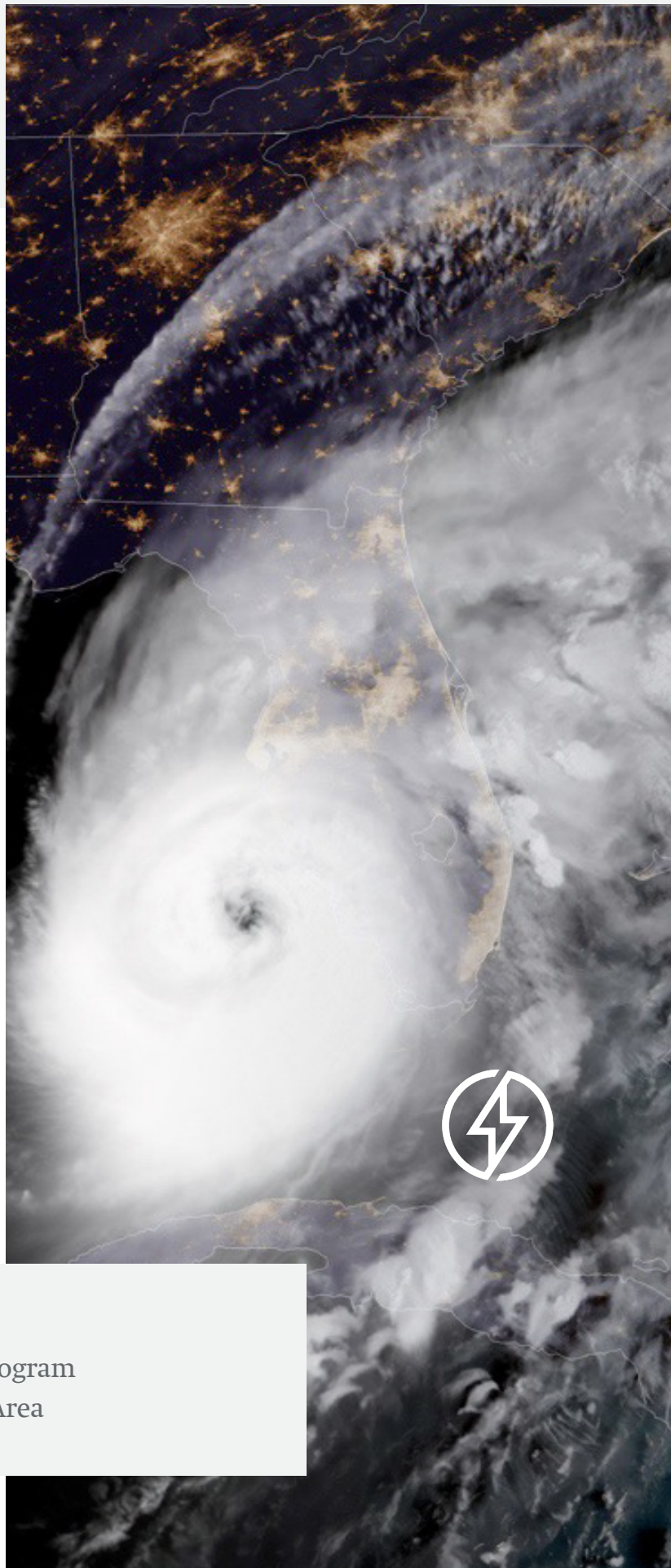
EARTH SCIENCE
APPLIED SCIENCES

2022 ANNUAL SUMMARY



DISASTERS

NASA Earth Science
Applied Sciences Program
Disasters Program Area

DISASTERS
2022 ANNUAL SUMMARY

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Cover Image:

A satellite image from the National Oceanic and Atmospheric Administration shows Hurricane Ian approaching Florida on Sept. 28, 2022, at 7:56 a.m. ET.

Source: NOAA/NASA

DISASTERS

I. WELCOME

Thank you for exploring the work of NASA's Earth Science Applied Sciences Disasters program area through our 2022 annual summary.

2022 was a year of transition for the NASA Disasters program, with changes in staffing and leadership and a re-assessment of the program's processes and strategic goals. The program focused on strengthening existing partnerships and forging new ones by participating in disaster readiness exercises with State Emergency Managers, including CAL FIRE BurnEx, and the Understanding Risk Global Forum, an international event that brings scientists, policy makers, and practitioners together to advance disaster risk management. In November, the program hosted its first annual retreat. This strategic planning and team-building event brought together program staff, applications scientists, and partners to share knowledge and collectively map the program's future.

This annual summary illustrates how NASA's Disasters program is advancing science to build disaster resilience around the world. It features work we've accomplished this past year to help communities make more confident decisions for disaster planning. You'll see how we work directly with local governments and other organizations to support disaster response efforts by providing Earth observing data and expertise. Throughout the report, we highlight key partnerships we've fostered with organizations across the globe to build capacity and strengthen global disaster management efforts.

People can't manage the risks they don't see. In this summary, we are pleased to highlight collaborations with a diverse range of academic, government, and industry partners to develop applications that leverage the unique power and perspective of Earth observations to offer innovative approaches to decision support across the entire disaster cycle. Many of the user-centered tools resulting from these efforts are already enabling organizations to respond boldly and proactively to the growing threats of climate change and extreme events.

On behalf of the Disasters program team, I would like to thank our many partners, stakeholders, and the disasters community that help us impact the lives and livelihoods of people worldwide. We invite you to learn about the opportunities and challenges we encountered in 2022 and look ahead to what 2023 holds.

Shanna N. McClain, PhD
Disasters Program Manager

NASA's Disasters program team participated in a strategic retreat at Esri Headquarters in Redlands, California, Nov. 15-17, 2022, to ensure collective understanding of the program's vision and mission and explore collaborative opportunities to advance cutting-edge applications and approaches to disaster management.

Source: NASA

NASA Disasters program science writer Gabriella Lewis (left), chats with a visitor at the NASA booth.

Source: NASA/Seph Allen

II. INTRODUCTION & OVERVIEW

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Disaster coordinators from Coordination Centre for the Prevention of Natural Disasters in Central America (CEPREDENAC) using NASA data to analyze potential impacts from Hurricane Iota.

Source: CEPREDENAC

INTRODUCTION

NASA's Earth Science Division (ESD) Applied Sciences Program (ASP) promotes efforts to discover and demonstrate innovative and practical applications of Earth observations. The ASP has eight program areas: Agriculture, Capacity Building, Climate & Resilience, Disasters, Ecological Conservation, Health & Air Quality, Water, and Wildland Fire Management. Each of these program areas supports ESD's goal to use NASA's unique perspective on Earth to benefit communities worldwide. The NASA Applied Sciences Disasters program area advances the use of Earth-observing data and applied science to improve the prediction of, preparation for, response to, and recovery from disasters around the world. Before, during, and after disasters strike, our team coordinates with domestic and international partners, decision-makers, and local governments to provide actionable data to recover from disaster impacts and build resilient communities.

> A world where Earth science data and knowledge routinely guide decisions at all levels of society – and people want more.
>
> NASA Applied Sciences Strategic Plan (2021-2026)

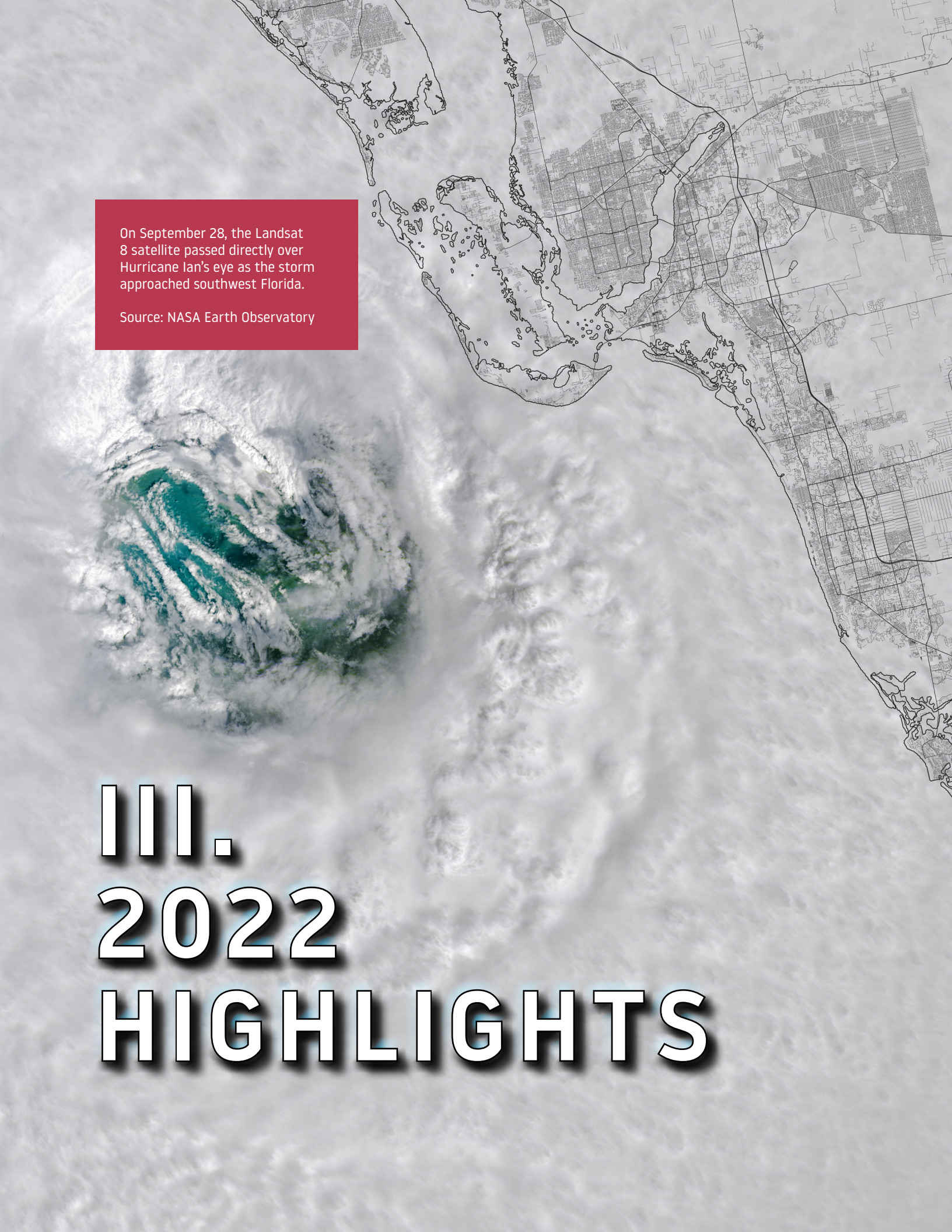
PROGRAM ELEMENTS

Three core elements provide the foundation for the Disasters program's goal to advance disaster science and enable communities around the globe to apply Earth science insights throughout disaster planning, management, and recovery.

Disaster Applications advance the use of Earth observations to support decisions across the disaster cycle – from disaster risk reduction to preparedness and mitigation, early warning and anticipatory action, response, recovery, and resilience. Our portfolio of applied projects is at the heart of our goal to aid effective decision-making for disaster-prone communities everywhere. These projects advance disaster science and technology by leveraging Earth observations in conjunction with data on societal vulnerability, exposure, and coping capacity to provide a unique and holistic view of how disasters can impact communities and the steps people can take to mitigate them. Each project exemplifies the NASA Applied Sciences Program's strategic goal to create impactful applications by developing tools and technologies that provide direct value to communities, enabling easier and broader uptake of tools that support disaster awareness and disaster risk management.

Disaster Assessment and Response Teams connect emergency managers and humanitarian teams actively responding to disasters with near real-time Earth-observing data and analysis. The Applied Sciences Program seeks to expand impact through the creation of thriving partnerships and private sector venues. We accomplish this goal by working with domestic and international government agencies, non-governmental agencies (NGOs), and private sector partners to provide actionable data that informs decision-making and reduces the impacts of disasters on lives and livelihoods. In 2022, our team actively supported and coordinated response efforts for eighteen disasters around the globe, supporting domestic and international stakeholders' response efforts across a variety of sectors. While NASA is not an operational disaster response agency, it has unique access to resources, relationships, and scientific expertise that can provide critical help to those with boots on the ground. These resources can help stakeholders better understand and visualize the extent of floods, damage from tornados, and susceptibility of communities to landslide risk, and can provide an overarching and systemic multi-hazard assessment of current and potential future risk.

NASA's Disasters Mapping Portal is a primary resource for collaboration among our information producers, applications specialists, partners, and users. This free and openly accessible online portal hosts the program's geospatial disaster data, providing an array of products created to assess specific disaster events, as well as near real-time products that increase situational awareness for hazards and disasters anywhere on Earth. The portal provides NASA and partner data in a standardized geographic information system (GIS) format that is easy for partners to access and integrate into their existing technologies and workflows for decision support. For example, portal users have overlaid fire hot-spot detection and smoke plume data with infrastructure data to assess air quality risks for fire, and visualized hurricane cloud-tops and storm structures in 3D to help identify the rapid strengthening of a storm. In 2022, the mapping portal remained an essential element of our program, providing an interface for data products that aided response efforts for major floods, hurricanes, and volcanoes across the globe.



On September 28, the Landsat 8 satellite passed directly over Hurricane Ian's eye as the storm approached southwest Florida.

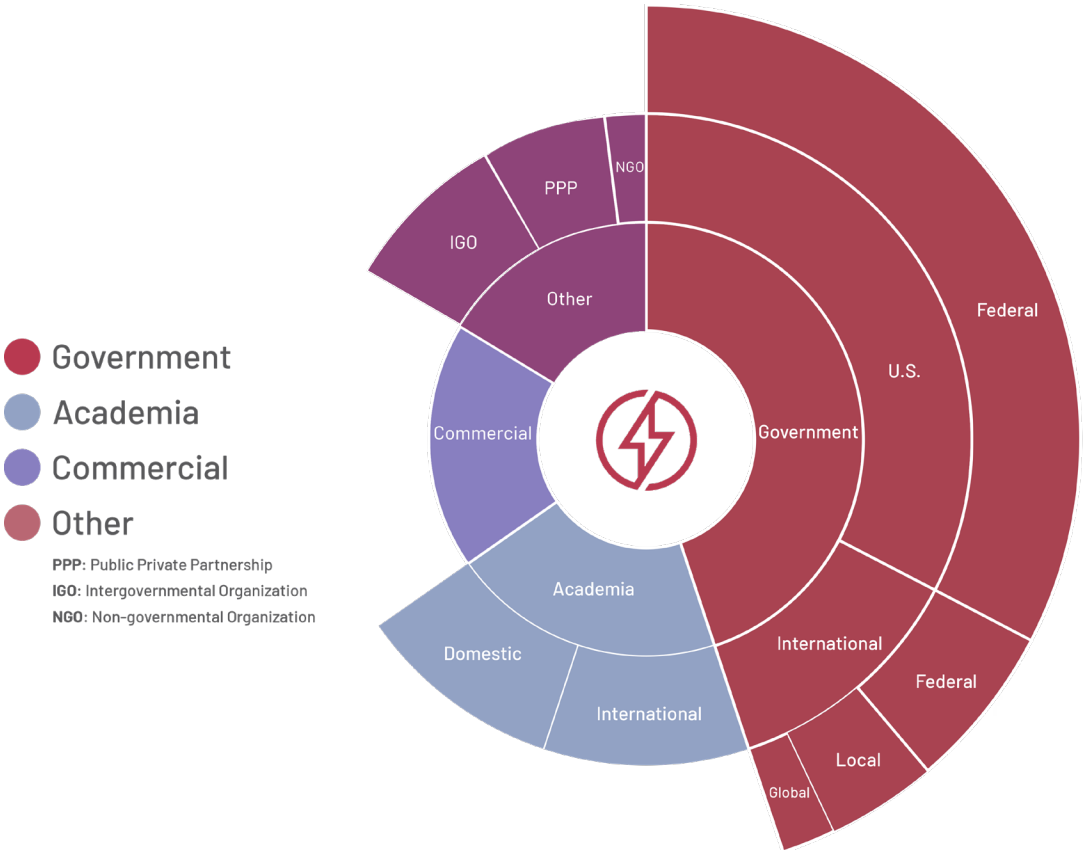
Source: NASA Earth Observatory

III. 2022 HIGHLIGHTS

DISASTER APPLICATIONS

2023 marks the final year of the NASA Research Opportunities in Space and Earth Sciences (ROSES) A.37 solicitation on Disaster Risk Reduction and Response. The projects selected via this solicitation demonstrated significant maturity and advancement toward operational integration in 2022. They cover a range of hazards, from flood mapping and landslide forecasting to measuring oil spill thickness and tracking volcanic ash. Throughout the project lifecycle, each project team assembled scientifically defensible studies on disaster risk management, demonstrated Earth observing applications for understanding disasters, and worked to mature the technologies and techniques developed from the project for operational use.

APPLICATIONS BY PARTNER SECTOR



Collaboration is a vital component of each project in the Disasters Applications portfolio, advancing the Applied Program's strategic goal to foster thriving partnerships. The project teams work with a broad range of public-sector and private-sector partners from around the globe to achieve sustained use, durability, and societal benefits. Each project's data products and expertise also feed into the program's disaster assessment and response efforts through Disaster Application and Response & Recovery Teams (DARRT), providing a valuable real-world testbed to gather end-user feedback and further enhance each project's utility, while simultaneously aiding our stakeholders across the globe.

NASA ROSES A.37 PROJECTS ON DISASTER RISK REDUCTION AND RESPONSE

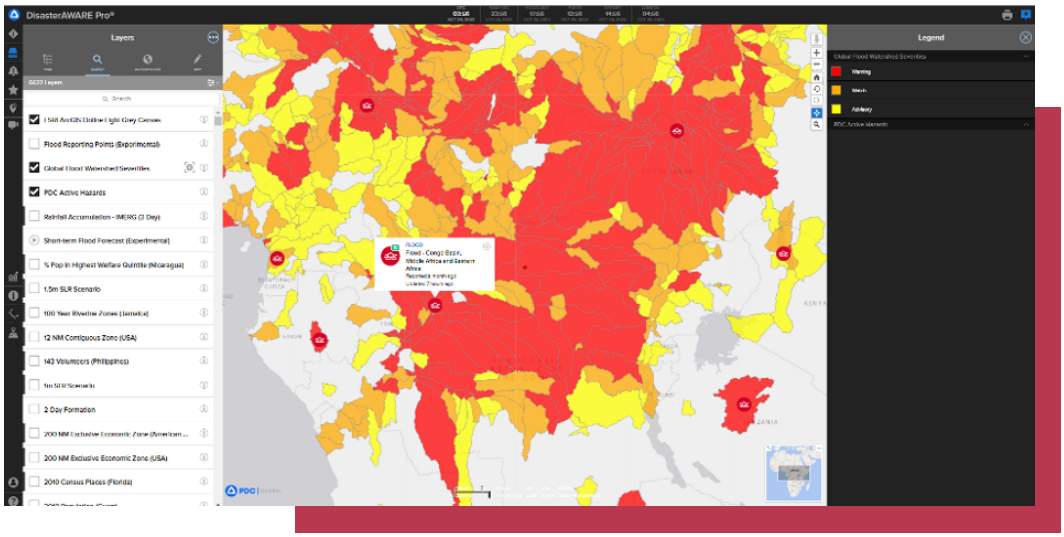
	Project	Regions	PI/Affiliation
	Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies	Global	Margaret Glasscoe (University of Alabama in Huntsville)
	Coupled Interactive Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making	North America	Kyle Hilburn (Colorado State University)
	Day-Night Monitoring of Volcanic SO2 and Ash for Aviation Avoidance at Northern Polar Latitudes: Enhancing Direct Readout Capabilities for EOS, SNPP and NOAA 20	Arctic	Nickolay Krotkov (NASA GSFC)
	Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context	North America, Global	Frank Monaldo (University of Maryland College Park)
	Enabling Landslide Disaster Risk Reduction and Response Throughout the Disaster Lifecycle with Multi-Scale Toolbox	Global	Dalia Kirschbaum (NASA GSFC)
	Global Rapid Damage Mapping System with Spaceborne SAR	Global	Eric Fielding (NASA JPL)
	Hail and Severe Storm Risk Assessment Using Spaceborne Remote Sensing Observations and Reanalysis Data	Africa, Europe, North America, South America, Global	Kris Bedka (NASA LaRC)
	Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters	North America, Oceania, South America, Global	Franz Meyer (University of Alaska-Fairbanks)
	Local Tsunami Early Warning with GNSS EarthquakeSource Products	North America, Oceania, South America	Diego Melgar (University of Oregon)
	Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation, and Response	Asia, North America	Charles Huyck (ImageCat Inc.)

DISASTER APPLICATIONS HIGHLIGHTS

The Disasters application projects featured below demonstrated significant advancements in 2022. These projects demonstrated deep collaboration with partner organizations as they moved their applications towards operational use and provided exceptional value to the communities they worked with by developing and delivering tools that enhance disaster risk understanding.

Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies

Principal Investigator: Margaret Glasscoe
Co-Investigators: Bandana Kar, Doug Bausch, ZhiQiang Chen, Ron Eguchi, Charlie Huyck, Guy Schumann, Marlon Pierce, Kristy Tiampo



This screenshot from DisasterAWARE Pro shows flood severity warnings at a sub-watershed level generated using NASA's Model of Models (MoM) for the Congo Basin region of Africa in Oct. 2022.

Source: Pacific Disaster Center, NASA

In late 2022 the Pacific Disaster Center (PDC) integrated NASA's "Model of Models" (MoM) flood early warning technology into its DisasterAWARE global multi-hazard alerting platform, a crowning achievement for the "Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies" project. With this operational integration, flood early warnings at the sub-watershed level are now more easily accessible to communities worldwide. This access will be particularly impactful for communities in small island nations and developing countries that may currently lack effective flood early warning technologies.

MoM combines data from open-source hydrological models with Earth-observing satellite data to generate global flood risk severity updates several times a day. Inputs include forecasts from GloFAS (Global Flood Awareness System), GFMS (Global Flood Monitoring System), and HWRF (Hurricane Weather Research and Forecasting); observations from MODIS (Moderate Resolution Imaging Spectroradiometer); and flood products derived from optical sensors. When the MoM detects a high likelihood of flooding in a region, DisasterAWARE sends a flood early warning notification to impacted communities, so they can quickly take steps to protect lives and livelihoods. Local authorities may use this information to activate emergency response plans, order evacuations, or deploy response teams and humanitarian relief.

"The 'Model of Models' approach makes use of already existing technologies and combines them in unique ways that give us a powerful understanding of flood risk," said NASA's Margaret Glasscoe, Research Associate at the University of Alabama in Huntsville and principal investigator for the project.

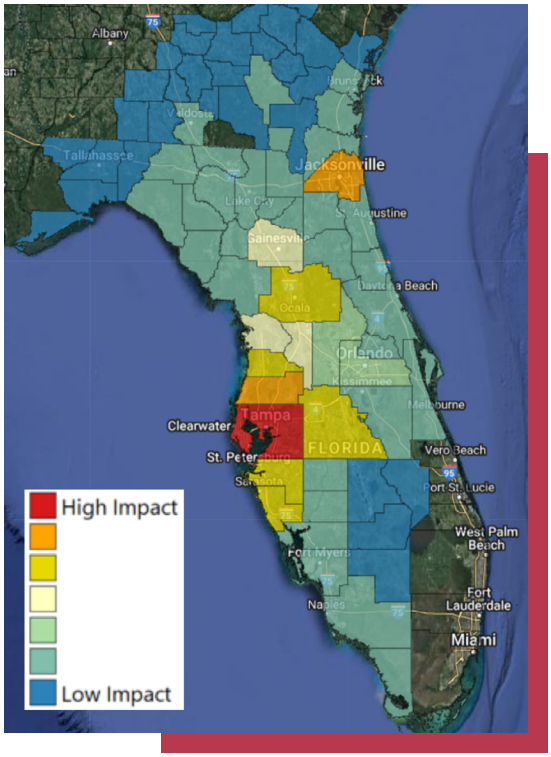
This project is a prime example of the Disaster program's cross-discipline and collaborative approach to disaster risk management. Still, the partnership with PDC is just one of several key partnerships contributing to the project's success. Throughout the project's development, the team worked with several other Disasters projects, including the "Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response" project led by Charles Huyck (ImageCat) and the "Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters" project led by Franz Meyer

(University of Alaska Fairbanks). These partnerships, organized under the Global Initiative for Flood Forecasting and Alerting (GIFFT), augmented MoM by incorporating features such as triggers for synthetic aperture radar (SAR) analysis and exposure analysis through ImageCat's Global Economic Disruption Index (GEDI), as well as running a pilot project in Vadodara, India in 2021.

According to a recent study by the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Meteorological Organization (WMO), roughly half of the world's countries currently lack adequate hazard early warning systems. In the Sendai Framework for Disaster Risk Reduction, the UNDRR has called on the global community to take urgent action to implement flood early warning systems. Thanks to MoM, NASA and the Pacific Disaster Center are now well-positioned to help meet this need.

Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation, and Response

Principal Investigator: Charles K. Huyck
Co-Investigators: Ron Eguchi/ImageCat, Shubharoop Ghosh/ImageCat, Roop Dave/ImageCat, Tyler Radford/OpenStreetMap, and Greg Yetman/Columbia Univ. - CIESIN



In the advisory for Hurricane Ian, the GEDI rank of III was posted for the entire event, but intermediate values calculated at the county level could be used to develop a localized disruption index with proper validation.

Source: ImageCat, Kinetic Analysis Corporation (advisory date: 09/26/22)

Disasters often damage critical infrastructure in the regions they strike, resulting in widespread economic peril that can change the socioeconomic characteristics of a community. Losses can include much more than the direct costs to repair damage to buildings or rebuild infrastructure. For instance, supply chain impacts can lead to massive job losses and decreased agricultural and industrial production. Subsequent reductions in the economic growth rate can lead to income inequality and increased poverty. These cascading effects can create a "tipping point" of human suffering that endures long after a storm passes or floodwaters recede.

The ability to accurately predict the severity of economic disruption in specific places is critical for improved disaster management and risk reduction.

Accurate and easy-to-understand visualization tools can also unlock risk managers' ability to implement financial instruments such as parametric insurance, where insurers agree to pay a fixed benefit in the event of certain conditions – such as wind speed reaching a certain threshold during a hurricane. This simplicity supports faster claims processing for both insurance companies and their clients.

Through support and collaboration with NASA's Disasters program, ImageCat, Inc. has developed a groundbreaking tool to assess the economic impacts of disasters and help identify the potential for cascading disasters so that governments, non-governmental organizations (NGOs), and private companies can plan accordingly.

The Global Economic Disruption Index (GEDI) employs a multi-disciplinary approach that fuses Earth observations, remote sensing, traditional loss estimation, and economic modeling to enable long-term visualization and an improved understanding of potential economic disruption. For example, communities can apply GEDI's ranking system in concert with a hurricane's Saffir-Simpson Wind Scale to estimate the general amount of economic disruption the storm will cause.

The GEDI modeling framework builds on the team's previous work enabled by NASA, the Group on Earth Observations (GEO), and Google, involving the Critical Infrastructure Interdependency Index (CIII) and Critical Infrastructure Interdependency Risk Index (CIIRI). This current project expands capabilities for modeling the catastrophic impacts of infrastructure

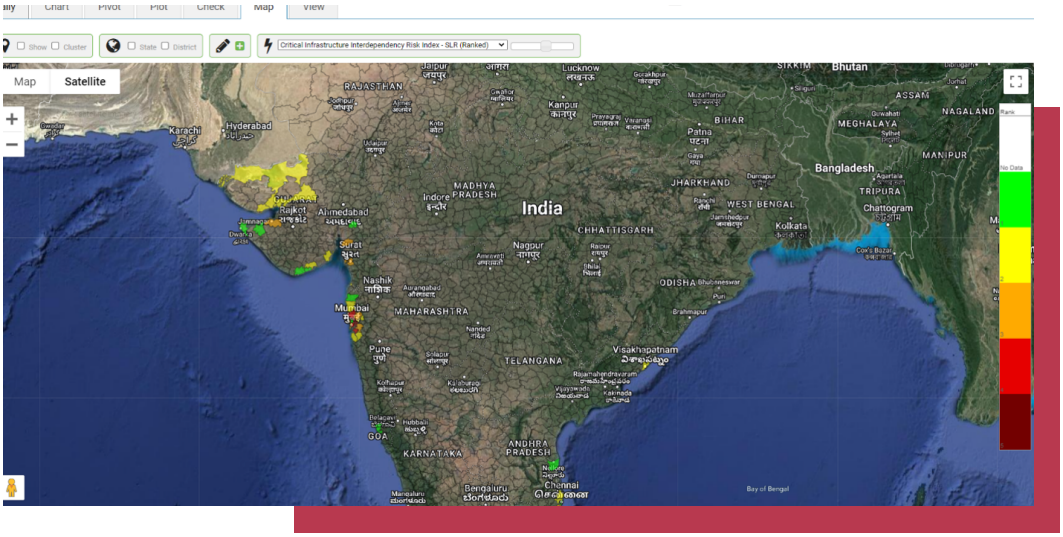
disruption and provides a foundation for critical infrastructure exposure development in concert with satellite-based remote-sensing Earth observations.

Rank	Description	Restoration
I	Slight	Rapid restoration on the order of a few hours to a few days expected.
II	Moderate	Economic activities typically resume in less than a week.
III	Major	Economic activities are likely to rebound on the order of weeks.
IV	Severe	Economic rebound expected after months of restoration.
V	Catastrophic	Major disruption in economic activities requires years of recovery.

The Global Economic Disruption Index features a ranking system that can be used along with natural hazard event categories to characterize the potential severity of economic disruption in an area.

Source: ImageCat

The project team has successfully demonstrated the results of their work in real-world relevant environments. As mentioned above, the team supporting this work joined forces with NASA Disasters-supported team working on the "Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies" project to conduct a successful pilot study with the city of Vadodara, India, to develop and implement a framework for flood detection, analysis, and alerting using this risk modeling approach with Earth observation data. During this pilot, the application development team incorporated exposure analysis through GEDI into NASA's new flood detection technology "Model of Models" (MoM). MoM uses an ensemble approach, integrating forecasted flood extent outputs from hydrologic models with near real-time optical imagery to provide comprehensive global flood early warnings at the sub-watershed level. Through the Pacific Disaster Center's (PDC) DisasterAWARE multi-hazard tracking platform, decision-makers in Vadodara took advantage of GEDI's integration into MoM to identify heavy industrial and power plant locations in and around the city while quantifying flood hazards.



Identification of "accidents waiting to happen" from climate change, in this case frequent storm surge and coastal flooding combined with sea level rise (evaluated under an RCP 8.5 scenario, 2050, demonstrated with the mapping platform Enhance.

Source: Pacific Disaster Center, NASA

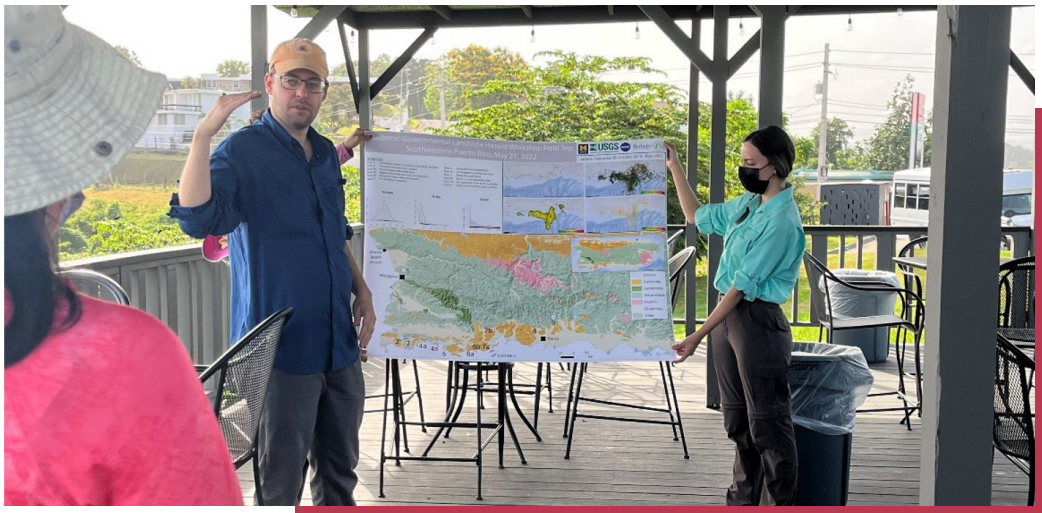
Through the project, the city of Vadodara and various government agencies received data in a format suitable for modeling to assess potential losses from hazards. The resulting models will help inform policies for risk mitigation, which can also support post-event disaster needs assessments. The team also used this pilot study to develop methods to characterize poor quality or missing critical infrastructure exposure data.

In 2022, the GEDI score was validated and implemented for hurricanes Ian and Fiona, as well as an earthquake planning scenario for Guatemala. Because the GEDI framework provides a flexible method to characterize economic disruption, it can be incorporated into a variety of risk analytics methods. The GEDI framework was also adapted into a Regional Resilience Assessment (RRA) to help real estate investment funds prioritize acquisitions based on climate risk. These funds used GEDI to identify previously undocumented disproportionate vulnerability of the black community in Los Angeles to large seismic events. Several companies are evaluating GEDI's potential to support parametric-triggered insurance products and corporate ESG (Environmental, Social, and Governance) reporting requirements.

As team members continue to optimize their products, they envision a future where government organizations, NGOs, and commercial companies around the globe can leverage products from this project to inform policy and actions and ultimately ease potential suffering worldwide.

Enabling Landslide Disaster Risk Reduction and Response Throughout the Disaster Life Cycle with a Multi-scale Toolbox

Principal Investigator: Dalia Kirschbaum
Co-Principal Investigators: Marin Clark and Dimitrios Zekko
Co-Investigators: Thomas Stanley, Christopher Chiesa, Doug Bausch, Robert Emberson, Jonathan Godt, Felipe Mandarino, and Ricardo D'Orsi



Associate Professor Stephen Hughes and M.Sc. student Tania Figueroa from the University of Puerto Rico, Mayagüez, review the plan for the geological field trip in southwest Puerto Rico.

Source: NASA, Dalia Kirschbaum

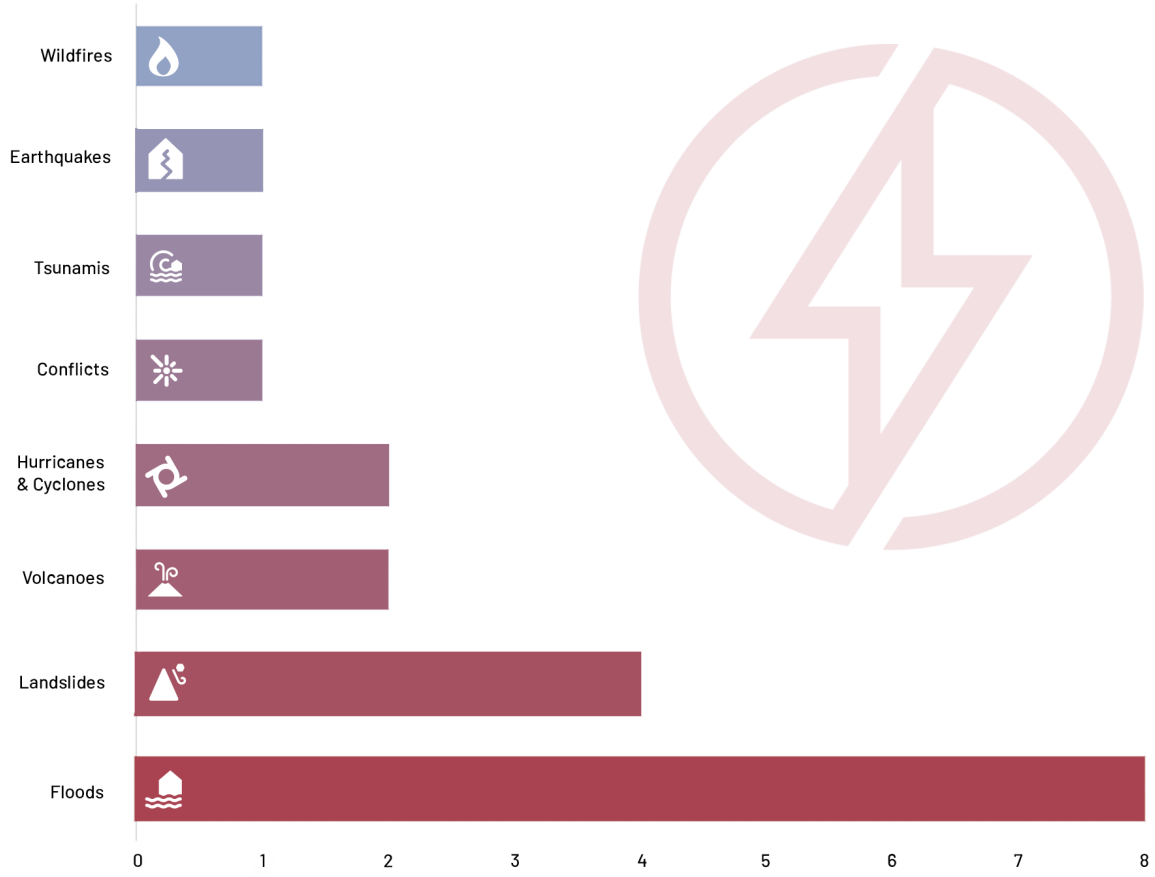
Dr. Kirschbaum and her team's landslide project are creating a suite of open-source tools to map where landslides have occurred following a disaster and building models to help communities prepare for and respond to disasters worldwide. Currently, the team has created a Global Landslide Catalog (GLC) to record landslide events everywhere on Earth and a Landslide Susceptibility Map to show where the terrain is most prone to landslides. The team is also developing the Landslide Hazard Assessment for Situational Awareness (LHASA) model. LHASA identifies locations with high potential for landslides by combining satellite data with ground information on slope, geology, road networks, fault zones, and forest loss. In 2022, the team added post-fire debris flows and landslides triggered by heavy rainfall following a wildfire to their risk model. They accomplished this task by leveraging Google Earth Engine's (GEE) freely available data and cloud computing capabilities to assess burn severity from Landsat imagery. This updated risk model will help communities prepare for the threat of landslides in fire-prone areas and make informed decisions to manage their risk.

Kirschbaum's project also made considerable advancements in the area of landslide response coordination. Last year, the landslide team collaborated with the U.S. Geological Survey (USGS) and the University of Puerto Rico, Mayagüez to host a workshop on landslide disaster response and planning in Puerto Rico. At the workshop, the team worked with the USGS to develop a landslide response playbook to guide agencies in responding to landslide threats. The workshop focused on multi-agency and academic coordination, with participants from the University of Michigan; University of California Berkeley; University of Puerto Rico, Mayagüez; NASA Goddard Space Flight Center (GSFC); the USGS; and other regional stakeholders. The group engaged with local stakeholders to learn more about their specific needs when managing landslide risk and addressed questions that will inform NASA's approach to supporting future landslide-stricken communities. "This helps us to consider what types of information are most valuable to share with people on the ground in the affected areas, and what may be less useful in terms of distribution, information, and access," explained Kirschbaum, who also serves as the Director of the Earth Science Division at NASA's Goddard Space Flight Center. This collaboration created more efficient communication channels among NASA, the USGS, and academic institutions, paving the way for a more streamlined and efficient landslide response process.

DISASTER ASSESSMENT AND RESPONSE

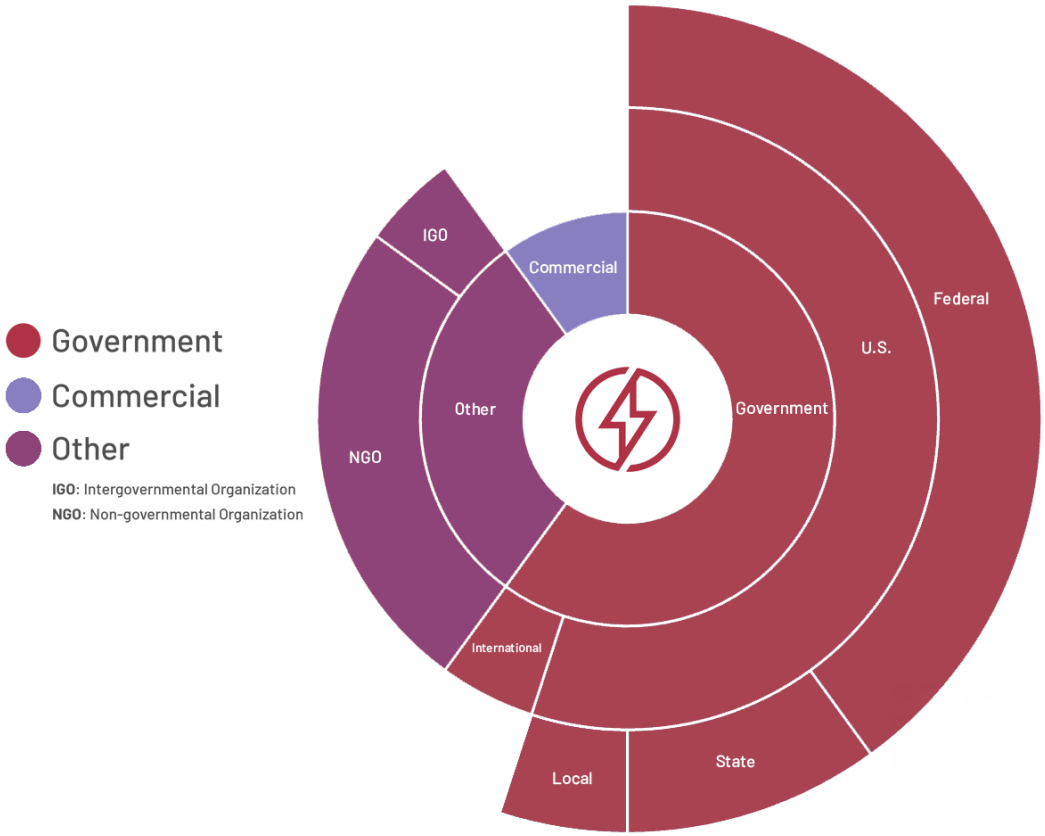
The response element of the Disasters program places Earth science data into the hands of those who seek to improve their situational awareness of disasters. When disasters strike, NASA Disaster Coordinators connect end users with Disasters program team members who can provide actionable data products for ongoing response efforts, such as maps of damaged infrastructure, the location of flood waters, or changes in nighttime lights indicating potential power outages.

2022 DISASTER RESPONSES BY HAZARD



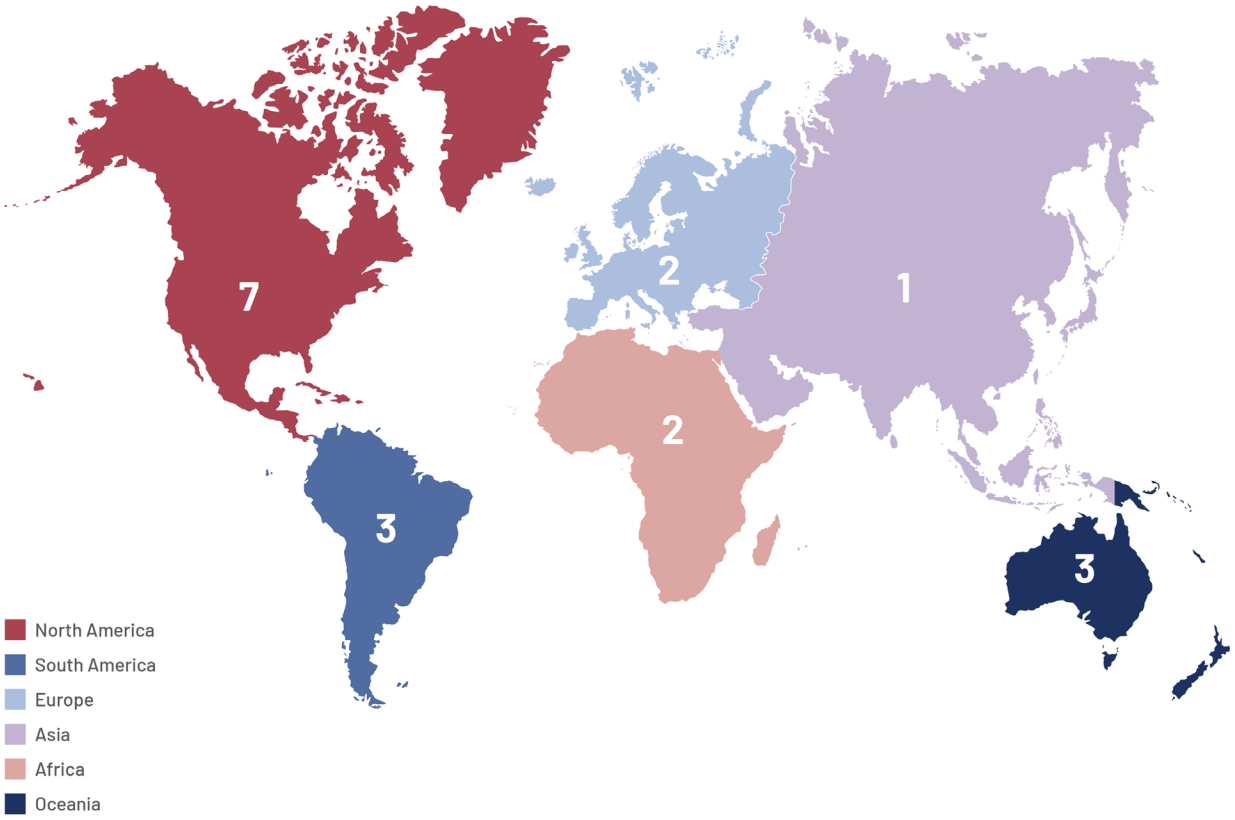
These products include data from some of the program's disaster applications projects that are focused on disaster response, such as Franz Meyer's "Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters" project. The program's geographic information system (GIS) specialists then add these disaster response products to the Disasters Mapping Portal—a mapping interface powered by Esri's ArcGIS software and hosted by the NASA Center for Climate Simulation (NCCS)—where end users can view, analyze, and download data products to aid their disaster response efforts.

2022 DISASTER RESPONSES BY PARTNER SECTOR



Diversity among team members and end users is crucial to the Disasters program's success. The NASA Disaster response team brings together capabilities and expertise from NASA centers across the nation to combine efforts and develop a more comprehensive approach to disaster response and recovery. A key goal of the Applied Sciences Strategic Plan is to create thriving partnerships and private sector ventures to achieve impact through expanded reach. The Disasters program accomplishes this goal by facilitating response and recovery efforts with a diverse group of end users at the local, regional, and national levels, encompassing a wide range of private and public sector organizations. In 2022, the NASA Disaster response team continued to provide disaster information to government agencies such as FEMA and the Hawaiian Emergency Management Agency (HI-EMA), while also building rapport with private sector organizations such as AC Disaster Consulting, and the Puerto Rico Science, Technology and Research Trust.

2022 DISASTER RESPONSES BY REGION



The program's response capabilities have historically spanned ten different hazard types and six continents. In 2022, the Disasters program moved away from the more ad hoc response style to focus on consistent implementation of the NASA Disasters Program Playbook. This disciplined approach resulted in fewer overall responses in 2022 but provided a consistent process that will enable accurate assessment and calibration of those guidelines for continual improvement in years to come. Nevertheless, in 2022 the program provided valuable assistance for eighteen disaster events around the world.

DISASTER ASSESSMENT AND RESPONSE HIGHLIGHTS

The Disaster program's assessment and response activities in 2022 not only reflected the continuation of hard work and effort from prior years, but also provided an opportunity to lay foundations for future changes. The 2022 disaster responses highlighted below show how the NASA Disasters program demonstrated significant impact, providing Earth observing data and expertise to stakeholders to increase their situational awareness and aid their response efforts to reduce impacts on lives and livelihoods.

HURRICANE IAN

Hurricane Ian's high wind speeds and devastating storm surge razed critical infrastructure throughout Florida.

Source: Florida Fish and Wildlife Conservation Commission (FWC)

Last fall, Hurricane Ian dropped over 20 inches of rain on Florida and flooded parts of the state with a historic storm surge of over 12 feet. It was the third most costly weather disaster on record in Florida, and caused widespread damage across western Cuba and the southeast U.S., especially the states of Florida, South Carolina, and North Carolina. Leading up to and immediately following the event, the NASA Disaster response team supported a series of calls with government agencies and emergency managers, including FEMA, to help coordinate ongoing response efforts. During the calls, the agencies coordinated with NASA and other attendees to determine where our data could be helpful to responders. The lead coordinator for this response activation was Robert Emberson, Center Disaster Coordinator at NASA's Goddard Space Flight Center (GSFC). Lori Schultz, Center Disasters Coordinator at NASA's Marshall Space Flight Center (MSFC), served as the partnership liaison between FEMA and the Disasters program over the course of several weeks. Schultz and her colleagues at MSFC also provided product processing, development, translation, and integration.

Due to the extensive scale of Hurricane Ian's impact, FEMA's resources were stretched across a wide geographic area, leading to coverage gaps in the imagery that the agency uses to assess damage and flooding. The Disasters program was able to help fill in the missing information in critical areas by processing high-resolution optical imagery from Planet Labs that allowed for the assessment of impacts across central Florida. The program also collaborated with partners at the Dartmouth Flood Observatory (DFO) and the University of Alabama in Huntsville (UAH) to develop a series of flood extent maps to address this issue. While creating these flood products, the Disasters program team used a technique combining RADARSAT Constellation Mission (RCM) data with United States Department of Agriculture (USDA) crop masks and other datasets. This innovative approach provided a more accurate distinction between water bodies, marshes, and flood areas. NASA's flood products contributed to FEMA's high-resolution overview of the event, which the agency combined with other datasets to better comprehend the damage extent.

NGOs also used NASA data to aid their response and recovery efforts for Hurricane Ian. The Disasters program shared maps of the potentially damaged areas with the World Central Kitchen (WCK) to help them determine where to set up relief kitchens. The WCK provides meals to communities in crisis when they may not have access to food and kitchens. With the assistance of NASA's damage maps, WCK identified communities affected by the hurricane and targeted their relief efforts accordingly. Team Rubicon, a veteran-led disaster organization, discovered the products developed for FEMA and WCK on

the Disasters Mapping Portal. They combined NASA's products with their own data to determine if they could return to previously inaccessible areas following the hurricane and aid the local community. During Hurricane Ian, the need for rapid and geographically extensive information drove NASA-funded scientists to find innovative ways to assist response efforts – an effort the program will continue to pursue in 2023.

TONGA VOLCANIC ERUPTION & TSUNAMI

Preliminary Damage Proxy Map (DPM) depicting buildings and vegetation likely damaged in the Tongatapu and southern Ha'apai islands of Tonga.

Source: Nanyang Technological University – Earth Observatory of Singapore, ARIA Team, NASA JPL, JAXA

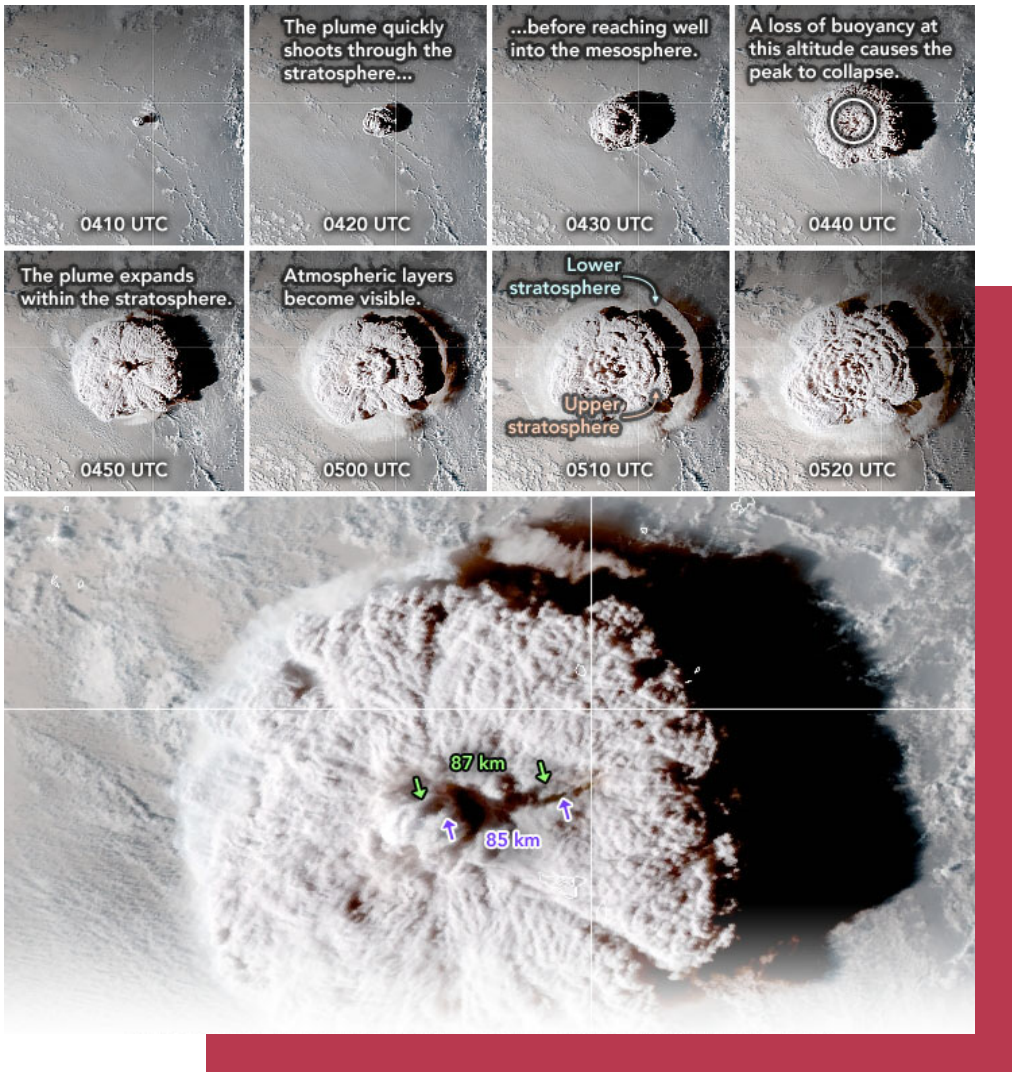
On Jan. 15, 2022, the eruption of the underwater volcano Hunga Tonga Hunga Ha'apai shook the globe. The powerful explosive eruption brought destructive tsunami waves and heavy ashfall to islands in the nation of Tonga, damaging coastal infrastructure, destroying crops, and contaminating water supplies. It lofted volcanic ash and gas high into the stratosphere, triggered extreme lighting, and sent tsunamis, meteotsunamis, and atmospheric gravity waves across our planet.

Upon learning of the event, NASA's Disasters program quickly mobilized to contact relevant partners and stakeholders and determine what Earth observations could be used to study the event and aid response efforts on the ground. The event severed undersea communications cables to Tonga, and airports were shut down for several days due to ashfall, making initial damage assessment and relief efforts difficult.

The Disasters program team and partners developed damage proxy maps derived from synthetic aperture radar (SAR) data, high-resolution optical imagery from Planet Labs' satellites, and sulfur dioxide (SO2) emissions data from the Ozone Mapping and Profiler Suite (OMPS) instrument, and provided these maps to stakeholders including NOAA and WCK. As soon as service providers restored communications to the island, the Disasters program team connected with representatives from the Tonga Ministry of Lands and Natural Resources to share land movement, sea level, and bathymetric data near the volcano. The NASA JPL Advanced Rapid Imaging and Analysis (ARIA) team and the Earth Observatory of Singapore, supported in part by funding from the ROSES A.37 project, "Global Rapid Damage Mapping System with Spaceborne SAR Data," also developed DPMs for the Tonga islands to aid in identifying damaged buildings, infrastructure, and vegetation. The Disasters program distributed these products on the NASA Disasters Mapping Portal.

The size and power of the eruption, and the fact that multiple Earth-observing satellites captured it, presented a unique opportunity for scientists around the globe to study the unprecedented nature of the volcano and its interconnected impacts on Earth's systems.

"The intensity of this event far exceeds that of any storm cloud I have ever studied," said Kristopher Bedka, an atmospheric scientist at NASA Langley Research Center who specializes in studying extreme storms, and principal investigator for the NASA Disasters project "Hail Storm Risk Assessment Using Space-Borne Remote Sensing Observations and Reanalysis Data." "We are fortunate that it was viewed so well by our latest generation of geostationary satellites, and we can use this data in innovative ways to document its evolution."



Stereoscopic observations of the eruption by GOES-17 (shown above) and Himawari-8, along with heights determined from the lengths of shadows, allow scientists to model the altitude of the entire plume.

Source: NASA Earth Observatory

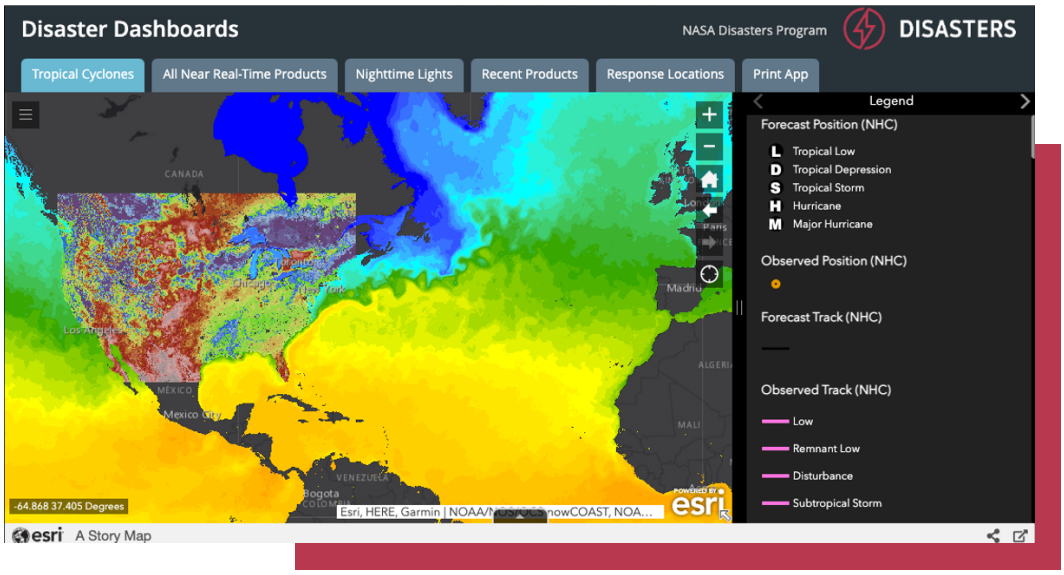
Using a technique originally designed to study severe thunderstorms, Bedka and his colleague Konstantin Khlopenkov (NASA Langley Research Center) matched simultaneous observations of the same cloud scene from two satellites, then used stereoscopy to construct a three-dimensional profile of elevated clouds and estimate the size and height of the volcanic plume. They calculated that the plume from the eruption rose to 58 kilometers (36 miles) at its highest point, making it about 1.5 times higher than the 1991 Mt. Pinatubo eruption, the previous largest known volcanic plume that occurred during the satellite era. The umbrella cloud of ash and gas generated by the Tonga eruption then spread out in the stratosphere at an altitude of ~30 km (20 miles), eventually covering an area of ~157,000 km² (60,000 square miles) - larger than the state of Georgia.

The eruption was so powerful it also caused ripples in Earth's ionosphere, according to measurements from the Global Differential GPS System (GDGPS) managed by NASA's Jet Propulsion Laboratory in Southern California. The GDGPS observed ionospheric disturbances caused by the explosion and subsequent meteotsunami in real time by tracking the delay of global navigation satellite systems (GNSS) signals as they traveled through the atmosphere and were affected by the density of electrons in the ionosphere.

GNSS data can serve an essential role in contributing to tsunami early warning systems, shaving precious time off warnings when every second of advanced notice can save lives. The Disasters project, "Local Tsunami Early Warning with GNSS Earthquake Source Products," led by Diego Melgar (University of Oregon) uses GNSS data to detect ground movement and model earthquake activity that could lead to tsunamis and integrates this data into tsunami early warning systems operated by the National Oceanic and Atmospheric Administration's Center for Tsunami Research (CTR). In the future, the ionospheric disturbance recorded by the GDGPS could also be integrated into these tsunami warning systems to further optimize efforts to warn communities to get people out of harm's way before tsunami waves strike.

DISASTERS MAPPING PORTAL

The NASA Disasters Mapping Portal is an online interface that hosts the program's geospatial disaster data, including both routine near real-time data and products created in response to specific disaster events. The portal is openly accessible and enables the program to share valuable resources with communities throughout the world, fulfilling the Applied Sciences Program's strategic goal to integrate Earth observations into tools that amplify the reach of Earth science. The portrayal of complex data in an intuitive, visual format helps to bridge the gap between NASA scientists and end users, allowing the program to collaborate with stakeholders from diverse scientific backgrounds. Additionally, the portal hosts StoryMaps (interactive online stories containing text, maps, and multimedia content) for specific disasters that can build users' capacity to interpret information about NASA's disaster products.



The Tropical Cyclones Dashboard is one of many near real-time hazard monitoring tools available on the NASA Disasters Mapping Portal.

Source: NASA

DISASTERS MAPPING PORTAL HIGHLIGHTS

Last year, the portal hosted products for nine disaster events and provided 37 GIS services – 16 of which were created by the program's disaster applications projects. A GIS service is a resource, like a map or data product, that a client application can access without the user needing to download or store it locally. This feature enables us to easily share data with partners and the public, increasing accessibility and allowing users to analyze the data and incorporate it into their own GIS mapping tools.

Thriving Partnerships: Engaging the GIS User Community

NASA's Earth Science Division staff a booth at the 42nd Esri User Conference, July 11-15, 2022, in San Diego, California. (Standing left to right: Brian Tisdale, Brady Helms, Leah Schwizer. Allison Alcott, Genevieve Studer-Ellis, Rachel Soobitsky, Ronan Lucey, Garrett Layne, Stinger Guala.)

Source: NASA

A key strategic goal of the NASA Applied Sciences Program is to achieve greater impacts by connecting Earth science with new and growing audiences by embedding Earth science data in the products and services that partners provide to the world. In July 2022, Disasters program staff contributed to this goal by joining other members of NASA ESD at the Esri User Conference (Esri UC), the largest geographic information systems (GIS) conference in the world with over 14,000 in-person attendees. The Disasters program team hosted a user-group session with over 100 guests, where they introduced the Disasters program, showcased the data we provide for disasters, and informed potential users about the Disasters Mapping Portal and applications of GIS for disaster risk management. After the session, the team gathered valuable feedback from attendees regarding the program's disaster tools and resources. One noteworthy outcome of the Esri UC NASA Disasters user meeting was the establishment of a new connection with Team Rubicon, which led to fruitful follow-up meetings to foster coordination between the two groups. Team Rubicon later became a key stakeholder during the program's response to Hurricane Ian and provided us with valuable feedback and ground validation data during the event.

The Disasters program team also supported the NASA ESD user group session and supported the NASA ESD exhibit booth, connecting with a wide range of attendees from important partner organizations such as FEMA, the Department of Defense, state and local governments, and more. Jack Dangermond, Esri's founder and president, visited the NASA booth during the conference to recognize the critical work of NASA and the Disasters program and their use of GIS technologies to support disaster risk reduction.

Attending the 2022 Esri UC increased awareness among the GIS community of the NASA Disasters program and other NASA Earth data resources. It also allowed us to share the Disasters Mapping Portal with organizations interested in expanding their GIS capabilities and enabled us to learn how we can better meet our partner's needs.

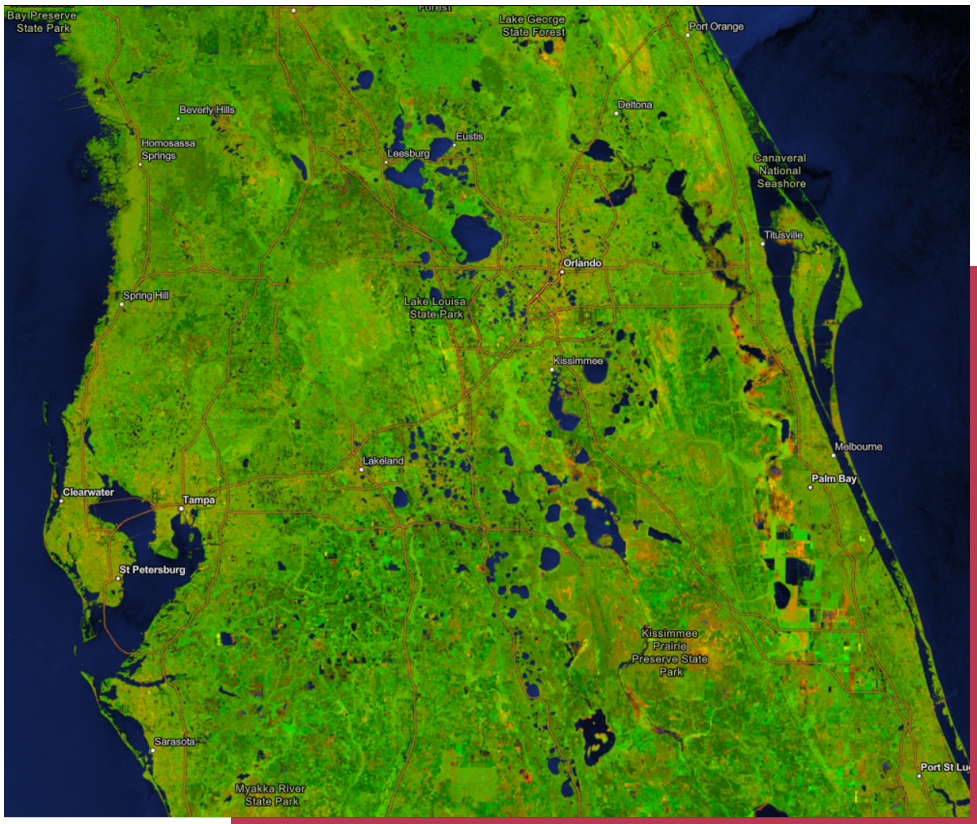
Knowledgeable and Skilled Communities: Open Science for Disaster Response

A volunteer with Team Rubicon moves debris from destroyed homes into a pile following Hurricane Ian. Team Rubicon used NASA Disaster program resources to assist in disaster response and recovery efforts in Florida.

Source: Team Rubicon

A core function of the Disasters Mapping Portal is to offer new skill-building approaches that can dramatically expand the audiences capable of using Earth science data and increase the capacity of and avenues for partners and communities to benefit from these approaches. Last September, Floridians braced themselves for the impending threat of Hurricane Ian. With media reports indicating 149 deaths, Ian was the deadliest hurricane to hit Florida since the 1930s. The Disasters program created maps of the potentially damaged or flooded areas, which our GIS team then uploaded to the Disasters Mapping Portal. The portal provides an inclusive environment for agencies, organizations, and communities to rapidly access a broad range of disaster-focused products and capabilities that can accelerate scientific discovery, broaden the integration and application of data for decision support, and build the capacity, understanding, and adoption of these technologies to address global disaster risk at scale. Open science and accessibility are critical success factors in this environment. For example, products the Disasters program initially developed for FEMA and WCK were discovered by Team Rubicon, who used them to support their disaster response efforts. Team Rubicon took advantage of the portal's ability to translate complex satellite data into visual maps to determine if they could return to previously inaccessible areas following the hurricane and aid the local community.

Impactful Applications: Enhancing Partners' Capabilities



The Alaska Satellite Facility (ASF) archives synthetic aperture radar (SAR) products from a variety of satellites. This ASF image used SAR to obtain information on water, vegetation, and urban areas following Hurricane Ian's landfall in central Florida.

Achieving impactful applications requires fostering tools and information products that are of value to multiple actors and user communities, enabling easy access and use of information, and designing creative mechanisms and collaboration spaces to achieve greater impact. One example of how the Disasters program achieves impactful applications is through a partnership with the Alaska Satellite Facility (ASF) and Esri. Between 2021-2022, the Disasters GIS team worked with Esri and the ASF to enable ASF to stand up its own ArcGIS Image Server. The ASF is a partnership between NASA and the University of Alaska Fairbanks' Geophysical Institute that processes and distributes remote-sensing data to end users all over the world. With an ArcGIS Image Server, the ASF can now host data products derived from Copernicus Sentinel-1 satellites, enabling more rapid (nearly real-time) access to synthetic aperture radar (SAR) and SAR-derived data products. This collaboration has freed time for the NASA Disasters GIS team to focus on other data products, such as Planetscope imagery, which were shared during last year's hurricane season for the first time through NASA's Commercial Smallsat Data Acquisition (CSDA) program. This work harmonizes multiple products from diverse partners and automates the products to rapidly provide enhanced understanding of flooding.

For technically advanced users, the Disaster program team can create a direct portal-to-portal connection between the Disasters Mapping Portal their internal GIS portals. In 2022, NASA's Disasters program enabled such a connection with the world's largest humanitarian organization, the United Nations World Food Programme (WFP), which provides 15 billion life-saving meals every year to communities in crisis. Through this partnership, members of the WFP can now automatically receive NASA data and resources directly from the Disasters Mapping Portal, saving time and allowing them to avoid data formatting issues. In times of crisis, WFP members can benefit from this streamlined connection and quickly access critical information for their humanitarian relief efforts.

Attendees of the 2022 Understanding Risk Global Forum show off their NASA temporary tattoos.

Source: NASA/Seph Allen

IV. LOOKING AHEAD

DISASTERS PROGRAM PLAN (2023-2028)

Disasters Associate Program Manager Robert Emberson (right) moderates a brainstorming session during the 2022 Disasters Program Retreat.

Source: NASA, Jacob Reed

In November 2022, teams from the three core elements of the Disasters program gathered with partners from the U.S. Government, NGOs, and the private sector to help create a 2023-2028 Disasters Program Plan at a three-day inaugural program retreat. Joint conversations with key partners in multiple conference sessions informed the plan and addressed key disaster science and management challenges.

Since its inception, the Disasters program has helped define remote sensing science for disaster analysis. The program has funded capabilities that enabled a new generation of applications to observe and model hazards. NASA's Disasters program will build on this foundation, using the knowledge and experience gained so far to enable resilient communities around the world. This evolution of programmatic activities reflects the emerging needs of the disaster science community and disaster response stakeholders while simultaneously addressing strategic goals across NASA and the U.S. government at multiple levels.

Disasters Program Manager Dr. Shanna McClain leads a planning session during the 2022 Disasters Program Retreat.

Source: NASA, Karen Freidt

Earth observation data have historically been used to great effect to map the footprints of hazards. Still, without knowledge of the exposure and vulnerability of communities and infrastructure, the overall picture of disaster impacts that is generated from space-based observations remains incomplete. The Disasters program will support the next generation of science that addresses this critical gap, enabling a holistic approach to disaster risk assessment that incorporates remote sensing data alongside socio-economic information to quantify disaster impacts in both human and economic terms.

> By more effectively observing and modeling disaster risk, the Disasters program will enable decision-makers to build disaster-resilient communities with the capacity to absorb shocks from disasters in upcoming decades.

DISASTERS APPLICATIONS

The NASA ROSES A.37 Disaster Risk and Response Applications portfolio (2017-2023) provided an innovative step towards bridging the divide between long-term applied science activities and supporting disaster response activations. However, balancing the many demands associated with this approach was sometimes a challenge for the application project teams and across the entire program. Conflicting timelines often limited the project teams' abilities to ensure long-term deliveries to meet established project priorities while simultaneously responding to requests for immediate product development and delivery in times of crisis. Lessons from these challenges are shaping the future Disasters program applications portfolio.

In 2025, we will solicit and fund a new generation of large project teams that will not only advance fundamental disaster science but also develop solutions to inform disaster risk and impact relevant decisions, empowering local and global stakeholders to build resilient communities. The Disasters program will serve as a nexus for exchanging ideas from these applications projects to ensure that the teams consider multi-hazard scenarios and that "lessons learned" are shared with partner organizations.

These projects will maintain the program's position as a leader in disaster science and applications. While the natural hazards community now recognizes that a significant amount of data and tools are available to characterize hazards, there are no clear methods to connect that information to users in an accessible and effective format to support improved decision-making. The solicitation will also ask projects to address the interplay of natural and anthropogenic disasters with climate change and extreme events, providing the knowledge to support sustainable and resilient disaster management practices in the upcoming century.

THE NASA DISASTER RESPONSE COORDINATION SYSTEM

In June 2022, NASA's Office of Inspector General released a formal audit of the NASA Disasters program, noting the program "effectively collects and distributes relevant imagery, data products, and damage assessments to domestic and international partners and stakeholders to predict, prepare for, respond to, and recover from disasters." The report also affirmed the importance of several internal program objectives that NASA Disasters leadership and staff prioritized and advanced throughout 2022. These objectives include bringing focus and discipline to program operations to ensure clarity of purpose and efficient processes.

To achieve these goals, the NASA Disasters program team is working on updating and consistently implementing the NASA Disasters Program Playbook. This document guides program efforts in aiding responses to active disasters around the globe. Improvements to the playbook, such as requirements for after-action assessments, will safeguard knowledge continuity within the program workforce and allow the team to learn from previous responses to improve its effectiveness. In 2023, these new elements will be part of a formal training system for all NASA disaster response coordination, addressing issues noted by the OIG report and delivering a more systematic and effective approach to disaster response.

The program also made significant progress toward developing the Disaster Response Coordination System (DRCS), a restructuring of the Disasters program's disaster response and assessment component. Launching in 2023, the "One-NASA" approach of the DRCS optimizes and clarifies roles and responsibilities, organizational structures, and procedures for accessing expertise across NASA centers to aid disaster response. This will result in a system that is more closely integrated with the people, the applications, and the activities that advance disasters science. The program aims to pursue a more strategic approach to partnership development, with dedicated team members at the DRCS tasked with connecting with key partners during blue-sky periods (i.e. when they are not actively responding to a disaster). This system will allow for broader engagement in diverse disaster events in 2023 and beyond.

The DRCS will consist of a program office hosted at NASA's Langley Research Center with committed staff to support response activities, process improvement, stakeholder engagement, and GIS development. The program office along with dedicated Center Disaster Coordinators embedded across multiple NASA centers, will represent the DRCS, drawing from the vast array of expertise and knowledge at each center to effectively deliver the best science that NASA has available to aid decision-makers during disaster responses.

Throughout 2022, the NASA Disasters program team engaged with leadership from each center and NASA Headquarters in Washington, DC to develop the DRCS. This collaborative process has allowed voices across NASA to be represented in the outcome. Developing the DRCS through a consultative approach also provided extensive and pragmatic feedback to the program management team.

As the Disasters program moves to focus more closely on the human factors associated with disaster impacts, the DRCS will provide a platform to test solutions from the funded applications projects in real disaster settings, but moreover will allow feedback and experience from stakeholders to flow the other way—enabling two-way communication between applications developers and end users. The DRCS will put humans squarely at the center of its activities, both by improving the recognition of NASA Disaster response team members' work and by emphasizing close connections to communities at risk from disasters in critical regions. By building and deepening relationships with stakeholders in vulnerable areas such as the Caribbean and collaborating with global response agencies like the Red Cross and the World Food Programme (WFP), the DRCS will have not only global reach, but also local connections and experience, maximizing the benefits of NASA data at all spatial scales.

Equally, if not more important to the work done during active disasters, the DRCS will also work closely with stakeholders during blue-sky periods, helping build their capacity to use NASA data and enabling them to understand how they can use a combination of various data streams to inform a range of decisions. Capacity-building efforts tailored to the different stakeholders of interest will allow the DRCS to connect with major international agencies with extensive GIS experience and co-develop solutions with community groups. By working with stakeholders during scenario exercises and through hands-on training, the DRCS will build a knowledge base of best practices for data usage during disaster response. By delivering this understanding to teams on the ground, the DRSC will help build resilient communities and systems.

THE NASA DISASTERS OPEN ACCESS PORTAL

The Disasters Mapping Portal serves as the program's primary platform connecting applications data to a diverse collection of users, supporting decision-makers involved in policy, development, early warning, disaster response, and recovery. It is a highly flexible geographic information system that hosts data for disaster response activities and provides an open and accessible location for users to view, analyze, and download a vast array of NASA and non-NASA datasets to aid disaster response and risk reduction. The portal has become a leading example of open science at NASA; the disasters data it stores is formatted such that even stakeholders with relatively rudimentary technical skills can use it. The portal has also become a testbed for experimental products developed by the program's application scientists to observe and model hazards, facilitating a connection between the applications and response elements of the program and enabling external stakeholders to test and provide feedback on novel datasets.

In September 2022, more than 300 GB of data on Hurricane Ian was uploaded to the portal—the largest amount of data for a single event in the portal's lifetime. The large quantity of data reflects the program's success at using high-resolution commercial data through the Commercial Smallsat Data Acquisition Program (CSDAP) and developing more efficient workflows to add routine products to the portal. However, working with such massive amounts of data, especially at such a high resolution, made balancing data organization, loading speed, responsiveness, and functionality challenging and highlights the need for continual innovation to scale. In support of this effort, the program plans to integrate the portal into a cloud environment, one component of a new **Disasters Open Access Portal** that will deliver added functionality, providing easier access to NASA applications and data for users inside and outside the agency. This integration will allow the portal to connect more easily to NASA Earth science data and other NASA GIS technologies hosted in the cloud.

NASA, along with the White House and other federal agencies, has declared 2023 "the Year of Open Science to celebrate the benefits and successes created through open sharing of data, information, and knowledge." In this context, the Disasters program will continue to innovate and develop new disaster applications for Earth science, maximizing the value and replicability of our efforts for societal benefit.

FINAL THOUGHTS

We are moving towards a future of Earth Science in Action – a paradigm focused on enabling greater access to the information and knowledge unique to NASA. In this new era, we aim to create scalable and impactful services and solutions for partners across the globe, transforming Earth system science to address the accelerating rate of climate change by providing wide-ranging pathways for building resilience to disasters and extreme events. Human systems' exposure to disasters is increasing and will likely continue to rise over the next century. As populations grow, more people will become vulnerable to disaster impacts. The NASA Disasters program is evolving its outlooks and objectives to center on the human dimensions of disasters across the applications portfolio it supports.

To effectively equip communities with the science needed to make disaster-informed decisions, it is crucial to realize potential social, language, and cultural barriers to adaptation. We are lowering those barriers through technical advancements, such as enhanced data transfer and visualization techniques, and by applying emerging insights from fields such as sociology and risk communication. This multi-dimensional approach will allow us to imagine and create new paths to place the science, the tools, and the user know-how into the hands of those who protect lives and livelihoods in the most vulnerable communities.

As we move forward into 2023, we continue to develop novel approaches, deliver open access, and improve the integration of Earth science information into the myriad decision-making processes that support disaster risk reduction and build resilience. The examples in this report demonstrate our continued commitment to work with local governments and response teams to build deeper connections, foster mutual understanding, and increase user capacity—all of which enable our work to scale for increased impact.

APPENDIX

DISASTERS PROGRAM LEADERSHIP

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IMPORTANT LINKS

NASA Applied Sciences Program Website: https://appliedsciences.nasa.gov

NASA Disasters Program Website: https://appliedsciences.nasa.gov/what-we-do/disasters

NASA Disasters Mapping Portal: https://maps.disasters.nasa.gov