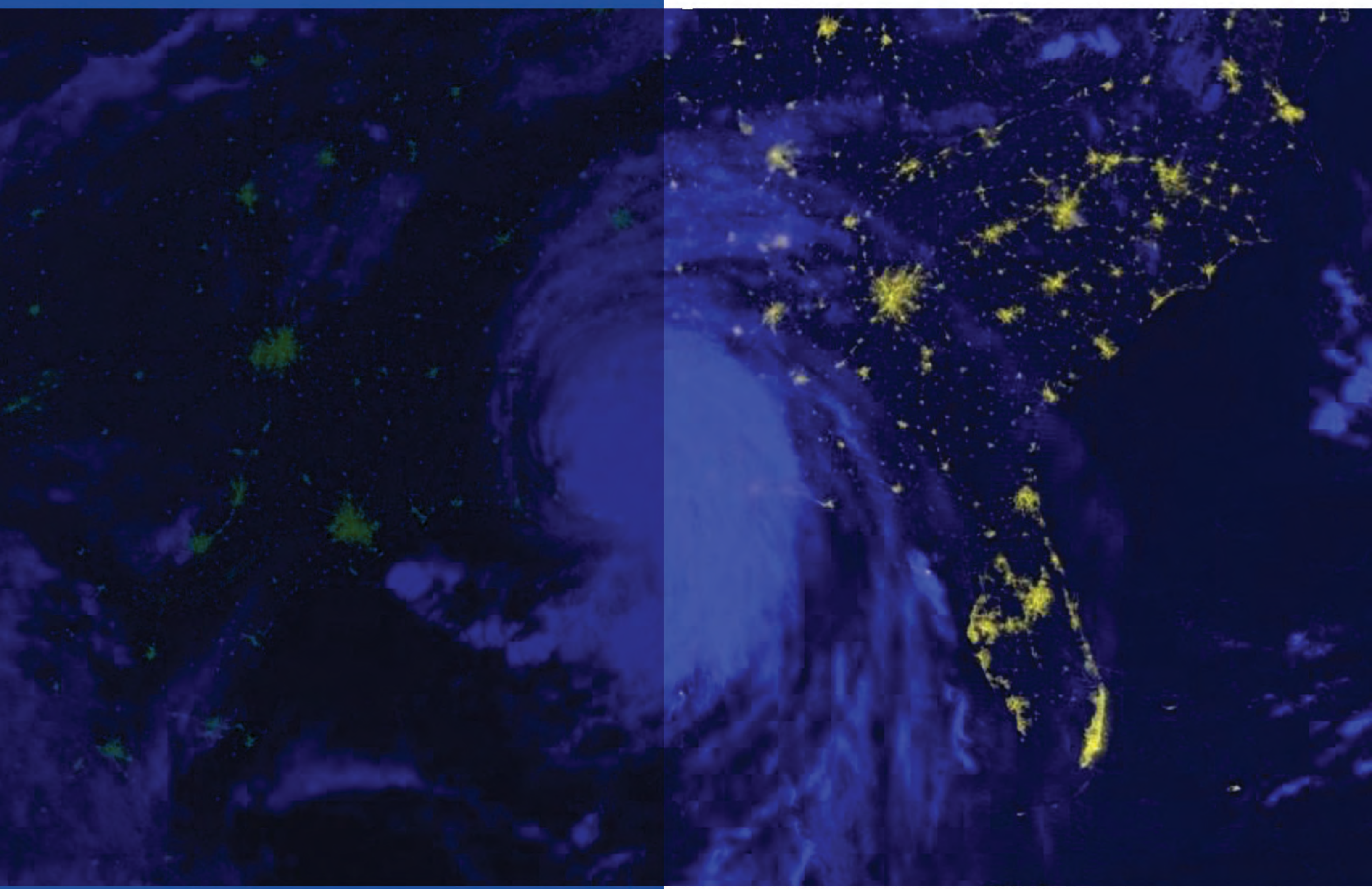
EARTH SCIENCE
APPLIED SCIENCES
DISASTERS

2021 Annual Summary



DISASTERS

2021 Annual Summary

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Cover Image: Day/night-band imagery of Hurricane Ida approaching the United States Gulf Coast was captured by the VIIRS instrument onboard the NASA/NOAA Suomi-NPP satellite early the morning of Aug. 30, 2021. Day/night-band imagery is useful for identifying nighttime lights from cities and can be used to monitor for loss of light which may indicate power outages in the wake of a disaster. Credits: NASA

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I. Introduction

Earth science data and knowledge can help guide intelligent decisions at all levels of society. Good information shared with trust informs choice and supports good decisions, and good decisions guide actions that reduce risk. Hazardous natural events such as hurricanes, earthquakes, wildfires, tsunamis, and droughts, certainly require knowledge of geophysics, physical geography, or climatology to comprehend, but whether a natural event becomes a disaster ultimately depends on its location and its impact on humans. As the intensity and frequency of natural hazards continue to increase, vulnerabilities and exposures grow, putting communities and economies at risk.

In 2021, the Disasters program area of NASA's Earth Science Applied Sciences Program fostered the development, access, and translation of the best available Earth system science into applications that equip users to help avert suffering when natural hazards threaten to become disasters. In this summary, you'll see examples of NASA Disasters-sponsored application science. You'll read how we are advancing the creation and distribution of rapid and accurate information and collaborating to learn and share information that improves disaster management practices, advances damage reduction, and builds resilience. By providing information and tools to increase understanding, we help the world address systemic disaster risk and increase sustainable resilience throughout the disaster management cycle.

This report illustrates numerous examples of how the Disasters program area actively developed connections, nurtured relationships, and collaborated with organizations to engage global, regional, and local disaster management leaders. We ensure NASA's research, expertise, and Earth observation (EO) data provide the most value and positive impact through these efforts.

Disaster Response

The response team within the NASA Disasters program area is tasked with engaging any person or group across the entire NASA community who may contribute disaster-relevant information or data. These efforts contribute to science awareness and understanding that ultimately translates to improved decision-making before, during and after disasters occur.

43 Disasters Supported

32 International

11 Domestic

In 2021, NASA Disasters coordinated 11 domestic and 32 international activations for a total of 43 disasters supported. Asia was the most common part of the world for disaster activations, with 14 events supported in that region throughout the year. North America was not far behind with 11 activations in 2021. Tropical cyclones/hurricanes and volcanoes were the most common hazard type supported, each accounting for nine of the 43 activations. We also activated for eight flooding, five fire, and four earthquake events in 2021.

This summary highlights our response team's participation in events such as California's BurnEx21 Fire Exercise, which demonstrate our efforts to explore, experiment, and strategically target support to ready our applications for more significant impact. We also provide a glimpse into our support for disaster events, such as the La Soufrière Volcano, that reveal the complexities of the program's work and the value we provide to engaged stakeholders. We illustrate how collaborations and lessons learned from an event response, such as Hurricane Ida, can lead to opportunities to deliver enhanced value to stakeholders and decision-makers during disasters of other types and in other locations, such as the California Oil Spill.

We also outline how NASA Disasters' efforts provided increased situational awareness for key domestic and international partners. In 2021 the Disasters program area provided 1,497 total data products on the NASA Disasters Mapping Portal and produced or contributed to over 300 stories, publications, and subject matter expert interviews. NASA Disasters also supported four rapid response projects, 20 research augmentations, three international Mapathons, and a dozen internships.

1,497	**Disasters Mapping Portal Data Products**
+ 300	**Outreach Publications/SME Interviews**
20	**Research Augmentations**
3	**International Mapathons**
12	**Internships**

Disaster Research

A portfolio of diverse disaster research projects is at the program area's core. These projects include 10 NASA Research Opportunities in Space and Earth Science (ROSES) Disasters A.37 Disaster Response and Risk Reduction projects and six Group on Earth Observations (GEO) Work Programme Projects. Despite the ongoing global pandemic, these projects made substantial progress in advancing Application Readiness Levels (ARL). A.37 projects supported by NASA Disasters currently average an ARL over 6, having been demonstrated in relevant environments. The majority of our Disaster's research projects are currently at ARL 7 or higher, fully integrated into an end-user's operational environment and used for decision-making activities. Section IV of this report provides additional information about that research.

Communications

In a world where science and the public have become so separated that many people consider science just another opinion, the skills to translate and share the goals, the nuances, and the results of research is not a "bonus," it is core to the advancement of science itself. To that end, we are proud to spotlight some of the successful communications initiatives achieved in 2021 to make disasters applied science and Earth-observing resources available and accessible to as broad an audience as possible. These include publication and distribution of new quarterly Disasters Community newsletters, improvements to the Disasters program area website, collaborations with programs across NASA and our Science Writer internship program.

Looking Forward

In late 2021, NASA Disasters began undergoing a series of leadership transformations as one Associate Program Manager, Michael Goodman retired, and another, John Murray moved to other responsibilities at NASA. At the time of publication of this report, the previous Disasters Program Manager, David Green is assuming duties in a different program area of Applied Sciences. It would be remiss not to note the significant contributions each of these leaders have made to the Disasters program area over the years, and we thank them for the foundation of excellence they have helped create.

With these and other personnel shifts in research and technical areas of the program, we must be mindful of ways to safeguard the continuity of knowledge within the program area workforce to benefit from previous lessons learned. We understand that ongoing COVID-19 pandemic and the inherent high stress of working with major disasters every day add risks of workforce burnout.

That said, we are proud to see our 2021 efforts make a difference around the globe, and we remain enthusiastic about the program area's future vision and potential. At local, regional, national and international levels, stakeholders look to our team as leaders. We look forward to connecting them with the technologies, resources, relationships, and scientific expertise that ultimately enables our world to become safer, more resilient, and sustainable.

A television news crew in Mayfield. Kentucky, prepares to report on a series of tornadoes that tore across several U.S. states Dec. 10–11, 2021. The event was one of 43 disasters supported by NASA Disasters program area in 2021. Credits: Seph Allen/NASA Disasters

II. Disaster Response

The response portion of the Disasters program area functions in a unique way within the Applied Sciences Program, as well as across the greater NASA community. The team is comprised of program management and support, emergency managers, and Geographic Information System (GIS) specialists, as well as disaster coordinators located at six NASA centers across the United States. The role of each coordinator includes engagement with any person or group at their respective centers who may be able to contribute disaster-relevant information or data. Bringing these relationships and bodies of knowledge together across NASA centers promotes and strengthens the program's effectiveness and reach, allowing the team to provide end-users with improved situational awareness before, during, and after disasters.

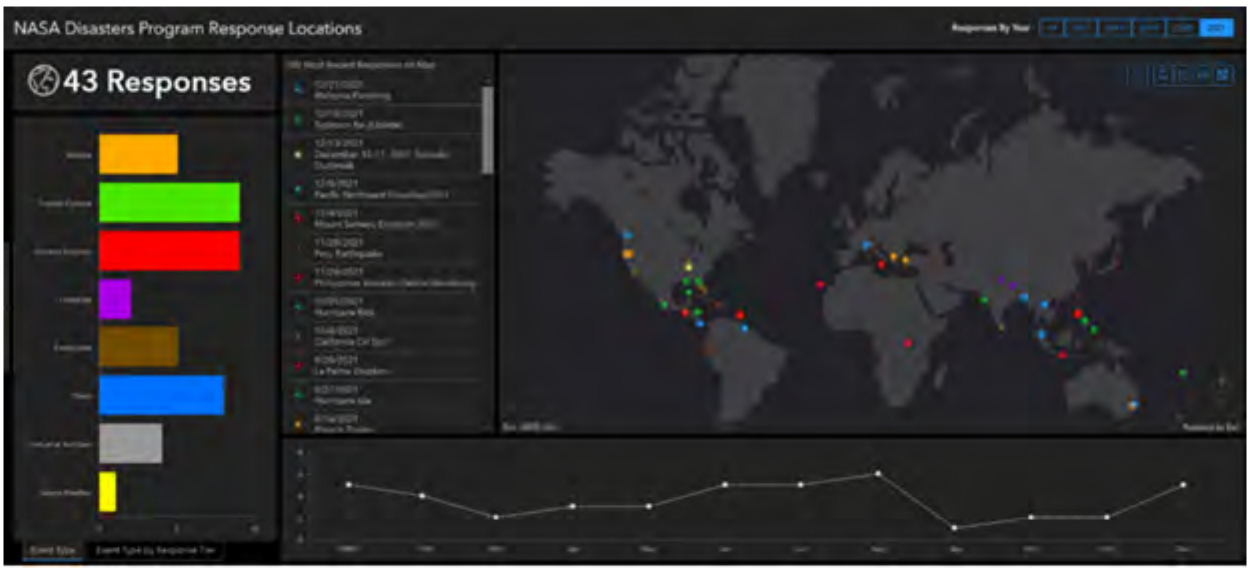


***Figure 1**. In 2021, there were 43 separate responses, covering 10 unique hazard types in eight different regions of the world.*

The Disasters program area coordinated 43 activations in 2021. These included 10 unique hazard categories that developed into disasters. Tropical Cyclones/Hurricanes and volcanoes were most common, each accounting for nine of the 43 activations. There were eight flooding, five fire, and four earthquake events. Visit the Disasters program areas website (https://appliedsciences.nasa.gov/what-we-do/disasters) and the NASA Disasters Mapping Portal (https://disasters-nasa.hub.arcgis.com) to find more details and information regarding data provided to end-users. The total number of events supported in 2021 is slightly less than in some years past. Nonetheless, many of these disasters were large and complex events, demanding extensive support over weeks or months and stretching Disasters program personnel resources. The extensive support pulled personnel away from endeavors, such as partnership building and collaboration with external agencies and other internal NASA programs, and holistic program improvement planning based on lessons learned from these events.

Upon notification/awareness of an event, the program makes a determination for monitoring or activation. Once the program determines that an activation should occur, a core team is established to provide support and coordination throughout the event and participate in post-support evaluations and discussions.

The program uses an established multi-tiered framework to track the level-of-effort associated with activations:

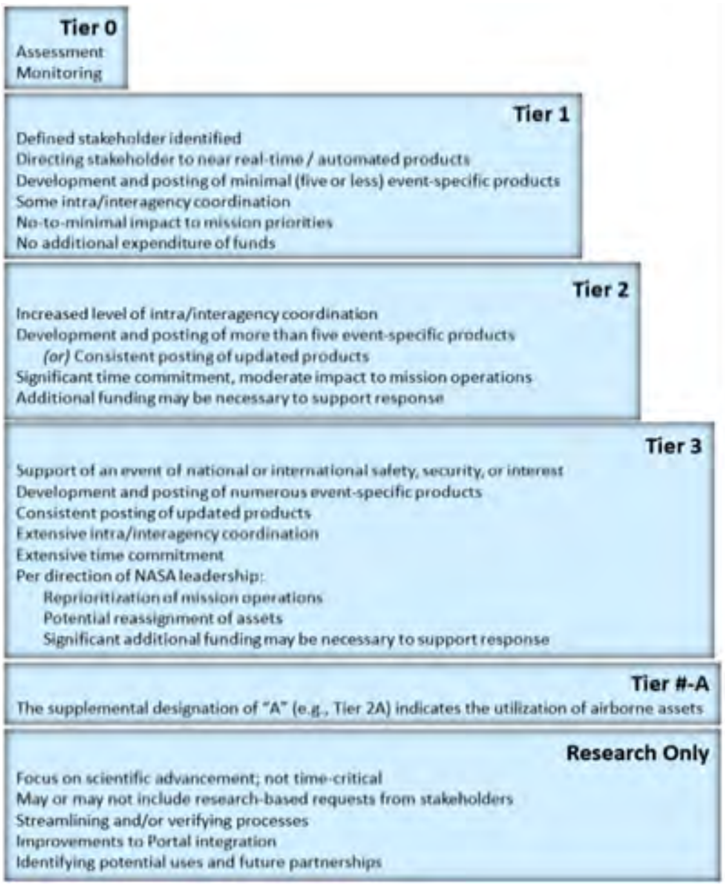


Figure 2. *Tier designations denote NASA level-of-effort for a given disaster event. As events require more or fewer resources, the core team adjusts the tier level accordingly.*

Tier 0: Assessment to determine initial support. The program may also choose to simply monitor the situation and reassess later. Events under initial assessment or in the monitoring-only phase often do not have much tangible information, so we do not necessarily highlight these on the Disasters Program website with an Activation Page.

Tier 1: The allocation of time and resources beyond initial monitoring and automated data collection/distribution processes already in place. This level of effort indicates one or more identified end-users/stakeholders, the occurrence of limited intra/interagency coordination, and the development and posting of a limited number of timely, useful, event-specific products (typically five or less, to include story maps). Support will have no-to-minimal effect on mission priorities nor require any additional funds outside of already-allocated internal coordination funding.

Tier 2: Contributions are considerable given the extent of the disaster and will likely impact ongoing activities of NASA centers and programs. This level of effort indicates an increased level of intra/interagency coordination. Either there is an expectation that more than five event-specific products will be developed and posted, *or* there will be continuous updating and posting of any number of products. This tier represents a significant time commitment from program personnel. Additional allocation or expenditure of funds may be necessary.

Tier 3: An event that directly affects national or international safety, security, or interests. All relevant personnel review their activities for possible support to the disaster. This tier may include a reprioritization of assets and resources, as directed by the Core Team, to focus on stakeholder requests. Should an emergency require redirection of mission priorities, concurrence with agency leadership to refocus space and airborne assets should be coordinated. This level of effort indicates the development and posting of numerous event-specific products, consistent posting of updated products, extensive intra/interagency coordination, an extensive time commitment from program personnel, and the likely need for significant additional funding for event support.

Supplemental Designations: The supplemental designation of **"A"** (e.g., Tier 2A) indicates the utilization of airborne assets during event support. The supplemental designation of "**M**" (e.g., Tier 1M) denotes a pre-event (mitigation or preparedness) activation, such as looking at the vulnerability of an area prior to an actual event, such as a hurricane or volcano. The supplemental designation of "**R**" (e.g., Tier 1R) indicates a post-event (recovery or resilience) activation to assist in rebuilding and restoration.

Research Only: There may also be activations strictly focused on research where the program does not generate results specifically for stakeholder time-sensitive decision making but where research objectives require additional program resources beyond usual day-to-day activities. These events may or may not include research-based stakeholder requests. Nonetheless, they serve as opportunities to advance scientific research, streamline or verify processes, support portal advancements, and identify future partnerships.

An event of scientific interest with ongoing NASA observations, Research & Analysis, or Applied Science research may not warrant active event support. However, the work may still produce products, further collaboration, and provide opportunities to highlight the value of NASA's work via online, social media and outreach efforts.

The Core Team will revisit the initial event screening and tier structure categorization if research conditions change.

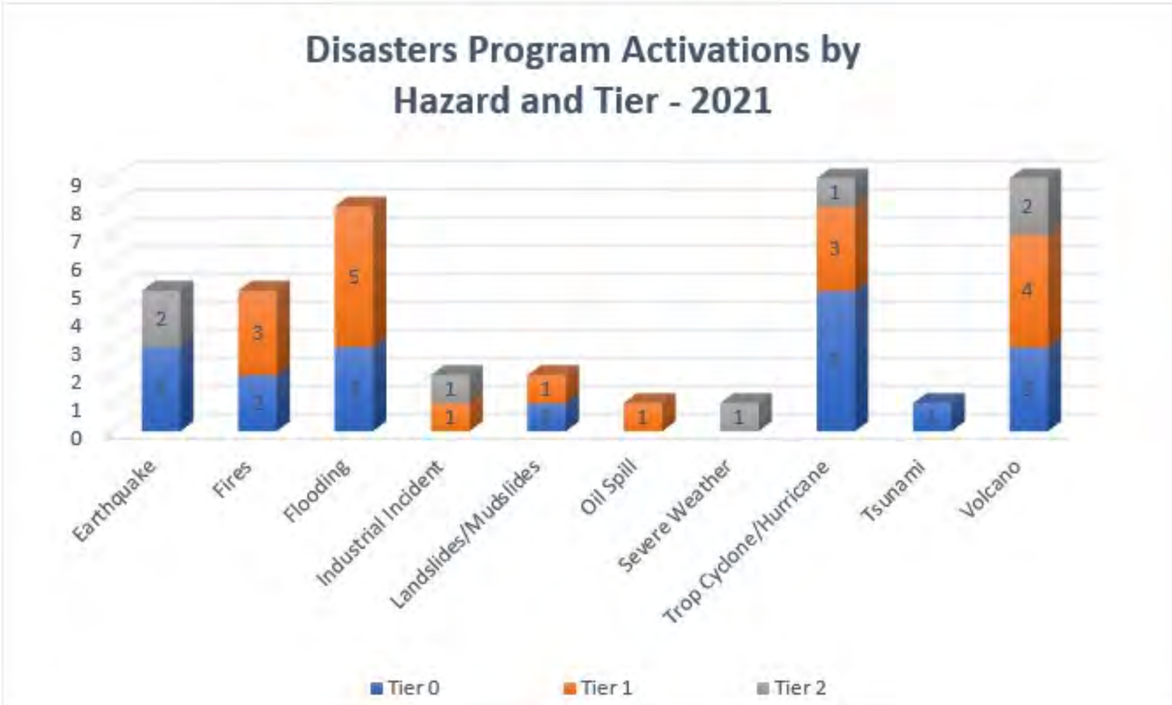


Figure 3. *2021 Disaster activations by hazard and tier*

Figure 4*. 2021 Program activations by region. *Note: North America includes Canada, Mexico, and the United States.*

The Disasters program area engaged numerous external partner organizations to strengthen relationships that, in turn, support preparedness and resiliency efforts. In 2021, this engagment included four exercises, BURNEX with CalFIRE and the California National Guard, TRADEWINDS oil spill scenario with U.S. Southern Command, and pre-season hurricane exercises with both North Carolina and Louisiana. As disaster severity increased, we activated our team, drawing on six NASA Centers, 10 ROSES teams, and many established and new partners. Through a tiered approach, response support included 43 activations (11 domestic, 32 international) where science-informed actions could help the most exposed and vulnerable communities. Overall, NASA Disasters made 1,497 total data products available on the NASA Disasters Mapping Portal and produced or contributed to over 300 stories, publications, and subject matter expert interviews. Our efforts provided increased situational awareness for key partners such as the Federal Emergency Management Agency (FEMA), USAID's Bureau of Humanitarian Affairs (BHA), The World Food Programme (WFP), and The International Federation of Red Cross and Red Crescent Societies (IFRC). Lessons learned revealed further opportunities for us to explore, experiment and strategically target support to ready our applications for more significant impact. We supported four rapid response projects, 20 research augmentations, three international Mapathons, and a dozen internships to improve response to impacts on economies and how to improve decision-making. 2020 highlights also include collaborations for both training and disaster event response, such as:

Exercise – BurnEx21

Figure 5. *Brady Helms (center), NASA HQ Disaster Management Coordinator, showing California National Guard Incident Awareness and Assessment Chief Warrant Officer, Mark Johnson (left) and Private First Class, Pio Tuban (right), the model output created for the exercise from NASA research activity, "Coupled Interactive Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making Project." Credits: California Guard Joint Forces Headquarters Public Affairs/SSG Kimberly Hill.*

In June, NASA Disasters participated in California's BurnEx21 Fire Exercise conducted by California National Guard and CalFire. The exercise included multiple live prescribed burns and focused on the coordination between local, state, and federal partners. NASA Disasters personnel were specifically invited based on past support to the state during previous fires. Disaster Management Coordinator, Brady Helms clarified processes used in the state and refined coordination channels to provide more streamlined support. The program also provided a model from the Coupled Interactive Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making research project, led by Kyle Hilburn of Colorado State University, based on the prescribed burn ignition points.

La Soufrière Volcano

On Jan. 8, 2021, NASA Earth Applied Science's SERVIR program contacted NASA Disasters on behalf of USAID to assist with monitoring volcanic activity of La Soufrière volcano in St. Vincent. The Disasters program team held meetings with USAID to discuss potential support to the island and determined both USAID and the Prime Minister of St. Vincent would continue their usual practice of receiving related information from the Volcano Disaster Assistance Program (VDAP) at the USGS. In consideration of that, the Disasters team began working directly with VDAP to provide data, interpretation guidance and NASA product usage expertise. As part of this support, the program provided thermal infrared imagery from the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to assist in monitoring changes.

By the end of January, and at the request of VDAP, NASA Disasters began working directly with the Seismic Research Center at the University of the West Indies for St. Vincent (SRC/UWI). Since NASA Disasters had previously worked with the SRC, we were able to expand on the existing relationship and provide JAXA ALOS-2 based interferograms and temperature data to help decision-makers understand changes to the volcano over time, and potential impacts should an eruption occur. This data indicated the lava dome continued to grow, indicating a potential eruption.

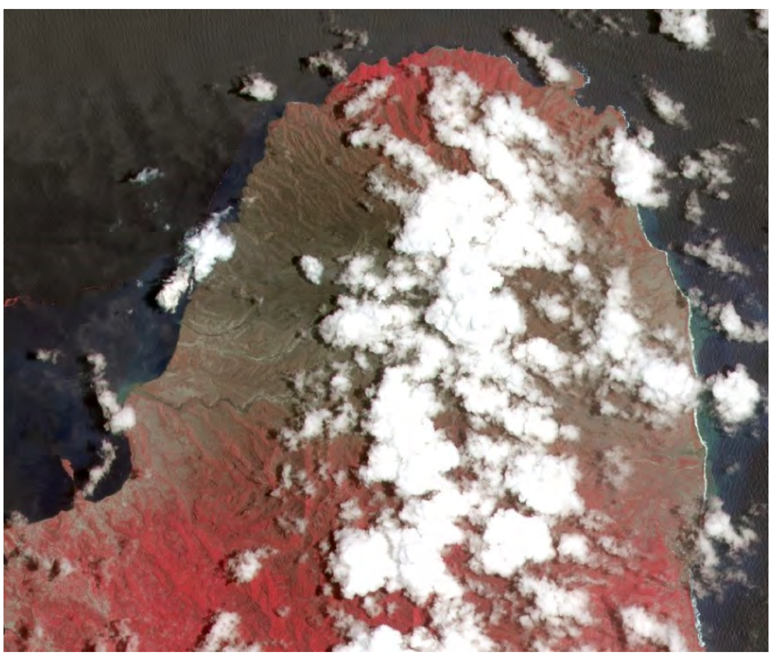


Figure 6. *This false-color infrared image from Sentinel-2 on April 23, 2021 shows areas covered by ash and lava flow. In this image, red indicates healthy vegetation, and black is ash and lava flow. Credits: NASA/MSFC, USGS, ESA Copernicus. Contains modified Copernicus Sentinel data (2021) analyzed by NASA Marshall Space Flight Center*

The first explosive eruption occurred on April 9 and continued for several days. Thanks to interpretive guidance and science-backed data from the program, collaboration with SRC's ground-based monitoring stations placed around the volcano and a partnership with VDAP, authorities were able to evacuate residents around the volcano before the eruptions. Throughout the eruption phase, the program worked with numerous stakeholders, including the SRC, IFRC, the USAID's BHA, and the Caribbean Disaster Emergency Management Agency (CDEMA), as well as various partners, such as VDAP, Institute of Earth Physics of Paris (IPGP), and JAXA. Through this collaborative effort, the group looked at the risk and impact of pyroclastic flows, ash deposition both on land and in the ocean, agricultural damage, and long-term recovery. NASA Disasters conducted an ash cover analysis over St. Vincent using Sentinel 2 and Landsat 8 data. Comparison between pre- (April 8, 2021) and post-event (April 13, 2021) Sentinel-2 False Color Infrared (IR) and Natural Red, Green, Blue (RGB) imagery revealed changes associated with damages and ash deposition over vegetation. Notable changes also included ash cover over the international airport and the city of Georgetown.

In addition to on-the-ground impacts, NASA Disasters also monitored atmospheric impacts from the ash and sulfur dioxide (SO2). Volcanic ash can be transported downwind of the eruption and cover vegetation, pollute water, and re-route air traffic, as the ash can cause grave damage to aircraft components. The SO2 can change atmospheric chemistry impacting climate and weather patterns, as well as contaminate the air within aircraft and at ground level. Through the ROSES A.37 *Day-Night Monitoring of Volcanic SO2 and Ash for Aviation Avoidance at Northern Polar Latitudes: Enhancing Direct Readout capabilities from EOS, SNPP and NOAA20 Project*, (National Oceanic and Atmospheric Administration) NASA Disasters provided Ozone Mapping and Profiler Suite (OMPS) SO2 data for four levels of the atmosphere and provided an OMPS Aerosol Index map, showing the path of the volcanic ash cloud.

Following the initial response portion of the event, NASA Disasters met with stakeholders and partners to understand how the support assisted each agency and discussed ways to improve future support and collaboration. One of the main lessons learned was that some of the partners and stakeholders involved in the response were not familiar with NASA support or NASA data. This obeservation substantiates the program's goal of engaging with stakeholders prior to incidents. By engaging before incidents occur, the partners and stakeholders can receive key training on the NASA Disasters Mapping Portal, other NASA data tools, and how to use the products NASA provides.

Problem	Solution	Action
Stakeholders recognized the importance of our Disasters Portal; however, since they weren't familiar with it before the event, they weren't as comfortable navigating through the site.	Provide training opportunities	1) Partner with ARSET for creation of using satellite data before, during and after volcanic eruption(s) 2) Create a short Disasters Portal video (2-5 minutes) on how to navigate and use data 3) Develop WorldView case studies
Many data sets are not routine, so networks of partners (typically academia) are doing the analysis as trusted partners.	Re-engage with VDAP and inquire if Value-Add for International Charter is a route moving forward to better collaborate and develop relationships with stakeholders across the globe. Stakeholders need to know what to expect, what is to come, how to request, and in what format we can best get data to them.	Set up meeting with VDAP

Hurricane Ida

On Aug. 29, Hurricane Ida made landfall as a Category 4 hurricane on the southern Louisiana coast. The storm brought catastrophic storm surge and winds far inland to Louisiana and Mississippi. The NASA Disasters program area supported the FEMA National Response Coordination Center and FEMA Region IV along with their interagency and state partners. Additionally, the JPL Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) and ROSES A.37 Marine Oil Spill Thickness (MOST) research teams worked with NOAA's Oil Desk to develop methodologies to contribute research information that led to the generation of marine pollution surveillance oil spill reports. NASA Disasters posted 373 data products, including JPL's UAVSAR flight lines over Houma, Lousiana, to the Hurricane Ida Product Gallery on the NASA Disasters Mapping Portal. The teams discussed lessons learned and agreed to continue developing and refining efforts to improve the delivery of decision-ready and situational awareness products to the end-user community for response and recovery efforts. This paid off in a big way when, approximately two weeks later, NASA's Disasters program area, joined forces with the UAVSAR and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) teams again to help coordinate another federal response effort with NOAA's Oil Desk, Ocean Science and National Environmental Satellite, Data, and Information Service Satellite Analysis Branch (NESDIS-SAB) teams for an oil spill off the coast of California. NASA Disasters and our collaborators siezed the opportunity to immediately enact lessons learned from Hurricane Ida and apply them directly toward this unexpected oil spill event.

California Oil Spill

Fresh off the heels of the Hurricane Ida response, an oil spill off the coast of California spewed 126,000-gal of oil along Orange County beaches over the Oct. 1 weekend. According to news reports, a damaged pipeline spewing oil connected to a processing platform (one of three) approximately 17.5 miles off the coast. NASA Disasters activated to assist with a request from NOAA's Ocean Service team. Initially, there was a lack of information on surface oil distribution beyond the Marine Pollution Surveillance Report's (MPSR) the NOAA/NESDIS-SAB usually prepares. Additionally, satellite coverage was blacked out, which meant there were limited extended offshore observations for Unified Command to reference to help inform decisions on where to deploy Shoreline Cleanup Assessment Teams (SCAT). Aerial observations and analysis over the channel, specifically between Catalina Island and the coast was necessary to help provide operations with accurate reports. UAVSAR was deployed in the area making passes for another project, so linking up with Unified Command was essential to enable data sharing for the response. AVIRIS was also on the west coast, performing separate research. This rare opportunity provided observations in real-time. Timing is critical during operational response events, so we are proud that even despite a slight time delay to bring the teams together (due to the spill event occurring over a weekend), there was enough continuity in the assessment to be confident in the results.

The UAVSAR team completed refined processing of images captured during their flight and generated GeoTIFF images available to download from the UAVSAR website. That imagery was uploaded to NOAA's Environmental Response Management Application (ERMA) portal; this portal provided a common operating picture for response where SCAT data was downloaded daily. The NOAA NESDIS-SAB reviewed the full data and compared it to the latest satellite data. NASA Disasters connected with several members of the JPL AVIRIS team to prepare additional flight plans and further collaborated with their instrumentation ground-based team, Orange County Parks staff, and the SCAT teams out of Unified Command for a full analysis. NOAA and other designated partners can act as natural resource trustees during environmental disasters,working together on a preliminary assessment to identify the extent of natural resource injuries, best methods for restoring them, and the type and amount of restoration required. The Natural Resource Damage Assessment (NRDA) can then provide recommendations on the type and amount of restoration needed to offset impacts to fisheries, wildlife habitats, and human uses impacted by oil spills, hazardous waste sites, and vessel groundings. Aerial and ground-based measurements were analyzed and provided to NOAA's Ocean Service team as an additional information source to supplement with the NRDA and the daily SCAT samples.

An immediate priority for this event was ground verification of imaging needs and guidance for mapping spectroscopies along the west coast for AVIRIS flight planning. Through our collaboration on this event, we demonstrated that oil spill thickness detection can be further analyzed through the use of UAVSAR, and that oil differentiation can be made through comparison of AVIRIS flight data to ground-based oil reports.

Partners Engaged	Stakeholders Engaged	Products
NOAA • Oil Spill Desk • NESDIS-SAB • Ocean Service JPL • AVIRIS • UAVSAR	Southern California Coastal Ocean Observing System (SCCOOS) from University of California, San Diego (UCSD)/Scripps Orange County, CA Parks	Lori Schultz/MSFC • Optical Sensor RGB products • UAF/ASF Sentinel-1 RGB Franz Meyer (A.37 ROSES Project) • Geocoded Sentinel-1 Imagery for visualization and mapping

Strengths	Improvements
This event helped advance both UAVSAR and AVIRIS use for rapid response product generation of current science algorithms to meet identified partners' needs during the event. NOAA was able to effectively compare their ground-based data with NASA's airborne data and provide to decision-makers within Unified Command in timely manner.	Provide further opportunity to collaborate with new and existing partners and stakeholders. Provide further training opportunities to enhance knowledge and understanding of air and ground-based assets before, during and after emergencies.
Harmonized LANDSAT and Sentinel data. Corrected for atmosphere using historical data. Made data available within two to three days.	Provide further opportunity for use of scaling high-resolution data.
	Provide opportunity, separate from current ROSES Project, to build off response for future projects using AVIRIS (potential uses: debris, methane detection, other greenhouse gas detections).

III. Disaster Resource Highlights

Disasters Mapping Portal

The NASA Disasters Mapping Portal, is the data-sharing hub of geospatially-enabled NASA Disasters products, making them openly accessible and discoverable for the disaster management community and the public. The portal helps demonstrate what is possible by combining NASA Disasters data with other NASA and non-NASA products and using web applications, story maps, and dashboards to explain and enhance the usability of the data. The portal is one of the primary tools used for outreach in the Disasters Program area by connecting the program's data to stakeholders and allowing any NASA Disasters team member to showcase our data from current and previous responses in real time.

In 2021, we launched a new homepage built on NASA's ArcGIS Online account to allow for a consistent theme across the updated Applied Science website, Disasters Program area website, and the Disasters Mapping Portal. The portal hosted products for 15 disaster activations consisting of 58 published GIS web services and nearly 1,500 data products. The most significant activations on the portal were La Soufriere Eruption, Hurricane Ida, and the Dec. 10-11, 2021 Tornado Outbreak. The story map for La Soufriere Eruption had more than 5,700 views, while the three Sentinel-2 imagery services published for the activation had more than 18,000 views each.

In 2021, NASA Disasters utilized NASA's Commercial Smallsat Data Acquisition (CSDA) Program more heavily to access and provide imagery from Planet to stakeholders for the Dec. 2021 Tornado Outbreak. FEMA and the National Weather Service used the Planet imagery, and the NWS used the data to update and modify their official tornado paths. With help from a portal intern project, the Disasters Mapping Portal was able to add new Near Real-Time (NRT) products, including four OMPS Sulfur Dioxide products and three Land Information System (LIS) Soil Moisture Percentile products. The mapping portal also transferred its existing MODIS Flood Product NRT services to the new MODIS Flood Product data location hosted at LANCE.

Seven of the Disaster program area's 10 ROSES A.37 projects had data hosted on the portal for disaster activations and an eighth is now referenced on the Portal. We established a portal-to-portal collaboration was established with a team at the World Food Programme (WFP) allowing for seamless data sharing into the WFP GIS system when they are a stakeholder for a NASA Disasters program area activation. Members of the NASA Disasters also participated in a North Carolina Emergency Management Hurricane Exercise, which simulated the state's response to a landfalling hurricane in North Carolina. NASA Disasters also contributed by providing data to the stakeholders though the portal throughout the exercise.

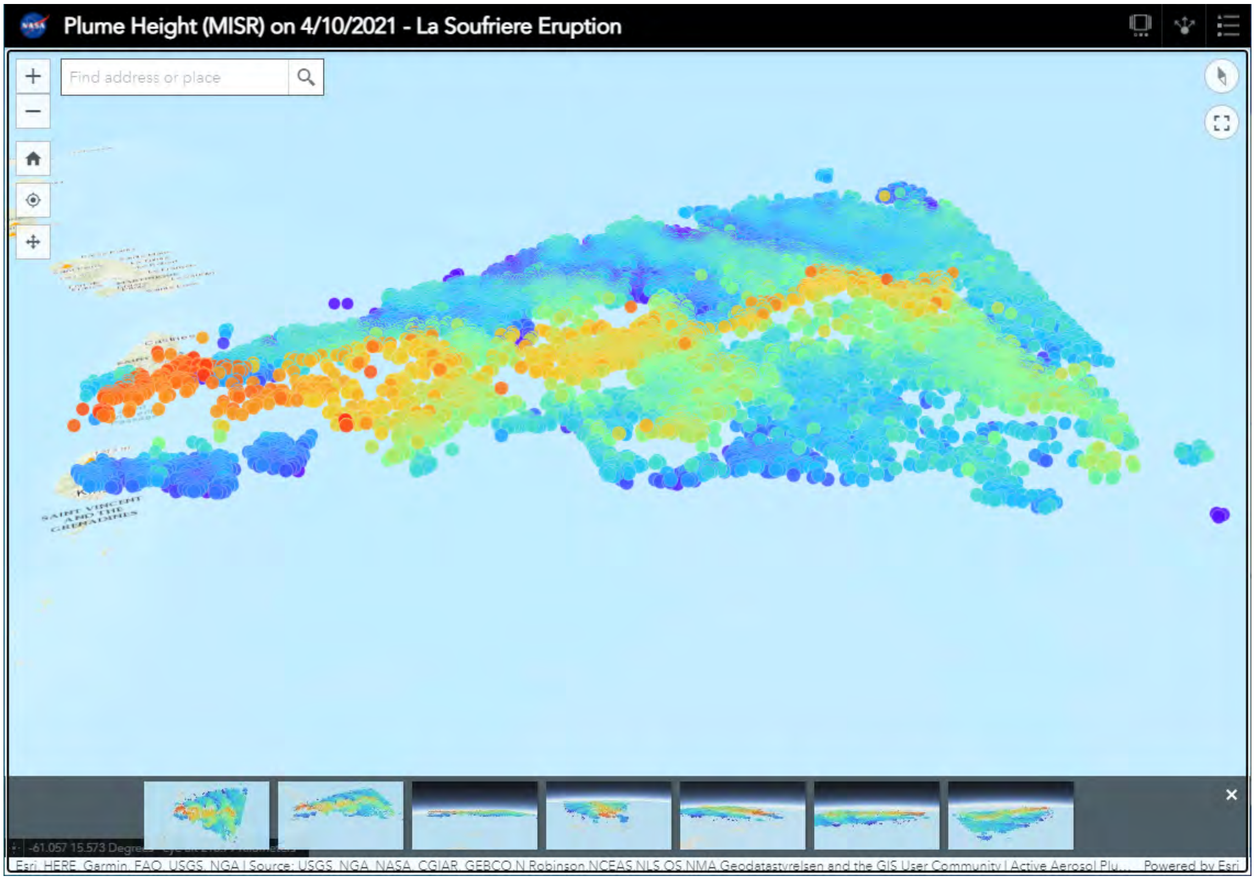


Figure 1. *Using the Multi-angle Imaging SpectroRadiometer (MISR) researchers from Goddard Space Flight Center's MISR Active Aerosol Plume-Height (AAP) project were able to provide plume height in the days following the eruption of La Soufriere. The NASA Disaster Mapping Portal's GIS team created an interactive 3D visualization of the volcanic plume, which reached heights above 20 kilometers into the atmosphere. Credits: NASA Disasters Program, Active Aerosol Plume (AAP) Project, V. Flower, R. Kahn, K. Junghenn-Noyes, Smithsonian Institution; 3D rendering by Garrett Layne*

NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE)

The Land, Atmosphere Near real-time Capability for EOS (Earth Observing System) (LANCE) distributes global satellite data and imagery within three hours from satellite observations. As one of the prime users of LANCE, the NASA Disasters program area promotes the use of LANCE near-real-time (NRT) data products to support disaster risk reduction activities before, during and after disasters events. The LANCE team provides support when NASA Disasters assists stakeholders and end-users in preparing, responding, and recovering from disasters. The Disasters program area increases the visibility of LANCE by giving presentations in meetings, coordinating with Satellite Needs Working Group (SNWG), Decadal Designated Observable Study teams and the applications community.

Partially supported by the NASA Disasters program area, the legacy NRT GSFC MODIS Global Flood Mapping was transitioned to NASA's LANCE and has been available since April 2021. This NRT global flood product provides 1-, 2- and 3-day global flood maps based on imagery from the MODIS instruments onboard the Terra and Aqua satellites. The combination of lower latency and making the product available in NASA Disasters Mapping Portal and Worldview provides quicker information on surface water extent change over time to support decision-making in disaster scenarios.

Some new products, funded through NASA A.37 ROSES calls, have the potential to become the new NRT products in LANCE in the future. Examples include the WRF-SFIRE Fire Forecast product developed by Dr. Kyle Hilburn; the VIIRS Thermal Infrared (TIR) RGB product and VIIRS SO2/Ash Index products developed by Dr. Vincent Realmuto and Dr. Nick Krotkov; and the Hailstorm Detection Data Product developed by Dan Cecil, Sarah Bang, and Dr. Kristopher Bedka.

Invited by Paraguayan Space Agency, NASA Disasters gave a presentation to introduce application users to NASA's LANCE Near Real-time Earth Observations for Disaster Risk Reduction at the 2nd International Forum on Applications of Earth Observations in Paraguay. The meeting organizer Alejandro Román acknowledged the support and help from NASA.

The NASA Disasters program area conducted an interval survey within NASA's Applied Science Program (ASP) to better understand how widely low latency and NRT products are used and to identify needs for new products. The survey results have been shared with the LANCE User Working Group (UWG) to identify gaps and to improve the process of transitioning LANCE NRT products to end-users. One of the outcomes from the ASP interval survey was the identification of the need for NRT Sentinel satellites products. Per a request from LANCE users, NASA Disasters program area summarized information on NRT product availability from ESA Sentinel satellites and published the document on the Applied Science Program website. In response to the request from the Disasters Mapping Portal team for NRT products in user-friendly and GIS-analysis ready format, the NASA LANCE AMSR2 team developed a Data Recipe to convert NRT products from HDF-EOS5 format to GeoTIFF format, which is compatible with nearly all GIS applications.

NASA Disasters arranged discussions between the Satellite Needs Working Group (SNWG), the LANCE team, and Decadal Designated Observable Study teams to promote awareness. The Disasters Program and the LANCE team made suggestions to the Surface Biology and Geology (SBG) survey team regarding the collection of information on data latency from end-users in the SBG 2nd User Needs Study.

IV. Disaster Research

The foundation of the Applied Sciences Program's mission is its applied science and research, which the NASA Disasters program area implements through a robust portfolio of collaborative projects to accomplish its objectives.

In 2021, the program's research portfolio primarily consisted of the ten NASA Research Opportunities in Space and Earth Science (ROSES) Disasters A.37 Disaster Response and Risk Reduction projects (Table 1) and six Group on Earth Observation (GEO) Work Programme Projects. The GEO projects include three GEO Flood Risk Monitoring (GFRM) Community Activity projects and three GEO Global Wildfire Information System (GWIS) Initiative projects (Table 2).

PI	Organization	Proposal Title
Bedka	NASA LaRC	**Hail and Severe Storm Risk Assessment** Using Spaceborne Remote Sensing Observations and Reanalysis Data
Fielding	NASA JPL	**Global Rapid Damage Mapping System** with Spaceborne SAR
Glasscoe	NASA JPL	Advancing Access to **Global Flood Modeling and Alerting** using the PDC DisasterAWARE Platform and Remote Sensing Technologies
Hilburn	Colorado State University	Coupled Interactive Forecasting of **Weather, Fire Behavior, and Smoke Impact** for Improved Wildland Fire Decision Making
Huyck	ImageCat Inc.	Open **Critical Infrastructure Exposure** for Disaster Forecasting, Mitigation, and Response
Kirschbaum	NASA GSFC	Enabling **Landslide Disaster Risk Reduction** and Response Throughout the Disaster Lifecycle with Multi-Scale Toolbox
Krotkov	NASA GSFC	**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
Melgar	University of Oregon	**Local Tsunami Early Warning** with GNSS Earthquake Source Products
Meyer	University of Alaska-Fairbanks	Integrating SAR Data for **Improved Resilience and Response to Weather-Related Disasters**
Monaldo	University of Maryland-College Park	Development and Implementation of Remote Sensing Techniques for **Oil Spill Monitoring and Storm Damage Assessment** in an Operational Context

Table 1. NASA ROSES 2018 A.37 NASA Disaster Response and Risk Reduction project portfolio

PI Name	Organization	Proposal Title
Kettner	University of Colorado-Boulder	Integrating Global Remote Sensing and Modeling Systems for Local Flood Prediction and Impact Assessment
Kruczkiewicz	Columbia University	Toward a Global Flood and Flash Flood Early Warning Action System Driven by NASA Earth Observations and Hydrologic Models
Yun	NASA JPL	Global Flood Mapping System with Spaceborne Synthetic Aperture Radar Data
Boschetti	University of Idaho	Polar Orbiting Fire Product Record for GWIS
Field	NASA GSFC	Fire Danger Rating Additions to GWIS and Applications for Indonesia
Giglio	University of Maryland	Multi-SensorHarmonizing Geostationary Satellite Global Active Fire Data for GWIS

Table 2. *NASA ROSES 2016 A.50 Group on Earth Observation (GEO) Work Programme Projects*

NASA ROSES 2018 A.37 NASA Disaster Response and Risk Reduction Projects

The NASA Disasters Program sponsors application science to support disaster risk reduction, response, and recovery through a series of grants and partnerships funded by the NASA Research Opportunities in Space and Earth Science (ROSES) program. The current portfolio of projects from the 2019 ROSES A.37 solicitation covers a broad swath of hazard and disaster research, from tsunami and landslide forecasting to volcanic ash and wildfire smoke plume tracking. It represents the cutting edge of applied disasters research. The program's research efforts aim to assemble scientifically defensible studies on disaster risk management, demonstrate the applications of NASA Earth-observing data for studying disasters, and mature the technologies and techniques developed from these projects to operational use.

Hailstorm Risk Assessment Using Spaceborne Remote Sensing Observations and Reanalysis Data

Principal Investigator: Kristopher Bedka/NASA LaRC (NASA's Langley Research Center)
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

This project, conducted by the NASA Satellite Mapping and Analysis of Severe Hailstorms (SMASH) team, represents a partnership between NASA Langley Research Center and Marshall Space Flight Center, Willis Towers Watson (WTW), Karlsruhe Institute of Technology (KIT), a variety of international partners across South America and South Africa, and several U.S. academic partners. WTW provides global advisory and brokering services by working with clients to understand risk better and provide financial resilience against extreme loss-making events such as hailstorms. The project focuses on detecting and characterizing intense thunderstorm updraft regions, also known as overshooting cloud tops, where hail and other forms of severe weather such as tornadoes and damaging straight-line winds are concentrated. Updrafts were studied using Geostationary Operational Environmental Satellite (GOES) and European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Meteosat Second Generation (MSG) geostationary infrared imagery and low-Earth-orbiting passive microwave imagers aboard the NASA Tropical Rainfall Measuring Mission (TRMM), Global Precipitation Mission (GPM), and NASA Aqua satellite, and the Japan Aerospace Exploration Agency (JAXA) GCOM-W1 satellite. Damage to vegetation from hail and other severe weather is being studied using optical imagers like MODIS, VIIRS, Landsat, and the European Space Agency (ESA) Sentinel-2, and synthetic aperture radar aboard Sentinel-1.

In March 2021, the WTW South African Hail Catastrophe Model (CatModel) became operational. The model is based on a combination of a 15-year Meteosat Second Generation geostationary infrared overshooting top detection database developed by NASA LaRC, a 23-year TRMM and GPM passive microwave imager hailstorm detection climatology developed by

NASA MSFC, and environmental data from the ERA-5 reanalysis. WTW published two web features that announced the model release and described its technical background: https://www.wtwco.com/en-za/news/2021/03/willis-re-launches-new-south-african-hail-risk-model and https://www.wtwco.com/en-GB/Insights/2021/03/a-new-view-of-south-african-hail-risk-for-the-re-insurance-industry. A web interview featuring the chief executive officer for Willis Re South Africa offering her perspectives on the model is available online at: https://cover.co.za/modeling-hail-risk-with-willis-re/. According to WTW, the model is already being used for work with seven of WTW's clients. Release of this model increases the ARL to 8 for this component of the project with the goal of increasing to ARL 9 after sustained industry usage. A journal article that summarizes the technical background of the model is under review within the journal Natural Hazards and Earth System Sciences.
The project team is using machine learning to quantify how well severe hailstorms can be discriminated from non-severe storms using a combination of historical GOES-13 and -16 data, U.S. weather radar observations, reanalyses, passive microwave imager hailstorm detections, and severe weather reports from human spotters. This work represents the crux of this project, where we seek to use historical geostationary remote sensing data to map hailstorms at high temporal resolution with as long of a satellite data record, image spatial detail and detection accuracy as possible, using pattern recognition and advanced machine learning methods. The team is collaborating with leading severe storm researchers at the University of Oklahoma and Central Michigan University, who provided a five-year database of NEXRAD radar hail size estimates and a comprehensive set of environmental parameters such as atmospheric instability and vertical wind shear from the MERRA-2 and ERA-5 reanalyses.

Cloud top properties derived from GOES include tropopause-relative infrared temperature, overshooting top probability and area, anvil temperature and area, and cloud top height. This research is showing that nearly 70% of all severe hailstorms that occurred from 2013-2017 were detected using GOES-13 and reanalysis data, an accuracy exceeding that from previous satellite-based studies. Use of satellite data in combination with reanalysis was found to improve upon hailstorm detection accuracy versus use of reanalysis alone. An example showing possible overshooting tops during a storm outbreak in May 2017, colored by hail likelihood derived from machine learning, are shown in Figure 1 (left panel). Regions of high hail likelihood (warm colors) agree well with hailstorm tracks detected using NEXRAD observations (Figure 1, middle panel), and human spotter reports and National Weather Service warnings (Figure 1, right panel). This work is being summarized in a paper to be submitted for publication in early 2022.

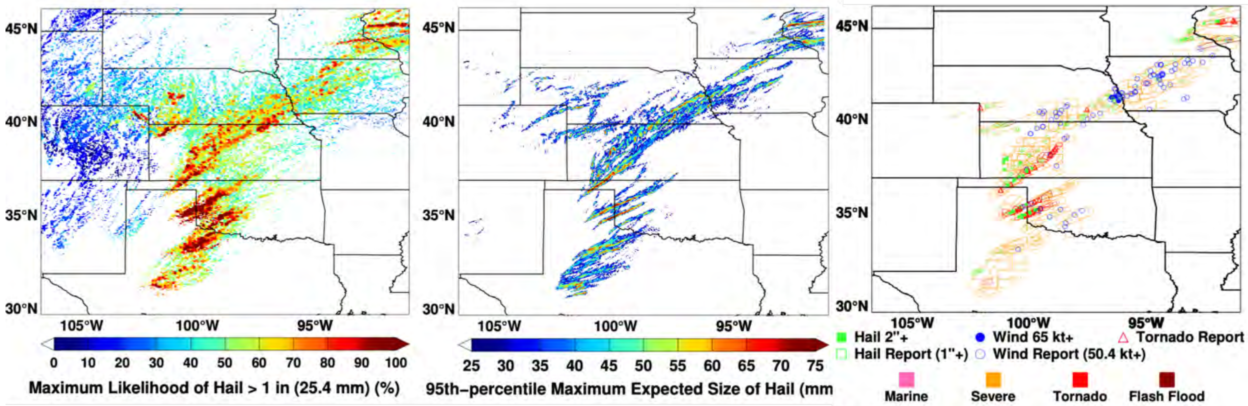


Figure 1. *(left) Hailstorm likelihood derived from a combination of GOES-13 cloud top infrared spatial patterns and temperature parameters and ERA-5 reanalysis parameters aggregated from 16 UTC on May 16 to 06 UTC on May 17, 2017. (middle) NEXRAD weather radar Maximum Expected Size of Hail exceeding 1-inch diameter, a threshold corresponding to severe hail as defined by the National Weather Service. (right) Severe thunderstorm and tornado warnings issued by the National Weather Service (polygons) and severe weather reports from human spotters (symbols).*

This framework will be applied to a recently developed 22-year GOES climatology of thunderstorm anvil and overshooting cloud top detections over South America to determine hail risk and develop a CatModel. Figure 2 shows a comparison of anvil (lower-left) and overshooting top (lower-middle) detection frequency compared with hail frequency derived from TRMM and GPM imager data. This graphic illustrates 1) the significant improvement in spatial resolution provided by the GOES-8 to -13 data compared to TRMM/GPM and that 2) storms are most frequent over the Amazon River basin and northwest South America, but storms with overshooting tops (very intense updrafts capable of producing severe hail) are most common over Argentina, Paraguay, Uruguay, Brazil, and Colombia. This agrees with the hailstorm distributions depicted by TRMM and GPM. After the South America GOES climatology is fully quality controlled in Spring 2022, it will be shared with project partners for analysis and CatModel development.

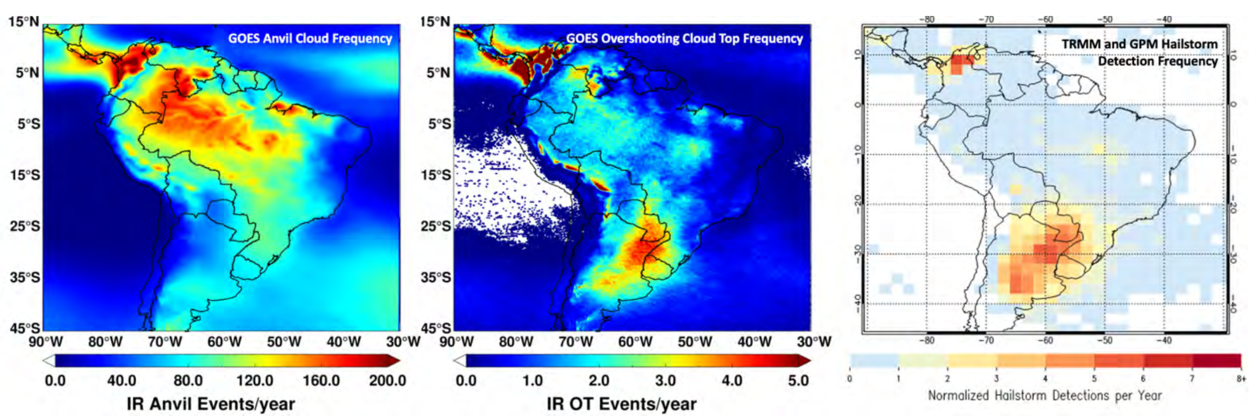


Figure 2. *A 22-year climatology of GOES-8 to -13 thunderstorm anvil detection (lower-left) and overshooting cloud top detection frequency (lower-middle), and a 23-year climatology of TRMM and GPM hailstorm detection frequency (lower-right).*

The team continued to respond to severe storm disasters as they occurred in 2021, and closely analyze historical outbreaks to demonstrate detection performance and assess limitations of datasets and methods. Automated detections of overshooting tops using GOES-16 1-minute mesoscale domain sector imagery was shown to agree well with storm cell tracks during a historic Iowa tornado outbreak on July 14, 2021 and a catastrophic tornado outbreak across the Midwest U.S. on Dec. 10, 2021 (https://appliedsciences.nasa.gov/what-we-do/disasters/disasters-activations/midwest-us-tornado-outbreak-December-2021).

The Bulletin of the American Meteorology accepted a paper summarizing remote sensing observations of the Aug. 10, 2020 Midwest U.S. derecho for publication in: https://journals.ametsoc.org/view/journals/bams/aop/BAMS-D-21-0023.1/BAMS-D-21-0023.1.xml. This paper showed:

1) Capabilities and limitations for identifying locally intense cells responsible for generating damaging winds, hail, and tornadoes throughout the derecho event using GOES-16 infrared and lightning observations,

2) Use of VIIRS Day/Night band imagery for mapping power outages from the derecho, and

3) Advantages of using synthetic aperture radar (SAR) data over optical imagers for mapping wind and hail damage.

The SAR-based estimate of damage to corn and soybean crops in this study agreed much better with damage estimates from the agriculture industry than a previous study conducted by NASA Harvest. The team also analyzed 20 years of NASA Aqua and Terra MODIS imagery using the NASA Worldview tool to identify and digitize hail damage scars across the Central and Upper Midwest U.S. They found that over 71 million acres showed visual evidence of hail damage from 2000-2020 in the domain shown in Figure 3. Hail damage swaths from this analysis will be analyzed with machine learning to develop automated methods for identifying hail damage with optical imager and SAR data.

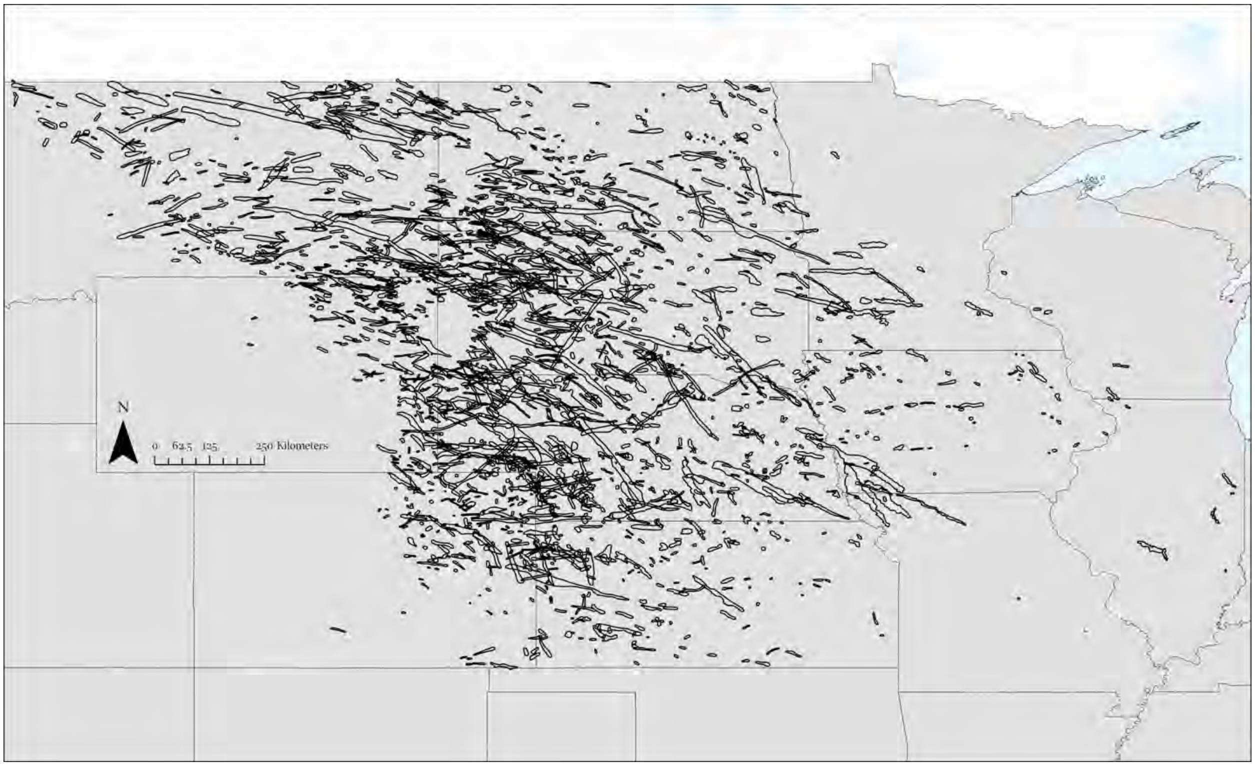


Figure 3. *Hail damage swaths manually identified by human analysts using NASA Worldview displays of Terra and Aqua MODIS imagery over the Upper Midwest from 2000-2020. Note that many hailstorms occur each year in Texas, Oklahoma, and Arkansas, but these often occur in winter or early spring prior to the growing season when damage to vegetation cannot be seen from space.*

Project Summary	Hailstorm Risk Assessment Using Spaceborne Remote Sensing Observations and Reanalysis Data
Application Products	South African CatModel, South American CatModel, Global Passive Microwave Hailstorm Detections, Web-based GIS Hailstorm Visualization Portal
ARL Advancement	CatModel Application Current ARL 8. Goal ARL 9.
Geographic Region	South Africa, South America, Continental U.S., and global hailstorm climatologies
Partners	Willis Towers Watson, Karlsruhe Institute of Technology, South African Weather Service, Centro de Previsão do Tempo e Estudos Climáticos (Brazil), Servicio Meteorologico Nacional (Argentina), Universidad de Buenos Aires, Universidad Nacional de Columbia, University of Oklahoma, Central Michigan University
Prospective Partners	USDA National Agricultural Statistics Survey, Foreign Agriculture Service
2021 Journal Papers	6
2021 Media Features	7
2021 Scientific Presentations	15

Global Rapid Damage Mapping System with Space-borne SAR Data

Principal Investigator: 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

The project used satellite Synthetic Aperture Radar (SAR) observations for rapid damage mapping of a large number of disaster events in the last several years. Users have found those maps critically useful. That said, the quality of damage maps varied depending on the choice of reference SAR images, and a high level of false positives has been recognized over vegetated areas and agricultural lands with presently operating satellites. Therefore, we developed a multitemporal interferometric SAR (InSAR) coherence analysis that characterizes each pixels behavior over time to improve the sensitivity of SAR to detecting damage and reduce the level of noise that is not relevant to disaster events.

The project developed a novel technique to implement the multi-temporal InSAR coherence analysis. The first step is to create a stack of co-registered SAR images and calculate interferometric coherence from all possible pairs. Then, an estimate is made of the temporal change of coherence for each pixel. The multitemporal SAR analysis applies different thresholds for different pixels and different temporal baselines. This contrasts with conventional InSAR damage estimation, which involves three SAR images and applies a uniform threshold to the entire image. The pixel-based thresholding is adaptive to different land cover and better captures the anomalous signals due to disaster events.

We have found that the multi-temporal InSAR coherence Damage Proxy Map (DPM) is much more effective in areas where coherence significantly changes over time due to temporally decaying characteristics. It can better distinguish between changes due to natural coherence variations over time and coherence changes due to damage from an event, such as an earthquake, tornado, hurricane, volcanic eruption, or other disaster. One example is the outbreak of powerful tornados that struck four states on the night of Dec. 10-11, 2021. There was severe damage in Mayfield, Kentucky, and our multi-temporal DPM (which we call DPM2) was able to map the likely damage there (Figure 1) and in other parts of the state.

Figure 1. *Mayfield, Kentucky. This Damage Proxy Map (DPM2) was created from 15 SAR scenes acquired by the Copernicus Sentinel-1 satellites before and after the Dec. 10–11, 2021 tornadoes that devastated this area. Red color indicates a high likelihood of damage. Contains modified Copernicus Sentinel data (2021). NASA/JPL-Caltech/ESA/Google Earth*

We also developed an extension to the multi-temporal InSAR coherence analysis to explore the change measurements for events that last days or weeks. We applied this to the 2021 Cumbre Vieja volcanic eruption on the island of La Palma in the Canary Islands. The eruption started in September but continued through November 2021, with lava flows and volcanic ash fall affecting a larger and larger area with time. We used the multi-temporal InSAR coherence from before the eruption to look at how coherence changed during the eruption and mapped the increasing area of surface changes caused by the eruption (Figure 2). The Copernicus Sentinel-1A and Sentinel-1B satellites were together acquiring data over La Palma every 6 days, enabling new coherence change maps every week showing the areas with significant surface changes due to the lava flows and thick ash or tephra accumulation even during times when it was cloudy.

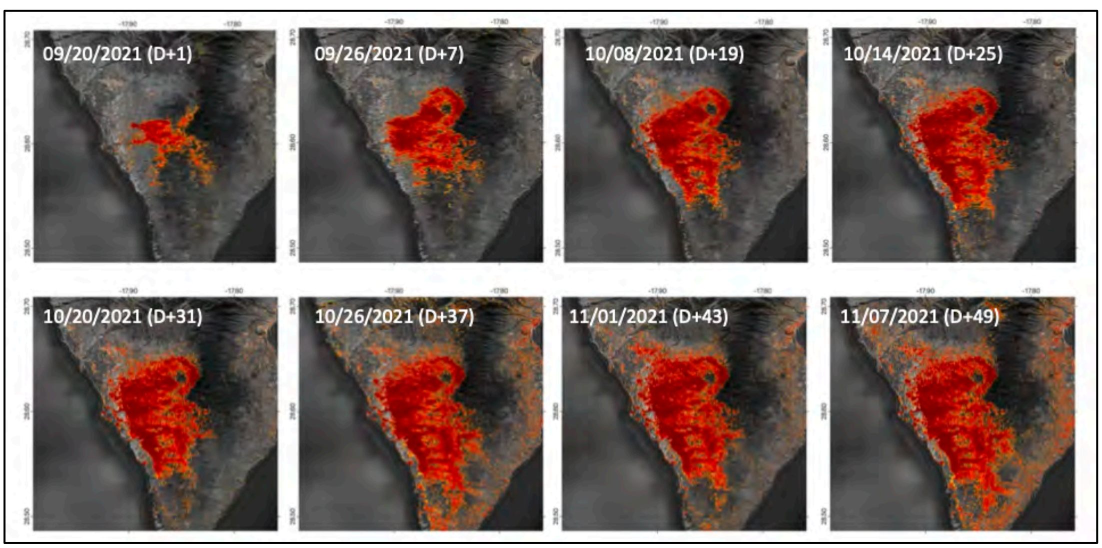


Figure 2. *La Palma volcanic eruption maps. A set of Damage Proxy Maps (DPM2) were calculated over central La Palma island and Cumbre Vieja volcanic eruption area from multi-temporal InSAR coherence analysis of Copernicus Sentinel-1 data. The dark red color indicates strong surface change (most lava flows), medium red and orange indicates moderate surface change largely due to ash and tephra accumulation. Contains modified Copernicus Sentinel data (2021). NASA/JPL-Caltech/ESA/Google Earth*

In addition to the multi-temporal InSAR coherence analysis, the project also produced surface displacement maps for large earthquakes and volcanic eruptions from InSAR and SAR pixel offset analysis. InSAR measures moderate amounts of surface displacement with high precision, and SAR pixel offset tracking measures large displacements with coarser precision, so the combination reveals the range of surface displacements. The displacement maps provide information on the extent of fault slip at depth, the extent of surface ruptures that could affect roads or other infrastructure, and vertical land motions caused by the earthquake or volcanic processes. Coastal areas where the land moved downward may be subject to permanent flooding after the event. An example of a surface displacement map is shown in Figure 3, with the surface displacements due to the Aug. 14, 2021 magnitude 7.2 Haiti Earthquake, measured with InSAR from Japan Aerospace Exploration Agency (JAXA) ALOS-2 data. The surface displacements show that the 2021 earthquake ruptured westward from the starting point, which directed the seismic shaking westward and reduced damage in the more heavily populated eastern part of Haiti. (Figure 3).

On the system side, we worked to make the rapid damage mapping software more portable and adaptable for deployment in different systems. The Advanced Rapid Imaging and Analysis (ARIA) system has been evolving, so the damage mapping system was adapted and generalized. We infused technology from a JPL-based NASA Advanced Information Systems and Technology (AIST) project, including implementation of an option for using the NASA High-End Computing Center to reduce processing costs. The AIST SAR stack processor is implemented with a Jupyter notebook for easier control. We are now translating the rest of the ARIA DPM processing to run as Jupyter notebooks. This year, the project ARL level increased from ARL 6 to ARL 7, as "Application Prototype in Partner's decision making (Functionality Demonstrated)." The USGS has started using our products for some of their decision making and to improve earthquake-derived products.

The improved damage proxy algorithm was successfully applied to support disaster response efforts, including the January 2021 Indonesia earthquake; April 2021 Cyclone Seroja, Indonesia; April 2021 La Soufriere volcano, St. Vincent; June 2021 Nepal landslide; July 2021 Sullana, Peru earthquake; Aug. 2021 Haiti earthquake; Sept. 2021 Hurricane Ida, Louisiana; Sept. 2021 Acapulco earthquake; Sept.-Nov. 2021 La Palma, Canary Islands volcanic eruption; Dec. 2021 Semeru volcano, Indonesia; Dec. 2021 Typhoon Odette, Philippines; and Dec. 2021 Kentucky tornados (Figure 1).

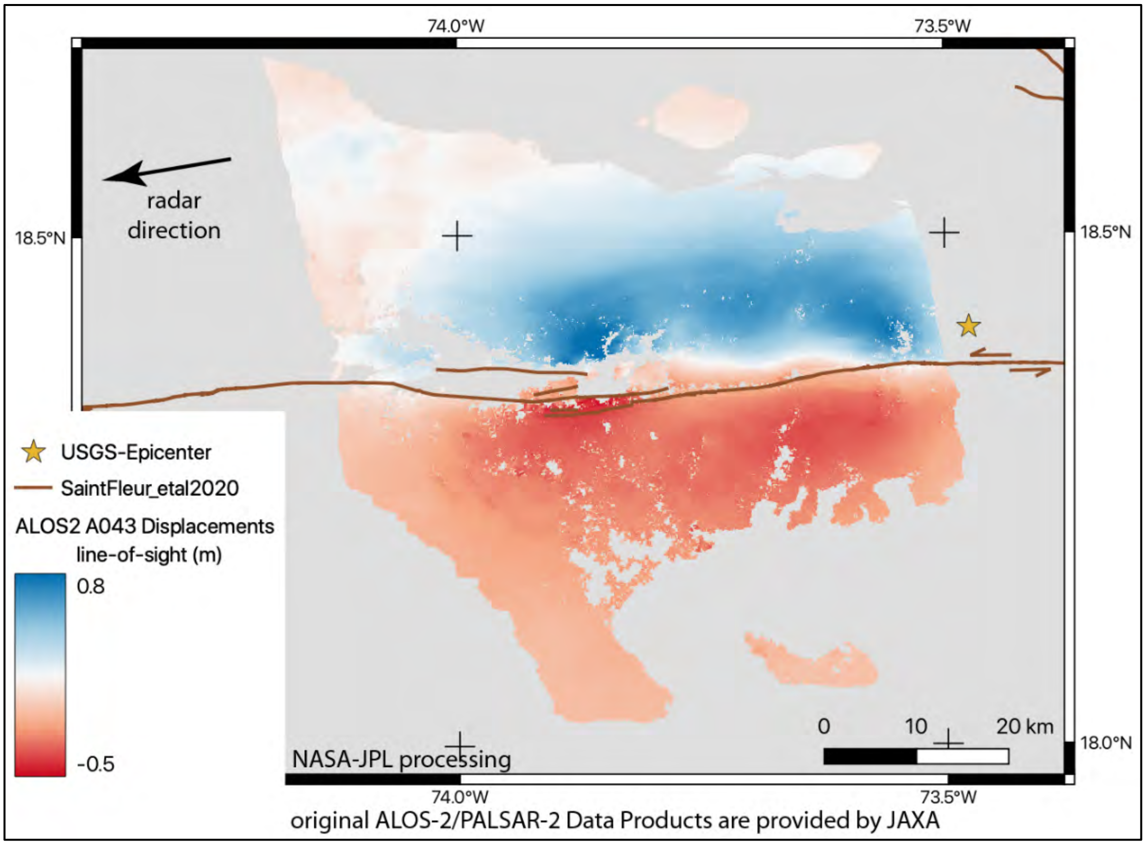


Figure 3. *Haiti Earthquake displacement map. The surface displacments in the radar line-of-sight (LOS) direction (shown by arrow) were calculated from InSAR analysis of JAXA ALOS-2 data. The blue colors show westward and upward motion, while the red tones show eastward and downward motion. The earthquake started at the epicenter (star) and ruptured faults some 50 km to the west. Previous ground map of faults (dark brown lines) from Saint Fleur, N., Y. Klinger, and N. Feuillet (2020), Detailed map, displacement, paleoseismology, and segmentation of the Enriquillo-Plantain Garden Fault in Haiti, Tectonophysics, 778, 228368, doi:10.1016/j.tecto.2020.228368. Original ALOS-2 data (2020-2021) JAXA. NASA/JPL-Caltech/JAXA.*

Project Summary	Global Rapid Damage Mapping System with Space-borne SAR Data
Application Products	DPM Damage Proxy Map DPM2 with multitemporal coherence analysis DPM3 with multitemporal coherence and amplitude analysis DPM4 with deep learning multitemporal coherence analysis
ARL Advancement	Current ARL 7, advanced one ARL level in 2021
Geographic Region	Global
Partners	Earth Observatory of Singapore (EOS), US Geological Survey (USGS) Univ. California-Los Angeles (UCLA) Federal Emergency Management Agency (FEMA), Geotechnical Extreme Events Reconnaissance (GEER) and Swiss Re

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

Primary Investigator: Margaret (Maggi) Glasscoe, University of Alabama in Huntsville
Co-Investigators: Bandana Kar/Oak Ridge National Laboratory, Doug Bausch/Pacific Disaster Center, ZhiQiang Chen/University of Missouri Kansas City, Ron Eguchi, Charlie Huyck, and Guy Schumann/ImageCat, Marlon Pierce/Indiana University, Kristy Tiampo/University of Colorado Boulder

Flooding is a major hydro-meteorological event that impacts billions of people across the world on a daily basis. Models and Earth Observation data are used to forecast flood severity, extent and depth, but these models and derived products are not globally operational, and they often provide different outputs. Therefore, we seek to rapidly classify flood severity by incorporating flood model outputs and remote sensing derived products from multiple platforms to help with flood risk mitigation and increase the resilience of impacted communities, and disseminate alerts using the Pacific Disaster Center's DisasterAWARE®, similar to the USGS PAGER impact analysis for earthquakes.

DisasterAWARE is maintained by end-user partners the Pacific Disaster Center, a University of Hawaii Applied Research Center. DisasterAWARE provides multi-hazard warning and situational awareness information through mobile apps and web-based platforms to millions of users globally. Its operational version is used by multiple national and international agencies including the U.N., but DisasterAWARE currently lacks a global flood identification and alerting component and does not integrate remote sensing components to enable near real-time validation of simulated flood modeling results. The flood severity and impact products generated in this project will be disseminated by DisasterAWARE, thereby enhancing its capability to be a multi-hazard alerting platform. These innovative, global results will be advanced to ARL 9 using a combination of modeling, machine learning, and Earth Observations, including SAR and optical sensors.

Global Flood Alerting

We have deployed an ensembled approach – Model of Models (MoM**)** that integrates flood data products from open source models and Earth observation data. The current version of MoM integrates forecasted outputs from GloFAS (Global Flood Awareness System), GFMS (Global Flood Monitoring System), HWRF (Hurricane Weather Research and Forecasting) with MODIS (Moderate Resolution Imaging Spectroradiometer) and optical sensor derived flood products to forecast flood severity on a daily basis globally at sub-watershed level. Now, MoM is

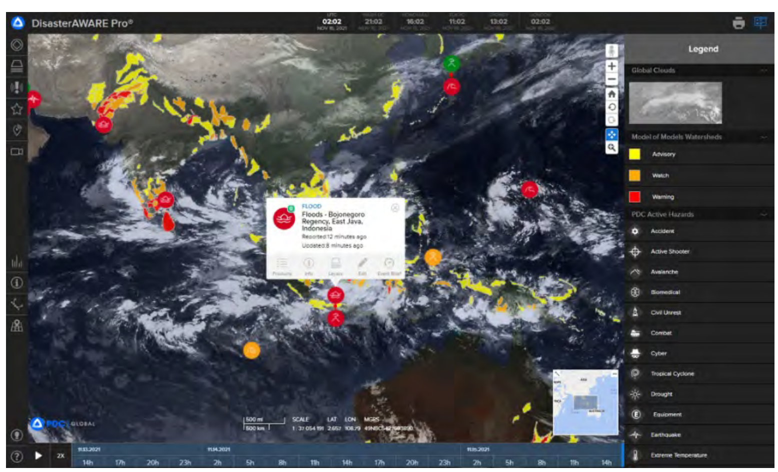


Figure 1. *A screenshot of the DisasterAware Platform*

operational and is in the production environment of Pacific Disaster Center to disseminate flood severity and alerts using the DisasterAWARE platform. While the flood severity and subsequent alert aid with preparedness activities, the SAR products derived for countries experiencing high severity will be used to assess impacts and for response efforts. The SAR products will be used for validation as well as determination of flood extent and depth at a finer scale.

Project Summary	Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE® Platform and Remote Sensing Technologies
Application Products	1. Model of Models 2. EO-based Flood Extraction 3. EO-based Damage Detection 4. End-to-end pipeline to PDC DisasterAWARE
ARL Advancement	6
Geographic Region	Global
Publications	4
Media Features	2
Conference Presentations	10
Partners	1. Pacific Disaster Center 2. Kirschbaum A.37 -- Enabling Landslide Disaster Risk Reduction and Response throughout the disaster life cycle with a multi-scale toolbox 3. Huyck A.37 -- Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response 4. Meyer A.37 -- Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters
Prospective Partners	1. Melgar A.37 -- Local Tsunami Early Warning with GNSS Earthquake Source Products 2. CEOS Flood Pilot 3. NASA GEO GFRM projects 4. Global Flood Partnership (GFP)

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

Principal Investigator: Kyle Hilburn/Colorado State University
Co-Investigators: Adam Kochanski and Angel Farguell/San Jose State University (SJSU), Jan Mandel/Colorado University

The United States has entered a new era of increasing wildfire frequency and intensity, with four of the top twenty largest fires in California history occurring in 2021. Fire-prone landscapes have become more densely populated and developed, resulting in steeply rising fire-suppression costs. But fire plays a crucial ecosystem role, and its prevention can lead to excessive fuel accumulation and catastrophic fires. Therefore, making decisions and taking actions based on the risks and benefits associated with wildfires and prescribed burns requires decision-support tools that integrate remote sensing with a coupled modeling framework for fire, weather, fuel, and smoke impacts.

WRF-SFIRE couples the Weather Research and Forecasting (WRF) atmospheric model with a fire spread model (SFIRE), fuel moisture model, and smoke emissions model. WRF-SFIRE is unique among decision-support tools because of its full coupling that allows representation of the interactions among the fuel, fire, atmosphere, and smoke components of the Earth System. This gives WRF-SFIRE the ability to simulate fires that create their own weather. U.S. Forest Service partner Ned Nikolov has stated, "WRF-SFIRE offers a new paradigm to assess and forecast the wildland fire environment which integrates in a physically consistent manner all components of fire behavior, i.e., local weather dynamics and its two-way interactions with the released heat by fires, the 2-D fire spread, and fire smoke emissions and trajectories. There is no operational tool currently available to fire and air-quality managers at any land-management agency that can quantitatively account for these simultaneous interactions. This makes WRF-SFIRE uniquely valuable to the field."

Our project has demonstrated that the era of operational real-time coupled fire forecasting capabilities is no longer off in some distant future but is a reality now. This year our project reached the major milestone of having achieved a "push button" system, where a user can specify where and when to run a forecast. Then, the system automatically gathers all the required data and begins the forecast without requiring additional user input or intervention. This capability allowed our team to produce more fire forecasts this year than ever before. Those forecasts include the Dixie Fire (*Figure 1A*) that grew to 963,309 acres and produced pyro-convection, which WRF-SFIRE correctly forecasted on July 29 as observed by GOES-17 satellite imagery. *Figure 1B* shows a WRF-SFIRE forecast of the Caldor Fire, which burned 221,835 acres.

WRF-SFIRE provides three-dimensional profiles of smoke, filling a gap in current remote sensing capabilities. Achieving a fully automated workflow also allowed us to conduct a one-week demonstration of the value of low-latency VIIRS data for initializing fires in WRF-SFIRE (*Figure 1C*). This work was in collaboration with Louis Nguyen who used Amazon Web Services to bring the compute resources to the data right after being downlinked to Earth, allowing us to initialize forecasts with observations only minutes old. We found a clear benefit in improved forecasts of fire spread using the low latency data. Our project partners at U.S. Forest Service also reached a significant milestone of producing real-time fire ignition probabilities and disseminating them on the Rocky Mountain Center website (*Figure 1D*). We also contributed fire and smoke forecasts to the BURNEX21 training activity in June 2021.

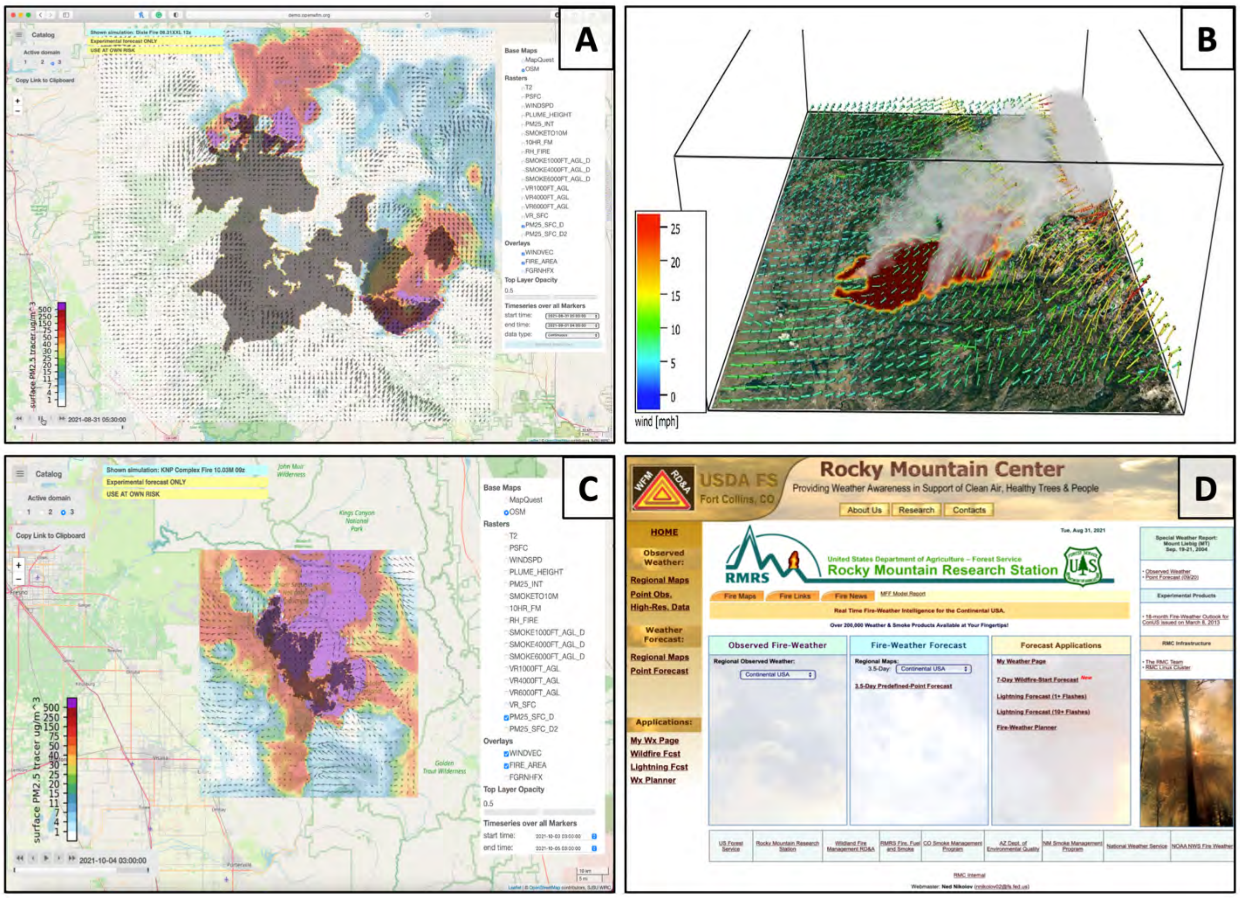


Figure 1. *(A) WRF-SFIRE forecast of fire spread (gray) and smoke (colors) for the Dixie Fire (Aug. 2021). (B) WRF-SFIRE forecast for the Caldor Fire (Sept. 2021) visualized in 3-D to show the vertical structure of the smoke (C) WRF-SFIRE Forecast for the KNP Complex Fire (Oct. 2021) using Low Latency VIIRS Active Fire Detections (D) Fire Ignition Probabilities on the Rocky Mountain Center website*

Project Summary	Coupled Interactive Forecasting of Weather, Fire Behavior and Smoke Impact for Improved Wildland Fire Decision-Making
Application Products	WRF-SFIRE Wildland Fire Information and Forecasting System WRF-SFIRE Smoke and Visibility WRF-SFIRE Fire Perimeter WRF-SFIRE Fuel Moisture
ARL Advancement	Current ARL 6, advanced one ARL level in 2021, Goal ARL 7
Geographic Region	CONUS, but extended system to provide global coverage
Partners	USFS Rocky Mountain Center for Fire-Weather Intelligence (RMC) and USFS Wildland Fire-Management Research, Development & Application (WFM RD&A), National Predictive Services
Prospective Partners	USFS – Ned Nikolov, Susan O'Neill, Richfield, Utah USFS Office U.S. Department of the Interior (DOI) Office of Wildland Fire – Kimber Roshelle Pederson NOAA National Weather Service – Mark Struthwolf and Darren Van Cleave National Predictive Services – Nick Nausler NASA Earth Science Technology Office (ESTO) AIST NOS (Advanced Information System Technology New Observing Strategies) program – Louis Nguyen (NASA LaRC)
2021 Journal Papers	3
2021 Media Features	2
2021 Scientific Presentations	12

Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response

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

Damage to critical infrastructure from natural hazards and climate change can result in cascading (indirect) economic impacts. These losses are often far greater than the (direct) cost to repair or rebuild but are poorly understood. Incorporation of economic modeling into risk analysis is rarely achieved, given the complexity of disaggregating macro-based economic data to a spatial resolution suitable for modeling. Therefore, we will use Earth Observation (EO)-based datasets to develop methods of allocating production potential into a format suitable for incorporating into economic modeling tools.

In the last year, the Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response project has developed the Critical Infrastructure Interdependency Index (CIII) and Critical Infrastructure Interdependency Risk Index (CIIRI) integrating EO, CAT modeling, and economic modeling. The Critical Infrastructure Interdependency Index (CIII) of a region (e.g., a country, a state, or a county) measures how much international and domestic economic activities depend on that region's production output to produce other goods. This index provides a synthetic indication of the interdependencies within and across domestic and international supply chains. The Interdependency Index allows for the comparison and ranking of different regions in terms of their contribution and role in global supply chains.

The Critical Infrastructure Interdependency Risk Index (CIIRI) combines the notion of the Interdependency Index with the hazard and the vulnerability of the exposed CI to obtain an indication of risk. The hazard is incorporated through a probabilistic approach, while the vulnerability is embedded in damage functions for CI. The CI Interdependency Risk Index allows for the comparison and ranking of different regions according to their risk for supply chain disruption and cascading impacts in domestic and international economies. It also highlights areas/regions where more in-depth analyses are required (e.g., first a physical inventory and then a team-based qualitative risk approach). These indices have been ported to an insurance platform (ARL 5) and used to explore practical applications and pilot programs with collaborators, including the Global Facility for Disaster Risk Reduction (GFDRR) and WTW (Willis Towers Watson). Reponses have reinforced the importance of Environmental Science and Governance (ESG) and climate change given the need for a global approach that minimizes bias. Pilots are being discussed to test results with international investment organizations as such groups are under new pressure to address emerging climate risks and are seeking understanding and tools to do so.

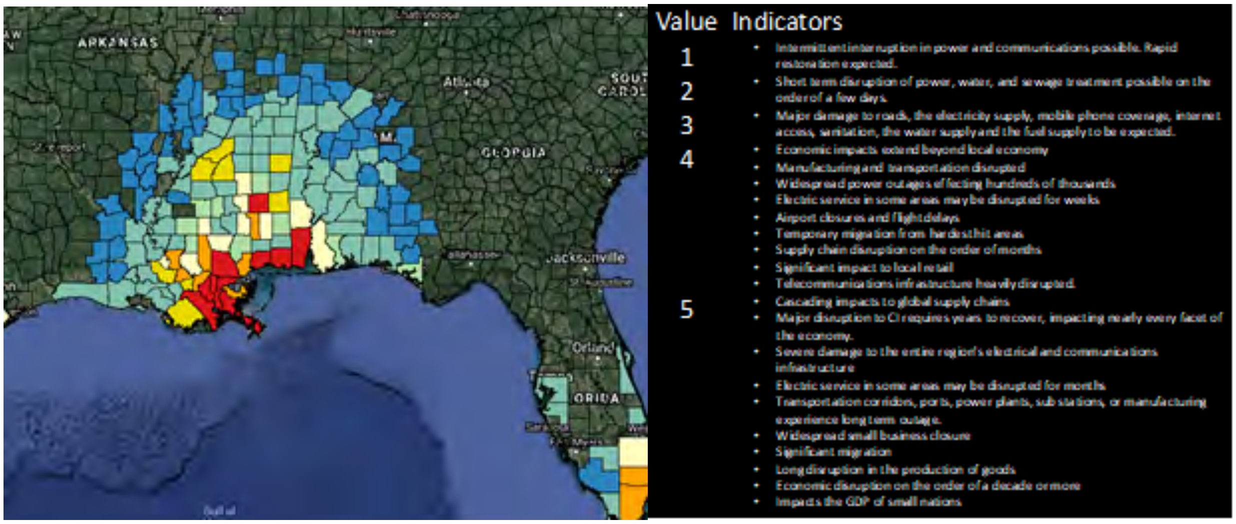


Figure 1. *The CIIRI (left) captures the economic impact from disruption for a given peril, in this case, Hurricane Katrina. These raw results are then aggregated to the county level and indicate the disruption capacity. The next phase of work will link these fiscal disruption numbers to indications of disruption (working title: Economic Disruption Index or EDI, right).*

Stakeholders have also provided constructive feedback, including: 1) there has to be a method to establish accuracy (i.e., how good is it?), and 2) there has to be a way to relate results of the index back to potential real-world impacts (i.e., what does a high-risk result mean?). To relate results to real-world impacts, an Economic Disruption Index was developed that scales dollar figures resulting from the analysis to a scale that presents the type of impacts to be expected given disruption. To establish accuracy, major 21st century hurricane scenarios provided by Kinetic are being run to compare predicted and actual hurricane disruption. Additional improvements based on user feedback have included: adjustment of fragility functions to reflect power and equipment failure, rather than building damage, modification of global fragility functions to reflect regional construction practices, and the incorporation of National Resilience Indices to reflect diminished capacity given damage.

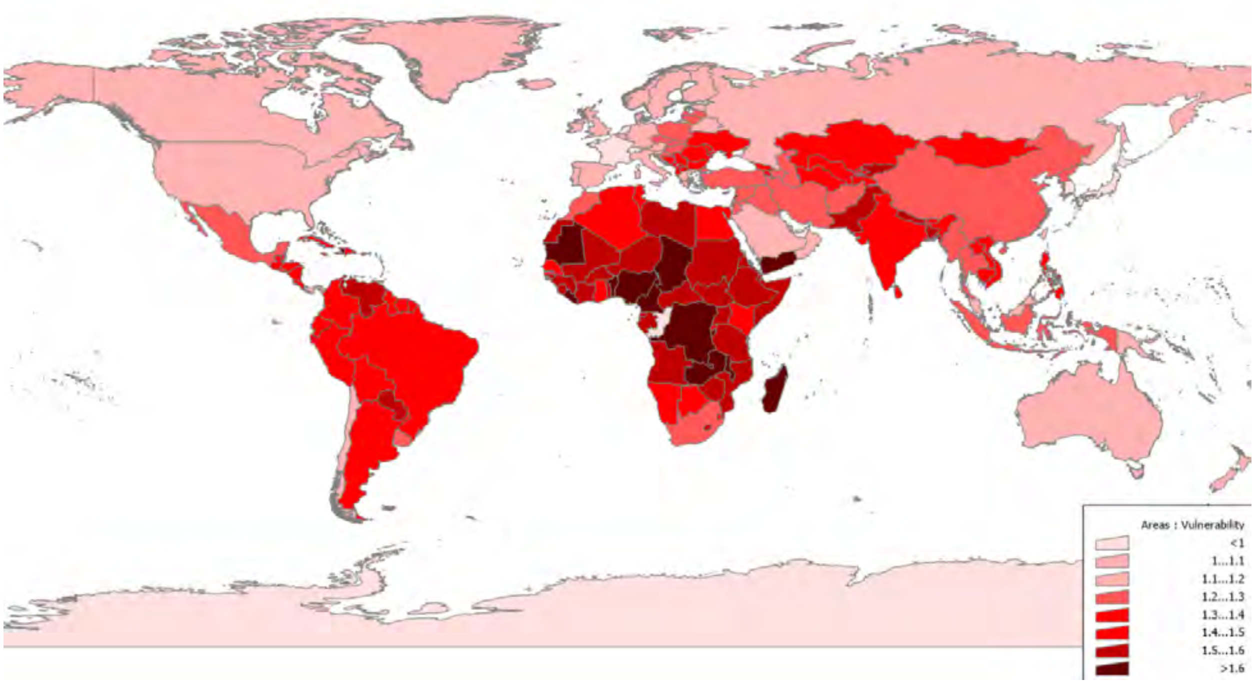


Figure 2. *The vulnerability index provides an indication of the quality of infrastructure of interest and incorporates NASA research in developing building vulnerability databases that characterize the likelihood of potential damage.*

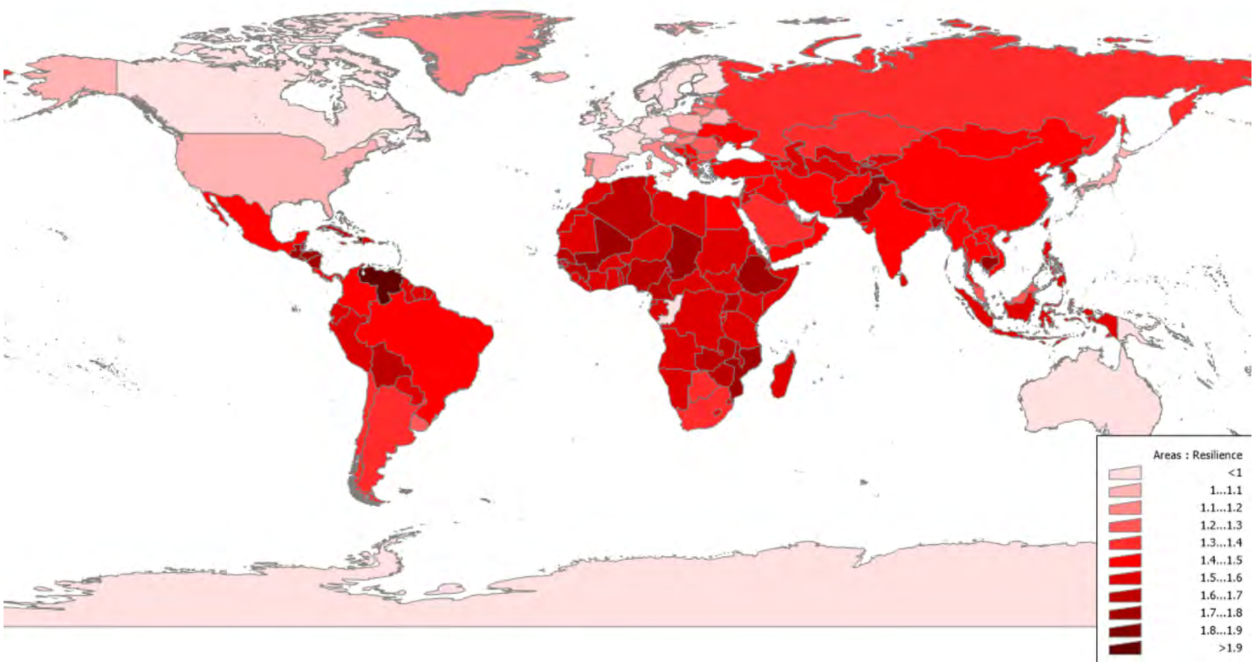


Figure 3*. Resilience adjustment factors, ranging from 0.9 to 2.0. The factors normalize to the US specific given availability of fragility and vulnerability curves for critical infrastructure. For example, Haiti returned a resilience score of 2.0, therefore risks returned (such as downtime, output) can be expected as twice that of the U.S.*

The Vadodara pilot successfully demonstrated the utility of Earth Observation (EO)-based approaches for developing flood risk products to support mitigation and response activities. Working with initial input and direction from the Vadodara city officials, this research sought to demonstrate the applicability of EO-based flood forecast and inundation maps in decision-making and to assist city officials and other government stakeholders with their disaster risk reduction and risk management initiatives.

Four major components of the research focused on different aspects of flood risk management. First, hydrodynamic models and EO data (Synthetic Aperture Radar SAR imagery) were used as a part of a Model of Models (MoM) approach. This approach integrated forecasted flood extent outputs from the hydrodynamic models and optical-imagery-derived near real-time inundation information to forecast flood severity daily at sub-watershed level globally. For the study, imagery from the European Space Agency's (ESA) Sentinel-1A/B satellite (C-band SAR) with 6-12 day repeat period was used to identify inundation at high-resolution in Vadodara for the floods of 2019 and 2020. A flood "saturation index" was developed to establish inundated areas in Vadodara. The saturation index showed an increase in value for both 2019 and 2020 floods as areas become inundated, reaching a maximum at the height around peak flooding days and then reducing in value as floodwaters receded. The third area of research focused on developing a critical infrastructure risk index combining critical infrastructure exposure data and flood extents for Vadodara and the surrounding region to indicate risk. The CIIRI identifies regions where damage to infrastructure caused by floodwater depth and/or velocity can result in significant cascading impacts due to supply chain disruption. Finally, the various flood products will be tested and distributed through the DisasterAWARE® enterprise platform.

As a result of NASA's recent realignment initiative, ImageCat has teamed with Diego Melgar's A.37 team to focus on extending his work into tsunami loss estimation. The A.37 Tsunami Loss Estimation Group, which met for the fourth time this fiscal year, includes the University of Oregon, the University of Washington, Central Washington University, Tohoku University (Japan)/RTi-Cast, and ImageCat. The goal of this work is to demonstrate through a pilot study how the following model components can be combined to produce first-order estimates of tsunami damage and loss to western U.S. coastlines: tsunami generation source model, coastal inundation model, building and infrastructure fragility and exposure models, and loss calculation engine for assessing scenario-based losses.

So far, the group has agreed on the following assumptions: a) the pilot study area will be coastal Washington, b) up to two candidate "high risk" areas will be selected, c) the pilot will initially use empirical damage functions produced by Tohoku University and d) using ImageCat's loss calculation engine, losses from at least one major tsunami.

Dr. Marina Mendoza has been working alongside and Zhenghui Hu to do much of the research, including incorporating economic modeling into the loss modeling and EO process. The project team is also coordinating with Murtala M. Badamasi to explore applications in the flood arena. In addition, the project has explored disproportionate impacts of seismic hazards on the African American community in Los Angeles using EO-generated building exposure data.

Project Summary	Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response
Application Products	Critical Infrastructure Interdependency Index (CIII) and Critical Infrastructure Interdependency Risk Index (CIIRI)
ARL Advancement	ARL 5
Geographic Region	India, Southeast Asia
Partners	Willis Towers Watson (WTW), Humanitarian Open Street Map Team (HOT OSM), Center for International Earth Science Information Network (CIESIN), and City of Vadodara, Gujarat, India
Prospective Partners	Global Facility for Disaster Risk Reduction (GFDRR)
2021 Journal Papers	4
2021 Media Features	1
2021 Scientific Presentations	23

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

Principal Investigator: 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 have pervasive impacts globally and effective modeling of the hazard and exposure of these processes is critical for accurate and dynamic impact estimates to support decision making throughout the disaster lifecycle. But, rarely do studies approach modeling processes from different scales with the goal of using local scale scenario-based assessment of cascading landslide hazards to inform global scale modeling. Therefore, we use Earth observation data from multiple sensor types, platforms and spatiotemporal scales to develop a suite of tools to model susceptibility, hazard, and risk from landslide hazards to support key decision-making and resilience-building.

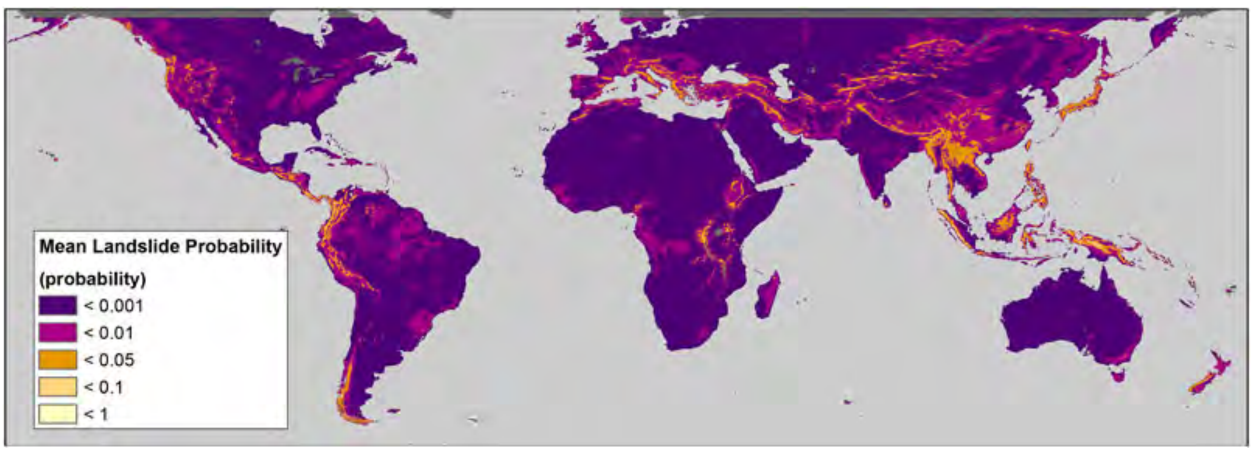


Figure 1. *The mean landslide hazard prediction over the time period May 1, 2015 to April 30, 2020, showing the global distribution based on new model estimates. Credits: Reproduced from: Stanley et al. 2021; https://doi.org/10.3389/feart.2021.640043.*

As part of this project, a new version of the Landslide Hazard for Situational Awareness (LHASA) model was developd using a data-driven approach to assess landslide hazard globally. The goal of this work is to advance from categorical to probabilistic global nowcasts of rainfall-triggered landslide hazard estimates. Figure 1 highlights the mean landslide hazard estimate based on the new Version 2 model based on the period of 2015–2020. New landslide inventories and modeled data products, such as soil moisture and snow mass have been incorporated to improve the overall perfoamnce accuray of this system. These nowcasts are intended to facilitate disaster planning and response at regional to global scales by a broad range of stakeholders such as governments, relief agencies, emergency responders, and insurers. The new LHASA model is currently being incorporated into the DisasterAware system at the Pacific Disaster Center with the goal of identifying alerts for landslide hazards and exposure in near real-time with a semi-automated appraoch. The LHASA model has matured from research and development (ARL 2 to a ARL 7) during this project.

A fundamental component of the LHASA version 2 is the machine-learning approach it takes to characterize relatively probability for landsliding. The model draws upon satellite rainfall data, slope, soil moisture, lithology and other surface information to highlight areas where hazards and exposure are elevated and requires robust landslide inventory data to train the model. The Semi-Automatic Landslide Detection (SALaD) system has matured from ARL 3 through 6 and is now publicly-available on Github at NASA. The SALaD system has been critical to increasing the number of high-quality inventories to train LHASA version 2 (Figure 2). SALaD has also been deployed to support rapid mapping efforts for major events including the Haiti earthquake (August 2021) among many others. The landslide locations were provided to a number of decision makers to help inform critical decisions about landslide impacts. It was also used to identify potential hazards in more remote locations.

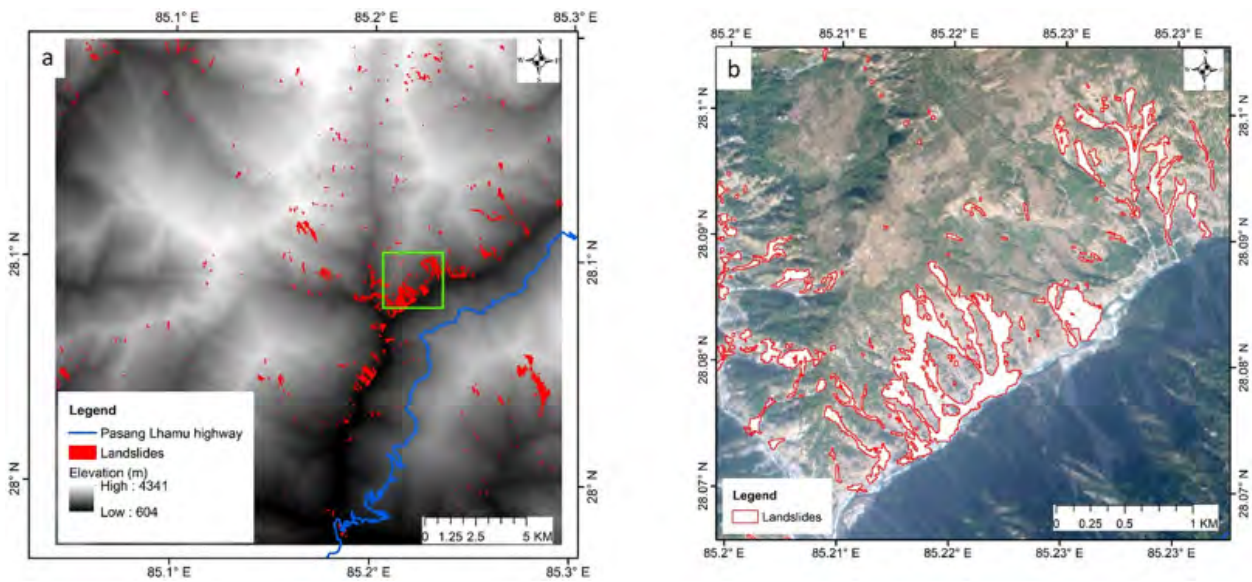


***Figure 2**. Distribution of landslides detected by SALaD in a study area along the Pasang Lhamu Highway in Nepal (Left) and a zoomed in view of green box of the mapped landslides (Right). Reproduced from Amatya et al. 2021; https://doi.org/10.1016/j.enggeo.2021.106000*

In order to better characterze the impacts that landslides may have around the world, the LHASA model incorporates estimates of landslide exposure. A new study by Emberson et al. 2021 highlights the patterns of landslide exposure and how teleconnections such as El Nino Southern Oscillation (ENSO) may affect the landslide exposure differently across geographic regions. Figure 3 highlights these patterns in changing exposure relative to the average rates defined based on LHASA's exposure estimates, finding that in some parts of the world exposure can increase or decrease by as much as 50% in a strong El Nino or La Nina year.

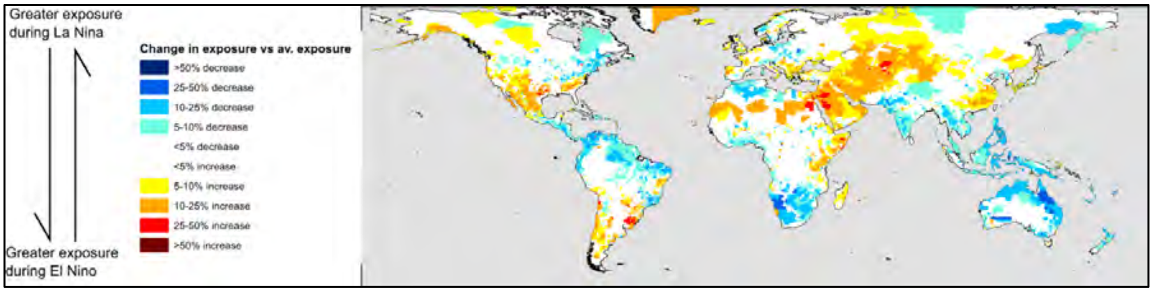


***Figure 3**. This figure highlights how landslide exposure changes based on variations of the Multi-variate ENSO index, normalized by the long-term average exposure. Yellow and red colors indicate increases in population exposure during El Nino conditions, while blue colors indicate increases in exposure during La Nina conditions. The results are represented according to administrative district 2. Credits: Figure reproduced from Emberson et al. 2021; https://doi.org/10.1038/s41467-021-22398-4.*

Project Summary	Enabling Landslide Disaster Risk Reduction and Response Throughout the Disaster Life Cycle With a Multi-Scale Toolbox
Application Products	Landslide Hazard Assessment for Situational Awareness (LHASA) Semi-Automatic Landslide Detection (SALaD) Landslide Exposure Model (LEx) Coseismic landslide model
ARL Advancement	Current ARL 7, advanced ARL 2 levels in 2021. LHASA-Rio implementation is ARL 9
Geographic Region	Global and operational implementation in Rio de Janeiro (LHASA-Rio)
Partners	Pacific Disaster Center (PDC), USGS, National Geospatial-Intelligence Agency (NGA), Rio de Janeiro, Aga Khan Agency for Habitat (AKAH), Army Geospatial Center, Global Facility for Disaster Risk Reduction (GFDRR)
Prospective Partners	BGC Engineering, Risk Management Solutions (RMS), Google Crisis Mapper
2021 Journal Papers/technical publications	10
2021 Media Features	4
2021 Scientific Presentations	20

Day-Night Monitoring of Volcanic Sulfur Dioxide and Ash for Aviation Avoidance at Northern Polar Latitudes

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

Dangers that volcanic ash clouds pose on inflight air traffic safety can lead to prolonged flight cancellations that affect the airline industry, economy, and personal travel. Low-latency satellite observations provide crucial information for rerouting air traffic around volcanic clouds. But, existing ultraviolet-based (UV) ash and sulfur dioxide (SO_2) monitoring is unavailable at night or under low-light conditions. Therefore, NASA Disasters supports Earth observation applications for advanced monitoring capabilities that better serve the private sector (aviation control services and operational users) and the public for the ever-increasing number of flights that operate at night or fly over the Arctic polar region.

The team is operationalizing its *Arctic Volcanic Plume Tracker (AVPT) application*, which includes the integration of enhanced UV-based and thermal infrared (IR)-based Science Processing Algorithms (SPAs) into NASA's Direct Readout Laboratory (DRL) International Planetary Orbiter Processing Package (IPOPP). The UV-based SPA (OMPSnadir v2.7.1) retrieves quantitative SO_2 column density and UV Ash Index day-time products from the Ozone Mapping and Profiling Suite. The IR-based SPA (VIIRS-SO2 v1.3) retrieves day-night volcanic SO_2 and ash indices from the Brightness Temperature Difference (BTD) measured by the Visible Infrared Imaging Radiometer Suite (VIIRS). The AVPT application supports both the SNPP and Joint Polar Satellite System-1 (JPSS-1/NOAA-20) missions.

In 2021 the AVPT functionality was demonstrated in DRL's Global View environment (https://directreadout.sci.gsfc.nasa.gov/?id=dspContent&cid=207) and in partner's operational environments at the Geographic Information Network of Alaska (GINA/UAF), USGS Alaska Volcano Observatory (AVO) and at the Finnish Meteorological Institute's (FMI) Sodankylä Ground Station, reaching ARL 7. Co-investigators at GINA provide real-time satellite data acquisitions and immediately stage AVPT data to public-facing data distribution servers. GINA also pushes data to the NWS Alaska Region Headquarters in Anchorage and AVO. From there, data are distributed to the NWS weather forecast offices and A-VAAC. In Dec. GINA started producing VIIRS volcanic SO_2 and ash products and bringing those products into AWIPS to make them available for operations at Anchorage VAAC (NWS Arctic region).

In 2021 the USGS/AVO co-investigator, David Schneider incorporated GINA DR volcanic ash and SO_2 products, including AVPT data into the publicly available VolcView image browser environment (Figure 1). He evaluates AVPT data utility during eruption responses by the USGS Alaska Volcano Observatory (AVO) and provides feedback to the team. He will provide training to AVO satellite duty scientists on the AVPT products. Additionally, the USGS co-investigator will provide guidance (e.g., informal case studies, consultation about algorithm strengths and limitations) to the Anchorage Volcanic Ash Advisory Center (VAAC) and to the Science Officer from the National Weather Service (NWS) Alaska Aviation Weather Unitwhich houses the VAAC) as they develop training materials for forecasters, bringing the project to ARL 8/9).

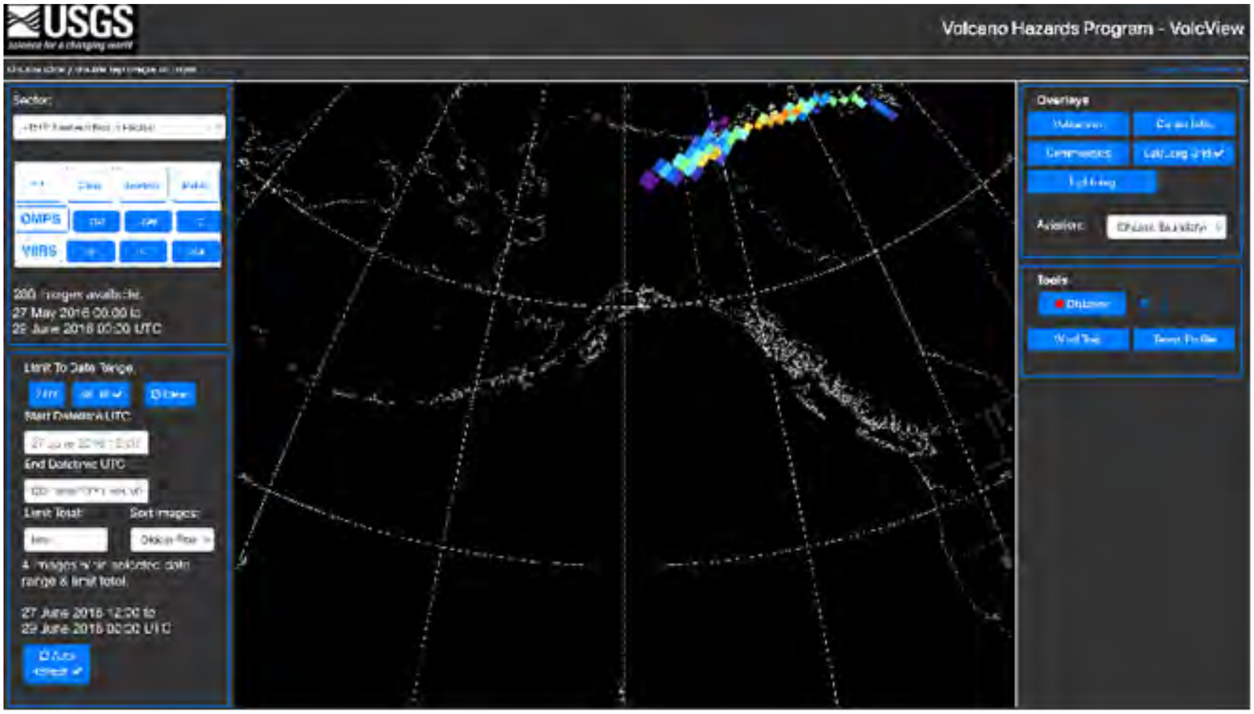


Figure 1. Direct readout SNPP/OMPS volcanic SO2 data for the March 2016 Mount Pavlof eruption integrated into the AVO VolcView Decision Support Tool (DST) (https://volcview.wr.usgs.gov/vv-gui/). VIIRS IR SO2 data are ingested into this DST at AVO and Anchorage Volcanic Ash Advisory Center (VAAC) for day and nighttime coverage. This milestone demonstrates AVPT application use in partner's decision making (ARL 7).

Currently, partners at FMI's DR satellite center in Sodankylä use SNPP/OMPS data and fetch GINA OMPS data from Alaska. Together, the Sodankylä and GINA ground stations provide near-complete coverage of the Arctic. The AVPT data from Sodankylä are available via FTP, and both Sodankylä and GINA received data are re-distributed for users via EUMETSAT's EUMETCast multicast service. The SO_2 and UVAI maps for the Arctic are also publicly available for visual examination on the recently redesigned FMI's SAMPO website: https://sampo.fmi.fi/products. VIIRS SO_2 processing is currently under implementation and testing, with data expected to be available later in 2022. Furthermore, the NOAA-20 OMPS and VIIRS processing will be implemented to enhance SAMPO's service in the future.

In 2021 the team participated in DARRT responses to volcanic eruptions and answered user questions and requests. The team responses included Fagradalsfjall (Iceland) eruption in March, the Feb.-March eruptions of Etna volcano (Sicily, Italy), the Soufriere/St. Vincent eruption in April, the Mt. Nyiragongo Volcano eruption in May, the Taal (Philippines) eruption in July, Cumbre Vieja in La Palma (the Canary Islands, Spain) in Sept.-Nov. and the Mt. Semeru (Indonesia) eruption in Dec. The team produced volcanic SO_2 maps in several formats, contributed to story maps and posted them on the public website: https://so2.gsfc.nasa.gov and NASA's Disasters Mapping Portal. VAAC forecasters use the webpage for post-event analysis and post-activity reports and science papers. A-VAAC acting manager, Nate Eckstein, introduced AVPT volcanic SO_2 products from the Nov. 3 eruption of Karymsky volcano to his staff. This information was also shared with Scott Lindstrom at SSEC/CIMSS, who added it to one of his blogs about the Karymsky eruption: https://cimss.ssec.wisc.edu/satellite-blog/archives/43108. The project paper (Krotkov et al., Remote Sens. 2021,13(19), https://doi.org/10.3390/rs13194003 was shared with A-VAAC staff to raise awareness of NASA's new AVPT products and how to interpret them.

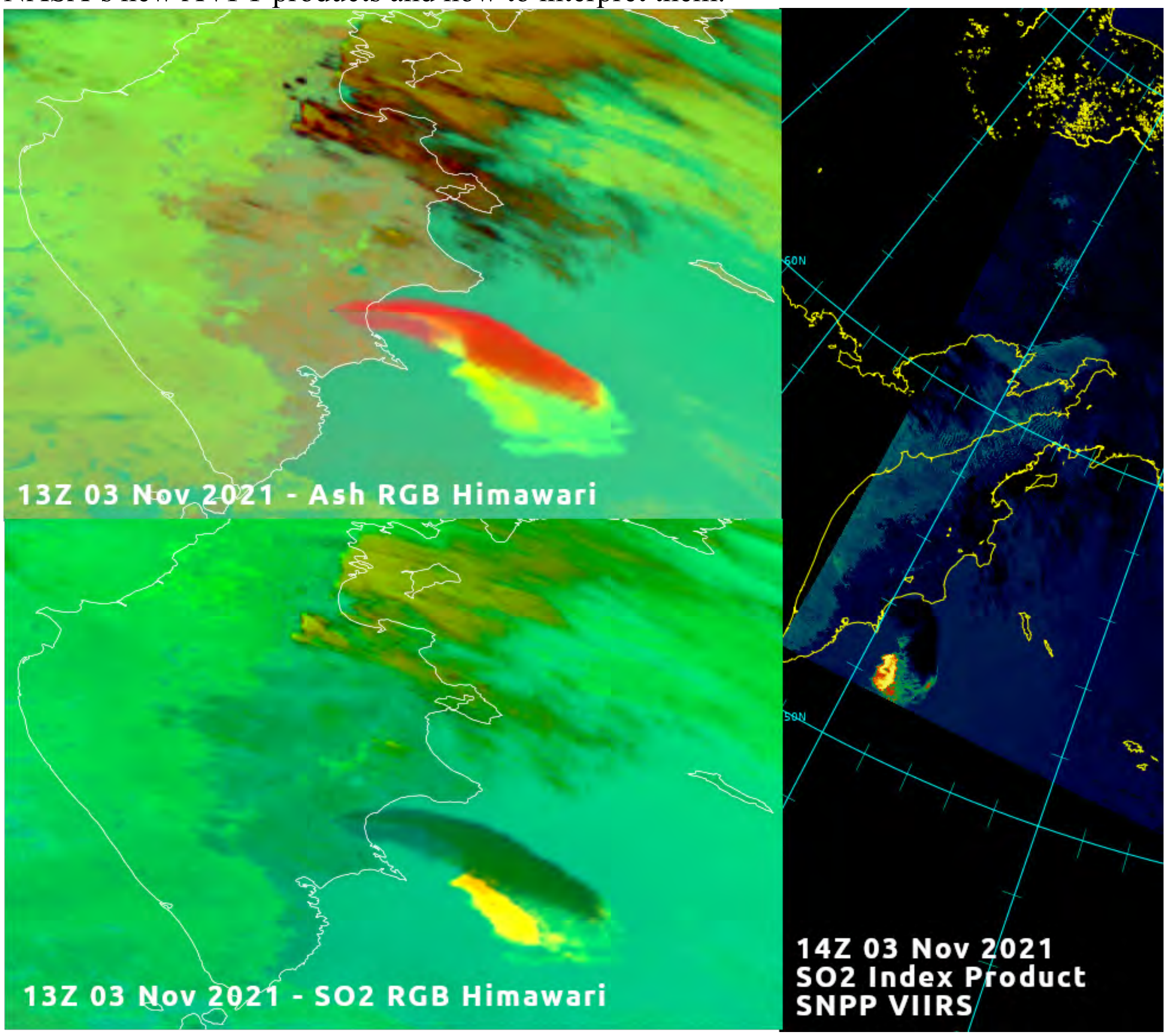


Figure 2. *Anchorage VAAC imagery of Karymsky (Kamchatka) volcanic Ash (top left) and SO_2 (bottom left) clouds. Right: GINA VIIRS SO_2 imagery of Karymsky SO_2 cloud using real-time AVPT products. High values of VIIRS SO2 Index (red-white) from NOAA-20 VIIRS allow tracking volcanic plume from Karymsky eruption.*

The team is actively engaged in retrospective studies of past volcanic eruptions updating the multi-satellite volcanic SO_2 web page: https://so2.gsfc.nasa.gov and the volcanic SO_2 emissions database: https://so2.gsfc.nasa.gov/eruptions/MSVOLSO2L4_20220105.txt. The team continues collaborations with volcanologists and atmospheric scientists. Following the response to the Cumbre Vieja eruption in La Palma, Dr. Emilio Cuevas, director of Izaña Atmospheric Research Center, State Meteorological Agency of Spain (AEMET) wrote, "AEMET highly appreciates your support in this volcanic emergency and is looking forward to collaborating on the proposed activities."

Project Summary	Day-Night Monitoring of Volcanic Sulfur Dioxide and Ash for Aviation Avoidance at Northern Polar Latitudes
Application Products	Arctic Volcanic Plume Tracker (AVPT) 2 Applications for NASA's DRL IPOPP (OMPS nadir v2.7.1, VIIRS-SO2 v1.3)
ARL Advancement	Current ARL 7, advanced one ARL level in 2021
Geographic Region	Alaska, Aleutians, North Pacific, Kamchatka, Kuril Islands, Iceland and Scandinavia but globally extensible
Partners	USGS AVO, NOAA's NWS Alaska Volcanic Ash Advisory Center (A-VAAC), European Support to Aviation Control Service, NASA Direct Readout user community, Smithsonian Institution Global Volcanology Program, Finnish Meteorological Institute
Prospective Partners	Franz Mayer UAF, Kyle Hilburn CSU, Jean-Paul Vernier LaRC, Simon Carn MTU
2021 Journal Papers	4
2020 Media Features	1
2020 Scientific Presentations	7

Local Tsunami Early Warning with GNSS Earthquake Source Products

Principal Investigator: Dr. Diego Melgar/Oregon State University,
Co-Investigators: Dr. Brendan Crowell/University of Washington, and Dr. Tim Melbourne/Central Washington University.

Throughout the 21st century, the world has experienced many large tsunamis and has seen catastrophic consequences from them through loss of life and long-lasting damage to infrastructure. Advances in geophysical instrumentation and methods have led to early warnings and rapid forecasts of expected impacts for many natural hazards, but warning for tsunamis, especially for those at the coasts closest to the earthquakes, remains an open problem. Therefore, this project implements novel techniques that rely on measurements from onshore Global Navigation Satellite System (GNSS) sites of the deformation produced by the earthquake. This is then ingested into hydrodynamic model to produce rapid forecasts of tsunami amplitudes.

Large earthquakes produce deformation, often on the order of several meters, which can be measured in real-time with permanent GNSS stations. As these networks have proliferated worldwide, researchers have developed algorithms that leverage this real-time data to characterize events as they are occurring. One of these algorithms, Geodetic-First Approximation of Size and Timing (G-FAST), was developed by the investigators of this project. It can deliver real-time estimates of the magnitude of an earthquake, its geographic extent, and details of the amount of motion (slip) on a fault. The 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. It has been routinely triggering in real-time when global events occur and is undergoing testing and evaluation within this framework.

Knowledge of the earthquake, however, is not sufficient for a successful tsunami warning. A rapid forecast of the expected amplitudes at the coasts closest to the earthquake, where the tsunami arrives in as little as 10 minutes, is of paramount importance. In the last year, the software has been built to connect the real-time output of G-FAST to NOAA's hydrodynamic modeling capabilities. This software can now produce Rapid Forecast Tsunami Amplitudes (RFTAs) for every earthquake that triggers the system. In addition to the real-time evaluation of G-FAST in this project period, the reliability of these rapid tsunami forecasts is being carried out. Constant communication with the National and Pacific Tsunami Warning Centers (TWCs), who are also operated by NOAA and are the ultimate issuers of warnings, is already underway. The expectation is to translate the code from the NOAA CTR to the operational warning centers in Honolulu and Alaska to produce RFTAs for events of consequence on the U.S. west coast in the first five minutes after the earthquake.

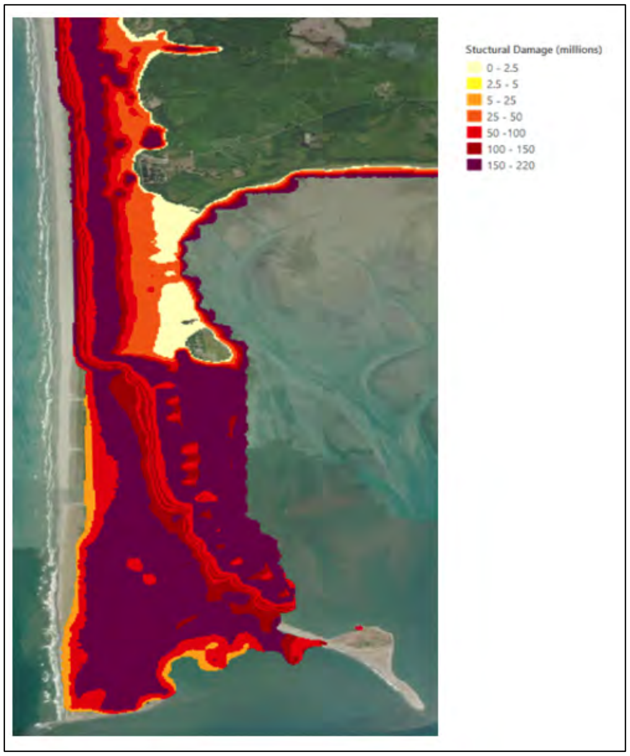


Figure 1*. Estimated losses from an M9 earthquake in the Greys Harbor region in southern Washington state. This is obtained by combining a similated event with hydrodynamic modeling and exposure databases.*

While the project's immediate goal focuses on the U.S. West Coast, the expectation is that its impacts will be felt across the Pacific at all earthquake prone regions. NOAA provides warnings that are used by all international governments. Better and faster tsunami warnings from NOAA will benefit many. However, there is also interest from developing nations that operate real-time GNSS networks in becoming self-reliant. These countries do not yet have the expertise to develop or implement real-time modeling codes. We have an ongoing collaboration with GNS in New Zealand to deploy and test G-FAST. Through that collaboration, we have generated large testing suites of GNSS data for them and are assisting with code deployment. This is significant because New Zealand provides geophysical services for many Pacific island nations. The open-sourcing of G-FAST has been mutually beneficial as a form of science diplomacy. In exchange for the code and training, countries are willing to offer access to their real-time networks. This broadens the number of regions for which NOAA can issue faster warnings.

Following realignment efforts, the project has also begun focusing energy on moving past hazard assessments and started studying the issue of risk through a collaboration with the A.37 project led by ImageCat, principal investigator Huyck, "Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response," and Tohoku University's International Research Institute of Disaster Science. We have begun a two-pronged analysis of (1) whether simulated tsunami data used for testing the RFTAs can be combined with population and exposure data to reasonably estimate expected losses from a great Cascadia earthquake and (2) whether the RFTA product can be used to quickly estimate loses in the immediate aftermath of a tsunami. This use would be analogous to the PAGER product produced by the USGS for shaking purposes. Our early findings suggest that (1) is possible. An example of losses for an M9 earthquake in Southern Washington is shown in Figure 1. Work is ongoing with the group for (2).

The project is also training the next generation of diverse geodesy and tsunami scientists. These fields of Earth Science are still underrepresented by women and minority researchers. This year, it has funded Dr. Kevin Kwong to work on realignment tasks as part of his postdoc research and Sean Santellanes and David Small for work toward their doctoral degrees.

Project Summary	Local Tsunami Early Warning with GNSS Earthquake Source Products
Application Products	Geodetic-First Approximation of Size and Timing (G-FAST) Rapid Tsunami Forecast Amplitude (RTFA)
ARL Advancement	Current ARL 6, Advanced 1 level in 2021
Geographic Region	Cascadia Pacific Northwest and Pacific Ocean Basin
Partners	NOAA Center for Tsunami Research, NOAA Pacific Tsunami Warning Center, and NOAA National Tsunami Warning Center
Prospective Partners	U. California-Berkley, USGS ShakeAlert, Centro Sismologico Nacional (Chile), GNS Science (New Zealand)
2021 Journal Articles	3
2021 Media Features	2
2021 Scientific Presentations	2

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

Principal Investigator: Franz Meyer, University of Alaska, Fairbanks
Co-Investigators: Andrew Molthan/NASA MSFC, Lori Schultz/NASA MSFC, Jordan Bell/ NASA MSFC, Batu Osmanoglu, and MinJeon Jo, NASA/GSFC

Weather-related hazards are ubiquitous in the United States, including 1) hurricane storm surges; 2) rapid snowmelt and heavy rainfall; 3) severe weather leading to flash floods and tornadoes, and 4) seasonal freeze and thaw of rivers that may lead to ice jams. In each setting, end-user partners engaged in disaster risk management need access to data-processing tools helpful in mapping past and current disasters to capture their impacts.

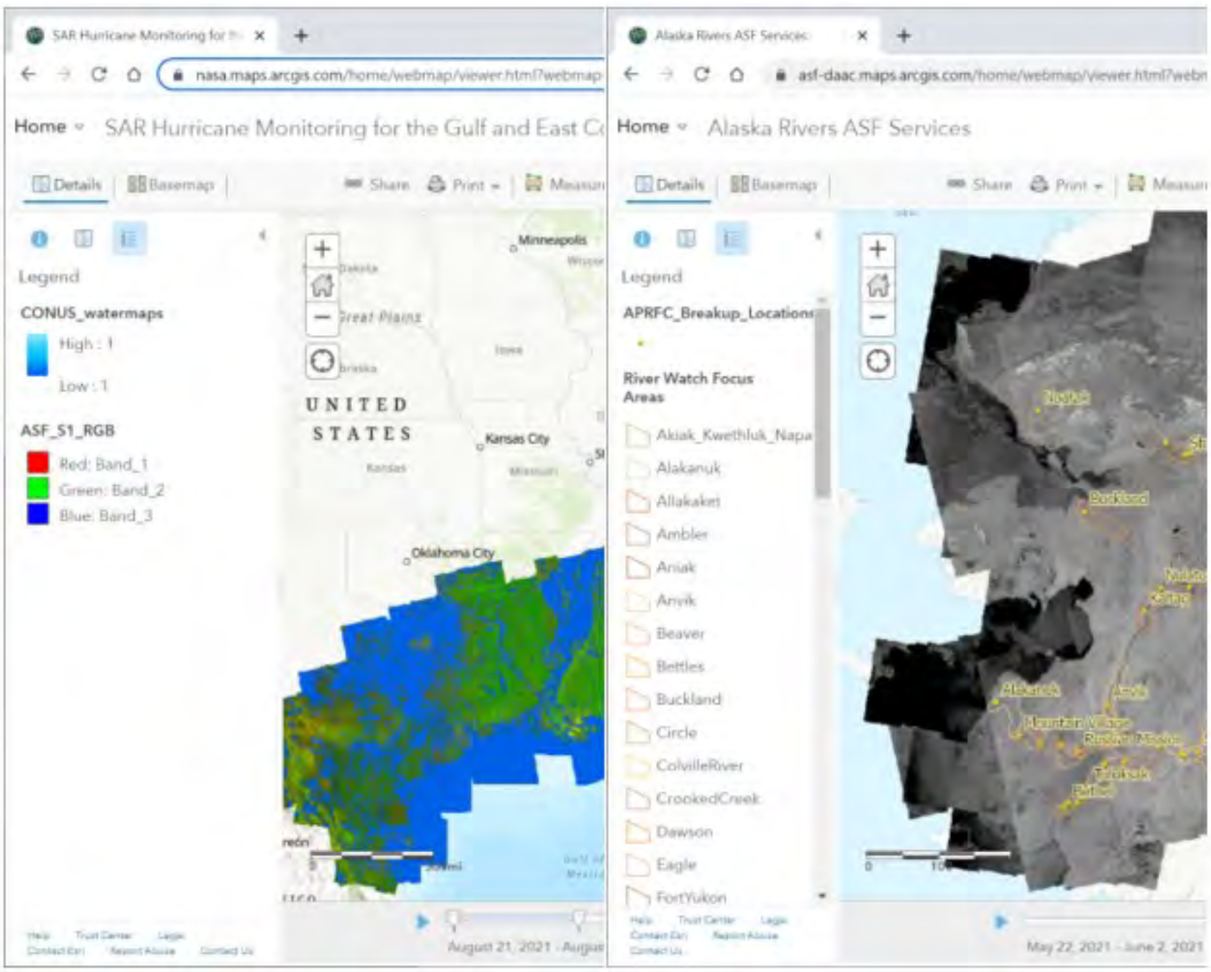
Analyzing past events supports risk mitigation by providing understanding of what has already occurred and how to alleviate impacts in the future. Generating the same or similar products during adaptive response means that lessons learned from risk analysis, including economic/finance implications, will carry forward to an event. SAR data are particularly useful for these activities due to their all-weather, 24/7 monitoring capabilities. Still, complex processing and high computational costs associated with SAR require the development of approaches that streamline product generation. To meet this need, this project is developing a cloud-based automatic data analysis toolbox to process SAR data into value-added products that address the mapping of meteorological and hydrological disasters. The integration of these products into end-user decision-making workflows will improve capacity in the use of SAR in response situations. Furthermore, the SAR analysis tools will help users prepare for and mitigate risk by allowing them to process image time series gathered from NASA, or through their purchases of commercial data. To ensure adoption of the developed technology, the project partners with the U.S. Department of Agriculture Foreign Agricultural Service (USDA-FAS), the National Weather Service Alaska-Pacific River Forecast Center (APRFC), the Federal Emergency Management Agency and private industry representative Corteva.

In 2021, the team finalized the development and high ARL implementation of its main hazard information products such as RTC30 image time series, RTC30-Color product, HYDRO30 Surface Water extent, and FD30 Flood Depth Information. We also completed our cloud-based production pipeline to now be able to **generate SAR-based hazard products automatically and across large spatial scales**. The system is implemented in the Amazon Web Services cloud and allows the generation of hundreds of data products per hour in an efficient and cost-effective cloud-based implementation.

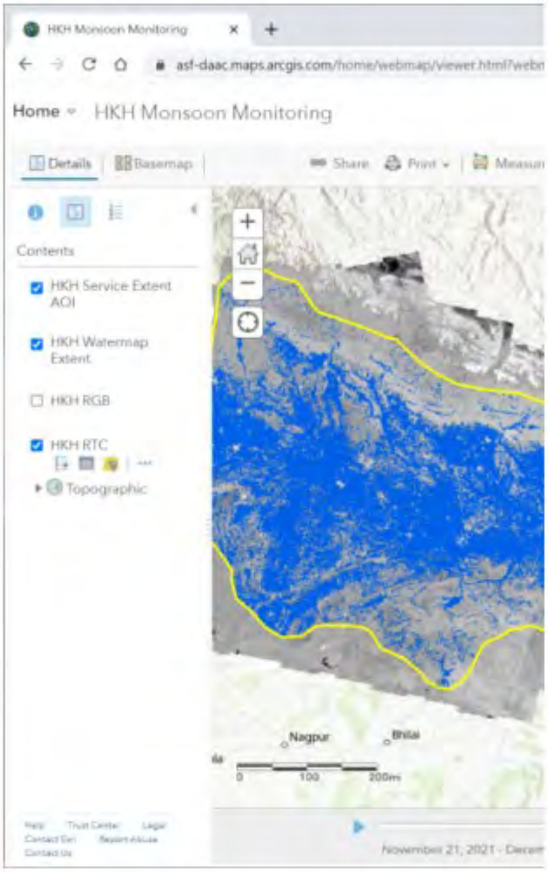
In 2021, the developed project capabilities have been used to support three large-scale and long-duration hydrology monitoring activities:

- In the first of these activities, we have been cooperating with the NASA Applied Sciences Disaster program area to routinely generate SAR-derived products (RTC30, RTC30-Color, HYDRO30) along the U.S. coastline from the Gulf of Mexico to the Canadian border (Figure 1a). This activity started in spring 2021, is still ongoing, and supports NASA's hurricane monitoring efforts.

- The second operational monitoring effort supported project partner, Alaska Pacific River Forecast Center, with statewide SAR information to monitor the 2021 Alaska Spring Breakup floods (Figure 1b). This activity lasted from April to Aug. 2021.
- The third activity is providing operational SAR-derived hazard information (RTC30, RT30-Color, HYRO30) to partner ICIMOD, a regional organization in the Hindu Kush Himalaya, to support monitoring of the 2021 South Asia Monsoon floods (Figure 1c). This activity lasted from April to Dec. 2021 and will restart in April 2022. Water authorities in Bangladesh, Bhutan, and Nepal routinely used project-derived data.



(a) (b)



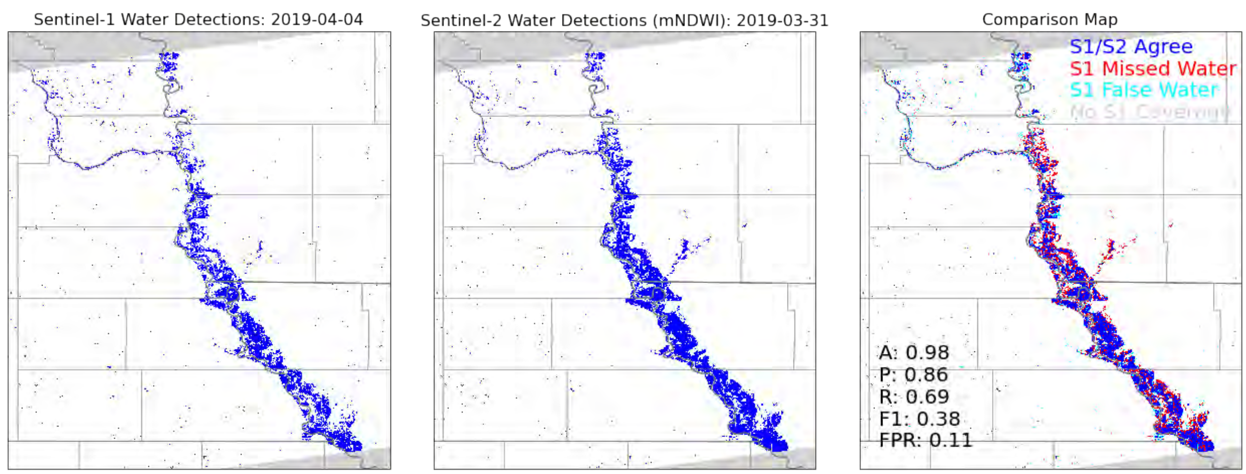
(c)

Figure 1. *Examples of automatically-generated SAR-derived hazard products created by the project team for three different monitoring activities: (a) hurricane watch service developed to support the NASA Applied Science Disasters program area with SAR-based flood information across the hurricane-prone regions of the U.S.; (b) Alaska Spring Breakup Watch service, providing SAR-based information to track flooding related to the Alaska spring river breakup; (c) Monsoon watch service, providing flood extent information across the Hindu Kush Himalaya to support efforts to monitor seasonal monsoon floods. In all cases, data are generated automatically, across vast spatial scales, and across several months of event duration.*

To make our SAR-derived products easily discoverable and accessible by end-users, we worked in 2021 with NASA's Applied Sciences program to develop novel ESRI Image Service solutions that can serve large volume SAR data directly from a cloud-based data bucket. The developed Image Services allow users to stream SAR data directly into their desktop GIS environment. They also make it easy to integrate SAR data into existing decision support systems and other web portals. In the examples shown in Figure 1, image services are used to stream SAR products directly from a cloud-based location to web GIS platforms. Image Services facilitated the integration of SAR-derived products into the decision support system at project stakeholder USDA Foreign Agriculture Service, who are now using our data their Global Agriculture and Disaster Assessment System (GADAS).

In 2021, the project also continued its work on the calibration and validation of quantitative hazard products using test sites in the U.S. and abroad. Our validation efforts effort demonstrated good performance of HYDRO30 flood extent (Figure 2a) and FD30 flood depth products for sites in Nebraska and in the Hindu Kush Himalaya (Figure 2b).

(a)



(b)

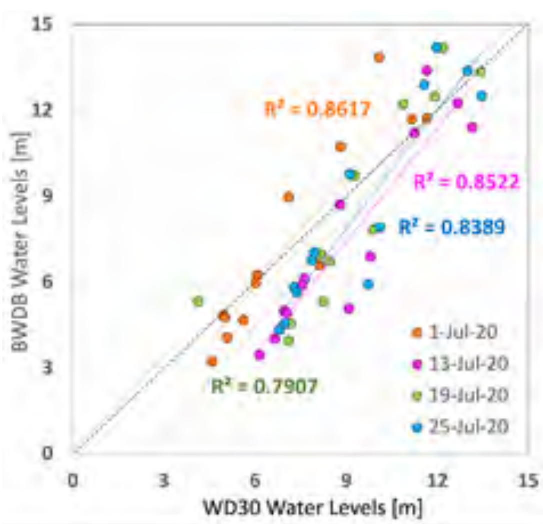


Figure 2. *Example of product validation efforts: (a) a comparison of HYDRO30 water extent information to detections derived from Sentinel-2 data using mNDWI. Data acquired over the Missouri River in Nebraska (Sentinel-2 on April 4, 2019; Sentinel-1 on March 31, 2019). The overall accuracy of the water extent information in this example is 98% (b) comparison of WD30 to water level information from BWDB for the confluence of Padma and Meghna rivers, Bangladesh. Difference colors correspond to different observation dates. An R2R2 near or larger than 0.8 can be observed for different dates in 2020. Also, an RMSE of less than 2m was achieved for each of the analyzed dates.*

Beyond these activities, the project has continued to make project capabilities available to other NASA and non-NASA efforts: (1) NISAR: the team worked with the NASA-ISRO (Indian Space Research Organisation) SAR (NISAR) project and science teams to provide access to cloud-based platforms and support NISAR applications activities with the weather-related hazard community; (2) CEOS (Committee on Earth Observation Satellites): The team is part of the CEOS Application-Ready Data for Land (CARD4L) initiative, providing input into CARD4L specifications for SAR-derived ARDs; (3) AmeriGEO: The team has integrated workflows and materials into AmeriGEO capacity-building activities funded under NASA GEO grant #80NSSC18K0317; (4) OPERA: As a member of the OPERA Project Science Team, the principle investigator of this project has been able to support the development of the OPERA Surface Water Extent products.

The project team is composed of personnel with diverse backgrounds and working from a dispersed set of locations. The team includes personnel with German, Turkish, Korean, and U.S. backgrounds with near-even gender contribution. Team members are working from locations across the U.S. The team has worked closely with partners all around the world. In 2021, it provided trainings on SAR-based Weather-Hazards monitoring to audiences in the Hindu Kush Himalaya (India, Bangladesh, Bhutan, Nepal), Central American (Honduras, El Salvador, SICA) and South America (Colombia, Ecuador). The project also supports two graduate students.

Project Summary	Integrating Synthetic Aperture Radar Data for Improved Resilience and Response to Weather-Related Disasters
Application Products	7 SARVIEWS Products (RTC30; RTC30-Color; CCD30; HYDRO30; FD30; AG100; AG100-IN), 1 Tool (operational cloud-based platform)
ARL Advancement	Current ARL 7, advanced to ARL 7 in Nov. 2021
Geographic Region	Global with emphasis on USA, Bangladesh, India, Argentina
Partners	(1) U.S. Department of Agriculture – Foreign Agriculture Service (USDA-FAS); (2) NOAA APRFC
Prospective Partners	(1) Corteva Agriscience; (2) Alaska Volcano Observatory; (3) NGA; (4) AmeriGEO; (5) NASA ROSES 18 Disasters A.37 PIs Krotkov, Kirschbaum, Glasscoe have all been added as collaborators.
2021 Journal Papers	3
2021 Media Features	4
2021 Scientific Presentations	8

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

Primary Investigator: Francis M. Monaldo/University of Maryland, College Park
Co-Investigators: Cathleen Jones, Ben Holt/NASA JPL, Ellen Ramirez/NOAA Satellite Applications Branch (SAB), Sean Helfrich /NOAA National 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

Marine oil spills are a significant environmental problem whose optimal response requires knowledge of at least relative oil thickness. The recent increase in the availability of satellite Synthetic Aperture Radar (SAR) imagery offers the possibility of more frequent oil thickness measurement. Still, there is no operational or routine implementation of a validated algorithm for relative oil thickness. Therefore, this project will produce, validate, and implement an oil thickness product in an operational context. The team is proud to include racially and gender-diverse team members—especially from the Hispanic community— involved in both research and leadership. Oil spills usually have the most impact on poor and marginalized communities. Mitigation of these effects will have a disproportionately positive effect on individuals in such communities.

NOAA is responsible for monitoring U.S. waters for accidental and intentional oil spill events. This information is provided to the U.S. Coast Guard (USCG) and the NOAA Office of Response and Restoration (OR&R). George Graettinger and Lisa DiPinto of OR&R are co-investigators and provide stakeholder guidance. Graettinger has noted that “understanding the extent of an impacted area and potentially exposed species and habitats is key to understanding the implication of an oil spill; however, the identification of the greatest potential risk is critical to minimizing injury to these resources. The ability to prioritize this risk requires timely and accurate oil volume and thickness data so that the response community can act effectively to mitigate risk as quickly as possible.”

Ellen Ramirez of NOAA contributed to NASA’s disasters response to the Huntington Beach, California spill, coordinating satellite observations. Oscar Garcia of Water Mapping provided in situ oil measurements. NASA’s Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) was located nearby and provided SAR imagery over the spill.

Knowledge of the location of the thickest areas of oil during a spill event can be critical in response and restoration. There are a variety of optically-based sensors that provide important information to characterize oil spills. However, such sensors are constrained by illumination angles, whether it is day or night, and cloud cover. SAR imagery is a day-night, all-weather sensor. With the launch and operation of Sentinel-1A/B and Radarsat Constellation Mission, commercially tasked systems, and especially the upcoming launch of the NASA-ISRO SAR (NISAR), SAR imagery of oil spills will continue to have great impact.

Over the past year, the project has identified a "contrast ratio" algorithm that compares the amount of SAR image brightness reduction in oil-covered areas with open water to estimate oil thickness. The algorithm has been implemented in the SAR Ocean Products System (SAROPS), NOAA research and operations environment for SAR imagery.

COVID constraints had limited our planned fields tests in 2020, but in 2021 we were able to conduct two field tests off the coast of Santa Barbara. Santa Barbara has natural oil seeps. UAVSAR imagery over this area allowed us to apply the contrast ratio approach. The United States Coast Guard provided a vessel for in situ oil measurements and deployment of a drone with a multispectral imager to classify oil.

Figure 1. *Drone deployment from the USCG cutter Blackfin*

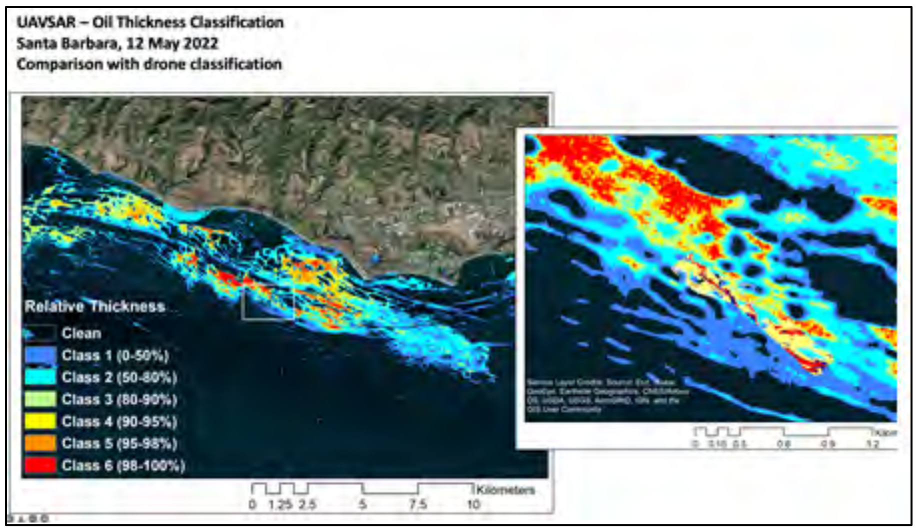


Figure 2. *Oil classification from the UAVSAR. The right-side image shows a zoomed inversion of this classification. Superimposed on the is the drone classification retrieval. The two show a similar structure in the oil classification distribution. Similar comparisons will allow us to calibrate the contrast ratio approach.*

Project Summary	Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context
Application Products	Marine Oil Spill Thickness (MOST). NOAA's SAROPS (SAR Ocean Product System) operationally produces synthetic aperture radar (SAR)-derived wind speed and marine oil spill extent products.
ARL Advancement	4-5 (6 submitted for review)
Geographic Region	Global coastal areas with emphasis on U.S. coastal areas
Partners	University of Maryland, Earth System Science Interdisciplinary Center; NASA/JPL; NOAA/NESDIS/STAR; NOAA/NESDIS/SAB; NOAA/OR&R; Water Mapping LLC; MDA (formerly known as MacDonald, Dettwiler and Associates, U.S. Coast Guard University of Norway; NOAA Emergency Response Division (ERD), Bureau of Safety and Environmental Enforcement (BSEE); Environment and Climate Change, Government of Canada; Marine Spill Response Corporation (MSRC) recently added to the project.
2021 Journal Papers	0
2021 Media Features	4
2021 Scientific Presentations	6

NASA ROSES 2016 A.50 Group on Earth Observation (GEO) Flood Risk Monitoring (GFRM) Community Activity Projects

The Disasters program area leads the Group on Earth Observations (GEO) Global Flood Risk Monitoring (GFRM) Community Activity, which supports and integrates efforts that leverage Earth observations to improve the ability to assess flood risk on a global scale and translate risk information to impacts at regional, national and sub-national levels by supporting risk-informed decision-making. NASA Disasters funded three GEO GFRM projects in 2021, which addressed a wide variety of technical challenges related to global flood risk monitoring and served multiple stakeholders by providing critical EO-derived flood risk information.

Integrating Global Remote Sensing and Modeling Systems for Local Flood Prediction and Impact Assessment

Principal Investigator: Albert J. Kettner/Univ. of Colorado-Boulder/Dartmouth Flood Observatory
Co-Investigators and collaborators: Bob Brakenridge/UC-Boulder, Bob Adler/U. Maryland-College Park, Guy Schumann/Remote Sensing Solutions Inc, Fritz Policelli/NASA-GSFC, Cinzia Zuffada/NASA-JPL, and Emmalina Glinskis/CloudToStreet

As a contribution to the GEO Element "Global Flood Risk Monitoring," previous efforts for this project were primarily directed towards producing state-of-the-art, globally scoped, mostly automated flood prediction, flood alert system, with monitoring capabilities and risk evaluations. And although these flood information systems are not all in an implementation phase where data can automatically be provided to the various partners, most of the work has been done to share data with the larger community. This project focuses on regions in Africa, Central America, Pacific states, and the Caribbean. The above-mentioned larger team will work closely together with end-users through organizations like the World Food Programme (WFP) HQ and regional offices, UN Food and Agriculture Organization (FAO), and US AID (OCHA), Red Cross 510 HQ and their field offices, reinsurance companies, the African Risk Capacity network, potentially the World Bank when feasible, and the West African SERVIR Hub, to form a community of practice and add value to their existing flood-related work. And the project builds on an international community of practice consisting of experts and institutions (the Global Flood Partnership) who are data providers and product end-users involved in flood remote sensing, measurement and disaster response and preparedness.

Support, available from additional projects provided to the University of Colorado/DFO, made it possible to purchase a new state-of-the-art server in 2021. The previous server has been operating for six years and we are in the process of decommissioning it. The new server is operating on the latest Linux Red Hat operating system. To minimize security incidents. The server is placed into the University of Colorado network, behind the firewall with only a few ports directed to the outside. The latest software for the Web Map Server (WMS) has been installed and will soon be operational. WMS data layers include the NASA NRT Global Flood processor, University of Maryland GFMS simulation flood extent and depth and the DFO flood products. Several of the products mentioned above are also made available through a phone app developed with prior NASA support that was provided to the University of Colorado/DFO.

Collaborations with the CYGNSS project of NASA JPL are in an advanced stage. Although outside the project's scope, the ultimate goal is to incorporate flood products derived from GNSS-Reflectometry data into partnering platforms. The availability of the Cyclone Global Navigation Satellite System (CYGNSS) data globally in the latitudinal band +/-38 degrees provides the opportunity to develop a new flood product at a nearly daily frequency. Advantages of CYGNSS-derived water extent products compared to optical surface water products are that surface water can be detected in all weather conditions, and surface water can be detected under vegetation. First-order comparison has been done for a case study in *IGARSS* where GNSS-Reflectometry data is compared with operational MODIS flood maps to evaluate potential applicable surface water algorithms (Figure 1). All explored algorithms tend to overestimate surface water extent. Results will be presented at the 2022 IGARSS conference, Kuala Lumpur, Malaysia. In the next phase we will extend the number of case studies to determine if overestimation of surface water extent is more likely during certain conditions and use additional satellite data (e.g. Sentinel 1 and 2) to quantitatively evaluate the CYGNNS-derived flood products. CYGNNS products will be also compared to products of the Global Flood Monitoring System (GFMS). The GFMS Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrievals for GPM (IMERG) precipitation information as input to a quasi-global (50°N - 50°S) hydrological runoff and routing model running. GFPM flood extent products generated by collaborators from the University of Maryland are currently integrated in the DFO Interactive Flood Maps Portal and are freely available as Web Map Service (WMS) to integrate on other platforms.

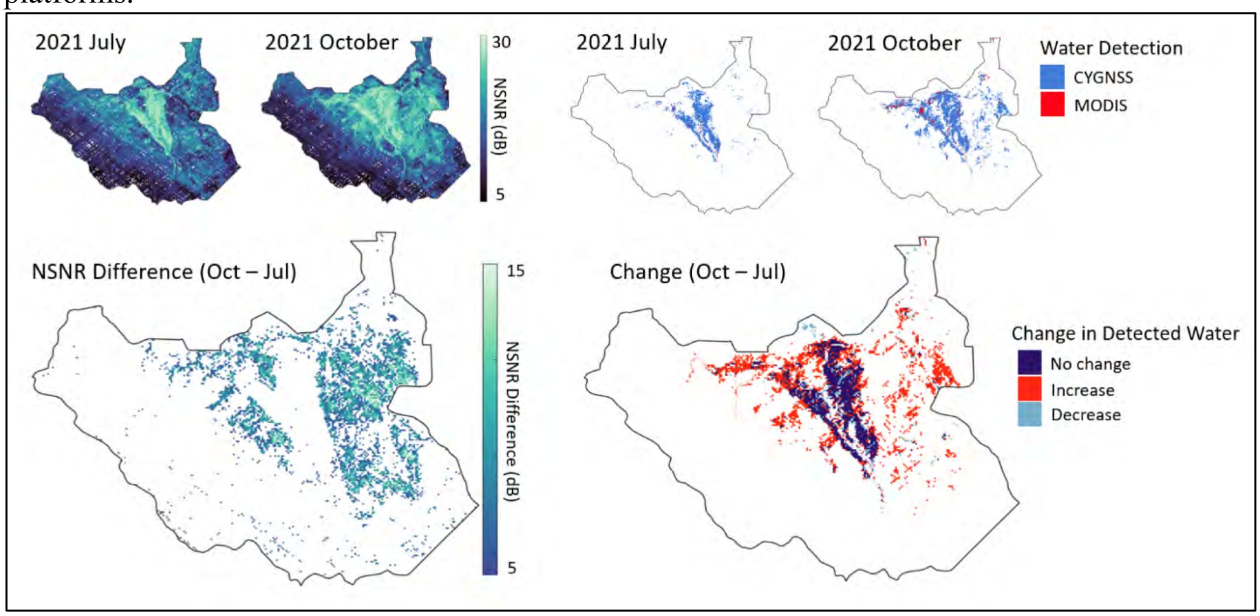


Figure 1. *Top left: CYGNSS NSNR before (July) and during (Oct.) the flood of 2021 in South Sudan became widespread. Top right: Water detected for both months shown by CYGNSS and MODIS. Bottom: Change in CYGNSS NSNR (left) and change in water detected by MODIS and CYGNSS (right) from July to Oct. After IGARSS publication, Wilson-Downs et al., 2022.*

In collaboration with the NASA's Goddard Space Flight Center team, we have made significant progress on developing a flood alert system. The need of a flood alert system is maybe best expressed by one of our end-users, the UN-FAO: "*If I try to summarize an ideal flood alert system from the perspective of the emergency geospatial community, I would say that there is an unmet need for a service that keeps the following principles at its core: Global Coverage, Daily Coverage, Minimized false-positive and false-negative, Moderate-resolution (at least), Automated detection and reporting of daily noteworthy events, Automated (or at least facilitated and smooth) linkage with high-resolution on demand SAR imagery [(the entire data pipeline: check SAR image availability, obtaining images, analysis, mapping, outcomes dissemination)], Data licensed for free use for humanitarian purposes, and usable for secondary analysis (such as impact estimation on agriculture, infrastructures, road accessibility...), Data easily accessible, disseminated via web services in a stable and reliable machine-readable format (WFS and WMS, FTP repositories, user-friendly APIs.), Some sort of early event-specific grading estimation (from low to severe potential humanitarian impact; estimation based on flood magnitude, extension, population density, historical events in the same area, social media...) To my knowledge, existing services satisfy only a subset of these characteristics, and users have always to decide to sacrifice either the resolution, or the global coverage, or the timeliness of the information, and so on. The principles in the above list are sorted by importance and urgency (solely based on my partial personal experience, of course), but I think that they are all important, and the more elements are incorporated the more useful the system will be.*"

The current project did not have sufficient support to accomplish all the necessary elements indicated by end users but does accommodate for a pilot study where part of such an alert system is realized. Already, the outcome of this pilot has made it possible to apply for additional support from NASA successfully. Under this project, an experimental flood alert system is developed. Currently, users can subscribe to receive a daily automated email that provides information about the eight largest floods, where they occur, and how large the flood extent is. With additional support, we will further automate this, so WMS are automatically created with high-resolution flood extent maps for each location. These services can then be automatically incorporated into the end-users GIS platforms or viewed through an interactive web portal.

Project Summary	Integrating Global Remote Sensing and Modeling Systems for Local Flood Prediction and Impact Assessment
Application Products	NASA NRT Global Flood Mapping DFO Current Flooding Displays DFO River and Reservoir Watch DFO Flood Event Summaries DFO Web Map Server
ARL Advancement	Current ARL 5 with sub-elements at 6 and 7 in 2021. Goal ARL 7 in 2022
Geographic Region	Global with emphasis on Africa, South Asia, and Latin America
Partners	UN WFP, UN FAO, and Red Cross 540 are the most active partners.
2021 Peer Reviewed Publications	6
2021 Presentations	6

Towards a Global Flood and Flash Flood Early Warning Early Action System Driven by NASA Earth Observations and Hydrologic Models

Principal Investigator: Andrew Kruczkiewicz/Columbia University-International Research Institute for Climate and Society
Co-Investigators: JJ Gourley/U. Oklahoma-Norman, Humberto Vergara/U. Oklahoma-Norman, Helen Greatrex/Columbia U.

Led by Andrew Kruczkiewicz of Columbia University, International Research Institute for Climate and Society (IRI), this project proposed to enhance disaster manager capacity to better prepare, respond and recover to floods. Currently, disaster management organizations in developing countries are not preparing sufficiently for flash floods. The lack of available, accessible and usable information, combined with a lack of capacity to take action, has led to a state of insufficient preparedness.

This project team is collating and standardizing information from multiple disaster impact datasets to illuminate existing flood datasets and create a global flash flood dataset and maps of flash flood risk, vulnerability, and exposure. Action-based, in-depth case studies are in development that will highlight Standard Operating Procedures/Early Action Protocols, or the actions/lead-times available to different organizations and floods to include the Rohingya refugee camps in Bangladesh and new case studies in Latin America.

Several new flash flood forecasting tools, including the Ensemble Framework for Flash Flood Forecasting (EF5), are being validated and tested against observed flash floods with the intent to see if they can forecast flash flood impact (Figure 1). All project elements will be pulled together to create user-defined validations of flash flood forecasts, with hazard parameters, evaluation metrics and lead time directly informed by the disaster managers.

This GFRM Community Activity, with the support of these dedicated research project teams and under the guidance of the Steering Committee, continues to conduct outreach and integration efforts to align existing flood risk-related activities and leverage the global GEO community to connect science activities with decision making authorities.

One major highlight of 2021 was working with interns. Interns included graduate students from Columbia University and Lehman College (a public college in the Bronx with most students from backgrounds that are traditionally underrepresented in STEM). All students are paid. Each of the Columbia students was funded by their respective departments through a competitive process. The Lehman students are funded through the NASA SEDAC initiative to include non-traditional students in research.

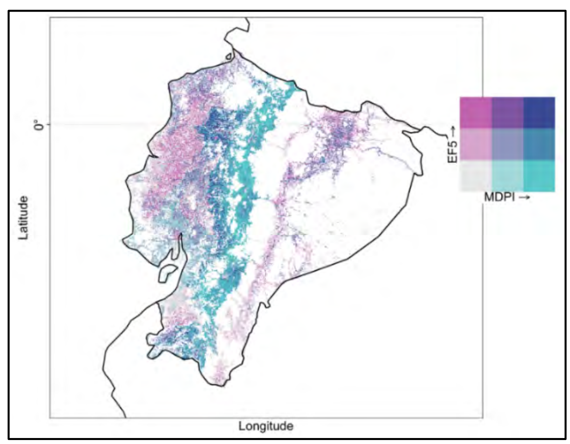


Figure 1. *Ecuador is mapped at 1km showing a bivariate relationship between higher probability of flooding from EF5 and higher levels of deprivation from SEDAC layer. Credit: Carolynne Hultquist*

Students	Organization
Lauren Mahoney, Anushka Srivastava	Columbia University Department of Earth and Environmental Sciences, Climate and Society graduate program
Colleen Neely	Columbia University School of International and Public Affairs, MPA in Environmental Science and Policy
Chris Aime, Lauren Carey, Raychell Velez, Dina Calderon, Natalia Bermudez	Lehman College City University of New York

***Table 1**. 2021 student interns*

As this project is linked to the Red Cross Forecast-based Financing program, the principal investigator participated in the Forecast-based Financing Dialogue platforms. This participation proved extremely useful in sharing outputs and outcomes of the GEO project to a humanitarian audience that is interested in integrated EO data into policy and practice.

Additionally, project efforts are featured in an upcoming book chapter, with the principal investigator as lead author, entitled, *'Moving from Availability to Use of Flood Risk and Flood Monitoring Data to Inform Decision Making for Preparedness and Response.'* The chapter has been submitted to be published in an American Geophysical Union (AGU) Monograph Series book, "Global Drought and Flood."

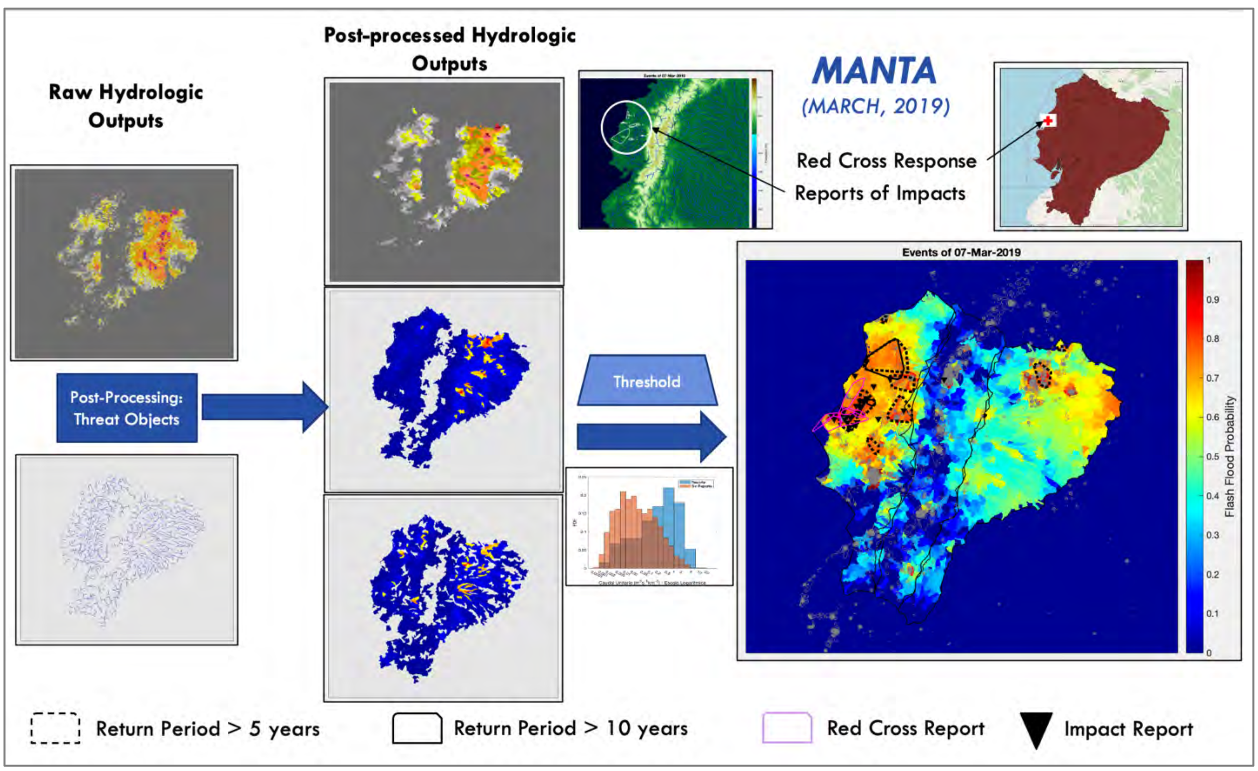


***Figure 2.** Schematic of the flash flood post-processing system in Ecuador. Credits: Humberto Vergara,* [*https://geo.floods.global*](https://geo.floods.global)

Two recent advancements within the academic literature are noteworthy. First, the article, "Perspectives on Flood Forecast-Based Early Action and Opportunities for Earth Observations" by Neuman and seven co-authors, including the principal investigator, highlights the opportunities and challenges of integrated EO data for risk and resilience programming, including for anticipatory financing and early action was recently published in the Journal of Applied Remote Sensing. Second, GFRM will be represented by Andrew Kruczkiewicz as guest editor in an upcoming edition of the Journal of Flood Risk Management. The title will be "Operational Flood Forecasting and Early Warning Systems." It will be co-edited by co-authors from Deltares, University of Reading, WMO Associated Programme on Flood Management, International Research Institute for Climate and Society at Columbia University, Red Cross and the Red Crescent Climate Center. Kruczkiewcz is also lead guest editor of a special edition in Frontiers Climate, "Climate Services for Risk Informed Anticipatory Action."

Project Summary	Towards a Global Flood and Flash Flood Early Warning Early Action System Driven by NASA Earth Observations and Hydrologic Models
Application Products	EF5 flash flood system in Ecuador, Flash Flood Anticipatory Humanitarian Action process
ARL Advancement	7
Geographic Region	Global, Ecuador
Partners	Ecuador Red Cross, Red Cross Red Crescent Climate Centre, Center for International Earth Science Information Network (CIESIN)
2021 Journal Papers	5

Global Rapid Flood Mapping System with Spaceborne Synthetic Aperture Radar (SAR) Data

Principal Investigator: Sang-Ho Yun/JPL
Co-Investigators: Piyush Agram/JPL, Razi Ahmed/JPL, Hook Hua/JPL, Seungbum
Kim/JPL, Gerald Manipon/JPL, and Susan Owen/JPL

Over the past several years, satellite Synthetic Aperture Radar (SAR) observations have been used for rapid flood extent mapping for many flooding events. Those maps have been repeatedly identified as critically useful due to the sensors' capability to see through clouds day and night. But flood mapping of urban areas has been mostly neglected due to the high level of noise and complexity of radar reflection coming from various orientations of building facades.

A goal of the project is to support the Group on Earth Observations (GEO) Work Programme Community Activity, "Global Flood Risk Monitoring," by completing a robust end-to-end automatic system to rapidly generate and deliver flood extent maps to responding agencies in 10 GEO member countries and to support the flood response community. To that end, we have developed a multi-temporal SAR analysis that characterizes each pixel's behavior over time to improve the sensitivity of SAR to flooding in urban areas.

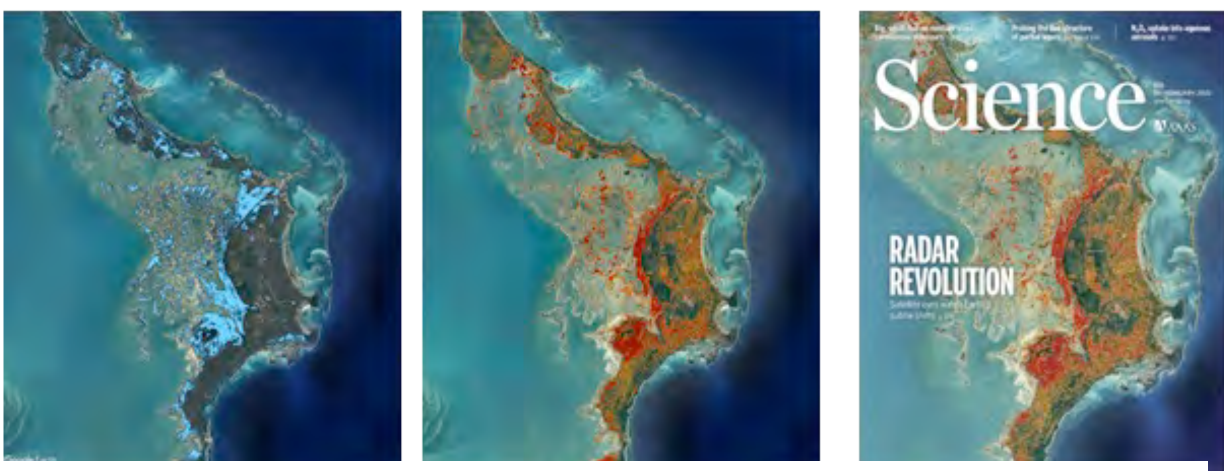


Figure 1*. Work from this project supporting Hurricane Dorian in 2019 was featured in a story and as the cover image of the Feb. 26, 2021 issue of Science. Credits: ARIA, JPL-Caltech, Earth Observatory of Singapore, Nanyang Technological University, NASA Earth Applied Sciences Disasters Program. Contains modified Copernicus Sentinel data.*

The first step to implement multitemporal SAR analysis was to create a stack of calibrated, co-registered SAR images and calculate Bayesian probability based on estimated Gaussian parameters of dry pixels and flooded pixels. The multi-temporal SAR analysis applies different thresholds for different pixels, whereas conventional SAR analyses, either using one or two SAR images, apply a uniform threshold to the entire image.

The pixel-based thresholding is adaptive to different land cover scenarios and better captures the anomalous signals due to flooding. The Bayesian approach enables the possibility of automatic implementation of the algorithm in the future without human intervention for threshold determination. Automation efforts progressed in 2021 in both the algorithm and the system sides.

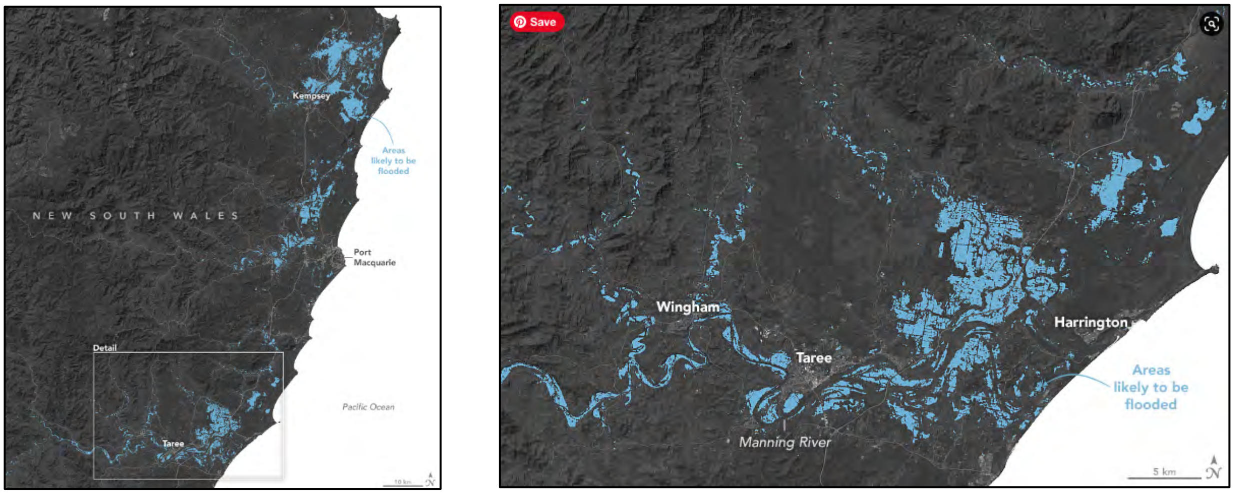


Figure 2. *Flood Proxy Maps of New South Wales Floods in Australia highlight areas of the Mid North Coast region of New South Wales Australia, likely to be flooded (indicated in blue) on March 20, 2021. The maps were derived from synthetic aperture radar (SAR) data acquired by the Copernicus Sentinel-1 satellites, operated by the European Space Agency (ESA) and created by the National Central University of Taiwan in collaboration with the Advanced Rapid Imaging and Analysis (ARIA) team at the Jet Propulsion Laboratory and Caltech. The ARIA team is supported by NASA's Earth Science Disasters Program.*

Flood Proxy Map (FPM) algorithms developed in this project include:

- FPM1: before/after SAR
- FPM2: multi-temporal SAR analysis (N pre-event SAR + 1 post-event)
- FPM3: machine learning-based (CNN) semantic segmentation
- FPM4: machine learning-based (RNN) anomaly score map

FPM1 and FPM2 codes have been widely tested for supporting flooding events. In 2021, The FPM2 code (multi-temporal SAR analysis) was beta-tested with real event response for activities, including the Malaysia floods, moving the ARL from 4 to 5. The Flood Proxy Map (FPM) algorithm has supported more than 35 flood events to date. 2021 disaster response support included floods in Malaysia, in Jan., floods related to Cyclone Seroja in Indonesia in April, and flooding in Laos in June.

End-users include:

- Federal Emergency Management Agency (FEMA)
- Search and Rescue Assistance in Disasters (SARAID)
- United Nations Development Programme (UNDP) Crisis Bureau
- United Nations International Children's Emergency Fund (UNICEF)
- United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA)
- United States Forest Service (USDA) Forest Service
- United States Air Force
- World Bank
- World Food Programme (WFP)
- United States Southern Command (Southcom)
- Sentinel Asia
- ASEAN Humanitarian Assistance (AHA) Centre
- Asian Disaster Reduction Center (ADRC)
- Badan Nasional Penanggulangan Bencana (BNPB)
- Changi Regional HADR Coordination Centre (RHCC)

Project Summary*	Global Rapid Damage Mapping System with Space-borne SAR Data*
Application Products	DPM Damage Proxy Map DPM2 with multitemporal coherence analysis DPM3 with multitemporal coherence and amplitude analysis DPM4 with deep learning multitemporal coherence analysis
ARL Advancement	Current ARL 5, advanced one ARL level in 2021
Geographic Region	Global
Partners	Earth Observatory of Singapore (EOS), Academia Sinica, National Central University (Taiwan), NOAA, University of Maryland, GSFC, PetaBencana.id
Journal Papers	5*
Media Features	39*

** Total reported at project close-out, July 2021*

NASA ROSES 2016 A.50 Group on Earth Observation (GEO) Global Wildfire Information System (GWIS) Initiative projects

Using the NASA Polar Orbiting Fire Product Record to Enhance and Expand the Global Wildfire Information System

Principal Investigator: Luigi Boschetti / University of Idaho
Co-Investigator: David Roy / Michigan State University

Fire plays an important role in determining the structure of ecosystems worldwide, and many are becoming vulnerable due to changing human populations and land-use practices. Regions have been subject to increasingly extensive and severe wildfires, with mega-fires and longer fire seasons becoming more common. In addition to their ecological and economic impacts, fires contribute to the carbon cycle, releasing the equivalent of 22% of fossil fuel emissions. Since 2000, satellite observations have been the primary data source for monitoring fire activity globally. The NASA MODIS MCD64 Global Burned Product (MCD64A1) is sufficiently mature to support policymaking (i.e., national and subnational fire activity reporting and carbon inventories). Still, when our project was proposed, there was no service for the systematic generation of summary fire activity information (i.e., maps, statistics, charts) specifically accessible to non-technical users. Therefore, this project has developed a new module within the Global Wildfire Information System (GWIS) to provide global to sub-national science-quality information on fire seasonality, fire size, and annual rankings of fire activity. The information is disseminated in easily accessible formats, derived from the NASA MODIS Global Burned Area Product using transparent, reproducible and documented methods. The module is operational and is publicly and freely accessible by users worldwide, hence reaching ARL 8.

In 2021, the project team, in collaboration with the GWIS team at the Joint Research Center of the European Commission (JRC), successfully developed and deployed the proposed new GWIS module ‘Country Profile Application’ (Figure 1). After extensive beta-testing, the system is now fully functional (ARL 8: “Finalized application system tested, proven operational, and shown to operate as expected within user's environment”). The system allows users to interactively visualize maps of burned areas, tables and charts reporting fire activity metrics of area burned, number of fires, seasonality, and fire size distribution. All source data are also available for download.

Documentation, including a detailed user guide and a “quick start” guide, has been developed to document the methods and help users navigate the application. Users can freely access the application at: https://gwis.jrc.ec.europa.eu/apps/country.profile.

Throughout the project, our team consulted and engaged prospective users by distributing pre-release versions of the dataset and providing live demonstrations of the web application. We conducted this outreach through collaborations with the Global Observation of Forest Cover regional partners, U.N. Food and Agriculture Organization and AmeriGEO. In 2021, the project team supported virtual training classes and guidance on the new module to several international partner entities, including Bolivia, Guatemala, and Paraguay. The Paraguay Ministry for Environment, as an “early adopter,” is using the GWIS Burned Area module data set as part of their national Carbon Emissions Inventory. The module development efforts are specifically focused on providing datasets and readily available fire information for the compilation of fire assessments and carbon inventories in Non-Annex I UNFCCC Parties, including least developed countries, because of their limited capacity and high vulnerability to climate change and natural disasters.

Due to a processing error of the MODIS MCD64 Global Burned Product (MCD64A1) discovered in late 2021, the serving of the Global Burned Area Product was temporarily halted in Oct. 2021, while a code fix is developed, and all archive scenes are reprocessed. The project efforts will continue through a No-Cost Extension (NCE) into 2022 to finalize the processing error correction and reimplement it into the GWIS Country Profile Module.

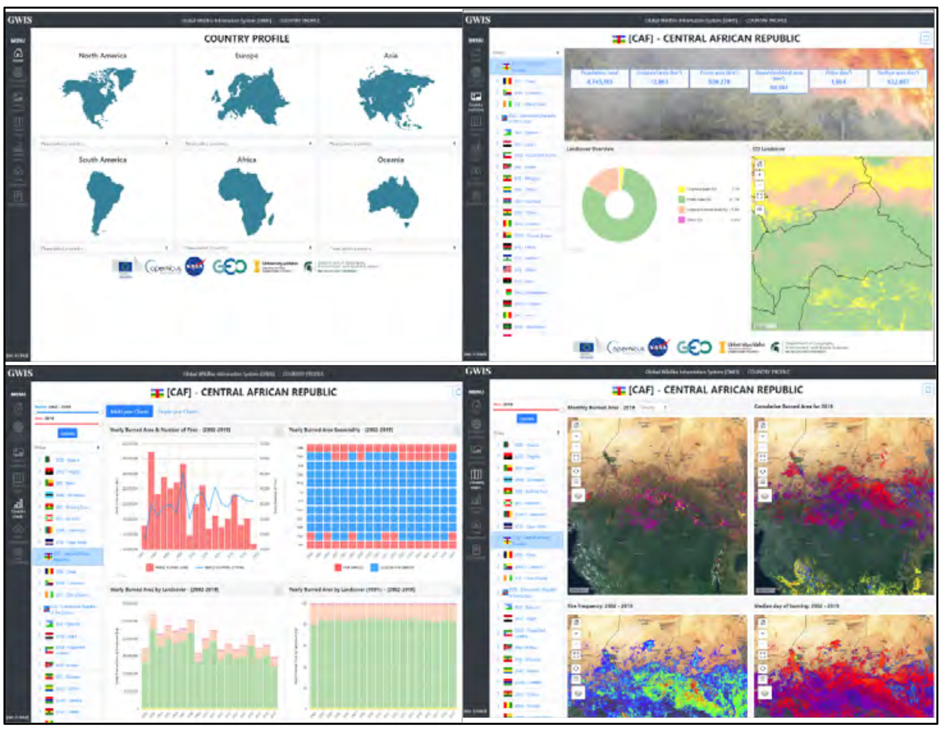


Figure 1. *Example of GWIS Country Profile pages, illustrating the graphic interface and the charts and plots generated for a sample country (Central African Republic). Simple drop-down and slider menus allow users to select the area of interest and the temporal reporting period.*

Project Summary	Using the NASA Polar Orbiting Fire Product Record to Enhance and Expand the Global Wildfire Information System

Application Products	National and sub-national fire activity assessments, emissions reporting, fire damage assessments
ARL Advancement	Current ARL 8, advanced four ARL levels in 2020, Goal ARL 9
Geographic Region	Global
Partners	Michigan State University (Co-I: David Roy), European Union Joint Research Centre (GWIS coordinator: Jesus San Miguel)
Prospective Partners	End-Users/Stakeholders: GOFC-Fire Implementation Team, UN-FAO, AmeriGEO
2021 Journal Papers	1 (submitted)
2021 Scientific Presentations	3

Enhancements to the Global Wildfire Fire Information System: Fire Danger Rating and Applications in Indonesia

Principal Investigator: Robert Field / Columbia University (GISS)

Fire danger rating systems (FDRS) are cornerstones of wildland fire management, but fire danger data are not available in many fire-prone parts of the world. The NASA GISS Global Fire Weather Database (GFWED), (https://data.giss.nasa.gov/impacts/gfwed) was developed to meet the global fire research and management communities' needs for consistent fire danger data anywhere in the world. GFWED is a small ensemble of Fire Weather Index (FWI) products calculated using weather data from reanalysis, rain gauges, weather forecasts, and satellite precipitation retrievals, available from 1981-present at different resolutions and in near-real-time. Production of all GFWED products continued in 2021, with a subset distributed in NRT through the Global Wildfire Information System. The GPM-based Indonesian Fire Danger Rating System developed in 2020 also continued operations through 2021.

NASA ARSET included an introductory module on GFWED, "Satellite Observations and Tools for Fire Risk, Detection and Analysis" with their online training on May 11, 2021. The module was delivered in English and Spanish, covering the basics of fire danger rating, an overview of the GFWED products and access, and examples of different GFWED applications in Mexico. Studies of future fire weather over Greece under climate change, global relationships between present-day fire weather and burned area, and calibration of an operational fire danger rating system over mainland Southeast Asia are currently under peer review.

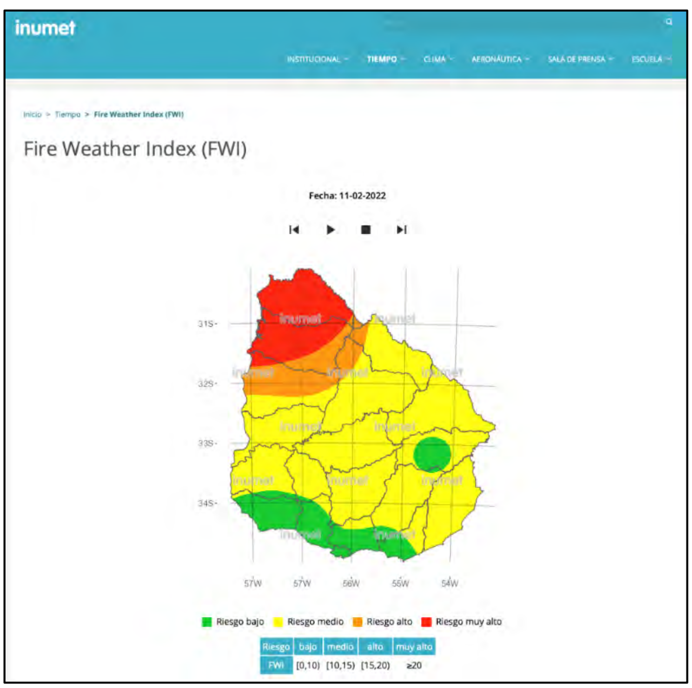


Figure 1. *Fire Weather Index Map for Feb. 11, 2022, over Uruguay (courtesy of Fernando Arizmendi and Roxana Sagarra, Uruguayan Institute of Meteorology).*

The development of Uruguay's fire danger rating system continued. Using the GFWED code-base, the Uruguayan Institute of Meteorology has calibrated the Fire Weather Index System for local conditions. Maps are produced each day by the Uruguayan Institute of Meteorology (INUMET, Instituto Uruguayo de Meteorología) using synoptic weather reports. These maps are publicly available alongside FWI maps from GFWED distributed internally through Telegram. The system is undergoing evaluation during the current fire season.

Improvements for 2022

The original project included a 'train-the-trainers' program with agencies in Indonesia to develop a sustainable curriculum for fire danger rating education in the country in collaboration with the FAO. To that end, progress was made at workshops in Jakarta in 2018 and 2019, but the program could not be completed due to the COVID-19 pandemic and consequent travel restrictions. An online program could have, in theory, been developed, but in retrospect, there was not enough 'traction' with local agencies to overcome language barriers and time zones. The online module delivered through ARSET is a good starting point for alternative cost-effective fire danger rating training for other regions and in other languages.

Project Summary	Enhancements to the Global Wildfire Fire Information System: Fire Danger Rating and Applications in Indonesia
Application Products	NASA GISS Global Fire Weather Database (GFWED), blended TRMM.GPM IMERGv-006, serving as an FDRS in GWIS; Indonesian FDRS
ARL Advancement	Remained at ARL-7 in 2021
Geographic Region	Global & Indonesia
Partners	JRC, Indonesian Agency for Meteorology, Climatology and Geophysics, Uruguayan Meteorological Institute, the global fire research community.
2021 Journal Papers	3 (submitted)
2020 Media Features*	6
2020 Scientific Presentations	1

Development of a Harmonized Multi-Sensor Global Active Fire Data Set

Principal Investigator: Louis Giglio / University of Maryland
Co-Investigator: Wilfrid Schroeder / NOAA

Fires are ubiquitous throughout the globe and monitoring them requires a combination of sensors with differing spatial, temporal, and radiometric resolutions. For the past two decades, the primary source of global fire observations has been NASA's Terra and Aqua polar-orbiting satellites, which carry the Moderate Resolution Imaging Spectroradiometer (MODIS), followed by the NASA-NOAA Suomi-National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS). Still, these systems are limited to two to eight observations per day, with acquisition times that often do not coincide with the most intense period of fire, or which are more susceptible to cloud obscuration. This results in limited mapping of fire occurrence. The next generation of geostationary weather satellites, which include the NOAA GOES, EUMETSAT Meteosat Second Generation (MSG), and Japan Meteorological Agency Himawari platforms, now include a fire monitoring capability and incorporate refinements in spatial and temporal resolution as well as radiometric performance. These platforms provide an unrivaled temporal sampling of fire activity every 1–30 minutes. Still, they are operated by different agencies and carry different sensor payloads, resulting in a disparate set of fire products in multiple formats, produced using different fire detection algorithms, thus complicating interoperability for end users. Therefore, this project augments the existing Global Wildfire Information System (GWIS) with the addition of a near-global, multi-platform, harmonized geostationary fire data set that has undergone comprehensive data validation and quality assessment. The project is also educating users about the characteristics and potential applications of the harmonized geostationary fire data as well as the capabilities of the underlying geostationary satellite platforms and sensors.

The harmonized fire data suite consists of a near-real-time (NRT) and near-global geostationary active fire product delivered to end-users in two formats: (1) harmonized, 0.25° gridded hourly summaries of active fire properties, including fire radiative power, and ancillary information (e.g., cloud cover, coverage, etc.), and (2) blended, geocoded delimited text files that preserve the spatial and temporal resolutions of the underlying hemisphere-specific fire products.

In early 2021, the project team: (1) Updated the FRP-PIXEL GOES-16, GOES-17, and Himawari validation; (2) Continued coordination with GWIS to integrate the prototype operational system into end-users operational environment; (3) Continued working with FIRMS US/Canada to facilitate the distribution of the harmonized products (the team added the USDA Forest Service as an additional partner to host our harmonized geostationary fire products as well a subset of the production software on the recently-developed FIRMS US/Canada web map service/portal (https://firms.modaps.eosdis.nasa.gov/usfs). FIRMS US/Canada has integrated the harmonized geostationary fire product and provided a preliminary evaluation of such. This integration and evaluation is a significant step toward achieving ARL 7 for our second partner. In addition, FIRMS has successfully implemented the python codes that download (in near real-time) the FDC and FRP fire products. The University of Maryland (UMD) is currently supporting the prototyping of the data harmonization code written in IDL on FIRMS servers. The harmonized active fire products from this project will become available for download using the same user interface currently deployed by FIRMS for the download of MODIS and VIIRS active fire products.

The Harmonized, Multi-Sensor Global Active Fire Data implementation in GWIS and (later) FIRMS US/Canada, only reached a demonstration level (ARL 7), as further product maturation is required to operationalize (ARL 9), within respective production systems (GWIS and NASA/USFS FRMS). Compounding this problem was the fact that the underlying geostationary fire products, particularly the NOAA FDC product, remain in various states of flux and consequently require a new validation and evaluation with each update; an effort/solution that will be addressed in 2022.

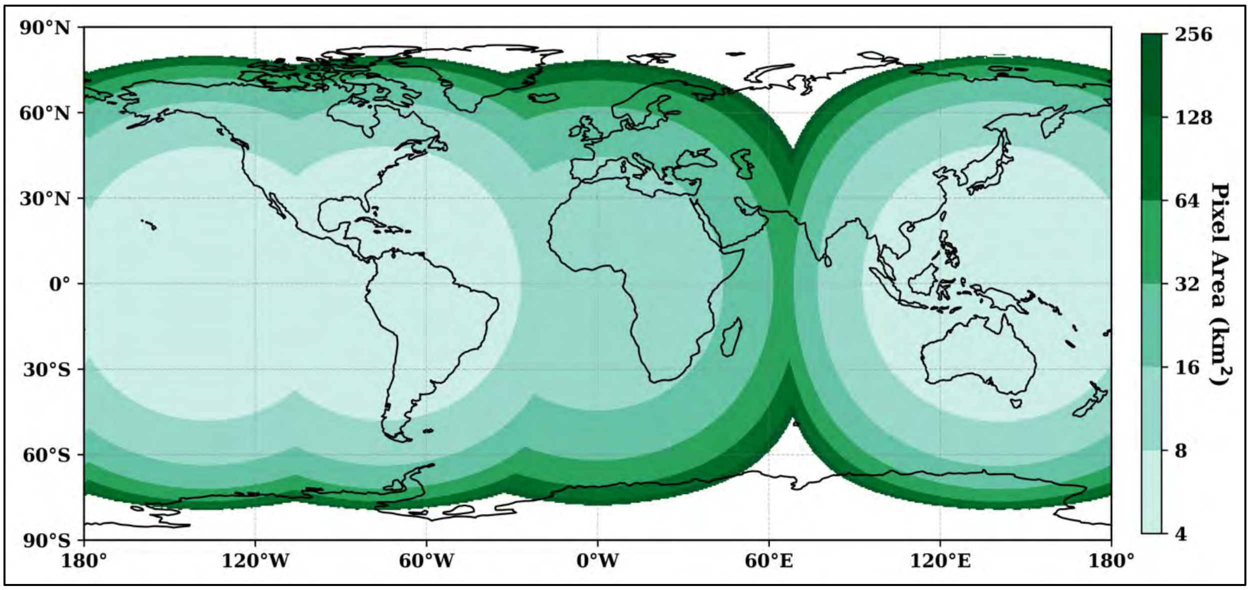


Figure 1. *Spatial coverage and pixel area (km2) of the GOES-16, GOES-17, MSG, and Himawari disks. The pixel footprint increases systematically from each sensor's sub-satellite point.*

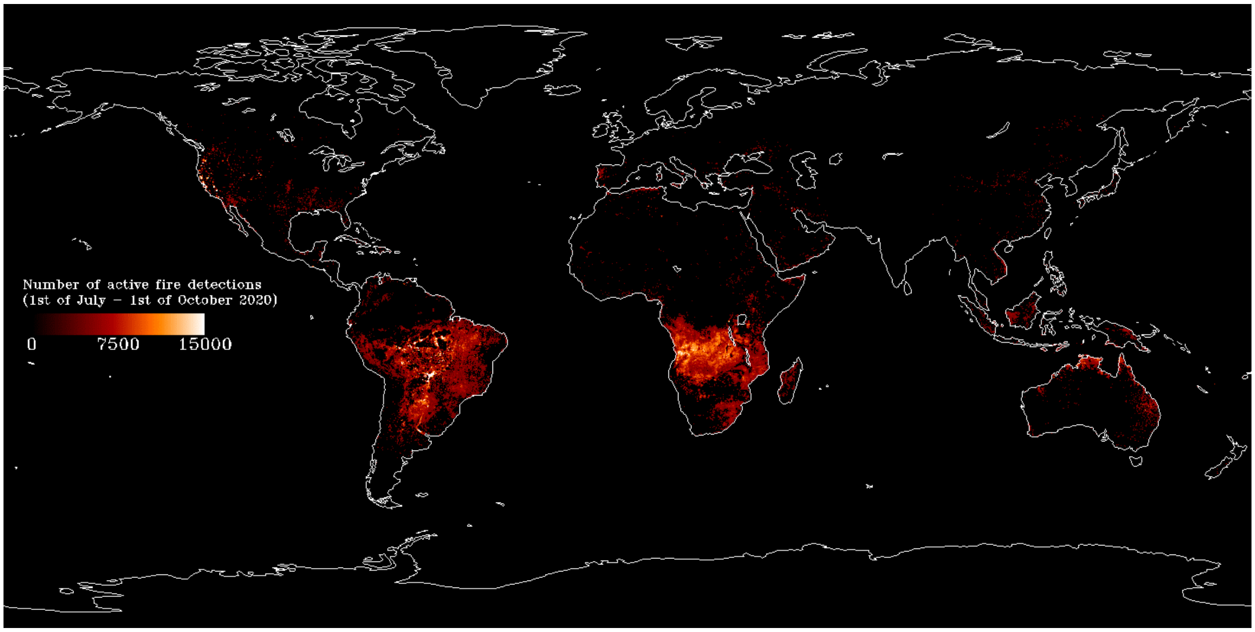


Figure 2. *Total number of active fire detections for the summer validation period (07/01/2020 – 10/01/2020) derived from the Harmonized Geostationary satellite products. The harmonized gridded product can be easily investigated to monitor hourly, daily, seasonal, and annual fire activity.*

Project Summary	Development of a Harmonized Multi-Sensor Global Active Fire Data Set
Applications Products	GWIS serving NOAA GOES, EUMETSAT Meteosat Second Generation (MSG), and Japan Meteorological Agency Himawari fire products including fire distribution, fire spread, fire intensity surrogate, diurnal fire variation, etc.)
ARL Advancement	Current ARL: 7, Goal ARL-9
Geographic Region	Global
Partners	European Commission-Joint Research Center (JRC), NOAA
Prospective / New Partners	USDA Forest Service (NASA / USFS FIRMS), global community using GWIS
End-Users/Stakeholders	National policymakers and fire services, FAO, NASA FIRMS, Conservation International (CI) Firecast, UNEP
2021 Journal Papers	1 (submitted)
2021 Scientific Presentations	1 (Scientific Product User's Guide)

V. Communications Highlights

In 2021 the Disasters communications team continued its mission to educate the world about NASA resources and activities that support disaster risk reduction and response. Through new initiatives such as a community newsletter, continued improvements to the Applied Sciences website, and collaborations with programs across NASA, the communications team has worked diligently to make disasters applied science and Earth-observing resources available and accessible to as wide an audience as possible.

Expanding to New Platforms and Audiences

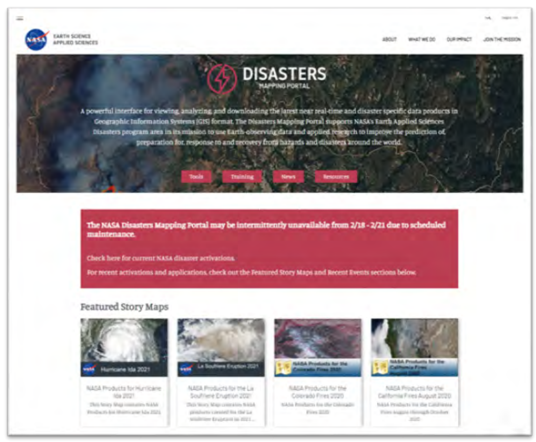
A highlight of 2021 was the launch of the NASA Disasters Community Newsletter, a quarterly email newsletter that highlights the people enabling action, innovative technologies, cutting-edge research, and ways to access geospatial information that can help communities throughout every phase of the disaster cycle. The program published two editions of the newsletter in 2021, with a third published shortly after the new year. The newsletter now reaches an audience of 1,506 subscribers (as of Feb. 16, 2022), including readers from 27 unique government agencies and over 70 unique U.S. Universities. Engagement with the newsletter exceeds industry standards, with an email open rate of 53% (industry average is 27%) and a click-through rate of 9% (industry average is 1%).

The Disasters team also worked with the National Institute of Aerospace to create Disasters - focused episodes for “Innovation Now,” a 90-second radio series and podcast that explores science and technologies that shape our future. In 2021 the team developed two stories featuring the work of Disasters program area A.37 researchers - “InSAR for Disasters” and “Mapping Oil Spills.” The stories were shared on hundreds of radio stations and on the NPR Radio App to a worldwide audience.

Enhancing Web Usability

In the second year of operation for the redesigned Applied Sciences website, the Disasters communications team worked closely with users within the program to identify potential areas of improvement on the new site to increase its utility and usability and better serve our audience. The Disasters team developed a new "Latest Disasters" button for the Disasters homepage, allowing users to quickly jump to the latest resources for ongoing activations, and developed a new event summary format to allow for rapidly posting the most essential information and resources when a new disaster activation occurs. The Disasters team also worked with U.Group to implement site-wide usability enhancements such as improvements to the search functionality, allowing users to find specific information more quickly and easily.

The Disasters comms team also worked closely with the GIS team to help redesign the homepage of the NASA Disasters Mapping Portal, bringing it up to the latest web usability and accessibility standards and giving it a more modern look and feel to appeal to users. The mapping portal is now fully responsive to be accessible on multiple display sizes and can be more easily updated by the GIS team to highlight the latest disaster datasets available on the portal.



Screenshot of the newly redesigned NASA Disasters Mapping Portal homepage.

Communication Collaborations

The Disasters communications team expanded its efforts in working with other communications teams throughout NASA's SMD and ESD to amplify the reach of our messaging and tell stories that cut across missions and programs. The team continued collaboration efforts with NASA's Earth Observatory, putting them in touch with subject matter experts from the disasters community to provide analysis and quotes, and providing them with compelling visuals to augment their storytelling.

A tweet from the @NASA_es account sharing Disasters program area activities

The comms team also continued its social media outreach efforts, frequently sharing stories and highlights to be posted by @NASAEarth, @NASAAtmosphere, @NASAEarthData, and center social media accounts. The ability of the Disasters comms team to rapidly produce narratives and imagery for quickly evolving situations helped keep NASA social media relevant and stay on top of the news cycle. The comms team also expanded its Spanish-language outreach efforts, translating several articles and working with the NASA Spanish Communications team to share these on the @NASA_Es social media accounts and on https://ciencia.nasa.gov. Additionally, the team worked with ESD comms to get several NASA Disasters stories published to the www.nasa.gov website, including the interactive storymap "2021 Disasters: A Look Back," which was featured on NASA's flagship website's front page for more than a week.

Mentoring the Next Generation of Earth Science Communicators

The NASA Disasters program area continued its successful Science Writer internship program, with a cohort of five interns in the Fall 2020/Spring 2021 semester and four others joining in the Fall 2021/Spring 2022 semester. Five of these students have hailed from one of the oldest Historically Black Colleges and Universities (HBCUs), in the U.S, Hampton University. Others have come from Millersville University, in Millersville, Pennsylvania, Western Washington University in Bellingham, Washington, and William & Mary in Williamsburg, Virginia.

The communications team worked closely with these interns to educate them about NASA and the Disasters program area and integrate them into meetings and workflows, providing them with real-world experience as well opportunities to publish their work online, which will aid their future endeavors. Science communication experts from across NASA serve as guest mentors, on topics such as "Communicating Controversial Science," "Interviewing Subject Matter Experts" and "Navigating a Science Communications Career as a Woman."

The internship initiative's success was demonstrated as the Disasters program area hired Gabriella Lewis, a former communications intern, as a junior science writer in spring 2021. Ms. Lewis has significantly contributed to the success of NASA Disasters communications efforts, publishing numerous articles and using new storytelling methods, such as the interactive multimedia storymap, "2021 Disasters: A Look Back" that was featured on www.nasa.gov.

VI. Abbreviations and Acronyms

ADRC	Asian Disaster Reduction Center
AGU	American Geophysical Union
AHA CENTRE	ASEAN Coordinating Centre for Humanitarian Assistance
ALOS-2	Advanced Land Observing Satellite-2
APRFC	Alaska-Pacific River Forecast Center (NOAA, NWS)
ARL	Application Readiness Level
ARSET	Applied Remote Sensing Training Program
ASEAN	Association of Southeast Asian Nations
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AVO	Alaska Volcano Observatory
BNPB	Badan Nasional Penanggulangan Bencana (Indonesia's National Disaster Management Agency)
BURNEX	Annual Fire Exercise conducted by California Fire and the California National Guard
CalFIRE	California Fire
CDEMA	Caribbean Disaster Emergency Management Agency
CEOS	Committee on Earth Observation Satellites
CIII	Critical Infrastructure Interdependency Index (CIII)
CIIRI	Critical Infrastructure Interdependency Risk Index (CIIRI)
CYGNSS	Cyclone Global Navigation Satellite System
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EOS	Earth Observing System
EOS	Earth Observatory of Singapore
ERMA	Environmental Response Management Application
ESA	European Space Agency
ESTO	Earth Science Technology Office (NASA)
FAO	U.N. Food and Agriculture Organization
FDC	Fire Detection and Characterization
FEMA	Federal Emergency Management Agency (part of DHS)
FRP	Fire Radiative Power product

FWI	Fire Weather Index
GEO	Group on Earth Observations
GFDRR	Global Facility for Disaster Reduction and Recovery (World Bank)
GFRM	Global Flood Risk Monitoring (GEO)
GFWED	Global Fire Weather Database
GINA	Geophysical Institute Network of Alaska
GIS	Geographic Information System
GNNS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center (NASA)
GWIS	Global Wildfire Information System
HQ	Headquarters
IFRC	International Federation of Red Cross and Red Crescent Societies
IPGP	Institute of Earth Physics of Paris
ISRO	The Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory (NASA)
JRC	Joint Research Council
JSC	Johnson Space Center (NASA)
LANCE	Land Atmosphere Near real-time Capabilities for EOS
LANDSAT	Land Remote-Sensing Satellite (System)
LaRC	Langley Research Center (NASA)
MODIS	Moderate Resolution Imaging SpectroRadiometer
MNDWI	Modified Normalized Difference Water Index
MPSR	Marine Pollution Surveillance Report
MSFC	Marshall Space Flight Center (NASA)
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration
NESDIS-SAB	National Environmental Satellite, Data, and Information Service Satellite Analysis Branch
NISAR	NASA ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration

NOS	National Ocean Service (NOAA)
NPP	National Polar-orbiting Partnership
NRDA	Natural Resource Damage AssessmentNSF National Science Foundation
NWS	National Weather Service
OMPS	Ozone Mapping Profiler Suite
PDC	Pacific Disaster Center
PI	Principal Investigator
RGB	Red, Green and Blue (natural imagery)
ROSES	Research Opportunities in Space and Earth Sciences (NASA)
RHCC	Changi Regional Humanitarian Assistance and Disaster Relief (HADR) Coordination Centre
SAR	Synthetic Aperture Radar
SARAID	Search and Rescue Assistance in Disasters
SCAT	Shoreline Cleanup Assessment Team
SCCOOS	Southern California Coastal Ocean Observing System
SERVIR	"To Serve" – joint endeavor between USAID and NASA
SICA	Central American Integration System
SMD	Science Mission Directorate
SNPP	Suomi National Polar-orbiting Partnership
SO2	Sulfur Dioxide
SOUTHCOM	United States Southern Command
TRADEWINDS	Annual Exercise conducted on behalf of the United States Southern Command
UAF/ASF	University of Alaska Fairbanks / Alaska Satellite Facility
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCSD/Scripps	University of California, San Diego / Scripps Institution of Oceanography
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
USAF	United States Air Force
USDA	United States Department of Agriculture

USFS	United States Forest Service
USGS	United States Geological Survey
VAAC	Volcanic Ash Advisory Centre
VDAP	Volcano Disaster Assistance Program
VIIRS	Visible Infrared Imaging Radiometer Suite
WFP	World Food Programme
WMO	Word Meteorological Organization (UN)