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Proposing "Applying Satellite Remote Sensing to Disaster Management" based on Holistic Case Studies by Sentinel Asia and JAXA (2006–2014)

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Highlights

What are the main findings?

- This article proposes "Applying Satellite Remote Sensing to Disaster Management" as an academic field.
- As a methodology, a holistic case-study was introduced for practical analysis.
- The empirical project, Sentinel Asia (SA) (2006-2014), was implemented.

What are the implications of the main findings?

- This research indicates one direction for research in this field.
- It contributes to the accumulation, sharing, and succession of knowledge, which are crucial in disaster management.

Abstract

Since the launch of the Advanced Land Observing Satellite (ALOS) in 2006, the Japan Aerospace Exploration Agency (JAXA) has been leading both disaster response within Japan and Sentinel Asia, which targets disasters in the Asia-Pacific region, as well as participating in the International Charter: Space and Major Disasters, which is international framework. The author was involved in these activities from 2006 to 2014. Based on this experience, this article proposes an approach to "how to utilize satellite remote sensing in the activities of disaster management users." The methodology involves treating each activity as a case study for "how to utilize satellite remote sensing in the activities of disaster management users." and examining them from a holistic perspective.

Keywords: satellite remote sensing; disaster management; applying satellite remote sensing to disaster management; holistic case study

1. Introduction

1.1. History

The global effort to utilize satellite data in disaster response began in the early 2000s. Frameworks such as the International Charter: Space and Major Disasters (or "the International Charter") [1] and the United Nations (UN) [2] played a crucial role in establishing Earth observation as an important support tool for rapid disaster response.

Since 2006, JAXA has been using the ALOS series to support disaster response activities not only in Japan but also overseas through Sentinel Asia (SA) and the International Charter (see Figure 1). This international framework enables Japan to receive support from overseas satellites in the event of a domestic disaster. Furthermore, JAXA aims to expand the use of satellite data and imagery in disaster management to end users as well.

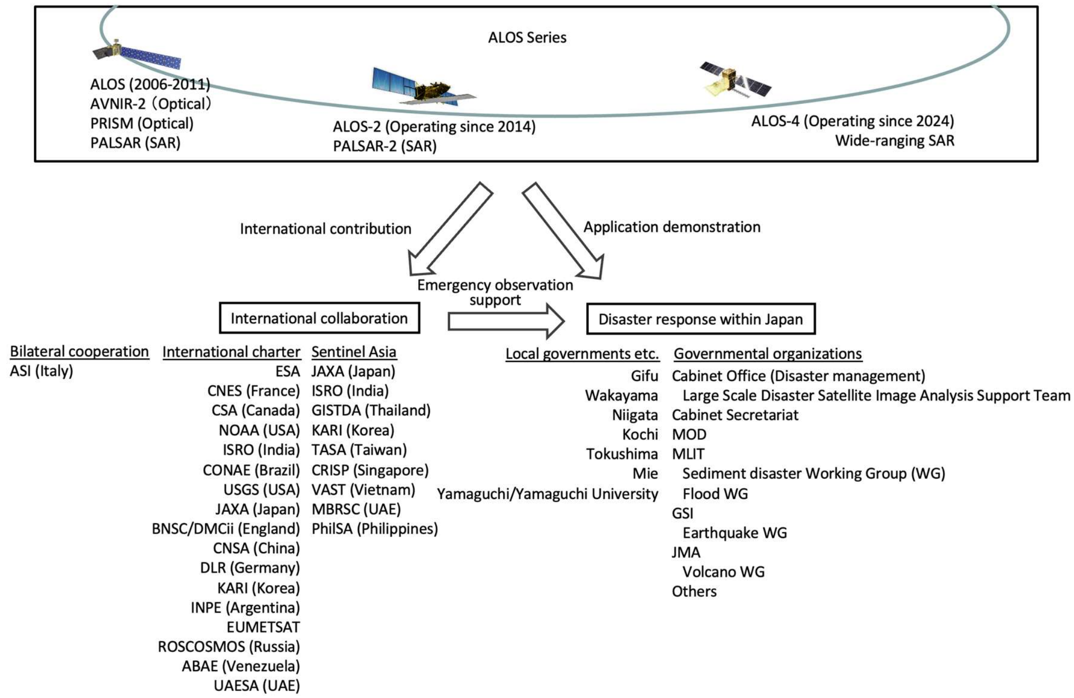

Figure 1. Domestic and international collaboration of JAXA in disaster response.

1.2. Overall System of "Applying Satellite Remote Sensing to Disaster Management"

Overall system of "Applying satellite remote sensing to disaster management", integrates five key elements: radiation sources (sunlight, Earth's surface, or artificial radiation), atmospheric pathways, surface interactions, and dedicated segments for space (satellites/sensors) and ground operations (Figure 2). In ground operations, the effectiveness of this technological infrastructure is deeply intertwined with human factors, including the expertise of system operators and the specific needs of ground-based end-users.

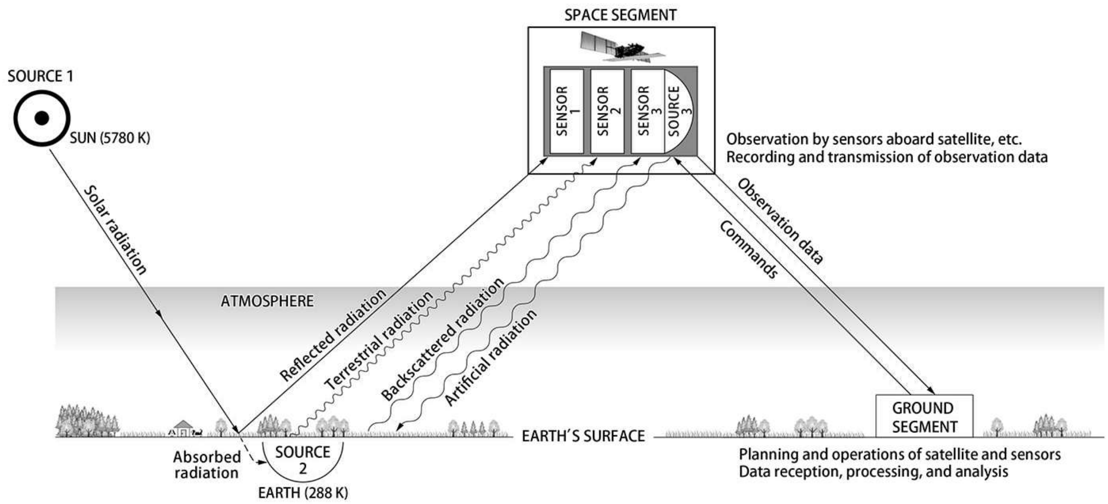

Figure 2. Overall system of "Applying satellite remote sensing to disaster management": radiation sources, interaction with the atmosphere and the Earth's surface, and space and ground segments ([3], with modifications).

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Remote sensing relies on detecting energy from three main energy sources: reflected solar radiation, thermal radiation from the Earth's surface, and a composite signal generated by the satellite itself. Systems that utilize natural energy are called passive (see Figure 2), while systems that emit their own radiation, such as radar, are called active. In satellite observations, the wavelength ranges of solar radiation ("shortwave," Figure 3(a)) and surface radiation ("longwave," Figure 3(b)) are clearly distinguished, and the boundary between them usually changes depending on the surface temperature. During the day, solar energy dominates the shortwave range, but at night, only thermal radiation becomes a detectable energy source. This is a crucial characteristic for monitoring wildfires and volcanic activity.

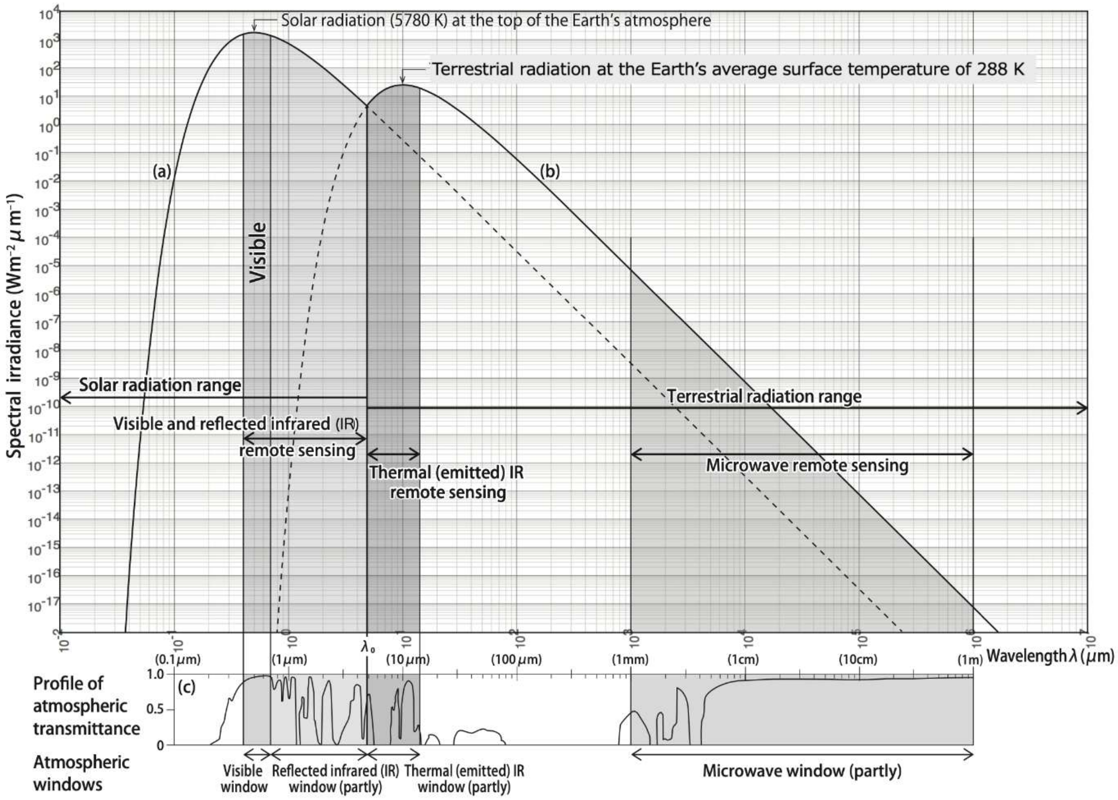

Figure 3. Passive satellite remote sensing: (a) solar radiation, 5780 K, at the top of the Earth's atmosphere [4], (b) terrestrial radiation at the Earth's average surface temperature, 288 K, and (c) atmospheric windows. Source of atmospheric transmittance: NASA Earth Observatory. (a), (b): with MAC/Grapher v2.

The Earth's atmosphere acts as a filter, absorbing or scattering radiation with gases such as water vapor. Sensors are designed to utilize highly transmittance spectral regions called "atmospheric windows" to observe the Earth's surface. These windows are mainly located in in the visible band (0.4–0.7 μm); the partly infrared band (0.7–14 μm), consisting of the reflected infrared band (0.7–3 μm) and the thermal (emitted) infrared band (3–14 μm); and the partly radio-wave band (1 mm–30 m) (see Figure 3(c)). Figure 3 and Table 1 show the classification of satellite remote sensing considering atmospheric windows and radiation sources, while Table 1 shows the correspondence between representative sensors in the space segment and categories of satellite remote sensing.

Table 1. Classification of Satellite Remote Sensing (RS) and reprisentative sensors.

Remote Sensing (RS) Category	Spectral Range (Atmospheric Windows)	Natural Source (Passive)	Synthetic Source (Active)	Representative Sensors
Visible and reflected infrared (IR) RS	Visible: 0.4–0.7 µm Reflected IR: 0.7–3 µm (partly)	Solar radiation	Artificial radiation	Passive: Optical sensors Active: LiDAR (light detection and ranging)
Thermal infrared RS	Thermal (emitted) infrared 3–14 µm (partly)	Terrestrial radiation	Not applicable (NA)	Passive: Infrared sensors Active NA
Microwave RS	Microwave 1 mm–1 m (partly)	Terrestrial radiation	Artificial radiation	Passive: Microwave radiometers Active: Radar - synthetic aperture radar (SAR) - precipitation radar (PR) - radar scatterometer - radar altimeter

1.3. Disaster Management and Related Terms

According to terminology on disaster risk reduction (DRR) by the United Nations Office for Disaster Risk Reduction (UNDRR), disaster management and related terms are defined as follows (citation):

"(1) ***Disaster*** *is defined as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.*

(2) ***Disaster management*** *is the organization, planning and application of measures preparing for, responding to and recovering from disasters. Disaster management may not completely avert or eliminate the threats; it focuses on creating and implementing preparedness and other plans to decrease the impact of disasters and build back better. Failure to create and apply a plan could lead to damage to life and assets as well as lost revenue.*

(3) ***Prevention*** *refers to activities and measures to avoid existing and new disaster risks. Prevention* (i.e., *disaster prevention) expresses the concept and intention to completely avoid potential adverse impacts of hazardous events. While certain disaster risks cannot be eliminated, prevention aims at reducing vulnerability and exposure in such contexts where, as a result, the risk of disaster is removed. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high-risk zones, seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake, and immunization against vaccine-preventable diseases. Prevention measures can also be taken during or after a hazardous event or disaster to prevent secondary hazards or their consequences, such as measures to prevent the contamination of water.*

(4) ***Mitigation*** *is the lessening or minimizing of the adverse impacts of a hazardous event. The adverse impacts of hazards, in particular natural hazards, often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures include engineering techniques and hazard-resistant construction, as well as improved environmental and social policies and public awareness. It should be noted that, in climate change policy, mitigation is defined differently and is the term used for the reduction of greenhouse gas emissions that are the source of climate change.*

(5) ***Preparedness*** *is the knowledge and capacities developed by governments, response and recovery organizations, communities, and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters. Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response to sustained recovery.*

(6) ***Response*** *is actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected. Disaster response is predominantly focused on immediate and short-term needs and is sometimes called disaster relief. Effective, efficient, and timely response relies on disaster risk–informed preparedness measures, including the development of the response capacities of individuals, communities, organizations, countries, and the international community.*

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*(7) **Recovery** is the restoring or improving of livelihoods and health, as well as eco nomic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and build back better, to avoid or reduce future disaster risk."*

Disaster management is expressed as a disaster management cycle, as illustrated in Figure 4.

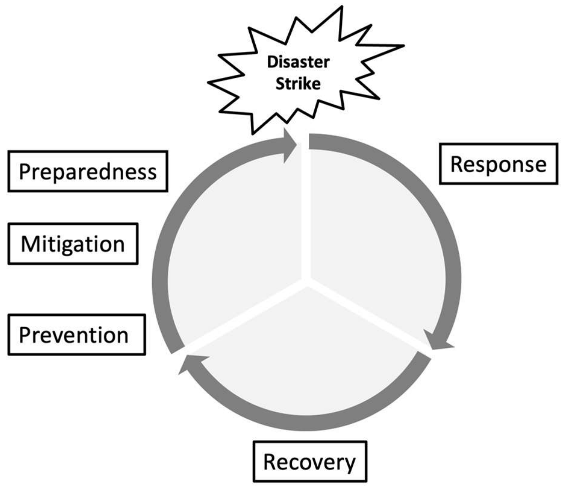

Figure 4. Disaster management cycle.

2. Methods

2.1. Definition of "Applying Satellite Remote Sensing to Disaster Management"

"Applying satellite remote sensing to disaster management" is defined in this article as the employment of satellite-based disaster information/data by users working for disaster management, including rescue/relief/evacuation; not just disclosing them on the Internet, as illustrated in Figure 5, which includes human factors such as users who are working in disaster response, such as emergency responders, policy makers, administrative officials, researchers. This is not merely the application of technology, but a field that integrates technology, organization, and human systems.

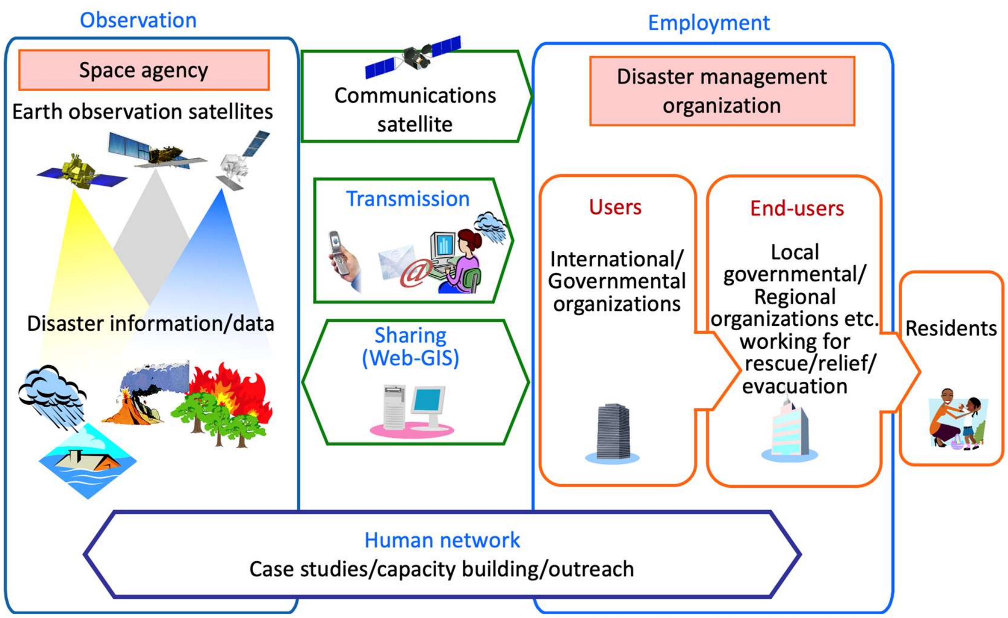

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Figure 5. "Applying satellite remote sensing to disaster management" including technology, organization, and human systems.

2.2. Method for "Applying Satellite Remote Sensing to Disaster Management": A Holistic Case-Study Approach

This field is historically young (see Section 1.1) and there is little systematic knowledge accumulated. In applied science research fields like this, research results are often expected to have practical significance. Given these factors, the case study method is particularly well-suited to this field. Furthermore, *"each individual case study of a particular complex social event is considered to be an entity that constitutes one whole, allowing a holistic approach to the event* [5]*."* This study uses this approach to analyze case studies, extract systematic knowledge, and identify common patterns in how satellite technology is useful in disaster management as shown in Figure 6 [6–8].

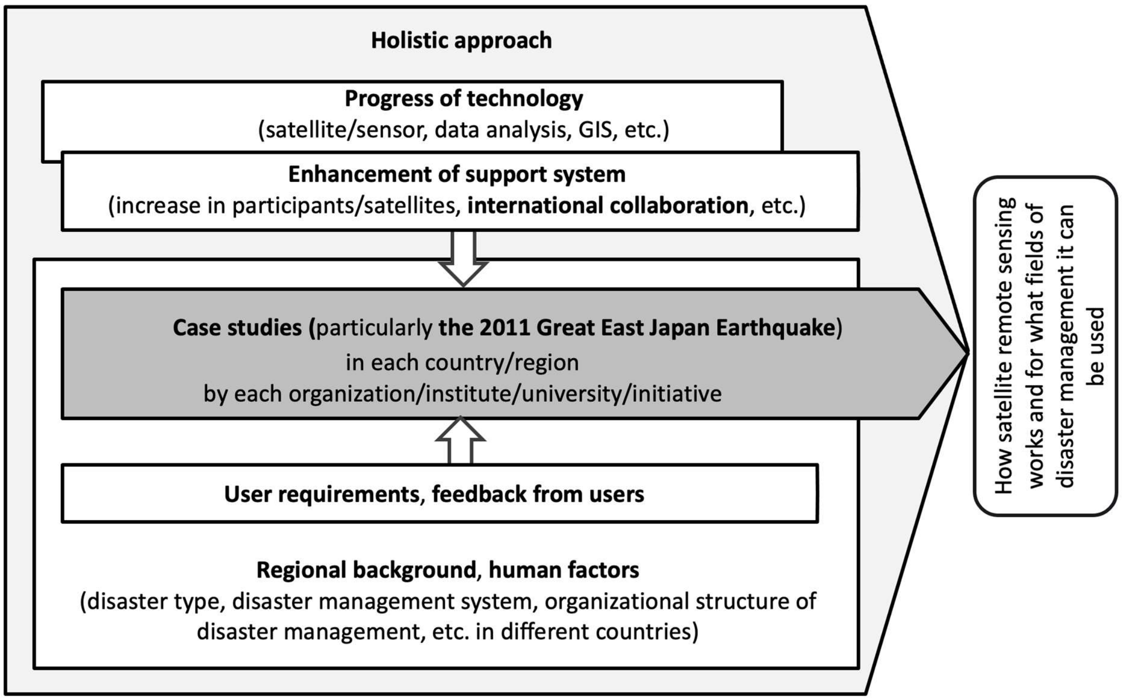

Figure 6. A holistic case-study approach: to consider each activity as an empirical case study of how satellite remote sensing can be applied to disaster management, and examined them from a holistic viewpoint.

3. Results

3.1. Case Studies in Sentinel Asia and JAXA

3.1.1. Sentinel Asia

Following the devastating damage caused by the 2004 Indian Ocean tsunami, the Sentinel Asia (SA) initiative was rapidly proposed with the aim of building a resilient humanitarian assistance network in the Asia-Pacific region [9,10]. This voluntary cooperation framework, formally launched at the 12th Asia-Pacific Regional Space Agency Forum (APRSAF-12) held in Kitakyushu, Japan, 2005, utilizes Earth observation and Web-GIS to strengthen collaboration between space agencies and disaster management authorities.

SA was launched in February 2006 as a voluntary, best-effort initiative under the collaboration of the Asia-Pacific Regional Space Agency Forum (APRSAF). It involves collaboration from space agencies, international organizations (the United Nations Economic and Social Commission for Asia

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and the Pacific (UNESCAP), the Asian Institute of Technology (AIT), etc.), academia (universities, research institutions), and disaster management organizations (ADRC and its member organizations) as shown in Figure 7.

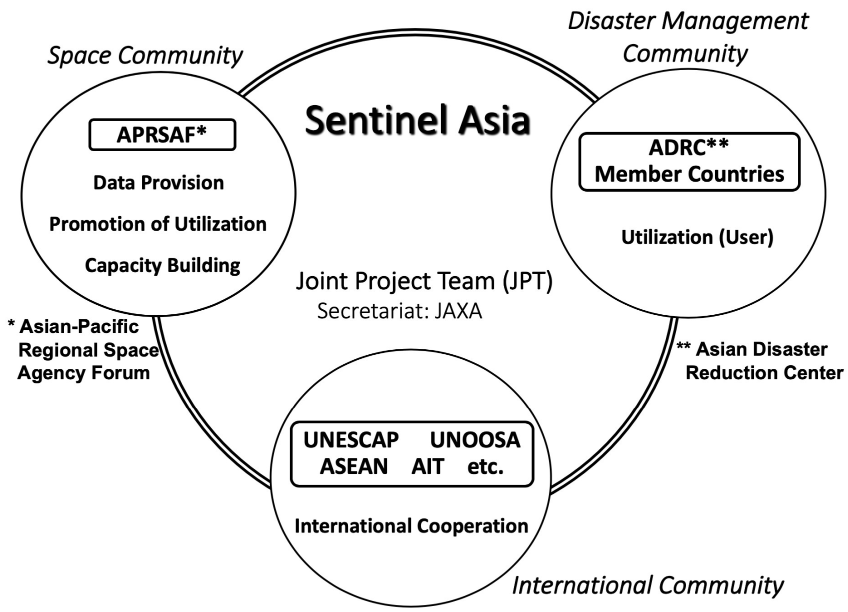

Figure 7. Institutional framework of Sentinel Asia (SA).

Key feature of SA is its emphasis on utilizing satellite data in actual rescue and evacuation operations. SA covers the entire disaster management cycle, from disaster mitigation to recovery; and of course, emergency response to disasters. As shown in Figure 8, SA functions as a platform for demonstrating and validating the usefulness of satellite data and imagery through phased deployment and a comprehensive evaluation framework. Sentinel Asia is one project that realizes the "Applying satellite remote sensing to disaster management" proposed in this paper.

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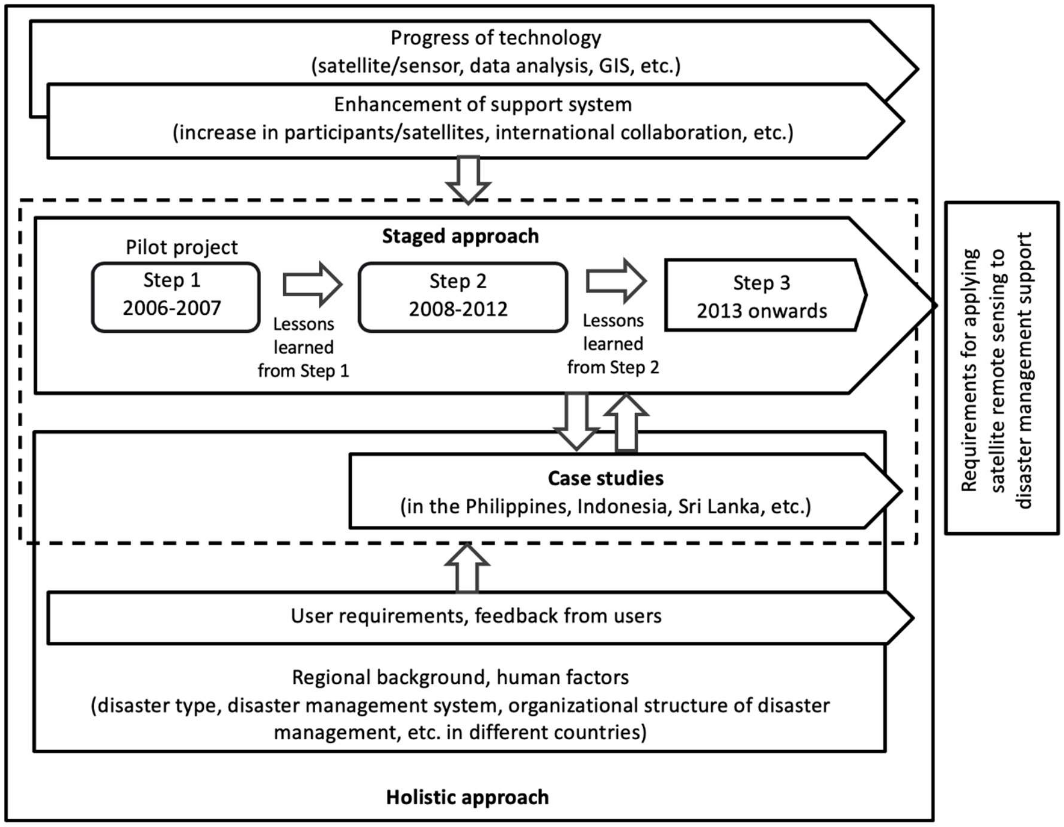

Figure 8. Approach of Sentinel Asia (SA) including step-by-step approach and a holistic case-study approach.

The organizational structure within SA (see Figure 9) is as follows:

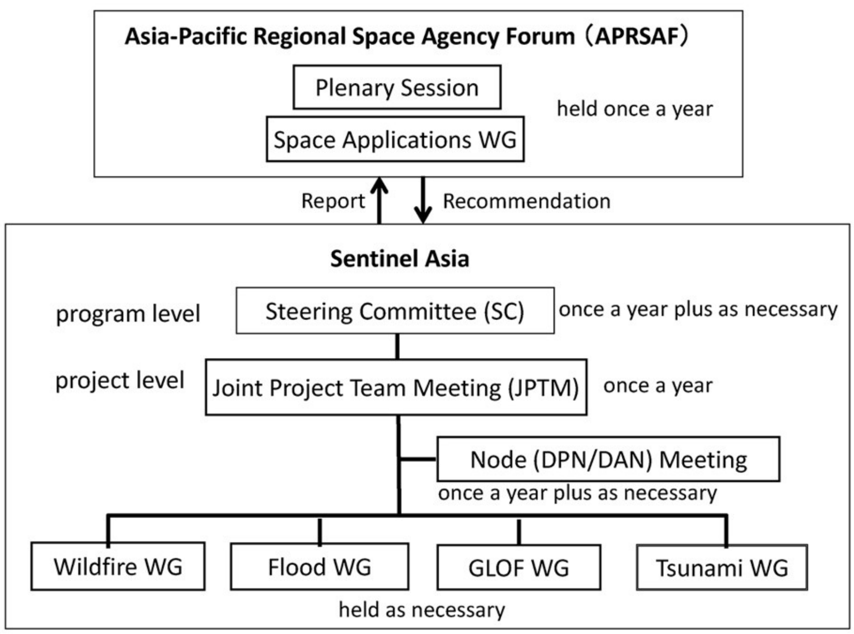

Figure 9. Organizational structure within Sentinel Asia (SA).

(1) Joint Project Team (JPT)

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Joint Project Team (JPT) was organized to implement SA in February 2006, with JAXA serving as the secretariat. Joint Project Team (JPT) consists of 126 organizations in total, including 107 organizations from 30 countries/region in the Asia-Pacific region and 19 international organizations as of April 2026.

(2) Data Provider Node (DPN)

Data Provider Node (DPN) consists of space agencies in the Asia-Pacific region (see Figure 10), and provides observation data from their Earth observation satellites to SA based on their respective data policies. The Philippine Space Agency (PhilSA) of the Philippines and the JSC National Company Kazakhstan Gharysh Sapary (KGS) of Kazakhstan are new members of the DPN as of April 2026.

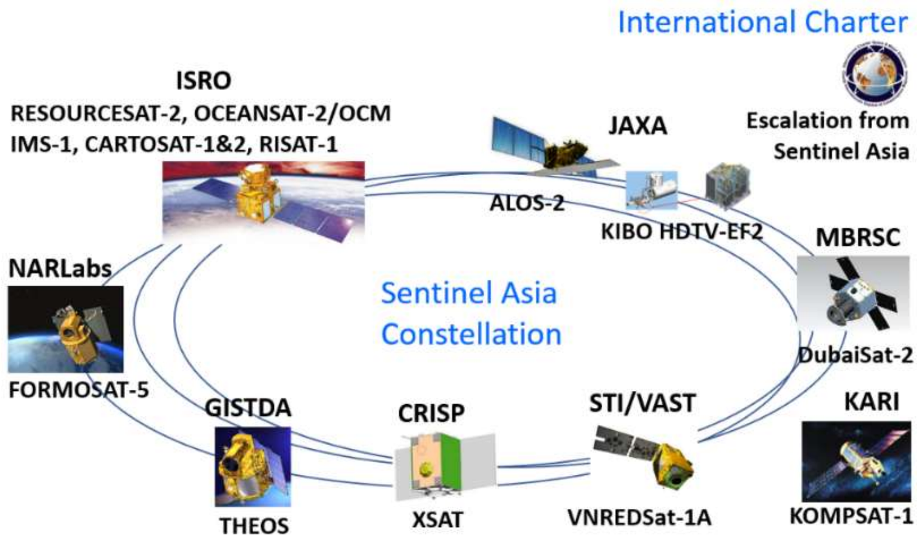

Figure 10. Sentinel Asia (SA) constellation of Data Provider Node (DPN).

(3) Data Analysis Node (DAN)

Data Analysis Node (DAN) analyzes satellite data provided by DPN to extract disaster information. Users, such as disaster management organizations, are requesting more easily understandable presentation of the information. Members of DAN include universities, space agencies, and research institutions. As of April 2026, 63 organizations are registered.

(4) Technical Working Group

Working Group (WG) is a group focused on a specific disaster and is composed of experts in that field. Based on user requests, wildfires, floods, glacial lake outburst floods (GLOFs), and tsunamis have been implemented.

- Step 1 (2006-2007) [11]: Emergency response support using ALOS started from October 2006. A data sharing infrastructure was established using a Web-GIS platform based on the Digital Asia platform of Keio University.
- Step 2 (2008-2012) [12]: The DAN was newly organized to analyze satellite data provided by the DPN. Satellite communications using WINDS were integrated to alleviate the constraints on internet bandwidth in developing regions. At this stage, collaboration with the International Charter was achieved.
- Step 3 (launched in 2013) [9]: Currently in operation. Step 3 aims to encompass the entire disaster management cycle, including not only emergency response but also pre-disaster preparation and post-disaster recovery, and to promote a robust human network and inter-agency collaboration (see Figure 11).

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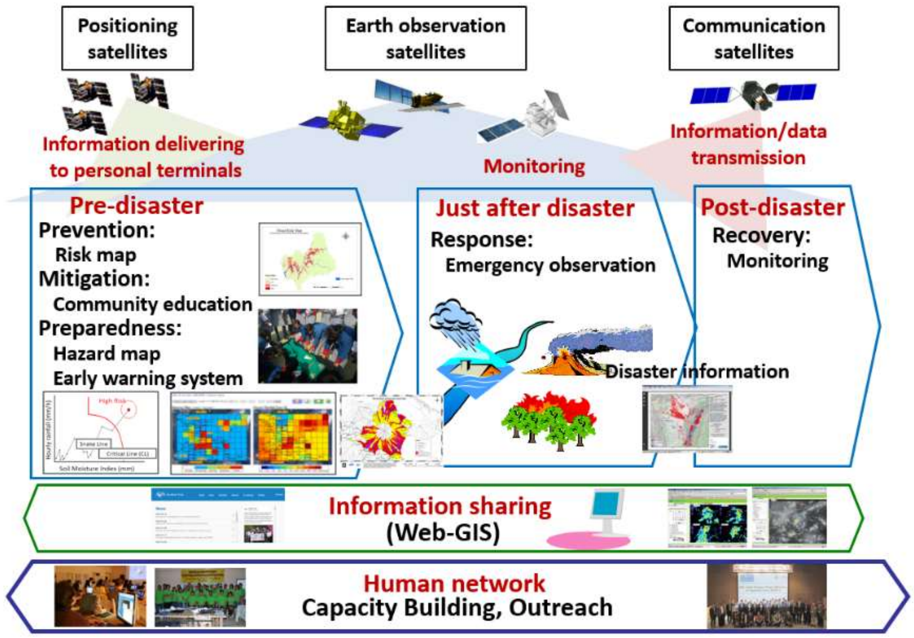
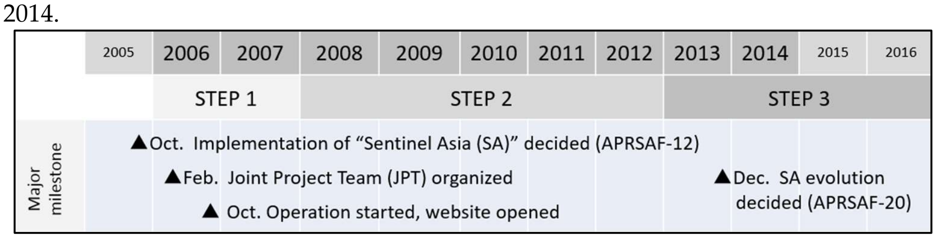


Figure 11. Conceptual illustration of Sentinel Asia (SA) Step 3 including human systems: to expand activities to cover all the disaster management cycle with further collaboration for operation and human networking by the Joint Project Team (JPT).

3.1.2. Case Studies

In the case of SA and JAXA, as shown in Figure 12a to 12d, case studies were conducted from 2006 to 2014.



(**a**)

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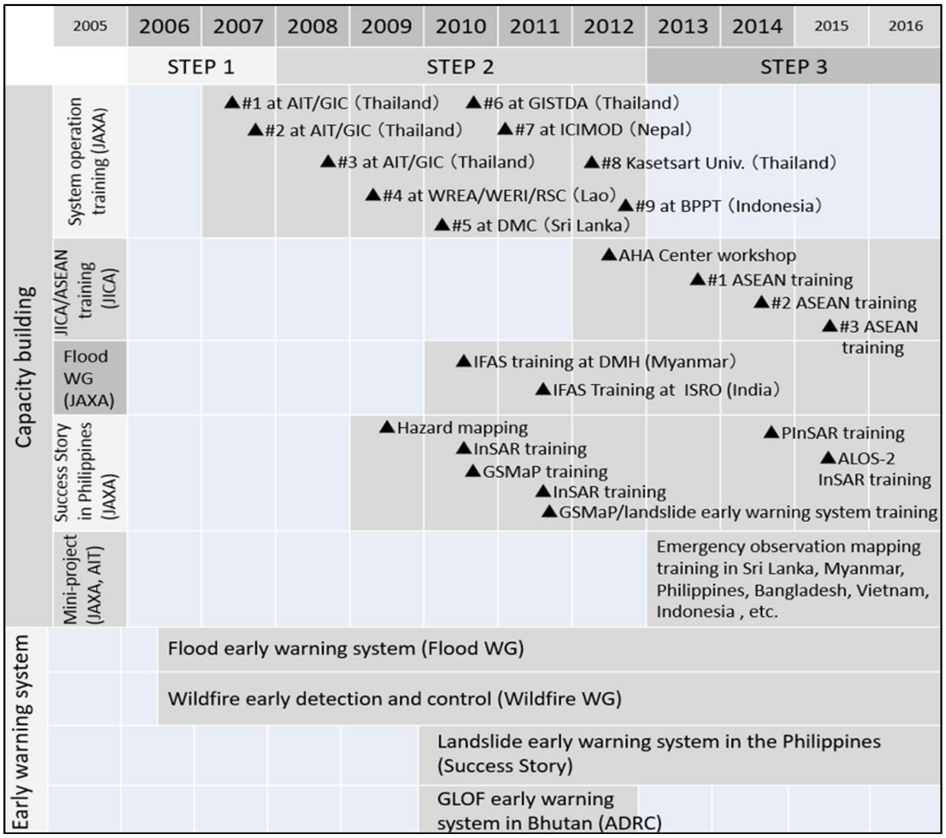

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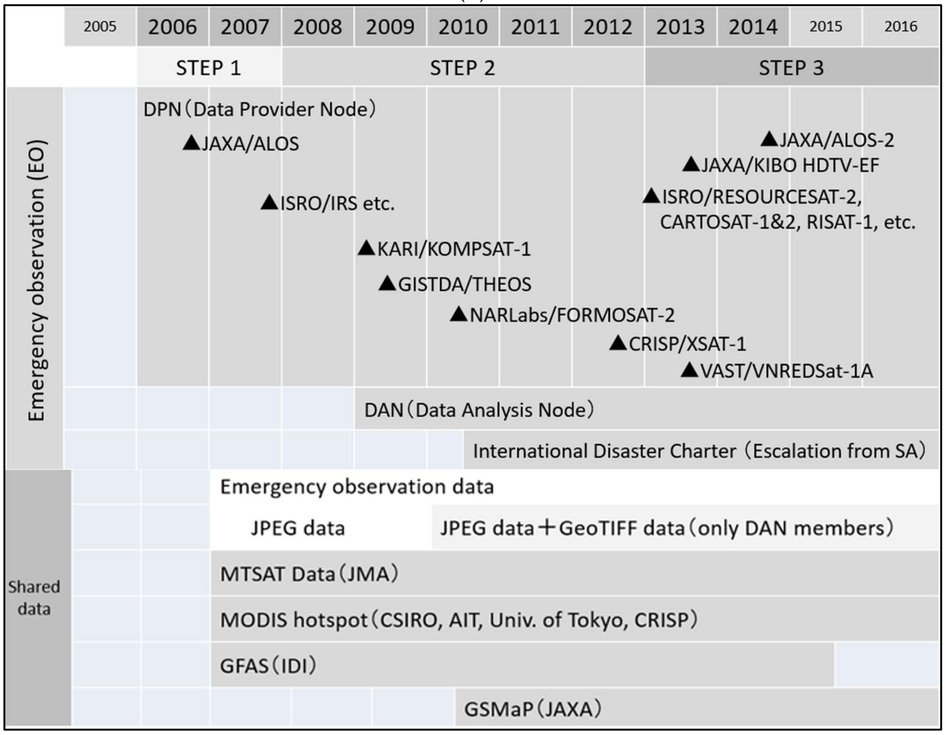

(**c**)

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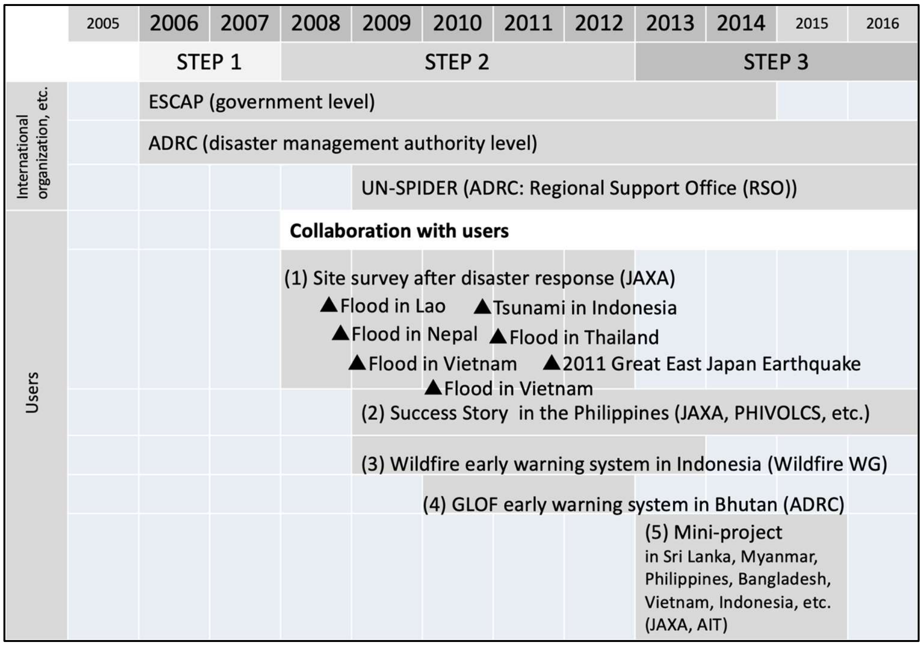

(**d**)

Figure 12. a. Major milestone of Sentinel Asia (SA). **b.** Case studies in Sentinel Asia (SA) for pre-disaster phase (prevention, mitigation, and preparedness). **c.** Emergency observation and data sharing in Sentinel Asia (SA). **d.** Collaboration with international organizations and users.

3.1.3. Results of Case Studies

Tables 2a and 2b shows examples of case studies for each phase of the disaster management cycle. In the SA Success Story in the Philippines (see (3-2) in Table 2a and Figure 13), the well-organized structure on the Philippine side, including the end users (see Figure 14), was a key factor in its success.

Table 2. a. Examples of case studies by Sentinel Asia and JAXA (2008-2017) in pre-disaster phase. **b.** Examples of case studies by Sentinel Asia and JAXA (2008-2017) in post-disaster phase.

(**a**)

Phases (a)	Project/ Case study	Region	Technology/ Satellite Data	Key Results/Achievements	Maturity (b)	Additional Observations
Pre-vention	(1-1) JAXA/AIT Mini-Project	Lower Kalu-Ganga River Basin, Sri Lanka	- Flood modelling - Hazard and risk mapping - ALOS/PALSAR	Developed the region's first 10- to 100-year return period risk maps for infrastructure and population.	DEMO	Executed by JAXA/AIT (2008).
MITI-GATION	(2-1) GLOF WG (Working Group)	Mo River basin, Bhutan	- Hazard mapping - ALOS/ AVNIR-2	Established community level disaster education and training among residents.	ACTUAL	Integrated into JICA project for Capacity Development of GLOF and Rainstorm Flood Forecasting and Early Warning in Bhutan (2013-2016).
PREPAREDNESS	(3-1) National Disaster Strategic Planning	Japan	-ALOS-2/ PALSAR-2 - DInSAR (Differential Interferometric SAR)	Satellite data officially integrated into the Basic Disaster Management Plan by the Central Disaster Prevention Council of Japan in April, 2017,	ACTUAL	Formal inclusion in national information-sharing policy (2017).
	(3-2) SA Success Story	Mayon volcano, Philippines	- Hazard mapping for lahars - ALOS/PRISM DSM (Digital Surface Model) -ALOS/AVNIR-2	Provided critical lava deposit assessments to the NDCC (the National Disaster Coordinating Council) during the 2009 eruption for tactical decisions.	ACTUAL	- Continuously updated by PHIVOLCS (the Philippine Institute of Volcanology and Seismology). - see Figures 13 and 14
	(3-3) SA Success Story	Antipolo City and Rizal Province, Philippines	- GSMaP_NOW - RBFN (Radial Basis Function Network)	Created a localized prototype for nationwide landslide risk assessment using Japanese algorithmic standards.	PROTO-TYPE	- Undergoing national calibration. - The algorithm used to detect landslides is the same as the one in Japan. - see Figure 14
	(3-4) SA Success Story	Mt. Mayon and in and around Manila, Philippines Kirishimayama and Mt. Hakone, Japan	- DInSAR - ALOS/PALSAR - ALOS-2/ PALSAR-2	Successfully demonstrated using DInSAR technology at Mt. Mayon, etc. In Japan, operationalized by Japan's GSI since 2014.	DEMO & ACTUAL	- PHIVOLCS evaluating long-term adoption. - In Japan ACTUAL. - see Figure 14
	(3-5) Wildfire WG (Working Group)	Kalimantan, Indonesia	- Hotspots detection - Terra and Aqua/MODIS	Demonstrated early fire detection and control aiming at an operational cycle with firefighters in Kalimantan.	DEMO	If the REDD-plus framework recognizes carbon storage in peatlands, the implementation of this system could be promoted.
	(3-6) GLOF WG	Mo River basin, Bhutan	- Hazard mapping - ALOS/AVNIR-2	Combined satellite data with community-based gauges for local warning infrastructure.	DEMO	Part of sustained JICA-led cooperation (2013-2016).
	(3-7) SA Mini-Project	Sri Lanka, Philippines, Bangladesh, Myanmar, and others	- Emergency mapping - Hazard mapping - ALOS/AVNIR-2 and PALSAR	Focused on making emergency observation data actionable for local end-users in each country.	DEMO	Because the plan was not sufficiently clear, it was decided to revise it so that it could be used in actual operations.

(**b**)

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RESPONSE	(4-1) SA Emergency Observation: Large-scale flood in Nepal, August 2008	Sunsari district, Nepal	- Emergency mapping - ALOS/PALSAR	Direct application of satellite maps for victim rescue operations by the government.	DEMO	
	(4-2) SA Emergency Observation: Heavy rain in Vietnam, October 2008	Northern and central parts, Vietnam	- Emergency mapping - ALOS/PALSAR	Quick flood damage maps by NRSC using multiple satellite data.	DEMO	Subject of a JAXA site survey (2009).
	(4-3) SA Emergency Observation: The 2011 Great East Japan Earthquake	Japan	- Emergency mapping - ALOS/AVNIR-2, PALSAR and others	Empirically demonstrated that satellite data is indispensable for relief in mega-disasters.	DEMO	- By March 14, 2011, succeeded in observing almost the entire coastal area. - see Figures 19–21
	(4-4) JAXA Emergency Observation: Volcano eruption	Japan	- DInSAR - ALOS-2/ PALSAR-2	Transitioned to a fully operational monitoring state by the GSI (Geospatial Information Authority of Japan) since 2014.	ACTUAL	
RECOVERY	(5-1) SA Emergency Observation: Large-scale flood in Nepal in August 2008	Nepal	- Emergency mapping - ALOS/PALSAR	Maps utilized for long-term recovery strategies and managing compensation payments.	DEMO	Provided objective evidence for financial aid.
	(5-2) SA Emergency Observation: Tsunami in Mentawai islands, Indonesia in October 2010	Mentawai Islands, Indonesia	- Emergency mapping - ALOS/AVNIR-2 - The International Charter:	Tsunami inundation zones mapped for safer residential rebuilding and future hazard modeling.	DEMO	Highlighted the need for faster data turnaround.
	(5-3) SA Emergency Observation: 50-year long-term deluge in Thailand in October 2010	Central and northeastern parts, Thailand	- Emergency mapping - ALOS/PALSAR	Satellite-based flood extent data used as a basis for government relief funding.	DEMO	Provided objective evidence for financial aid.

Note: (a) Phases correspond to the Disaster Management Cycle. (b) Maturity Levels: AC TUAL (Operational/Sustained use), PROTOTYPE (System integrated into user environment), DEMO (Demonstration level).

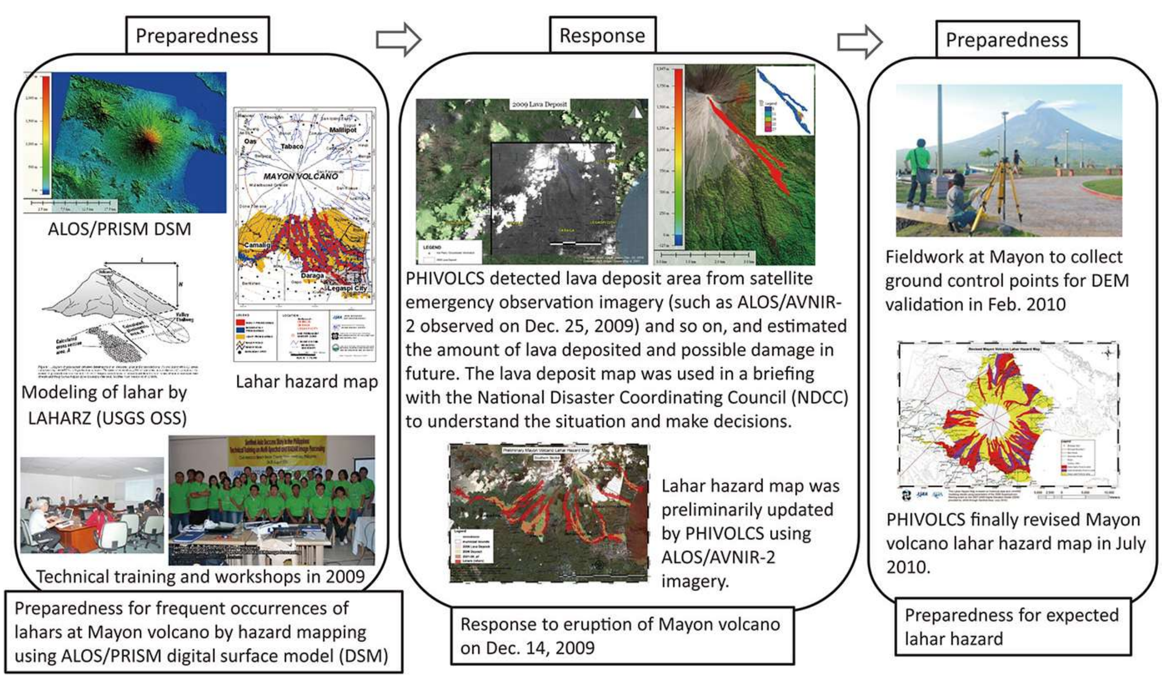

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Figure 13. Sentinel Asia (SA) Success Story in the Philippines (see (3-2) in Table 2a): Hazard mapping for lahars at Mayon volcano. Source: A. S. Daag and R. U. Solidum, Jr. of PHIVOLCS at Joint Project Team (JPT) meetings and reply to feedback questionnaire.

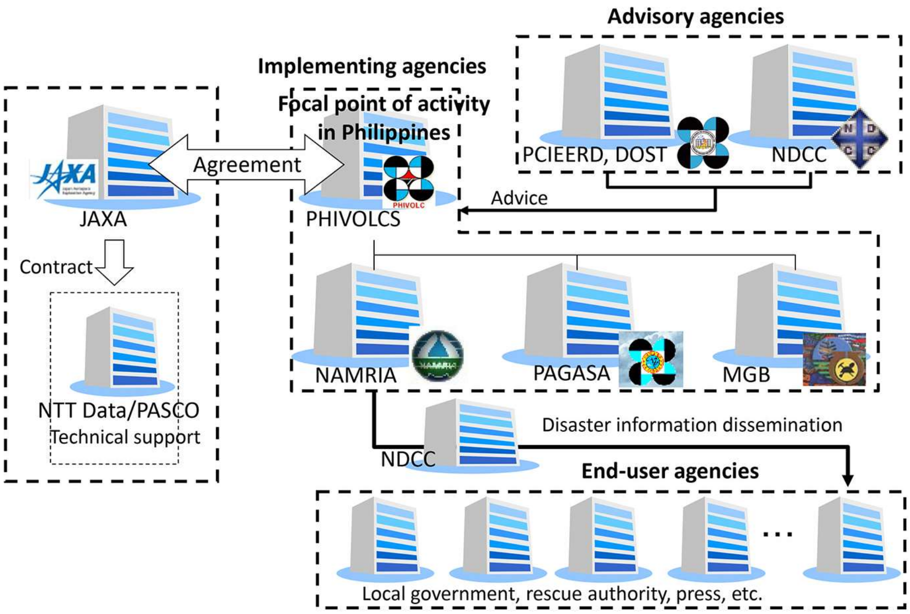

Figure 14. Framework of SA Success Story in the Philippines (see (3-2) to (3-4) in Table 2a), including end-users. Notes: Philippine Institute of Volcanology and Seismology (PHIVOLCS), Philippine Council for Industry, Energy, and Emerging Technology Research and Development/Department of Science and Technology (PCIEERD/DOST), National Disaster Coordinating Council (NDCC), National Mapping and Resource Information Authority (NAMRIA), Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), Mines and Geoscience Bureau (MGB).

3.2. Holistic Studies

Figure 15 shows an updated version of Figure 5, reflecting the results of the case studies.

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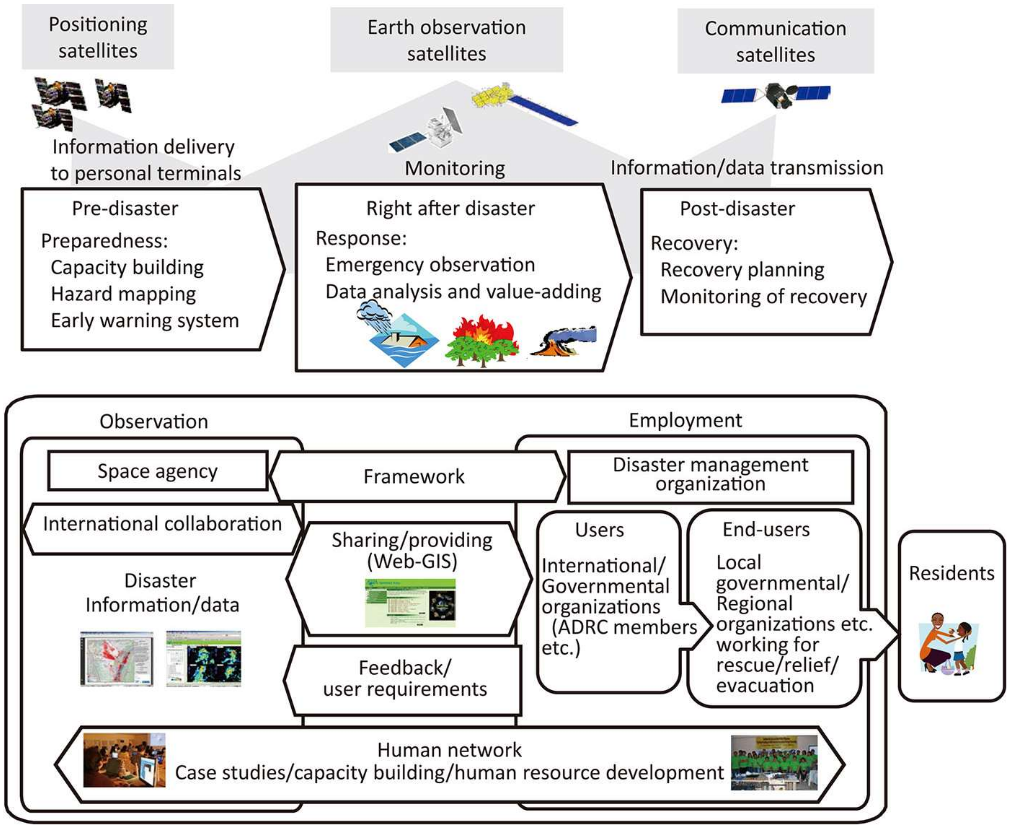

Figure 15. Conceptual illustration of "Applying satellite remote sensing to disaster management".

The results of holistic studies to date include the following:

- Requirements for applying satellite remote sensing to disaster management (see references [6,8])
- Requirements for applying satellite remote sensing to disaster response (see references [8,13])
- Proposing "Applying satellite remote sensing to disaster management" (this article itself)

This section presents an example of a holistic study, specifically an analysis from the user's perspective: user-based approach to applying satellite remote sensing.

3.2.1. User Positioning Within a Project

In this field, "users" are not passive recipients, but active components of the system. This research revealed that face-to-face human relationships are a fundamental element of disaster management. Maintaining such "human relationship networks" (Figure 16) requires continuous support for raising awareness, education, and joint training. In other words, user development and maintenance must be considered as part of the project activities. Without this, even the most sophisticated data will not be fully utilized.

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Figure 16. Human networking in Sentinel Asia (SA).

3.2.2. Collecting User Requirements

User requirements are one of the important considerations when implementing Sentinel Asia (SA). These have been discussed at the joint project meetings (JPTs) held once or twice a year since the project was launched in February 2006. In addition, following the 2011 Great East Japan Earthquake, from August 2011 to March 2012, JAXA surveyed Japanese users about how satellite imagery was used in disaster response and what was hindering its use. Interview surveys were conducted with 29 organizations, including local governments, universities, research institutes, fisheries and agriculture stakeholders, private companies, and NPOs in the affected areas, regarding the purpose of using satellite imagery and information, the timing of provision, and the results of its use. Furthermore, as Sentinel Asia moved to Step 3, in 2012 JAXA conducted interview surveys with 27 regional disaster management authorities in 27 countries in the Asia-Pacific region (23 of which are ADRC members) to promote SA and collect specific user requirements.

User feedback during each disaster response is extremely important for data providers. If the satellite data and imagery provided were not useful in the response, it serves as a lesson for improving operations; if they were useful, it serves as evidence of their success.

3.2.3. Examples of User Requirements

(1) Framework of institutional collaboration

Users have consistently requested a framework to provide satellite data and imagery free of charge during emergencies. Sentinel Asia is concretely realizing this need as a voluntary "maximum effort" initiative. This framework involves collaboration between space agencies, disaster management organizations (such as ADRC), and academic institutions, resulting in a collective humanitarian assistance effort (see Figure 17).

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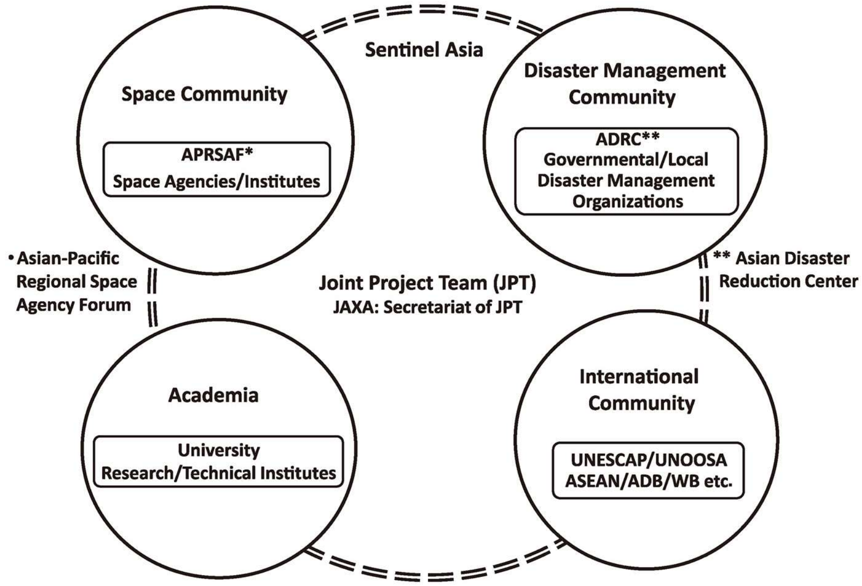

Figure 17. Institutional framework of Sentinel Asia (SA).

It is impossible for a single country to maintain the monitoring frequency necessary to respond to various types of disasters. International cooperation is most effective in terms of monitoring frequency, response speed, geographical reach, sensor diversity (SAR and optical), and weather-independent monitoring using SAR. Key initiatives include Sentinel Asia (SA), the International Disaster Charter, the European Union's (EU) Copernicus program, the UN Space Information Platform for Disaster Management and Emergency Response (UN-SPIDER) (UN program), and others. The collaboration between Sentinel Asia and the International Disaster Charter for Disasters has been in place since 2010 and yielded significant results during the 2011 Great East Japan Earthquake.

(2) Activities

Satellite observations have long been highly valued in emergency response, but user demand now reflects a desire for support across the entire disaster management cycle (Figure 18).

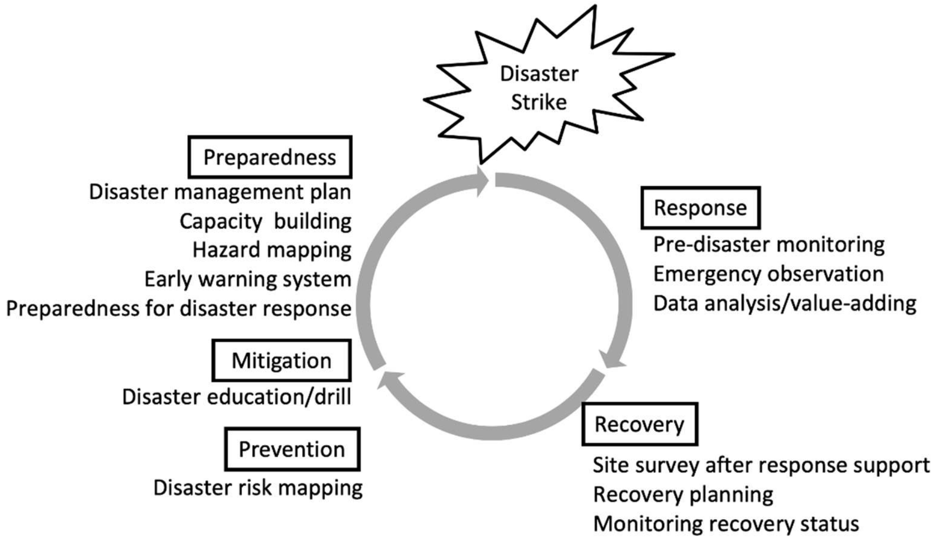

Figure 18. Activities applicable for each phase of disaster management cycle (see Section 1.3).

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Pre-disaster (prevention, mitigation, preparation): Hazard maps and risk maps created from satellite imagery form the foundation for long-term resilience. These efforts align with the Sendai framework for disaster risk reduction (DRR) 2015–2030 [14].

Response: This stage is the most time-constrained application phase. Global trend analysis (2000-2014) [2] shows that Asia and Europe are leading in emergency mapping using satellite imagery. However, there is a high user need for “imminent disaster monitoring,” that is, predicting disasters using data before they occur. Therefore, flexible data policies from data providers are a challenge for the future.

Recovery and reconstruction: Emergency observation images immediately following a disaster are useful for developing recovery and reconstruction plans. Furthermore, in the case of recurring disasters, they can be used to prepare for future disasters.

(3) Provision time and observation scales of satellite imagery

Regarding observation and data provision, users have specific time requirements, such as understanding the extent of damage within one hour of a disaster, detecting landslides within two to three days, and estimating the amount of rubble after one week. To meet these requirements, the system must operate 24/7, 365 days a year, and be automated as much as possible. Examples include automated analysis of satellite data and automated distribution of disaster-related information.

Furthermore, users require two different observation scales. The 2011 Great East Japan Earthquake [13,15] is a prime example. Figure 19 classifies Earth observation satellites that conducted emergency observations during the Great East Japan Earthquake based on their observation scale.

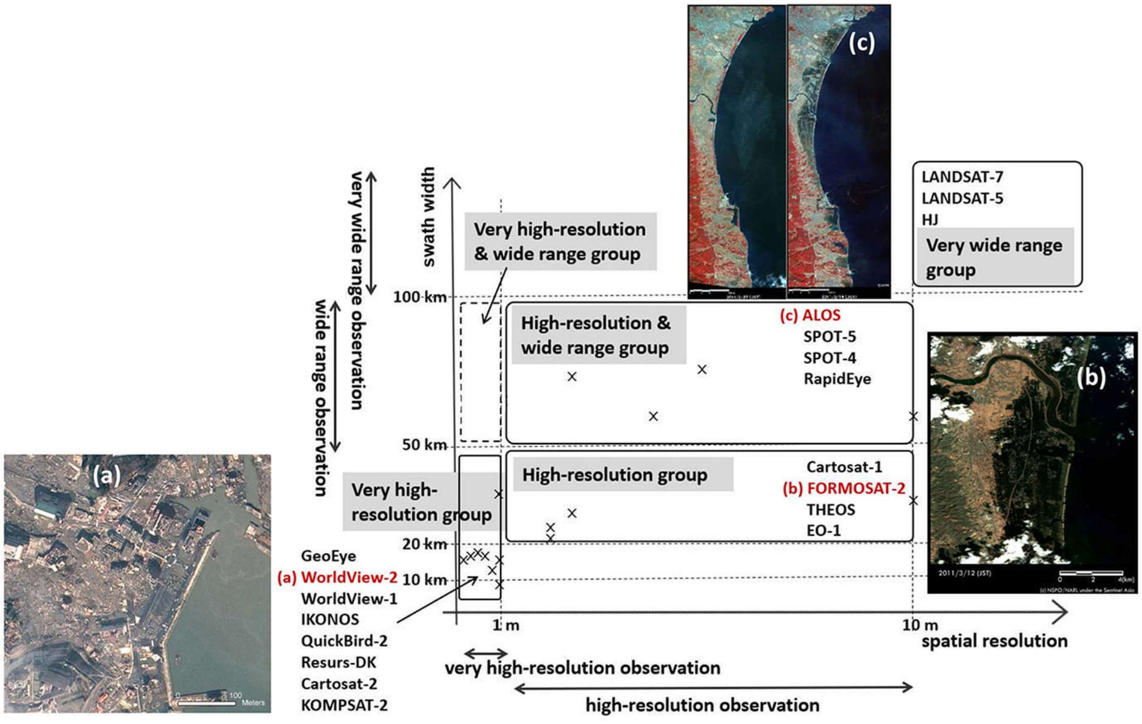

Figure 19. A classification of optical Earth-observation satellites with respect to spatial resolution and swath width, which supported the response to the 2011 Great East Japan Earthquake.

Overall monitoring: Immediately after a disaster, responders need wide-area images to grasp the overall picture of the damage. This enables broad resource allocation and situational awareness (see Figure 20).

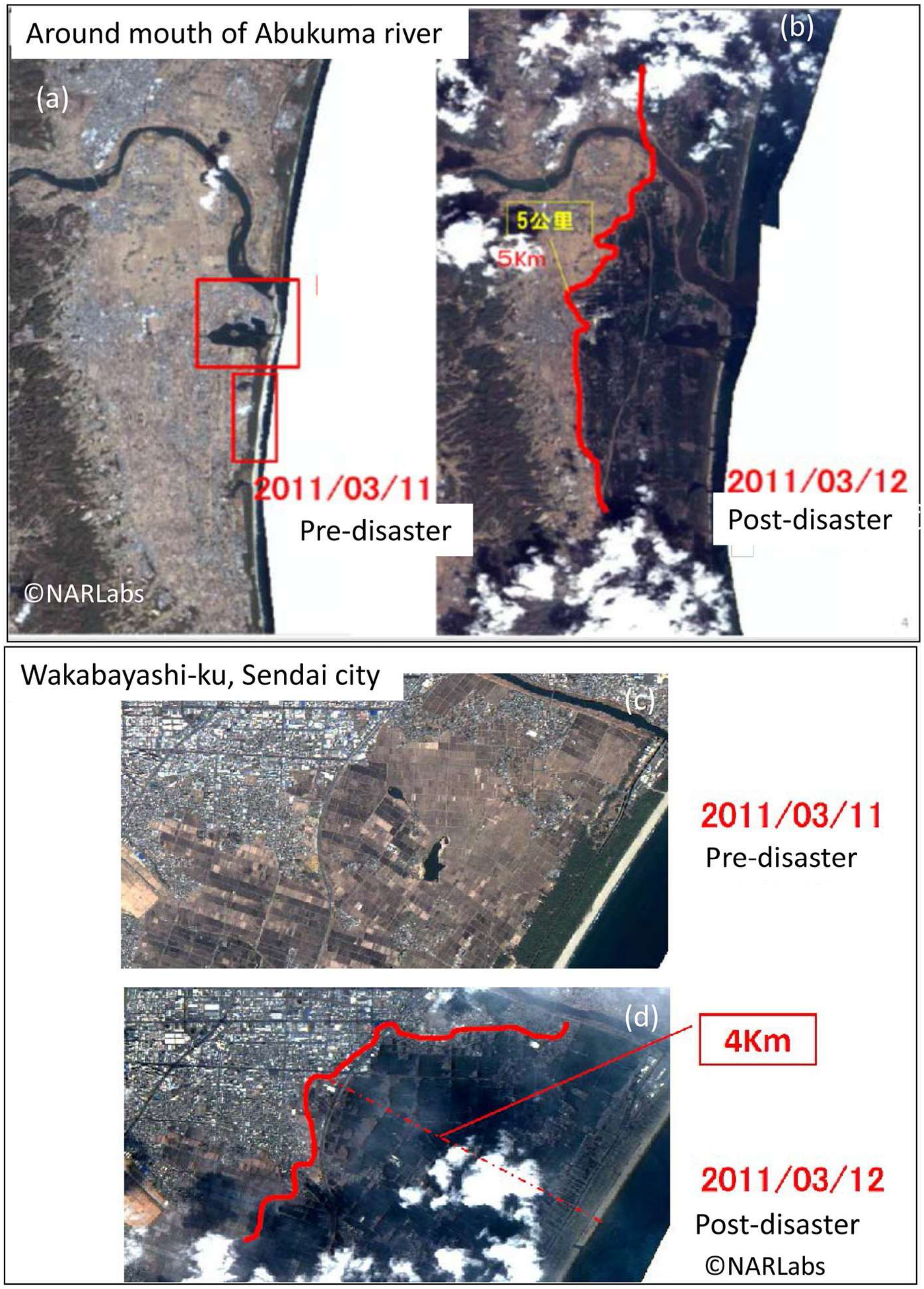

Figure 20. FORMOSAT-2 (a spatial resolution of 2 m or 8 m at the nadir, 24-km swath width) pre- and post-disaster images (observed on March 11, just before the disaster, and 12), analyzed by NARLabs. Dark areas indicate flooding by the tsunami. The results showed areas clearly affected by the tsunami, contributing to a rapid understanding of the extent of the damage. Source: SA Step-2 website.

Availability monitoring: On the other hand, localized activities such as rescue operations and evacuation route planning require very high-resolution data. Checking the integrity of roads and critical infrastructure requires a spatial resolution of less than one meter (see Figure 21).

Figure 21. CARTOSAT-2 (a spatial resolution of less than 1 m and a 9.6-km swath width) image observed on March 14, 2011, over Sendai area, provided by ISRO in the framework of SA. Sendai East Road worked as a dike. Dark areas indicate flooding by the tsunami. The embankment at Sendai East Road, about 5–6 m high, parallel to and a few kilometers away from the coastal line, had been effective in stopping tsunami waves from flowing further inland. Source: SA Step-3 website.

(4) Information distribution and sharing infrastructure

A robust Web-GIS platform is essential for transmitting and sharing data and information with stakeholders, including users. Such systems must balance accessibility with secure access control and comply with the data policies of various data providers (Figure 22). Furthermore, integrating communication satellites enables the transmission of satellite data even in areas with weak or failing ground infrastructure. Sentinel Asia implemented data transmission using WINDS satellite

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communications in Step 2. Currently, the distribution of evacuation warning messages using positioning satellites is being considered [16].

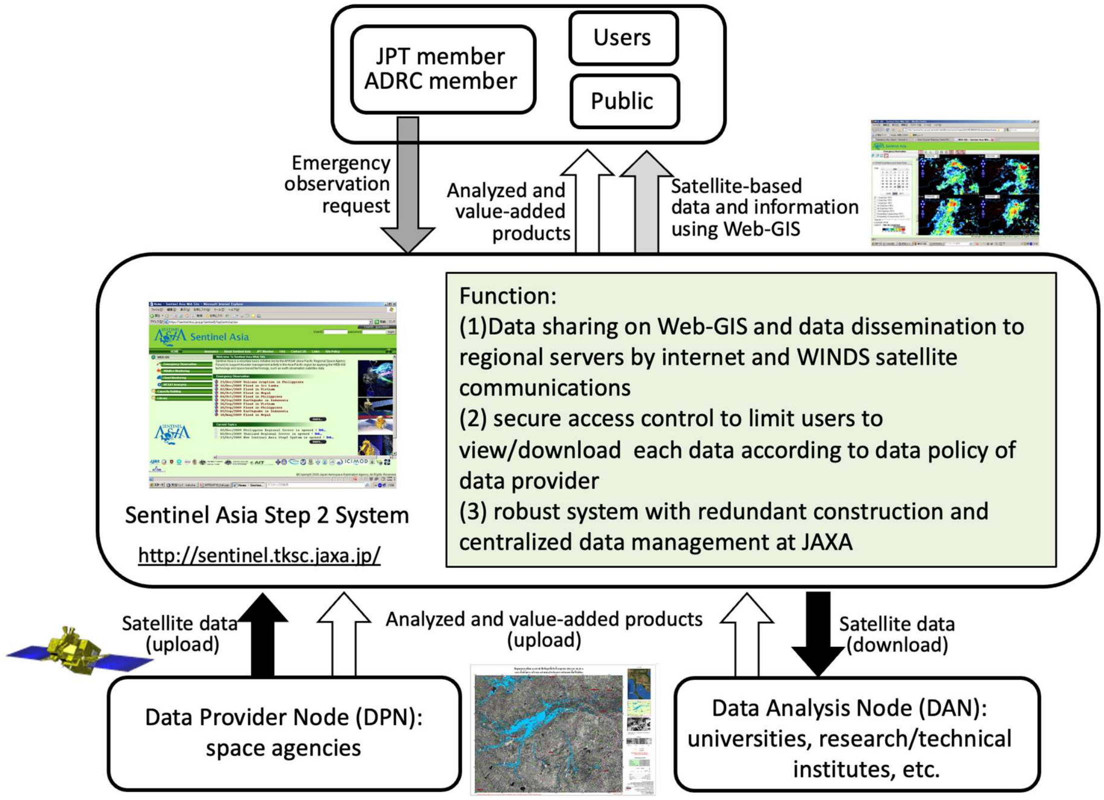

Figure 22. Sentinel Asia (SA) Step-2 system (Web-GIS) for data/information sharing and dissemination.

4. Discussion

While this article focuses on activities in the Asia-Pacific region, the methodology presented here is likely applicable to activities in other regions or even the entire world.

Furthermore, this approach will likely be effective not only in satellite remote sensing but also in other technological fields involving social implementation, users, and other relevant factors.

I received the following message (excerpt): *"I came across your paper 'Satellite Remote Sensing for Disaster Management Support: A Holistic and Staged Approach Based on Case Studies in Sentinel Asia'* [6] *and felt that your work is distinctive for this research domain. This research may indeed prove to be significant to fellow researchers and scientists working in the same discipline. I also followed your profile and read your another significant research paper, 'Space-based response to the 2011 Great East Japan Earthquake: Lessons learnt from JAXA's support using earth observation satellites'* [15]." *Dr. Stephen E. Haggerty, Editor, Department of Humanities and Social Sciences, Global Journals, 2019/03/21.*

5. Conclusions

This approach will contribute to the accumulation, sharing, and succession of knowledge, for example:

- for beginners in this field, like me in 2006. I was at a loss as to what to do, when I first became involved in this field;
- in the case of a generational change in personnel in this field; and
- lessons beyond generations in major disasters that occur only every few hundred years. This article features case studies from 2006 to 2014, including the 2011 Great East Japan Earthquake;

some experts say this kind of earthquake and the subsequent tsunami have a return period of 1,000 years.

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Data Availability Statement: Details of each case study can be found in the references [5,7,8,10,12]. Images from the emergency observations are available on the Sentinel Asia and International Charter websites. https://sentinel-asia.org/EO/EmergencyObservation.html https://disasterscharter.org/activations.

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