Best Practice

Addressing Challenges and Exploring Solutions to Enhance Earth Observation Applications for Emergency Management

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Abstract: Earth observations (EO) and remote sensing technology provide essential data for understanding natural hazards and their effect on the environment and society. Emergency management relies on data-driven decision making to address disruptive and damaging events, increasingly using remote sensing to improve situational awareness. Unfortunately, gaps between the cutting edge of remote sensing science and application in emergency management diminish the value of data before use. Challenges include: the trade-offs in temporal resolution, spatial resolution, and area coverage; geographic nuances affecting asset utility; complexity in the tasking, collection, processing, exploitation, and dissemination process; expectations for analysis and interpretation; data accessibility; and the rapid advancement of remote sensing and space technology. The NASA Disasters Program's Disasters Response Coordination System (DRCS) launched in June 2024 to improve the application of NASA science for disaster response. This paper shares challenges the DRCS experienced throughout its first year and discusses best practices to improve the effectiveness of remote sensing support of emergency management activities. To bridge the gap, the DRCS proposes better curation and communication of product catalogues, tailored and varied approaches to capacity building, and enhanced coordination and collaboration.

Keywords: remote sensing, Earth observation, emergency management, disaster response

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1. Introduction

Researchers routinely harness Earth observations (EO) and remote sensing data to monitor natural hazards and improve our understanding of their consequences on the environment and society (Kirschbaum *et al.*, 2017). Remote sensing technology has developed rapidly for scientific, civil, and commercial applications, elevating its potential utility across fields, including emergency management (Denis *et al.*, 2016). When coordinating a response, emergency managers require timely, relevant data to inform decisions and increasingly look to EO to fill gaps in field reporting (Cova, 1999; Drabek and Hoetmer, 1991). But despite emerging technology, novel applications, and an emergency management (EM) community eager to maximize its impact, remote sensing often fails to meet emergency managers' expectations.

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This paper describes persistent challenges limiting the use of remote sensing to support disaster response and shares lessons learned from the first year of the NASA Disasters Response Coordination System (DRCS). The DRCS launched in June 2024 to better connect NASA's remote sensing capabilities with the emergency management community. Through 18 activations since its launch supporting federal, state, international, and non-governmental organizations, the DRCS observed a disconnect between the scientific and disaster response communities. Emergency managers can at times struggle to effectively request and utilize products derived from EO, while scientists and technologists lack understanding of emergency managers' informational needs or how best to provide decision-ready data. Although this problem is not new, sparse literature reveals the nature of this disconnect and solutions.

The DRCS asserts that bridging the gap between data providers and emergency managers is feasible. Here the authors highlight six challenges separating remote sensing science from practical applications in disaster response and emergency management. These challenges include: trade-offs in temporal resolution, spatial resolution, and area coverage; geographic nuances affecting asset utility; complexity in the tasking, collection, processing, exploitation, and dissemination process; expectations for analysis and interpretation; data accessibility; and the rapid advancement of remote sensing and space technology. The authors propose several best practices for improving outcomes, including better curation and communication of product catalogues, tailored and varied approaches to capacity building, and enhanced collaboration. This paper is intended for scientists and engineers hoping to support disaster response and for emergency managers seeking to understand how remote sensing might better meet their needs.

2. Background

2.1. Remote Sensing in Disaster Response

In April 1906, a devastating earthquake (retroactively estimated as 7.9 on the Richter scale) shook San Francisco, California. The initial tremor destroyed 5,000 homes and subsequent damage to stoves and gas lines caused a major fire that destroyed 28,000 buildings throughout the city (Strupp, 2006; Canton, 2006). In the aftermath, photographer George R. Lawrence used a creative system of kites to hoist a camera into the sky to document the damage from above. These images are considered the first use of imagery for assessing disaster damage and inspired subsequent use of remote sensing to understand the effects of disasters (Kerle *et al*., 2019).

Lawrence's ingenuity represents a larger trend in remote sensing and its application for disaster response. Although incredibly valuable for disaster response, the best available remote sensing technology is often not designed specifically for that application and therefore carries various limitations. Today, instruments mounted on overhead platforms such as satellites, unmanned aerial vehicles (UAV), or aircraft, passively or actively measure energy across the electromagnetic spectrum to provide data about features on the ground or in the atmosphere (Kirschbaum *et al*., 2017; Picchione *et al*., 2024). Emergency managers commonly leverage remote sensing products during disasters today, including multispectral imagery, hyperspectral imagery, panchromatic imagery, optical imagery, light detection and ranging (LiDAR), and synthetic aperture radar (SAR) (Hodgson *et al*., 2013; Picchione *et al*., 2024).

2.2. Emergency Management Remote Sensing End Users

The value of remote sensing products for disaster response is largely determined by those actively using it during a crisis. End users of remote sensing data include first responders, survivors, and emergency managers (Picchione *et al*., 2024). First responders such as firefighters, paramedics, and search and rescue teams can use remote sensing to gain insights into damage, inaccessible and dangerous areas, impacted structures, and validate other reports and data sources (Hodgson *et al*., 2013). Disaster survivors are becoming more engaged with geospatial data aided by an increase in public-facing data platforms including mobile navigation apps, weather apps, news outlets that frequently publish public overhead imagery during disasters, such as NASA Worldview, and others (McCormick, 2012). However, the primary end users of remote sensing and geospatial data are typically emergency managers. Responsible for coordinating response activities in affected areas, emergency managers constantly collect and share information, identify priorities, and align response operations across many independent organizations. Timely, accurate data help emergency managers make informed decisions, increase situational awareness, validate ground reports, and allocate resources.

2.3. Geospatial Needs of Emergency Management End Users

Emergency managers need data within a reasonable timeline, with an adequate level of detail, and covering the entire area of interest (AOI). Data that satisfy these needs contribute to understanding response capabilities, community conditions, and incident conditions (FEMA, 2018). Timeliness is crucial. Once a disaster happens, information from overhead imagery is most valuable to emergency managers within the first 24–72 hours (Hodgson *et al*., 2013; Battersby *et al*., 2012). After this period, the impact of the imagery diminishes as other data become available and situational awareness increases. Hodgson *et al*. (2013) found in a survey of emergency managers that 90% of state EM offices needed information on damage to structures within 72 hours of the incident.

Identifying damage to structures, as well as addressing other common asks such as determining the status of roads, estimating damage to infrastructure, and identifying the extent and boundaries of hazards depend on sufficient spatial resolution, or detail, of imagery. Battersby *et al*. (2012) found that imagery with a resolution greater than 1.5 m created limitations. Different remote sensing instruments offer different advantages and disadvantages. Understanding the limitations and trade-offs of each clarifies how remote sensing can address EM end user needs.

2.4. Response Coordination Case Studies

The DRCS only activates when end users directly request support that NASA data and expertise can help address. Requestors can include federal, state, tribal, territorial, or local government units, and private or non-profit organizations operating at national or international levels. End users request DRCS support by contacting the team and sharing details such as the area of interest, desired products or expertise, response needs remote sensing products are expected to address, and the timeframe needed to support decision making. The DRCS then enters a screening process to ensure that it has the capacity and scope to satisfy the request, that NASA products can add novel perspective and value, and that the team has the available resources to meet the need. This section illustrates four disasters where the DRCS responded to requests from partners for operational support. Each case reveals challenges and best practices discussed further in the following sections.

2.4.1. Hurricane Helene

Hurricane Helene made landfall in Florida as a category 4 hurricane on September 26, 2024. It caused extensive flooding, power outages, landslides, and severe wind damage to areas across six states and resulted in over 200 deaths and $78 billion in economic losses (Amorim *et al*., 2025; NCEI, 2025). The geographical scale and severity of the storm and its protracted impacts across the region delayed ground-based reports, rendering EO data critical to building situational awareness. The DRCS activated on September 24, 2024, supporting numerous state, federal, and non-governmental partners.

Table 1. Selected products from the DRCS response to Hurricane Helene.

Request	Product Highlights
Power Outage Awareness	An experimental power outage assessment created with Black Marble nighttime lights daily blue-yellow composite imagery visualized locations experiencing extended power outages, particularly in rural communities.
Locations of Flooding and Damage	Normalized difference vegetation index (NDVI) is an analysis used to assess vegetation health (Huang et al., 2021). To help identify areas damaged by the hurricane's water and wind impacts, the DRCS created an experimental NDVI binary change detection product that highlights areas that experienced change of any kind since before the event.
Locations of Landslides	The DRCS collaborated with the USGS Landslide Assessments, Situational Awareness, and Event Response Research (LASER) team in an interagency effort that utilized optical imagery from Sentinel-2 and other higher-resolution data to map the landslides on the ground (Macias et al., 2024).

Initial requests focused on nighttime lights data and coordination around flood mapping, but a need for information on landslides developed as well. The DRCS provided a wide array of products to support requestors' needs (Table 1) and developed new products to bring additional insights to responders (Figure 1). Feedback from partners highlighted an overabundance of SAR-derived flood products made it difficult to know which one best addressed their needs. This incident also highlighted the need during large-scale incidents for clear strategies that minimize processing and publication bottlenecks often associated with the computer systems that analyze and display geospatial data, also known as Geographic Information Systems (GIS) (USGS, 2025).

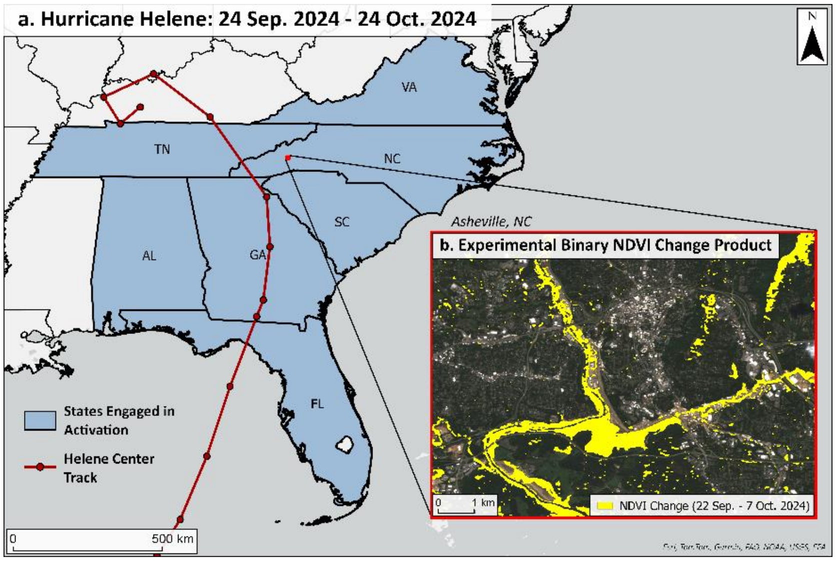

Figure 1. NDVI binary change detection product for Hurricane Helene. (a) A visualization of Hurricane Helene's storm track over the southeastern U.S. with states involved in the DRCS activation from 24 September to 24 October 2024 shaded in blue; (b) A subset of the experimental binary NDVI change product over Asheville, NC generated using ESA Sentinel-2 imagery from 22 September 2024 (pre-incident) and 7 October 2024 (post-incident) which highlights areas of change potentially associated with storm damage (yellow). Contains modified Copernicus Sentinel data processed by ESA, 2024.

2.4.2. Houston Derecho and Extreme Heat Incident

On May 16, 2024, a derecho, or convectively generated windstorm, unleashed tornadoes and destructive winds across Central Texas and Houston, causing extensive damage and knocking out power for over one million homes and businesses (Ashley *et al*., 2005, CenterPoint Energy, 2024). In the days following, extreme heat exacerbated the risk of power outages. Federal partners requested that the DRCS use EO data to identify rural communities and vulnerable neighborhoods without power to help delineate areas to prioritize aid. The DRCS provided nighttime light imagery created by the NASA Black Marble science team with data from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor (Table 2).

In addition to imagery for situational awareness and clear visualization of outages, the DRCS created experimental value-added products, or products intended to be more immediately useful to end users, that integrate sociodemographic information with EO to identify vulnerable communities (Figure 2). Through this activation and the subsequent response to Hurricane Beryl in July 2024, the DRCS expanded its knowledge of the Black Marble nighttime light data and identified the optimal data products and pipelines to create power loss proxy maps for future incidents.

Table 2. Selected products from the DRCS response to the Houston derecho and extreme heat incident.

Request	Product Highlights
Vulnerable Populations with Power Loss	The DRCS provided nighttime light imagery maps created by the NASA Black Marble science team with data from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the NASA–NOAA Suomi NPP satellite.

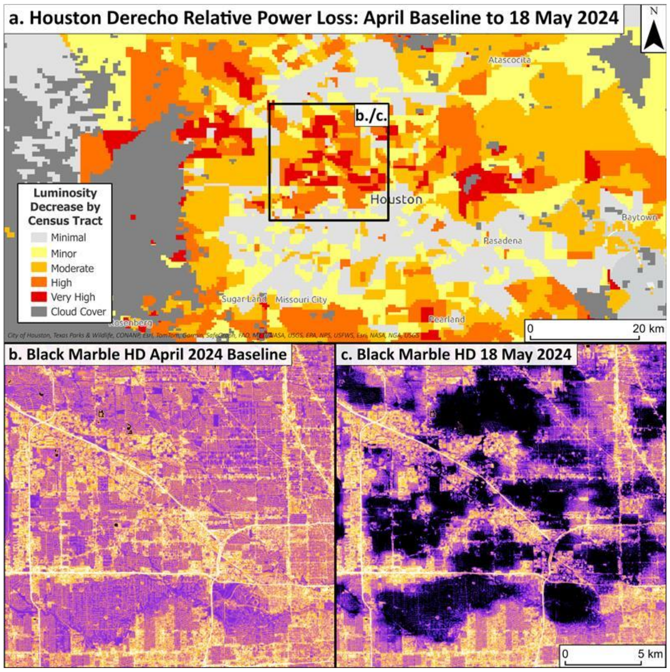

Figure 2. (a) A comparison of luminosity decrease by census tract observed by VIIRS over Houston following the derecho; (b) The Black Marble HD Baseline for April 2024, which averages luminosity over the month using cloud-free observations; (c) Black Marble HD imagery over Houston on 18 May 2024, two days after the derecho.

2.4.3. Los Angeles Fires

In early January 2025, severe drought conditions, extremely dry vegetation, and hurricane-force winds contributed to the rapid spread of two fires in heavily populated areas of Los Angeles County. By the end of January, the wildfires burned more than 57,000 acres, destroyed over 16,000 structures, and resulted in substantial loss of life and property damage.

Table 3. Selected products from the DRCS response to the Los Angeles Fires.

Request	Product Highlights
Active Fire Detection and Perimeters	Fire Information for Resource Management System (FIRMS) - Fire mapping and detection were provided through high-resolution VIIRS data to update active fire detections and perimeters every 12 hours. These timely updates significantly aided firefighting and evacuation strategies in rapidly evolving conditions.
Burned Area and Burn Severity	Normalized Burn Ratio difference (dNBR) maps from Sentinel-2 imagery, burned area perimeters, and detailed severity classifications from Sentinel-1 radar and Sentinel-2 optical imagery (OptiSAR method). These assessments distinguished between burned vegetation and damaged urban areas, providing additional context for damage evaluation and recovery planning.
Structure-level Damage Assessments	Damage analysis products from interferometric Sentinel-1 radar (InSAR) were compared with pre-disaster building footprint data and gain insight on potentially damaged areas and structures. Analysis by Corey Scher of CUNY Graduate Center and Jamon Van Den Hoek of Oregon State University.
Detection and Locations of Environmental Hazards and Health Risks.	Hyperspectral imagery from the Earth Surface Mineral Dust Source Investigation (EMIT), Greenhouse Gas Satellite (GHGSat), and the Airborne Visible and InfraRed Imaging Spectrometer 3 (AVIRIS-3) airborne instrument were analyzed for traces of methane leaks, though none were found. AVIRIS-3 hyperspectral data was also used to create an ash and char fraction map, showing where hazardous ash was located. Both analyses proved useful to CalGuard's field operations.

The DRCS responded to requests from a variety of local, state, and federal EM partners for multispectral satellite imagery and detailed burned-area assessments to inform ongoing firefighting and recovery planning as well as imagery to support damage assessment through change detection (Table 3). Additional requests included air quality and smoke plume analyses, active fire detections with regularly updated perimeter maps, and thermal imagery for hotspot identification. In response to these needs, NASA's DRCS produced and delivered over twenty remote sensing products, directly supporting operational decision-making (Figure 3).

While DRCS products effectively served the mid-to-late phases of disaster response (24+ hours after incident initiation), inherent satellite latency limited their impact in the critical initial hours. The incident represented a unique challenge as the fire heavily impacted the Jet Propulsion Laboratory (JPL) community, which includes DRCS team members and subject matter experts (SMEs). The incident also emphasized the importance of strong pre-incident relationships with state and local emergency management agencies. Prior relationships that established trust and familiarity with agencies increased the speed of the request and efficiency of product use. A key finding was the importance of streamlining and curating the products delivered to response teams. The large volume and variety of available datasets underscored the need for targeted, concise information tailored specifically to operational needs and decision-making contexts.

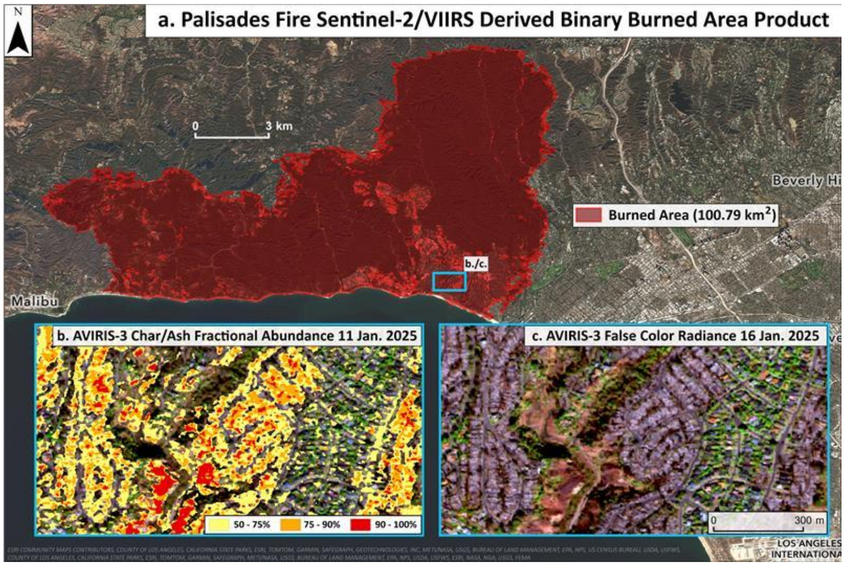

Figure 3. (a) A view of the estimated ~101 km^2 total burned area for the Palisades fire northwest of Los Angeles, CA derived from Sentinel-2 and VIIRS imagery; (b) AVIRIS-3 Char/Ash Fractional Abundance product for 11 January 2025; (c) AVIRIS-3 False Color Radiance on 16 January 2025. Contains modified Copernicus Sentinel data processed by ESA, 2024.

2.4.4. Brazil Flooding

From April 24 to May 2, 2024, a devastating flood and subsequent landslides heavily impacted southern Brazil and northern Uruguay. According to the Pan American Health Organization (PAHO), the flooding displaced nearly half a million individuals in Rio Grande do Sul alone and caused nearly 200 fatalities and 1,000 injuries (PAHO, 2024). Various agencies and organizations affected by the flooding and landslides requested data to support response activities. The DRCS responded to multiple data requests and provided imagery that helped show flooding, identify landslides, and give insights into power outage extent (Table 4). Beyond providing data, the DRCS used imagery taken before and after the incident to manually flag over 4,000 landslides in the affected region (Figure 4).

The DRCS after-action review process found that while many organizations valued the products provided, they were unsure how to best utilize and disseminate some of the resources in a timely and effective manner. Optical imagery for identifying landslides, isolated areas, environmental impact, and escape routes were among the most useful. When requestors were consumed with their response efforts, the DRCS struggled with whether to continue product creation without requestor input. Workflow improvements could also better define file formats and processing times to ensure that delivered products are available on a useful timeline in a digestible format.

Table 4. Selected products from the DRCS response to the Brazil flooding.

Request	Product Highlights
Locations of Flooding and Damage	The Advanced Rapid Imaging and Analysis (ARIA) and Observational Products for End-Users from Remote Sensing Analysis (OPERA) teams at NASA's Jet Propulsion Laboratory (JPL) and California Institute of Technology derived water maps and flood depth estimates from Harmonized Landsat Sentinel (HLS) data. Sentinel-1A SAR data was also used to create water extent maps.
Locations of Landslides	PlanetScope imagery taken before and after the event was used to manually flag over 4,000 landslides.
Power Outage Awareness	Black Marble nighttime lights product derived from the VIIRS Day/Night band on the Suomi NPP satellite.

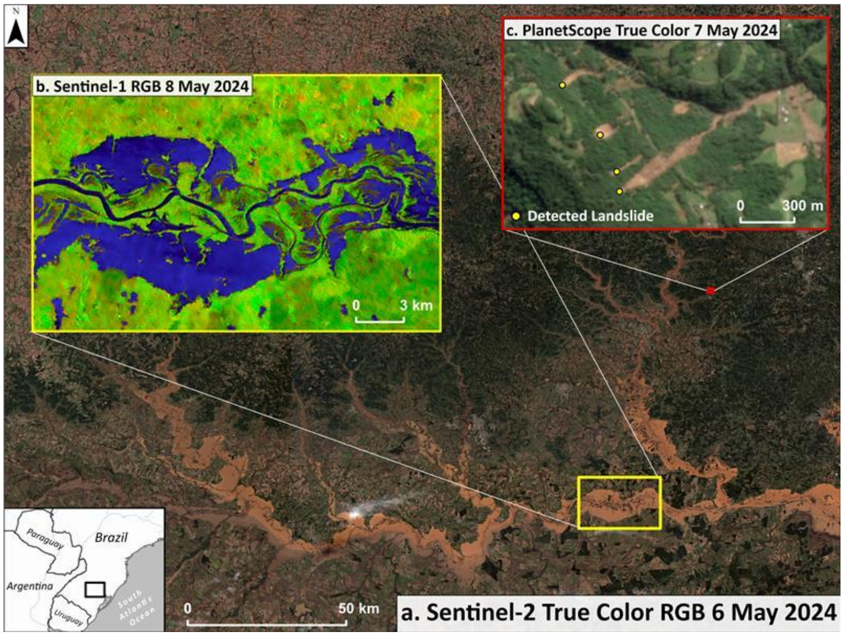

Figure 4. (a) A large-scale view of the extensive flooding in Brazil observed by Sentinel-2 on 6 May 2024; (b) A Sentinel-1 C-band SAR RGB observation of flooding from 8 May 2024; (c) An example of expert-labeled landslide detections in high-resolution PlanetScope optical imagery from 7 May 2024. Contains modified Copernicus Sentinel data processed by ESA and ASF DAAC, 2024. Includes copyrighted material of Planet Labs PBC. All rights reserved.

3. Gaps Between Earth Observation Data, Science, and Emergency Management Use

Despite a wealth of news articles, social media posts, and websites extolling the virtues of satellite remote sensing in disaster response, the DRCS's experience shows that emergency managers often remain dissatisfied with the availability and quality of remote sensing data products during disasters. This section describes how technical trade-offs, procedural complexity, and policies can limit the successful application of remote sensing data to support disaster response.

Success requires multiple decision-makers and operators having a shared understanding of end user needs and available technology. Remote sensing often falls short in meeting end user needs due to coordination failures inherent in this system (Picchione *et al.*, 2024). When an incident occurs, relationships often must be established or reestablished due to employee turnover, the involvement of new organizations or assets, or technology upgrades. In addition, coordination failures are more likely when a disaster occurs in an area that has been disaster-free for some time, or when the disaster results from a less common hazard that requires different types of remote sensing products (e.g., oil spills). Constant communication, relationship building, capacity building, and innovation are necessary to anticipate and mitigate coordination failures in this complex socio-technical environment.

3.1. Remote Sensing Trade-offs: Temporal Latency, Spatial Resolution, and Area Coverage

Three attributes influence the capabilities and use of a remote sensing instrument: spatial resolution, temporal resolution, and the areal footprint of the captured image (Tatem *et al*., 2008). Different spatial and temporal resolutions offer unique trade-offs (Tatem *et al*., 2008). Understanding these trade-offs and why they exist helps providers and end-users determine which geospatial data and tools best address emergency management needs.

Table 5. Assets frequently associated with disaster response. Data from assets in this table are published publicly during disasters or routinely available from public assets.

	Asset	Number of Satellites	Orbit	Approximate resolution	Constellation Revisit Rate	Area coverage	Narrative
Multispectral Imaging Assets	Landsat	2	Polar SSO	30m	8 days	185 km swath width	Detect flood, landslides, active fires, burned area, and vegetation change over several counties within a week.
	Sentinel-2	2	Polar SSO	10m	5 days	290 km swath width	Detect flood, landslides, active fires, burned area, and vegetation change over several counties within 4–5 days.
	PlanetScope*	130+	Polar SSO	3m	24 hours	24x8km to 32x19km	Detect landcover change over towns and cities, may observe severe damage to structures.
	MODIS	2	Polar SSO	250m	24 hours	Global, daily	Global daily low-resolution imagery shows landcover change at the city-block scale.
	VIIRS	3	Polar SSO	375m	24 hours	Global, daily	Global daily low-resolution imagery shows landcover change at the city-block scale.
	GOES-R	2	Geostationary	500m	10 min	Western Hemisphere	Low-resolution, low-latency data shows active fires, standing water for severe floods, and some damage from severe weather in real time.
Synthetic Aperture Radar (SAR)	Sentinel-1	2	Polar	10m	6 days	250 km swath width	Detect flood and landcover change over several counties within a week.
	NISAR **	1	Polar	10m	12 days	240 km swath width	Detect flood and landcover change over several counties within a week.

*PlanetScope data is provided under contract through the NASA Commercial Satellite Data Acquisition (CSDA).

**NISAR launched on July 30, 2025.

Timing is considered in two ways: collection timing and processing time. The frequency, or revisit rate, of satellite overpasses impacts the date and time of data collection. Delivery is also influenced by data downlink and post-processing time. Raw data or simple band combinations can give insights, but some end users may require processed data such as maps that identify flooding or landslides. These requests increase the value of the data but also lengthen delivery times.

Satellites maintain stable orbits around the Earth, but differences in orbital characteristics influence the application of an instrument. Sun-synchronous orbits (SSO) align with areas of the Earth illuminated by sunlight and cover the entire planet in relatively high or moderate spatial resolutions, but the revisit rate is limiting. Geostationary orbits keep satellites positioned over a fixed point by maintaining an orbital velocity that matches the Earth's rotation. This allows for continuous or nearly continuous observations of the AOI but sacrifices spatial resolution (Tatem *et al*., 2008).

There is an inverse relationship between the spatial resolution and area covered by an instrument. As the level of detail an instrument captures increases, the area imaged decreases (Table 5). For example, sun synchronous instruments such as the Landsat and Sentinel constellations have spatial resolutions of 10–30 m and image 185–290-km-wide swaths. Geostationary satellites such as the Geostationary Operational Environmental Satellite (GOES) constellation have a much lower spatial resolution of 500 m or higher, depending on the instrument, but offer near real-time coverage of the Western Hemisphere.

The spatial resolutions of satellite-based instruments vary but are theoretically limited by atmospheric turbulence and distortion of light near the surface to around 10 cm (Evvard, 1965). Some commercial satellites have high-resolution data under 1m, while federal civilian agencies' satellites range from 10 m to 1 km per pixel. Depending on the use-case, higher spatial resolution may not always be needed — for example, large-scale trends across a landscape can be tracked with coarser resolution imagery, but a single small landslide may be missed. Each instrument offers a unique perspective on Earth and its atmosphere. Understanding the technological nuances helps providers and requestors understand how these tools can deliver the most impact.

3.2. Geographic Nuances

Regional variations also influence the use of remote sensing in disaster response. Emergency management agencies across the globe operate under diverse geographic environments that shape their specific information needs and challenges. While the designs of EO products often consider broad applicability, they may not perform equally well across all geographic regions or align with localized priorities. These misalignments create operational challenges for integrating EO data into state and local decision-making processes.

In Alaska, for instance, emergency managers rely heavily on sea ice data to support maritime search and rescue and monitor coastal hazards. However, common optical EO systems are limited in high-latitude regions due to persistent cloud cover and long periods of darkness. While SAR offers a potential workaround, its effective use requires not only increased technical capacity but also tailored products that account for ice type, motion, and hazard potential; needs that are often unmet by standard products.

In desert regions, heavy rain often causes flash flooding with little warning. The terrain in these regions frequently creates problems for satellite detection of water (Garg *et al*., 2024). Dry soil, highly reflective surfaces in urban settings, and low vegetation cover challenge both optical and SAR-based flood detection algorithms to distinguish real flood signals from noise (Pierdicca *et al*., 2018). Automated products developed in wetter regions may not transfer well to these contexts, limiting their reliability and operational usefulness.

Machine learning is often seen as a universal solution to overcome these limitations; however, its effectiveness can be similarly challenged by geographic diversity. Training sets are typically created manually, making the process time consuming and arduous, thus limiting the geographic and temporal diversity of the input data. For example, a study evaluating an automated landslide detection system found that landslide classification is highly sensitive to regional terrain characteristics, vegetation cover, and imagery types. Although the model generates results much faster than manual mapping, its outputs often require manual correction and adaptation to local conditions (Pierdicca *et al*., 2018).

EO data products, even when technically advanced, must be grounded in the environmental and operational realities of their intended users. Emergency response agencies often serve as the first line of response, and their information needs are shaped by geography, infrastructure, and resource availability.

3.3. Interpretation and Application

Remote sensing instruments now downlink hundreds of terabytes of telemetry each day, yet these raw data offer little benefit to emergency managers upon acquisition; significant calibration, processing, and interpretation must occur before the raw sensor data become actionable geospatial products that can be mapped, queried, and integrated into operational decision-making frameworks (Voigt *et al*., 2016). The Data-Information-Knowledge-Wisdom (DIKW) hierarchy proposed by Ackoff (1989) illustrates that data alone hold limited intrinsic value; their utility increases as they are transformed into contextualized information, actionable knowledge, and ultimately the wisdom to effectively utilize knowledge for decision-making. Hodgson *et al*. (2013) emphasize that remote sensing products frequently fail to influence disaster response effectively when they arrive too late, in incompatible formats, or do not align with responder procedures. Understanding the processing latencies, product formats at various data levels, and their corresponding operational use cases help ensure that remote sensing outputs align more closely with emergency management requirements.

Table 6. Summary of NASA EOSDIS data processing levels, including descriptions, typical applications in disaster response, and representative MODIS data products.

	Description	Use in disaster response	Example data product from MODIS
Level 0	Time-ordered instrument telemetry reconstructed from downlinked packets; detector counts remain in raw engineering units.	Rarely used operationally. Engineers might revisit Level 0 after the fact (e.g., to recalibrate sensor drift).	MOD00F - Raw telemetry packets as downlinked from the instrument.
Level 1A	Uncalibrated detector counts together with synchronized attitude, ephemeris, and on-board calibration metadata.	Specialist pre-processing. Level 1A quick-look images from optical sensors can be used to spot smoke plumes or ash clouds before calibrated data arrive.	MOD01 - Digitized detector counts + all ancillary engineering data, still in instrument counts.
Level 1B	Radiometric calibration coefficients have been applied, converting counts to at-sensor spectral radiance (or reflectance); data is geolocated.	Rapid visual situational awareness. Near-real-time true-color or false-color images. Also, the base layer for automatic hotspot detection systems such as NASA FIRMS.	MOD021KM - Radiometric calibration & geolocation applied. Product shows at-aperture spectral radiance/ reflectance.
Level 2	Geophysical variables retrieved on a per-pixel basis at native sensor resolution via physics-based or statistical inversion of Level-1 radiances.	Single-hazard metrics ready for GIS. Examples include: land-surface temperature which gives insight into fire intensity & residual heat for active fires or heatwave response); aerosol/ash optical depth for aviation alerts.	MOD11_L2 – Per-pixel land-surface temperature & emissivity.
Level 3	Level-2 geophysical fields composited or mapped onto a uniform spatial–temporal grid (daily, 8-day, monthly, etc.) through averaging, maximum-value compositing, or optimal interpolation.	Change detection and time-averaged data. Examples include: NDVI/EVI composites to quantify drought stress, crop loss, or post-fire vegetation recovery. Surface displacement maps that compare post-incident land surface changes to pre-incident baseline.	MOD13A1 - 16-day, 500 m global NDVI/EVI grid (Level-2 vegetation indices composited onto a sinusoidal grid).
Level 4	Model output or analyses generated by assimilating multiple Level 1–3 data streams into numerical models or statistical frameworks; may provide variables not directly observed (e.g., damage proxy).	Multi-source data fusion & modeling for impact assessment and forecasting. Examples include ARIA Damage Proxy Maps that fuse InSAR coherence layers with modeling to produce a damage likelihood layer; LHASA Landslide Hazard v2 forecasting that uses modeling to estimate landslide probability.	MOD17A2H (GPP) – Terra/MODIS Gross Primary Productivity, an 8-day composite of gross primary productivity used in carbon- and water-cycle models.

NASA's Earth Observing System Data and Information System (EOSDIS) establishes a standardized hierarchy (Levels 0 through 4) for tracking the processing of data from raw sensor readout to higher-level decision-support and forecasting products. Level 0 is raw telemetry, Level 1 applies calibration and geolocation, Level 2 derives per-pixel geophysical variables at the native sensor resolution, Level 3 aggregates or resamples those variables onto uniform spatial-temporal grids, and Level 4 represents products derived through modeling by assimilating multiple lower-level data streams (NASA EOSDIS, 2020). As detailed in Table 6, operationally useful remote sensing products can emerge at many levels. For example, a Level 1B true-color image may detect an ash plume within minutes, whereas a Level 4 flood forecast might guide evacuation plans. However, each level also carries distinct operational vulnerabilities: delayed or missing ephemeris data can stall Level 1B outputs; retrieval algorithms may misclassify features at Level 2; expert quality-control steps can delay the release of higher-level Level 3 and Level 4 products; and finally, the data itself may not be presented in a way that emergency management and responders find operationally useful or interpretable. A disruption at any of these data processing steps risks rendering a technically sound product operationally ineffective.

Once a hazard layer is produced, its value for operational response often depends on how quickly it can be related to people and infrastructure. A common step is to vectorize single-hazard raster layers (flood water, burn scars, or low-coherence change layers) into closed polygons that bound homogeneous impact zones (UN-SPIDER, 2025). Vector features can be ingested directly into GIS platforms and intersected with ancillary layers such as census blocks, road networks, lifeline utilities, and critical facilities. Exposure statistics (e.g., miles of road inundated or the number of homes within a burn perimeter) can then be generated quickly after product delivery, giving incident responders evidence for resource allocation.

3.4. Data Delivery and Accessibility

The successful transfer of information between providers and end-users depends on effective data delivery and accessibility. Some of the weakest links in the process: interoperability, navigation, and symbology present major challenges that limit the use of remote sensing in disaster response.

To benefit from remote sensing, users rely on specialized software, subscription-based software services, or web interfaces to interact with data. The large size of imagery data requires sufficient computer memory and processing power and takes time to load and download. Data format also plays an important role in interoperability. Consistently delivering data in preferred formats increases their useability. Unfortunately, the options are plentiful and overwhelming, and the best available format varies depending on its application or user. If data are not intentionally delivered in interoperable formats, users may struggle to put it to use under the time constraints of a disaster (CEOS, 2008). In addition to software, these data often require specialized access which can be a problem for some agencies and end users. The numerous data platforms and portals hosting geospatial data from different sources further exacerbate this problem. Even if an end user knows exactly what data they need, locating it is not always a simple task and requires precious time that over-scoped EM or GIS professionals often don't have. The capacity challenge is exacerbated further when the practical limitations of there being a small handful of (or zero) geospatial professionals that are dedicated to supporting EM operations. Those who are dedicated to the EM mission often find themselves pressed for time, resources, and leadership expectations and often struggle to conduct more advanced geospatial analytics (Kumar *et al*., 2020). Finally, disasters that wipe out power and affect internet access make it difficult, or impossible for people in the field to utilize remote sensing data.

There is a significant gap between the ways geospatial specialists handle, analyze, visualize, and publish datasets and how users are equipped to receive them. Improving the ease of access to often cumbersome data portals, and strategic use of symbology and semiotics make it easier for end-users to convert data into action.

3.5. Complex and Rapidly Advancing Technology

Remote sensing and associated technologies advance rapidly with commercial and civil players releasing a steady stream of new instruments, platforms, and products (Tweedie, 2025). This causes an inundation of new capabilities that far exceeds what emergency managers can effectively utilize. Nevertheless, many of these developments present exciting and novel ways to harness remote sensing for disaster response. Advancements include improvements in machine learning and artificial intelligence, the fusion of products for analysis, and higher availability of analysis-ready products. Similarities between products with different data and analysis processes or nuanced use cases exacerbate the challenge of selecting the right tool.

Consequently, despite federal, state, and local responders seeking advantages to maximize response efforts, capitalizing on the cutting edge of remote sensing remains difficult.

4. Best Practices and Proposed Solutions

In its first year, the DRCS observed three categories of best practices that help bridge the gap between remote sensing scientists and emergency managers: cataloging capabilities, capacity building, and coordination calls. Together, these approaches allow both scientists and emergency managers to transcend the norms of their disciplines.

4.1. Curation of Capabilities

One tool the disasters science community can provide to end users is a detailed catalog or menu of available products with guidance on their use cases and comparative value. Useful menus are comprehensive yet concise, enabling emergency managers to quickly identify and request resources. Additional documentation must also be available for those who require in-depth technical details. Menus should focus on the derived data product that will be delivered, not the EO assets used.

Crafting a menu is as much an ontological challenge as a technological one. Catalogs are boundary objects; disambiguating terms such as “product”, “asset”, and “capability” (Table 7) improves communication and understanding regarding what is available and useful to meet response needs. Typically, emergency managers request products relevant to one or two hazard types at a time. The nature of the incident – or state of the environment, such as the presence of clouds – may narrow user needs down to a certain sensor type, like SAR or multispectral imagery. Detailed records of each component allow those providing remote sensing imagery to set clear expectations and help end users make informed requests.

The DRCS is developing a set of menus and technical documentation to catalog NASA’s EO assets available for disaster response. To date, the DRCS has cataloged nearly 200 unique data products that NASA can provide or has provided in the past to support disaster response.

Table 7. Proposed terminology and definitions.

Term	Proposed definition
Capability	All-encompassing terms for products, assets, subject matter experts, or other resources that provide clear value for disaster response.
Asset	Any sensing system (satellite, aerial, UAV, or ground), sensor, model, algorithm, workflow, software package, or other “tool” that used to acquire data or develop products. Assets may be tangible or intangible, hardware or software.
Product	Any reproducible, unique dataset, Web Map, web application, or document that meets user needs. DRCS products are often geospatial in nature and consist of or are derived from EO. Ideally, products are generated with the same methodology and workflow for different disasters. The term product may refer to both an individual dataset for a specific incident and the generalized form of that dataset which could be produced for any incident.
Product Groups or Suites	A collection of products organized use case, hazard, or asset. Deliberately malleable to adapt to the needs of user community.

4.2. Capacity Building and Training

Capacity building helps bridge the gap between satellite data products and their use in disaster response. Defined by the United Nations as “the process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in a fast-changing world,” capacity building must employ an approach for emergency managers that builds their awareness of, access to, and ability to rapidly request and apply EO during a disaster (UN, 2025). Emergency managers cannot be expected to be remote sensing experts in addition to their other responsibilities, nor can remote sensing scientists be expected to be experts in the emergency management field. This impasse highlights the need for a synergistic approach to the development of trainings, scenario and tabletop exercises, and co-development of products, tools, and portals to facilitate the continuous exchange of information and each field's best practices. To facilitate the most effective use of EO in disaster response, relationships between data providers, remote sensing scientists, and emergency managers must be strengthened through continuous interdisciplinary exchange of information.

During a disaster, timely access to data and information is crucial and many emergency managers prefer "plug-and-play" data utilization services (Zheng *et al*., 2021; Kumar *et al*., 2020). Building skills in emergency managers to be better requestors and users of EO data requires a tailored approach compared to graduate students or academia as working professionals face time constraints, organizational barriers, and often limited technical capacity (Prados *et al*., 2019). Scenario exercises and data portal demonstrations can strengthen the uptake of synthesized and curated training information. By incorporating insights and feedback gleaned from engagement with emergency managers on available or in-development tools and data products, the usability and utility of remote sensing resources improve.

4.3. Collaboration and Coordination

Emergency managers and scientists must build a mutual understanding of needs and limitations to work together effectively. Given the logistical challenges and time-sensitive decisions disaster responses entail, it is not effective for emergency managers to build connections with scientists during a disaster (i.e., "gray sky" periods). Thus, effective collaboration and coordination begin outside of disasters (i.e., "blue sky" periods).

Emergency management revolves around highly effective collaboration between parties to provide lifesaving and life sustaining services (Waugh and Streib, 2006). Practitioners leverage conferences, virtual meetings, and in-person collaborative co-development opportunities to build communications pathways and critical familiarity. Intentional collaboration with scientists also offers the chance for emergency managers to share input that helps guide the production of value-added datasets, new algorithms, and models that address data gaps. Blue sky periods also serve as an optimal time to offer capacity building opportunities, such as demonstrations of data portals or training on emergency management principles.

Deliberate actions during gray sky periods establish a unified vision and set of objectives. An important mechanism for supporting response efforts comes through regular "geospatial coordination calls." These calls allow data providers critical opportunities to deconflict areas of interest, reconcile end user requirements, and identify opportunities and barriers to support broader incident response. They afford impacted EM personnel a structured opportunity to engage with NASA, USGS, FEMA and other agencies and ensure their needs are met. Geospatial calls also provide an opportunity to coordinate collaborative mapping with other agencies, especially for deployment of airborne instruments and the tasking of high-resolution private satellite products (between emergency management and science agencies).

5. Conclusions

Data scientists, technical experts, and geospatial professionals are highly effective at advancing and refining the quality and sophistication of EO data and information. These data have the potential to help emergency managers make more informed decisions, allocate scarce resources more efficiently, and better meet the needs of the communities they serve. Tragically, the data too often lose value between their production and application. Emergency managers at the public, private, and non-profit levels enable robust capabilities to rapidly scale matrixed organizations and provide lifesaving and life-sustaining care to those in need after incidents. These emergency managers often must position themselves to be a "mile wide" but an "inch deep" and serve as collaborators-in-chief, stitching together the otherwise disparate resources to mount effective incident response and recovery efforts. However, being an "inch deep" for understanding and utilizing the technical information available in remote sensing is inadequate. Similarly, it is insufficient for technical experts to focus their advancements for socialization within their professional circles. Instead, both the remote sensing and emergency management communities need to undergo a transformation of relatability. As described here, there are specific and tangible actions that science agencies can and should undertake to meet emergency managers where they are to improve the accessibility and usefulness of the data and science they provide. In turn, emergency managers should continue to build the networks in blue sky conditions to integrate remote sensing requirements, capabilities, and technical understanding. By both parties inching closer to one another, the true value that remote sensing has for supporting disaster response can come to fruition.

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