should be addressed. In 2019, NASA initiated a major revision and modernization of the AMP. The development of the AMP is an iterative process involving close consultation between Agency organizational, functional, and program leadership and its field installations, with a strong emphasis on mission-driven requirements and strategies. The AMP is a resource of information on NASA facility land use, constraints, and opportunities. It is a road map for future development and redevelopment of Agency real property. The AMP serves as a strategy in which future projects and proposals are examined to ensure alignment with the Agency Strategic Plan. Although proposed projects are subject to approval based on evolving NASA mission requirements and the availability of funds, the AMP provides an invaluable internal framework for conducting advanced facilities planning.

NASA expects to publish the revised AMP in 2022; it will include specific goals and objectives focused on climate risks and adaptation and will clearly demonstrate NASA's commitment to integrate climate risk management into Agency management processes and tools. This commitment is further reflected in the individual NASA Center Master Plans (CMPs), which align with the AMP. Like the AMP, CMPs will address climate change adaptation to increase resilience. The AMP and CMPs promote sustainability actions that drive the co-benefit of greenhouse gas (GHG) reductions to mitigate climate change.

**Action Description:** Modernize AMP to better integrate climate risk analysis and adaptation strategies into facility and infrastructure project prioritization processes.

**Goals:**

a. Integrated long-term risk mitigation strategy in keeping with AMP Goal 4.
b. Integrated sustainability best practices in keeping with AMP Goal 5.

**Agency Leads:**

a. Agency Master Planner, FRED, OSI, MSD
b. Agency Community Planner, FRED, OSI, MSD

**Risk or Opportunity:**

a. *Risk:* NASA has examined climate change scenarios out to the end of the century. Climate projections for long-onset hazards like sea level rise can involve timeframes beyond the AMP time horizon of 20 years.
b. *Risk:* Future climate conditions depend on several input factors, including potential GHG emission pathways and the climate's sensitivity to GHG concentrations. Therefore, climate projections differ based on model inputs and provide a range of possible future conditions at various confidence levels. The AMP does not provide guidance on acceptable uncertainty, such as whether to require a particular confidence level, when making siting or design/build decisions.
c. *Opportunity:* NASA's 2018 Strategic Plan Strategic Goal 4.6 is "Sustain Infrastructure Capabilities and Operations." To address challenges associated with aging infrastructure, NASA is aggressively managing its facility portfolio to consolidate and modernize into fewer, more efficient, and sustainable facilities. Through a systematic assessment of service areas, NASA is consolidating and improving operations to balance risks across services and activities to provide a safe and reliable infrastructure. Including adaptation considerations in this process will yield life-cycle cost-effective improvements and help avoid maladaptation.
d. *Opportunity:* A proactive risk management approach will better align limited resources with infrastructure vulnerabilities and GHG reduction strategies.

**Scale:** The AMP encompasses all NASA real property, including lands and waters, at NASA Centers and facilities.

a. *National:* Agencywide
b. *Local:* Center-specific

**Timeframe:**

a. The AMP strategy covers 20 years and can accommodate decadal climate change and sustainability best practice considerations.
b. The AMP updates occur every four years and can address more frequent, iterative incorporation of evolving scientific understanding of climate change and associated modeling capabilities.
c. NASA develops Sustainability Plans annually.

**Implementation Methods:**

a. Develop and implement Agency guidance and a standardized process for holistic resilience planning that includes climate risk management. (AMP approval in winter 2022, to be updated every four years)
b. Update and approve CMPs every five years. (Two Centers per year)
c. Develop CMP checklists that will track performance against metrics specific to the inclusion of climate change adaptation strategies in AMP and CMP risk management products.
d. Integrate prioritized adaptation strategies in the Agency's long-term facilities renewal process, and develop an Agency-wide prioritized list of assets for hardening, relocation, or development of a redundant capability.
e. Update Agency policy to strengthen roles and responsibilities in implementing sustainability best practices and formalize recognition of the NASA Sustainability Plan. (Timeframe TBD)

**Performance:**

a. Track performance of CMPs against metrics specific to adaptation. (To be developed in FY 2022 through FY 2023)
b. Meet annual performance targets in the NASA Sustainability Plan to support climate change mitigation co-benefits.

**Intergovernmental Coordination:**

a. Resilience planning is coordinated with the Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL)—see Priority Action 3 for detailed discussion.
b. Climate change data development and sharing in collaboration with NOAA and other science-focused agencies enables an understanding of hazard exposure to assess vulnerabilities for use in Master Plan development.

**Resource Implications:**

a. Resources have been identified and assigned to develop the AMP.
b. Resources to implement the recommended strategies within the AMP are not yet identified. Prioritized strategies will be aligned with available funding as part of the planning, programming, budget, and execution (PPBE) process.
c. Existing resources will be realigned to support sustainability best practices, prioritizing efforts with quickest payback.

**Challenges/Further Considerations:**

a. *Challenge:* Approximately 80 percent of NASA's infrastructure is more than 40 years old and typically exhibits greater climate vulnerability due to age and historical construction requirements that did not adequately address a changing climate. The Mission Support Council set a strategic Agency rightsizing goal toward affordability by reducing infrastructure by 25 percent by 2037. This 25 percent infrastructure reduction goal is a consideration during Construction of Facilities (CoF) project prioritization. Limited budgets for the facilities renewal process extend the timeframe for replacement with climate-ready facilities. NASA's CoF budget has been reduced annually for several years. Simultaneously, Artemis and other priority mission needs have focused where NASA spends its limited construction resources. Identifying and securing funds to continue making the necessary adaptations to NASA infrastructure in the current and projected resource-constrained environment will be a challenge.
b. *Further Consideration:* NASA continues to strengthen its design standards and criteria to accommodate changing weather conditions and long-term climate change. NASA needs to investigate how to incorporate these considerations more effectively within the process of investing in new facilities and revitalizing existing facilities and aging equipment from an Agency-wide perspective. This task is prioritized through a risk-informed construction project selection and PPBE process that considers adaptation as one factor among a range of other competing priorities.
c. *Challenge:* Agency climate risk management strategy is currently in development and has not been finalized, so the AMP will need to retain flexibility to accommodate the evolving strategy.
d. *Challenge:* Scope and cost of adaptation measures to address climate risks tend to be large in scale and extend over long timeframes. The ability to strategize and incorporate required adaptations into discrete, implementable projects will require challenging prioritization through the PPBE process.
e. *Further Consideration:* Climate change implementation strategies developed in compliance with the AMP may compete for limited resources with other mission priorities.

**Highlights of Accomplishments to Date:**

a. In FY 2017 through FY 2018, NASA conducted an investigation of changes in precipitation patterns for all its Centers to understand how the intensity, duration, and frequency of precipitation events may increase due to climate change. Intense rainfall can exacerbate mission risk. The Agency has begun to analyze how this information can impact decision making, such as through the AMP. NASA has shared this and other studies with national stakeholders to improve vulnerability assessments through consideration of compounding impacts from changing precipitation patterns with sea level rise, as well as storm surge during extreme events.

b. In December 2020, the AMP received approval on its vision, goals, and objectives, including risk management strategies and sustainability best practices. The completion of the AMP in the winter of 2022 will further align and prioritize climate change efforts.
c. NASA's Sustainability Plans, developed since 2010, have described climate change mitigation efforts. In FY 2020, NASA had reduced Scope 1 and Scope 2 GHG emissions by 44 percent since FY 2008 (see NASA's Sustainability Plan).

## **Priority 3:** Integrate Climate Risks into Risk Analysis and Agency Resilience Planning

NASA is developing an Agency resilience framework (ARF) that will include adaptation to climate change. The framework will be integrated into the AMP and CMPs. The ARF will provide guidance for development of Center resilience plans (CRPs) that will include a process for identifying threats, vulnerabilities, and risks; developing adaptation strategies; and prioritizing adaptation actions. Centers will use mission essential functions, COOP plans, and key objectives as inputs in preparing baseline resilience assessments and strategies for real property, infrastructure, and public lands and waters. Figure 4 shows the methodology to be used in the Agency's resilience framework.

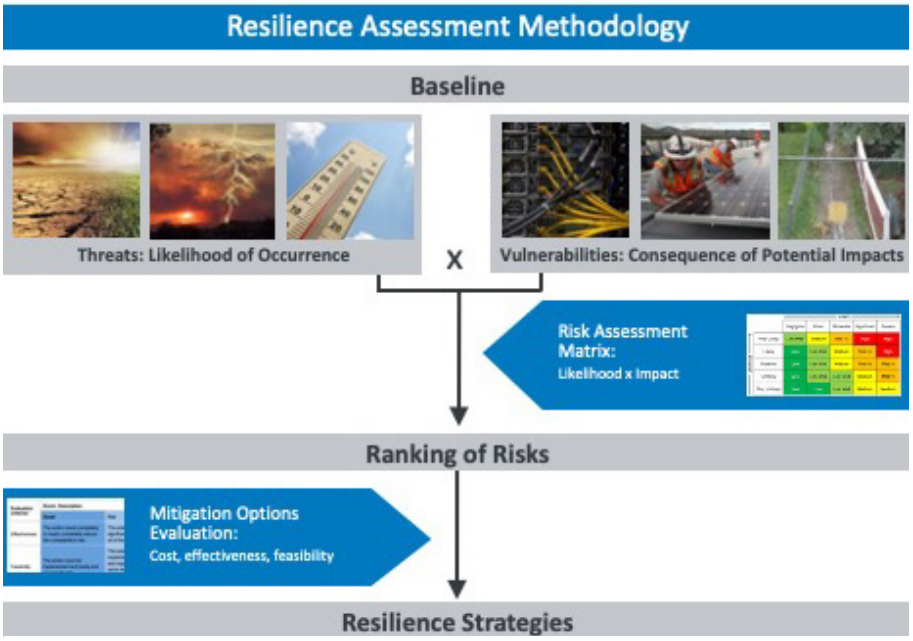


***Figure 4. Resilience Assessment Methodology***
(Adapted from a National Renewable Energy Laboratory presentation, with permission [February 19, 2020])

**Action Description:** Develop an ARF and CRPs that include Center climate change resilience strategies. The results of resilience planning will serve as input to Center master planning, and operations and maintenance processes.

**Goals:**

a. Proactive ARF that incorporates the identification of climate change hazards, exposure, and vulnerability to enable tactical and strategic risk management.
b. Climate-informed ARF that aligns with Agency enterprise risk management and guides strategic investment for critical assets through the PPBE process.

**Agency Lead:**

a. Agency Critical Infrastructure Engineer, FRED, OSI, MSD

**Risk or Opportunity:**

a. *Risk*: Increasing resilience to climate threats requires systems analyses and iterative improvement over time. For example, heat waves can cause stress concurrently with human, energy, transportation, and other systems in a complex, interactive manner. Systems include those within and outside of the Agency fence line. Managing associated impacts requires cycles of broad stakeholder coordination and planning.
b. *Risk*: Climate threats interact with other stressors, impacting resilience. NASA must continue to progress in its ability to prepare for and recover from disruptions that have a climate driver but are also caused or otherwise influenced by other critical factors, such as landslides triggered by a flood event.

c. *Opportunity:* Development and analysis of CRPs will assist in identifying the Agency-wide total resource requirement and may allow for knowledge sharing that leads to further risk reduction and efficiencies.

**Scale:** The ARF encompasses all NASA real property, NASA Centers, and facilities, but focuses on mission-critical infrastructure.

a. *National:* Agencywide
b. *Local:* Center-specific

**Timeframe:**

a. The ARF and CRPs should be developed within the next five to six years, contingent on funding.

**Implementation Methods:**

a. Develop ARF. (Fall 2021/winter 2022)
b. Complete Goddard Space Flight Center CRP. (FY 2022)
c. Complete Kennedy Space Center CRP. (FY 2022)

**Performance:**

a. NASA will incorporate climate risk management into the Agency enterprise risk management process in alignment with an updated vulnerability assessment (see Special Topic 1). Measures and metrics will be applied from NASA's enterprise risk management framework.
b. CRPs are to be developed in the next five years (two Centers per year). Each CRP will include resilience goals, measures, and metrics specific to addressing the needs of each Center, which will further allow for prioritization at the Agency level and enable implementation of adaptation strategies.

**Intergovernmental Coordination:**

a. ARF and CRP goals and objectives are being developed with direct contracted support from NREL.

**Resource Implications:**

a. Resource needs have been identified to develop the ARF, and activities will be executed within resource constraints.
b. Resources to develop two CRPs have been identified, and the effort is underway (Kennedy Space Center and Goddard Space Flight Center).
c. Resources to implement the recommended activities within the CRPs are not yet identified but will be integrated into NASA's risk planning and analysis, as well as the PPBE process.

**Challenges/Further Considerations:**

a. *Challenge:* Climate risk management strategy that addresses risk at the Agency level is currently in development and has not been finalized.
b. *Further Consideration:* The Agency resilience planning effort is being integrated into the AMP initiatives. Leadership decisions need to be made on the resilience planning component of the AMP regarding how to incorporate climate change implementation strategies.

**Highlights of Accomplishments to Date:**

a. A CRP was completed at Johnson Space Center in 2020. The Sensitive but Unclassified designation prevents disclosure of detailed information. Publicly available information on opportunities includes the potential for coordinating climate resilience with GHG reduction and energy resilience co-benefits, such as through Johnson Space Center's Combined Heat and Power (CHP) Plant. Figure 5 features images from a communications handout on the CHP, including the projected days above 90 degrees Fahrenheit for the Houston area.
b. An Interagency Agreement has been executed with NREL to conduct resilience assessments and develop CRPs at Kennedy Space Center and Goddard Space Flight Center. NASA expects to finalize the CRPs in 2022. Discussions with NREL in preparation for CAP development included potential incorporation of NASA climate modeling data to enhance site-specific vulnerability assessments.

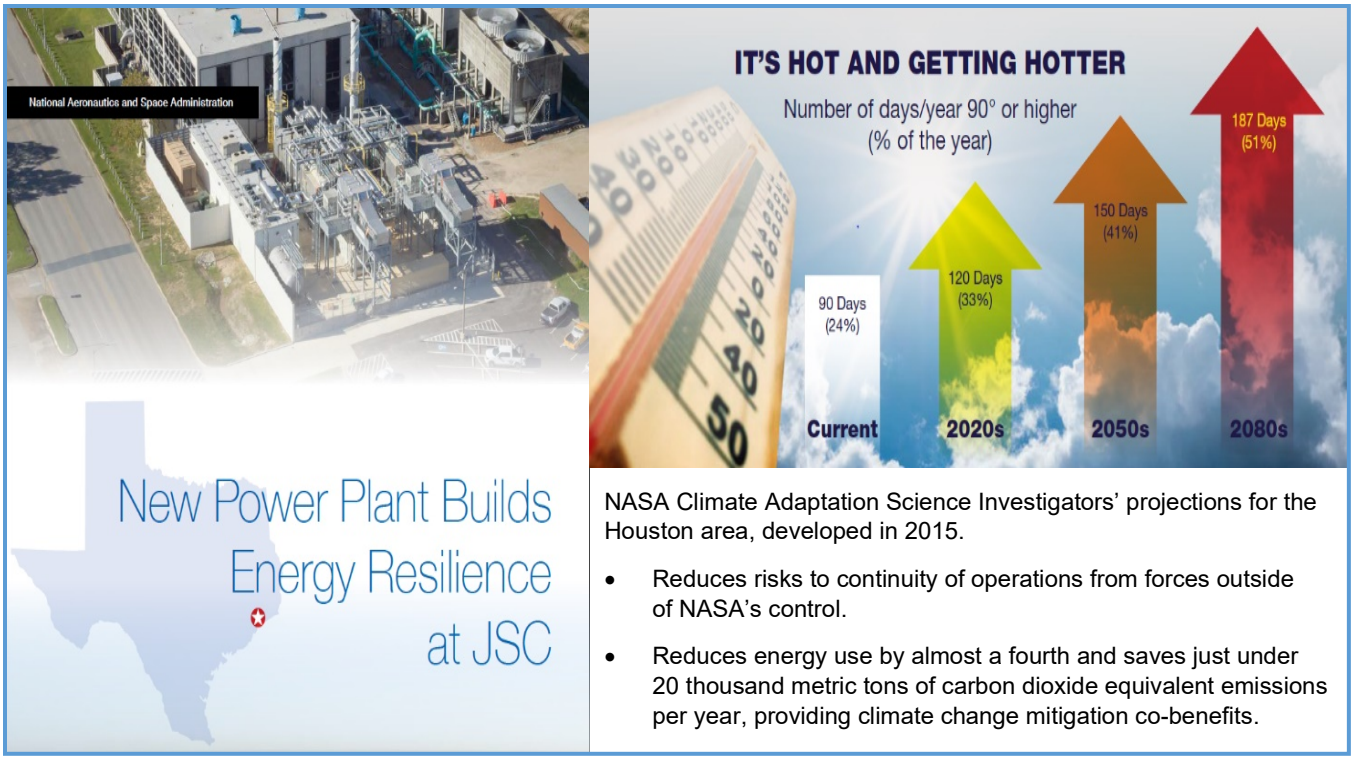


***Figure 5. Images from Communications Handout on Johnson Space Center's Combined Heat and Power Plant (NP-2018-03-006-JSC)***

## **Priority 4:** Update Climate Modeling to Better Understand Agency Threats and Vulnerabilities

The Science Mission Directorate (SMD) influences the global climate science community by promoting principles of open data and science that foster more rapid progress in climate adaptation. NASA leads and contributes to the latest climate science, observations, models, and analyses to provide foundational and decisional knowledge in cooperation with many partners.

Global climate models do not provide projections at a resolution necessary to support local decision making. NASA, through the Goddard Institute for Space Studies (GISS) and others, is one of the few government agencies involved in the scientific community that generates downscaled, regional climate projections. NASA will use this climate change knowledge and Agency GIS capabilities to assess exposure, identify vulnerabilities, and develop adaptation strategies to address climate risk, some of which may also have climate change mitigation co-benefits.

### Action Description:

a. Develop next generation climate models to expand understanding of Earth's climate and climate change, and use the latest analytical outputs to more accurately assess Agency-wide hazard exposure.
b. Supply improved data on Earth's water and energy cycle to agencies responsible for weather forecasting, which in turn allows NASA to prepare in advance for extreme events.
c. Create a connection between NASA climate science data and NASA GIS capabilities to identify and map asset-level hazard exposure for NASA Centers, and incorporate this capability within vulnerability assessments for mission-critical assets.

### Goals:

a. Enhanced NASA climate downscaling modeling capabilities, such as a Regional Climate Model Evaluation System, that result in a more granular understanding of hazard exposure, promote climate change mitigation co-benefits, including GHG accounting, and improve sustainability efforts such as biodiversity management.

b. Improved early warning predictions for extreme events to enable scenario planning, anticipate and take action on climate disturbances, and inform long-range decision making.
c. Refined GIS visualization platforms that integrate future climate conditions with geospatial asset data and land cover change. Visualization supports scenario comparisons, vulnerability assessment, risk management, and policy decision making and guides management of adaptation resources.

**Agency Lead:**

a. Division Director, Earth Science Division (ESD), SMD

**Risk or Opportunity:**

a. *Risk:* Determining how climate change influences the frequency and magnitude of specific disasters and how specific disaster impacts are attributable to climate change will require significant contribution from ESD. For example, NASA must continue working with the scientific community to further advance modeling capabilities to accurately project changes in local precipitation intensity, duration, and frequency. Better understanding of attribution will allow the Agency to build greater adaptive capacity.
b. *Risk:* Gaps remain between current observations and prior projections of well-understood long-term climate change phenomena, such as increased average temperature and sea level rise. To better understand Agency exposure, NASA must continue driving toward improvement of model parameters and calculation methodologies that take into account a growing understanding of feedback loops and nonlinear climate forcings.
c. *Opportunity:* NASA can help drive research and application feedback loops. For instance, by identifying flood-prone roads and intersections, NASA can help target critical locations at its facilities for deployment of water level sensors. The data from these sensors can be fed back into models to inform stormwater network modeling and road improvement plans.
d. *Opportunity:* High-accuracy satellite measurements will enable more rapid detection of climate change trends, providing the data needed to inform the Agency's climate change-related strategic planning. NASA can assist in analyzing supply disruption for optimized risk management, such as through distribution modeling or emergency response routing.

**Scale:** SMD's mission supports the global community. NASA's Earth science research is primarily conducted at Ames Research Center, Goddard Space Flight Center, and Langley Research Center. Figure 6 illustrates the global nature of NASA data collection and analysis.

a. *Global:* Lead and incentivize cutting-edge climate knowledge development that feeds in to climate models, which NASA utilizes in hazard exposure and vulnerability assessments to manage risk.
b. *National and Local:* Support vulnerability assessments for the Agency.

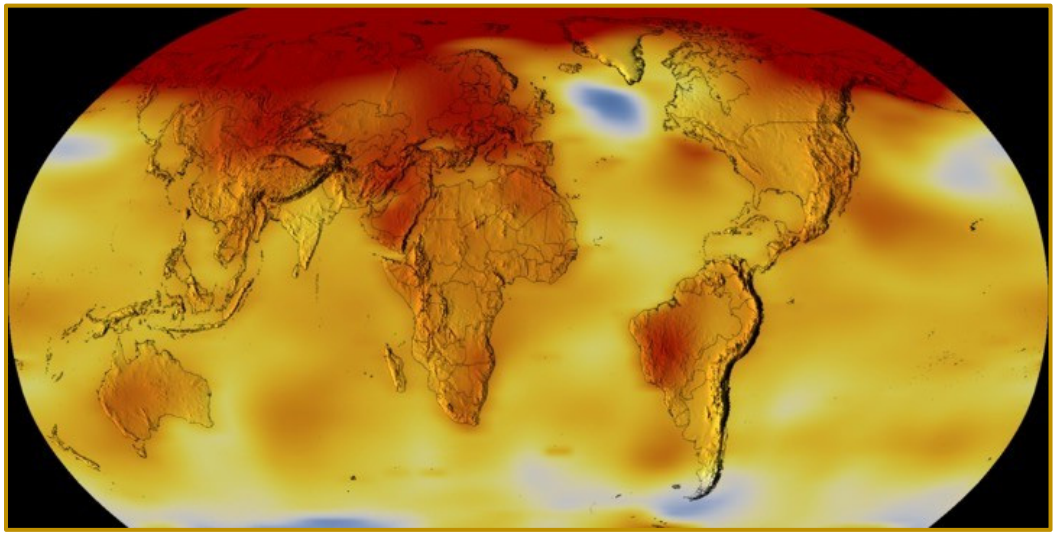

***Figure 6. Temperature Anomalies from 1880 to 2020***

(This color-coded map in Robinson projection displays 2016–2020 global surface temperature anomalies. A video of the 1880–2020 anomalies can be found at https://climate.nasa.gov/climate_resources/139/video-global-warming-from-1880-to-2020/.)

**Timeframe:**

a. Continue data gathering for ongoing modeling activities and implement new research capabilities. (Ongoing)
b. Incorporate cutting-edge climate modeling data with GIS capabilities to enhance site-specific vulnerability assessments; integrate GIS climate data with NASA Resilience Model PrimeE (see Special Topic 3). (Through FY 2025)

**Implementation Methods:** The following provides examples of how NASA's science mission research will allow for improved climate projections and the ability to incorporate this data into adaptation planning.

a. Measure the height of the ocean—a key component to understanding how Earth's climate is changing. Sentinel-6 Michael Freilich launched in 2020 and Sentinel-6B's launch is scheduled for 2025. Staggered launches will help to ensure the continuation of a decades-long record of sea level observations. (Through FY 2030)
b. Make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change over time through the Surface Water and Ocean Topography (SWOT) launch. (Scheduled for FY 2022)
c. Continue and advance observations of global ocean color, biogeochemistry, and ecology, as well as the carbon cycle, aerosols, and clouds, through the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) launch. (Scheduled for FY 2023)
d. Measure Earth's changing ecosystems, dynamic surfaces, and ice masses (providing information about biomass, natural hazards, sea level rise, and groundwater) and support other applications through the NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) launch. (Scheduled for FY 2023)
e. Complete first GIS climate hazard layer concept validation, such as projected sea level rise using different climate scenarios and future epochs; this will include incorporation of the Agency GIS team's subsidence monitoring data. (FY 2022–FY 2023)

**Performance:**

a. Implement Earth science missions required for data collection to advance understanding of Earth's climate, and enhance capabilities for projecting long-term climate change and predicting weather. Climate science data will inform development of qualitative and quantitative measures and metrics specific to improving NASA adaptations.
b. Pursue concept validation of future climate data GIS layers to support NASA's updated vulnerability assessment. Develop GIS layers to visualize the spatial distribution of climate threats under various timeframes and scenarios, and overlay specific Center asset locations and supply chain routes to assess vulnerability. Establish scoring systems to assist in assessment and planning for climate-related threats, vulnerabilities, and potential adaptations.

**Intergovernmental Coordination:** Figure 7 illustrates NASA's partners, each of which plays a role in advancing climate modeling capabilities, through collaboration and information sharing, to inform Agency adaptation plans.

a. Federal partners include science agencies (e.g., NOAA and the United States [U.S.] Geological Survey), other civil agencies (e.g., DOE and the Department of the Interior), and DOD. NASA is a co-founder and an active participant in the Inter-Agency Forum on Climate Risks, Impacts and Adaptation, which provides knowledge sharing across the Federal Government and many other participating organizations.
b. Other critical partners include the European Space Agency, Japan Aerospace Exploration Agency, and the Intergovernmental Panel on Climate Change. NASA supports international efforts such as the Coordinated Regional Climate Downscaling Experiment.

**Resource Implications:**

a. Research and modeling capabilities are primarily mission-funded and benefit from strategic partnering with many organizations.
b. The resources necessary to integrate cutting-edge climate science with Agency GIS capabilities to support climate vulnerability assessments have not been quantified. The work will be conducted with available resources.

**Intergovernmental Coordination:**
NASA and its Centers coordinate with numerous government partners, as well as Non-Governmental Organizations, educational institutions, and the private sector to provide United States leadership in developing and carrying out a cooperative international Earth observations-based research program that enables strategic climate adaptation.

***Figure 7. NASA Partners***

**Challenges/Further Considerations:**

a. *Challenge:* While internal and external partners associated with SMD research provide access to shared resources and other collaborative benefits, NASA needs to make challenging decisions regarding the best available datasets among many, to inform agency exposure, vulnerability, and risk assessments.
b. *Further Consideration:* Beyond climate observation capabilities, NASA needs to explore the potential for interaction among climate and geological, industrial, technological, nuclear, or other disasters in future scenarios, to better manage associated risk and increase resilience.

**Highlights of Accomplishments to Date:**

a. In the early 2010s, NASA GISS and the Climate Adaptation Science Investigators group developed downscaled projections to inform previous climate exposure fact sheets for all NASA Centers, which were used in Center-level climate risk workshops (see Special Topic 1).
b. Integrated Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-on mission data support flood and drought forecasts for the continental United States. Integration of this data and other observations within a land surface model allows downscaled seasonal weather predictions. The products are distributed to multiple end users by the National Drought Mitigation Center and tested by NOAA's North Central River Forecast Center and the Army Corps of Engineers. The products created by these end users inform NASA and other agency vulnerability assessments through improved spatial and temporal granularity.

## **Priority 5:** Advance Aeronautics Research on Technologies and Processes that Reduce Contributors to Climate Change

NASA's Aeronautics Research Mission Directorate (ARMD) explores aviation concepts and technologies, some of which support NASA climate resilience. ARMD's aviation concepts, combined with ESD's observational data, help NASA and other agencies reduce vulnerability to extreme events and long-term climate change. ARMD research and development of advanced technology and aircraft operations lead to climate change mitigation co-benefits for the global community, including GHG emission reductions through electric propulsion systems, as well as advanced composites and vehicle configurations.

**Action Description:** Collaborate with Federal partners, industry, and other stakeholders to develop and implement aviation solutions that enable climate adaptation, while supporting the aviation community's goal to aggressively reduce emissions of carbon dioxide—the dominant aviation GHG.

**Goals:**

a. Improved preparation for, response to, and recovery from disasters through collaborative aviation research programs, which may reduce GHG emissions from these disasters (e.g., improving control of wildfires and management of cascading impacts).

b. Less vulnerable aeronautics supply chain through adaptation solutions that address complex interactions between climate change, raw material logistics, and the industrial base.
c. Advanced technologies that reduce GHG emissions through increased efficiency and air traffic management automation tools.

**Agency Leads:**

a. Deputy Associate Administrator for Policy, ARMD
b. Disasters Program Lead, ESD
c. Director, Logistics Management Division, OSI, MSD

**Risk or Opportunity:**

a. *Risk:* Disasters such as those associated with hurricanes, floods, and wildfires are costly in lives and livelihoods and disruptive. Effective preparedness, response, and recovery operations across Federal, state, and local authorities require extensive coordination and common situational awareness. Current efforts do not sufficiently leverage advanced aviation concepts and technologies or shared data sources and analysis that could improve the efficiency and effectiveness of their operations and logistical support.
b. *Risk:* Critical minerals are key elements in technical aerospace applications. Climate hazards can impact availability and cost of these raw materials and finished products. This can cause interdependent and cascading risks to the mission.
c. *Opportunity:* Coordination among NASA organizations and with external entities on data and operational concepts to support disaster risk management and emergency operations can greatly enhance the collective ability to manage impacts of these climate-influenced events. For example, NASA can better detect and manage pre-fire conditions with improved fuel moisture measurements, detect wildfire radiance, and model fire weather. These capabilities can assist with transport and infrastructure preparedness for burn areas. Development and integration of new technologies and operational concepts for emergency operations, and improved methods for synthesis and analysis of data about the emergency, can improve the effectiveness and timeliness of emergency response operations. Cascading effects, such as increased landslide vulnerability, can also be better controlled.
d. *Opportunity:* There is potential for coordinating climate resilience with GHG reductions, such as through NASA aeronautics concepts currently being researched. One such example is the Truss-Braced Transonic Wing (TTBW) subsonic aircraft shown in Figure 8, which has a wing shape that provides lower drag for fuel use reduction. "Red and violet colors show areas of higher drag, and the green and blue show areas of lower drag. The triangular, pyramid-looking 'cells' represent airflow around the aircraft, helping scientists understand the vehicle's aerodynamics and improve its efficiency. Aircraft concepts like the TTBW are part of an initiative by NASA and industry partners to make aviation cleaner and more sustainable."

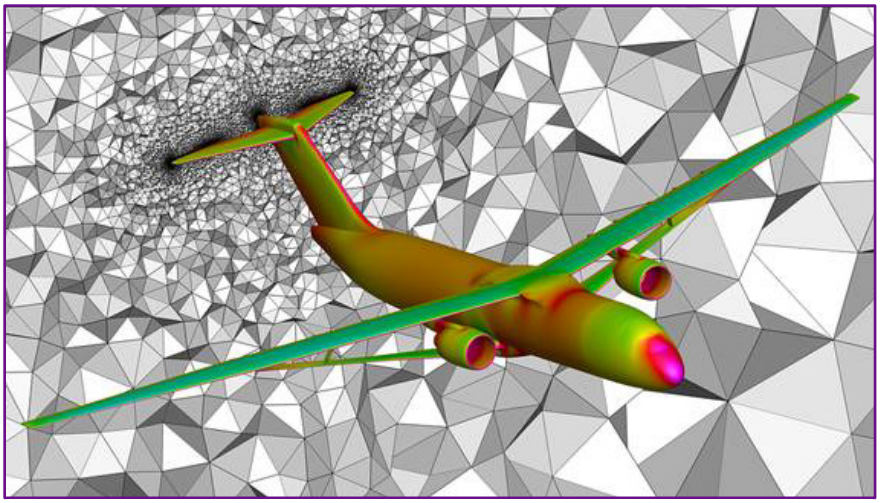

***Figure 8. Computational Fluid Dynamics Simulation View of the Truss-Braced Transonic Wing***

(https://www.nasa.gov/aeroresearch/an-artistic-view-of-the-ttbw)

**Scale:** NASA's missions support the national aviation community and Federal, state, and local emergency response communities. NASA's aeronautics research is primarily conducted at four NASA Centers: Ames

Research Center and Armstrong Flight Research Center in California, Glenn Research Center in Ohio, and Langley Research Center in Virginia.

a. *National:* Agency-wide mission and national resilience
b. *Local:* Center-specific capabilities

**Timeframe:**

a. Support disaster management and emergency action. (Ongoing)
b. Continue research to improve aviation technologies that support adaptation. (Ongoing)
c. Coordinate with supply chain analytics teams. (FY 2022–FY 2024)

**Implementation Methods:**

a. Improve preparation for, response to, and recovery from disasters through application of Advanced Air Mobility (AAM) mission research capabilities (AAM research encompasses the safe integration of diverse vehicles and operations in congested airspace, particularly focused on other than traditional commercial aviation operations) and integration of Earth science data. This could include use of drones, special sensors, and advanced air traffic management systems to improve disaster management. (FY 2020–FY 2021)
b. Complete targeted analyses of potential climate-driven constraints on primary critical mineral supply lines. (Pilot analysis [FY 2022–FY 2023])
c. Accelerate research in aviation technologies for commercial aircraft to reduce GHG emissions. (Timeframe TBD)

**Performance:**

a. Advance emergency response capabilities for pinpointing and tracking hazards. This will include wildfire activity with AAM, such as through the Scalable Traffic Management for Emergency Response Operations (STEReO) project—a research activity dedicated to reducing response times, scaling up the role of aircraft, and providing operations that can adapt to rapidly changing conditions during a disaster.
b. Enable better access to and synthesis of Earth science data to inform aviation research.
c. Complete focused studies on the supply chain of raw materials used in aeronautics.

**Intergovernmental Coordination:**

a. ARMD and SMD activities involve partnering with Federal agencies, city and state governments, nongovernmental organizations, academia, utilities, and private companies. For example, NASA works with the U.S. Forest Service; the Federal Aviation Administration (FAA); NOAA; the California Department of Forestry and Fire Protection; Microsoft; AiRXOS, Inc.; Avision, Inc.; and SFIRE.
b. NASA coordinates with FAA and other agencies to deliver safety and efficiency optimization technology for every U.S. commercial aircraft and U.S. air traffic control tower.

**Resource Implications:**

a. Execution of existing AAM research is funded by ARMD (the STEReO demonstration activity is funded through FY 2021 and will be completed with existing resources).
b. Earth science data and analysis are provided through the SMD Disaster Program.
c. Resources required for targeted future studies, research, and pilot programs have not been determined but will be executed within existing resources.

**Challenges/Further Considerations:**

a. *Challenge:* Often, research activities are siloed within organizations that must partner closely to most effectively manage climate risks. Federal disaster management efforts require data sharing, synthesis, and alignment across several agencies and domains to support first responders. This includes satellite- and aviation-based information sources to guide local understanding of economic and infrastructure exposure, community vulnerability, ecosystem status and impacts, regional air quality impacts from fire emissions, and application of aviation concepts and technologies for improved operational response.

**Highlights of Accomplishments to Date:**

a. NASA's AAM mission leverages technologies and expertise to integrate solutions from multiple agencies involved in disaster risk management. AAM demonstrates this capability through projects including STEReO, ad hoc groups including the Tactical Fire Remote Sensing Advisory Committee, and formal interagency bodies including the Science for Disaster Reduction coordination group and the White House National Science and Technology Council's Subcommittee on Resilience Science and Technology.

b. NASA leads cooperative efforts on the Global Fire Emissions Database that allow for near real-time emissions estimates, now available from https://www.globalfiredata.org; NASA's Fire Earth Information System Pilot Project and Agency projects like Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making deliver information products to users through https://maps.disasters.nasa.gov.

c. NASA hosted the *Resilient Aviation Infrastructure Workshop* in partnership with the DOD Strategic Environmental Research and Development Program in 2019.

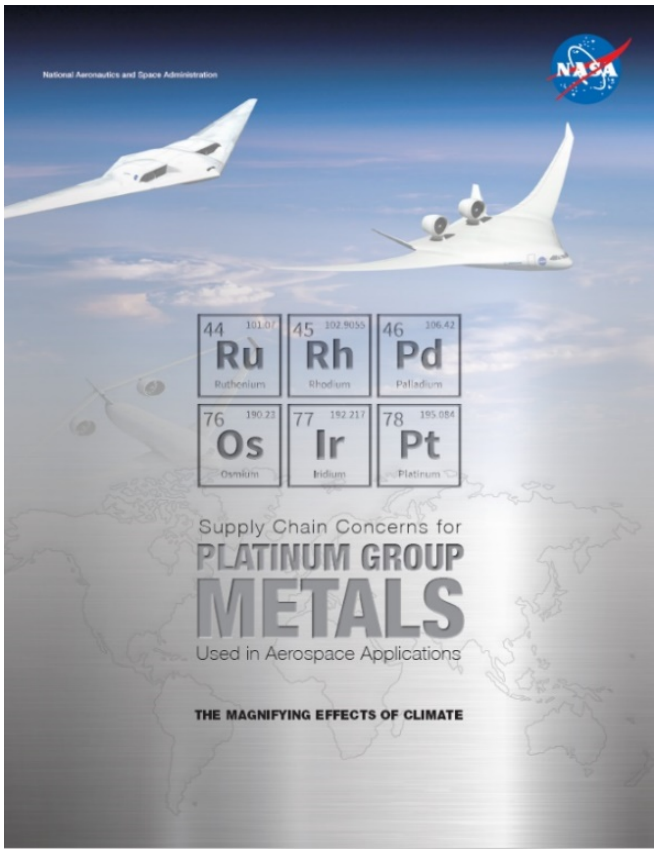


***Figure 9. Cover of the 2017–2018 Study on Supply Chain Concerns for Platinum Group Metals***

d. NASA and the entire U.S. aeronautics and aerospace sector relies heavily on imported platinum group metals (PGMs). Often, this includes mission-critical applications where no viable alternatives exist in the marketplace. The United States depends on PGM imports due to the lack of domestic production. Demand can change quickly, but changes in production can take years. Warming temperatures and an increase in precipitation and extreme weather events are projected to increase vulnerabilities to infrastructure, agriculture, and other components integral to the PGM supply chain. NASA's Environmental Management Division conducted a PGM study (2017 through 2018) to understand how climate change can magnify supply chain concerns related to maintaining aerospace capabilities. Figure 9 shows the front cover of the PGM study. A database that records availability, country of origin, method of transport, and other indicators helps organizations assess and determine materials of choice. NASA's single point source for material properties is the Materials and Processes Technical Information System.

## VII. Special Topics

### **Special Topic 1:** Update Climate Vulnerability Assessments

***NASA has continually built upon previous initiatives.***

Over the past several years, NASA has invested in multiple studies to identify and analyze Center-specific and organizational vulnerabilities and risks. Table 2 names each study or workshop, its focus, and the dates they were conducted. NASA's studies and experience have confirmed that natural hazards could severely impact NASA Centers and their ability to execute mission activities. The Agency has since refined its process for considering climate exposure and vulnerability and emphasized a need to build Center-level awareness.

| NASA Site Workshops 2009-2012 Sponsored by NASA-HQ Environmental Management Division | NASA Climate Adaptation Science Investigator (CASI) Workgroup 2010-2016 | NASA Goddard Institute of Space Studies (GISS) 2015 | NASA-wide Climate Change Subcommittee of the Engineering & Construction Innovation Committee (ECIC) | NASA Kennedy Space Center Engineering Directorate 2019 |
|---|---|---|---|---|
| *9 Sites - Workshops* | *8 Sites - Workgroups*<br>*"NASA's CASI Building Climate-Resilient NASA Centers" – 2011*<br>*"Enhancing climate resilience at NASA Centers" – 2014* | *11 Sites - "2015 Climate Projections"– October 2015* | *10 Sites - "Screening Level Vulnerabilities Assessment Survey (SLVAS)" – March 2018* | *Single NASA site -*<br>*"Study of Upgrade Infrastructure for Climate Adaptation" – August 2019*<br>*(Focus is primarily in sea level change)* |

***Table 2. Sample of Workshops and Studies Conducted on Center-Specific Exposure to Climate Hazards***

NASA developed and conducted Center climate risk workshops from 2009 through 2012. During these workshops, NASA climate scientists from GISS provided downscaled, Center-specific climate data to NASA asset stewards and operations managers. This data allowed workshop participants to develop a greater understanding of climate exposure. It also enabled the participants to capture their understanding of potential Center-level climate impacts over time. Figure 10 illustrates how qualitative exposure assessment results were captured.

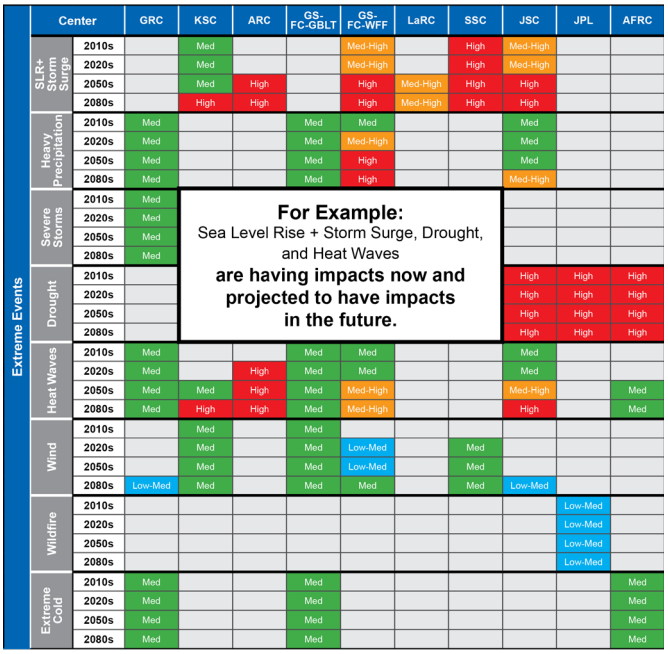


***Figure 10. Screening-Level Exposure Assessment Results for Select NASA Centers***

Climate hazards analyzed for each Center include the following:

- mean annual changes for temperature and precipitation;
- seasonal changes for temperature and precipitation;
- sea level rise; and
- extreme events
  - number of days per year with maximum temperature at or above 90 degrees Fahrenheit
  - number of days per year with minimum temperature at or below 40 degrees Fahrenheit
  - number of days per year with rainfall at or above 1 inch
  - number of days per year with rainfall at or above 2 inches
  - number of heat waves per year
  - average heat wave duration (in days).

From 2015 through 2018, NASA conducted an internal stakeholder survey and analyzed the results to develop a screening level vulnerability assessment at the Center level. The Screening Level Vulnerability Assessment Survey (SLVAS) provided a preliminary understanding of where assessments that are more comprehensive would be needed for each Center. The questions in NASA's initial survey had a limited focus on observed effects from past severe weather events, the potential consequences of an increase in mean sea level, and the proximity of site acreage to any flood-prone areas. Vulnerabilities differ greatly across the Agency, and the Center-specific reviews did not address vulnerability from the Agency-wide perspective. The survey required input on impacts to NASA site assets, as well as any observed impacts on similar assets in the surrounding community that provided supporting services (e.g., utilities, transportation, and emergency response) for the NASA site. Asset categories included built infrastructure, technical capabilities, built infrastructure mission support, and

natural systems and workforce. Figure 11 illustrates a follow-on process to SLVAS involving a detailed analysis of climate impacts. In this case, the process was applied specifically to horizontal infrastructure. The NASA Engineering and Construction Innovations Committee captured findings in an Agency internal white paper in 2016. NASA amended this white paper in 2017 and 2018 to add an assessment of vertical infrastructure vulnerabilities and include comments on hurricane impacts at Johnson Space Center and Kennedy Space Center.

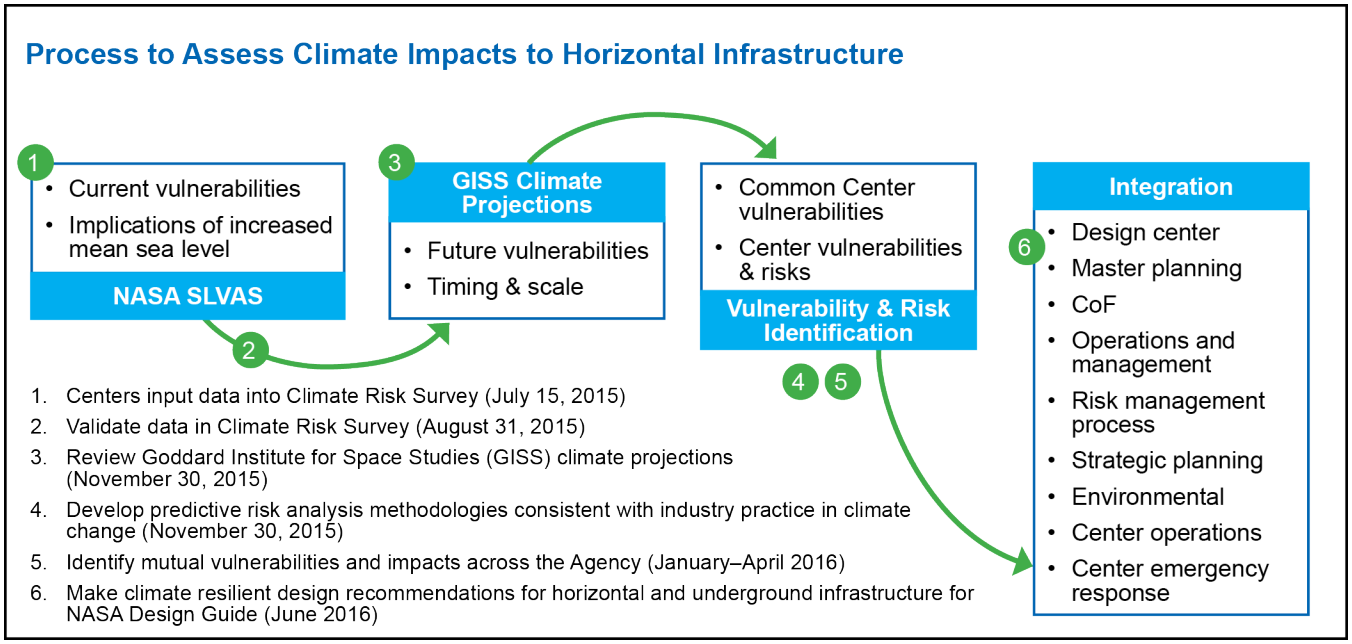


***Figure 11. Process to Assess Climate Impacts to Horizontal Infrastructure***

Figure 12 provides an illustrative sample of how NASA documented information on location, climate hazard, timeframe, and magnitude of impact. This sample shows the variation in level of qualitative detail available for individual assets following the assessment of impacts to horizontal infrastructure.

| | | Timeframe / Scale of Impact | | | | |
|---|---|---|---|---|---|---|
| Center | Climate Hazard | 2010s | 2020s | 2050s | 2080s | Asset Vulnerability (Qualitative) |
| Jet Propulsion Laboratory | Drought | high | high | high | high | 200+ buildings and structures |
| Johnson Space Center | SLR + storm surge | med-high | med-high | high | high | a) JSC Tunnel System<br>b) Utility distribution to main JSC campus |
| Kennedy Space Center | Wind | low | med | med | med | Transportation Infrastructure and Routes<br>a) Primary Routes: NASA Causeway (SR 405), including IR and BR Bridges; NASA Parkway (SR 3), Beach Road (SR A1A)<br>b) Secondary Routes: LC-39 Roadways; KSC Industrial Area Roadways |
| Glenn Research Center | Heavy precipitation | low | low | med | med | a) Process system and controls, valve controls, research air lube oil, and cooling tower water systems, piping and valves for the above, and refrigerated and service air systems<br>b) Electronic switches are particularly vulnerable to electric storms, equipment which needs to remain at a certain temperature to run properly is particularly vulnerable to high heat -- both of these system components are necessary for mission critical research operations. Facilities with multiple air compressors are also vulnerable to shutdowns due to heat waves. HVAC systems in basements (particularly 64 and ERB) are subject to flooding risks in downpours. |

Key:
SLR = Sea level rise
med = Medium
SR = State route
IR = Indian River
BR = Banana River
LC = Launch Complex
ERB = Engine Research Building

***Figure 12. Excerpt of Qualitative Risk Assessment for Horizontal Infrastructure in 2015–2016***

### *How NASA plans to conduct an updated vulnerability assessment*

Anticipating and responding to climate change requires an ongoing, iterative cycle of assessment, action, reassessment, learning, and response. NASA's prior exposure data and screening-level vulnerability assessments have a limited focus. Figure 13 shows prior climate projections, based on quantitative model outputs and qualitative vulnerability assessments conducted at the Center level. Based on these historical analyses, NASA knows that facility climate vulnerabilities are primarily driven by exposure to sea level rise, extreme weather events, drought, and wildfires. A lack of supply chain visibility has more recently come into focus as a significant vulnerability. Advancements in climate science, modeling, and data visualization will support more rigorous vulnerability assessments. NASA will need to incorporate updated climate projections and shift its climate baseline to incorporate modeling capabilities that are more robust. An Agency-wide vulnerability assessment will also need to incorporate a broader mission focus, moving beyond a primarily facilities-oriented viewpoint. In implementing this CAP, NASA will process updated exposure data and conduct an updated vulnerability assessment to enable an Agency-wide, risk-informed prioritization of adaptation actions. NASA will update its vulnerability assessment, as appropriate and feasible, to include these more advanced capabilities. NASA will revise these assessments through incorporation of its own advanced climate modeling capabilities over time.

**NASA SITE CLIMATE INFORMATION & DATA – *Aggregate***

| NASA SITE | NASA SITE CLIMATE SELF ASSESSMENT INFORMATION[1] - Qualitative | | | | | | | NASA SITE CLIMATE SCIENCE DATA[2] - Quantitative | | | | | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NASA SITE CLIMATE CONCERNS | | | | NASA SITE CLIMATE VULNERABILITIES | | | NASA SITE CLIMATE PROJECTIONS *(Change from Baseline [1971-2000] to future [2080s], 90th Percentile)* | | | | | |
| | TEMP. | FLOODING | | OTHER | PHYSICAL ASSETS | | OPERATIONS | HIGH TEMP. & HEAT WAVE | | | FLOODING | | |
| | High Temp. & Heat Waves | Heavy Precip. Events | Sea Level Change | Cited Areas | Land | Structures | Cited Operations & Maintenance Areas | High Temp. *Days per year > 90oF* | Heat Wave *Number per year* | Heat Wave *Days per year* | Heavy Precip. *Days per year > 2 inches* | Sea Level Rise *Inches* | |
| Armstrong Flight Research Center, CA | X | X | | Drought, Wind, Extreme Cold, Dust Storms | Operations & Maintenance | Structural Damage, Facilities Damage | Power, HVAC, water supply | 106 → 164 | 7 → 8 | 14 → 21 | 0.1 → 0.4 | | |
| Ames Research Center, CA | X | X | X | Extreme Cold | Areas | Electrical Infrastructure, Storm & Sanitary Sewers, Transportation, Building Basements Flooding, Building Envelopes Design for Heat Gain/Loss | HVAC, Power | 6 → 42 | 0.7 → 5 | 3 → 4 | 0.1 → 0.6 | ↑ 59 | |
| Glenn Research Center, OH | X | X | | | Stormwater Flooding, Stormwater Erosion | Power Infrastructure Damage, Roads & Buildings Collapse due to Erosion, Flooding of Roads, Flooding Basements, Building Envelope (Walls, Windows, Roof), Sewer Systems, Electrical Systems, Telecom Systems, Structural Damage | HVAC, roads, utilities cost | 9 → 92 | 0.7 → 10 | 4 → 8 | 0.7 → 2 | | |
| Goddard Space Flight Center, MD | X | X | | Wind, Extreme Cold | Stormwater Flooding | Flooding of Roadways, Utility Power Loss due to Winds, Basement Flooding, Building Envelope (Walls, Windows, Roof) Heat Gain & Loss | Power, HVAC, roads, utilities cost | 29 → 119 | 3 → 9 | 5 → 13 | 2 → 4 | | |
| Jet Propulsion Laboratory, CA | X | X | | Drought, Wind, Wildfire | Wildfires | Structural Damage, Power Supply Damage, Basement Flooding, Electrical System Overload | Power, HVAC, water supply, utilities cost | 22 → 119 | 3 → 12 | 5 → 9 | 0.2 → 2 | | |
| Johnson Space Center, TX | X | X | X | Wind | Flooding | Flooding Roadways, Loss of Utility Power due Winds, Building Envelope Issues, Loss of Primary & Redundant Power | Power, roads | 90 → 187 | 7 → 11 | 11 → 19 | 5 → 8 | ↑ 50 | |
| Kennedy Space Center, FL | | | X | Wind | Flooding | Flooding Roadways | Power, roads | 85 → 200 | 8 → 11 | 8 → 20 | 4 → 6 | ↑ 49 | Human Space Flight Spaceport |
| Langley Research Center, VA | | | X | | Flooding | Sea Level Rise Flooding of Wastewater Treatment Facilities; Sea Level Rise on Roads Electrical & Communications | Power, roads | 34 → 113 | 4 → 11 | 5 → 9 | 4 → 3 | ↑ 49 | Hampton Roads has extreme Sea Level issues |
| Marshall Space Flight Center, AL | {X} | {X} | | {Wind, Tornadoes} | | {Building Envelope Structural Damage from Severe Storms} | {Power, HVAC, utility costs} | 47 → 146 | 5 → 10 | 8 → 18 | 4 → 8 | | { } = Assessment from Supplementary Sources |
| Stennis Space Center, MS | X | | X | Wind | Flooding | Flooding Roadways, Buildings at or Below Flood Elevation | Power, HVAC, roads | 33 → 163 | 4 → 7 | 8 → 33 | 7 → 9 | ↑ 49 | |
| Wallops Flight Facility, VA | | | X | Wind | Shore Line Erosion, Island Launch & Support Facilities subject to Storm Surges & Sea Level Rise | Energy Infrastructure, Launch Pad, Runways, Storm & Sanitary Sewers, Roadways | Power, roads | 13 → 79 | 1 → 8 | 4 → 8 | 2 → 4 | ↑ 50 | Spaceport |
| NASA-wide | 7 | 7 | 6 | | | | | 8: (~1/3 of year) | 7: (> x2) | 7: (> x2) | 8: (> x2) | 6: (> 4 feet) | |

[1] NASA –Climate Change Subcommittee of the Engineering & Construction Innovations Committee (ECIC), "White Paper – An Assessment of Climate Change Impacts to NASA Center Horizontal Infrastructure and the Potential Need to Update Design or Operational Standards" August 2016; "Amended November 2017 and March 2018 to add Vertical Infrastructure Vulnerabilities …"

[2]NASA – Climate Adaptation Science Investigator (CASI) Workgroup, "2015 CASI Climate Projections (11 Documents for NASA Sites – Daniel Bader)"

Temp. = Temperature, Precip. = Precipitation

***Figure 13. NASA Site Climate Information and Data***

The NASA-wide Institutional GIS Portal will provide crucial support in enabling the Agency to conduct asset-specific vulnerability assessments. GIS layers depict all infrastructure critical to NASA's mission, including buildings/structures, roads, bridges, tanks, etc. The GIS portal can support NASA's effort to adapt to climate change by helping decision makers assess asset vulnerability to climate-related hazards. NASA can view building attributes in the Real Property Management System, such as the Mission Dependency Index and Facility Condition Index, and Centers can provide additional data on locality-specific impacts. NASA will investigate how additional GIS layers could support calculating the value of facilities subject to flooding and enable accurate disclosures of vulnerability in annual Agency financial reporting.

NASA will reassess vulnerabilities tied to management functions and decision points for managing procurement, real property, public lands and waters, and financial programs. NASA will leverage existing tools, such as the NOAA Climate Resilience Toolkit and the Naval Facilities Engineering Command Installation Adaptation and Resilience Planning Handbook, to determine potential adaptation actions. This process will include an analysis of barriers to implementation, rough timeline estimates, and measures for indicating progress over time. NASA will assess risk to its mission, value chain, personnel, and financial position. An understanding of Agency climate vulnerabilities and integration into the Agency's enterprise risk management process will allow for accurate materiality assessments and disclosures in annual Agency financial reporting.

Two priority areas identified for management consideration include launch site and critical supply chain vulnerability. The Agency will include consideration of top climate vulnerabilities through the annual PPBE process, which includes a five-year outlook. The PPBE process can enable tracking of budgetary requirements for climate adaptation planning and disclosure in annual financial reporting. However, this will require iterative improvement, as the PPBE process involves many organizational inputs across different mission directorates and programs, as well as consideration of appropriations and the CoF process through OSI.

NASA will determine whether managing the risk and overcoming associated barriers is achievable within existing Agency resources or consistent with its budget request.

## **Special Topic 2:** Describe Agency Efforts to Enhance Climate Literacy in its Management Workforce

NASA will enhance climate literacy across the Agency. NASA management personnel across all Agency organizations need to understand climate factors to the extent necessary to inform decision making in their area of responsibility. NASA has begun to identify offices with a critical need for climate education, including the Office of the Chief Financial Officer, Office of Procurement, and leadership across mission directorates and Centers.

NASA will enhance climate literacy to its management workforce through a top-down approach of a town hall, workshops, briefings, and messages from the Administrator. NASA will use the education process to advance a climate-change-aware culture throughout its workforce. These venues will reinforce and build upon the Agency's commitment to identifying and addressing climate change issues and implementing adaptation and mitigation solutions. The Agency Senior Climate Advisor will be responsible for the development and implementation of the climate literacy effort.

NASA will assess the climate literacy level of the overall Agency workforce through a survey, or series of surveys, regarding climate change and its impacts on the Agency's ability to fulfill its missions. The survey will also solicit input on climate topics the workforce would like to learn more about. From the survey results, training programs can be developed through the NASA System for Administration, Training, and Education Resources, which can include online basic climate change awareness, as well as in-depth courses on specific climate-related topics. The Agency has extensive experience in developing engaging educational tools.

A detailed timeline will be developed for each educational activity once the overarching strategy has taken shape. Planning activities continue in preparation for the following:

- FY 2021: senior leadership education;
- FY 2022: initial workforce survey; and
- FY 2022–FY 2023: broader training buildup and rollout.

Existing capabilities may be adapted into learning module content, to educate management chains and the broader workforce further:

- Current Applied Science Educational Activities
  - Science-informed adaptation and resilience is promoted through the use of geospatial information and data on vulnerabilities to tailor solutions to specific audiences.
  - SMD has partnered with the Human Exploration and Operations Mission Directorate in providing entry-level astronaut candidate training on climate literacy, with a number of lessons learned about lack of scientific understanding in the human space-flight-focused community at NASA.

  - Services that incorporate geospatial data to guide management of water resources are provided to help communities mitigate risks from severe weather, flooding, and drought.
  - Food security decision making is supported through forecasts and modeling, helping countries anticipate and take action on agricultural conditions in response to drought and other climate disturbances.
  - Data on land use and land cover is used to help inform activities, from carbon accounting to biodiversity management.

- NASA Climate Communication Websites
  - Climate.nasa.gov
  - Sealevel.nasa.gov
  - Nasa.gov/earth
  - Appliedsciences.nasa.gov
  - disasters.nasa.gov

## **Special Topic 3:** Describe Agency Actions to Enhance Climate Resilience

NASA directives and policies incorporate climate adaptation considerations in the Agency's management functions and procedures for sites, facilities, and supply chain. NASA's National Environmental Policy Act process provides a platform to inform surrounding communities about proposed projects and helps maintain strong community relationships. This platform requires the consideration of environmental justice, including the equal distribution of environmental risk and benefit and the avoidance of maladaptation. The Agency climate adaptation and resilience policy will place increased emphasis on climate considerations in these management functions and procedures. This emphasis will include requirements for the consideration of changing temperatures, sea level rise, storm surge, changing precipitation patterns, flooding and erosion, wildfires, water supply, and mobilization of contaminants at remediation sites.

### *Actions for Climate-Ready Sites and Facilities*

NASA Policy Directive (NPD) 8500.1c (revalidated October 29, 2018) requires that the Agency "apply NASA's scientific expertise and products so that climate information can be incorporated in NASA decision making and planning; create innovative, sustainable, and flexible solutions; and share best practices to create climate-resilient NASA centers," and "taking actions to improve climate change resilience of critical agency assets." The NASA Facilities Design Guide includes requirements for consideration of climate for new and existing facilities, and the Agency can consider facility vulnerability as part of efforts to reduce its footprint. NASA continues to ensure that new facilities are designed and constructed to meet the Guiding Principles for Sustainable Federal Buildings and each earns at least a Leadership in Energy and Environmental Design (LEED) Silver certification by the U.S. Green Building Council or equivalent Green Globes independent third-party certification. NASA's green infrastructure projects provide climate adaptation benefits, such as green roofs, bioretention systems, permeable pavers, and tree box systems that can help manage stormwater runoff. Expansion of forested riparian buffers can help manage erosion. The Agency is evaluating the Envision certification system for future infrastructure projects. Envision provides a system of criteria and performance objectives for infrastructure projects, including climate change risks and impacts. This includes identifying sustainable, resilient, and equitable approaches during planning, design, and construction and throughout the infrastructure project's operations, maintenance, and end-of-life phases.

NASA Centers already monitor risk and often apply projections of future conditions in their planning processes. This is particularly true for potential high-impact climate events, like hurricane flooding. Johnson Space Center is conducting a study on flood risk reduction for a Component Facility. Johnson Space Center had previously conducted a flood assessment in 2004 to understand the scope of flood threats and determined that 14 percent of its facilities' square footage lies in the 500-year Federal Emergency Management Agency floodplain. A study conducted by Langley Research Center projected flooding from a storm equal in magnitude to Hurricane Isabel, plus 18 inches of sea level rise (see Figure 14). Centers can use this or similar information to evaluate the area of property subject to flooding under hurricane conditions. As an example, hardening and other adaptation measures are taken during new construction projects as a result of the Langley study. Langley Research Center has raised buildings significantly compared to older construction and considered flood projections in its future campus plan, siting new buildings in a central campus area where flooding is least likely.

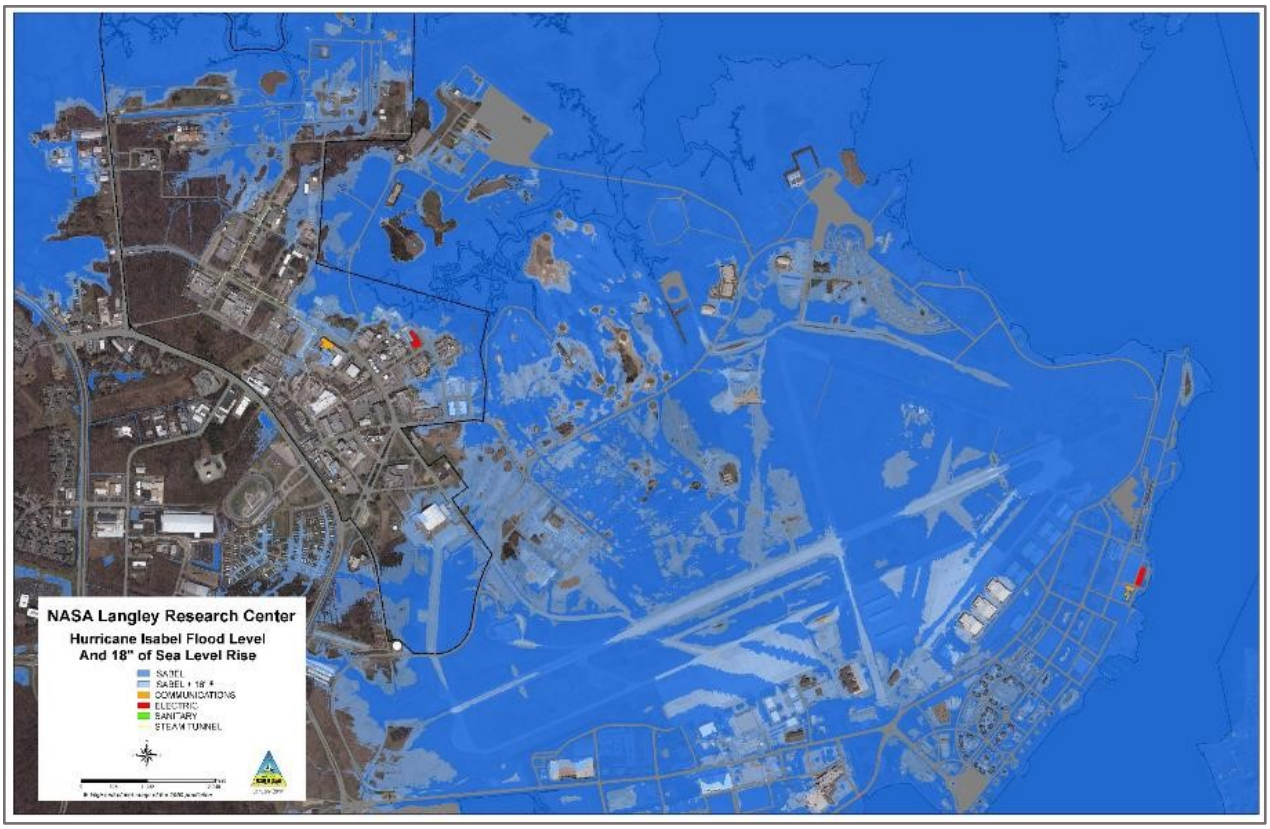


***Figure 14. Projected Potential Flooding at Langley Research Center (area in black outline) if 18 Inches of Sea Level Rise Were Added to 2003 Hurricane Isabel***
(Adjacent Langley Air Force Base runways are visible in the lower right.)

Centers also conduct detailed onsite assessments, following industry best practices. Kennedy Space Center conducted a study that concluded in 2019, which applied an assessment methodology depicted in Figure 15.

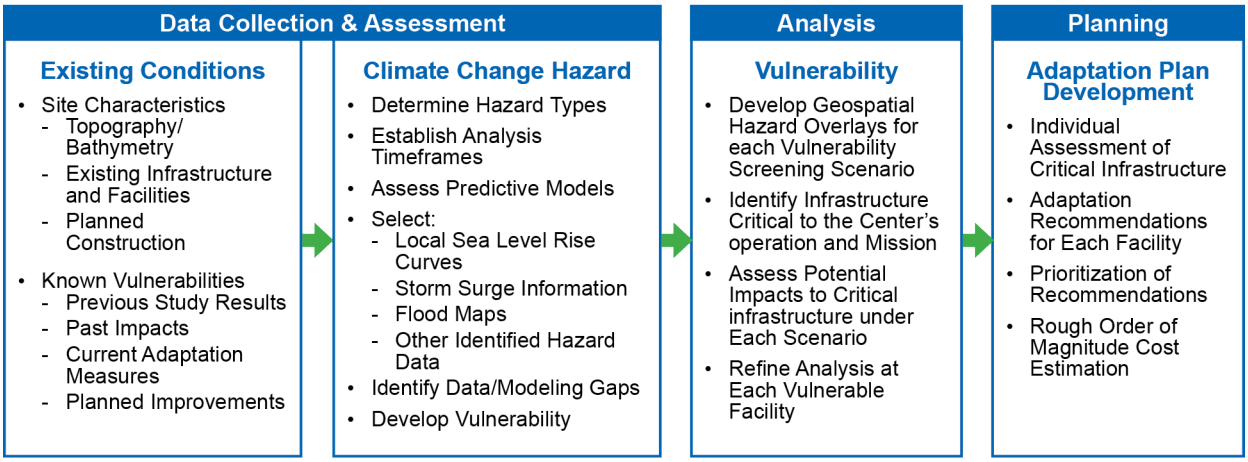


***Figure 15. Kennedy Space Center's Standardized Process Flow Diagram for Incorporating Climate Risks into Planning***

Climate change impacts natural systems at NASA properties. NASA will adapt its natural resource management practices where conditions are changing due to climate change to improve ecosystem resilience against climate hazards. This adaptation includes adjusting management of threatened and endangered species to adapt to potential climate impacts (e.g., invasive species and changes in precipitation patterns). The Agency will use nature-based solutions to reduce infrastructure vulnerability.

NPD 8500.1c requires “improving energy efficiency and reduction of energy consumption and greenhouse gas emissions.” NASA’s strategy for climate change mitigation incorporates the Agency’s overall vision for energy and water management—to minimize the use of resources (and thereby minimize GHG emissions), while still successfully accomplishing the mission. NASA employs a diverse mix of renewable sources and technologies, including solar photovoltaic systems, ground-source heat pumps, landfill methane boilers, and waste-to-energy steam plants. NASA will continue to install onsite renewable generation wherever life-cycle cost-effective or where needed for critical infrastructure resilience. The Agency Strategic Energy Investment Plan summarizes potential renewable energy projects (solar, wind, and battery storage) at each site and provides estimates for economic viability. The Agency continues to partner with local utilities and/or adjoining military installations on potential projects. NASA is evaluating other clean energy technologies such as ground-source heat pumps in new construction projects. NASA continues to evaluate covered facilities for potential energy conservation measures (ECM) and incorporates these ECMs into future energy investments using Construction and Environmental Compliance and Restoration appropriations and performance contracting. The Agency will continue to buy additional renewable electricity and/or renewable energy credits needed to meet Federal goals and drive climate change mitigation. NASA plans to research and identify opportunities for improved fluorinated gas inventory management and potential alternative materials to meet mission requirements for wind tunnel research. This investigation may provide a complementary mitigation opportunity in alignment with the need to address energy consumption from significant energy uses. NASA also reduces potable water consumption by upgrading infrastructure, installing metering, and reducing water waste through no-cost or low-cost measures. NASA applies reuse of non-potable water for irrigation or toilet flushing, which can greatly reduce potable water use. NASA conducted a Western NASA Facility Drought Study to inform Agency understanding of climate vulnerability in drought-threatened areas.

### *Actions to Ensure a Climate-Ready Supply of Products and Services*

NASA is committed to ensuring the security and reliability of its supply chain. The NASA industrial base sometimes includes a single supplier of a particular material, part, or service. Potential climate impacts to missions create the need for NASA to make decisions today about its industrial base needs for the future. NASA will investigate opportunities to incorporate advanced climate modeling and vulnerability analysis capabilities to complement agency supply chain management tools. Rather than replacing legacy supply chain systems, the Agency continues enhancing its existing software suite in collaboration with other agencies. While supply chain criticality assessments have evolved over time, they have not included climate change considerations. NASA’s Logistics Management Division has performed supplier facility mapping and modeling to analyze spatial distribution of supply routes and expenditures. These existing data and decision support tools provide a good base for incorporating climate-focused analytics to support supply chain resilience planning. Similar to hurricane spaghetti models, integrating these capabilities across multiple model platforms will enhance climate robustness of the supply chain over time. The Agency will screen its top mission-critical supplies of goods and services to identify those at risk due to disruption by acute extreme weather events or long-term climate change.

NASA will put into action several steps to improve resilience through PrimeE, a supply chain analytics tool, and other capabilities. This will also support sustainability and maintain U.S. competitiveness, national security, and a steady state for NASA sources and the industrial base. These supply chain resilience steps will include modeling and developing a digital ecosystem of the supply chain for tighter coordination and visibility into all upstream and downstream tiers, maintaining industrial capacity by scenario-based planning, analyzing key performance indicators, developing dashboards, and applying visualization to continuously analyze tactical adjustments and longer-term strategies. Figure 16 lists key features of PrimeE.

NASA’s Office of Procurement plays a significant role in understanding program risks associated with safety, occupational health, security, and environmental factors. Procurement teams conduct robust financial impact analyses under various scenarios. However, these risk management activities and analyses do not incorporate projections of future climate hazard exposure or fully address associated Agency vulnerabilities. This challenges NASA’s ability to ensure a climate-robust supply of goods and services and improve climate resilience.

***Figure 16. PrimeE Supply Chain Analytics Features***

The Office of Procurement uses COOP plans, the Federal Acquisition Regulation (FAR), the NASA FAR Supplement (NFS), and other regulations and tools to quantify the relative magnitude of various risks. The Agency will evaluate application of these mechanisms to investigate and implement climate adaptation solutions. These efforts will enable a more complete understanding of how climate change can exacerbate risks to vulnerable communities and how NASA can develop procurement criteria updates that ensure equitable distribution of risks and benefits.

- Individual Acquisition Planning
  - Current State: NASA manages procurement risk through its acquisition planning process, including risks driven or exacerbated by climate hazards from a perspective of stationary climate conditions.
  - Planned Actions: The Agency will investigate opportunities to expand from single, event-focused risk management considerations under climate stationarity to explicit inclusion of projected long-term changes in climate, including consideration of how extreme events may become more frequent and intense and increase in duration.
- Procurement Process Review
  - Current State: NASA applies FAR, NFS, and other rules, requirements, and tools to govern the process by which it buys goods and services. Two of the areas receiving emphasis promote sustainability and reduction of GHG emissions.
  - Planned Actions: The Agency will review procurement processes to more completely factor short- and long-term climate risk into its acquisition planning process, including methods for determining which products and services would better meet NASA needs, given these additional risks.

To improve management of Agency climate-related risk through procurement processes, new analyses could include an expanded assessment of how evolving climate hazards cause unexpected supply chain disruptions, such as “down days” and how assessment of associated risk may need to evolve over time. For example, an increase in the number of days per year above 90 degrees Fahrenheit may affect workforce productivity. Longer lasting, multiday heat waves may stress the workforce and limit the number of days per year in which outdoor work can take place at full capacity. Increased rate or severity of inland flooding may also result in more frequent limitations on site access or access to mission-critical supplies. The Office of Procurement will investigate the need for cooperative analyses with NASA Logistics and Supply Chain teams, as well as other Federal partners.