National Aeronautics and
Space Administration

DISASTERS PROGRAM
# 2023 ANNUAL SUMMARY

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Cover image: Two tropical cyclones form over the Atlantic Ocean and move toward the Caribbean in June 2023, marking the first time on record that more than one such storm developed in the month of June.
Credit: NASA Earth Observatory/Lauren Dauphin using DSCOVR EPIC data

# WELCOME

Welcome to the NASA Disasters Program's 2023 annual summary. This past year, our program experienced significant evolution in its path to advance science for disaster resilience, and I am grateful for this opportunity to share some of the impacts from these efforts with you. Throughout every project and initiative, we have strived to place people at the very heart of our work.

This year, our suite of Disaster Risk Reduction and Response projects came to a close. The project teams and partners achieved incredible successes – including operational integration of landslide susceptibility and flood warning into Pacific Disaster Center's DisasterAWARE platform; and the first-ever direct-broadcast data available to U.S. Geological Survey's operational volcanic ash advisory centers within 30 minutes for enhanced aircraft rerouting around volcanic plumes—to name a few.

Following two years of planning, design, and preparation, we established the Disasters Response Coordination System (DRCS), a newly structured approach to supporting operational response organizations during active disasters. We finalized the DRCS Playbook and After-Action Assessment process and began building the teams for the DRCS Project Office and the Center Response Coordinators across six NASA centers. These teams will lead the charge in supporting domestic and international emergency response communities with NASA science, technology, and expertise. We also brought the DRCS team together to train on the new playbook, test new ideas, and build connections that will enable seamless collaboration during times of crisis.

We focused much of our time in 2023 to listening to our stakeholders and partners, by leading and participating in many meetings, conferences, and workshops. This included hosting a Disasters Program stakeholder needs workshop, a workshop on technology for disaster risk reduction, and a workshop on advancing the use and Integration of synthetic aperture radar technologies for disaster management. Understanding the immense interest and need for better integration of Earth observations into humanitarian efforts, we launched NASA Lifelines, a six-year consortium led by DevGlobal that brings scientists and humanitarians together to forge connections and build shared capacity towards improving lives and livelihoods around the world.

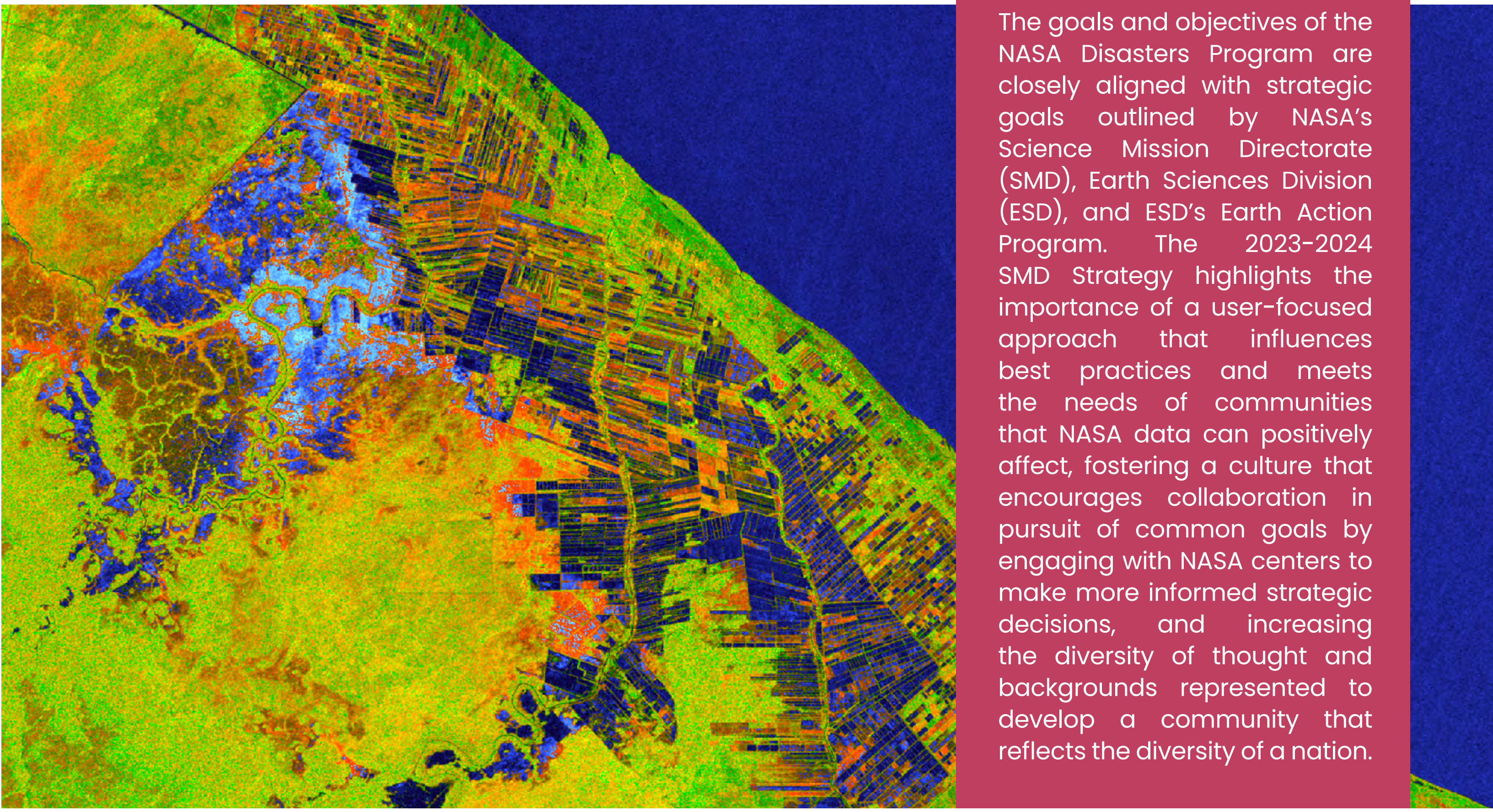
We dedicated 2023 as a year of learning and growth in order to ensure we are ready and successful for multiple programmatic launches planned in 2024, including the ROSES-24 A.42 Disaster Risk Reduction, Recovery, and Resilience solicitation, the June launch of the Disasters Response Coordination System, and the fall launch of a new NASA Disasters geospatial portal.

We are excited to share this journey with you and are grateful for all of you – our disasters community – that helps us achieve global impact.

*Shanna McClain*

Shanna N. McClain, Ph.D.
NASA Disasters Program Manager

# DISASTERS PROGRAM OVERVIEW



## Alignment with NASA's Strategic Goals

The goals and objectives of the NASA Disasters Program are closely aligned with strategic goals outlined by NASA's Science Mission Directorate (SMD), Earth Sciences Division (ESD), and ESD's Earth Action Program. The 2023-2024 SMD Strategy highlights the importance of a user-focused approach that influences best practices and meets the needs of communities that NASA data can positively affect, fostering a culture that encourages collaboration in pursuit of common goals by engaging with NASA centers to make more informed strategic decisions, and increasing the diversity of thought and backgrounds represented to develop a community that reflects the diversity of a nation.

## Earth Science to Action

The Earth Science to Action strategy is the Earth Science Division's 2024-2034 strategic plan. Technology innovation, Earth observation missions, and the data from those missions are the foundation of the Earth Science to Action Strategy. From that foundation, we grow our scientific understanding of Earth's systems. This understanding helps us deliver actionable science and applications to inform partner and societal decisions. As the science is put to use, new challenges and needs are revealed. These are fed back in a virtuous cycle that informs development of new Earth observing instruments, models, and applications. ESD's new Earth Action Program (EAP) is managed alongside the Flight, Earth Science Data Systems, Earth Science Technology Office, and Research & Analysis programs. The EAP is dedicated to accelerating the impacts from NASA's Earth science activities by building bridges, advancing user-centered design, and developing scalable solutions for society.

# THE NASA DISASTERS PROGRAM

The NASA Disasters Program supports effective disaster management decision-making through innovative uses of Earth science information and technology. We work with partners to co-design and scale Earth observation-based solutions, and build bridges between science and disaster management communities through effective learning and information exchange. From understanding and reducing disaster risk, to aiding disaster response, to building resilience, the Disasters Program works to mitigate disaster impacts on lives and livelihoods for communities around the world. We achieve this vision through three program elements:

## Disasters Program Elements

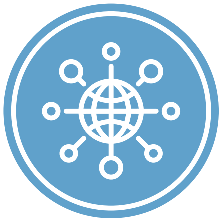
### Disasters Science to Action Projects

We fund projects that address the most critical topics in disaster management today. These include assessing the dynamic nature of natural hazards and extreme events in a changing climate, improving understanding of disaster risk and recovery over short and long-term time scales, enhancing disaster resilience through modeling of systemic disasters, and identifying new methods to address cascading, compound, and complex disasters, and the long-term implications of catastrophic risks. We build multidisciplinary approaches that address the systemic nature of hazards, vulnerability, and exposure, co-developing solutions with government agencies and public and private sector partners to provide scalable solutions that inform decision-making to reduce disaster impacts.

### Disasters Response Coordination System

The Disasters Response Coordination System (DRCS) uses NASA's science, technology, and expertise to support operational response organizations during active disasters. The system's structure includes a central project office at NASA's Langley Research Center and Center Response Coordinators across six NASA centers, ensuring robust representation and use of NASA's collective capabilities. The DRCS facilitates proactive engagement with global agencies and local communities by prioritizing human-centered responses and stakeholder collaboration. This dual focus on active disaster response assistance and two-way learning during blue-sky periods enables stakeholders to effectively integrate NASA data into their operations, enhancing disaster resilience worldwide.

### Disasters Partnership and Learning Agenda



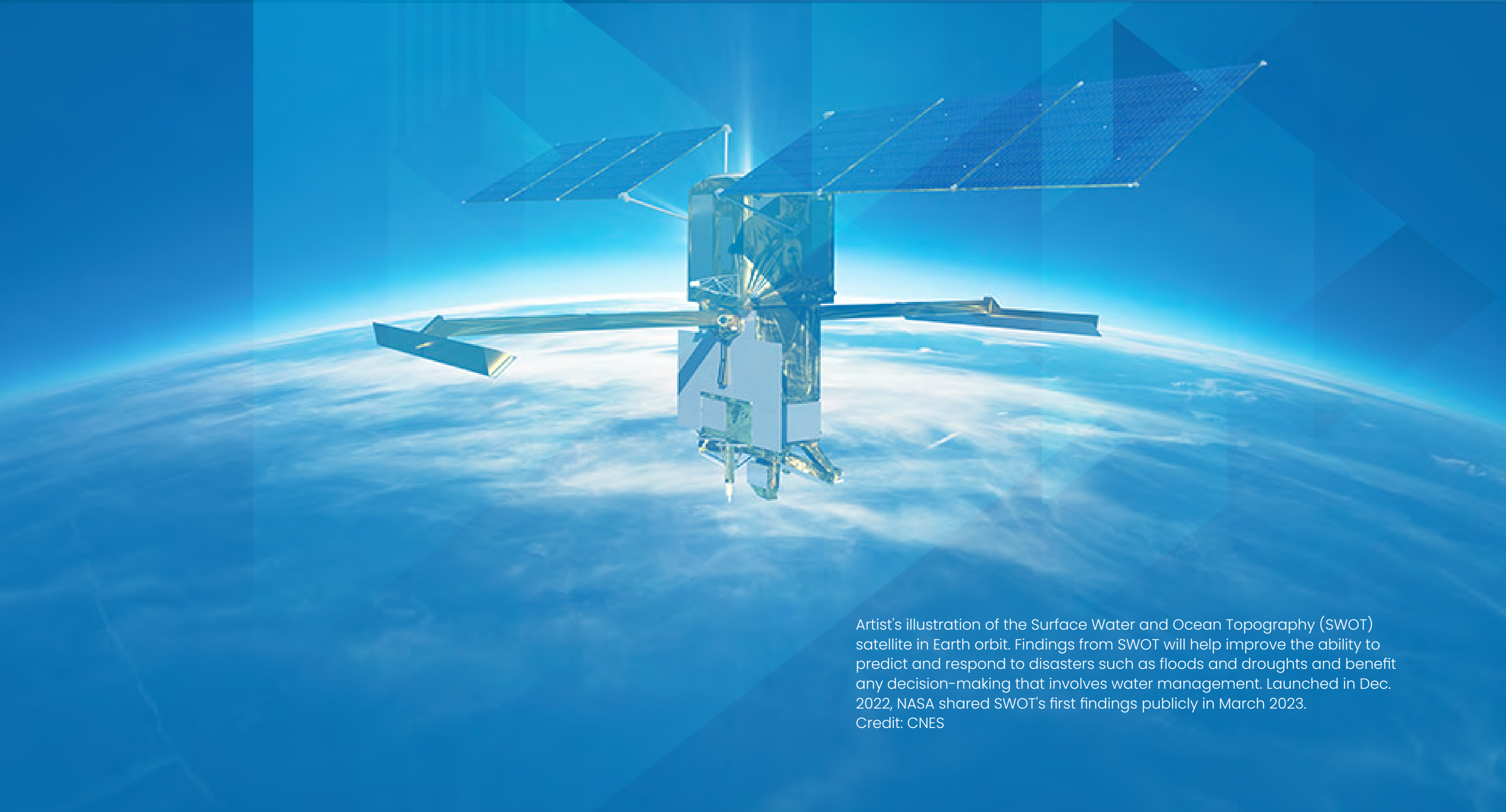
Our partnerships and learning agenda advances awareness, understanding, and applications of Earth science for disaster management communities around the world. We work to understand our partners needs through frequent two-way engagement, ensuring that our program learns and adapts over time. With collaborative learning approaches, including webinars, tutorials, and interactive tools, we equip partners to use Earth science information more effectively for disaster management. Our open-access disasters portal shares geospatial data and tools that support our three program elements, providing a collaborative platform to share Earth observation data, test new capabilities, and gather partner feedback. With the capability to combine diverse datasets, such as hazards and socioeconomic information, the portal enables new insights across the disaster management cycle.

# DISASTERS
# SCIENCE TO ACTION PROJECTS

2023 marked the final year of the NASA ROSES A.37 Disaster Risk Reduction and Response projects. Although the projects have ended, the work they have done will carry on and continue to aid communities around the world for years to come thanks to deep integration with partner toolsets.

The Disasters program also directly funds projects spanning a broad range of subjects at the intersection of extreme events and society, from providing deep insights into post-disaster impacts to exploring how communities can prepare for the unexpected disasters of the future.

Join us as we reflect on each project and the many positive impacts they brought around the world. By partnering with a diverse range of organizations across sectors, these Disaster Science to Action projects integrated NASA science directly into decision-making workflows, providing data-driven insights to reduce disaster risk.



Artist's illustration of the Surface Water and Ocean Topography (SWOT) satellite in Earth orbit. Findings from SWOT will help improve the ability to predict and respond to disasters such as floods and droughts and benefit any decision-making that involves water management. Launched in Dec. 2022, NASA shared SWOT's first findings publicly in March 2023.
Credit: CNES

| | 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) |
| | Coseismic Landslides and Cascading Hazards of the Feb 6, 2023, Türkiye earthquake: Preliminary Database Development and Modeling Analysis | Europe, Asia | Erkan Istanbulluoğlu (University of Washington) |
| | 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 Oceania, America, South America, Global | Franz Meyer (University of Alaska-Fairbanks) |
| | Local Tsunami Early Warning with GNSS Earthquake Source 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.) |
| | Satellite Monitoring of Informal Settlement Dynamics and Displaced Person Mobility in the Complex Humanitarian Crisis of Tigray, Ethiopia | Africa | Jamon Van Den Hoek (Oregon State University) |
| | Today's Risk of Extreme Events | North America | Erin Coughlan de Perez (Tufts University) |

# Global Flood Forecasting

## "Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies"+ "Leveraging A.37 Projects to Disseminate Global Surface Water Mapping from SAR and Optical Data to Global Stakeholders - GIFFT"

PI: Margaret Glasscoe - Univ. of Alabama in Huntsville

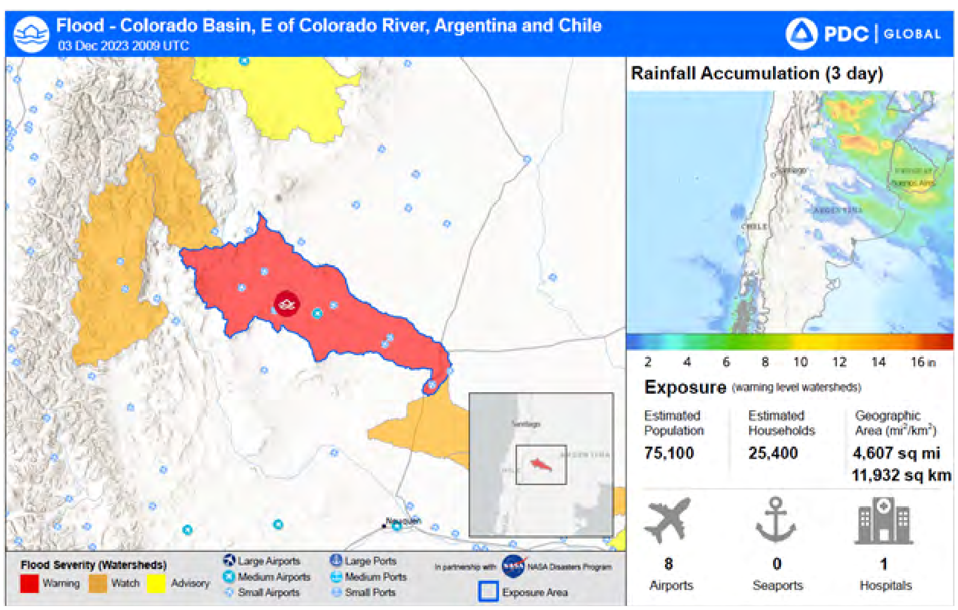
Co-Investigators: Bandana Kar/ORNL, AAAS STP Fellow at Building Tech. Office, Dept. of Energy (initially awarded at Oak Ridge Nat. Lab), Franz Meyer/Univ of Alaska Fairbanks, Kristy Tiampo/Univ. of Colorado Boulder, Charles Huyck/ImageCat Inc., Chris Chiesa and Greg Hampe/PDC, Batuhan Osmanoglu/GSFC, Lori Schultz/MSFC

Floods are among the most common and devastating natural hazards worldwide, impacting millions of lives and costing economies billions of dollars annually. The ability to predict and prepare for flood events can significantly reduce both the human and financial toll, especially in developing regions that are particularly vulnerable to the impacts of disasters and climate change but have not been well-equipped to deal with them.

Recognizing the critical need for timely flood awareness, this international multi-institutional team, with global partners from industry, academia, and national labs, developed and implemented a data fusion pipeline that integrates Earth observation and model datasets for flood extent and depth mapping and risk forecasting. Originally developed through the "Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies" A.37 project, the Model of Models (MoM) approach first combined two globally operationally flood models - GloFAS (Global Flood Awareness System) and GFMS (Global Flood Monitoring System) to classify flood severity and send alerts based on severity level. By uniting disparate data streams and analytical methods, the framework offers a nuanced perspective of flood scenarios, empowering stakeholders with actionable insights for mitigating the adverse effects of potential flood disasters and bridging the gap between localized flood monitoring and a global forecasting system.

The team partnered with the Pacific Disaster Center (PDC) to integrate MoM into their multi-hazard monitoring and alerting system, DisasterAWARE. This integration provided a single source of global information on floods supported by a common, normalized data model. It also brought flood severity analysis and flood hazard awareness capabilities to many users around the globe who previously had no access to these tools. That success laid the groundwork for the subsequent Global Initiative for Flood Forecasting and Alerting (GIFFT) project, which utilizes two other NASA ROSES A.37 projects to augment MoM with advanced capabilities, including triggers for synthetic aperture radar (SAR) analysis and an in-depth exposure analysis using ImageCat's Global Economic Disruption Index (GEDI). Elevating the reach and impact of the team's work, the International Federation of Red Cross and Red Crescent Societies (IFRC) incorporated DisasterAWARE's early warnings into its Go Platform, bringing unprecedented global flood awareness capabilities to tens of thousands of disaster management professionals and over two million users worldwide.
The project has transformed flood awareness capabilities, enhancing the capacity for early action worldwide.
The project team next hopes to fully integrate MoM, SAR, and GEDI pipelines into DisasterAWARE, improving the platform's predictive accuracy and widening the scope for economic risk assessment of floods. The long-term vision is to establish a sustained, globally accessible framework that not only forecasts floods but also empowers communities with the knowledge and tools necessary to mitigate their impacts.

View from a Vermont National Guard helicopter surveying flood damage in the state's capital, Montpelier, Vt., July 11, 2023. Credits: U.S. Department of Defense, Air Force Senior Master Sgt. Michael Davis




This situational awareness map product was created for a recent flood hazard in Argentina and Chile on PDC's DisasterAWARE Platform using the Model of Models data. The product indicates potentially affected populations within the exposure area of the flood hazard. Credits: Pacific Disaster Center/NASA

# Advanced Forecasting for Wildland Fires

## "Coupled Interactive Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making"

PI: Kyle Hilburn - Colorado State University

Co-Investigators: Adam Kochanski and Angel Farguell/San Jose State Univ, Jan Mandel/Colorado Univ.

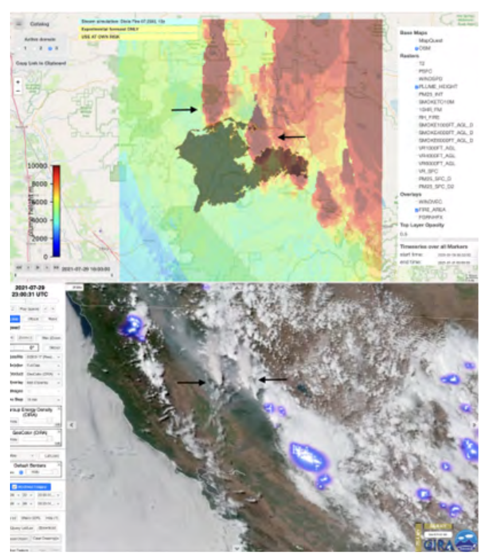
Wildfires are becoming larger and more frequent. More extreme behavior, longer fire seasons and population growth in the wildland-urban interface means more people at risk. Scientists have used satellite remote sensing to detect thermal signatures of active wildfires for over 20 years, but the need for high-resolution information about weather, fuels, fire, and smoke in and around active fires, especially in areas of complex terrain and near population, has never been greater. This project aims to revolutionize wildland fire management by improving decision-making processes, strengthening disaster resilience and supporting effective emergency response.

The team coupled the Weather Research and Forecasting (WRF) atmospheric model with a fire spread model (SFIRE), fuel moisture model, and smoke emissions model to create WRF-SFIRE, a pivotal enhancement in the resources available to disaster and fire response professionals. WRF-SFIRE combines detailed weather data, surface fuel moisture observations, satellite fire detection, and cutting-edge numerical weather prediction models. This integration enables a physically consistent picture to provide precise, daily forecasts of wildfire behavior, its interactions with weather patterns, and the resulting smoke dispersion. WRF-SFIRE provides three-dimensional profiles of smoke, filling a gap in current remote sensing capabilities. The tool stands alone in its ability to simulate and forecast pyro-convection (fire that makes its own weather), which is essential for understanding smoke transport and improving firefighter safety. The team advanced the WRF-SFIRE code to make it essentially a "push-button" system, allowing even non-experts to use satellite fire detections to initialize active fire forecasts. An array of experts in meteorology, fire behavior analysis, and computational modeling worked together throughout the project to ensure the system benefits from the latest scientific and technical developments. In particular, the U.S. Forest Service and Rocky Mountain Research Station staff supplied critical knowledge, resources, and data. In turn, they achieved their goal of producing real-time ignition probability forecasts.

As the only operational tool currently available to fire and air-quality managers at any land-management agency that can quantitatively account for simultaneous interactions of local weather dynamics and its two-way interactions with the released heat by fires, 2-D fire spread, and fire smoke emissions and trajectories, WRF-SFIRE's integration of weather forecasting, fire behavior modeling, and smoke impact assessment offers a new paradigm to assess and forecast the wildland fire environment leds to more precise predictions which are essential for informed fire management. The system has aided in precise predictions of fire spread, the impact on local weather, and smoke paths for several events with products shared via NASA's Disasters Portal. During this project, WRF-SFIRE correctly produced pyro-convection forecasts for events such as the 2018 Mallard Fire in Texas, and the 2020 Creek Fire and 2021 Dixie Fire in California. The team also contributed forecasts for the BURNEX training activities in California. WRF-SFIRE proved valuable for planning resource deployment, firefighting strategies, aircraft operations, and evacuations. The system has also been coupled into the AIRPACT (Air Information Report for Public Awareness and Community Tracking) air quality monitoring system, improving the accuracy of that system via improved wildfire plume rise estimates. WRF-SFIRE was also featured in congressional testimony in 2021 as an example of the type of open-source coupled modeling needed to advance fire science.

The team behind WRF-SFIRE looks forward to further improving the model's precision by incorporating real-time data and leveraging machine learning to enhance the timeliness and reliability of forecasts. Efforts are also being made to extend collaborations internationally, with the goal of establishing consistent standards for wildland fire management worldwide.

Fire scientists used a prescribed burn in Utah's Fishlake National Forest to test how well a NASA-funded fire prediction model, accessible on cell phones, forecasts how a fire spreads and interacts with local weather.
Credits: NASA / James Roud



(Top Right) July 29, 2021, forecast plume height indicated likelihood of pyro-convection on the east and west sides of the Dixie Fire. (Bottom right) GOES-17 observed pyro-convection at the same time as forecast, with Geostationary Lightning Mapper observing lightning flashes in the eastern storm. Credits: NASA / CIRA

# Helping Aircraft Avoid Volcanic Ash

PI: Nickolay Krotkov/NASA Goddard Space Flight Center

Co-Investigators: Vince Realmuto/ NASA JPL, Kelvin Brentzel/DRL, Can Li/U. Maryland, David Schneider/USGS, Martin Stuefer and Jennifer Delamere/U. Alaska-Fairbanks

### "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"

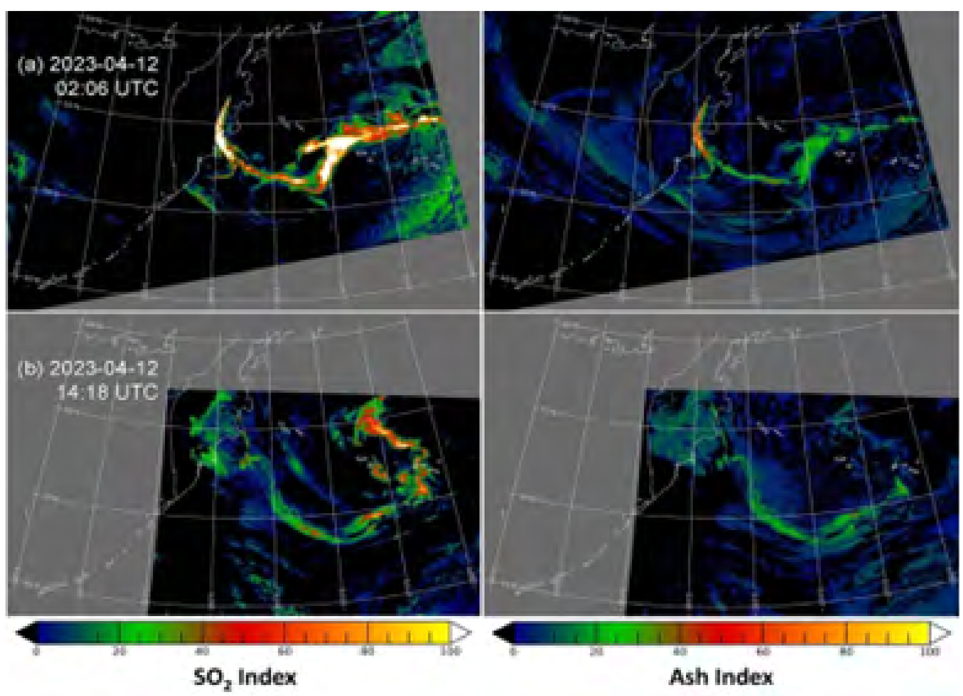
Volcanic eruptions release vast amounts of sulfur dioxide and volcanic ash into the atmosphere, creating a serious threat to aviation safety. Volcanic ash encroaching on flight paths reduces pilot visibility and the mixture of tiny rock and glass fragments that make up the ash can seriously damage aircraft, even to the point of engine failure. But, until now, ultraviolet-based ash and sulfur dioxide monitoring was not possible at night or under low-light conditions, such as polar regions endure for long periods of each year. This project focuses on integrating real-time volcanic data from satellites to enhance volcanic ash forecasts day or night to enhance aviation safety.

By leveraging instruments like OMPS and VIIRS on Earth observing satellites including Suomi-NPP, NOAA-20, and NOAA-21, the project team has created new capabilities to characterize the variation in surface conditions, discriminate between volcanic and meteorological clouds, and assess the impacts of these variations. Partnerships with two Direct-Broadcast centers, the Geographic Information Network of Alaska (GINA) at the University of Alaska Fairbanks and the Finnish Meteorological Institute (FMI), have accelerating data processing from these instruments to reduce latency.

The joint research and collaboration with partners at NASA's Jet Propulsion Laboratory. the U.S. Geological Survey's Alaska Volcano Observatory and the Anchorage Volcanic Ash Advisory Center has led to a suite of direct-broadcast satellite products that allows comprehensive monitoring of high-latitude volcanic eruptions – day or night. For the first time, detailed volcanic direct-broadcast data are available to key operational centers within 30 minutes, fostering enhanced situational awareness and response to volcanic events. For instance, during the April 2023 eruption of the Shiveluch volcano in Russia, forecasters were able to discriminate SO2 plumes from ash plumes, which led them to recognize that the clouds over the Aleutians were primarily sulfur dioxide. This allowed them to swiftly adjust their forecasts, leading to the reopening of airspace and minimizing flight disruptions.

Looking forward, the team plans further integration of its satellite data products into operational systems to provide continued support for air traffic safety. Ongoing workshops with project scientists and Volcanic Ash Advisory Center representatives continue to show how near real-time insights can support and strengthen efforts to produce detailed ash cloud forecasts. Having discovered that the products from this effort can also be used to track smoke plumes from forest fires and dust storms above or mixed with water clouds–an ability not currently possible with operational satellite data, Krotkov and his team look forward to additional applications of the technology that light the way to safer and more efficient flights around the globe.

An ISS Expedition 20 crew member captured this oblique angle photograph of an eruption of the Sarychev Volcano in the Kuril Islands, northeast of Japan, on June 12, 2009. Optical imagery is one tool among many that helps scientists understand the nature of volcanic clouds (ash, water, sulfate aerosols) but it cannot discriminate between ash and water/ice clouds from large distances away. Credits: NASA, Photo ID: ISS020-E-9048




The multispectral thermal infrared measurements acquired by VIIRS are sensitive to volcanic SO2 and ash. Index maps of SO2 (upper left) and ash (upper right) depict the Shiveluch eruption plume at 02:06 UTC on April 12, 2023. Index maps of SO2 (bottom left) and ash (bottom right) derived from VIIRS night-time observations acquired at 14:18 UTC, highlight the dispersion of the eruption plumes in the 12 hours following initial observation. Credit: NASA

# Mapping Oil Spills from Space to Speed Cleanup

## "Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context"

PI: Frank Monaldo/University of Maryland-College Park

Co-Investigators: Cathleen Jones, Ben Holt (NASA JPL), Ellen Ramirez (NOAA Satellite Applications Branch (SAB), Sean Helfrich / NOAA Nat. Environmental Satellite, Data, and Information Service (NESDIS) Center for Satellite Applications and Research (STAR), Lisa DiPinto and George Graettinger/NOAA OR&R, Oscar Garcia-Pineda /Water Mapping, Gordon Staples/MDA, Anna Milan Kristin Johansson/UiT Arctic University of Norway

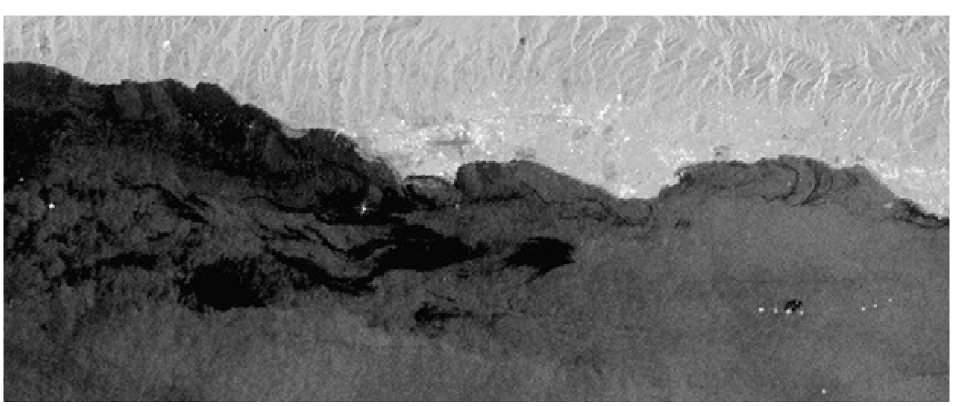
This project addresses the critical challenge of efficiently monitoring coastal oil spills and evaluating storm damage to offshore infrastructure with a goal to enhance the speed and effectiveness of disaster response operations that mitigate the environmental impacts of oil spills and natural disasters. Combining the power of Synthetic Aperture Radar (SAR) with optical imagery, and simulation models, the project team created a "contrast ratio" algorithm that compares the amount of SAR image brightness reduction in oil-covered areas with open water to estimate oil thickness with a high degree of precision. The resulting Marine Oil Spill Thickness, or "MOST" technology enables federal agencies tasked with responding to oil spills to quickly identify 'actionable oil'—thicker accumulations that pose a greater threat to marine life and the environment and equips them to create more effective and efficient response strategies.

MOST has been implemented in the SAR Ocean Products System (SAROPS), National Oceanic and Atmospheric Administration (NOAA) research and operations environment, and the resulting SAR imagery products have become an integral part of NOAA's oil response toolkit. Collaborations with NOAA as well as the European Space Agency (ESA), and the Italian Space Agency (ASI) have been crucial, with each contributing vital satellite data and expertise in SAR technology and broadening the project's scope and enriching its scientific rigor. The U.S. Coast Guard (USCG), team members at NASA's Jet Propulsion Laboratory (JPL) and within private industry have also been integral in both refining algorithm development as well as operational applications of the project's outputs.

MOST's real-world efficacy was highlighted during field tests, such as one off the coast of Santa Barbara in 2019, which took advantage of the area's natural oil seeps as a testing ground. An unexpected but equally valuable demonstration of the project's usefulness in emergency situations came with an oil spill off Huntington Beach, California in Oct. 2021, where the MOST products enhanced the deployment of response crews and informed remediation efforts by those tasked with responding to the spill. Data collected from events such as this also serve as a foundation for enhancing the automated algorithms to enable precise and informed action.

By providing a comprehensive view of spill evolution and potential impacts, this project is expanding the tools available for disaster response agencies. The team continues to refine its SAR applications further and explore the integration and routine operational use of the MOST technologies as it also looks forward to future capabilities enhanced by new sensors such as those aboard the NASA-ISRO Synthetic Aperture Radar (NISAR) satellite scheduled to launch in the near future. With each milestone, MOST continues to pave the way for a future where environmental and societal impacts of disasters can be minimized through swift and informed action.


The research team and partners aboard the Coast Guard cutter Blackfin during a Marine Oil Spill Thickness field campaign off the coast of Santa Barbara, California. Credits: NASA/ University of Maryland/Frank Monaldo



*This ESA Sentinel-1A image, taken May 11, 2021, over Santa Barbara, California during the Marine Oil Spill Thickness (MOST) field test campaign, shows a dark area off the coast with natural oil seepage. The light area at the top of the image is land and the dark area off the coast bottom indicates the presence of natural oil seepage. Bright dots in the ocean are offshore platforms and ships. Credits: NASA (Contains modified ESA Copernicus Sentinel-1A data.)*

# Modeling Landslide Hazards Around the World

**"Enabling Landslide Disaster Risk Reduction and Response throughout the disaster life cycle with a multi-scale toolbox"**

PI: Dalia B. Kirschbaum/NASA GSFC

Co-Principal Investigators: Dimitrios Zekkos/USC Berkeley, Marin Clark/U. Michigan, Co-Investigators, Robert Emberson/UMBC, Thomas Stanley/ UMBC, Jon Godt/USGS, Doug Bausch/Pacific Disaster Center, Chris Chiesa/Pacific Disaster Center, Felipe Mandarino/City of Rio de Janeiro

Landslides cause thousands of deaths and billions of dollars in damage every year. Developing countries often bear disproportionate losses due to lack of access to hazard early warning systems and other resources for effective risk reduction and recovery. Predicting landslides is challenging due to their localized nature and the many factors that combine to make areas susceptible, such as soil moisture, local geology, the condition of nearby infrastructure, and the angle of nearby hill and mountain slopes. When a landslide trigger—such as sudden heavy rainfall or an earthquake—occurs in a susceptible area, massive amounts of soil, rock, and other debris can cascade down slopes with the power to destroy roads, buildings, and entire villages.

Many communities around the world have developed their own systems to track landslide hazards, but until now there has not been an accessible landslide modeling system that works globally. To address this gap, Dalia Kirschbaum and the NASA landslides team developed LHASA – Landslide Hazard Assessment for Situational Awareness – a machine learning model that maps landslide hazard likeliness across most of the world. LHASA is trained on a first-of-its-kind database they developed of historical landslides and the conditions surrounding them, gathered from news reports, historical records, and citizen scientists. It combines this knowledge with the latest near real-time NASA IMERG precipitation data, allowing it to recognize patterns that indicate a landslide is likely. The result is landslide "nowcast" – a map showing the potential of rainfall-triggered landslides occurring for any given region within the past day. This map of hazard likelihood can help agencies and officials rapidly assess areas where the current landslide risk is high and give disaster response teams critical information on where a landslide may have occurred so they can investigate and deploy life-saving resources.

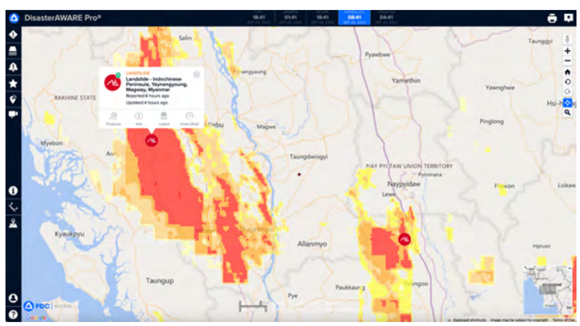
The LHASA model and data are open source and freely available, but the team recognized the need to go further get this valuable tool into the hands of communities that need it most. To achieve this, the project partnered with the Pacific Disaster Center (PDC), an applied research center managed by the University of Hawaii. PDC's flagship software DisasterAWARE provides early warnings and risk assessment tools to aid decision-making for 18 types of natural hazards. Prominent users include the International Federation of Red Cross and Red Crescent Societies (IFRC), the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA), and the World Food Programme (WFP).

The NASA landslides team collaborated closely with PDC for months to integrate LHASA into DisasterAWARE, working to convert LHASA's outputs into landslide alerts and regional risk reports that can provide actional info to local decision-makers. This integration increased LHASA's accessibility for a wide global audience of disaster management agencies, local governments, and humanitarian organizations. Communities are already seeing the fruits of these efforts, with teams in El Salvador, Honduras, and the Dominican Republic using these new capabilities to assess landslide hazards during the 2023 rainy season.

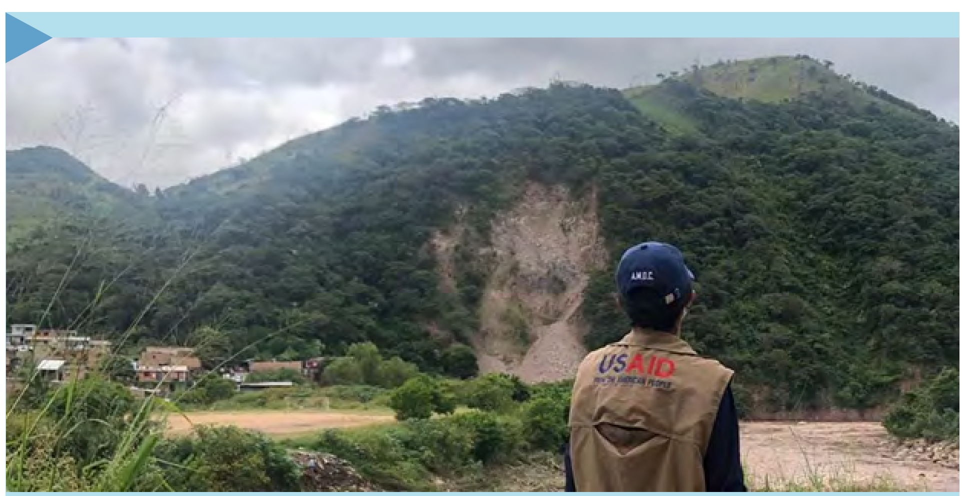
Links & Resources:

NASA Landslides Team

LHASA on GitHub




This screenshot from PDC's DisasterAWARE Pro software shows LHASA landslide hazard probabilities for Myanmar in Sept. 2023. Red areas indicate the highest risk for landslide occurrence within the past three hours, while orange and yellow indicate lesser risk. Credit: Pacific Disaster Center




A humanitarian worker from USAID observes the impacts of a landslide. USAID deployed an elite Disaster Assistance Response Team on Nov. 17, 2020, to lead the U.S. response to Hurricanes Eta and Iota. Credit: USAID's Bureau for Humanitarian Assistance

# Mapping Damage to Buildings and Infrastructure

### "Global Rapid Damage Mapping System with Spaceborne SAR Data"

PI: Eric Fielding/Jet Propulsion Laboratory

Co-Investigators: Sang-Ho Yun/Nanyang Technical Univ. Earth Observatory, Shi Tong Chin/Earth Observatory Singapore, Emma Hill/Nanyang Technical Univ., Hook Hua/JPL, MinJeong Jo/USRA, Jungkyo Jung/JPL, Nina Lin/ Earth Observatory Singapore, Sabine Loos/Stanford Univ., Batu Osmanoglu/GSFC, Melda Salhab/University College London, Oliver Stephenson/California Institute of Technology Jonathon Stewart/UCLA, Gopika Suresh/ Earth Observatory Singapore, Cheryl Tay/Nanyang Technical Univ., Alexander Torres/JPL, David Wald/USGS, Paolo Zimmaro/UCLA

In the immediate aftermath of a disaster, the window for effective response narrows quickly, making the rapid acquisition of accurate on-the-ground conditions both vital and challenging for emergency response teams. Mapping the scale of destruction to buildings and infrastructure accurately and rapidly can enable first responders and humanitarian teams to assess and address areas of concern quickly.

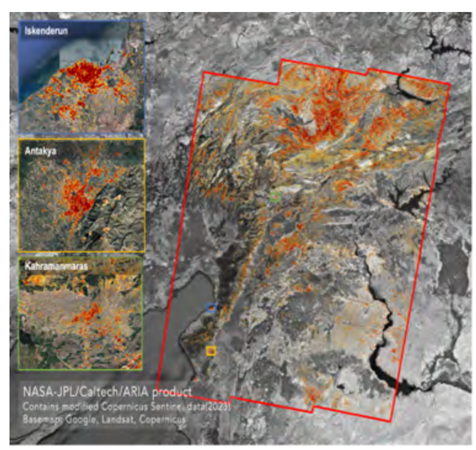
This project team has developed a system that automates rapid production of Damage Proxy Maps from satellite-acquired SAR data and ground deformation maps. The result significantly accelerates the delivery of critical information, such as building damage and surface change, and gives response teams a consistent and reliable tool for evaluating widespread damage. This system's continuous operation ensures access to that vital data around the clock, enabling decision-makers to act swiftly and effectively. Due in part to the advancements made through this project, space-based SAR data has become a key component in disaster response toolkits, widely valued for its utility in enhancing situational awareness when it matters most.

The project employs a process known as multitemporal interferometric SAR (InSAR) coherence analysis to refine the accuracy of damage detection. In simple terms, it looks at how the radar signals differ from one image to another over a period-particularly before and after hazards such as earthquakes, landslides or storms-and tracks the consistency, or 'coherence,' of the radar signal patterns across these times. If the coherence is disrupted between images, analysts can pinpoint change due to potential damage. This project improves upon conventional practices by analyzing each pixel's temporal behavior, thereby tailoring the damage mapping to various land covers and reducing irrelevant noise in the data. Along with the work done by the Advanced Rapid Imaging and Analysis (ARIA) team at NASA's Jet Propulsion Laboratory (JPL) and California Institute of Technology, partners such as the Earth Observatory of Singapore (EOS) and the USGS have contributed significantly to the project, with contributions ranging from system cloning and functionality expansion to integrating Damage Proxy Maps with other data types for improved damage estimation. The program has also developed techniques for measuring large-scale ground movement from earthquakes and volcanic eruptions, which can provide cruical information on fault activity and the potential for infrastructure damage or even permanent changes in coastal landscapes due to land subsidence. The multi-temporal InSAR coherence Damage Proxy Map, or DPM2, has been particularly successful in distinguishing actual damage from natural changes over time, providing clear, actionable information for responders.

The tools and improved DPMs developed through this collaborative team have been applied to a wide range of events, including earthquakes in Indonesia and Haiti, cyclones and landslides in Indonesia and Nepal, volcanic eruptions in St. Vincent and Indonesia, tornados in Tennessee and Kentucky and hurricanes in Louisiana. In 2021, the technology was instrumental in tracking changes caused by the Cumbre Vieja volcanic eruption in La Palma in the Canary Islands over several weeks. This past year, when a series of powerful earthquakes struck Türkiye near the Syrian border, the ARIA team at the JPL generated displacement maps and shared them with the USGS and other stakeholders to increase understanding of the earthquakes' geological conditions. Each application has helped to refine the algorithms and improve the system's overall efficiency and reliability in providing timely, accurate data to disaster response teams. These maps have not only advanced the scientific understanding of disaster impacts but also provided invaluable insights for societal needs, influencing infrastructure planning and risk assessment.

Looking forward, the team is focused on enhancing the efficiency of time-series SAR damage mapping, drawing on methods from the NASA OPERA project. The upcoming launch of the NISAR mission in 2024 is set to further advance the project's capabilities, ushering in a new era of improved rapid damage assessment.

Virginia's Fairfax County International Urban Search and Rescue team and hundreds of other U.S. experts assisted in the 2023 earthquake response in Türkiye. Credit: USAID




Technology from this project helped create this Damage Proxy Map depicting areas likely damaged by earthquakes that struck Türkiye and Syria in Feb. 2023. Credits: Earth Observatory of Singapore Remote Sensing Lab, with data from Copernicus Sentinel-1 satellites operated by the European Space Agency.

# Hailstorm Climatology and Early Warnings

## "Hailstorm Risk Assessment Using Spaceborne Remote Sensing Observations and Reanalysis Data"

**PI: Kristopher Bedka/NASA LaRC**

Co-Investigators: Sarah Bang/NASA MSFC, Jordan Bell/NASA MSFC, Dan Cecil/NASA MSFC, Kyle Itterly/LaRC-SSAI, Konstantin Khlopenkov/LaRC-SSAI, Ben Scarino/LaRC-SSAI, Chris Schultz/NASA MSFC

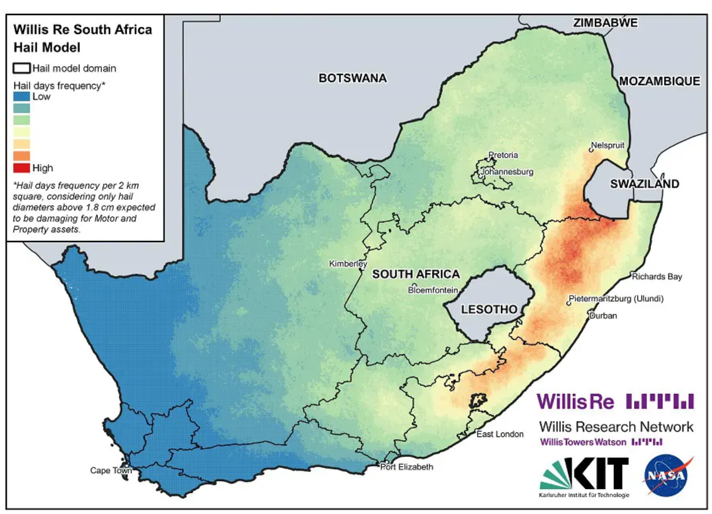
Hailstorms pose severe risks with their unpredictable nature and track record of significant economic and environmental damage. Severe hail–with stones larger than one inch in diameter–is historically the costliest storm hazard for the insurance industry, responsible for roughly 60-70% of the average annualized loss of the three primary severe weather hazards in the United States – hail, straight-line winds, and tornadoes and amounting to more than $10B of loss in a typical year. This project, led by Kris Bedka at NASA's Langley Research Center, leverages advanced remote sensing technologies onboard Earth-orbiting satellites to improve the understanding and prediction of severe hailstorms. By improving risk models and providing more accurate forecasts, the project is closing a significant gap in meteorological research and helping address a critical societal need for improved disaster preparedness.

The team at Langley is using cutting-edge satellite observations alongside reanalysis data to detect hail and assess its potential damage around the globe. This approach has led to more precise data than traditional ground-based methods. Overcoming hurdles related to acquiring and organizing hundreds of terabytes of satellite observations and reanalysis model data required creative use of computing clusters and satellite data acquisition software and the development of a litany of processing tools. The team also developed new neural network-based artificial intelligence methods to enhance hailstorm detection. Collaborative efforts with partners such as Willis Re and the Karlsruhe Institute of Technology have been pivotal, contributing specialized expertise and resources to expand the project's capabilities. These partnerships have facilitated the creation of a detailed hailstorm climate record and a catastrophe model tailored for South Africa.

This work has also led to the creation of a comprehensive hailstorm climate data record, which has been instrumental in developing a catastrophe model that improves the ability of insurers and policymakers to manage hailstorm risk. The impact of this data record extends beyond the immediate field of meteorology, with broader implications for disaster prediction, community safety, economic stability, and environmental conservation. The team continues to refine its predictive models further and extend its geographical reach. This project focused on several geographic regions, including the U.S., South Africa, South America, Italy, and Australia. Still, there are other regions, such as continental Europe, tropical Africa, Bangladesh, northern India and Pakistan, and northeastern China, where satellite data can now define hailstorm frequency at hourly timescales.

Before this project, there had been limited quantitative analyses of the characteristics of hailstorms and other severe storm types using satellite data. Now, the team's expertise is featured in a training module routinely available to National Weather Service forecasters, illustrating how the project has set a new paradigm for forecasting severe storms. In 2023, Bedka won the most prestigious award in the global severe weather research community for his work with this project team, the Nikolai Dotzek Award, for "outstanding contribution to the science of severe storms." As Bedka and the team continue to improve data resolution and the processes for automating hail damage detection methods, the advancements made through this project are already bringing significant societal benefits in understanding and mitigating the risks associated with severe hailstorms.

Hail damage is among the costliest weather disasters with residential and agricultural losses of billions of dollars annually. Image Credit: National Oceanic and Atmospheric Administration/Department of Commerce




A map of the relative hailstorm frequency over South Africa derived by Willis Re using Bedkas' "Satellite Mapping and Analysis of Severe Hailstorms" (SMASH) team's satellite datasets including overshooting cloud top detections from a 14-year database of 15-minute resolution Meteosat Second Generation infrared brightness temperatures, TRMM and GPM hailstorm detections, and ERA5 reanalysis data. Credits: Wills Re

# Streamlining Satellite Data Processing for Extreme Weather Events

## "Integrating Synthetic Aperture Radar Data for Improved Resilience and Response to Weather-Related Disasters"

PI: Franz Meyer/University of Alaska, Fairbanks

Co-Investigators: Andrew Molthan/NASA MSFC, Lori Schultz/NASA MSFC, Jordan Bell/NASA MSFC, Batu Osmanoglu, and MinJeong Jo, NASA/GSFC

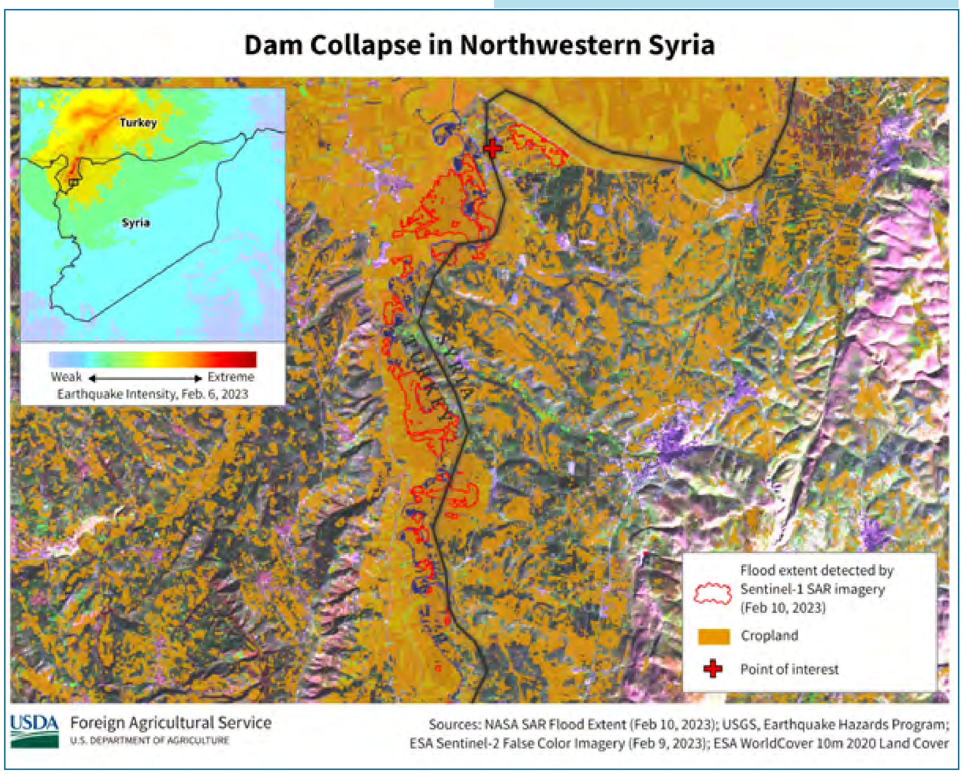
Synthetic Aperture Radar (SAR) data, with its capacity for all-weather, round-the-clock monitoring, is crucial for providing near real-time, actionable information and for retrospective analyses to mitigate the effects of hydrological hazards, including flash floods, storm surges, and rapid snow and ice melt. However, the complexity and computational intensity of SAR data processing create barriers to its timely use to analyze such hazards.

To overcome those processing challenges, this project team developed a cloud-based production pipeline that can generate SAR-based hazard products automatically and across large spatial scales. The result is value-added products that address the mapping of meteorological and hydrological disasters for improved disaster prediction and understanding. The system, implemented in the Amazon Web Services cloud, allows the generation of hundreds of data products per hour. Users can also deploy the service on a local server, providing a flexible option for sustaining the service in the long term. The integration of these products from the pipeline into end-user decision-making workflows has enhanced the operational response to a variety of hydrological disasters since the project began. New capabilities from the toolbox have bolstered critical flood monitoring activities, including SAR-derived product generation after a dam broke during the Türkiye /Syria Earthquake in 2023, as well as numerous other events in previous years, such as hurricane monitoring along the U.S. coastline, flood monitoring in Alaska, and monsoon flood surveillance in South Asia with the International Centre for Integrated Mountain Development (ICIMOD).

The team achieved efficient dissemination and accessibility of SAR products by developing novel Esri Image Service solutions. These services permit direct streaming of SAR data into desktop GIS environments and web platforms for integration into decision-making systems. The USDA Foreign Agriculture Service now incorporates these SAR products into their Global Agriculture and Disaster Assessment System (GADAS). The team has actively collaborated with NASA A.37 projects (e.g., Krotkov, Kirschbaum and Glasscoe). Outside of the agency, partnerships with the U.S. Department of Agriculture Foreign Agricultural Service (USDA-FAS), National Weather Service Alaska-Pacific River Forecast Center (APRFC), the Federal Emergency Management Agency (FEMA), and the private agriculture company Corteva Agriscience provided crucial support toward integrating these tools into operational workflows and decision-making processes.

The technology developed through this project has also been shared with other agencies and initiatives, such as the upcoming NASA-ISRO SAR (NISAR), the CEOS Application-Ready Data for Land initiative, AmeriGEO capacity-building activities, and the Observational Products for End-Users from Remote Sensing Analysis (OPERA) project at the Jet Propulsion Laboratory. The team also focused on the calibration and validation of these products, with successful results for flood extent and depth at multiple sites around the globe. Collaborations such as these underscore the project's contributions to broader applications of SAR data and its utility in improving preparedness and response to weather-related disasters around our planet.

Direct streaming of SAR data into desktop GIS environments and web platforms can help provide situational awareness for response agencies. In this Aug. 2021 photo, Louisiana National Guardsmen conduct rescue operations in the aftermath of Hurricane Ida.
Credit Louisiana National Guard/CC BY 2.0




Analysts at the Foreign Agriculteral Service's Inernatinoal Production Assessmsnt Divisino (IPAD) investigated the potential damage done by flooding when a dam broek after the Türkiye/Syria Earthquake in 2023. Data processes through this new pipeline helps analysts estimate potential cropland damage to help identify possible changes to crop production around the world. Credits: USDA Foreign Agriculterual Service.

# Improving Tsunami Early Warnings

Principal Investigator: Dr. Diego Melgar/Oregon State University

Co-Investigators: Dr. Brendan Crowell/University of Washington, and Dr. Tim Melbourne/Central Washington University

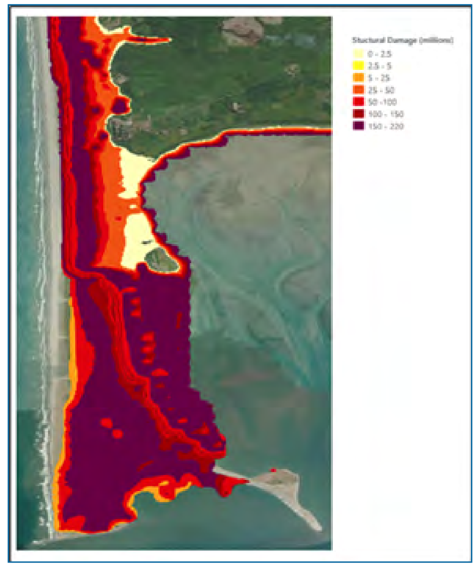
## "Local Tsunami Early Warning with GNSS Earthquake Source Products"

According to the United Nations, tsunamis claimed over a quarter million lives in the past century, surpassing any other natural hazard. By the end of this decade, half of the world's population will live in coastal areas exposed to the massive flooding they can bring. Timely and accurate tsunami alerts – especially within the critical 5-to-15-minute window after the initial quake - can mean the difference between life and death. Unfortunately, traditional tsunami warning systems have struggled to offer rapid alerts for tsunami, especially within the 'near-field' area, immediately adjacent to an earthquake. This project uses satellite-based technology coupled with ground stations and accelerated data processing and distribution to improve forecasts and early warning systems and enhance the ability to respond quickly to imminent tsunami threats and protect coastal communities.

Large earthquakes produce deformation, often on the order of several meters, which permanent Global Navigation Satellite System (GNSS) stations can measure in real time. The research team for this project envisioned new capabilities for an algorithm they'd developed earlier, called Geodetic-First Approximation of Size and Timing (G-FAST). G-FAST delivers real-time estimates of the magnitude of an earthquake, its geographic extent, and details of the amount of motion (slip) on a fault. By combining G-FAST data with the National OAA's hydrodynamic modeling code, the team and their partners at NOAA, have enabled the production of Rapid Forecast Tsunami Amplitudes – forecasts that can quickly and accurately warn of dangerous impending tsunami. This approach offers capabilities over traditional seismic measurement methods, including overcoming 'magnitude saturation'—a phenomenon where real-time systems fail to differentiate between large earthquakes (M8+) and massive ones (M9+). Development time with NOAA's Pacific Tsunami Warning Center and National Tsunami Warning Center has been instrumental in creating, testing, debugging, and optimizing the workflow to ensure that the theoretical models are effectively transformed into practical warning systems.

The advancements made possible through this project allow forecasters to characterize earthquakes and their subsequent tsunamis accurately and distribute that critical information in as little as five minutes - a significant leap forward. G-FAST code has successfully been deployed at the National Oceanic and Atmospheric Administration's (NOAA) Center for Tsunami Research (CTR) and is receiving real-time GNSS data from more than 1,000 sites worldwide. Through the partnership with NOAA, the system has been routinely triggered in real-time when global events occur, and it now provides fast and accurate alerts for large earthquakes in the Cascadia subduction zone along the U.S. West Coast.

And, while the project focused on the U.S. West Coast first, its impacts are likely to be felt across the Pacific in all earthquake-prone regions. G-FAST is open-source, which opens prospects for developing nations that operate real-time GNSS networks to become self-reliant. That open-source license benefits the development team, partners at NOAA, and those who want to take advantage of these new tsunami forecast and warning capabilities in their own region. Network operators in countries from Chile to New Zealand have offered access to their real-time networks in exchange for the code and training. As for the future, the project aims to leverage the global network of GNSS stations to extend its utility beyond the U.S. West Coast with the potential to standardize tsunami early warning systems worldwide and help coastal communities protect against catastrophic consequences, loss of life and long-lasting damage to infrastructure from tsunami.




Estimated losses from an M9 earthquake in the Greys Harbor region in southern Washington state. This visualization is obtained by combining a simulated event with hydrodynamic modeling and exposure databases.
Credit: Diego Melgar, Oregon State University

mproved early warning aims to prevent casualties and loss of property from tsunami due to underwater earthquakes. In this photo, debris lines the streets of downtown Banda Aceh, Indonesia after a historic tsunami struck the area in Dec. 2004. Credit: Michael L. Bak/U.S. Department of Defense

# Quantifying Economic Impacts from Disasters

PI: Charles Huyck/ImageCat Inc

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

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

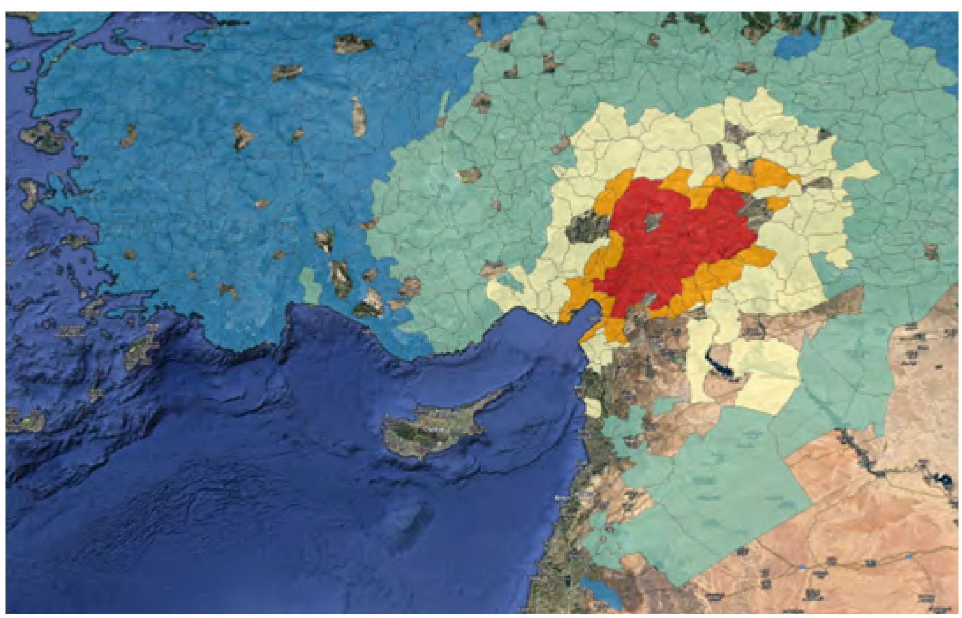
The "Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation, and Response" A.37 project uses Geographic Information System (GIS) data to enable critical infrastructure assessment in developing countries and other places where detailed data may be limited. Since the project began in 2019, the team has made significant strides in mapping critical infrastructure, which is instrumental in disaster risk management. The introduction of the Critical Infrastructure Interdependency Index (CIII) and Risk Index (CIIRI) marked a leap forward, combining Earth Observation (EO) data, catastrophe modeling, and economic analysis to unravel the intricate ties between global economies and infrastructure vulnerability. By identifying the critical gap in disaster risk models—specifically, the absence of economic downtime considerations—this team built upon CIII and CIIRI to create the Global Economic Disruption Index (GEDI). Inspired by a concept made famous by Malcolm Gladwell, GEDI applies the idea of a "tipping point" to resilience and economic robustness.

Valuable partnerships around the globe have contributed to the refinement and proving of the efficacy of GEDI. The project's initial phase included a pilot initiative in Mexico set to demonstrate the viability of a GEDI-based parametric insurance product, refine exposure data, and fine-tune vulnerability assessments. A collaboration with the City of Vadodara, India, also highlighted the practical application of these tools. Integrating GEDI into decision support systems has influenced investment strategies, particularly in real estate and public funds, with an eye toward climate change resilience. Discussions with organizations such as Yokahu Insurance aim to create parametric insurance products that integrate GEDI insights to enhance the scope of disaster-related financial products. Partnerships such as these have validated the project's approach and expanded its reach into diverse applications, such as environmental, social and governance (ESG) reporting and risk assessment in the insurance sector. The framework has also been adopted in community resilience measures, demonstrating its utility and impact.

The GEDI framework embodies a new modeling paradigm, connecting Earth observation, economic, and infrastructure data to produce a graded scale of economic resilience. This scale effectively predicts economic restoration times across a spectrum from hours to years, depending on the severity of the disaster. In doing so, GEDI enables users to estimate the time required for economic recovery post-disaster, a crucial factor that traditional models have persistently overlooked. As the project has advanced, GEDI has proven its ability to accurately predict economic disruption index values, with a kappa value indicating "substantial agreement" with historical events and reflected resilience factors affecting economic recovery in specific events.

Plans for the work include widening GEDI's applicability to more sectors and geographic regions to provide a more comprehensive assessment of economic vulnerabilities and inform better resource allocation before or in response to disasters. The team is now working with the NASA Disasters program and others to envision a "GEDI Direct" framework that could build on expanding a catastrophe modeling framework using EO-based products developed through the NASA Disasters program to extend the benefits of GEDI even further to support communities that existing risk assessment tools have traditionally underserved.

The Global Economic Disruption Index (GEDI) can help communities leaders and decision-makers gauge how much time post-disaster economic recovery may take. This photo shows damage from a 7.8-magnitude earthquake that hit the southeastern part of Türkiye, June 2, 2023. Credit: Eren Bozkurt/AA/picture alliance



Results from the GEDI framework in Türkiye indicated significant economic disruption following the earthquake, which proved accurate. Credit: ImageCat

# Predicting Landslides, Debris Flow and Floods After Earthquakes

**"Coseismic Landslides and Cascading Hazards of the Feb. 6, 2023, Türkiye Earthquake: Preliminary Database Development and Modeling Analysis"**

Principal Investigator:
Erkan İstanbulluoğlu

Co-Investigators: Pukar Amatya/Goddard Space Flight Center and Thomas Stanley/ Goddard Space Flight Center

Powerful earthquakes can often trigger dangerous chains of events that extend far beyond the initial shaking and damage. Changes to geological conditions can lead to landslides, debris flows, and flooding that continue for years following a major earthquake, putting infrastructure and communities at prolonged risk.

When a series of powerful earthquakes struck Türkiye and Syria in Feb. 2023 they destabilized slopes across the region, triggering a devastating series of landslides and debris flows that impacted communities for many months. They damaged towns and villages, disrupted critical infrastructure and transportation paths, and contaminated water sources, causing a widespread humanitarian crisis that continues to impact residents to this day.

Erkan İstanbulluoğlu and his team's project addresses the critical need for improved tools and processes to predict and prepare for these cascading geological events that occur in the aftermath of large earthquakes. To achieve this, they are building Landlab - an open-source community-driven earth surface modeling toolkit to inform rapid risk analysis for landslides and floods. Landlab aims to provide actionable information at local scales, aiding on-the-ground response efforts both at the landslides source and downstream. Landlab incorporates several models that work together to assess landslide risk, including a model that attempts to predict where and when landslides will be triggered based on seismic data, as well as a debris-flow model which is designed to work for large regions.

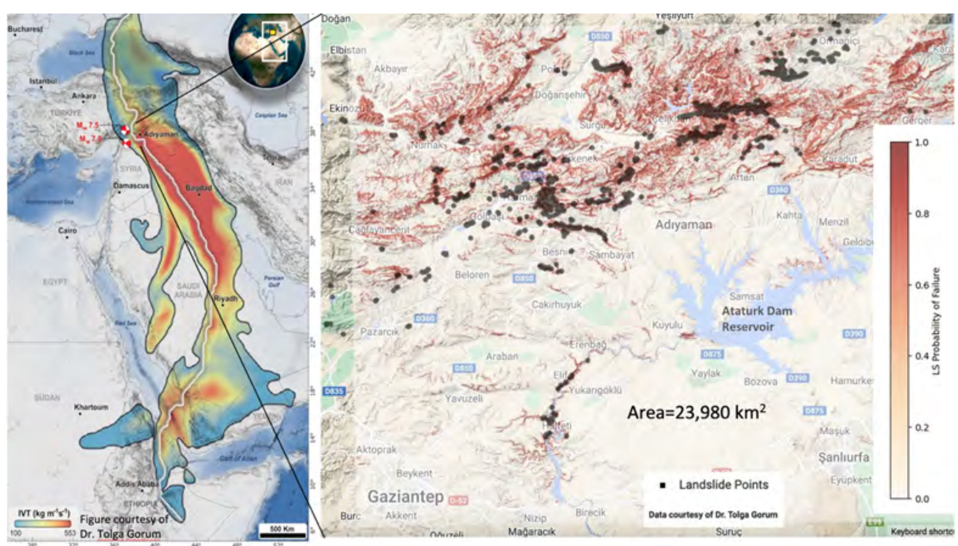
To inform Landlab, the project is studying impacts to Kahramanmarash, Türkiye, a city heavily impacted by the 2023 quakes. They are examining hazards associated with the chain of secondary events stemming from the Feb. 6, 2023, quakes, including debris flows and their influence on flooding.

The project partnered closely with Istanbul Technical University (ITU) who provided geologic and hydrologic expertise. ITU also provided field observations, including a landslide inventory, weather station data, streamflow gauge data from the impacted areas. In addition, they provided detailed rainfall records from local rain gauges which are being used to correct biases in near real-time NASA IMERG satellite precipitation estimates to more accurately inform Landlab's models.

Users can already try out an early version of the Landlab model online by vising the Collaborative Center for Landslides and Ground Failure Geohazards (CICESEG) website. By making the model widely available, İstanbulluoğlu and his team hope to garner feedback and integrate community needs as they continue development. The Landlab team are also working closely with the Disaster and Emergency Management Agency of Türkiye (AFAD), and İstanbulluoğlu plans to travel to Türkiye in 2024 to provide AFAD with training to use Landlab for their own landslide risk analysis.

With Landlab, İstanbulluoğlu and his team are making rapid risk assessment for post-earthquake hazards scalable and accessible. Timely monitoring and prediction of these hazards will allow for more effective disaster management across the world, helping protect communities as they recover from cascading earthquake impacts.

Aerial view of the Hatay Province in Türkiye, on Feb. 19, 2023.
Credits: U.S. State Department/Ron Przysucha




This map shows rainfall estimates for a rare atmospheric river event (left) that struck areas of Türkiye and Syria following the Feb. 6, 2023, earthquakes, and the associated landslide risk (right) calculated by the Landlab soil moisture model.
Credits: Erkan Istanbulluoglu

# Tracking Conflict Displacement Trends from Space

**"Satellite Monitoring of Informal Settlement Dynamics and Displaced Person Mobility in the Complex Humanitarian Crisis of Tigray, Ethiopia"**

**Principle Investigator:**
**Jamon Van Den Hoek**

**Co-Investigators: Michael Puma and Keren Mezuman/Columbia University**

Conflicts and disasters often force people to flee their communities to avoid harm. These people, known as Internally Displaced Persons (IDPs), are often forced to rapidly establish new informal settlements to live in, and these settlements are frequently developed without proper planning and infrastructure. This lack of planning leaves them vulnerable to many humanitarian issues including lack of access to food, clean water, medical services, and other resources to protect them from further hazards.

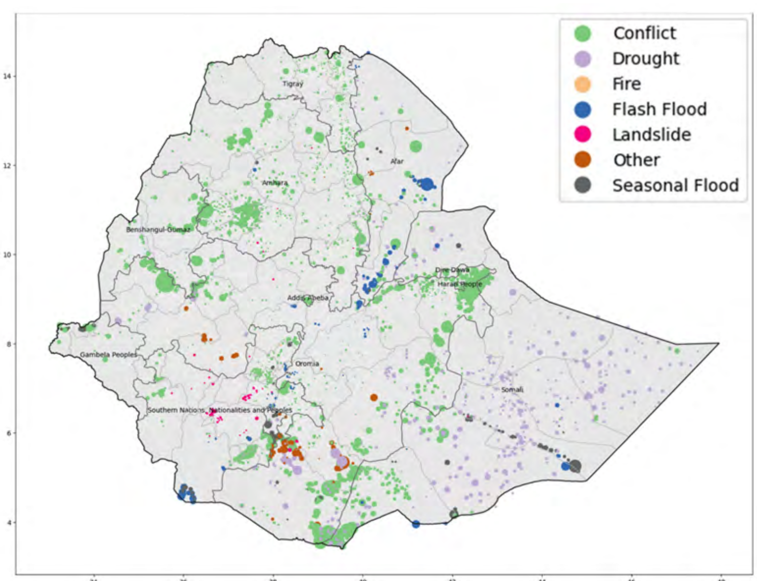
Tracking these new settlements provides relief organizations with information that allows them to aid the displaced people and provide them with humanitarian resources, but doing this quickly and accurately is a major challenge. Traditional ground-based tracking methods are often slow, resource-intensive, and may not be feasible during ongoing conflicts or in the immediate aftermath of disasters.

Jamon Van Den Hoek and his team's project is tackling this challenge by developing new methods to identify and track IDP settlements using Earth observation data, providing critical information that will allow humanitarian organizations to better aid these communities. To develop this Van Den Hoek's project partnered with the United Nations Office of Migration (IOM) and studied displacement and settlement trends in Tigray, Ethiopia, stemming from the Tigray civil conflict that primarily took place from 2020 to 2022. The conflict resulted in over 2.8 million displaced persons, and as of Feb. 2024 the humanitarian situation remains dire.

Van Den Hoek's project developed a new method using synthetic aperture radar (SAR) satellite data to detect informal settlements by comparing changes in the data over time. They also developed a framework to compare this satellite-based data with field-data collected on the ground by the UN IOM Displacement Tracking Matrix team in Ethiopia. The two groups worked closely to develop an understanding of the assumptions, limitations, and value of their data, and how these two tracking approaches could complement and inform each-other.
This work represents one of the first widespread uses of Earth observation data for IDP settlement tracking ever deployed. It forged new connections between space-based and ground-based methods and serves as a critical foundation for developing tools that can efficiently track changes in IDP settlements over large regions and long time periods. While the studies done in Ethiopia were retrospective and required much manual processing, Van Den Hoek and his team aim to one day develop fully-automated processing tools, providing decision-makers with up-to-date settlement tracking information that augments their day-to-day relief planning tasks.

This novel space-based approach also holds the potential to produce unique insights into IDP settlement trends that simply can't be achieved with other methods. Ideally, this work will one day equip humanitarian organizations with tools to deploy life-saving resources more efficiently and effectively in disaster and conflict regions around the world, at scale.

A family in a crowded IDP camp in Shire, Tigray in June 2021. Such displacement camps are often overcrowded, which exacerbates humanitarian challenges. Credits: Yan Boechat/ Voice of America




This map shows the estimated location of internally displaced person (IDP) settlements in Ethiopia from 2015 to 2022. Each site is colored by the main cause of internal displacement and is sized by the maximum population recorded in the Displacement Tracking Matrix database. Credit: Jamon Van Den Hoekt

# Planning for Unseen Future Disasters

**Principal Investigator:**
**Erin Coughlan de Perez**

Co-investigators: Amy Myers Jaffe/NYU and Nirajan Dhakal/Spelman College

## "Today's Risk of Extreme Events"

Disaster management organizations typically look to historical disaster records to help plan and prepare for future disasters. But these records are limited, covering only a small subset of the potential disaster impacts that could occur. When disaster policies and preparation only account for what we already know, the unknown and unexpected can throw plans into disarray, worsening impacts and lengthening recovery time for affected communities. With climate change making extreme events more frequent and intense, the likelihood of unexpected disasters is increasing yearly. Looking only to past disasters to prepare for the future is like driving while staring in the rearview mirror—but how can communities prepare for disasters they've never encountered before?

Erin Coughlan de Perez and her team are partnering with the American Red Cross to address this challenge. Together they are developing a typology to better classify and describe the potential for unexpected disasters and identify high-risk regions that may require updates to their current disaster management plans. They are working to share these findings with communities across the U.S., helping them identify ways to become better prepared.

The team initially focused on five case-study locations across the Southeastern U.S., using a large-ensemble weather model called UNSEEN (Unprecedented Simulated Extreme Ensemble) to examine the changing frequency of extreme events over the past several decades. This research showed that the frequency of extreme temperature and precipitation events have been increasing over time and will likely happen even more frequently in the future. It also showed that events we currently consider extreme – for example, recent "extreme" heatwaves in the Southeast U.S. – are actually not extreme outliers in the context of our current climate. Thus, many communities need to prepare for much worse conditions.

Using this information, the team developed two categories to describe the case study areas, which can be used to classify other potential areas of interest. The first, "High potential for surprise," describes areas with a large increase in frequency of extreme events over time, but where extreme events have historically been infrequent, meaning these area areas are likely unprepared. The second category, "Historical analogues" describes areas that have historically experienced many extreme events. Communities can study these historical analogue areas to better understand how to increase their own disaster preparedness.

The team shared these results with stakeholders from California, Kentucky, and Mississippi in a series of workshops that explored plausible-yet-unseen disasters and how organizations in those regions can better prepare for them. The workshops explored both the physical aspects of the disasters as well as the vulnerability and exposure of the regions they took place in, providing valuable information to increase their disaster readiness.
Attendees reported many key takeaways that can help strengthen their communities, including the need for better integration of county and local disaster management plans, increased cooperation between agencies, and a need for increased shelter facilities. The workshop also showed the need for further studies on topics such as extreme heat vulnerability, access to clean water resources, and ways to make disaster shelters more helpful for victims.

Thanks to these workshops and research, these organizations are now better equipped to mitigate the unknown disasters of the future and protect their communities from extreme events. Coughlan de Perez and her team hope to expand this research by working with new communities and developing a national-scale approach to identifying high-risk areas.

*"The discussions regarding the risk of extreme weather and disasters has revamped the minds of our partners in Yazoo County, Mississippi. How we view natural disasters and preparedness must change to really address the climate crisis of today."*

— Dr. April M. Jones, Risk Reduction Manager of American National Red Cross Community Adaptation Program, Yazoo County, Mississippi

Stakeholders from Yazoo County Mississippi attending a stakeholder workshop on unseen disasters on Aug. 10, 2023. Credit: Erin Coughlan de Perez

"I'd like to thank each of the Principle Investigators and their teams for their hard work in bringing the benefits of Earth science to reducing global disaster risk. Your projects have made an immeasurable impact across many communities around the world."

**— Shanna N. McClain, Ph.D., NASA Disasters Program Manager**

Above: Members of the NASA Disasters Program stand together with many of the principal investigators from the NASA Disasters Science to Action Projects at the NASA Disasters Program strategic planning retreat in Nov. 2022. Credit: NASA

# DISASTERS
# RESPONSE AND COORDINATION

The NASA Disasters Program aids response during active disasters, working closely with organizations around the world to equip them with NASA science and technology for improved decision-making. 2023 once again saw the program excelling at this goal, activating for 13 disasters across a wide range of hazards and cascading impacts, and working with diverse partners in the U.S. and **abroad.**

Burned out cars and the remains of buildings are seen in Lahaina town in Maui, Hawaii on Aug. 9, 2023 after wildfires tore through the area.
Credits: U.S. Civil Air Patrol

# Disasters Response and Coordination
## Partner-driven Response

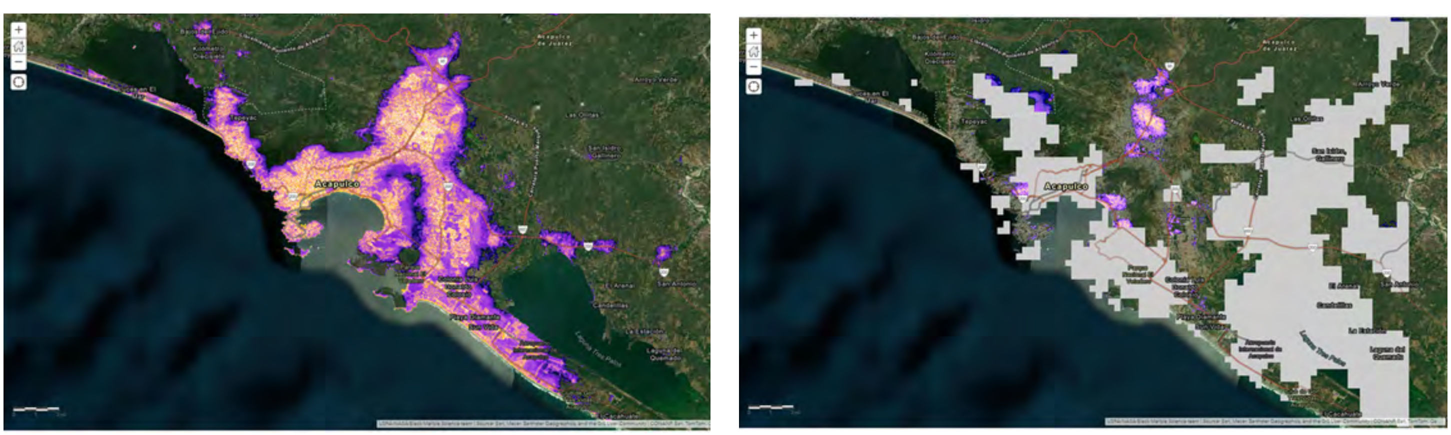
Our success in disaster response is only as strong as the relationships that we build with our partners and stakeholders. The Disasters Program takes a partner-driven approach that benefits both the organizations we work with and our program, forming synergistic relationships in which we learn them and them from us. Participating in working group meetings, conferences, and interagency calls is key to building and strengthening these partnerships, and has led to many fruitful connections with federal, state, and  local agencies.

Flooding in Montpelier, Vermont, July 11, 2023
Credits: U.S. Army National Guard/Sgt. Denis Nunez

For example, the Louisiana Hurricane Season Geospatial Data Mining Workshop, which Disasters team members have participated in the past four years, led to a strong relationship with researchers at the University of Louisiana at Lafayette (ULL). This proved invaluable during the April 2023 Vermont floods, where our connections at ULL put us in touch with colleagues at the University of Vermont who were providing GIS support for Vermont Emergency Management. This allowed us to provide maps and data that aided their understanding of the event.

In 2023 a FEMA-led working group meeting provided key awareness that allowed us to rapidly assist with the tornadoes that struck the southeast U.S. in March 2023. We also worked with FEMA to support response for Hurricane Idalia, which brought widespread flooding and power outages to Florida in Aug. and Sept. 2023. The NASA Disasters team shared near real-time Black Marble blue/yellow composite data to help identify regions that may have lost power in the storm's wake. After the event, the Disasters team shared feedback from FEMA with the Black Marble team at NASA's Goddard Space Flight Center, resulting in improvements that included daily updates and a cloud mask layer to help users differentiate between clouded areas and areas that may be lacking nighttime lights.

These improvements proved useful several months later during Hurricane Otis, which brought flooding and destruction to Acapulco Mexico. The Disasters team shared this updated Black Marble data with stakeholders from Mexico's Centro Nacional de Prevención de Desastres (CENAPRED) and Laboratorio Nacional de Observación de la Tierra (LANOT), who said the daily updates were extremely helpful in supporting their on-the-ground efforts.




Black Marble HD imagery of Acapulco, Mexico showing nighttime lights before (left, Oct. 13, 2024) and after (right, Oct. 29, 2024) Hurricane Otis made landfall on Oct. 25, 2024.
The gray areas in the second image are cloud masks where the data may not be available due to likely cloud cover. Credits: NASA

# Disasters Response and Coordination

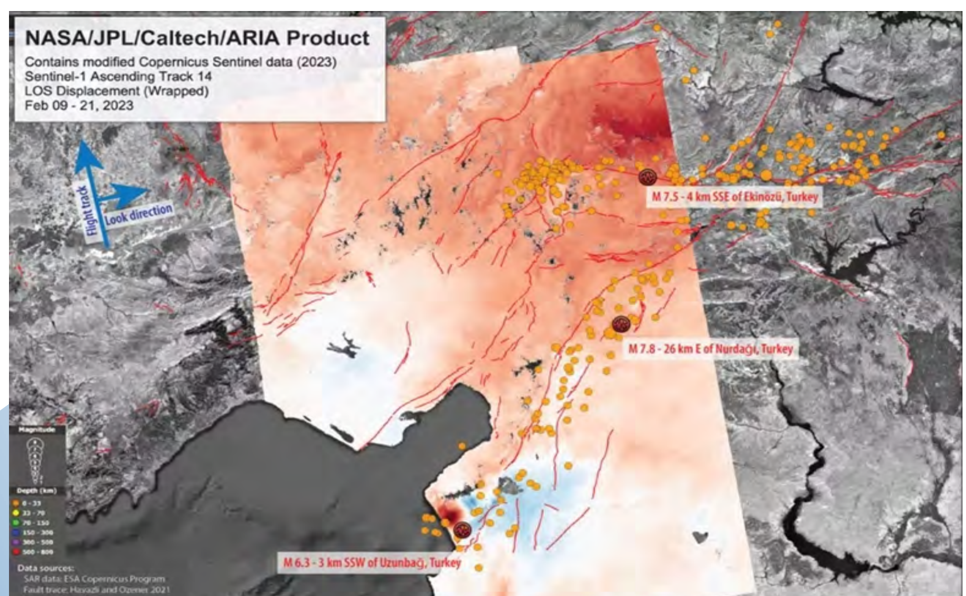
## Partner-driven Response (continued)

From local to regional scales, from academia to government, from U.S. to international agencies, the NASA Disasters program builds bridges that quickly provide critical information to aid decision-makers when disaster strikes.  Nowhere was this more evident than in our response efforts for the powerful series of earthquakes that impacted Türkiye and Syria in Feb. 2023. The vast destruction caused by these quakes and their cascading impacts marshalled a global community of disaster management organizations to confront the many challenges the afflicted the people living in the region.

To aid these stakeholders, the Disasters Program shared displacement maps using synthetic aperture radar data from ESA Copernicus Sentinel and JAXA ALOS-2 satellites, which the USGS used in their analysis of the geological conditions leading to the earthquakes and assessing risk of further aftershocks in the regions. The Disasters team also shared damage proxy maps with the California Seismic Safety Commission and Miyamoto Global Disasters Relief (a non-profit engineering firm). These maps showed the likely locations of damaged buildings and infrastructure, which aided the World Bank and the Turkish government's relief efforts on the ground.

Esri, who has worked closely with NASA for nearly a decade in building our Disasters Mapping Portal, was instrumental in sharing many of our products for Türkiye on their own disaster response data portal. This brought NASA products to a broader audience, expanding their reach and utility.

Search and rescue teams in Türkiye following the devastating Feb. 6 earthquake.
Credits: USAID




This unwrapped displacement map depicts changes to Earth's surface from the Feb. 20 earthquake. Blue areas show land movement away from the satellite, while red areas depict land movement toward the satellite. The epicenters of the three major earthquakes are shown by red icons, while the numerous aftershocks are shown in yellow. Credits: NASA's Jet Propulsion Laboratory. Copyright contains modified Copernicus Sentinel data (2023) processed by the ESA.

Connections from our funded projects have also led to effective response partnerships. Our close working relationship with the Pacific Disaster Center deploying NASA flood and landslide hazard models allowed us to effectively support them when their hometown of Maui, Hawaii was unexpectedly struck by devastating wildfires in Aug. 2023.

World Central Kitchen (WCK) was another key collaborator with whom we strengthened our relationship in 2023. We worked closely with WCK for several responses throughout the year, including wildfires in Maui and Greece, Hurricane Otis in Mexico, and the devastating earthquakes that struck Türkiye and Syria in Feb. 2023. In Nov. 2023 WCK invited our team to their warehouse in Maryland, providing a tour of their warehouse and sharing key details of their operation methods as well as the types of data that could most effectively aid their efforts.

"Over the years, NASA's Disasters program has provided invaluable support to World Central Kitchen, offering crucial situational awareness to assist our ground teams during natural disasters. Our recent meeting with NASA further strengthened the relationship between our organizations and deepened our understanding of NASA's capabilities in supporting our humanitarian efforts.

**— Adina Anton, World Central Kitchen Data Sr. Manager**

One of the deadliest U.S. wildfires in more than a century ravaged Lahaina, Maui, Hawaii in Aug. 2023. The Disasters Program coordinated across NASA centers to develop maps and data and provide scientific expertise to support response and recovery efforts with stakeholders including FEMA, World Central Kitchen, the Pacific Disaster Center and others.
Credits: U.S. Coast Guard

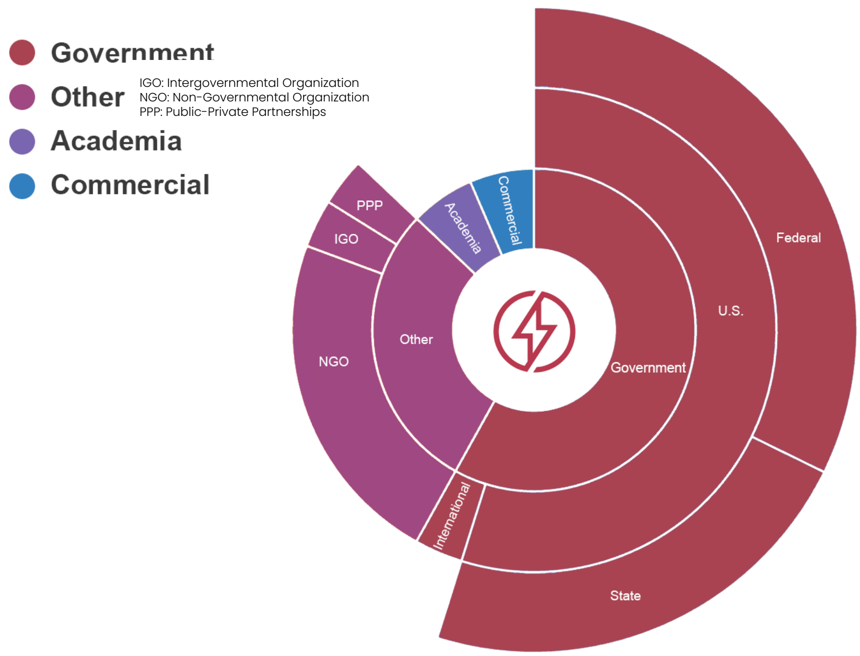
NASA Disasters Associate Program Manager Robert Emberson (left), NASA GSFC Center Disaster Coordinator Rachel Soobitsky (center), and NASA GSFC Director of Earth Science Dr. Dalia Kirschbaum (right), stand behind a large mobile paella pan at a World Central Kitchen warehouse in Maryland. Credit: NASA / Rachel Soobitsky

# 2023 Disaster Response Activations

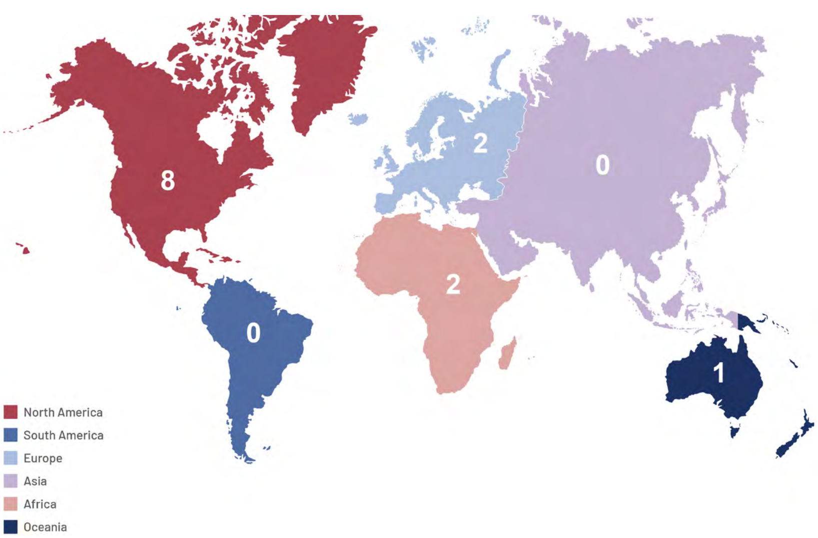
by the numbers

**13** Disaster Response Activations in 2023

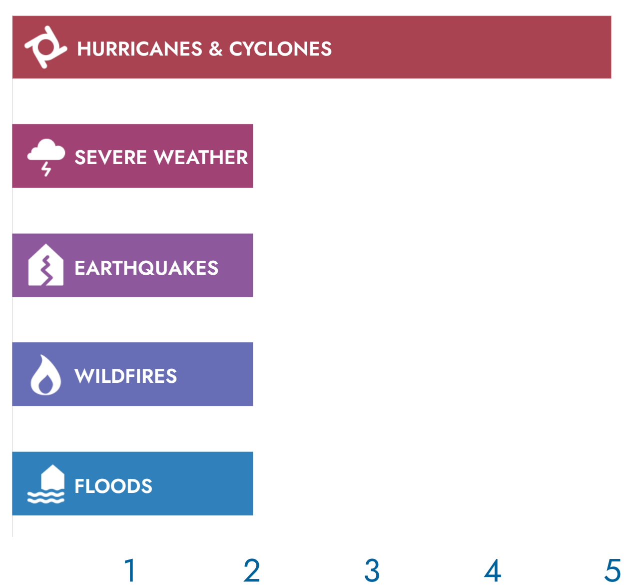
## Partners




## Regions




## Hazards




## 2023 Disaster Events Activations

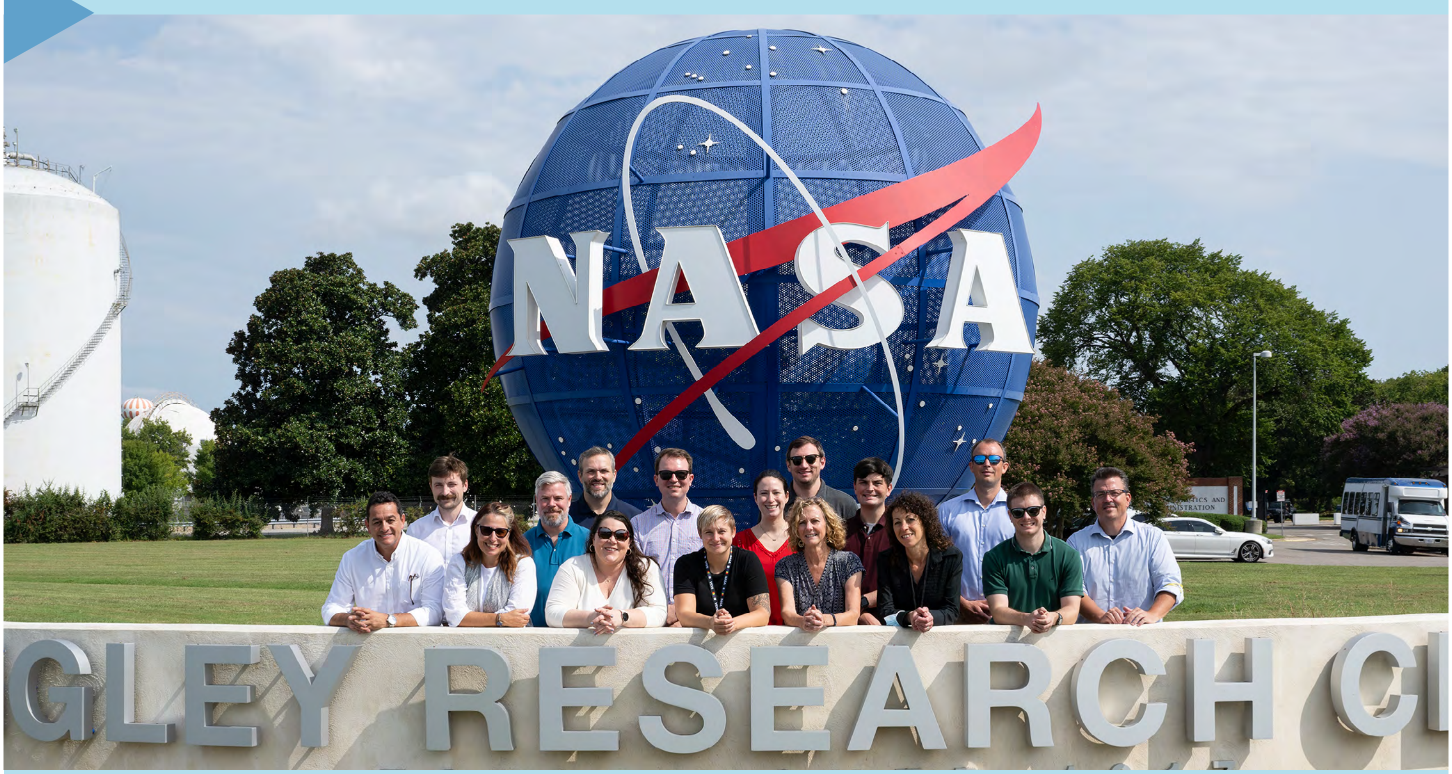
- California Atmospheric River
- Türkiye Earthquakes
- Cyclone Freddy
- Super Typhoon Mawar
- Vermont Flooding
- North Carolina Tornado
- Greece Wildfires
- Hawai'i Wildfires
- Hurricane Hilary
- Hurricane Idalia
- Morocco Earthquake
- Hurricane Otis
- Flooding in New England

Top left - Wildfire as seen from Ilion, Greece, July 18, 2023.
Credit: Sthivaios under CC BY-SA 4.0
Top right - Hurricane Idalia as seen from the International Space Station Aug. 30, 2023.
Credit: NASA/Expedition 69 crew.
Middle left - A sunken vessel at a harbor in Guam following Typhoon Mawar.
Credit: U.S. Coast Guard
Middle right - An aerial view of extensive wildfire damage, in Maui, Hawaii, Aug. 2023.
Credit: Hawai'i Department of Land and Natural Resources
Bottom left - Earthquake impact in DTaroudant Province, Morocco. Sept. 2023.
Credit: alyaoum24 under CC BY-SA 4.0
Bottom right - Damage in Puerto Marqués Guerrero, Mexico in the aftermath of Hurricane Otis, Nov. 4, 2023.
Credit: ProtoplasmaKid under CC BY-SA 4

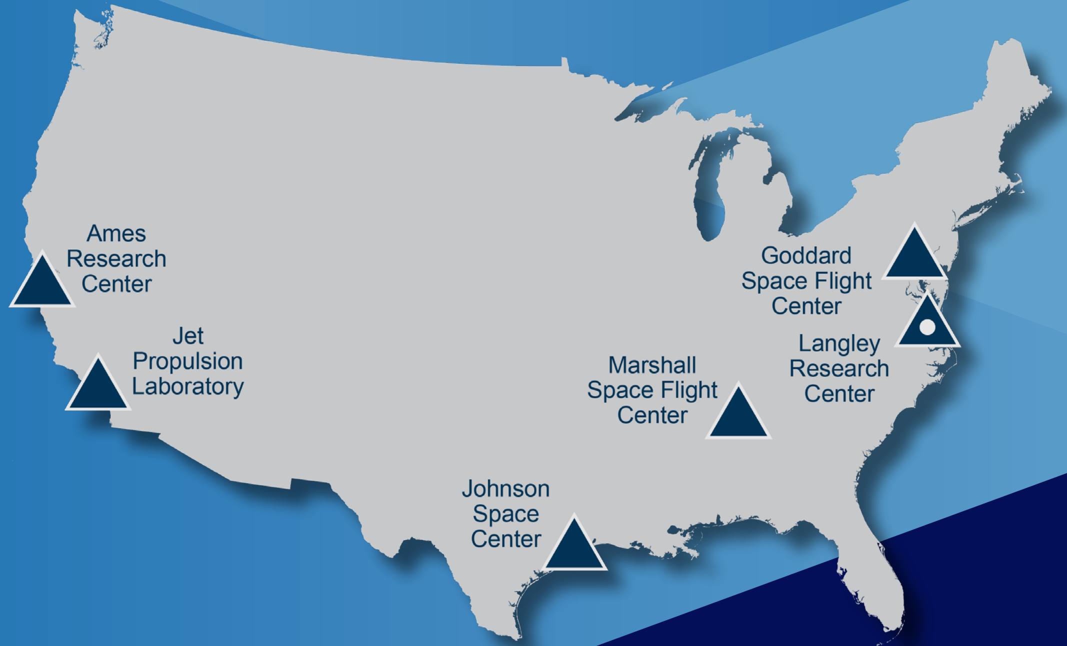
# Disasters Response and Coordination
## Building the Disasters Response Coordination System

In 2023 the program also made significant strides towards launching the Disasters Response Coordination System (DRCS), which employs a one-NASA approach to bring Earth science and data to aid organizations actively responding to disasters.

In preparation for the June 2024 launch of the DRCS, the Disasters Program hosted a DRCS Team-building and Scenario Exercise at NASA's Langley Research Center that brought together the Disasters Program and DRCS teams for three consecutive days of intensive process development training, scenario exercises, and program strategizing. The Tatham  Company, led by Michael Tatham, supported the event with training to enhance organizational efficiency and team cohesion. During the workshop, the team simulated activating for two theoretical disaster response scenarios. These exercises clarified and reinforced roles and responsibilities within the DRCS playbook and helped to identify areas of improvement and new methods of collaboration. With these planning and team-building activities, the program laid a strong foundation for the launch of the DRCS in 2024.




*NASA Disasters team members stand in front of the NASA "meatball" at the DRCS Team-building and Scenario Exercise in Sept. 2023. Credits: NASA*




The Disasters Response Coordination System's structure includes a central project office at NASA's Langley Research Center and Center Response Coordinators across six NASA centers, ensuring robust representation and use of NASA's collective capabilities.

Learn more at:
[https://disasters.nasa.gov/response](https://disasters.nasa.gov/response)

*Disasters Program staff working together during a simulated disaster response exercise at the DRCS Team-building and Scenario Exercise in Sept. 2023. Credits: NASA*

DISASTERS

# PARTNERSHIP AND LEARNING AGENDA

In 2023, we continued to actively engage with organizations around the world through working groups, science meetings, and industry events, building a strong community of disaster practitioners that can share knowledge and help identify common challenges and opportunities for growth. We developed resources that build capacity to using Earth science data for disaster management and leveraged our network to spread awareness of these resources and their potential for positive impact.

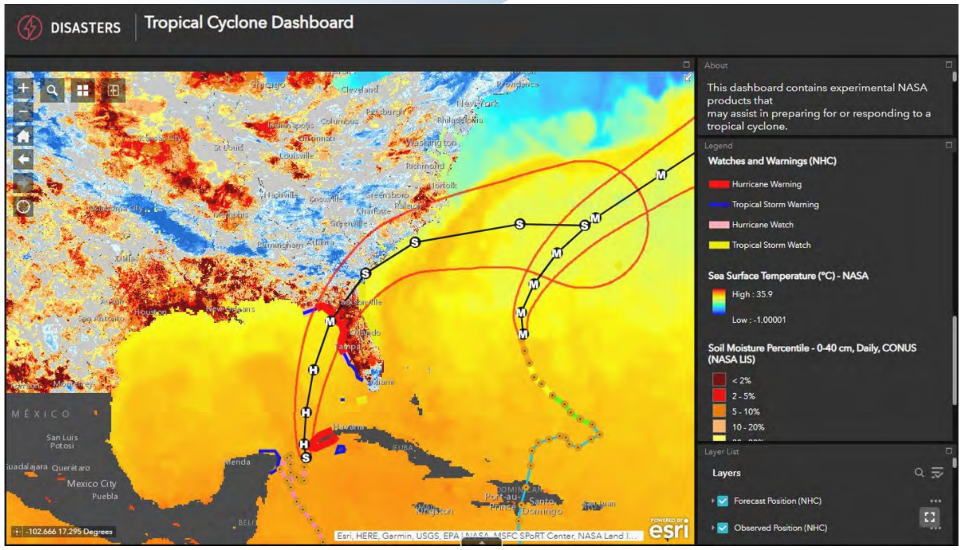
# The NASA Disasters Geospatial Portal

Our geospatial portal is a critical component of our engagement with disaster management organizations and communities impacted by disasters, serving as our primary tool for sharing maps and data directly with decision-makers. The portal is free and openly accessible to all, with data available in standardized geographic-information systems (GIS) format, making it easy to integrate into team's existing decision-support tools and workflows. In support of our program's 13 responses in 2023, the portal hosted 61 image services and 2035 images, in addition to the broad selection of near real-time datasets that are available at any time. The portal also hosts products developed by our applications projects, with 11 project-related services and 150 images shared in 2023. Our program's capacity to provide high-resolution Planet Labs imagery through the Commercial Smallsat Data Acquisition Program was also of great value to our partners in 2023, with the portal hosting 932 of these images this year.

The Disasters Program is working to fully redesign our geospatial portal from the ground-up, using the principles of human-centered design and engaging directly with our community to build a tool custom-suited to their specific needs.

A key step towards this was our first ever Stakeholders Needs Workshop which took place over two days in Aug. 2023 at the Center for Strategic and International Studies in Washington D.C. The event brought together a diverse range of stakeholders from around the world, including representatives from the U.S. State Department, the World Bank, the U.S. Geological Survey, and the Rosebud Sioux Tribe, among many others. Over two days, attendees shared their individual workflows, needs, and pain points, providing our program with a more comprehensive understanding of how different organizations process and use information through all stages of the disaster lifecycle.

The program plans to continue engaging with this stakeholder community as development continues, with a second workshop to share portal progress and gain further feedback tentatively scheduled for 2024.




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

## 2023 Portal by the Numbers

- **13** Responses Supported
- **61** Image Services
- **2035** Images
- **11** Applications Project Image Services
- **150** Applications Project Images
- **932** Planet images

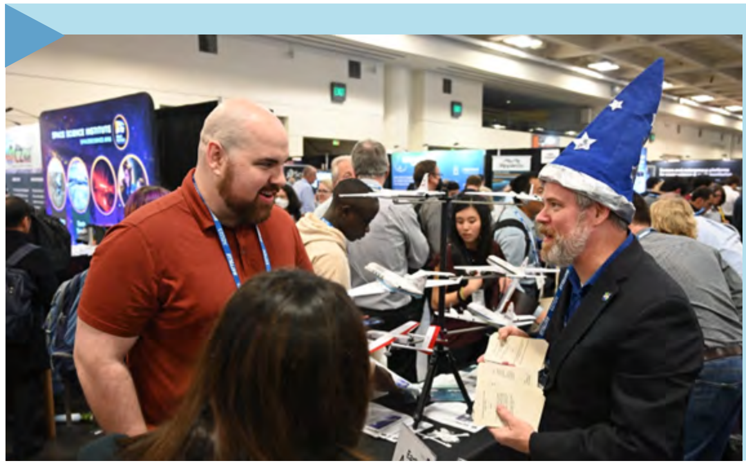
# Collaboration and Community Building

In 2023 Disasters program staff participated in multiple workshops, science meetings, and other events around the world, connecting directly with scientists and disaster management professionals to spread awareness of our program and contribute to the advancement of global initiatives for disaster risk reduction.

A key engagement was the Technology for Disaster Risk Reduction or "Tech4DRR" Workshop in Oct. 2023, co-convened by the United Nations Office for Disaster Risk Reduction – Regional Office for the Americas and the Caribbean and NASA, among others. The workshop brought together an international group of experts to draft guidelines for responsible technology use, exploring themes including technology for early warning, bridging the gap between early warning and early action, and ensuring inclusivity in disaster management efforts. These guidelines will contribute to a 2024 UNDRR special report on technology for disaster risk reduction, in support of the UN Sendai Framework's goals to reduce disaster risk and losses in the 21st century.

The Tech4DRR workshop was just one of many Disasters program engagements with stakeholders in the Americas and the Caribbean in 2023. Another key event that NASA's Disasters program supported was the 3rd Regional Simulation of Disaster Response and Humanitarian Assistance in Panama City, Panama, which brought together public and private sector stakeholders from across the region to simulate multiple cascading disaster scenarios and test the readiness of regional and national disaster response strategies and protocols. The NASA Disasters program also hosted a workshop during AmeriGEO Week 2023 on the use and development of our geospatial disaster capabilities.

NASA Disasters Program staff joined stakeholders from the private and public sector, government, academia, the non-profit community and more at the Tech-4DRR regional workshop held in collaboration with the United Nations Office for Disaster Risk Reduction's (UNDRR) Regional Office for the Americas and the Caribbean at Belmont University, Nashville, Tenn., Oct. 2023 Credits: NASA/Seph Allen

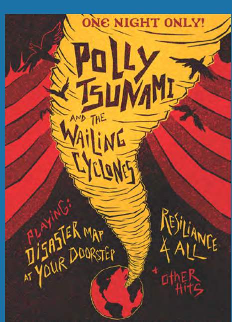


NASA Disasters Program's Seph Allen engaging visitors with the "Mythed It by That Much" trivia game at the AGU23 Fall Meeting. Credits: NASA/ Jacob Reed

NASA Disasters Program Digital Outreach Lead Jacob Reed shared key takeaways from a breakout session during the 2023 NASA Disasters Program Stakeholder Needs Workshop. Credits: NASA

The 2023 American Geophysical Union Fall Meeting (AGU 23), one of the largest Earth science conferences in the world, was well attended by NASA Disasters program scientists, Center Response Coordinators, and core team members. The team participated in oral and poster sessions, and supported a table at the NASA Science Mission Directorate exhibit hall booth.

AGU 23 also served as the in-person debut of NASA Earth Action's newest cooperative agreement, NASA Lifelines, a six-year initiative to build bridges between Earth science and humanitarian communities. Dr. Shanna McClain, NASA Disasters Program Manager, and Rhiannan Price, NASA Lifelines PI, gave a joint talk on the NASA Hyperwall where they introduced Lifelines and discussed how they the two programs are working together to help build a future without disasters. By developing a robust community through a series of networking events, mentorship and funding opportunities, and creative outreach campaigns, NASA Lifelines aims to increase the use of Earth science and technology to solve some of the most pressing humanitarian challenges around the world.



Three rock-band style Disasters Program posters served as prizes for the "Mythed it By That Much" educational disasters trivia game that the Disasters team debuted at AGU 23. Credits: NASA


NASA Lifelines Principal Investigator Rhiannan Price presenting on the NASA Hyperwall at the AGU 2023 Fall Meeting. Credits: NASA/Seph Allen

**LIFELINES**

NASA Lifelines is building a diverse community to advance the use of Earth science for humanitarian decision-making.

Visit nasalifelines.org to get involved.

## Sign up for our NASA Disasters Community Email Newsletter!

The NASA Disasters Community Newsletter connects us with a growing network of subscribers across diverse sectors and organizations. Through the newsletter we share success stories of putting Earth science into action for disaster risk reduction, introduce readers to the people behind the science, and share innovative tools and resources for disaster management.

# LOOKING AHEAD

Noctilucent clouds in the northern hemisphere as seen from the International Space Station as it passed over cental Asia, July 27, 2003.
Credits: NASA/Ed Lu

What you've read on these pages is not just the story of our program; it's the story of our partners and the communities who work with us to protect the people and places they love.

Our focus on the human dimensions of disasters is leading to new paths for placing science, tools, and user know-how into the hands of those who protect lives and livelihoods in vulnerable communities. Our continued collaboration with local governments and response teams continues to deepen connections, foster mutual understanding, and increase user awareness of NASA's contributions to Earth science and how people everywhere can apply those resources to reduce and mitigate disaster impacts. This collaborative approach helps scale the impact of NASA's efforts and equips communities with the information and capability to make informed decisions and build resilience against disasters.

There is much to anticipate in the coming year. Our new Disasters Response Coordination System will expand our capabilities during active disasters, bringing NASA science, technology, and expertise to even more organizations around the world. We will continue efforts working with our stakeholders to build a modern, human-centered, geospatial portal that will serve as a key platform for public disaster understanding and multi-directional information exchange. And we will announce our new ROSES A.42 solicitation for innovative Disasters Science to Actions projects that address critical elements of hazard, exposure, and vulnerability, with a clear connection between scientific data and community safety and sustainability improvements.

We look forward to 2024 with a keen sense of purpose, delivering solutions that empower communities to make informed decisions and build a more resilient future.


Members of the NASA Disasters Program stand alongside representatives from key stakeholder organizations at the 2023 NASA Disasters Program Stakeholder Needs Workshop. Credits: NASA disasters.nasa.gov