Risk management using Remote Sensing data : moving from scientific to operational applications

F.Sarti [(1)], J.Inglada [(1)], R.Landry [(2)], T. Pultz [(2)]
(1)CNES/QTIS, 18 av. E. Belin, 31401 Toulouse, France
Francesco.Sarti@cnes.fr , Jordi.Inglada@cnes.fr Tel. 0033-561-282133
(2)CCRS, 588 Booth Str., Ottawa, Ontario K1AOY7, Canada
Robert.Landry@ccrs.nrcan.gc.ca , Terry.Pultz@ccrs.nrcan.gc.ca Tel. 001-613-9471241

1. Introduction

The potential of remote sensing for the monitoring of the Earth environment and the detection of its temporal variations is well known. A variety of applications in the fields of flood monitoring, forest fire detection, landslide and subsidence, surface deformation and land cover variations were shown in the last ten years using space optical and radar data. However, the real-time utilisation of spaceborne remote sensing for emergency situations is still a difficult task because of the lack of a dedicated system (constellation) providing a day-to-day revisit of hazardous areas. Remote sensing data can easily allow for prevention (mapping of hazardous areas, drainage networks and land cover mapping, and precise basin modelling), or a-posteriori evaluation of damaged areas. On a case-to-case basis, one may need to provide cartographic products (maps of damaged and hazardous areas) issued from available satellite data with the shortest delay.

In this paper, we will attempt a description of the expected performance and limitations of the available satellite data (the SPOT constellation, plus ERS-2 and RADARSAT-1) for risk management applications, as well as an analysis of the impact of future systems (ENVISAT, RADARSAT-2, SPOT-5, ALOS and later on, the Pléiades satellite constellation). We will describe some possible criteria of satellite acquisition selection and programming for the purpose of risk management. Finally, we will show some examples of recent applications performed at CNES and RSI using SPOT, RADARSAT and ERS data.

2. General requirements on an operational spaceborne remote sensing system for risk management

We will consider here spaceborne optical and radar systems. Earth observation optical systems are passive sensors, measuring the sun reflectivity originating from a target on the earth surface and/or from the atmosphere, in a range of wavelenghts varying between 0.4µ - 0.7 µ (visible spectrum), 0.8 µ - 0.9 µ (near-infrared) and 1.5 µ - 1.8 µ (medium-infrared). If these measurements are of easy interpretation and have a rich thematic content, they suffer from the well-known limitations of being subject to meteorological constraints making their utilisation non-operational for the case of an emergency. Moreover, emergency situations such as floods, fires, eruptions, storms are typically accompanied by meteorological perturbations or smoke, that may drastically decrease the reliability of optical sensors in an operational context.

Radar sensors are active instruments providing their own source of illumination. For this reason, they are independent of sun illumination (both ascending and descending orbits are useful for image acquisitions). Operating in the microwave spectrum, where the atmosphere absorption is negligeable, they are independent as well of atmospheric conditions. This fact makes these sensors *operational* in an emergency context, where remote sensing information should be retrieved in a short delay, irrespective of meteorological conditions. Moreover, because of the different wavelenghts involved, the physics of radar acquisition allows to retrieve different physical parameters compared to optical sensors (high sensitivity to roughness and humidity), making radar and optical sensors *complementary* to each other.

Whenever possible, radar acquisitions should always be activated at the same time as optical acquisitions in an emergency situation. This allows to cope with the uncertainties originating from meteorology. Moreover, an operational spaceborne system for risk management, should also guarantee the following aspects:

- the revisit-time (maximum period between two consecutive acquisitions on a given site) shall be compatible with the delay allowed for product generation in the case of an emergency
- the resolution and the coverage of optical/radar images shall be appropriate for the required application.

We will see that the revisit-time constraint can be achieved by means of increased acquisition flexibility (variety of acquisition modes and incidence angles), but this flexibility has a counterpart in the case of radar images (the need and the difficulty of finding an archive image acquired in the same conditions). The resolution constraint can also be problematic in the case of urban damages, where a very high resolution (a few meters) is often required. We should finally point out that for the case of floods, the use of radar intensity images alone may be insufficient for the purpose of water detection (distinction land/floods) in the case of a strong wind. Other indexes (such as image texture) should be then taken into account, provided that the spatial resolution allows for this kind of analysis.

3. Current constellation

Only 3 systems will be considered here. These are: CNES' SPOT system (3 satellites: SPOT-1, SPOT-2 and SPOT-4), CSA's RADARSAT-1 and ESA's ERS-2. This gives an acceptable revisit period for a given area of the globe.

Optical Systems:

SPOT satellites can give medium resolution (20 m) colour images (3 or 4 bands), as well as high-resolution (10 m) panchromatic (one frequency band) images, with a 60-km swath. With 3 operating SPOT satellites and an oblique viewing capacity, about one image acquisition per day is possible on any given site.
On board SPOT-4, a fourth band is available. It is a medium infrared (MIR) channel which is very sensitive to moisture and water. SPOT-4 has also the VEGETATION sensor with a large (2250 km) swath allowing a 1-day revisit time at our latitudes, in spite of the 26-days orbit cycle of the SPOT platform. Spatial resolution is low (1-km pixel) but it allows monitoring of major floods and fires. Data acquired by VEGETATION allow mapping vegetation cover, forecasting crop yields and many other thematic applications.

Radar Systems:

ERS-2, with a resolution of 20 m for standard (PRI, 3 looks) products, is the least flexible among the available sensors since it has a single acquisition mode: single frequency, single polarisation and fixed incidence angle. At the same time, this feature ensures the availability of archive images taken in the same configuration. Archive images are very important for change detection and interferometric analysis. Furthermore, ERS-2 images are fully compatible with ERS-1 archives. Generally speaking, 2 image acquisitions every 35 days (ascending and descending orbits) are available (4 images at very high latitudes).

Conversely, RADARSAT-1 has a great variety of modes (multi-incidence, several resolutions and swaths: from 10 m resolution and 50 km swath with Fine mode, to 100 m resolution and 500 km swath with ScanSAR Wide mode), giving an extended covering flexibility. However, a counterpart of this acquisition variety (which will apply to ENVISAT, as well) is that the number of archive acquisitions in a given mode and given incidence is more limited than for ERS. This has to be taken into account when programming, in case an acquisition is needed for comparison with an archive image, at the same resolution and incidence angle (as it is often the case for the purpose of damage assessment using radar observations). This difficulty can however be overcome by the fact that a Global ScanSAR Wide Archive was acquired with the Radarsat Background Mission during the first two years of RADARSAT-1 operations. This mission has also acquired several seasonal ScanSAR Narrow coverages, resulting in mosaics as snapshots of regions of the world. Moreover, the Standard 7 coverage (the base layer for generating a landmass stereo database) is 80% complete and the Standard 2 coverage is complete over several parts of the world. The recently implemented Background Mission Completion plans to complete the beam pair global stereo coverage within the nominal life span of the satellite. This include the Fine 4 coverage of cities of the world (over 150) and a Fine beam interferometric mission over the whole of Canada, Greenland, Iceland, several mining and exploration sites, and a large number of watershed glaciers.

We can conclude that a good complementarity exists between these sensors in terms of the physical properties, but the temporal frequency of acquisitions for a given area is not enough to guarantee coverage at high resolution and high temporal frequency (a few days) in the case of a major disaster. Fortunately, this situation is very likely to change in the near future with the launch of at least 4 new satellite systems.

4. Satellite programming policy in the case of an emergency (acquisition selection criteria)

In an operational framework in the case of a natural disaster, the satellite programming has to be decided with a very short delay and a standard procedure (programming and processing for a given event) has to be defined in advance. Whenever possible, new acquisitions should be compatible with existing archive data in order to easily map temporal variations and damaged areas. We will limit ourselves to the case of SPOT, ERS and RADARSAT-1, because of our past experience with these systems. However, considerations on SPOT programming can be easily extended to other similar high resolution optical data (such as LANDSAT, IRS etc.).

Presently available satellites (SPOT, ERS and RADARSAT-1) are normally programmed after a major disaster for some days or a few weeks. However, it is advisable to ask for a specific programming (SPOT and RADARSAT-1 mode selection), as a function of the event, whenever added-value products have to be generated. A few criteria for image programming and archive selection, depending on the damage occurred, are given hereafter, based on common sense and on our limited experience. These considerations are resumed in Table 1.

VEGETATION (on board SPOT 4): its acquisitions allow daily monitoring (if weather permits), at low spatial resolution, of a given land site without the need of an explicit programming. These data can be of use for the monitoring of all major disasters (floods, fires, land) (see par. 5.2).

SPOT satellites (SPOT 1, 2 and 4): daily acquisitions over an hazardous or damaged areas should be programmed, in panchromatic and/or multi-spectral mode. Panchromatic acquisitions have the advantage of high resolution (10 m). If panchromatic acquisitions alone are programmed, two parallel segments (each with a 60-km swath) can be acquired simultaneously, once per day on a given site. This mode is to be chosen for precise damage assessment (such as urban damage), maximising the coverage area. If the area to be covered is limited (less than 60 km swath) simultaneous panchromatic and multi-spectral acquisitions can be programmed: thematic information is richer, but the coverage is limited to one 60-km wide segment. In the event of volcanic eruptions and fires, night imagery (especially with SPOT 4 – MIR channel) can be useful. SPOT images can be of use for all types of disaster monitoring applications (floods, fires, land). Less routine applications of SPOT data are oil spills ("sun-glint" effect on east-looking acquisitions and seismic fault detection (using precise correlation, see Ref [1]).

ERS-2: Generally speaking, from 2 to 4 image acquisitions every 35 days (ascending and descending orbits) can be programmed on a given site, depending on the latitude. However, this means that the delay for an acquisition may be of several weeks. Tandem mode is no more possible (since ERS-1 was switched-off). The most recent archive images for a given frame/track should be retrieved, possibly acquired in a similar season as new acquisitions. We remark that archives (ERS-1 & ERS-2) are richer in descending orbits. ERS SAR data can be used for all applications of damage assessment. Since February 2001 ESA do not guarantee anymore the interferometric quality of ERS-2 acquisitions (because of relaxed orbit constraints and attitude performances – resulting in larger Doppler variations), but the image quality is not affected.

RADARSAT-1 programming is more complex, given the variety of possible modes (resolution/swath) and incidences. Such variety provides a shorter access time (of the order of 2-3 days), unless a specific constraint exists on the resolution (e.g. Fine) or the incidence (e.g. in order to match existing archives). A trade-off between spatial resolution and swath has to be done, choosing the highest resolution while covering the zone to be observed. RADARSAT-1 data can be used for all applications of damage assessment. For water-related applications, being able to choose the incidence is a major advantage: high incidence shall be selected for flood detection (to minimise water clutter, in the attempt to maximise the contrast between water and land) whereas low incidence shall be selected for oil spills (to maximise sea clutter and therefore the contrast between polluted and clean water surfaces). For this reason, RADARSAT (or ENVISAT) is potentially more adequate than ERS for oil spill detection (despite the fact that the VV polarisation of ERS theoretically results in a high sea clutter).

We remark that especially when selecting radar acquisitions for the purpose of damage assessment, the matching (same incidence and resolution) between archives and new acquisitions plays an essential role. The variation information is derived from the comparison between acquisitions obtained before and after an event. Only images acquired at identical incidences (both ascending or both descending) can be compared satisfactorily (effect of slope on radiometry). It is also preferable to compare images acquired during identical periods (seasons), while minimising the time interval. The only exception to this rule are oil pollution events (where archive images are obviously not needed) and, to a lesser extent, floods, where one can derive the information from a single image if a precise map is available. This problem concerns especially RADARSAT (and soon ENVISAT), given the variety of incidences.

IKONOS high-resolution data can be of obvious utility for the purpose of infra-structural damage assessment (roads, buildings). However, apart from cost considerations, the problem is the lack (at present) of archive data for the purpose of comparison and automatic detection of temporal variations.

5. Examples of disaster monitoring

5.1 An example of flood monitoring using multitemporal SPOT: Gloucester flood of November 2000

Flood detection over Gloucester (UK) using SPOT multispectral data is shown here. Heavy rains took place over England between October and November 2000 (from October 30th until mid November), causing a severe flooding problem in the basin of River Severn. CNES programmed SPOT multispectral acquisitions over the region and a few cloud-free images could be acquired during flooding:

- SPOT 4 XI (multi-spectral) of November, 1st
- SPOT 2 XS (multi-spectral) and P (panchromatic) of November 13th (end of flooding)

An archive image is also available: SPOT1 XS of September, 5th, 1999.

First, a radiometric calibration and geometric correction of all images was performed (using a DEM), aiming at obtaining comparable and super-imposable images (in terrain geometry). Several algorithms of change detection, based on ratios and differences between channels (radiometry) of multitemporal data, were tested, in order to produce a map of damage assessment; the algorithm we retained is based on a comparison between ratios.

In order to monitor the flood evolution, we used in an iterative way the simple algorithm of change detection expressed in Ref [2], applied to two dates: the reference image (SPOT1) and one image taken during flooding. One (single) SPOT band is used: the Near-Infrared Band B3- common to SPOT1, SPOT2 and SPOT4 – which is the most sensible to water and humidity, with the exception of the MIR (medium infrared) that is only available on SPOT4.

In order to produce an easily interpretable map, we chose to draw the detected changes on the archive image (SPOT 1). A simple visualisation technique was applied using the HSV colour space (Ref [2]): for each pixel we set the HUE to red, the SATURATION to the value given by the change detector and the VALUE to the grey level of the archive image, obtaining an image where the changes appear in red on a greyscale radar image. The intensity of the red gives information about the importance of the change. The flood map resulting of the HSV composition and of the change detection between SPOT 4 and SPOT 1 (using the latter image as a background) shows the flood extent on November 1st (Fig. 1).

The flood evolution between November 1st and November 13th can be derived using the same method of change detection between these two dates (and superposed to the archive image). In this way, a flood decrease can be detected.

5.2 An example of flood mapping using RADARSAT: Chine floods in summer 1999

The region analysed contains the lake Poyang Hu and the valley of Yang-Tse-Kiang (province of Jiangxi). This region was heavily flooded during summer 1999. Three RADARSAT-1 ScanSAR acquisitions were programmed and analysed: one reference image taken before floods (Dec.28th, 1997) and two images (24 days apart) taken during floods (July 27th and August 20th, 1999). Only one optical image (NOAA AVHRR) acquired on July 19th at the beginning of floods was available (Fig. 2)

Radarsat (amplitude) images were first processed in order to perform: (1) *A radiometric calibration, (2) Image superposition and multi-temporal filtering, (3) Cartographic Projection.*

Multi-temporal filtering was done using an adaptive anti-speckle filtering (refs.[3-4]) including structure detection. This allows preserving contour lines and structure variety while filtering out speckle.

A first, fast evaluation of flood evolution can be done easily by means of a coloured composition of the 3 images. Being radiometry-calibrated, these images are well comparable to each other. The results are shown in fig. 3. They can be interpreted in the following way:

- Urban areas: white (high radiometry on all images)
- Flooded areas in July and August: dark blue (low radiometry on July and August images)
- Flooded areas in July, not in August: violet
- Water saturated regions in July and August: mean blue

Indexes of temporal variations can also be defined by combining ratios and differences of radiometry (normalised by the archive radiometry, in order to get rid of global variations), with an adequate threshold, between the reference image and one image taken during floods. In this way, flooded areas and regions saturated with water can be characterized. A HSV visualisation using the change detection between the archive and the July acquisition, with the archive image as a background is shown in Fig. 4. Because of the confusion of roughness and humidity on a single image (ref. [5]), in general the distinction between water content and roughness cannot be done on the basis of radiometry alone, unless multi-incidence or multi-frequency or multi-polarisation (ex. HH and VV) are available. In our case, we did the hypothesis of homogeneous and constant roughness between geomorphologically similar areas.

Fig. 4 can be interpreted as follows: flooded areas in orange; saturation with water in grey.
Having a DEM of the region and combining the water saturated areas with the areas of high slope, a map of hazardous areas (landslide risk) could be derived.

The same processing as above was applied also to the August acquisition, in order to detect the flood evolution : the flooded areas southern and western of Poyang-Hu Lake stay nearly constant, meaning that the dike northern of Poyang-Hu was not opened between July and August. RADARSAT processing was performed for CNES by PRIVATEERS N.V. (ref. [6],[9])

We remark here that the good flood detection using radar data was possible because of the mirroring effect over water. This is possible when the wind force is below certain limits[1]. These limits depend mainly on the incidence and the frequency, and to a much lesser extent on the polarisation (HH better than VV, especially when the wind direction is normal to the flight direction). For these two reasons (high incidence possible, HH polarisation) RADARSAT (and soon ENVISAT) are to be preferred to ERS for the purposes of flood mapping.

Concerning optical data, AVHRR images (archive of June ’99 and acquisition of July ’99 at flood start) were used for the purpose of change detection. Band 2 is used in a colour composite image (June, July, July in R,G,B respectively): the flood extent on July 19th appears in red, Fig.5 (see ref. [7]). A satisfactory detection of floods over the same region during summer 1998 was also possible using VEGETATION, as shown in Fig. 6.

5.3 An example of flood mapping using RADARSAT: Canada/US Red River flood in summer 1997

The 1997 flooding of Manitoba’s Red River caused a state of emergency to be called in that Canadian province and North Dakota, in the US (Ref. [10], [11]). The Red River begins in the south and flows north. Spring swelling and inundation of the Red River in North Dakota allowed Manitoba residents to prepare for a flood including planning for acquisition of remote sensing data. Remote sensing provided a valuable tool for response to this natural disaster, as well as an important device to support rescue and mitigation efforts.

In preparation for the flood, organizations involved in emergency response in Canada and the US had explored and been monitoring satellite image availability over the area. RADARSAT-1 was determined to provide the most suitable and timely data for the response due, in part, to its steerable antenna and the high frequency of repeat coverage. Revisit, or repeat coverage, is important in emergency response situations to enable frequent updating of dramatically changing conditions.

RADARSAT-1 imagery being acquired for the flood emergency response became top priority at the receiving stations. In most cases, data received for the Red River Flood event was delivered in near real time as a path image product every 2-3 days. All standard beam modes (1 –7), with a nominal resolution of 25 metres and four looks, were popular data choices to map flooding in non-urban areas. However, extended high beam mode was also used. Urban area flooding was mapped with aerial

[1] In quiet conditions, the radar backscatter on water can be modeled by a mirror behavior. Because of the wind and wave effect on the sea surface, sea clutter increases because of Braggs scattering, local wave slope (towards radar), volume scattering

photography because of the effects of buildings on the radar's viewing geometry, however the wider coverage of satellite data allowed the flood to be assessed in its larger ecological context.

Value-added products included classifications, vector extraction and vector overlay products (Fig. 7). Classifications were performed on the imagery to enable calculation of flood extent. Flood extents were digitized as vectors for overlay on the imagery with transportation and other vector datasets to help response team members, who were not remote sensing specialists, interpret and use the data (Fig. 8). The overlay method helped coordinate rescue efforts by showing areas that were flooded or were becoming flooded, and how transportation networks were affected. Flood stage-damage curves were also generated and integrated within the GIS to create map products for damage assessment and the planning of flood control measures.

Since flooding is a natural ecological phenomenon and history tells us that the Red River will, indeed, flood again, remotely sensed imagery has been identified as an important and reliable tool for mapping, monitoring and managing flood events.

6. Future spatial systems

Optical systems:

CNES SPOT-5 satellite will be launched in 2002. The main payload consists of high resolution imaging instruments. Compared to SPOT-4, this new sensor will provide higher ground resolution: 5m (rather than 10 m)[2] in panchromatic mode, higher resolution in multispectral mode: 10 m (instead of 20 m) in all 4 spectral bands in the visible and 20 m in the near-infrared range. The oblique viewing capacity of each instrument is maintained providing rapid access to a given area, plus a dedicated instrument (HRS) for along-track stereo acquisition. The SPOT-5 spectral bands will be the same[3] as those for SPOT-4. As requested by many users, this will ensure continuity of the spectral bands established since SPOT-1. Finally, location performances are enhanced down to 10-20 m (from the 350 m currently achieved).

Radar systems:

The Canadian RADARSAT-2 (launch planned in 2002) Synthetic Aperture Radar (SAR) will offer new modes of operation that will open up new application opportunities. In comparison to RADARSAT-1, RADARSAT-2 will offer the following new modes: selectable polarisation; selectable dual polarisation; full polarimetry; and higher spatial resolution. As an example, Ultra-fine mode images will have a 3 m resolution (10 m for fully polarised data). In addition, RADARSAT-2 will have the capability to look left and right, therefore improving its revisit time, and more accurate knowledge of the satellite's position due to the onboard Global Positioning System (GPS).

Envisat is the future ESA earth observation mission, to be launched in September 2001. Envisat will have on board an Advanced Synthetic Aperture Radar (ASAR), operating at C-band. ASAR ensures continuity with the ERS SAR and the wave mode of the ERS AMI. It features enhanced capability in terms of coverage, range of incidence angles, polarisation, and modes of operation (analogous resolution to ERS for standard 3 looks PRI, images, and 30 m for alternate polarisation images). This enhanced capability with respect to ERS is provided by a fully active array antenna (allowing the selection of different swaths) and a ScanSAR mode (400-km wide) of operation by beam scanning in elevation. In alternating polarisation mode, transmit and receive polarisation can be selected allowing scenes to be imaged simultaneously in two polarisations.

The main drawback of Envisat and RADARSAT-2 ASAR is the fact that they will both use a frequency slightly different[4] from their predecessors (ERS and RADARSAT-1 respectively). This will make generally impossible generating interferometric product using the ERS archive (apart from a limited number of applications where the frequency shift in range can be compensated by large baselines, see [8])

[2] An even higher resolution (3 m) can be achieved as a result of a post-processing (so called "super-mode"). This will be available as a standard product.

[3] When using a series of SPOT 1,2,4 acquisitions for the purposes of monitoring temporal evolution, the fact that the panchromatic band is not the same between SPOT 4 and SPOT 1,2 has to be taken into account and may need a relative calibration

[4] The frequency shift is 31 MHz between ERS and ENVISAT, 101 MHz between RADARSAT-1 and RADARSAT-2

Optical and Radar systems:

In addition to these three satellites, a joint French-Italian project envisages a constellation of 7 satellites named Pléiades. This constellation (consisting of at least 3 optical and 4 radar satellites) will ensure a daily revisit time of every area of the globe. This constellation, to be launched in mid 2005, will consist of:

- Two satellites with a high-resolution optical system (0.7 m in panchromatic mode, 20-km field of view), four bands (R,G,B,NIR), with flexible incidence and two degrees of freedom (60° in roll and pitch), 500 acquisitions/day, precise location capability (1 m with GCP, 20 m without). This system will allow lateral accessibility and along-track stereo.
- One satellite carrying an optical system with a large FOV (40 km, 2.5 m resolution in panchromatic mode), four bands (R,G,B,NIR)
- Optionally, 2 or 3 mini-satellites carrying a multi-(10-20 optical and near-infrared bands) and hyper-spectral (100-200 bands) optical system
- Four satellites with a high resolution radar system with a daily revisit time, several acquisition modes with variable resolution (from 1 m to 100 m), flexible incidence and polarisation in X band

In 2003, a Japanese optical (high resolution, stereo capability) and radar (L-band) satellite, ALOS, will be launched as a follow-up of J-ERS and ADEOS. This mission includes three earth observation payloads:

- A L-band polarimetric SAR ("PALSAR") with beam steering (10-51 deg) in elevation and two modes of operation. Fine mode, polarimetric, 70-km swath width, 10-m resolution; ScanSAR mode, HH, VV polarisations, 300-km swath width, 100-m resolution.
- A Panchromatic Remote-Sensing Instrument for Stereo Mapping ("PRISM") for digital elevation mapping and precise land information (2.5-m spatial resolution). In order to obtain terrain data including elevation, PRISM has three optical systems for forward, nadir and backward view. The swath width is 35km (Triplet mode) or 70km (Nadir Only, Wide swath mode).
- An Advanced Visible and Near Infrared Radiometer ("AVNIR-2") for precise land coverage observation. Four bands (in the visible - B,G,R - and near-infrared) at high resolution (10 m at nadir) will provide thematic maps of coastal zones, land coverage and land-use classification for monitoring regional environment. Moreover, a cross-track pointing capability allows for disaster monitoring (revisit time improvement). The swath width is 70km (at Nadir), and the depointing capability of +/- 44deg.

In conclusion, we can state that the present situation will be largely improved in the next few years in terms of sensor availability and revisit period.

7. Conclusion

If complementarity between existing sensors (optical, radar, multi-incidence and multi-polarisation) and image processing tools theoretically allow for a fast and reliable monitoring of areas of difficult access and of large extent damaged by man-caused or natural catastrophes, the available systems (civilian satellite constellations) do not yet allow for a real-time monitoring with the few-hours constraints imposed by Civil Protection entities.

Using the SPOT constellation, a daily acquisition at 10 m resolution over any site is possible, however this is subject to the meteorological uncertainties of optical satellites. In order to have a high resolution radar acquisition with a given incidence (for the purpose of comparison with an existing archive) delays can be of the order of several weeks because of the lack of a constellation.

With ENVISAT in the end of 2001 and RADARSAT-2 in the end of 2002, as well as SPOT-5 (beginning of 2002), all equipped with onboard recorders and highly flexible in incidence and resolution, added to the present ERS-2 and RADARSAT-1, the situation will improve. It will be only with the launch of a dedicated constellation like Pleiades, allowing simultaneous optical and radar acquisition at very high spatial resolution, that a spaceborne operational service for risk monitoring at high temporal frequency will be possible.

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Event	SPOT	VEGETATION	ERS	RADARSAT
Forest Fires (need of archives)	Yes (especially SPOT4 with MIR). Visibility risk (smoke)	Yes, if large major damage	Yes	Yes. High resolution and incidence are preferable (F4,F5). Compatible archives
Storm damages (need of archives)	Yes Cloud cover risk			
Land Damages: earthquakes, lava, landslides (need of archives)	Yes (especially SPOT4 with MIR for lava)			
Floods (archives help)	Yes Cloud cover risk		Yes	Maximise contrast for easy detection (minimise water clutter with respect to land): high incidence. Favourable polarisation (HH). Compatible archives if available
Urban damages	Yes Panchromatic better than multispectral (or both)	No	Yes	Yes. High resolution and incidence are necessary (F4,F5). Compatible archives
Oil spills (no archive needed)	Yes: specular conditions for sun-glint (east-looking)		Yes Favourable polarisation (VV)	Maximise contrast for easy detection (maximise water clutter with respect to oil): low incidence (F1,W1,SN1). Mode selection: trade-off between resolution and coverage (uncertainty of location)
Earth deformation (volcanic, seismic) modelling. Absolute need of archives.	Yes, for correlation		Yes, with an archive in interferometric conditions. Possible correlation.	
				High resolution and incidence are preferable

Table 1: acquisition selection, as a function of the event. There is no need of programming for VEGETATION. Radar acquisitions should be programmed in all events, in order to cope with the meteorological uncertainty. This operational character of radar is especially important for fires, floods, storms (higher visibility risk) - on the other side the availability of archive images is more critical. Subsidence modelling is not included in this table because of the different context (slow movements, longer time-scales involved, different techniques such as permanent scatterers).

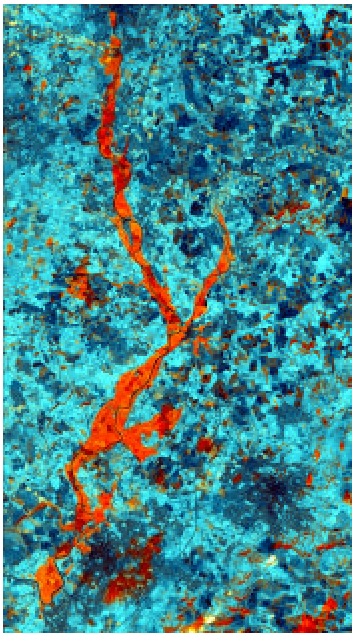


Fig.1. The flood map resulting of the HSV composition and of the change detection between SPOT 4 and SPOT 1 (using the latter image as a background) shows the flood extent on November 1st

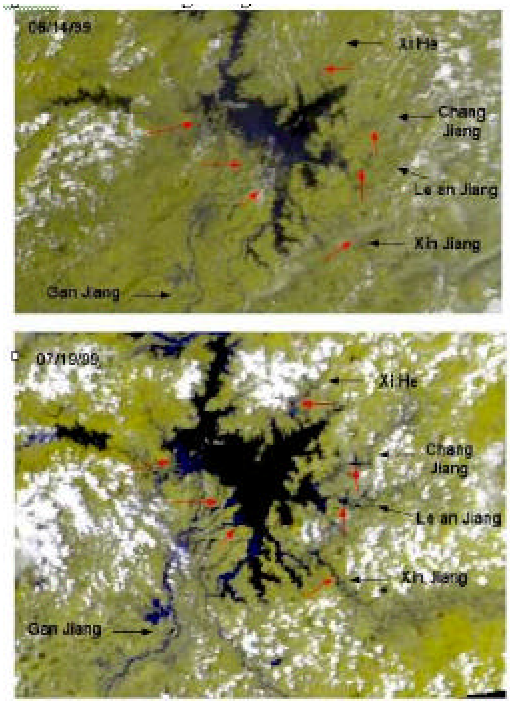


Fig.2 Comparison of NOAA AVHRR acquisition before floods and at the beginning of the floods of summer 1999.

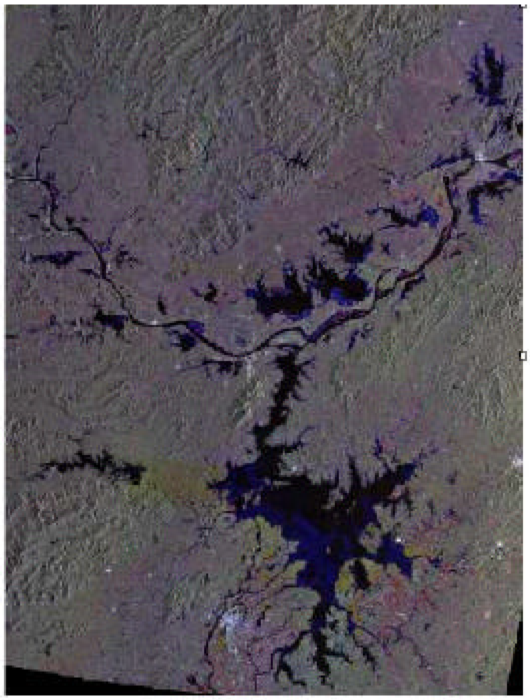


Fig.3 Coloured composition of three RADARSAT images acquired before, at the start and at the end of floods

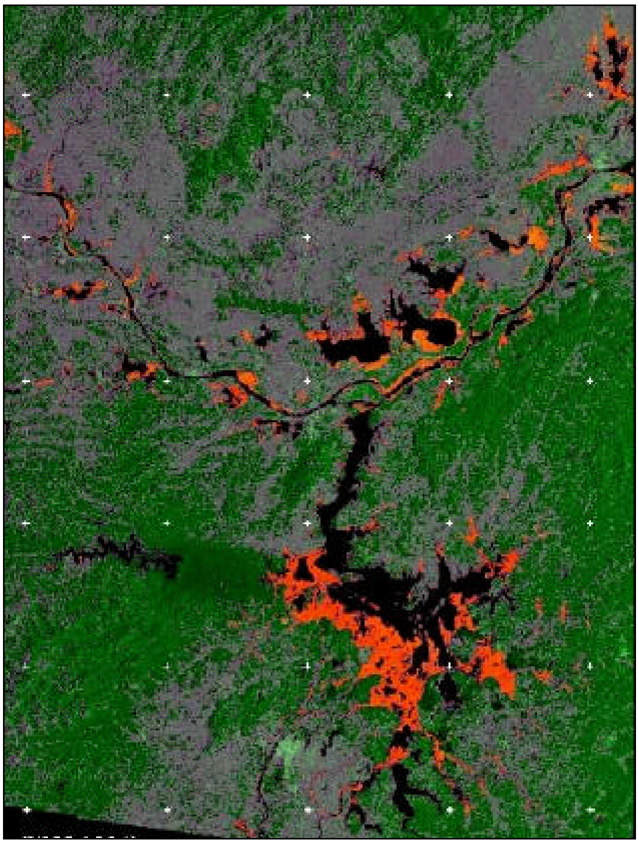


Fig. 4 A HSV visualisation using the change detection between the archive and the July acquisition, with the archive image as a background. Interpretation: flooded areas in orange; saturation with water in grey

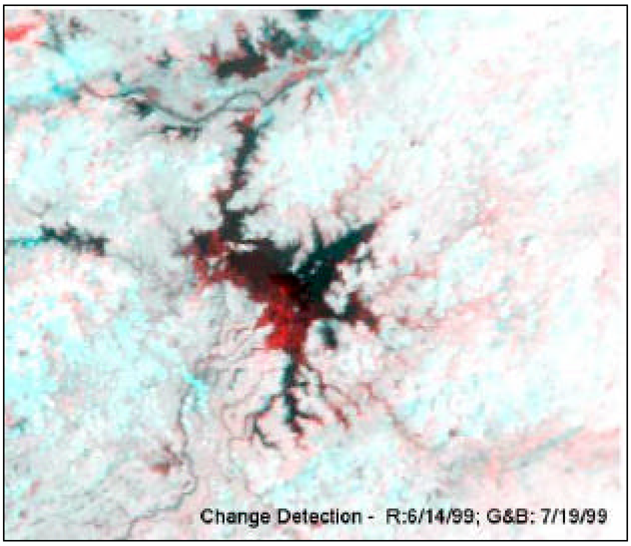


Fig. 5 Change detection using two AVHRR images (June, July, July in R,G,B respectively): the flood extent on July 19th appears in red.

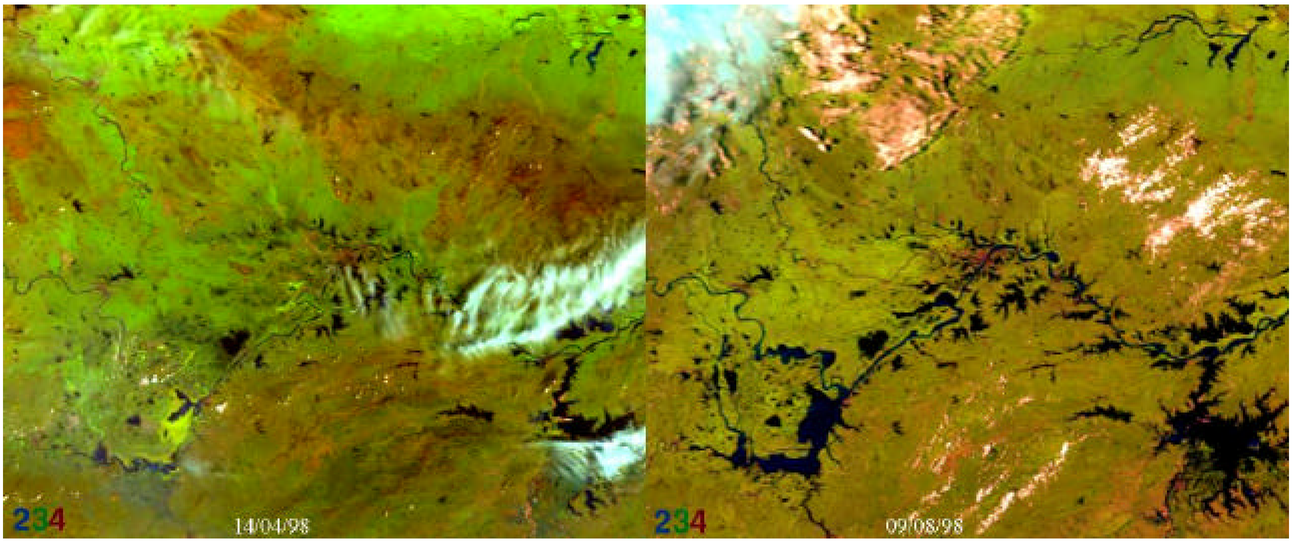
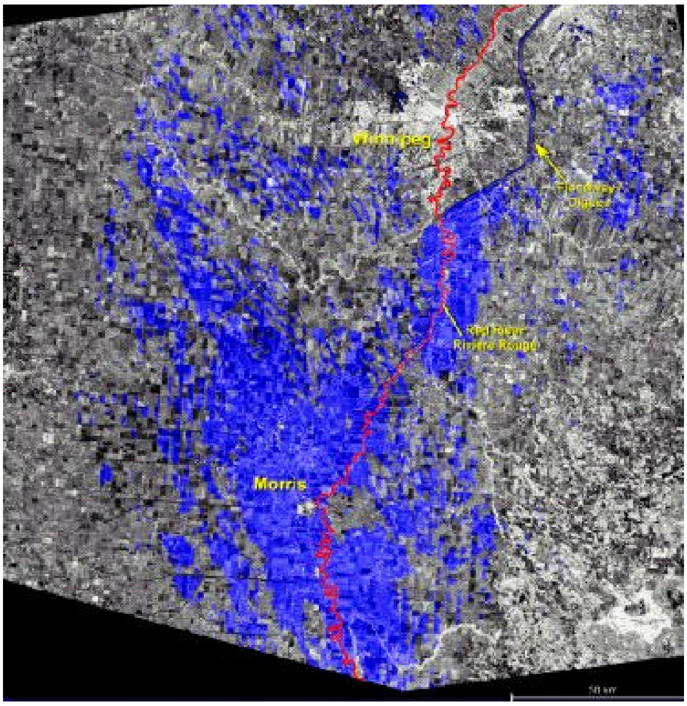


Fig. 6 Flood detection over the same region during summer 1998 using VEGETATION (courtesy of P.Henry, CNES



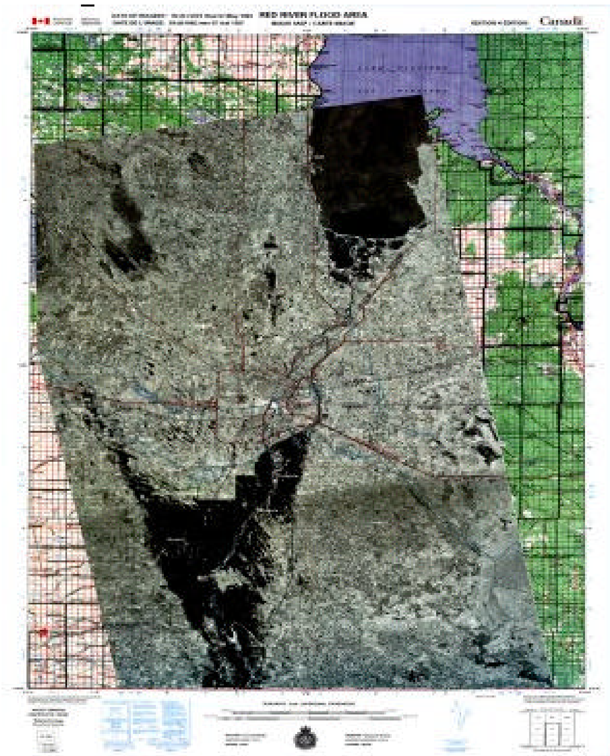


Fig. 7 A RADARSAT Standard 2 Desc. (April 27, 1997) captured the extent of the Red River flood (Canada/US border). The flooded region is colored in blue for ease of interpretation.

Fig. 8 RADARSAT integration with National Base Map delivered as the emergency briefing map during the Red River flood (Manitoba, Canada)