# SAR Altimetry at 80 Hz: Open Sea, Coastal Zone, Inland Water

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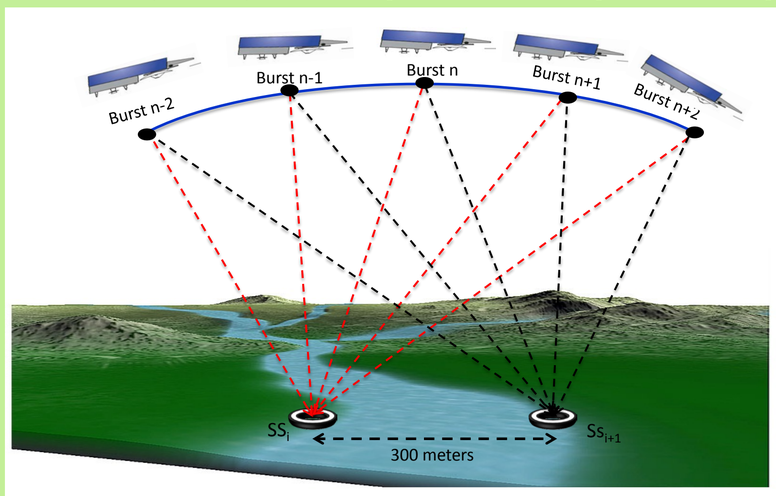
## Abstract

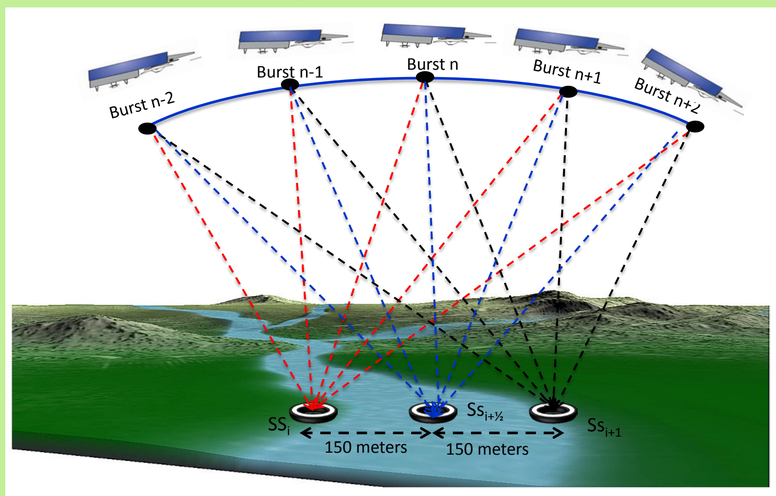
Thanks to the CryoSat-2 unique capacity to downlink unprocessed Full Bit Rate (FBR) data, different data-processing strategies and/or approaches can be attempted and implemented on ground.
This is particularly helpful, when operating in the coastal zone, inland water or land. On these particular domains, It seems sensible to have SAR-processed echoes treated at highest repetition frequency possible in order to capture all the short scale variability of the coastal scenario.
In the Delay-Doppler processing algorithm, the parameter controlling the echo posting frequency is the grid space step that conventionally has been fixed at frequency of 20 Hz (300 meter) in order to match the instrument along track resolution, but the grid space step can be arbitrarily defined to any desired value.
In the present work, we will attempt to Delay-Doppler process the FBR data with a finer space step, around 80 meter, that corresponds to a frequency of 80 Hz (Burst Repetition Frequency) and we will try to quantify the improvement, in term of precision and in term of observability of short scale signals, that is achieved from usage of that finer space step. It is worth to notice that, whereas the grid space step shrinks from 300 meters to 80 meter, the theoretical along-track resolution of 300 meter will remain unaltered.
Once that the L1B SAR echoes have been generated at 80 Hz, they will be re-tracked at 80 Hz using the SAMOSA model in order to retrieve the geophysical quantities: Sea Surface Height (SSH), Significant Wave Height (SWH) and Wind Speed at 10 meter (U10).
The experiment will be run in the waters of the German Bight (Wadden Sea) and Northern Caspian Sea and it will consist in processing the same FBR dataset at 20 Hz (standard grid case) and at 80 Hz (overgrid case) and in spotting the differences between the two cases in term of statistics and resolving power.
The current work is a feasibility study, preparatory for the data exploitation of the Sentinel-3 Topography Mission over coastal zone and inland water.


## The Delay-Doppler Concept: Spotlighted Altimetric Measurement or at finer Space Grid

The Synthetic Aperture (Delay-Doppler) Radar Altimetry Concept makes possible to steer the Doppler Beams to any along-track point of the overflown surface .
This means that with SAR Altimetry, it is possible to post an altimetric measurement located at any desired point along the satellite track.
This is a quite intriguing novelty for inland water or coastal domains wherein scientists would like to achieve an altimetric measurement exactly over quite sensible locations as river/coast banks or river-cross centers (spotlight observation), or , looking beyond, the application of this concept shall make feasible the usage of customized grids where users "a priori" request altimetric measurements exactly over the provided grid points.
CryoSat-2 gives the possibility for the first time to realize this principle since the instrument downlinks directly on ground the raw data (Full Bit Rate or FBR, aka L1a) and hence alternative processing approaches may be attempted.
In our first implementation, in order to explore the potentiality and utility of this concept, we decided to process a series of CryoSat-2 passes at a finer space grid step. For convention, in Delay-Doppler Altimetry, the grid step has been fixed at 300 meters (to be coincident with the instrument along track resolution).Now, instead of the conventional 300 meter grid step, we process the CryoSat-2 passes at a grid step of about 80 meters (or at a posting rate of 80 Hz). This number, 80 meter, is a convenient one: it has been chosen since it corresponds to the CryoSat-2 burst repetition interval (BRI) and the datation time and geo-location information are provided at each burst center in the FBR products. Hence, fixing the grid center locations exactly at burst centers (as we do) allows to skip the cumbersome operation to interpolate the satellite orbit at the grid locations which are 300 meter distant.



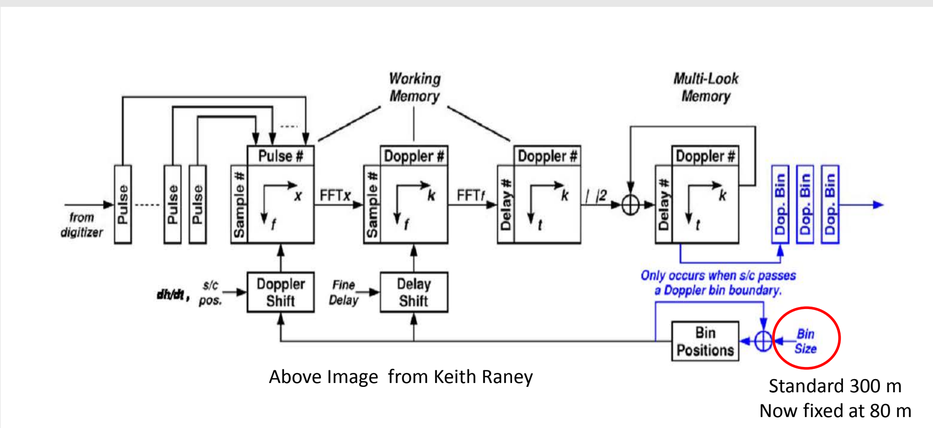

**The ground cells are localized on river banks: potentially we miss to observe the river cross center....**




**Now, we steer the Doppler beams at the river cross center: a new measurement exactly at river cross center is now achieved !**

## THE SPACE RESOLUTION IS IDENTICAL!

It is important to pinpoint that in this process, the space resolution is not **altered**: the theoretical resolution keeps to value around 300 meters; what we are changing is the **space sampling grid**; in all the Delay-Doppler scheme, the only change that we make regards the grid bin size.

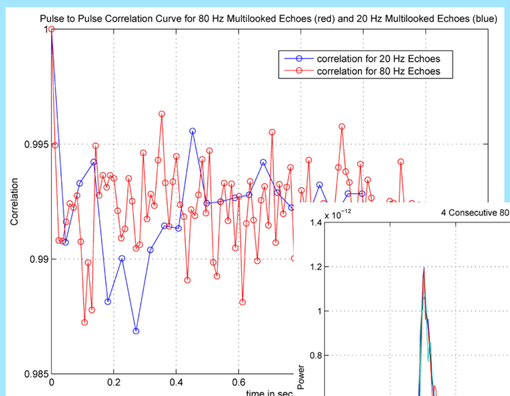


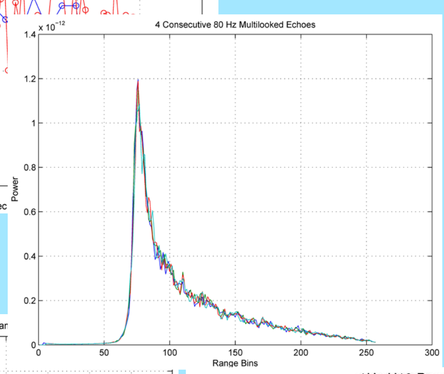

Above Image from Keith Raney

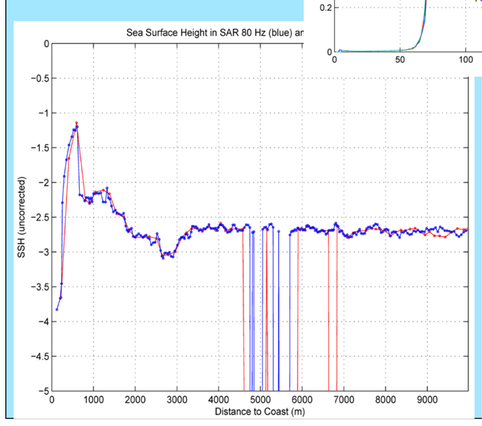
In the Delay-Doppler Scheme, the only change that we operate regards the grid bin size: **WE DONT CHANGE THE THEORETICAL ALONG TRACK RESOLUTION, ONLY THE GRID STEP SIZE!**

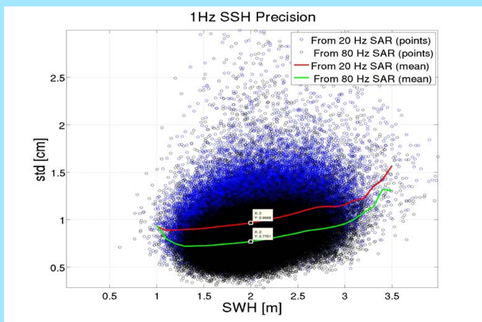
## Enhancement over Coastal Zone and Open Sea

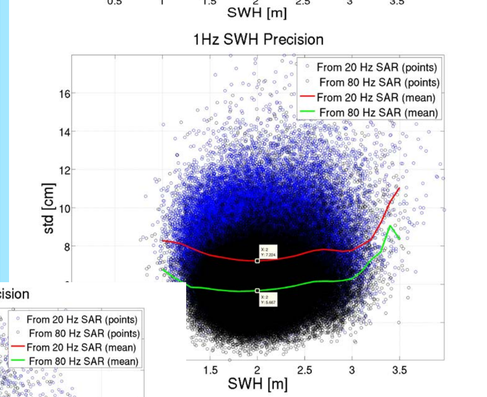
Over open sea, we re-track the SAR Multilooked Echoes at 80 Hz using the SAMOSA Model and then we generate the altimetric geophysical parameters (Sea Level Height, Significant Wave Height and Wind Speed) at 80 Hz.
Therefore, what we are realizing is to carry out a sub-pixel re-tracking of the SAR Echoes (i.e. retracking SAR echoes at 80 m whereas the SAR space resolution is 300 m in along track direction).
This is in continuity with Pulse-limited (LRM) altimetry wherein the retracking is operated at 20 Hz (300 m) whereas the instrument resolution (pulse-limited circle) is varying between 1.5-7 km (5Hz-1 Hz) (exact value depending on the sea state).
The multi-looked SAR Echoes generated at 80 Hz are still partially uncorrelated (that means that averaging them allows to knock down the speckle noise.. See the top left picture in this box).
After generating the Echoes at 80 Hz, the geophysical parameters (Sea Level Height, Significant Wave Height and Wind Speed) are downscaled at 20 Hz, applying a simple average of 4 consecutive values; subsequently, having generated the geo-parameters at 20 Hz , the standard statistics are calculated on this 20 Hz dataset (performance curves and scatter plot).
Over open sea, a 25% of improvement in term of noise is obtained for all the geo-physical parameters wrt 20 Hz case.

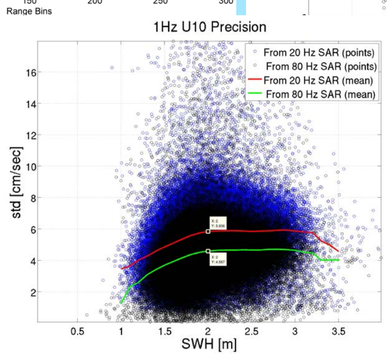


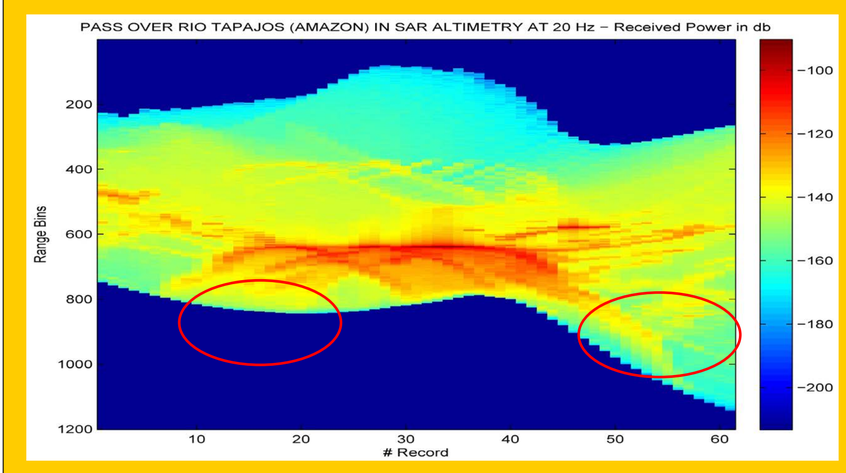



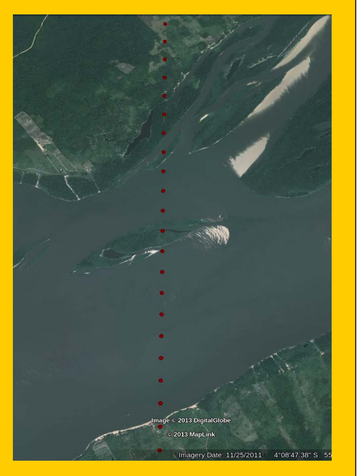



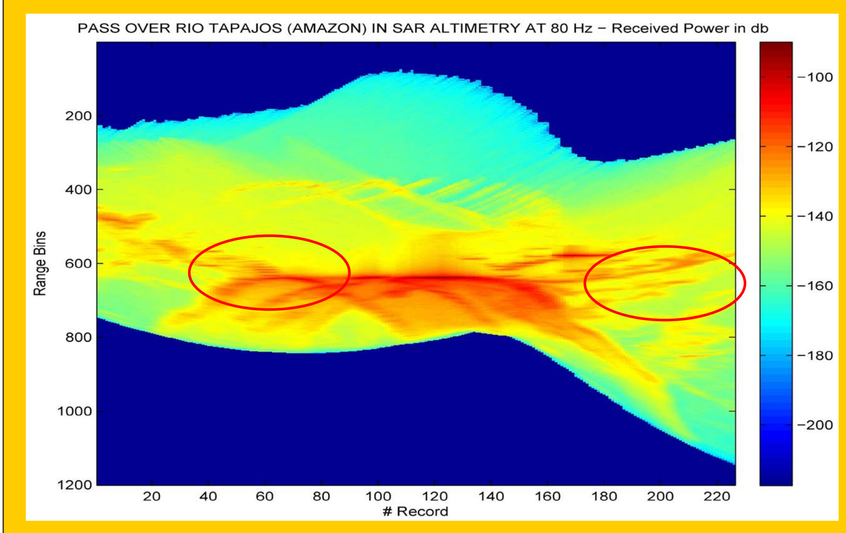



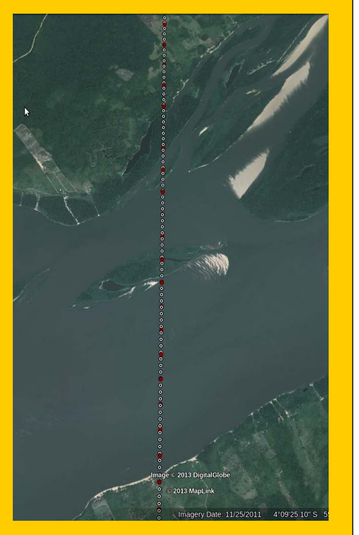

## Passes over Rio Tapajos (Amazon)



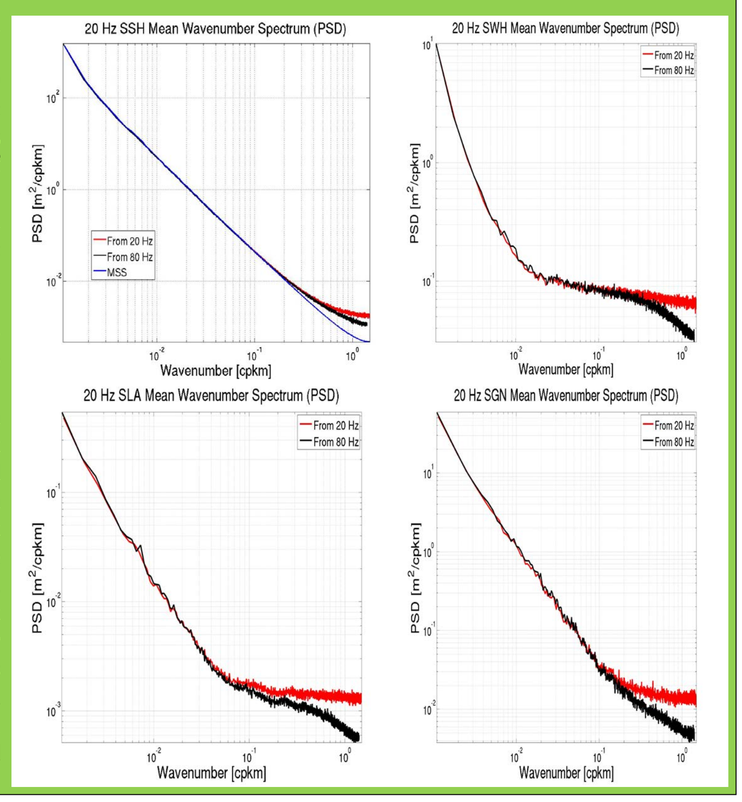



**On left, the radar image (Radar Echogram) for the Rio Tapajos River Cross at standard 300 m grid step, on right the gridding over the river cross (red points)**



**On left, the radar image (Radar Echogram) for the Rio Tapajos River Cross at finer 80 m grid step, on right the finer gridding over the river cross (white points)... the enhanced sharpness of the radar image is striking !!!**

## Wave Number spectra and Final Words

The open sea averaged wave number spectra have been computed for three months (2014/1 to 2014/3) in the south east pacific box at 20 Hz and 80 Hz. The spectra confirm that the SSH, SWH and U1o when generated at 80 Hz and averaged to 20 Hz exhibit lower level of noise with respect to data generated at 20 Hz.
In building the spectra, an operation of data editing has been applied so to that all the contaminated data have been ruled out from spectral analysis.
The concept to Delay-Doppler process CryoSat-2 data at finer space grid step is quite promising. The 80 Hz SAR Radar Echogram image on river crosses or coastal zone to sea transitions appear to be sharper than in SAR at 20 Hz; more subtleties become visible and distinguishable. Sea Surface Height and Sigma zero plots (approaching the coast) show that now is possible to detect more short scale features in coastal zone and closer to the coast.
The exploitation of the 80 Hz SAR Data at finer grid step is also very encouraging over open sea where a range noise of 0.75 cm is now achieved ( whereas it was 0.95 cm in SAR at 20 Hz) and wave number spectra confirm the improvement for all the geo-physical parameters.