Investigating the Application of Synthetic Aperture Altimetry over oceans, coastal and inland waters.

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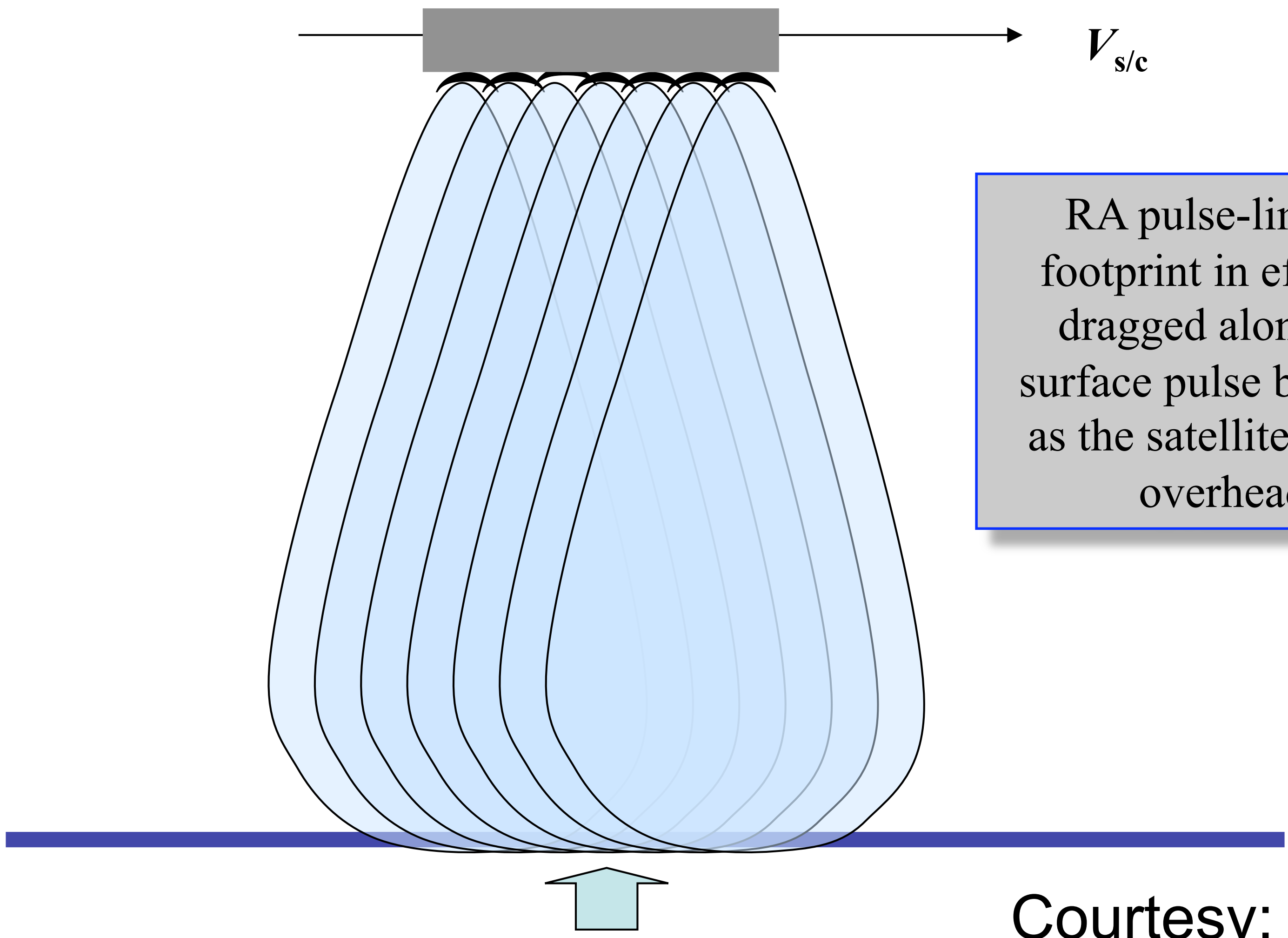
Presentation Content

- What is Delay-Doppler Altimetry (DDA)?
- The ESA SAMOSA project
- Developing a waveform echo model
- First results from Inland Water Simulations
- Conclusions

What is Delay-Doppler Altimetry (SAR) ?

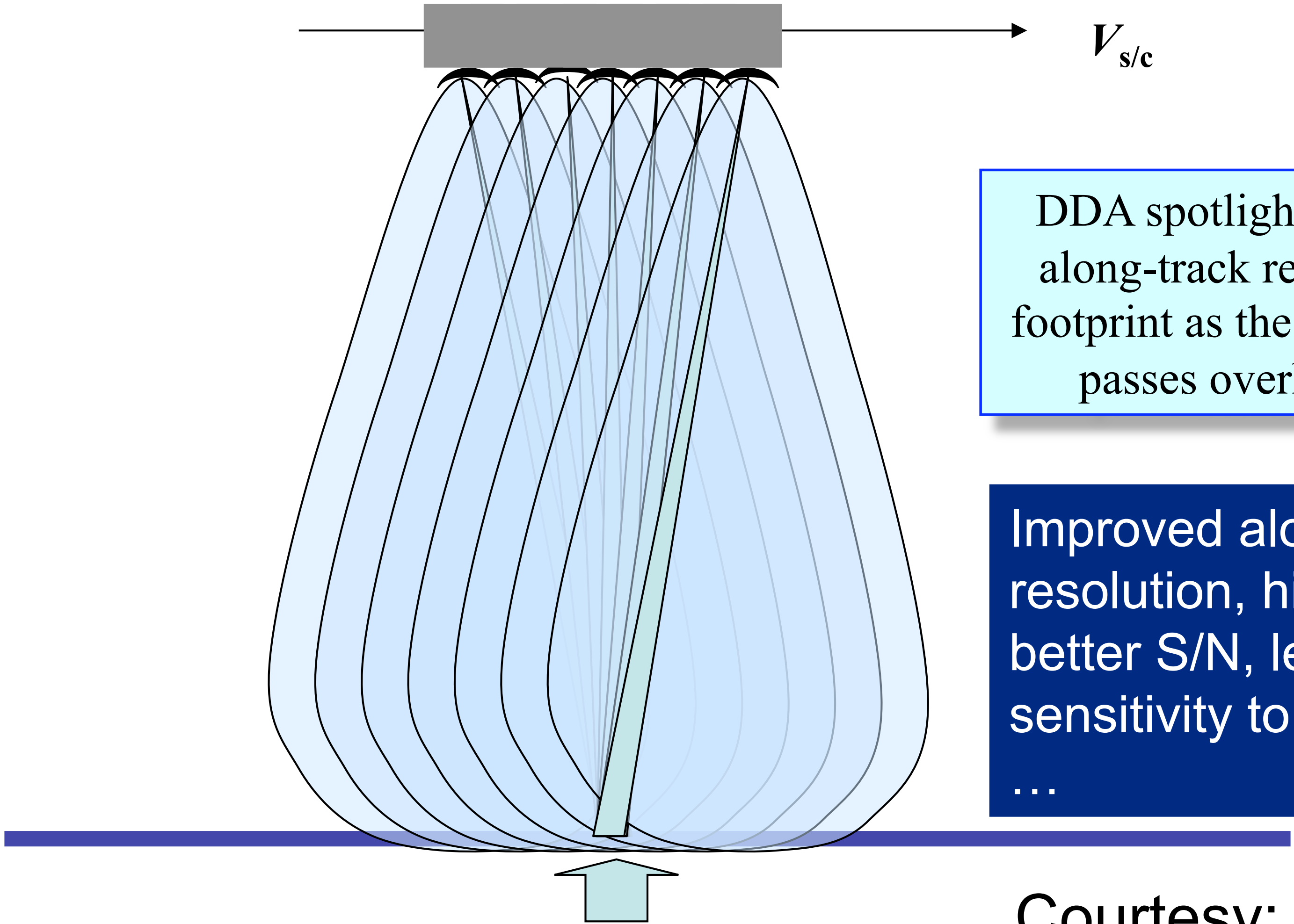
Conventional ALT footprint scan



RA pulse-limited footprint in effect is dragged along the surface pulse by pulse as the satellite passes overhead

Courtesy: K.Raney

DDA: a fundamentally different method



DDA spotlights each along-track resolved footprint as the satellite passes overhead

Improved along-track resolution, higher PRF, better S/N, less sensitivity to sea state, …

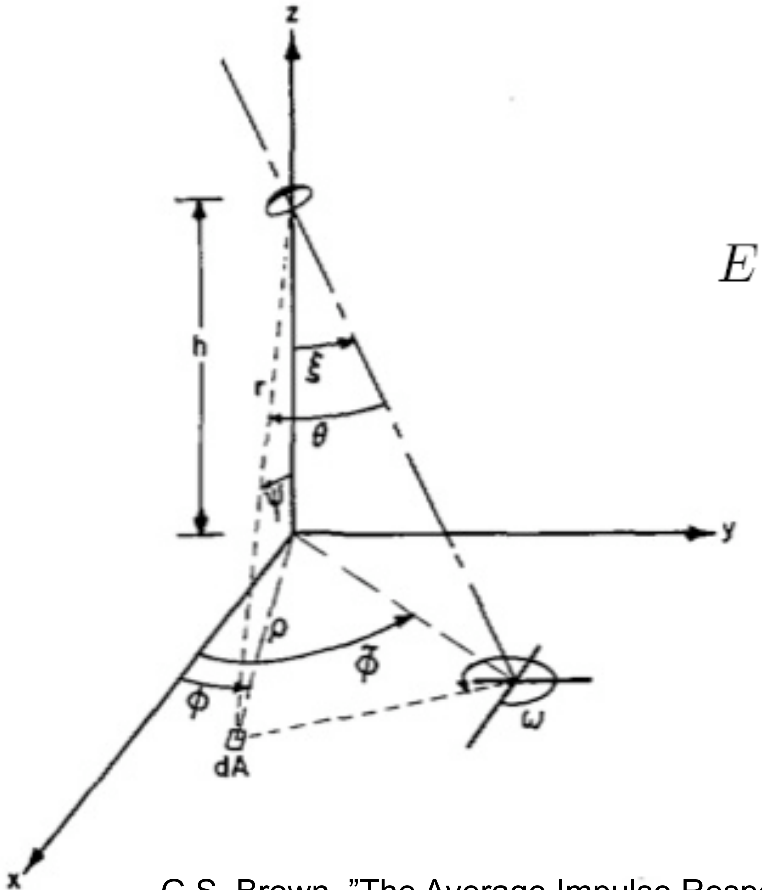
Courtesy: K.Raney

ESA SAMOSA project

- SAMOSA - Development of SAR Altimetry Mode Studies and Applications over Ocean, Coastal Zones and Inland Water
- Project management: David Cotton, SatOC
- Consortium members: EAPRS - De Montfort University, NOCS, Starlab, Danish National Space Centre
- Tasks:
  1. Review state of the art (Starlab)
  2. Quantify improved range error in different sea states (NOCS)
  3. Assess recovery of short scale surface slope signals (DNSC)
  4. Develop theoretical model for DDA waveforms (Starlab)
  5. Assess capability in coastal zone and inland waters (DMU)
  6. Application to RA-2 individual echoes (NOCS)
  7. Validation with ASIRAS data (DNSC)

Theoretical DDA Echo Waveform Model over ocean

Progress done on theoretical model



G.S. Brown, "The Average Impulse Response of a Rough Surface and Its applications", IEEE Trans. Antennas Propag., vol. AP-25, pp. 67-74, Jan. 1977.

- It has been proved that previous to multi-look and after accumulation the DDA waveform for a given Doppler bin shall be expressed as a triplefold convolution

$$E[I_R] = P_{FS}(\tau, f_a) \ * * \ S_R(\tau, f_a) \ * \ \left(\frac{c}{2}\right) P_z\left(\frac{c\tau}{2}\right)$$

- No curvature effects across track have been introduced in the analysis, but along track curvature effects have been accounted for
- Circular antenna pattern considered
- Ocean Gaussian statistics have been assumed
- Earth curvature along track and off-nadir (ξ,ϕ) angle effects have been introduced in waveform model
- A final analytical solution for ϕ = 0 has been defined for waveform previous to multi-look
- Vertical spacecraft velocity component has not be considered in the analysis

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Flat surface impulse response

- **Flat surface impulse response:**
  - ✓ Assumed Gaussian approximation for the antenna Gain

$$P_{FS}(\tau, f_a) = \frac{\lambda_0^2}{(4\pi)^2\, L_p} \int G^2(\vec{\rho})\, \frac{1}{r^4}\, \sigma_0(\vec{\rho})\, \delta^2(\, \tau - \tau_s(\vec{\rho}), f_a - f_s(\vec{\rho}))\, d^2\vec{\rho}$$

$$\tau_s = \frac{1}{hc}(y^2 + (h-z)^2 - h^2)$$

$$f_s = \alpha f_D$$

$$f_D = \frac{2V_S}{\lambda_0 h}(x_0 - x_n)$$

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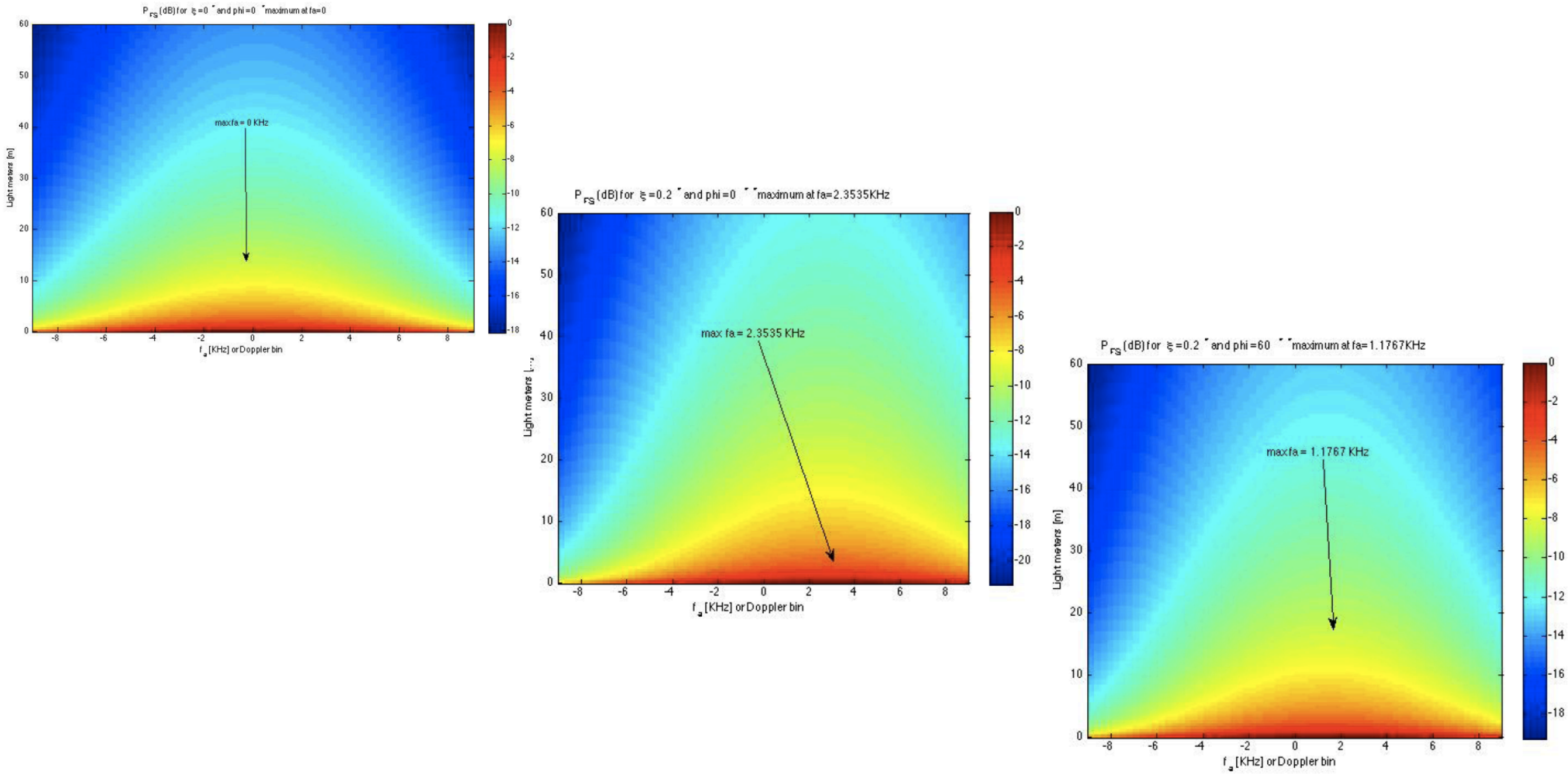
P_{FS} simulations for a scatter

- P_{FS} as a f^{on} of f_a and τ:



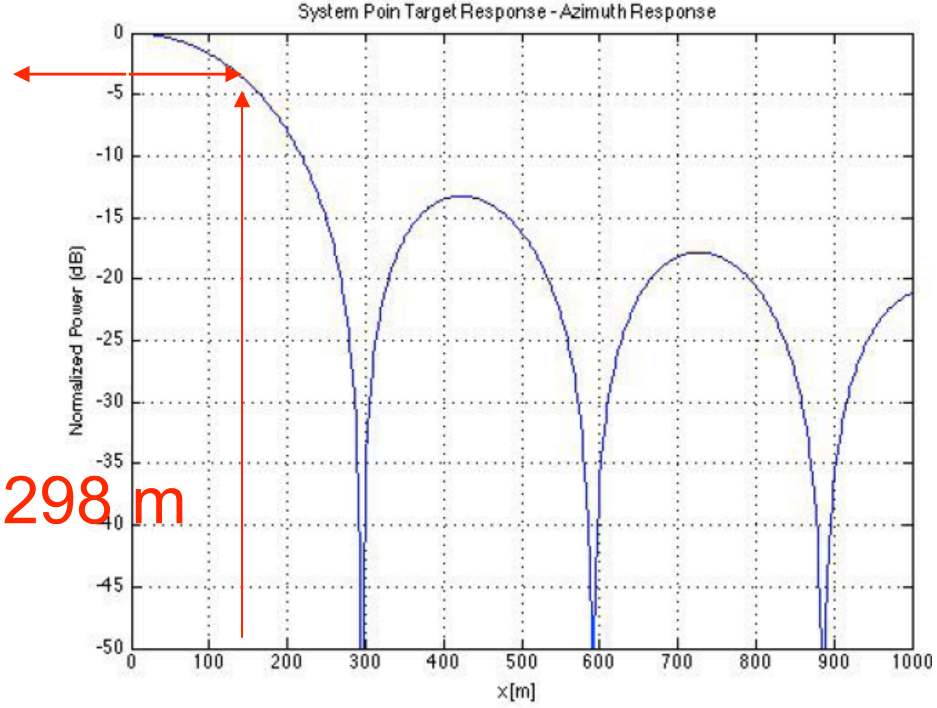
SPTR

- Radar System Point Target Response

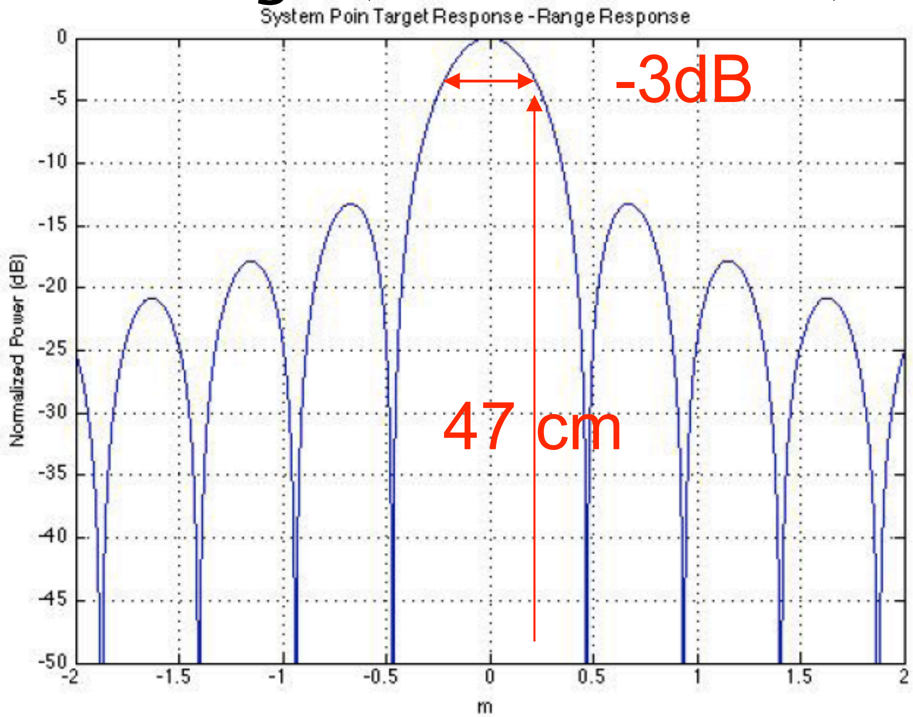
Along track boxcar time

$$S_R(\tau, f_a) = \mathrm{sinc}^2(T\ f_a)\ \mathrm{sinc}^2(\tau_u\ s\tau)$$

Azimuth (along-track)



Range (vertical datum)



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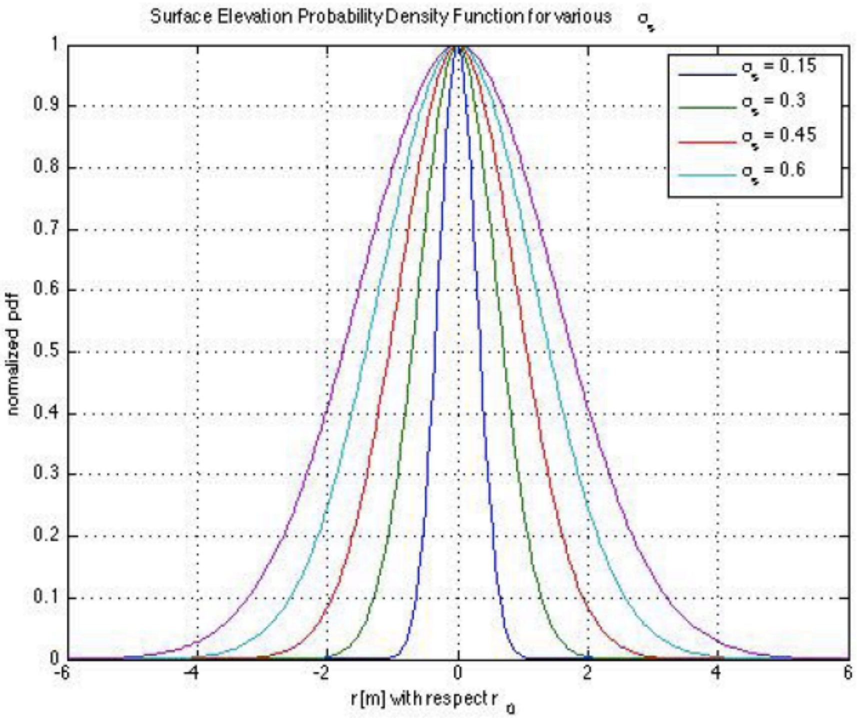
SEpdf

- Surface Elevation Probability Density Function (SEpdf)

$$\left(\frac{c}{2}\right) P_z\left(\frac{c\tau}{2}\right) = \frac{1}{\sqrt{2\pi\left(\frac{2\sigma_s}{c}\right)^2}}\exp\left[-\frac{\tau^2}{2\left(\frac{2\sigma_s}{c}\right)^2}\right]$$



$$\mathrm{SWH} = 4\sigma_s$$

SWH=0.60 m

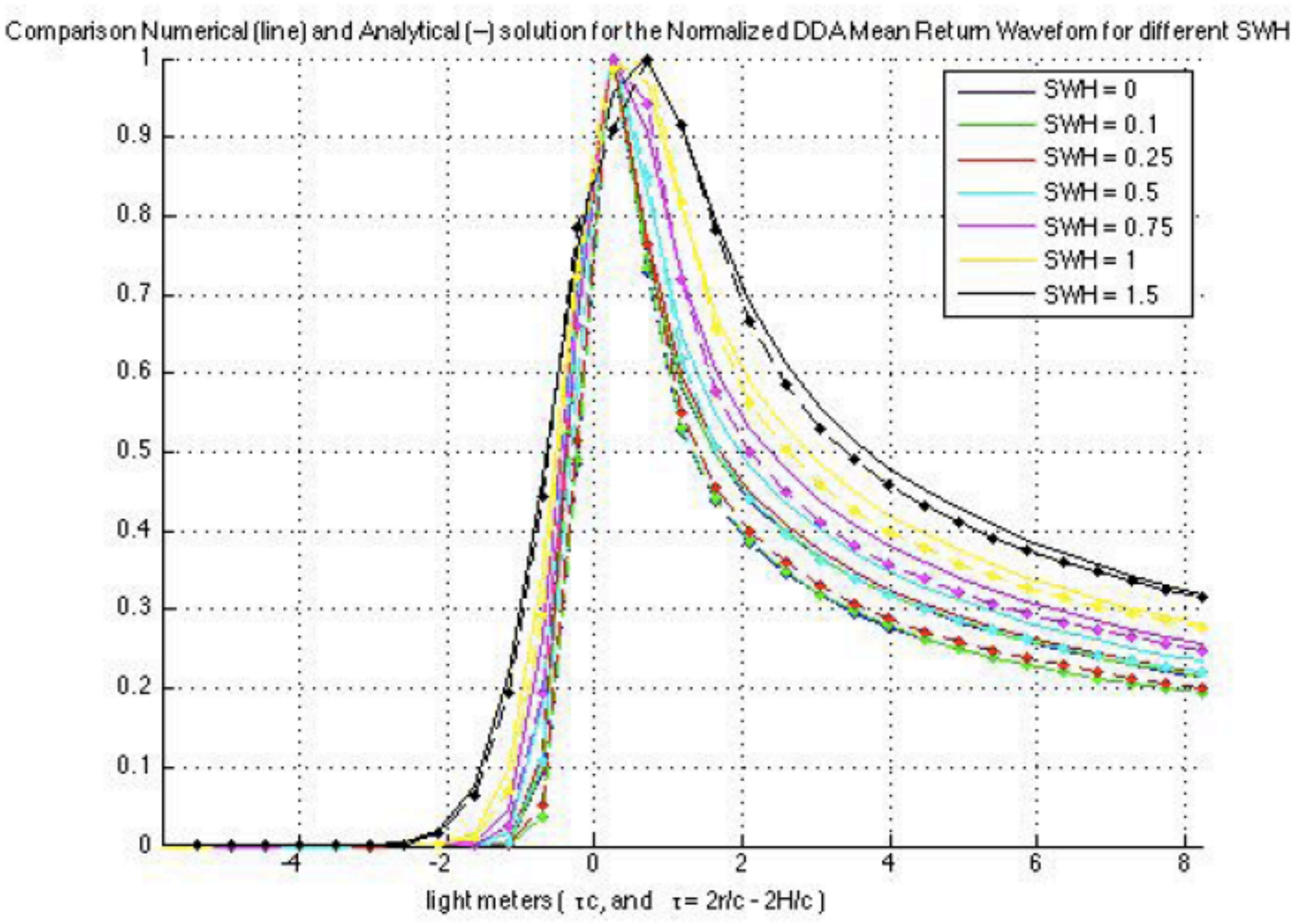
SWH=1.20 m

SWH=1.80 m

SWH=2.40 m

SWH=3.00 m

Comparison of numerical and analytical solutions



CRYMPS simulations over inlands water scenarios

Methodology

- CRYMPS: Cryosat Mission Performance Simulator
- CRYMPS developed & run at University College London/MSSL, in collaboration with ESA/ESTEC
- Simulates the CryoSat platform orbit and instrument operation, generates official Cryosat products for LRM, SAR and SARIn mode, for a given (explicit) surface
- Simulator and surface descriptors optimised for ice/sea ice surfaces
- Here, CRYMPS is applied to inland water and ocean surfaces

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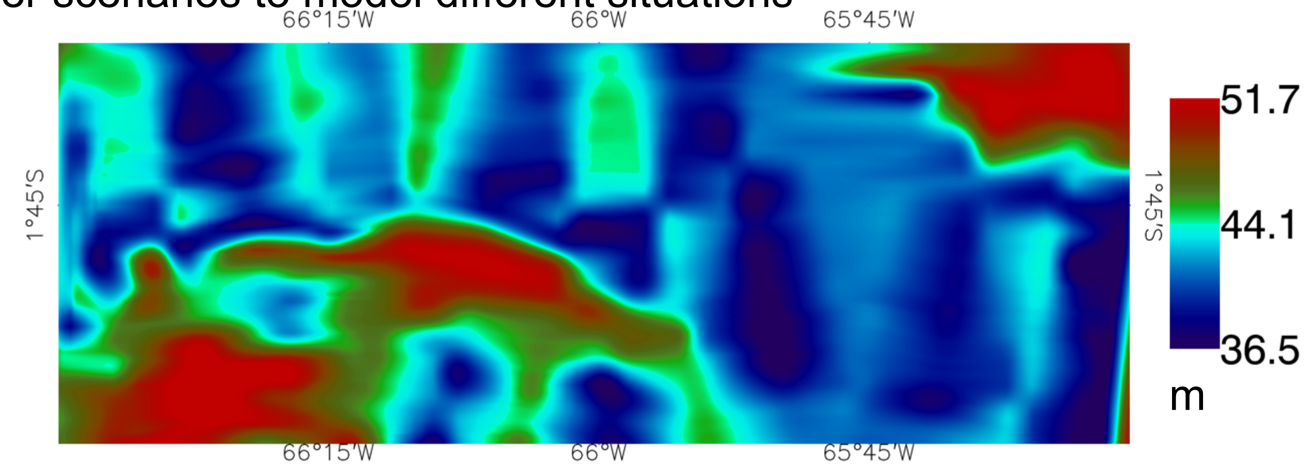
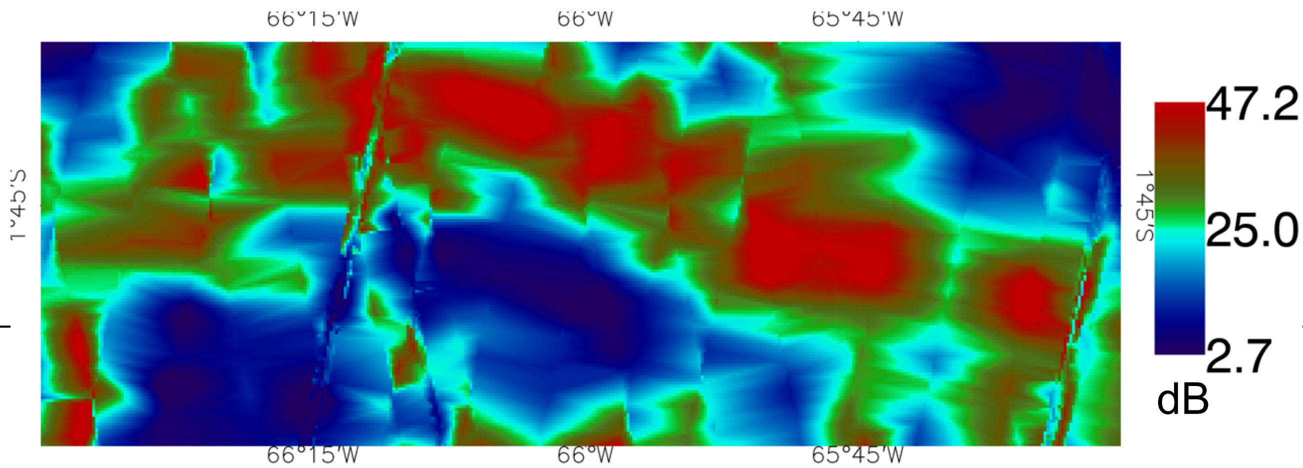
CRYMPS scenarios

- First DMU scenario area selected over Amazon basin
- Inputs comprised DEM (from ACE2) and Sigma0 model over area of 40 x 107km
- Area characterised by gradual topographical change with large Sigma0 variation

- 2 other scenarios to model different situations





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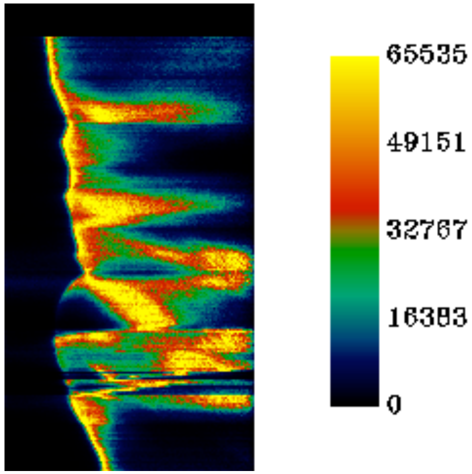
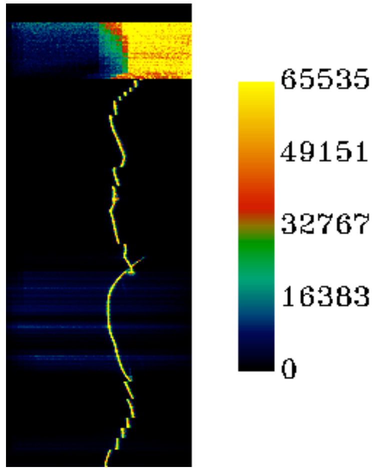
Level1-b

- Level 1-b are averaged echoes which equate to the standard PRF of existing altimeters.
- Scenario processed with differing polar angle response produced very different results
- Run 1 polar angle: 0.2618<Rads> waveforms show significant power throughout the bins
- Run 2 polar angle: 0.001 <Rads> waveforms for the most part display clear quasi-specular peaks
- Waveforms then processed using the Berry expert system to determine if retracking were possible
- In both runs around 70% of all the waveforms could be successfully retracked



Run 1 (rough)



Run 2 (specular)

Process	Run 1 (wide)	Run 2 (qs)
Total input	240	320
No power_	17	13
No leading edge	56	86
Retrack viability failures	0	0
Accepted	167 (~70%)	221 (~69%)

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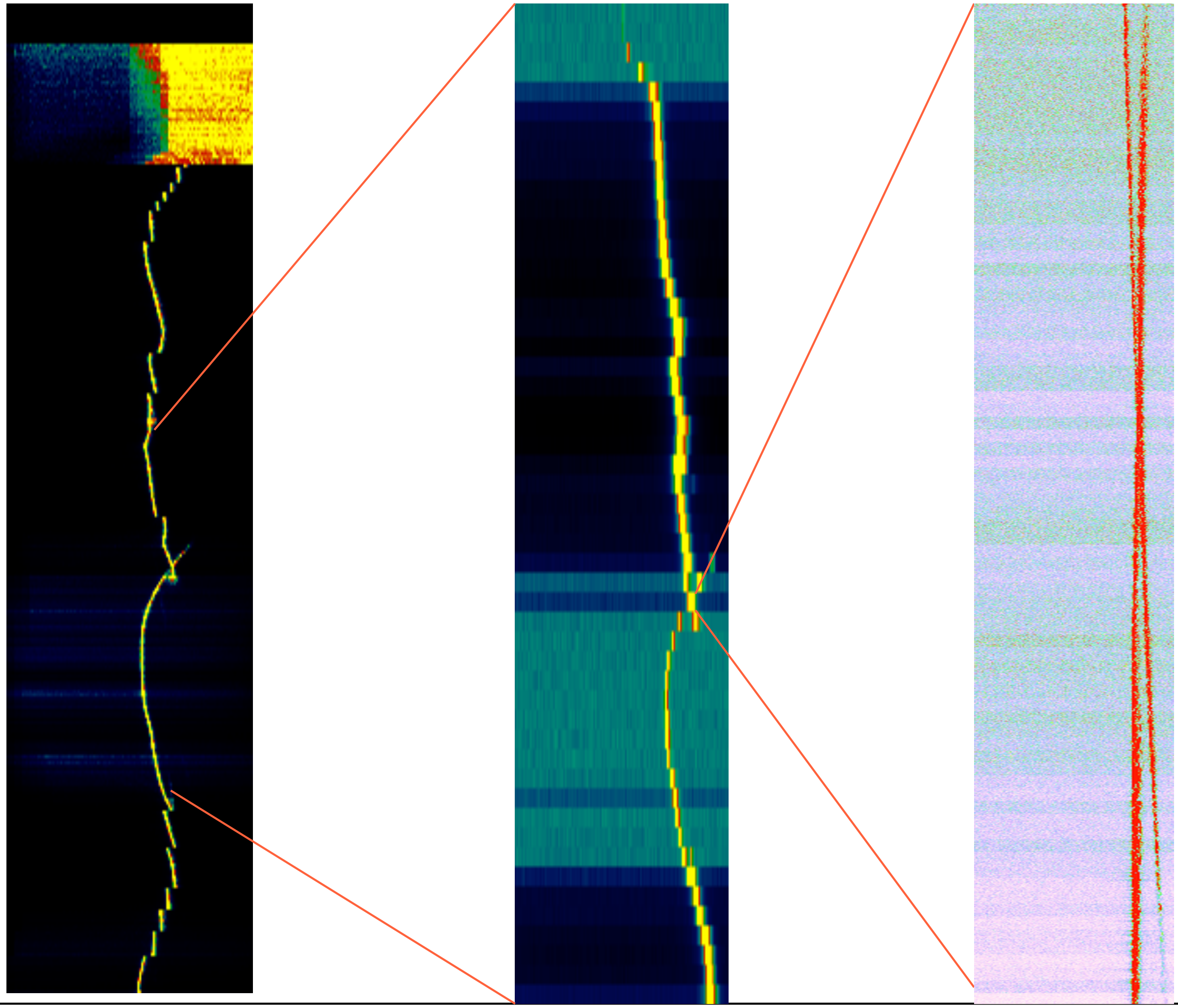
Individual echoes (SAR mode)



Level 1-b

Summed SAR mode data

Full resolution SAR mode data

- SAR mode provides dense along-track sampling. Left shows waveforms, centre is reconstructed waveforms from IEs, right shows sample of full resolution SAR mode data.

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Individual Echoes phase content

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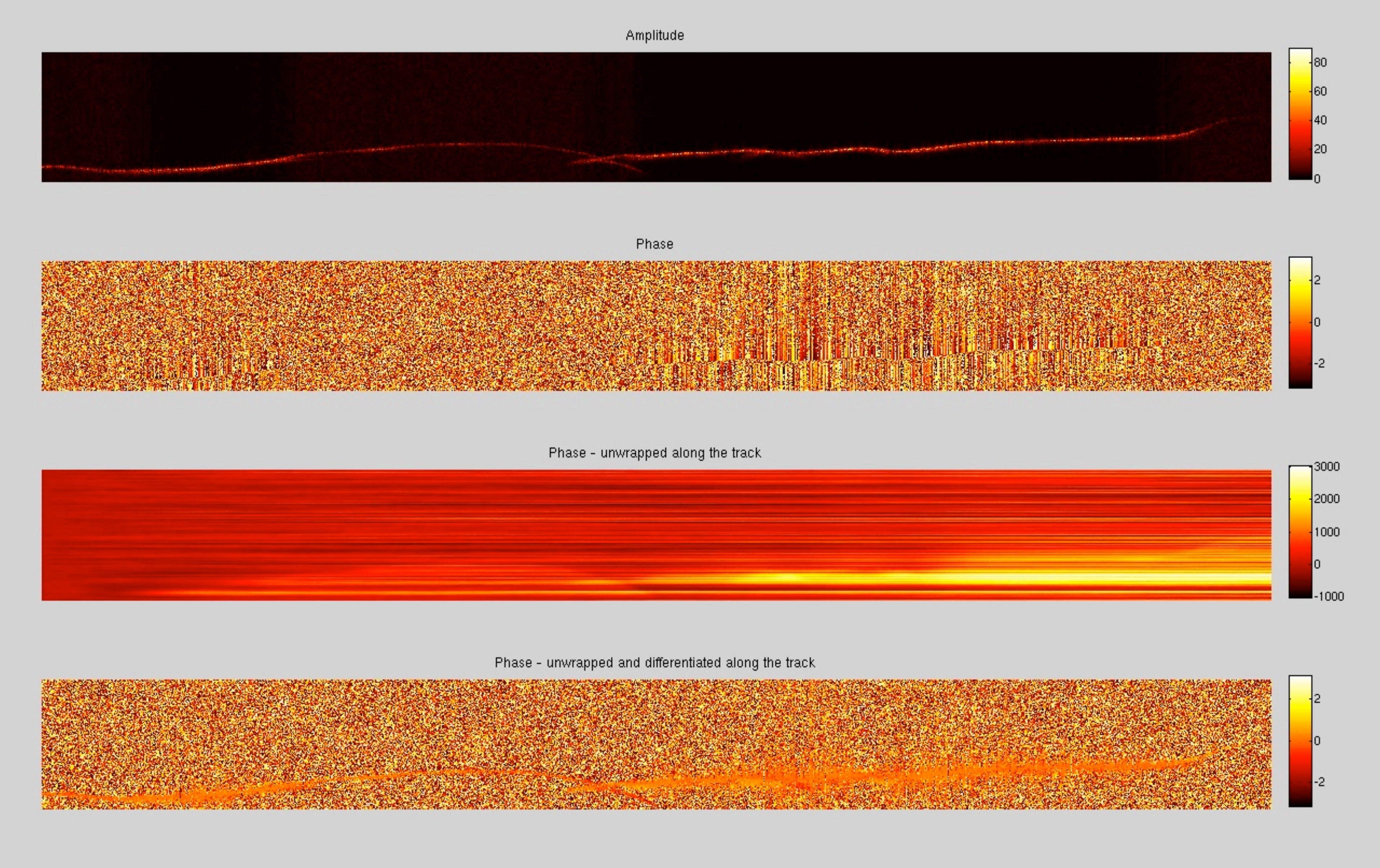
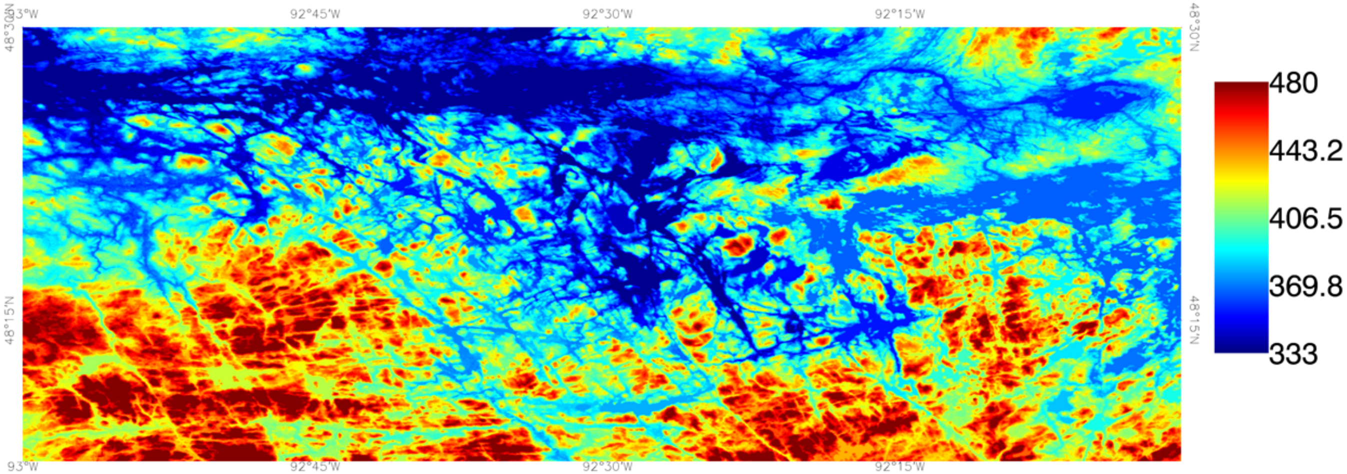
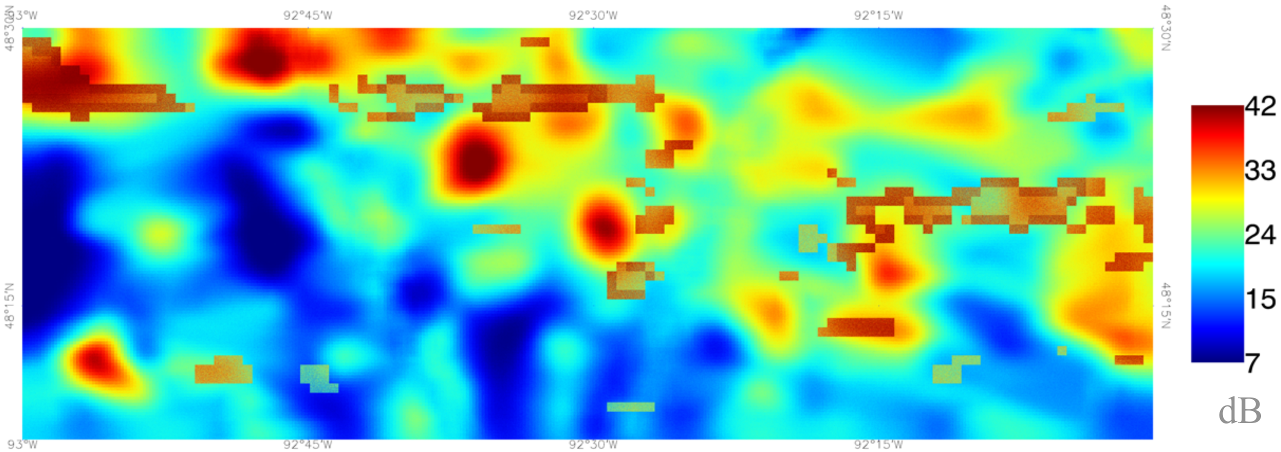


Next Scenario





- Scenario over Northern USA lakes
- DEM generated using SRTM 1” dataset
- Polar angle response at 0.087 rads

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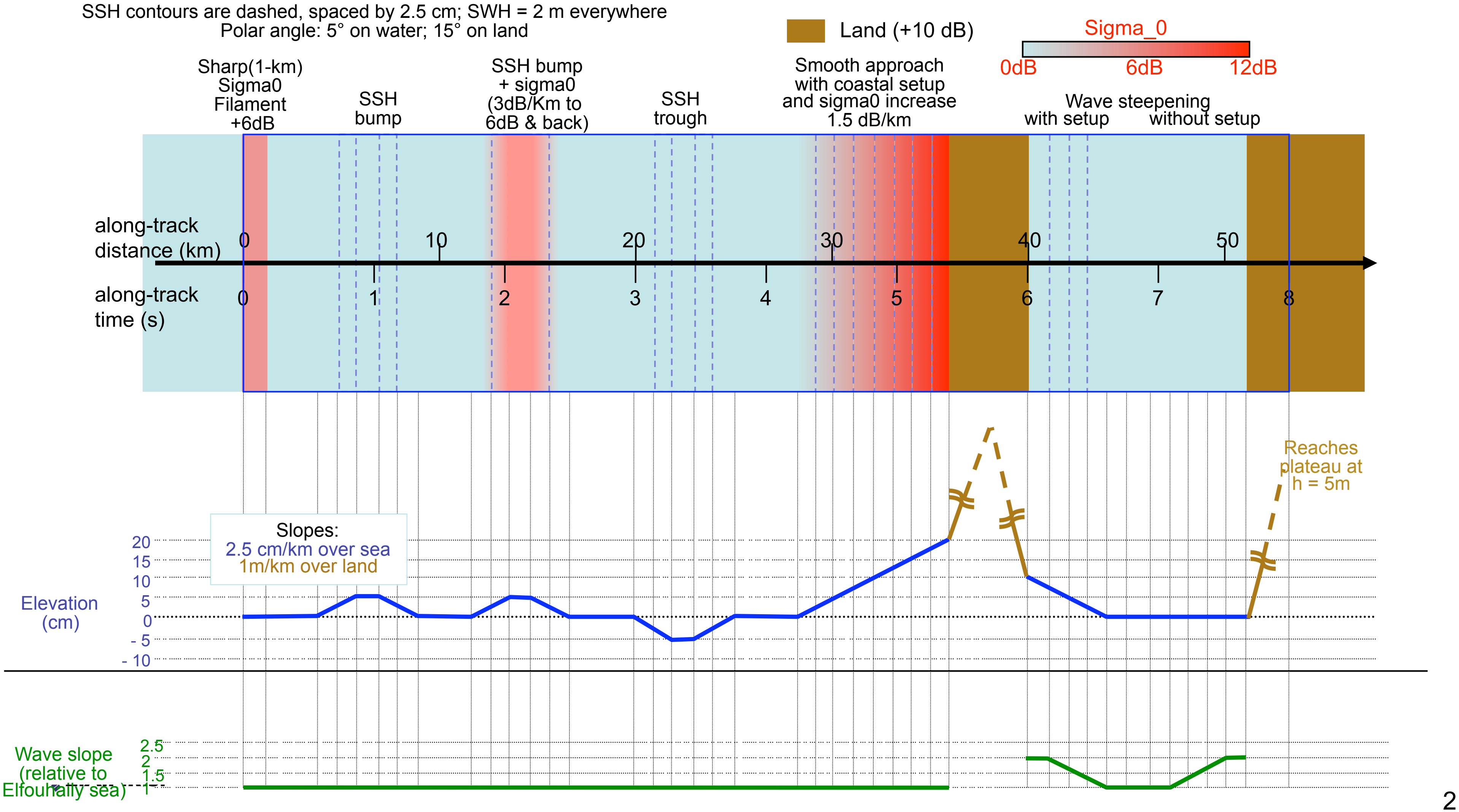
Coastal Ocean Scenario

- Simple scenario with idealized coastal features: sigma0 variation, SSH variation, coastal setup, wave steepening, presence of land



Conclusions

- SAMOSA will assess the improved performance of DDA w.r.t. pulse-limited altimetry to:
  - Retrieve higher-accuracy ocean range, detect short-scale surface slope, extend altimetry to the coastal zone, applications over inland water surfaces.
- Initial investigations of CRYMPS output over inland waters show much promise.
- Further work
  - will develop and experimentally test new ocean re-tracking method based on these theoretical waveform developments.
  - Will analyse CRYMPS output over more realistic inland water surfaces.
  - Further developments will contribute to preparations for Sentinel-3.

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Thank You !