

SHORT-TERM STABILITY OF CASPIAN COASTAL COVERS CHARACTERIZED BY REPEAT PASS SAR INTERFEROMETRY

Alexander Zakharov

*Institute of Radioengineering and Electronics RAS
141190, Vvedensky sq.1, Fryazino, Russian Federation
+7095-7855639, ext 1365 (t), +7095-7029572 (f), e-mail: aizakhar@ire.rssi.ru*

ABSTRACT

The goal of this paper based on ERS and ENVISAT SAR data is interferometric study of the backscattering mechanisms for Caspian coast covers and temporal stability of backscatter on relatively short period of time – from one day till half of the year. One of the results obtained is a discovery of double-bounce scattering mechanism for the reed zone, what allowed observing the fluctuations of sea water level in the submerged reed. Another effect observed is a manifestation of fluctuations of SAR signal phase because of troposphere irregularities. Coherence maps provided us an opportunity to estimate temporal stability of coastal vegetation covers in the case of different spatial and temporal baselines as well as different seasonal conditions.

INTRODUCTION

The Caspian Sea is characterized by unsteady hydrological regime with continuous annual and seasonal oscillations of sea level. The Caspian Sea level oscillations cause the modifications of the coastal zone and affect the ecological situation and economy of the region. The last rise of the sea in level 1980th – beginning of 1990th resulted in the abrupt change of the coastal areas state. Among the consequences was the flooding of large coastal areas and reed drainage zone, formation of inland reservoirs in the rear of this zone, underflooding of urban territories, displacement of the shoreline. Spaceborne SAR observations are very helpful in the dynamic mapping of the territory under study including classification of different types of the covers, monitoring of the surface modifications and observation of ecological situation of the region. Interferometry using ERS and ENVISAT data is an efficient method of surface covers study.

AREA OF STUDY

Two typical regions of Russian Caspian coast: Kalmykia shore and Astrakhansky Biosphere Reserve in the Volga estuary have been chosen to study the influence of the sea level variation on the coast state. The topography of the study area is plain with a little slope to the sea. Two processes cause a formation of the delta surface: oscillations of the sea level and the transportation of solid parts by the river stream. When the sea level is stable, the coastal surface demonstrates slow annual rise and displacement of shoreline in seaward direction. Three typical coastal zones may be distinguished here: marine part of the avandelta, covered by water vegetation, reed drainage zone with many ilmen lakes and dry alluvial plain, cleaved by Volga river arms and covered by meadows and fields. Another area of interest is the Kalmykia coast containing zone of semi-desert vegetation. The marine part of delta, reed growth drainage zone and the alluvial plains are exposed to combined influence of two processes: the fluctuations of the sea level and man-made regulation of the discharge of river water. Strong seasonal variations of the delta and sea landscapes result in changes of vegetation covers state and shoreline.

USED MATERIALS AND METHODS

Most important part of the analysis was based on ERS SAR tandem pair obtained on 2 and 3 May 1996 and a pair of the ERS scenes from 1997. This part of work resulted in the delineation of major classes of surface covers and detection of the impressive surface cover dynamics. To explanation of the origin of the dynamics observed on the differential interferogram we used SIR-C SAR data polarimetric collected on April 18, 1994. A series of ENVISAT ASAR scenes allowed studying coherence properties of the surface covers at various temporal and spatial baselines. The main processing technique was interferometric processing which allowed the generation of coherence maps and interferograms. Our selection of the data with low spatial baselines and the fact the study area is completely flat allowed us to interpret the interferograms as differential ones.

RESULTS

One of significant effects discovered in the area of study may be seen on the Fig. 1, covering area 40*100 km. The left pseudo-color image was generated using two intensity images and a coherence map.

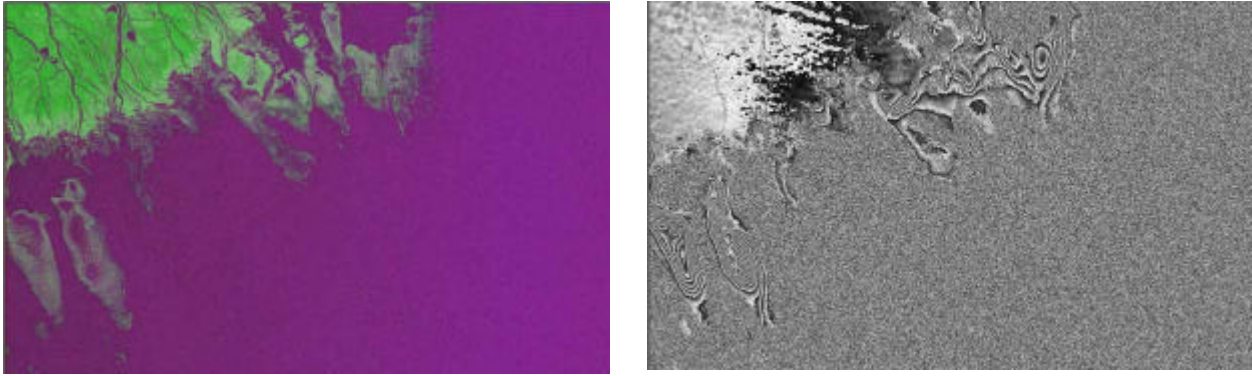


Fig. 1. On the left: pseudo-color image of Zudev island area using tandem interferometric data of ERS SAR, where R-intensity image from May 2, 1996; G – coherence, B- intensity image from May 3, 1996. On the right – flattened interferogram.

On the image the water surfaces are marked by cyan color because the intensity of the backscatter was very high in the presence of strong winds and the coherence had zero value. Continent territory is bright green, as the coherence is very high here and level of radar signal backscatter from a flat area was low. Reed dewatering zone near the shoreline is light green because of intermediate level of coherence and level of backscatter. Flooded reed in avandelta looks gray because of low coherence and level of backscatter.

The surface of the region presented on Fig. 1 is totally flat, according to cartographic information fluctuations of the altitude are below 5 meters and the interferogram on the right should not have any fringes, as the spatial baseline here is about 60 meters. At the same time in the area of Makarkin and Zudev islands (in the lower left corner of the image) one can see 6-10 fringes situated around the islands center. It should be noted here that similar interferometric fringes could be observed in numerous places in avandelta (not presented here). Taking into consideration 60 m spatial baseline of the interferometric observation scheme one could suppose here 1500 m topography variations. But some scattering surface dynamics might provide better explanation of the fringes observed. Moreover, the tandem pair from August 1998 did not show such a prominent phase variations on the islands surface. The same was true for the interferograms made from various combinations of ENVISAT data

We supposed that the origin of the fringes was the oscillation of the sea level between the SAR observations and these sea level oscillations were generated by seiches of the Caspian Sea. The mechanism of the generation of the coherent backscatter from a water surface become clear after analysis of SIR-C polarimetric SAR data collected over the North Caspian coast on April 18, 1994. This unique SIR-C SAR equipment provided the possibility of measurements the full scattering matrix in L and C bands. It is well known that phase difference of copolarized V and H signals (polarimetric phase difference) allows the identification of the single and double bounce scattering mechanisms. For such a targets as water surface or denudated soils polarimetric phase difference Δj_{HH-VV} is zero. In the case of double bounce scattering from dihedral corner reflector or the system {wet soil (water) / vegetation trunk} the phase difference is equal to 180° .

On the Figures 25 the ERS and SIR-C SAR intensity images as well as interferometric and polarimetric phase differences for the North Caspian coast with a segment of Volga estuary are presented. Area size within the image is 30*50 km. Bright pixels of intensity image correspond to higher backscatter. Higher phase difference values are marked with bright pixels also. In the byte representation of brightness on the phase image the number 255 corresponds to 360° .

Histograms of the polarimetric phase difference for 3 different surfaces are presented on Fig. 6. The histogram maximum for the case of water surface and arid soil is located at 44, what corresponds to 62° . In the avandelta covered with flooded reed the phase difference is 260° , what is 180° more then in the case of water surface. The numbers obtained are analogous both in C and L bands of SIR-C SAR. Such an observation allows us to make a conclusion about the presence of double bounce scattering mechanism {wet soil (water) / vegetation trunk} in the reed dewatering zone and flooded reed on the coast and over the avandelta islands. Most of the reed-dewatering zone has the same coherence as arid soils; both these areas do not demonstrate any surface dynamics. Reed vegetation in avandelta has lower coherence. This is the area, where numerous interferometric fringes are concentrated. We may conclude that because of oscillation of the water level with an amplitude of 15-20 cm the signal path length in the scheme {water / reed trunk} was changing approximately at the twice the same value. For the signal with 6 cm wavelength 6-10 interferometric fringes could be generated. We have to underline that there is no any fringes on the sea surface in general as in general there is no coherence of the scattered signals in the single scattering scheme. Given effect was observed for the Caspian coastal area and got such an explanation for the first time and should be treated as one of important results here.

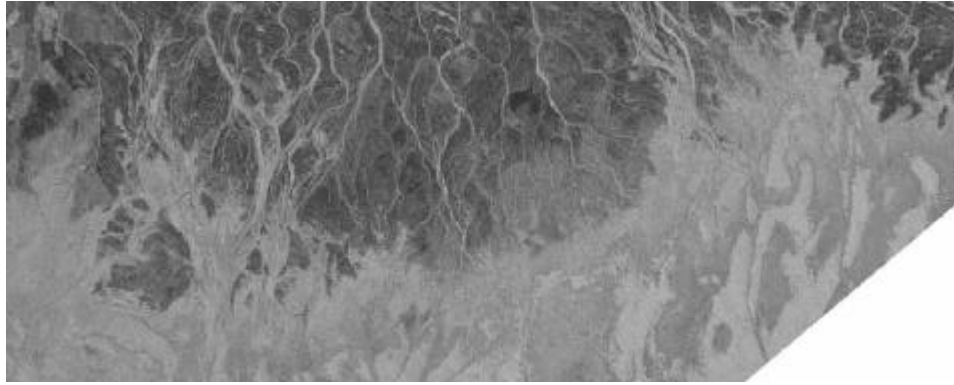


Fig. 2. ERS SAR intensity image of Volga estuary

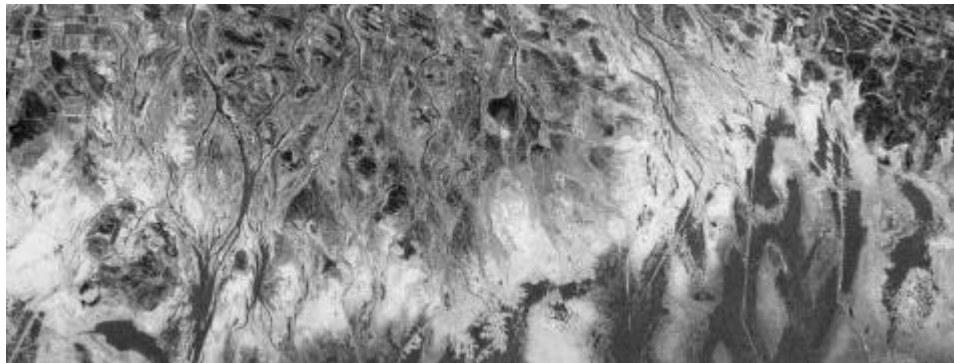


Fig. 3. SIR-C SAR intensity image of Volga estuary

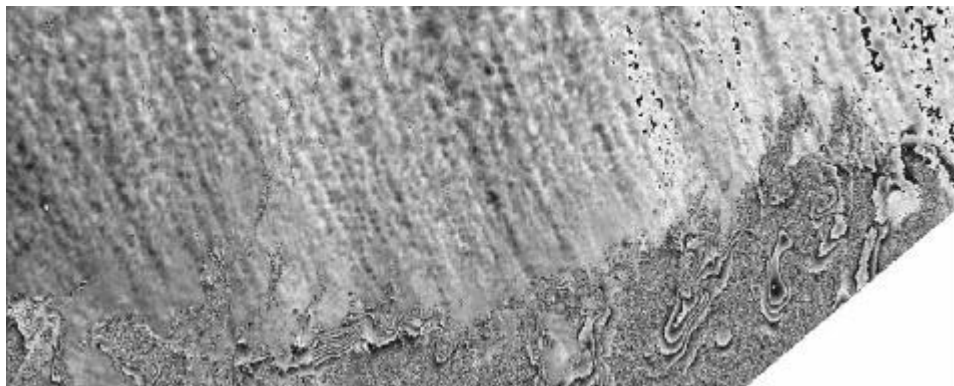


Fig. 4. ERS SAR interferometric phase difference

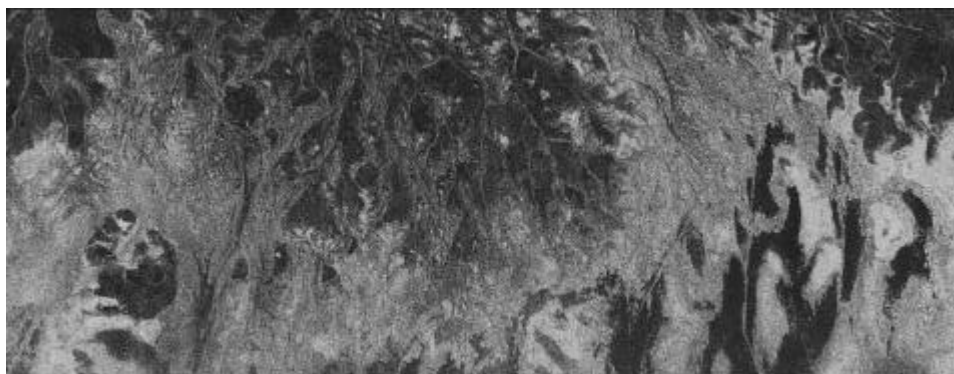


Fig. 5. SIR-C SAR polarimetric phase difference

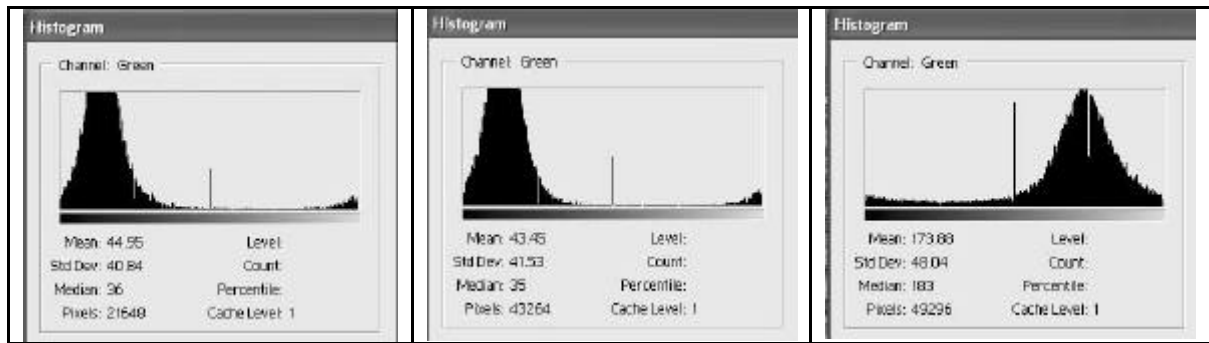


Fig. 6. Histogram of polarimetric phase difference extracted from SIR-C SAR data for different surface covers (left - arid soils, center – water surface, right – flooded reed vegetation on the Somovy island)

Final case of observation of the dynamics on the interferograms is tied to the phase variations on the coastal surface far from the sea. One can see on the ERS SAR interferograms presented on Figs. 1 and 4 specific phase variations, which cannot be explained by topography (relief height variations should be as large as 70-100 m) or solid surface displacements. Obvious and reasonable explanation of the phase difference oscillations is in the troposphere turbulence, which caused refraction coefficient fluctuations and affected the signal path length. Our analysis shows that daily signal phase fluctuations here reach 0.03π and characteristic spots on the interferograms have size 100m – 3 km.

The last part of study was based on a use of 6 ENVISAT ASAR data obtained on October 8, 2003 – June 9, 2004 with interval of 35 days, which is repeat orbit interval for ENVISAT. Three winter images were made in the different soils freeze/thaw state. Spring and summer images are characteristic by appearance of fresh vegetation on the coast.

The interferometric baselines in different scenes combinations were varying from 10 m to 1000 m. As there was no clear manifestation of the dynamics in the reed zone in the case of frozen surface in winter or absence of coherence in reed zones for the pairs obtained in different seasons, we put our attention to coherence maps of the North Caspian coast area.

We have discovered low coherence for the combination of October image with spring and summer ones. Combination of winter and summer scenes also shows low coherence because of change of the vegetation state. Combination of winter images shows highest coherence because of higher stability of frozen micro relief.

We may mention typically high coherence of the backscatter from most of arid soils and practically total decorrelation from reed dewatering zone, if not speaking about vegetated areas of avandelta. There is no any indication of the dynamics (as well as coherence) from the areas of avandelta mentioned earlier what is explained by practically total modification of structure and geometry of vegetation there between the observations. At the same time we do see spots of increased coherence in the reed-dewatering zone, first of all in the Makarkin peninsula. For the {December – January} combination of scenes the coherence is present in most of the places in the reed dewatering zone because frozen soil demonstrates higher temporal stability of micro relief. Having a set of coherence maps from different combinations of the scenes and seasons of the year we could discern between the sections of the coastal surfaces demonstrating different coherence and temporal stability of micro relief and different state and content of the vegetation.

CONCLUSIONS

Interferometric study of the backscattering mechanisms for Caspian coast covers and temporal stability of backscatter on relatively short period of time – from one day till half a year was made using ERS and ENVISAT SAR data. One of the results obtained with additional use of SIR-C polarimetric SAR data was a discovery of double-bounce scattering mechanism for the reed zone, what allowed observing the fluctuations of sea water level in the submerged reed area. Another effect observed here is a manifestation of fluctuations of SAR signal phase because of troposphere irregularities. Coherence maps made using various combinations of ENVISAT ASAR data provided us an opportunity to estimate temporal stability of coastal vegetation covers in the case of different spatial and temporal baselines as well as different seasonal conditions.

ACKNOWLEDGMENTS

Author wants to express thanks ESA for the data provided under research projects AO3-276 and AOE-549.