International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R RS.1859-1
(12/2018)

Use of remote sensing systems for data collections to be used in the event of natural disasters and similar emergencies

RS Series
Remote sensing systems

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R RS.1859-1

Use of remote sensing systems for data collections to be used in the event of natural disasters and similar emergencies

(2010-2018)

Scope

This Recommendation provides guidelines on the provision of satellite-provided remote sensing data in the event of different phases of disaster management:

1 pre-disaster (mitigation, or measures taken to reduce damage, disruption and casualties; preparation, or measures enabling a rapid response to disasters; and prevention, or avoiding adverse impacts of hazards and related disasters),

2 during the disaster (detection of a disaster and the immediate response in the form of emergency services and assistance), and

3 post-disaster (recovery from the immediate effects of the disaster and the long term rehabilitation and restoration to near pre-disaster conditions).

This Recommendation does not provide information on dissemination of data.

Keywords

EESS (active), EESS (passive), Earth exploration-satellite service, remote sensing, disasters, disaster management

Related ITU-R Recommendations and Reports

Recommendation ITU-R RS.1883 – Use of remote sensing systems in the study of climate change and the effects thereof

Report ITU-R RS.2178 – The essential role and global importance of radio spectrum use for Earth observations and for related applications.

The ITU Radiocommunication Assembly,

considering

a) that disaster management in the field of radiocommunications comprises the following, equally important, aspects:

1 early warning and prevention, through:

– disaster prediction, including the acquisition and processing of data concerning the probability of future disaster occurrence, location, and duration;

– disaster detection, including the detailed analysis of the topical likelihood and severity of a disaster event;

2 disaster mitigation including the rapid promulgation of imminent disaster information and corresponding alerts to disaster relief agencies;

3 post-disaster relief radiocommunications, including the provision of *in situ* terrestrial and satellite communication systems to aid in securing and stabilizing life and property in the affected area;

b) that inherent to natural disasters is their unpredictability, thus implying the need for prompt, global, Earth observing capabilities which are uniquely met by satellite-borne remote sensing instrumentation;

c) that such satellite-borne remote sensors exist and are operated in frequency bands allocated to the Earth exploration-satellite service (EESS) today;

d) that there are agencies whose purpose is to facilitate the processing and delivery of disaster-related data from the satellite operator-provider to the user relief agency,

recognizing

a) that Resolution ITU-R 55 – ITU-R studies of disaster prediction, detection, mitigation and relief, and Resolution **646 (Rev.WRC-15)** – Public protection and disaster relief; acknowledge the importance of the aspects of radiocommunications/ICT that are relevant to disaster prevention, prediction, detection, warning, mitigation and relief operations and also acknowledge the important role of Radiocommunication Study Group 7 and remote sensing in disaster management;

b) that Resolution **673 (Rev.WRC-12)** resolves: "to continue to recognize that the use of spectrum by Earth observation applications has a considerable societal and economic value; to urge administrations to take into account Earth observation radio-frequency requirements and in particular protection of the Earth observation systems in the related frequency bands; and, to encourage administrations to consider the importance of the use and availability of spectrum for Earth observation applications prior to taking decisions that would negatively impact the operation of these applications",

noting

that ITU-D Report Question 22/2 – Utilization of ICT for disaster management, resources, and active and passive space-based sensing systems as they apply to disaster and emergency relief situations, is a guideline document meant to facilitate the implementation of the Common Alerting Protocol (CAP) standard for public alerting and hazard notification in disasters and emergency situations,

recommends

1 that administrations should become familiar with the applications of satellite-borne remote sensors relevant to managing the response to natural disasters and similar emergencies as explained in Annex 1;

2 that administrations and operators should continue supplying disaster-related environmental data as described in Annex 2.

NOTE 1 – This Recommendation should be complemented by a new Recommendation on the use of collected data.

Annex 1

Use of remote sensing systems for data collections to be used in the event of natural disasters and similar emergencies

1 Introduction

Meteorological aids, meteorological-satellite and Earth exploration-satellite services play a major role in activities such as:

– identifying areas at risk;

– forecasting weather and predicting climate change;

– detecting and tracking earthquakes, tsunamis, hurricanes, forest fires, oil leaks, etc.;

– providing alerting/warning information of such disasters;

– assessing the damage caused by such disasters;

– providing information for planning relief operations; and

– monitoring recovery from a disaster.

These services provide useful if not essential data for maintaining and improving accuracy of weather forecasts, monitoring and predicting climate changes and for information on natural resources. The frequencies used by those services and their associated applications are summarized in Table 1.

TABLE 1

Frequency bands used in remote sensing for disaster prediction and detection

Band (GHz)	Hazard allocation	Coastal hazards and tsunamis	Drought	Earthquake	Extreme weather	Floods	Landslides	Pollution (Ocean)	Sea and lake ice	Volcanoes	Wildfires
0.43	A	X	X	X		X	X			X	X
1.25	A	X	X	X		X	X	X	X	X	
1.42	P		X			X	X				X
1.67	P										
2.65	p		X			X	X				X
3.20	a										
4.30	p										
4.90	p		X								
5.30	A	X	X	X		X	X	X	X	X	X
6.70	p		X								
7.15	p		X						X		
8.60	A		X	X	X	X	X		X		X
9.60	A		X	X	X	X	X		X		X
10.65	P	X	X		X	X	X		X		
13.50	A		X		X	X	X		X		X
15.30	p										
15.40	P	X			X	X	X				
17.25	A		X		X						X
18.70	P	X	X		X	X	X				
21.30	P	X	X		X	X	X		X		
22.30	P	X	X		X	X	X				
23.80	P	X	X		X	X	X				

TABLE 1 (*end*)

Band (GHz)	Hazard allocation	Coastal hazards and tsunamis	Drought	Earthquake	Extreme weather	Floods	Landslides	Pollution (Ocean)	Sea and lake ice	Volcanoes	Wildfires
24.10	A		X		X	X	X				
31.50	P	X	X		X	X	X		X		
35.55	A		X		X	X	X				
36.50	P	X	X		X	X	X		X		
50.30	P	X	X		X	X	X				
55.00	P	X	X		X	X	X				
64.50	P										
78.50	A				X						
89.00	P					X	X		X		
94.00	A				X						
101.0	P		X		X						
110.0	P										
118.0	P	X	X		X	X	X				
150.5	P	X	X		X	X	X				
157.0	P										
166.0	P	X	X		X	X	X				
175.5	P	X	X		X	X	X				
183.0	P	X	X		X	X	X				
201.0	P	X	X		X	X	X				

NOTE – A and P refer to active and passive allocations for remote sensing in these frequency bands. Upper case indicates a primary allocation, and lower case indicates a secondary allocation.

On-the-ground, at-the-spot (*in situ*), at-the-time measurements or observations are usually more precise and more accurate than similar observations made from space. These kinds of observations are known as "ground truth" and are used to calibrate spaceborne instrumentation. However, when *in situ* instrumentation or the supporting infrastructures necessary to use such instrumentation are not in place or have been disabled by the disaster, or the ground measurements are not accurate enough, spaceborne observations can provide information helpful in responding to the effects of disasters. Spaceborne observations are particularly useful when the areas are vast, the population densities low, and the technical infrastructure is vulnerable or not well developed.

Descriptions of how data products from satellites may be useful in responding to the effects of natural and man-made disasters follow. These application include those which are in current operation as well as those which are plausible for future implementation. This list is not exhaustive.

2 Coastal hazards/tsunami

Spaceborne sensors can help identify areas at risk by using synthetic aperture radar (SAR)-generated digital elevation models (DEMs) to locate low areas subject to flooding, or by using SAR-generated bathymetry to identify ocean bottom structure that might worsen the incoming tsunami or storm surge.

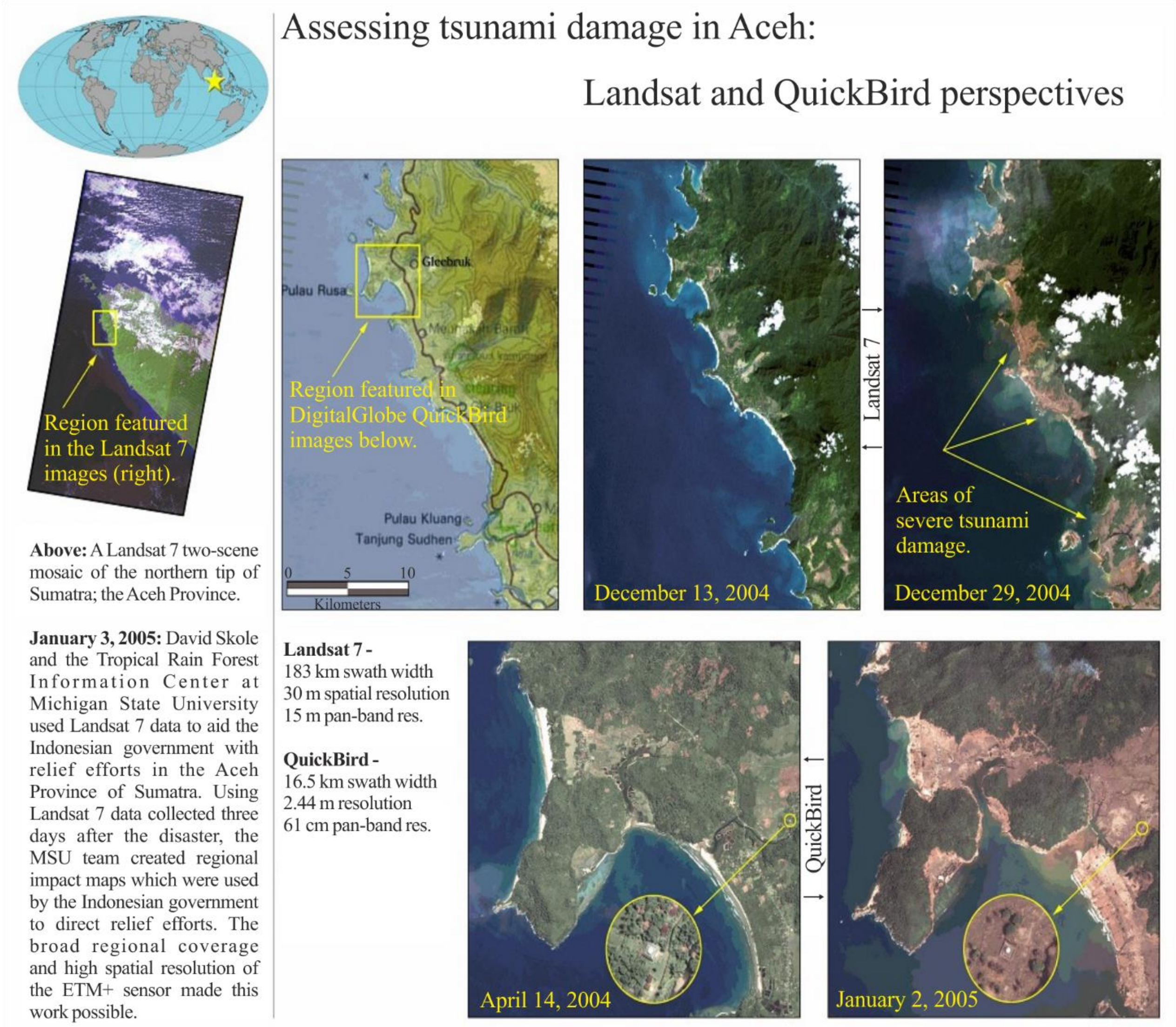
Severe weather events, such as tropical cyclones and typhoons that produce storm surges, can be tracked by weather satellites. Such tracking can be used to alert vulnerable areas of the potential danger, usually days in advance.

The extent of the damage can be determined using moderate- and high-resolution visible/infrared imagery from satellite-borne instruments. Lower resolution SAR imagery, which is unaffected by rain, cloud cover, and nightfall can also be used to show the areas affected. The ability of SARs to penetrate clouds and provide all-weather capability is particularly useful in cloud-prone areas such as central Africa, the Amazon, and island areas such as Indonesia.

As an example, following a 9.0 magnitude earthquake off the coast of Sumatra, a massive tsunami and tremors struck Indonesia and southern Thailand on 26 December 2004, killing over 104 000 people in Indonesia and over 5 000 in Thailand. Medium and high resolution optical images of the Aceh Province in Indonesia taken before and after the tsunami of 26 December 2004 by low Earth orbiting satellites are shown in Fig. 1. Images, such as these, provided authorities a comprehensive assessment of the damage.

FIGURE 1

Tsunami damage in Aceh Province, Indonesia



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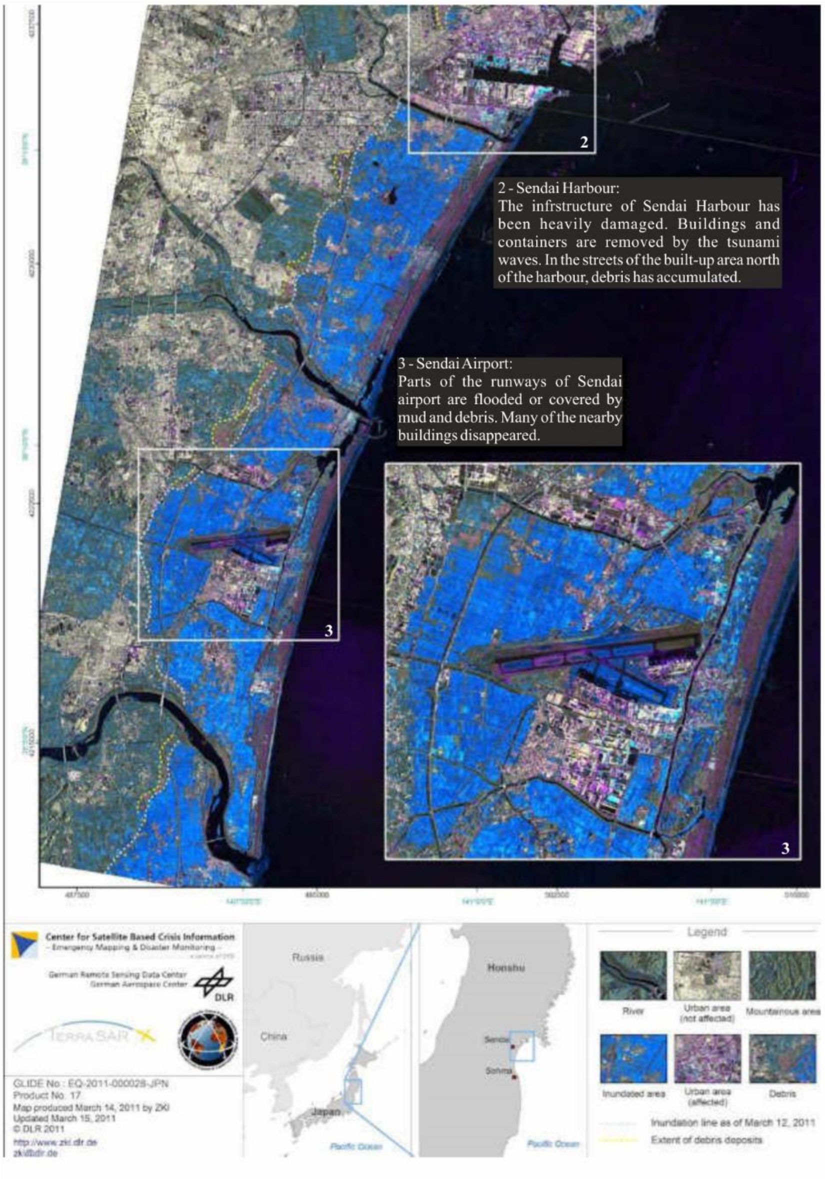
The two sets of images in Fig. 1 show the value of having two different instruments. Landsat imagery covers a larger area and helps identify regions impacted, while the QuickBird imagery shows the damage in greater detail but is limited to a much smaller area.

SAR imagery provides a very accurate indication of flooded areas, as the backward reflection from surface water into side scanning SARs is virtually zero. An example is given in Fig. 2 which shows the flooding following the tsunami of 11 March 2011, which struck Japan following an undersea earthquake.

FIGURE 2

Flooded areas around Sendai, Japan following the 11 March 2011 Tsunami



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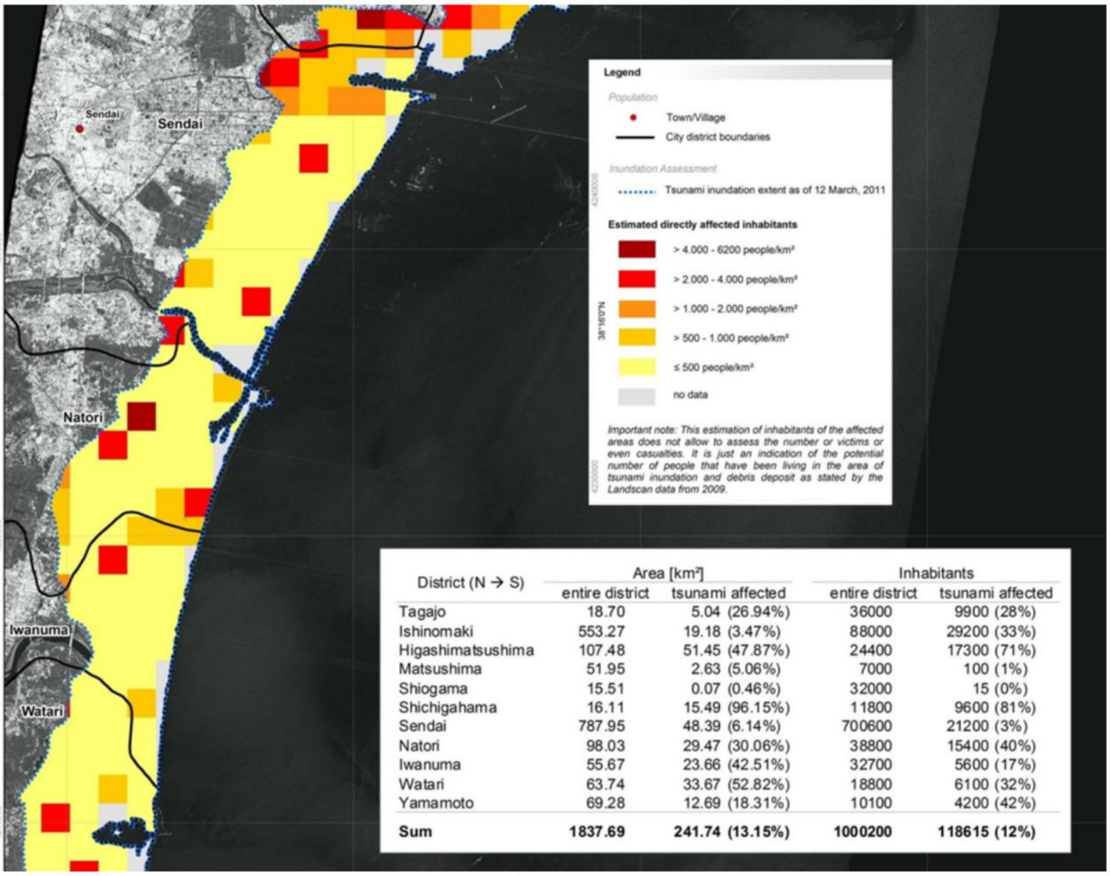
The areas inundated are clearly indicated in blue. By combining such information with population data, the most affected populated areas can be found as seen in Fig. 3.

FIGURE 3

Determining the severity of the population at risk through an analysis of flood and population data



District (N → S)	Area [km²]		Inhabitants	
	entire district	tsunami affected	entire district	tsunami affected
Tagajo	18.70	5.04 (26.94%)	36000	9900 (28%)
Ishinomaki	553.27	19.18 (3.47%)	88000	29200 (33%)
Higashimatsushima	107.48	51.45 (47.87%)	24400	17300 (71%)
Matsushima	51.95	2.63 (5.06%)	7000	100 (1%)
Shiogama	15.51	0.07 (0.46%)	32000	15 (0%)
Shichigahama	16.11	15.49 (96.15%)	11800	9600 (81%)
Sendai	787.95	48.39 (6.14%)	700600	21200 (3%)
Natori	98.03	29.47 (30.06%)	38800	15400 (40%)
Iwanuma	55.67	23.66 (42.51%)	32700	5600 (17%)
Watari	63.74	33.67 (52.82%)	18800	6100 (32%)
Yamamoto	69.28	12.69 (18.31%)	10100	4200 (42%)
Sum	**1837.69**	**241.74 (13.15%)**	**1000200**	**118615 (12%)**

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Such analyses can guide rescue efforts and maximize their effectiveness.

3 Drought

The onset and progress of a drought can be observed from space by noting soil moisture, rainfall, and the distress level of the vegetation in the affected areas. Long-range predictions of regional drought conditions can be made by tracking the Pacific Ocean temperatures and sea levels, which give an indication of the onset of an El Nino event, or the opposite condition, a La Nina event.

During an El Nino event, the equatorial eastern Pacific is warmer and the ocean is high due to thermal expansion. Droughts frequently occur in Australia and Indonesia under these conditions, and the trade winds are weaker. Conversely, during a La Nina event, the equatorial eastern Pacific is cooler and the ocean height is lower due to thermal compression. The western coasts of the Americas experience dry conditions, and the trade winds are stronger. Among the indicators used to forecast El Nino/La Nina events are zonal winds, sea surface temperatures and temperature anomalies, sea level anomalies, and outgoing longwave radiation, all of which are monitored by satellites. Monitoring conditions in the Pacific from remote sensing satellites provides advance notice of the onset of an El Nino/La Nina event (see Fig. 4).

FIGURE 4

El Nino and La Nina events in the Pacific Ocean

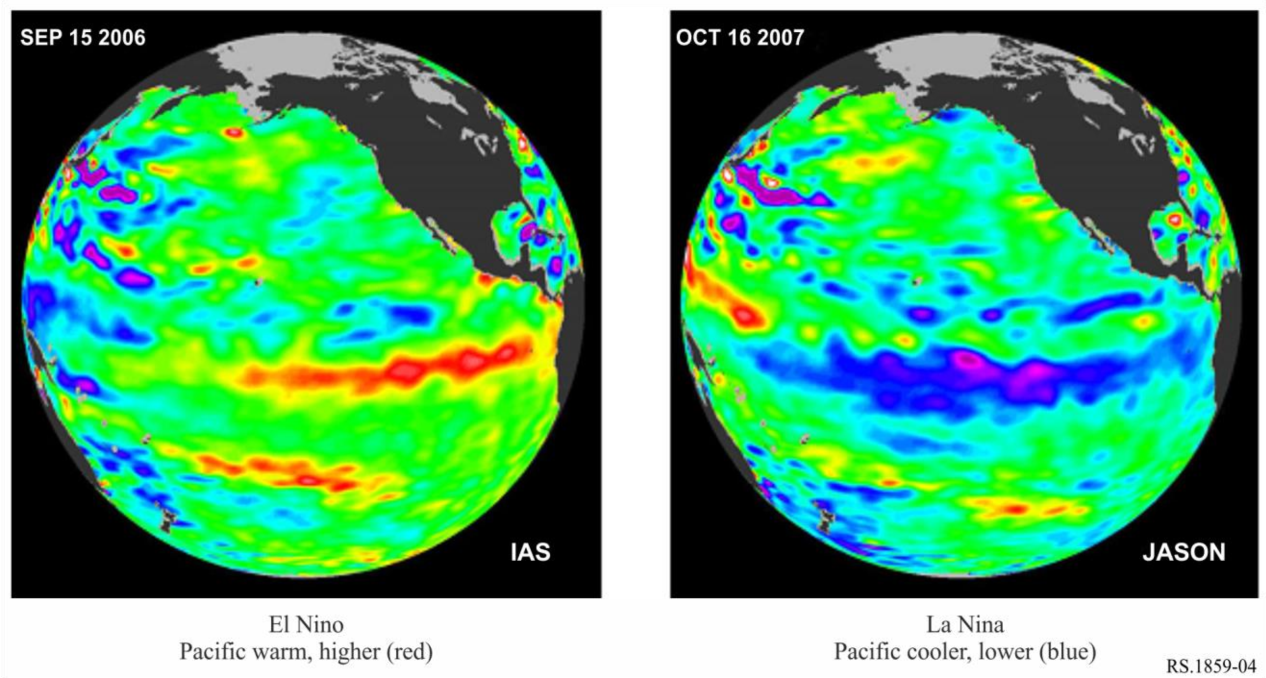
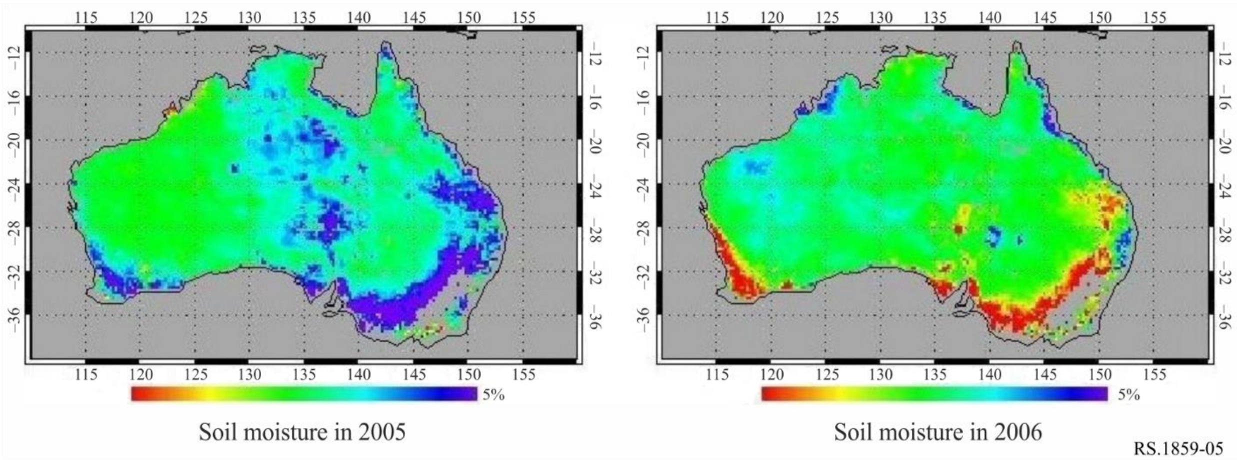


Figure 5 shows a yearly change of soil moisture distribution in Australia during October in 2005 and in 2006. This data was acquired by channels of AMSR-E mounted on Aqua. Red indicates low amounts of soil moisture, while blue indicates higher amounts of soil moisture. The percentage indicated (unit of soil moisture) means the difference from averaged soil moisture for two years (2005-2006). A drought occurred in the south east area (Granary area) of Australia in 2006. This condition is consistent with the El Nino observations shown in Fig. 4.

FIGURE 5

AMSR-E measurements of drought in Australia in October 2005 and October 2006



Source: AMSR-E on AQUA

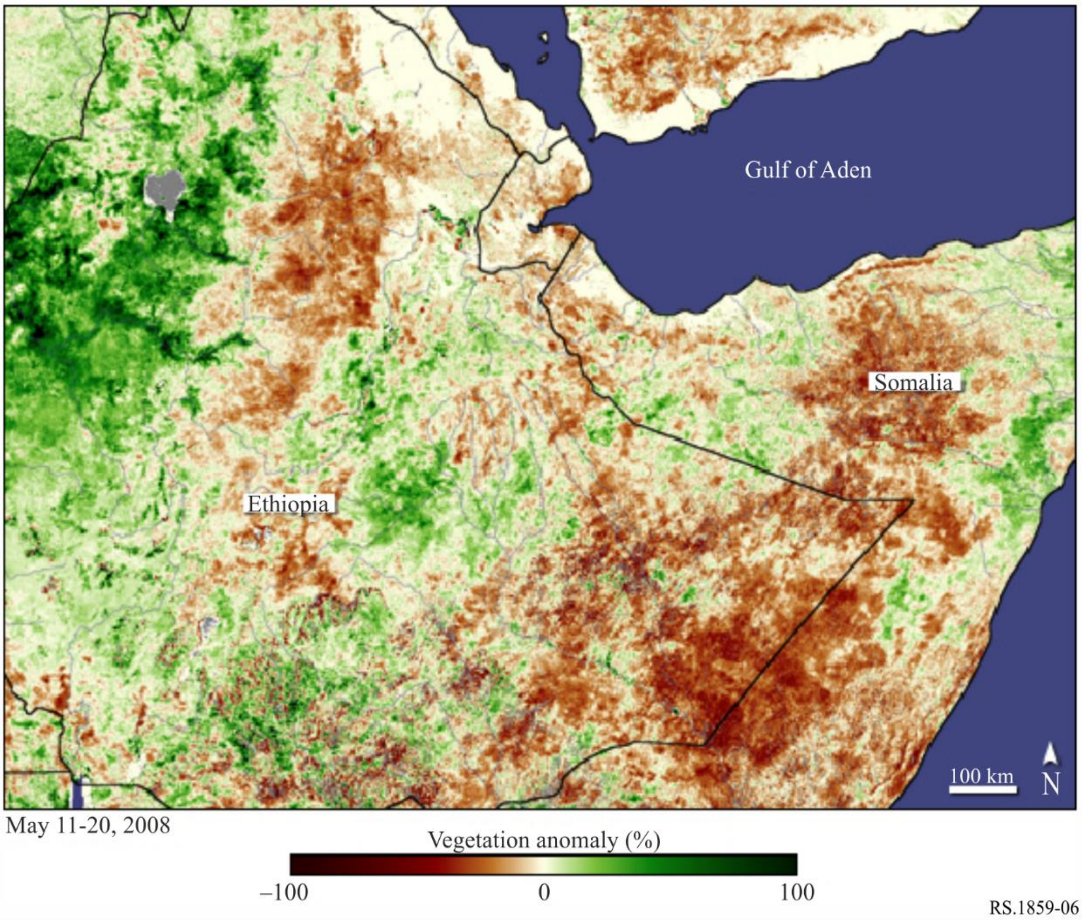
By the end of May 2008, the United Nations Children's Fund (UNICEF) reported that millions faced hunger in eastern Ethiopia as crops failed and food prices soared. Two successive seasons of poor rains left eastern Ethiopia in drought, and the effect on vegetation is shown Fig. 6. Made from data collected by the SPOT Vegetation satellite between 11 May and 20 May 2008, the vegetation anomaly image compares the relative healthiness of plants to average conditions. Areas in which plants were smaller, less thick, or grew more slowly than average are brown, while areas where vegetation was experiencing better than average conditions are illustrated in green.

Satellite-based remote sensors have proven useful in providing an overall assessment of drought conditions, and have on occasion identified nearby, previously unrecognized areas having much better than average crops. Such information enabled quick yet inexpensive relief to be provided since transportation time and costs were minimized (i.e. using nearby trucks instead of distant airplanes). The situation in Ethiopia presented such a picture of contrasts. While the eastern half of the country withered in drought, western crop areas received ample rain and thrived. The drought limited the production of both food and cash crops like coffee, said the Famine Early Warning Systems Network[1]. UNICEF estimated that 3.4 million people would need food aid in June, July and August as crops continued to fail.

FIGURE 6

Vegetation state during the Ethiopian drought of 2008

Brown indicates distressed vegetation; green indicates healthy vegetation



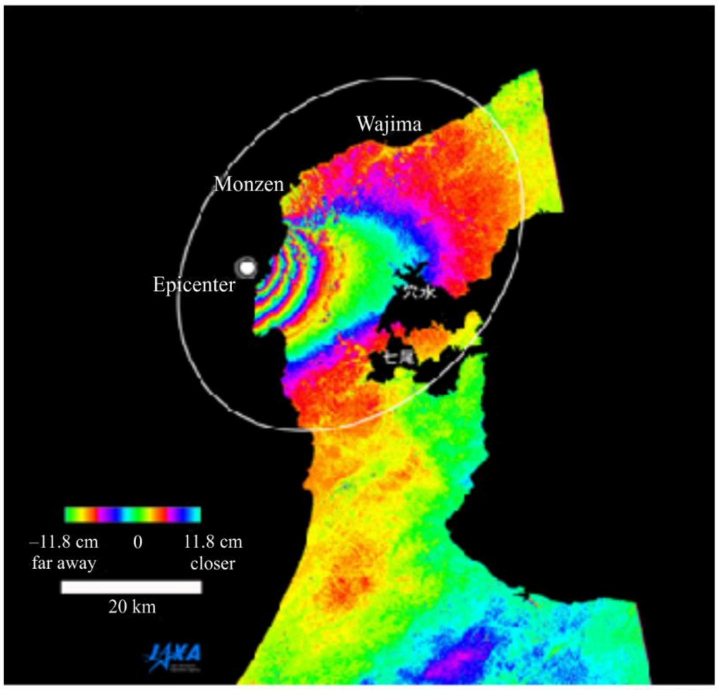
1 http://www.fews.net/

4 Earthquake

After a major earthquake has occurred, the sooner an accurate damage estimate is made, the sooner the appropriate rescue assets can be mobilized. The damage-estimate decision support systems employed by administrations and NGOs utilize population density, type of building construction, and local terrain (topography and soil type) and the location and magnitude of the earthquake to estimate the damage. Seismographs, interferometric SAR measurements (InSAR), and *in situ* measurements using Global navigation satellite systems (GNSS) provide a means of determining the location and extent of the rupture for use in estimating the damage. InSAR observations pinpoint the location of earthquake epicentres far more accurately than remote seismographs, thus enabling more precise damage estimates which in turn define relief efforts. The recent launches of fleets of SAR-equipped satellites (COSMO-SkyMed (ASI), TDX and TSX (DLR), the Sentinel–1 series (ESA), and the upcoming RADARSAT constellation (CSA) have made these assessments more readily available than in the past.

FIGURE 7

PALSAR measurements of change of land surface before and after earthquake in Noto peninsula of Japan on 25 March 2007



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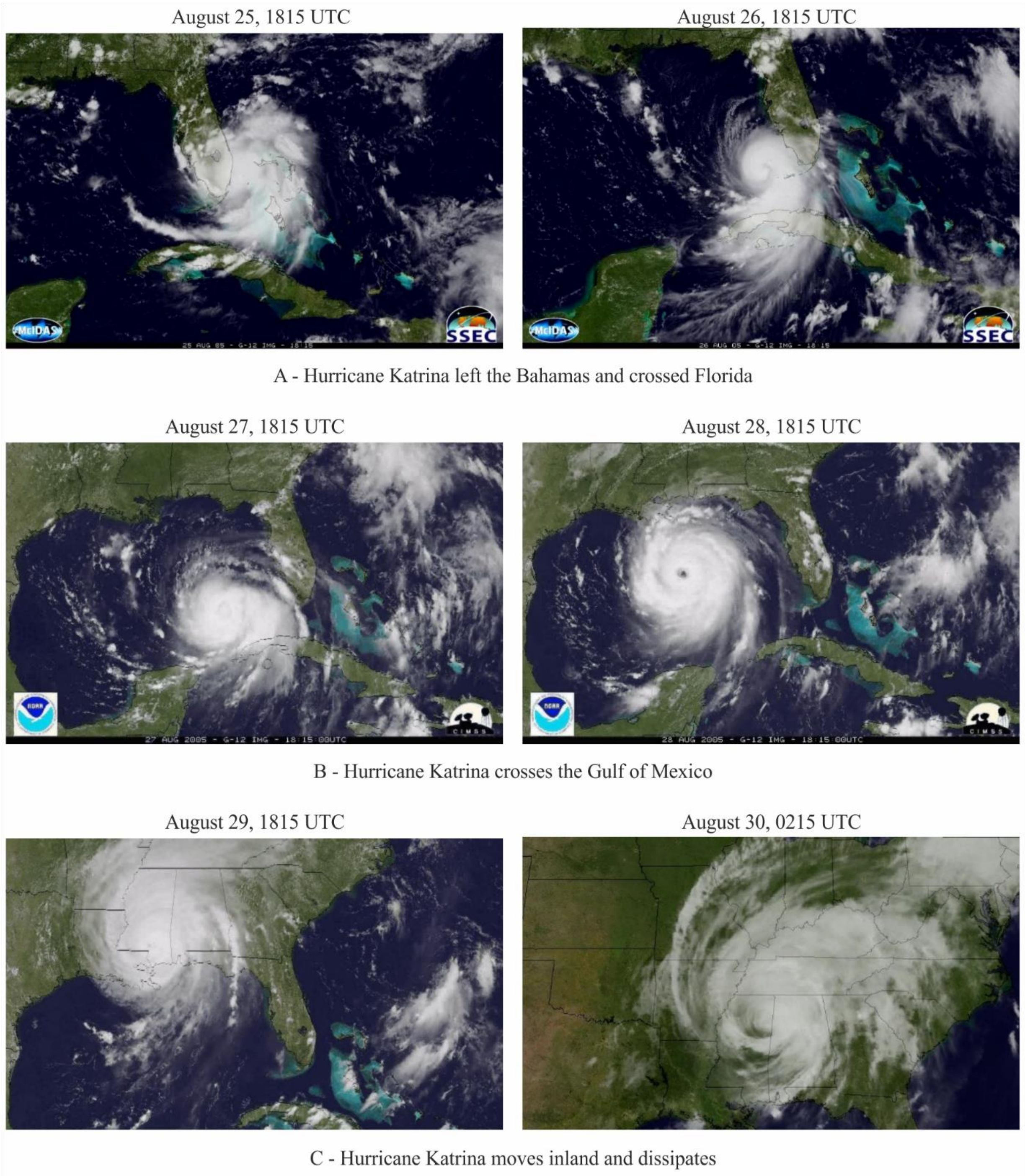
Usually the ground movements associated with earthquakes are too small to appear in satellite visible or infrared imagery. However, visual imagery can be very useful in directly assessing the damage caused by an earthquake and in guiding rescue efforts.

5 Extreme weather

Today, operational meteorological, or weather, satellites GOES, Meteosat, MetOp, POES cover almost the entire globe and are either geostationary or in low-Earth polar orbits. Geostationary satellites orbit at the same rate as the Earth and appear as a stationary point in the sky at an altitude of about 35 800 km. Such satellites provide superior temporal resolution with images available every 15-30 min (see Fig. 9) and support monitoring the cloud structure, extent, and overall motion of extreme weather. In using the data from these geostationary weather satellites, one can see where the damage has already occurred, and forecast where the storm is going. Major storms can be tracked as they cross the oceans, and the landfall areas at risk can be identified allowing the inhabitants to be warned days in advance. Figures 8A to 8C show the daily location of hurricane Katrina, including the day it struck the city of New Orleans, 29 August 2005. It was observed as a tropical storm over the Bahamas on 24 August, crossed the Florida peninsula on 25-26 August, and gained strength over the warm waters of the Gulf of Mexico on 26 and 27 August.

FIGURE 8

A –Hurricane Katrina left the Bahamas and crossed Florida



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The eye of the hurricane was fully developed on August 28.

Hurricane Katrina hit New Orleans on 29 August 2005 and caused considerable devastation.

Hurricane Katrina dissipated after crossing onto dry land and was downgraded to a tropical storm, and then to a tropical depression on 30 August.

Polar orbiting satellites operate at much lower altitudes than geostationary satellites and typically overfly an area twice a day, once in daylight and once in the night. Polar orbiting satellites provide more detailed, but less timely, observations. Much of this pertinent data is available through the Internet a few days after it has been collected and processed. When local weather information is needed immediately, relatively inexpensive ground stations can be purchased, installed, and used to gather real-time data that is continually broadcast from polar orbiting satellites passing overhead.

Figure 9 shows an image of Hurricane Dean observed by GOES from geosynchronous altitude.

More detailed weather conditions can be observed using radar scatterometer techniques which measure sea surface wind speed and direction. Figure 10 shows a QuikScat observation of Hurricane Dean (2007) revealing the sea surface wind speed and direction. QuikScat was a low Earth orbiting spacecraft in polar orbit and could not provide the continuous coverage afforded by the GOES observations from geosynchronous orbit. Unfortunately, scatterometers cannot operate in the geosynchronous orbit. Nonetheless, radar scatterometers such as QuikScat and its replacement, RapidScat on the International Space Station, can provide very useful additional information to weather forecasters.

The combination of data from these and other satellites help provide a better understanding of the nature of each hurricane and help predict where, when, and how strong the hurricane will be in the near future.

FIGURE 9

Hurricane Dean observed by GOES from geosynchronous altitude

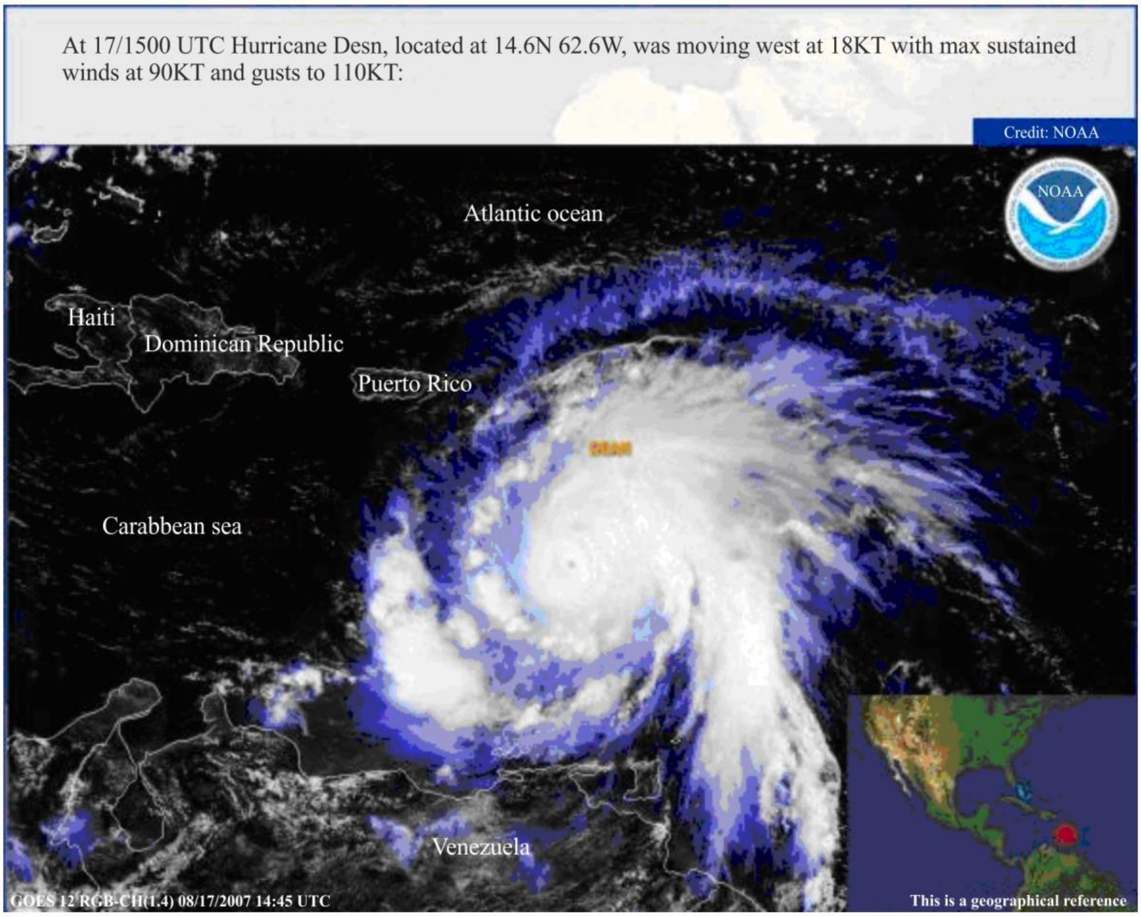

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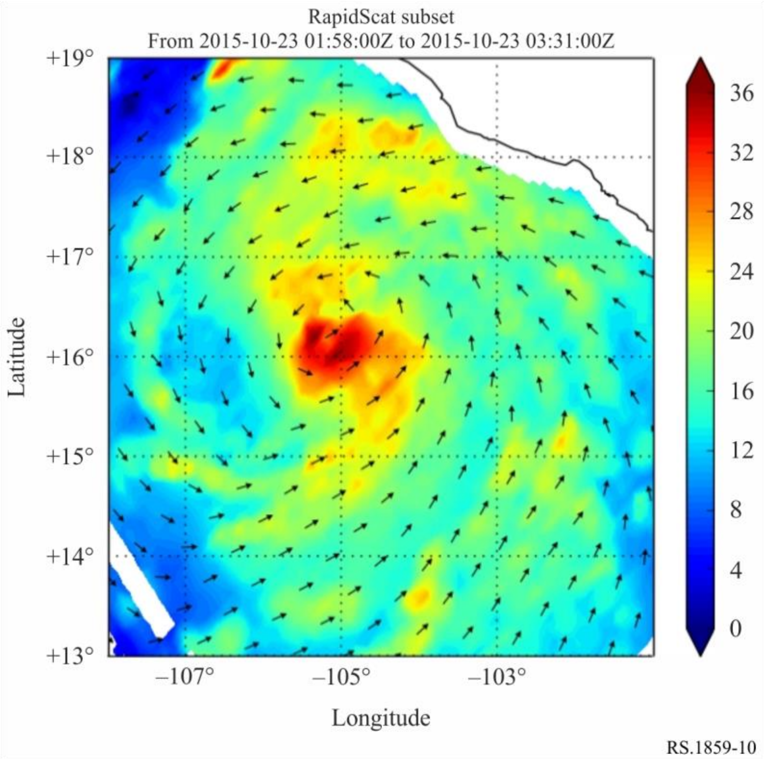
FIGURE 10

RapidScat observation of Hurricane Patricia, 23 October 2015

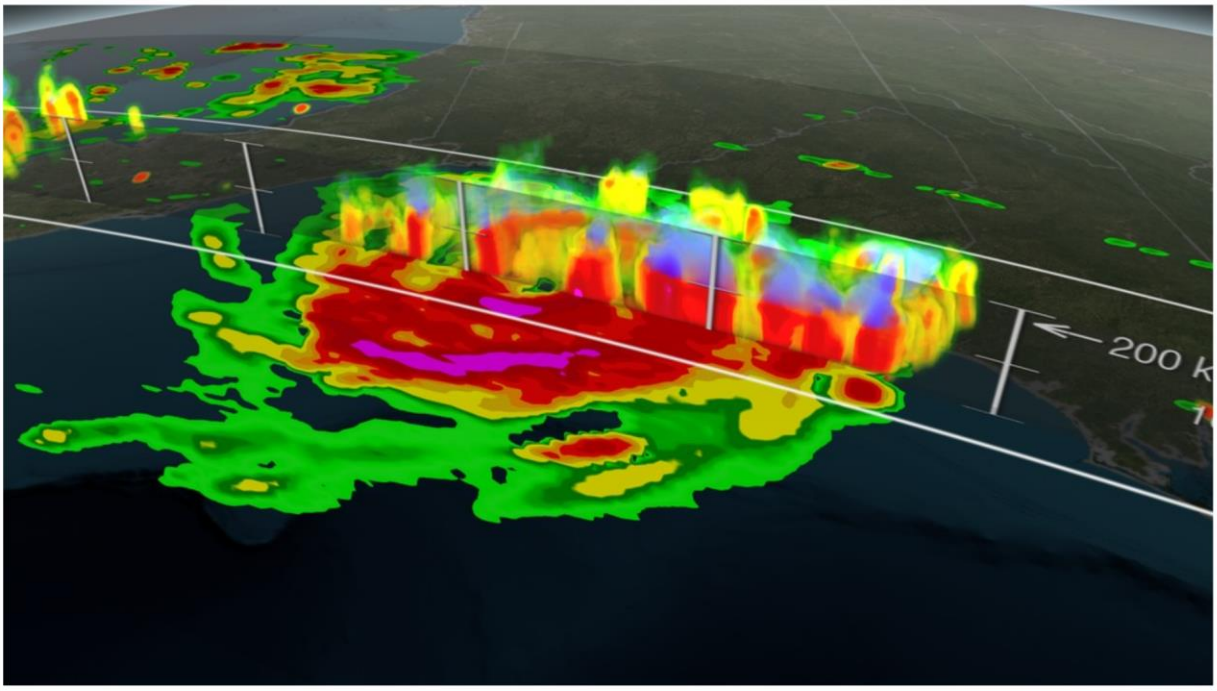


Precipitation radars flown on the Global Precipitation Mission (GPM) provide three-dimensional images of the rainfall from severe storms. This mission includes passive instruments which provide complimentary storm information extending beyond the swath of the radar.

Figure 11 shows Hurricane Arthur as seen by GPM's GPM Microwave Imager (swath 680 km) and Dual Precipitation Radars (Ka band swath width 120 km, Ku band swath width 245 km) sensors. This is Hurricane Arthur on 3 July 2014 off the South Carolina coast. Colours ranging from light green to red indicate areas of low to high liquid precipitation. The violet areas in the upper atmosphere are areas showing frozen precipitation.

FIGURE 11

GPM observations of Hurricane Arthur on 3 July 2014



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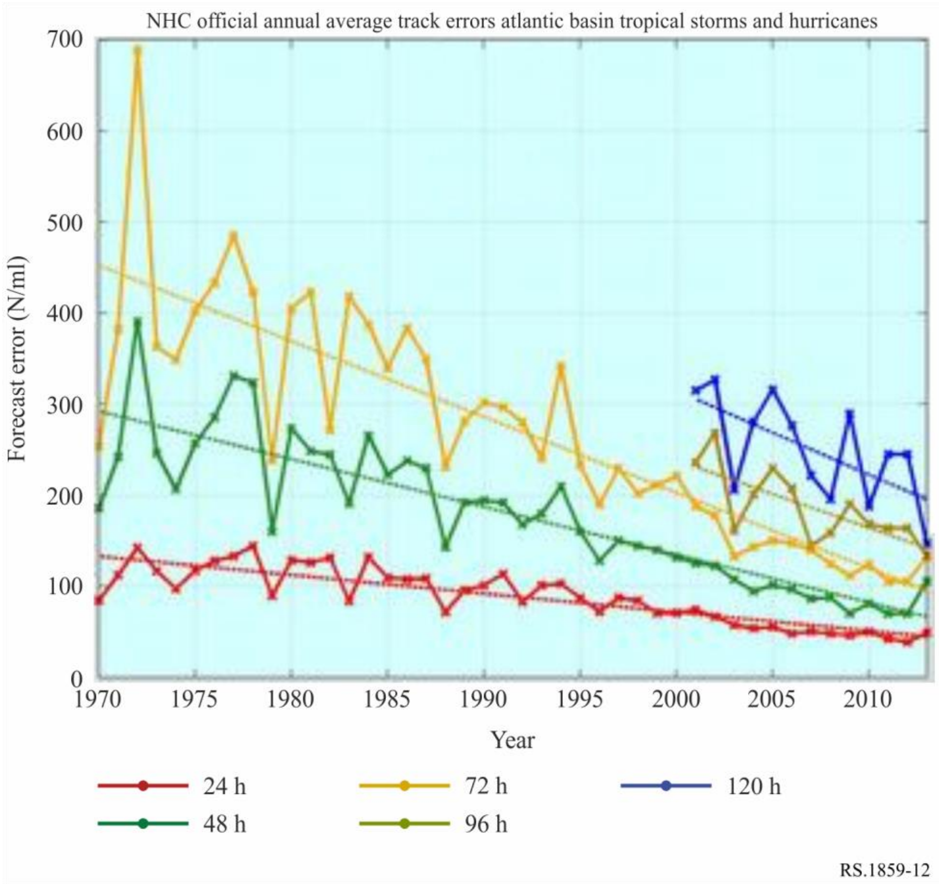
The combination of data from these and other satellites help provide a better understanding of the nature of each hurricane and help predict where, when, and how strong the hurricane will be in the near future. The error in forecasting the tracks of Atlantic hurricanes has improved markedly in the last 35 years (see Fig. 12), and has resulted in saving lives and preventing property damage.

FIGURE 12

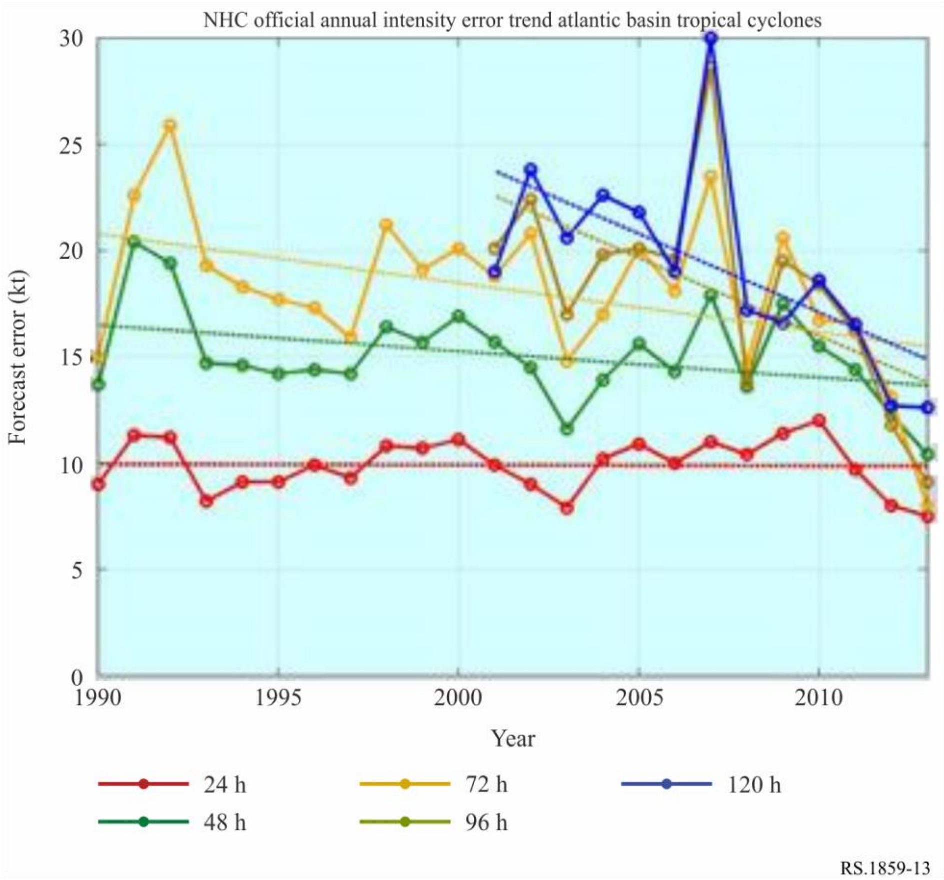
Track error trend for Atlantic basin forecasts



Unfortunately, the ability to forecast the intensity of such storms, as determined by wind speed, has not improved as much (see Fig. 13).

FIGURE 13

Intensity error trend for Atlantic basin forecasts



Modern weather forecast centres provide higher quality forecasts than were available in the past and constitute another source of extremely useful data. A partial list of major weather forecast centres includes:

1 European Centre for Medium-Range Weather Forecasts (http://www.ecmwf.int/)

2 Italian Meteorological Service (http://www.meteoam.it/)

3 National Center for Environmental Prediction (http://www.ncep.noaa.gov/)

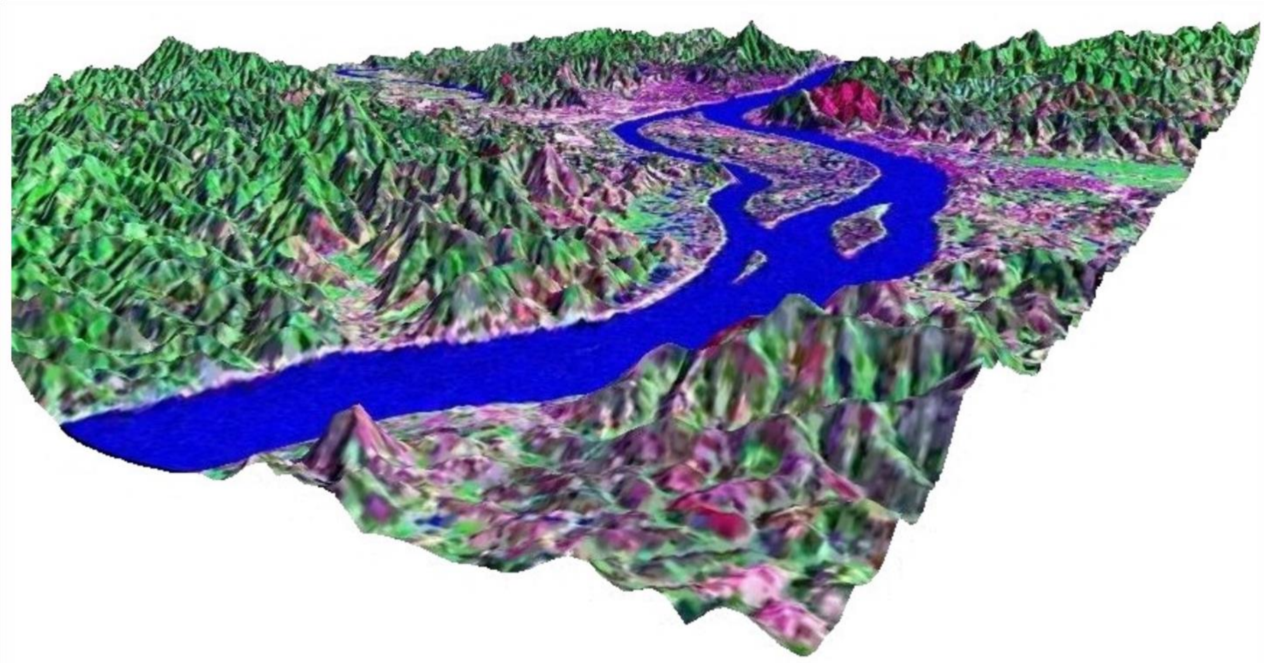
The World Meteorological Organization (WMO) (http://www.wmo.int/) coordinates the distribution, format, and organization of such data worldwide.

6 Floods

Long before a flood occurs, the areas vulnerable to being flooded (areas at risk) can be identified with the help of satellite-derived DEMs. These DEMs enable the topology of remote low-lying areas to be mapped. Land-use maps help quantify the risk by identifying populated areas. Attention can then be focused on identifying the infrastructure (roads, bridges, communications, etc.) needed to help when a flood occurs (see Fig. 14) and on planning appropriate evacuation strategies.

FIGURE 14

A Landsat image, circa 2000, draped over a SRTM[2] DEM of the city of Wuzhou in the province of Guangxi in China (populated areas appear as reddish-purple)



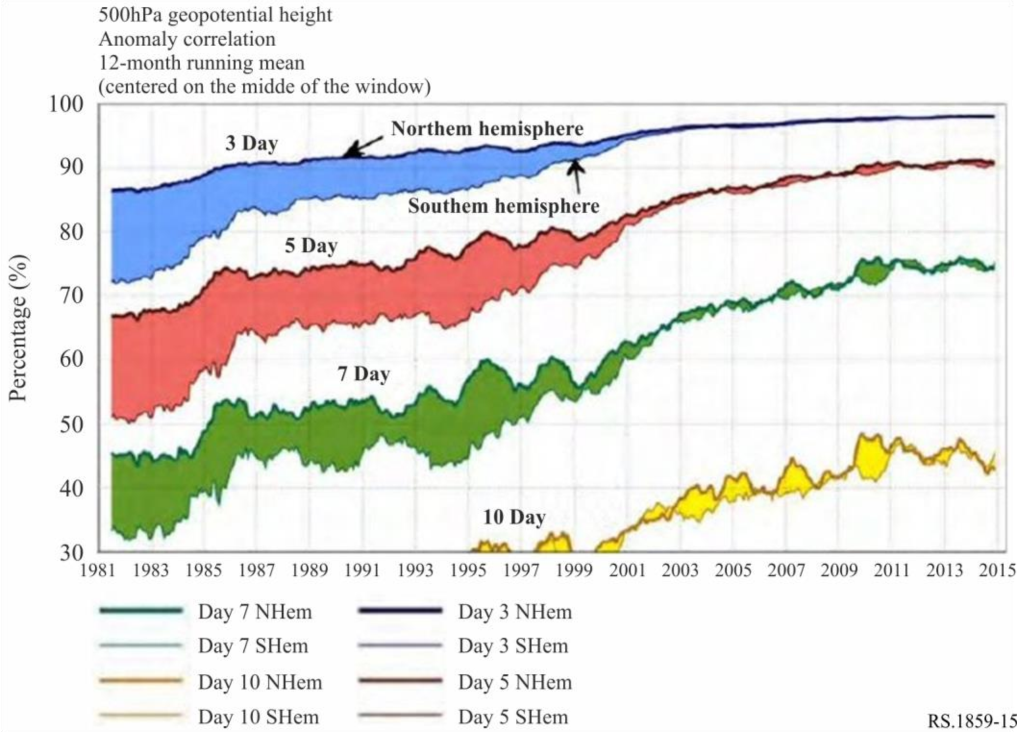
Weather monitoring and weather forecasts can provide warnings that floods are possible or imminent. Supporting data products include areal precipitation, water equivalent from snowfall, and soil moisture, which, in combination, indicate whether the ground will absorb more rain or is saturated. The issuance of earlier credible warnings can result in improving the movement of populations out of flood plains. Fortunately, intermediate-range weather forecasting (3 to 10 days) has improved markedly in recent decades.

Much of the improvement in such weather forecasts resulted from better forecasting weather models, faster computers to run the models, and better and more complete data to be assimilated by the software. A major improvement resulted from satellite-based remote sensors providing atmospheric temperature and humidity profiles. Although such profiles have been gathered in the past from data from radiosondes flown on balloons twice daily worldwide, the coverage in the southern hemisphere and over the oceans did not match the coverage available over more densely populated areas in the northern hemisphere. This improvement in forecasting provided by the addition of satellite-based remote sensors is shown on Fig. 15 below.

[2] Shuttle Radar Topography Mission (SRTM), https://lta.cr.usgs.gov/SRTM1Arc.

FIGURE 15

Mean annual forecast skill for the European Centre for Medium Range Weather Forecasting

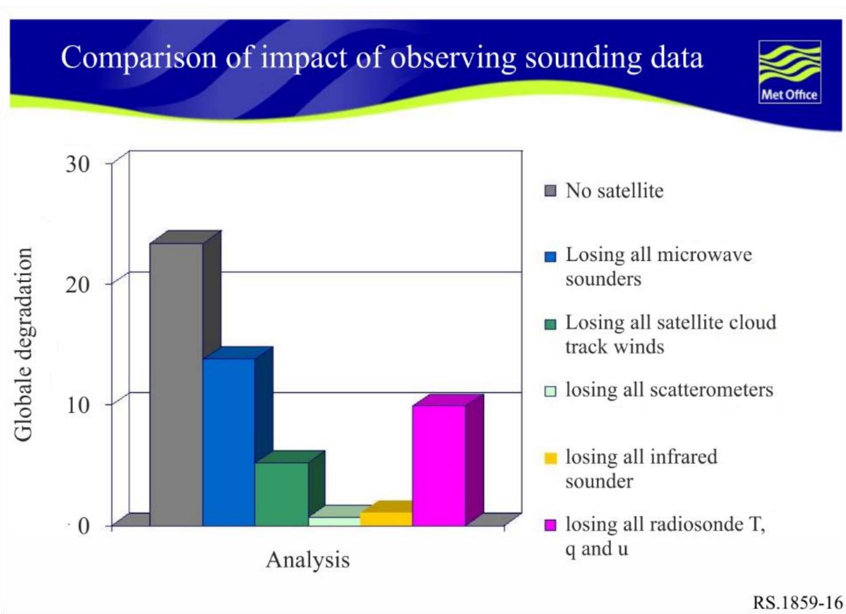


The improvement in forecasting skill and utility is largely due to the atmospheric temperature and humidity profile data provided by passive microwave instruments operating in bands protected by RR No. **5.340**.

These profiles are the most important data gathered from satellite and balloon sources when comparing the relative impact of various data inputs in weather forecast accuracy (see Fig. 16).

FIGURE 16

Comparison of the worth of sounding data



While infrared sounders and radiosondes provide more precise measurements, the ability of satellite microwave sounders to operate regardless of cloud cover (which typically obscures 60% of the

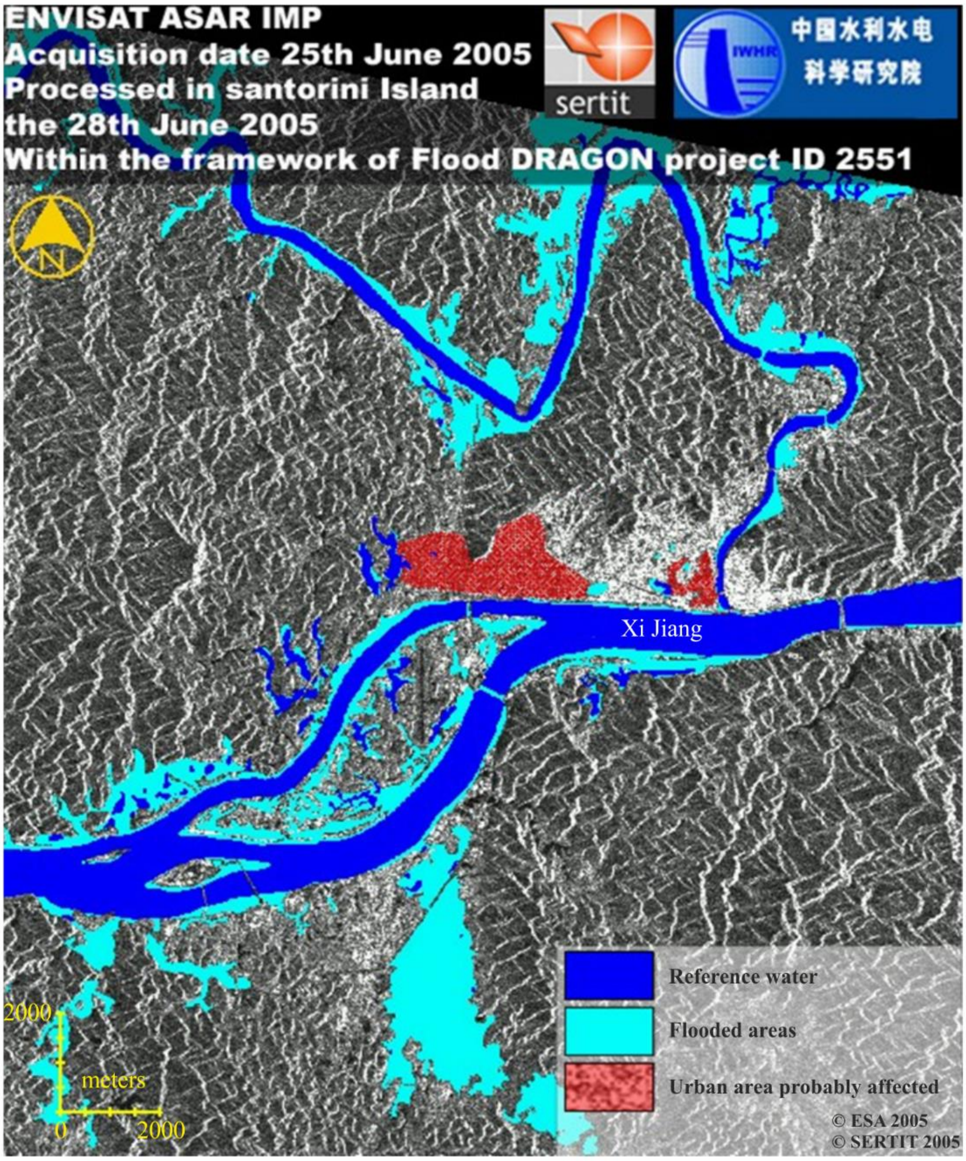
Earth and hinders infrared observations) and to provide global coverage twice daily (unlike the non-uniform coverage provided by radiosondes) yields greater value to the forecasting community.

When one buys a loaf of bread, one rarely sees the field of wheat or a single stalk of the wheat needed to produce the bread. Similarly, when one reads or hears a weather forecast, one does not see the data that went into the forecast. Without the satellite profiles of atmospheric temperature and humidity, there would be no modern weather forecasts. Although not obvious to the general public, the passive frequency bands used to produce the data used in weather forecasts are crucial and must be protected.

During a flood event, imagery from multispectral and/or panchromatic imagers and synthetic aperture radars can help guide rescue workers to the specific areas affected and help assess the overall damage. Prior to a flood, SAR images may be combined to produce elevation maps which make it easier to identify areas vulnerable to flooding. The ability of SARs to penetrate clouds and provide all-weather and day-and-night capability is particularly useful during a flood-producing storm or rainy season. As SARs are side-looking radars and the off-axis backscatter from water is minimal, and as a result, flooded areas are easier to identify on SAR images than on optical images. An example of the ability of SARs to define flooded areas is given in Fig. 17.

FIGURE 17

Flooding of the Xi River, affecting the city of Wuzhou in Guangxi Province
Reference data are from Landsat; flood data are from ASAR on Envisat



RS.1859-17

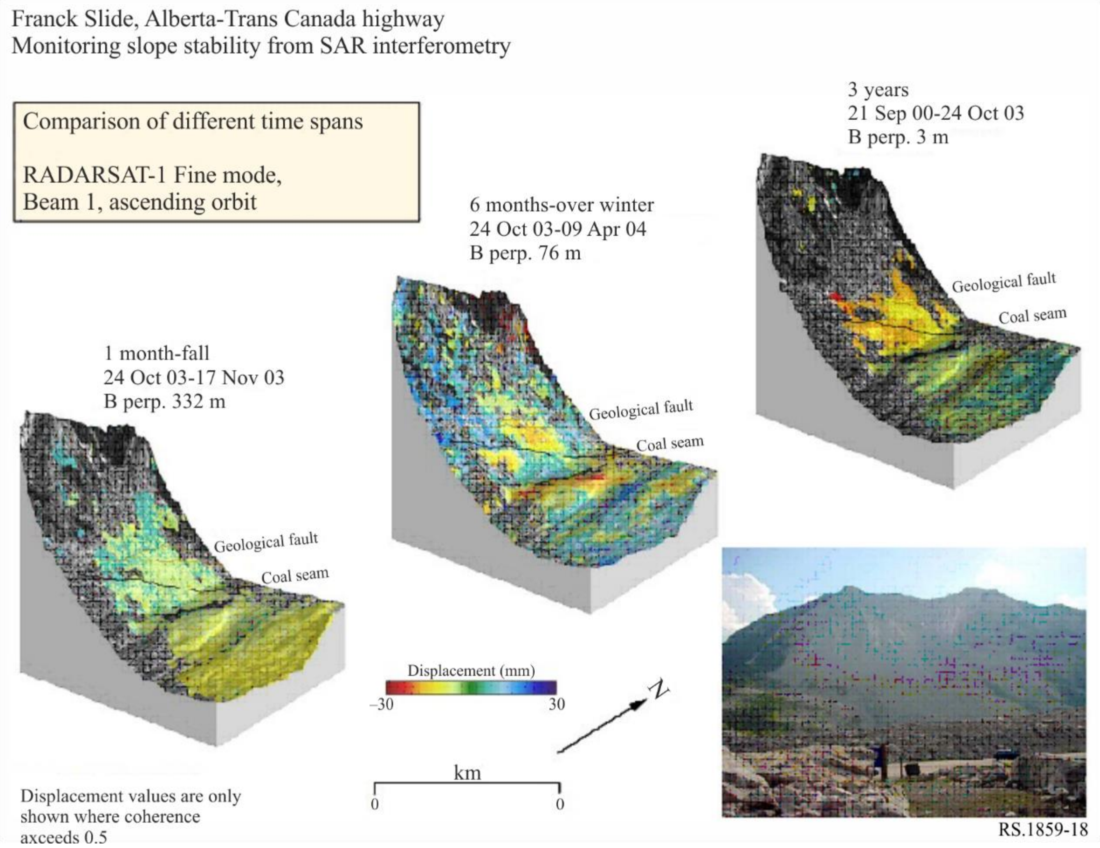
7 Landslides/subsidence/avalanches

Areas vulnerable to landslide activity can be identified using Digital Elevation Maps (DEMs) from SAR measurements. In this case, the slopes rather than the elevations are used. When subtle ground movement is suspected, InSAR and *in situ* GNSS units can provide accurate measurements of where and by how much an area has moved in relation to previous measurements.

After the largest landslide in history in North America, Turtle Mountain, Canada remains a threat. Its ground movement, shown in Fig. 18, is being monitored by Canada's RADARSAT-1 using the InSAR technique.

FIGURE 18

RADARSAT InSAR tracks ground displacement between 2000 et 2004



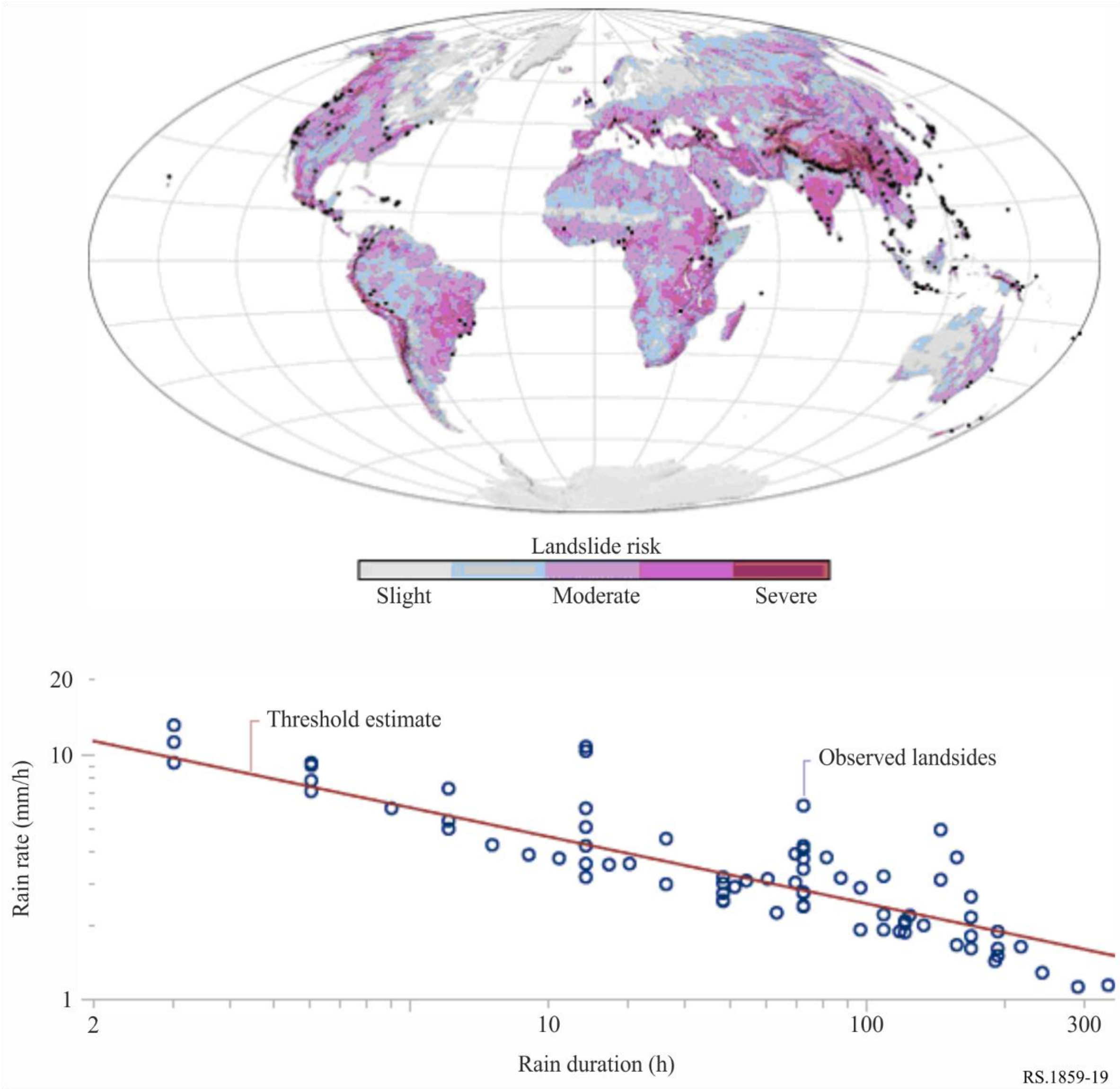
Changes in land cover or land usage can increase the risk of landslides. For example, a heavily logged (deforested) area is far more susceptible to landslides than an area with an established ecosystem that stabilizes the ground. Land-use maps help quantify the risk by identifying populated areas that may be vulnerable. Land cover/land usage can be monitored from space and changes detected to aid in monitoring the risk.

When soil on hillsides becomes saturated with water during a very heavy rainfall, it becomes vulnerable to producing landslides. Thus, forecasts of heavy rainfall coupled with knowledge of the pre-rainfall soil moisture, can be used to provide warnings that landslides may occur. Such information is available from the Global Flood Monitoring System on the Internet (at http://flood.umd.edu).

Satellite data can be used to provide maps indicating the risk of landslides. Data shown on Fig. 19 were derived from topography from SRTM, land cover/usage from MODIS, and rainfall from TRMM.

FIGURE 19

Satellite-derived landslide risk map. Black dots indicate landslides reported from 2003 through 2006



After a landslide has occurred, InSAR images can provide an accurate mapping of the ground movement (subsidence) by comparing before and after SAR imagery of the bare Earth. Other imagery can show the vegetation and other surface features for these affected areas.

As an example of the devastation that can occur with a landslide, the magnitude 7.6 earthquake that occurred in Pakistan on 8 October 2005, caused the most damage in the region surrounding the city of Muzaffarabad, about 10 km southwest of the earthquake's epicentre. The quake flattened buildings and triggered landslides throughout Kashmir. The Ikonos satellite captured a visible spectrum image of a landslide (Fig. 20, right) in Makhri, a village on the northern outskirts of Muzzaffarabad, on 9 October 2005. The western face of the mountain has collapsed, sending a cascade of white-grey rock into the Neelum River.

FIGURE 20

Satellite imagery showing effects of Neelum River Landslide of 8 October 2005 following an earthquake in Pakistan

September 15.2002 October 9.2005

RS.1859-20

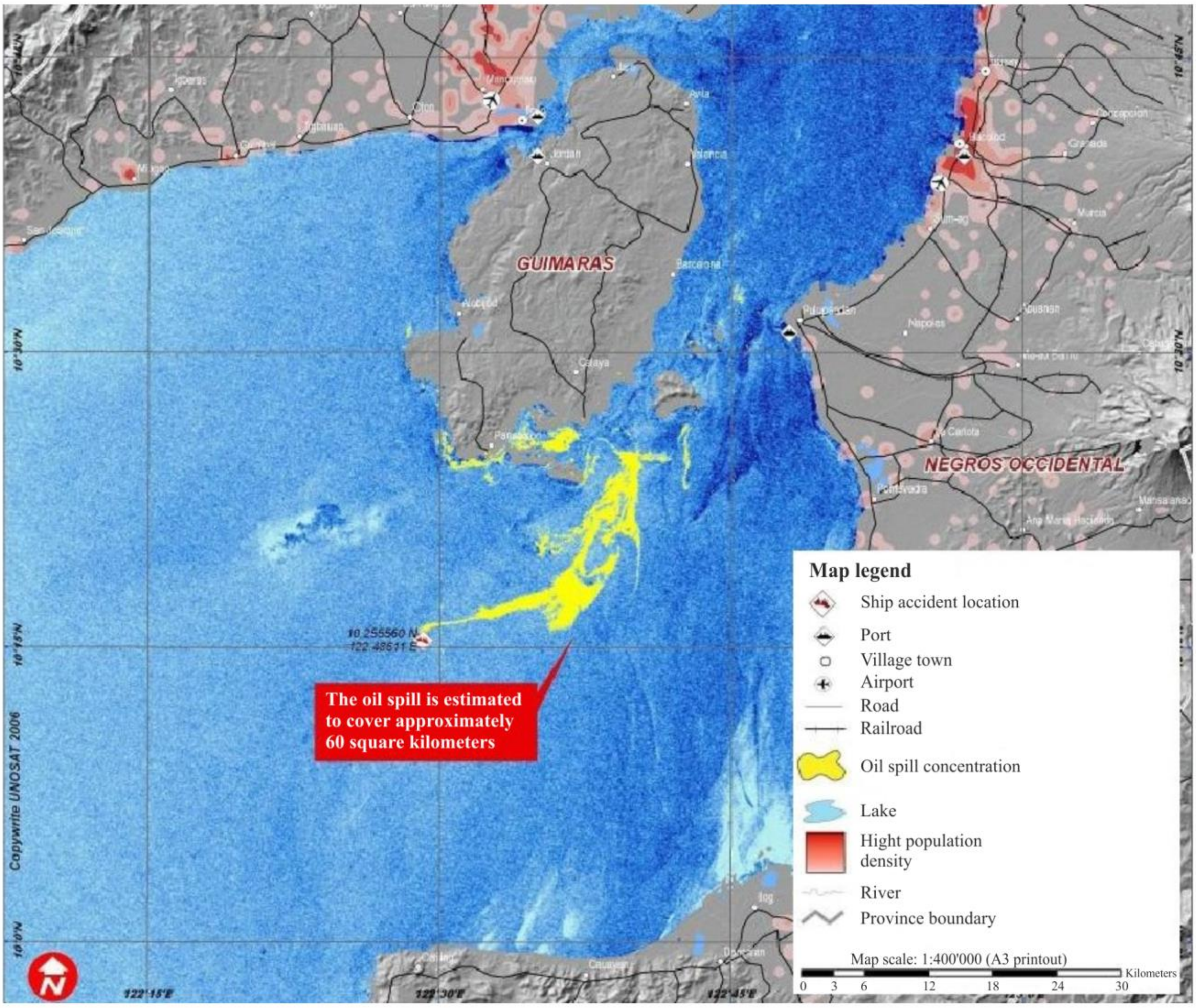
8 Oceanic pollution

Oceanic oil spills can be detected using SAR imagery. Operationally, oceanic oil spill detections are treated as preliminary observations and are immediately confirmed via seaborne, *in situ* measurements. This technique allows large areas to be monitored at lower cost. After an oil spill is confirmed *in situ*, the area affected can be monitored and tracked by satellite.

On 11 August 2006, the oil tanker Solar sank off the coast of Guimaras Island in the Philippines. By 24 August 2006, some 50 000 gallons of oil had leaked into the sea, polluting more than 300 km of coastline and threatening fishing as well as other islands of the Philippines. The SAR on the ENVISAT satellite was used to derive the image in Fig. 21. It shows the exact location and the extension of the oil slick on 24 August 2006.

FIGURE 21

Oil spill near Guimaras Island, Philippines: Synthetic aperture radar image

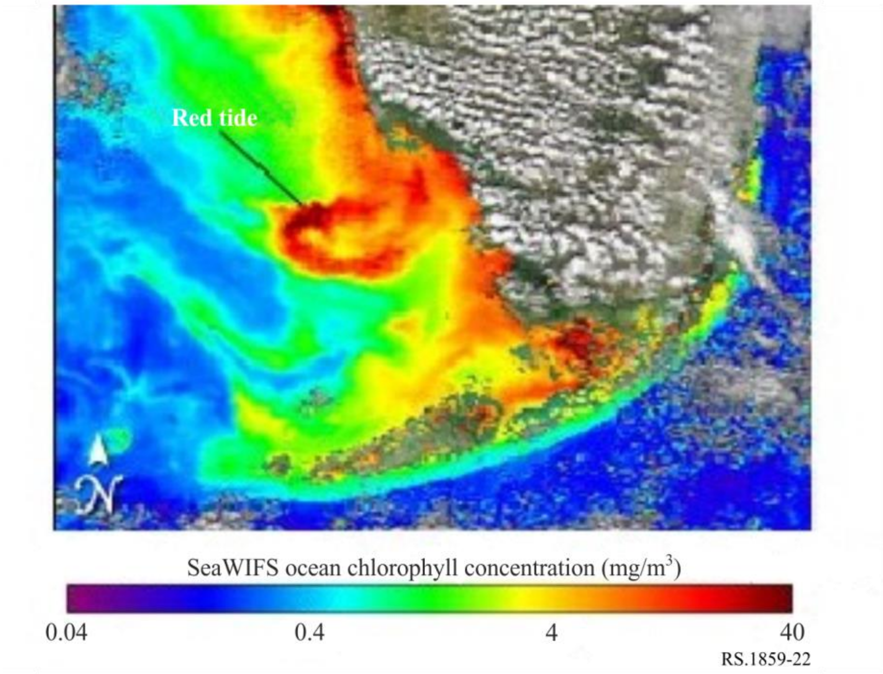


RS.1859-21

Natural oceanic pollution in the form of a "red tide" (a common name for an algal bloom which is associated with the production of natural toxins and the depletion of dissolved oxygen or other harmful conditions) can be detected and monitored from space by observing ocean colour. Identifying and quarantining areas afflicted by a red tide protects human health. Other pollution forms (e.g. water pollutants, coastal sediments) can be detected using satellite images in the visible and/or infrared spectrum (see Fig. 22).

FIGURE 22

Red tide observed with the SeaWiFS instrument 21 November 2004 of Florida in the south-eastern corner of the United States of America



9 Sea and lake ice

Satellite-borne passive microwave sensors (Fig. 23) have mapped sea ice extent for decades, and SARs (Fig. 24) are used operationally to guide Arctic and high latitude lake shipping and to extend the shipping season at high latitudes.

FIGURE 23

Ice over North America in January 2007 (Hudson's Bay blocked)

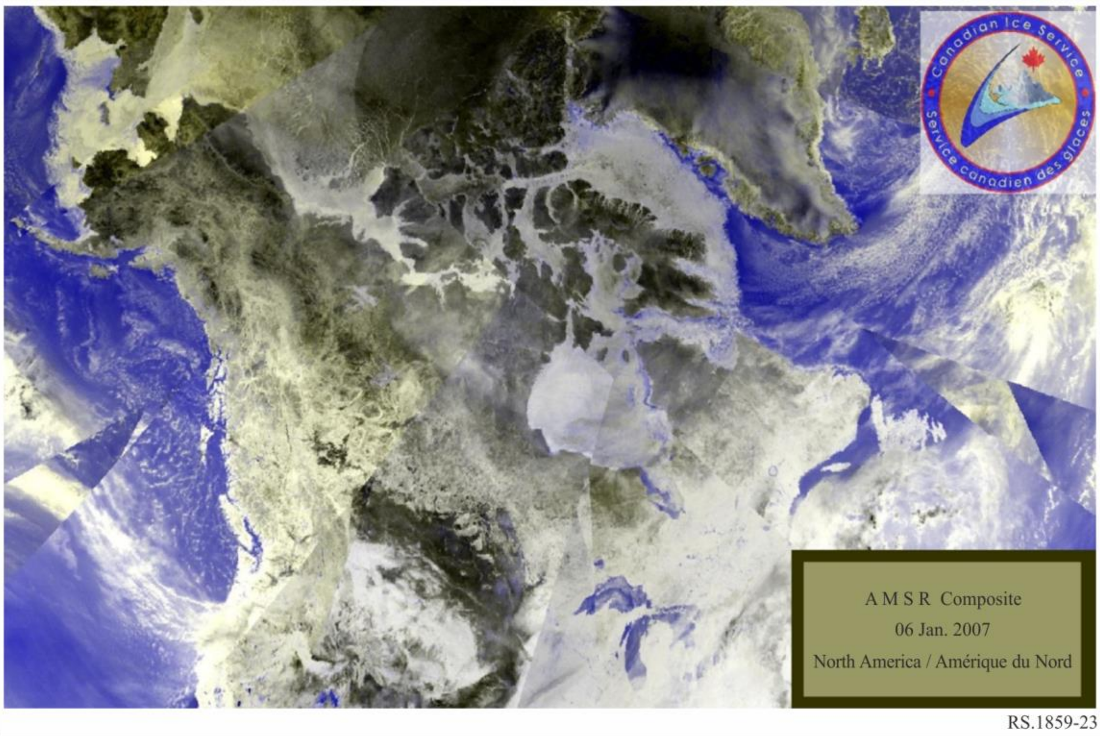
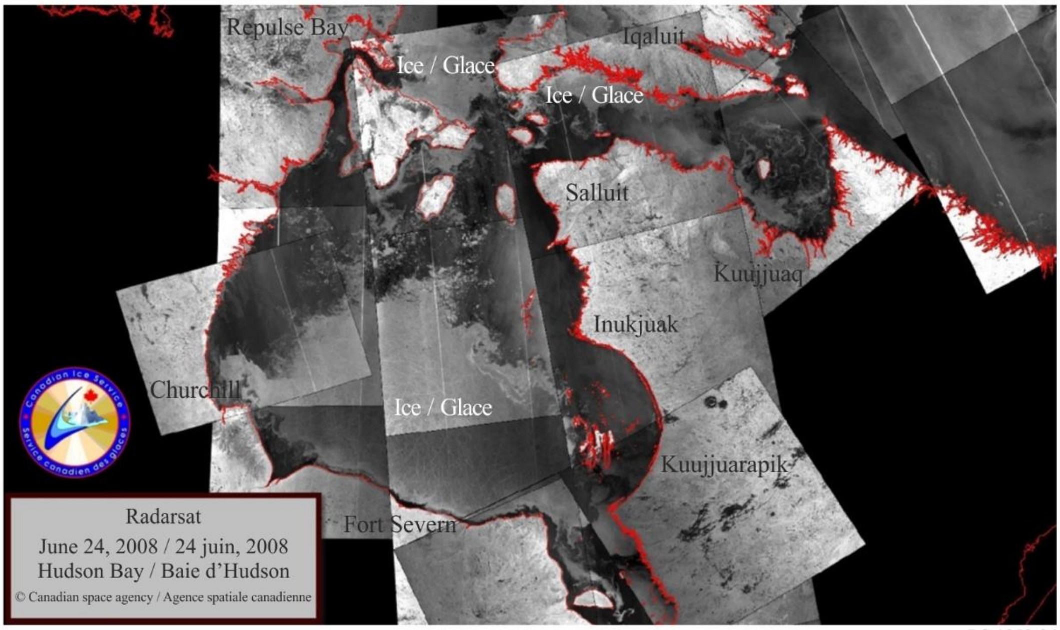


FIGURE 24

Ice in Hudson's Bay, Canada in June 2008 (open water along the eastern shore)



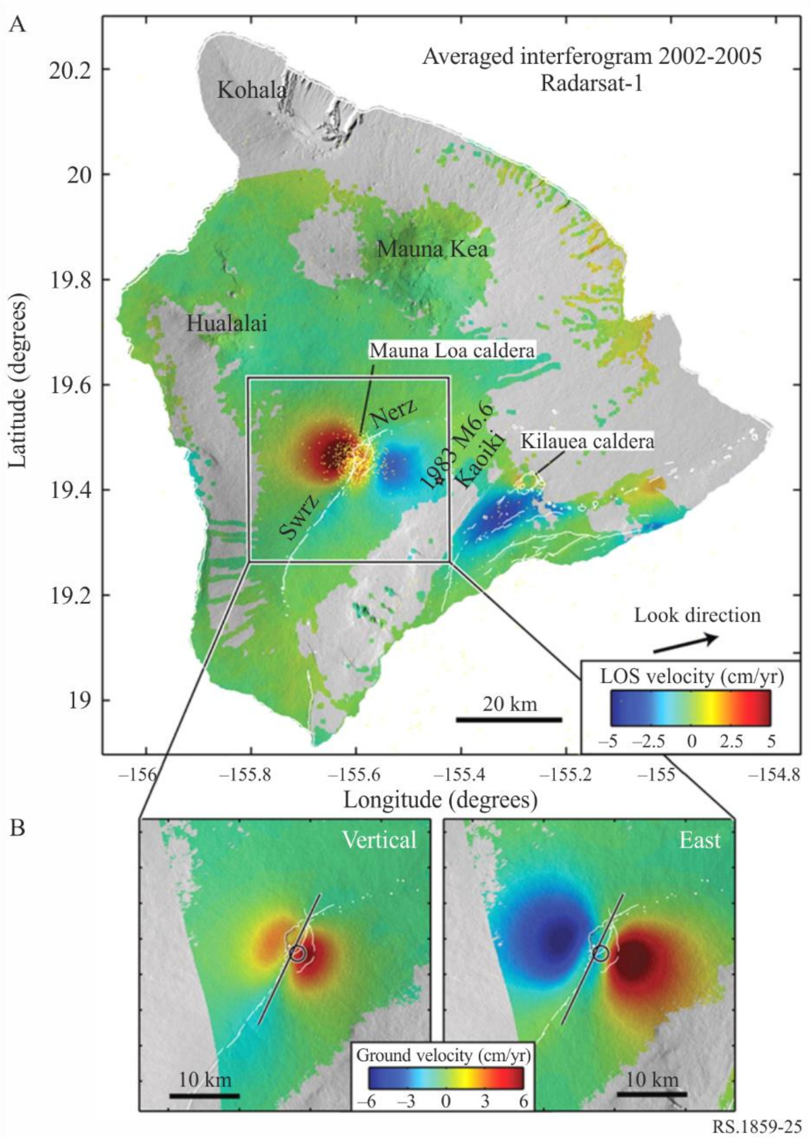
RS.1859-24

10 Volcanoes

Since volcanic activity is frequently preceded by swelling/uplifting of the ground in the immediate area, potential volcanic activity can be monitored, to some degree, by mapping such ground movements. *In situ* GNSS units can provide local monitoring while polar orbiting InSAR observations can provide less timely measurements at remote locations where the placement of *in situ* GNSS units is not practical. An InSAR image of the Hawaiian volcano Mauna Loa (Fig. 25) shows long-term change in the surface, indicating swelling which is indicative of subterranean volcanic activity. Both Mauna Loa and Kilauea are known to be active volcanoes. An astronomy observatory is located atop Mauna Kea, which has been volcanically quiet in recent history. The detection of subtle ground motions by satellite-based InSAR operations can be used to identify potential volcanic hazards anywhere in the world.

FIGURE 25

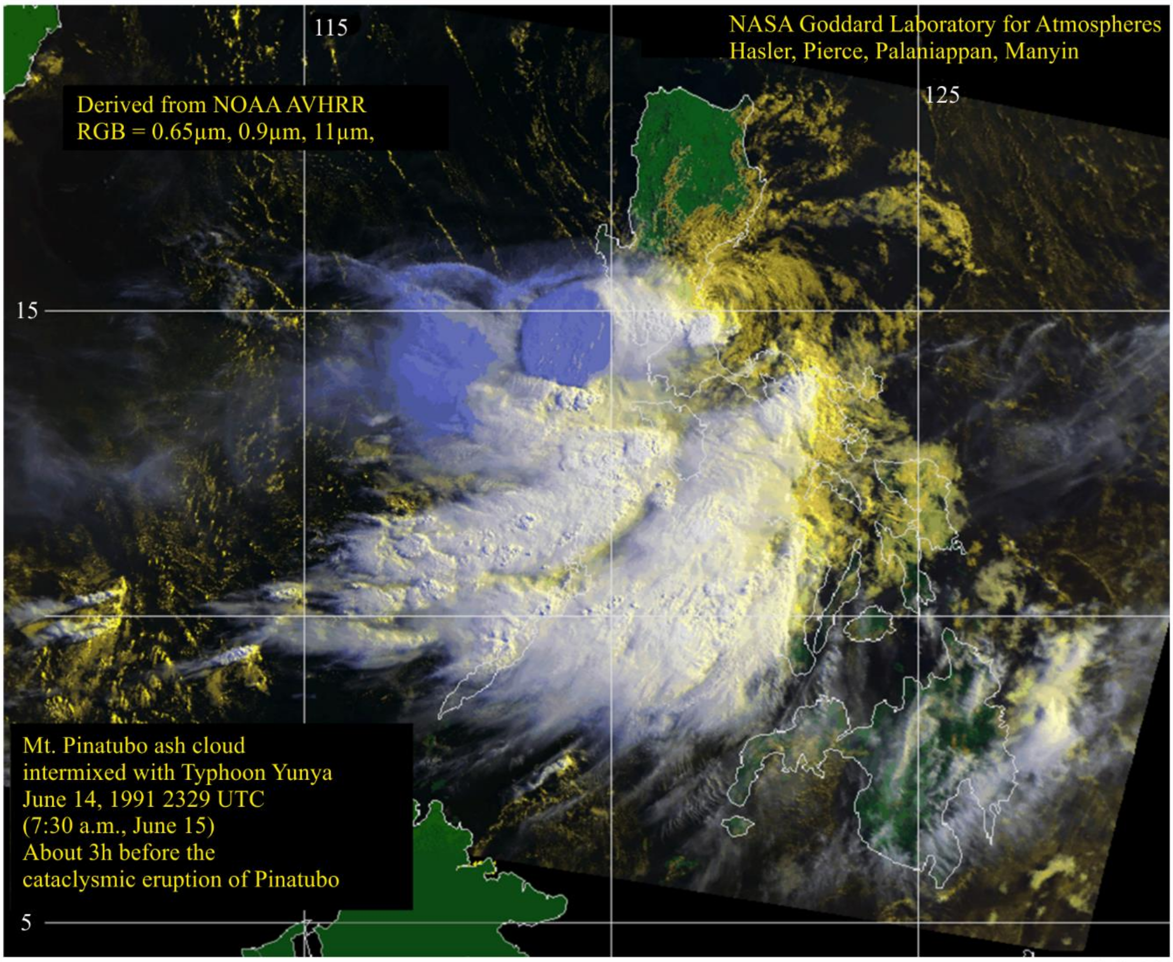
**Interferometric SAR image of the Mauna Loa Caldera in Hawaii
Ground motion indicates dangerous underground volcanic activity**



During and after a volcanic eruption, the thermal signature of the lava, ash, and hot gases are routinely monitored using infrared and visual observations from space. In particular, the volcanic ash in the atmosphere poses serious hazards to aircraft in flight. The volcanic ash ejected by the 2010 eruptions of the Eyjafjallajokull volcano in Iceland resulted in the largest air-traffic shutdown since World War II. Nine Volcanic Ash Advisory Centres have been established to monitor volcanic ash plumes in their assigned airspace (http://www.ssd.noaa.gov/VAAC/vaac.html).

FIGURE 26

Mount Pinatubo ash cloud intermixed with Typhoon Yunya 3 h before the 15 June 1991 eruption

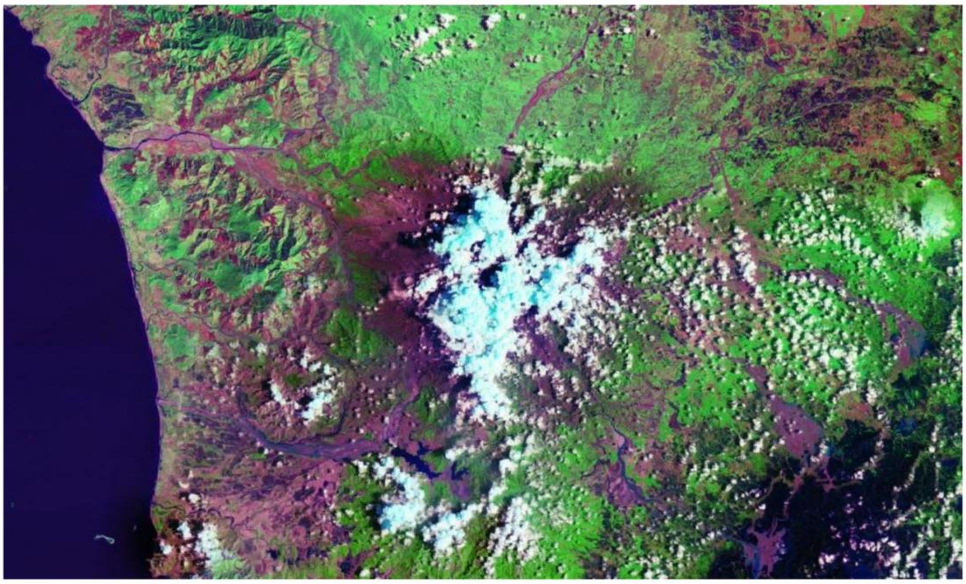


RS.1859-26

Imaging from satellites supports identifying impacted areas and ~~the~~ monitoring the recovery. Images from visible and infrared wavelengths support the monitoring of vegetative recovery (see Figs 27, 29 and 30). In areas where cloud cover poses a problem, SAR images provide another source of information (see Fig. 28). The following sequence of images follow the aftermath of the Pinatubo volcano eruption in the Philippines which occurred on 15 June 1991. The dark diagonal wedges in Fig. 30 are due to a failure on Landsat 7 when the on-board device which converted the zig-zag scans into linear raster scans failed.

FIGURE 27

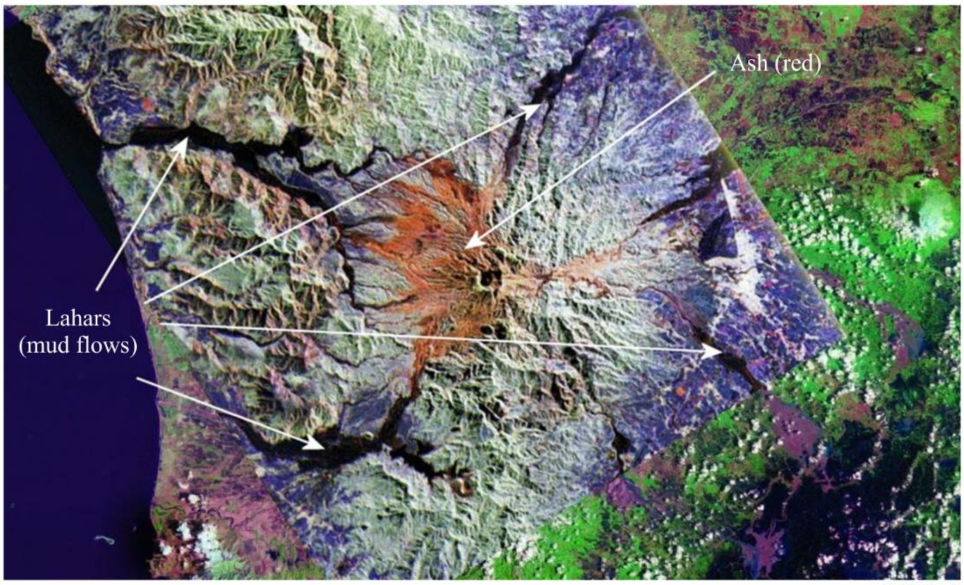
Landsat 5-9 September 1991. Damaged vegetation is red-brown



RS.1859-27

FIGURE 28

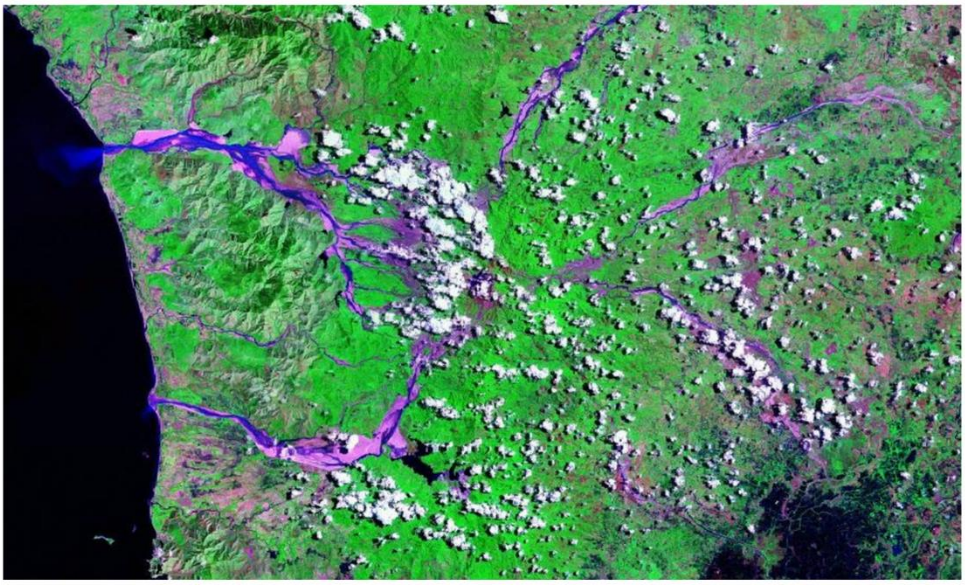
Landsat 5 overlaid with SIR-C – Oct. 1994. No cloud problem, terrain is visible, and lahars (mud flows) are distinct and easily recognized



RS.1859-28

FIGURE 29

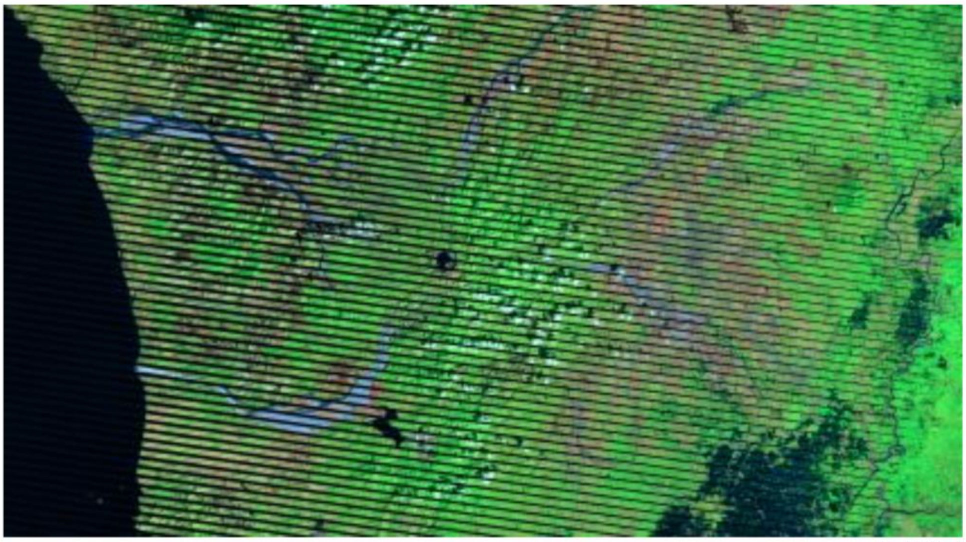
Landsat 7-18 May 2001. Vegetation recovered



RS:1859-29

FIGURE 30

Landsat 7-4 February 2010, further recovery and lake formed



RS:1859-30

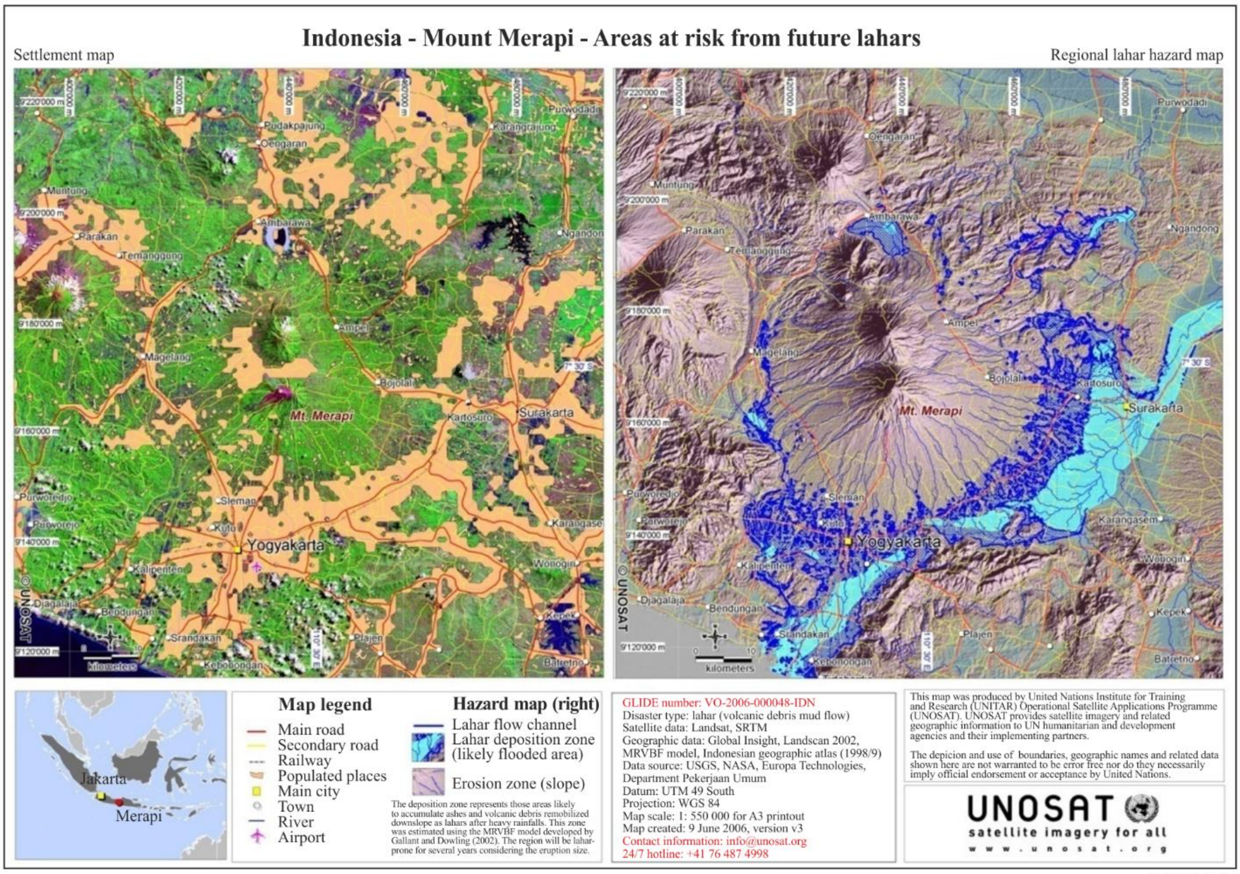
SAR imagery is also useful in identifying areas at risk. The Pinatubo eruption produced several "lahars", or mud flows. These lahars are easily identified in SAR images (Fig. 28), and could be re-activated by heavy rains. One such occasion occurred in 1994 and was observed by the Shuttle Imaging Radar. Nearby inhabited areas were placed at risk. A very acidic lake formed in the caldera is visible on Fig. 30, but obscured by clouds in Fig. 29.

DEMs have proven useful in predicting where such lahars may occur. The lahars follow the gullies and flow into low areas.

Such DEMs can be combined with land use/land cover maps, such as derived from Landsat or MODIS, to identify and map areas at risk. An example of such a risk map is shown in Fig. 31.

FIGURE 31

Landsat and SRTM combine to identify vulnerable areas and populations



RS.1859-31

On the left image, Landsat data was used to identify urban areas as contrasted with agricultural fields. On the right image, topographic data from NASA's Shuttle Radar Topographic Mission (SRTM) was used to identify the areas that would likely be buried under mud or ash. The combination of the two maps gives the local authorities a tool to plan actions to take in the event of an eruption of Mount Merapi in the future.

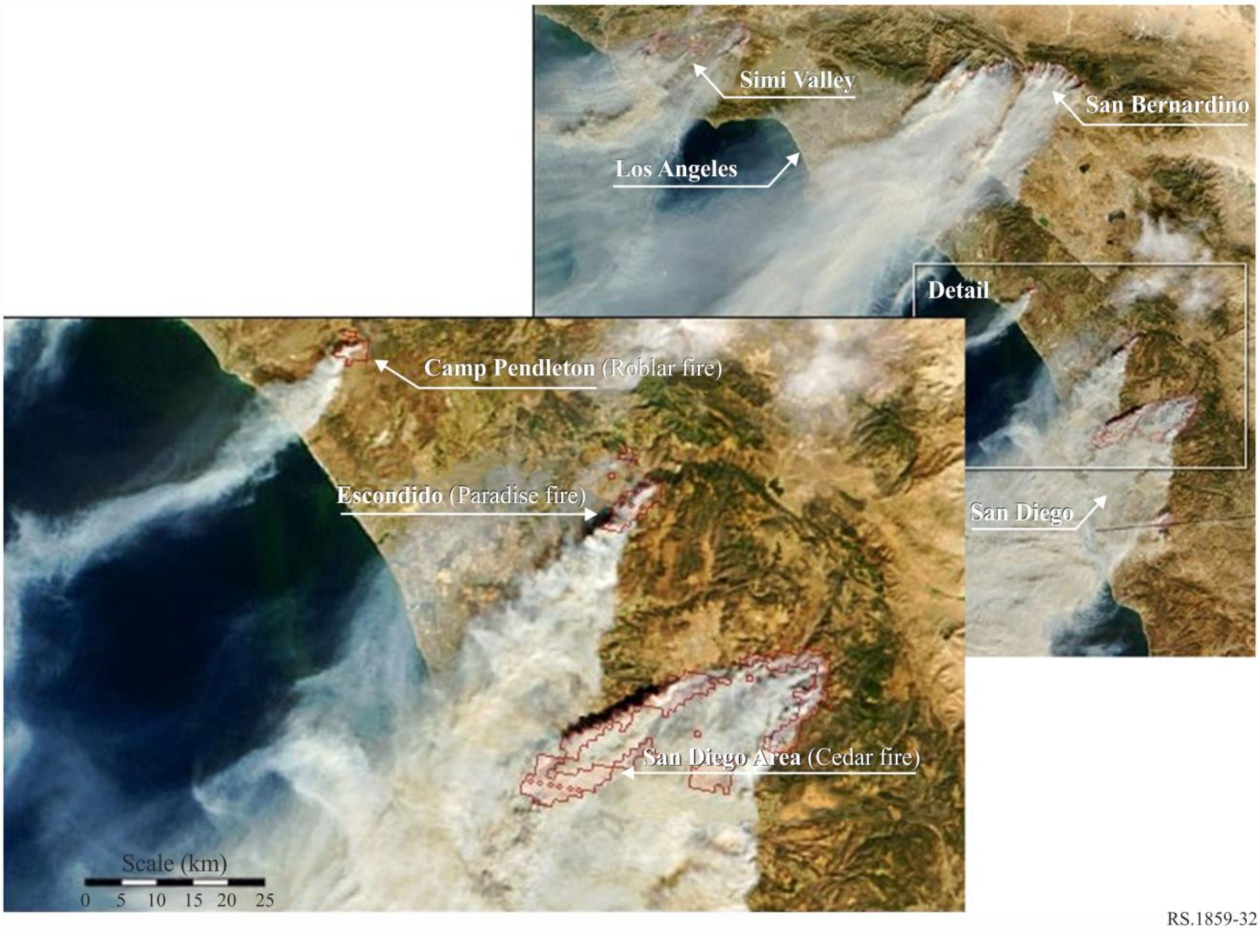
11 Wildland fires

The risk for wildland fires in remote, sparsely populated areas can be estimated from space measurements of soil moisture and vegetative state (i.e. is the vegetation healthy or distressed/parched?). Wildland fires can be detected using certain infrared channels being flown on spaceborne instruments. These channels effectively penetrate the smoke and haze which obscure visible-wavelength observations. Such data can be found at the NASA Fire Information for Resource Management System (FIRMS) web site (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms) and at the Worldview site (https://worldview.earthdata.nasa.gov/), specifically the "Fires and Thermal Anomalies" product. To reduce the time separation between the satellite observation and the generation of needed data products, several agencies, governments, and non-governmental organizations worldwide have installed ground stations to receive real-time data every time an appropriate polar orbiting satellite passes overhead.

These images are useful in combating wildfires. Southern California in the United States is prone to wildfire outbreaks during its dry season (see Fig. 32). These fires are intensified by the local Santa Ana winds, which make fighting them difficult. Satellite imagery helps guide fire fighters and is particularly useful in remote, unpopulated areas.

FIGURE 32

Fires in Southern California, 26 October 2003



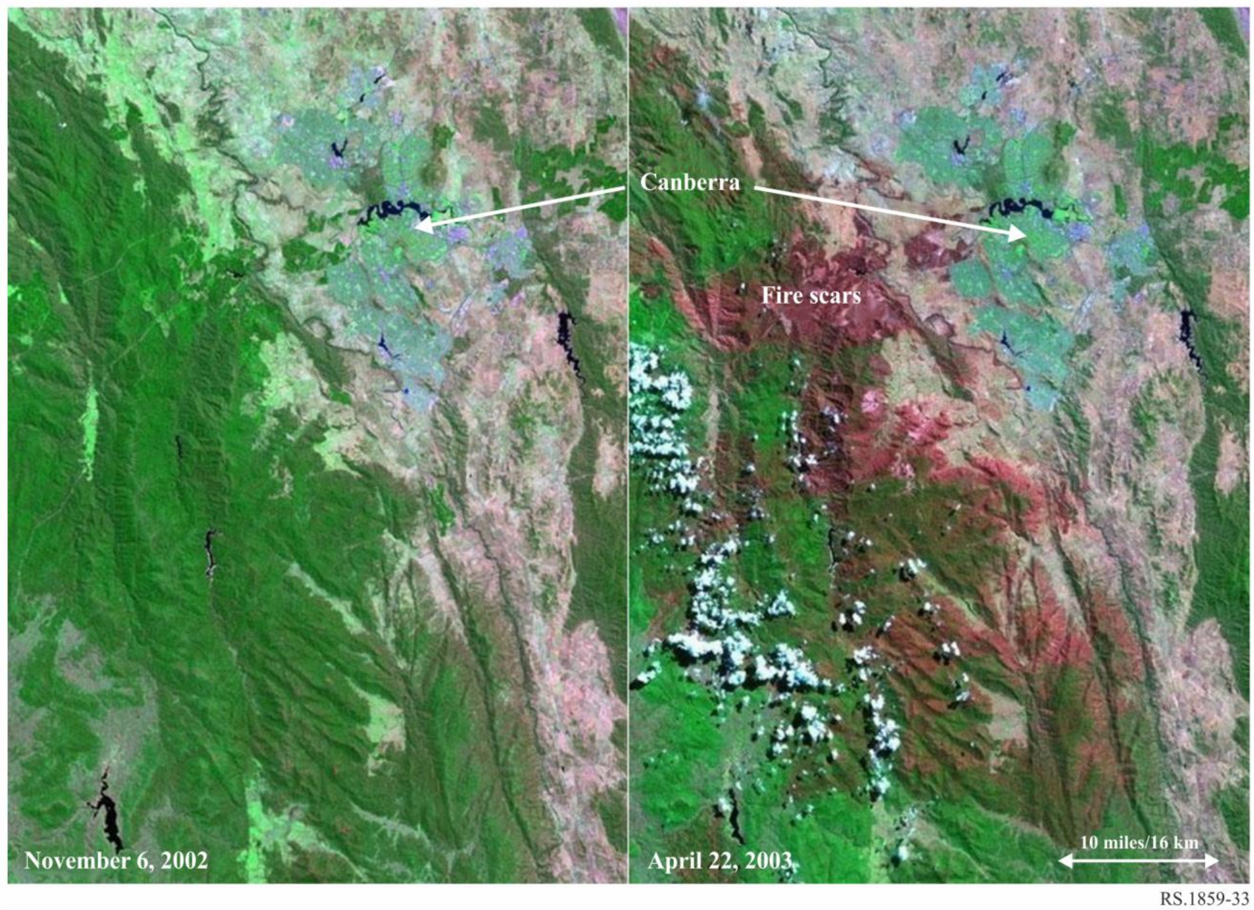
RS.1859-32

After a fire has been extinguished, satellite visible and infrared imagery and SAR imagery can be used to determine the extent of the damage and to monitor the recovery of the vegetation.

Wildfires were rampant in the Australian summer of 2002-2003, with over 50 separate fires in the southeast portion of the continent. The capital city of Canberra was threatened by a bush fire that began on 18 January in the Namadgi National Park. Within a few days, the fires had spread to the outskirts of the city, forcing thousands of people to evacuate the city and prompting thousands more to volunteer as fire fighters to protect Canberra from the flames. By the time the fire was under control, four people had died and 419 homes had been destroyed. In the Landsat 7 images below (Fig. 33), healthy vegetation appears green while burned regions appear in varying shades of red.

FIGURE 33

Before and after Landsat images of Canberra, Australia during the fires of 2002-2003



12 Remote sensor databases

The following sources of data are available to the general public but do not respond to specific incidents. Organizations which do respond to calls for assistance are listed in the summary.

As a result of studies compiled in the ITU-D, a "Remote Sensing Disaster Database" has been prepared to provide a survey of terrestrial and space-based active and passive sensor data sources for disaster support. This summary database is in the form of a spreadsheet accessible through the internet at: https://www.sfcgonline.org/home.aspx. It is not necessary for a user of this database to log into the system.

NASA supports Internet web sites providing near real time remote sensing data regarding air quality, ash plumes, drought, dust storms, fires, floods, severe storms, shipping (primarily polar ice-related), smoke plumes, and vegetation at:

https://earthdata.nasa.gov/earth-observation-data/near-real-time/hazards-and-disasters

Additional flood management data is available at: http://floodobservatory.colorado.edu/ and at the Global Flood Monitoring System on the internet (at http://flood.umd.edu).

13 Summary

The above examples demonstrate the usefulness of remote sensing data in managing the effects of natural disasters. To gain the maximum benefit from remote sensing data, a local emergency management agency is needed to direct the appropriate information to people in the field who need it. The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) is an organization focused on helping nations develop the capacity to manage disasters. While the UN-SPIDER helps organize relief organizations and train their personnel, other organizations are more data oriented. However, the UN-SPIDER web site includes listings of geographic information system (GIS) software (both free and commercial) and data sources. The UN-SPIDER internet site is: http://www.un-spider.org/.

To use the data collected by remote sensing systems and other sources, a single point of contact for summoning international disaster support using space resources has been established following the UNISPACE III conference held in Vienna, Austria in July 1999. An authorized user can now call a single number, supported 24 hours a day, to request the mobilization of the space and associated ground resources (*RADARSAT, COSMO-SkyMed, Sentinel, SPOT, IRS, SAC-C, NOAA-series, LANDSAT*, *ALOS-2*, *DMC* satellites and others) of the member agencies to obtain data and information on a disaster occurrence. Member agencies include the space agencies of Europe, France, Canada, India, Argentina, Japan, the United Kingdom, DMC International Imaging (Algeria, Nigeria, and Turkey), China, Germany, Korea, Brazil, Russia, and Venezuela, as well as the National Oceanic and Atmospheric Administration (USA) and the United States Geological Survey (USA) and EUMETSAT (Europe). Examples of data provided can be found at: http://www.disasterscharter.org. Any questions or comments for the Charter members or about the website should be directed to: webmaster@disasterscharter.org.

Another source of analysed remote sensing data is UNOSAT, a United Nations programme created to provide the international community and developing nations with enhanced access to satellite imagery and geographic information systems services. These tools are used mainly for humanitarian relief, disaster prevention, and post-crisis reconstruction. The services provided include satellite imagery selection and procurement assistance, image processing, map production, methodological guidance, technical assistance, and training. Their internet site is: http://www.unitar.org/unosat/.

A third source of remote sensing support is SERVIR, a regional visualization and monitoring system, which can be found at: https://www.servirglobal.net/ (in Spanish at: http://www.servir.net).

SERVIR is a joint development initiative of National Aeronautics and Space Administration (NASA) and United States Agency for International Development (USAID). SERVIR works in partnership with leading regional organizations world-wide to help developing countries use information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use. SERVIR provides decision-makers with tools, products, and services to act locally on climate-sensitive issues such as disasters, agriculture, water, and ecosystems and land use.

SERVIR has established centres in Africa (Nairobi, Kenya), Hindu Kush-Himalaya (Kathmandu, Nepal), Lower Mekong (Bangkok, Thailand), and Mesoamerica (Panama City, Panama) to manage challenges in the areas of food security, water resources, land use change, and natural disasters.

NOTE 1 – It would be advisable for parties with potential, or probable, need to seek help from any or all of the above agencies to contact them in advance of any disaster and to establish a procedure (e.g. assign liaison personnel with names, e-mail addresses, telephone numbers, etc.) for obtaining help should a disaster occur. Such advance planning would significantly shorten the time required to get help when it is needed.

Annex 2

Status of observations useful in the event of natural disaster and other emergencies

The following tables summarize the status of space-based observations useful in managing the effects of natural disasters and other emergencies. Table A2-1 maps the types of disaster against the technology used, which is detailed in Table A2-2. Table A2-2 lists the status of the technology used, the observations and the missions available to provide those observations both circa 2015 (when this Annex was written) and in the future.

TABLE A2-1

The Technologies Helpful in Managing Natural Disasters

Technology / **Objective**	**SAR Imagery**	**InSAR Imagery**	**Active MW Imagery**	**Radar Altimetry**	**Radar Scatterometry**	**Precipitation Radar**	**GPS Radio Occultation**	**Passive MW Imagery**	**Passive MW Sounder**	**Geo. Visual and IR Imagery**	**Optical Imagery**	**Multispectral Optical Imagery**	**IR Imagery**
Coastal Hazards	X										X		
Drought	X		X	X	X			X		X	X	X	
Earthquakes	X	X					X				X		
Extreme Weather					X	X	X	X	X	X	X		
Floods	X		X		X	X	X	X	X		X		
Landslides	X	X									X	X	
Ocean Pollution	X											X	
Pollution											X	X	
Sea/Lake Ice	X							X			X		
Volcanoes	X	X						X			X	X	X
Wildland Fires								X			X	X	X

TABLE A2-2

Status of disaster support

Technology	Disaster Type(s)	Measurement	Status (circa 2018)	Follow-on (2018-2025)
SAR imagery	Coastal hazards, Floods, Landslides, Volcanoes	Digital Elevation Models (DEMs)	SARs on RADARSATs (1995, +), TSX (2007), TDX (2010), COSMO-SkyMeds (2007, +), Sentinel-1 (2014); HJ-1C (2012); COSI on KOMPSAT-5 (2013); PALSAR-2 on ALOS-2 (2014); RISAT-SAR on RISAT-1 (2012);X-SAR on RISAT-2 (2009); S-M OBRC on METEOR-M2 (2014); SAR-10 on Kondor-E1 (2013); X-SAR on TECSAR (2008)	BRLK on METEOR-MP (2021); CSG-SAR on CSG (2019); PAZ-SAR on PAZ (2018); RISAT-SAR on RISAT-1A (2019); SAR on RADARSAT constellation (2018. +); S-SAR on NovaSAR-S (2018); SAR on TSX-NG (2018); SAR-L on SAOCOM-1,2 (2018); SAR-P on BIOMASS (2020); SAR-X on METEOR-MP (2021); SAR on HJ-C
	Coastal hazards, Earthquakes, Floods, Landslides, Pollution, ice, Volcanoes	Areas Affected		
	Oceanic Pollution	Oil Spill Detection		
	Sea and Lake Ice Hazards	Sea and Lake Ice extent	SARs on RADARSATs (1995, +), TSX (2007), TDX (2010), COSMO-SkyMeds (2007, +), Sentinel-1a (2014); SIRAL on CRYOSAT-2 (2010)	SAR on RADARSAT constellation (2018. +); InSAR on NISAR (2021)
	Flood, Drought	Snow Depth		SAR-X/Ku on SCLP (2030)
InSAR Imagery	Earthquakes, Volcanoes, Landslides	Ground Motion	RADARSATs (1995, +), TSX (2007), TDX (2010), COSMO-SkyMeds (2007, +); Sentinel-1a (2014)	InSAR on NISAR (2021) and above SAR missions
Radar Altimetry	Droughts	Ocean Height	SSALT on JASON series (2001, +); Altika-AMU on SARAL (2013); RA on HY-2A / (2011); SRAL on Sentinel-3 (2016)	KaRIN on SWOT (2020); JASON-3 (2015); SRAL on JASON-CS/SENTINEL-6 (2020, +); SHIOSAI on COMPIRA (2019);

TABLE A2-2 (*continued*)

Technology	**Disaster Type(s)**	**Measurement**	**Status (circa 2018)**	**Follow-on (2018-2025)**
Precipitation Radar	Extreme weather, Floods	Rain	DPR on GPM (2014)	
Radar Scatterometry	Droughts, Extreme Weather	Sea surface wind vector, Sea State	ASCAT on MetOps (2006, +); SCAT on HY-2A (2011); OSCAT on OceanSat-2 (2009); ALScat on SAC-D; DDMI on CYGNSS (2017); OSCAT on ScatSAT-1 (2015)	OSCAT on OceanSat-3 (2018; SCA on MetOp-SG-B (2022); SCAT on CFOSAT (2018); SCAT on METEOR- MP (2021); SWIM on CFOSAT (2018); WindRAD on FY-3 (2018)
	Droughts, Floods	Snow Properties (cover, water equivalent)		SCA on METOP-SG-B (2022)
	Droughts, Floods, Landslides	Land soil moisture		
	Sea and Lake Ice Hazards	Sea and Lake Ice extent		
	Droughts, Volcanoes (recovery), Wildland Fires (recovery)	Vegetation Health (leaf area index)	ASCAT on MetOps (2006, +)	
GPS radio occultation	Extreme weather, Floods	Atmospheric Temperature Profile	COSMIC/FORMOSAT-2; DDMI on CYGNSS (2017); (2006); KOMPSAT-5 (2013); FY-3 -C (2013); MetOp (2006, 2012); TDX (2010); TSX (2007); Megha-Tropiques (2011); OceanSat-2 (2009)	COSMIC-2/FORMOSAT-7 (2018); FY-3D.-3F(2016-2020); JASON-CS/SENTINEL-6 (2020+); GRACE-FO (2018); METEOR-M-N3, METEOR-MP-N1,-N3 (2018); METOP-SG-A,-B (2022)
		Atmospheric Humidity Profile		

TABLE A2-2 (*continued*)

Technology	**Disaster Type(s)**	**Measurement**	**Status (circa 2018)**	**Follow-on (2018-2025)**
Passive Microwave Imagery	Droughts, Floods	Soil Moisture	MIRAS on SMOS (2009); Radiometer on SMAP (2015); SSM/I on DMSP series (1987, +), SSMIS on DMSP series (2003, +); MWRI on FY-3 series (2008, +); VIIRS on SNPP (2011)	SSM/IS on DMSP (2020); MWI on METOP-SG-A (2022) MWI on MetOp-SG-A (2022)
	Extreme weather, Floods	Rain rate and area	GMI on GPM (2014); SSM/I on DMSP series (1987, +), SSMIS on DMSP series (2003, +); MADRAS on Megha-Tropiques (2011); MWRI on FY-3 series (2008, +)	
	Sea and Lake Ice Hazards	Sea and Lake Ice extent	SSM/I on DMSP series (1987, +), SSMIS on DMSP series (2003, +); AMSR-2 on GCOM-W1 (2012);	
	Volcanoes, Wildland Fires	Ground Temperature	AMSU on AQUA (2002), MetOp series (2006+), NOAA series (1998, +); ATMS on SNPP (2011) and NOAA-20 (2018); SSM/T on DMSP series (1999, +)	
	Flood, Drought	Snow Water Equivalent	SSM/I on DMSP (1995, +); AMSR-2 on GCOM-W1 (2012)	
	Droughts, Extreme Weather	Ocean Winds	SSM/I on DMSP series (1987, +), SSMIS on DMSP series (2003, +); Windsat on Coriolus (2003), AMSR-2 on GVCOM-W1 (2012); MTVZA-GY on Meteor-M series (2009, +) MWR on SAC-D (2011); MWRI on HY-2A (2011)	

TABLE A2-2 (*continued*)

Technology	**Disaster Type(s)**	**Measurement**	**Status (circa 2018)**	**Follow-on (2018-2025)**
Passive microwave sounders	Droughts	Ocean Temperature	AMSR-2 on GCOM-W1 (2012); MWRI on HY-2A (2011); MIRAS on SMOS (2009); WindSat on Coriolus (2003); CrIS, ATMS on SNPP(2011) and NOAA-20 (2017)	
	Extreme weather, Floods	Atmospheric Temperature Profile	MSU since 1979 currently on NOAA series (2002, +); SSM/I on DMSP (1995, +); AMSU on Aqua (2002), MetOp (2006, +); DFMRM on FAST-T; MTVZA-GY on Meteor-M Series (2009, +); MWTS on FY-3 series (2003, +) CrIS, ATMS on SNPP (2011) and NOAA-20(2018);	MWS and MWI on MetOp-SGs (2018, +); MTVZA-GY-MP on METEOR-MP (2021);
		Atmospheric Humidity Profile and total column water content	AMSU on AQUA (2002) & POES's (1998, +); ATMS on SNPP (2011) and NOAA-20(2018) ; MHS on POES's (1998, +) & MetOps (2006, +); SSM/T on DMSP series (1999, +); MTVZA-GY on Meteor-M series (2009, +); MWHS on FY-3 series (2003, +); SAPHIR on Megha-Tropiques (2011): AMR-2 on JASON-3 (2016); MWR on Sentinel-3 (2016)	AMR on SWOT (2020); AMR-C on JASON-CS/SENTINEL-6 (2020); MTVZA-GP-MP on METEOR-MP (2021); MWI and MWS on METOP-SG-A (2022)
Geostationary visible and IR observations	Extreme weather	Cloud Motion	GOES-series since 1975, METEOSAT series since 1977	GOES series (2016, +), METEOSAT series (2018)

TABLE A2-2 (*end*)

Technology	**Disaster Type(s)**	**Measurement**	**Status (circa 2018)**	**Follow-on (2018-2025)**
Optical Imagery	Coastal hazards, Floods, Landslides, Volcanoes	Digital Elevation Models (DEMs)	ASTER on TERRA (1999)	
	Coastal hazards, Drought, Earthquakes, Weather, Floods, Landslides, Pollution, ice, Volcanoes, Fires	Areas Affected	Moderate Resolution: AVHRR since 1981, on NOAA series (2002, +); AwiFS on Resourcesats (2011); Landsat since 1973, -7,- 8 (1999, 2013); SPOT series (1994, +); MODIS on TERRA (1999), AQUA (2002); AVHRR on Metops (2006, +); Cameras and IRMSS on HJ-1 (2008); MSI on Sentinel-2 (2015); OLCI on Sentinel-3 (2015): VIIRS on SNPP (2011) and NOAA-20 (2018)	MSI on Sentinel-2 (2015PRISM-2 on ALOS-3 (2019); SGLI on GCOM-C1 (2018); NOAA-20
			High Resolution: (commercial) IKONOS-2 (1999); QuickBird (2001); WorldView-1 (2007), WV-2 (2009), WV-3 (2014); GeoEye-1 (2008)	
Multispectral Optical imagery	Droughts, Volcanoes (recovery), Wildland Fires (recovery)	Vegetation Health (leaf area index)	AVHRR since 1981, on NOAA series (2002, +); MODIS on Terra (2000), Aqua (2002); MISR on Terra (2000); Landsat since 1973, -7,- 8 (1999, 2013); SPOT series (1994, +); SeaWiFS on SeaStar (1997); VIIRS on SNPP (2011) and NOAA-20 (2018)	
	Landslides, Volcanoes (recovery)	Land Cover / Land Usage		
	Oceanic Pollution	Natural Ocean Pollution (red tide)		
IR Imagery	Volcanoes, Wildland Fires	Ground Temperature	Landsat since 1973, -7, -8 (1999, 2013); SPOT series (1994, +); MODIS on TERRA (1999), AQUA (2002)	

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