Breaking new grounds for remote sensing in support of disaster relief efforts: detecting and pinpointing earthquake damages in near-real time (El-Salvador, January 2001)

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ABSTRACT

On January 13th 2001, a very strong earthquake stroke El-Salvador, causing almost 1000 deaths and huge destruction, leaving more than one million people homeless.
In support to the rescue teams, a project was put up to provide up-to date maps and to identify damages to housing and infrastructures, covering the whole country.
Based on the analysis of SPOT Panchromatic satellite imagery, updated maps were delivered to the rescue teams within 72 hours after the earthquake. In addition, during the 10 days following the earthquake, high resolution mapping of the damages was carried out in cooperation and coordination with rescue teams and relief organizations. Some areas of particular interest were even processed and damage maps delivered through the Internet 3 hours after request.
For the first time in the history of spaceborne Earth observation, identification and evaluation of the damages have been delivered on-site, in real-time (during the interventions), to local authorities, rescue teams and humanitarian organizations. In this operation, 24 hours a day operationally and technical ability were the keys for success and contributed to save lives.

1. THE EL-SALVADOR EARTHQUAKE (13 JANUARY 2001)

An extremely violent earthquake (magnitude 7.9 on the Richter scale) stroke the El-Salvador, in Central America, during the night of the Saturday 13 January to the Sunday 14 January 2001.
The epicenter of the earthquake was located in the Pacific Ocean, some 80 kilometers away from the coast of the El-Salvador. The shockwave of the earthquake, propagating towards the coast of the country, and then towards the inland, caused considerable damages and destructions over the whole width of the country.
The balance of losses amounted, two months after the event, to 827 deaths, more than 3000 missing, and about 1 million homeless. Material damages were huge.

The neighbouring countries of Guatemala and Honduras had also been suffered from the earthquake, although in a least measure.
During the next weeks, this first earthquake was followed by several hundreds of replicas. The most important ones were real earthquakes: on the 18th of January (magnitude 4.6 on the Richter scale), on the 13th of February (magnitude 5.7 on the Richter scale, causing 283 deaths, 3000 wounded, and more than 2000 missing), and the 18th of February (magnitude 5.3 on the Richter scale).
Given the size of this disaster, which stroke a country already extremely afflicted by the effects of the "Mitch" hurricane in November 1998 [1], numerous european, north-american and center-american NGO's acted immediately to rescue the victims and bring help to the populations.
Similarly, but much better equipped for the task, the French DDSC (Direction de la Défense et de la Sécurité Civile), among other similar organisations from a number of countries in the world, did rapidly engage important means (teams and materials) in El-Salvador to rescue the victims in the emergency phase. Indeed, in this phase, covering the two weeks after the earthquake, people trapped under the ruins of their collapsed houses were still found alive and saved.
This project has been carried out by PRIVATEERS NV for the CNES (French Space Agency) from the 19th of January 2001 to the 31st of January 2001, to provide, first the French DDSC, then other rescue teams and authorized humanitarian organisations with accurate information regarding the location and extent of damages within urban areas and built-up areas. The aim of this operation was to allow the rescue teams to immediately and accurately know what and where were the most heavily devastated places or quarters, in order to enable an optimal (and if possible, coordinated) use of their means and personals and save time in the intervention.
In terms of remote sensing, rapidity in the execution of the work, accuracy of detection and information, and immediate transmission of information to the rescue teams were the main requirements of the project.
The CNES initiative has been taken in the framework of the international charter on natural disasters announced at UNISPACE'99 [2].

2. PLANNING SATELLITE IMAGERY

The company Spot Image from Toulouse (France) immediately programmed the SPOT-1 and SPOT-4 satellites to acquire imagery over El-Salvador. Indeed, SPOT-1 acquired useful imagery on the 16th of January 2001, and SPOT-4 on the 18th of January 2001.
All SPOT images used in this project are Panchromatic images. Both their spatial resolution and spatial sampling rate are 10 x 10 meters.
The 5 SPOT archive images used had been acquired on the 15th of February 2000, on the 11th of November 2000, on the 17th of November 2000 (2 images), and on the 27th of November 2000.
The 5 SPOT images acquired very shortly after the earthquake and used in this operation have been acquired on the 16th of January 2001 (SPOT-1, 3 images), and on the 18th of January 2001 (SPOT-4, 2 images).

Given the indisponibility of the SAR onboard the european satellite ERS-2 of the European Space Agency (indisponibility originally announced by ESA for the period from the 13th of January to the 24th of February 2001), there was no possibility at all to use any european SAR imagery.

3. DELIVERY OF UPDATED MAPPING OF THE COUNTRY TO RESCUE TEAMS

First of all, the DDSC operating in El-Salvador needed most urgently an up-to-date cartography of the areas in which it had to work. Since such a cartography was not available, we had to build a spatio-map of the country, in a way that it could be easy to use from the terrain with the means available within DDSC's teams (portable computers, and Internet links).

Satellite imagery used for mapping:

The SPOT-4 archive images, acquired between February and November 2000, are recent enough for the purpose of mapping, since they are posterior to the changes caused by the "Mitch" hurricane in November 1998). These images have been delivered to PRIVATEERS NV the 19th of January at 17:00 p.m.
These images had been produced by Spot Image at level 2A, using the known acquisition parameters. Nominally, the absolute location of SPOT level 2A images is not affected by location errors exceeding 500 meters on flat terrain [3].

Making the use of maps easy:

Ii is noteworthy that the 5 SPOT-4 archive images were of particularly good quality in terms of cloud cover. In addition, these images present overlap each other. Therefore, the global cartographic mosaïc of El-Salvador was built by favorizing the less cloud-covered SPOT-4 image within overlap areas. This way, we obtained a final spatio-map more than 95% cloud-free.
A statistical analysis of the geographical information associated to the SPOT-4 products has enable to improve the accuracy of the absolute location of the spatio-map. As a result, the spatio-map of El-Salvador does not present errors of absolute location exceeding 210 mètres, ex parallax effects in the presence of strong relief.
This spatio-map (*cf.* figure 1) covers 138,35 kilometers from north to south and 231,85 kilometres from west to east, *i.e.* almost two thirds of the country. In one piece, this spatio-map represents, in digital form, the very respectable, but hard to handle, volume of 320 Mb of data, which could make it useless for terrain operations. For this reason, this global map has been divided into 19 cartographic sheets (*cf.* figure 1), whose use is made clear to any potential user and easy on whatever computer, even a modest one: with a size of 16 Mb for a coverage of 40 x 40 kilometers, each cartographic sheet represents a volume of data any portable computer with 32 Mb of RAM can easily display.
In order to ease their use in operations, the cartographic sheets overlap each other by 5 kilometers.

Final cartographic products:

In addition to the original cartographic sheets, their JPG lossless compressed versions (still at the full spatial resolution of 10 x 10 meters), representing a modest data volume of 0.7 Mb to 2.6 Mb depending on the sheet, were delivered on-line. They could be easily downloaded from El-Salvador within minutes.
The final cartographic products were delivered in HTML format, and accessible with a simple Internet browser.
These final cartographic products were delivered on Monday 22nd of January 2001 at 10:30 a.m., when DDSC's rescue teams were still in the capital San-Salvador and were about to leave for their operation area in the Sonsonate province in western El-Salvador.

4. OPERATIONAL STRATEGY

A number of correspondents in El-Salvador provided preliminary information about the current status of the cities and towns which had most particularly suffered from the earthquake. In particular, NGO's already at work in El-Salvador transmitted the listings of the most damaged cities and villages, as well as a preliminary evaluation of the severity and the extent of the observed and/or presumed damages.
Finally, since DDSC had to operate in the provinces ("*comarcas*") of Sonsonate and in the metropolitan area of San Salvador, these areas needed absolute priority.
These informations, the operational requirements of DDSC, and a visual inspection of the SPOT images acquired on the 16th and 18th of January 2001, enabled to establish a priority order with regard to the processing and the analysis of the areas damaged by the earthquake, with a particular emphasis to built-up areas.

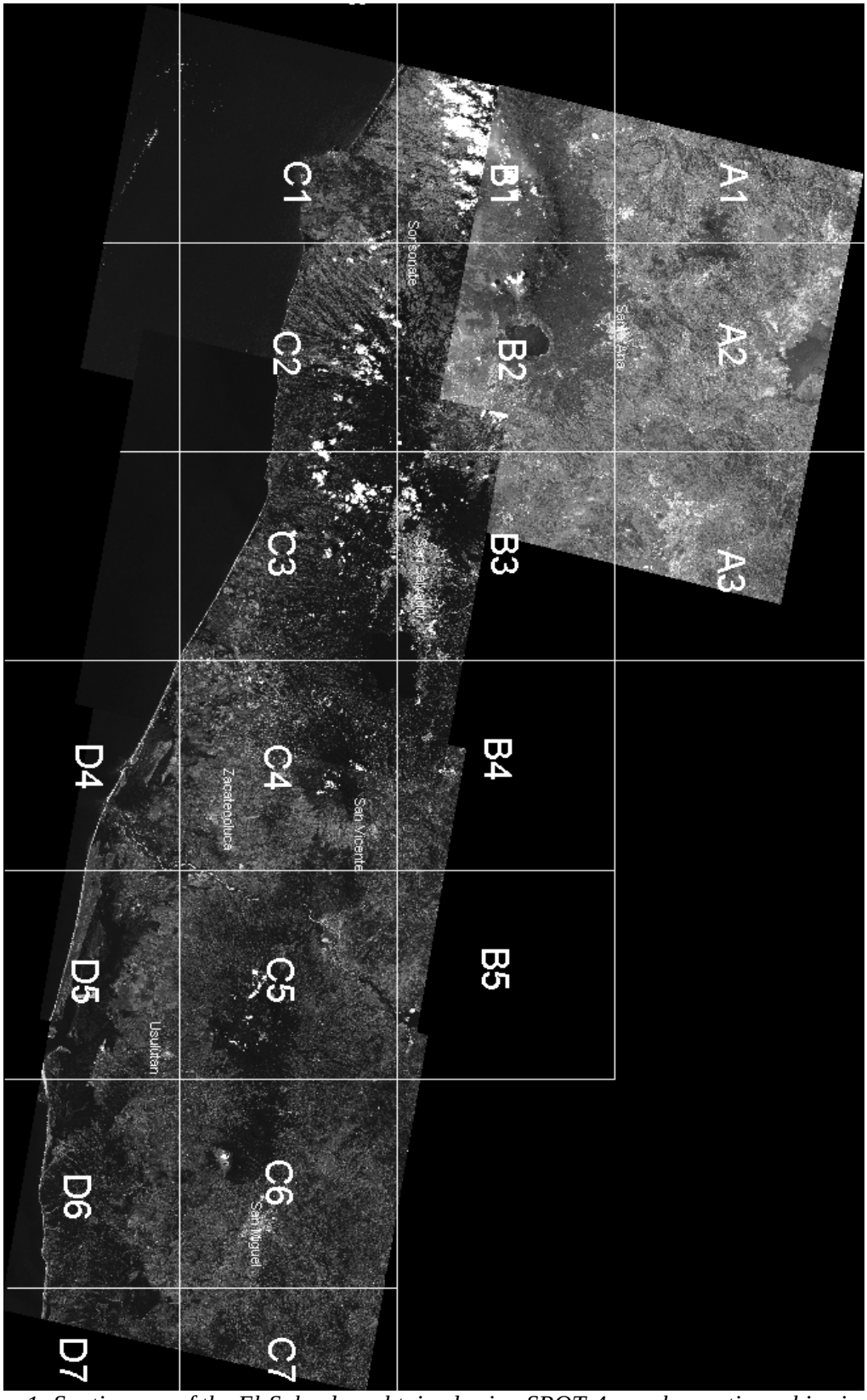

Figure 1: Spatio-map of the El-Salvador, obtained using SPOT-4 panchromatic archive images, and its cut-out in 19 cartographic sheets (© PRIVATEERS N.V., CNES, 2001).

To optimise the rapidity of processing and analyse, as well as quick and reliable transmission of the results as they were produced, the processes areas were squares of 10 x 10 kilometers, *i.e.* 1000 km^2, including the presumed most severely damaged urban areas and/or villages.
A total of 23 sites of 1000 km^2 each in El-Salvador have been studied. These site include all the metropolitan area of San-Salvador, as well as the major cities in the area affected by the earthquake, and several areas where severe damages have been found (*cf.* Figure 2). More details regarding each one of these sites can be found in [4].

As it was produced, each of the 10 x 10 kilometers areas was immediately installed in an HTML on-line Internet site [4], containing the following associated products:

- The corresponding location map, *i.e.* a colored composition of the SPOT images acquired before and after the earthquake, and corrected for the deformations due to terrain effects,
- The map of identification of the damages, at the spatial resolution of 10 x 10 meters.
- A brief description of the, area and an evaluation of the detected damages, as well as the cartographic reference of the area (Projection UTM, geoid WGS 1984, zone 16).

The maps of damages and the location maps were compressed in JPEG format, with a quality loss not exceeding 15% (i.e. not noticable). In practice, this compression resulted in data volumes ranging from 117 kB to 405 kB per area of 10 x 10 kilometers.
The Internet site was made accessible by CNES to DDSC users and authorized organisations.

A front HTML page allowed to check the updated status of the cartography of the damages as it progressed. From this front page, HTML links enables to access and download the newly processed areas.
A data volume of 250 kB to 750 kB per area could then be downloaded by the users in El-Salvador from any computer through a regular phone line in less than 2 minutes, *i.e.* a fairly reliable way, even with poor telephone lines.

Figure 2: Location of the areas where evaluation/identification of earthquake damages has been carried out

5. DETECTION AND EVALUATION OF DAMAGES

Identification of earthquake damages:

To work out identification and evaluation of the damages, we had to front 5 categories of problems:

a) The necessity to rapidly execute processing and identification tasks, since the DDSC and similar rescue teams were still recovering living, and often wounded and exhausted, people from under the wreckages.
b) To this aim, we needed to maintain and eventually update a list of priorities for the areas to study.
c) Technically, the SPOT images from before and after the earthquake had been acquired at (sometimes very) different incidence angles and presented important spatial deformations, especially in the presence of strong relief (which is almost always the case in El-Salvador). To compare acquisitions and detect the damages, these deformations had to be corrected, in the present case without any digital terrain model previously available.
d) Useful results and information had to be presented a way it could be easily understood, even by users who were not familiar at all with remote sensing imagery and products.
e) Once produced, this information had to be put immediately at the disposition of the DDSC and the authorized organisations, for the reasons given in a).

Problems b) et e) have been solved by defining an operational strategy, as exposed above in section 4.
Problem a), has been solved, adopting a continuous pace of work, 24 hours a day, 7 days a week.
Problem c), purely technical, has been solved, adopting the so-called "*rubber-band*" [5] superimposition technique, This is a theoretically very basic technique, which is nevertheless considered as antiquated by remote-sensers. Indeed, this technique does not enable to correct in absolute the geometric deformations due to relief. Nevertheless, it enable to superimpose with an extremely good accuracy images acquired in different viewing geometries.
Problem d) has been solved adopting for the products of detection of damages a color encoding where the destroyed houses and buildings appear in violet tones. Outside towns and villages, the color encoding does not present any interest, since we were looking only for destroyed buildings. Therefore, within built-up areas, violet points correspond to isolated destroyed houses, and violet areas to whole blocks or quarters destroyed.

Evaluation of earthquake damages:

Detailed information about all study sites can be found in [4]. An evaluation of damages has been carried out, to guide the users of the products of detection of damages. This section provides a synthesis of this evaluation:

Destruction's:	Total	Very important	Important	Light	Intact (no destruction)
<u>Comarca de Sonsonate:</u>					
Sonsonate		X			
Izalco		X			
Armenia		X			
Los Mangos		X			
<u>Comarca de Santa Ana:</u>					
El Congo		X			
Coatepeque			X		
Village 2 km W de Coatepeque	X				
Zapotitàn		X			
Village 4 km E de Zapotitàn			X		
Village 7 km SE de Zapotitàn				X	
<u>Comarca de La Libertad:</u>					
Ciudad Arce		X			
Village 8 km N de Ciudad Arce			X		

Destruction:	Total	Very important	Important	Light	Intact (no destruction)
Valle Nuevo				X	
Village 3 km W de Valle Nuevo				X	
Village 6 km WNW de Valle Nuevo					X
Village 6 km WSW de Valle Nuevo				X	
Village 5 km SW de Valle Nuevo			X		
Village 9 km SW de Valle Nuevo			X		
Village 8 km SSW de Valle Nuevo				X	
Tamanique				X	
Comasagua			X		
Quezaltepeque				X	
Village 1,5 km W de Quezaltepeque				X	
Village 3 km SW de Quezaltepeque				X	
San Matias					X
Nueva San Salvador		X			
Nuevo Cuscatlàn			X		
Colón					X
<u>Comarca de San Salvador:</u>					
Nejapa				X	
Village 3 km SW de Nejapa				X	
Apopa				X	
San Salvador (Ouest)			X		
San Salvador (Centre)			X		
San Salvador (Est)		X			
San Salvador (Sud)		X			
Ilopango		X			
Santo Tomas		X			
<u>Comarca de Cuscatlàn:</u>					
Cojutepeque			X		
Village 0.8 km S de Cojutepeque		X			
Santa Cruz Michapa		X			
Santa Cruz Analquito			X		
<u>Comarca de La Paz:</u>					
Olocuilta		X			
Village 1,5 km SE d'Olocuilta	X				
Village 4 km E d'Olocuilta					X
San Antonio Masahuat			X		
Village 2 km S de San Antonio Masahuat			X		
Zacatecoluca				X	
Village 6 km W de Zacatecoluca				X	
Village 8 km W de Zacatecoluca			X		
El Pajel				X	
<u>Comarca de San Vicente:</u>					
Tecoluca		X			
San Vicente				X	
San José			X		
<u>Comarca de Usulutàn:</u>					
Ozatlàn				X	
Village 5 km N d'Ozatlàn			X		
Berlin	X				
Loma Alta		X			
San Agustìn					X?
Los Planes				X	
Village 4 km NNW de Los Planes			X		
Village 2 km S de Los Planes			X		

Destruction:	Total	Very important	Important	Light	Intact (no destruction's)
El Triunfo		X			
Santiago de Maria	X				
Santa Elena					X
Usulutàn					X
Villages jusqu'à 6 km E d'Usulutàn					X

6. AGENDA OF EVENTS

- Saturday 13 January 2001 in the night: Earthquake (magnitude 7.9 on the Richter scale).
- Tuesday 16 January 2001, 18:30: CNES is Project Manager in the framework of the international charter.
- Wednesday 17 January 2001, 11:00: Organisation and planning of SPOT acquisitions.
- Thursday 18 January 2001, 07:20: First informations received from ONG's already operating in El-Salvador.
- Thursday 18 January 2001, 16:40: FTP site for data transfer installed by CNES
- Thursday 18 January 2001: New earthquake in El-Salvador (magnitude 4.6 on the Richter scale).
- Friday 19 January 2001, 17:00: Archive SPOT imagery delivered to PRIVATEERS NV
- Monday 22 January 2001, 09:30: PRIVATEERS NV delivers the SPOT spatio-maps to CNES.
- Tuesday 23 January 2001, 20:00: Spot Image delivers the SPOT data of January 2001 to PRIVATEERS NV
- Wednesday 24 January 2001, 10:00: PRIVATEERS NV delivers the first damage maps.
- Wednesday 24 January 2001: 6 damage maps delivered on-line
- Thursday 25 January 2001: 6 damage maps delivered on-line
- Friday 26 January 2001: 3 damage maps delivered on-line
- Saturday 27 January 2001: 2 damage maps delivered on-line
- Sunday 28 January 2001: 2 damage maps delivered on-line
- Monday 29 January 2001: 1 damage maps delivered on-line
- Tuesday 30 January 2001: 2 damage maps delivered on-line
- Wednesday 31 January 2001: 1 damage maps delivered on-line
- Thursday 01 February 2001: El-Salvador real-time operation closed by the Project Manager (CNES).

7. CONCLUSION

Previously, techniques similar to those used in the present work have been successfully used to assess the effects of the "Mitch" hurricane [1] (Honduras, El Salvador, Nicaragua, November 1998), the damages of the giant floods of the Yang-Tse-Kiang river in China [6] (July/August 1999), the damages caused by the Izmit earthquake [7] (Turkey, 17th August 1999), the damages due to the "Lenny" hurricane [8] (Guadeloupe Island, November 1999), and the damages due to heavy rains in Venezuela [9] (December 1999 - January 2000).

It was also not the first time PRIVATEERS NV was working out such a project for CNES [6,7]. These first common experiences have prepared the success of the El-Salvador operation.

With the present operation in El-Salvador, for the first time in the history of spaceborne Earth observation, identification and evaluation of the damages have been delivered, or put at disposition, on-site, in real-time (within a few hours to a few days), to local authorities, rescue teams and humanitarian organizations authorized by CNES. In some cases, maps of the damages have been produced and delivered on demand within not more than 3 hours after request.

For the first time in the history of spaceborne Earth observation, remote semsing value added products have been effectively and efficiently used on the terrain of operations by rescue teams who were not or little familiarized with this kind of information products.
Operationality (24 hours a day, 7 days a week), experience, and technical mastering of remote sensing related problems, in particular in the framework of natural disasters, determined the success of the operation [10], and contributed to save lives [11,12].
Above all, success has been permitted by a high velocity of working out, using only already proven technical workmanship, with a great concern for the quality of results and products.
NGO's and humanitarian organisations present in El-Salvador have also considerably contributed to the success of the project.

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