BRIGHT TARGETS IN THE COASTAL ZONE: A TOMOGRAPHIC RECONSTRUCTION APPROACH APPLIED TO ENVISAT RA-2 DATA

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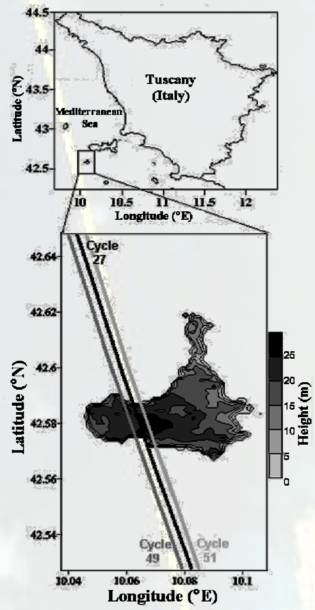
Abstract

Usage and availability of Sea Surface Height (SSH) information from satellite radar altimeters undergo known limitations in the coastal zone, where such data are of great importance and usefulness. In fact, coastal regions are a crucial zone to be investigated and monitored, due to the high impact of sea level and circulation changes on the environmental security and the related economic and societal aspects. It is known that radar returns from the sea surface sometimes present target-like echoes ("bright targets"), especially in correspondence of particular features of the coastal zone, thus entailing a potential interference with SSH measurements. In the recent literature, the hyperbolic patterns in the radargram domain generated by such spiky echoes have been tentatively explained as resulting from flat water areas in the proximity of the coastline, but the physical mechanism which underlies their occurrence was still unclear. This work describes the experimentation of a microwave tomographic reconstruction approach applied to Envisat RA-2 waveforms, tested on selected passes over the Pianosa Island, with the aim of identifying the signal contamination sources in terms of their location and extent. The obtained results encourage the idea that the origin of such signatures is associated with particular conditions of the sea surface, which are easier to be found in the proximity of coastal closed areas such as gulfs, but presumably not limited to such circumstances.



Target focusing approach

The tomographic reconstruction technique falls within the inverse scattering approaches [Colton and Kress, 1992], where the unknown is a contrast function, which identifies the target as an electromagnetic anomaly with respect to a given background scenario. Here, we exploit a linear inverse scattering scheme under the simplifying hypothesis that the mutual electromagnetic interactions among the targets in the scene can be neglected (Born Approximation) [Soldovieri and Solimene, 2010].

The integral equation that has to be solved [Soldovieri and Solimene, 2010] is:

$$E_s(\omega, x_s, z_s) = k_0 \int_{z_{\min}}^{z_{\max}} dz' \int_{-a}^{a} \frac{\chi(x', z')}{R} e^{-j2k_0 R} dx' \quad (1)$$

$Es(\omega,x_s,z_s)$ is the datum of the problem, i.e. the scattered field collected at pulsation $\omega=2\pi f$ and at the spatial location (x_s,z_s) of the altimeter; k_0 is the wavenumber in the free space, R is the distance between the altimeter and the generic point (x',z') of the investigation domain. The contrast function $\chi(x',z')$ is the unknown of the problem and is defined as:

$$\chi(x', z') = \frac{\varepsilon(x', z')}{\varepsilon_0} - 1 \quad (2)$$

being $\varepsilon(x',y')$ the (unknown) permittivity function of the target and ε_0 the dielectric permittivity of the free space medium.

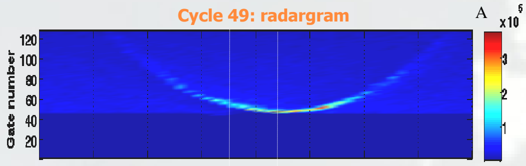
After the discretization of the integral equation, the problem can be formulated as a matrix inversion problem in the following form:

$$\underline{E}_s = \underline{A}\underline{\chi} \quad (3)$$

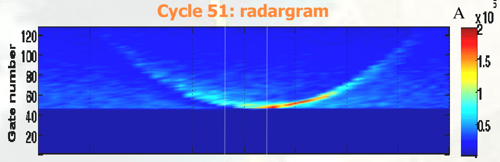
where $\underline{A}$ is a matrix arising from the discretization of the integral equation (1), which is achieved by the method of moments [Harrington, 1961]; $\underline{E}_s$ is the stacked data vector made of the NxM elements, where N is the number of spatial points (i.e., the number of the waveforms acquired at 18 Hz rate) and M is the number of working frequencies; $\underline{\chi}$ is the discretized contrast function in the investigation domain D.

The reconstruction result is given as the modulus of the contrast function, where the regions characterised by a significant modulus are representative of the targets' location and geometry.

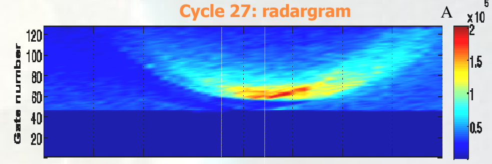
Cycle 49: radargram



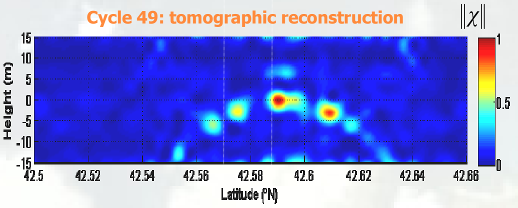
Cycle 51: radargram



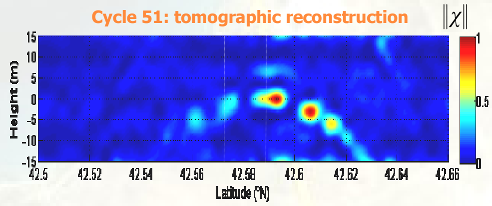
Cycle 27: radargram



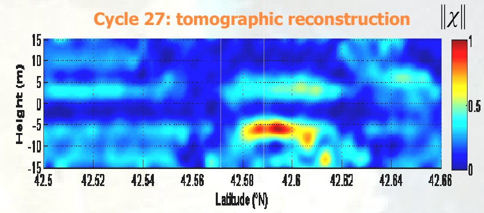
Cycle 49: tomographic reconstruction



Cycle 51: tomographic reconstruction



Cycle 27: tomographic reconstruction

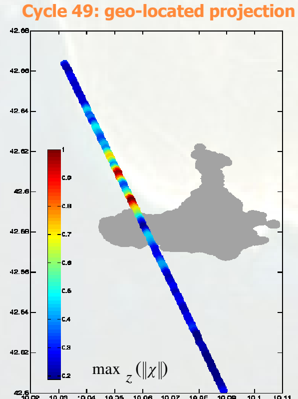


Radargrams of **cycles 49** and **51** show hyperbolic features, that are characterised by the apex located at the air-sea interface. Both tomographic images exhibit contrast function anomalies at the north of the island (where Golfo della Botte is located) that assume the shape of two main reflective targets: one target just attached to the coastline, and one placed further from the coast. The average dimension of the focused targets along the x-axis is about 450 m; the distance of the furthest target from the coast, calculated by projecting the contrast function modulus on the true satellite orbits, is about 2.3 Km. In both cycles, the closest anomalies to the coast have a reconstructed depth placed at z = 0 in the discretized domain. This peculiarity, together with their particular location, assigns such targets to the air-sea interface region, in an area just next to the coastline.

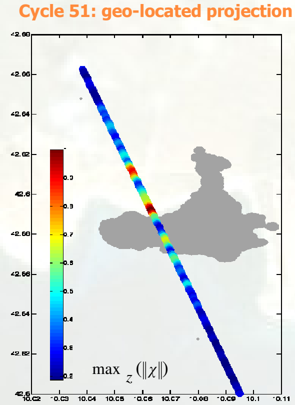
Radargram of **cycle 27** shows a strong hyperbolic pattern, in the form of a wide target-like overpeaking with respect to the typical Brown return. The apex of such hyperbola is above the air-sea interface in the radargram domain, thus revealing an off-track reflector which is responsible for the observed strong burst. The tomographic reconstruction points out a relatively wide anomaly of the contrast function at the north of the island, which appears to be extended for about 1.5 Km in the along-track direction.

The maximum modulus of the contrast function is located at 1.1 Km off the island, at an apparent depth z = -6 m, which identifies the anomaly at about 3.2 Km off the center of the footprint, under the hypothesis that the target lies on the air-sea interface. Alternative sources connected with terrain structures or floating vessels can be hardly responsible for such strong return. In fact, an eventual flat land surface oriented normal to the line of sight would generate a permanent strong nadir backscatter; particular moisture conditions can actually modulate such intermittent effect, but the absence of particular rain events preceding satellite passages lead to the exclusion of this eventuality.

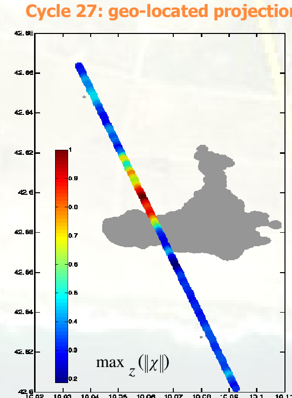
Cycle 49: geo-located projection



Cycle 51: geo-located projection



Cycle 27: geo-located projection



Figures aside show the maximum modulus of the contrast function along the zenith direction (z-axis) projected on each point of the satellite orbit crossing the island.

The individuated reflective zones are systematically located inside the shoreline of the Golfo della Botte, at the north of the island.

Target-like echoes in radar observations of the ocean surface are reported to be caused by very local phenomena, such as unbroken wave crests and white caps, but also by calm water circumstances, which may regard relatively large areas [Long, 2001].

Summary

Pianosa Island represents an effective site for benchmarking methods to better understand the triggering mechanisms of target-like responses in radar altimetry measurements. In particular, target-like features in the collected waveforms can potentially alter the derived parameters, such as SSH, SWH and wind speed. The application of a mature tomographic technique to this specific context enhances the analytical possibilities available for this kind of investigation, by providing information on the location and extent of the detected anomalies (targets) in the electromagnetic scenario. Results of this work confirm and reinforce the hypothesis that bright targets are connected with particular sea state circumstances, such as unbroken wave crests, white caps, and calm water areas. These results suggest further investigations of altimetry datasets featured by bright target effects, including data gathered in the open ocean, which is not necessarily immune from such conditions.

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