THE USE OF SAR INTERFEROMETRIC COHERENCE IMAGES TO STUDY SANDY DESERTIFICATION IN SOUTHEAST NIGER: PRELIMINARY RESULTS

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ABSTRACT

Sand encroachment is the dominant form of desertification in southeast Niger. In this Sahel region, the reactivation of the fossil dunes results from the reduction of the natural vegetation cover which is mainly controlled by the interaction of human activity and climatic variability. In this paper, we discuss some results of AO824 project FADA (Fight Against Desertification in West Africa). One of the goals of this project is to evaluate the potential of Envisat ASAR and ERS ½ data for their application to desertification study. As preliminary research, the value of ERS ½ interferometric coherence images was assessed using seven tandem pairs in southeast Niger. The interpretation of the coherence was validated using aerial photos, very high resolution satellite data and field observations. The results illustrate the potential of interferometric coherence images as a useful source of information for the detection of light sand dune movements in semi-arid zones.

1. INTRODUCTION

Desertification is considered one of the most critically relevant issues in many countries ([1], [2]). The United Nations Convention to Combat Desertification (UNCCD) defines it as "land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities" (http://www.unccd.int). Particularly, in West Africa, desertification is a problem of major importance since it prompts a situation of misery together with drought and poverty. In the late 1960s, the whole Sahelian area, like Southern Niger (fig.1), was affected by a terrible drought ([3], [4]). This climatic deterioration during the 1970s and 1980s has generated, together with human factors, serious environmental alterations and sand dune reactivation. Currently, on the edge of the Sahara desert, moving dunes threaten the existence of many farmlands, water points, settlements and transport links ([3], [5], [6], [7]). In order to fight against sand dunes encroachments and desertification in an efficient manner and ensure successful and sustainable projects, a good understanding of the driving mechanisms through an integrated approach is required including mapping and monitoring of sensitive zones.

Radar remote sensing and Interferometry have proved their utility in a wide range of earth observation studies on Sahelian regions ([8], [9], [10], [11], [12]). The purpose of this paper is thus to show how synthetic aperture radar (SAR) interferometry can be used as a tool, among different remote sensing-based techniques, for the study of sandy desertification, namely, for the detection and monitoring of active sand dunes.

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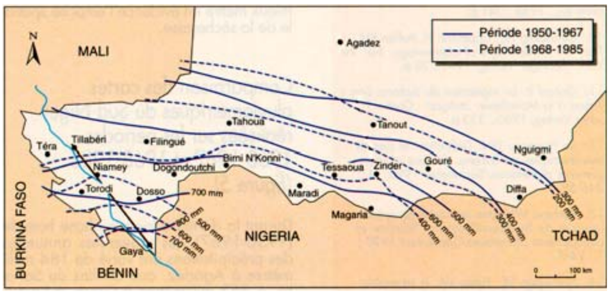

Figure1. Pluviometric map of Southern Niger. Migration of the 300 mm isohyet (limit of the millet culture) to the south suggesting an increase in aridity. (from [3])

2. STUDY AREA

2.1. Description of the study area

The study area, presented in Fig. 2, measures about 100 km from north to south and 300 km width. It is located in southeast Niger, within the Sahelian zone, at the west of the Lake Chad basin region. It stretches approximately between 10°E and 10°40'E and between 13°50'N and 14°N. The landscape consists of a large sandy plateau whose elevation ranges from 300 to 400 meters. This plateau is peppered with small deep inter-

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dune depressions roughly circular and elongated dips. These inter-dune basins show evidences of an ancient network of temporary rivers active during the wet periods of the Quaternary.

The climate is semi-arid with an average annual rainfall between 200 and 400 mm. It is characterized by a long dry season (from October to June) followed by violent and very short precipitations. The climatic variations recorded in the Gouré area between 1936 and 2003 reveal that the dramatic drought started since the late 1960s ended in the late 1980s (fig. 3). However, the annual average rainfall increase did not lead to an extension of the length of the rainy season [4]. Moreover, recent environmental studies in that region ([2], [3], [5]) show that the end of the drought did not led to any landscape improvement. Increasing human pressure tends to be the main driving factor of land degradation.

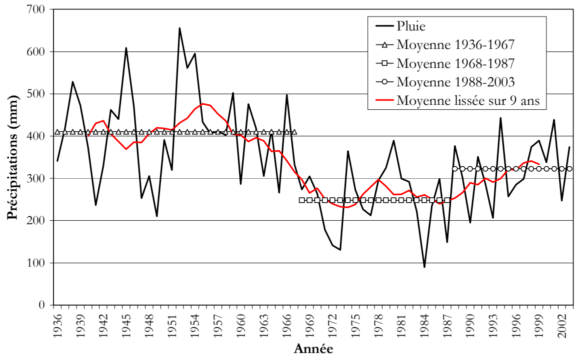

Figure 3. Annual rainfall and subseries average for 3 distinct periods: "humid", "dry" and "actual". (from [4])

The actual agricultural system combines seasonal agriculture (millet, sorghum and cowpea) with annual agriculture in the depressions where the water table nearly surfacing allows producing several agricultural products (manioc, maize, potatoes, onion, sugar cane, date and wheat). These products constitute an important income less sensitive to precipitations fluctuation than rainfed farming.

2.2. Sandy desertification

Southeast Niger is characterized by old transverse dunes which came into existence during the dry ogolian period (18000 y. BP). While these dunes are stabilized by vegetation since the Holocene period, it appears that many of them are now reactivated by a reduction in the vegetation cover and an increase in wind erosivity. This land degradation results from variations in aridity (drought) and is also induced by human activities, such as trampling, overgrazing, unsustainable agricultural practices, collecting wood for fuel, expanding urban areas, etc.

In the Gouré area, reactivated sands threaten the existence of several villages, farmlands and many inter-dune basins which represent the main source of production and agricultural diversification in these areas with reduced potentialities (fig.4). These various processes lead undoubtedly to a deep modification of the agro-pastoral economy in southeast Niger.

Figure 4. Interdunar depression threatened by a reactivated dune in southeast Niger

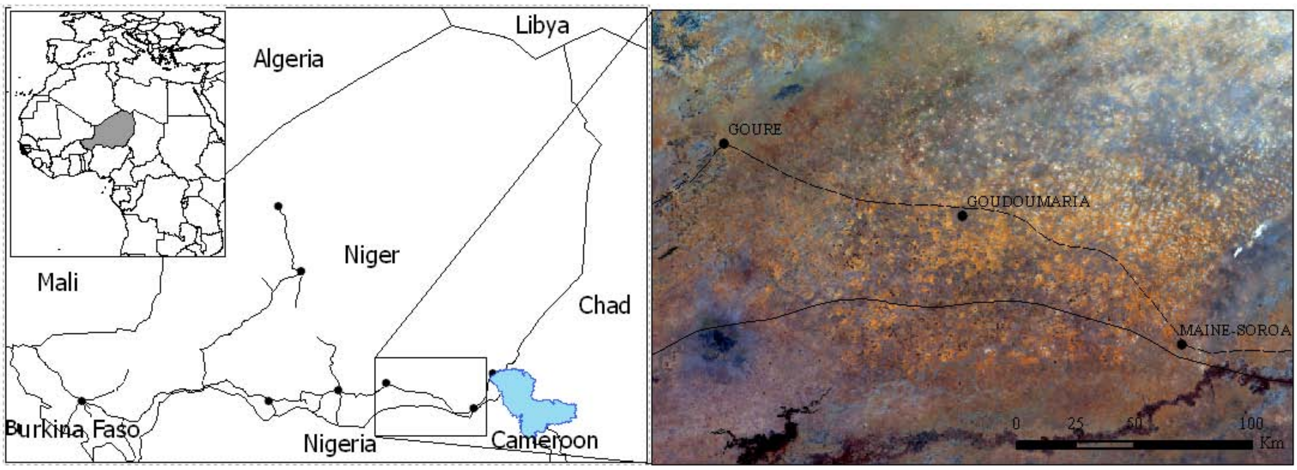

Figure 2. Location of the study area (image MERIS 24/02/2004, R:13/G:5/B:2)

3. DATA SET AND PROCESSING

3.1. SAR interferometry

Synthetic Aperture Radar sensors have an inherent advantage over optical sensors. Since SAR sensors illuminate the surface with his own energy and penetrates through cloud cover and atmospheric disturbance, they can be used day or night and in all weather conditions. A SAR image is composed of complex numbers recording not only the intensity but also the phase of the signal.

Interferometric Synthetic Aperture Radar (InSAR) is a technique that extracts three dimensional information of the observed surface by using the phase content derived from a couple of SAR images.

The ERS ½ tandem mission was a unique opportunity to develop SAR interferometry techniques. Between May 1995 and March 2000, it provided tandem pair images of the same area characterized by a temporal interval of only twenty-four hours. This very short interval increased the probability of having a high coherence between acquired data and thus an accurate Digital Elevation Model (DEM) of the covered scene. The coherence image measures the local phase correlation between two complex SAR images, which in turn corresponds to a quantitative measurement of the noise in the SAR interferogram [13]. Furthermore, through the coherence measurement, interferometric SAR data contain information about the temporal change increasing the range of measurable parameter with regard to the intensity of the SAR backscatter.

3.2. SAR imagery

In a first step, only tandem pairs of twenty-four hours interval from ERS ½ C-band SAR were acquired in single look complex (SLC) format. Tab 1 lists all the available image pairs with their respective baseline distance, i.e., the drift between antenna positions at the time of acquisitions.

Table 1. Tandem pairs from ERS 1-2 data.

Date	Track	Baseline
07-08/12/1995	451	-91
25-26/041996	451	-107
06-07/04/1996	179	120
07-08/11/1998	179	330
04-05/12/1995	408	-160
22-23/04/1996	408	-135
01-02/02/1999	408	-254

Note that only relatively scarce SAR data suitable for interferometry exist in these regions, i.e. on the edge of the Sahara desert, which might prove to be a major limitation for more expanded investigations. Over the study area, the data set of ERS ½ tandem images available consisted of seven image pairs acquired between December 1995 and February 1999 and imaged along three different tracks (fig.5).

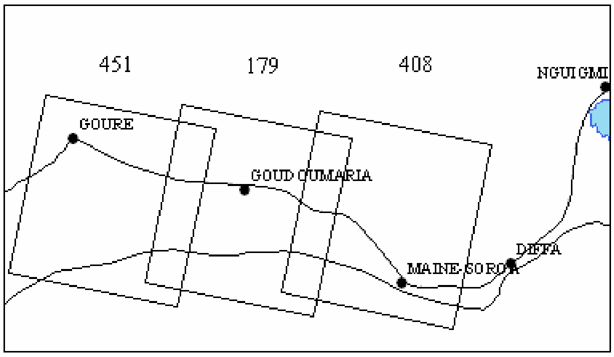

Figure 5. Location of the three data sets over the study area.

All scenes were captured in descending mode covered the same approximate 100x100km area. In addition, Spot multispectral images were acquired in order to match the best possible with the ERS ½ tandem pairs, and latterly to compare them to SAR data to asses their usefulness in detecting active dunes. All the interpretations were also cross-checked with high resolution optical data (SPOT 5, IKONOS, and QUICKBIRD), aerial photos and field observations when available.

InSAR processing, including georeferencement, was performed using the InSAR/DInSAR processor of the "Centre Spatial de Liège" (CSL) [13]. In order to study aeolian formations and transport processes, our evaluation focused on analyzing the following interferometric products for each of the tandem pairs:

- The DEM
- The coherence image
- And the two corresponding amplitude images

SLC images were co-registered at sub-pixel level in three separated data sets corresponding to the three different ERS tracks (451, 179 and 408). For each data set, the first image was considered as the master scene while the other images of the same track were used as slave scenes to be co-registered to the master. So, the coherence, the intensity and the DEM images can be perfectly superimposed on each track. Then each of the products was georeferenced to 40x40 m pixel size using the DEM of the first image pair of each track.

The temporal change that causes a loss of coherence can be induced by two different types of decorrelation factors: a permittivity change or a scatterer geometry change between the two acquisitions [12]. In a semi-arid region, the soil moisture is expected to be stable over such a short period of time (except during the rainy season). Therefore, the InSar signal coherence provides a reliable detection of random change on the land surface as it is mainly driven by the position change of the scatterers within a resolution cell.

4. RESULTS

4.1. Analysis of sand formations

On the one hand, the Digital Elevation Model (DEM) generated by interferometry provided us with morphologic information and an eolian model of the studied area while giving us some insight into the spatial distribution of sand formations (fig.6) [9].

Reference [8] constitutes also a good example on the use on an interferometric DEM to map and characterize large sand seas on Earth.

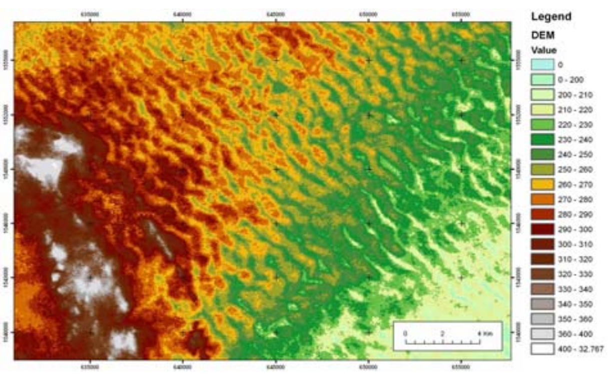

Figure 6. DEM generated from ERS½ (25-26 April 1996). (from [9])

4.2. Detection of mobile dunes

To interpret the coherence and intensity images in an easy manner, RGB colour composites were generated with the coherence image in the Red channel, the intensity image of the first acquisition in the Green channel and the intensity image of the second acquisition in the Blue channel (fig.7) [9].

Therefore, a high coherence level (value approaching 1) arises in red indicating a very good phase correlation between the two acquisitions (high stability of the scene), whereas dark colours suggest a loss of coherence (value approaching 0) which means that the scatterer geometry have change during the one day interval. Finally, white spots correspond to areas with a high coherence level and a strong radar signal backscattering during the two days, as for example relief zones.

The colour composite inspection enables us to find out where sand dunes movements occurred. For instance, coherence losses were identified around the city of Gouré (fig.7). In the present case, they correspond to a ring of sand dune reworking linked to the urban area extension [5]. Moreover, isolated active dunes could also be easily spotted within the area under concern (fig.7). It appears that the temporal decorrelation is substantially due to the wind as it changes the position of the scatterers within a resolution cell between two image acquisitions.

The same methodology for detecting active dunes was applied successfully in another Sahelian region in Mauritania and on the northern border of the Sahara desert, in Southern Morocco (Draa valley) ([6], [7], [9]).

5. CONCLUDING REMARKS

Although the coherence information is generally used as a quality indicator for DEMs, quality and/or phase noise estimation, it can also be used as an information channel in itself [13]. As such, it provided crucial information on small sand dune movements, i.e. movements that occurred only within twenty-four hours.

In the southeast of Niger, the validation of the coherence image interpretation using high resolution data and field observations confirms the results of [10] and [11] that InSAR can be a reliable tool to detect and locate sand movements.

These preliminary results highlight the benefits of radar remote sensing and interferometry through the development of added value products in the study of sand movements and suggest that interferometric radar

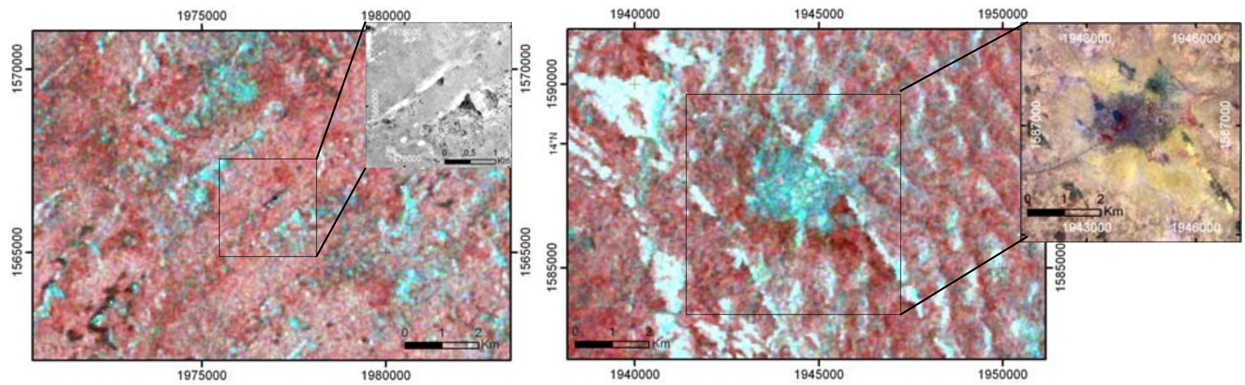

Figure 7. RGB Colour composite (tandem pair of 25-26 April 1996) Red: coherence image, Green: intensity image of 25April 1996, Blue: intensity image of 26 April 1996. Left: Isolated active dunes - Aerial photo IGN France (1996) Right: City of Gouré - Spot 3 Image (31 October 1996). (from [9])

data can complement other remote sensing data in order to evaluate and indicate sandy desertification in West Africa.

Considering the previous results, in further researches, we would like to develop a methodology to map all sorts of sand activity and to monitor the coherence of these zones using multi-temporal coherence imagery with ERS images acquired with more than one day of temporal separation and by ordering the acquisition of new ENVISAT ASAR images for the longer possible period. At the moment, the processing of some archived ENVISAT ASAR images is ongoing to test their potential for the detection of active sand surfaces.

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