Fully Focused SAR Altimetry: Theory and Applications

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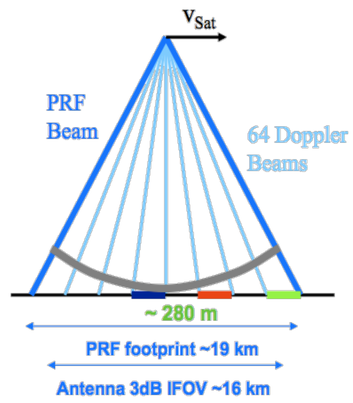
Introduction

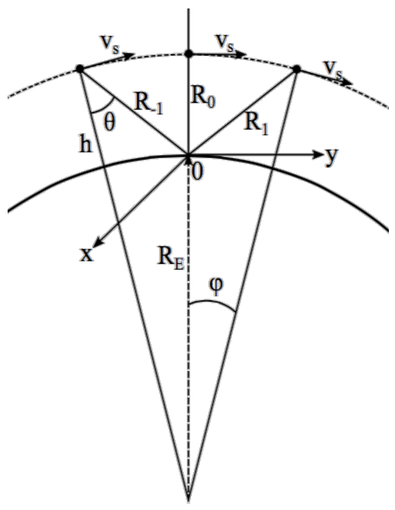
- Delay/Doppler (DD) altimeters achieve an improved along-track resolution with respect to conventional altimeters by means of an unfocused Synthetic Aperture Radar (SAR) processing technique [1].
- The result is a stretched footprint on the surface which is beam limited along-track and pulsed limited across-track (~300m x ~2km), [2].
- This resolution could be improved even further by means of advanced SAR processing techniques: fully focused SAR processing
- The resulting data products have, not only an improved resolution along-track, but also better signal characteristics that lead to improved geophysical parameters estimation



Delay-Doppler resolution cell.

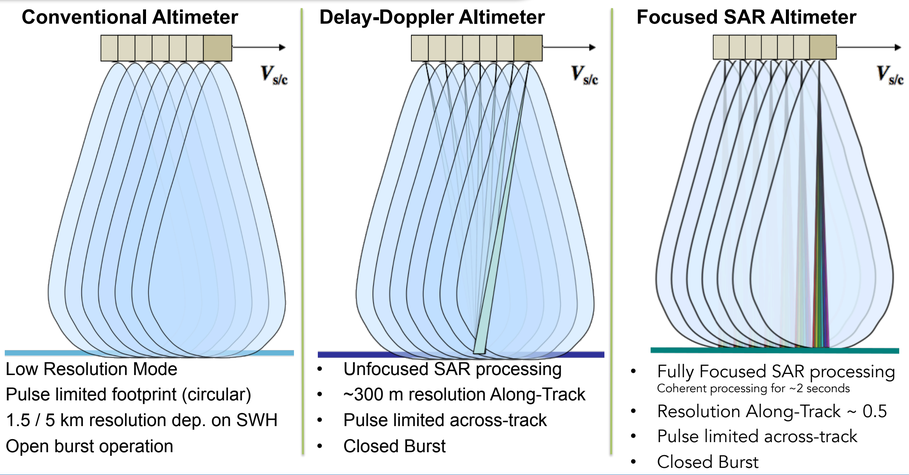
Fully Focused SAR Processing

- The fully focused SAR processing is based on a coherent processing of the radar echoes during the whole illumination time of a scatterer on the surface
- For that, the radar echoes need to be aligned, both in delay and phase, according to the range history of the scatterers
- This processing, similar to SAR imaging radars, reduces the along-track resolution down to the theoretical limit equal to L/2, where L is the antenna on the flight dimension
- Given the signal characteristics of SAR altimeters we have used a FMCW-SAR back-projection algorithm, [3,4], to achieve the focused SAR processing. The processing entails the following steps:
  - Range Cell Migration Correction
  - Range compression
  - Residual Video Phase Compensation
  - Phase Counter rotation and focusing



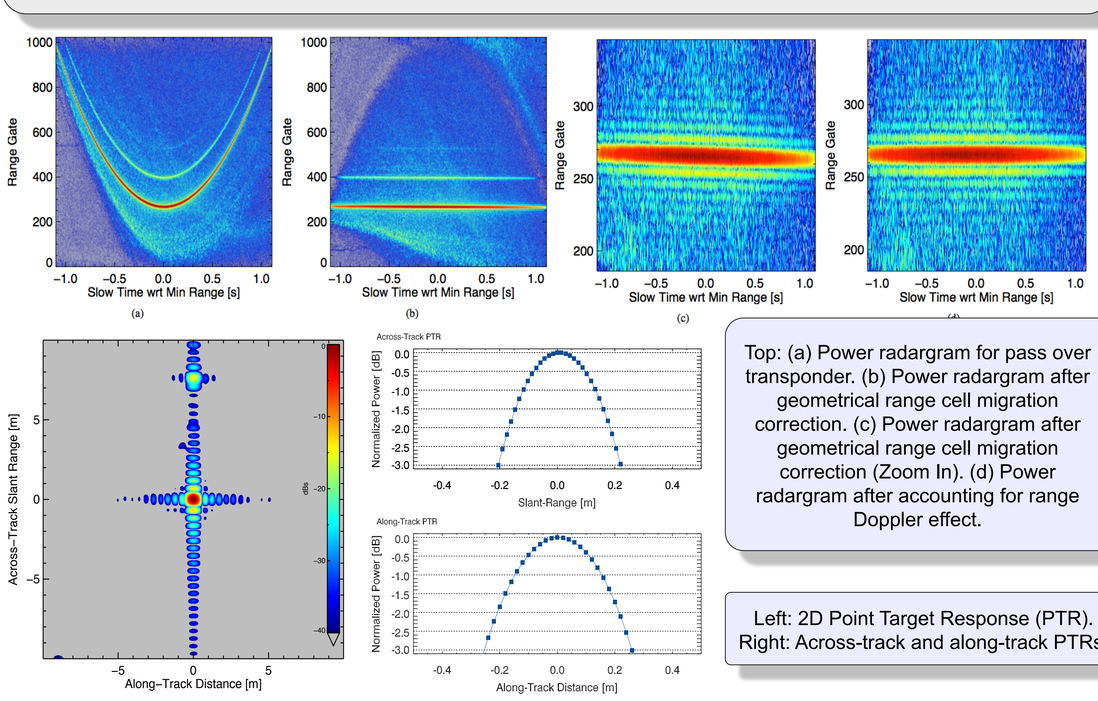
Top: representation of the altimeter geometry. The illumination time of a target on the surface is defined by the observation geometry and the antenna beam-width, θ.

Bottom: Comparison of the conventional, delay-Doppler and fully focused SAR altimeter



Technique Development and Validation

- For the development of the technique we have used the CryoSat-2 SAR Mode data, but our methods could also be used with similar data from Sentinel-3 or Sentinel-6/Jason-CS.
- For the demonstration and validation of the technique we have used Full-bit Rate (FBR) data of passes over the Svalbard ESA transponder.
- After focused SAR processing, the across-track and along-track point target response show the theoretical resolution in both dimensions: an along-track resolution of 0.5 m was achieved!

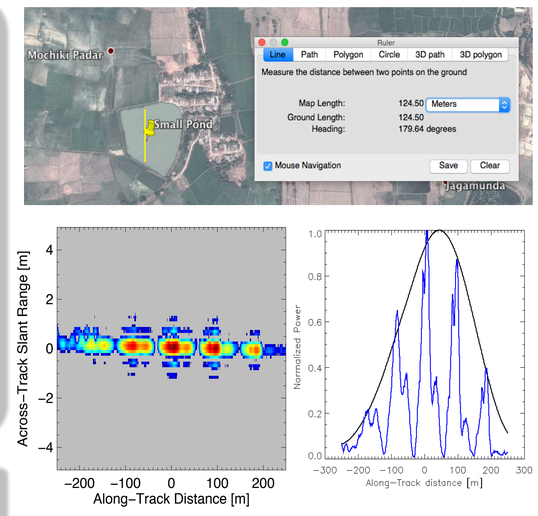


Top: (a) Power radargram for pass over transponder. (b) Power radargram after geometrical range cell migration correction. (c) Power radargram after geometrical range cell migration correction (Zoom In). (d) Power radargram after accounting for range Doppler effect.

Left: 2D Point Target Response (PTR). Right: Across-track and along-track PTRs.

Hydrology Applications

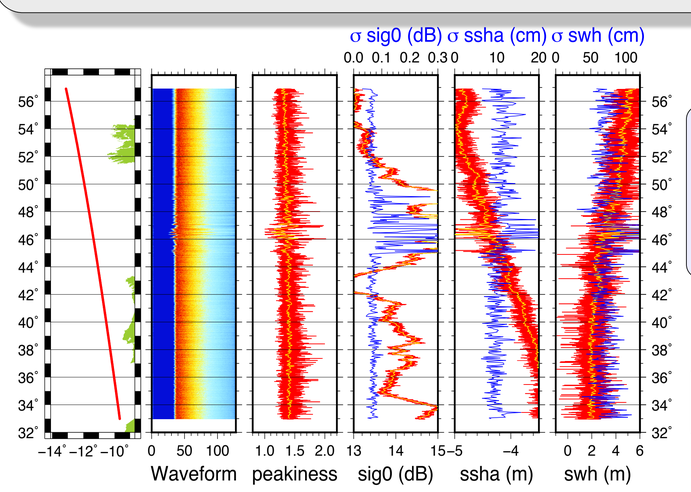
- Because of the improved resolution along-track of the focused SAR altimeter, this technique has a wide range of applications in hydrology, where the extent of water bodies can be small.
- The technique was demonstrated over a small lake in India, where the extent of the lake, much smaller than the DD resolution cell could be clearly determined
- Ghosts images appear in the along-track response due to CryoSat closed burst operation



Top: Google Earth image of the pond in India; Bottom left: SAR Image over the pond; bottom right: along-track response, in black delay/Doppler, in blue focused SAR

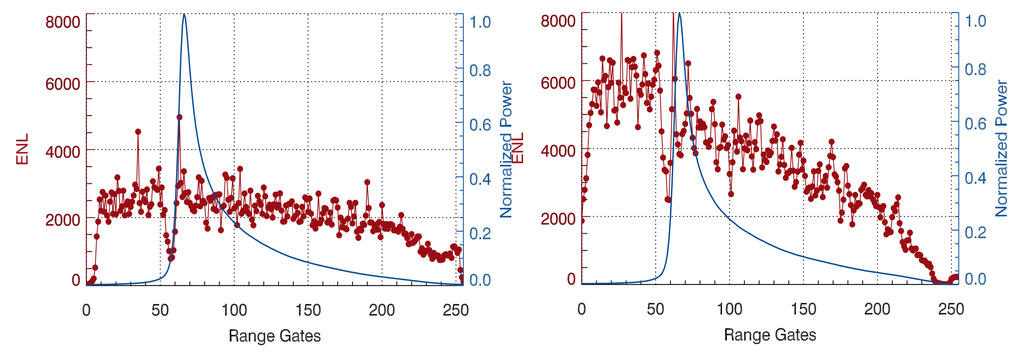
Open-Ocean Applications

- The fully focused SAR processing can also be applied to the Open-Ocean:
- The 0.5 m resolution cells represent inherently independent looks of the ocean surface, which can be incoherently averaged in order to improve the Effective Number of Looks (ENL) of the surface, which will result in improved geophysical parameters estimation
- We have processed a CryoSat-2 SAR mode track over the North East Atlantic
- The comparison of focused SAR with respect to DD shows an improvement of a factor of 2 in ENL. This corresponds to a factor of 4 with respect to conventional altimetry.



Left: SAR Track over North East Atlantic. Power radargram and geophysical parameters estimation. The ENL was analysed over an area with relatively constant ocean conditions, i.e. between 34N and 42N

Bottom left: ENL for delay/Doppler altimeter
Bottom right: ENL for focused SAR



Conclusions and Further Work

- A novel processing technique for altimeter data has been developed: the fully focused SAR allows to coherently combine the echoes from a target on the surface during its whole illumination time, which results in an along-track resolution of 0.5 meters.
- A pre-operational processing chain for both delay/Doppler and fully-focused SAR altimeter data from L0 to L2 has been developed
- The fully focused SAR has been applied to CryoSat-2 SAR mode data over small in-land water bodies and the open-ocean, showing very promising capabilities.
- Further work entails the complete validation of the technique by the analysis of extended datasets, the development of these, and other applications, such as sea-ice/leads detection, and the development of improved ocean data products.

References

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