EARTH SCIENCE
APPLIED SCIENCES

2019 ANNUAL SUMMARY

NASA Earth Science Applied Sciences Program

NASA Disasters Program 2019 Annual Summary

Applied Sciences Division:

Lawrence Friedl, Applied Sciences Program Director (*lfriedl@nasa.gov*)

Disasters Program Management Team:

David Green, Program Manager (*david.s.green@nasa.gov*)

John Murray, Associate Program Manager for ROSES (*john.j.murray@nasa.gov*)

H. Michael Goodman, Associate Program Manager for ROSES (*michael.goodman@nasa.gov*)

Disasters Program Websites:

http://appliedsciences.nasa.gov/programs/disasters-program

https://disasters.nasa.gov/

https://maps.disasters.nasa.gov

NASA Disasters Program 2019 Annual Summary

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I. Introduction to Earth Observation for Disaster Risk Reduction

This was a transformative year for NASA's Disasters Program with substantial and measureable progress that increased the use and benefit of Earth Observations to address systemic disaster risk.

By putting greater emphasis on risk-informed science and the integration of physical and social processes, the program made a strategic pivot to better address disaster impact. Disasters are the consequences of societal decisions, where and how we build, how much resources go into mitigation and early action, impact response, and how we take action regarding exposure and vulnerability through stages of recovery and rehabilitation. The program goal is to ready **actionable knowledge** to strengthen disaster resilience, which is the ability to prepare for, adapt to, and withstand changing conditions and recover rapidly from disruptions and loss. It is clear that stakeholders are looking for leadership, experience, and support in the use of trusted data, science and technology for managing the volatility and instabilities amplified by disasters – and they are finding these values of risk reduction and response in NASA's Disasters program. In 2019, over 60% of the stakeholders, partners and users were new to the program.

The strategic priority is providing institutional knowledge and specialized expertise as well as leading, facilitating, or supporting the disaster research within NASA's designated authority and associated activities in the multi-hazards environment. As a small program, in both staff and financial resources, but with global reach and strong networks, the tactical approach is to pilot and demonstrate capabilities of open and accessible Earth Observation data and science results. NASA's applications leverage practices and approaches strengthening human and infrastructure security through increased

HIGHLIGHTS

- 10 New Multihazard teams
- 6 New Principal Investigators
- 40 New Co-Investigators
- 1 New regional data agreement
- 1 New partnership with the re-insurance sector
- 1 New global-flood risk monitoring pilot under CEOS and GEO
- 3 Regional priority engagements including data sharing, situational awareness and resilience impacts for Americas and adjacent Caribbean, Africa and S.E Asia
- 38 Disaster event response activations
- 30 US States supported
- 25 countries engaged and supported
- 10 recently-developed applications tested in real world events
- 83 GIS products published to the Disasters Mapping Portal https://maps.disasters.nasa.gov/
- 10 Story Maps created for the Portal
- 3 widgets added to the Disasters Portal
- 2 dashboards launched on the Portal
- 10 new routine products on the Portal
- 133,964 total page views on the Situational Awareness website https://disasters.nasa.gov
- 43 online contact-form inquires addressed (https://disasters.nasa.gov/contact)
- 79 new pages added to https://disasters.nasa.gov (news stories, disaster updates, activations)
- 1 UN Global Risk Framework adopted
- 4 key Research application cross-cuts in observation test beds, tsunami geodesy, coastal storm and ecological risk, landslide and flash flood vulnerability

environmental intelligence to reduce impact. Alignment with the Sendai Framework for Disaster Risk Reduction (SFDRR) solidifies a paradigm shift from managing disasters to managing current and future risks, bringing in resilience-building as the core target to be reached by 2030.

Notable achievements in 2019 included the creation of 10 new application research teams and the launch of an innovative global "collaboratory" to increase the use of data and the reliability, readiness, and uptake of information products. Underpinning these projects are new approaches based on transforming how we promote readiness of modeling to impact results. The projects automate where they can – such as data inputs, processing, and running algorithms to create standardized outputs and scalable capabilities. Many are embracing use of machine learning to synthesize more inputs and crate richer models and predictive data products that give users better results and insights that are more actionable. One size solutions do not fit all during the best of times, let along for a potential or active disaster that impact every community differently. Still, the program found it important to seek a few innovative applications and best practices that are widely applicable across many geographies. This helped the program ensure baseline effectiveness for our applications. Using a test-and-learn mindset to explore diverse capabilities, the program sampled small –scale and large-scale, frequent and infrequent, sudden and slow-onset disasters, made by multiple and cascading hazards as well as related environmental, socio-economic, financial, technological, and biological risks.

Innovation is core to everything done in the NASA Disaster program implementation, whether it is product development or event activation. Prioritizing a selection of matured applications, transdisciplinary expertise and public-private contributions that have clear goals, budgets, and measurements empowered us to think and act bigger by making our results more broadly transferable and our engagement more efficient. Global coverage increased through formal and informal partnerships including with emergency management and disaster centers as well as with small and medium enterprise partners and larger private sector stakeholders from the re-insurance sector, finance and heavy industry. Key academic institutions, United Nations bodies and regional initiatives broadened reach. These augmented the existing NASA Centers and Laboratories, staffing the Earth Science Divisions disaster "response" team, which *activates* to interpret, test and evaluate science application and improve dissemination and communication of information in real-world scenarios. This strategy gained the commitment of partners, users, and stakeholders in the form of cost-sharing, co-development, and translation of research results toward sustained use. The assembled collaborative established a lean multihazard and increasingly agile capability contributing to a geospatial intelligence platform and dashboard (see Figures 1 and 2) –the *Disasters Mapping Portal* - to improve the prediction of, preparation for, response to, and recovery from disasters.

The Disasters Mapping Portal is in itself an application as well as a means for testing and learning personalization: matching custom data and products to specific audience and user segments to deliver experiences that are more relevant. Tools like the dashboards and story maps incorporating input from the ROSES projects as well as from across other NASA programs and external partners help us stimulate the appetite for experimentation while demonstrating this efficiently at scale. We have seen great return-on-investment, as the Portal value includes increased user engagement and outreach, co-development of applications, the incorporation of partner and user data to improve vulnerability and exposure mapping, as well as through global media's story uptake.

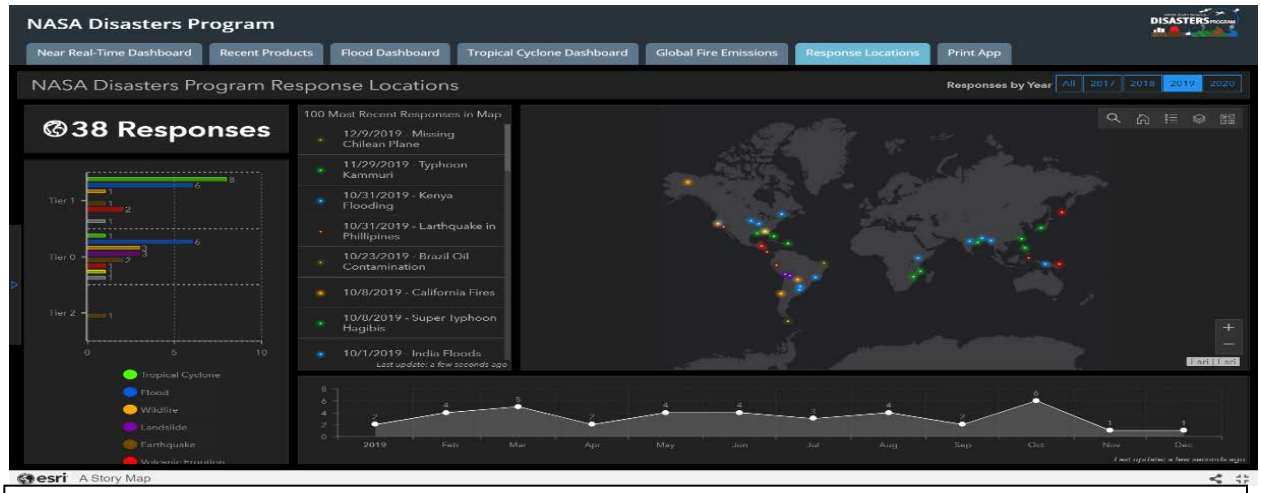


Figure 1. NASA Disasters Portal application showing the dashboard information on location, and timeline of 2019 Disasters Response Team activations, mobilized in response to real world events.

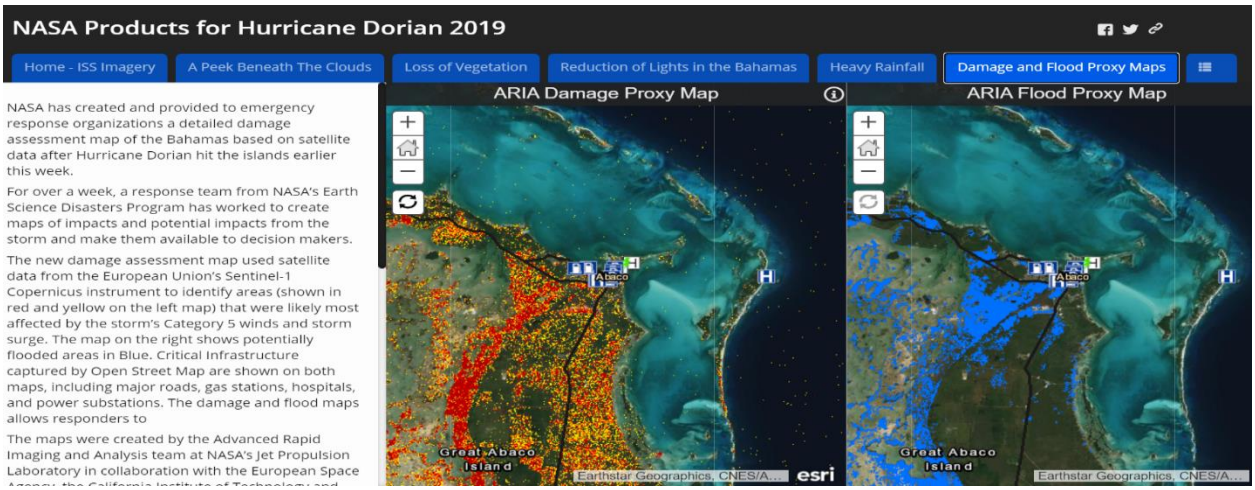


Fig.2. NASA Disasters story-map GIS application for Hurricane Dorian illustrating the combined data from multiple satellite remote sensing missions with information on land cover and use to reveal the extent of flood damage and loss; other tabs show the regional scale of the storm as well as the disruptions along food and energy lifelines.

This year the Program introduced a set of Pillars to guide programmatic priorities and practice including greater appreciation for diversity and equity, crosscutting coordination, open communication and transparency, as well as commitment to building and maintaining partnerships. Disaster risk reduction recognizes "differential vulnerabilities" between different populations and the program made a best effort to increase outreach to empower at-risk groups, and increase access to actionable knowledge while being constrained by a cut to the NASA

Pillars:

- To integrate equity, diversity, and global engagement
- To facilitate coordination and collaboration
- To promote transparency
- To foster trust

Communities At Intensive Risk CAIR initiative. In targeted pilot projects, the program explored risk analysis combining environmental with financial and other combining environmental with infrastructure lifelines. By realignment of application science teams, embracing early career and youth groups, STEM educators, and value-added private sector and humanitarian partners, the program put words into action. Program leveraged networking experience, with an emphasis on underserved and vulnerable communities in lower-income, coastal, island, and indigenous communities through workshops and partnerships with the intent of augmenting plans and protocols to guide action. The program "responded" with agility to real world threats by balancing science and technology with a growing emphasis on humanitarian relief and people-centric measures through partnerships such as with the Red Cross. As a small Program, Disasters invested heavily in coordination to fill gaps and avoid overlap, tailoring its limited human and financial resources to reflect NASA's unique role in the mobilization and integration of earth systems science. The emphasis on geospatial analytics also enabled integration with community-level risk mapping and regional disaster knowledge platforms. The highlights of 2019 reflected tactics to tackle novel science-area questions such where are the most vulnerable people and who needs support? This translated into increasing access to low-latency data products at the right time as events unfolded and new questions arose, increasing personalization of mapping solutions and visualization aids. The program sponsored competitions and challenges, such as hack-a-thons, to discover choices for local action, and facilitating the convergence of research disciplines to satisfy the reality of complex decision-making.

NOTABLE ENHANCEMENTS

- Increased coverage of coastlines, islands and community lifelines
- Increased support for disasters in arctic and indigenous communities
- Decision support for displaced populations and settlement communities
- Direct information with actors in humanitarian assistance and relief
- Timeliness of damage assessment and mapping products improved
- Dashboard capabilities added socio-economic and population factors
- Geospatial information and visualization platform linked with operational emergency management partners across government agencies and regional bodies
- Virtual and augmented reality tools piloted for real-world disasters

NASA's program galvanized its community by recognizing the ever more complex and interconnected nature of risk and "risk appetite" concerning economic, cultural and ecosystem sustainability. The program prioritized opportunities to grow its network of investigators, coordinators, partners and stakeholders while also working to refine their respective roles and contributions, identify leadership positions, and better inform and consult with others. Increased inclusivity and access demonstrated by diverse staffing and outreach projects engaging vulnerable communities demonstrated the potential for a user-centric approach that emphasized equity and cultural context. Examples of specific work included applications of flood, tsunami, and landslide tools for marginalized and displaced groups in settlement camps and near island coastlines settings disproportionally impacted by disasters. Public-private partnerships targeted consistent methodologies to assess insurable risk and established relationships with the re-insurance, utilities, telecommunications, and civil engineering sectors. Other areas of enhanced engagement included attention to public health, agriculture, humanitarian early action and environmental security. The program's weekly conference calls among Coordinators and

investigators provided value by sharing insight from dedicated representation on working groups and routine virtual meetings with niche partners. The program sponsored a variety of virtual and face-to-face workshops, symposia and conferences as well as webinars and trainings. The deliverables of the program continued to shift from product-centric to user-centric, bringing a renewed earth system perspective to managing situational risk. With greater geospatial awareness, enhanced disaster mitigation and community resilience practices increased confidence in readiness of new capabilities for transition to decision makers, authorized users and local actors.

The Disasters Situational Awareness website https://disasters.nasa.gov and Mapping Portal https://maps. disasters.nasa.gov provided a pair of platforms to share peer-contributed content, support private messaging, and facilitate connections with stakeholders. This reinforced the applications available and organizational coordination to address current and future risks. Initial steps were taken to modernize the website, including increased harmonization with web standards and integration with NASA's Applied Science program. This began the process of relating risk reduction and resilience development outcomes to strengthening sectors in disaster relief and humanitarian action including health, food, water, and logistics. The investment in Disaster coordination aims to ensure a coherent and complementary approach among these sectors (also reflected in the transverse programs of NASA Earth Science) to work better together when protecting and repairing disruptions to lifelines. The mapping portal is more than a website and is in fact officially designated "an application" that is fully integrated with NASA's data and information enterprise. The portal and geospatial analytics team worked closely with NASA's missions and data centers (including the Distributed Active Archive Centers) as well as those of other agencies, especially with the FEMA geospatial hub, with the private sector (notably with Esri's Disaster Response Program) and regional portals (such as with AmeriGEO's Disasters Thematic Community) to enable and pioneer capabilities.

In 2019, teams were created to focus on data quality and outlook modeling, providing new tools for hazard susceptibility and for considering the likelihood of impacts from changing exposure and vulnerability. While only modest progress was made to go beyond the immediate response phase, implementing the new research portfolio introduced opportunities for "adaptive" response and includes multiple projects. Over the past year, the program has learned that responding to emergencies and disasters requires adaptation to meet the demands of an event, and that

STRATEGIC HIGHLIGHTS

- Alignment with targets of the *UN Office of Disaster Risk Reduction Sendai Framework 2015-2030* and *Sustainable Development Goals including Group on Earth Observations* (Fig. 3)
- Contributor to US Sendai Reporting Indicators
- Lead contributor to the publication of the 2019 *UNDRR Global Risk Assessment Framework* (GRAF)
- New humanitarian relief projects on vulnerability to examine adaptation to disaster risk for sustainable resilience (Fig. 4)
- Major contributor to the *UNDRR Global Risk Assessment* (GAR)
- Support for the New Urban Agenda with projects on urban flood and landslide risk
- Disaster impact mapping for restoration and recovery in Caribbean
- Lead for *US-Caribbean Partnership* for Resilience lines of effort in flood, oil spill, landslide, and scenario exercises

the program must reallocate or augment resources, adjust work schedules, and, depending on severity and duration of the event, even compromise routine service outputs. The emphasis on agile and changing relationships, working with partners willing to share data, experience and scenarios also resulted in new agreements to improve forecasts and predictions for proactive measures including risk management and intervention. Progress leveraged the disaster portal as a mechanism to go beyond product generation and integration toward establishing a virtual community for collecting, analyzing and visualizing information for disaster risk assessment and prevention. Using the website as a platform to highlighting experimental results and resources before events, and creating a dynamic place for interaction during events, combined with increased use of digital media to enhance the reach of the program to new users. Combined with the geospatial portal and engagement with many non-traditional partners, the program demonstrated new insights into situational awareness such as the impacts to community lifelines (such as energy, water, transport, food and health systems) and business continuity.

Results achieved this year by NASA's program made contributions that materialized in release of the first Global Risk Assessment (GAR) since international adoption of the 2030 Agendas including the Sustainable Development Goals (SDGs), Climate Adaptation and the Sendai Framework (see Figure 3 and 4). This includes the innovation put forward by NASA Disasters and colleagues to formalize the earth systems approach within and the first Global Risk Assessment Framework (GRAF). The collective outcome seeks to transform the level of environmental intelligence to anticipate growing risk and build the knowledge needed to trigger early action before the next disaster strikes. Such exploration tests and evaluates the maturity of science understanding, and enables partners to assess and utilize EO solutions to reach targets (Figure 3) and outcomes (Figure 4).

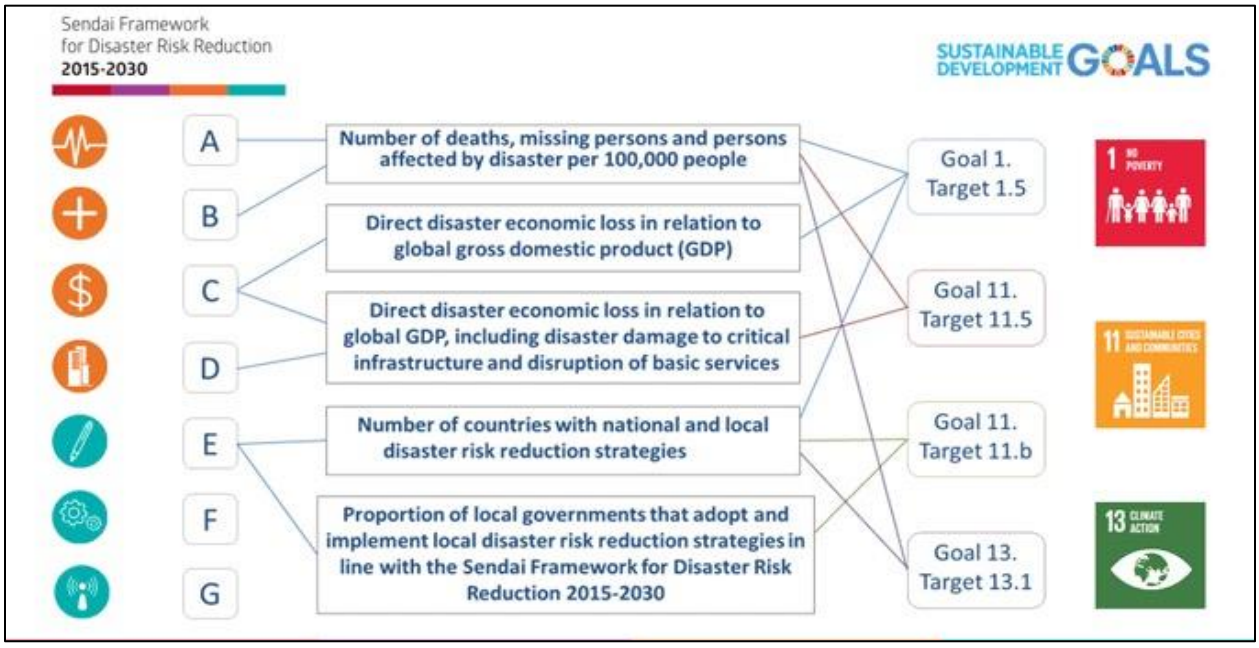


Fig. 3 Alignment of Sendai and Sustainable Development Targets

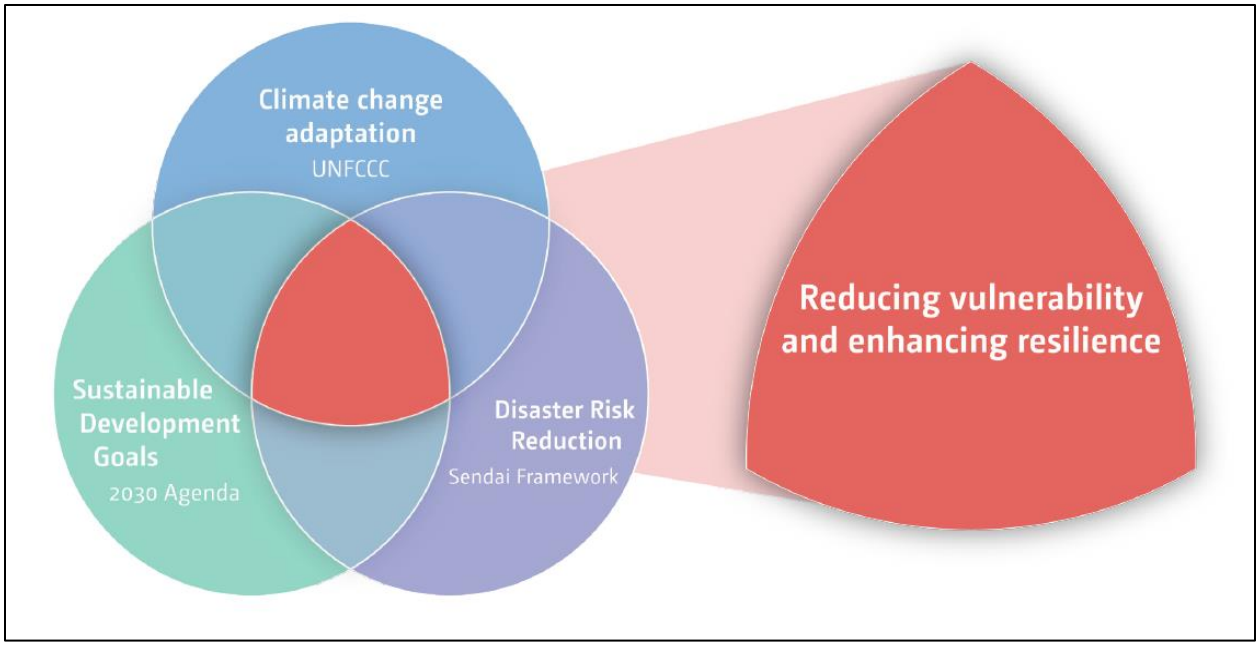


Fig. 4 Interconnectedness of climate change, sustainable development and disaster risk Reduction to a shared outcome of developing resilience.

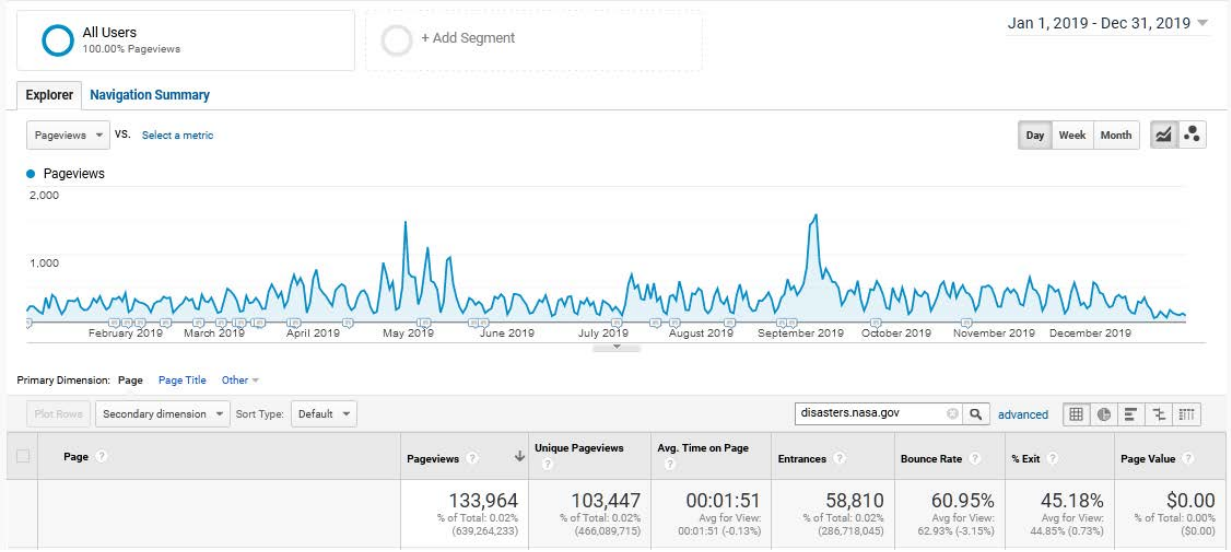
With sector partners, such as those concerned with infrastructure and property risk, humanitarian relief, and community resilience the program worked to infuse new capability that move society toward preventing disasters. This includes increased emphasis on prediction and using earth observations to better anticipate changes and access choices to address disaster risk so decision makers and actors can spot ex-ante opportunities or mitigation measures. While still a new pivot for the program, several projects and partners made progress to inform preparedness and planning, which includes enhancements to early warning and visualization tools to catalyze changes in behavior, such as working with the International Federation of Red Cross Red Crescent, to demonstrate lowering barriers for earlier humanitarian intervention and forecast based financing. Informing preparedness measures contributed toward reducing damage, minimizing disruption and lessoning impacts in isolated, displaced and settlement communities across several continents and national boundaries. When disaster events do happen, many of the capacities can be coordinated and moved in place for adaptive response, to act faster or more effectively. Certainly with a pre-existing relationships and contacts, the program of subject matter or regional experts demonstrated that they can be prepared to help answer additional questions not available from operational service providers. Similarly, the program has taken initial steps to work with other agencies and sectors on novel and unique approaches to using the earth system perspective to guide reconstruction. In cases of human and lifeline disruption, the program continued to emphasis pro-active steps to create unique data sets, models and information products, which could be provided in a timely and easily ingested manner.

Ongoing projects and engagement helped expand the reach to local influencers and connectors, able to leverage a global network of creative partners motivated to work with NASA. Not sufficient to create routine products or tailored products for science users only, the program made progress harnessing available science results and technology that combined with partner capabilities and capacities to make better choices and guide actions. According to feedback from local and niche stakeholders in risk management and relief, NASA data products gained increased effectiveness in demonstrating why Earth Observations can help minimize disruption and displacement. The quality of disaster activations, rather than the quantity of activations, translated into providing mapping data in the aftermath of disasters to help relief efforts understand the area and plan accordingly (See Figure 2). In particular, after Hurricane Dorian slammed into the Bahamas in early September, 2019, program members worked quickly to distribute imagery and damage impact and severity maps through its web portal to humanitarian response and recovery efforts.

Engagement and Outreach

- Community Meetings
  - Workshops
  - Conferences
  - Symposia
  - Working Groups
- Focus Groups
- Surveys
- Online Engagement
  - Peer-contributed content
  - Virtual meetings
  - Webinars
  - Blogs and features
- Conference calls
- Fact sheets
- Social media

In 2019, the Program targeted a broad spectrum of hazards and cascading events including, but not limited to, floods, earthquakes, tsunamis, volcanoes, landslides, severe storms, tropical storms, wildfires, and oil spills, as well as combined hazards and cascading impacts. Managers, coordinators and investigators associated with the program had mixed success transitioning from what many perceived to be a hazards program to a disaster program, which necessitates the integration and consideration of exposure and vulnerability as well as coping capacity. It is worth noting, that this pivot to disaster risk coincides with relatively new changes in national and international frameworks for disaster risk and resilience. Over the course of the last 20 years, those in the disaster science reduction and resilience community have come to realize that new approaches were needed to work well in advance of disasters and waiting until events happened was simply ineffective. Therefore, the program research portfolio and activation efforts placed a growing emphasis on tasks and work plans that help distinguish a hazard from a catastrophe and piloted new ways to deliver the right information to the right place at the right time. This also introduced a cultural shift from protection to prevention by answering key partner questions that informed risk reduction and resilience. This revealed some programmatic gaps in skills, organizational structure and resources, necessitating new metrics and measures of program success related to training and partnering that emphasized more time, tools, and resources toward cross-cutting and interdisciplinary stakeholder engagement. Nevertheless, the program saw significant pull from stakeholder and user communities gravitating toward the disasters portal earlier and spike in an around events.



The program implementation is one build on a foundation of people, processes and partnerships. This address more than providing imagery or co-developing capacity, but for Disasters program this means explicitly implementing and sponsoring activities around questions of inclusion, diversity and justice by working with communities of highest social and economic vulnerability. With a portfolio of interdependent projects coming together to form a collaborative network, pro-active information sharing and engagement has increased. As such, the program is intended to be agile by design and management approach, able to "sprint" in development to address changing conditions from global to regional to local scales. The workplans, staffing roles and collaborative tasks flex to accommodate the full disaster lifecycle, and incentivize program researchers and partners to create and recreate innovative portfolios of data, mapping, modeling, communication, and visualization capabilities. As such, coordination roles were encouraged to promote awareness and learning and finding a better balance with service providers and operational product generators. The new research sponsored project teams were introduced in 2019 toward creating through a solicitation calling for "a toolbox" of decision support capacities over the next 3 to 4 years. This collaboratory phase was launched and would be explored in 2019 and then a re-alignment developed throughout 2020 to craft an integrated workplan and strategy.

The program's portfolio includes multi-year projects (typically 4 years with some adjustments due to funding rephasings, leveraging opportunities and tactical augmentations), which incorporate support mobilization for short-term surges of experimentation during real-world events. In some instances the projects include airborne campaigns and use of partner facilities as well as access to unique data sets that have required flexibility. The intent is the new Principal Investigators and their complement of Co-Investigators and Collaborators will contribute to Disaster Application and Response & Recovery Teams (DARRTs). In 2019, all the project teams were given roles and responsibilities to learn about each of the other projects, their plans, expertise and coverage. From the time of the kick-off meeting in June 2019 through the end of the calendar year, many of these groups contributed in novel and innovative ways to disaster event activations. DARRT teams along with Coordinators and partners contributed to such tasks as management of risk operations or acquiring data and processing data products for delivery to users, as well as consulting and sharing knowledge. The level of complexity of the incidents dictated the roles activated and the At the same time, the core NASA teams across headquarters, centers, labs as well as partnering organizations continued to form temporary organizational

structures around these real world events. This unique blending of science teams and cross-cut of research, application, technology and stakeholder in effect mean that 10 traditional research projects turn into 100's of short term experiments, with informal sprint teams, with an amplification of potential value to users and decision makers. Furthermore, the activations created a multitude of added-value studies and publications, and the transition of science knowledge into practice. Each multiyear project team activation support follows a variety of approaches, which lend themselves to being captured in playbooks and workflows that contribute to the NASA coordination efforts. Through 2019, existing activation concepts and experiences were shared with the new teams, and progress made toward transitioning applications to information brokers such as regional disaster centers or piloting new damage extent maps or methodologies to assess complex risks of displaced communities.

The Disasters program and its network of coordinators, investigators, partners and volunteers assist with hazard and resilience assessment, evaluation of susceptibility to risk, extent of severity, and identification of impacts to communities. In 2019, particular attention was paid to regional and local community vulnerabilities such as the functions of infrastructure, the loss of crops or disruption to food systems, and the reconstitution and continuity of urban lifelines (including supply chains and logistics), especially in disaster-prone areas, remote locations and islands where observations are sparse or fragmented.

In 2019, the Program explored new scientific boundaries in risk reduction, especially data collection, modeling and analysis of multihazard risks that are insurable and several examples of operational risk in energy and transport sectors. Consistent with NASA's organizational vision to explore the earth, the program kicked off 10 new multiyear projects with case studies to create applications harnessing geospatial intelligence to protect lives, livelihoods and economies of value over diverse geographies and for distinct stakeholders. The tactics included the emphasis on transdisciplinary science and disruptive technologies. New projects targeted coastal and water communities, created novel data products for wildfires and floods, and tested real-world applications in food system and pollution risks. Targeted investments and engagements expanded the Program's international contribution to humanitarian assistance and commercial resilience to financial, environmental and social crises; and advanced situational awareness tools for development banks and recovery investors.

Disaster Research

The Disasters program's research investment strategy evolves with the needs of communities and society, with both long term multiyear projects and early-career development as well as short term flexibility through rapid response and directed exercises and workshops. In 2019, the Disasters Program launched a new applications portfolio by funding 10 new project teams, representing a diverse array of scientific and technical expertise with 116 primary and co-investigators and collaborators. All under the umbrella of the NASA Research Opportunities in Space and Earth Sciences (ROSES) 2018 A.37 Disaster Response and Risk Reduction solicitation (hereafter referred to as A.37), the project teams are required to be highly collaborative and involved in both the transition of research to application as well as contribute to disaster risk reduction through DARRT teams. While the projects were solicited in 2018 and reviewed, there was an unfortunate delay in the initiation of the projects due in part to the government budget calendar and early 2019 furlough. As a consequence, the projects started

mid-way through the fiscal year and project years are now rephrased across an extended period. Nevertheless, the 10 teams did meet for a collective kickoff and have been slowly spinning up. In mid 2020, the groups are expected to realign plans and prepare for their 18 month review in 2021. The objectives of the collective portfolio is to align with those of the Sendai Framework, including the annual targets as well as the Global Risk Assessment Framework (GRAF). Further, each of the projects and the collective portfolio are expected to promote and demonstrate practices consistent with open data polices of the CEOS and GEO work plans. For further details, see Solicitation: NNH18ZDA001N-DISASTERS

Fundamental to that call were specific capabilities in the following Earth Science areas:

- Satellite remote sensing studies aimed at better characterizing hurricane and tropical cyclones, severe weather, earthquake, volcano/volcanic ash, and cascading hazards throughout geographical areas or environments with intensive risk.
- Modeling of these processes to support earth-system application science and the applied research results to understand risk, producing ex-ante risk and resilience assessments, timely damage, loss and recovery maps, and end-to-end predictive decision tools.
- Obtaining and developing data sets and applications to validate and/or improve the skill, convergence, and integration.
- Advance testing, evaluation, and deployment of risk-informed modeling and mapping products to support and build towards risk-based monitoring, emergency and disaster response adaptation as well as recovery and planning systems.

The Program incorporated this research in its disaster support activities by aggregating projects and integrating science and technology into real-world situations to assess social and environmental choices that aid stakeholders. Development, coordination, and demonstration activities improved uptake and utilization of application science results, predictive tools, and assessments. The specific science applications, tools, and expertise, which investigators bring to this process, are noteworthy, as are their 2019 accomplishments, detailed in Section II.

Disaster Team Activation and Adaptive Response

The intent of Disaster Team activation and adaptive response as it relates to the NASA Disasters Program is to apply the appropriate methods of scientific research and application to the full disaster management cycle and accelerate impact by testing progress in real-world disasters. This matures a paradigm shift from managing disasters to managing current and future risks, bringing in resilience-building as the core outcome. In this capacity, the Disasters Program acts as a force multiplier, leveraging science missions and expertise to support disaster risk reduction, minimize impacts through early action, improve situational awareness for response, identify scope and scale of impacts to hasten relief and recovery, and inform a systemic approach to foster sustainable resilience. Since NASA is a science-based agency, responding to emergencies and disasters requires adaptation to meet the demands of the situation while balancing multiple competing interests of the organization. The Disasters program maintains funding for research portfolio as well as a standing team of individuals to help with community coordination, subject matter expertise and product generation.

The Disasters program team (Program Manager and Associates) use a strategic framework with measureable performance metrics to execute finance and budget tactics that dynamically

reallocate or augment resources, adjust work schedules, and, depending on severity and duration of the event, even promote compromise routine NASA science and service outputs. With regard to the multi-year grants, this includes a major re-alignment plan after the first year and performance review in the second year of execution, augmentations as appropriate and enablement of opportunistic collaborative opportunities.

The Program's unique capabilities help identify information gaps and make new scientific connections to provide added awareness of physical, geographical and socio-economic factors assists information brokers, decision makers and the actions of end users. Supporting disasters in this manner is a complementary process; the maturation, testing and evaluation of program science results in real-world conditions and with various users enhances the disaster risk management capabilities of external organizations, which in turn further advances the research and data products. This research-to-applications and applications-to-research approach focused on partner engagement and building reliable and trustworthy data products and tools. Further work is needed to reach goals and objectives associated with pro-active measures for disaster prevention. Additional details and highlights are in Section III.

Disaster Risk Reduction and Resilience

The NASA Disasters program has been building a growing portfolio of activities and experience related to disaster risk reduction, prevention and disaster resilience, which seeks to expand the application of Earth-observation systems to elements across the disaster cycle—including disaster mitigation and preparedness, and reconstruction and recovery. From a policy perspective, the Disasters Program supports the 2030 Agenda for Sustainable Development, specifically through implementation of the Sendai Framework for Disaster Risk Reduction and the provision of guidance towards the development of the Global Risk Assessment Framework, the Secretariat of which is the United Nations Office for Disaster Risk Reduction (UNDRR). In 2019, this set of perspectives led to the strengthening of key partnerships and advancement of new projects with nongovernmental and humanitarian organizations including the World Bank Disaster Risk Management Team, Mercy Corps, and the International Federation of Red Cross and Red Crescent Societies. The program made substantial progress in partnership with a number of United Nations (UN) organizations, including the UN Office for the Coordination of Humanitarian Affairs (UN OCHA), UN Office for Disaster Risk Reduction (UNDRR), UN High Commissioner for Refugees (UNHCR), the International Organization for Migration (IOM), and the UN Development Programme (UNDP). These activities also integrate international Earth observation Community Activities and Initiatives of the Group on Earth Observations (GEO) as well as projects with the Committee on Earth Observation Satellites (CEOS).

The NASA Disasters program created and sponsored partnership opportunities to accelerate the use and infusion of technological innovations, experience exchange, and translation of practical knowledge into application. This year continued to focus on advanced geospatial information systems (GIS) and web services, big data analytics and cloud computing, smart sensor webs and autonomy, machine learning (ML) and artificial intelligence (AI), and visualization capabilities including augmented and virtual reality AR and VR. Each of these partnerships considers risk from the standpoint of the partner, and endeavors to adopt a human-centered design approach where products are developed and tested with the partner throughout the partnership engagement. The purpose of all risk reduction and resilience-focused activities is to co-develop

products directly with brokers and, in some cases, with end user to optimize transition of data knowledge for sustained application. For further details on the associated projects, see Section IV.

II. Disaster Research

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

In 2019, the program's portfolio grew substantially with the addition of 10 new NASA Research

PI Name	Organization	Proposal Title
Hilburn	CO State University	Coupled Interactive Forecasting of Weather, Fire Behavior, and Smoke Impact for Improved Wildland Fire Decision Making
Krotkov	NASA GSFC	Day-Night Monitoring of Volcanic SO_2 and Ash for Aviation Avoidance at Northern Polar Latitudes: Enhancing Direct Readout capabilities from EOS, SNPP and NOAA20
Bedka	NASA LaRC	Hail Storm Risk Assessment Using Space-Borne Remote Sensing Observations and Reanalysis Data
Glasscoe	JPL	Advancing Access to Global Flood Modeling and Alerting using the PDC DisasterAWARE Platform and Remote Sensing Technologies
Kirschbaum	NASA GSFC	Enabling Landslide Disaster Risk Reduction and Response throughout the disaster life cycle with a multi-scale toolbox
Monaldo, Francis	UMD College Park	Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context
Melgar	University of OR	Local Tsunami Early Warning with GNSS Earthquake Source Products
Yun	JPL	Global Rapid Damage Mapping System with Spaceborne SAR Data
Meyer	University of AK, Fairbanks	Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters
Huyck	ImageCat, Inc.	Open Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response

Table 1. NASA Disaster Response and Risk Reduction project portfolio

Opportunities in Space and Earth Science (ROSES) Disasters A.37 Disaster Response and Risk Reduction projects, listed in Table 1.

In addition, the program advanced alignment with and leveraging of the results from six ROSES 2016 A.50 Group on Earth Observation (GEO) Work Programme Projects. This included three GEO Flood Risk Monitoring (GFRM) Community Activity projects and three GEO Global Wildfire Information System (GWIS) Initiative projects.

PI Name	Project Number Community	Title Summary
Brackenridge	17-GEOGFRM	Global Systems for Local Flood Prediction and Impact
Kruczkiewicz	16-GEO16 GFRM	Global Flood and Flash Flood Early Warning
Yun	16-GEO16 GFRM	Global Rapid Flood Mapping
Boschetti	16-GEO16 GWIS	Polar Orbiting Fire Product Record
Field	16-GEO16 WIS	Fire Danger Rating and Applications Indonesia
Giglio	16-GEO16 GWIS	Multi-sensor Global Active Fire Data

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

PI Name	Project Number	Title Summary
Abshire	19-SMDSS19	AMS Project Atmosphere
Arrighi	18-TWSC18	Red Cross – Humanitarian Early Action
Gaffney	17-RRNES17	Sonoma Country Post-Fire Assessment
Kruczkiewicz	18-RRNES18	Decision Support for SE Asia Settlements
Schumann	18-TWSC18	Global Flood Risk
Melbourne	18-RRNES18	GNSS-enabled Tsunami Warnings

Table 3. NASA Disasters Program directed research projects and workshops

Three Rapid Response and Novel Research in Earth Science (RRNES) projects, and two NASA ROSES Topical Workshops, Symposia, and Conferences (TWSC) projects supplemented the research portfolio. Preparation for one directed workshop on the topic of disaster risk for indigenous populations advanced this year. With a strategic objective to advance workforce and human capacity, the program supported six NASA Earth and Space Science Fellowship (NESSF)

PI Name	Project Number	Title Summary
Charbonnier / Macorps	16-EARTH16	DEMs and Mitigation of Volcano Hazards
Durand / Shastry	16-EARTH16	Flood Inundation and Topography
Marrani / Zoretto	16-EARTH16	Global Extreme Rainfall Estimates
McQuarrie / Buford	16-EARTH16	Landslide hazard Assessment
Sheng / An	16EARTH16	Levee Seepage and Subsidence
Tiampo / Jacquemart	16-EARTH16	Landslide hazard Assessment

student or post-doctoral projects as well as various teacher and early career trainings and hackathons. All of these projects provided the intrinsic Disasters Program research knowledge base and expanded networks in support of all of the program's deliverables in 2019.

Table 4. NASA Earth and Space Science Fellowship (NESSF) projects

A.37 Consortia and Team Building

From July 17-19, 2019, in Broomfield, Colorado, the NASA Disasters Program held an initiation workshop to launch the ten individual A.37 teams of Principal Investigators (PIs) and Co-Investigators (Co-Is) and facilitate their collaborative cross-cutting work plans. All ten teams participated, and presentations provided and exercises familiarized everyone with both the Program objectives and goals. Unique to the program is the agile consortia approach that includes shared support structures such as the GIS portal, program website, international projects and outreach, and access to NASA's Disaster Associates, Coordinators and global network of partners. Each PI team shared their unique capabilities, described their team management approach, their geographical focus and timelines, and relationships with stakeholders and user organizations. The NASA Program facilitated sessions that enabled the PIs and Co-Is to 1) determine complementarity of research areas across the ten projects, 2) to identify opportunities and challenges for collaboration, 3) to map the current and intended locations of focus for each project, and 4) to develop working groups to begin implementation of the integration and alignment of the projects.

Figure 1. NASA Disasters Program A.37 Kickoff Meeting Broomfield, Colorado, July 17-19, 2019

An outbreak of severe wildfires across Alaska with plumes spreading across the continent provided a real-world activation opportunity during the workshop. In this case, a literal "trial-by-fire" initiated the new project representatives working alongside the existing Disasters program Coordinators and partners. This initial formulation of the DARRTs assessed capabilities and contacts, stakeholders and unique contributions. As with the activation part of the Disasters Program the contributors can be activated in adaptive response to disasters and other emergencies. There are four levels of activation, depending on the scale of the event. The Tier 0 being a rapid assessment, to identify resources and choices against known criteria, leads to a decision whether key to elevate involvement. In the case of this wildfire incident, the Program invoked a Tier 1 activation involving collaborative development of models, maps and awareness products to answer questions for a user group, in this instance serving the interests posed by Congress. The outcome of the workshop included a report and network analysis to identify areas of shared interest and effective practice, gap-filling opportunities, and the mechanisms to change the scope and phasing of the initially proposed work plans.

Ongoing dialogue at conferences and site visits, community calls and website resource documents, reinforced accomplishments from the initial workshop. Several project teams subsequently met to revise and optimize cross-cutting activities and many contributed substantially to 2019 disaster activations.

A.37 Projects

DISASTERS18-08: Hail Storm Risk Assessment Using Space-Borne Remote Sensing Observations and Reanalysis Data

Principal Investigator: Kristopher Bedka

Led by Kristopher Bedka at NASA Langley Research Center, this project seeks to mitigate hail disasters over South Africa and South American countries by aiding development of new satellite-based severe storm nowcasting tools by regional partners and developing climatologies to improve societal and industry understanding of hail frequency. Much of the world is impacted by severe thunderstorms, but whether they become disasters depends upon resilience: the capacity to prepare, mitigate, respond, and recover. Hail is the costliest severe weather hazard for the insurance industry, generating ~70% of severe convective storm losses in 2017 due to damage to assets such as homes, businesses, crops, and infrastructure. Most insurance companies do not reserve enough capital to cover catastrophes, so they acquire reinsurance. The reinsurance industry uses Catastrophe Models (CatModels) to estimate statistically the risk to an insurer's portfolio.

This project creates a framework for developing continental to global scale hail climatologies and CatModels based on NASA satellite data and capabilities. This is a collaboration between NASA's Langley Research Center and Marshall Space Flight Center, Willis Towers Watson (WTW) reinsurance, and partners in Germany, South Africa, Brazil, and Argentina to improve socioeconomic resilience through development of new CatModels. South Africa, Uruguay, Paraguay, Argentina, and southern Brazil feature some of the most intense thunderstorms on Earth. South Africa and South America are developing insurance markets of interest to WTW clients and are similar to other regions routinely impacted by hail that do not have comprehensive hail reporting or radars to assess hailstorm frequency. The project is maturing land surface imaging satellite methods for identifying hail damage to improve disaster mapping. Up to 30 years of Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) satellite-imagery and reanalysis data combine to detect with reliability the presence of hailstorms, their extend and trends, and enable estimates of their severity. Incorporating Global Lightning Mapper data from the U.S. Geostationary Operational Environmental Satellite-16 (GOES-16) improves hailstorm analyses. The project is working closely with regional partners to advance, test and evaluate novel nowcasting capabilities and help transition capabilities that demonstrate improved warnings and disaster risk mitigation. The project includes elements of capacity building and co-development aimed at adopting and infusing these methods into resilient practice.

In 2019, the project made substantial progress by advancing the capability to analyze GOES datasets with severe hail reports, and radar-based storm cells with hail inferences over the United States. Milestones included production of a 14-year duration database of Meteosat Second Generation infrared overshooting cloud top detections at 3 km spatial and 15 min temporal resolution over South Africa with project partners Karlsruhe Institute to create. In addition, the project created a 5-year climatology of hailstorm events derived from GPM passive microwave observations. Use of these datasets, in combination with reanalysis data, enabled development of an initial hailstorm frequency analyses over the country. Delivery of near real-time GOES-16 severe storm detection datasets over southern South began for experimental operational evaluation by the National Meteorological Service of Argentina and other partners.

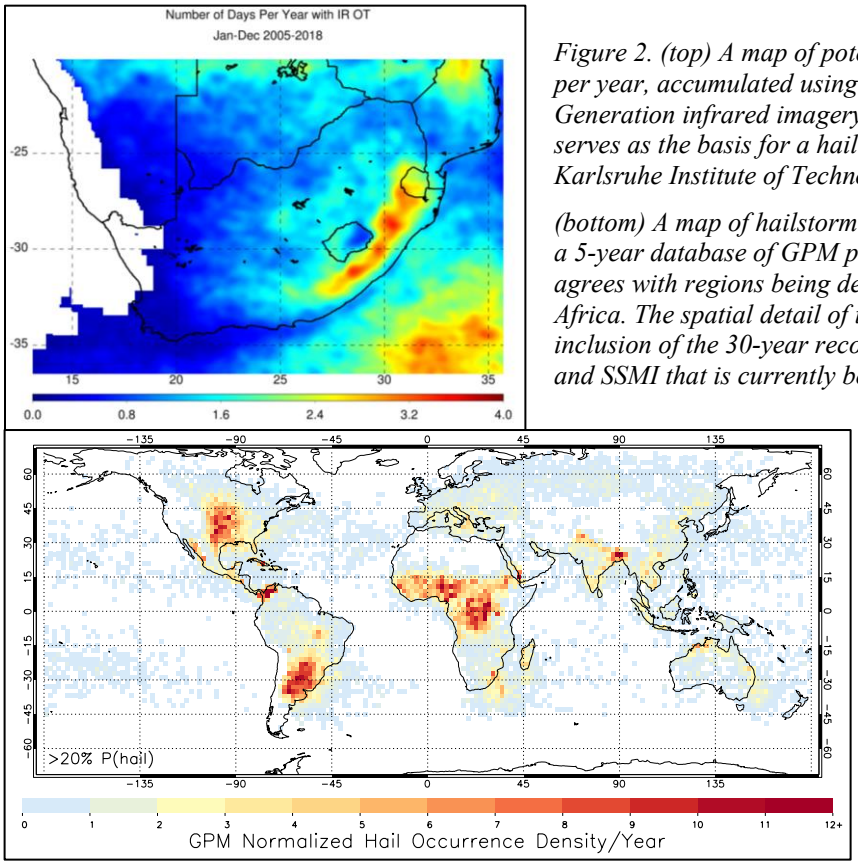


Figure 2. (top) A map of potential hailstorm updraft detections per year, accumulated using 15-minute, 3 km Meteosat Second Generation infrared imagery over South Africa. This data serves as the basis for a hail CatModel in development by Karlsruhe Institute of Technology and Willis Towers Watson.

(bottom) A map of hailstorm detections per year derived from a 5-year database of GPM passive microwave imagery, which agrees with regions being detected by infrared data over South Africa. The spatial detail of this map will be improved upon inclusion of the 30-year record of TRMM, AMSR-E, AMSR-2, and SSMI that is currently being analyzed by the project team.

DISASTERS18-09: Advancing Access to Global Flood Modeling and Alerting

Principal Investigator: Margaret T. Glasscoe

Obtaining highly reliable information about flooding events on a global scale currently requires the manual review and integration of multiple sources. There is a great variety of data, each part of which may or may not be relevant for a particular scenario, and each with different access mechanisms. Given that floods are both the most deadly and most costly hazard, this project will integrate flood inundation and risk information from multiple sources into the Pacific Disaster Center (PDC) DisasterAWARE (All-hazard Warnings, Analysis, and Risk Evaluation) platform, providing a single source of global information on floods supported by a common, normalized data model. End users will no longer be required to extract and merge data from multiple sources by hand, as this will be done automatically by the middleware.

By using a model-of-models approach, including innovative new interferometric Synthetic Aperture Radar (SAR), the team will create flood alerts and send them to the PDC's DisasterAWARE platform. Using SAR-based sources, as well as existing third-party sources, will furthermore create a repository of flood information that will potentially be greater than the sum of its parts, providing higher levels of confidence and supplemental information than any single source. The model-of-models approach will apply recent innovations in machine learning to create a unified picture that progressively improves over time as more data become available.

Figure 3. By integrating with DisasterAWARE, the project will create a situational awareness tool that will specifically identify flood events and push this information to end users through various mechanisms. Conversely, end users will be able to register for notifications about events detected by the system in areas of interest. This will streamline the delivery of data and remove the requirements for navigating through multiple sources. End users will be presented with the data of interest immediately.

This project started in June 2019 and within a short time began evaluating flood models and investigating case studies for retrospective forecasts, including Hurricane Harvey over Houston in 2017. A detailed six-month work plan outlines major tasks and deliverables for Year 1 and key assignments by project team investigator for each task. The project has already implemented several of the subtasks including collaboration with flood model developers and implementers.

PI Glasscoe, Co-I Eguchi, and Collaborator Schumann (as an organizer) presented the results of their work at the Dartmouth Flood Observatory (DFO) Flood Models Demonstration Workshop at the University of Colorado, Boulder, in September 2019. The team co-organized a collaborative meeting with the A.37 Landslides team, also working with the PDC, for a week at PDC in Kihei, Hawaii to discuss data generation and integration into DisasterAWARE.

DISASTERS18-12: Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment

Principal Investigator: Francis Monaldo

Satellite remote sensing is finding increased value when monitoring coastal waters for accidental and deliberate oil spills, as well as for the emergency and disaster response, environmental assessment and restoration following such events. In the aftermath of severe storms, the National Oceanic and Atmospheric Administration (NOAA) is responsible for assessing the status of and potential damage to offshore platforms and pipelines, which are potential sources of significant oil leaks and marine debris. All-weather and high-resolution data from the enlarging set of spaceborne SARs and high-resolution optical satellites offer an important opportunity for NOAA to exploit remote sensing for automated oil spill response, remediation, and post-storm offshore infrastructure assessment.

This work supports the hurricane/tropical cyclone primary hazard scenario with cascading risks, focusing on semi-automated oil-spill characterization that can adapt response and direct efforts to areas with more oil; health status assessment of offshore platforms, especially small and un-crewed; and identification of marine debris. Marine technological hazards are addressed. The work is designed to develop and mature automated oil spill detection and thickness estimates

from SAR and optical imagery, based on focused field testing combined with in situ oil sampling and incorporation of new sensors; to improve post-storm assessment of offshore oil and gas production facilities and marine debris; and to implement new algorithms and databases in a semi-automatic system that NOAA uses operationally to detect and assess oil spills and post-storm offshore damage and debris.

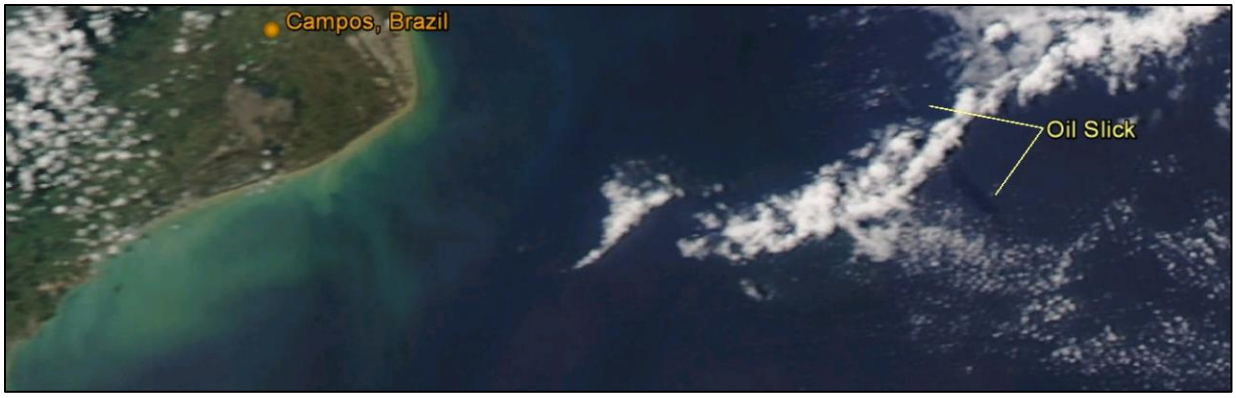


Figure 4. On October 8, 2019, the Brazilian Navy contacted NOAA NESDIS and NASA Disasters for assistance to determine the source of suspected oil contaminating thousands of miles of beaches since July. On October 10th, the project lead the evaluation of Moderate Resolution Imaging Spectroradiometer (MODIS) and other imagery of the suspected spill area to help provide an assessment.

The project anticipates that SAR instrumentation will improve NOAA National Environmental Satellite, Data, and Information Service (NESDIS) support to the NOAA Office of Response and Recovery efforts on behalf of the US Coast Guard and the Environmental Protection Agency (EPA) by providing a greater quantity of open data and more frequent coastal ocean imaging. For post-storm assessment of the marine environment, there is also a need for a validated detection database of offshore platforms as a function of wind speed and sensor mode and type to support existing algorithms for the detection of offshore platforms and ships from remote sensing data. In a post-storm environment, this database will be used to assess whether the platform has actually moved, been destroyed, or is simply undetectable in the given meteorological conditions. Similar well-understood relationships exist between marine debris object size and detectability.

The project began in August 2019 and is primarily in the planning phase for a spring field test with the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) and surface measurements March 10-11, 2020, off the coast of Santa Barbara. Four related presentations delivered November 13-15, 2019, by the project team of Monaldo, Holt, DiPinto, Staples, Garcia, and Graettinger at the Comparing Recent Advances in Estimating and Measuring Oil Slick Thickness Workshop, enhanced translation to users.

DISASTERS18-15: Enhanced Forecasting of Weather, Fire Behavior and Smoke Impact for Improved Wildland Fire Decision Making

Principal Investigator: Kyle Hilburn, Colorado State University

Over the past decade, the United States has entered a new era of increasing wildfire frequency and intensity culminating in a number of devastating wildfire seasons. Fire-prone landscapes are also more densely settled and developed than in previous years, resulting in steeply rising fire-suppression costs. Fire plays a crucial ecosystem role, but its prevention can often lead to

excessive fuel accumulation and catastrophic fires. Optimizing choices, decisions and actions based on the risks and benefits associated with wildfires and prescribed burns require better and more advanced decision-support tools that integrate satellite/aerial remote sensing and economic data with a coupled fire, weather, fuel and smoke-modeling framework.

This project has the primary goal of reducing the risks associated with wildland fires through the development and deployment of new decision support and situational awareness tools. These new tools will focus on rendering the spatial and temporal variability of weather and fuel conditions, and the two-way interactions between fire behavior, local weather, and smoke, which do not currently exist in operational fire risk management. The project aims to improve situational awareness and support decisions, especially for wildland fires that are impacted by significant weather variability and are difficult to handle with the current system. Through a seamless integration of weather data, surface fuel moisture observations, satellite fire detections, operational numerical weather prediction models and a state-of-the-art high-resolution, coupled fire-atmosphere smoke modeling, the project will deploy novel integrated decision-support tools that designed to reduce the risk associated with wildfire risk management. The new system will provide a 3-D spatial representation of essential elements that affect fire behavior, including dead-fuel moisture, fire spread and smoke.

Figure 5. Co-Investigator Adam Kochanski of the University of Utah was featured in a NASA video showing WRF-SFIRE used in the field during the Manning Creek Unit Prescribed Fire in Utah's Fishlake National Forest. Adam was participating in the Fire and Smoke Model Evaluate Experiment (FASMEE), a multiagency effort to advance fire and smoke forecasting, supported by the Joint Fire Science Program, US Forest Service Washington Office, and Pacific Northwest Research Station.

In 2019, significant scientific progress was accomplished to implement a prototype to integrate fuel moisture data assimilation and the operational fire forecasting system. Automated ingest of fire products from GOES-16/17 was been accomplished and evaluation of the data for model assimilation was begun. The project also developed a support vector machine technique to assimilate fire arrival time using satellite fire detections. The project's system was used to support Richfield USFS office and local incident meteorologist in making prescribed burn decisions. Incident meteorologists at National Weather Service Salt Lake City Office also expressed interest in using the system to run spot forecasts for prescribed burns. Based on user input, the visualization system has also been extended to provide precipitation and snow melt information. In 2019, the project published one peer reviewed article (Mandel et al. 2019) in *Urgent HPC*, and seven conference presentations at: AMS-EUMETSAT-NOAA Joint Satellite Conference, National Academies Modeling and Simulation of Wildfires Workshop, EXFHIRE Workshop, and American Geophysical Union Fall Meeting. The project's primary investigator, Kyle Hilburn also contributed GOES-16 Advanced Baseline Imager Fire Temperature and GeoColor Smoke products for a NASA Disasters News article on the Saddleridge Fire in Southern California.

DISASTERS18-19: Identifying Critical Infrastructure Exposure for Disaster Forecasting, Mitigation and Response

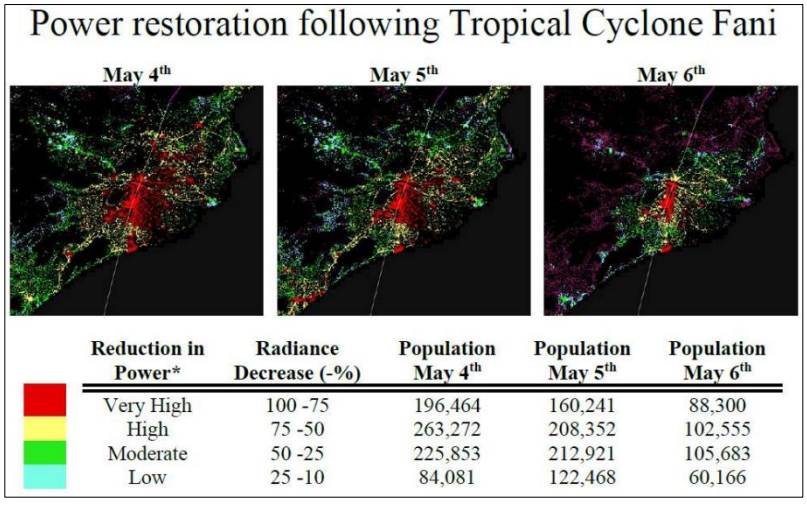
Principal Investigator: Charles K. Huyck

Cities are complex systems with interconnected "lifeline networks" enabled by critical infrastructure, which can be severely damaged or destroyed in the aftermath of disasters. Following Hurricanes Maria and Katrina and the Tōhoku earthquake and tsunami, damage to critical systems resulted in cascading effects that severely impeded recovery and crippled regional economies. Geographic Information System (GIS) data gives the location of critical infrastructure (CI) and can be used to identify and mitigate damage, but in many cases, the locations of key components are unmapped or unshared, particularly in developing countries.

Without pinpointing the physical location of key assets in a consistent manner, it is not possible to identify where the regional risk from infrastructure disruption can lead to cascading damage that, in some cases, could significantly reverse progress in developing countries. This project is expanding the ability to model the catastrophic impacts of infrastructure disruption by providing a foundation for CI exposure development in concert with remote-sensing Earth observations made via satellite.

The project team is composed ImageCat Inc., Humanitarian OpenStreetMap, and the Center for International Earth Science Information Network at Columbia University. Key products produced during the initial project kickoff period include 1) the power restoration imagery following Tropical Cyclone Fani product that were delivered to the Indian Ministry of Power, Ministry of Home Affairs, the National Disaster Management Authority, and the State of Odisha State Disaster Management Authority; 2) the delivery of a flood risk product for the NASA Disasters GIS Portal; and 3) the delivery of building and hazard data sets for Norfolk, Virginia for the visualization of future impacts from sea level rise.

The team is working in India and will expand to developing countries globally, prioritizing based on end-user requirements. A pilot kick-off meeting with the Indian "Smart" City of Vadodara and Indian Institute of Technology occurred on January 16 - 17, 2020. As with buildings, identifying lifeline networks is a data-fusion process requiring collection of existing datasets and use of segmentation and edge-detection algorithms. Data will be delivered openly and globally to developing countries and all those interested in risk, as well as integrated into commercial products for global risk identification and management.



Reduction in Power*	Radiance Decrease (-%)	Population May 4th	Population May 5th	Population May 6th
Very High	100 -75	196,464	160,241	88,300
High	75 -50	263,272	208,352	102,555
Moderate	50 -25	225,853	212,921	105,683
Low	25 -10	84,081	122,468	60,166

Fig 6. The Visible Infrared Imaging Radiometer Suite (VIRRS) night-time lights radiance change (in percentage) for given dates against March 2019 VIIRS monthly composite, centered around the Bhubaneshwar-Cuttack-Puri city regions of India where Tropical Cyclone Fani first made landfall. The percentages of change are represented as negative radiance percentage values where [Very High] indicates a 75-100% decrease

in radiance on the given date compared to the VIIRS values from the March monthly composite. The [High] indicates a 50-75% decrease, [Moderate] is a 25-50% decrease, and [Low] indicates a 10-25% radiance decrease.

DISASTERS18-22: Development of Predictive Models to Improve Landslide Disaster Risk Reduction and Response

Principal Investigator: Dalia Bach Kirschbaum

Landslides globally cause loss of life and lasting damage to critical infrastructure. A major rainfall or earthquake can trigger tens of thousands of landslides, compounding losses from damage to transportation networks that inhibit adaptation of disaster response, resulting in cascading effects such as flooding and debris hazards. Despite their ubiquitous nature in many disaster scenarios, there is little integration of pervasive landslide impacts throughout the complete landslide disaster life cycle, including preparation, recovery, and mitigation.

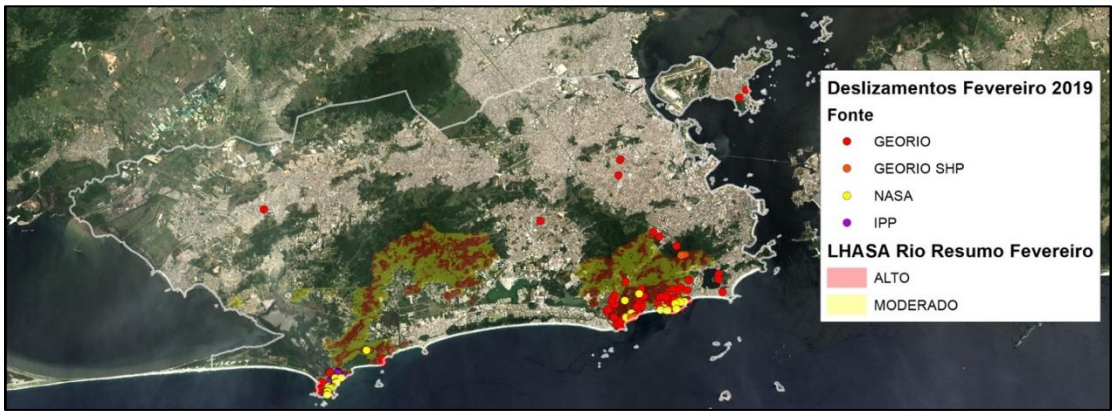


Fig 7. LHASA-Rio model is running operationally in Rio de Janeiro, Brazil and has provided excellent results during major rainfall events on February 2, 2019 and April 9, 2019. The project team mapped landslides following the February event using high resolution satellite data and combined the inventory with data from the City of Rio de Janiero Geotecnica Institute (Geo-Rio) and found that the LHASA Rio model performed well, with a 92% hit rate. Data Sources: LHASA-Rio, Geo-Rio, NASA and Instituto Municipal de Urbanismo Pereira Passos (high resolution imagery)

This project supports key decision-making and resilience-building capabilities related to landsliding for a wide range of stakeholder partners, as well as publicly served data and models that will be available through project partner websites (City of Rio de Janeiro, PDC, and the U.S. Geological Survey (USGS)). The team will advance landslide forecasting using the predictive Landslide Hazard Assessment for Situational Awareness (LHASA) model, satellite data and ground observations, including evaluation of landslide risk based on the hazard model outputs combined with exposure and vulnerability data. The project addresses the impact of widespread landsliding triggered by disaster events, including tropical cyclones and earthquakes, where landslides are a significant secondary hazard interrelated with the effects of strong ground shaking and flooding.

Over the duration of this award, the team will contribute nowcasts, forecasts, real-time updates on evolving hazards, and post-event data collection in support of rescue and recovery efforts and longer-term model improvement/validation. The stakeholder partners participating in this effort will directly contribute to and co-develop the products and tools to ensure a seamless transition and uptake within their decision- making systems. These efforts will provide improved situational awareness for disaster risk reduction, adaptive response, and sustainable resilience of

landslide hazards relevant to both scientific and stakeholder communities. In 2019, the team met with city managers of Rio de Janeiro and operationally deployed the LHASA-Rio model to improve prediction of landslide events using rainfall forecasts and extend analysis of landslide impacts to better characterize areas of exposure and risk. During and following the visit with the Rio, the team discussed strategies for advancing for advancing the LHASA-Rio model to incorporate exposure analysis and more effectively categorize landslide hazard for local decision making.

DISASTERS18-25: Integrating Synthetic Aperture Radar Data for Improved Resilience and Response to Weather-Related Disasters

Principal Investigator: Franz Meyer

Weather-related hazards are ubiquitous in the United States, including: 1) hurricane storm surges impacting coastal areas; 2) rapid snow melt and heavy rainfall causing basin-scale flooding; 3) severe weather leading to flash floods and tornadoes; and 4) seasonal freeze and thaw of rivers that may lead to ice jams. Each of these hazards affects human settlements ranging from major cities to rural areas and has the potential to significantly impact agricultural productivity. 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. Analysis of past events supports risk mitigation by understanding 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. However, complex processing and high computational costs associated with SAR require the development of approaches that streamline product generation.

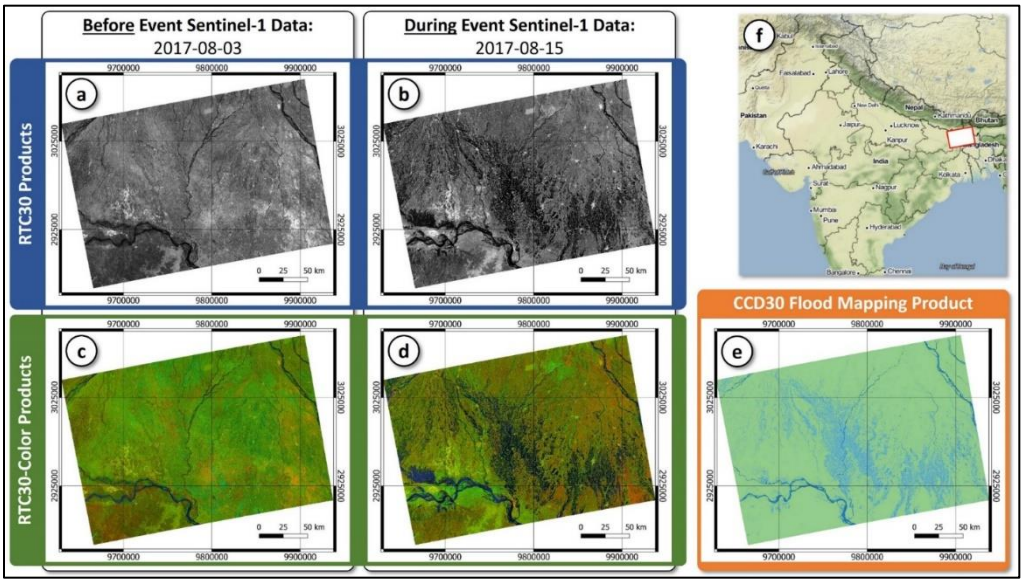


Figure 8. Examples of prototype flood hazard products RTC30, RTC30-Color, and CCD30 for the 2017 flood season in Bangladesh.

To meet this need, this project is developing a cloud-based automatic data analysis toolbox for the processing of SAR data into value-added products that address the mapping of meteorological and hydrological disasters, such as heavy rainfall and flooding, as well as related cascading hazards, such as landslides and levee instability. 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 assist in preparing for and mitigating risk by allowing users to process image time series gathered from NASA Distributed Active Archive Centers or through their purchasing 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.

A kick-off meeting for this project was held in September 2019 where end-user project expectations, an approach to hazard assessment, and project actions items for the first quarterly project period were defined. With NOAA APRFC, past flooding events were identified for product development & evaluation. With USDA-FAS, past events with agriculture impacts were selected for validation. By year's end the first prototype cloud-based environment for Level-1 (original sensor data) to Level-3 (science/applications product) processing was developed. The team has implemented first prototypes for RTC30, RTC30-Color, and CCD30 flood hazard product, as shown below. Development of FD30 and AG100 data was also started.

DISASTERS18-28: Day-Night Monitoring of Volcanic Sulphur Dioxide and Ash for Aviation Avoidance at Northern Polar Latitudes

Principal Investigator: Nickolay A. Krotkov

Volcanic ash clouds pose a significant threat to inflight air traffic safety, leading to prolonged flight cancellations that affect the economy and personal travel. Low-latency satellite observations provide crucial information for rerouting air traffic around volcanic clouds. During a previous Applied Sciences Program project, this team established partnerships between the Geographic Information Network of Alaska (GINA), NASA's Direct Readout Laboratory (DRL), NASA's ozone processing team, and the Finnish Meteorological Institute, so as to locally process ultraviolet-based (UV) direct-readout (DR), satellite-observed volcanic ash and sulfur dioxide (SO_2) data for distribution to a number of end users.

UV-based monitoring is unavailable at night or under low-light conditions, so users requested the team expand DR monitoring capabilities to better serve the increasing number of flights at night and over polar regions. To address this, the team is developing critical DR volcanic ash and SO_2 products based on thermal infrared data, acquired by several operational satellite-borne instruments. The team will also improve and extend DR-UV products to monitor smoke plumes from forest fires. Collaborators from the Finnish Meteorological Institute will evaluate the DR plume products for the northern Atlantic and the Norwegian, Barents, and Kara Seas, and distribute them to European users. The combined use of ground-based stations and multiple satellite platforms, each with several overpasses over the polar region, will then provide low-latency coverage of all high-latitude volcanoes in the Northern Hemisphere.

This project began in July 2019 and continues processing NASA's Aura near real-time SO_2 data from the Ozone Monitoring Instrument to feed several web sites at NOAA, European Support to Aviation Control Service, and NASA Worldview. They continue advancing satellite volcanic SO_2 web service to implement DR day-night volcanic SO_2 processing utilizing Suomi-NPP and NOAA20 satellites. These new products are evaluated and assessed by several organizations,

including USGS and the National Weather Service Anchorage Volcanic Ash Advisory Centre (VAAC). The data will then be available to worldwide DR community, all World Meteorological Organization (WMO) VAACs, and International Civil Aviation Organization/International Airways Volcano Watch (ICAO/IAVW) users.

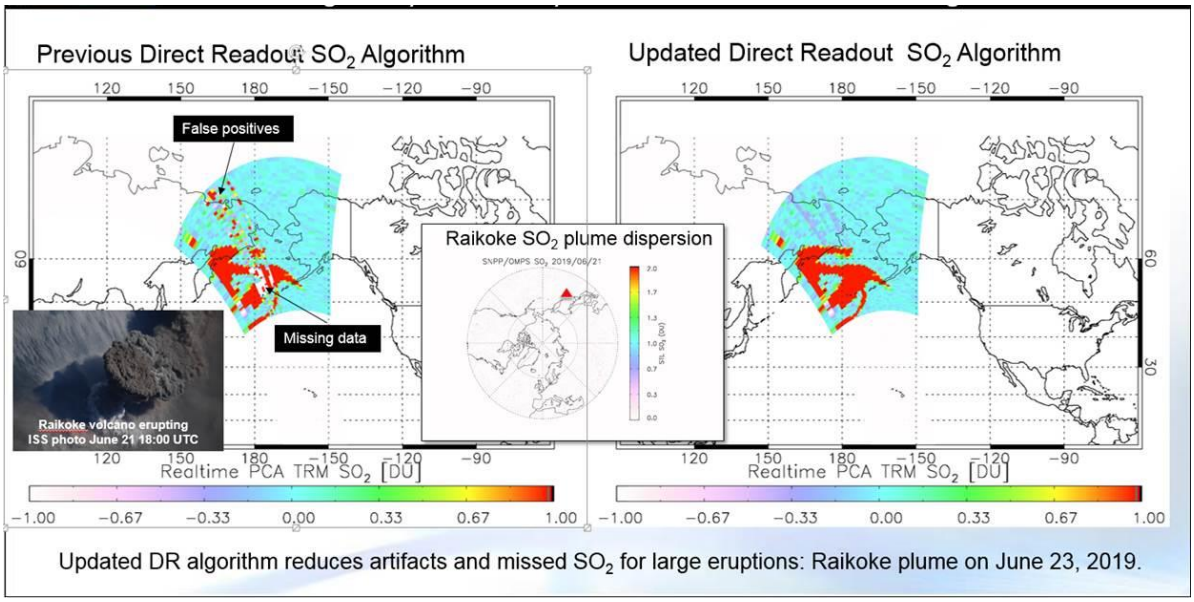


Figure 9. Significant technical accomplishments in 2019 included the provision of data by the NASA Disasters Program for eruptions of the Raikoke, White Island, NZ , and Taal, Philippines volcanoes. DRL provided real-time SNPP imagery to the NASA Disasters Mapping Portal to create animation for Raikoke SO_2 and ash cloud dispersion: https://so2.gsfc.nasa.gov/links.html.

In November the project PI attended the conjoint 7th WMO VAAC Best Practices Workshop and 9th WMO International Union of Geodesy and Geophysics Volcanic Ash Scientific Advisory Group Meetings (https://www.wmo.int/aemp/VAAC-BP-7-VASAG-9). The WMO is now considering developing new quantitative volcanic ash and SO_2 forecast services for ICAO/IAVW users. While there, PI Krotkov met with A-VAAC manager Jeffrey Osiensky and discussed transferring real time SO_2 data from GINA to the A-VAAC and with the USGS Alaska Volcano Observatory concerning the formulation of a WMO/VAAC quantitative volcanic ash information service and testing for a future SO_2 information service.

DISASTERS18-34: Using Spaceborne Synthetic Aperture Radar to Rapidly Map Global Damage

Principal Investigator: Sang-Ho Yun

Led by Dr. Sang-Ho Yun, this project seeks to rapidly produce, validate, and deliver damage proxy maps (DPMs) to stakeholders and key partner agencies around the world. Rapid mapping of disasters is of financial and humanitarian importance. Radar is an ideal tool for this, as it sees through clouds and can image day and night. The number of SAR sensors is increasing such that a SAR satellite will overpass an affected area in less than 12 hours of a disaster occurrence.

The project team is composed of scientists from the Jet Propulsion Laboratory (JPL), NASA Goddard Space Flight Center, U. S. Geological Survey, Tonkin + Taylor, Geotechnical Extreme

Events Reconnaissance Association, the University of California Los Angeles, and the Earth Observatory of Singapore. The team has extensive experience using SAR data for rapid post-disaster mapping following earthquakes, hurricanes, volcanic eruptions, and wildfires.

The project will complete the automation of a system that will deliver SAR-derived DPMs and ground deformation maps to stakeholders, especially those who once informed of location risk can take mitigation, response or recovery actions. These DPMs can indicate building damage and surface change due to disasters. By maturing the system, the project aims to deliver these maps within 24 hours of data acquisition.

The project team is first focusing on generating and automating the DPMs and tools for three SAR satellite (European Space Agency's Sentinel-1, Japanese Exploration Agency's ALOS-2, and Italian Space Agency's COSMO-SkyMed) missions. This work opens the potential to explore additional tools such as translation of DPMs into a building damage ratio (i.e., the cost of damage repair), and a post-disaster construction monitoring tool to support post-disaster needs assessments and recovery efforts. In 2019, the project produced scripts for generating DPMs from Sentinel-1 observations and integration into the Advanced Rapid Imaging and Analysis (ARIA) system at JPL. Following the California earthquakes, Hurricane Dorian, and Typhoon Hagibis, the team produced DPMs of the storm surge, flood, and wind damage from these two disastrous events.

Fig 10. Typhoon Hagibis, one of the most destructive storms to hit Japan in decades, made landfall on Saturday, Oct. 12, 2019 southwest of Tokyo with wind speeds equivalent to a Category 3 hurricane. The damage left in its wake is visible from space. The image shows areas in Japan that are likely damaged as a result of Typhoon Hagibis. The color variation from yellow to red indicates increasingly more significant ground surface change, or damage. These damage proxy maps were delivered to Sentinel Asia, an international cooperation project with the aim of contributing to disaster risk management in the Asia-Pacific region using spaceborne Earth observing satellites. Maps like this one can be used as guidance to help responders identify damaged areas and to allocate resources accordingly.

DISASTERS18-40: Enlisting Satellite Data to Modernize Local Tsunami Early Warning

Principal Investigator: Diego Melgar

Compared to other hazards such as hurricanes or forest fires that occur annually, large tsunamis are infrequent. As a result, over the last 50 years as geophysical instrumentation has matured, local tsunami warning systems that alert the coastlines immediately adjacent to a large event have not been a priority of national or international monitoring agencies. The incidence of return periods of large events is usually measured in many decades to centuries. Thus, local warning systems do not exist in the majority of countries located along subduction zones, including the United States. However, recent events in Indonesia, Chile, and Japan, have shown that despite their comparative rarity, tsunamis can be generation-defining events that can lead to hundreds of thousands of casualties as well as to the total economic collapse of the affected regions.

Compounding the problem are steady increases in population in tsunami-prone areas over the last 25 years. Because evacuation start time is the most important variable in tsunami mortality rates, rapid tsunami information systems that forecast intensities at the local level in the first five minutes are essential in providing actionable information to emergency responders and decision makers to order evacuations in the affected regions as quickly as possible.

The use of Global Navigation Satellite System (GNSS) displacement data in the near-field is a paradigm shifting technology thanks to its ability to track the motions of large earthquakes. Real-time, high-data rate GNSS networks are currently operational in many countries around the Pacific Rim. These networks were originally installed to measure long-term tectonic motions, and over time, were upgraded with higher sample rate receivers and robust telemetry. Because of this, these networks are primed to both record long-term tectonic motions and strong ground motions from nearby great earthquakes.

The project team, composed of researchers from the University of Oregon, University of Washington, and Central Washington University, are modernizing near-field (local) operational tsunami forecasting and early warning through the addition of GNSS-derived earthquake source products and the seamless connection to already existing tsunami modeling codes at the National Oceanic and Atmospheric Administration (NOAA) Center for Tsunami Research in Seattle. Extensive testing, both online and offline is being performed using historical and synthetic earthquake datasets. These tests will help to guide modifications in the software and

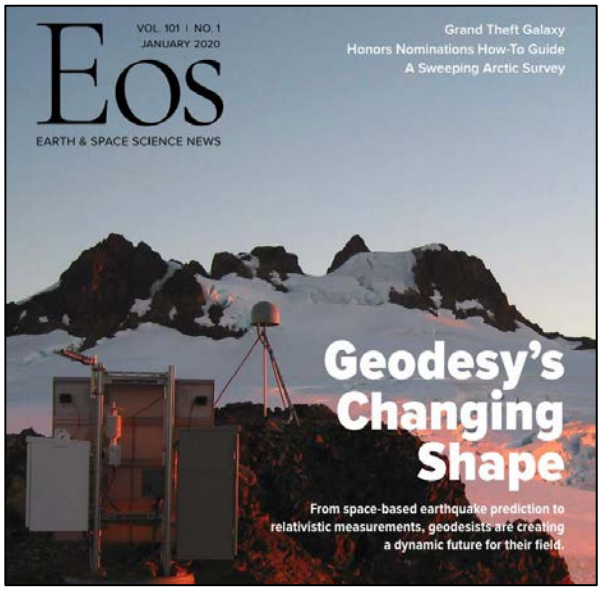


Fig 11: Article on "Real-Time High-Rate GNSS Displacements: Performance Demonstration during the 2019 Ridgecrest

familiarize practitioners with the strengths and limitations of the different codes.

GEO Global Flood Risk Monitoring (GFRM)

Photo Credit: David Borges

The GEO GFRM Community Activity integrates information from multiple Earth observation systems to derive and deliver environmental intelligence characterizing intensive flood risk for the benefit of decision makers. This includes the coordination and analysis of timely, reliable and suitable observations with earth system modeling and geospatial data management. To be more resilient to flood perils, GFRM enhances the ability to prepare for the anticipated hazards – to have both quantitative and qualitative analytical capability – helping adapt to changing conditions, and withstand and recover rapidly from disruptions.

Elements of the GFRM Community Activity include a Community of Practice (CoP) able to collect, process, and analyze changes due to complex and rapid flood stresses. Through early and ongoing stakeholder engagement, the CoP supports the assessment of impacts and applies knowledge to fill gaps with trusted data to yield scientifically-defensible guidance supporting timely, reliable and suitable decisions. In addition, multiple pilot projects increase access to diverse data sets, models and visualization products while testing the ability to provide efficient and actionable information. Finally, integration of existing flood risk-related activities and research is a high priority to bring together tool sets and capacity building to develop and maintain resilience and risk reduction efforts, in the context of global policy frameworks, such as the UN Sendai Framework for Disaster Risk Reduction.

As a GEO Community Activity, GFRM is an inherently collaborative and transdisciplinary capability, which creates key partnerships and maintains engagement among diverse stakeholders and actors. Contributors promote shared access and use of open data standards for research, development and operations. Routine and timely coordination, co-design and cooperation through projects, workshops and capacity development drives the pace of innovation, improves modeling and mapping skills, spreads learning and advances readiness of

research results for applications. This in turn builds trust and modifies local behavior through greater certainty, learning, and awareness of flood perils, early action and security measures.

This Community Activity is led by a Steering Committee and NASA directly supports three research projects that contribute to this Community Activity, managed by the Disasters Program.

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

Led by Sang-Ho Yun of NASA JPL, this effort is streamlining an end-to-end automated flood awareness process and demonstrating success by providing applications to assist in planning or responding to extreme flood events in multiple GEO member countries partnering with key agencies, international GEO member organizations, and USGEO member agencies. Their goals and implementation details have been designed based on lessons learned from historical flood planning, response and recovery efforts. Key partners in coordination have included the Federal Emergency Management Agency (FEMA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), World Bank, and the International Centre for Water Hazard (ICHARM) at UNESCO.

Named the Advanced Rapid Imaging and Analysis (ARIA) system, it previously included capabilities to automatically respond to USGS NEIC's major earthquake event notification. The system is automated to discover, ingest, and process specific data sources, including the open data provided by the European Sentinel-1 SAR, to produce maps of ground deformation caused by earthquakes. Now, the ARIA system is being optimized and automated for rapid flood activations, and continues to mature into a multihazard system with optimized performance with additional location and model data types to address flood risk mapping and seamless end-to-end automation from triggering to delivery.

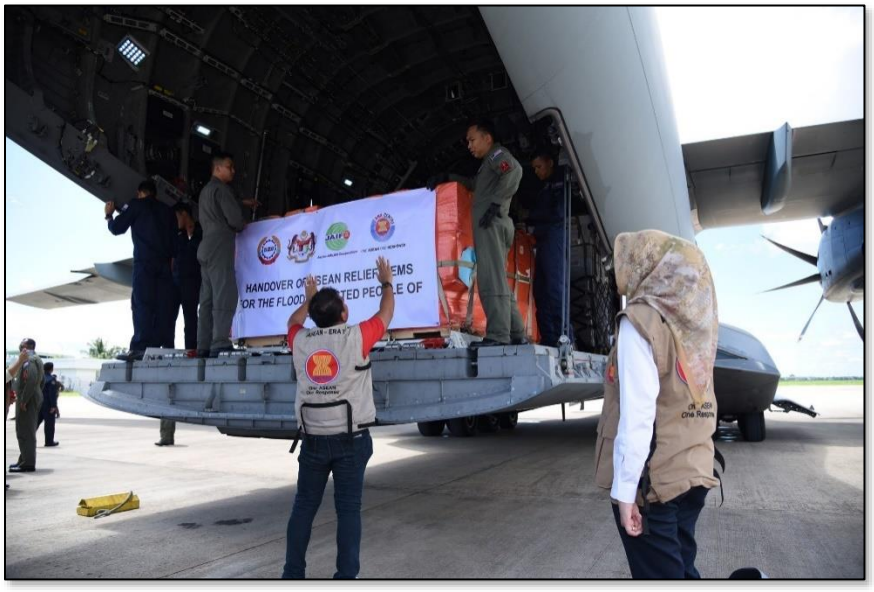


Photo Credit: @AHACenter

On September 6, 2019, Co-Investigator Emma Hill of the Earth Observatory of Singapore (EOS) was asked by the ASEAN Humanitarian Assistance (AHA) Center for help to map floods in Laos. AHA coordinates humanitarian interventions and adaptive responses for disasters in the ASEAN region. Multiple project members worked to generate Flood Proxy Maps for both Laos and Vietnam. AHA used these products, in collaboration with the Pacific Disaster Center, to estimate needed supplies that should be sent for disaster relief and humanitarian .

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

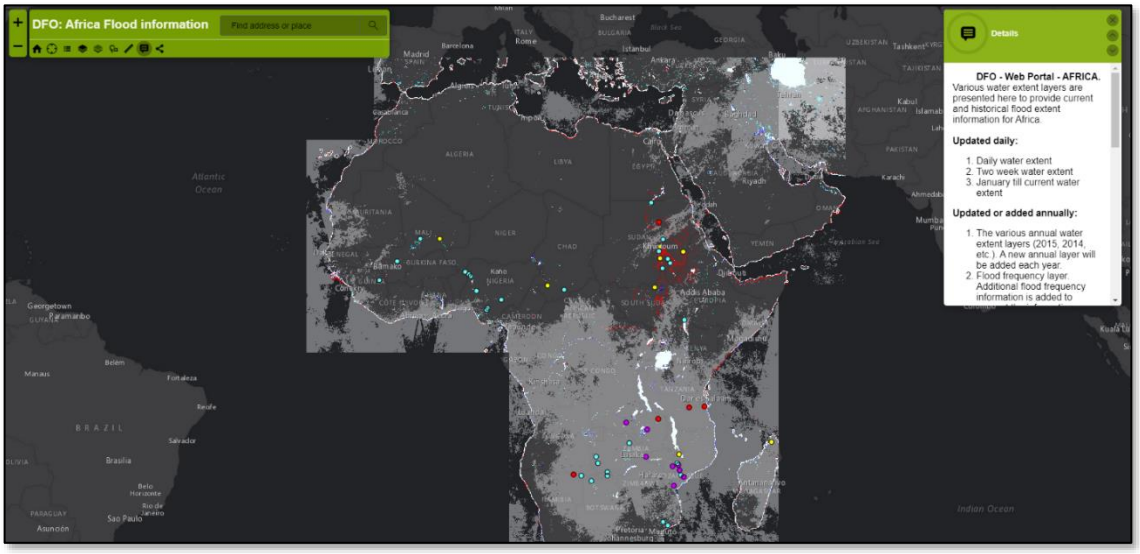


Photo Credit: Dartmouth Flood Observatory

Led by Robert Brakenridge of the Dartmouth Flood Observatory, this project's efforts are directed towards producing state-of-the-art, globally-scoped, flood prediction, monitoring capabilities and risk evaluations, automating where possible the systems and how they link together, and, finally, directly addressing the needed connections to multiple end users that provide them useful information. The focus remains the integration of aspects of NASA-based global flood systems, including DFO River Watch, UMD Global Flood Monitoring System (GFMS), the NASA Goddard automated MODIS flood product, and SAR-based flood mapping.

The project team in 2019 matured its ability to develop and publish, in graphical views via web pages and as Web Map Services (WMS) and Esri ArcGIS Image data services, global flood forecasting, flood alerts, and flood impact assessments. All events are added to an archive system, in collaboration with the Global Flood Partnership (GFP), so that each new event becomes part of an integrated global flood record.

In addition, the team forged a close working relationship with World Food Programme staff, integrating product delivery with the WFP Operations Centre (OPSCEN) GIS Team at WFP Headquarters as well as staff deployed in the field in Mozambique. Persistent flood events had profound impacts across East Africa in 2019 and the team worked to create products in a useful

timeframe and integrate feedback from these stakeholders and end users. "The World Food Programme has on several occasions used NASA MODIS Flood data, produced by NASA Goddard Space Flight Center in collaboration with the Dartmouth Flood Observatory. It has provided WFP with invaluable information in the early stages of a flood, especially for planning and prioritizing the locations of needs assessments and logistical routes. Furthermore, the historical record of flood events can also contribute to more effective preparedness within the humanitarian community by informing logistic teams as to where best to preposition food or other stocks for emergency response," said Ms. Sheila Grudem, Deputy Director of Emergencies, WFP.

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

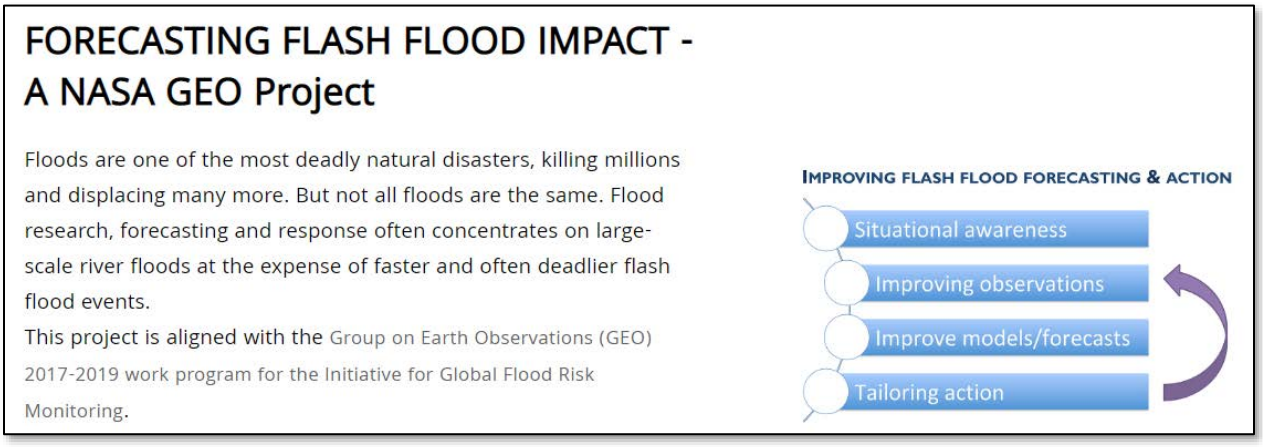


Photo Credit: Andrew Kruczkiewicz / https://geo.floods.global/

Led by Andrew Kruczkiewicz of Columbia University International Research Institute for Climate and Society, this project proposed to enhance disaster manager capacity to better prepare, respond and recover to floods. In the current state, disaster risk 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 to 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 cases 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 intent to see if they can forecast flash flood impact. 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.

Global Wildfire Information System (GWIS) Initiative

GWIS (http://gwis.jrc.ec.europa.eu/) aims to provide a continuous and smooth web map platform of harmonized information on wildfires that could be used at different scales, from national to global. At the global level, where information on wildfires is scattered and not harmonized, GWIS is a unique source of information for global initiatives and policies, while supporting the analysis of wildfire regimes at multiple scales. The calibration of the system and the validation of the different modules will require the close collaboration with regional and national partners. In countries that currently do not have a wildfire information system, GWIS will fill this gap and help countries engage in international collaboration. For countries and regions where wildfire information systems exist, GWIS will provide a complementary and independent source of harmonized information adding to the national/regional information sources.

NASA Disasters continued to contribute to the global GWIS effort throughout 2019, promoting the awareness and integration of three Applied Sciences funded GEO ROSES projects that helped GWIS towards its goal of transforming scientific results into value added operations.

The GWIS was matured from the European Forest Fire Information System (EFFIS) in the late 1990s, and expanded into the GWIS system by a consortium of contributing international wildfire remote sensing community members. GWIS is housed, maintained and served by the European Commission (EC) Joint Research Council (JRC) in Ispra, Italy. NASA EO data (primarily MODIS) has been the foundational sensor data for supporting the GWIS. Additional sensor data include the VIIRS sensors for active fire detection (complementary to the coarser resolution MODIS data). Newer active fire imaging data sets in GWIS are to include GOES 16 & 17 weather satellite data, in conjunction with METEOSAT SEVIRI, and JAXA's HIMAWARI weather satellite. NASA serves on the GEO-GWIS Coordination Board, providing guidance on the GWIS developments. The GWIS – GEO Global Initiative submitted in early 2019 to the GEO Work Program 2020-2022, builds on the work already performed in GEO GI-09, in the WP 2016, and the GWIS Initiative in the GEO WP 2017–19.

In 2017, NASA solicited proposals to support enhancements to GWIS to enable operational deployment globally. Three proposals were selected for support, and the follow describes their second year activities (2019).

GEO16-18: Development of a Harmonized Multi-Sensor Global Active Fire Data Set

Led by Louis Giglio (University of Maryland) and Wilfrid Schroeder (NOAA), this project effort will include the integration of new generation geostationary satellite sensors offering greatly improved capabilities for routine fire detection and characterization. Building on these new capabilities, they propose to develop a global geostationary "network of fire products" (GOES 16 & 17 (East and West)), JAXA Himawari, and METEOSAT SEVIRI) to complement existing

polar orbiting satellite fire monitoring products, such as those collected by MODIS, Landsat 8, Sentinel-2A/B, and VIIRS to enhance the GWIS-provided fire information. Outreach and training activities in coordination with regional fire networks are being developed to provide original material to educate fire data users and practitioners on those new capabilities.

Accomplishments in 2019 included revising the first project year (2018) computer code to account for product changes to various geostationary satellites and conducted a comprehensive validation of the GOES-16 and MSG SEVIRI fire products. Based on the validation results, the team developed a plan for product harmonization and began creating a product prototype. The harmonized raster product will be delivered as a daily product with hourly breakdown of fire counts. Giglio and team had one peer-reviewed journal publication in 2019, and presented their work at three wildland fire-related conferences / meetings / workshops, including the 7th International Wildland Fire Conference in Campo Grande, Brazil and at the 2019 Fall AGU meeting in San Francisco, California.

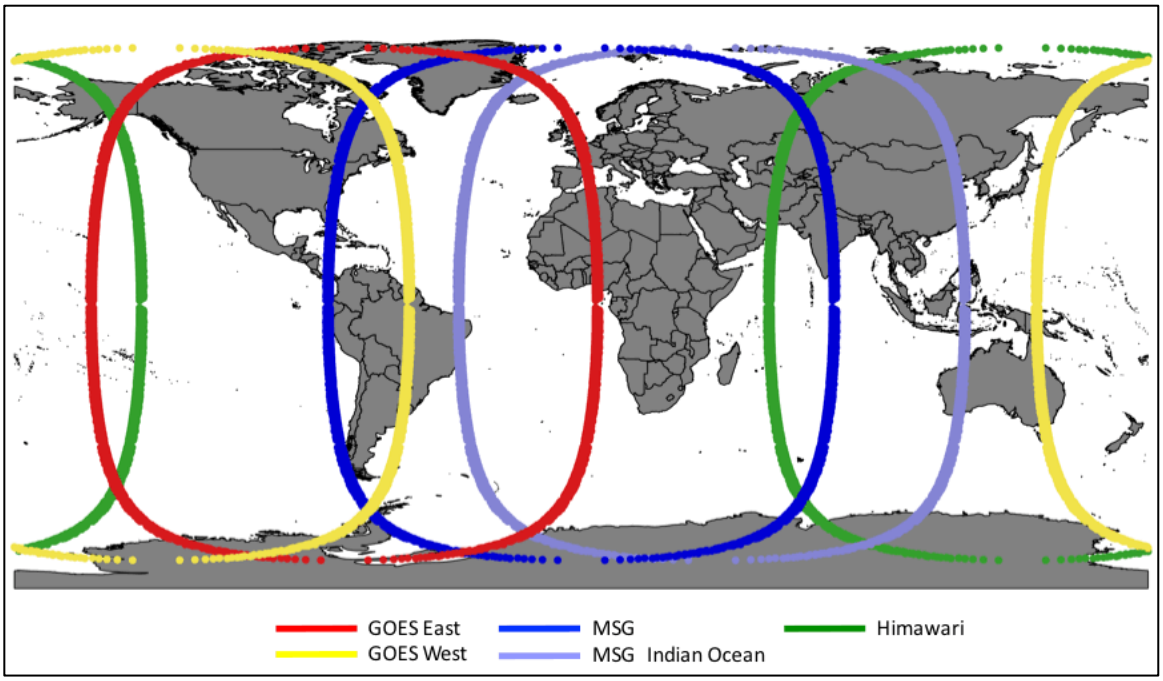


Figure 10: Coverage of existing geostationary sensor network.

GEO16-64: Enhancements to the Global Wildfire Fire Information System: Fire Danger Rating and Applications in Indonesia

Robert Field (Columbia University), leads an effort to develop a 10-day global Fire Weather Index (FWI) forecasts by integrating the Global Fire Weather Database (GFWED) data into GWIS, which will increase the real-time FWI data sets in use there from one to four, increase historical FWI data from one to eight, and add an additional 10-day FWI forecast to GWIS. Because of the close collaboration with Indonesia, Field and team will regionalize their focus in this high fire-prone section of the globe to advance the current Fire Danger Rating System there, and train personnel in the use of the enhanced GWIS fire risk management products developed in their efforts and other investigators. Effort during Year 1 (2018) focused on the production of Global Fire Weather Database short-term forecasts in near-real time. Effort in 2019 focused on

the skill evaluation of the forecasts developed in 2018, and comparisons to weather station data. These results have been submitted as a peer-reviewed paper submission to Natural Hazards and Earth System Science journal. Also in 2019, Field's efforts focused on distributing the FDRS / FWI data alongside complementary European Centre for Medium-Range Weather Forecasts (ECMWF) products through the public GWIS portal. Field also led a Fire Danger Rating System, Fire Detection / Monitoring and Smoke Modeling Workshop at the Indonesian National Institute for Aeronautics and Space in Jakarta, Indonesia, in December 2019, to exchange information and conduct training related to fire danger rating and fire monitoring in Indonesia.

R. Field presented at the GWIS Workshop held in conjunction with the 7th International Wildfire Conference in Campo Grande, Brazil in November 2019. He also was an invited speaker on "Fire in Indonesia at the 2019 Fall AGU Meeting in San Francisco, CA, and was interviewed for an AGU EOS article on the Australian Fires. He had two peer-reviewed papers submitted for review in 2019.

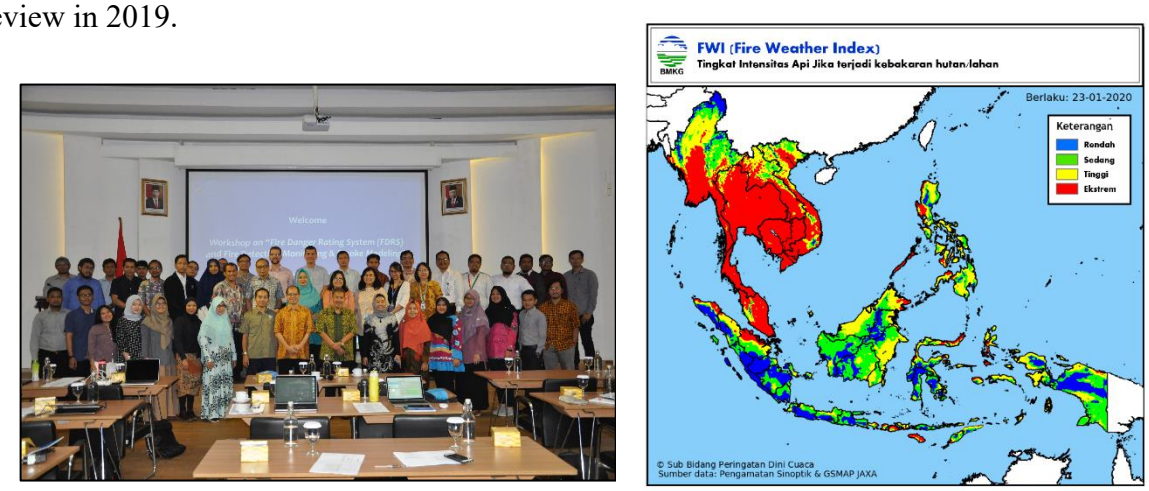


Figure 11. Workshop on Fire Danger Rating System, Fire Detection / Monitoring and Smoke Modeling, 2-5 December 2019 at the Indonesian National Institute for Aeronautics and Space in Jakarta, Indonesia. Prototype of the Fire Danger Rating System (FDRS) / Fire Weather Index (FWI) improvements in Indonesia and SE Asia, from the incorporation of GSMaP (JAXA GPM product).

All three of the GWIS Principal Investigator teams, as well as V. Ambrosia (Assoc. Program Manager-Wildland Fire) organized and participated in the GWIS Workshop at the 7th International Wildfire Conference in Campo Grande, Brazil in November 2019.

GEO16-72: Using the NASA Polar Orbiting Fire Product Record to Enhance and Expand the Global Wildfire Information System

Led by Luigi Boschetti (Idaho State University) and David Roy (University of Michigan), this effort provides GWIS enhancements for improved on-demand statistics, tabular information, and graphical information at state, regional, national, sub-continental, continental, and global scales, at monthly, seasonal and annual time periods, based on 15-years of MODIS Collection 6 fire products. A suite of software to generate scientifically accepted, reproducible fire information, documented for non-technical users in easily accessible formats, will be developed that describe:

- **Fire activity over different spatial regions and temporal period**
  - Total area burnt and number of active fire detections metrics:

    - Total area burned (ha and km2) with uncertainty estimates;
    - Total number of active fire detections (counts);
    - Temporal ranking of the above and the year/month that the ranked values occurred on;
    - Counts of the number of months / years where there was fire;
  - Fire seasonality metrics:
    - Start and end of the fire season, peak month of burning;
    - Temporal ranking of the above and the year / month that the ranked values occurred on;
  - Fire size metrics:
    - Mean, median and maximum fire size, number and minimum fire size of the fires responsible for 25%, 50%, 75% of the total annual burned area;
- **On-demand tables, charts and plots of the above information**
- **Global visualizations generalized appropriately at different spatial scales**

As a result, GWIS will become the only portal that provides global to sub-national summary, science-quality information on fire seasonality, fire size, and annual rankings of fire activity, in easily accessible formats for national policy makers and resource managers.

Accomplishments in 2019 included implementing a fully functional prototype of the processing chain for deriving fire activity statistics on the U. of Idaho servers, to be delivered to JRC; the system will be the back-end of the new GWIS 'Fire Analysis Portal' (FAP) component. The system generates: a) Monthly MCD64 composites for visualization in GWIS of the MCD64A1 burned area maps; b) ASCII text files of monthly burned area stratified by Level 0 (Country) and Level 1 (State/Region) administrative subdivision, and by land-cover class; c) Summary plots of annual/multiannual burned area by administrative subdivision.

The team also designed a front-end of the Fire Analysis Portal (FAP), which will be implemented by the developers at JRC for operational use in the GWIS. Also in 2019, the project team consulted and involved stakeholders and potential users of the proposed fire metrics though the GOFC-GOLD Fire IT and regional network meeting, and established a collaboration with the UN Food and Agriculture Organization (FAO).

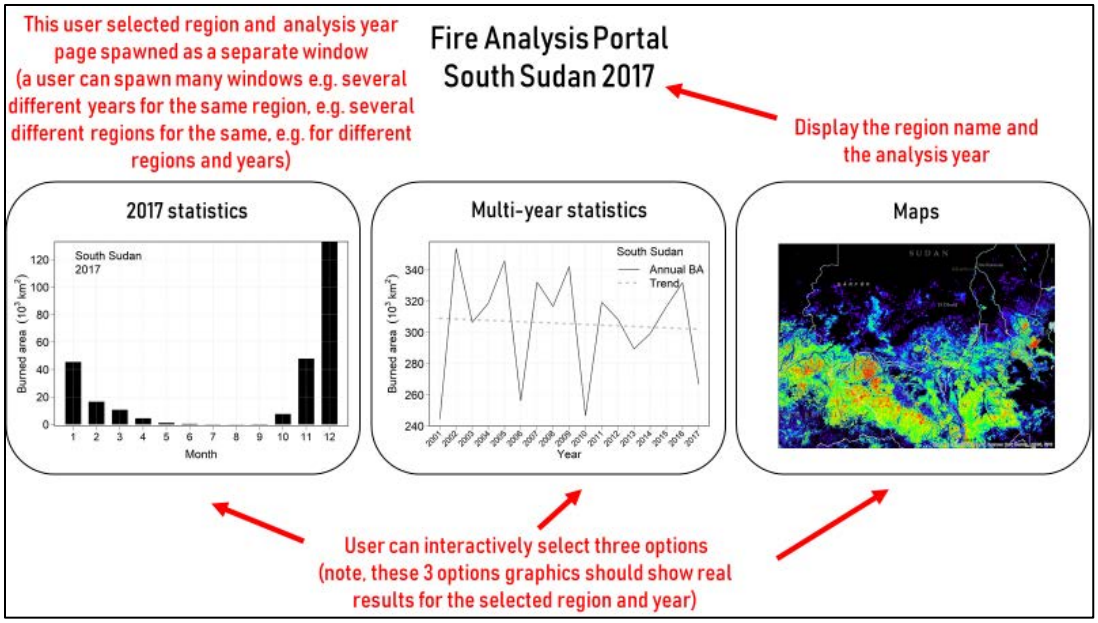


Figure 12: Fire Analysis Portal (FAP) second level menu. Once the geographic region and year of interest are selected, the user can access (1) the single year statistics (2) the multi-year statistics and (3) the map products page to develop output graphic, tabular, and map information

During 2019, Boschetti and Roy authored three peer-reviewed publications and three international conference presentations, describing their work to the community. The team presented at a GWIS Workshop held in conjunction with the 7th International Wildfire Conference in Campo Grande.

III. Disaster Adaptive Response

The disaster support portion of the Disasters Program functions in a unique way within the Applied Sciences Program, as well as across the greater NASA community. The team is comprised of program and project management, emergency managers, and Geographic Information System (GIS) and visualization specialists, multihazard subject matter experts and product providers, social scientists and regional experts, as well as disaster coordinators located at multiple 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 in a position to contribute disaster-relevant information or data, provide points of contact or supply physical, geographical and socio-economic context. Bringing these relationships and bodies of knowledge together across centers promotes and strengthens the program's effectiveness and reach, allowing the Program to provide stakeholders, key partners and users with improved situational awareness on the nature of risk and resilience before, during, and after disasters.

The Program uses a four-tiered framework depending of the severity, duration and scale of the incident to adapt to meet the demands, reallocate or augment resources, adjust work schedules, and adjust routines while tracking the level of effort and commitments associated with activations:

Tier 0: The lowest level of activation, is a rapid assessment to determine if initial support may be provided to stakeholders. Subject matter experts available to provide technical insights, historical and cultural context, or situational knowledge are called upon. HQ and core team staff with emergency management, geospatial mapping expertise, regional knowledge and communication may also assist with the assessment. Considerations include prospective data and knowledge users, opportunities to advance research understanding, integrating a significant volume and variety of different earth observation types and models, and the potential to provide a unique application contribution or product advancement. The availability of staff and partners to engage at a higher level are assessed as well as the network of potential key partners and new stakeholders. This level of activation may also include consultation or the proactive provision of near real-time or automated products through the NASA Disasters Mapping Portal or exploitation of various NASA information systems and processing centers. The Program may also choose to simply monitor the situation and reassess at a later time.

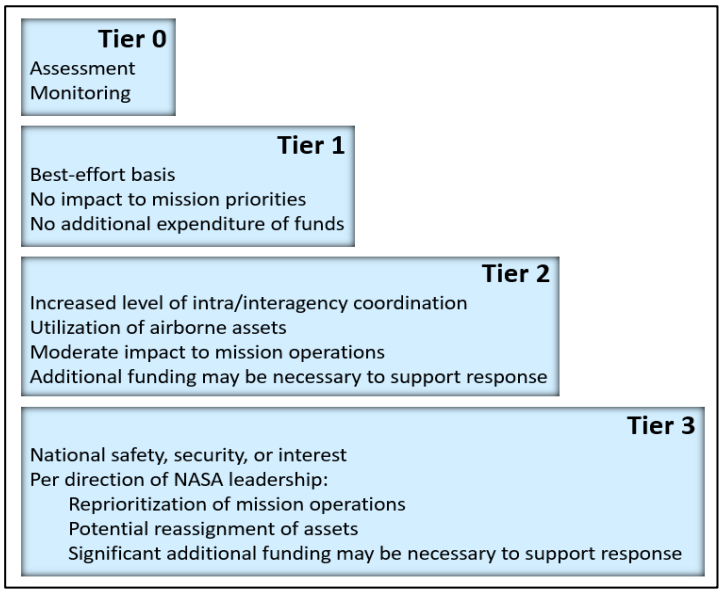


Figure 13: NASA Disasters Program Tiers

Tier 1: Involves a larger number of staff from the NASA centers and laboratories, from relevant Earth Science Division elements and research project areas, and partners. Time sensitive tasks may extent beyond the usual core business hours. The allocation of time and resources extend beyond initial monitoring. This oftentimes includes identified end users and the development of timely, useful, event-specific products on an "as available" basis.

Tier 2: Requires an Earth Science Division wide engagement and the potential for added staff and financial resources or timely commitments of assets. The contributions are considerable given the extent of the disaster and may potentially impact ongoing activities of NASA centers and programs. Airborne assets may be utilized, if available, to provide more detailed datasets for support. It is typical that there are a small number of Tier 2 events in a given year. The type of incident may be associated with major seasonal tropical storms and cyclones or wildfires, significant earthquakes and tsunamis, or extensive flooding.

Tier 3: Is the highest level of activation. This may require a 24/7-type agency wide effort. As of the close of 2019, there had been no events of this magnitude where NASA was in a position to play this type of role. An event of such magnitude would be one that directly affects national safety, lifelines, environmental security, or community interests. In some instances, NASA's unique role may be one of providing technical capacities such as computer and modeling, airborne monitoring or geospatial environmental intelligence. All relevant personnel are expected to review their capacities and capabilities for adapting possible roles in support to the disaster preparedness, response and recovery. Space and airborne assets, data and information

systems, as well as subject matter experts and staff may be assigned to support the activation as directed by appropriate agency leadership.

The Disasters program managed 38 activations in 2019. These included 11 unique hazard categories that developed into disasters. Flooding (and in combination with landslides) were most common, accounting for 12 of the 38. There were nine tropical cyclones, four earthquakes, four fires, and three volcano incidents. Additional details and data provided to end users, can be found on the Disasters Program website.

Exercises: In addition to preparing, responding and supporting recovery for real world incidents, the Program also engages in exercises. The purpose of exercises is to evaluate the maturity of science understanding and the readiness of applications as well as gauge the ability of the program members to activate quickly and effectively. Examples of exercises include simulated events such as hurricanes, floods, oil spills, and wildfires. In 2019, the Program engaged in exercises with several partner federal agencies, including preparation for a major regional disaster resilience exercise, *Tradewinds*, in the Caribbean-wide flood and oil-spill scenario to be executed in 2020. NASA Disasters has typically sponsored several exercises per year as part of regional workshops and conferences or in partnerships with National Response Exercises and Continuity-of-Operations drills.

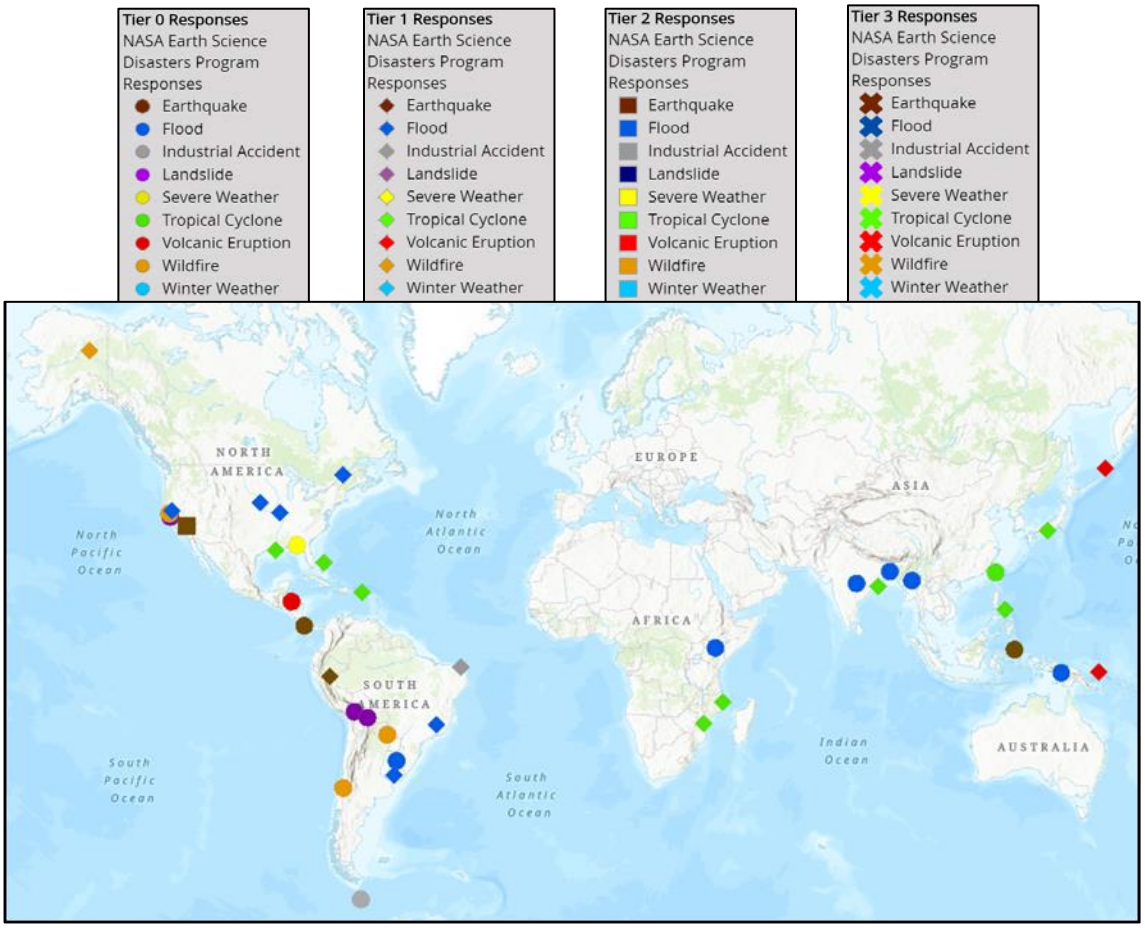


Figure 14: Program activations in 2019.

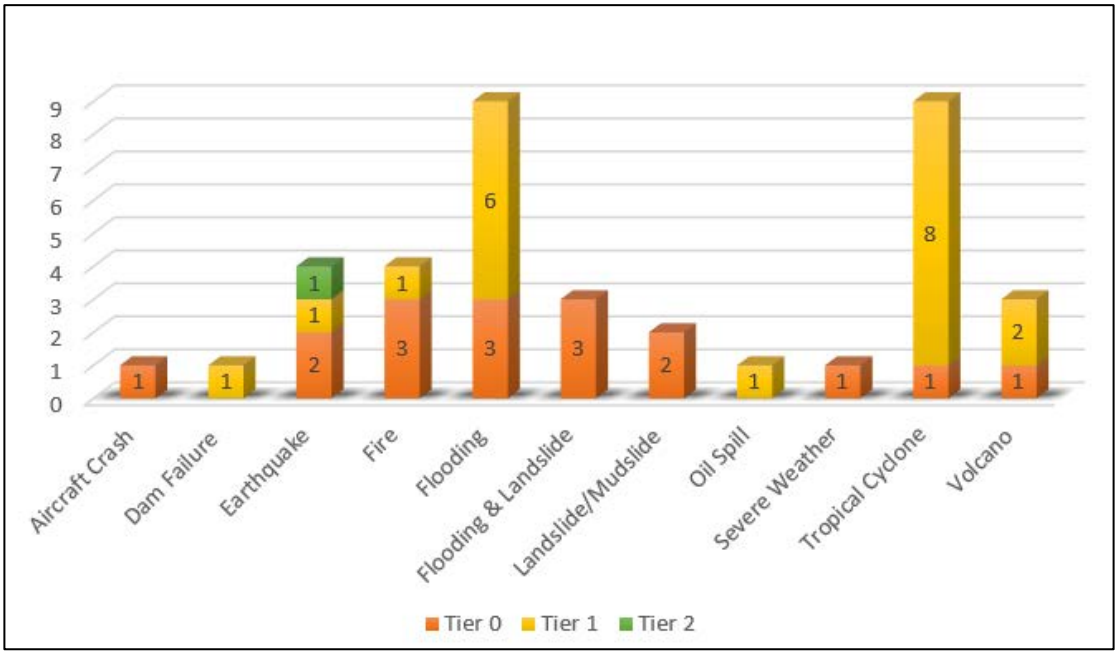


Figure 15: 2019 Activations categorized by primary hazard.

Midwest Floods

The Midwestern area of the United States experienced major flooding during the early part of 2019. Rapid snowmelt, early spring rains and a late season snowfall combined with high soil moisture conditions resulted in excessive flooding across the upper Mississippi and Missouri River basins in late March, impacting residents, farms, and livestock, as well as utilities and transportation throughout the area. Thousands were evacuated from their homes, and tens of thousands of acres of farmland was inundated. Floodwaters threatened the water supply for many individual wells and for municipalities along the rivers. At times during the event, over 200 river gauges were in flood stage in the across the upper Midwest.

NASA has many different ways to view the Earth across the whole electromagnetic spectrum. Satellites with optical sensors, such as Landsat 8 and NASA's Aqua and Terra satellites, provide mid-resolution information about the presence of water but are subject to cloud cover blocking the view. SAR instruments provide the advantage of being sable to "see" through the clouds and at all times of the day, where optical sensors are restricted to day-time passes only. SAR usage continues to be a strong desire, and the NASA Disasters Program continues to collaborate with the Alaska Satellite Facility and ESA on Sentinel 1A/B access and data product generation, along with scientific collaboration with SAR scientists and user community within NASA and academia. For this Tier 1 event, any available satellite information was leveraged due to both the spatial scale of the flooding and the length the event lasted.

The Program worked to help operationalize satellite imagery and products to end-users and partners who don't normally use this data in their everyday routines. The big question from stakeholders during this event was "Where is the water?", and NASA satellites and products were just one piece of the puzzle to help answering that ask.

Due to past contributions from the Program, FEMA Headquarters Geospatial Office reached out to the NASA Disasters Program for satellite-based products. As there are numerous sources of information, FEMA acted as a clearinghouse not only for NASA data, but all Federal Agencies in support of this event. The NASA Disasters Program provided the following products:

- Sentinel-2 True/Natural Color RGBs; processed at MSFC
- Water Extent Map Produced using Copernicus Sentinel-2; processed at MSFC
- MODIS False Color Infrared RGB; processed at GSFC
- Landsat 7/8 Modified Normalized Difference Water Index (MNDWI); processed at MSFC
- Sentinel-1 False Color RGBs; processed with help from Alaska Satellite Facility (ASF)
- Sentinel-1 Flood Extent Maps; processed at MSFC with help from ASF
- Landsat-7 & -8 Imagery and derived products processed at MSFC
- Sentinel-2 Imagery and derived products processed at MSFC
- Daily MODIS products; processed at GSFC
- 2 Day Composite MODIS Flood Maps (MODIS); processed at GSFC
- Land Information System (LIS) Soil Moisture; Relative Soil Moisture; processed at MSFC with cooperation at GSFC

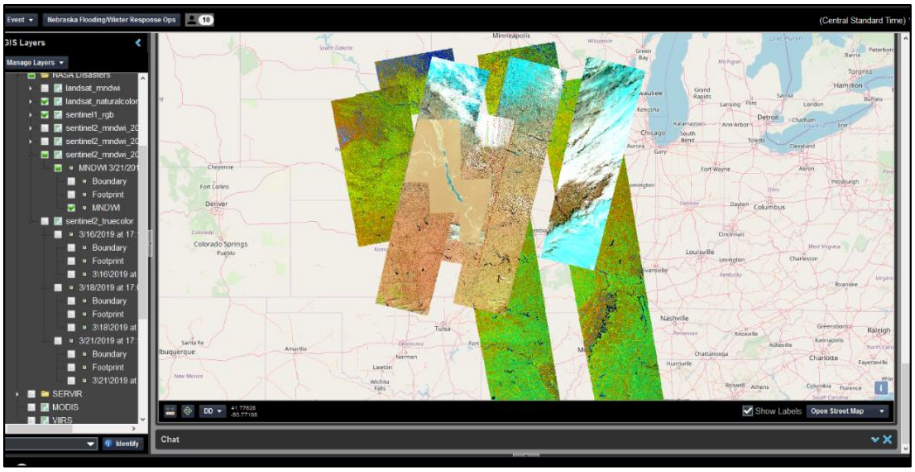


Figure 13: Example image of the layers of imagery provided by the NASA Disasters program within the NGB's DAART system. This system is used by the National Guard units to provide geospatial analysis and damage assessment.

Another primary stakeholder was the National Guard Bureau (NGB), in support of the State of Nebraska. FEMA and NGB facilitated further use of NASA products through sharing and discussion, including FEMA Region VII and the National Guard Unclassified Processing, Assessment and Dissemination (UPADs) (satellite interpretation) who used imagery and products to provide situational awareness, water extents in combination with other datasets to assist with both situational awareness, and preliminary damage estimations. Feedback received from FEMA and the NGB has indicated that the NASA data was both timely and helpful.

Additionally, the USDA's National Agricultural Statistics Service (NASS) used NASA data to derive quantitative assessments to estimate the amount of inundated cropland and hay/pasture areas. While the USDA usually handles this assessment in-house, their capabilities were stretched thin with the large extent of the flooding. NASA data allowed for rapid analysis of the entire extent of the flooding.

> "*NASS (The USDA National Agricultural Statistics Service) was able to successfully utilize NASA Disaster Programs web services and water extent products to provide quantitative and qualitative data products for a near real-time response at the request of the NASS Nebraska Regional Field Office, as well as the NASS Agricultural Statistics Board, in preparation for the March Prospective Plantings Report.*"
>
> -- Rick Mueller, Head of the Spatial Research Unit
> USDA National Agricultural Statistics Service

The Program leveraged team experience in land surface remote sensing and knowledge of the mapping of water extent from visible, near-infrared remote sensing. The Program also leveraged NASA collaborations with data centers (DAACs), interagency partnerships with agencies like USGS/HDDS to get access to key products from Landsat and Charter/commercial holdings, and worked with international partners such as ESA on leveraging Sentinel-1 SAR and Sentinel-2 Optical remote sensing. Lastly, the Program also utilized expertise in land surface soil moisture remote sensing and modeling to develop and incorporate information from SMAP and relevant land surface models (e.g. Land Information System).

In total, the Program supported the Midwest flooding event from mid-March through June 2019 and continued to work with stakeholders and partners on how to make further improvements in the products and continuing to explore ways to further collaborate for future events.

Tropical Cyclone Idai

Cyclone Idai made landfall on the coast of Mozambique late Thursday, March 14th, bringing torrential rains, high winds, and storm surge to an area of high exposure and vulnerability with low coping capacity. Preparedness was limited, and the death toll from the storm was over 960 with over three million impacted. Over 90% of Beira, a coastal city with a population of more than 500,000, was destroyed. Many other villages were destroyed as well, and citizens were cut off from their lifelines due to flooding that washed away roads and crops. Unsanitary conditions also led to outbreaks of diseases such as cholera.

The NASA Disasters Program worked with The International Federation of Red Cross and Red Crescent Societies (IFRC), as they were working with the Mozambique Red Cross on the ground in Beira, near where the storm made landfall. The IFRC identified Beira as a priority area of interest due to homes submerged. The program worked directly with the IFRC Remote Sensing Coordinator and GIS team in Washington, DC to provide integrated mapping products, including story maps, for situational awareness. The IFRC provided NASA Disasters data products to the Government of Mozambique to help decide where to direct personnel to do initial assessments.

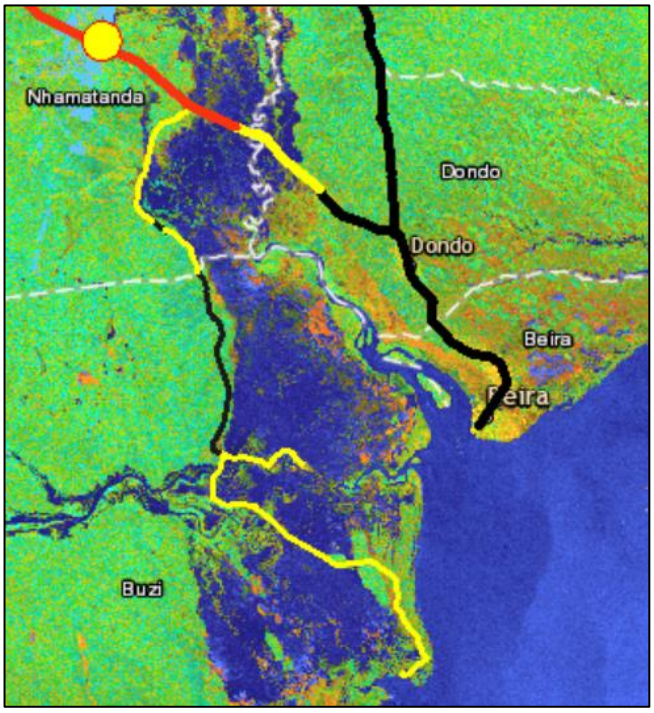


Figure 14: Infrastructure impacted by potential floodwaters following Cyclone Idai. Impacted roads are shown in yellow, based on Sentinel-1 flood products, and red, based on ARIA FPM products. The yellow dot indicates a potentially impacted power substation. FPM: Original Data provided by JAXA. Analyzed by the NASA-JPL/Caltech ARIA team. Research carried out at JPL funded by NASA Disasters Program. Sentinel-1: Contains modified Copernicus Sentinel data; processed by ESA, Alaska Satellite Facility, and NASA Marshall Space Flight Center. OpenStreetMap Contributors; data available under Open Database License.

In addition to IFRC, the Program also worked with the World Bank, USAID Office of Foreign Disaster Assistance (OFDA), the National Geospatial-Intelligence Agency (NGA), Humanitarian Open Streetmap, Department of State's Humanitarian Information Unit, and UN OCHA.

Working across multiple centers throughout this Tier 1 event, numerous products were provided by the Program to those stakeholders, helping to answer many questions, as few other information and data sources were available due to the extent of damage in the area. The Program provided products such as flood proxy maps produced by NASA-JPL/Caltech's Advanced Rapid Imaging and Analysis (ARIA) using Original ALOS-2 Data provided by JAXA. GSFC produced Landslide and GPM Precipitation Accumulation products and Black Marble nighttime power outage images. MSFC produced NASA/USGS Landsat and Copernicus Sentinel-1 SAR data (2019) products in collaboration with the Alaska Satellite Facility and other NASA Disasters Team partners. The Program also facilitated the sharing of Dartmouth Flood Observatory Color Composite flood maps, using Copernicus Sentinel-1 SAR data (2019), through the NASA Disasters Portal.

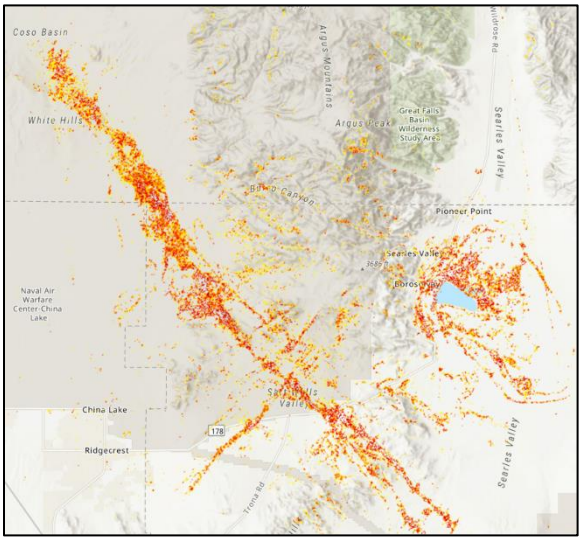
California Earthquakes

The largest earthquake in 20 years struck Southern California during the Ridgecrest earthquake sequence in July of 2019. On July 4, a magnitude 6.4 earthquake occurred northeast of the town of Ridgecrest, CA, followed by a larger magnitude 7.1 earthquake on July 5. The NASA Disasters Program provided support for this event at the Tier 2 level, partnering with the California Earthquake Clearinghouse, USGS, the California Geological Survey, and the US Navy, among others. Remote sensing products from satellite and airborne assets were provided to partners to support mapping and decision-making efforts.

Satellite products included interferograms derived from JAXA's ALOS-2 satellite, damage assessments (damage proxy maps) produced by the ARIA team derived from ESA's Copernicus Sentinel-1 satellite, surface deformation maps derived from Copernicus Sentinel-1, and decorrelation maps derived from Copernicus Sentinel-1. A small UAS was flown over the surface rupture and 3D topographic reconstructions from the flights were used by the USGS and other California Earthquake Clearinghouse partners to map the effects of the earthquake. UAVSAR was flown in October 2019 over the affected area.

The earthquake caused significant damage at the nearby China Lake Naval Air Weapons Station and cut power to many residents of Ridgecrest. Interferograms were used by the US Navy China Lake Facility to identify assets and infrastructure in need of assessment due to the detected ground movement. Should NASA facilities ever be similarly impacted, this instance can serve as the example for the use of program data products.

Fig 15 (below, left). Potential damage from the earthquakes. Images taken July 4th and July 10th. The variation from yellow to red indicates increasingly more significant surface change. The image covers an area of 250 by 300 kilometers (155 by 186 miles), shown by the large red polygon. Each pixel measures about 30 meters across. Created by ARIA, derived from SAR images from the Copernicus Sentinel-1 satellites, operated by the ESA.



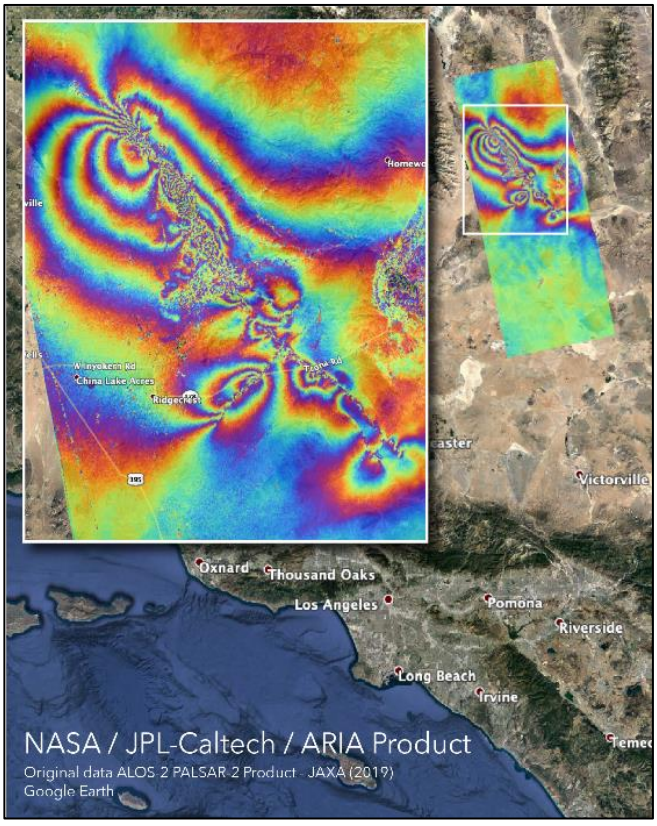


Fig 16 (above, right). Imagery acquired July 8, 2019 and compared with April 8, 2018 shows surface displacement from the earthquakes. Each color cycle represents 4.8 inches (12 cm) of ground displacement either toward or away from the satellite. The linear features that cut the color fringes in the southeast indicate likely locations of surface rupture caused by the earthquakes.

Hurricane Dorian

Tropical Storm Dorian formed on August 24, 2019, moving through the Lesser Antilles before strengthening into a hurricane just north of the Greater Antilles on August 28. Hurricane Dorian passed between Puerto Rico and the Virgin Islands as a Category 1 storm, after which it intensified into a major Category 5, stalling for two days over the Bahamas as the strongest known tropical cyclone to hit the area. The prolonged exposure to the islands brought sustained winds of 185 miles per hour and over three feet of rain.

Hurricane Dorian caused an estimated $1.5 - $3 billion worth of damage in the Caribbean. Meanwhile, back in the U.S., tropical storm-force winds continued to impact the eastern shoreline of the United States with tornados, storm-surge, and flooding. The storm made brief landfall over Cape Hatteras, North Carolina, before heading back toward the Atlantic. More than 190,000 North Carolina homes lost power during the storm.

The Disasters Program managed a Tier 1 level of effort from Tuesday, August 27, 2019, through Friday, September 13, 2019. The focus was on understanding the needs of entities supporting preparedness for, analysis of, adaptive response to, and recovery from the impacts of the storm, while communicating to partners and the public the unique vantage point of the storm and impacts afforded by remote sensing.

Adaptive response activities leveraged program and agency expertise in global flood modeling, development of landslide risk analysis and mapping tools, and extensive facilitation of products derived from SAR, focused on rapid mapping of land surface changes (as associated with possible structural damage and extensive flooding from coastal surge and heavy inland rainfall).

Routine participation in organizational calls with the Federal Emergency Management Agency (FEMA) and the U.S. National Guard emphasized the collection of pre- and post-event imagery for comparison in changes to nighttime light (potential power outages), flood extent, and structural damage. Staging of pre-event imagery through GIS services were established for integration into partner decision-making systems; one such example was the Domestic Operations Awareness and Assessment Response Tool, hosted by the National Guard Bureau and accessed by FEMA Region IV and state Emergency Managers for use in their initial assessment and coordination activities.

Similarly, products developed by the team were integrated by the U.S. National Geospatial-Intelligence Agency (NGA) to support analysis of impacts, situational awareness, and U.S. governmental response to the event in collaboration with international partners. To support those actively deploying to event relief and assistance, SAR-based damage proxy and flood maps were provided along with other Disasters Program information to prepare teams such as the U.S. Task Force Two Urban Search and Rescue Team for potential deployments.

As impacts from Dorian transitioned to the Bahamas, the extent of the storm's severity was promptly mapped by NASA collaborators through the production of damage proxy and flood maps derived from SARs including ESA Sentinel-1A/B. The rapid delivery of products and effective partnerships supported the Caribbean Department of Emergency Management in their post-event damage to develop estimates of reconstruction and recovery costs, in addition to a preliminary recovery plan.

> *"We were immediately on the ground, ready to compile the situational awareness for the post-impact with very accurate impact assessment."*
>
> Dr. Ronald Jackson, Director, CDEMA

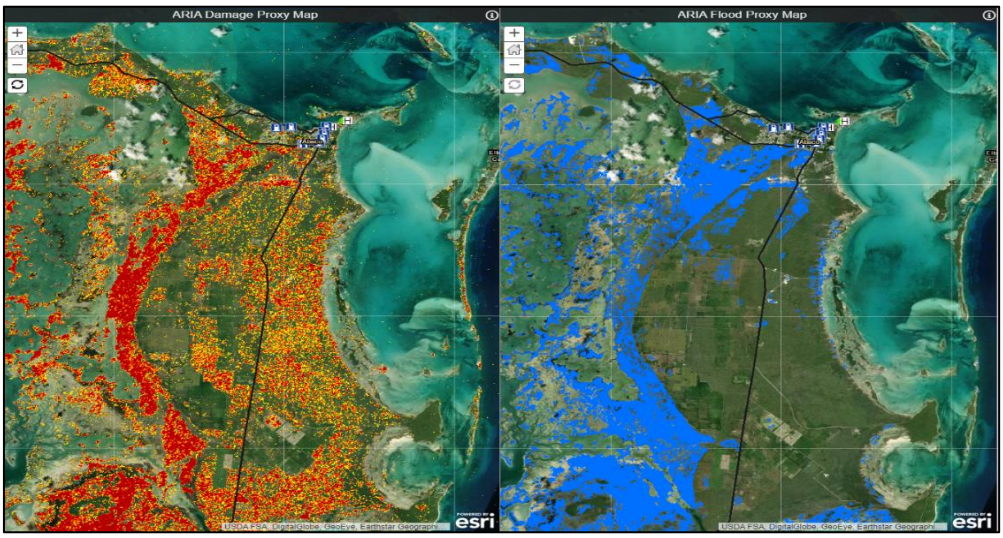


Figure 17: The region shown in the map is Marsh Harbour, a town in the Abaco Islands, a group of Bahamian islands and cays that form a 120-mile–long chain. Marsh Harbour is the commercial center of the Abacos. On the left are areas of potential damage (shown in red and yellow) likely due to Hurricane Dorian's Category 5 winds and storm surge. The map on the right identifies areas of potential flooding in blue. Critical infrastructure captured by Open Street Map are shown, including major roads, gas stations, hospitals, and power substations. Contains modified Copernicus Sentinel data (2019) processed by the ARIA team at NASA-JPL and Caltech. This task was funded by NASA Disasters Program.

Earlier in the year, a joint workshop led by the NASA Disasters Program and the Puerto Rico Science, Technology, and Research Trust (PRST) on "Resilient Recovery Approaches" helped initiate the collaboration between the NASA Disasters Mapping Portal and the PRST Portal. This new Portal-to-Portal relationship allowed for seamless and accelerated Dorian activation data and derived product sharing between the Disasters Program and the Trust. PRST was then also able to further disseminate these data products to local partners, such as the Puerto Rico Emergency Management Agency (PREMA).

Collaborations in Puerto Rico demonstrated the importance of understanding regional needs and prepared the team for further regional collaboration – the NASA team provided routine MODIS products emphasizing availability of near real-time flood mapping products, and the Program and GIS integration set the stage for future efforts.

> *"My heartfelt appreciation for the inclusion and the products developed and shared… Our partners in PREMA felt secured knowing that we could link the scientific information for their action."*
>
> Gilberto Guevara, Director, Puerto Rico Response Innovation Lab, Puerto Rico Science, Technology & Research Trust

While supporting the needs of the disaster response and recovery community, the significant impacts from Dorian captured the attention of the public with strong interest in how the storm could be observed from a unique NASA research and applications perspective. Through a variety of outreach efforts, the general public was given an opportunity to see how NASA's remote sensing, research and analysis, and applied science efforts come together to explore all vantage points of major hurricane events ranging from understanding their fundamental physical processes to observations of their direct impacts and societal benefits these satellites provide when addressing the challenges of changing impacts and risks to inform action.

International Space Station Role in Disaster Activation

The International Space Station (ISS) participated in disaster efforts by collecting digital handheld, visible wavelength camera images acquired by astronauts for Hurricane Dorian, the eruption of the Raikoke volcano, and many other events throughout 2019.

Figure 18: This panoramic handheld, visible wavelength (red-green-blue) digital camera image of Hurricane Dorian was taken by a crew member on the International Space Station (ISS) on September 2, 2019 using a Nikon D5 camera and a 26 mm lens. The image shows Hurricane Dorian as it weakens to Category 4 status north of Grand Bahama. Crew members on the ISS were requested to take images during the storm by the JSC Earth Sciences and Remote Sensing (ESRS) Unit.

Target requests for both events were developed for the ISS crew by the JSC Earth Science and Remote Sensing (ESRS) Unit, which assessed opportunities for imagery throughout the duration of each event. Following collection and downlink of data, the ESRS team then fully georeferenced the handheld imagery for delivery to the USGS Hazards Data Distribution System and NASA Earth Science's Disasters program for access by end users.

ISS crew observations provide inherently different and complementary imagery when compared to typical (nadir facing) remote sensing imagery. Oblique imagery of disasters, especially of storms and eruptions as seen in the examples, can be highly beneficial for researchers studying these events.

Figure 19: This handheld, visible wavelength (red-green-blue) digital camera image of the Raikoke eruption was taken by a crew member on the International Space Station (ISS) on June 22, 2019 using a Nikon D5 camera and a 78 mm lens. The image shows extent of the plume of ash as it streamed east over the North Pacific. B) This handheld, visible wavelength digital camera image of Raikoke was taken using a Nikon D5 camera and 500 mm lens. The image shows the narrow column of ash rising up into the umbrella region where it then begins to spread out. Crew members on the ISS were requested to take images during the eruption by the JSC Earth Sciences and Remote Sensing (ESRS) Unit.

***Placeholder*: Land, Atmosphere Near real-time Capability for Earth Observing System**

IV. Disaster Risk Reduction and Resilience

The Disaster Risk Reduction and Resilience components of the Disasters Program focuses on direct end-user engagement to enable partners to identify challenges they are experiencing, and to design approaches that are iteratively developed with the partners data capabilities in mind, as well as the scale and timing with which they make decisions in relation to disaster risk. Working with humanitarian actors, including UNHCR, UNDP, IOM, Mercy Corps, and the Red Cross Red Crescent movement, has been essential for understanding how humanitarian actors manage risk on the ground, and how to collaboratively work towards science-informed humanitarian action.

Risk Reduction & the Sendai Framework

Since the release of the Sendai Framework for Disaster Risk Reduction, the Disasters Program has worked to identify entry points for bolstering the framework that supports both the achievement of the Sustainable Development Goals and the greater 2030 Agenda (Paris Agreement, Sendai Framework, New Urban Agenda, and SDGs). The Secretariat of the Sendai Framework is the UN Office for Disaster Risk Reduction (UNDRR), and in 2019, the Disasters Program Manager, David Green, and Risk Reduction and Resilience Lead, Shanna McClain, were invited to sit as experts in the inception and development of the Global Risk Assessment Framework (GRAF) and its associated Working Groups on Risk Communication, Integrated Systems Thinking, Mapping & Gap Analysis, and Pilots and Demonstrators. The GRAF seeks to improve the understanding and management of current and future risks, across multiple sectors and scales, to better manage uncertainties, and mobilize people, innovation, and finance – all elements complementary to the Sendai Framework.

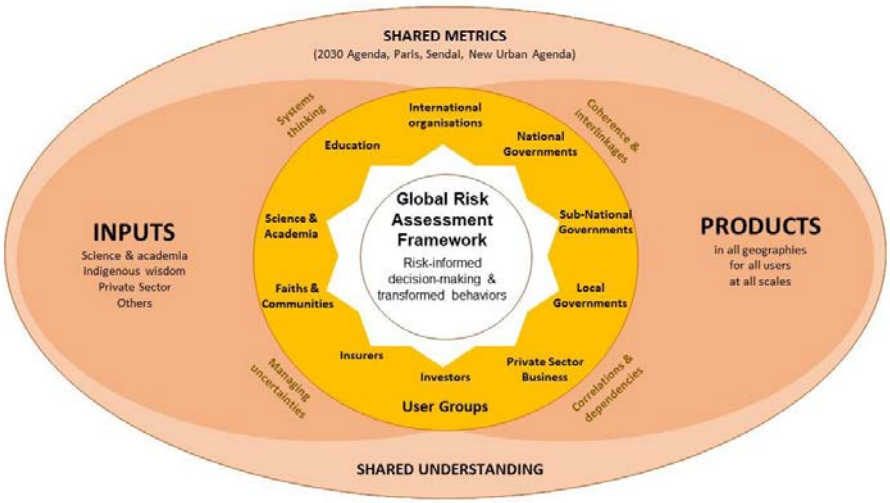


Figure X. The elements of the GRAF that contribute to the UNDRR's "theory of change" in regard to the understanding and implementation of disaster risk reduction.

The Disasters Program also supports the Sendai Framework and broader 2030 Agenda by contributing to the Science and Policy Working Group of the Sendai Framework, which bolsters the elements of Earth observations can play in understanding risk, and the elements of risk related to early warning and early action led by the World Meteorological Organization (WMO). In 2019, these elements of support came together under the UNDRR Global Platform on Risk Reduction, which convenes every two years, this time in Geneva, Switzerland. At this event, the Disasters Program contributed to the formal launch of the GRAF, and called for the risk community to adopt and participate in its development. In 2020, the GRAF will begin a series of pilot activities that the Disasters Program will also participate in.

Figure X. Shanna McClain (Lead for Risk Reduction and Resilience) sits on panel for the UN Office of Science and Technology Integration (left), David Green (Disasters Program Manager) participates in the formal launch of the GRAF (right), and Shanna participates in the WMO Multi-hazard Early Warning Conference on the value of integrated approaches for impact.

Connecting Earth Observations to Decision Makers for Preparedness Actions (COMPAS)

In 2019, the Rapid Response and Novel Research in Earth Science (RRNES) project on Connecting Earth Observations to Decision Makers for Preparedness Actions (COMPAS) was developed to identify new approaches for working directly with humanitarian actors and tailoring risk-informed products and outputs based on humanitarian needs. The COMPAS activity provided an opportunity to pilot this approach in the Rohingya refugee camps of Cox's Bazar, Bangladesh, where more than740,000 refugees now reside after fleeing persecution and violence in their home country of Myanmar. The areas where informal settlements were built for the refugees are located in hilly areas where 80 percent of Bangladesh's rain falls in just five months, leading to increased risk of landslides and flash floods. The COMPAS work concluded in 2019, after achieving a number of successes including:

1) The invitation by UN hosts to tour the Rohingya refugee camps to better understand and identify the challenges relating to landslide susceptibility, the current platforms and data capabilities of UN partners, and the timing and information necessary for co-development of data products;

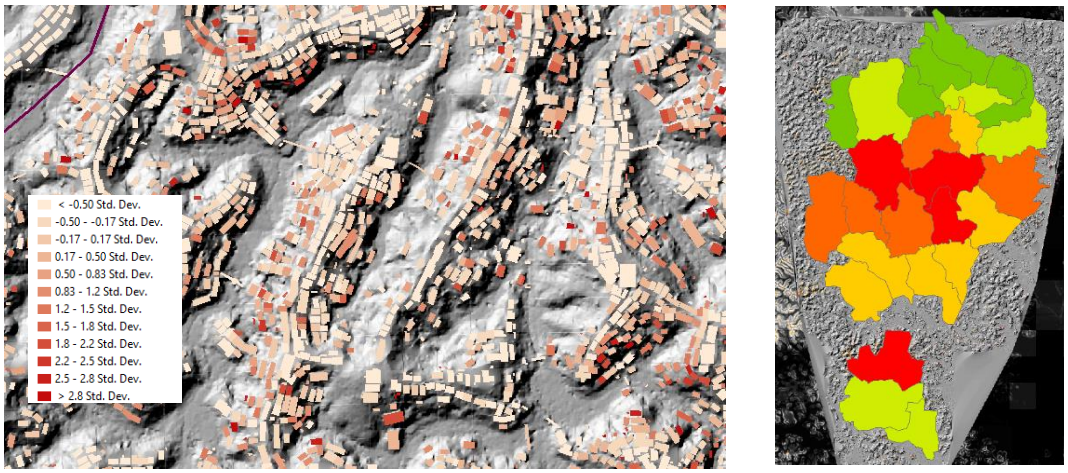


Figure X. NASA Disasters Landslide Risk Products |relative exposure of buildings to landslide hazard (left) and relative hazard level in each camp (right). The color schema reflects those areas with the deepest colors are those most highly exposed to landslides.

Figure X. Program tours Rohingya Refugee Camps |Photos of informal settlements in the camps susceptible to landslides (left) and Disasters Program team member, Shanna McClain, speaking with UNDP colleagues about timing of evacuations based on landslide susceptibility (right).

2) The NASA and UN co-development of a landslide inventory for the camps, a landslide susceptibility map for the Cox's Bazar region, dynamic landslide and exposure online portal, and landslide runout and impact maps – all of which were integrated into the platforms used by UN partners in Cox's Bazar; and

3) The development of UN policy guidelines by the UN Office for Disaster Risk Reduction on "Integrating Disaster Risk Information into Humanitarian Response". These guidelines identified the COMPAS group and methodology as a successful design method and suggested to humanitarian relief and disaster assistance (HADR) actors that risk monitoring for site planning, like that developed for COMPAS, be considered in future programming. Additionally, COMPAS published a Lessons Learned set of Guidelines from UNDP, NASA and Columbia International Research Institute for Climate and Society on the use of risk information in refugee relief.

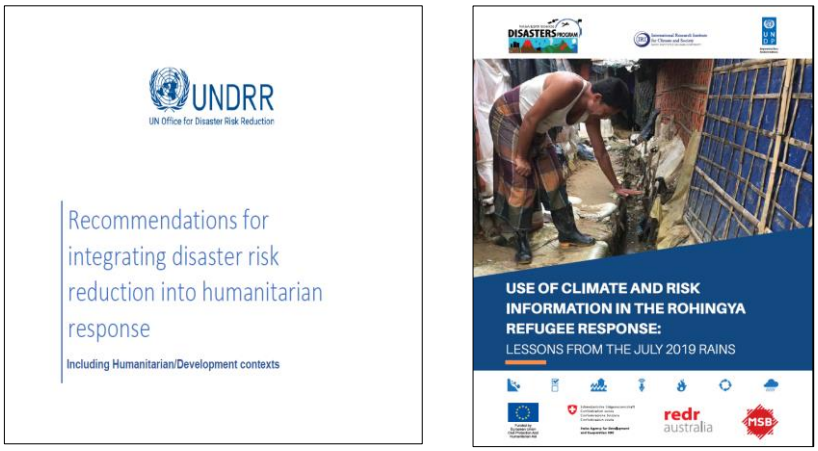


Figure X. UN Guidelines on Risk and Humanitarian Action |UNDRR Guidelines recommending the COMPAS methodology (left) and the NASA and UNDP Lessons from the Rohingya Response (right).

NASA and Red Cross Early Warning, Early Action Workshop

The NASA Disasters Program and the Red Cross Red Crescent Movement – including International Federation of Red Cross Red Crescent Societies, the American Red Cross, and the Red Cross Red Crescent Climate Centre - hosted a joint workshop to explore challenges and opportunities in working together on the Red Cross Early Warning, Early Action portfolio. The workshop worked across the various Red Cross Movement's subject matter experts and support teams, and in the end identified cities and urban areas to be some of the most challenging places for implementing their portfolio. The workshop concluded with the intent to develop a 2020 partnership plan for Early Warning, Early Action in the context of cities and urban areas.

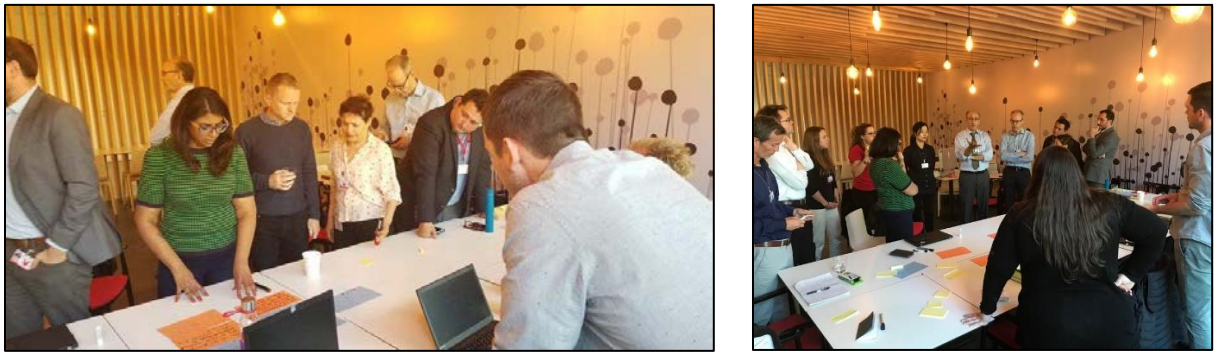


Figure X. NASA and Red Cross Red Crescent Workshop on Disaster Risk and Early Action |The team of Red Cross members working on participatory mapping exercise (left) and Disasters Program Manager, David Green, summarizing the results of the mapping exercise and the next steps of the NASA and Red Cross partnership (right).

NASA + Mercy Corps Partnership

The ESD-level partnership between NASA and Mercy Corps, led by the Disasters Program, seeks to leverage the knowledge of fragile and crisis-affected areas to build a better understanding and ability to visualize resilience in humanitarian contexts. The partnership focuses on a collaborative approach to understanding multi scale and sector humanitarian challenges by integrating Mercy Corps' expertise in resilience-focused humanitarian intervention

and in-country stakeholder relationships along with NASA's expertise in Earth system science and global datasets. Outcomes from this partnership will include the increased use and effectiveness of Earth observations in the humanitarian and development sector, and the ability to assess human resilience of communities vulnerable to shocks and stresses at global, national, and sub-national scales. In 2019, NASA and Mercy Corps designed a participatory mapping exercise to develop a common understanding and approach to building resilience. This included developing a shared language that enabled NASA scientists and the Mercy Corps technical units to better communicate technical information into humanitarian decisions. NASA and Mercy Corps also signed a Space Act Agreement on March 29th at the Mercy Corps Washington DC office to formalize their partnership and shared vision towards resilience.

Figure X. Sandra Cauffman, Acting Director, Earth Science Division (front, second from left) and Dina Esposito, Executive Director, Mercy Corps (front, third from left) with the joint Mercy Corps and NASA leadership team at the signing event.

Virtual Reality for Understanding Risk

The NASA Disasters Program and Navteca – a technology company pioneering the use of Virtual Reality (VR) for Earth sciences – have been working to develop virtual reality technology to better visualize flood risk. In 2019, the project team explored the utility of VR to interact with projected flood measurements and developed the ability to ingest new datasets in near-real time. Through a custom-developed VR interface displaying 3D city and terrain models and global maps, the end user can order and view data in an immersive environment. This type of visualization tool is scalable to many types of disasters and extreme weather events, potentially improving the use of geospatial and Earth observation data. An interactive visualization using VR may bring better understanding and communication of Earth data to a variety of end users, from scientists to decision makers, and enhance decision-making tools for disaster planning, recovery, and resilience. In this regard, future engagements will include the NASA ROSES teams whose research is focused on the risk of multiple hazards.

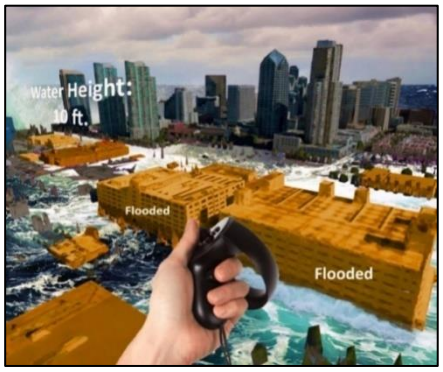


Figure X. (top) VR 3D interface display at AGU Conference allowing flood risk to be viewed in an immersive environment. (bottom) Participant using VR to better understand SAR data and surface deformation.

Regional Engagements: Americas and the Caribbean

Considering that disasters do not observe borders or language barriers, the NASA Disasters Program applies an inclusive approach in the Americas and the Caribbean, acting as a key actor capable of bringing communities together through its strategic credibility and value in science and technology. It's expertise in satellite data and relationships with multiple actors at the global, regional, national and local levels, helps foster community resiliency in the face of disasters.

Thirty-five countries coexist in the Americas, with a billion people from multiple cultures and languages ranging from developed countries to indigenous peoples who have no contact with civilization. However, the challenges facing disaster risk and its impacts are common to all, being necessary to implement multidisciplinary strategies in which local communities can be empowered to environmentally order their territories, live with risk without stopping development by building resilience. The program has fostered dialogue with ambassadors in the Americas, national governments, and regional organizations such as the Caribbean Community and the Central American Integration System (SICA) to create coordination and joint actions for disaster risk reduction in the Americas. The NASA Disaster Program plays a crucial leadership role creating strong ties of cooperation in science and technology in multiple languages and facilitates the participation of the international scientific, governmental and civil community in the cooperation frameworks of the Group on Earth Observations (GEO), and for the development of the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030.

Resilient Recovery Approaches Workshop: Using Earth Observations to Understand Vulnerability and Exposure in Land and Infrastructure Planning

The Disasters Program led the development and execution of a workshop in partnership with the Puerto Rico Science, Technology, and Research Trust (PRST) on August 6-8, 2019 in San Juan, Puerto Rico. The workshop brought together a wide variety of attendees from the Federal, Territory and Local governments as well as private industry.

Figure X. Resilient Recovery Approaches.

This provided an opportunity for Disasters Program staff to learn firsthand the vulnerability and exposure issues that still to this day limit the resilience of Puerto Rico to future disaster situations, while providing a platform to educate attendees and partners about Earth observation resources available to them through the Disasters Program.

The Disasters Program team also had the opportunity to meet with the Puerto Rico Emergency Management Agency (PREMA) Commissioner, the FEMA Joint Recovery Office (JRO) GIS Coordination Team, the Puerto Rico Governor's Office Chief Information Officer (CIO) and the EPA's Puerto Rico Water Advisor.

As previously noted in the Hurricane Dorian activation highlight, the Disasters Mapping Portal and the PRST successfully connected their GIS Portals, allowing NASA Disasters products to be shared directly to the PRST. This workshop and subsequent meetings will serve as a foundation for continued partnership between the Disasters Program and relevant partners in Puerto Rico, to

identify additional applications and integrate NASA Earth observations into ongoing resilience and risk reduction activities on the island.

Central American Integration System (SICA)

As part of the larger regional focus on the Americas, the Disasters Program is working with SICA which coordinates the activities of Central American countries and the Dominican Republic. The engagement intends to build and strengthen the capacity of technical specialists in the SICA countries to use Earth observation data through webinars and pilot development for multi-risk assessments. NASA Disasters Program worked with delegates from the disaster agencies of several SICA countries to create a disaster research proposal with NASA's DEVELOP program on “Flood Risk Transportation and Infrastructure of Central America and Mapping the susceptibility to landslides in the Dominican Republic”. Future engagements with SICA are expected to focus on risk reduction and resilience throughout the region.

Figure X. Coordination meeting with members of the National Coordinator for Disaster - Reduction of Guatemala- CONRED

US Caribbean Partnership Interagency Group

Since the launch of the US-Caribbean Disasters Partnership -USCRP in Miami in May 2019, NASA Disasters Program has been actively participating in the working group for the implementation of this collaborative effort to build regional capacity to confront humanitarian assistance and disaster relief for sustainable resilience. It will strengthen the U.S.-Caribbean relationship and advance our shared interests in achieving greater resilience to disasters. The partnership involves several initiatives focused on understanding risk and enabling action, building resilient communities, and improving disaster sustainability and growth with Caribbean countries.

V. NASA Disasters Mapping Portal

The Disasters Mapping Portal is the data-sharing hub of NASA Disasters products, making them openly accessible for public use in mapping, assessment and planning. It helps demonstrate the possible by combining NASA data with other products and uses web applications such as Story Maps and Dashboards with tools and widgets to further enhance analytics and usability of data. The Portal serves as a method of outreach for the Program by connecting to end users at all levels from the general public to local, state, federal, and global stakeholders.

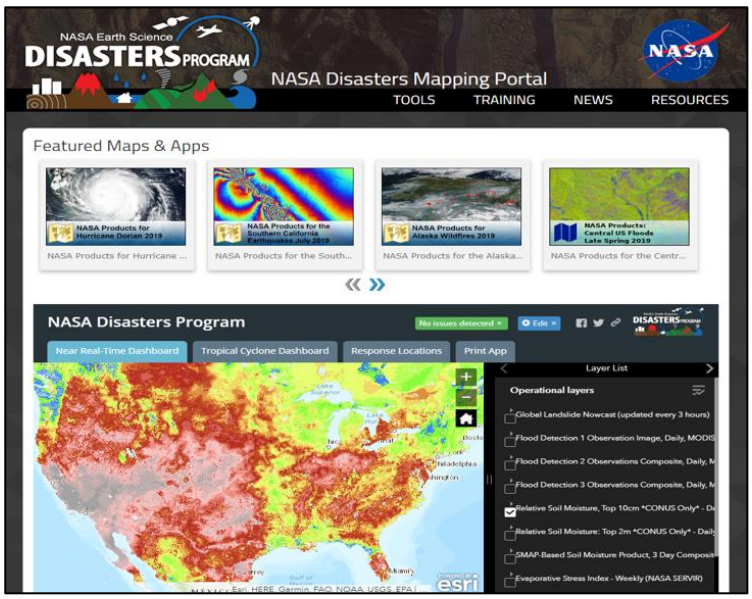


Figure X. NASA Disasters Mapping Portal.

The Portal saw a large number of improvements and became a cornerstone of the Disasters Program. The Portal hosted products for 17 different disaster activations. The most severe events were the central US floods and hurricane Dorian. The hurricane Dorian story map had more than 12,450 views and the Portal home page Story Map had over 3,700 views. The SO_2 Catalogue web app was embedded into Goddard's Global Sulfur Dioxide Monitoring home page, which is the first time a portal app has been embedded into a NASA mission page. Enterprise sites were created for each disaster type and multiple dashboards highlighted near real-time products, tropical cyclone products, and response locations. The LIS 2 meter and SMAP-based soil moisture near real-time products were added to the Portal. Of the 10 ROSES grant funded projects, five have already provided products for testing or as part of a disaster response. Portal to Portal Collaborations were established with FEMA, NASA's NCCS, the Puerto Rico Science & Technology Trust, and the Army Geospatial Center. A Collaboration was also established with NASA ArcGIS Online, allowing for an enormous global user base to easily discover NASA Disasters Program GIS products. The Open Data capability was enabled on these products as well, allowing them to be picked up by Open Data search engines.

NASA Worldview's WMS feed was added to the Portal, allowing for any of Worldview's 800 layers to be added to the Disasters Portal. To demonstrate this capability wind speed data from the Cyclone Global Navigation Satellite System (CYGNSS) was added to the Hurricane Dorian Story Map. In collaboration with Esri and the Worldview team, 3 new widgets were created and added to the Portal, allowing for better time slider and legend functionality.

There are a number of other products that should be added in 2020 to continue to expand the usefulness of the Portal. Overall the Disasters Mapping Portal made an enormous number of technological improvements, demonstrated what is possible to end users through new web applications, and established a significant number of new partnerships for the Disasters Program.

2019 Esri User Conference

The Disasters Program attended the Esri User Conference, attended by over 18,000 GIS users from around the world. A presentation was given on the Portal to over 100 attendees from a variety of local, state, and federal backgrounds. It demonstrated the ability of the Portal to share NASA data products to end users through an easy to access site with uniform data standards. Web apps including several Story Maps and the Tropical Cyclone dashboard were shown to highlight what is possible and inspire users to combine NASA data with other data sources.

Figure X. Disaster Management Coordinators and GIS Portal Administrators at the Esri User Conference in San Diego, California in July 2019.

An exhibit hall booth for the Program attracted approximately 2,500 people, resulting in a multitude of additional contacts, including the lead GIS officials for Texas, Florida, Oklahoma, and the National Geospatial Agency (NGA) Disaster Analysis and Domestic Support Branch. A follow-up Portal demonstration was provided to approximately 80 of the NGA's analysts who analyze various types of impacts to Department of Defense assets and operations.

The California Earthquakes occurred immediately prior to the User Conference held in San Diego, and products created by the program were for the first time demonstrated live to attendees as the response unfolded. This sparked a new relationship with the Navy, who saw the value of this emerging capability in operations and went on to use these products to evaluate areas of the China Lake Facility at risk to damage from the earthquake.

VI. GEO, AmeriGEO, and CEOS

Group on Earth Observations (GEO)

Group on Earth Observations (GEO) is a key international partner of the Disasters program, representing access and collaboration with governments and organizations. The Disasters program continued to make substantial progress within the GEO Work Plan by contributing results towards a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations (EO). NASA Disasters Program contributed to GEO through the U.S. Group on Earth Observations (USGEO) by linking with national priorities, policies and leveraged projects. USGEO is chartered as a subcommittee under the National Science and Technology Council (NSTC) and is an interagency body, with multiple government agencies represented who routinely work closely with the Disaster program and our pool of investigators and users.

Figure X. Ricardo Quiroga (NASA Disasters AmeriGEO Coordinator) at the Technological Institute of Santo Domingo (INTEC) discussing the value of EO to support preparedness and improve warnings to address high level of disaster risk in the Dominican Republic

GEO Ministerial Summit

The GEO Ministerial Summit was held in Canberra, Australia from November 4-9, 2019. The Disasters Program led a Key Technical Session on Earth Observations for Disaster Risk Reduction but focused on the human dimension of Earth observations. The session was developed based on an identified need by those working in fragile and crisis-affected contexts to better design and integrate science-based approaches for visualizing and managing systemic risk into humanitarian decisions and actions. This event was supported by GEO and CEOS flagships, initiatives, and community actions to showcase opportunities for ensuring a thriving society driven by Earth observations and humanitarian action (EO4HA). The primary outcome of this event was the GEO community identified interest in convening a formal initiative to create the Earth observation for Humanitarian Action activity.

Figure X. Andrew Lind (IOM Senior Crisis Specialist) discussing the need for EO to support humanitarian decisions (left) and David Green (Disasters Program Manager) discussing the opportunities to collaborate with humanitarian organizations (right).

AmeriGEO Disasters Working Group

NASA's Disaster program is Co-chair of the Disaster Working Group (DWG) of the AmeriGEO Earth Observation Group, establishing networks and coordinating activities linking with national and regional work plan priorities. To highlight the progress being made and strengthen the regional data and information sharing, Disasters organized a panel session during the AmeriGEO Week held in Lima, Peru in August 2019 in which delegates participated from eleven countries of the Americas. The Disasters program also made progress promoting early career communities and nontraditional partnerships across the region. NASA worked with the AmeriGEO-DWG to support a long-standing partnership with the Water Youth Network and UN Disaster Youth by conducting an exercise: "from data to decision-making in disaster risk management" in which technical experts from 10 countries participated. The disaster program has gained the active commitment in GEO of the countries of the Americas in disaster risk reduction activities by enabling the use of Earth observations and applications such as in Colombia during the map-a-thon entitled "*Hack the Risk*." In this map-a-thon, young professionals held center stage; the Dominican Republic, Bolivia, and Colombia in landslides; Peru, Bolivia, and Paraguay in the face of fire emergencies in the Amazon; Chile to search for a military aircraft missing in the Arctic; and Uruguay to support with products during the floods. NASA Disasters, working in coordination with the AmeriGEO-DWG, continued development of nine disaster impact assessment pilot projects all of which incorporate the Disasters portal linked with the AmeriGEO platform and open data standards. The results of these studies, map-a-thons and projects yielded effective practices that were shared among representatives of GEO, but also among other regional partners in the adjacent Caribbean and Central America.

The Disasters program increased the amount of data shared, models validated and location platforms strengthened across the AmeriGEO-DWG. By demonstrating results of projects and sharing expertise as well as data, the program encouraged the use of Earth observations for resilience at multiple scales. Several partners among the AmeriGEO country engaged in improvements to tools for land planning, urban design and disaster mitigation, risk atlases to know vulnerability and communicate exposure, and fill gaps in systemic risk variables need to work across the disaster cycle towards comprehensive resilience of at-risk communities.

The AmeriGEO-DWG has participated in the regional organization of different conferences in Disasters and has established a direct dialogue with the main regional and global actors in disasters such as United Nations Committee of Experts on Global Geospatial Information Management-UNGGIM, United Nations Regional office for Disasters Risk Reduction- UNDRR, International Investigation Center for el Niño Phenomenon- CIIFEN, The Network Of The University Students for The Management of Reduction of Emergency And Disaster Risks in Latin America and The Caribbean-"REDULAC, Word Bank, Center American Integration System – SICA, the Committee on Earth Observation Satellites (CEOS) Working Group Disasters (WGDisasters), the GEO Global Flood Risk Monitoring (GFRM) Community Activity and representatives in various thematic areas in disasters in each AmeriGEO member country.

Figure X. Group of participants from 10 countries. Training "from data to decision-making in disaster risk management "During the AmeriGEO week in Lima, Peru August 17/2019.

Figure X. "Hack the Risk" sponsored by NASA Disasters program April/2019 Bogota Colombia.

Committee on Earth Observation Satellites (CEOS)

Photo Credit: David Borges

CEOS is a mechanism to coordinate civil space-based Earth Observation Programmes globally and promote data exchange for society's benefit, and to inform decision-making to secure a prosperous and sustainable future for humankind. In October 2019, David Green became the CEOS WGDisasters Chair for a two year period. The CEOS WGDisasters ensures the sustained coordination of disaster-related activities undertaken by the CEOS Agencies and acts as an interface between CEOS and the community of stakeholders and users involved in risk management and disaster reduction. The main objectives of the CEOS WGDisasters are:

- To support the efforts of Disaster Risk Management authorities in protecting lives and safeguarding property by means of satellite-based EO and science-based analyses

- To foster increased use of EO in support of Disaster Risk Management
- To support the Implementation of the Sendai Framework for Disaster Risk Reduction, and in particular contribute to its Priority 1: "Understanding Risk"
- To raise awareness of politicians, decision-makers, and major stakeholders of the benefits of using satellite EO in all phases of Disaster Risk Management.

The WG coordinates efforts across multiple work streams, including a Volcano Demonstrator, Seismic Hazards Demonstrator, Landslide Pilot, GEO Data Access for Risk Management (GEO-DARMA) Initiative, Haiti Recovery Observatory, Generic Recovery Observatory, GEO Geohazard Supersites and Natural Laboratories (GSNL), and a Geohazards Lab.

The WG holds bi-annual meetings, which were held in Athens, Greece and Reykjavik, Iceland in 2019. An updated WG Terms of Reference (ToR) was also drafted and implemented at the 2019 CEOS Plenary in Ha Noi, Vietnam.

VII. Disasters Mission Applications

NASA ISRO Synthetic Aperture Radar (NISAR)

The *NISAR* Mission is scheduled for launch in 2022. The Project Scientist is Paul Rosen, JPL. The DPAs are Natasha Stavros, JPL and Batu Osmanoglu, GSFC.

In 2019 *NISAR* hosted two workshops with applications communities to assess their needs and work together to customize a roadmap for increasing the utility of *NISAR* data prior to launch in 2022. The two workshops hosted in 2019 included: 1) Volcano Applications and 2) Landslide Applications.

- At the Volcano Applications workshop participants from academia, all five USGS Volcano Observatories, the USGS Volcano Disaster Assistance Program, the USGS Volcano Hazards Program Office, the National Park Service and National Weather Service, and several state agencies with NASA scientists, engineers and NISAR science team members identified the highest priorities of the end-user community that would facilitate their ability to use NISAR data to improve operations. The community identified three priorities; reducing latency during volcanic events, atmospheric corrections for InSAR measurements, and surface deformation time series product.
- The landslide community representatives from federal agencies (USGS, USFS, USBR, NPS, FEMA), state agencies (WA DNR, AK DGGS), the City of Seattle, universities and geotechnical firms, and international participants from Canada and Norway highlighted NISAR's potential of providing game-changing information to the landslide applications. The participants concluded that NISAR's main contribution will come from time series information on ground motion to identify slow to very slow-moving landslides at the synoptic scale.

In 2019, the *NISAR* Science Team and Project completed the first phase of the Urgent Response Working Group (URWG) to develop a detailed Urgent Response Plan for activation of the mission capabilities when needed. The URWG will take a phased approach with sequential groups addressing individual and related sets of the issues. Working group members included science team members from each of the science disciplines and the Science Team Applications

Lead, people working on the *NISAR* project at JPL, and a *NISAR* Deputy Program Applications lead (representing NASA Applied Sciences Disaster program). The URWG #1 completed its report in January 2020, which considers the types of events to which *NISAR* should expect to respond; whether an automated mechanism for initiating the activation can be developed; and the criteria for triggering initiation and maintaining support. Events were classified by the degree to which they could be forecast. For example, an earthquake is not forewarned but sensor networks can be used to automate a request for measurement based on magnitude and proximity to population centers or critical infrastructure. In contrast, flooding from hurricanes can be anticipated and urgent activation downlink and processing requested in advance of landfall. The types of events considered covered geological hazards, ecosystem hazards and flooding, maritime hazards, and industrial/human accidents.

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)

The *TROPICS* mission, with an expected launch in 1-2 years, is a constellation of state-of-the-science observing platforms that will measure temperature and humidity soundings and precipitation with spatial resolution comparable to current operational passive microwave sounders but with unprecedented temporal resolution (median revisit time of 50 minutes). As a Venture Class mission, TROPICS is comprised of a constellation of three unit small spacecraft, also known as smallsats, each hosting a 12-channel passive microwave spectrometer. TROPICS will provide imagery near 91 and 205 GHz, temperature sounding near 118 GHz, and moisture sounding near 183 GHz. Spatial resolution at nadir will be around 27 km for temperature and 17 km for moisture and precipitation with a swath width of approximately 2000 km. The primary mission objective of TROPICS is to relate temperature, humidity, and precipitation structure to the evolution of tropical cyclone intensity. However, with high temporal resolution precipitation observations, TROPICS will provide observations relevant to disaster and risk management related to tropical cyclones, heavy precipitation, and associated flooding and landslide hazards.

An Early Adopter program was established in 2018 with four focus areas: 1) Tropical Cyclone Analysis and Forecasting, 2) Modeling and Data Assimilation, 3) Tropical Cyclone and Tropical Dynamics, and 4) Terrestrial/Disasters. There are four Early Adopters in the Terrestrial/Disasters focus area with two projects relevant to NASA Disasters inclusive of topics on improving precipitation forecasts, flash flood, and landslide prediction and informing risk decision making for such disasters. During 2019, the DPA, Dr. Emily Berndt (NASA MSFC), continued quarterly applications telecons, developed a new TROPICS Applications webpage, and began planning the 2nd TROPICS Applications Workshop to be held in early 2020. The planned workshop will have a dedicated session related to the precipitation, severe weather, and disasters. These activities continued to foster interaction between the community of end users and the TROPICS Science Team with active participation from PI Dr. Bill Blackwell (MIT Lincoln Laboratory).

Lidar Surface Topography (LIST)

This 2007 Tier 3 Decadal Survey mission remains in a concept design phase. The DPA is David Harding, NASA GSFC. Decadal survey concept: https://cce.nasa.gov/pdfs/LIST.pdf

VIII. Abbreviations and Acronyms

Placeholder

ADPC	Asian Disaster Preparedness Center
AGU	American Geophysical Union
APRFC	Alaska-Pacific River Forecast Center (NOAA, NWS)
ARC	Ames Research Center (NASA)
ARD	Analysis Ready Data
ARL	Application Readiness Level
ASI	Agenzia Spaziale Italiana (Italian space agency)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVO	Alaska Volcano Observatory
BAER	Burned Area Emergency Response
CAIR	Communities and Areas at Intensive Risk
CAL FIRE	California Department of Forestry and Fire Protection
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CDEMA	Caribbean Disaster Emergency Management Agency
CEOS	Committee on Earth Observation Satellites
CI	Critical Infrastructure
CNES	National Centre for Space Studies (French space agency)
CONAE	Comisión Nacional de Actividades Espaciales (Argentine space agency)
CSA	Canadian Space Agency
CYGNSS	Cyclone Global Navigation Satellite System
DAAC	Distributed Active Archive Center (NASA)
DEM	Digital Elevation Model
DHS	United States Department of Homeland Security
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DPA	Deputy Program Area Lead (NASA)
DRR	Disaster Risk Reduction
EA	Early Adopter (NASA)
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts

EO	Earth Observing
EOS	Earth Observatory of Singapore
EOSDIS	NASA's Earth Observing System Data and Information System
EPA	Environmental Protection Agency
ESA	European Space Agency
ESD	NASA's Earth Science Division
ESTO	Earth Science Technology Office (NASA)
FAO	UN Food and Agriculture Organization
FEMA	Federal Emergency Management Agency (DHS)
FEWS NET	Famine Early Warning System Network
FWI	Fire Weather Index
G-LIHT	Goddard's Lidar, Hyperspectral & Thermal Imager
GAR	Global Assessment of Risk (UNDRR)
GEO	Group on Earth Observations
GEO-DARMA	Data Access for Risk Management (GEO)
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
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
GLISTIN	Glacier and Ice Surface Topography Interferometer
GNNS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOFC-GOLD	Global Observations of Forest Cover and Land Dynamics
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GSFC	Goddard Space Flight Center (NASA)
GRAF	Global Risk Assessment Framework (UNDRR)
GSNL	Geohazard Supersites and Natural Laboratories (GEO)
GWIS	Global Wildfire Information System
HQ	Headquarters
IAVW	International Airways Volcano Watch

ICAO	International Civil Aviation Organization (UN)
IFRC	International Federation of Red Cross and Red Crescent
IOM	International Organization for Migration (UN Migration)
ISRO	The Indian Space Research Organisation
ISS	International Space Station
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
LaRC	Langley Research Center (NASA)
Lidar	Light Detection and Ranging
LIST	Lidar Surface Topography
MASTER	MODIS/ASTER Airborne Simulator
MISR:	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging SpectroRadiometer
MSFC	Marshall Space Flight Center (NASA)
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NGO	Non-Governmental Organization
NISAR	NASA ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service (NOAA)
NOS	Next Observing Strategy (NASA)
NPP	National Polar-orbiting Partnership
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTWC	National Tsunami Warning Center
NWS	National Weather Service
OGC	Open Geospatial Consortium
OMPS	Ozone Mapping Profiler Suite
OSTP	Office of Science and Technology Policy

PDC	Pacific Disaster Center
PI	Principal Investigator
PRST	Puerto Rico Science, Technology and Research Trust
PTWC	Pacific Tsunami Warning Center
RECOVER	Rehabilitation Capability Convergence for Ecosystem ***Recovery***
RGB	Red, Green and Blue
RO	Recovery Observatory
ROSES	Research Opportunities in Space and Earth Sciences (NASA)
RRNES	ROSES Rapid Response and Novel Research in Earth Science (NASA)
SAR	Synthetic Aperture Radar
SDGs	Sustainable Development Goals
SDR	Science for Disaster Reduction, former Subcommittee on Disaster Reduction
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SFDRR	Sendai Framework Disaster Risk Reduction
SICA	Central American Integration System
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SRST	Subcommittee on Resilience Science and Technology
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UN	United Nations Office for Outer Space Affairs
UNGA	United Nations General Assembly
UNDRR	United Nations Disaster Risk and Reduction (formerly UNISDR)
UNESCO	United Nations Environmental, Scientific and Cultural Organization
UNHCR	United Nations High Commissioner for Refugees
UNISDR	United Nations Office for Disaster Risk Reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office
UNDP	United Nations Development Programme
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
URWG	Urgent Response Working Group

USDA-FAS	United States Department of Agriculture Foreign Agricultural Service
USACE	United State Army Corps of Engineers
USFS	United States Forest Service
USGEO	United States Group on Earth Observations
USGS	United States Geological Survey
VAAC	Volcanic Ash Advisory Centre
VIIRS	*V*isible Infrared Imaging Radiometer Suite
VNSC	Vietnam National Space Center
VR	Virtual Reality
WGDisasters	Working Group Disasters
WMO	Word Meteorological Organization (UN)