SAR Altimetry in Open and Coastal Sea Water: Performances, Limits, Perspectives

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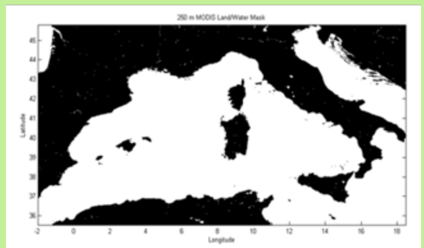
ABSTRACT: Up to now, any effort to retrieve the coastal zone phenomena from the space has been hindered by the intrinsic incapacity of conventional radar altimeters to sample all but largest scales involved in the coastal processes due to its insufficient along-track resolution. However, nowadays, a new technology in Space-borne Altimetry has become reality: the Synthetic Aperture Radar (SAR) Altimeter. The acquisition of altimetric data in SAR mode ensures a higher resolving measurement power that shall enable scientists for the first time to aspire to measure even short-scale weak coastal phenomena, thanks to the 20-fold smaller along track radar resolution and 10 dB higher Signal to Noise ratio. The secondary, but very significant in coastal zone, effect of the radar footprint shrinking is the expected reduced impact of land contamination on the radar waveforms in the proximity of the shore. As a consequence of this effect, the advent of SAR focusing promises to bring the satellite altimetry remote sensing closer to the shore up to around 500 meters. Anyway, this lower bound of 500 meter on coastal proximity is not always reachable, as the footprint shrinking occurs only in along track direction while the across track resolution shall remain basically unaltered. Hence, the orientation of the satellite ground-track with respect the coastline plays a role crucial for an effective filtering out of the off-nadir land-originated signals. In the present work, utilizing the current CryoSat-2 Altimeter Dataset (SAR L1b) acquired over coastal and open sea water, and by re-tracking the SAR L1b waveforms, a performances study of SAR altimetry in open and coastal sea waters will be addressed and the benefits and limits of this new technology highlighted. As particular study area, the Tyrrhenian Sea has been selected: statistics and metrics for sea surface height and significant wave height, as calculated from a cycle of passes, will be assessed, shown and interpreted. Finally, employing the CryoSat Interferometric mode (SARin), it will be attempted to retrieve the origin direction of the radar returns in order to prove how, in SARin mode, the land-originated radar returns can be recognized and eventually discriminated from the pure nadir ocean return.

Measured Precision in SAR Mode

To measure the range noise in SAR mode, the Sea Surface Height standard deviations inside each 20 records block of the 20 Hz retracked profile has been calculated for a 10 second segment from a pass over the Caspian Sea (low dynamic sea waters).
An average value of **4.5 cm** is observed at 22 Hertz to which corresponds to a value of 1cm at 1 Hertz.
Therefore, the observed range noise level is **1 cm at 1 Hz.**
This value is the half of the commonly accepted and measured precision of the conventional altimetry missions (as from Envisat Validation and Cross-Calibration Team, see [3]).
Further, the Significant Wave Height (SWH) standard deviations inside each 20 records block of the 20 Hz retracked profile has been calculated on the same data segment.
An average value of **35 cm** is observed at 22 Hertz to which corresponds to a value of 7 cm at 1 Hertz. Therefore, the observed wave-height noise level is **7 cm at 1 Hz**.
This value is comparable with the wave-height noise of conventional altimetry missions (9-10 cm). Hence in this case, the goal to halve the wave-height noise as measured in pulse-limited mode has been not yet achieved.
Concerning the noise over wind speed, we can say that the measured variability of the retracked Pu is under 1% for the 10 seconds segment. This ensures a resolution for backscattering better than **0.05 dB at 1Hz**

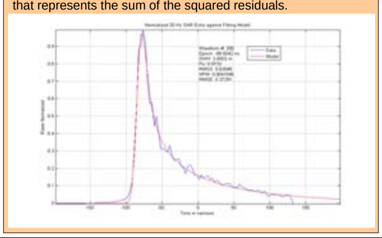
Data Set Description

The analyzed Dataset is composed by 4 months of CryoSat L1b SAR Data: May, June, July, August 2011.
The study area has been limited to the West Mediterranean Sea.
The distance to coast has been calculated using MODIS 250m land-water mask (High Res Mask).
The applied corrections are the ones stored in the CryoSat L1b Data and no sea state bias has been applied in the study.



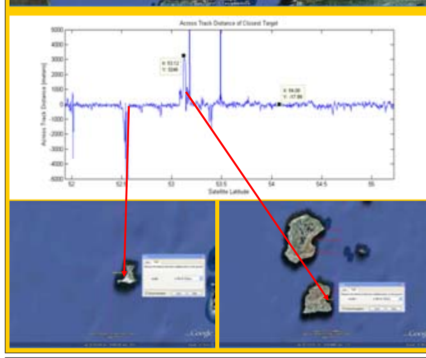
THE SAR MODE

This innovative Synthetic Aperture Radar (SAR) altimeter concept promises to revolutionize the oceanography science in open ocean, coastal zones and inland waters thanks to its unique features: the along-track space resolution is **20 times finer** than in pulse-limited mode and the Signal to Noise ratio is **10 dB higher** [1].
Furthermore, as an effect of the more numerous looks summed-up at multi-looking stage, applying the SAR focusing algorithms, the precision of the range and wave-height measurements is **theorized to be on average two times better than in pulse-limited mode** [2].
However, one of the side consequences of the SAR focusing over the raw radar data is that the characteristic quasi-step shape of the pulse-limited waveform is lost and the SAR focused waveforms assume now a particular sharp shape with long slow-decaying tail. Because of that, the exploitation of the SAR Altimeter data has been, so far, restrained due to the absence of a consolidated and sound model for the SAR echo power to apply in the retracking schemes.
The approach that seems to be more rigorous is to devise a mathematical solution in the definition of the SAR return power, based on physical principles, and to conceive a retracking scheme to fit this model to the data, with an appropriate fitting routine.
This approach is expected to provide better performances than using OCOG or threshold retracking schemes. In this respect, it has the non-negligible benefit to return the sea surface wave-height as well.
The retracker scheme used to fit the model to the L1b radar data is the non-linear Least Squares Algorithm (LSA) in the formulation proposed by Levenberg-Marquardt and applied once the waveforms have been normalized. The retracking scheme returns the parameter **GOF (Goodness of Fitting)** that represents the sum of the squared residuals.



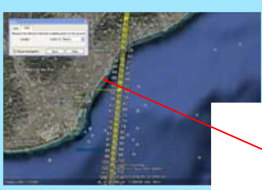
THE SARIN MODE

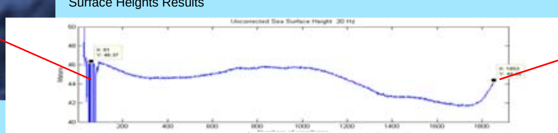
The same re-tracking operated in SAR mode can be repeated in SARIN mode, changing the number of range gate bins and the burst length value.
The acquisition of the data in SARin mode by two antennas allows to calculate the difference between the phase of one receiving channel with respect to the other. From the Phase Difference, it is possible to determine the angle of the echo at each range gate and in particular angle of the echo at closest range (first return). Knowing the range of this first scattering point to the antenna, it is finally possible to derive the across-track distance of the scattering point.
This across track distance can be used in coastal altimetry zone to solve the ambiguity of the origin direction of the radar echo: over open ocean it is expected such across-track distance to be around zero while in presence of targets in across track direction as islands, steep banks and Cliffs, this parameter returns a value no
This principle has been applied for a CryoSat pass over the James Bay, (Canada) in 31 August. The satellite track is passing by a series of little islands (Twin Islands, Spencer and Weston Islands). Calculating the arrival angle on this pass allows to identify unambiguously the origin of the echo from the islands terrain. Good Agreement is found between the distance to the satellite track as calculated from the arrival angle and from Google Earth.

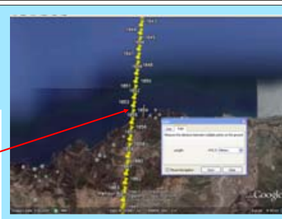


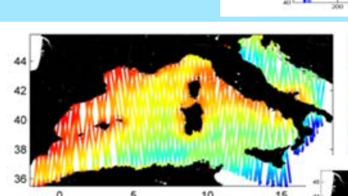
Analysis Results

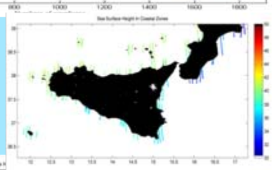
The SAR retracking algorithm has been run on the West Mediterranean Area for the months of May, June, July and August. In the bottom, you can see the computed Sea Surface Heights Results

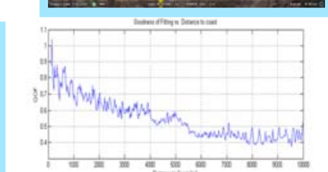


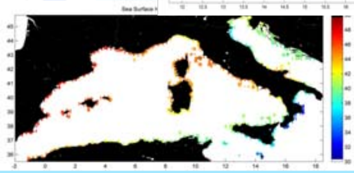


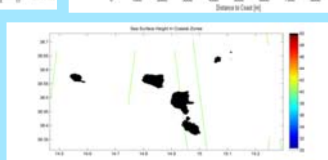












Conclusions & Way Forward

- The measured sea surface height precision of altimetry data in SAR mode is 1 cm for CryoSat-2. This is the half of the currently accepted altimetry precision in pulse-limited mode [7]. Hence it seems confirmed the factor two improvement gained thanks to SAR operability.
- The measured significant wave height precision of altimetry data in SAR mode is 7 cm for CryoSat-2. The accepted current altimetry SWH precision in pulse-limited mode is around 10 cm. Hence, in this case, it is not yet totally reached the factor two improvement but the results need to be confirmed over more scenarios.
- The shrinking of the along track resolution allows to receive physically valid data till 500 meters from the coast, but only in case of ground track nearly normal to landline. We recommend to calculate in the Next generation SAR Coastal Processor the track orientation with respect the land.
- The benefit to use the SARin mode in coastal zone to solve the ambiguity off-nadir/nadir echo origin has been highlighted. We recommend to calculate in the Next generation SAR Coastal Processor the arrival angles when applicable.
- All the analysis needs to be repeated using more consolidated geophysical corrections and sea state bias correction.

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Acknowledgments and References

[1] R. K. Raney, "The Delay Doppler radar altimeter," IEEE Transactions on Geoscience and Remote Sensing, vol. 36, pp. 1578-1588, 1998
[2] Jensen J.R. and Raney R.K. "Delay/Doppler Radar Altimeter: Better Measurement Precision", Geosci. and Remote Sensing Symposium Proceedings, 1998
[3] Benveniste, J. and the ENVISAT RA-2/MWR CCVT Team, "RA-2/MWR Cross-Calibration and Validation: Objectives, Approach, Results and Recommendations"