High temporal detection and monitoring of flood zone dynamic using ERS data around catastrophic natural events: The 1993 and 1994 Camargue flood events.

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Abstract

Within the framework of a Pilot Project, SERTIT has investigated the usefulness of high temporal ERS-1 SAR data acquisitions for flood detection and monitoring. The 1993 and 1994 floods in the Camargue region (France) are taken as the subject matter of the case study. An extensive data base has been developed which is composed of satellite data and exogenous data. The satellite data include twenty ERS-1 SAR scenes acquired essentially with a 3 day cycle before, during and after the floods. The detection and cartography of flooded zones is produced by the photo-interpretation of multi-temporal ERS-1 images together with auxiliary information and change detection techniques (colour composition, ratioing and differencing). The analysis of the detected flood evolution maps enables the understanding of flood dynamics. In addition, by taking the opportunity of the large number of georeferenced multi-temporal ERS-1 SAR scenes, a high radiometric resolution ERS SAR image was produced by the temporal merging of eighteen ERS-1 SAR images showing the usefulness of multi-temporal SAR data in cartography. These results lead to the interesting prospective of applications of high temporal acquisition SAR data in the forecasting, monitoring, impact and understanding of catastrophic natural events.

Keywords: ERS-1 SAR, 3 day mode, flood monitoring, temporal merging

1 Introduction

Within the framework of Pilot Project AO-F112 supported by the CNES and ESA, SERTIT has investigated the usefulness of high temporal acquisition ERS-1 SAR data for hydrological applications in exceptional hydrological conditions (Fellah *et al.*, 1997). The 1993 and 1994 floods in the Camargue region (France) were taken as the subject matter of the case study. One of the tasks was to study the backscattering coefficient behaviour in relation to different soil hydric conditions (flooded, saturated, moist). As a first step, in order to delimitate the hydric conditions, the detection and monitoring of flooded zones was carried out. This is the subject matter of this paper.

This study's originality lies in the number of processed ERS-1 SAR scenes and their temporal coverage of the floods. The study focuses on the 1994 flood as ERS-1 was in the Second Ice Phase (phase D) and therefore covered the Camargue flood every 3 days.

2 The Data base

SERTIT had already investigated the Camargue 1993 floods using ERS-1 SAR data (de Fraipont *et al*., 1994 ; Tholey *et al*., 1995), a data base concerning this event had been already built. This data base was completed in order to obtain an historic background to the 1994 flood and to acquire further information concerning the natural environment of the Camargue region. The data base is composed of georeferenced satellite and exogenous data.

2.1 Satellite Data

The satellite data include a SPOT XS scene plus twenty ERS-1 SAR scenes acquired before, during and after the floods. Most of these scenes were acquired during a three day ERS-1 acquisition mode. The SPOT XS scene was acquired on March the 26th 1993 and contains information concerning the Camargue's land cover. The ERS scenes were acquired between the 26th of September 1993 and the 16th of March 1994 (Table 1). The products of the SAR scenes are either ERS.SAR.PRI or ERS.SAR.GEC standard products (ESA, 1992). All the scenes have been georeferenced and then integrated into a GIS.

Date	**27/09/93**	**16/10/93**	**01/11/93**	**20/11/93**	**25/12/93**	**31/12/93**	**03/01/94**	**06/01/94**	**12/01/94**	**15/01/94**
Product	GEC	GEC	GEC	PRI	PRI	PRI	PRI	PRI	PRI	PRI
Orbit (Track 2727)	11504	11776	12005	12277	12778	12864	12907	12950	13036	13079
Date	**18/01/94**	**21/01/94**	**24/01/94**	**2701/94**	**02/02/94**	**08/02/94**	**14/02/94**	**26/02/94**	**04/03/94**	**16/03/94**
Product	PRI	PRI	PRI	PRI	PRI	PRI	PRI	PRI	PRI	PRI
Orbit (Track 2727)	13122	13165	13208	13251	13337	13423	13509	13681	13767	13939

Table 1: The ERS-1 SAR scenes

2.2 Exogenous data

The exogenous data include topographic maps, aerial photography, meteorological data, a flood report and flood evolution maps. The IGN topographic maps cover the entire Camargue region at a scale of 1/25000. Aerial photography were taken during the 1993 flood for the Mairie d'Arles. The meteorological data include daily precipitation for the period lasting from September 1993 to March 1994 and wind information (speed and direction) during ERS SAR image acquisitions. These data were recorded by METEO FRANCE at the Tour du Valat station located in the Camargue region. The flood report (Vianet, 1994) and flood evolution maps (Scale: 1/50 000) were established by the Parc Naturel Régional de Camargue (PNRC), the Camargue nature reserve authority, which plotted the 1993 and 1994 flood areas daily with conventional techniques during the flood-level rise.

3 The Camargue Flood Events

For the first time since the building of the Rhone river embankments in the XIX century, the Camargue region was flooded in October 1993 and January 1994.

3.1 The Camargue Region

It is located in the delta of the Rhône river in the South of France near the town of Arles (Fig. 1). The landcover of this region includes rice fields and other croplands, grassland and protected natural marshlands. A complex hydraulic network insures an artificial balance between the agricultural zones, which use a lot of fresh water, and the natural salt marsh zones. The Camargue is a very flat plain normally protected from Rhône floods by embankments. The study area is comprised of the October 1993 and January 1994 Camargue flood zones.

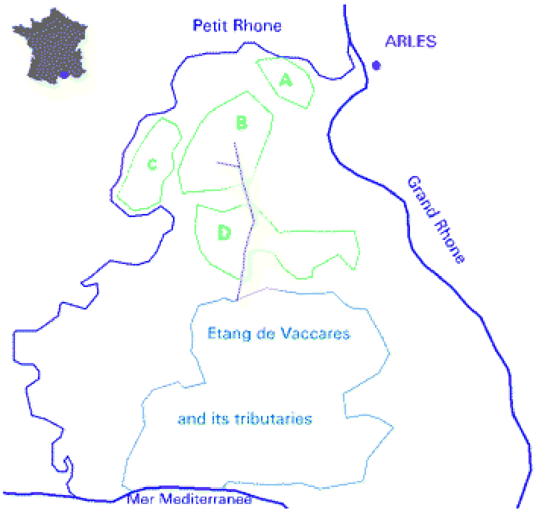

Figure 1: The Camargue region and its different flood basins (A: Tete de Camargue, B: Bernacles, C: Saliers, D: Grand Mar) and the Rousty canal in violet.

3.2 The 1993 and 1994 Floods

The PNRC's flood report analysis allowed a better understanding of the flood evolution. The October 1993 and January 1994 floods were caused by the formation of breaches in Petit Rhône river dykes. During the flood-level rise, Rhône water spread from breaches successively to the four Camargue flood basins. These flood basins are the Saliers, Tête de Camargue, Bernacles and Grand Mar basins (Fig. 1). The hydraulic network played a great role in the flood propagation. In particular, the Rousty canal had enabled the flood water to go from the Bernacles to the Grand Mar flood basin.

The evacuation of the flood water to the Mediterranean sea was a natural process with the water flowing from the Grand Mar basin to the étang du Vaccarès and its tributaries via the Rousty Canal and then to the sea helped by a northerly wind. Pumping stations were also used to transfer flood water from flood basins to the Rhône river and from the étang du Vaccarès tributaries to the sea. This process took much time and was only partial since large quantities of flood water were trapped in the Camargue soils.

4 Method and Results

Firstly the principle of the flood detection method used to map the Camargue floods is presented. Then the flood evolution maps employing ERS SAR data are analysed. Finally, Taking the opportunity that the multi-temporal ERS-1 SAR scenes available where georeferenced, SERTIT developed a radiometric enhancement method of SAR data which is finally described.

4.1 Flood Mapping Method

ERS-1, the earth observation satellite of the European Space Agency (ESA) carries a C band (wavelength = 5.3 cm), VV polarisation and 23° average incidence angle SAR which acquires images of the earth's surface in all meteorological conditions.

Theoretically, the interaction between the signal pulsed by ERS-1 SAR and open water when they can described as flat surfaces is specular generally making the detection of open water possible on a SAR image. Practically, the specular effect can be decreased or even cancelled out by bad weather conditions (in particular wind and precipitation) and/or the presence of vegetation making the detection of open water using a single ERS SAR scene difficult or even impossible.

The distinction between flooded zones and the hydrological network is done with the use of auxiliary information (topographic maps, ...) and/or with a change detection approach between multi-temporal ERS SAR scenes. Change detection techniques of multi-temporal ERS SAR images which are generally used are photo-interpretation (Matthews *et al*., 1994), colour composition (Blyth *et al.*, 1993), ratioing (Rignot *et al.,* 1993) and differencing (Badji *et al*., 1994).

Due to the number of scenes which had to be processed and in order to have quick but accurate flood delimitations, the detection and cartography of flooded zones were produced by the photo-interpretation of the multi-temporal ERS-1 images. In addition, auxiliary information were employed in order to overcome the problem of flood detection due to various surface parameters (soil moisture, surface roughness,...) which affect the backscattered signal. Colour composition, ratioing and differencing techniques were also used to facilitate the detection of flooded zones (Fig. 2).

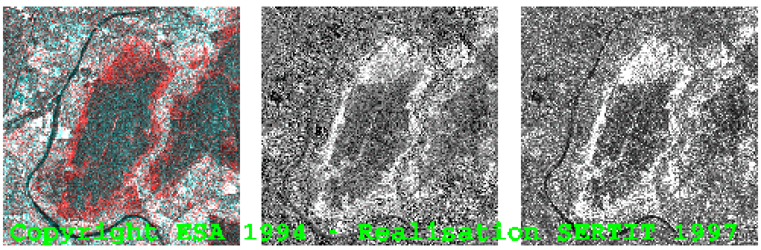

Figure 2: Change detection techniques
Colour composition (left), ratio (centre) and difference (right) images
showing the drop of the flood-level in the Saliers basin between 21/02/94 and 27/02/94.

Once all the scenes where processed, flood-level evolution maps showing the rise (Fig. 3) and the fall (Fig. 4) of flood-level were established. On these images the digitised flood extents are coloured from light blue to light purple and are superimposed on a high radiometric resolution ERS SAR image (see 4.3).

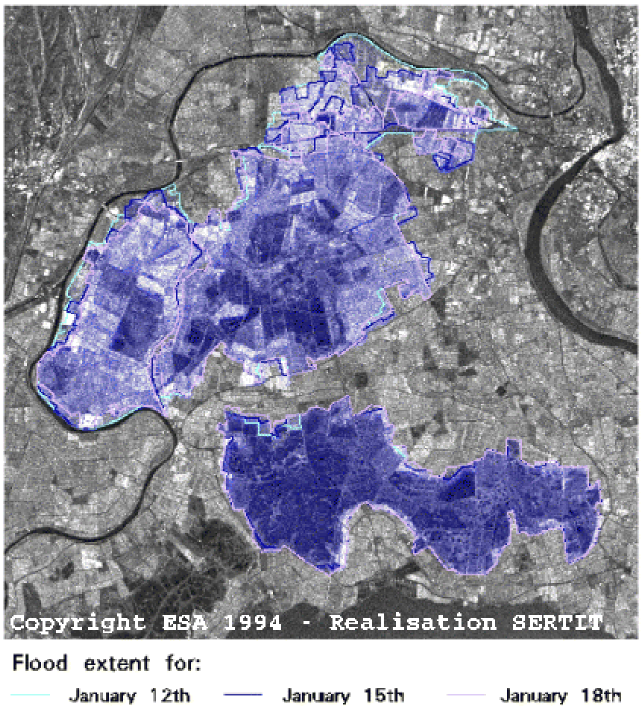

Figure 3: The rise of the flood-level between 12/01/94 and 18/01/94

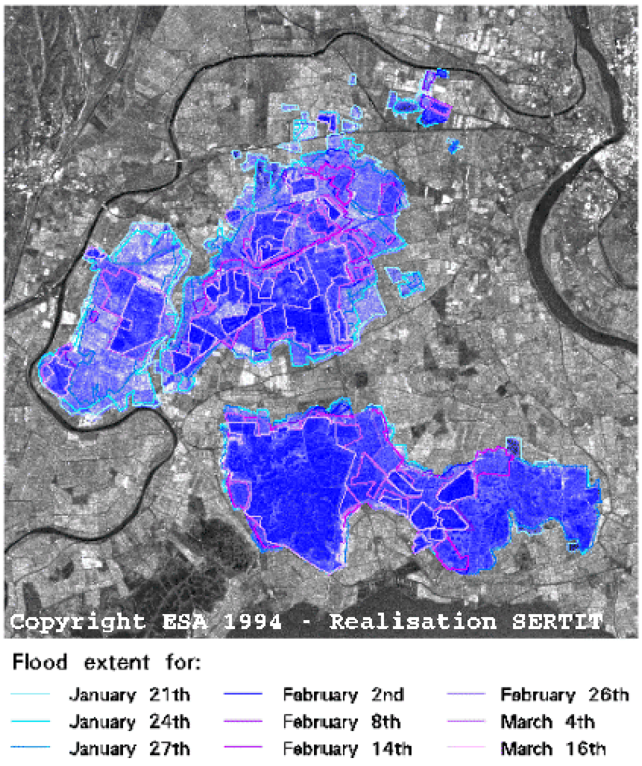

Figure 4: The drop of the flood-level between 21/01/94 and 16/03/94

4.2 Flood Evolution Analysis

The analysis of flood evolution maps enable the understanding of floods dynamics since this analysis provides information which are comparable to those extracted from the flood report and flood evolution maps established by PNRC:

- The Tête de Camargue, Saliers, Bernacles and Grand Mar basins are clearly detected on Fig. 3 and Fig. 4;
- The flood evolution maps show the spreading of the flood water in the different flood basins. On Fig. 3, the detected flooded zone surfaces decrease in the Tête de Camargue and Saliers basins between February 12th and 15th whereas the detected flooded zone surfaces increase in the Bernacles and Grand Mar basins. Fig. 4 clearly shows that the speed of the fall in the flood-level in the different flood basins are not the same;
- The flood water evacuation process took a long time. A figure showing detected flooded zone surfaces relating to ERS SAR image acquisition dates is presented (Fig. 5). It shows that in agreement with the flood report, the flood water evacuation process took much time. Indeed, there is a fast diminution of detected flooded zone surfaces until the beginning of February and a stagnation during the February 2nd-26th and March 4th-16th periods.

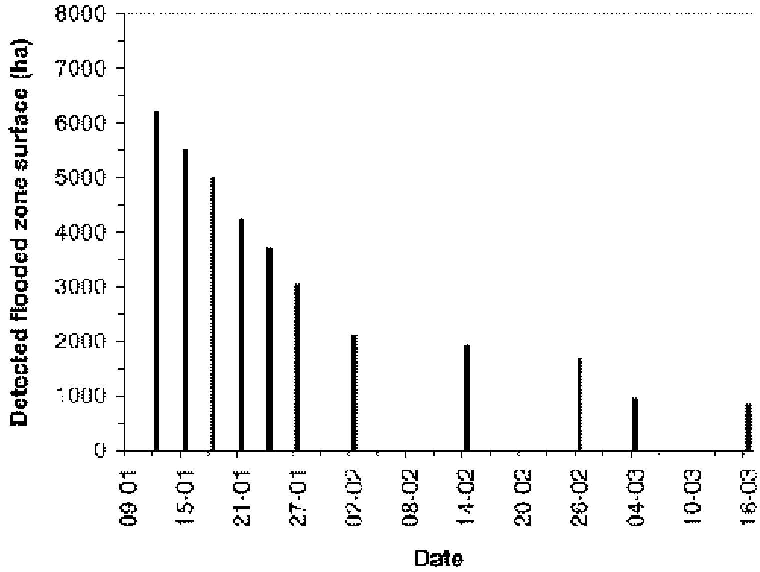

Figure 5: Evolution of detected flooded zone surfaces relating to ERS-1 SAR scene acquisition dates

The study of flooded zone limits with respect to roads and field's limits also shows that multi-temporal ERS-1 images enable the cartography of flood evolution with a satisfactory accuracy for a field process analysis.

4.3 Radiometric resolution enhancement method of ERS SAR images

Taking the opportunity that all the ERS images were georeferenced and integrated into a GIS and following theoretical studies (Fellah, 1994 ; Bruniquel *et al.*, 1997), SERTIT developed a SAR data temporal merging method which showed the usefulness of SAR data in cartography.

In fact, one of the greatest problems with SAR imagery is the speckle which affect the radiometric resolution. This problem is usually resolved by spatial averaging methods of SAR acquisitions which increase its radiometric resolution but alter its geometric resolution. A technique which is not yet often used is the temporal merging of SAR acquisitions which greatly enhances its radiometric resolution and preserves its spatial resolution as it is shown in Fig. 6. The high radiometric resolution ERS image results from the temporal merging of eighteen ERS-1 SAR scenes. One notices that in Figs. 3 and 4 road and hydrological networks, field limits and bridges can be detected. These images show that SAR data can be useful in precise cartography.

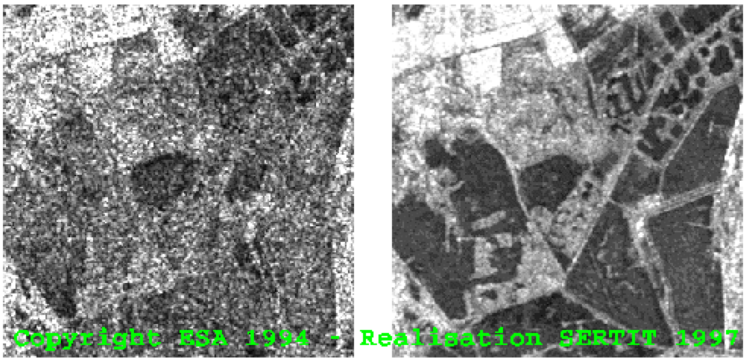

Figure 6: ERS-1.SAR.PRI scene acquired the 06/01/94 (left) and the high radiometric resolution ERS SAR image (right)

The number of processed ERS scenes (18) seems to show that the temporal merging of SAR data is not an economic method. However, the minimum number of SAR scenes which should be used in order to produce an accurate and cost effective cartography of a region may be much smaller than eighteen and it depends on the study's objective. For example, for geological applications a number of about three images seems to be a good compromise (Yesou *et al.*, 1997).

5 Conclusion

The analysis of 3 day mode ERS-1 SAR images allowed a flood evolution cartography with a satisfactory accuracy for a field process analysis and enabled an accurate description of flood dynamics. The comparison between this method and conventional mapping techniques shows the usefulness of SAR data in producing a quick and effective cartography of flood evolution.

Moreover, the high radiometric resolution ERS SAR image shows that multi-temporal SAR data can also be used for precise cartography, in particular for regions where adverse meteorological conditions make the use of optical space or air borne instruments difficult.

Since the ERS-1 3 day mode was only temporary, all these results show the great potential of high temporal SAR data acquisitions. In that context, the SAR data acquisition cycle seems to be a key factor in the environmental monitoring. The low resolution and high temporal acquisition mode of RADARSAT SAR and with a perspective towards the future ENVISAT ASAR will therefore certainly open up numerous applications in the anticipation, prevention, impact and monitoring of major environmental hazards.

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