Review Article

Sentinel Asia: A space-based disaster management support system in the Asia-Pacific region

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A B S T R A C T

The Sentinel Asia initiative was established in 2005, as a collaboration between regional space agencies and disaster management agencies, applying remote sensing and Web-GIS technologies to assist disaster management in the Asia-Pacific region. To date multiple national agencies of about 25 countries in the region have joined and benefited from the disaster support services provided by Sentinel Asia. This paper presents the vision and stepwise approach of establishment and continuous improvement of this regional program, as well as lessons learned throughout its implementation for 7 years from 2006 through 2012.

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1. Introduction

According to global statistics (Natural Disasters Data Book-2011 [1]), Asia has been disproportionately affected by a number of large-scale natural disasters over the past decades. The effects of these disasters are compounded by the high population levels (about four billion). Disasters occurring in Asia comprise 39% of the worldwide total. The region has sustained 53% of global fatalities, and is home to 88% of the total people affected by such disasters. In view of these circumstances, the Asia-Pacific Regional Space Agency Forum (APRSAF) proposed Sentinel Asia (SA) in November 2004, when it was realized that the rapid technological advances in the region could confer life-saving benefits, if satellite imagery and derived information could be delivered more quickly via the internet to disaster management agencies in affected countries, in the form of easily interpreted disaster-related information.

APRSAF itself was established in 1993 in response to a 1992 declaration adopted by the Asia-Pacific International Space Year Conference (APIC) to enhance the development of each country’s space program and to exchange views toward future cooperation in space activities in the Asia-Pacific region. It was originally designed to provide opportunities for regional space agencies and associated governmental bodies to exchange technical views, opinions, and information on national space programs and space resources.

SA is not designed to replace already active efforts by many of our regional agencies aimed at delivering information to emergency services. Rather, it intends to expand such efforts and make relevant data available to all countries and many more people in the region, in particular those in countries that do not own their own satellite reception facilities. Through such a backbone, information about disasters could begin to be delivered more efficiently through the world-wide-web, beyond national borders, in real-time or near real-time, and used as early-warning or as post-disaster information by various countries and relevant end-user agencies.

The decision to move forward in implementation of the SA system and associated partner network was made soon after the Indian Ocean tsunami disaster in 2004, to fast-track this project, and to complement current space and ground infrastructure in the region with a fast distribution system of disaster-related earth observation information to relevant agencies and the general public throughout the region. The technical concept was finalized at a meeting in May 2005 in Kuala Lumpur, hosted by the Malaysian Center for Remote Sensing (MACRES), and was promptly approved as a project for rapid implementation by the APRSAF-12 plenary held in Kitakyushu, Japan, in October 2005, with the adoption of the following recommendations: (1) to strengthen international cooperation and take concrete actions toward the establishment of a disaster risk management system within the framework of APRSAF, recognizing the timeliness of establishing such a system with the participation of as many entities as possible, such as space agencies, disaster management agencies, as well as relevant regional and international entities, and (2) to take concrete steps toward the establishment of the above disaster risk management system, and as the first step, to implement the “Sentinel Asia” pilot project through the formation of a “Joint Project Team” (JPT) at the earliest possible date, in order to refine the details of project implementation. As a result, the 1st JPT meeting of SA Step 1 was held in February 2006, in Hanoi, Vietnam, hosted by the Vietnamese Academy of Science and Technology (VAST), and Step 1 was launched.

2. Description of Sentinel Asia

The Sentinel Asia (SA) initiative has been a voluntary, grass-roots and best-efforts-based collaboration between regional space agencies and disaster management agencies for regional humanitarian purposes, applying remote sensing and Web-GIS technologies to assist disaster management in the Asia-Pacific region,1 in collaboration with the International Charter “Space and Major Disasters”2 (for short, the International Charter). SA also provides a regional enhancement to the International Charter, as it allows any country in the region to join the SA network and request disaster-relevant information, regardless of their membership of the International Charter or level of investment into space-related infrastructure. SA aims to: (1) enhance safety in society, through more efficient use of internet and other data distribution systems, as well as easier access to space technologies provided by countries

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1 Sentinel Asia website: http://sentinel.rksc.jaxa.jp/
2 The International Charter is a worldwide collaboration among space agencies to make satellite data available for the benefit of disaster management authorities during the response phase of an emergency. Its members, conscious of the need to improve its access globally, have adopted the principle of “Universal Access”: any national disaster management authority will be able to submit requests to the International Charter for emergency response. Proper procedures have to be followed, but the affected country does not have to be its member. A registration process is available for national authorities to express interest in participating in the International Charter (see http://www.disasterscharter.org/).
project, the membership in the Joint Project Team (JPT) is open to all APRSAF participants, disaster management organizations, and regional/international organizations that are prepared to contribute their experiences and technical capabilities and that wish to participate in technical aspects of disaster information-sharing activities. An organization wishing to participate in the JPT shall express its intention by sending a formal letter to the JPT secretariat, the Japan Aerospace Exploration Agency (JAXA). Current JPT members are listed in Table 1.

2.1.2. Data provider node

In the case of a regional disaster, several regional space agencies and related institutions act as “Data Provider Nodes” (DPNs), providing satellite data from their own national satellites to the Data Analysis Node (DAN), described below in Section 2.1.3, at the explicit request of a JPT member or ADRC member, to the extent permitted by the data policy of each DPN. DPN members include JAXA, the Indian Space Research Organisation (ISRO) of India, the Korea Aerospace Research Institute (KARI) of Korea, the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, the National Applied Research Laboratories (NARL) of Taiwan, and the Center for Remote Imaging, Sensing and Processing (CRISP) National University of Singapore. DPN’s satellites are called the “Sentinel Asia Constellation.” Current DPN members are listed in Table 1.

2.1.3. Data analysis node

A new framework of satellite data analysis and value-adding was subsequently established in Step 2 of Sentinel Asia, since it was quickly realized that merely providing satellite data may not be as useful to many emergency and disaster agencies that would rather prefer more advanced “information products” derived from the data for their uses. “Data Analysis Nodes” (DANs) of SA were organized to provide some level of data analysis and pre-processing to the satellite images provided by the DPNs, to make it easier for disaster management agencies to obtain easily comprehensible interpretations of available images. In the case of an emergency observation, the DAN members analyze the satellite data (in GeoTIFF format, or raw data in principle) provided by the DPN, together with their own data, such as local maps, and then make value-added products, and deliver such “disaster information products”, where possible in near real-time. One of these nodes is nominated to be the Primary Data Analysis Node (P-DAN), and thus has the additional responsibility of data analysis management: coordinating the response of all other DANs to each emergency observation request. The Asian Institute of Technology (AIT) in Thailand is currently the P-DAN. Current DAN members are listed in Table 1.

2.1.4. Technical working groups

To accelerate the development of key disaster information products and utilization of satellite-derived products related to disasters by end-users, several specific working groups have been set up in the framework of SA. Working groups focus on producing and testing data processing approaches for delivery of information on specific disasters...
| Country/region | Organization                                                                 | DPN | DAN |
|---------------|------------------------------------------------------------------------------|-----|-----|
| Australia     | Commonwealth Scientific and Industrial Research Organisation (CSIRO)          |     |     |
|               | Geoscience Australia (GA)                                                    |     |     |
|               | Australian Bureau of Meteorology                                            |     |     |
| Bangladesh    | Bangladesh Space Research and Remote Sensing Organization (SPARRSO)          |     |     |
|               | Ministry of Home & Cultural Affairs                                         |     |     |
| Bhutan        | Department of Survey and Land Records                                       |     |     |
|               | Royal University of Bhutan                                                  |     |     |
| Brunei        | Survey Department, Ministry of Development                                  |     |     |
| Cambodia      | Ministry of Land Management, Urban Planning and Construction                |     |     |
|               | National Disaster Reduction Center of China (NDRCC)                         |     |     |
| China         | Institute of Geology, China Earthquake Administration (IG, CEA)             |     |     |
|               | Beijing Normal University (BNU)                                              |     |     |
|               | Sichuan University                                                          |     |     |
|               | Institute of Space and Earth Information Science, Chinese University of Hong Kong (CUHK) |     |     |
|               | Institute of Mountain Hazards Environment (IMHE), Chinese Academy of Sciences (CAS) |     |     |
| Fiji          | Fiji National Disaster Management Office (NDMO)                             |     |     |
| India         | Indian Space Research Organisation (ISRO)                                    |     |     |
|               | University of Kashmir                                                       |     |     |
|               | Gauhati University                                                          |     |     |
| Indonesia     | Symbiosis Institute of Geoinformatics                                       |     |     |
|               | National Disaster Management Agency (BNPB)                                  |     |     |
|               | National Institute of Aeronautics and Space (JAPAN)                         |     |     |
|               | Institute of Technology Bandung (ITB)                                       |     |     |
|               | Universitas Jenderal Achmad Yani (UNJANI)                                   |     |     |
| Japan         | Agency for the Assessment and Application of Technology (BPPT)              |     |     |
|               | Keio University                                                             |     |     |
|               | Japan Aerospace Exploration Agency (JAXA)                                   |     |     |
|               | Infrastructure Development Institute (IDI) Japan (IFNet)                    |     |     |
|               | Hokkaido University                                                         |     |     |
|               | Yamaguchi University                                                        |     |     |
|               | International Digital Earth Applied Science Research Center (IDEAS), Chubu Institute for Advanced Studies, Chubu University |     |     |
|               | Chiba University                                                            |     |     |
|               | Hiroshima Institute of Technology                                           |     |     |
| Kazakhstan    | National Center of Space Researches and Technologies                        |     |     |
| Korea         | Korea Aerospace Research Institute (KARI)                                   |     |     |
| Kyrgyz        | Central Asian Institute of Applied Geosciences (CAIAG)                      |     |     |
| Lao P.D.R     | Ministry of Labor and Social Welfare                                        |     |     |
|               | Natural Resources and Environment Institute (NREI), Ministry of Natural Resources and Environment (MONRE) |     |     |
| Malaysia      | National Security Division, Prime Minister's Department                      |     |     |
|               | Malaysian Remote Sensing Agency                                             |     |     |
|               | National Space Agency of Malaysia (ANGKASA)                                 |     |     |
| Mongolia      | National Remote Sensing Center of Mongolia (NRSC)                           |     |     |
| Myanmar       | Department of Meteorology and Hydrology                                      |     |     |
|               | Relief and Resettlement Department                                          |     |     |
|               | Myanmar Earthquake Committee (MEC)                                          |     |     |
|               | Department of Water Induced Disaster Prevention                             |     |     |
| Nepal         | Survey Department of Nepal                                                  |     |     |
|               | Land Management Training Centre (LMTC)                                       |     |     |
| Pakistan      | Pakistan Space & Upper Atmosphere Research Commission (SUPARCO)             |     |     |
| Philippines   | National Disaster Risk Reduction and Management Council (NDRRMC), Office of Civil Defense (OCD) |     |     |
|               | National Mapping and Resource Information Authority (NAMRIA)                |     |     |
|               | Bureau of Soils and Water Management (BSWM)                                 |     |     |
|               | Mines and Geosciences Bureau (MGB)                                          |     |     |
|               | Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) |     |     |
|               | Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD) |     |     |
|               | Philippine Institute of Volcanology and Seismology (PHIVOLCS)               |     |     |
|               | Manila Observatory                                                          |     |     |
|               | National Institute of Geological Sciences, University of the Philippines (NIGS) |     |     |
| Singapore     | Centre for Remote Imaging, Sensing and Processing (CRISP) National University of Singapore |     |     |
| Sri Lanka     | Survey Department of Sri Lanka                                               |     |     |
|               | Ministry of Disaster Management                                              |     |     |
| Taiwan        | National Applied Research Laboratories (NARL)                               |     |     |
|               | Center for Space and Remote Sensing Research, National Central University (CSRSR, NCU) |     |     |
| Thailand      | Geo-Information & Space Technology Development Agency(GISTDA)                |     |     |
|               | Department of Disaster Prevention and Mitigation (DDPM)                      |     |     |
|               | Department of Water Resources(DWR)                                          |     |     |
|               | Royal Forest Department(RFD)                                                 |     |     |

Table 1
Sentinel Asia Joint Project Team members consisting of total 90 organizations including 76 organizations of 25 countries/region and 14 international organizations as of August 2013.
2.2. Implementation approach

A step-by-step approach for the implementation of SA was adopted. Through Step 1 (2006–2007) [4,5], implementation of an initial backbone SA data dissemination system was established, as a pilot project to showcase the value and impact of technology using standard internet dissemination systems. Subsequently, Step 2 (2008–2012) [6–10] concentrated on the expansion of the system with additional member countries and their agencies, and the expansion of the dissemination backbone with new satellite communication systems, such as the wideband Inter-networking Engineering Test and Demonstration Satellite (WINDS) of JAXA, and additional nodes and satellite data sources. The final implementation step “Step 3”, launched in January 2013, will oversee consolidation activities to establish a comprehensive, operational and enduring disaster management support system in the Asia-Pacific region.

2.3. Sentinel Asia Step 3

At APRSAF-19, held in Kuala Lumpur in December 2012, several new recommendations on SA were adopted, which declared the successful completion of SA Step 2, in recognition of achieving the goals and declared the launch of the final phase of SA in 2013. The goal of Step 3 is to further expand SA’s activities to a wider regional reach, to better cover the entire disaster management cycle (the mitigation/preparedness phase, response phase, and recovery phase), faster delivery of disaster information products to end-users, and utilizing many and varied satellites, such as earth observation, communication and navigation satellites, with further operational collaboration and human networking by the Joint Project Team.

The SA Step 3 has the following concept as shown in Fig. 3, based on experiences in Step 2 and user requirements (see Section 3.1): (1) a basic continuation of Step 2’s activities, (2) expansion from response (in Step 1 and Step 2) to cover the mitigation/preparedness and recovery phases in the disaster management cycle, (3) participation of various satellites: earth observation satellites, communication satellites, and navigation satellites, (4) further collaboration for operation, and (5) further utilization of human networking through capacity building and outreach.

2.4. Activity

The main activities of SA Step 3 are shown in Fig. 4. In Step 1, SA has focused on the response phase, and has expanded its activity gradually to cover the entire disaster management cycle.

2.4.1. Disaster mitigation and preparedness phase

2.4.1.1. Capacity building. Capacity building is essential to developing human resources and a human network to utilize the information provided by SA. A good human network is the foundation of the project. JAXA is conducting the System Operation Training to train the JPT and ADRC members to request an emergency observation and utilize data and information provided by SA Step 2 system (see Section 2.4.5).
2.4.1.2. Sentinel Asia success story. Sentinel Asia Success Story (SASS) is an activity aimed at: (1) outreach and cooperation for disaster risk reduction (DRR) in the mitigation/preparedness phase, (2) establishment of specific case-studies via regional cooperation that include end-users, (3) local awareness and knowledge transfer through capacity building, and (4) human resources and human network development. Among the first such case-studies, JAXA has been implementing the SASS in the Philippines since 2009 (see Fig. 5). By using Advanced Land Observing Satellite (ALOS) pan-sharpened imagery and a Digital Surface Model (DSM), hazard maps for lahars near Mt. Mayon, floods in Iloilo city and landslides in Antique province were created by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), and the Mines and Geoscience Bureau (MGB), respectively. This mapping occurred in the first phase, from the beginning of 2009 to March 2010. In the second phase, beginning in April 2010, an application of GSMaP (see Section 2.4.4.2) has been used to track landslide warning in Albay; interferometry has likewise been used to monitor land subsidence in the Manila area and earthquake/volcanic eruptions at Mt. Mayon, Mt. Taal, and Valley Fault. Mt. Mayon in Luzon, the Philippines, recorded volcanic activity beginning on 14 December 2009, and the lava that flowed out from the crater was confirmed on 20 December. About 47,000 people living near the Mayon Volcano evacuated after warnings issued by the Province government. JAXA made emergency observations with Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) and Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) aboard ALOS on 25 December 2009, at the request of PHIVOLCS through SA, and provided observed data to PHIVOLCS. PHIVOLCS created a lava deposit map of the eruption using such ALOS imagery and other sources, which were used to understand the situation and make a decision by the National Disaster Coordinating Council (NDCC). A lava flow hazard map and lahar hazard map had been prepared beforehand using ALOS DSM in cooperation between JAXA and PHIVOLCS, which were supplemented by updating lava deposit data during eruption emergencies as shown in Fig. 5.

2.4.1.3. Working group activities. Four Working Groups (WGs) dedicated to phenomena such as wildfires, floods, glacial lake outburst floods (GLOFs), and tsunami have been implemented. Wildfires are major and recurring phenomena that have serious impact on property and human health, affecting many countries in the region. Compared to other disasters in the area, they do not
necessarily cause many immediate fatalities. However, they can have a serious impact on property and regional human health impacts due to frequent smoke and haze, and contribute to greenhouse gas emissions by the region. Responding to the needs of Asian countries, wildfire has been chosen as one of SA’s working group activity areas. Having accurate information on the location and intensity of fires, and subsequent control of such fires is therefore very important. Furthermore, wildfires’ effects are of great relevance at both a regional and a global level: they bear a substantial influence on global warming given that fires change forests, originally sinks of CO₂, into sources of CO₂ emissions. In view of these circumstances, wildfire management is very important and an urgent task in the mitigation of global warming [11]. The Wildfire WG has been organized and operated under international cooperation in the framework of SA, based on the experience and knowledge drawn from similar activities, such as those targeting boreal-forest/tundra fires in Siberia/Alaska, bush/shrub/grass fires in Australia [12], and scrub/deciduous/mixed-grass/dry-dipterocarp fires in Thailand. Fukuda of Fukuyama City University was selected as the WG chair. The results of Step 1 and Step 2 (2006–2012) are as follows: (1) construction of Web-GIS for sharing hotspot information detected by using Moderate Resolution Imaging Spectroradiometer (MODIS) data on board NASA’s Earth-observing satellites Terra (launched in December 1999) and Aqua (launched in May 2002) and the NASA and University of Maryland “MOD14” algorithm implemented by several institutions including Asian Institute of Technology (AIT), University of Tokyo, Geoscience Australia (http://sentinel.ga.gov.au), and the Center for Remote Imaging, Sensing and Processing (CRISP) National University of Singapore, (2) validation of MODIS hotspot detections, through field campaigns in Indonesia, Thailand, and Mongolia, (3) local refinement of the MOD14 algorithm by Hokkaido University, CRISP, Soul National University, and JAXA [13,14], and (4) early fire control trials in cooperation with users: a project on wildfire and carbon management in peat forests in Indonesia has been implemented as a Science and Technology Research Partnership for Sustainable Development (SATREPS) project by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA) (see Section 3.3 for details).

Flooding is also a major and recurring phenomenon affecting many countries in the Asia-Pacific region, and thus it has been chosen as one of SA’s working group areas of activity. The Flood WG has been organized under international cooperation and as part of the framework of SA, chaired by Fukami of the International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of UNESCO. SA is providing accumulated precipitation data from Global Flood Alert System (GFAS) and GSMaP (see Section 2.4.4.2), meteorological satellite MTSAT imagery (see Section 2.4.4.1) on Web-GIS, and inundated area information observed by satellite (see Fig. 6). In addition to these data, the Integrated Flood Analysis System (IFAS) was introduced in Step 2, which is a computer software package designed specifically for flood runoff analyses with Graphical User Interface (GUI), using not only ground-based but also satellite-based rainfall data. The system is being developed by joint research efforts among ICHARM, Infrastructure Development Institute (IDI), and others.
In addition to wildfire and flood, the Glacial Lake Outburst Flood (GLOF) WG was initiated at the second JPT meeting of Step 2 held in Bali, Indonesia, in July 2009. The GLOF WG consists of the Asian Disaster Reduction Center (ADRC)'s project in Bhutan and Chubu University's project in Nepal, co-chaired by Fukui of Chubu University and Shrestha of the International Center for Integrated Mountain Development (ICIMOD). The main activities are: (1) to utilize satellite imagery to build an inventory of regional glacial lakes, (2) to identify potential outburst risks by glacial lakes, (3) to regularly monitor these lakes and establish an early warning system in the risk areas, (4) to model and simulate flood scenarios, (5) to promote information sharing through Sentinel Asia infrastructure, and (6) to advance local awareness and knowledge transfer through capacity building. The ADRC has since developed the GLOF early warning system in Bhutan (see Section 3.3 for details).

Following the devastating damage by the earthquake and subsequent tsunami in Japan on 11 March 2011, it was decided that a Tsunami WG should be formed under the framework of SA, which would focus on developing a tsunami early warning system enhanced by the use of cutting-edge technologies including space technology. Kaneda of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) serves as the WG chair. SA Tsunami WG activities principally are conducted in three areas: developing a tsunami detection system, improving the warning transmission system, and awareness/education/capacity-building for community and residents in each country. It is expected to apply Quasi-Zenith Satellites System and Global Navigation Satellite System (QZSS/GNSS) to tsunami detection and warning transmission, and communication satellites to warning transmission. Earth observation satellite data can be used for making hazard maps for tsunami preparedness. This information will be shared through the SA platform, along with local awareness and knowledge transfer through capacity building.

Furthermore, users are requesting WGs for drought, earthquake, volcanic eruption, landslide and others, which is a subject for future study.

2.4.2. Disaster response phase

2.4.2.1. Emergency observation. In case of a major disaster in the Asia-Pacific region, the Sentinel Asia team triggers an emergency observation by Earth observation satellites as illustrated in Fig. 7, based on specific observation requests of Joint Project Team (JPT) and Asian Disaster Reduction Center (ADRC) members. The overall flow of emergency observation is shown in Fig. 8. Emergency observation requests by JPT and ADRC members are passed to space agencies through the ADRC. ADRC has been working to manage the emergency observation process, including making judgments about whether or not to accept individual requests. In the case of accepting a request, ADRC requests the Data Provider Node (DPN) members to make an emergency observation. ADRC can escalate SA's emergency observation request for major disasters to the International Charter.

2.4.2.2. Data analysis and value-adding. In the case of emergency observation, the Data Analysis Node (DAN) members analyze the satellite data and make value-added products that can be used by disaster management agencies and their partners.
2.4.3. Disaster recovery phase

There is no present activity concerning the recovery phase, since this is not necessary the role of the Asia-Pacific Regional Space Agency Forum (APRSAF), but rather local disaster management authorities. However, some products produced by emergency observation can be utilized by governments to track the recovery and reconstruction phases as well. On the occasion of the long-term deluge that occurs once every 50 years in the central and northeastern parts of Thailand, which occurred in October 2010, JAXA made emergency observation with Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) and Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) aboard Advanced Land Observing Satellite (ALOS) on 21 October 2010 at the request of the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand through SA, and provided this data to GISTDA using the wideband Internetworking Engineering Test and Demonstration Satellite (WINDS) satellite communications. GISTDA made inundation maps using the ALOS imagery and reported to the cabinet every day. For this flooding episode, the Thai government decided to pay

Fig. 7. Conceptual illustration of emergency observation and data transmission via WINDS satellite communications. WINDS ground terminals are set up in Bangladesh, Fiji, Indonesia, Kyrgyz, Malaysia, Mongolia, Nepal, the Philippines, Sri Lanka, Thailand, and Vietnam.

Fig. 8. Emergency observation flow.
compensation money to households whose homes had been directly affected. By overlaying house distribution information on a Phased Array type L-band Synthetic Aperture Radar (PALSAR) image indicating the inundation area offered from SA, e.g., as shown in Fig. 9, the number of affected houses was counted and reported to the government. The Thailand government used this data to inform its relief payments.

2.4.4. Routine data acquisitions

2.4.4.1. Meteorological satellite. Under the framework of Sentinel Asia (SA), additional data sources such as meteorological satellite data such as from MTSAT-2 via the Japan Meteorological Agency (JMA) are also used. JAXA has been processing the data and providing visible (VIS: 0.63 μm), infrared (IR: 10.8 μm), and water vapor (WV: 6.8 μm) imagery on SA Web-GIS since September 2007. Hotspots [15] (for example, see Fig. 10) and cumulonimbus information detected by IR channels’ data from MTSAT-2 were added in April 2012, which were developed under a collaboration of JAXA and the Meteorological Research Institute of JMA. Hotspots are detected using the nighttime (11:00–20:00 UT) IR channels’ data, and each hotspot pixel (4 Km x 4 Km) is colored according to its confidence: red means high; blue, low; green, medium (see Fig. 10). As for CB information between latitude 25 degree south and 25 degree north, active cumulonimbus area, moderate cumulonimbus area at a forming stage, and remarkable subsidence area with very low possibility of cumulonimbus generation are all provided. In the near future, when the new generation Himawari-8/9 satellites are launched in late 2014, JAXA and JMA, in collaboration with colleagues from Australia and other countries in the region, will begin to evaluate such data for generation of additional disaster-related products from such data.

2.4.4.2. GFAS and GSMaP precipitation data. The Global Flood Alert System (GFAS) provides global satellite-based daily rainfall maps and heavy rainfall identification on the SA Web-GIS, which are provided by the Infrastructure Development Institute (IDI) Japan and International Flood Network (IFNet). GFAS, based on the NASA’s product “NASA-3B42RT”, provides an accumulated daily precipitation data map and precipitation probability analysis map with the areas exceeding 5-year or 10-year return period precipitation. SA also provides long-term accumulated precipitation for 3, 7, 30, 60, 100 days based on GFAS daily precipitation data (for example, see Fig. 11).

JAXA and ICHARM/Public Works Research Institute (PWRI) are jointly developing and validating a prototype
system based on the JST-Core Research for Evolutionary Science and Technology (CREST) GSMaP, which is global satellite-based hourly/10-km-grid near real-time (4 h after observation) rainfall mapping based on microwave imagery displayed on the SA Web-GIS.

2.4.5. Data and information sharing/dissemination

A new Step 2 information-sharing platform has been developed and operated by JAXA. This is a Web-GIS with centralized data at JAXA in Japan, whereas the Step 1 information-sharing platform was constructed using Digital Asia Web-GIS of Keio University with dispersed data at each data provider. The Step 2 platform is a robust system with redundant construction and centralized data management at JAXA. It functions to share information and data on Web-GIS and to disseminate data to regional servers by internet and the wideband Internetworking Engineering Test and Demonstration Satellite (WINDS) satellite communications. It also has a secure access control function to limit users from viewing data according to the data policies of the data providers. Data and information sharing through this system is illustrated in Fig. 12. In addition to information sharing via the internet, information transmission to facilitate access to disaster-related information using WINDS satellite communications has been introduced, as shown in Fig. 7. Regional servers mirroring the central server in Japan have been set up in 11 countries. Any of those servers can be accessed by users for the purpose of viewing the SA website or downloading data. In case of a disaster, large volumes of satellite imagery can be distributed using WINDS satellite communications and the internet to organizations handling emergency situations as well as organizations analyzing satellite imagery.

3. Results and discussions

3.1. Approach and lessons learned

When Sentinel Asia (SA) was launched in 2005, the space community under the Asia-Pacific Regional Space Agency Forum (APRSAF) was not so familiar with the urgent earth observation needs for disaster management and disaster risk reduction (DRR). For this reason, more direct and active collaborations with regional disaster management agencies and the community as a whole were established, and a step-by-step approach for the implementation of SA was adopted (see Fig. 13). This three-step approach, as described in Section 2.2, made it easier to progressively build and expand the regional network of data providers, data analysis nodes and user agencies in about 76 regional organizations.

The SA Step 1 was carried out from 2006 through 2007, as a collaborative project of space agencies (APRSAF community) and disaster management organizations (Asian Disaster Reduction Center, ADRC, and member organizations) in order to demonstrate what space agencies can do and find issues to be solved. This successful first step served as a good initial demonstrator project to quickly share disaster-related imagery and information obtained by several Earth observation satellites, such as Advanced Land Observing Satellite (ALOS), Indian Remote Sensing Satellites (IRS), Multi-functional Transport Satellite 1R (MTSAT-1R), NASA Terra and NASA Aqua, using

![Fig. 10. Typhoon Ketsana and wildfires in Kalimantan is September 2009. (a) imagery of MTSAT-1R, showing typhoon Ketsana in Vietnam and wildfires in Indonesia. (b) enlarged imagery of southern part of Kalimantan, Indonesia, with hotspots detected by MTSAT-1R infrared data, with confidence level shown by: (Low Confidence) , (High Confidence). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)](image-url)
primarily the Digital Asia (Web-GIS) platform provided by Keio University. It has demonstrated recent advances in web-mapping technologies and Information and Communication Technology (ICT) systems. Key lessons learned from Step 1 were as follows: (1) data transmission: it was found that internet bandwidth was still a major impediment for data transfer to many countries and disaster management agencies, making it difficult to use online visualization tools such as Web-GIS, (2) better customizing information: regional users from disaster management organizations in particular, stated repeatedly that they would rather receive derived information products quickly, rather than raw satellite imagery, while at the same time, users of space agencies and institutes request GeoTIFF-format data and/or raw data for their analysis, (3) information-sharing infrastructure: the original single server used for data delivery in Step 1 and the website server did not always perform on a 24-h, 7-day, 365 days basis, and frequently suspended operations due to server maintenance and others. A more robust and user-friendly website system was required, and (4) human network: maintaining a good human network between the space and disaster management communities has been recognized to be the foundation and life-line of the project, and just as important as the satellites and infrastructure that was implemented for this system.

Step 2 of SA was therefore rolled out to take the lessons of Step 1 from 2008, as follows: (1) use of data from various additional satellites: in addition to Step 1’s Earth observation satellites such as ALOS of the Japan Aerospace Exploration Agency (JAXA) and IRS of the Indian Space Research Organisation (ISRO) of India, new Earth observation satellites, such as the Korean Multi-purpose Satellite-1 (KOMPSAT-1) of the Korea Aerospace Research Institute (KARI) of Korea, Thai Earth Observation System (THEOS) of the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, FORMOSAT-2 of the National Applied Research Laboratories (NARL) of Taiwan, and XSAT of the Center for Remote Imaging, Sensing and Processing (CRISP) National University of Singapore, have all joined.

Fig. 11. Precipitation in September of 2007, 2008, and 2009 in Kalimantan, Indonesia, by GFAS. (a), (b), and (c) are enlarged imagery of Kalimantan region of (A), (B), and (C), respectively. Precipitation is shown by red (0 mm/day), orange (0–1 mm/day), yellow (1–5 mm/day), and white (5–20 mm/day). This figure shows little precipitation in 2009 in Kalimantan (especially southern part of Kalimantan). The occurrence of peatland fires in Kalimantan, Indonesia is closely related to precipitation. Little precipitation causes peatland dry and makes fires easy to spread. In fact, there were big fires in Kalimantan in 2009, as shown in Fig. 10. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)
Multi-functional Transport Satellite-2 (MTSAT-2) of the Japan Meteorological Agency (JMA) and communications satellites, such as the wideband Internetworking Engineering Test and Demonstration Satellite (WINDS) of JAXA, have also joined. Furthermore, formal collaboration with the International Charter began in 2010, and ADRC began to also escalate SA's emergency observation requests for major disasters to the International Charter, in order to further increase available satellite resources to observe disaster-affected areas, (2) improvement of accessibility to information: in addition to information sharing via the internet in Step 1, information transmission to facilitate access to disaster-related information using WINDS satellite communications has been introduced to overcome low internet bandwidth in several countries as described in Sections 2.4.5, (3) information-sharing platform: a new Step 2 information-sharing platform has been developed by JAXA as described in Sections 2.4.5, and (4) improved

Fig. 12. Information sharing via Sentinel Asia Step 2 System.

Fig. 13. Stepwise approach of Sentinel Asia.
value-added information delivery: a new framework of satellite data analysis and value-adding, the Data Analysis Node (DAN) of SA, has been organized as described in Section 2.1.3.

Through the operation of Sentinel Asia Step 2 from 2008 through 2012, the following feedback was received from Joint Project Team (JPT) members: (1) SA should continue as an autonomous regional activity, but actively contribute and collaborate with wider global activities such as Group on Earth Observations (GEO), United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) and the International Charter, for the benefit of the SA user community, (2) there is a need to extend the data services of SA further to provision of data for pre/post-disaster phases, (3) the current service of data delivery via the experimental WINDS satellite needs to be continued and extended through additional communication satellites, for example, deploying a mobile satellite receiving facility in support of specific regional disasters would be highly desirable, (4) a mechanism is needed to integrate SA with other initiatives such as United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP)’s regional Asia Pacific gateway to disaster risk reduction (DRR), (5) a longer-term arrangement for continuous data providing mechanism to monitor disasters is needed, and (6) a system for the exchange of information and the continuity of capacity building are desirable. Considering these requirements, SA Step 3’s concept (see Section 2.3) was derived.

3.2. Permeation into disaster management community

Collaboration with the disaster management community, via the Asian Disaster Reduction Center (ADRC) and its members’, has been a part of major vision of Sentinel Asia (SA) from the outset. Specifically, SA activities are described at the annual Asian Conferences on Disaster Reduction (ACDR) organized by the ADRC.

In addition, the Japan Aerospace Exploration Agency (JAXA) has carried out an interview survey in 2012 to 27 regional disaster management authorities, 23 organizations of which are ADRC members, of 27 Asian countries in order to promote SA, and also to learn more about specific user requirements. As a result, it was found that 18 of the 27 organizations did not know, or recognize Sentinel Asia. Through discussion, 14 of these 18 organizations showed a keen interest on SA, and requested training and human resource development on remote sensing technology. It cannot be denied that space technology is still out of their league for some disaster management authorities, and close relationship with them through capacity building is required.

3.3. How to better approach end-users and become community-operated system

Sentinel Asia (SA)’s target is to provide the disaster information to end-users who are fighting against disasters and help them utilize it more. Some activities including more case-studies with end-users focusing on a specific country and region are requested. In this context, SA has already started some activities such as SA Success Story in the Philippines (see Section 2.4.1.2), wildfire management in Indonesia, and Glacial Lake Outburst Flood (GLOF) early warning system in Bhutan, as described below. These kinds of activities should be expanded to other countries and regions.

The goal of the SA Wildfire Working Group (WG) is to establish an operational cycle that includes end-users such as firefighters in each country in order to mitigate the damages caused by the fires. A demonstration project for wildfire and carbon management in a peatland in Kalimantan, Indonesia, was initiated under the framework of a Science and Technology Research Partnership for Sustainable Development (SATREPS) by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA). The interdisciplinary project primarily consists of “early fire detection and control”, “forest (including peatland) management and conservation”, and “enlightenment and capacity building”. The SA Wildfire WG has participated in “early fire detection and control” aiming at establishment of an operational cycle cooperating with firefighters in Kalimantan, Indonesia as shown in Fig. 14. (see Figs. 10 and 11, for reference, about a situation of wildfires in Kalimantan, Indonesia)

Asian Disaster Reduction Center has implemented the Glacial Lake Outburst Flood (GLOF) early warning system in Bhutan, based on community cooperation in the Mo River basin, in cooperation with the Ministry of Home and Cultural Affairs, Bhutan. After creating a map with elevation data in the upstream area of the Mo River and a hazard map using Advanced Land Observing Satellite (ALOS) imagery based on past flood records in Punakha, community-based river level gauges were installed for a GLOF early warning system. In addition, capacity development on a community level for disaster education and training among local residents was conducted as shown in Fig. 15. In this system, a villager who is living in upstream, safe area and connected to the river level gauging system, is alerted by the alarm and warns the residents in downstream, hazardous areas.

Furthermore, SA’s final target is to become a community-operated system in each country or region, as shown in Fig. 13. Through the above-mentioned end-users-oriented activities, with enthusiastic cooperation from each country, SA could be operated as a community system. In fact, in the SA Success Story in the Philippines (see Section 2.4.1.2), volcano and subsidence monitoring and landslide early warning using satellite data have been implemented within an operational system.

3.4. Rapid disaster response

It is required to observe the damaged area by a disaster by Earth observation satellites as quickly as possible during the disaster response phase. For example, wildfire information is provided within 45 min after satellite overpass in Australia, since agencies require near real-time monitoring, and therefore the direct-broadcast data from wide-area, operational satellite systems such as the Terra and Aqua systems operated by NASA is used. Other users
in Japan request information from satellites within 3 h after the occurrence of other disasters, whereas, in the case of long-term flooding in the Asian region (for example, see Section 2.4.3), longer turnaround time of several days will be allowed. Another example related to the occasion of the record-breaking flood that occurred around Colombo—Sri Lanka in May 2010. The Japan Aerospace Exploration Agency (JAXA) made an emergency observation with a Phased Array type L-band Synthetic Aperture Radar (PALSAR) aboard the Advanced Land Observing Satellite (ALOS) late at night on 18 May, by request of the Disaster Management Centre (DMC) of Sri Lanka through SA on the same day. Observed data were provided to DMC in the morning of the next day.

Sentinel Asia encourages space agencies to continuously make best efforts to shorten the turnaround time from request, to acquisition and delivery as follows: (1) as many satellites as possible should participate in the observation, (2) radar sensors, capable of observation at night or of cloud-covered Earth surface, should be utilized as well as optical sensors, as shown in Fig. 16, (3) improvement of the observation frequency by use of satellite constellations, for example, “RapidEye” constellation consisting of five satellites in orbit is capable of providing disaster information within several hours, and (4) total turnaround time including data transmission from a satellite to ground and data processing and analysis at ground as well as observation by satellites should be considered and shortened.

3.5. Beyond Sentinel Asia

The success of the Sentinel Asia (SA) philosophy is its inclusiveness, highly collaborative nature and eventual delivery of value-added disaster information products to relevant national governments and agencies, via internet or WINDS satellite communications, rather than delivery of only raw satellite data. SA has its origins in the Asia-Pacific region, and its philosophy and staged implementation strategy could be extended to other regions. This should happen in close cooperation with related global initiatives such as the Committee on Earth Observation Satellites (CEOS), European Space Agency (ESA)’s Copernicus, and the Global Earth Observation System of Systems (GEOSS) disaster risk management initiatives, by expanding to a new grand concept that could be called “Sentinel Earth”—a kind of “Aufhebung” from existing initiatives—beyond SA. The goal however would be much more than just delivery of raw satellite Earth observation data, but rather provide more specific “services” around quick, on a 24-h, 7-day, 365 days basis, automated production and delivery of disaster-relevant information products to user agencies directly, by improved data distribution networks and associated communications infrastructure.
satellites, GEONETCast—a Task in Group on Earth Observations Work Plan on global network of satellite-based data dissemination systems, Google’s Orbital balloon data relay networks, etc.), as well as regional capacity-building programs to provide national government with the tools and knowledge to analyze Earth observation data as they require. Using all the present space-based disaster management initiatives listed above, as members of a “Sentinel Earth” system, wider cooperation and cost-sharing will be achieved as synergies develop among existing initiatives, and as new activities and users from smaller, developing countries will join. Under a Sentinel Earth scenario, all the Earth

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**Fig. 15.** GLOF early warning system in Bhutan based on community cooperation in the Mo River basin, Bhutan by ADRC and the Ministry of Home and Cultural Affairs. A photo at the left is provided courtesy of ADRC. Photos at the right are quoted from ADRC Highlights vol. 229, [http://www.adrc.asia/highlights/NewsNo229](http://www.adrc.asia/highlights/NewsNo229).

**Fig. 16.** Flood in Nepal caused by a collapse of embankment in August 2008. (a) imagery of AVNIR-2 (optical sensor), and (b) imagery of PALSAR (radar sensor) aboard ALOS. Inundated area is shown in red in (b). (c) a photo taken in December 2008, which shows the area of collapsed bank (dashed line) with approximately 2–3 km in length. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)
observation data by satellites are greatly desired to be provided gratis for disaster management, and not only in disaster response phase but also in mitigation/preparedness phase and recovery phase from the higher standpoint.

4. Conclusion

Sentinel Asia has developed as a regional, grass-roots effort steadily since 2006 by regional APRSAF space agencies and the disaster management community under the Sentinel Asia Joint Project Team membership. After an initial trial period of 7 years (Step 1 and Step 2), it has reached its final phase Step 3 in 2013, aiming at a comprehensive, operational space-based disaster management and information delivery system in the Asia-Pacific region. Through Step 1 and Step 2, valuable lessons and user requirements are obtained. In particular, a good human network has been constructed between the space and disaster management communities. A good community-based network has been the foundation of the project. The authors wish that Sentinel Asia experiences will be helpful for other similar initiatives.

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