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Operational mapping of storm forest damage and assessment of future VHR SAR and optical sensors

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ABSTRACT: In this paper the potential of actual EO data, both ERS coherence and SPOT, for forest damage monitoring is presented as well as a methodology for forest damage assessment, with the results obtained over the Bas-Rhin Department, France, the added valued products, fire start risks and fire propagation risk indices, generated for Civil Defense Service and their dissemination through a dedicated internet gateway. The second part is focused on the assessment of Very High Resolution images (VHR), both optical and SAR, simulating the newly launched SPOT 5 sensors as well as Pléiades HR and Cosmo Skymed whose launches are scheduled in the medium term.

1 STUDY GENERAL CONTEXT

The devastating storms, Lohart and Martin, that struck continental Western Europe in December 1999, destroyed the equivalent of several years ofnormal forest exploitation in France. In this context it was and still is of primordial importance to map the damage for short-term actions, the location of the damage, the assessment of fire risk in the damaged areas, as well as for long-term reforestation. Remote sensing data, more particularly SAR sensors with their “all-weather” capability and a very good potential for change detection within forested areas, seem to be useful for these applications. If applications based on the exploitation of EO data are more and more common, there are only a few references concerning damage mapping prior to the 99’ events, based on SIR-C/X-SAR or Landsat TM data (Winter and Keil, 1998; Murai and Hasegawa, 1999).

2 LOCATION OF THE STUDY AREA

The study has been carried over of the Alsatian Region in NE France one of the most affected areas, more precisely over the Bas-Rhin Department. Test and validation phases have been carried out principally over the Forest of Haguenau. Located 30 km North of Strasbourg, it is France's second largest plain forest consisting of 20 000 ha of deciduous and coniferous stands. Over this site a rich database has been made available containing classical forester’s information such as, stand species, exploitation information, soil, (Geldreich, 1994, 1999). A damage map per sub-parcel realised by the *Office National des Forêts* (ONF), shortly after the event was also available. This ONF forestry database has been used for EO data exploitation as well as for results analysis and validation.

3 DAMAGE MAPPING BASEDON SPOT AND ERS DATA AND FIRE RISK ASSESSMENT TOOLS

For an operational forest damage application, diachronical pairs of SPOT 4 and ERS products were used. The optical processing was based on classical change detection methods using 4 images obtained simultaneously along two paths for both dates, whereas ERS processing corresponds to the analysis of the coherence dynamic between two tandem pairs. tandem pairs.

3.1 *Methodology for the damage retrieval from ERS coherence data*

ERS coherence can be related to vegetation density: wooded areas generally have low coherence, while bare soils and cultivated areas are usually associated with high coherence (Proisy et al., 1999; Wegmuller and Werner, 1995; Askne and Hagber, 1993). In coherence products, associated with both the backscattering average and difference, forestry, characterized by its low coherence values and relatively high backscattering coefficients, appears well differentiated from the other land cover classes. After the storm, due to windfall there is a dramatic change in the forest's structure inducing a higher participation of the more stable parts of the trees, trunks and major branches as well as the soil. In the image, this corresponds to increased coherence where trees fell due to wind action. This hypothesis has been demonstrated by a number of studies realized by European labs and VACs. It was shown that it is possible to extract damaged areas within forestry based on analysing coherence dynamics (Herrmann et al, 2000; Weismann et al, 2000;Yésou et al, 2000; Dwyer et al., 2000; Ramminger et al., 2001).

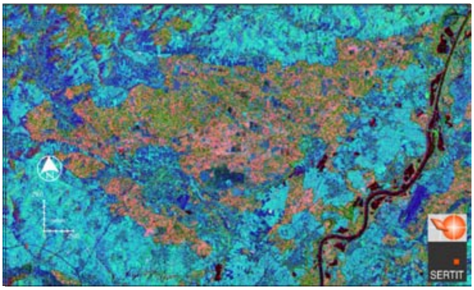

Figure 1. ERS dynamic coherence product; with the ratio of the two coherence channels on Red, associated with an averaged intensity image in Green and the after-storm coherence in Blue

For the damage mapping over the Bas-Rhin Department, ERS1/ERS2 tandem pairs were acquired before and the other after the storm. respectively 31st of October and the1st of November 1999 and the 9th and 10th of January 2000. From the two coherence derived products a "damage" image was generated based on the ratio of the two coherence channels, associated with an averaged intensity image and the after-storm coherence (Fig.1). Due the different temporal evolutions of coherence for deciduous and coniferous trees (Proisy et al., 1999), and using forest type maps derived from SPOT images, the two types of stands were processed separately.

Graduated maps using damage thresholds were produced at a scale of 1:25,000 at a pixel level plus, for Haguenau Forest, at a parcel level. These maps show that 60% of the coniferous forest was devastated and 25% of the deciduous forest. The results emphasise the potential of these new coherence products and enable the establishment of a damage product production chain in order to be able to provide valuable information to the forestry and security services at a very short time interval.

3.2 *Validation chain*

Validation of the results, i.e. damage maps, was performed at two levels by:

- Field survey with the direct integration of observation into a database
- Comparison of the damage maps with the map obtained by the ONF service at a parcel level for the Haguenau forest.

The field validation phase was carried out employing a GPS survey directly linked to the database on a laptop. The portable is the centre of the device, the core is constituted by the GIS software and the data base. This database consists of EO coverage, historical and post events images, derived products such as the damage maps, land cover maps, plus administrative maps, land parcels, etc., and topographic maps. The GPS measurements were automatically registered and were visualised in real time with thematic layers during the field survey.

This system has been tested over the plain area but also in a hilly context under the responsibility of SERTIT but also of the Private Forest Owners Association which found the system and results a very powerful tool. The location accuracy was a few metres i.e. better than that required by the forestry services.

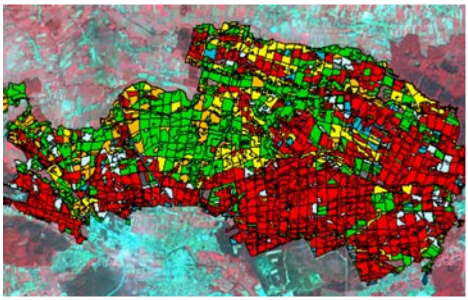

Figure 2. Comparison of the field mapping and damage derived from ERS coherence data , red and green concordant damage and intact parcels, yellow and orange, none detection, blue, false detection

In addition to the described field survey, a comparison with the ONF damage map was performed at a parcel level for the Haguenau Forest (Fig.2). It is shown that the detection based on the coherence product was very good for the coniferous stands, the detection rate being very good and the results accuracy very precise. For the deciduous stands, the detection rate is also good, but there are some false detections inducing an over-estimation of the damage for these stands. This is due to the validation approach at the parcel level, which induced an averaging, and also to the natural coherence dynamics of the deciduous stands.

3.3 *Fire risk assessment and result dissemination*

There are two major post storm risks: the development of parasite insect attacks which can destroy the equivalent of fallen wood, doubling the consequences of the storm, and fire starts within the devastated stands which have not been cleared, a risk which increases with time after the event. So, for post event monitoring, the regional headquarters of the Civil Defense, EMZ-EST of Metz, requested an aid to decision-making system in order to plan fire fighter location and intervention scheduling. Such a system containing indicators of fire start risks and fire propagation was designed and proposed. It was based on the integration of a regional forest damage map with exogenous information which would cover 17 French Departments. A demonstrator was set up over the Bas-Rhin Department (4,802 km^2). For this, after the validation phase over the Hagenau Forest, a generalization of the ERS coherence and SPOT 4 processing was performed over the Bas Rhin Department. Due to the size of the covered area and the type of rescue organization, the chosen cell of analysis was the municipality, the commune; 531 communes were taken into account.

A fire departure index (Fig. 3) was computed taking in account the level of damage within coniferous stands, as the wood from coniferous trees dries quickly but also includes flammable sap. The propagation index (Fig. 4) was computed as depending on the level of damage within the deciduous stands taking into account the topographic influence.

In order to disseminate information and to get regularly updates, a map server accessible over the internet was designed and a prototype realized. Major constraints to be taken into account were that the:

- cartographic tool must to be accessible to all navigators even old versions.;
- database must be rapidly and easily up dated;
- cartographic tool has to allow information diffusion between different administrative entities
- cartographic tool must be able to provide information emanating from the administrative entities to the community at large.

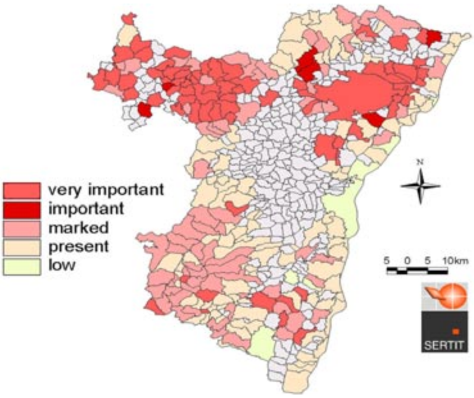

Figure 3. Fire departure index computed at a commune level based on the woodland density and damage level within coniferous stands both derived from EO data

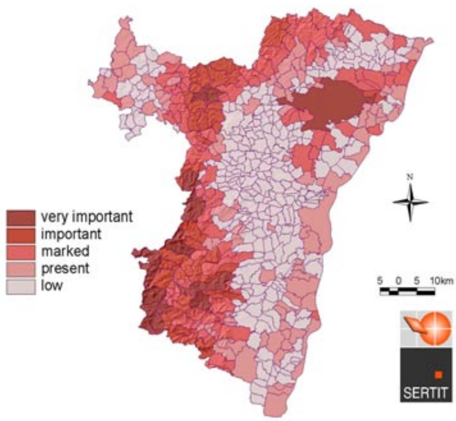

Figure 4. Propagation index depending of the level of damage within the deciduous stands taking in account the topographic influence

So the task was to provide geo-information to the users, administrative entities and public, using a tool enabling information manipulation, visualization, legend, shape and colour selection and also facilitate queries within the associated database.

From a practical point of view, a user friendly HTML interface allows access to an initial set of classical GIS functions such as request of the area of interest and selection of the cartographic layers to be visualized. A second functional set allows geo-spatial requests to be sent to the data server such as “which are the forests most at risk located near or within a given commune or group of communes”.

Technically speaking, it consists of adding to a classical Internet server an extension transferring the cartographic request to a GIS database. This GIS must be designed in order to take into account the requests arriving over the Internet. The answers to the customers requests are sent back coded as HTML pages containing the requested cartographical elements in an image format.

One of the interests of such a system resides in the updating facility of the database. As soon as new layers are generated these are automatically available and accessible through the server. In this application, this facility allows fire risk information provision combining a static element, storm damage which is static at the scale of a season, and elements with a high variability, the meteorological conditions, forecasted temperature and wind speed predictions, cumulated or not. One other advantage is system security. The customer never requests directly to the database. It is the HTML interface which determines the permitted actions. Moreover, it is possible to realize selective accesses depending on the customer’s profile (public, administrative entities, fire brigades etc.).

The adaptability of the proposed tool allows its adaptation for the dissemination of cartographic information relating to other hazards, floods, etc. It appears as a promising tool welcomed by the professional end users.

4 APPRAISAL OF FUTURE VHR SENSORS

An assessment of Very High Resolution images, optical and SAR, simulating newly launched SPOT 5 and future sensors such as, Pléiades HR and Cosmo Skymed whose launches are scheduled in the medium term have been carried out over the Haguenau Forest .

4.1 *SPOT 5 processing and results analysis*

Within the framework of pre-launch studies, an assessment of SPOT 5’s capabilities for damage mapping and forest management has been carried out. The main characteristics of SPOT 5 which was launched the 4th of May 2002 (Baudoin et al., 1996; Pauc et al., 2001; Fratter et al., 2001), are the following:

- An improvement of the spatial resolution of the HRG sensors: 10m multi-spectral mode and panchromatic modes with a resolution of 5m up to 2.5 m for the PAN supermode over a 60 km swath
- A new instrument the High Resolution Stereoscopic, HRS: a stereoscopic tool for HR DEM production covering 120*600 km^2
- An improved absolute location accuracy better than 15 m, without using ground control points
- VEGETATION 2 to ensure continued global monitoring of the planet

Two sets of simulated XS and panchromatic super mode SPOT 5 data (Fig. 5), acquired before and after the events, i.e. in July 1998 and June 2002, plus an extra super mode cover acquired in February 2002, were made available (Meyer et al., 2001; Pauc et al., 1996). Furthermore, SPOT 4 data acquired both before and after the storm has also been included in order to highlight the contribution of SPOT 5 data’s increased resolution

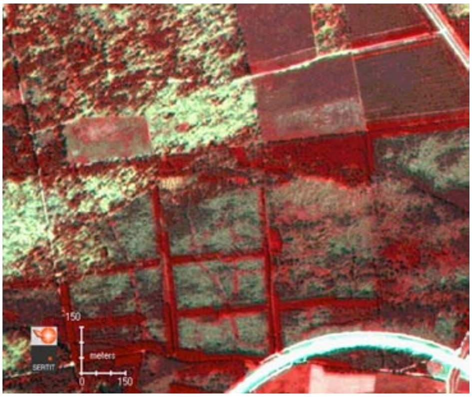

Figure 5. Merged XS+ P super mode SPOT 5 simulated image acquired after the storm

From the SPOT XS and PAN data sets classical change detection approaches have been implemented and damage maps generated at pixel level (Fig. 6). From these, damage maps at a parcel level, a binary damage map (Fig. 7) and a graduated four classes layer (Fig. 8) have been derived and compared with the ONF reference map (Meyer et al; 2001).

The results obtained through the processing and analysis of the diachronic SPOT 5 multi-spectral data, show that it is possible to produce a precise damage map (Meyer et al; 2001). In addition, it is demonstrated that highly affected forest areas that have not yet been cleared can be differentiated from those already cleared by June 2000.

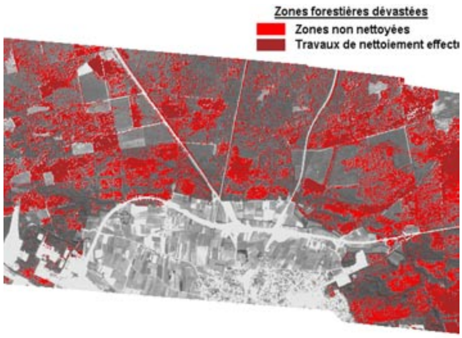

Figure 6. SPOT super mode image and windfall damaged forest extraction at a pixel level

Figure 7. Damage binary map derived from SPOT 5 panchromatic super mode data

The SPOT 5 multi-spectral data allow good damage recognition and mapping. The computed rate of detection is approximately 90% and the level of false detection is rather low. Furthermore, the damage map derived from SPOT 5 multi-spectral data is much more precise than that elaborated from SPOT 4 data. With the jump in resolution from 20 to 10 meters, the number of false detection is divided by a factor of 2.

The first assessment of SPOT 5 VHR panchromatic data, shows that for the end users, super mode images are of higher quality than classical 1:30 000 air photographs.

Based on the VHR panchromatic data due to its better resolution, a greatly improved damage assessment document was produced. A very precise map with four levels of damage has been produced and compared with the ONF reference (Fig.8). The two maps are very similar, the difference between devastated surface areas are within 1%.

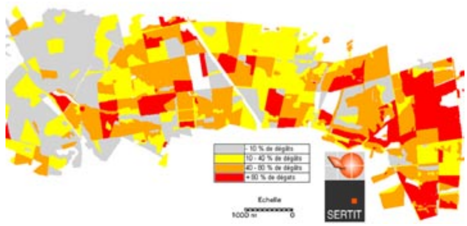

Figure 8. Graduated four classes layer map of forest damage derived from SPOT 5 panchromatic super mode image

Unfortunately, the analysis of the SPOT 5 super mode data acquired in February 2002, showed that despite a finer resolution, 2.5 m, the recognition of affected deciduous stands can be difficult when dealing with data acquired over the winter period. However, data acquired during the vegetation season should prove more useful and the availability in the short-term of sub-metric data, such as Pleiades, should resolve this problem.

4.2 *INSAR data processing and results analysis*

With the loss of ERS 1 in March 2000, the coherence approach is no longer available. It will be possible again in a medium term with such systems as Radarsat 2/3 (2006) or the Cosmo Skymed constellation (2005). Another advantage of interferometric systems is their capacity to derive topographic or altitude information. The altimetric precision of the derived DEM is usually decametric even if in some cases metric accuracy has been reached (Massonet et al., 1993, Damnert, 1996 ; Adragna, 1997; Toutin and Gray, 2000).

When derived from airborne INSAR data the related accuracy of generated DEM's is much better being infra-metric to centimetric (Holecz et al, 1998; Wimner et al., 2000). These airborne sensors allow, at least partially, the simulation of the future space systems containing X band with metric to multi-metric resolution such as Cosmo Skymed, or Terra SAR. With such systems due to their very short revisit period, preserving temporal coherence, it should be possible to generate very accurate DEM's even over forested areas. Another source of VHR DEM with metric vertical accuracy, would be the interferometric cartwheel (Massonet, 2001).

Figure 9. INSAR X band data, presenting felt trees

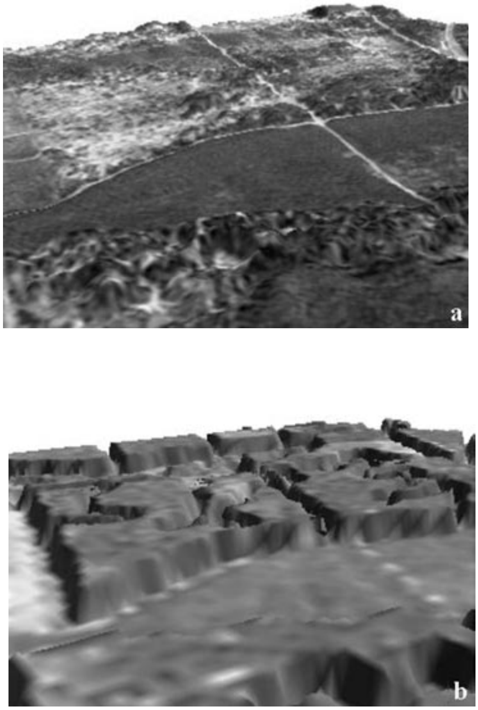

Figure 10. After storm VHR DEM derived from INSAR data (A) Before event modeled DEM (B)

Within the framework of the Haguenau CNES project, it was possible to test the operational potential of such systems for forest damage mapping and forest exploitation monitoring. Over the Haguenau test site VHR INSAR data, X band, with 0.5m resolution, had been acquired in May 2000 (Fig. 9) using the airborne AeS-1 system (Schawbisch and Moreira, 1999). Derived products such as a coherence image and a VHR DEM with a pixel size of 0.5m, were then generated by Aerosensing GmbH.

The hypothesis was the following: the INSAR DEM represented the top canopy after the storm (Fig. 10A). A pre storm top canopy was then generated based on a HR topographic DEM enhanced through the integration of more than 60 differential GPS measurements providing accurate soil level altimetric information. Then, at a parcel level, based on the use of the species database and of tree growth models provided by the National Forest Office, a top canopy height was generated (Fig. 10B). The altimetric accuracy of the two DEMs was within 3 meters which is very satisfactory in a forestry environment. So, larger changes observed between the two DEMs would represent logging due to normal exploitation as the last update of the forestry database was done in 98, and windfall due to the December 99 storm.

Two approaches of change computation have been tested (Maire, 2002). The first one corresponds to a simple difference between the two DEMs followed by a threshold. In this case the chosen threshold and the young stand height are very similar inducing some confusion. For the second one, a normalization was done based on the initial trees height before the threshold was applied.

This produced a damage map showing the location of very narrow affected areas, small spots (Fig. 11), which was then compared with the reference data of French Forestry Service. The calculated quality parameters of this mapping are very good, with a detection rate of 92% associated with low rates of false detection and of none detection, respectively 12% and 9%. The problematic parcels correspond in fact to young coniferous stands and to stands with two levels of trees where the higher, coniferous trees fell and the lower deciduous resisted the wind and kept upright.

5 CONCLUSION AND PERSPECTIVE

A complete processing chain of both radar and optical data for forest damage assessment, to use it as input in a fire risk decision making system as well as to design and implement an information dissemination tool through the internet was elaborated. At present, due to financial considerations this application has remained at the demonstrator level despite the great interest of the user communities.

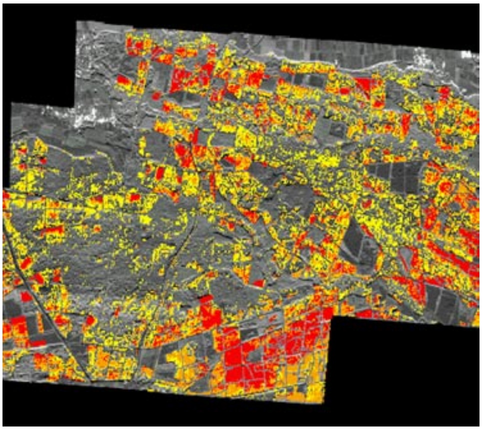

Figure 11. Damage forest map derived from diachronic DEMs analysis

6 CONCLUSION AND PERSPECTIVE

Important R&D work has been carried out emphasising the potentials of the newly launched optical sensors and the scheduled in a short term VHR SAR. The processing and analysis of several SPOT 5 data covers acquired after the storm has shown that SPOT 5 data has great potential in the forestry domain. Hence, after witnessing this potential, agencies and organizations in charge of forest management are very interested in the results and consider that SPOT 5 data will correspond to their expectations in many forestry exploitation and management fields. A mid-term action plan for Alsatian forest management has been set up based on the use of SPOT 5 data and internet technology

The obtained results based on the INSAR VHR data are also very interesting. Concerning future sensors it is shown that forest monitoring at a local or regional scale should be a possible application for future INSAR systems such as Skymed Cosmo or the Interferometric Cartwheel.

These results emphasise the potential of Earth observation data, optical images and SAR coherence products for operational forest damage mapping as well as the potential of future sensors. All the communities involved in forest management from State services, to the private owner associations and the Civil Defence have been very interested by the potential shown here.

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REFERENCES

Adragna F. 1997. Interférométrie radar : Principes, applications et limitations. *Bull Société Française Photogrammétrie Télédétection,* Vol.148, (N°4) :, 15-19

Askne J. and Hagberg J. 1993. *Potential of interferometric SAR for classification of land surfaces, Proc. IGARSS'93, vol. 93CH3294-6 Tokyo, Japan, pp. 985-987*

Baudoin., Fratter C. et Munier PH. 1996. Le programme SPOT 5 et la préparation des utilisations. *Bull Société Française Photogrammétrie Télédétection* Vol. 141 : 9-21

Damnert P.B.G. 1996. *Accuracy of INSAR measurements in forested areas. Proceedings of Symposium Fringe. ESA SP 406: 37-49.*

Dwyer E., Pasquali P., Holecz F. & Arino O. 2000. Mapping damage cause by the 1999 Lothar storm in Jura (France) using SAR interferometry. *Earth Observation Quarterly*, 65, 28-29.

Fratter C, Moulin M., Ruiz H., Charvet P. & Zobler D. 2001. La mission SPOT 5 Bull. SFPT. 164-165, 7-24

Geldreich P. 1994. Le nouvel aménagement de la forêt indivise, *Haguenau infos*, N°21, 3, 7-18.

Geldreich P. 1999. La forêt indivise de Haguenau. *Arborescences*, N°78, janvier-février 1999, 12-34.

Herrmann A., Fellah K., de Fraipont P. & Yésou H. 2000. Forest damage mapping using SAR coherence product in North Eastern part of France, *Earth Observation Quaterly* 65, 30-31

Holecz F., Pasquali P., Moreira J., Meier E. & Nuesch D. 1998. Automatic Generation and Quality Assessment of Digital Surface Models generated from AeS-1 InSAR data, Procedings of European Conference on Synthetic Aperture Radar , Freidrischshafen, Germany.

Maire C. 2002. Evaluation de l'apport de données optique et radar de Très Haute Résolution (THR) pour la cartographie de dégâts de tempête en milieu forestier, *Bull XYZ,* in print

Massonet D., Perlant F. & Rabaute Th. 1993. Précision et niveau d'artefacts dans les calculs modèles numériques de terrain par interférométrie. Actes du colloque ESA-CNES « De l'optique au Radar. Les applications SPOT et ERS ». Paris Mai 1993, Cépaduès éditions, 511-523

Massonet D. 2001. The interferometric cartwheel: a constellation of passive satellite to produce radar images to be coherently combined. *Int; J. Remote Sensing*, Vol. 22, N°10):30.

Meyer C., P. Geldreich & Yésou H. 2001. Apport des données simulées SPOT 5 pour l'évaluation des dégâts de tempête dans la forêt. Cas de la forêt de Haguenau (Alsace, France).

Bull Société Française Photogrammétrie Télédétection. Vol 164-165: 162-173

Mukai Y. & Hasegawa I. 1999. Extraction of damaged areas of windfall trees by typhoons using LANDSAT TM data, *Int. J. Remote Sensing,* Vol. 21: 647-654.

Pauc G., Baillaran S., Gleyes JP, Latry Ch. & Vadon H. [2001]: Les produits du système des instruments haute resolution géométrique de SPOT 5. *Bull Société Française Photogrammétrie Télédétection* Vol. 164-165 : 25-31

Pauc G., Latry Ch. & Pasquet A. 1996. Pourquoi et comment simuler des images SPOT 5. *Bull. Société française de photogrammétrie et de Télédétection*, Vol. 141 : 22-27

Proisy C., Sarti F., Mougin E., Lopes A., Dufrêne E., Le Dantec V., Ruiz C., Borderies P. & Chênerie I. 1999. *Temporal variations of interferometric coherence over deciduous forest. Proceedings of CEOS SAR Workshop, 26_29 October 1999, Toulouse, France.*

Ramminger G., Dees M. & Koch B. 2001. *STURMMON, schadenserfassung mit Radardaten aus forstlicher sicht Erste Ergebnisse. Tagungsband Zweites Forum Katastrophenvorsorge, 24-26 Sept 2001 Leipzig.*

Schwabisch M. & Moreira J. 1999. *The high resolution airborne interferometric SAR AeS1. Proceedings of Fourth Airborne Remote Sensing Symposium, Ottawa, Canada, 21-24 June 1999.*

Toutin TH. & Gray L. 2000. State-of-art of elevation derivation from satellite SAR data. *ISPRS*, Vol. 55: 13-33

Wegmüller U. & Werner C.L. 1995. SAR interferometric signatures of forest, *IEEE Geosci. Remote Sensing,* Vol. 33, (No. 5): 1153-1161

Wiesmann A., Demargne L., Ribbes F, Honikel M., Yésou H. & Wegmuller U. 2000. *Forest storm damage assessment with ERS tandem data. ERS-ENVISAT Symposium. Looking at our Earth for the New Millennium, Gothenburg, 16_20 October 2000, ESA SP 461*

Wimmer Ch., Siegmund R. Schwabisch M. & Moreira J., 2000. Generation of High precision DEMs of the Wadden Sea with Airborne interferomtric SAR, *IEEE, trans. Geosc. Remote Sensing,* 38.

Wynter R & Keil M. 1995. *Information extraction from shuttle Radar image for forest and agricultural applications.* JPL technical report.

Yésou H. , S. Weber, Herrmann, A. K. Fellah, Ph. Bally, J. Béquignon, & P. de Fraipont 2000. *Mapping storm forest damage using SAR coherence data. The case of the Haguenau forest - France. Looking at our Earth for the New Millennium. Gothenburg, 16_20 October 2000, ESA SP 461*