

ERS-ENVISAT CROSS-INTERFEROMETRY SIGNATURES OVER DESERTS

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ABSTRACT

In this contribution we report on ERS-ENVISAT (EET) cross-interferometry (CInSAR) results achieved over deserts in Egypt, Algeria, USA and Mauretania. In flat areas these long baseline pairs can be used to generate digital elevation models with meter precision [1,2]. Looking carefully at the CInSAR phase we could consistently identify some surface features which were not visible in the optical imagery available in Google Earth. The phase indicates fine differences in the surface elevation up to a few meters at most. Those are very likely related to subsurface structures such as craters. Another focus is on the interpretation of the backscattering and the coherence with respect to the desert land cover. For dry sand very low backscattering and very low EET CInSAR coherence was observed. We relate this to the penetration of the microwaves into the very dry surfaces and related volume decorrelation effects. Validation against optical data confirms a good potential to map sand dunes.

1. INTRODUCTION

In 2002 ESA launched the ENVISAT satellite with the Advanced SAR (ASAR). ENVISAT is operated in the same orbits as the ERS-2, preceding ERS-2 by approximately 28 minutes. One of the ASAR modes, namely IS2 at VV-polarization corresponds closely to the ERS SAR mode, except for the slightly different sensor frequency used. A unique opportunity offered by these two similar SAR instruments operated in the same orbital configuration is ERS – ENVISAT cross-interferometry (CInSAR). At perpendicular baselines of approximately 2 kilometers the look-angle effect on the reflectivity spectrum compensates for the carrier frequency difference effect. As was shown with examples over Germany, the Netherlands, Italy, and Switzerland [1] CInSAR has a good potential to generate accurate DEMs over relatively flat terrain.

In this contribution we report on ERS-ENVISAT Tandem (EET) CInSAR results over deserts in Egypt, Algeria, USA and Mauretania

2. DATA AND PROCESSING

2.1. Egypt

For a suited EET pair acquired on 17-Mar-2009 over Egypt a long strip (> 500km) was processed. Here we focus on the El Minya area which was used to study in particular the coherence over different desert surfaces. EET CInSAR is characterized by very short time intervals (28 minutes) and a long 2km baseline. For comparison ERS-1/2 Tandem pairs were processed, having 1 day intervals and baselines between 39m and 331m (see Table 1). Figure 1 shows a color composite of the average ERS-1/2 Tandem coherence used as red channel, the average backscatter as green channel and the backscatter temporal variation as the blue channel. The blue area is open water, characterized by low coherence, low backscatter and high backscatter variability. The orange and red areas are desert areas not covered by sand. High coherence and low backscatter variability originate from the high temporal stability. The bright green areas have low coherence and high backscatter and correspond to layover areas caused by steep topography. The sand covered area appears in pink color. The average coherence shows an intermediate level, the average backscattering is low and the backscatter variability is high. The only possible reason we can think of for the observed quick and strong variation of the backscattering is changing moisture. This can also explain why the coherence is sometimes very low (19960304_19960305) and sometime quite high (19951225_19951226, 19960513_19960514), as shown in Figure 2. The low coherence observed for the March 1996 pair is related to significant changes in the backscatter between the two days, relating to moisture changes. For the Nov. 1999 pair no backscatter change is observed, but still the coherence is very low (< 0.2).

Over the short 28 minute interval between the EET pair acquisition temporal changes to the sand characteristic are less likely, thus reducing the unknowns for an interpretation. Figure 3 shows the RGB coherence product for a pair acquired on 17-Mar-2009. The coherence over sand is very low. Related modeling considerations are presented below.

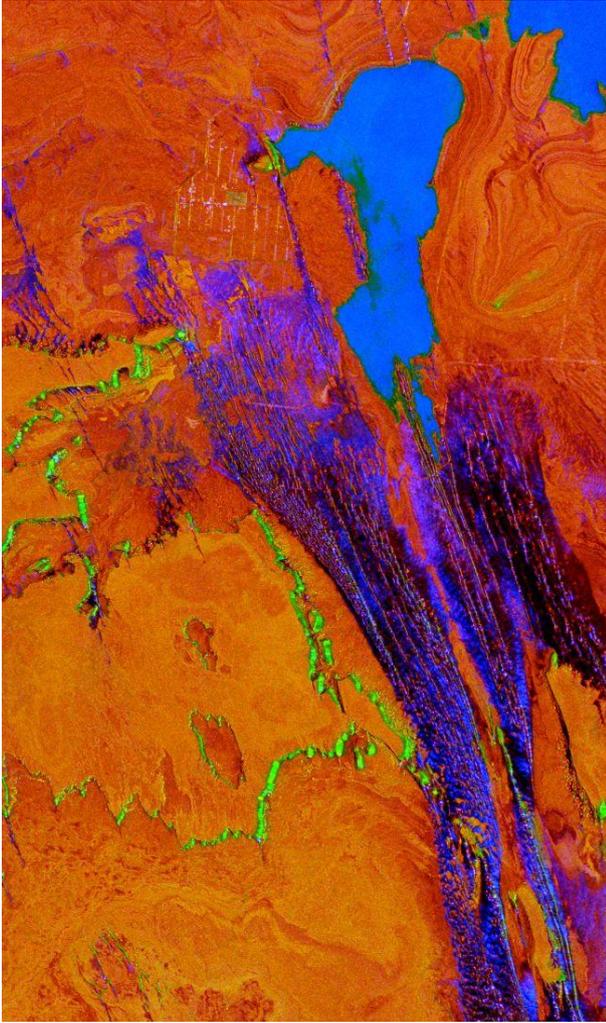


Figure 1 RGB composite of the average ERS-1/2 Tandem coherence (red, linear scale), average backscatter (green, log scale), and backscatter variability (blue, log scale) based on 4 ERS-1/2 pairs shown in Table 1.

Table 1 INSAR parameters of pairs over Egypt. dt stands for the time difference, B_{\perp} for the perpendicular baseline and dDC for the Doppler Centroid difference.

Dates	dt	B_{\perp}	dDC
20090317_20090317	28 min.	1948 m	516 Hz
19951225_19951226	1 day	-291 m	300 Hz
19960304_19960305	1 day	-39 m	300 Hz
19960513_19960514	1 day	-174 m	300 Hz
19991129_19991130	1 day	-331 m	300 Hz

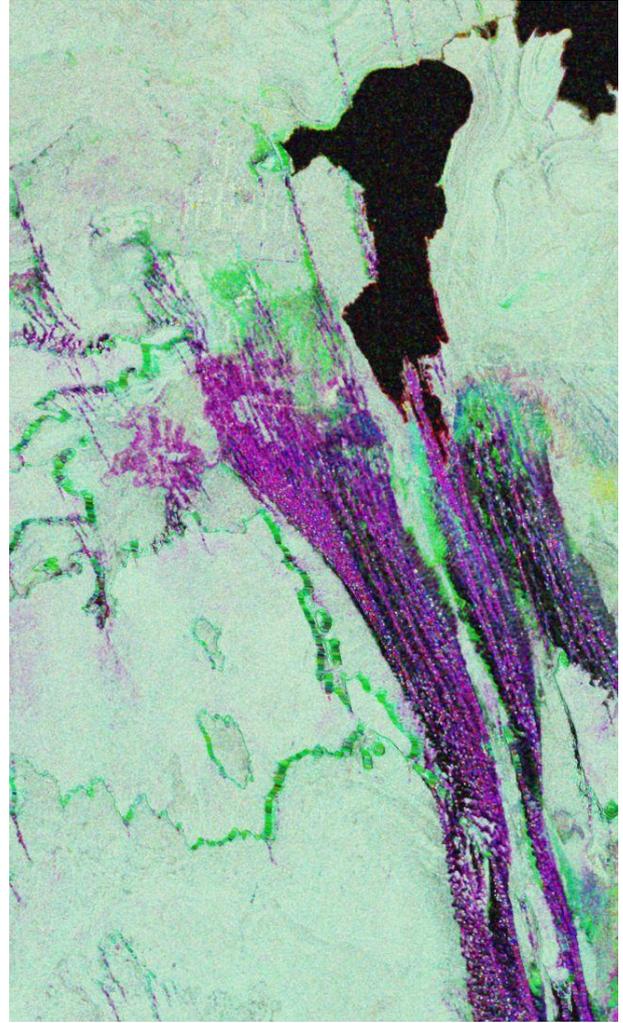


Figure 2 RGB composite of ERS-1/2 Tandem coherence of 19951225_19951226 (red), 19960304_19960305 (green), and 19960513_19960514 (blue).

Table 2: EET CInSAR parameters of pairs selected over El Oued, Algeria. Indicated are the perpendicular baseline component, B_{\perp} , and the Doppler Centroid difference, dDC .

track	$date$	B_{\perp}	dDC
480	20090301	2086m	70Hz
208	20090210	2148m	-210Hz
208	20090317	1997m	508Hz

Table 3: EET CInSAR parameters of pair selected over Mauretania Indicated are the perpendicular baseline component, B_{\perp} , and the Doppler Centroid difference, dDC .

track	$date$	B_{\perp}	dDC
309	20090324	1674m	430Hz

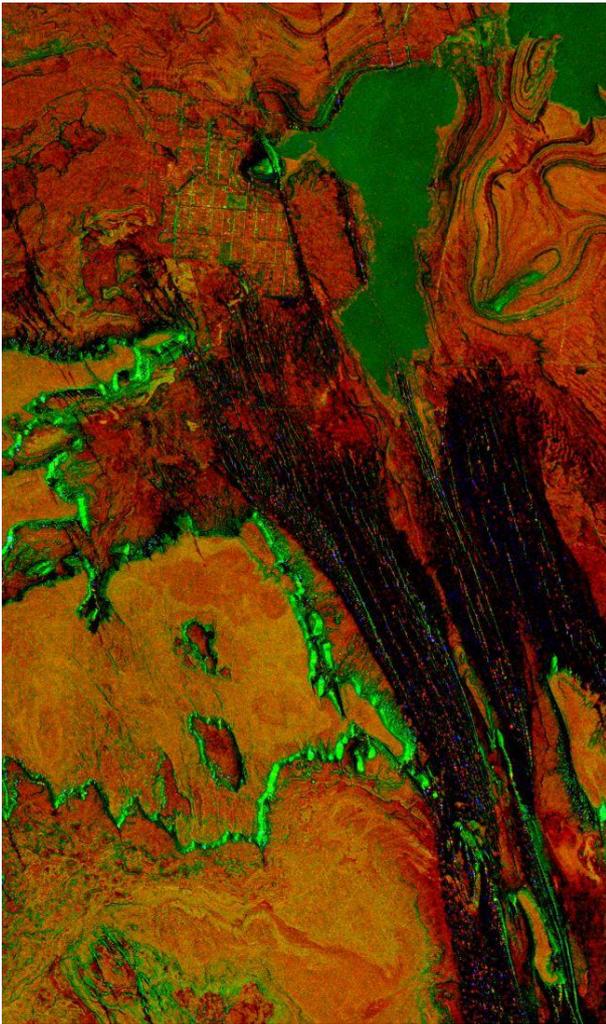


Figure 3 EET CInSAR coherence product (RGB composite of coherence (red, linear scale), average backscatter (green, log scale), and backscatter change (blue, log scale) for pair on 17-Mar-2009.

2.2. Algeria

Over Algeria three suited EET pairs in two adjacent overlapping tracks were processed. Dates and parameters of the selected pairs are shown in Table 2. Our discussion here focuses on the possibility to identify subsurface structures in EET data. Subsurface structures were already identified in SAR data, e.g. in L-band SAR backscatter, indicating craters and old river structures [6].

Figure 4 shows 3 EET cross-interferograms and optical imagery for the same area from Google Earth. In the red circle a crater like structure is visible in both the optical data and in the 3 EET pairs. The other crater like structure (yellow circle) is very clearly visible in the EET CInSAR phase in all three pairs but it is not seen in the optical image.

We don't think that these phases are related to directly seeing sub-surface features but rather that we see meter scale height variations on the surface thanks to the very high EET CInSAR phase sensitivity to topography.

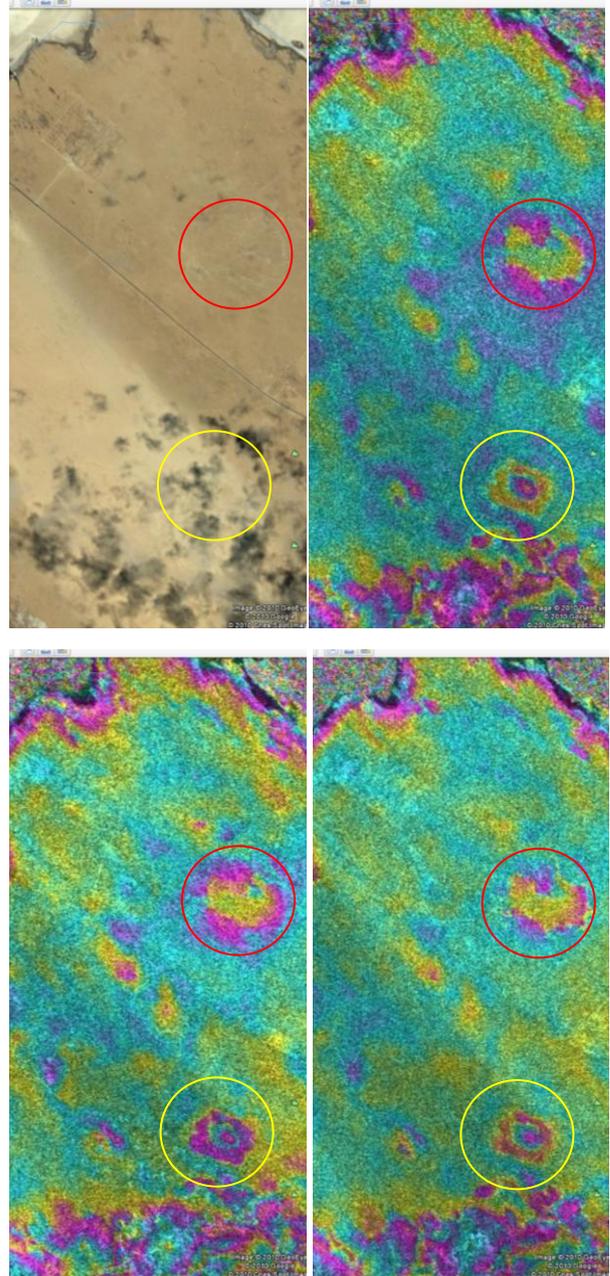


Figure 4 Google Earth view of area considered and EET CInSAR phase for the three pairs listed in Table 2.

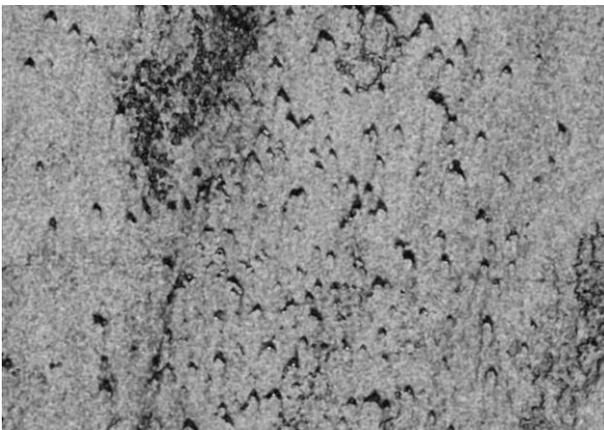
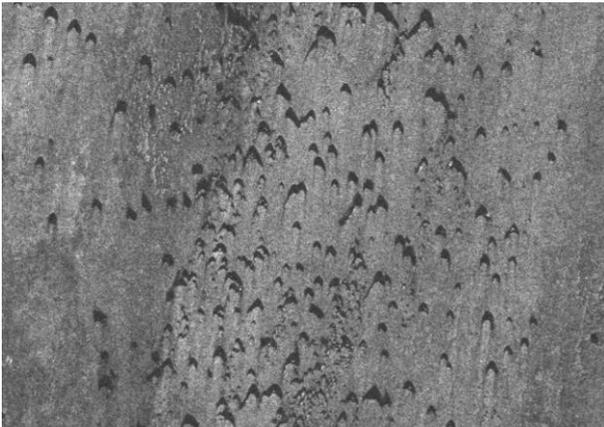


Figure 5 Google Earth view of area considered (top), backscattering (center) and EET CInSAR coherence (bottom) on 24-Mar-2009 over desert area in Mauretania with distinct sand dunes. For the coherence a linear gray scale with between 0.0 (black) and 1.0 (white) is used.

2.3. Mohave desert, USA

The Mohave desert site includes flat to mountainous terrain. In the flat parts a high quality DEM was retrieved using EET CInSAR. Nevertheless, no solution was found on the steep slopes of the mountain ranges. A

method to combine the EET CInSAR DEM (used for the relatively flat parts) with the SRTM DEM (used for the mountain areas) was presented in [4].

2.4. Mauretania

The EET pair analyzed over Mauretania (see Table 3 for parameters) includes an area with a large number of sand dunes with a distinctive shape. Comparison with Google Earth clearly showed that the dunes are characterized by very low backscatter and very low coherence (Figure 5).

The C-band backscatter and the coherence can be used to map the dunes. Multi-temporal data can be used to map its motions which is of interest as the locations of dunes changes over time and may affect infrastructure (settlements, roads, railway, pipelines, industrial sites).

3. EET CINSAR PHASE INTERPRETATION

3.1. DEM generation

In flat areas long baseline EET pairs can be used to generate digital elevation models with meter precision [1,2,3]. This methodology works well for much of the desert area. Exceptions are water surfaces such as salt lakes, steep slopes, and dry sand surfaces, which all show low coherence (<0.2).

3.2. Detection of underground structures

As discussed for the Algeria example, fine differences in the surface elevation up to a few meters may relate to subsurface structures such as craters or ancient river beds.

The C-band penetration depths are around 1m for dry sand [5] and up to 10m if the sand does not contain any hematite [7]. The potential for a direct retrieval of information on subsurface structures is limited to relatively short distances. Furthermore, the coherence is typically very low in this case, so that no information may be expected from the EET CInSAR phase.

4. EET CINSAR COHERENCE

Over many desert areas the EET CInSAR coherence is high. Low coherence, on the other hand, is observed for water surfaces such as salt lakes, steep slopes, and dry sand surfaces. In the case of water surfaces temporal change (of the wavers on the water surface) explains the low coherence. In the case of steep slopes non-overlapping reflectivity spectra and very high phase gradients are the likely reasons for low coherence.

In the case of dry sand surfaces we explain the low coherence observed as follows. For measurements of the

dielectric constant of dry sand it is referred to [5]. At C-band dry sand has a dielectric constant around $\varepsilon' = 2.6$ and $\varepsilon'' = 0.02$, resulting in a penetration depth around 1.0m. The additional two way path delay δ in dry sand over the corresponding vacuum path length is calculated as

$$\delta = \frac{4\pi}{\lambda} (\sqrt{\varepsilon'} - 1) \approx l \cdot 137 \text{ rad/m} \quad (1)$$

with l , the path length, and λ the wavelength (5.6cm). This corresponds to a path delay of 2π (one fringe) per 4.6cm of sand. With a baseline around 2km and 800km distance to the satellite the angular difference between the two observations of an EET pair is only 0.14deg. which results for 50cm of sand to a path difference of less than 0.2mm for the two observation paths. This is small compared to the 4.6cm ambiguity value and therefore it is not expected to cause significant decorrelation.

We think that spatial variations in the dielectric constant of the sand, may result in significant phase differences between different paths to a scatterer within the sand even for only slightly different paths. For a scatterer below 50cm of sand the 2-way path delay is around 70 radian. Therefore, spatial variations of the order of a significant fraction of a phase cycle, which will cause decorrelation, are likely.

To some degree we checked this explanation with the ERS-1/2 Tandem data which have much shorter baselines. Low coherence should also be observed for short baselines. While for two pairs this occurred, nevertheless, for two other pairs the coherence over sand was quite high. A possible explanation for the high coherence is reduced penetration because of a higher moisture of the sand. Such changes are realistic, as confirmed by very significant backscatter changes for one ERS-1/2 pair. For moist sand the scattering is stronger and originates predominantly from the layer near the surface which results in high coherence.

More experiments, in particular with better in-situ information, would be useful to further address this topic.

5. DISCUSSION AND CONCLUSIONS

EET CInSAR results over desert areas were presented and used to discuss the potential of the interferometric phase and coherence for DEM generation and mapping applications.

EET CInSAR has a good potential to generate DEMs in flat desert areas and this may also be of interest in the context of the detection of subsurface structures such as craters. The backscattering and EET CInSAR coherence

can be used to characterize different desert surface classes. In particular dry sand can quite easily be detected based on low coherence and low backscattering.

6. Acknowledgments

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7. REFERENCES

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