

Finer, Better, Closer:

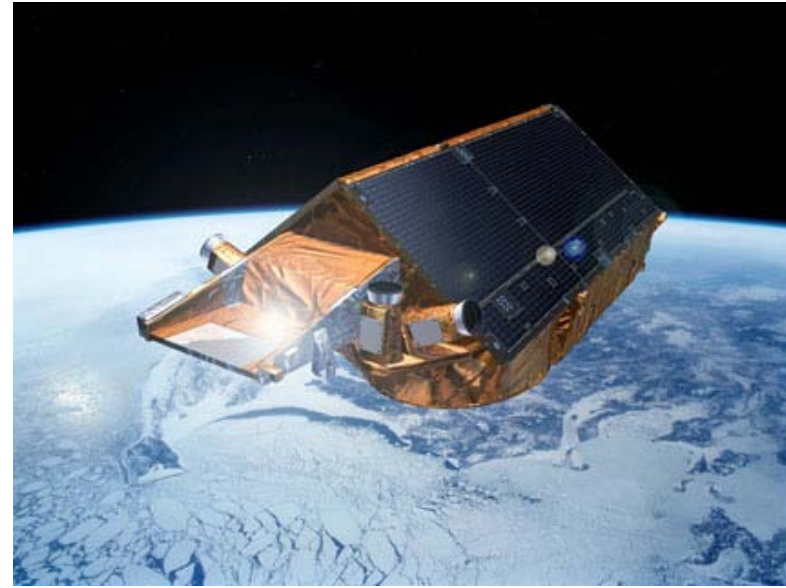
Advanced capabilities of SAR altimetry in the open ocean and the coastal zone

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& Jérôme Benveniste³

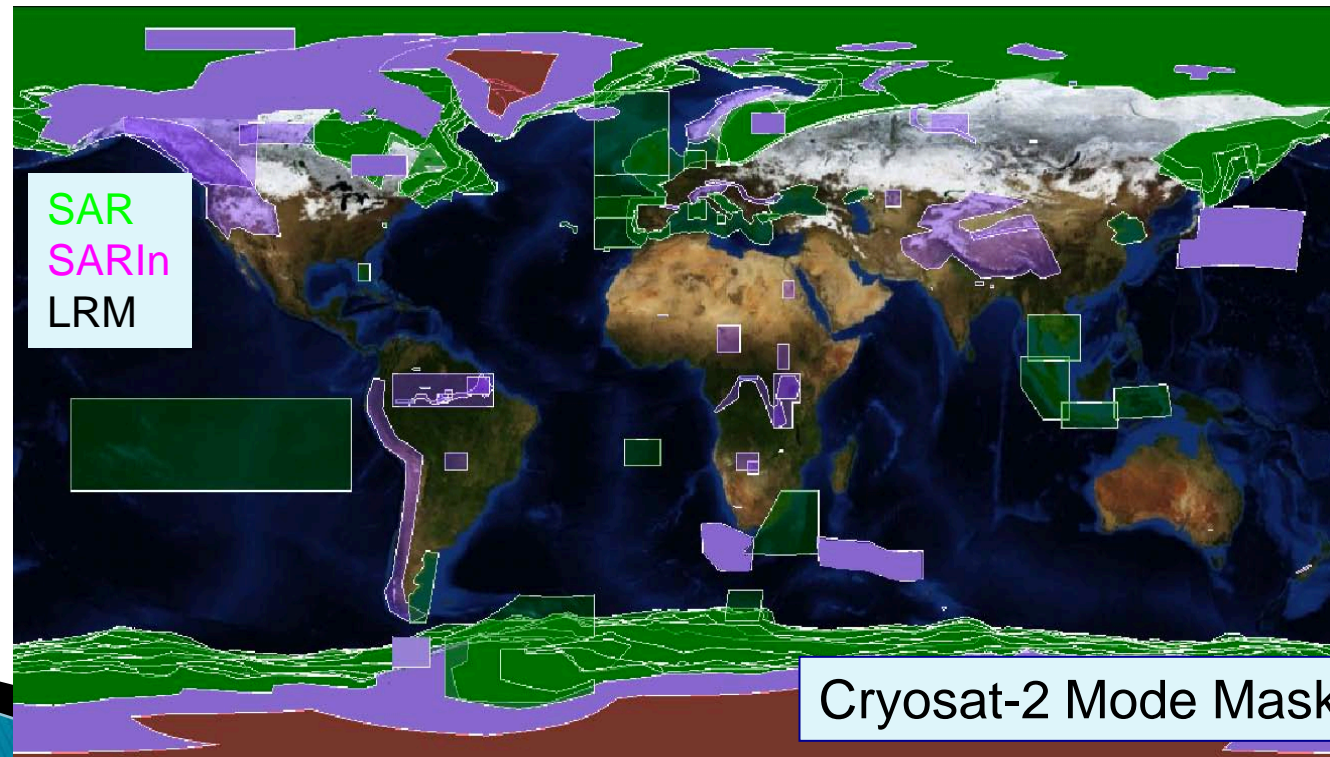
¹National Oceanography Centre, UK, ²Satellite Oceanographic
Consultants Ltd, UK, ³ESA-ESRIN

Motivation

- ▶ Cryosat-2 SIRAL => first SAR altimeter data from space
- ▶ SAR mode mainly over sea ice
- ▶ Also over some ocean & coastal regions

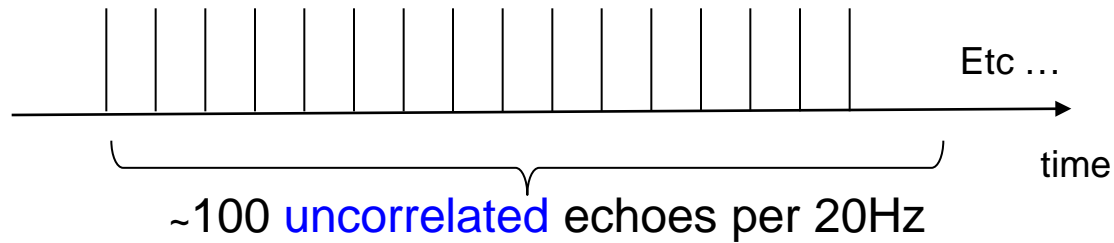


Assess capabilities of SAR altimetry over ocean & coastal zone, in anticipation of SAR altimeters mode on GMES Sentinel-3 & on Jason-CS

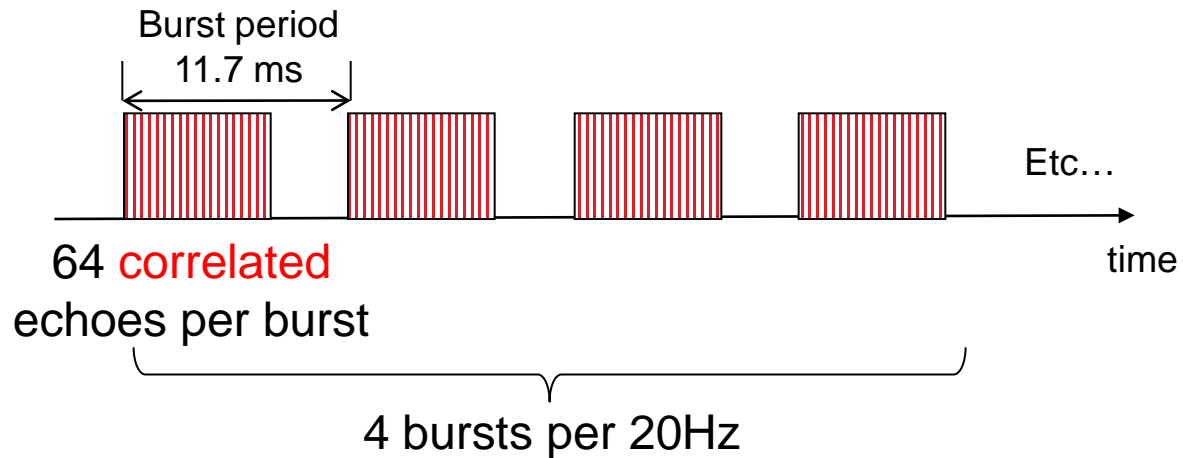


LRM & SAR mode

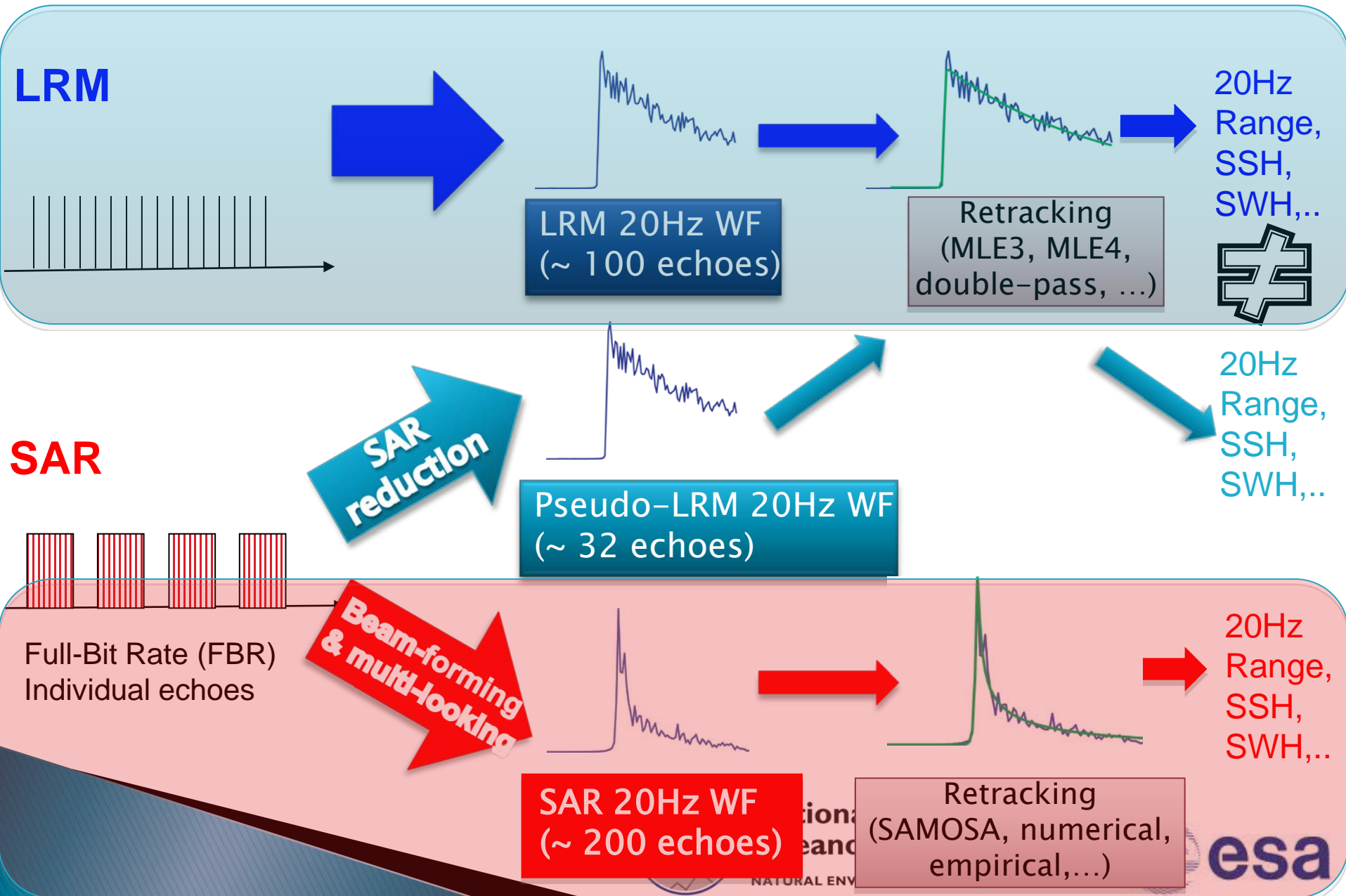
LRM
PRF~2kHz
Continuous



SAR
PRF~20 kHz
in bursts



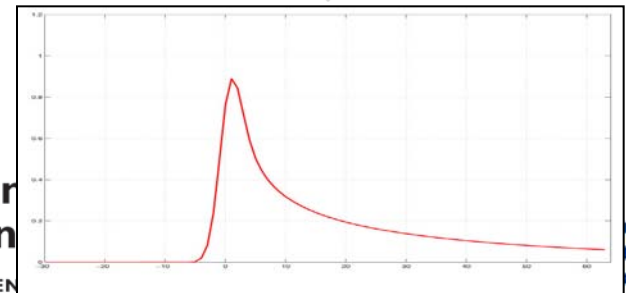
Why using correct terminology is essential...



The SAMOSA3 SAR waveform model

- ▶ Developed from physical principles by Starlab (Barcelona)
- ▶ SAM3: simple analytical formula, robust and fast to compute
- ▶ Computes 2D Delay Doppler Maps
- ▶ Function of epoch (range) significant wave height, Σ_0 , roll and pitch mispointing angles
- ▶ Apply Doppler beam-forming and multi-looking to obtain delay-only SAR altimeter waveforms

Beam-forming & multi-looking



Nation
Ocean
NATURAL EN

sa

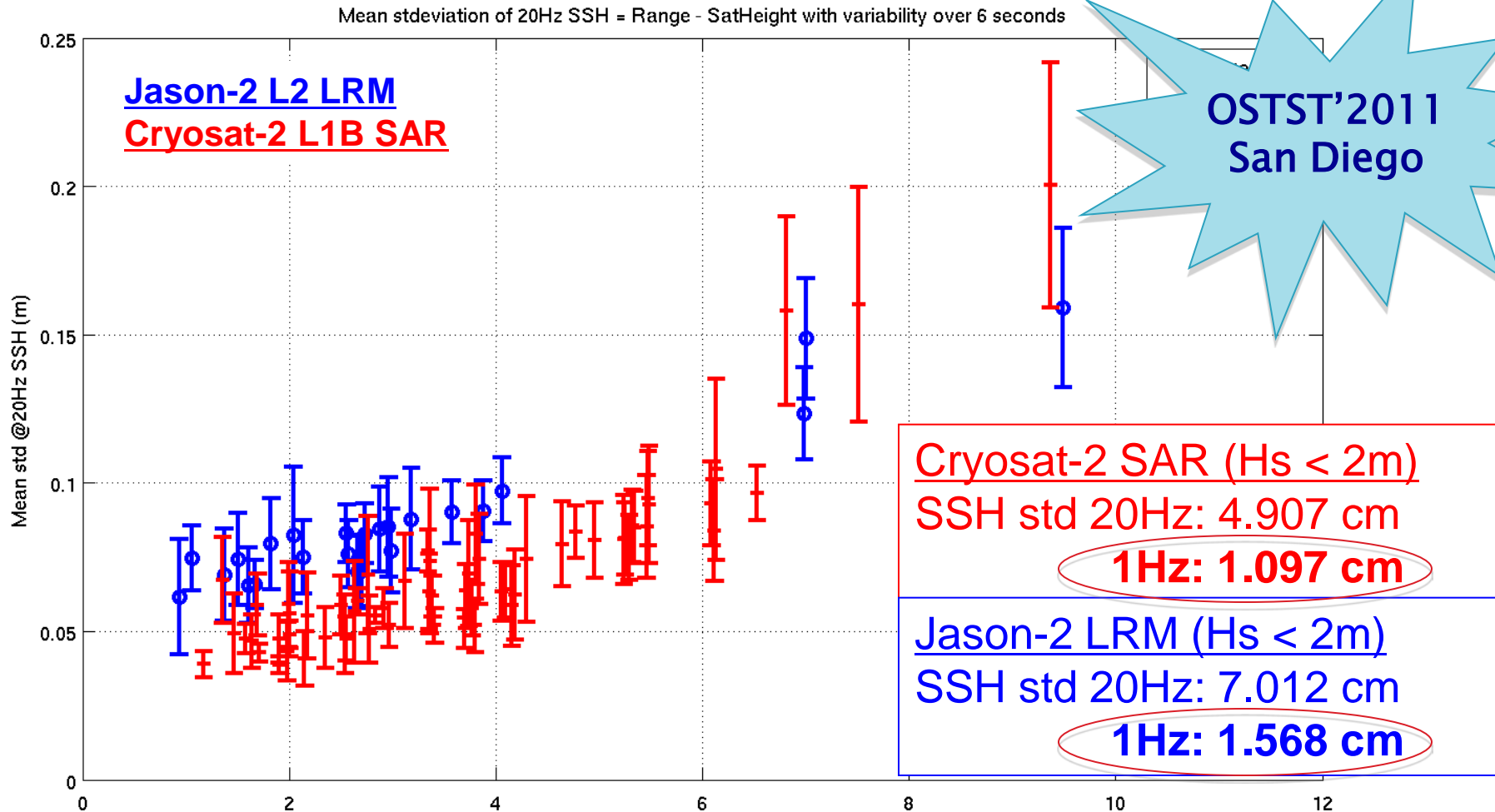
SSH noise in SAR & LRM

- ▶ Cryosat-2 LRM and SAR mutually exclusive
- ▶ Compare Cryosat-2 SAR against Jason-2 (pulse-limited)
 - Very few temporal collocations between the two satellites
- ▶ Select and retrack Cryosat-2 L1B 20Hz SAR waveforms with SAM3 in given area
 - e.g. Norwegian Sea
- ▶ Compute retrieval accuracy for SSH and SWH and plot against retrieved SWH
- ▶ Do the same for Jason-2
 - Based on L2 AVISO products



Norwegian Sea: SSH noise

(July 2010–Feb 2011)

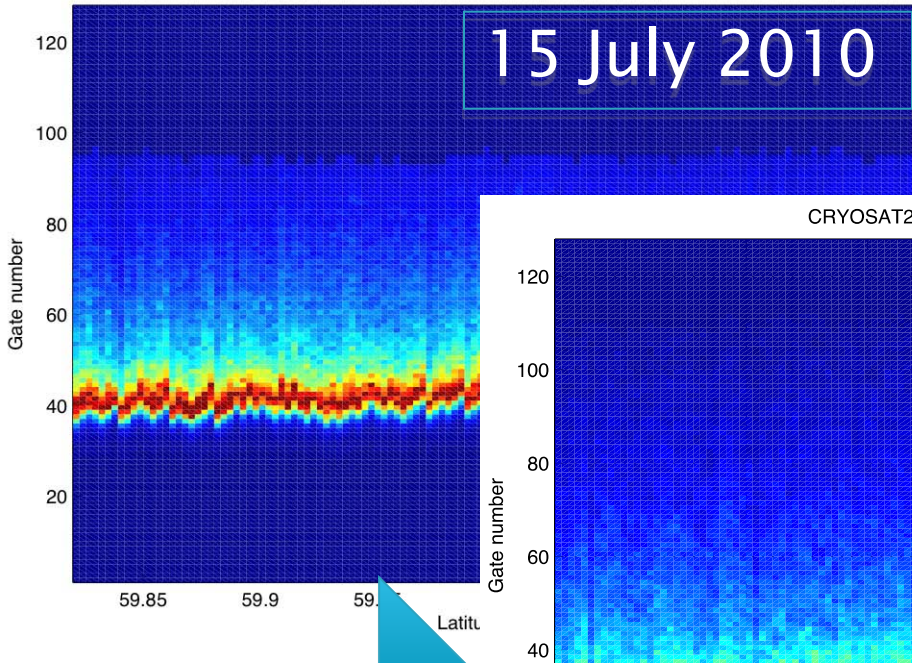


Factor of ~1.5 improvement of Cryosat-2 SAR versus Jason-2

Cryosat-2 SAR L1B products evolving in time !

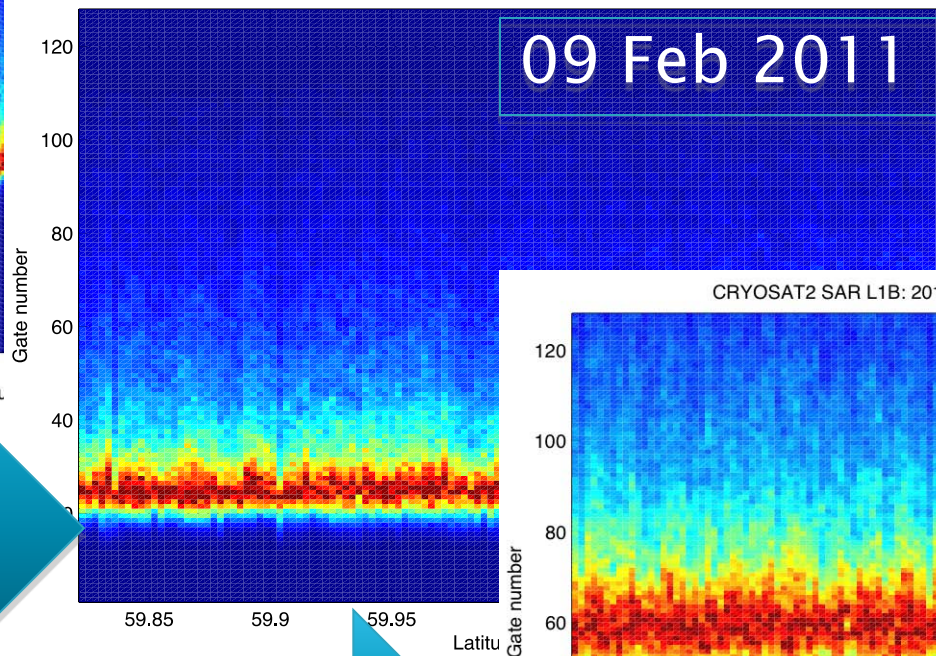
CRYOSAT2 SAR L1B: 20100715T133310

15 July 2010



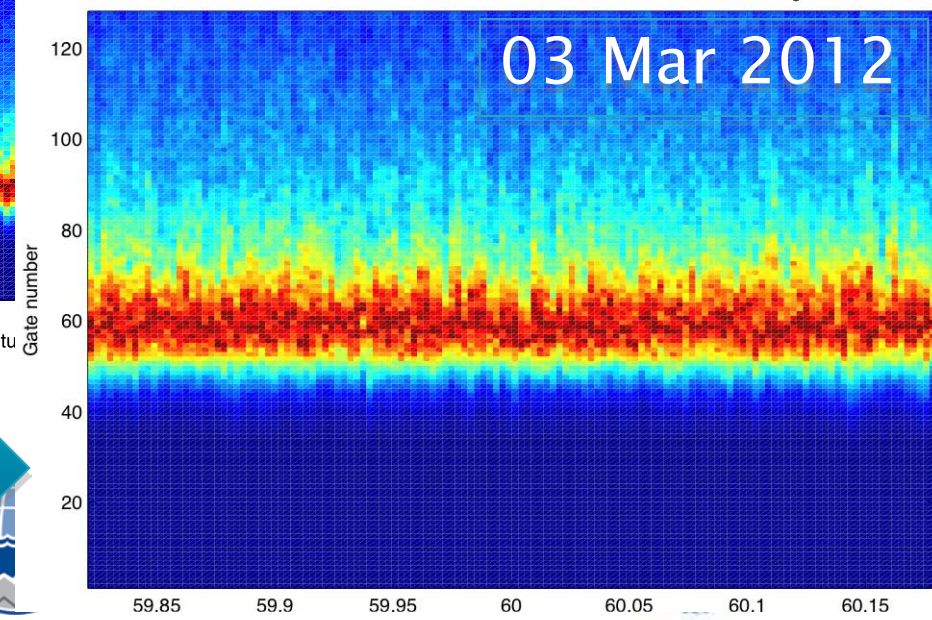
CRYOSAT2 SAR L1B: 20110209T144816

09 Feb 2011



CRYOSAT2 SAR L1B: 20120310T191057lat: 59.8208-60.1798deg

03 Mar 2012



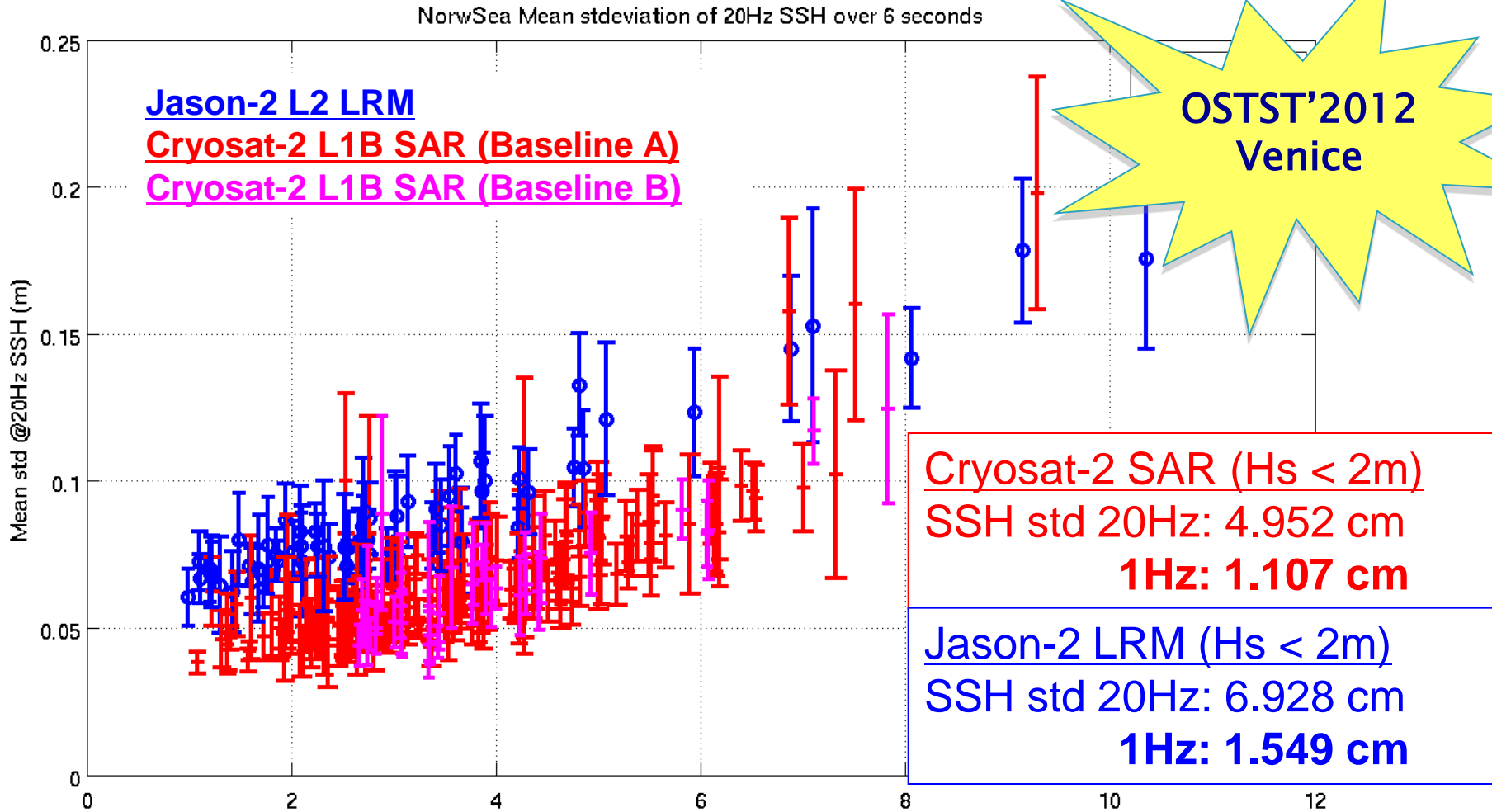
Smoother
leading edge
position

Switch to Baseline B
(finer gate spacing)
Feb 2012



Norwegian Sea: SSH noise

(July 2010–June 2012)

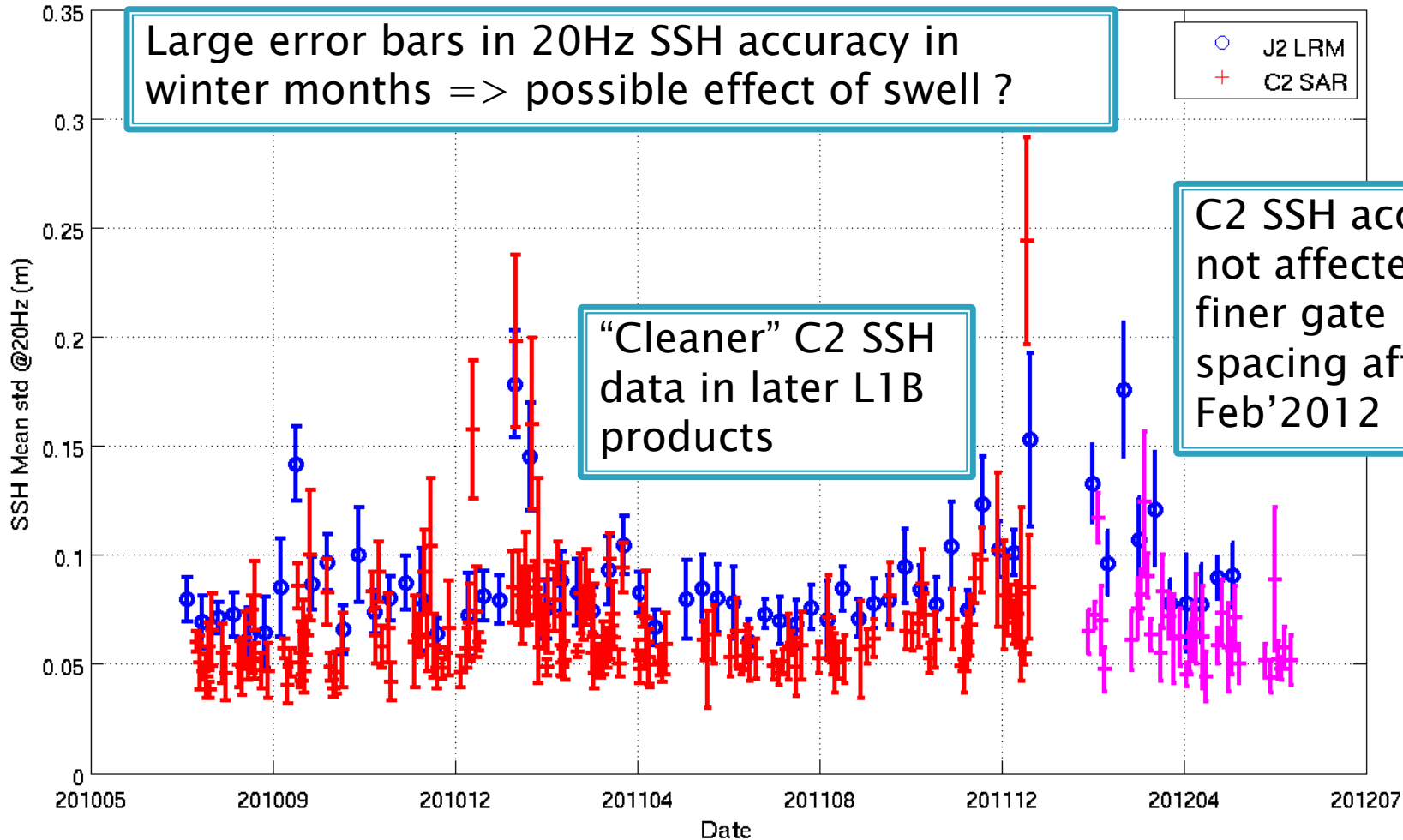


Factor of ~1.5 improvement of Cryosat-2 SAR versus Jason-2: CONFIRMED

Norwegian Sea: SSH noise

(July 2010–June 2012)

NorwSea Mean stdeviation of 20Hz SSH over 6 seconds



July 2010

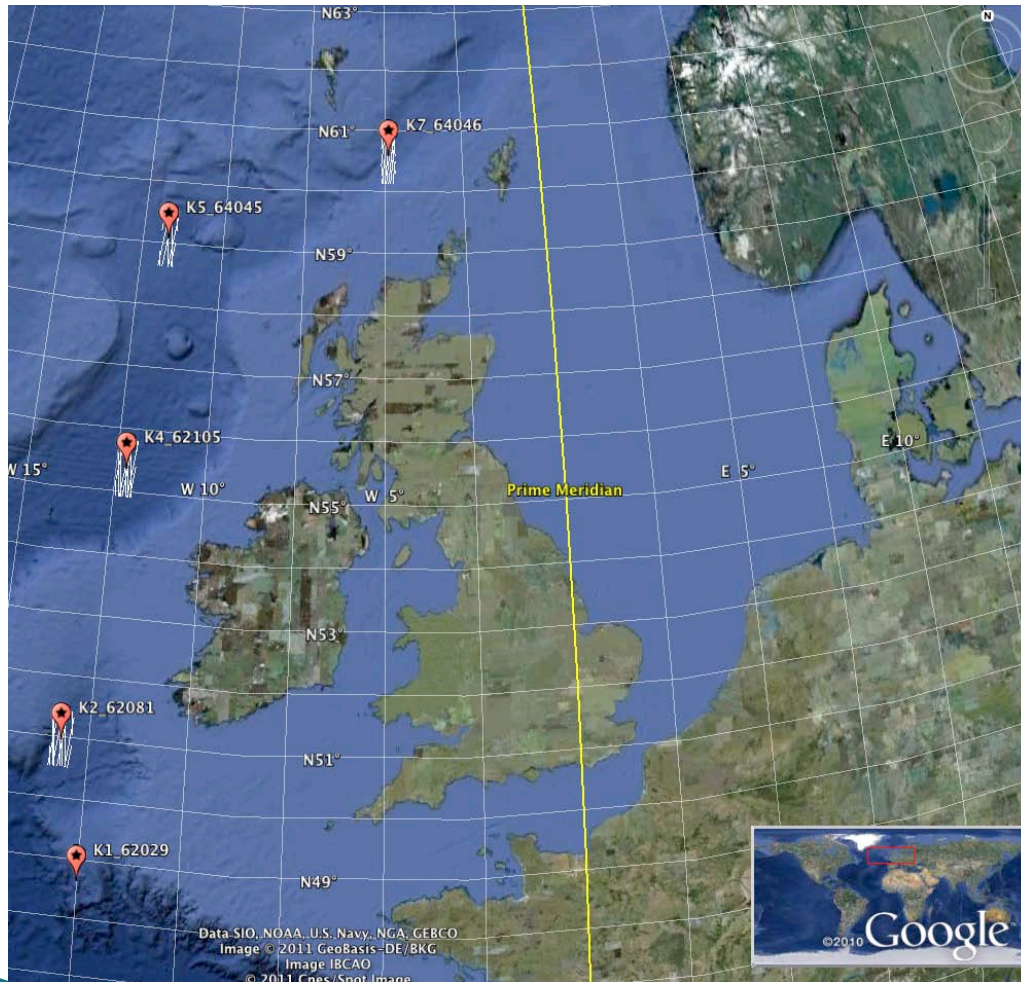
Feb'2011

Feb'2012



SAR significant wave height

Validation against wave buoys



Open ocean wave buoys from UK Met Office for in situ wave height data

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

July 2010 - May 2011



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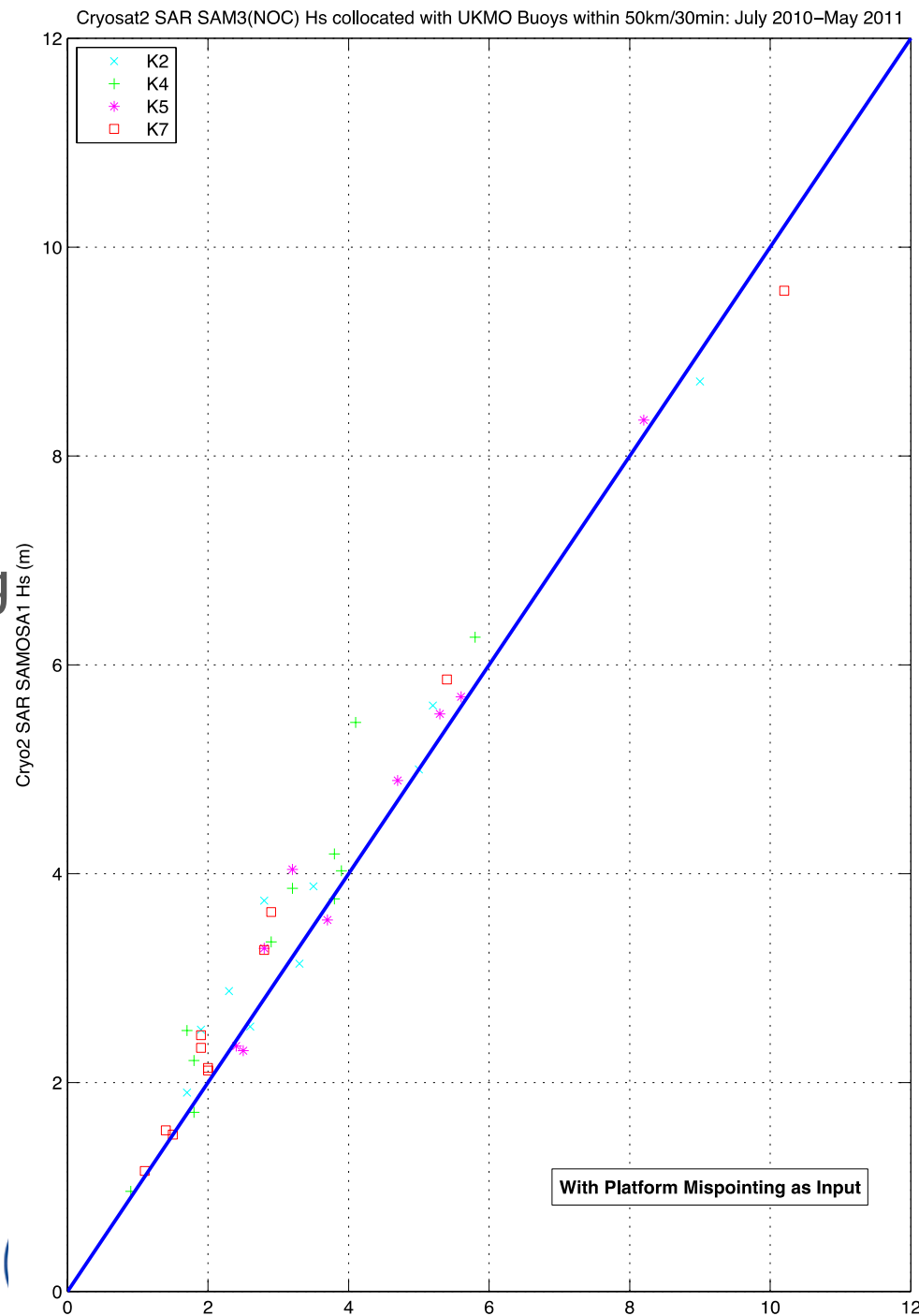
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Cryosat-2 SAR Hs against wave buoys

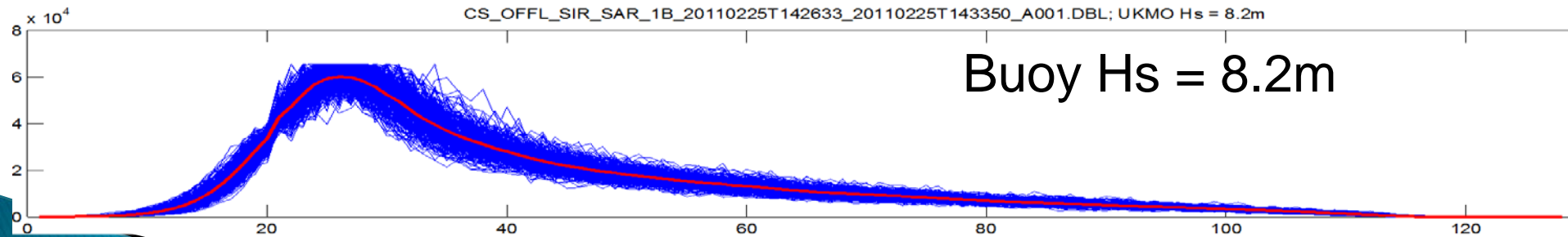
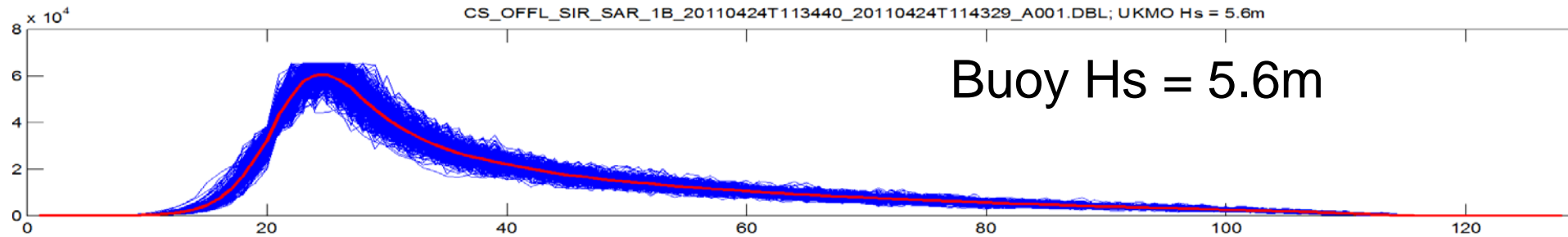
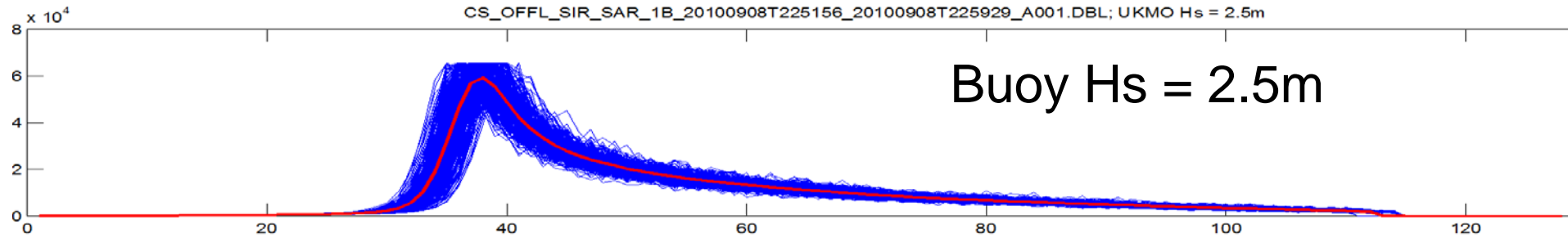
- ▶ Good correspondence between SAR and buoy Hs over wide range of sea states
- ▶ Hs bias due to mispointing
 - No bias when using platform mispointing (adjusted with R. Scharroo correction) as input to SAR retracker

Must account for roll mispointing or risk introducing biases in Hs (and probably also SSH)



Cryosat-2 SAR L1B WF in different sea states

SAR L1B 20Hz WF in 6 sec
"6-sec average" waveform



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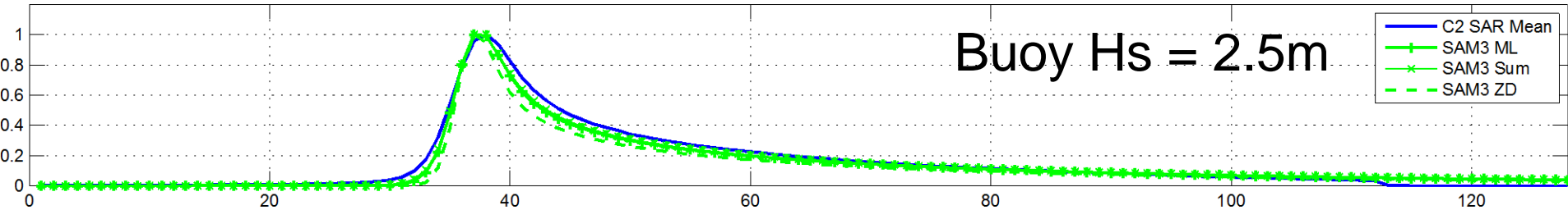


Cryosat-2 SAR v SAM3 ML model

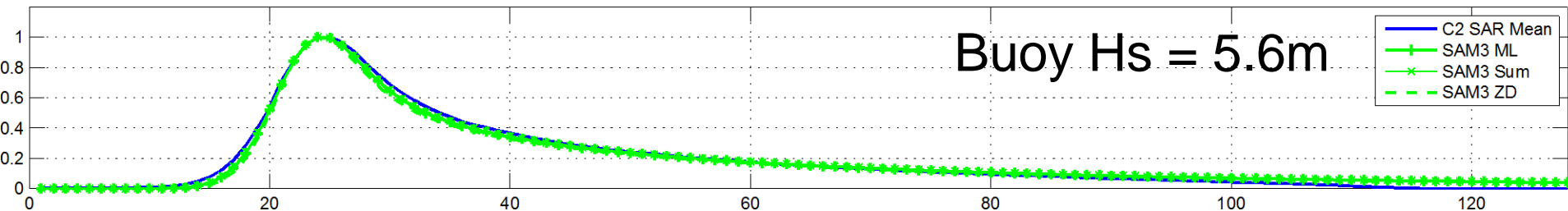
"6-sec average" waveform

SAM3 ML model waveform for Buoy Hs (NOT FITTED!)

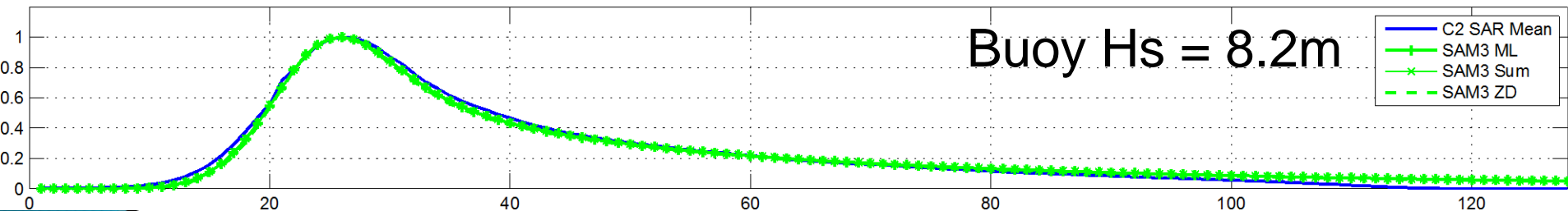
CS_OFFL_SIR_SAR_1B_201100908T225156_201100908T225929_A001.DBL; UKMO Hs = 2.5m



CS_OFFL_SIR_SAR_1B_20110424T113440_20110424T114329_A001.DBL; UKMO Hs = 5.6m



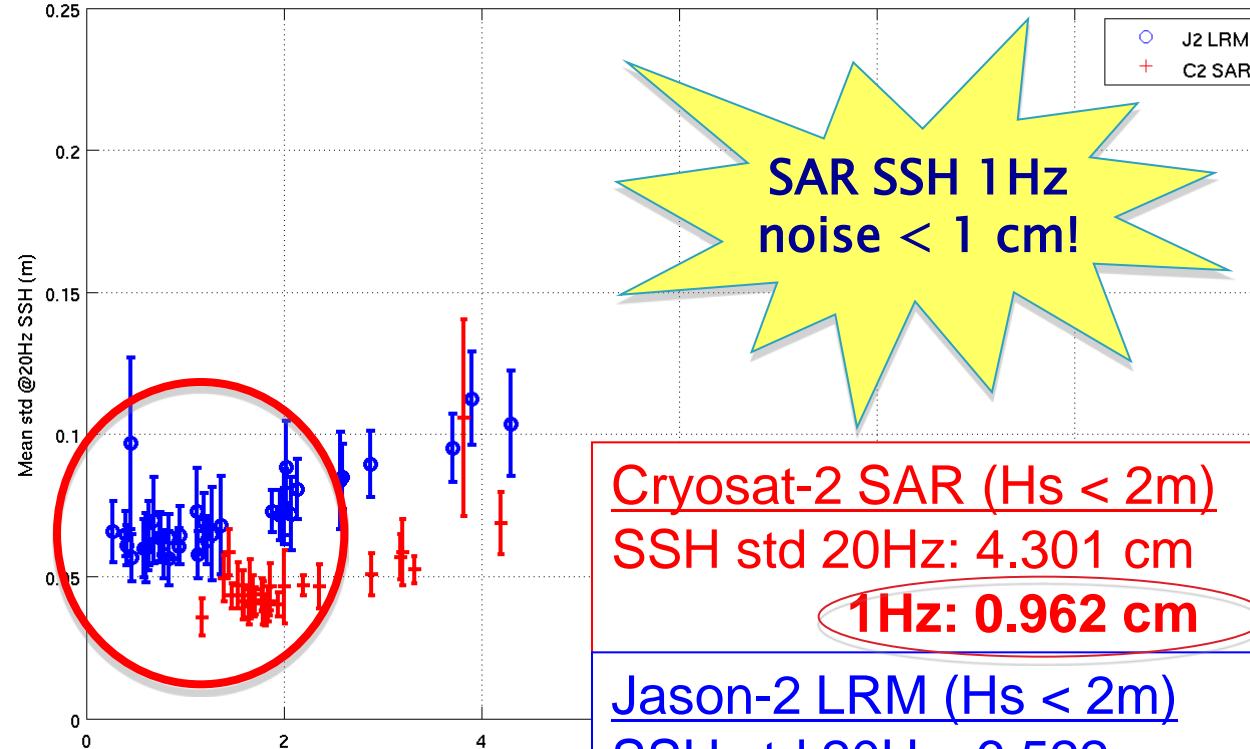
CS_OFFL_SIR_SAR_1B_20110225T142633_20110225T143350_A001.DBL; UKMO Hs = 8.2m



SSH noise in enclosed sea Caspian Sea Jan-Dec 2011

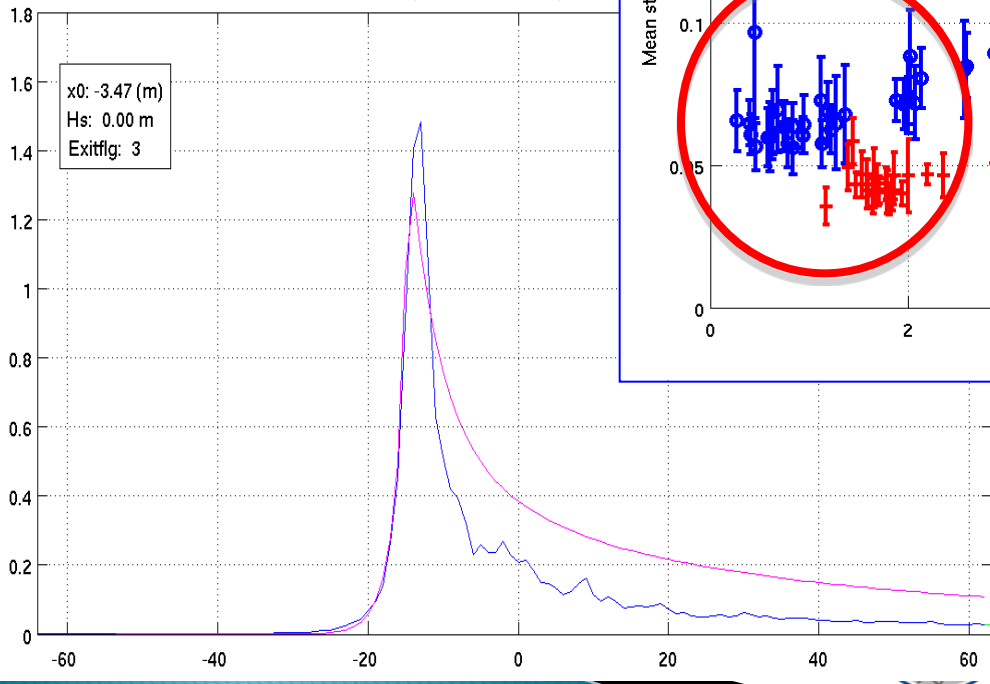


Caspian Sea Jan-Dec 2011 Mean stdeviation of 20Hz SSH over 6 seconds

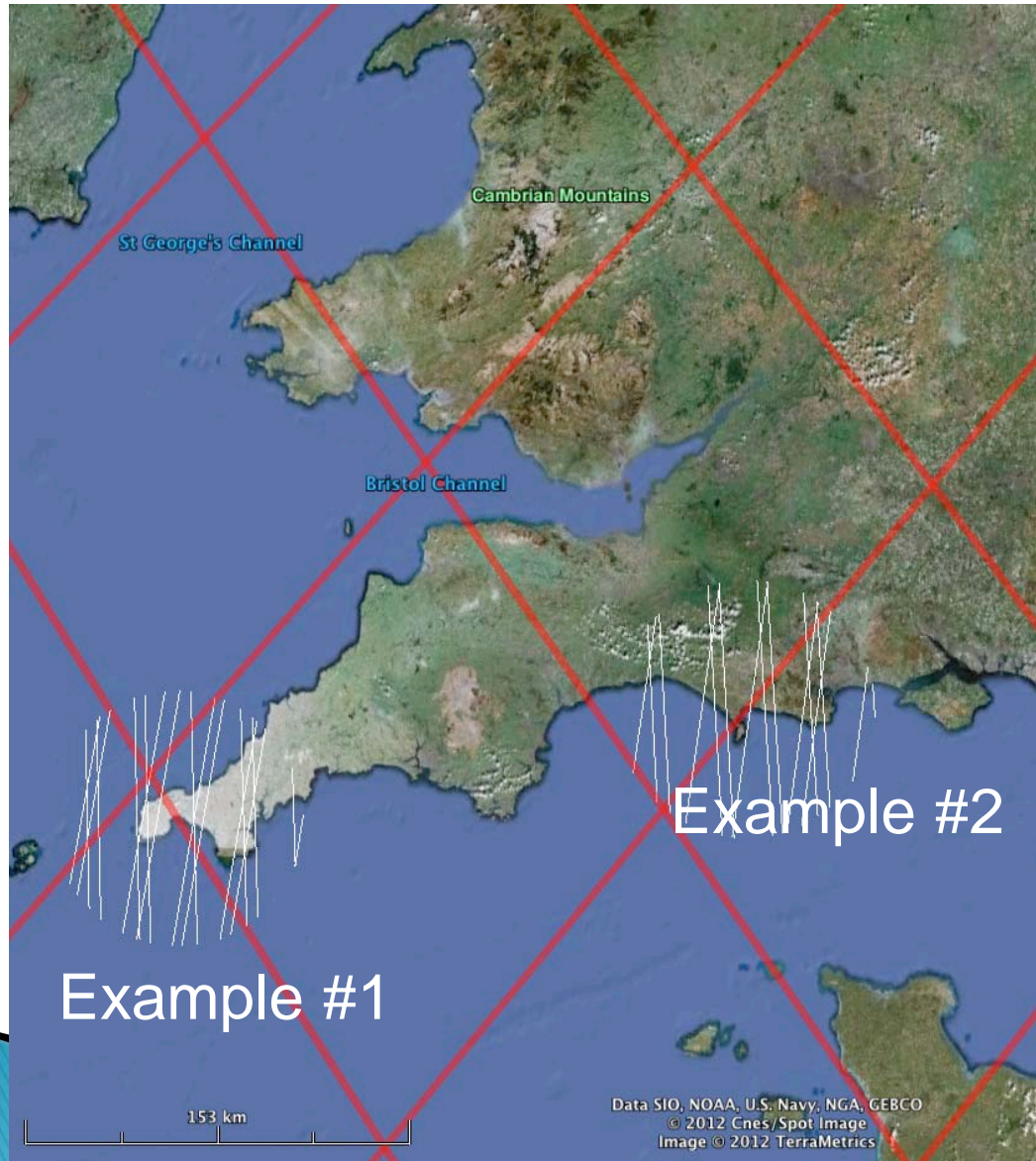


Cryosat-2 SAR (Hs < 2m)
 SSH std 20Hz: 4.301 cm
 1Hz: 0.962 cm

Jason-2 LRM (Hs < 2m)
 SSH std 20Hz: 6.522 cm
 1Hz: 1.458 cm

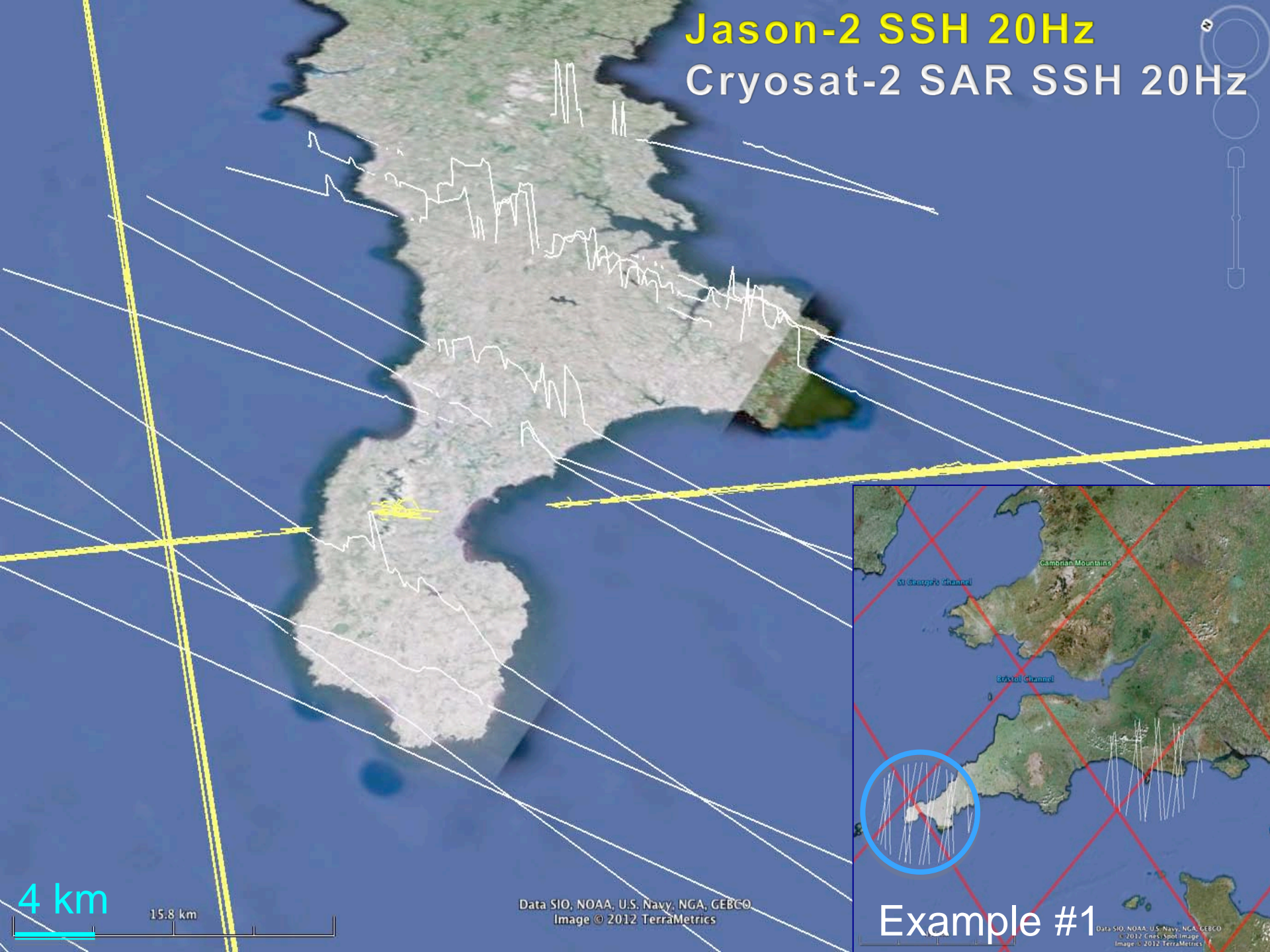


Performance in coastal zone ?



Jason-2 SSH 20Hz

Cryosat-2 SAR SSH 20Hz



4 km

15.8 km

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics

Example #1

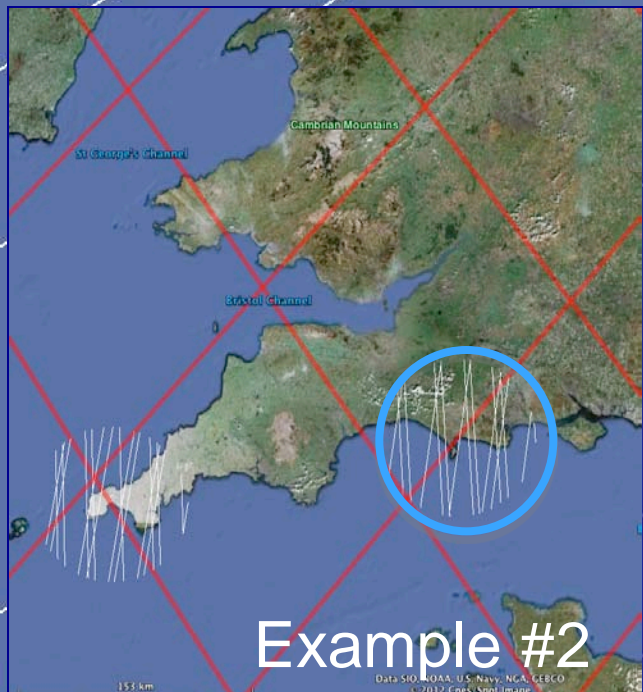
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Cnes/Airbus Image
Image © 2012 TerraMetrics



Brownsea Island

Cryosat-2 SAR SSH 2

2 km

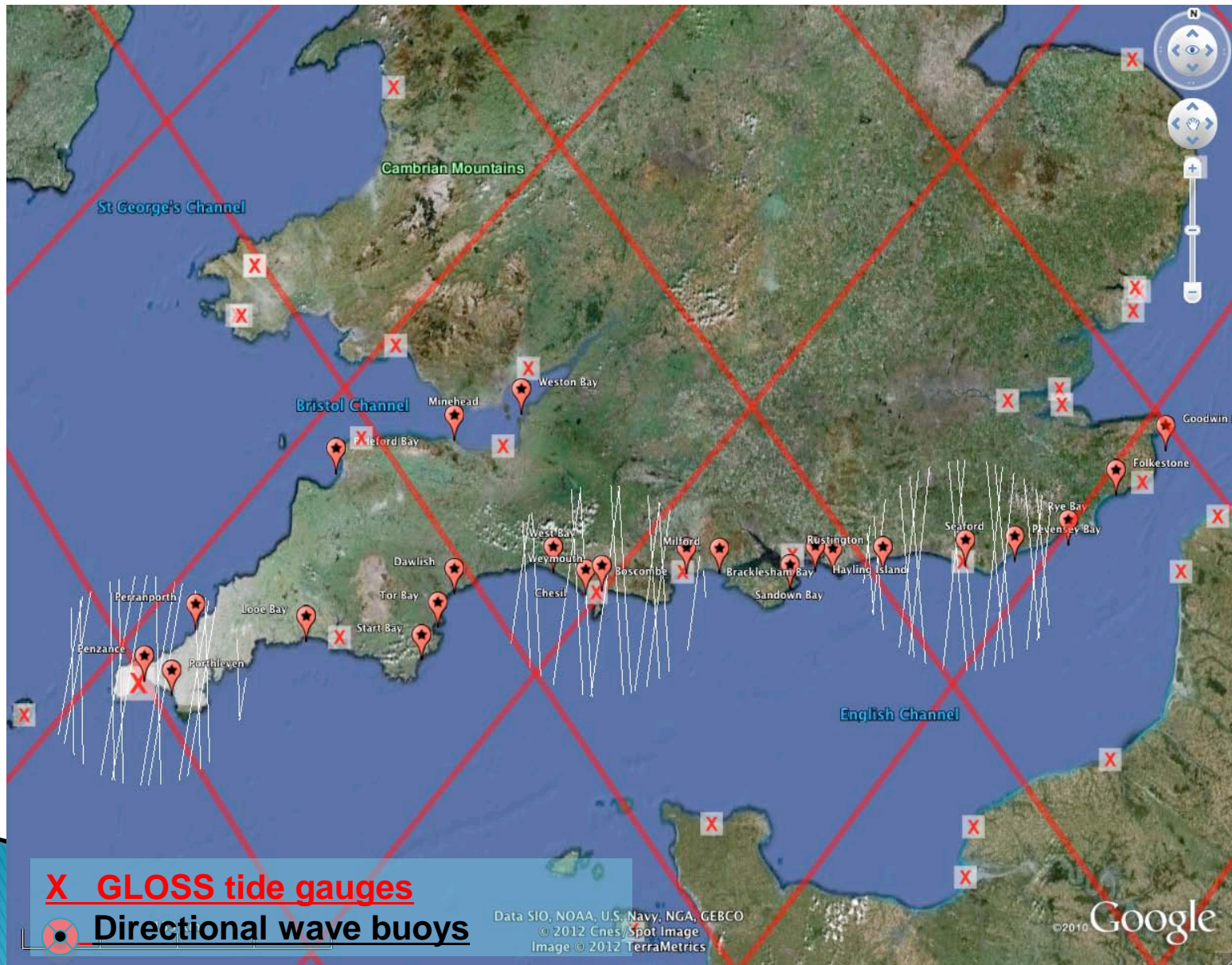


Example #2

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Infoterra Ltd & Bluesky
Image © 2012 TerraMetrics

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Opportunities for validation



Summary

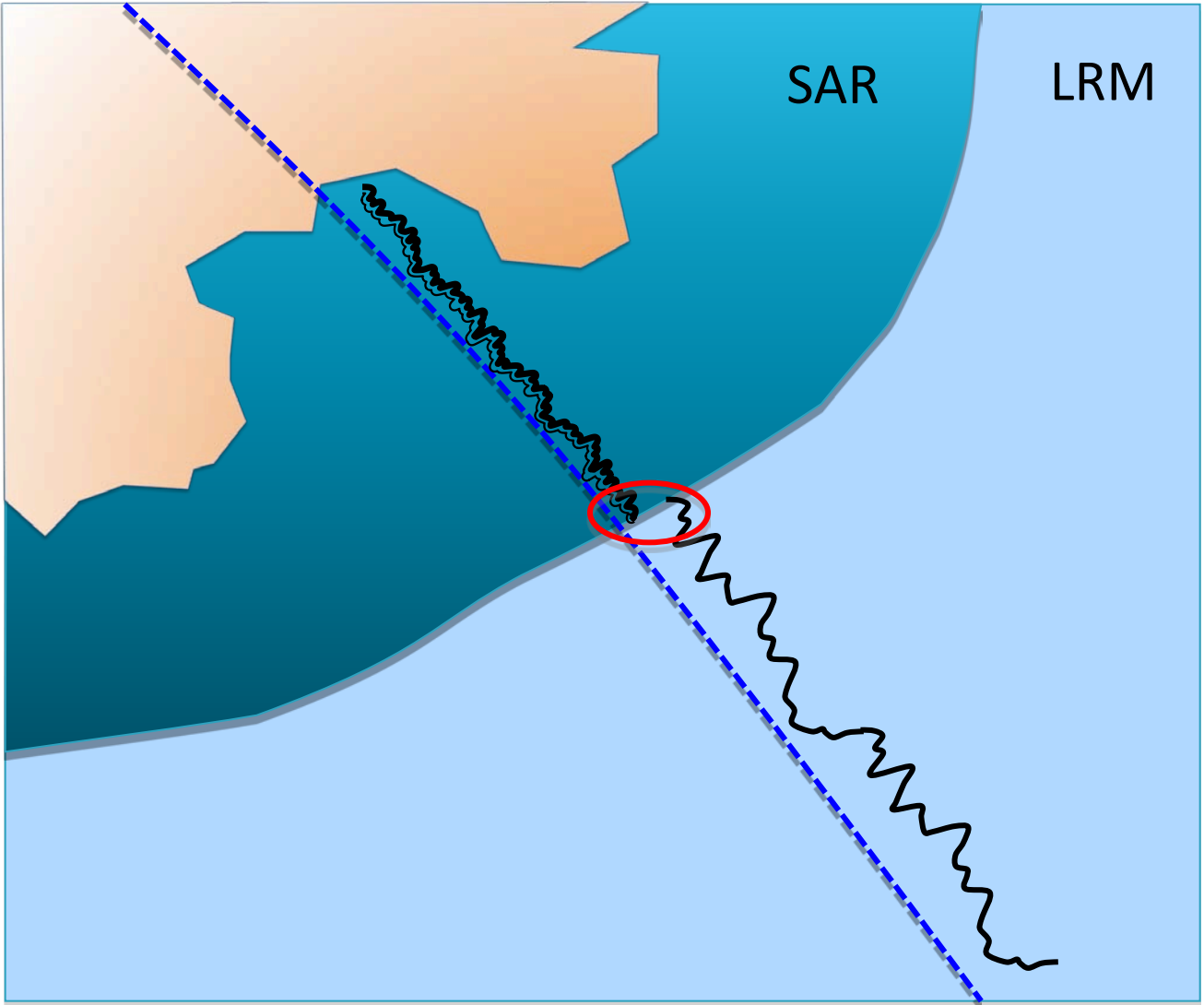
- ▶ SAMOSA3 is a **fully-analytical, robust and computationally fast** model able to simulate SAR altimeter waveforms over water (without tuning!)
- ▶ **SAM3 was validated against Cryosat-2 SAR L1B waveforms**
 - SAM3 has been proposed for Sentinel-3 operational SAR retracker
 - Papers in prep.
- ▶ Improvement in SSH noise with Cryosat-2 SAR L1B **by factor of 1.5** compared to Jason-2
 - SAR SSH 1Hz noise now < 1 cm in enclosed sea (no swell)
- ▶ Cryosat-2 **SAR Hs compares well with colocated buoy Hs** as long as mispointing is accounted for
- ▶ SAR shows **excellent performance near land**, with no data loss and smoothly varying SSH right up to/from the coast



Outstanding issues & challenges

- ▶ A lot of work ahead
 - Time for increased cooperation between scientists and inter-agencies
- ▶ Effect of long waves on SSH ?
 - Evidence that long waves increase noise on SAR SSH
 - *Planned analyses of SSH noise near directional wave buoys*
 - BIAS in SAR SSH due to long waves and \neq wave direction ?
 - *SAR SSB ?*
- ▶ Why do we see an improvement by “a factor of 1.5” and not by “a factor of 2” as theory/others predict ?
 - Many possible reasons including:
 - *Unaccounted noise and/or bugs in the Cryosat-2 L1B data & products*
 - *Imperfect model*
 - *Different beam-forming and multi-looking in data and model*
- ▶ LRM/SAR transitions ?
 - Biases and noise for LRM, SAR and pseudo-LRM at transitions ?





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Sticking my oar in...

- ▶ Let's use clear terminology
 - Pseudo-LRM is not "SAR" (and it is not "LRM" either) !
 - Double-pass LRM is not "LRM": SSH is less noisy because 1 less parameter is retrieved but spatial resolution is pulse-limited and information on H_s changes at short scales is lost
- ▶ Future SAR altimeter missions
 - Access to waveforms (coastal altimetry & other applications)
 - *Should be the default position for all modes (e.g. Sentinel-3 STM products)*
 - *For SAR, include stack and provide access to FBR/L0 (advanced users)*
 - Sentinel-3 STM mode mask
 - *SAR over the whole ocean ? What about SAR over inland waters?*
 - Jason-CS
 - *Lobby your national representatives to support Jason-CS ! (We have!)*
 - *Interleaved mode: the only way forward to solve the LRM/SAR issue, but at what cost ?*



Thank you



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