→ 8th COASTAL ALTIMETRY WORKSHOP

23–24 October 2014 | Lake Constance | Germany

Geo-referencing of the Delay/Doppler Level-1 Stack with Application on Coastal Altimetry

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Introduction

- This work was performed within the framework of the LOTUS project (FP7), “Preparing Land and Ocean Take Up from Sentinel-3"
  - Project Partners: DTU, CLS, DHI, UNEW, Starlab

Special acknowledgement to Thomas Moreau (CLS) and Pierre Thibaut (CLS)

for providing the CryoSat L1-b Stack data used in this study

SAR Altimetry Concept

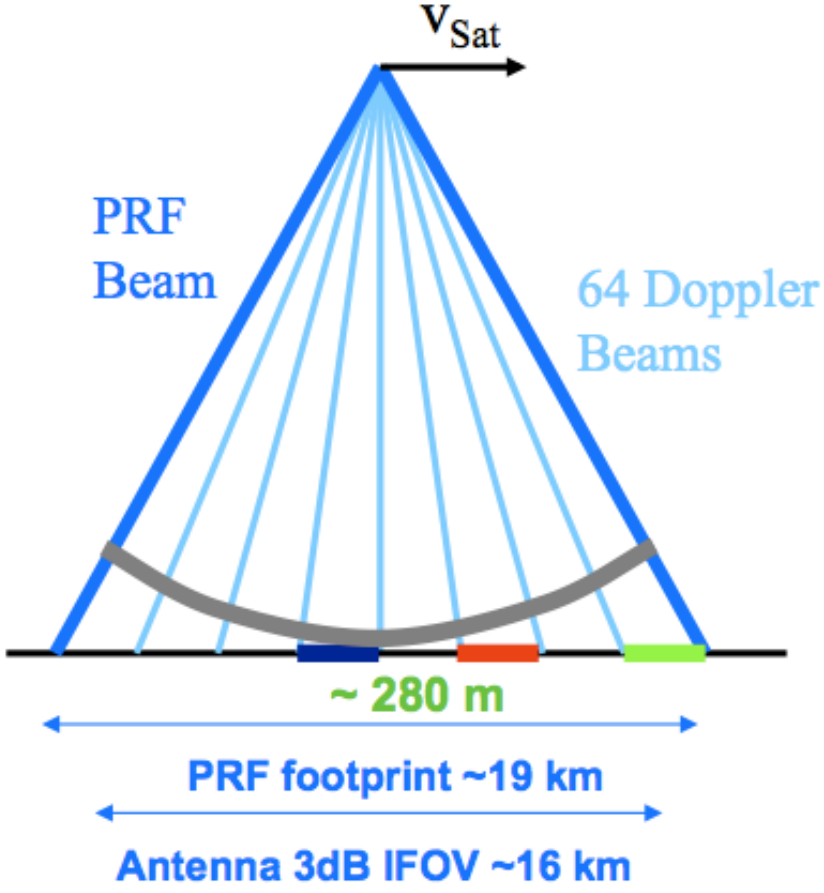
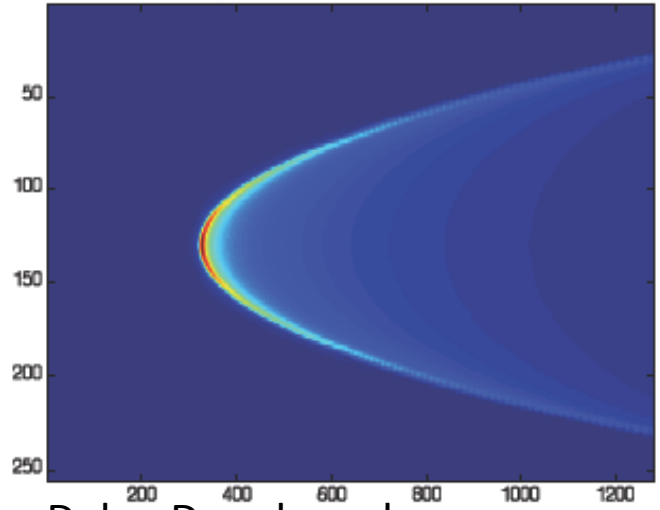


Image Courtesy: L. Phalippou, Thales-Alenia Space

Synthetic Aperture Radar Altimetry, or delay/Doppler altimeter

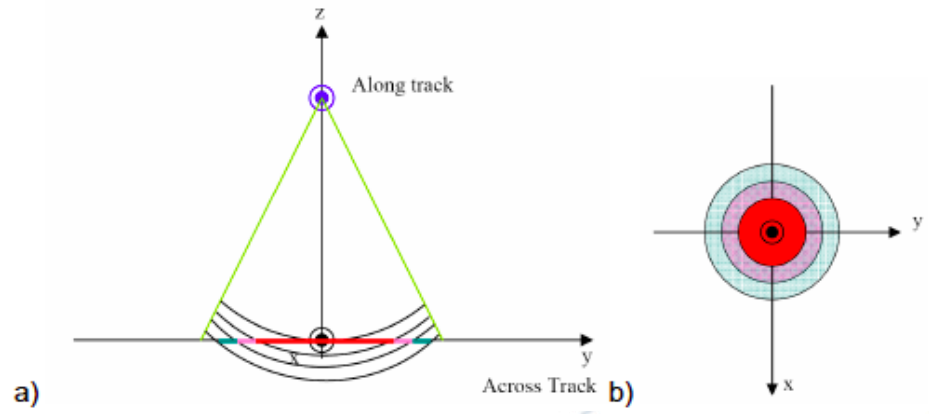
- Coherent processing of along-track radar echoes (unfocused SAR)
- Along-track resolution



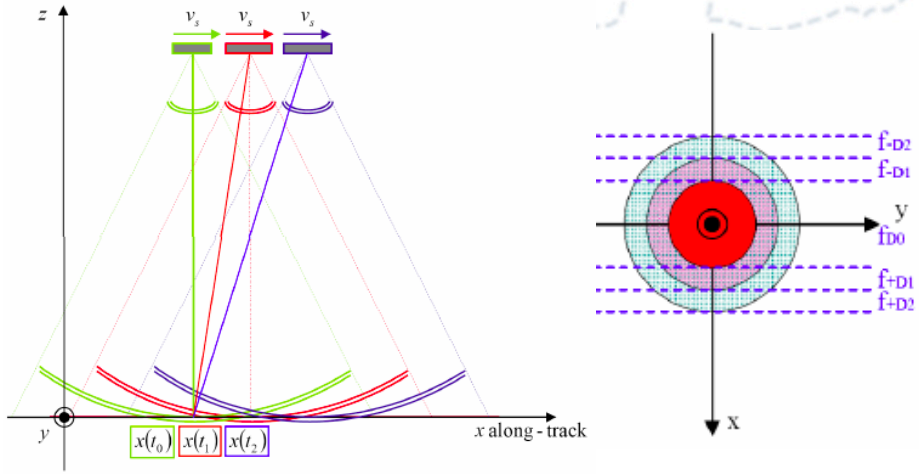
Delay-Doppler echo

LRM and SARM footprint dimension

- **LRM**
  - Pulse limited
    - Along- and across- track
  - E.g. RA-2 has a compressed pulse length in the order of ~ 3 ns →



- **SARM**
  - Along-track
    - Delay-Doppler processing (~ 300m)
  - Across-track
    - Same as RA-2



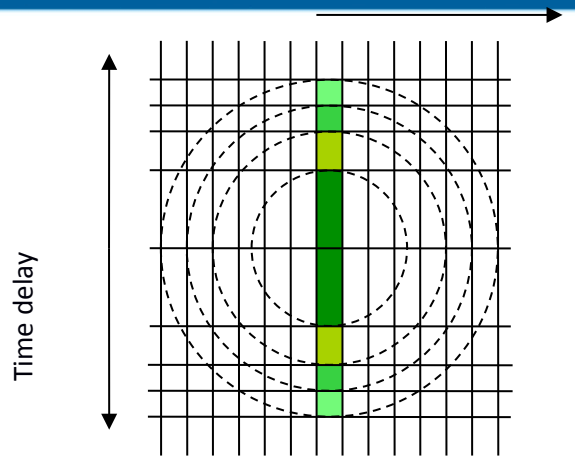
LRM and SARM products

- **LRM 20Hz**
  - Posting rate ~ 300m, not resolution ~ 300m!
  - 20Hz waveforms correspond to a footprint in the best case of ~ 1.7km + 300m
  - Since they correspond to LRM pulses incoherently integrated during 50ms
- **LRM 1Hz**
  - Posting rate ~7km
  - 1Hz waveforms correspond to a footprint of ~ 9Km
  - Since they correspond to LRM pulses incoherently integrated over 1 sec integration time
- **SARM 20Hz**
  - Posting rate and footprint resolution both ~ 300m!
  - Incoherent integration, in this case multi-look is done in the Delay-Doppler processor
  - 20 waveforms per record
- **SARM 1Hz**
  - Posting rate and resolution of ~ 7Km
  - 1 waveform per record

SAR Altimetry for Coastal Zones

SAR processing advantages in coastal areas

- Delay/Doppler altimeter improvements with respect to conventional altimetry:
  - Along-track resolution improvement
    - Capability to reach closer to the coast than conventional altimetry
  - Increased Signal to Noise Ratio:
    - Improved Sea Surface height, Wind Spee Significant wave height



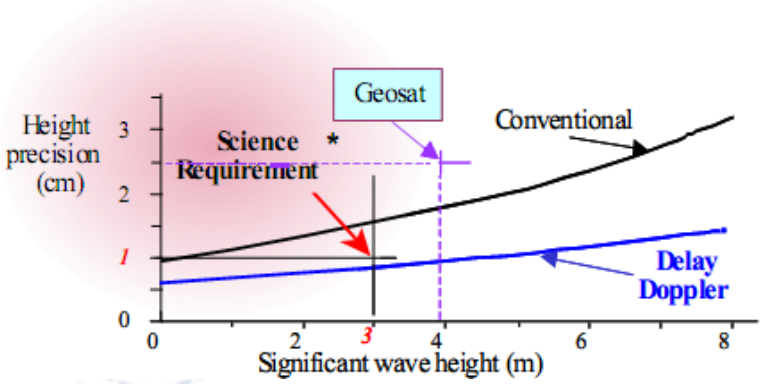
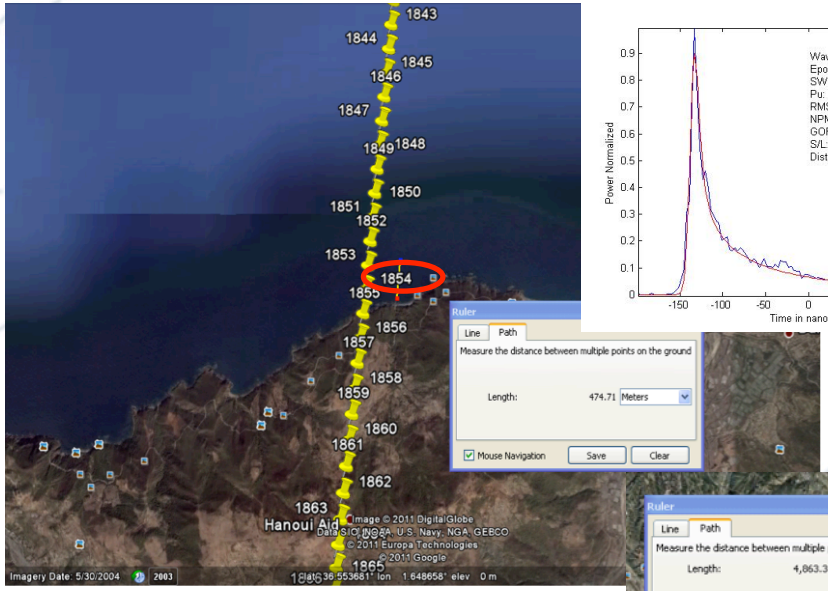
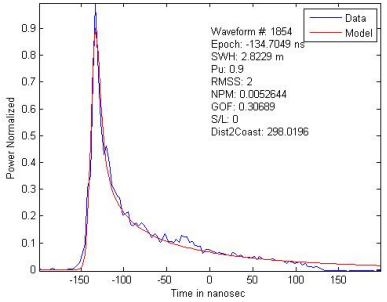
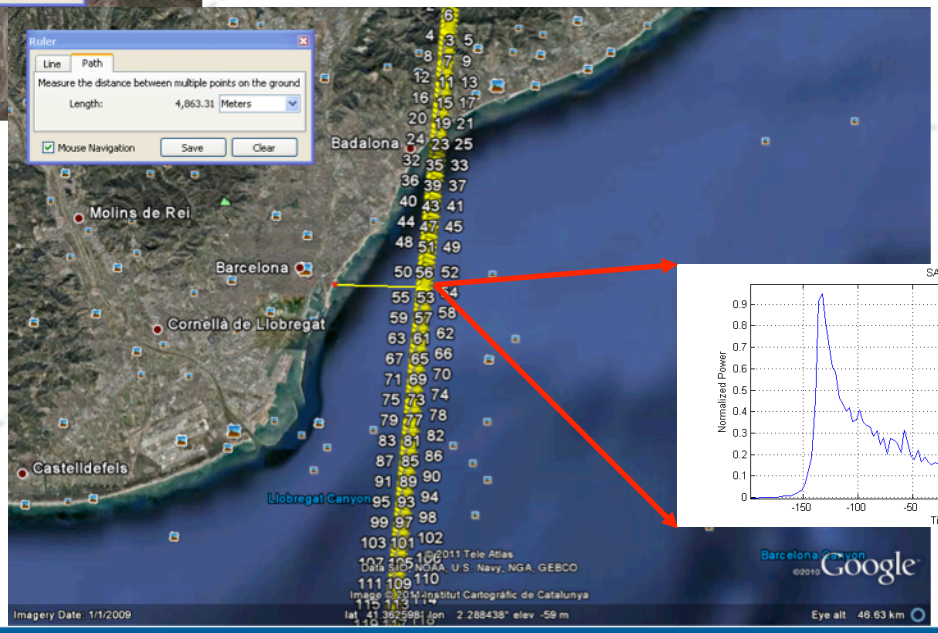


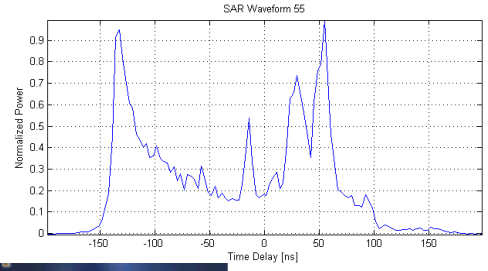
Image Courtesy: K. Raney, 2005



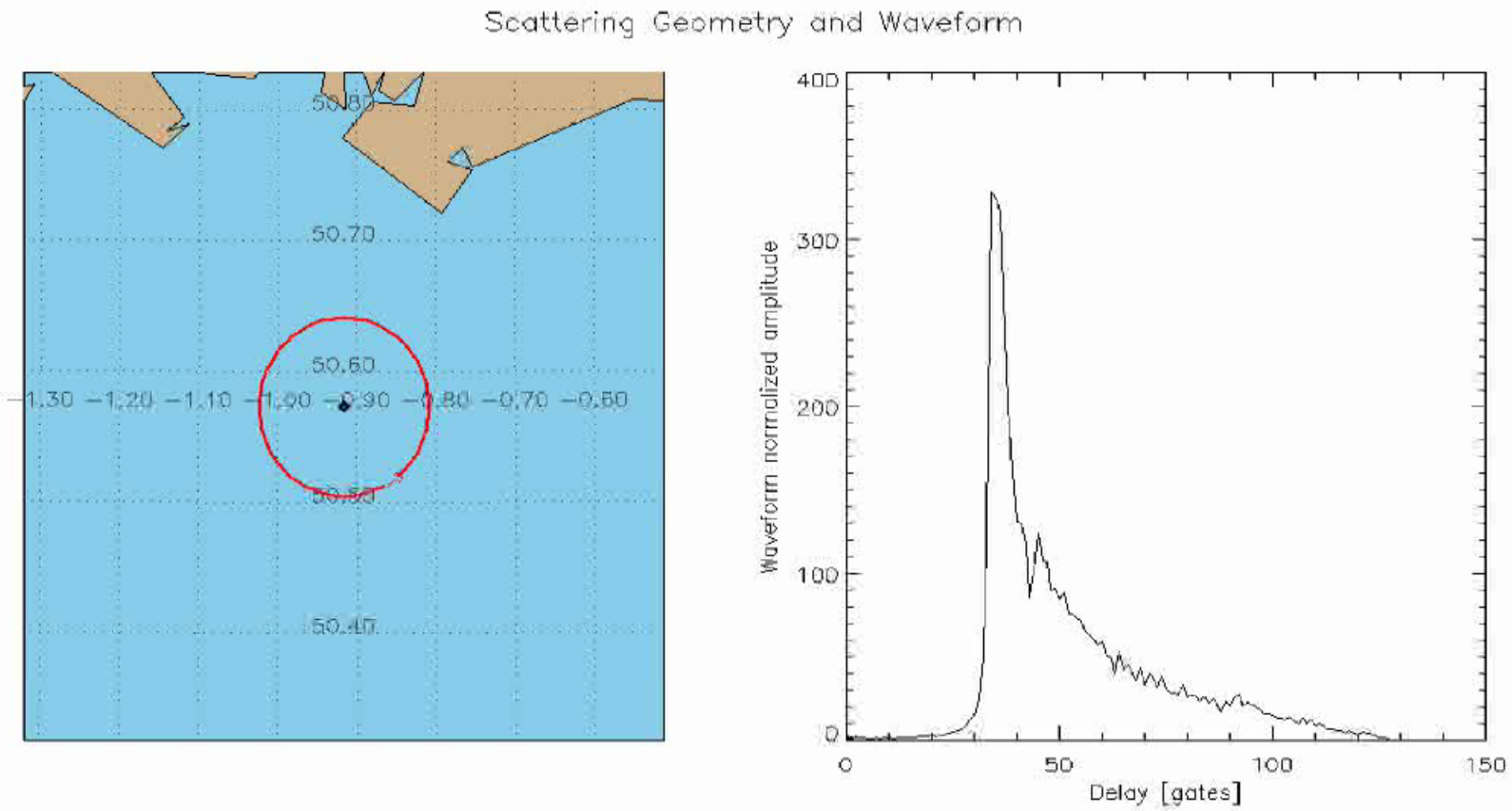


Images Courtesy: S. Dinardo, ESA





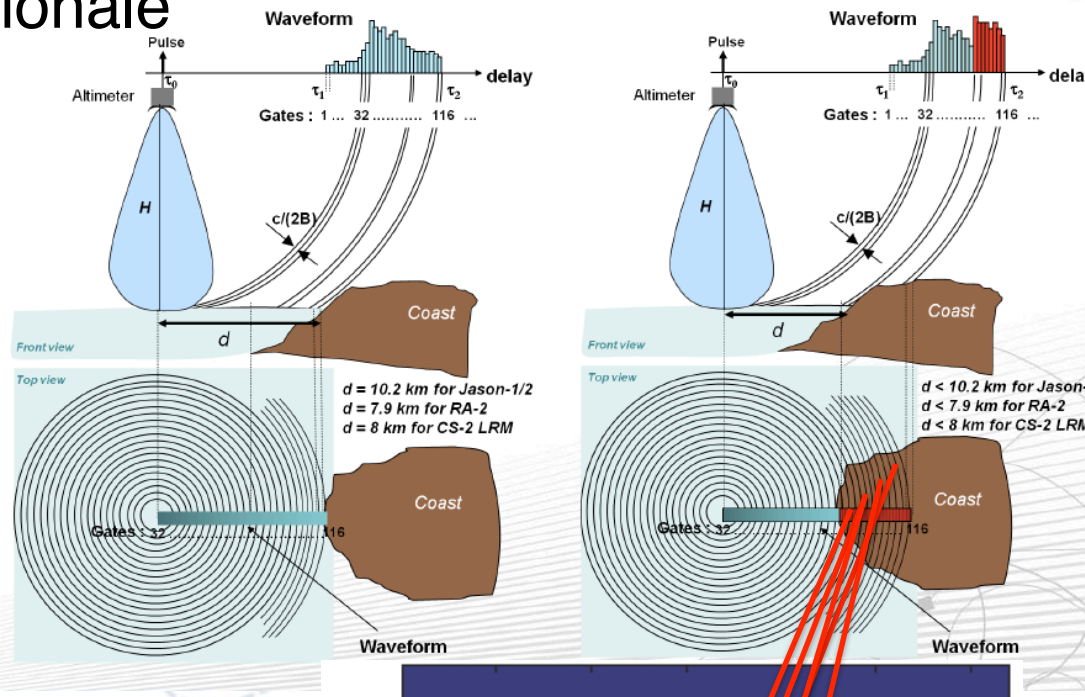
Scattering Geometry and Waveform

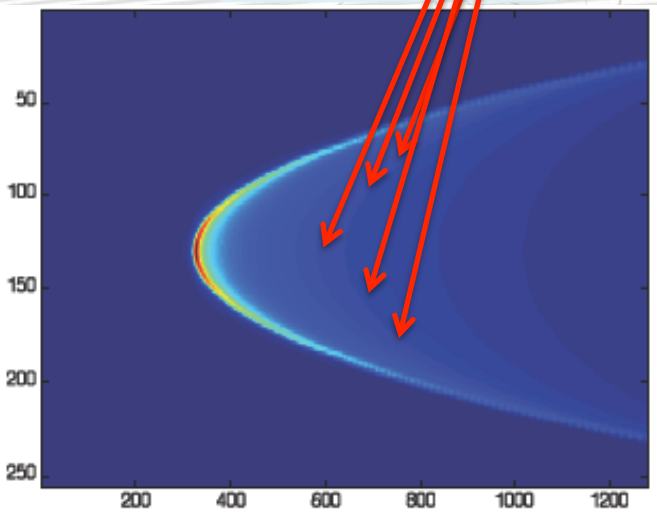


Coastal Zones Algorithm Rationale

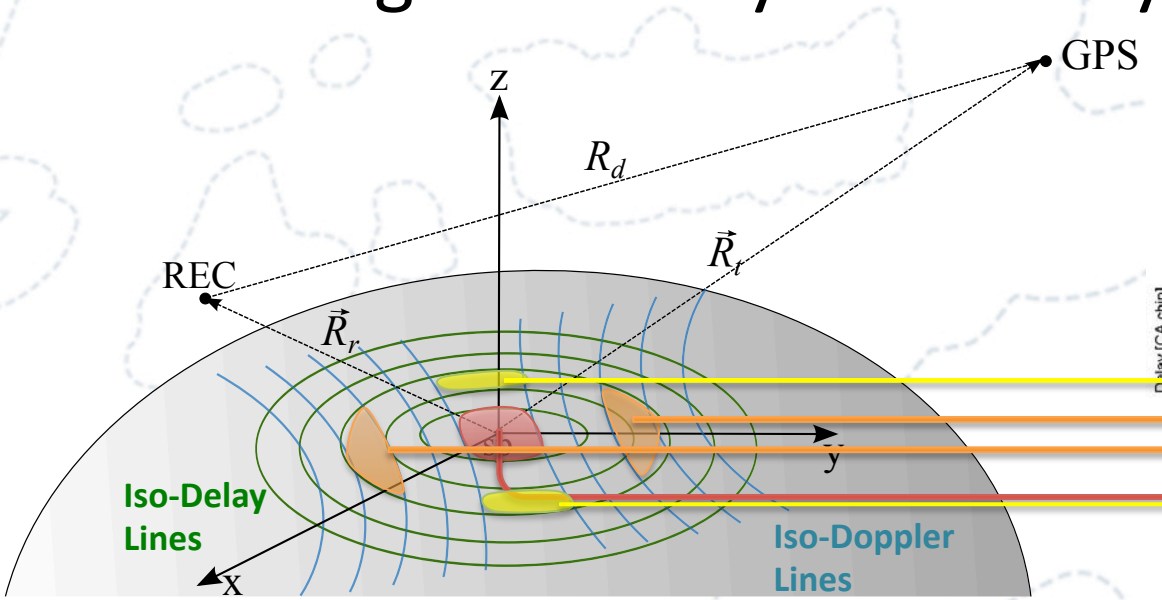
- Processing approach based on Stack analysis:
  - Delay/Doppler technique allows to generate a 2D map on the surface of backscattering response
  - Geo-referencing of Stack
- Apply Land mask to suppress delay/ Doppler bins potentially affected by land contamination effects
- Account for topography effect by means of Digital Elevation Model:
  - ASTER G-DEM
- Multilook on non-corrupted data
- SAR retracking algorithm

Image Courtesy: Pierre Thibaut, CLS

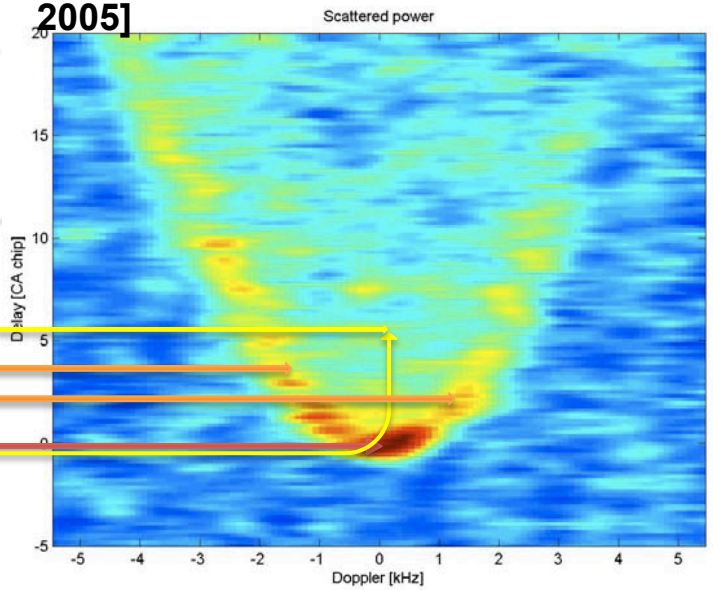




Scattering Geometry – iso delay/Doppler lines

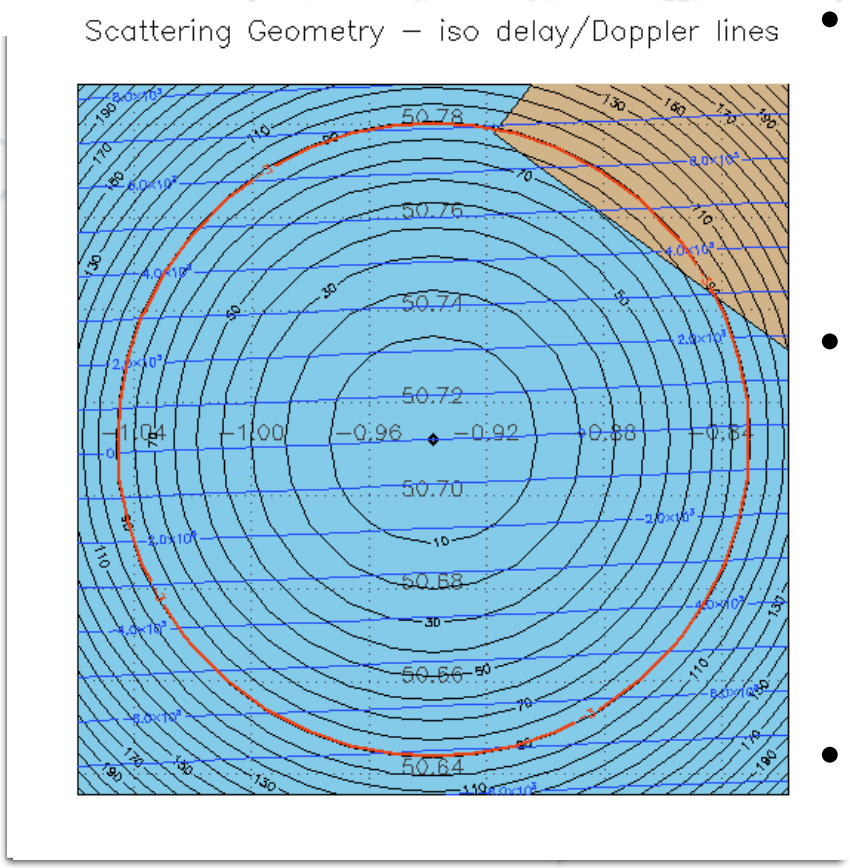


DDM from UK-DMC data, [Gleason, 2005]



- Bistatic scattering scenario
  - Nadir altimeter scenario is a particular case of this one…
- Different delay and Doppler bins define different regions on the surface
  - Delay/Doppler bins along the DDM ridge will be “loners”
  - Ambiguity for the points which area not on the ridge

Scattering Geometry – iso delay/Doppler lines



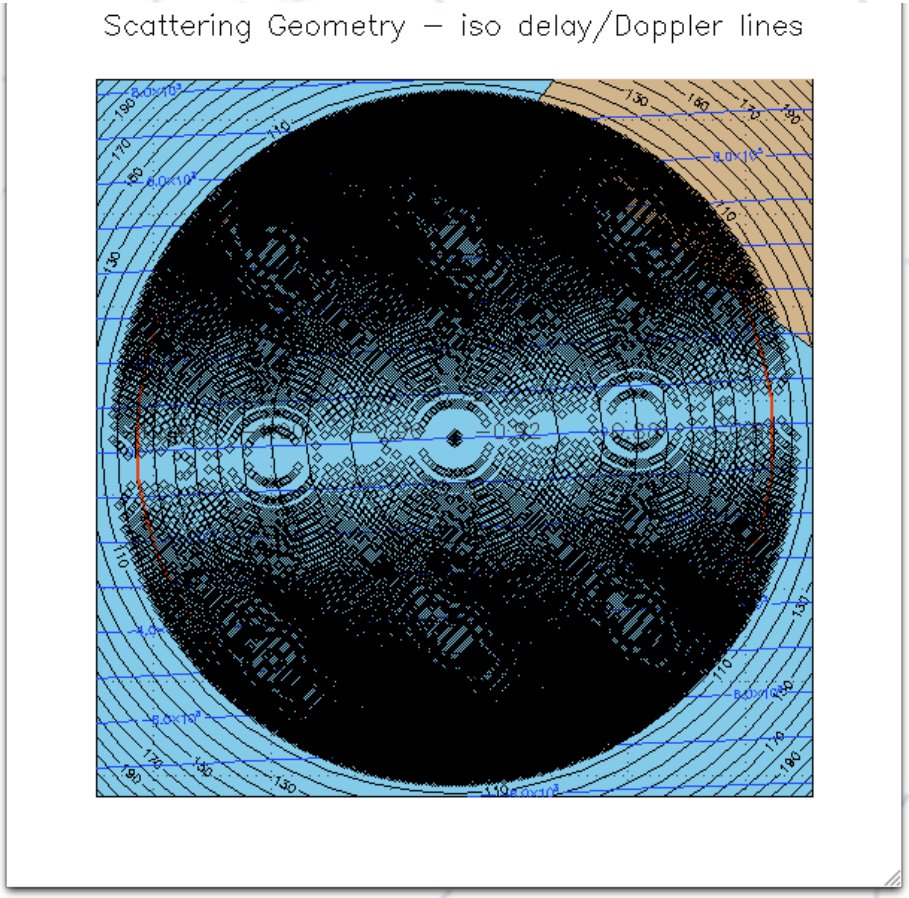
- Iso-delay/Doppler lines define locus of points on the surface with equal delay and Doppler with respect to the specular point
- Iso-delay lines define ellipses around the specular point (circumferences in the altimeter case):

$$\delta(\vec{\rho}) = R_0(\vec{\rho}) + R(\vec{\rho}) - (|\vec{R}_t| + |\vec{R}_r|)$$

- Iso-Doppler lines define hyperbolas:

$$f_D(\vec{\rho}) = (\vec{v}_t \cdot \hat{m}(\vec{\rho}) + \vec{v}_r \cdot \hat{n}(\vec{\rho}))/\lambda$$

Projection of DDM delay-Doppler Pairs on surface



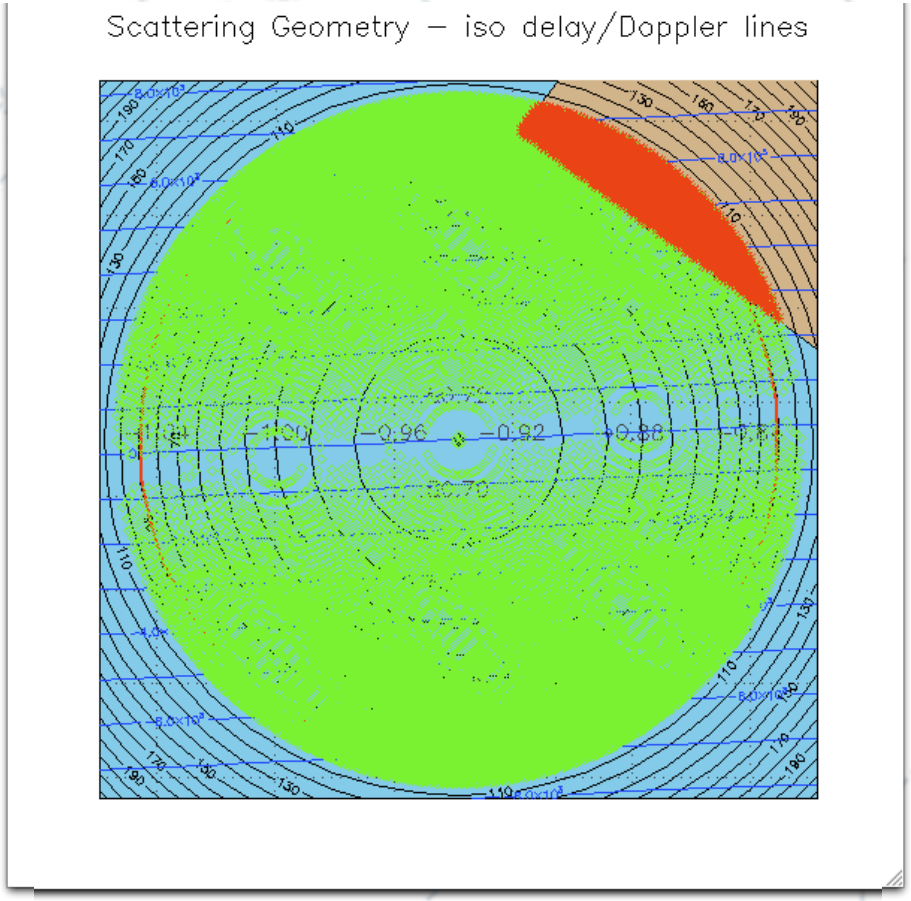
- Invertion of iso-Delay and iso-Doppler equations for each DDM doppler Pair:

$$\delta(\vec{\rho}) = R_0(\vec{\rho}) + R(\vec{\rho}) - (|\vec{R}_t| + |\vec{R}_r|)$$

$$f_D(\vec{\rho}) = (\vec{v_t} \cdot \hat{m}(\vec{\rho}) + \vec{v_r} \cdot \hat{n}(\vec{\rho}))/\lambda$$

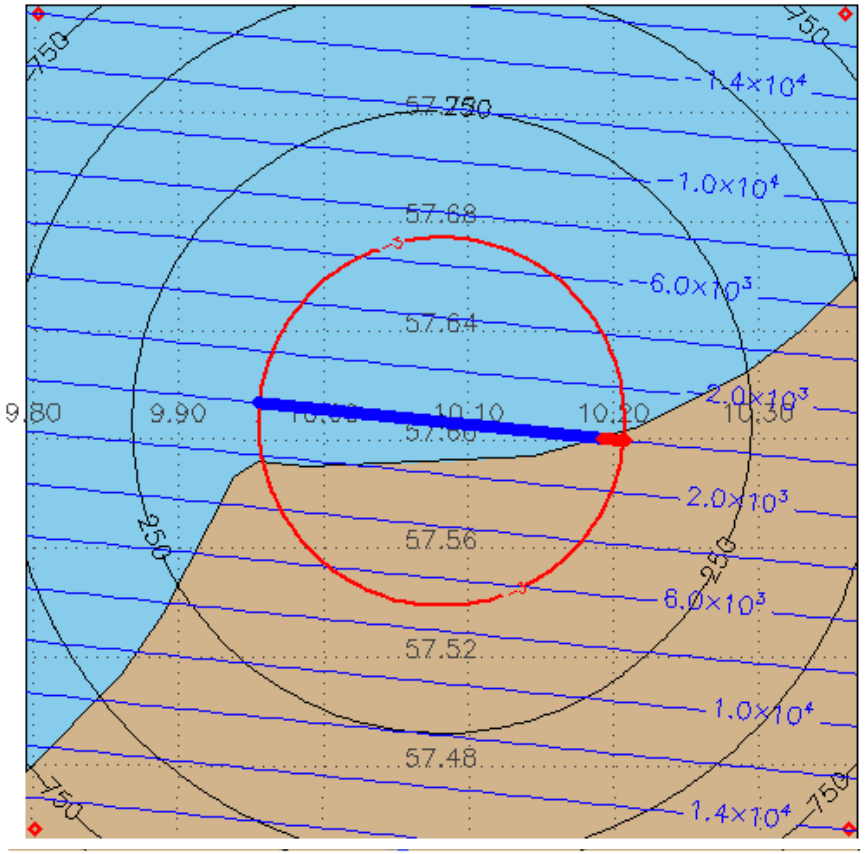
- These equation define a quadratic system of equations, that should be solved for ρ
- Two solutions are obtained, defining two points on the surface for each DDM delay-Doppler pair

Selection of DDM delay-Doppler pairs



- Cryosat delay-Dopp. SAR data pairs geo-located on the surface
- Shore/Coastline from NOAA's "*Global Self-consistent, Hierarchical, High-resolution Geography*" (GSHHG) Database
- Points on the land, prone to contamination are represented in red.
- These points should be therefore discarded from the SAR-Altimetry processing

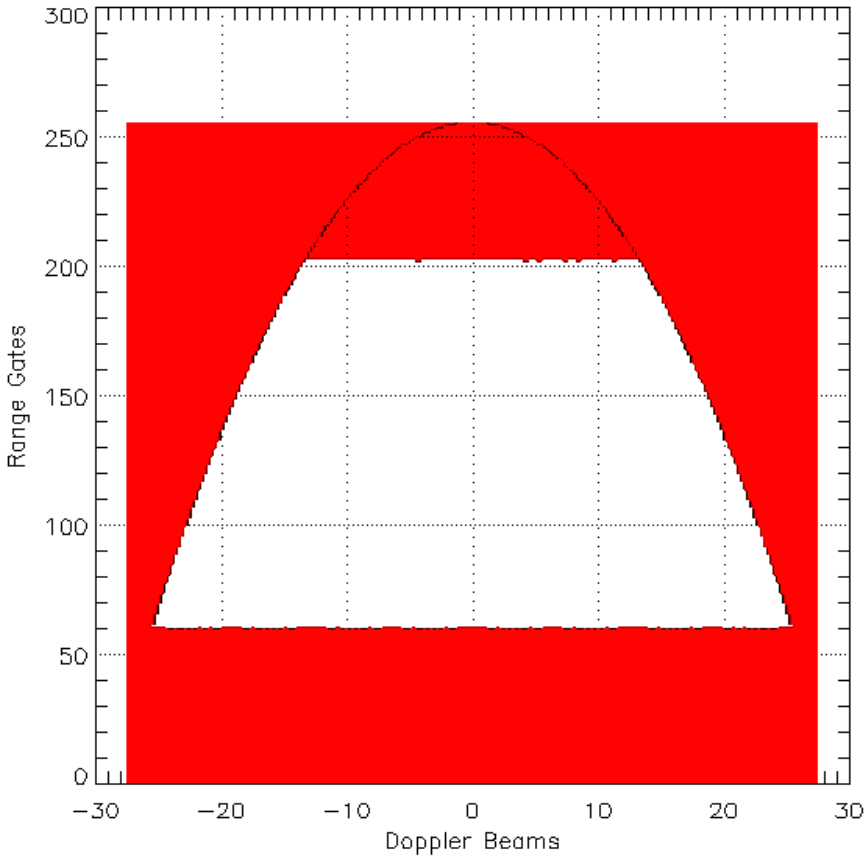
Stack delay/Doppler pairs geo-referencing



- The stack Doppler beams are centred on the sub-satellite point, and therefore should be aligned previous to the delay/ Doppler pair selection.

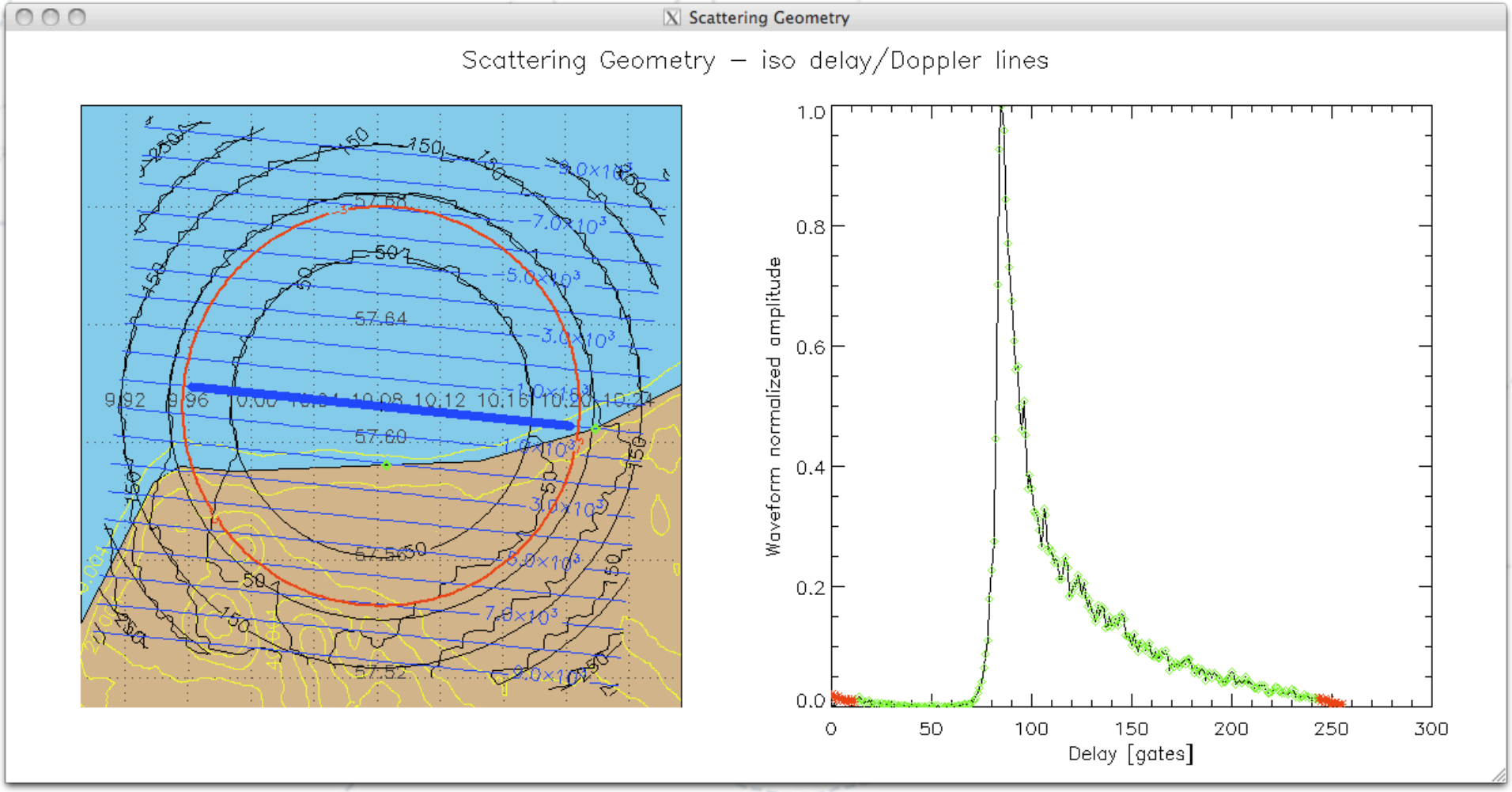
- Once all Doppler beams are geo-referenced it is possible to determine which delay/ Doppler pairs are likely affected by land contamination

Delay/Doppler pairs selection



- A Mask is directly applied to the L1B Stack to select the un-affected delay/Doppler bins.
- In red, the discarded delay-Doppler pairs

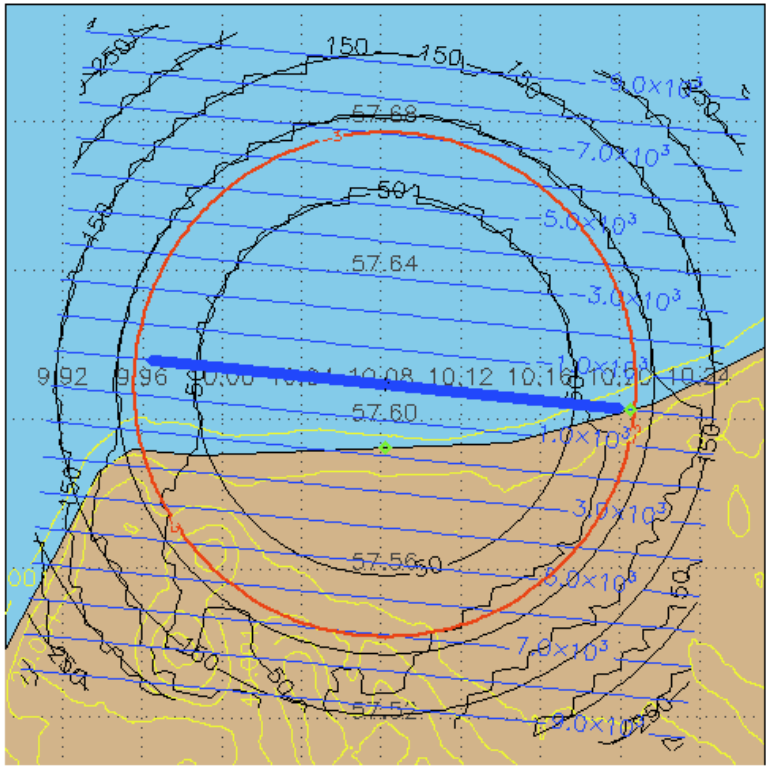
Range Gates Selection

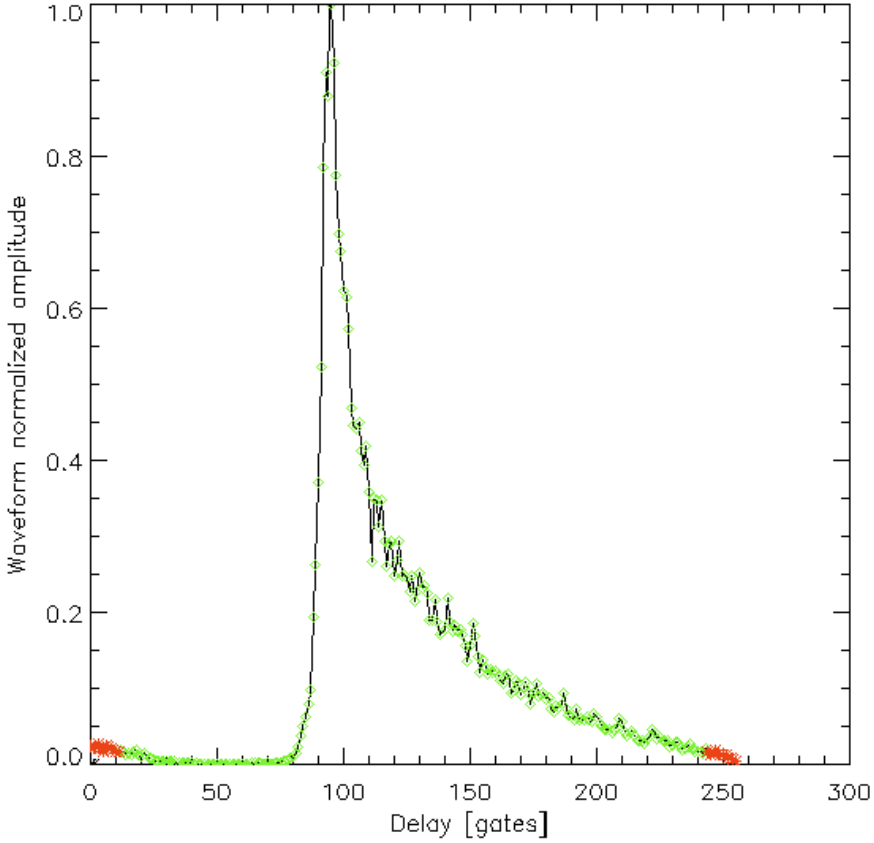


Range Gates Selection

Scattering Geometry

Scattering Geometry – iso delay/Doppler lines





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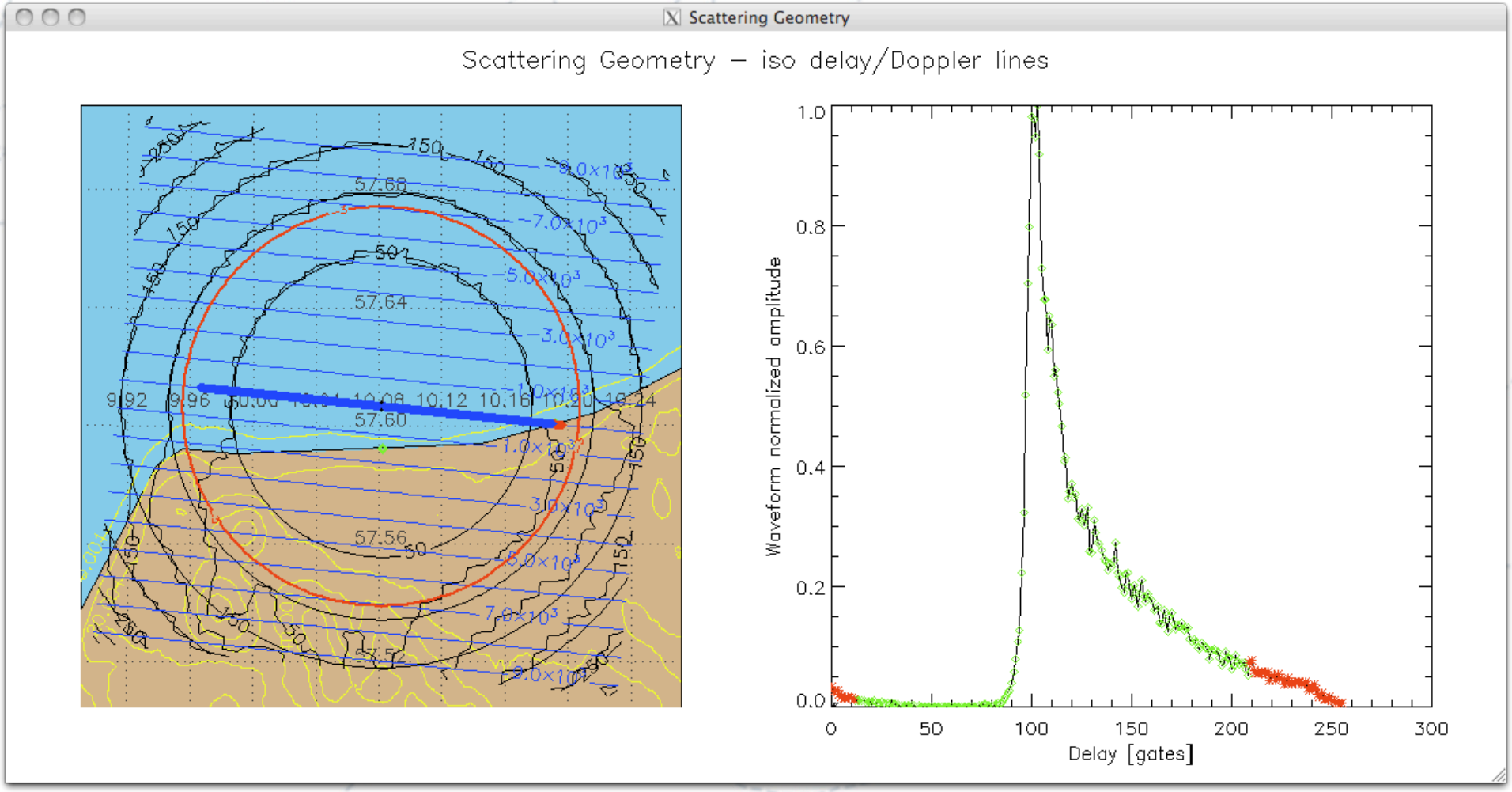

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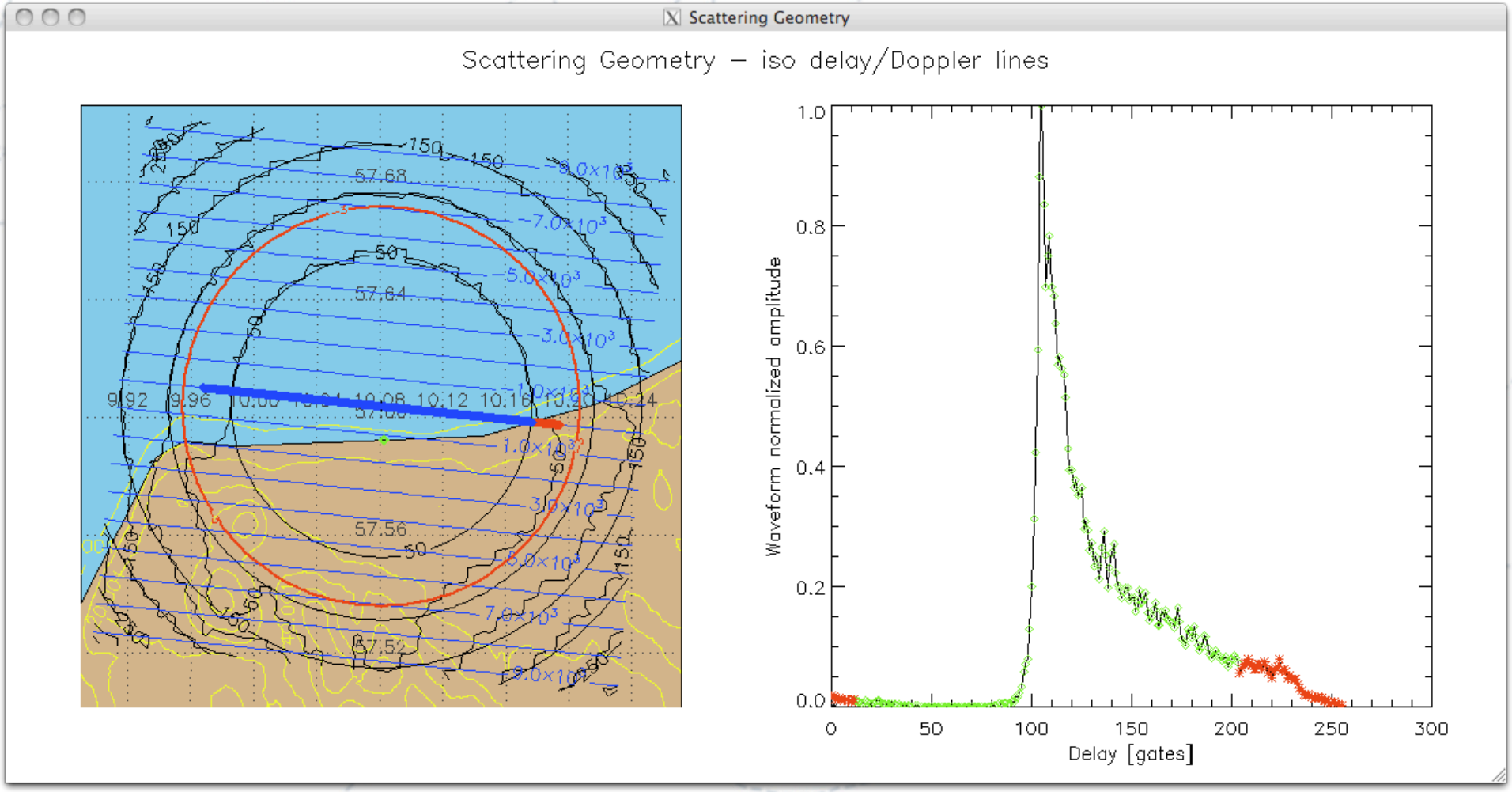
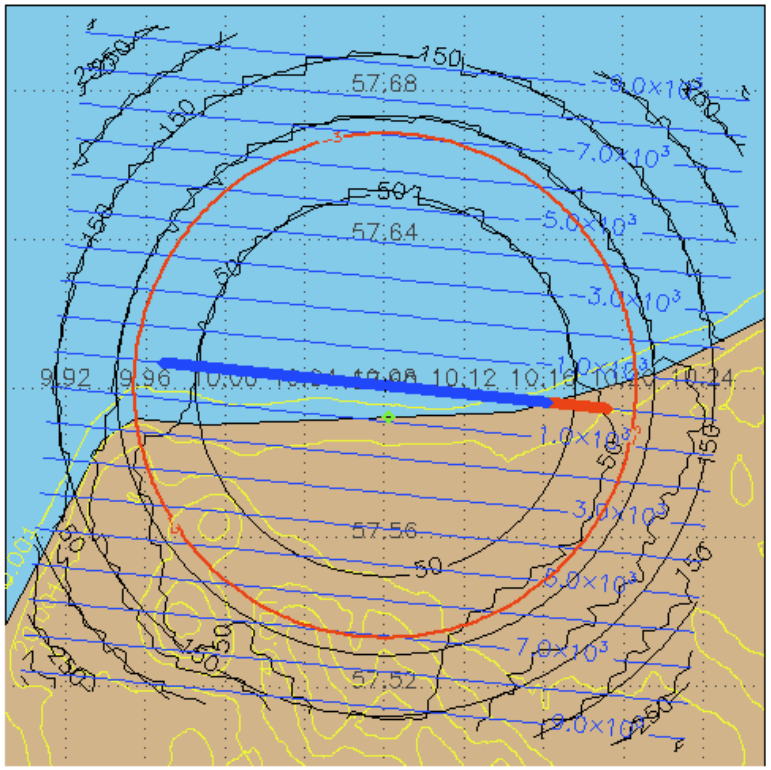
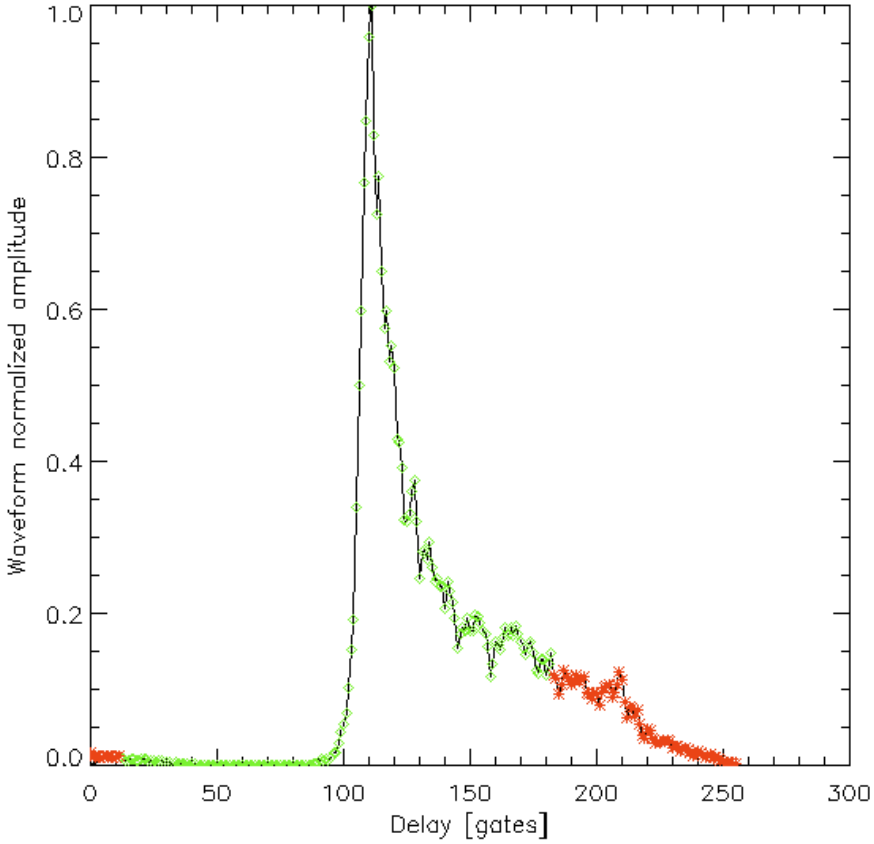


Range Gates Selection

Scattering Geometry

Scattering Geometry – iso delay/Doppler lines





Range Gates Selection

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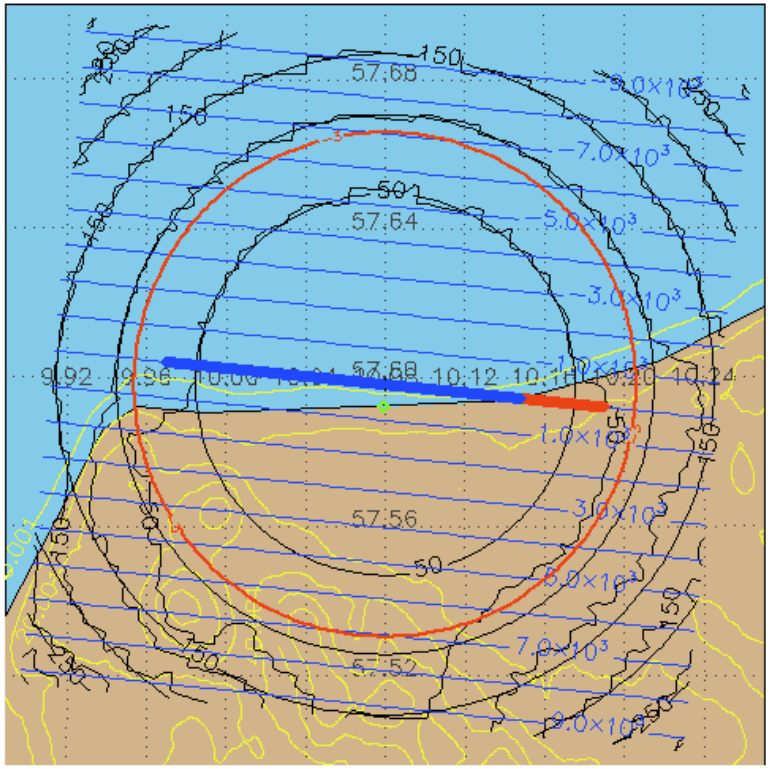

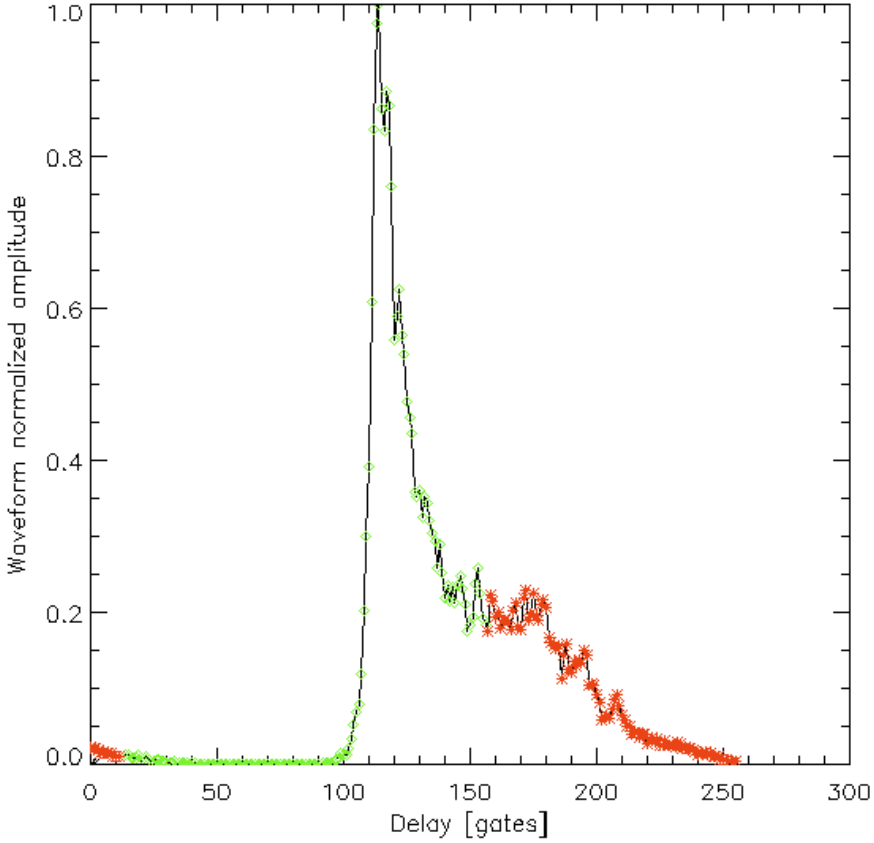

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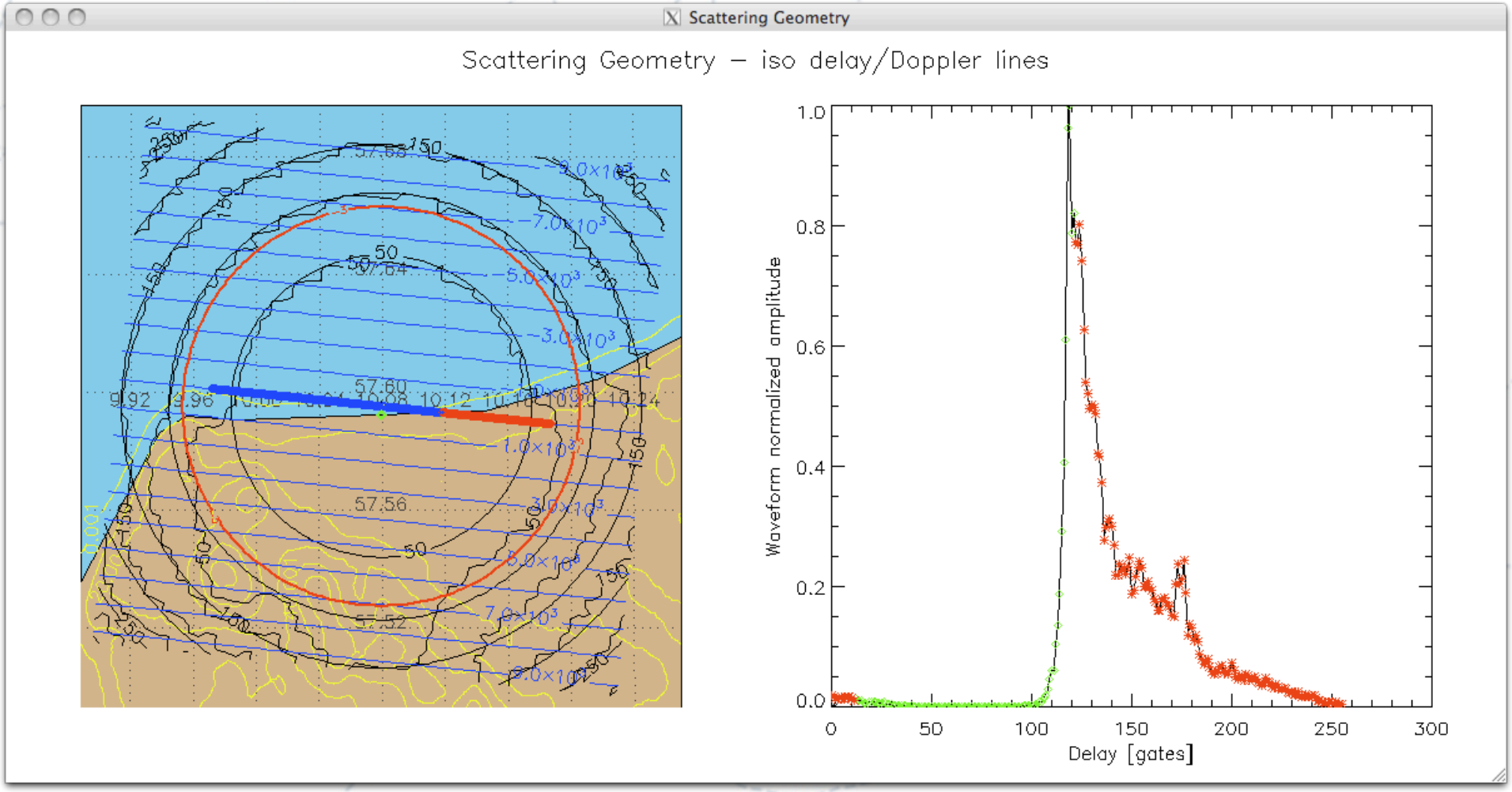
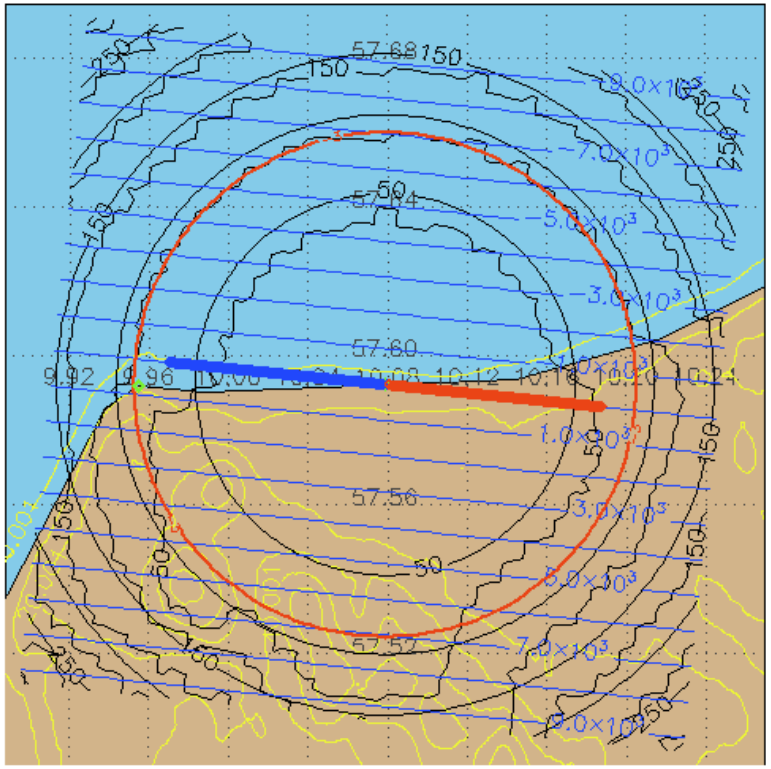
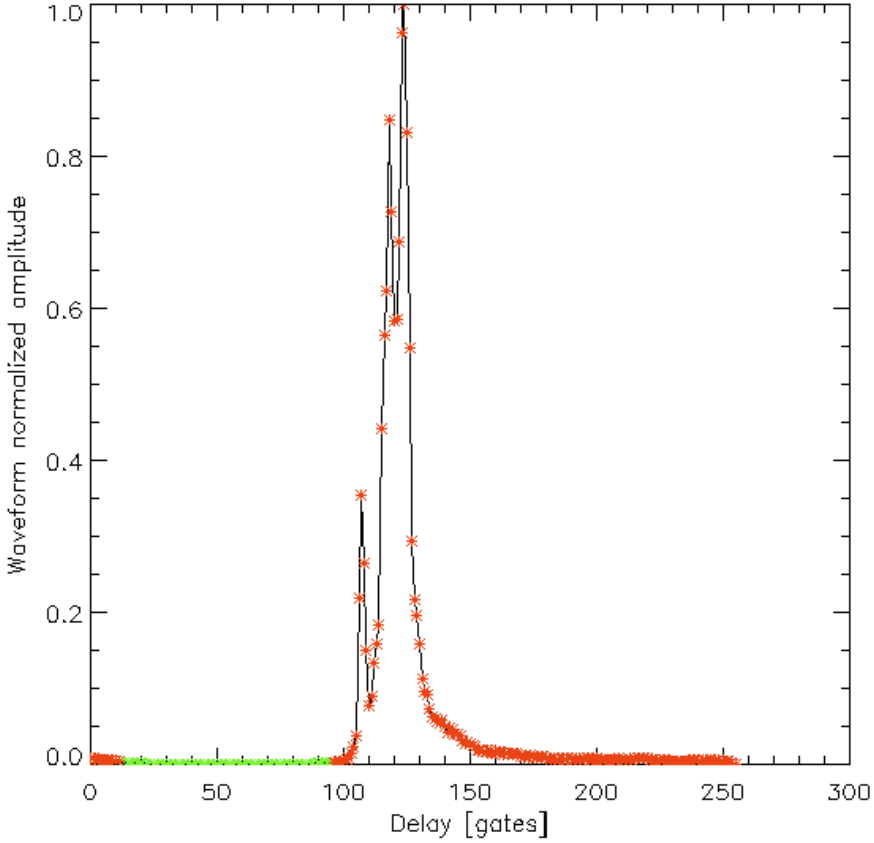


Range Gates Selection

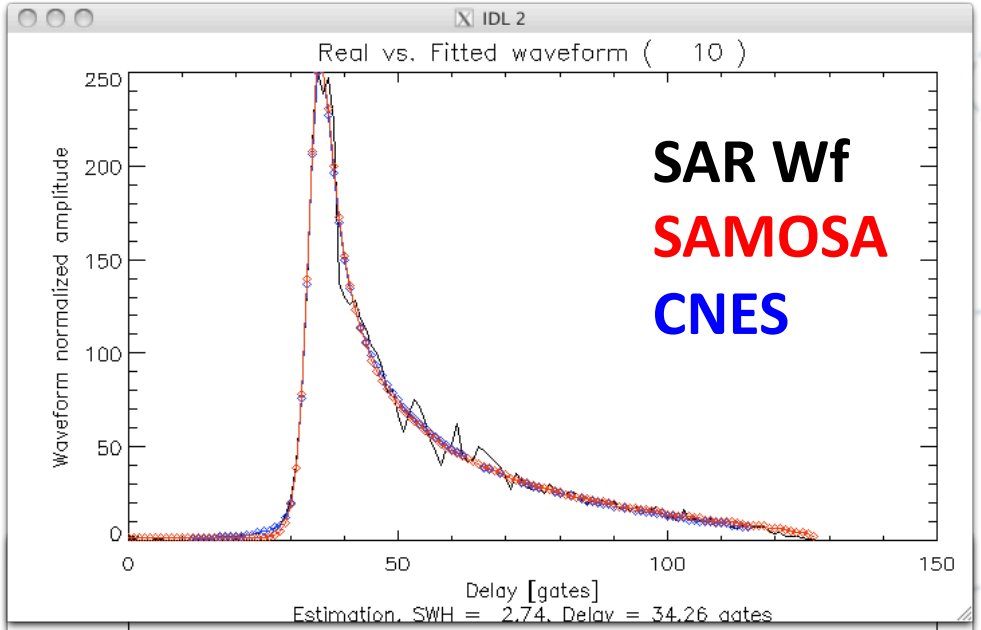
Scattering Geometry

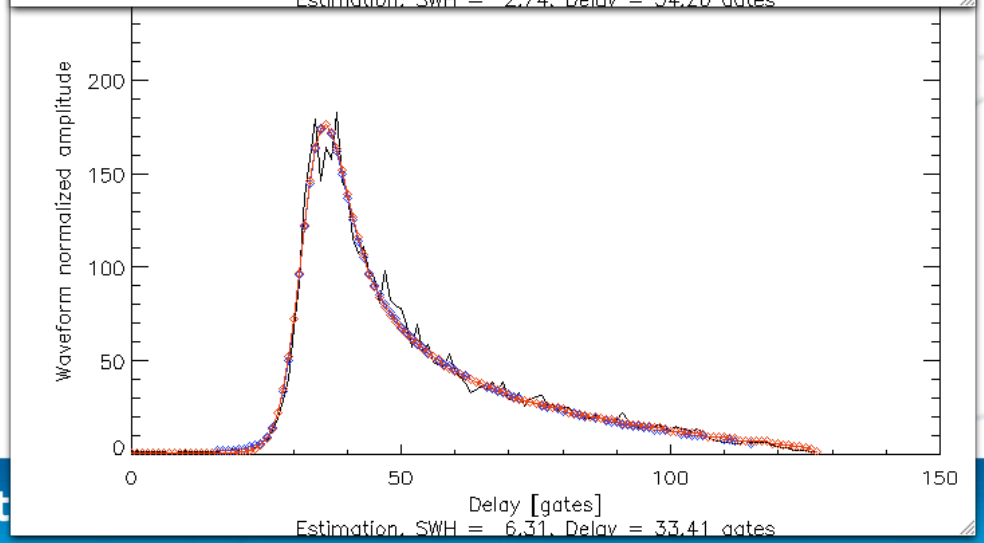
Scattering Geometry – iso delay/Doppler lines





Waveform Retracking – SAMOSA Model



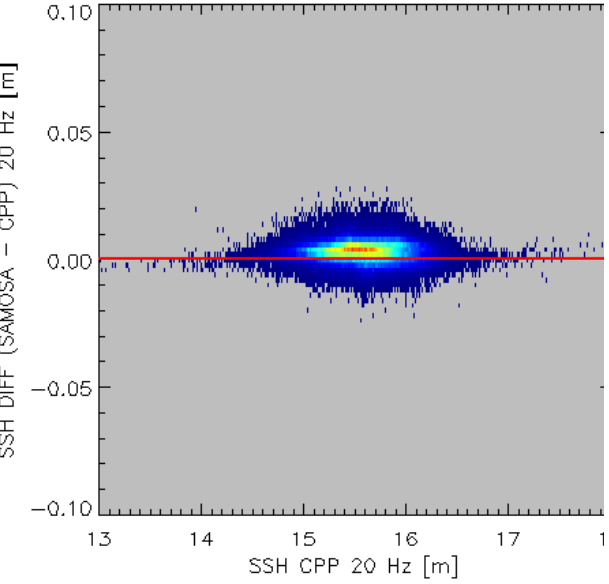


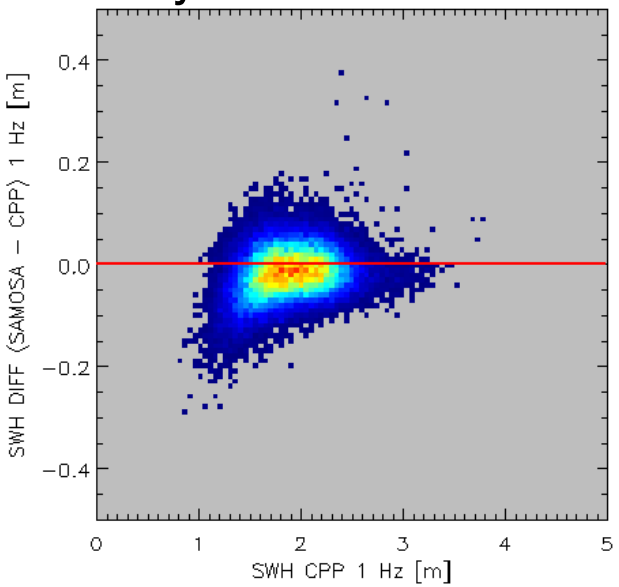
- Retracking based on SAMOSA Analytical Model (fully developed at Starlab Barcelona)
- Model updated within the frame of WP1 of the LOTUS project and CrosSat Plus for Ocean (ESA Project)
- Model updates:
  - Appropriate handling of energy distribution on stack
  - Variable width PTR
  - SAMOSA full implementation
  - Thermal noise estimation
- The comparison of CPP data, CNES numerical model, and SAMOSA model showed very good correspondence both in the waveform leading and trailing edges

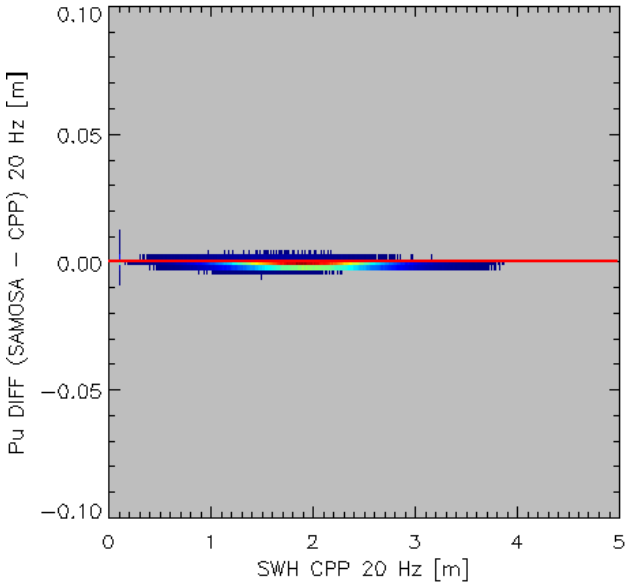
CP40 Round Robin Exercise Results

SAMOSA Model Validation

South Pacific Patch - January 2013







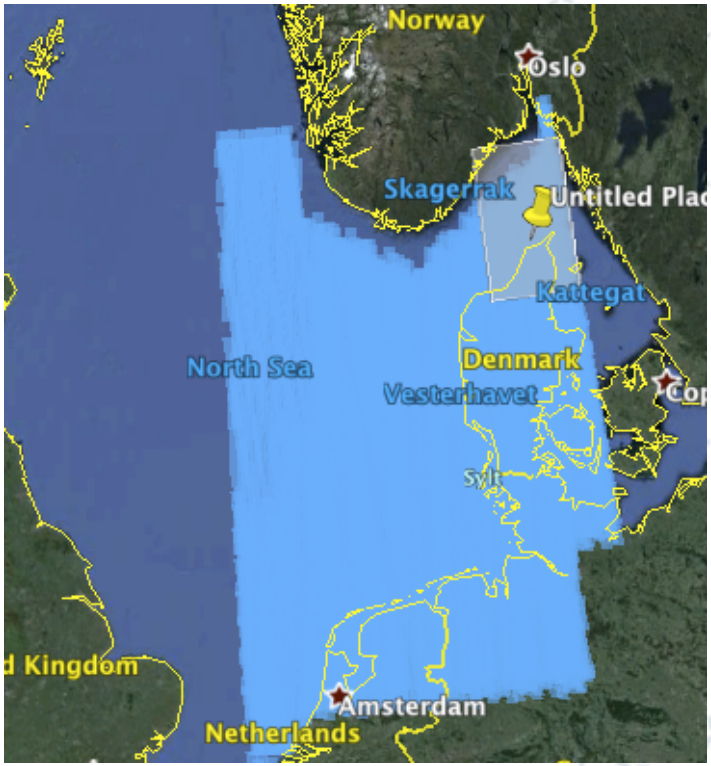
20 Hz - SAMOSA vs CPP, error Statistics

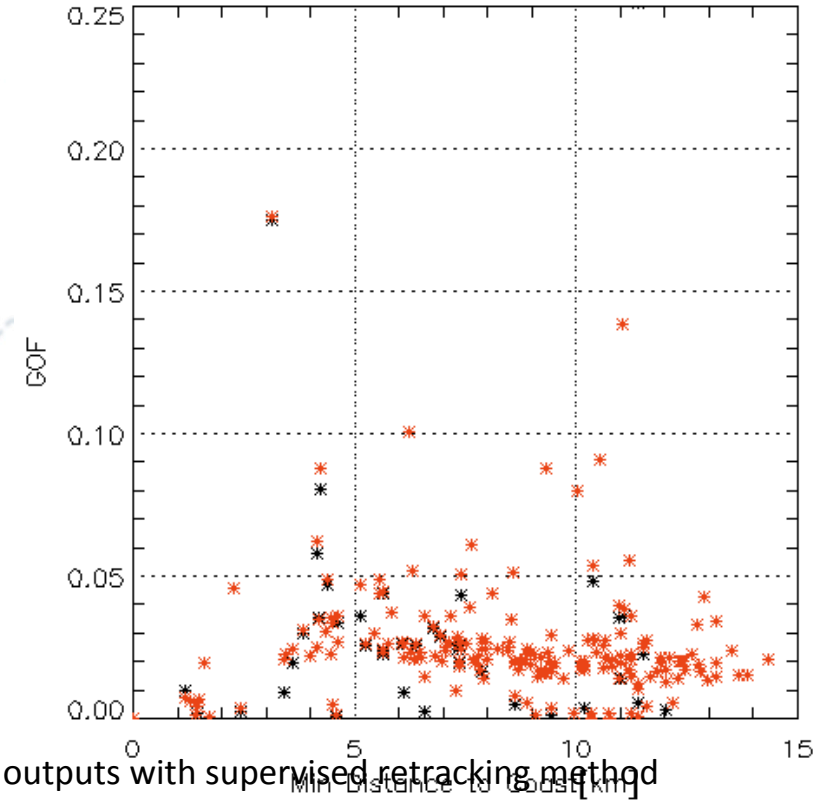
SSH Error bias	=	0.0031 [m]
SSH Error std	=	0.0063 [m]
SWH Error bias	=	-0.009 [m]
SWH Error std	=	0.1537 [m]

1 Hz - SAMOSA vs CPP, error Statistics

SSH Error bias	=	0.0031 [m]
SSH Error std	=	0.0022 [m]
SWH Error bias	=	-0.0091 [m]
SWH Error std	=	0.0457 [m]

Preliminary Performance Estimation





- Preliminary analysis of improvement on retracking outputs with supervised retracking method
- Limited set of tracks over NE Atlantic
- GOF of surpervised (black) vs un-supervised (red) retracking over non-contaminated range bins
  - The supervised retracking outputs shows consistently lower GOF than un-supervised ones
  - These preliminary results demonstrate

Conclusions

- Developed method for the mitigation of land contamination on coastal areas:
  - Algorithm is based on the geo-referrencing of the delay-Doppler stack
  - Coastline from NOAA's GSHHG Database
  - Topography considered by means of ASTER-GDEM
  - The delay-Doppler pairs prone to land contamination are selected based on coastline datafile and additional delay introduced by topography
  - Waveform retracking based on SAMOSA Waveform Model
- Preliminary validation results show consistenly better retracking outputs when supervised waveforms are used
- Coastal Areas algorithm integrated within the Level-2 processing chain…ready to process data
- Further work entails the extended validation of the algorithm and the introduction of coherent component on the waveform model