Separation of Coherent and Incoherent Scattering Components from Delay/Doppler Altimeter Waveforms

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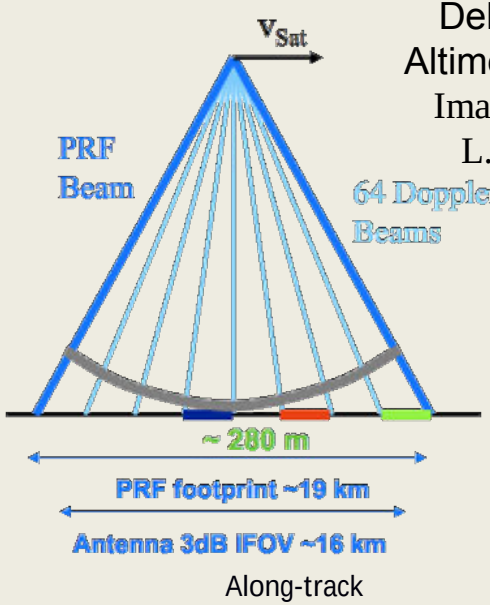
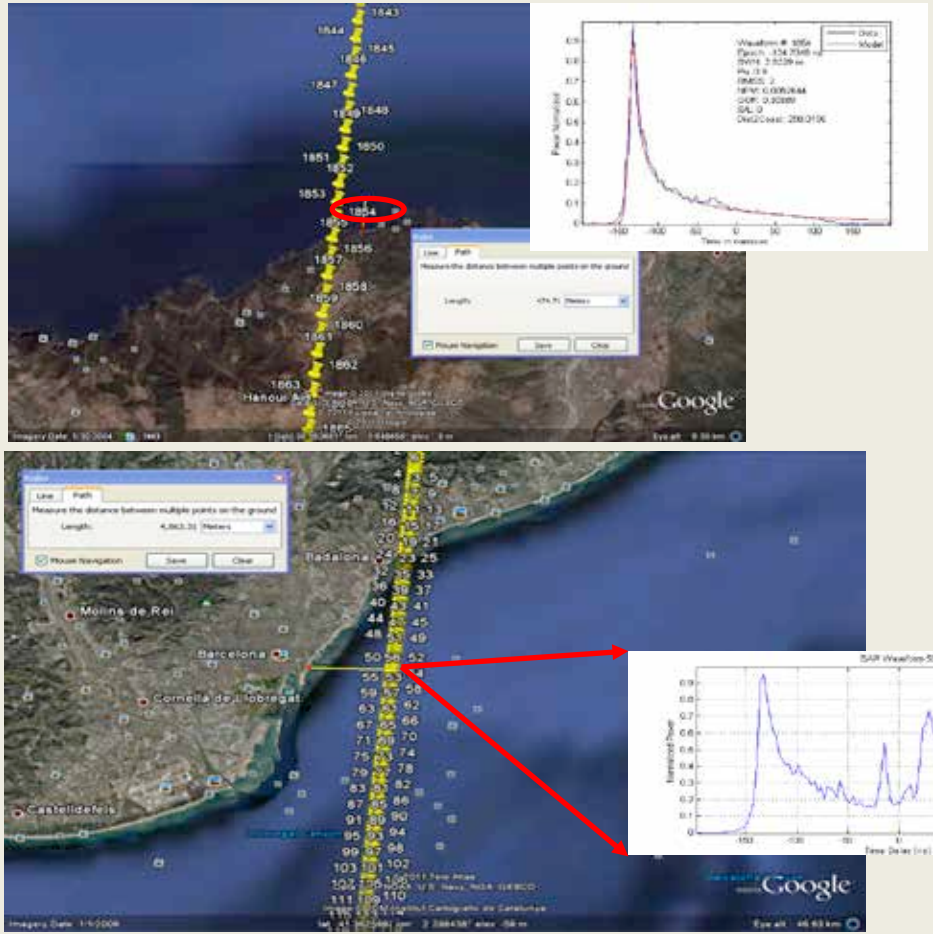
Introduction

The problem of Land Contamination in the DDA



Delay-Doppler Altimeter Concept. Image Courtesy: L. Phalippou

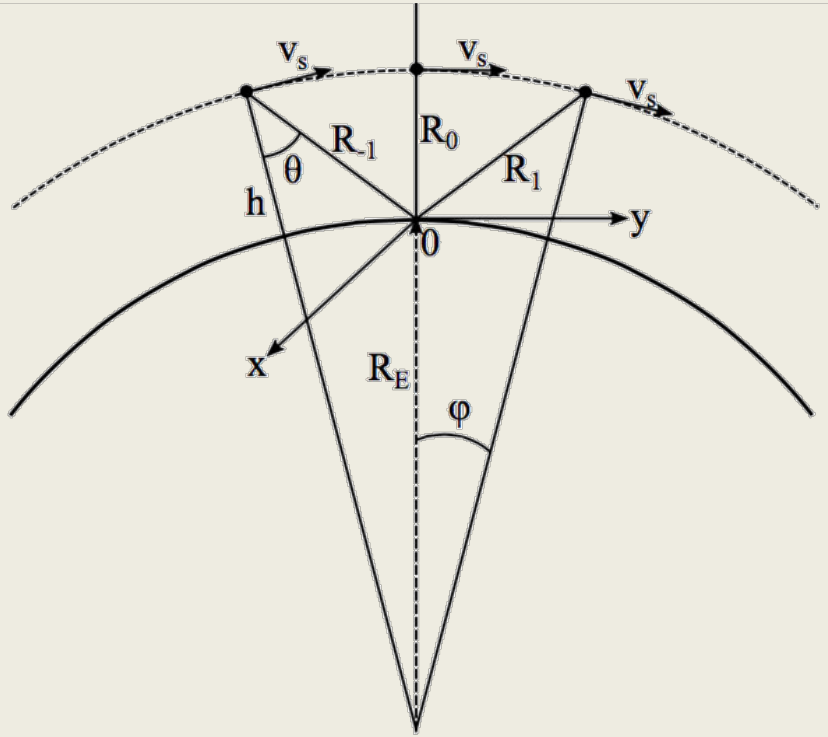
Delay-Doppler Altimeter Footprint. Image Courtesy: K. Raney



Images Courtesy: S. Dinardo, ESA

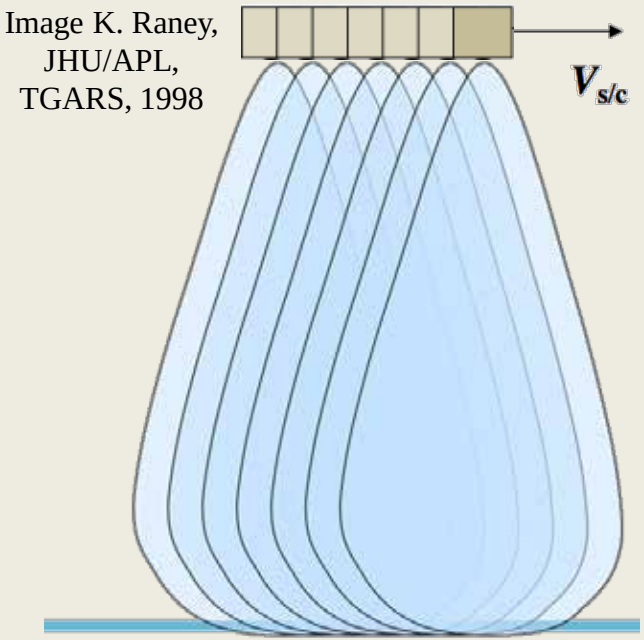
Separation of Land/Sea Scattering Components

- Land contamination is likely to occur from static coherent targets.
- On the contrary, the sea is essentially a distributed incoherent target (and it's moving!) à It decorrelates along time
- To separate both scattering components we proposed to use a fully-focused Synthetic Aperture Radar (SAR) processing technique, to single out the coherent components and then remove them from the unfocussed SAR delay-Doppler Altimeter Waveforms
- Fully focused SAR aims to combine *coherently* the response of a single point on the surface during its entire illumination time ~ 2 seconds
  - Achievable along-track resolution ~ L/2



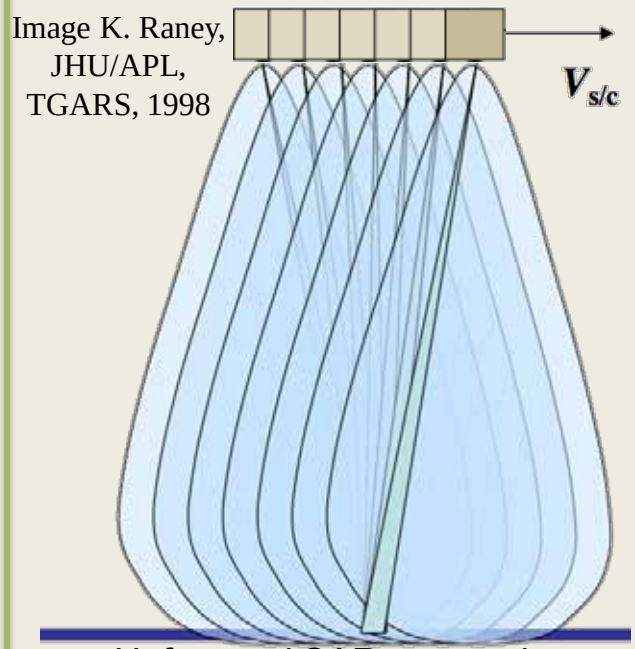
From Conventional to Focused SAR Altimetry

Conventional Altimeter



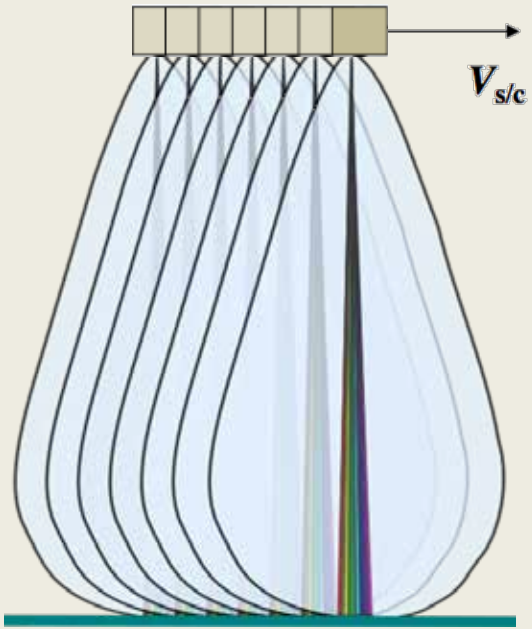
- Low Resolution Mode
- Pulse limited footprint (circular)
- 1.5 / 5 km resolution depending on SWH
- Open burst operation
- PRF ~ 2 kHz

Delay-Doppler Altimeter



- Unfocused SAR processing
- ~300 m resolution Along-Track
- Pulse limited across-track
- Closed Burst
- PRF ~ 18 KHz

Focused SAR Altimeter

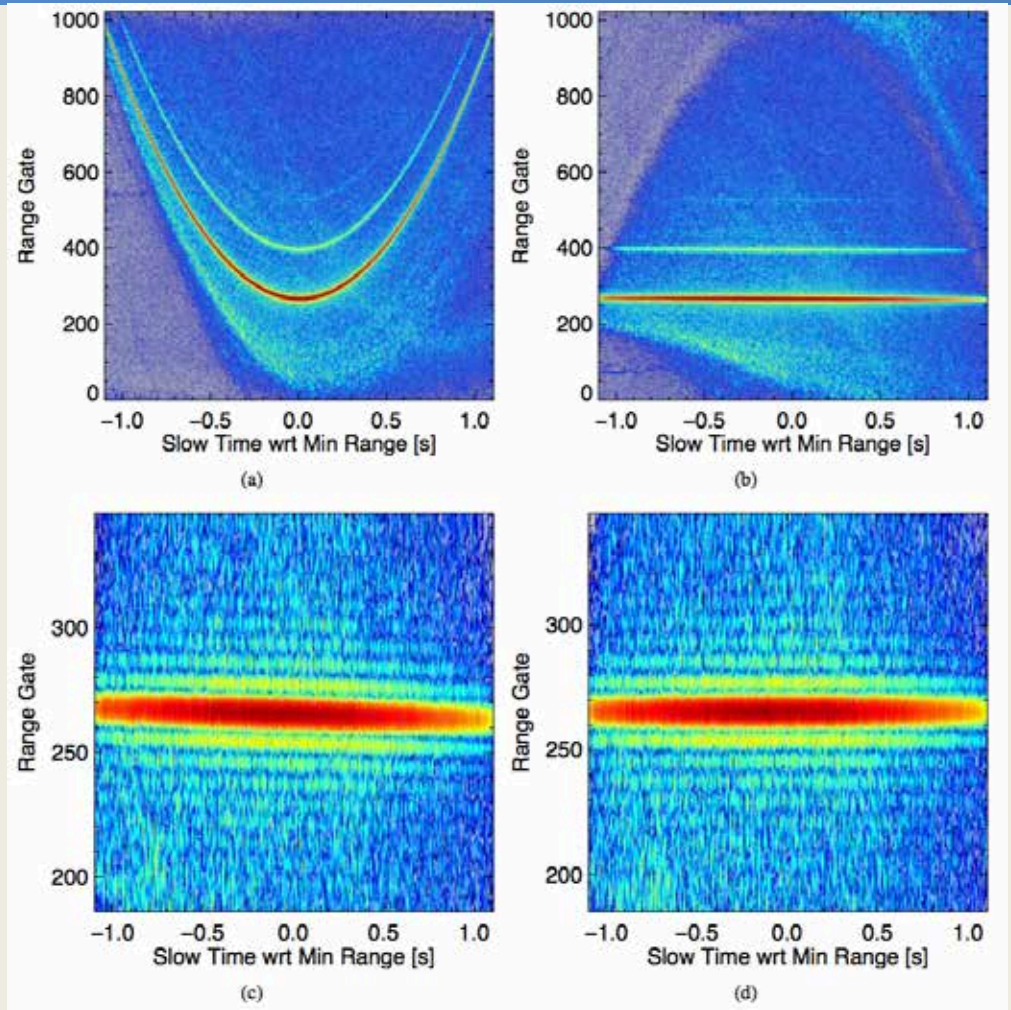


- Fully Focused SAR processing
  Coherent processing for ~2 seconds
- Resolution Along-Track ~ 0.5
- Pulse limited across-track
- Closed Burst
- PRF ~ 18 KHz

Focused SAR Altimetry Processing (i)

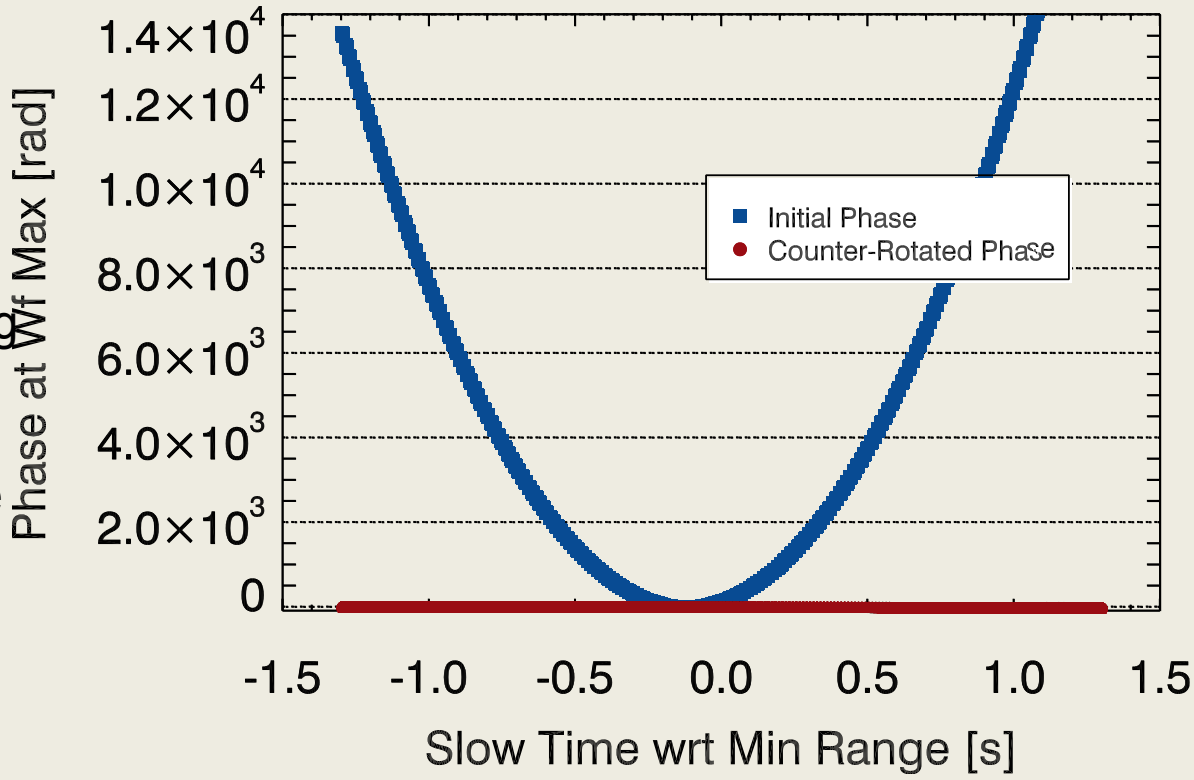
- The development of the focused SAR Altimetry processing technique was done based on CryoSat-2 Baseline-B transponder over passes.
- Processing based on back-projection SAR processing algorithm

- Image: Range Cell Migration
  - (a) Original FBR Radargram
  - (b) Range-Cell Migrated Stack
  - (c) Range-Cell Migrated Stack
  - (c) range-Doppler correction



Focused SAR Altimetry Processing (ii)

- The coherent processing implies that not only the power echoes need to be perfectly aligned…but also the phase!
- Errors of 0.5 cm in the position of the satellite during the whole 2 seconds of illumination time could destroy the coherency of the signal…
- Need to compensate for:
  - Platform Motion
  - Time-tagging errors
  - Inter-burst phase variation
  - Tracking variations
  - …



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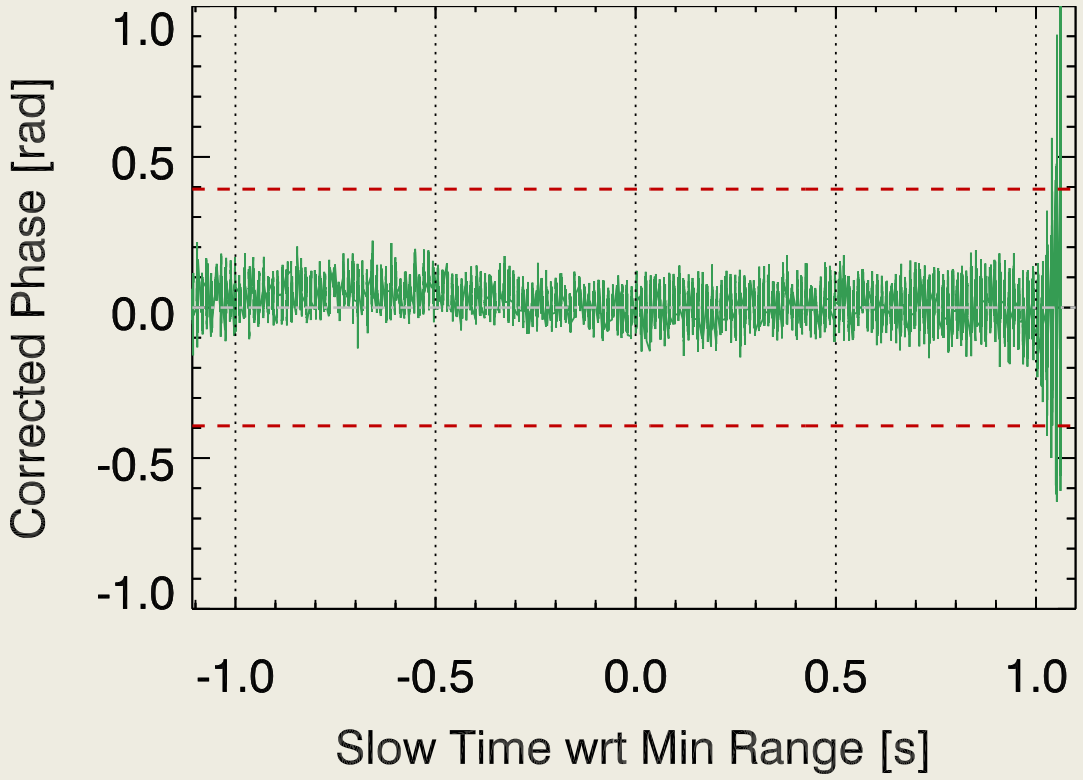


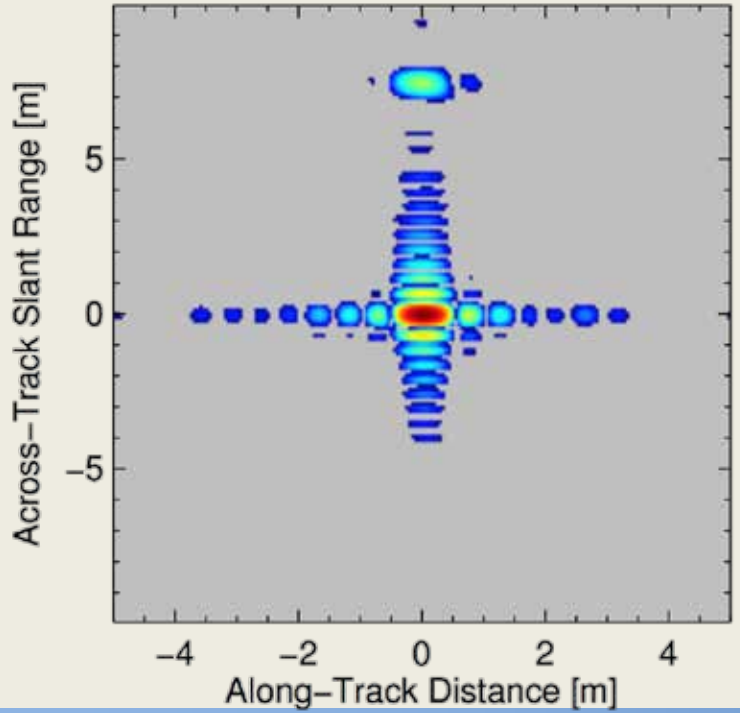
Phase std along aperture

~= 3 deg à 0.2 mm!

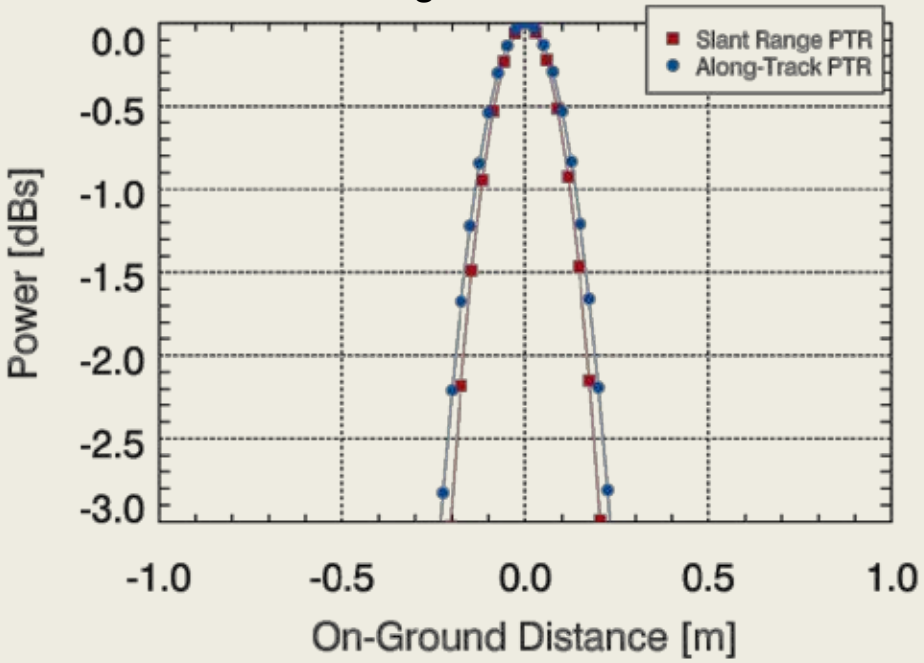
Focused SAR Altimetry Processing (iv)

- SAR Image formation:
  - Focusing along successive points on the track
  - Slant-range and Along-track resolution equal to theoretical values: ~0.5 m !
- Multi-looking of the single looks could be performed in a later stage

2D SAR Point Target Response

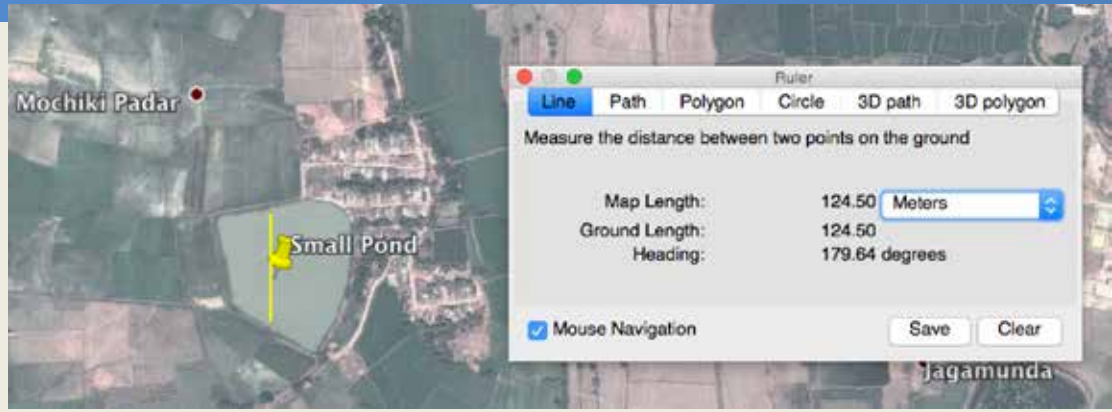


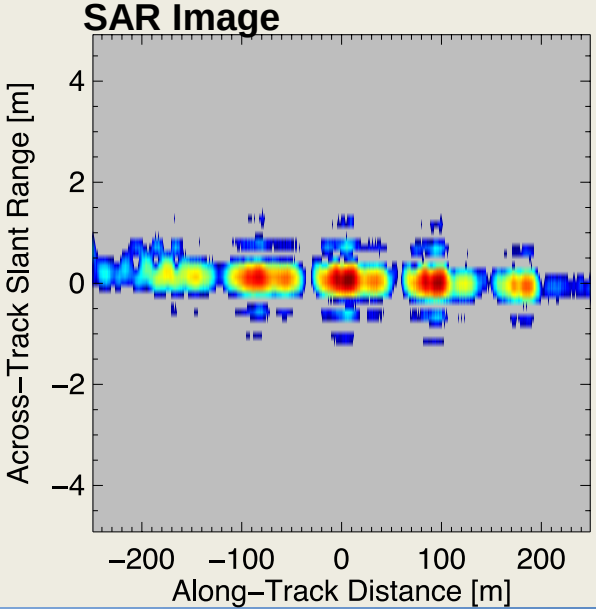
Across-Track and Along-Track Cuts

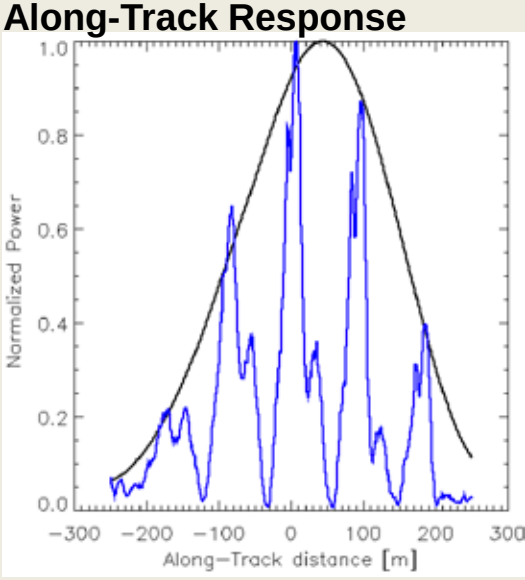


Focusing on real Targets

- Small pond in India
  - Calm in-land water body
  - Along-track size < delay-Doppler Resolution
- The pond is clearly resolved in focused SAR Image
- Multiple Impulse responses (ghosts images) due to closed burst operation
- Along-track response could be improved by deconvolution techniques
- Direct application on hydrology & sea-ice (leads) determination

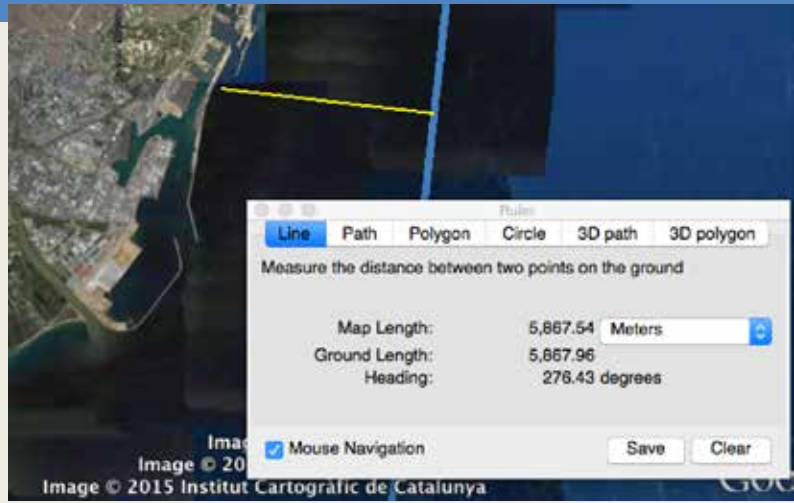


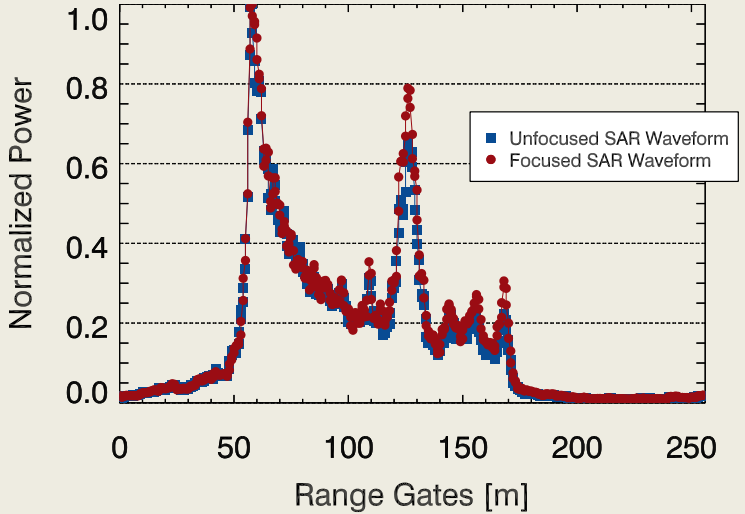




Separation of Scattering Components

- Fully Focused SAR and delay-Doppler processing applied on track off the coast of Barcelona, Catalonia, Spain
- Both waveforms show similar behavior even though they have been processed in very different ways
  - Unfocused SAR and multilooking over 1 stack
  - Focused SAR and multilooking of 160 looks over 80 m
- Despite the coherent focusing for 2 seconds the sea return is still present in the waveform…
- We could not achieve the separation of coherent and incoherent scattering components…
- …but why?
  - Shouldn't the surface of the ocean decorrelate after 2 seconds?
  - Could this actually be used to measure the ocean surface?
  - What is the performance of the fully focused SAR Altimeter over the ocean?

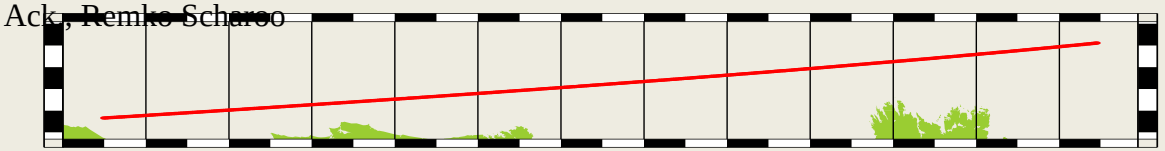


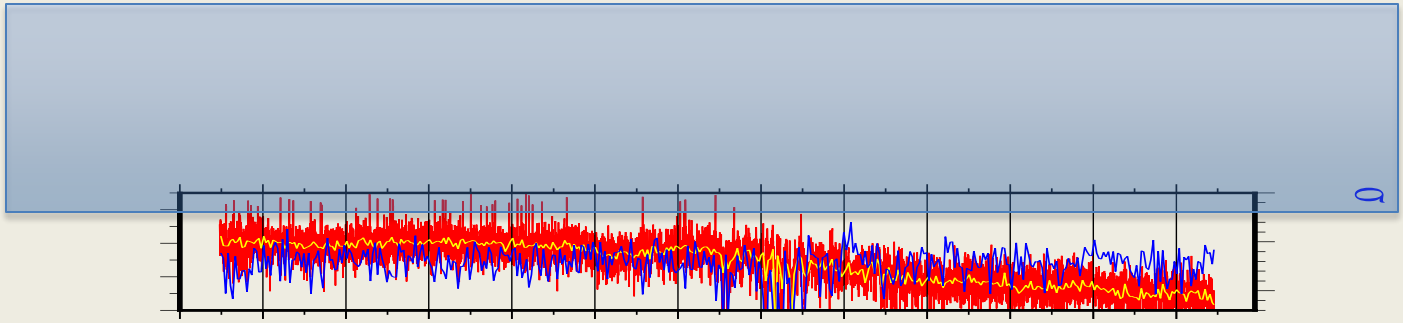


Focusing on the Ocean (i)

Performance Evaluation

- Analysis on SAR track over the North East Atlantic
- Long track with diverse SWH and wind conditions
- Concentrate on region with stable SWH ~2m for performance evaluation

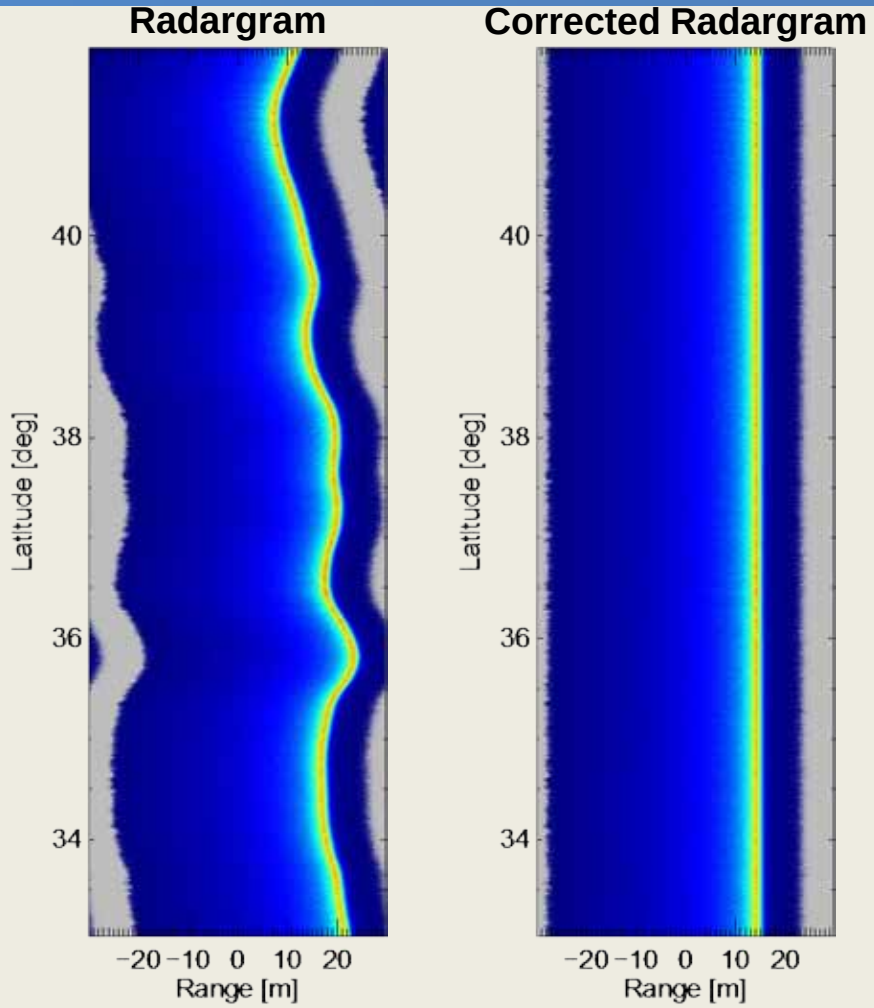




Focusing on the Ocean (ii)

Performance Evaluation – Equivalent Number of Looks

- Comparison of focused SAR vs DDA:
  - Focused SAR
    - Coherent processing = 2 seconds à 0.5 meters along track resolution
    - Multi-looked waveforms @ 80 Hz
  - Unfocused DDA
    - 181 Looks Along-track
    - Multi-looked waveforms @ 20 Hz (standard ESA product)
- Equivalent Number of Looks @ 1 Hz:
  - Radargrams centered to a common reference
  - Delta-Range removed from waveforms
- Retracking performed with full SAMOSA model taylored for each processing

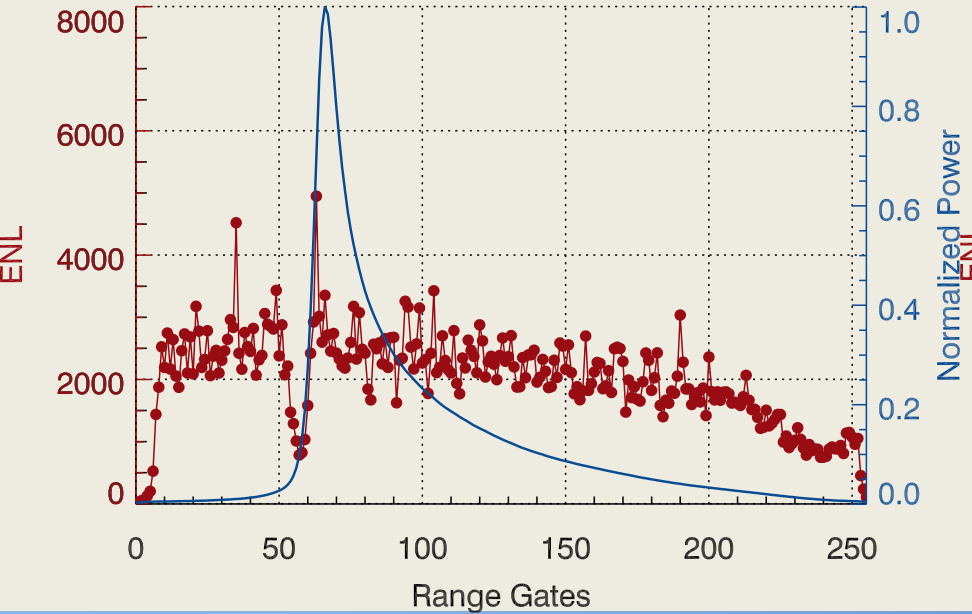


Focusing on the Ocean (ii)

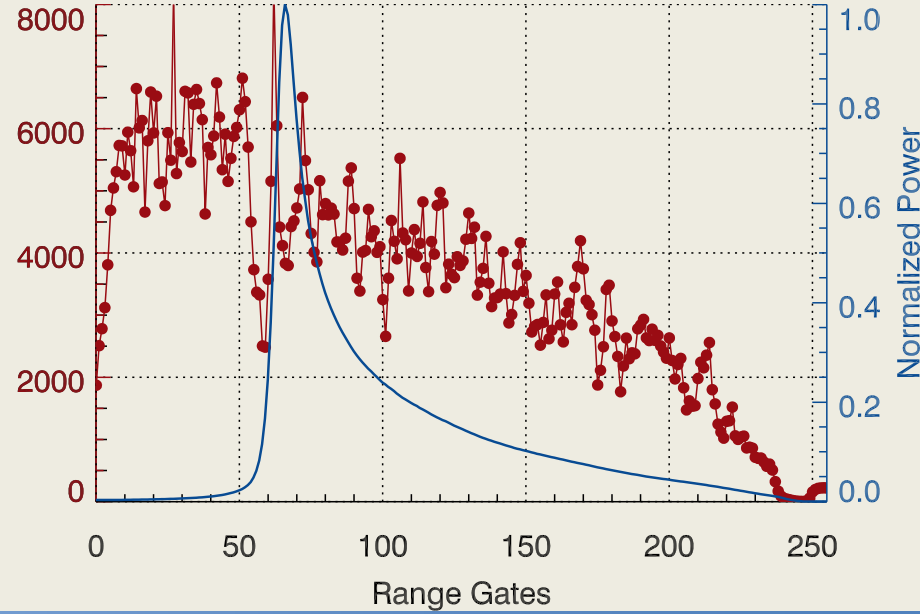
Performance Evaluation – Equivalent Number of Looks

- Equivalent Number of Looks computation
  - Averaged waveforms computed @ 1Hz
  - Noise computed out of 100 1Hz Averaged Wfs
- Focused SAR processing shows a significant improvement with respect to the delay/Doppler processing @ 20 Hz à Improvement in final SNR and speckle reduction

Delay/Doppler ENL @ 1Hz



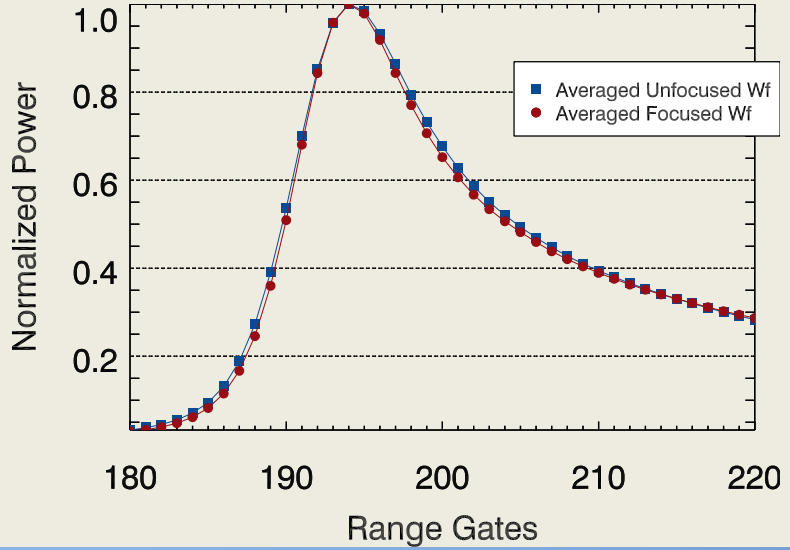
Focused SAR ENL @ 1Hz

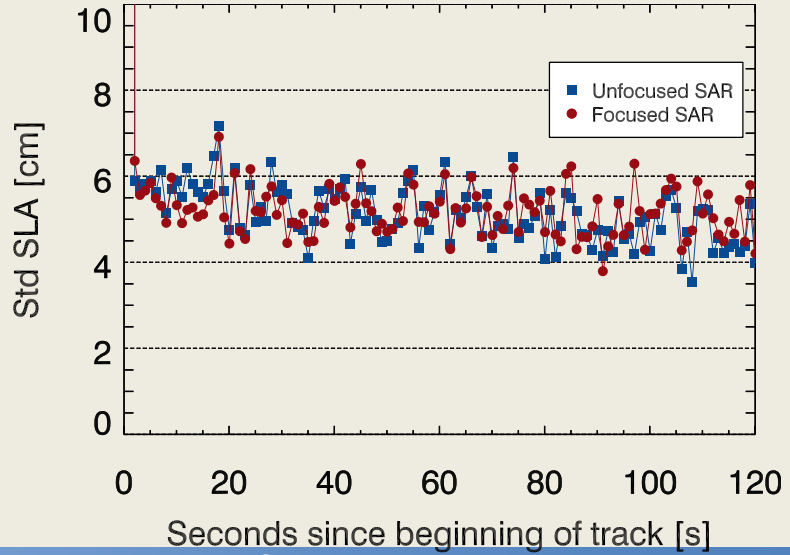


Focusing on the Ocean (iii)

Performance Evaluation – Geophysical Parameter Estimation

- Retracking with full SAMOSA model
- Averaged Focused SAR waveforms is slightly narrower than delay/Doppler waveform around the leading edge à Improvement in retracking (?)
- SLA noise:
  - DDA SLA noise ~ 5 cm @ 20 Hz à 1 cm @ 1Hz
  - Focused SAR noise ~ 5 cm @ 80 Hz! à 0.X ? cm @ 1Hz
    - If measurements are absolutely independent this could mean 0.5 cm @ 1Hz!





Conclusions

- Development of both unfocused delay/Doppler and fully focused SAR L1 processor
  - Measured along-track resolution in agreement with theoretical expectations, i.e. ~0.5 meters (SAR)
  - Direct application on hydrology and sea-ice/leads studies
- The coherent and incoherent scattering components could not be separated due to the presence of strong reflection from the ocean.
- In fact, the ocean remains coherent for a certain amount of time, which allows focusing on the ocean surface.
- The focused SAR multi-looked waveforms @ 1 Hz show an increase in the ENL by a factor of 2 with respect the “conventional” delay/Doppler processing (20 Hz processing)
- The focused SAR geophysical parameters noise @ 84 Hz is equivalent to the delay/Doppler noise @ 20 Hz.
  - Improvement by a factor of 2 (possible), $\sqrt{2}$ (conservative) @ 1Hz wrt DDA:
    - SLA noise @ 1Hz around 0.7cm (conservative); 0.5 cm (best case)…to be verified…
- Detailed description of technique soon in:

  Fully Focused SAR Altimetry: Theory and Applications; Egido & Smith, [in preparation]