Improved altimetric accuracy of SAR altimeters over ocean

Observational evidence from Cryosat-2 SAR and Jason-2

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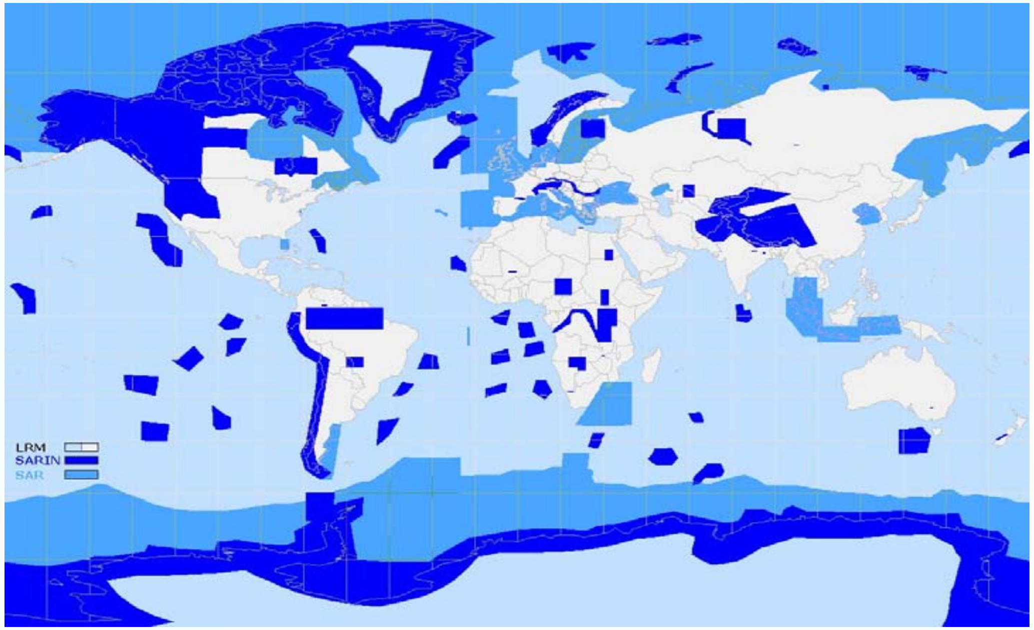
- The SAMOSA project: aims & methodology
- Key results from SAMOSA (not shown in this talk)
- Key results from SAMOSA (in this talk)
  - SAMOSA physically-based models for SAR ocean waveforms
  - Application of physically-based retrackers to Cryosat-2 SAR waveforms over ocean
  - Retrieval performance with Cryosat-2 SAR and Jason-2 for different sea states
  - Validation of Cryosat-2 SAR Hs against in situ
- Summary & Conclusions

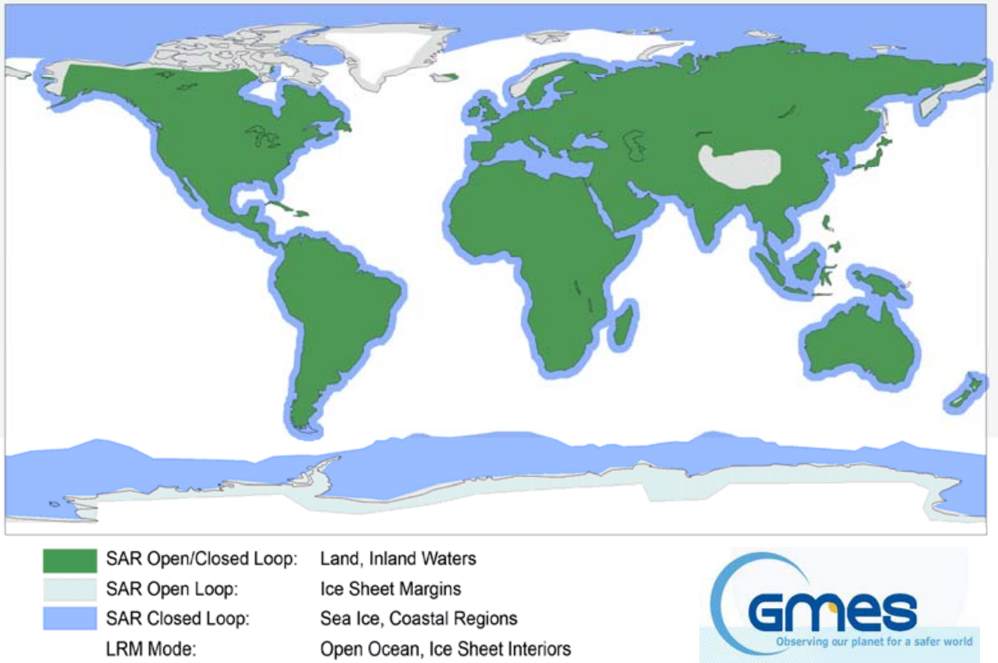
Cryosat-2



- Low Resolution Mode – open ocean
- SARIN – land ice
- SAR Mode – sea ice & some oceanic regions

Sentinel-3 Surface Topography Mission

- LRM – open ocean
- SAR – sea ice & global coastal ocean



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The SAMOSA project

- Study funded by ESA, led by David Cotton (SatOC)
  - Starlab, NOC, De Montfort University, DTU Space & expert support from Keith Raney (JHU/APL)
- Objectives & Methodology
  - Quantify range retrieval accuracy in pulse-limited and SAR mode as a function of significant wave height
    - Develop physically-based models for SAR altimeter ocean waveforms
    - Apply physically-based models to SAR ocean waveforms
      - Done for both simulated and real Cryosat SAR waveforms over ocean
  - Investigate method to reduce SAR mode data to pseudo-LRM (RDSAR)
  - Applications to ASIRAS, analyses of SAR waveforms over inland water, coastal regions, ocean bottom topography,…

Key results from SAMOSA

(not shown in this talk)

- Simulated SAR and LRM waveforms from Cryosat-2 Mission Simulator over ocean were used to confirm a 2-fold improvement in range retrieval accuracy with SAR compared to LRM
- Simulated SAR waveforms can be successfully transformed into pseudo-LRM waveforms that can be retracked with Brown model
  - RDSAR give the same range retrieval performance than LRM
- SAMOSA model was delivered to the Sentinel-3 Surface Topography Mission team (led by CLS) as a Detailed Processing Model (pseudo-code) for the operational S3-STM SAR ocean processor

Key results from SAMOSA in this talk

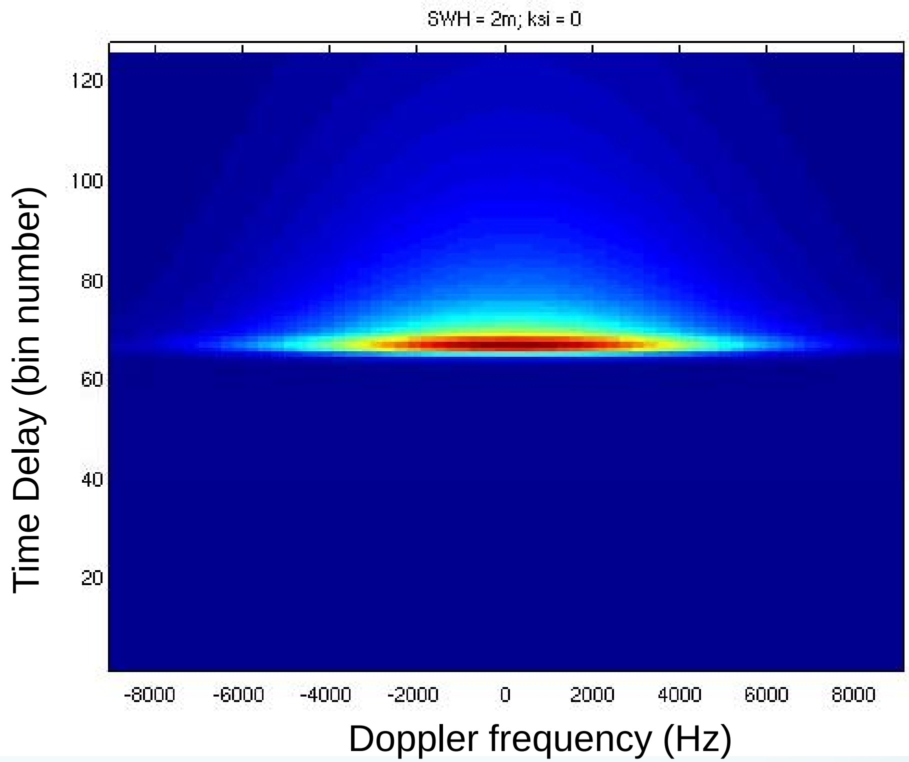
Physically-based SAMOSA models

Application to Cryosat-2 SAR ocean waveforms

Comparisons with Jason-2 and in situ data

SAMOSA SAR ocean waveform model

- Physically-based models developed by Starlab from first principles
- SAMOSA1, SAMOSA2 & SAMOSA3 formulations
- Numerical and analytical solutions to forward-model the SAR altimete[r] Delay Doppler Maps (DDM) for a burst of 64 pulses



- Models depend on epoch, significant wave height, normalised radar cross section and mispointing angle(s)

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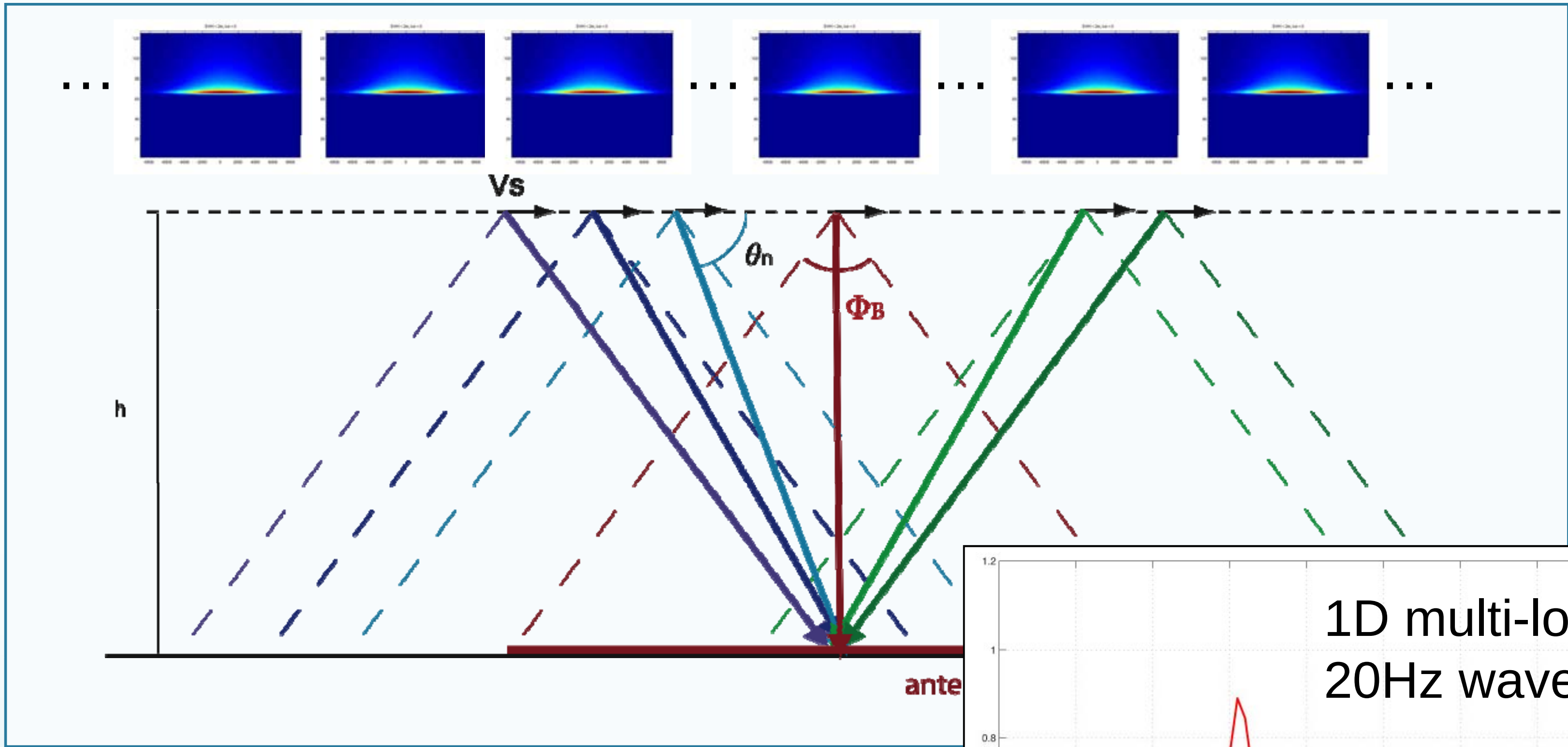
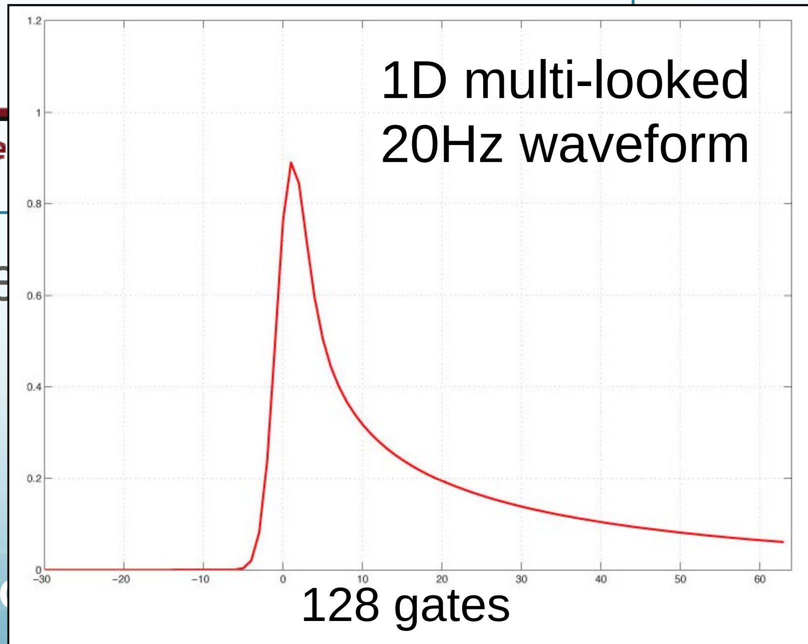
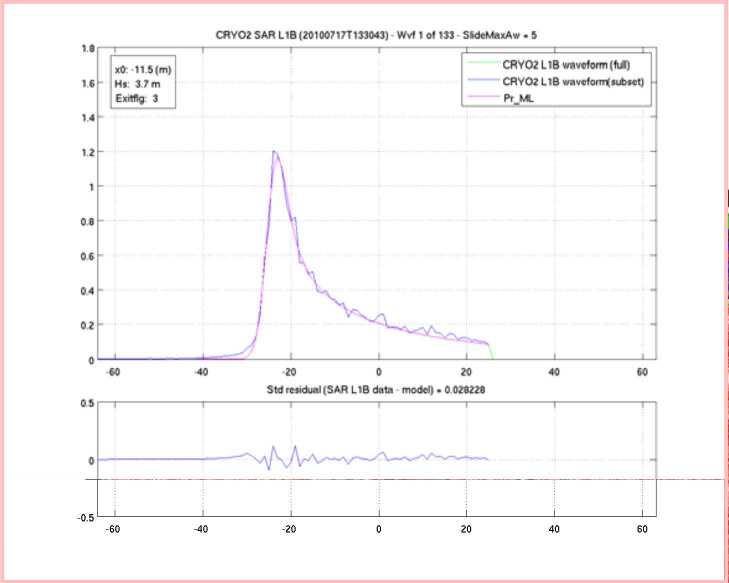
Multi-looking

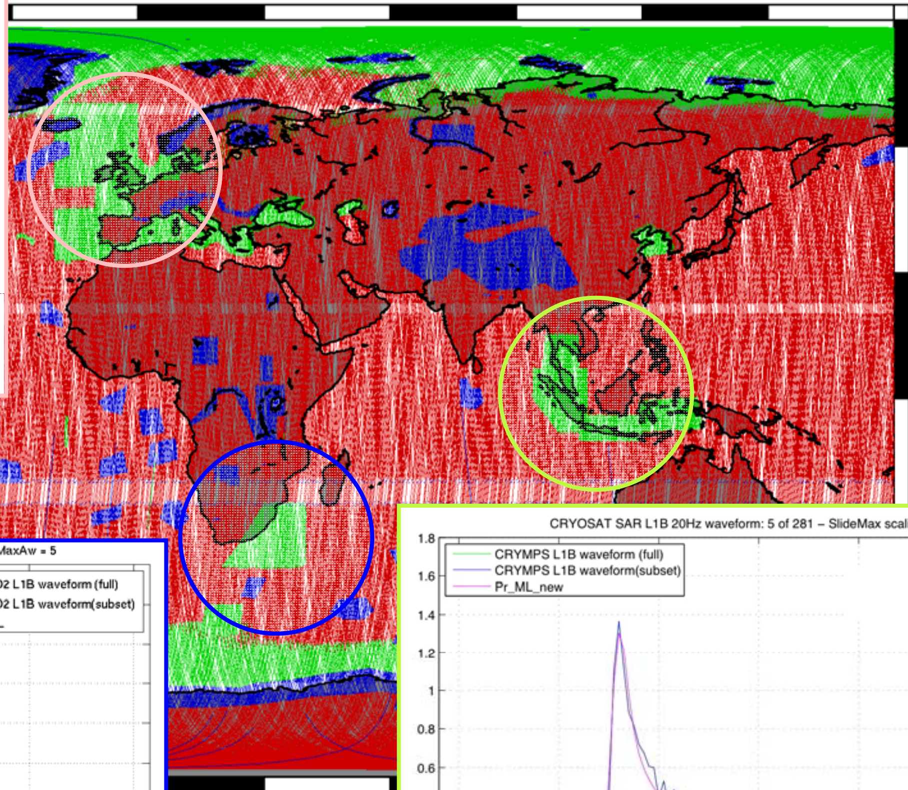


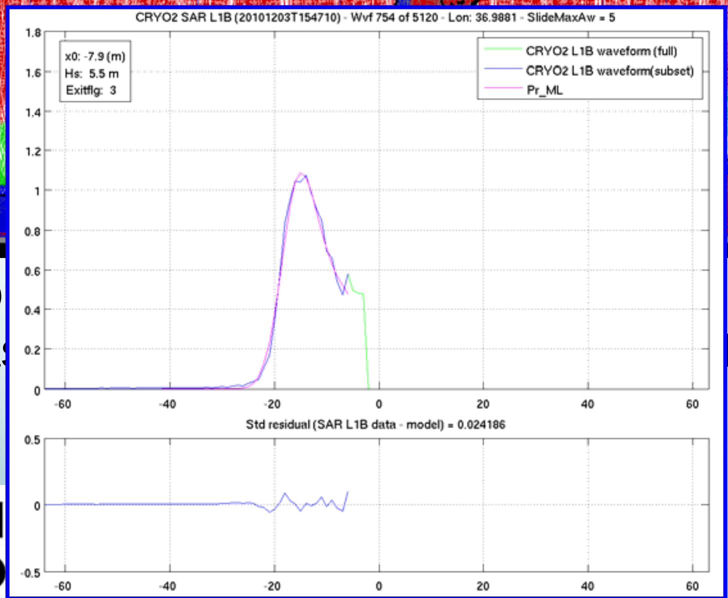


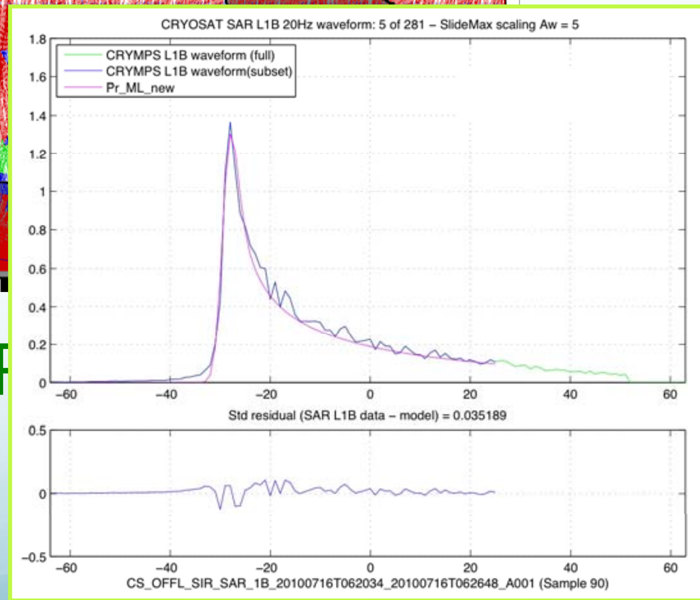
- Doppler-beam selection & incohe
  multiple bursts

at-2 SAR data with SAM1









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Improved SAMOSA models

- SAMOSA1 gives acceptable fit to Cryosat-2 SAR waveforms BUT…
  - Circular antenna beam, no across-track mispointing
  - Unphysical behaviour for large mispointing angles
  - Over-estimates significant wave height (Hs)
- Next generation model: SAMOSA2
  - entirely new physically-based formulation developed by Starlab
  - Accounts for asymmetric antenna beam, ellipticity of the Earth, along- AND across-track mispointing, non-linear ocean wave effects
  - Physically correct response to mispointing
  - Improved fit to Cryosat-2 SAR waveforms

Poster by Cristina Martin-Puig et al.

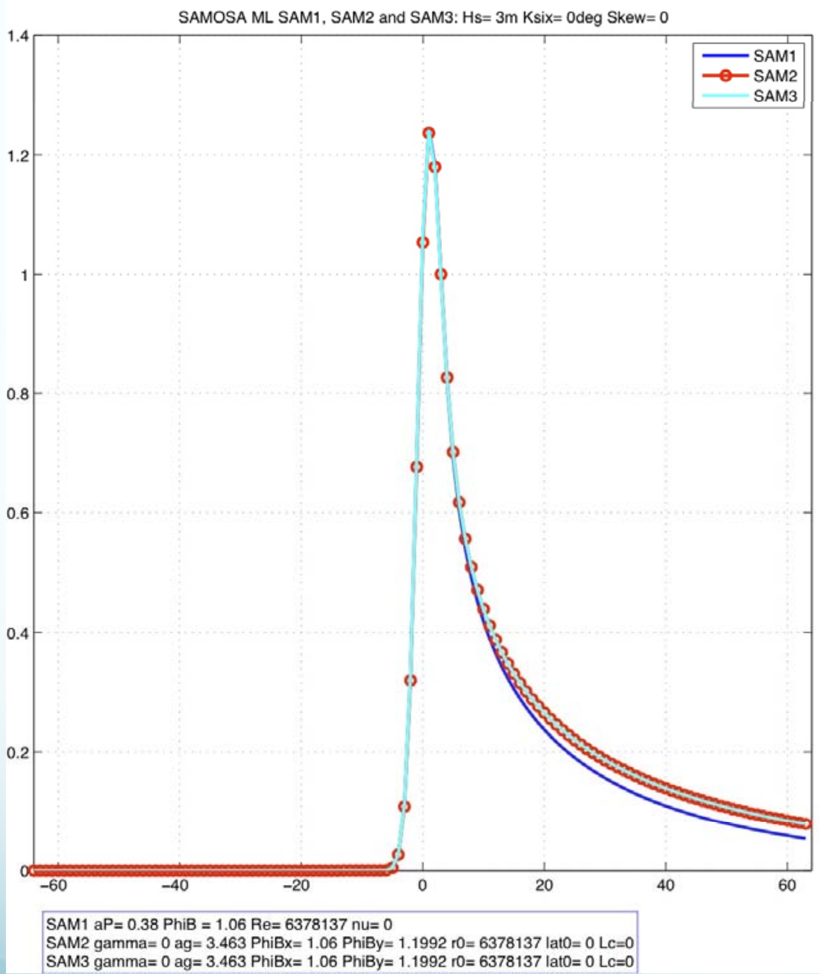
  - BUT… not fully-analytical & computational expensive

SAMOSA3 model

- Simplification of SAMOSA2 but keeps its advanced features
  - fully-analytical, robust and computationally fast !

	SAMOSA1	SAMOSA2	SAMOSA3
Non-linear wave statistics	N	Y	N
Asymmetric antenna	N	Y	Y
Earth ellipticity effects	N	Y	Y
Across-track mispointing	N	Y	Y
Correct response to mispointing	N	Y	Y
Fully analytical	Y	N	Y
Computationally efficient	Y	N	Y

Comparing SAM1, SAM2 and SAM3



- With ASYMMETRIC antenna beam and Earth ellipticity effects included:
  - SAM3 and SAM2 are equivalent

Simplifying SAM2 has negligible effect

  - Marked difference between SAM2/SAM3 and SAM1 in trailing edge
    - symmetric antenna in SAM1

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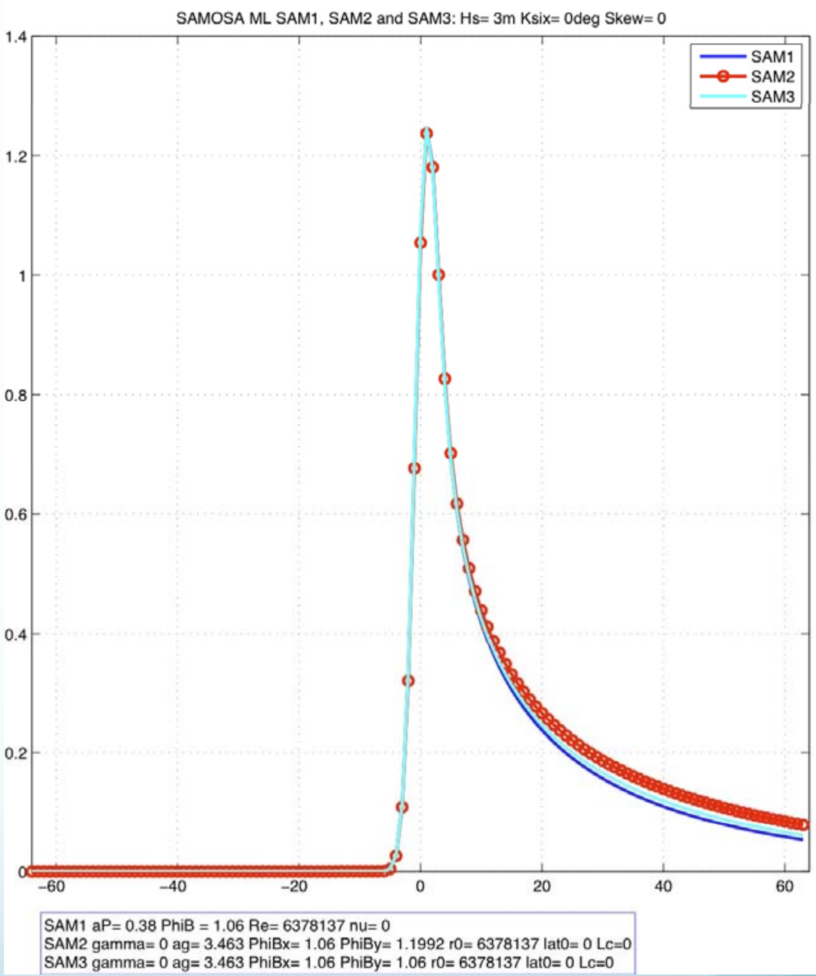
Comparing SAM1, SAM2 and SAM3

- With SYMMETRIC antenna beam and no Earth ellipticity effects:
  - SAM3 and SAM1 are equivalent

These two entirely independent theoretical models converge !



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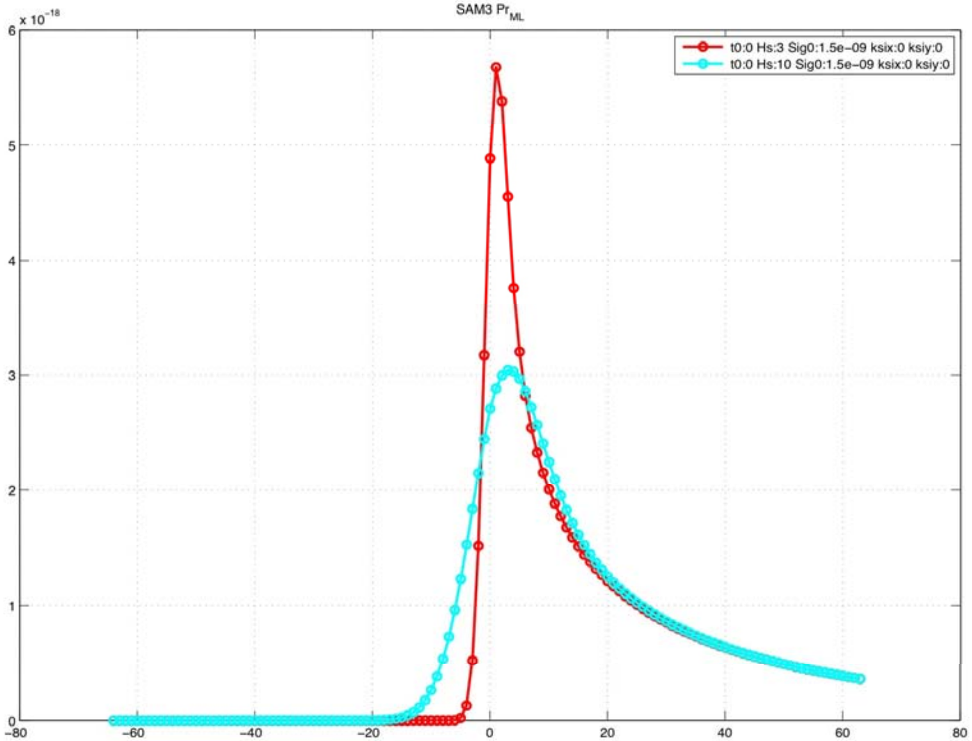
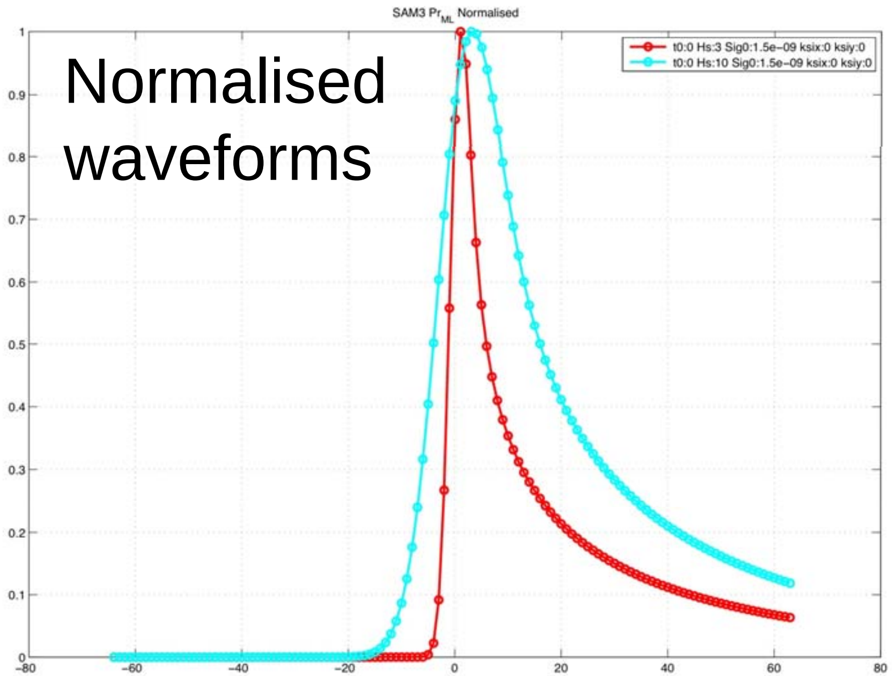
SAM3: Dependence on Hs



Hs = 3 and 10 m

Hs affects waveform amplitude and width of the peak

Normalised waveforms



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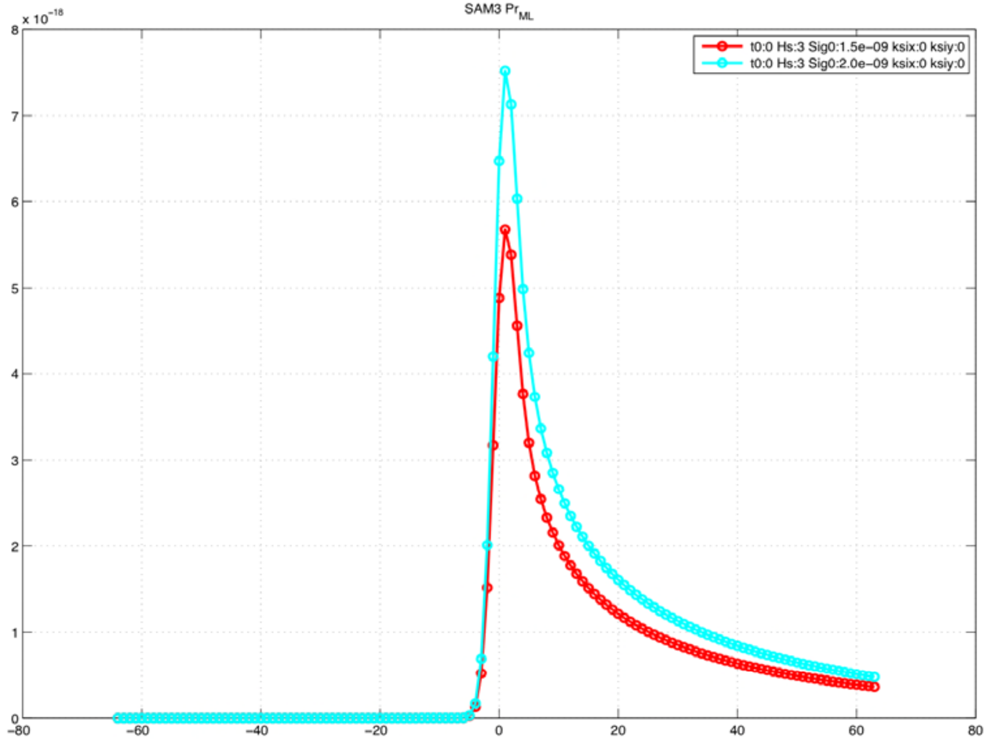
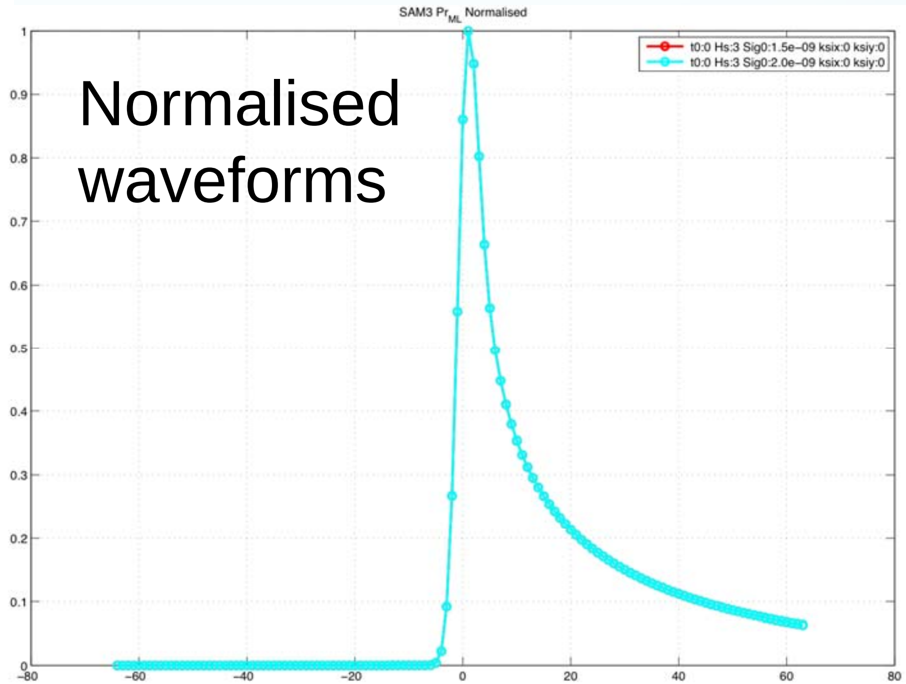
SAM3: Dependence on Sigma0



Sigma0 affects waveform amplitude but <u>not</u> the shape of normalised waveforms



Normalised waveforms

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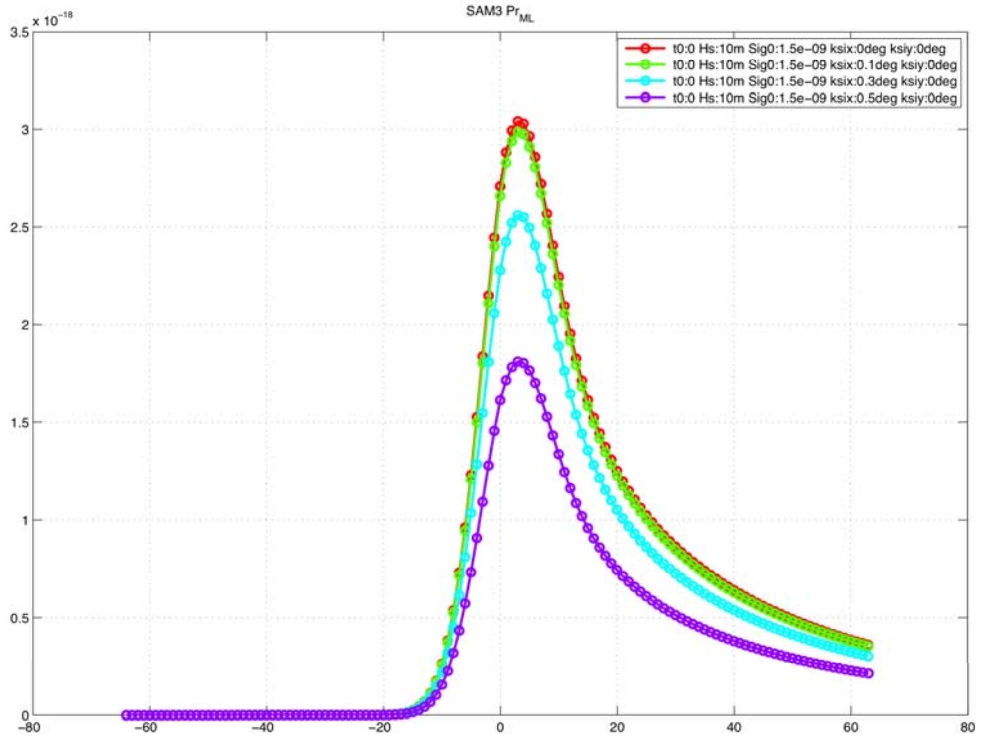
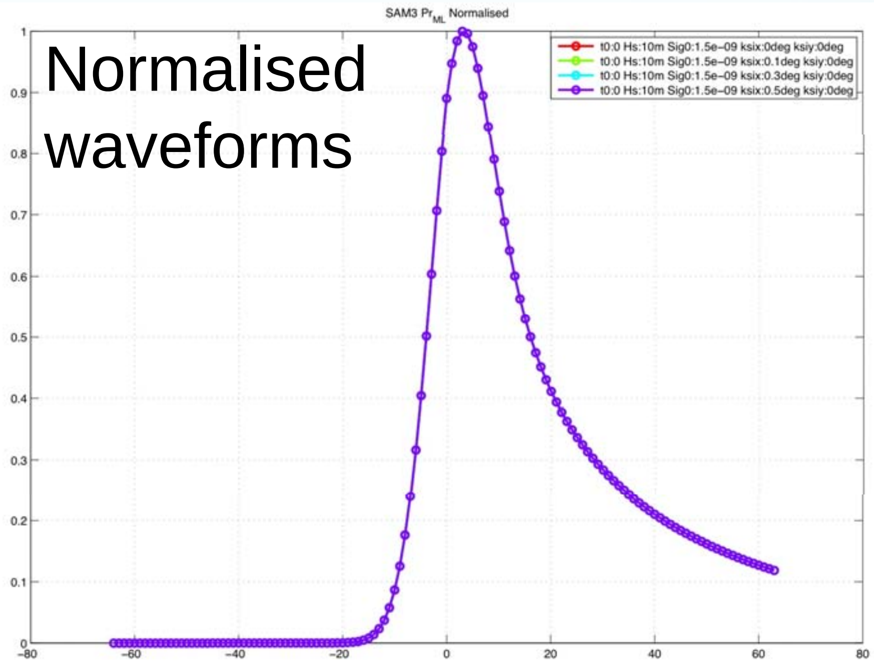
SAM3: Dependence on Ksix



Ksix = 0, 0.1, 0.3 and 0.5 deg

Along-track mispointing affects amplitude but not the shape of normalised waveforms

Note that the effect is small for ksix < 0.1 deg



Normalised waveforms

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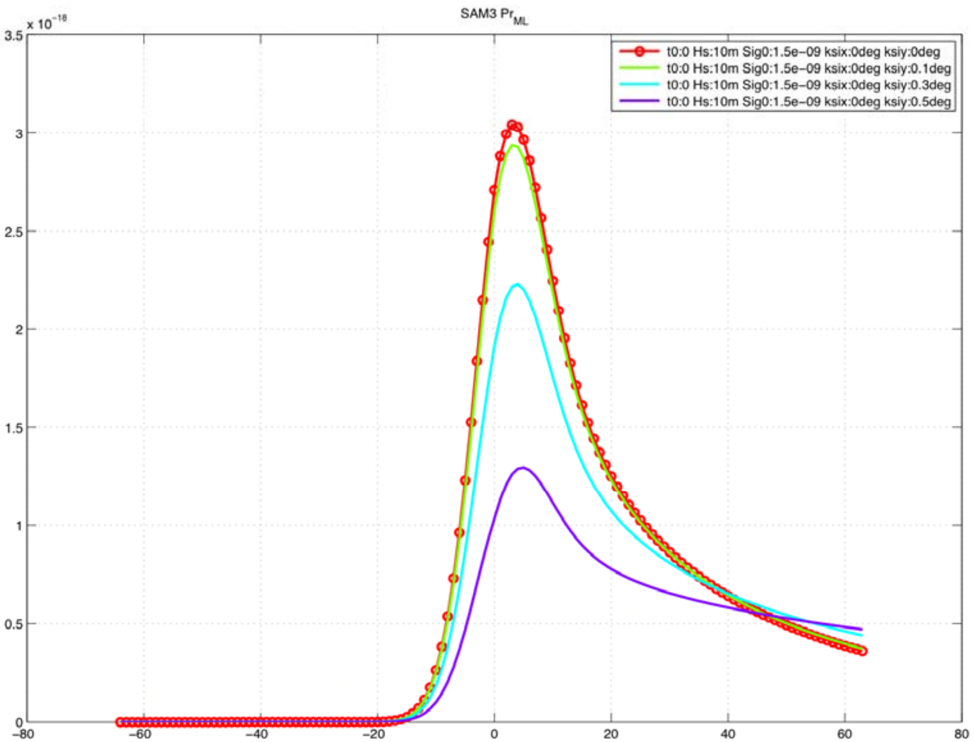
SAM3: Dependence on Ksiy

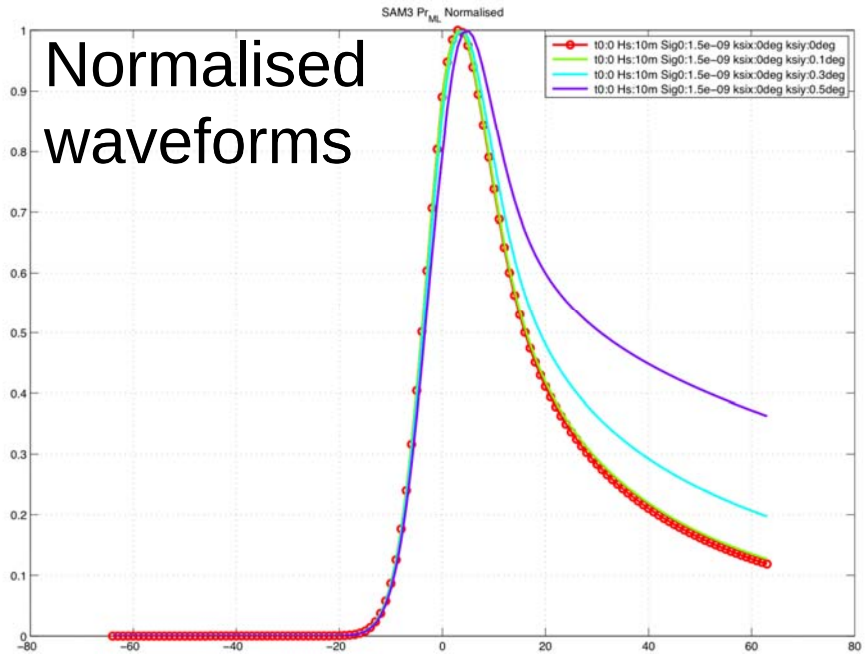


Ksiy = 0, 0.1, 0.3 and 0.5 deg

Across-track mispointing affects waveform amplitude and slope of the trailing edge

Note that the effect is small for ksiy < 0.1 deg

Normalised waveforms



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Application to Cryosat-2 SAR waveforms

Range error with C2 SAR & J2 LRM

Retrieval of Hs in SAR mode

Range error in SAR and LRM as a function of sea state

- Lots of Cryosat-2 data in LRM and SAR mode since July 2010 but not collocated (SAR and LRM are exclusive modes)

- Comparison of Cryosat2 SAR with Jason2 LRM
- Focus on small area in Norwegian Sea
- July 2010 – March 2011
  - Wide range of sea states

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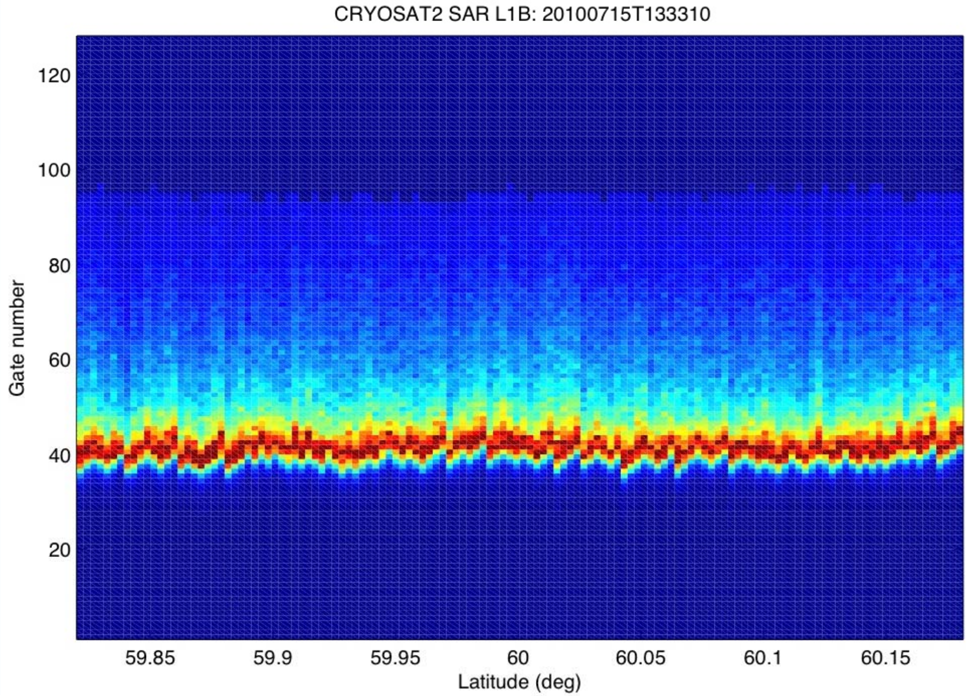
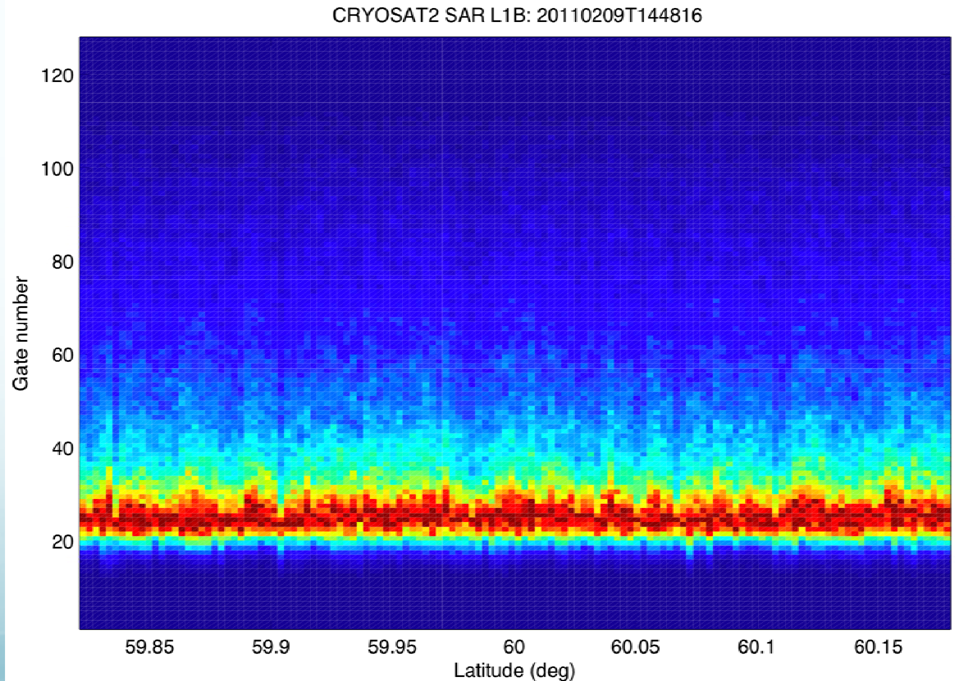
Cryosat-2 SAR in Norwegian Sea





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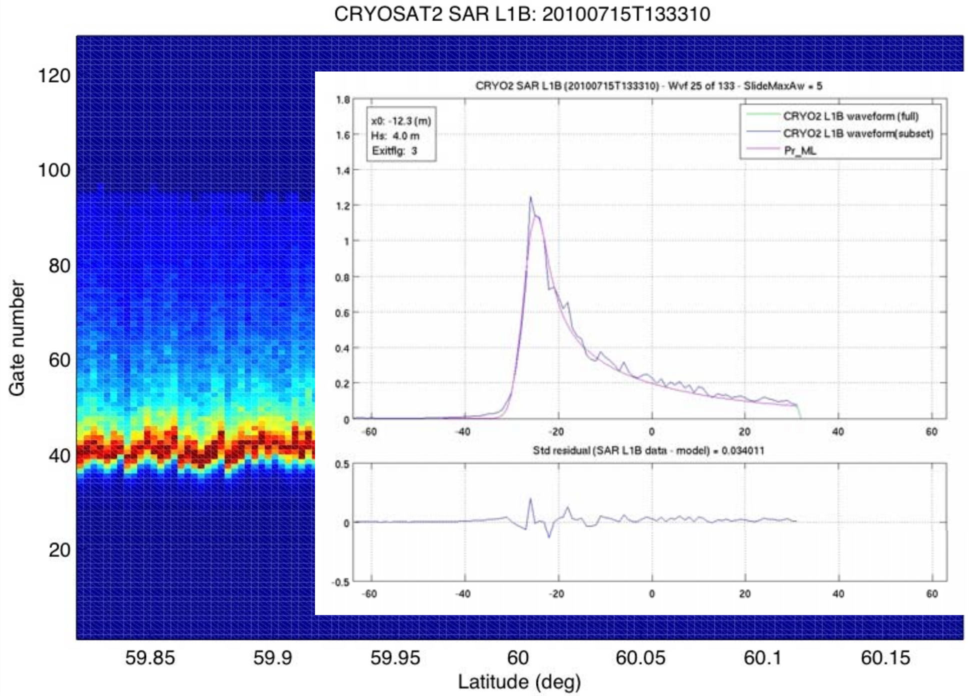
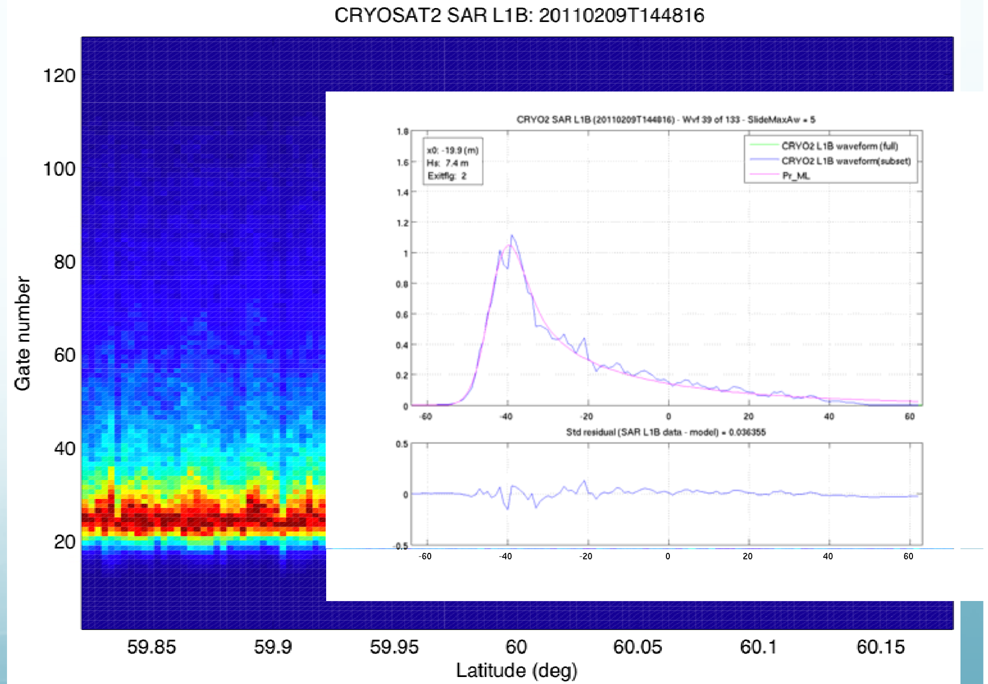
Cryosat-2 SAR in Norwegian Sea





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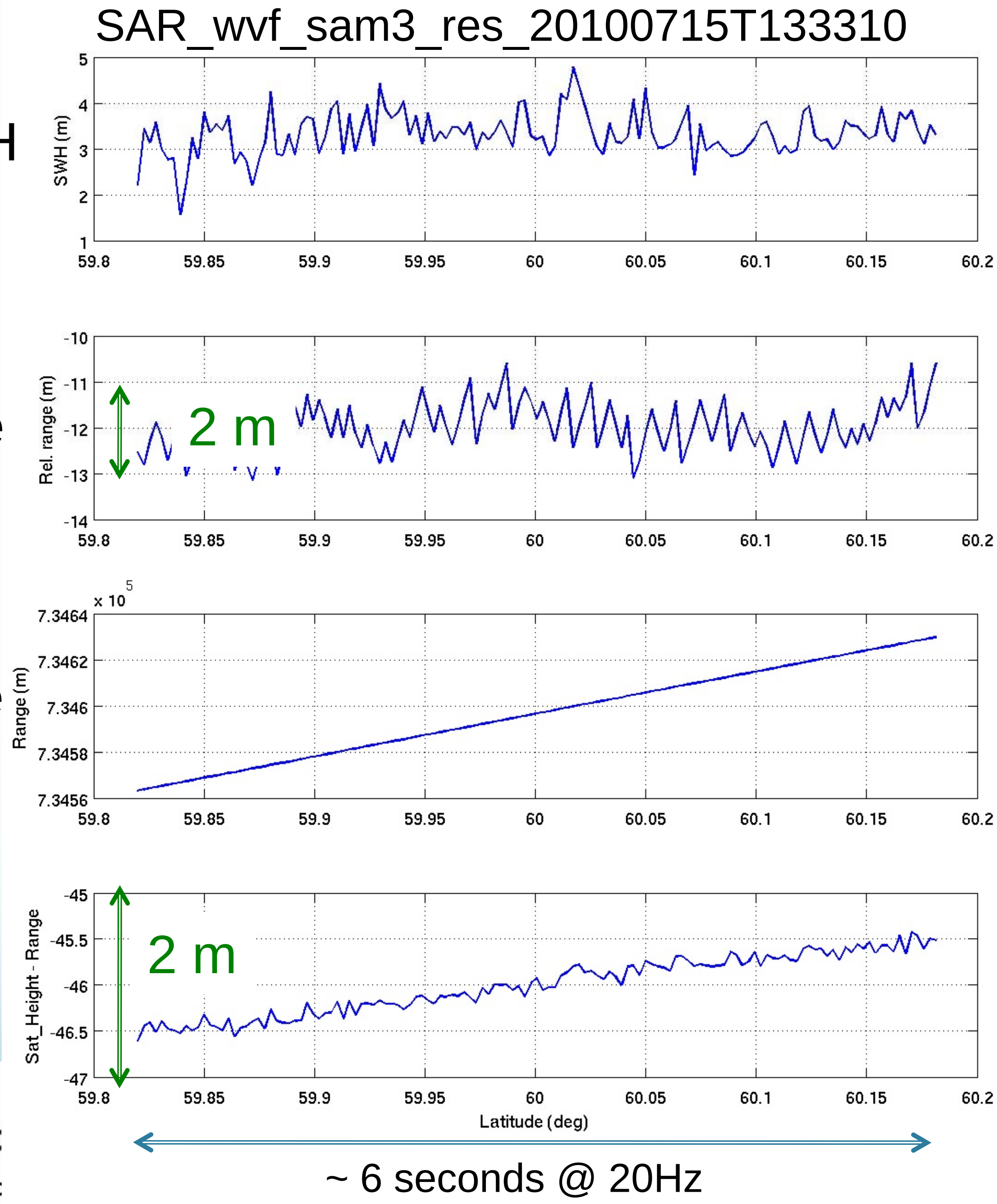
C2 SAR 20Hz L1B

SWH

Relative Range

Range to satellite

SSH = Altitude - Range



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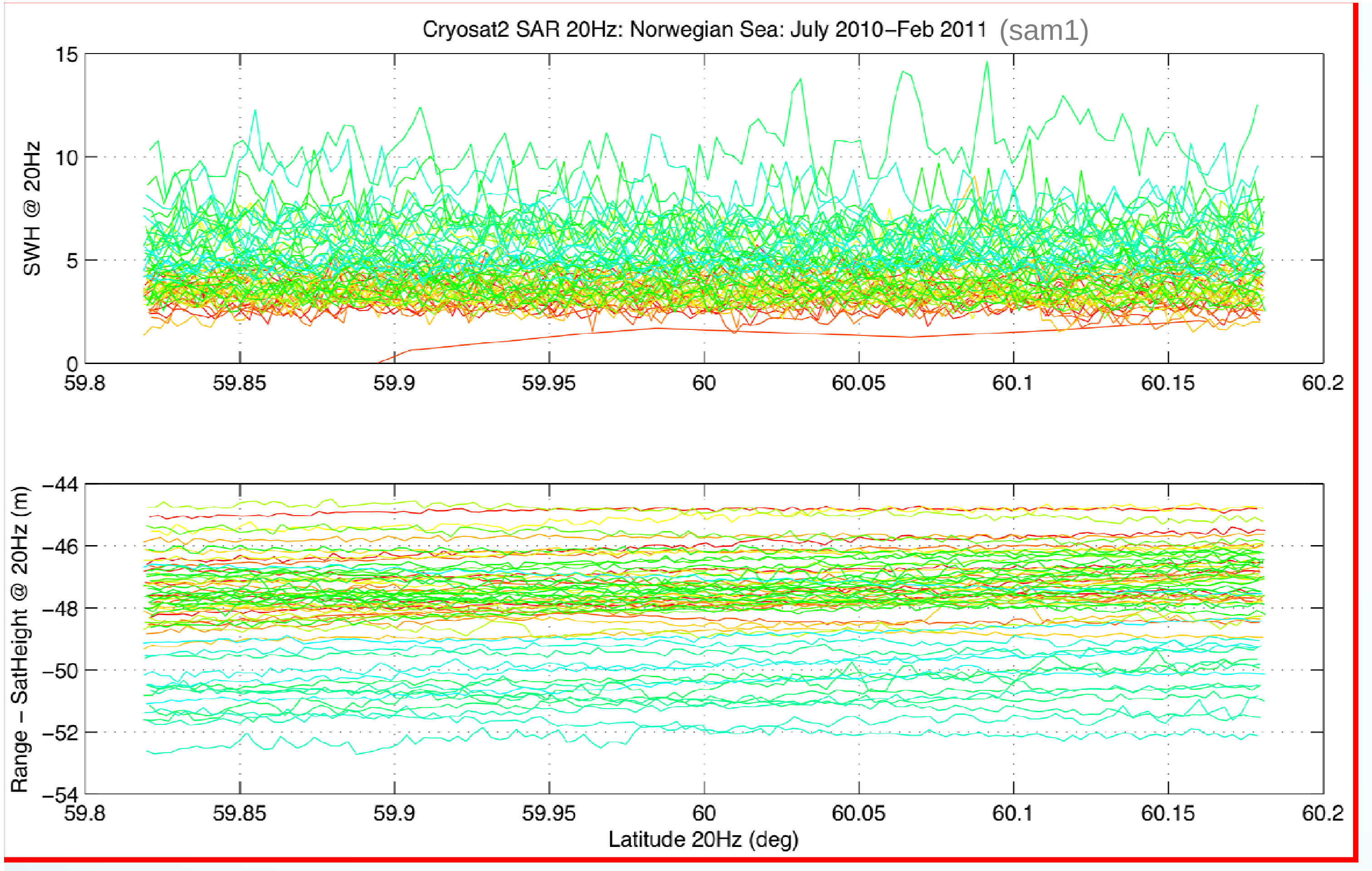
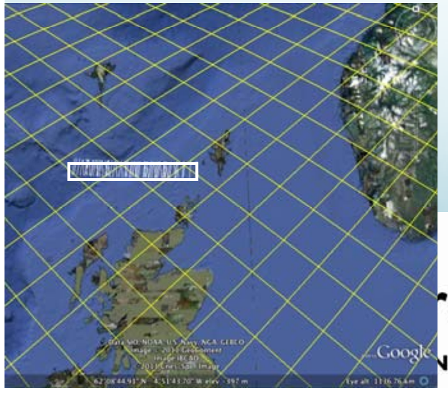


C2 L1B SAR 20Hz (SAM1)



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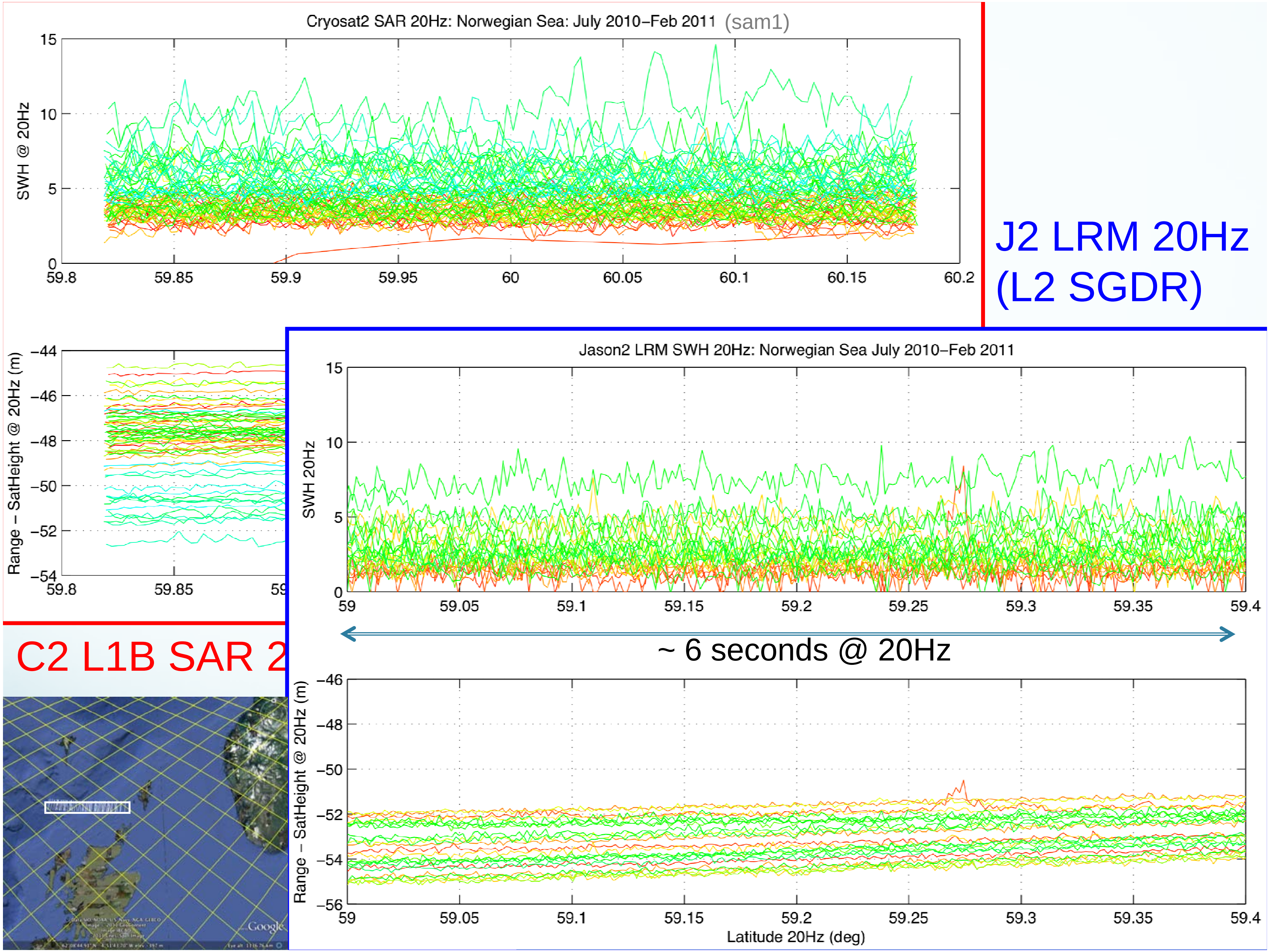
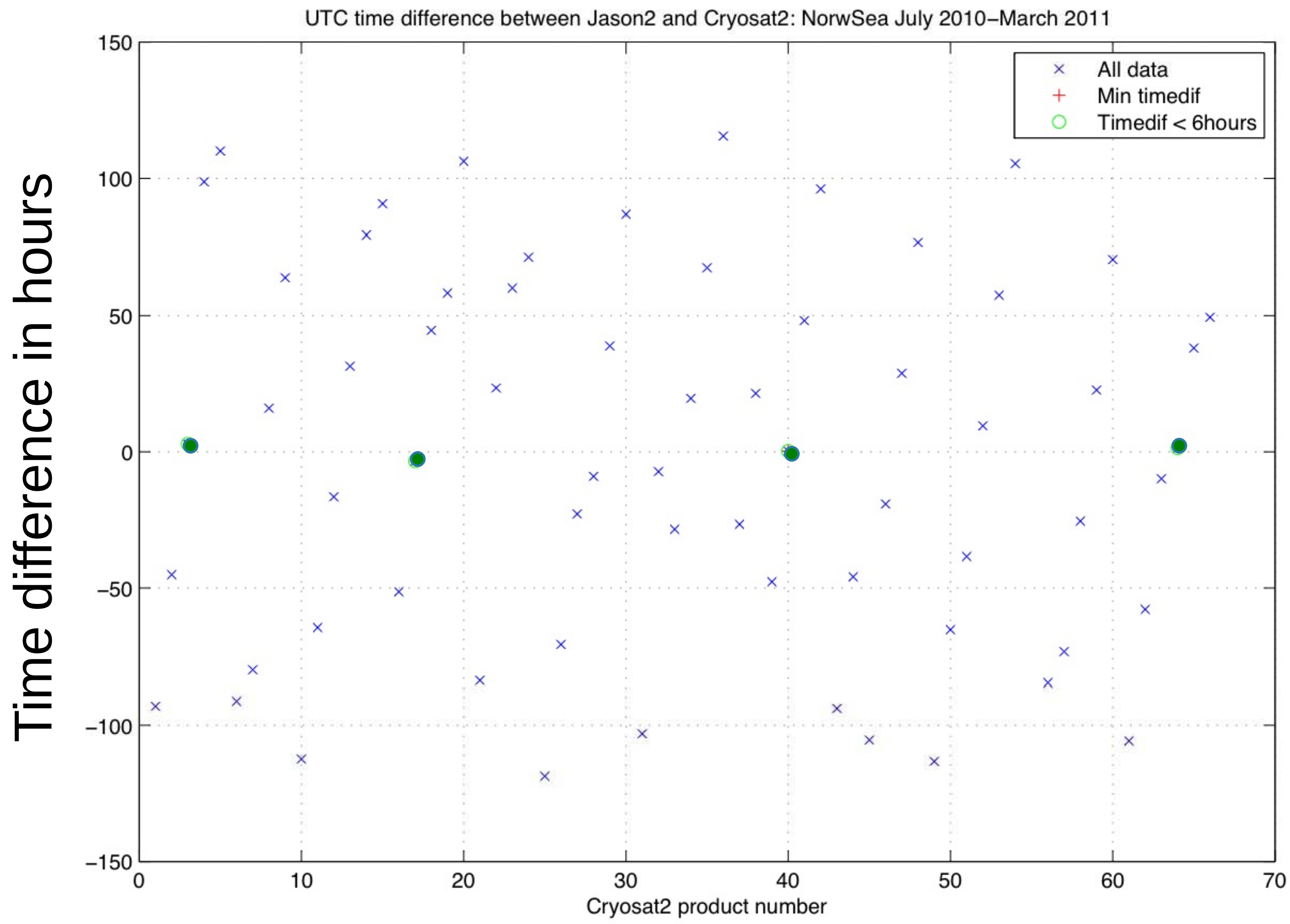
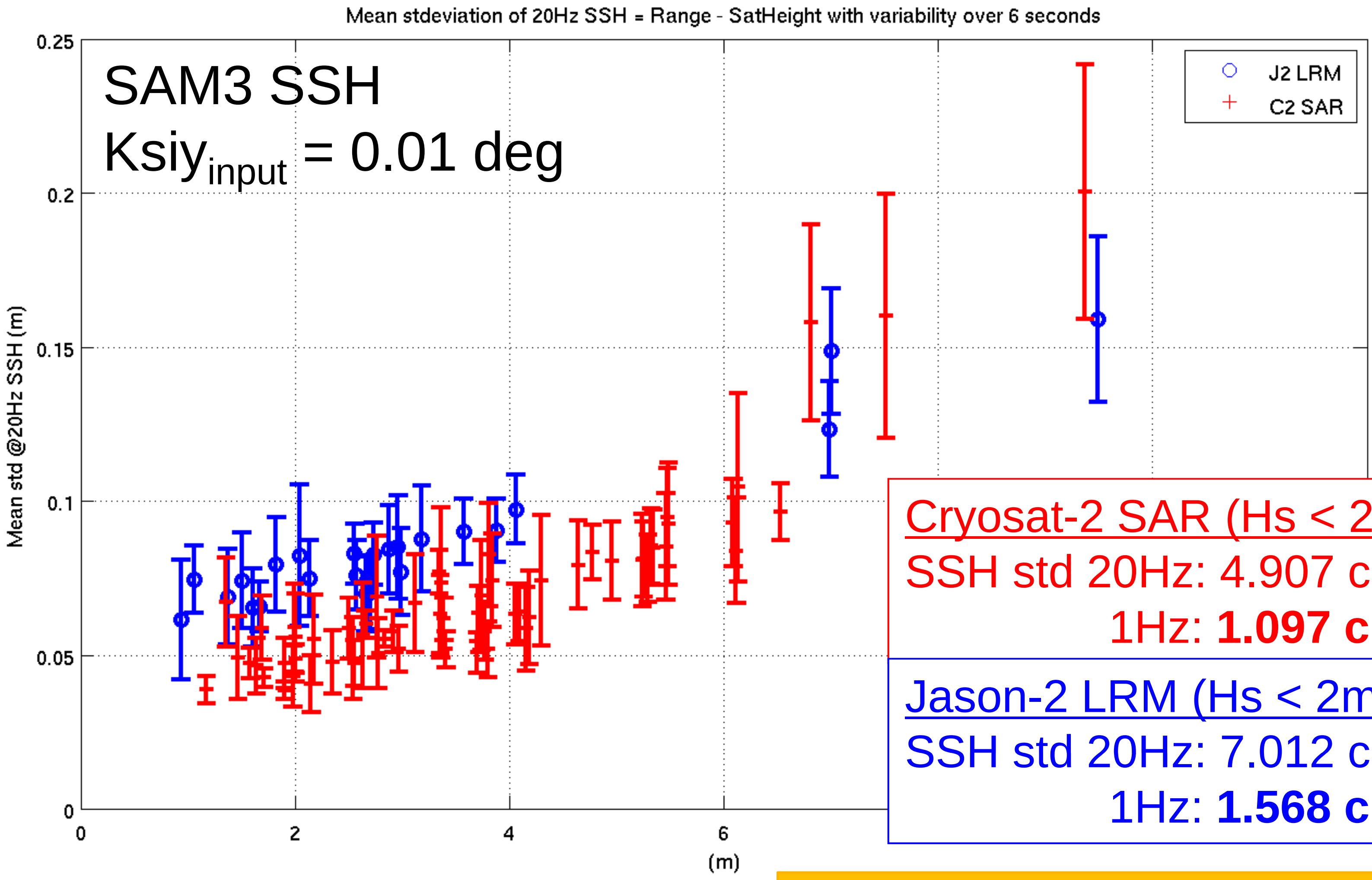


Cryosat2 SAR 20Hz: Norwegian Sea: July 2010–Feb 2011 (sam1)
SWH @ 20Hz
Range – SatHeight @ 20Hz (m)
J2 LRM 20Hz
(L2 SGDR)
C2 L1B SAR 2
Jason2 LRM SWH 20Hz: Norwegian Sea July 2010–Feb 2011
SWH 20Hz
~ 6 seconds @ 20Hz
Range – SatHeight @ 20Hz (m)
Latitude 20Hz (deg)
Google

Few C2/J2 collocations in time



Variability in SSH (Norwegian Sea)



Cryosat-2 SAR (Hs < 2m)
SSH std 20Hz: 4.907 cm
1Hz: **1.097 cm**

Jason-2 LRM (Hs < 2m)
SSH std 20Hz: 7.012 cm
1Hz: **1.568 cm**

Factor of 1.43 reduction in SSH error with C2 L1B SAR

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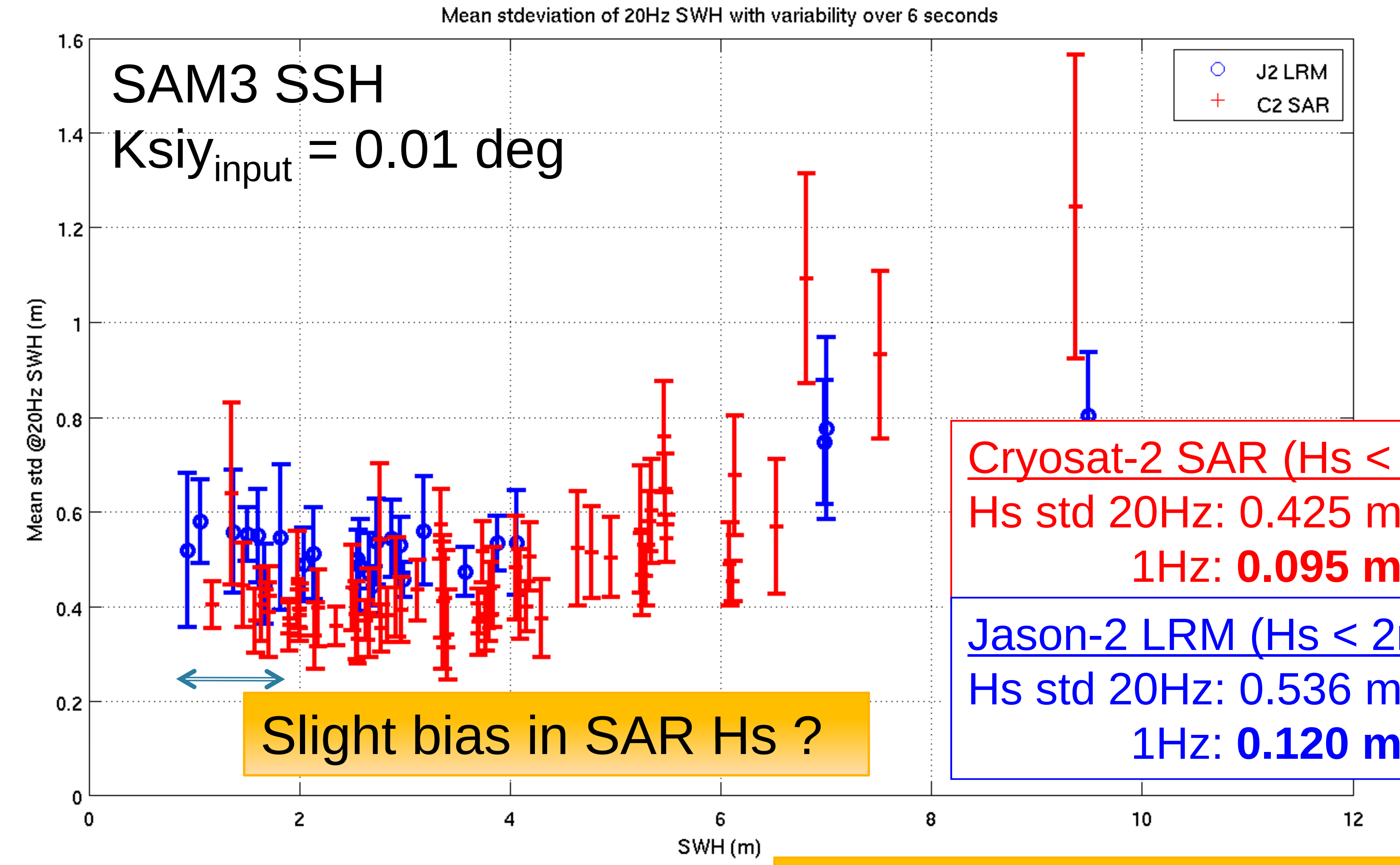
Variability in Hs (Norwegian Sea)



Slight bias in SAR Hs ?

Cryosat-2 SAR (Hs < 2m)
Hs std 20Hz: 0.425 m
1Hz: **0.095 m**

Jason-2 LRM (Hs < 2m)
Hs std 20Hz: 0.536 m
1Hz: **0.120 m**

Factor of 1.26 reduction in SWH error with C2 L1B SAR

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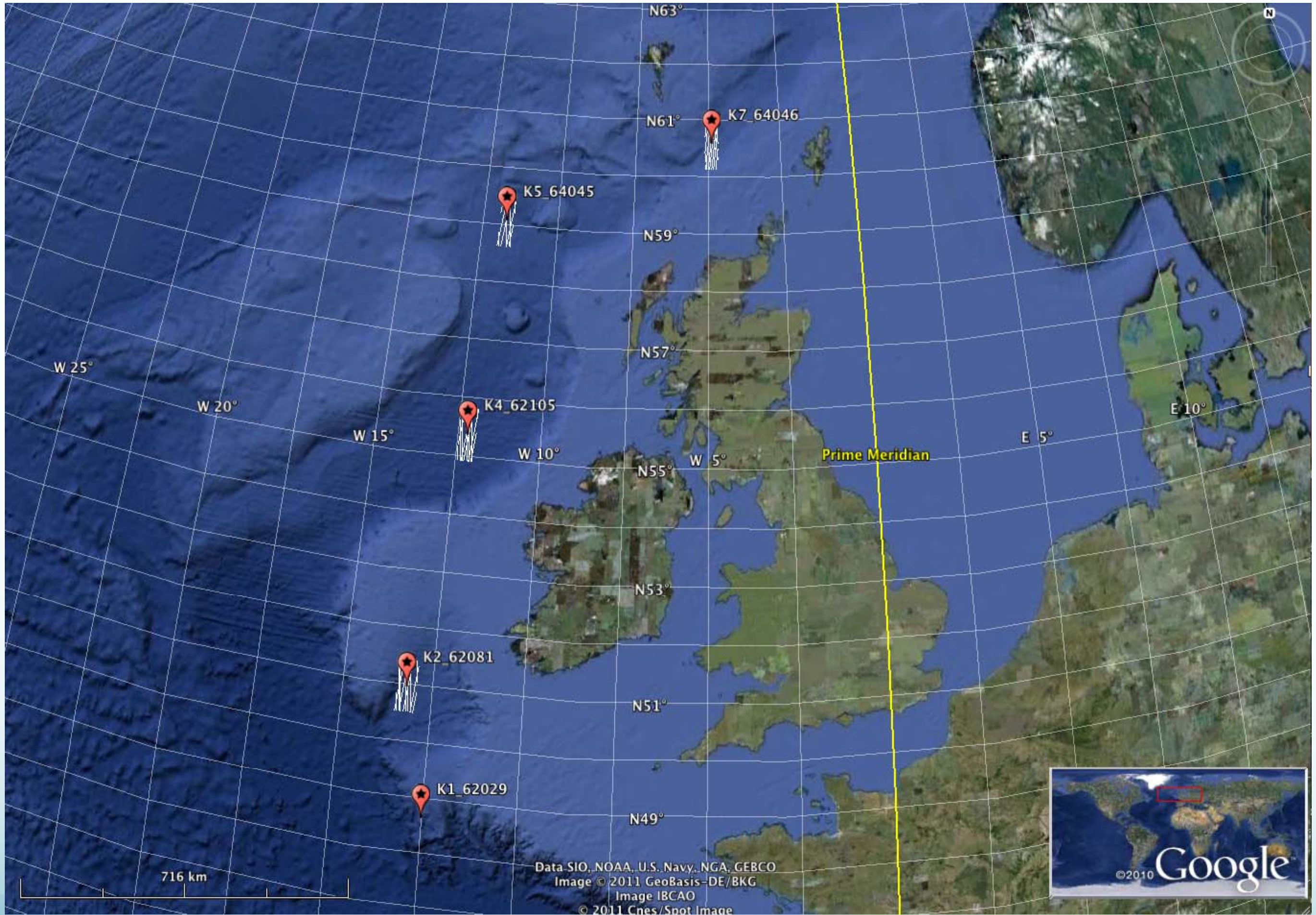
Bias in SAR Hs ?

Validation against wave buoys



Buoy wave height data from UK Met Office

C2 SAR data and buoys collocated within 50km and 30 minutes

Data for July 2010 - May 2011

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C2 SAR Hs against buoys

- Linear relation between C2 SAR Hs and buoy Hs over full range of sea states
- Small bias < 0.5 m; Std ~ 0.3 m
- Hs bias is directly linked to across-track mispointing used as input to the SAR retracker
  - use of platform mispointing data as input to the SAR retracker should reduce this bias

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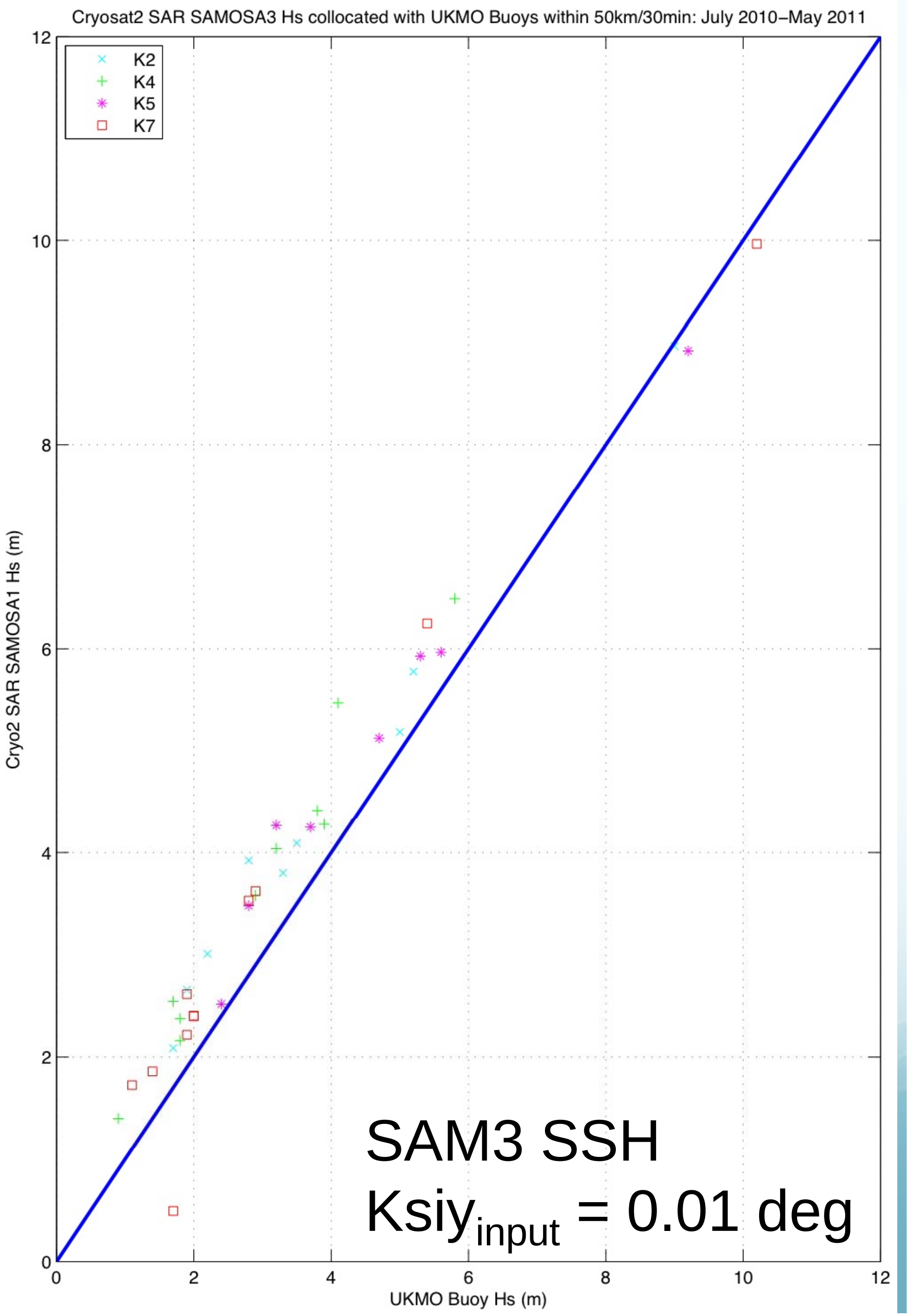

Summary & Conclusions

- Physically-based models of multi-looked SAR waveforms over the ocean have been developed in the SAMOSA project and used to retrack Cryosat-2 L1B SAR waveforms over the ocean
  - Cryosat-2 L1B SAR waveforms are generally of very high quality
  - Excellent fit between theoretical SAMOSA models and Cryosat-2 SAR data over a wide range of conditions
- The latest SAMOSA3 model offers a fully-analytical, robust and computationally efficient formulation, able to capture essential aspects of SAR ocean altimeter waveforms
  - E.g. asymmetric antenna beam and across-track mispointing
- SAMOSA3 will be recommended to update the Detailed Processing Model for Sentinel-3 STM SAR ocean operational retracking

Summary & Conclusions

- 20Hz and 1Hz variability in SSH and Hs were estimated for Cryosat-2 SAR and Jason-2 data over the same period in the Norwegian Sea
  - For SSH, variability at 1Hz is 1.1 cm for Cryosat-2 L1B SAR and 1.6 cm for Jason-2 LRM (factor of 1.43 reduction)
  - For Hs, variability at 1Hz is 9.5 cm for Cryosat-2 L1B SAR and 12.0 cm for Jason-2 LRM (factor of 1.26 reduction)

- Comparisons with buoys show that:
  - SAR mode will produce reliable estimates of Hs of similar or better quality than LRM
  - Slight bias high (< 0.5m) linked to across-track mispointing used in the SAR retracking

Summary & Conclusions

- Performance of Cryosat-2 SAR should improve with optimised SAR retracking that uses platform across-track mispointing as input
  - Both variability and Hs bias
  - Same analyses to be repeated in a less dynamic region
  - Analyses of Cryosat-2 SAR performance against pseudo-LRM products

- In summary:
  - Cryosat-2 SAR mode produces very good data over ocean
  - we have a fully-analytical, robust and computationally efficient model that successfully retracks Cryosat-2 SAR waveforms
  - SAR shows improved performance compared to LRM for both SSH and Hs

SAR opens up a wide range of new scientific possibilities over ocean and coastal zone

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Thank you for your attention

Supplementary slides

C2/J2 within 6 hours