# CONTRIBUTION OF SPACE SYSTEMS TO MAJOR RISKS MANAGEMENT

## An example: Management of Flood Risk

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***Abstract** : This paper gives an overview of the potential contribution of space systems to major risks management. The case of plain floods is more specifically considered. The respective role of satellites dedicated to meteorology, earth observation, data collection, telecommunication, localisation and navigation is described at each management stage : knowledge and prevention, warning and crisis, after crisis. As illustration, a satellite choice for the Meuse flood monitoring is developed. The need for a European service system to interface between the appropriate end-users and the satellite operators is emphasized.*

***Keywords** : Major risks management, Risk knowledge and prevention, Warning and crisis, After crisis, Space systems contribution, Meuse flood monitoring by satellite, Risk management services system*

## 1. INTRODUCTION

The prevention and management of natural and technological disasters is of prime importance, since the welfare and health of the population are concerned.

At the session of the Council of Europe on the 6th of October 1994 in Brussels, a resolution was carried to investigate the possibility of using space technology for the management of major risks ("EUR-OPA Major Hazards Agreement"). The study was put under the control of a steering committee co-presided by the European Space Agency (ESA) and the European Commission (DG XII), and comprising representatives of the national civil protection authorities and space agencies.

Two initial study phases respectively (a) identified the requirements of the bodies in charge of the risk management (study conducted by Tractebel Consult (B) and Geste (F)), and (b) made an inventory of the available satellite resources (task performed by ESA/ESTEC). A third phase consisted of a compliancy analysis of these requirements and resources, together with the definition of a system to access the space operators. A consortium, headed by Alcatel Telecom (F), and comprising CLEO (B), Eurospace (G), Geste (F), LHF (F), Planeta (R) and Scot Conseil (F), was entrusted with this task in 1996. Within this consortium, CLEO has examined, more specifically, the access system and its application to the study of plain floods.

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(1) [illegible] is an Economical Interest Grouping (EIG) of three leading Belgian companies: Alcatel Bell, Trasys Space (group Tractebel) and Sait Systems, putting together their experience and know-how in space activities. Its purpose is to promote the use of remote sensing data, distribute Earth Observation data and develop added-value projects based on these data.

## 2. OVERVIEW OF SPACE SYSTEMS CONTRIBUTION TO RISKS MANAGEMENT

### Major risks management

Major risks cover natural events (floods, forest fires, earthquakes, volcanic eruptions, etc.), as well as technological accidents (nuclear, chemical, pipeline, hazardous materials transportation, etc.). The management of these risks comprises three stages : risk knowledge and prevention, warning and crisis, after crisis.

In each country, the risks management concerns several bodies at governmental, institutional and scientific levels. Civil protection authorities and other relief services assume responsibility for operations during a crisis. Insurance companies are also interested in the identification of risk areas and the assessment of damages.

This paper will consider plain flood risk as a case study. Plain floods, generally, result from rivers' swelling gradually to the point of overflowing their banks due to snow melt and/or continuous rainfall. The floods duration varies from a few days to several weeks. More often this concerns large river basins due to the accumulation of water coming from tributaries.

Experience has shown that the success of risk management depends largely on the availability, distribution and effective use of information. At each management stage, space systems can contribute to this requirement.

### Risk knowledge and prevention

First of all, it is essential to have a good knowledge of the risk zone : topography, land use, urban areas, hydrologic characteristics of soil, etc. This knowledge derives mainly from maps, ground measurements, hydrologic studies. The identification of the vulnerable areas of the basin is based on previous flood data and hydraulic simulations. The superimposition, in a geographical information system (GIS), of the vulnerable areas map with the land use data, gives the risk map and shows the threatened infrastructure.

The imagery, supplied by the earth observation satellites (SPOT, LANDSAT,...), mainly feeds the general and land use cartography. As far as the topography of the river bed and the overflow zones are concerned, the fine representation requirements (1:1.000 at the local scale) do not permit the use of the satellites for this purpose because the spatial resolution of present sensors is insufficient (limited to 10 m). Although slow and expensive, aerial-photography complemented with plotted land data is, today again, a more accurate technique for the topographical needs. However, the expected availability in a few years of new means of earth observation by satellite, with a greater spatial resolution (for instance, Space Imaging with about 1 m in horizontal, 3 to 0.5 m in vertical), will provide an alternative method which will greatly facilitate the periodic updating of digital terrain models.

Prevention requires the monitoring of different parameters, the most important of which are the regional weather, the water flow and level of the river, the soil moisture and, in winter, the soil temperature and snow cover. Weather forecasts are already based on meteorological satellite services (METEOSAT, NOAA,...). Earth observation satellites can give some information on soil state: soil moisture (by radar imagery), snow cover (the radar imagery allows the calculation of the water equivalence of snow cover), etc. Other satellites (EUTELSAT, INMARSAT,...) can collect, relay and distribute the measurements made by ground sensors. In the future, the evolution of space techniques will allow the detection, in almost real time, of risk factors from physical parameters directly measurable or derived from images.

### Warning and crisis

It is necessary to detect pre-alarm and alarm thresholds, to know at any time the scale of the flooding and forecast its expansion, in order to allow the intervention of the relief teams in time. This requires real time monitoring of the meteorological conditions, the river and the soil state.

By monitoring the critical parameters, the meteorological satellites and, to some degree, those of earth observation help to provide these warnings. In order to watch and forecast flood expansion, satellites with optical sensors give excellent images in the daytime when the sky is clear. Those with radar sensors are effective day and night independently of the cloud cover but their availability is lower at present.

During a crisis, it is essential that telecommunications are effective, even if the ground infrastructure is down. This can be provided by satellites (EUTELSAT, INMARSAT,....) between ground mobile stations VSAT (Very Small Aperture Terminal). Guiding and keeping contact with the relief teams is another important aspect which can be solved, if needed, with positioning and navigation systems by satellites (GPS - Global Positioning System, GLONASS,...). All these techniques are well controlled.

### After crisis

After the flood's subsidence, it is necessary to assess globally the damage and to continue to maintain the communication until the terrestrial services are restored. The earth observation and telecommunication satellites contribute respectively to these objectives.

The disaster event has to be analysed in order to identify the topographical changes and update the models and the crisis scenarios. The techniques of the initial stage (knowledge & prevention) are again applicable here.

Table A gives, for each risk stage, an overview of the main parameters relevant to the earth observation, their requirements and the capability of the principal existing and planned satellites to satisfy them. The relevant characteristics of the instruments of the considered satellites are included in table B.

## 3. PLAIN FLOOD CASE

### Event description

In January 1995, heavy and continuous rainfall provoked a severe overflow of the Meuse river (Figure 1), in France (Ardennes department), Belgium and The Netherlands. The flood was exceptional in size (water level peak of 6.5 m) and duration (14 days), with a return period of 100 years for the higher course of the Meuse in Belgium.

In the previous month, the soil was already close to water saturation, due to rainfall. The saturation degree was maintained by moderate rainfall during the initial days of January. These conditions were followed by abundant rainfall in the middle third of the month and the exceptional rainfall in the Southern portion of the Meuse basin during the last ten days of January. The result was that the soil could no longer absorb any water run off, which triggered the sudden rise of the water in the tributaries and in the Meuse itself.

During the flood, the flow rate reached 300 m³/s. The water level at Chooz (F) rose to a peak of 5.5 m on the 30th of January. In a Belgian portion of the river, from Dinant (B) to Lixhe (B), the level reached peaks of 6.5 m in some places on the 31th. The floods decreased only after several days.

The region of Dinant (B) was one of the most affected : 3.500 flooded houses, 164 evacuated people, 400 emergency personnel active on the scene.

### Present monitoring system

Space data are currently used to determine the overall meteorological situation and forecasts: cloud coverage, cloud top height, precipitation, temperature, atmospheric pressure, wind speed and direction, water vapour concentration in the atmosphere, etc.

Raw data received from the METEOSAT satellites are processed by the Space Operations Centre of ESA (ESOC). The results are transmitted via satellite to European meteorological institutes. The Belgian IRM-KMI feeds its digital models with this received information, together with the daily data acquired from the ground weather stations of its meteorological network and the data which are transmitted, every 1/4 hour, by the weather radar of the Brussels international airport authorities. A short term weather forecast is issued every 6 hours, as well as a sliding medium term forecast covering a period of 5 to 6 days.

Based on the regional weather forecasts and the measurements of water flow and level, collected from a network of sensors along the Meuse, an institutional centre (SETHY - Service d'Etudes Hydrologiques) analyses the hydraulic situation of the river. After liaising with the concerned neighbouring regions concerned, it transmits bulletins and possible warnings to the authorities and field surveyors.

### Flood observation by satellite

The visits of the main earth observation satellites (cf. table B) over the Dinant region (latitude 50.16°N, longitude 4.55°E) during the 1995 flood have been analysed. Two elements have to be taken into account in order to select a satellite for a flood monitoring mission : the number of possible images during the flooding period and the delay

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[**] Cluster for Earth Observation

between two successive visits over the region. The smaller this delay is, the better will be the detection of a rapid change between two images.

Some assumptions have been made in the analysis of the images from different satellites:

- a complete image is possible when the region is situated in the viewing field of an instrument
- the number of images obtained during a visit is the sum of the images achieved by each instrument
- the image quality, which depends on the sensor and the incidence angle, is supposed acceptable.

Figure 2 indicates the visits of the satellites over the Dinant region during the flooding period and the corresponding number of possible images.

For the satellites with optical sensors, the number of images increases with the viewing field of the sensors. RESURS-01 gives the best results: 16 possible images during the 14 days flood period. This is due to the cumulative effect of its wide viewing field and the different spectral bands associated with its sensors. The worst results are those of LANDSAT-5 which has the narrowest accessibility.

SPOT-2 and SPOT-3[2] together give interesting results : the minimum revisit time over Dinant (50.16° N) is only one day. The visits of each of them are characterized by a periodicity of three consecutive days of visibility followed by two days without any visibility, taking into account the oblique viewing capabilities (27° off-nadir viewing). Combining the capabilities of the existing SPOT satellites with the planned SPOT-4 gives the best results.

The analysis of the radar sensors shows that RADARSAT seems also to be suitable for the task of natural disaster monitoring, because it has a great number of possible images during the flood period. ERS-1 and ERS-2 do not give satisfactory results. This is due to their viewing field being smaller than the one associated with RADARSAT or the planned ENVISAT.

Finally, the number of possible images which may be made with RESURS-01 or SPOT is far greater than the number of images achieved with RADARSAT. Nevertheless, a conclusion cannot be drawn from this result, because it is necessary to take into account the cloud coverage and/or illumination constraints. As a matter of fact, the cloud cover was almost permanent over the Dinant region during the period of the flood. The overall conclusion is that a combination of multiple satellites ought to be used, according programming which takes into account the cloud coverage forecasts.

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[2] SPOT-3 is no longer operational since mid November 1996

## 4. EUROPEAN RISK MANAGEMENT SERVICES SYSTEM

### Concept

For a flood, as for any other hazard, the space resources capable of being mobilized are multiple and complex. It is easy to imagine the difficulties of national or regional bodies, charged with risk management, trying to access space systems, particularly in a crisis period, when it is necessary to act urgently.

It is essential, therefore, for reasons of efficiency and cost, to establish a specialized service between the users and the space systems operators. It would supply a range of types of data, information, products, technical support to any national or regional risk management body requiring assistance.

This service, which could only be economically justified at a European level, would be based on an information and communication system (RMSS - Risk Management Services System) interfacing the bodies concerned (figure 3).

By virtue of this system, the user could request observation images, in situ measurements, communication, etc. This would be entrusted to someone at a focal point who would determine the best choice of space resources, get in touch with the satellite operators, collect the space data, interpret them as soon as possible and transmit them in a directly operational form to the end-users (civil protection authorities, scientific institutions etc.). To these users, RMSS would act as a value-added data server. It would also assume the monitoring of certain risks by expert systems, and, upon request, carry out specialized work : derived image products, simulations etc. Some tasks could be done by entities which already exist in Europe.

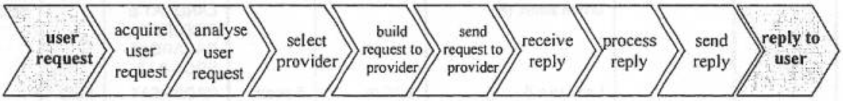
The space-based service system would thus produce information which could be exhibited on any national system to enhance it. Particular characteristics should be as follows:

- Dedicated only to earth observation ; the providers of other services (meteorology, data collection, telecommunication, localisation and navigation) would be connected directly to the end-users without transiting by RMSS; nevertheless, a returnlink from end users to RMSS could be useful for alarm purpose and mobilization of emergency services.
- System modularity allowing a centralized and/or distributed architecture.
- Direct interface with end users facilities which might be widely different, allowing, for example, the delivery of high level processed and interpreted images on the end users screens.
- Flexibility of the proposed services to user communities: direct services (supply of pre-processed data,...), standard services (interpreted data,...) or specific services (extraction of parameter values for a model,...).
- Fast in the crisis stage.

**Functions**

The required functions at the European level should be the following:

- Management subsystem: management of data for the benefit of user communities, orders to relevant service providers, accounting and billing of services etc.
- EO data server: the following diagram shows the steps in the processing of a request:



- Monitoring expert systems: for example, monitoring the degree of risk of forest fires.
- Processing subsystem: off-line processing, modelling and simulation support, GIS...
- Archiving subsystem: delivery of archived data related to past crises.
- Experts database: management and search for experts (persons or organisations) in various domains (nuclear, hydraulic, chemical...).
- Telecommunication subsystem: network management (channels, protocols and services), data transmision...

The services directly supplied to the end users would require local functions:

- Weather relay subsystem: acquisition of meteorological data and local forecast.
- Data collection subsystem: collection of measurements from in situ sensors.
- Localisation & navigation subsystems: localisation and guidance of rescue services.
- Telecommunication: communication tools.

Many of these functions already exist but what is missing today is their coordination for the purpose of space assistance to risks management.

## 5. CONCLUSIONS

Space technology, due to its many capabilities and its flexibility coupled with daily programming, is gradually becoming complementary to classical techniques in many activities. A consensus exists in Europe on their beneficial role for major risks management.

Earth observation systems already contribute to the knowledge and prevention of exposed areas and observation of disasters during the crisis and after crisis stages. Some new remote sensing techniques (high resolution, monitoring) are in emerging stages. A European body which interface users and operators, would allow rationalisation of the organisation of the use of space techniques and procurement of space data and services. It could also result in lower costs.

Satellites are being used more and more to monitor our planet. Soon they will allow better forecasting, detection, observation and assessment of natural disasters and technological accidents and, indeed, may even prevent them. There is no doubt that this use of space technology will soon be not just a choice but a must in order to better protect ourselves.

### *Table A* - Compliancy of requirements and earth observation satellites

| | | | Requirements | | Resources | | | |
|---|---|---|---|---|---|---|---|---|
| ***Risk stage*** | ***Need*** | ***Parameters*** *(R=regional ; L=local)* | ***Spatial Resolution*** | ***Freq.*** | ***Current satellites*** | ***Compli - ancy*** | ***Planned satellites*** | ***Compli - ancy*** |
| Knowledge & Prevention | Hydrological models | Topographic height (R) | 20 m (horiz.)<br>5 m (vert.) | 10 years | ERS-1, 2<br>RADARSAT | No | - | |
| | | Topographic height (L) | 5 m (horiz.)<br>0.5 m (vert.) | 10 years | - | | - | |
| | Risk areas | Land use & urban areas (R) | 10-30 m | 5 years | ERS-1, 2<br>LANDSAT-5<br>RESUR01<br>RADARSAT<br>SPOT-2 , 3 | Fully | ENVISAT<br>SPOT-4 | Fully |
| | | Land use & urban areas (L) | 2-10 m | 5 years | RADARSAT<br>RESURS01 | Fully | - | |
| | Routine monitoring | Soil humidity (R) | 500-1000 m | Weekly | ERS-1,2<br>RADARSAT | Partly | ENVISAT | Partly |
| | | Land surf. temperature & snow cover (R) | 500-1000 m | Weekly | NOOA-13 , 14 | Partly | NOOA-15 | Partly |
| | | River flow & water level *(data collection)* | | Daily | EUTELSAT<br>INMARSAT | Fully | - | |
| Warning & Crisis | Crisis monitoring | Flood extent (R) | 10-30 m | 1 day | ERS1, 2<br>RADARSAT | Fully | ENVISAT | Fully |
| | | Flood extent (L) | 2-10 m | 6 hours | RADARSAT | Fully | - | |
| | | River flow & water level *(data collection)* | | 6 hours | EUTELSAT<br>INMARSAT | Fully | - | |
| After Crisis | Damage assessment | Flooded areas (R) | 10-30 m | Once after flood | ERS1, 2<br>RADARSAT | Fully | ENVISAT<br>SPOT-4 | Fully |
| | | Flooded areas (L) | 1-5 m | | RADARSAT | | - | |
| | Changes | Land use & urban areas (R) | 10-30 m | After flood | ERS1, 2<br>LANDSAT-5<br>RESUR01<br>RADARSAT<br>SPOT-2 , 3 | Fully | ENVISAT<br>SPOT-4 | Fully |
| | | Land use & urban areas (L) | 2-10 m | | RADARSAT<br>RESUR01 | Fully | - | |
| | | Topographic height (R) | 20 m (horiz.)<br>5 m (vert.) | After flood | ERS1, 2<br>RADARSAT | No | - | |
| | | Topographic height (L) | 5 m (horiz.)<br>0.5 m (vert.) | | - | | - | |

### *Table B* - Characteristics of some earth observation satellite instruments

| *Sensor* | *Satellite* | *Origin* | *Launch* | *Instrument* | *Swath width* | *Pointing capab.* | *Horiz. resol.* | *Vert. resol.* |
|---|---|---|---|---|---|---|---|---|
| Optical | LANDSAT-5 | USA | 03/84 | TM<br>MSS | 185 km<br>185 km | nadir pointing | 30 m<br>80 m | no |
| | RESURS-01 | Russia | 11/94 | MSU-E<br>MSU-SK | 600 km<br>600 km | 30° off-nadir<br>nadir pointing | 45 m<br>170 m | no |
| | SPOT-2 | France | 01/90 | HRV-P<br>HRV-XS | 60 km<br>60 km | 27° off-nadir | 10 m<br>20 m | 10 m |
| | SPOT-3 (no longer operational since 11/96) | France | 09/93 | HRV-P<br>HRV-XS | 60 km<br>60 km | 27° off-nadir | 10 m<br>20 m | 10 m |
| | SPOT-4 (planned) | France | 03/98 | HRVIR-P<br>HRVIR-XS<br>VMI | 60 km<br>60 km<br>2200 km | 27° off-nadir | 10 m<br>20 m<br>1.15 km | 10 m |
| Radar | ERS-1 | Europe | 07/91 | SAR | 100 km | 23° off-nadir | 10-30 m | |
| | ERS-2 | Europe | 04/95 | SAR | 100 km | 23° off-nadir | 10-30 m | |
| | RADARSAT | Canada | 11/95 | SAR | 50-500 km | 10°-60° off-nadir | 10-100 m | |
| | ENVISAT(planned) | Europe | 12/98 | ASAR<br>MERIS<br>AATSR | 100-405 km<br>1450 km<br>500 km | 15°-45° off-nadir<br>41° off-nadir<br>47° off-nadir | 30 m-1 km<br>300 m<br>1 km | 10 m<br>no<br>no |

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*Figure 1* - **Meuse valley**

|  | Radar sensors |  |  |  |  | Optical sensors ( □ = visible freq. band ; O = IR/thermal IR band ) |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | ERS1 | ERS2 | Radarsat | Visits / day | ENVISAT* | SPOT2 | SPOT3** | RESURS | Landsat5 | Visits / day | SPOT4* |
| 20 Jan | ■ | ■ | ■ ■ | 4 |  |  | □ | □ |  | 2 | O |
| 21 Jan |  |  | ■ | 1 | ■ ■ |  | □ |  |  | 1 | O |
| 22 Jan |  |  |  | 0 |  | □ | □ | □ O O |  | 5 | O |
| 23 Jan |  | ■ | ■ | 2 |  | □ |  | □ O | □ | 4 | O O |
| 24 Jan |  |  | ■ ■ | 2 |  | □ |  |  |  | 1 | O |
| 25 Jan | ■ |  |  | 1 | ■ ■ |  | □ | □ O | □ | 4 | O |
| 26 Jan |  | ■ |  | 1 |  |  | □ | □ O | □ | 4 | O |
| 27 Jan |  |  | ■ ■ | 2 |  | □ | □ |  |  | 2 |  |
| 28 Jan |  |  |  | 0 | ■ | □ |  | □ O | □ | 4 | O |
| 29 Jan |  |  |  | 0 | ■ | □ |  | O |  | 2 | O |
| 30 Jan |  |  | ■ | 1 |  |  | □ |  |  | 1 | O |
| 31 Jan |  |  | ■ | 1 |  |  | □ | O |  | 2 | O |
| 01 Fev |  |  |  | 0 | ■ | □ | □ | □ O | □ | 5 | O |
| 02 Fev |  |  |  | 0 | ■ | □ |  |  |  | 1 | O |
| Total | 2 | 3 | 10 | - | 8 | 8 | 9 | 16 | 5 | - | 14 |

* planned
** no longer operational since mid November 1996

*Figure* 2 - **Visits of considered EO satellites over the flooded area**

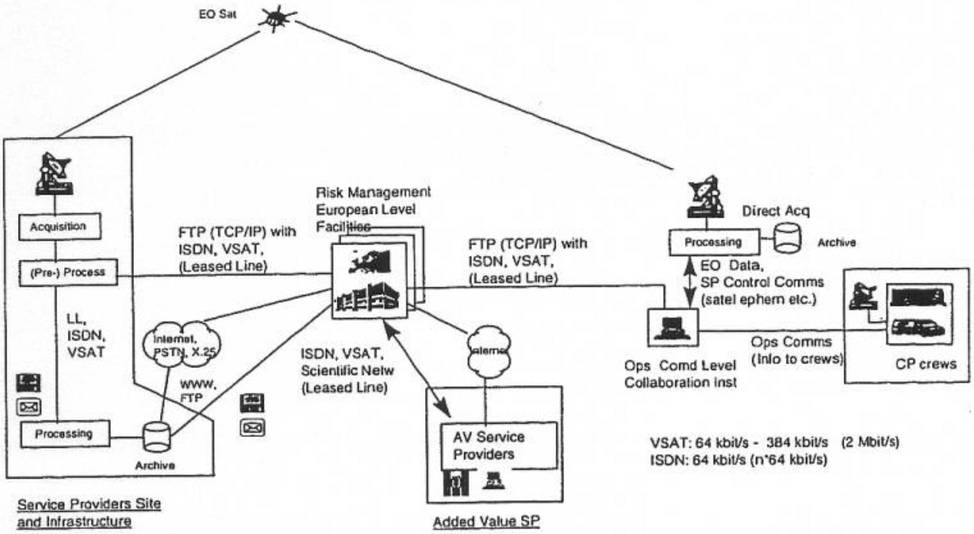

*Figure 3* - **Example of Earth observation system**

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