SAR altimetry over the open and coastal ocean:
Status and Open issues

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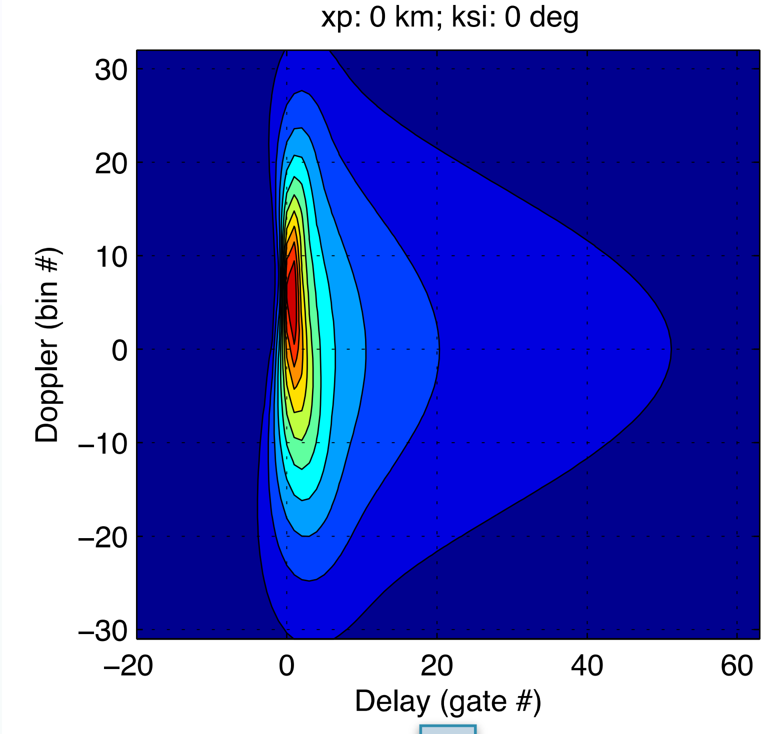
SAR altimetry expert group meeting
NOC – 26/27 June 2013

Content of this talk

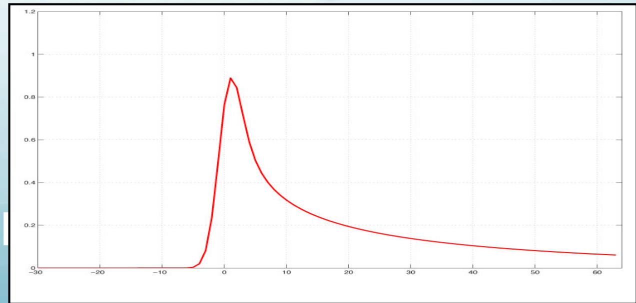
- Focus on Cryosat-2 SAR over ocean and coastal zone
  - Brief review of SAMOSA outcome and open issues
  - Ongoing work in Cryosat Plus for Ocean (CP4O) project
- Relevance to S-3
  - Existing and recent results with SAMOSA3 SAR waveform model
    - SAMOSA3 proposed for S-3 operational L2 SAR retracking
- Relevance to Jason-CS
  - Impact of swell and swell direction

The SAMOSA3 waveform model

- Suite of analytical and numerical models developed from physical principles by Starlab
- SAMOSA3: simple fully-analytical formula, robust and fast to compute
  - Elliptical antenna pattern, gaussian PTR, linear ocean wave statistics
- Computes 2D Delay Doppler Maps
- Function of epoch (range) significant wave height, Sigma0, roll and pitch mispointing angles
- Apply Doppler beam-forming and multi-looking to obtain delay-only SAR altimeter waveforms



Beam-forming & multi-looking



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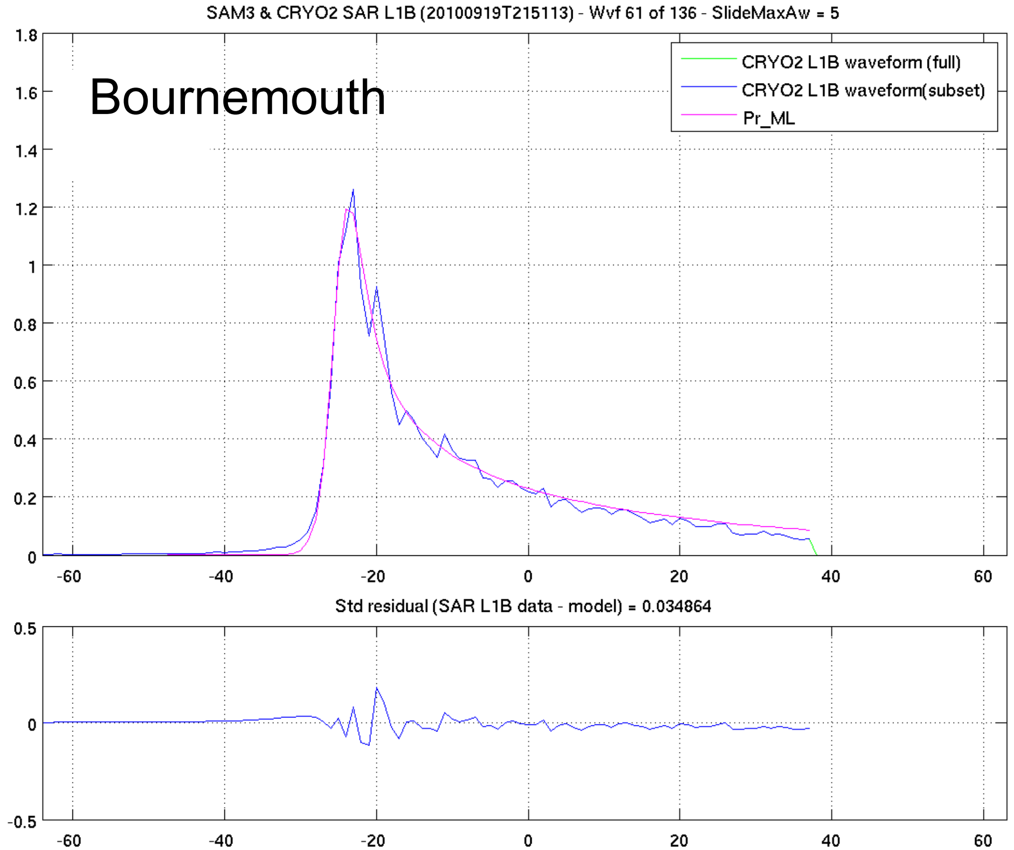
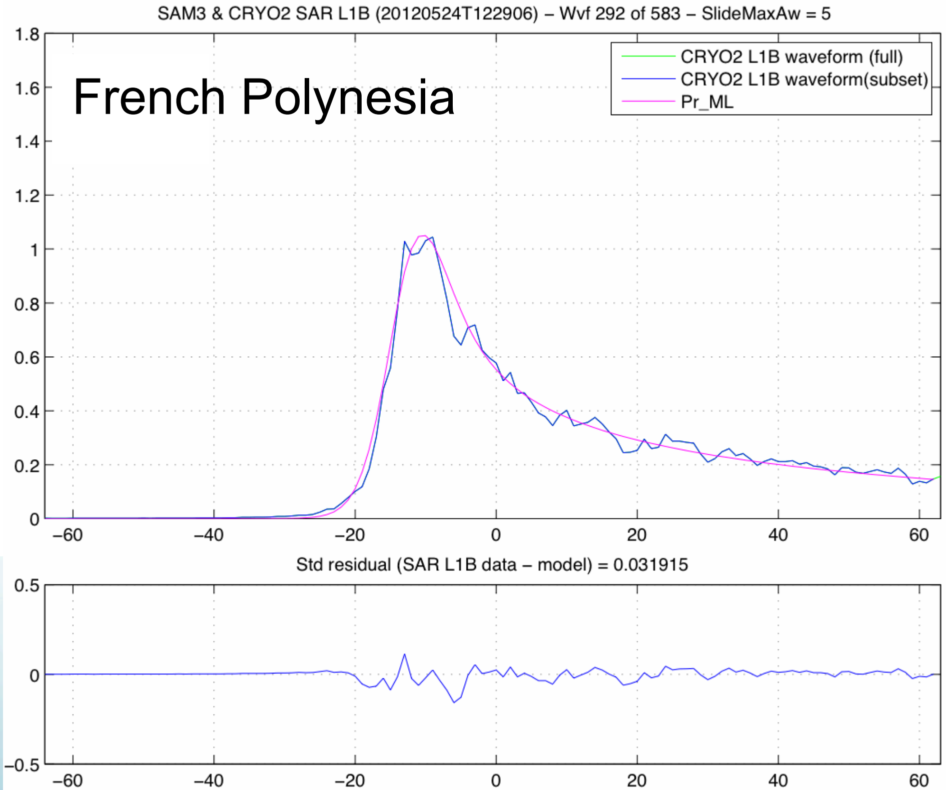
SAMOSA3 v Cryosat-2





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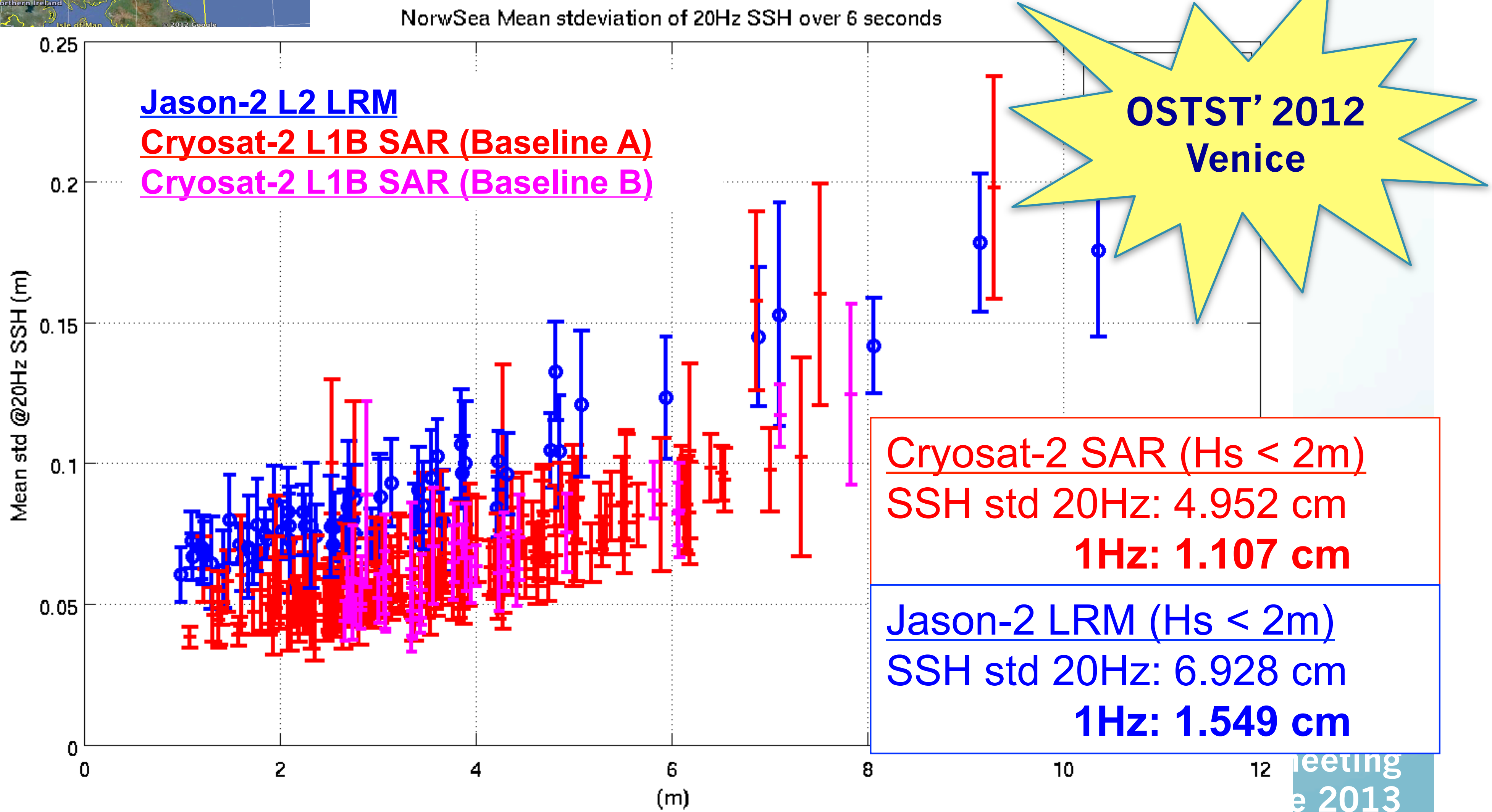
SSH noise: Norwegian Sea

(July 2010-June 2012)



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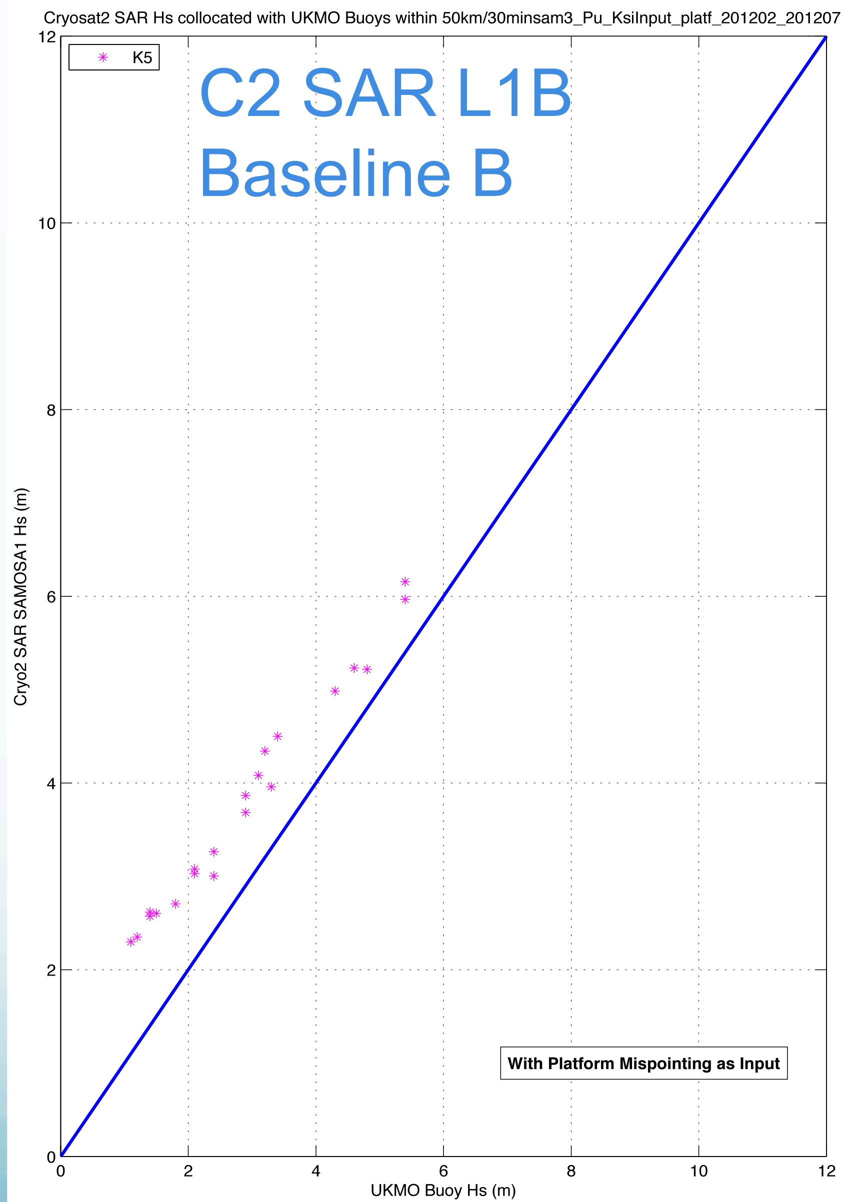
C2 SAR SWH v wave buoys

- Accounting for roll mispointing (adjusted "à la Remko") removes most of the SWH bias against wave buoys
- Large SWH bias for C2 Baseline B

	Baseline B	Baseline A
bias	**0.896 m**	0.295 m
Std deviation	**0.238**	0.516
Corr Coefficient	**0.991**	0.970



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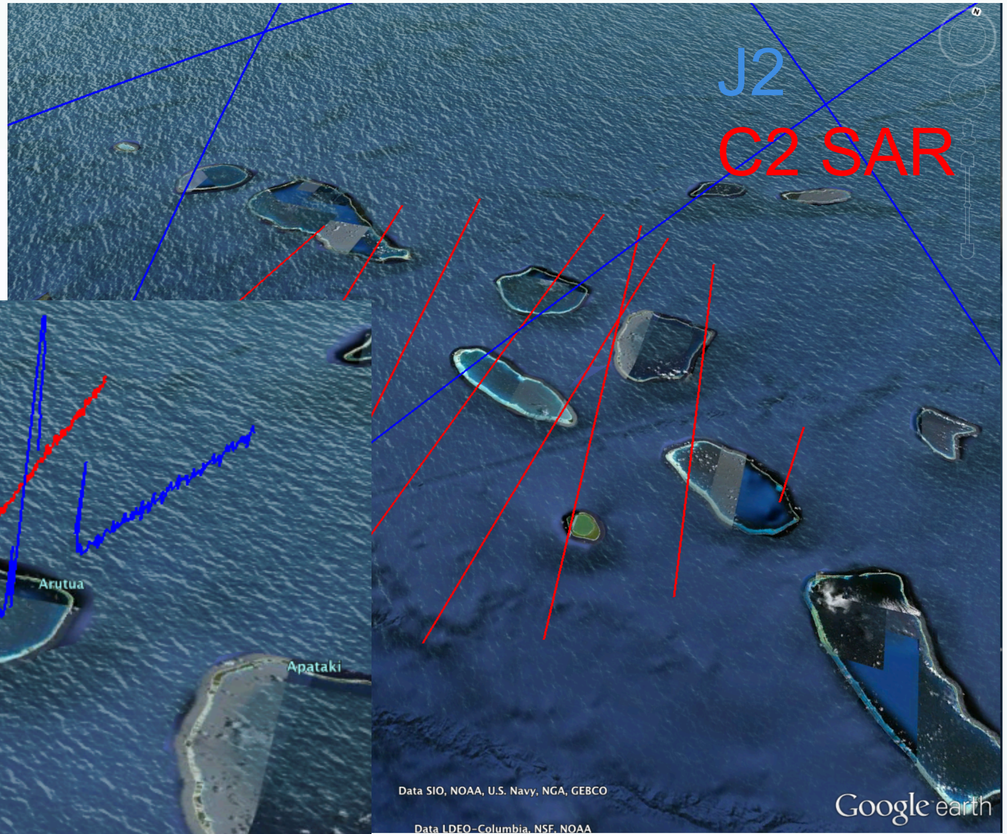
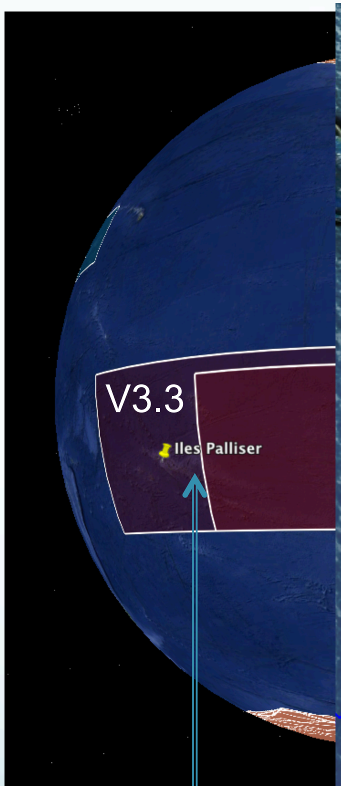
Cryosat-2 SAR SSH 20Hz
2 km
Brownsea Island
Cambrian Mountains
St George's Channel
Bristol Channel
153 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Infoterra Ltd & Bluesky
Image © 2012 TerraMetrics
Image © 2012 Getmapping plc
©2010 Google

C2 SAR & J2 LRM over atolls





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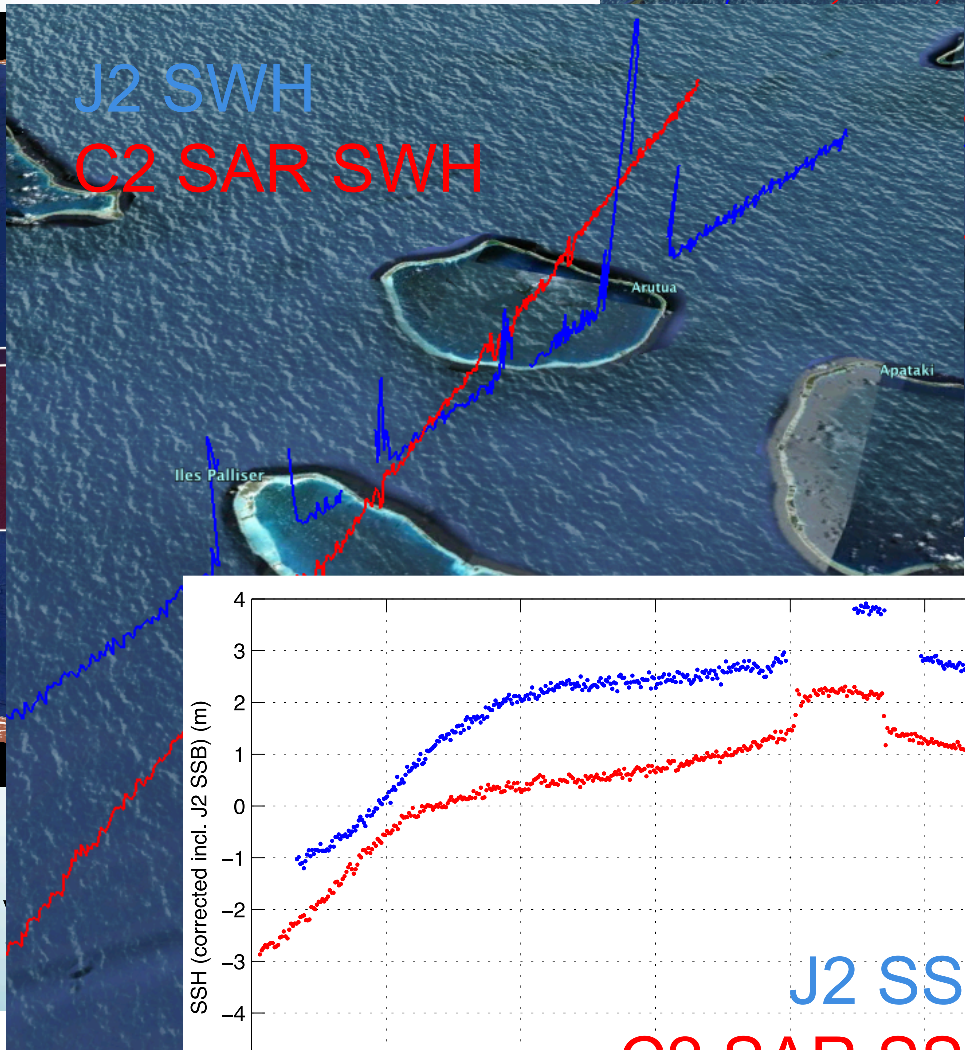

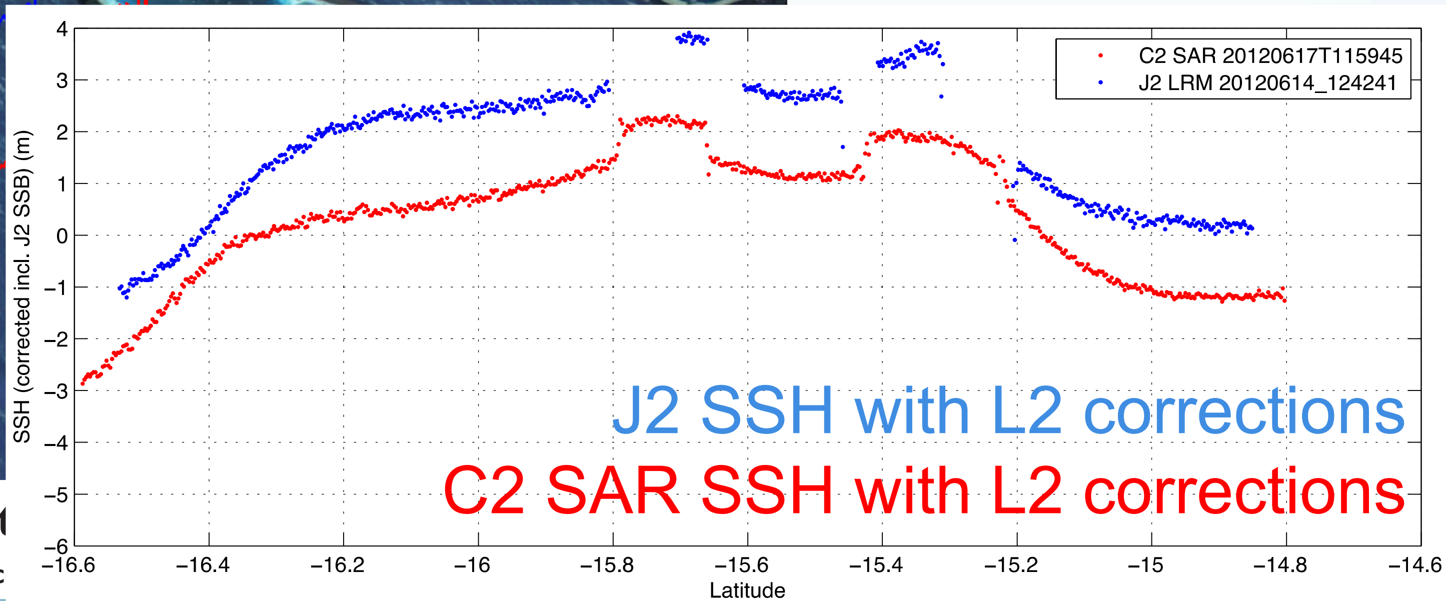

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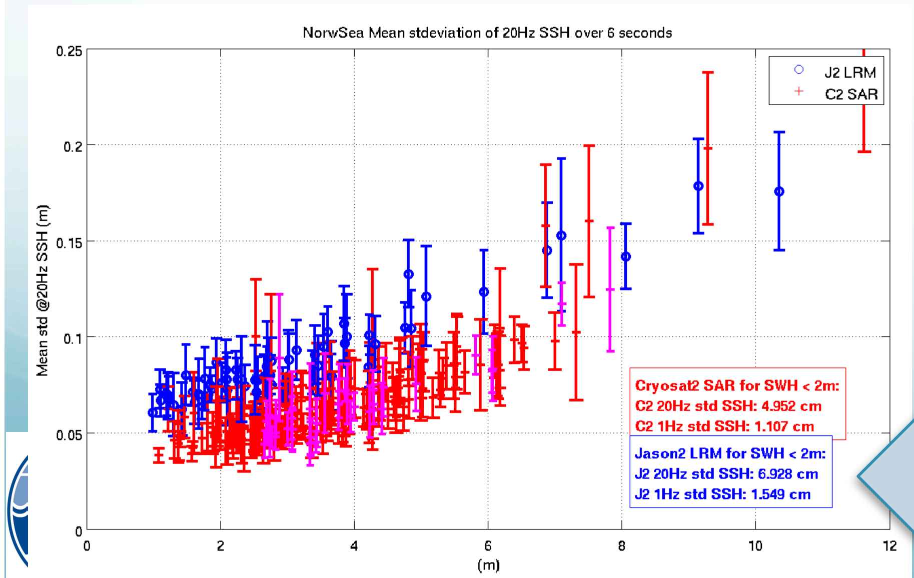
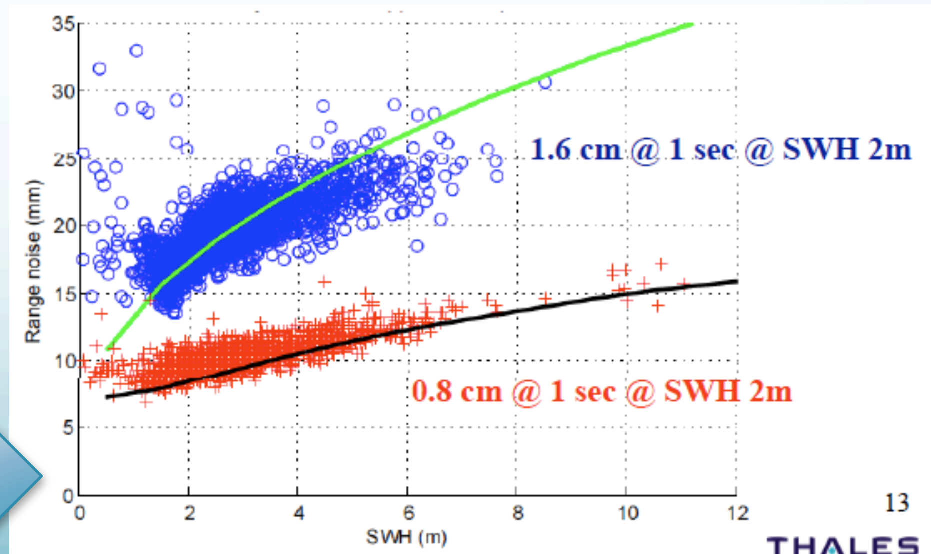
SAMOSA main results

- SAMOSA3 validated against Cryosat-2 SAR L1B waveforms
  - Reduced SSH and SWH noise v Jason-2 (by factor of 1.5)
  - Good SWH against buoys over wide range of wave conditions
  - Excellent performance close to land
- SAMOSA3 SAR model proposed for S-3 operational processor

SAMOSA open issues

- SAMOSA3 is an analytical model
  - Because that's <u>what we were asked to provide</u> to satisfy operational needs !
  - Is SAMOSA3 less accurate than complex models e.g SAMOSA2 or numerical retrackers (as used by TAS and CNES) ?
- SAR SWH biased high, especially at wave height < 2 m
- Why is SAR SSH noise improvement only by a factor of 1.5 ?
  - and not a factor of 2 as predicted by Jensen & Raney (1998) and shown by Phalippou et al., 2010 ?

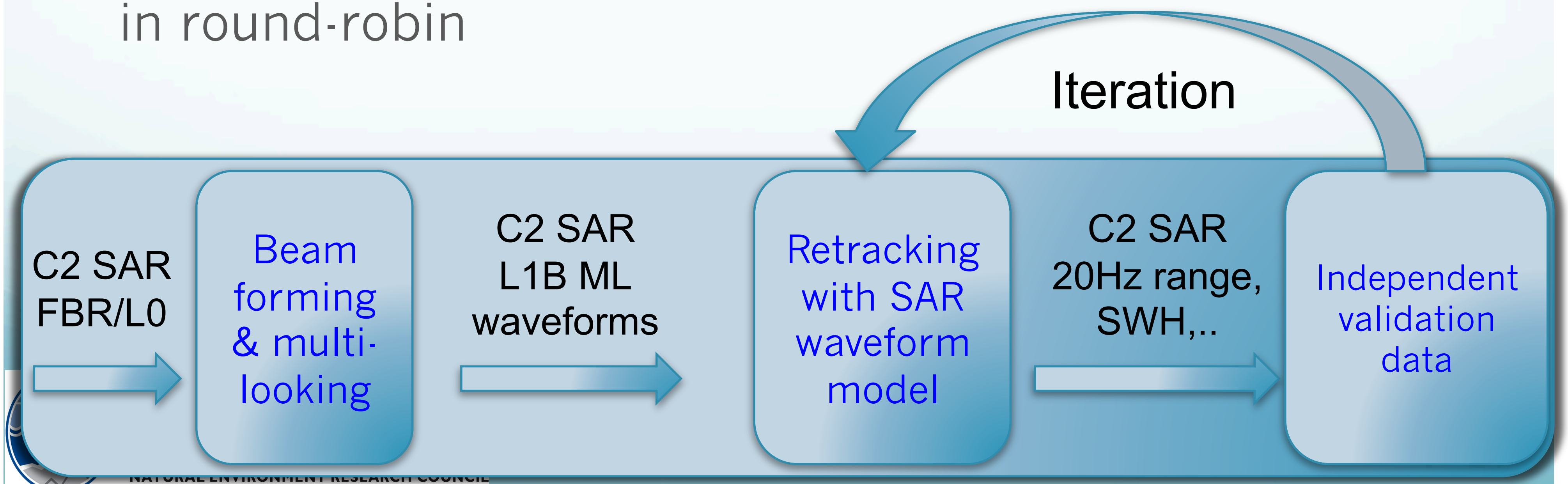




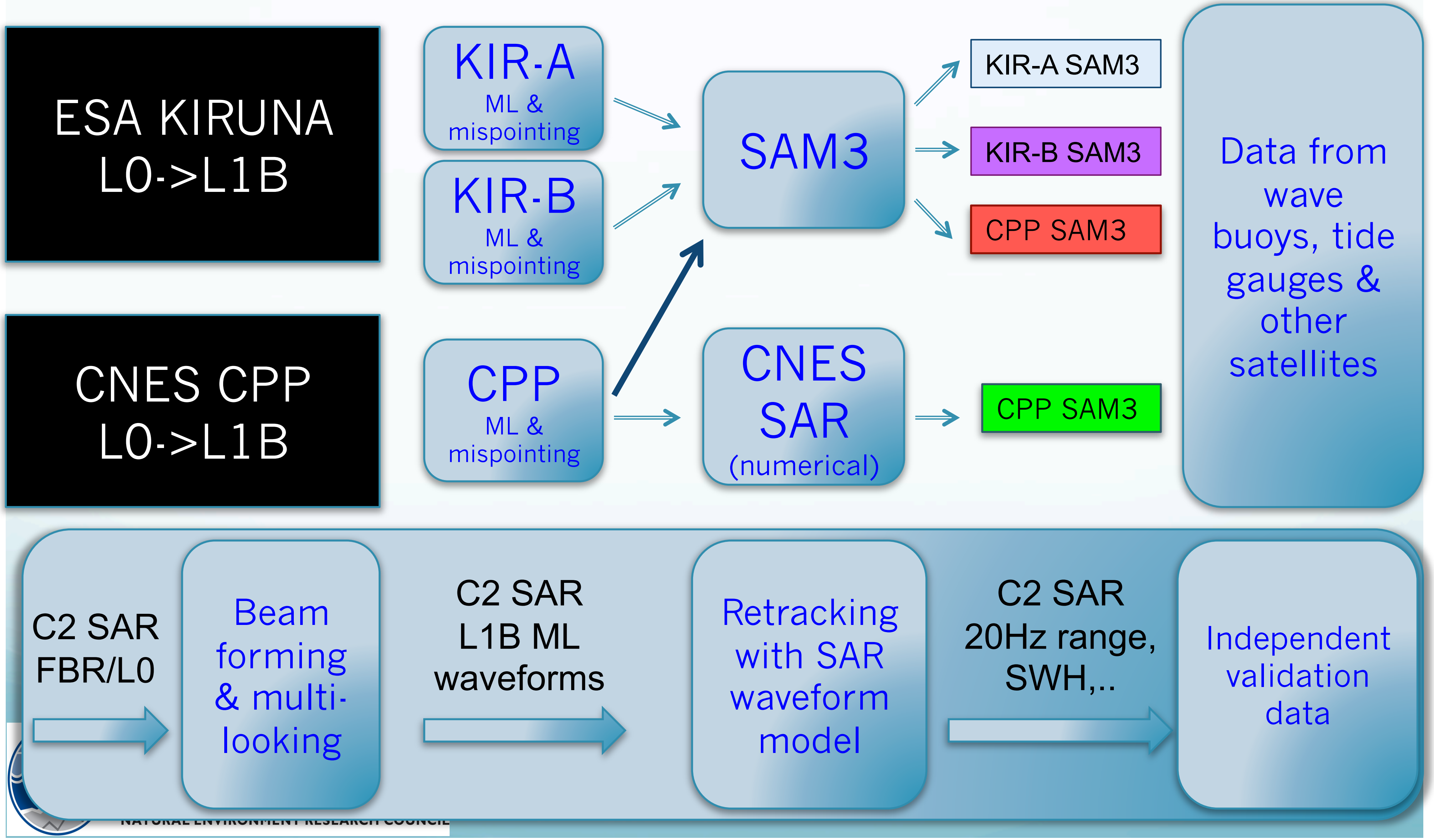
THALES

Cryosat Plus for Oceans
SAR in Ocean & Coastal zone

- To carry out a series of experiments to assess, test and improve the SAR altimeter retracking method
- To validate the method against independent measurements (in situ and satellites)
- Develop C2 SAR validation products for dissemination in round-robin

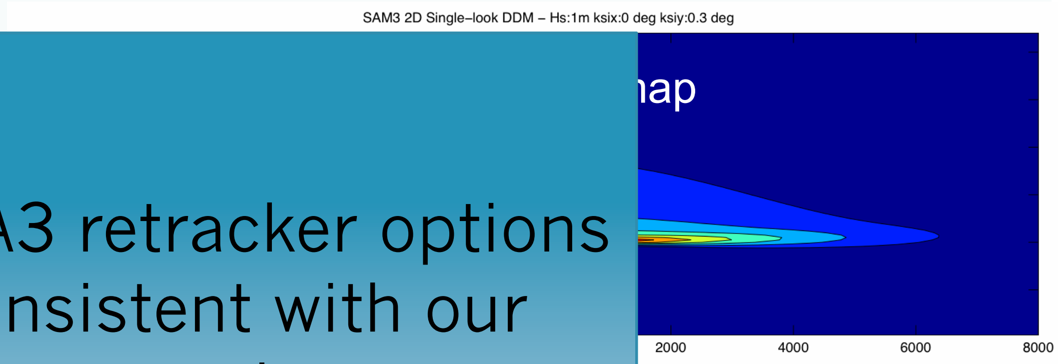


Experiments

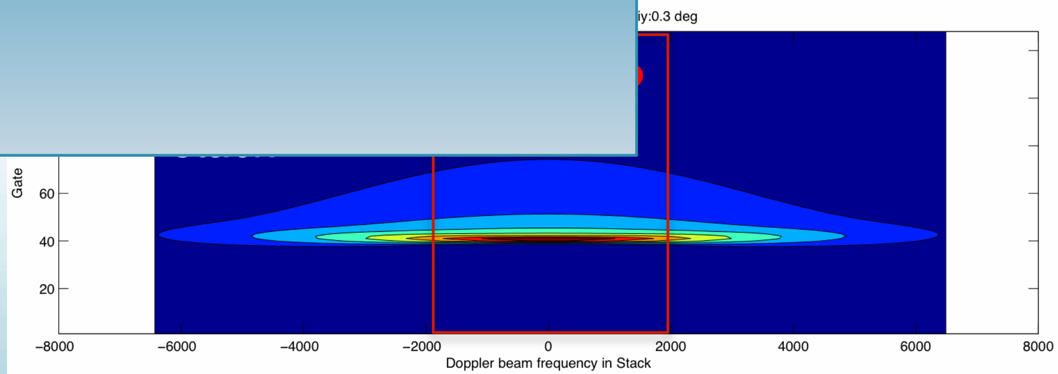


Implementation choices for SAMOSA3 SAR retracker

- Multi-looking: **in the absence of Doppler beam frequencies in the Cryosat-2 SAR L1B products**, we have to compute them ourselves to build the Stack from the SAMOSA3 model
  - Doppler frequencies computed from geometry, platform velocity and attitude
- **Hamming w**
  or not corre
- **Stack accu**
  - Over all D
  - Only cent
    - Which
- **PTR width ?**
- **Antenna be**
- Mispointing as input or retrieved ?
- Roll and Pitch mispointing bias values ?



Here, SAMOSA3 retracker options set to be consistent with our previous results



CNES CPP products

- CNES Cryosat prototype products (CPP)
- provided by CNES within CP4O project
- 1 week of data in April 2011
- 10 passes over UK
- Provides:
  - CNES L1B ML waveforms
  - CNES SAR retracker output
  - CNES SAR retracker fitted waveforms

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Validation data

- Wave buoys around the UK
- Open Ocean
  - mainly UK Met Office buoys
- Coastal Ocean
  - Within few km of land

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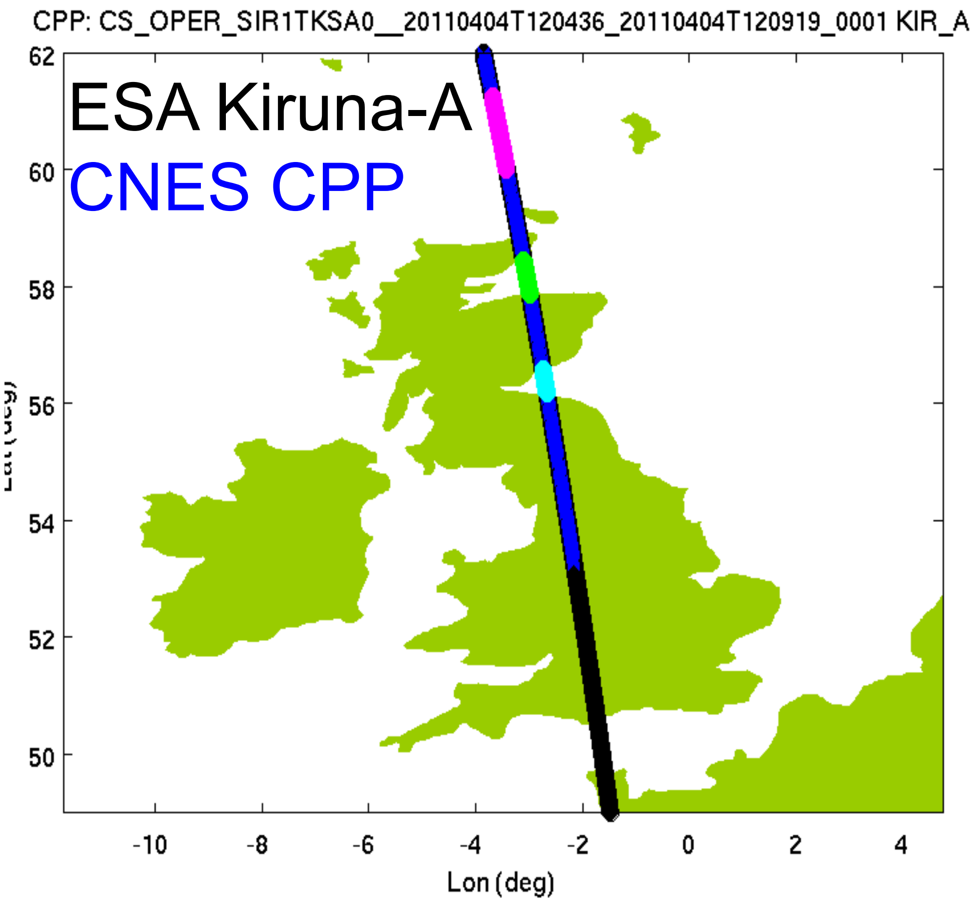
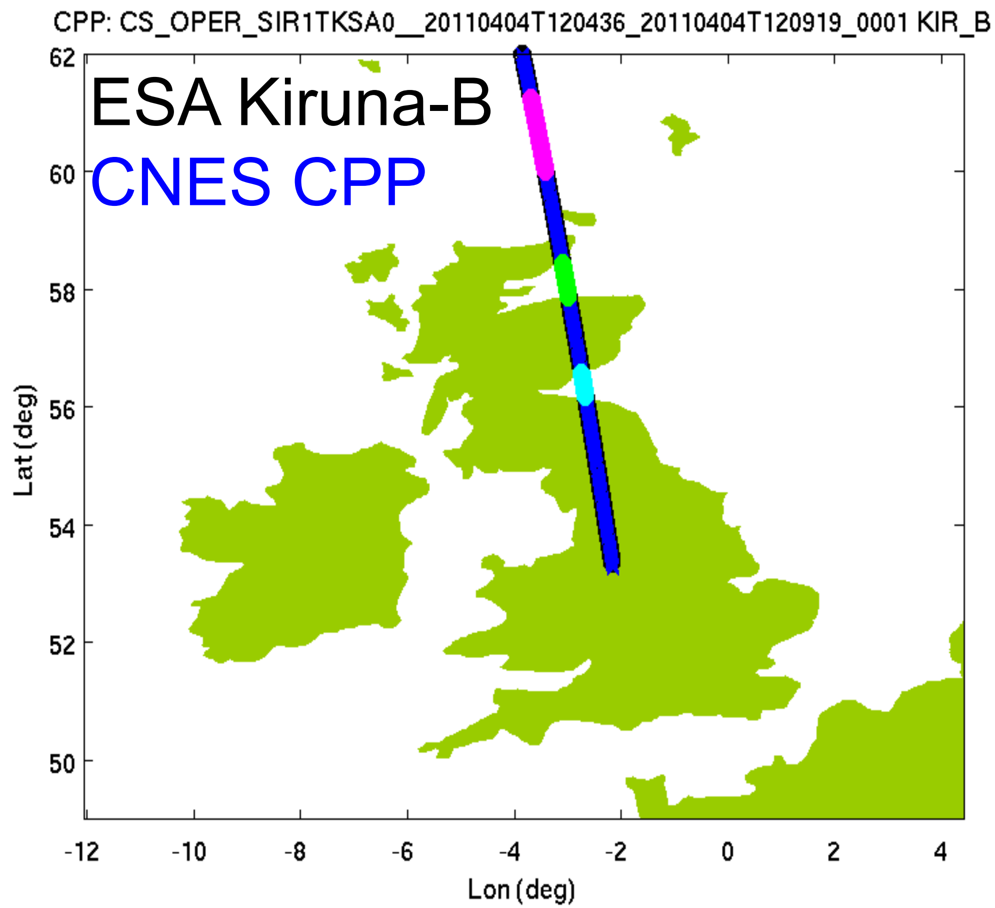
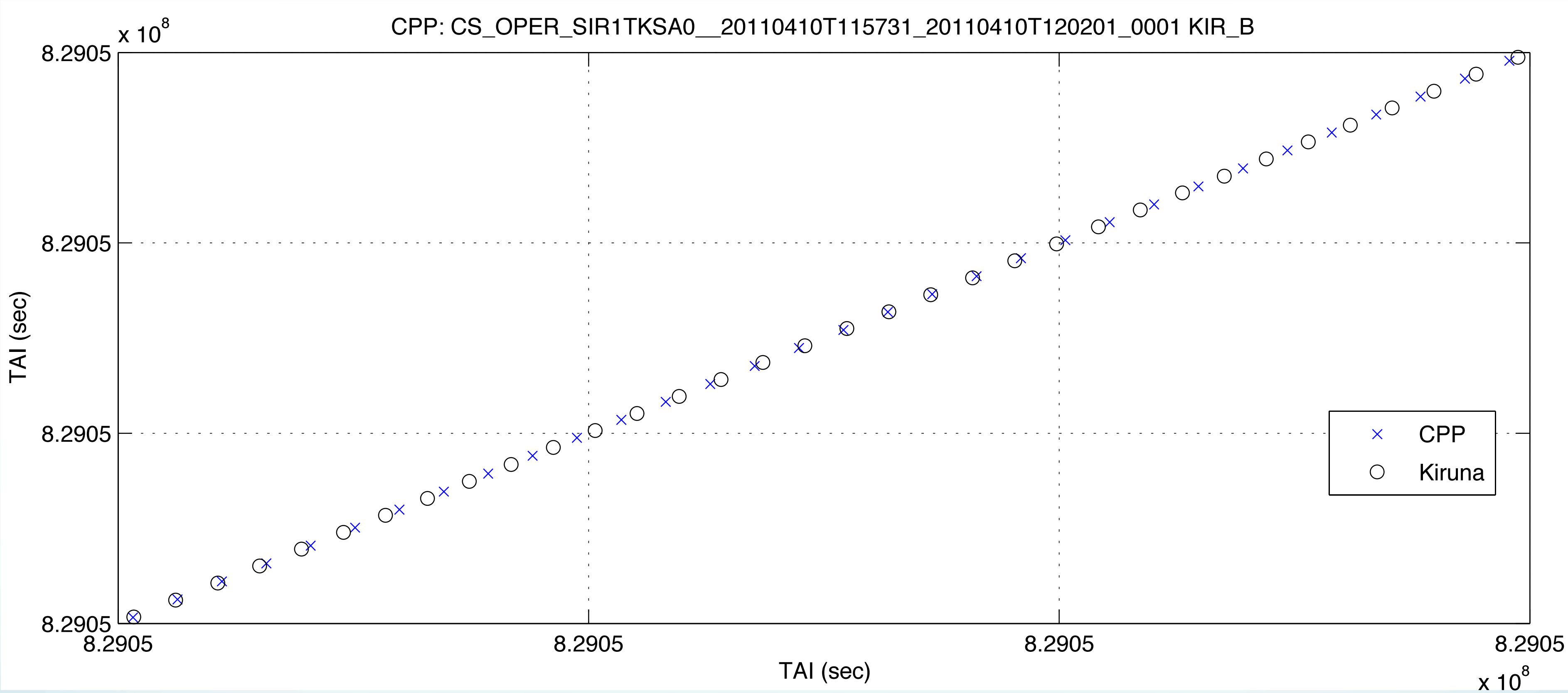
Selecting data segments

- Time-collocating CPP with ESA SAR L1B (KIR-A and KIR-B)





Collocating CPP and KIR

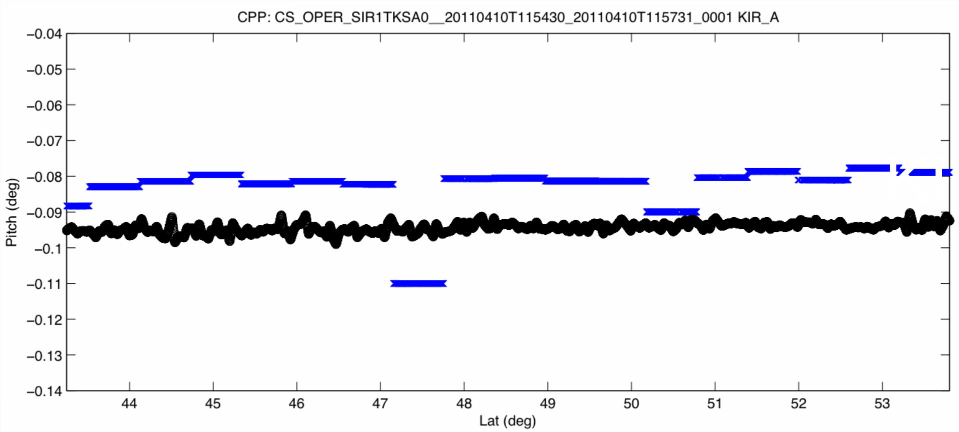


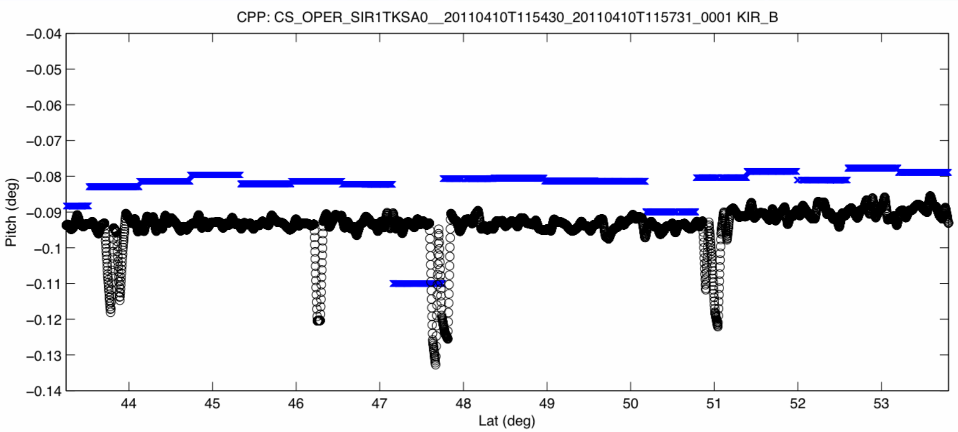
- CPP and Kiruna 20Hz samples not exactly collocated in either time or space !

Satellite platform attitude

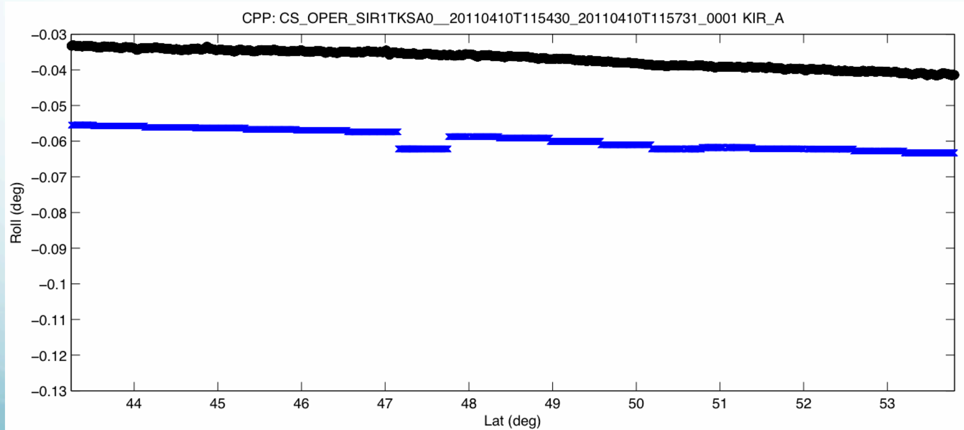
CNES CPP and KIR-A | CNES CPP and KIR-B

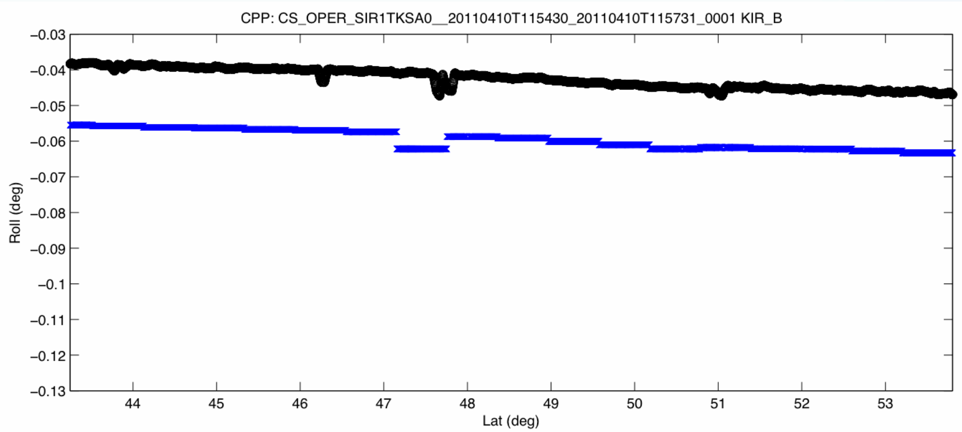
Pitch (deg)



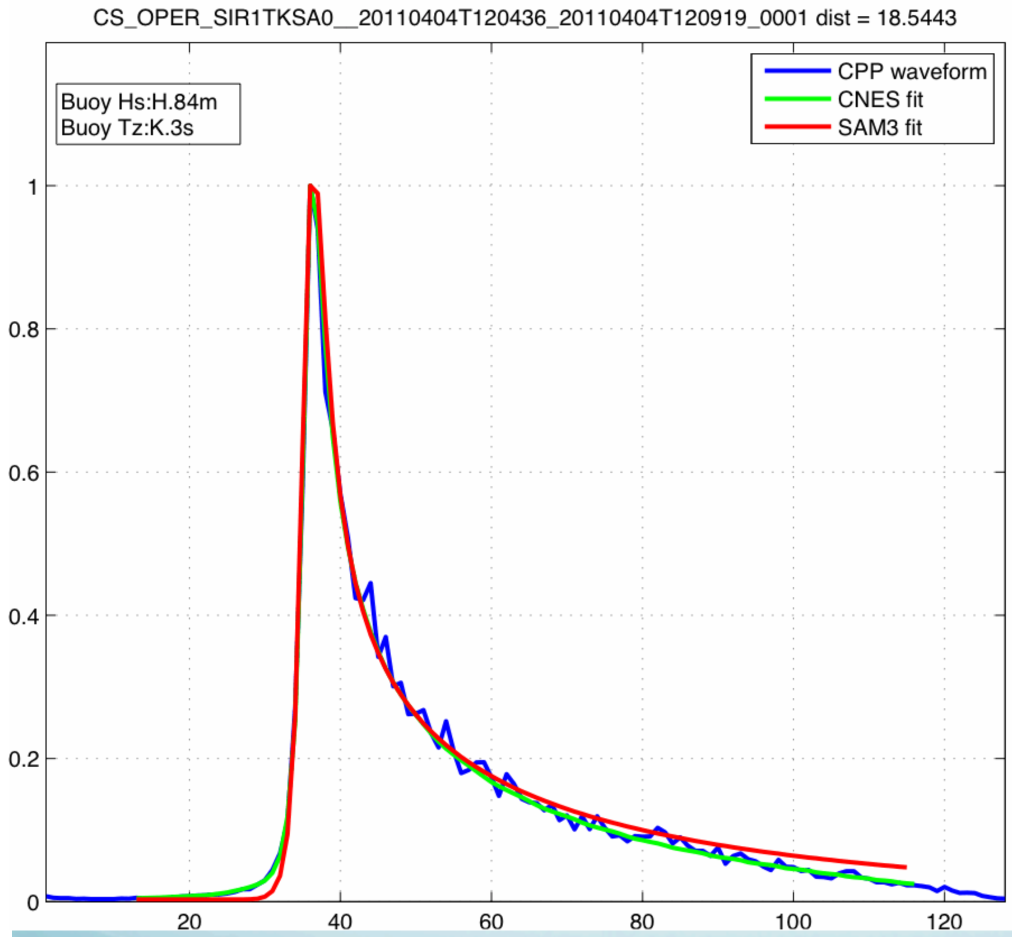


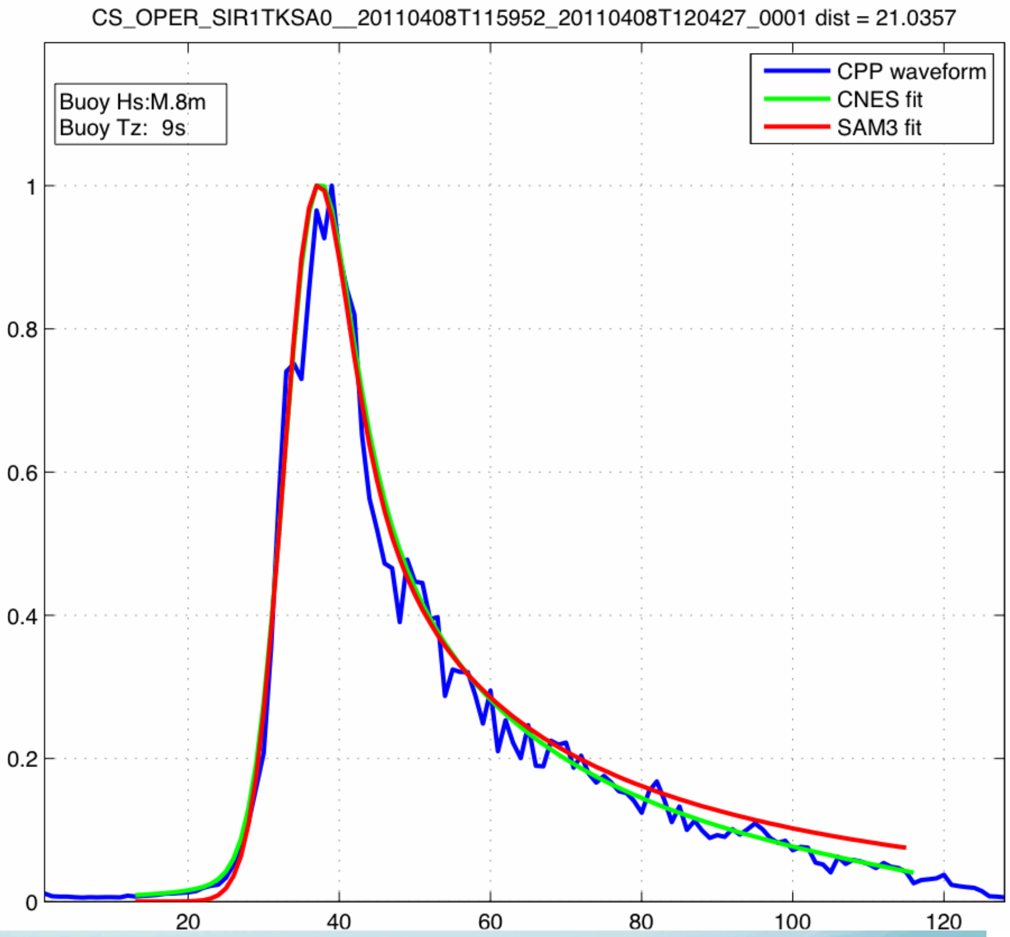
Roll (deg)

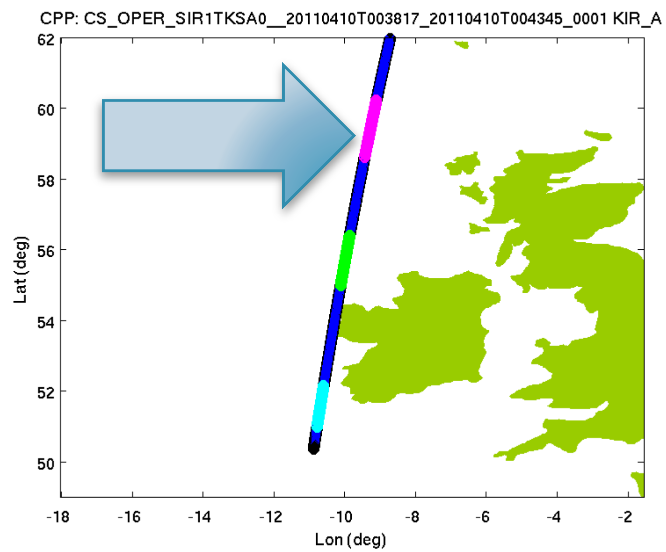


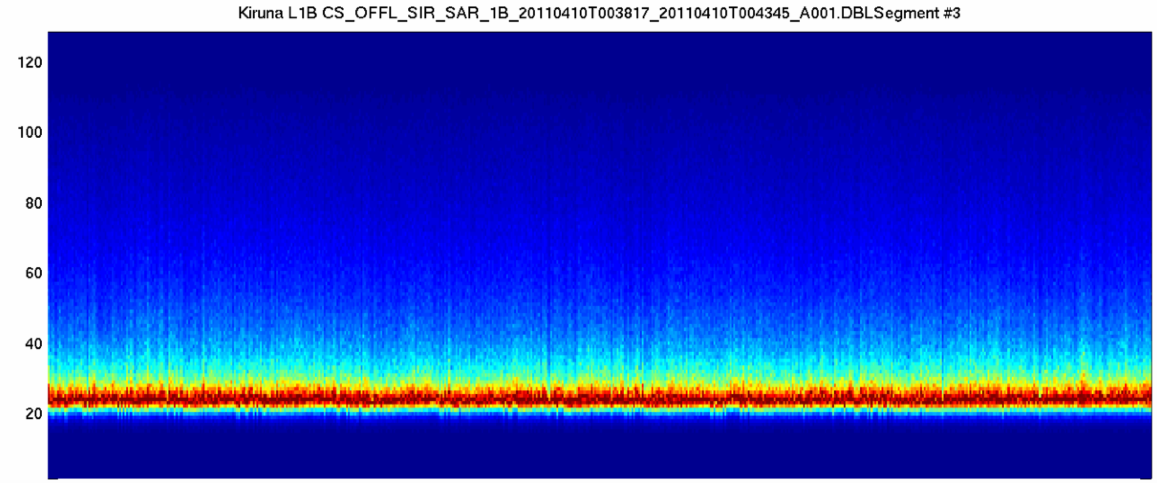


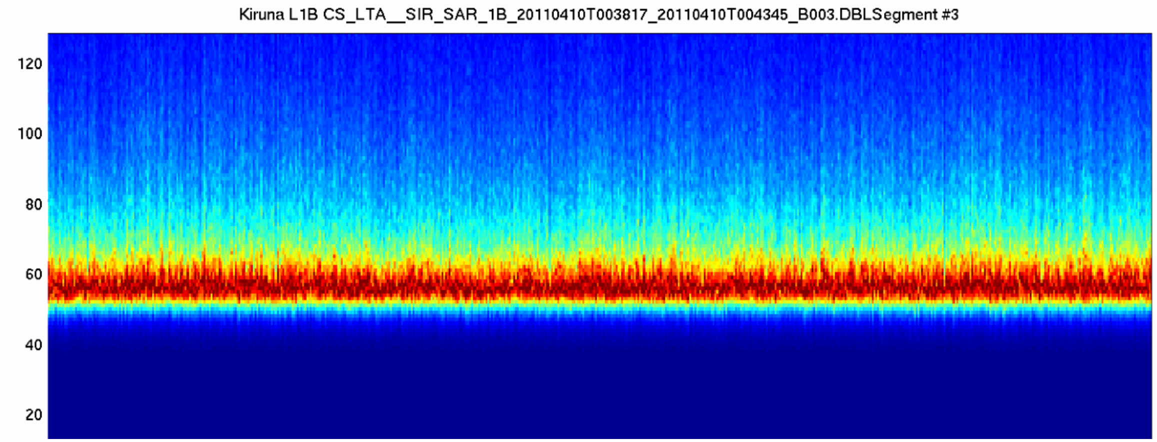
Example of waveform fits

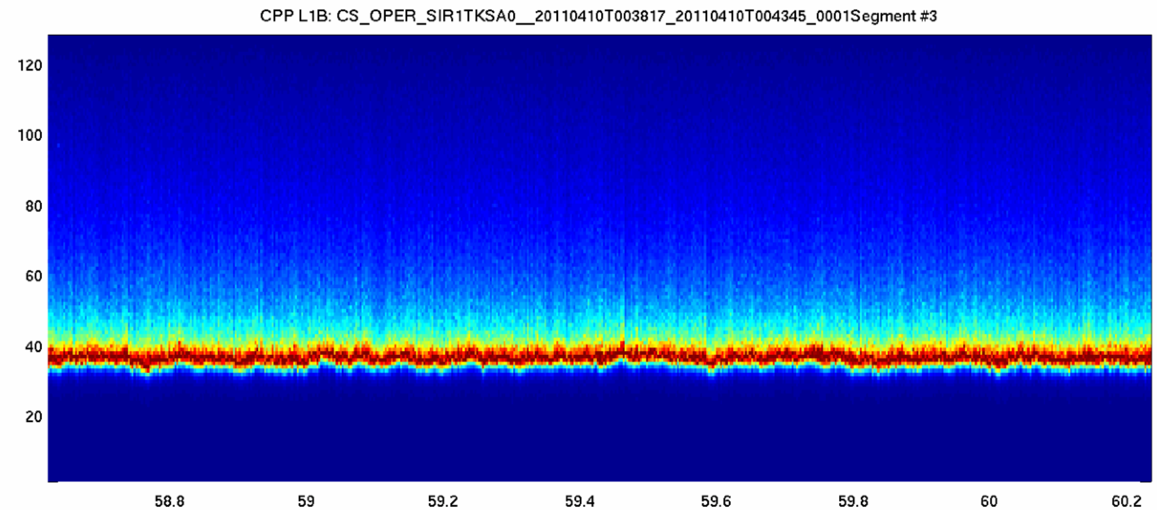












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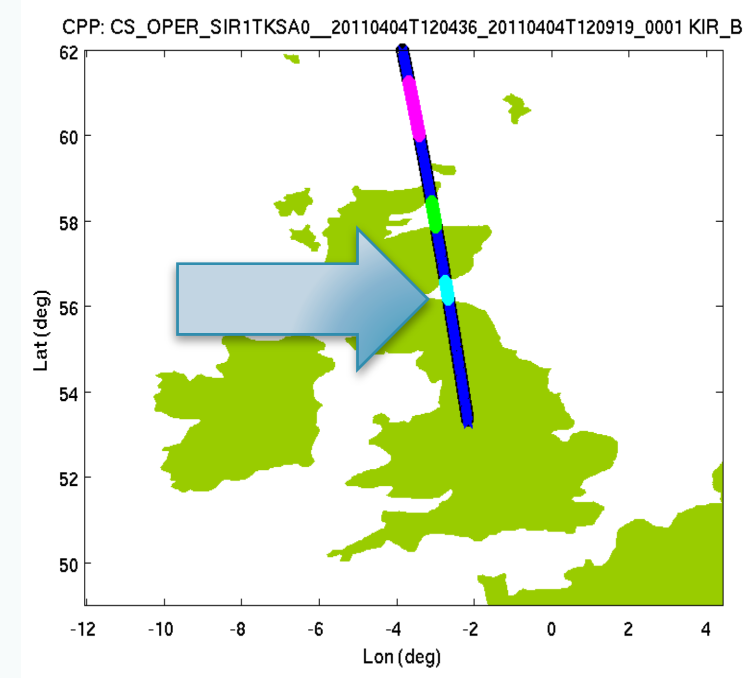

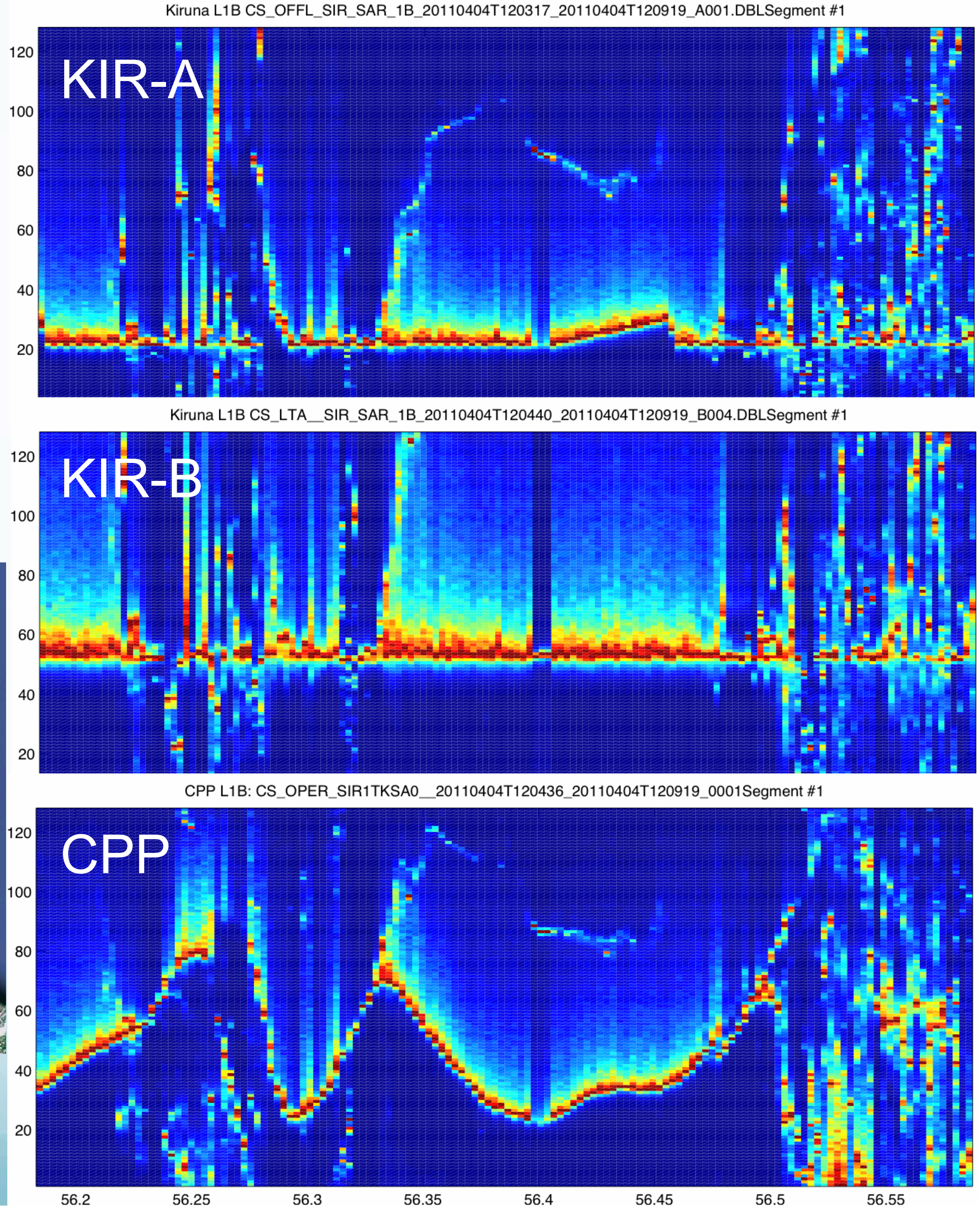

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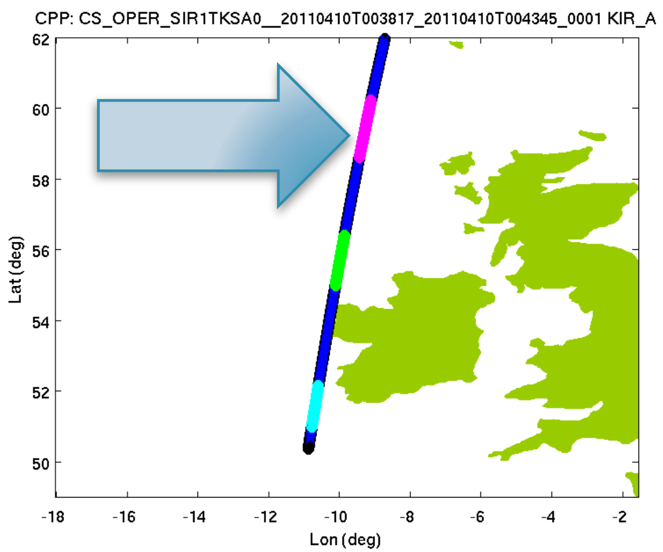

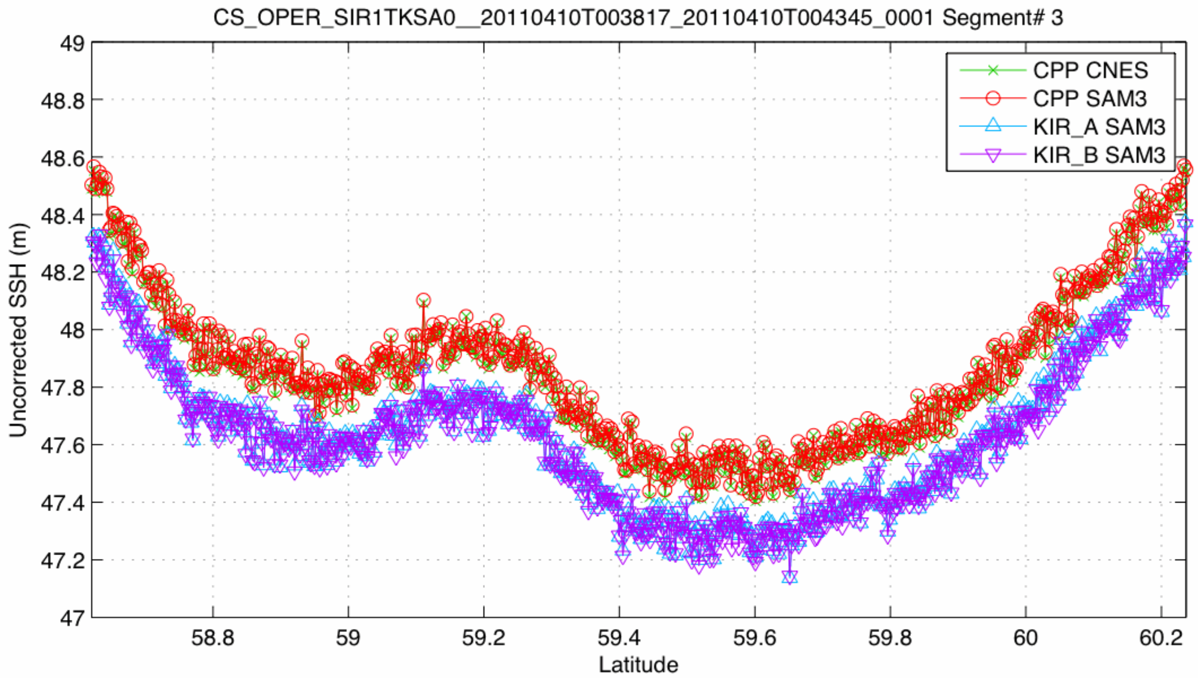

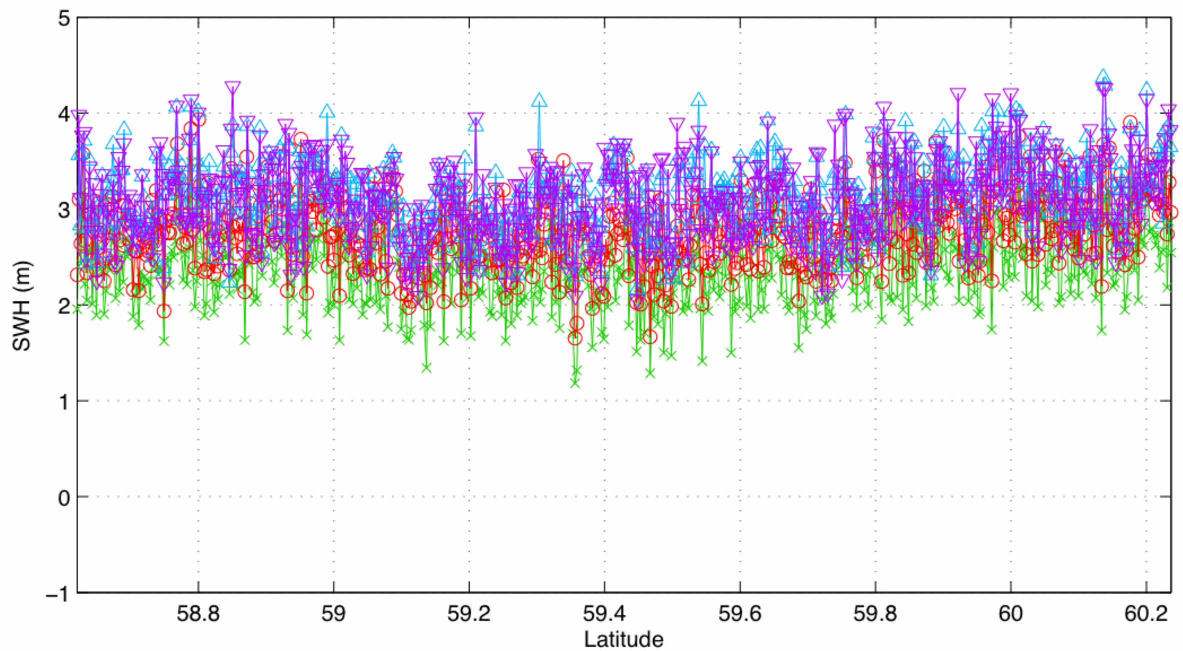

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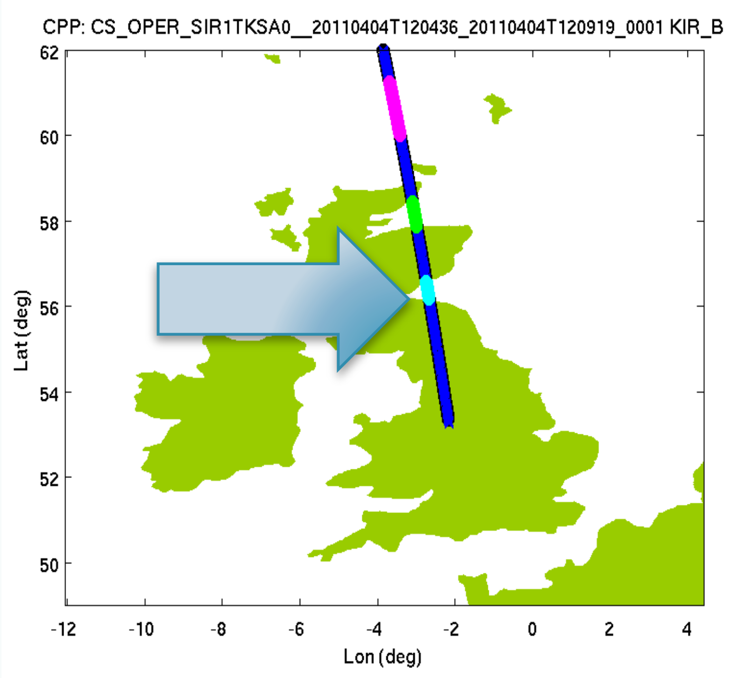

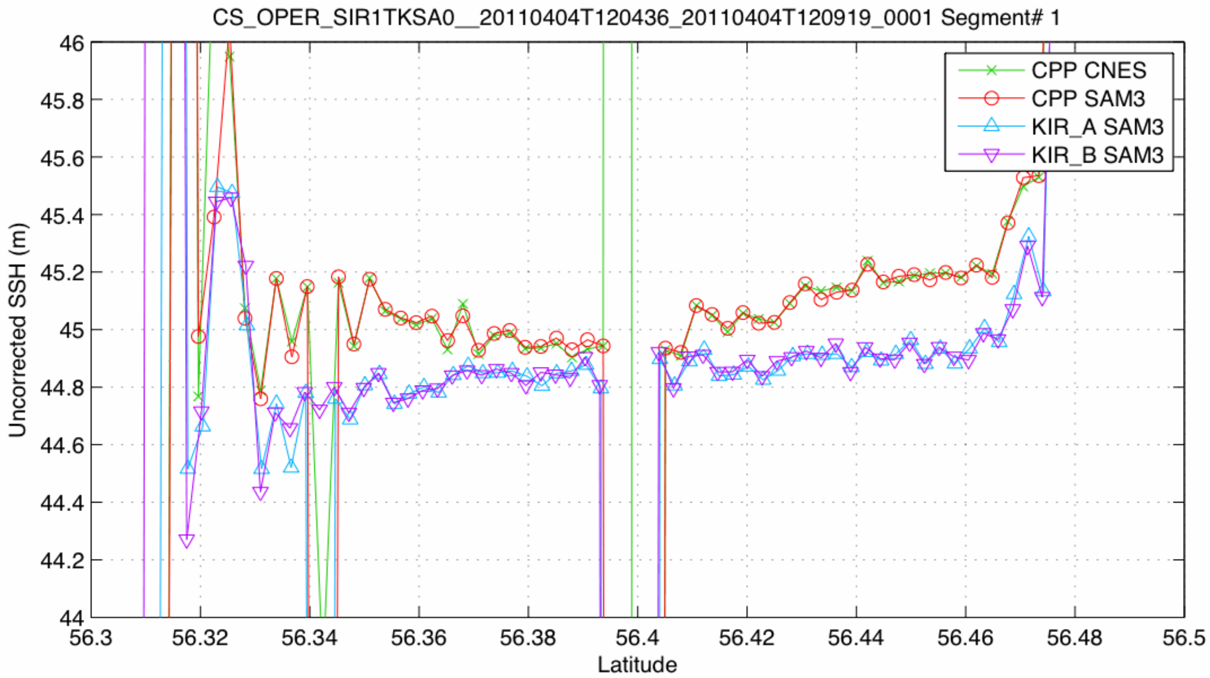

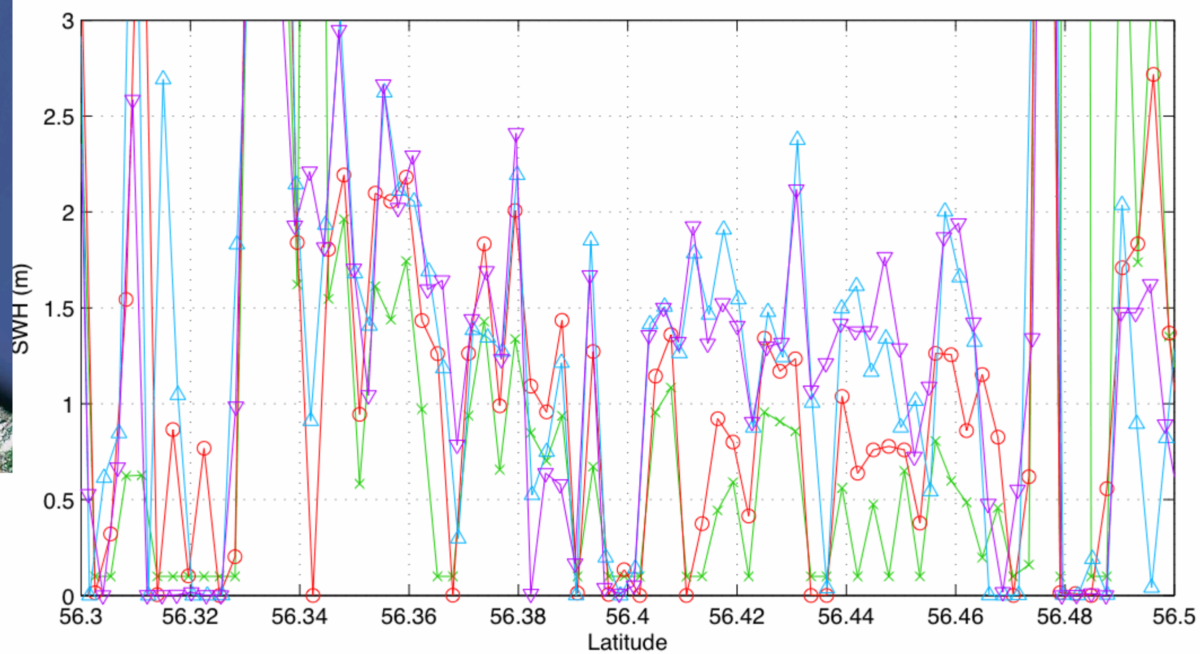

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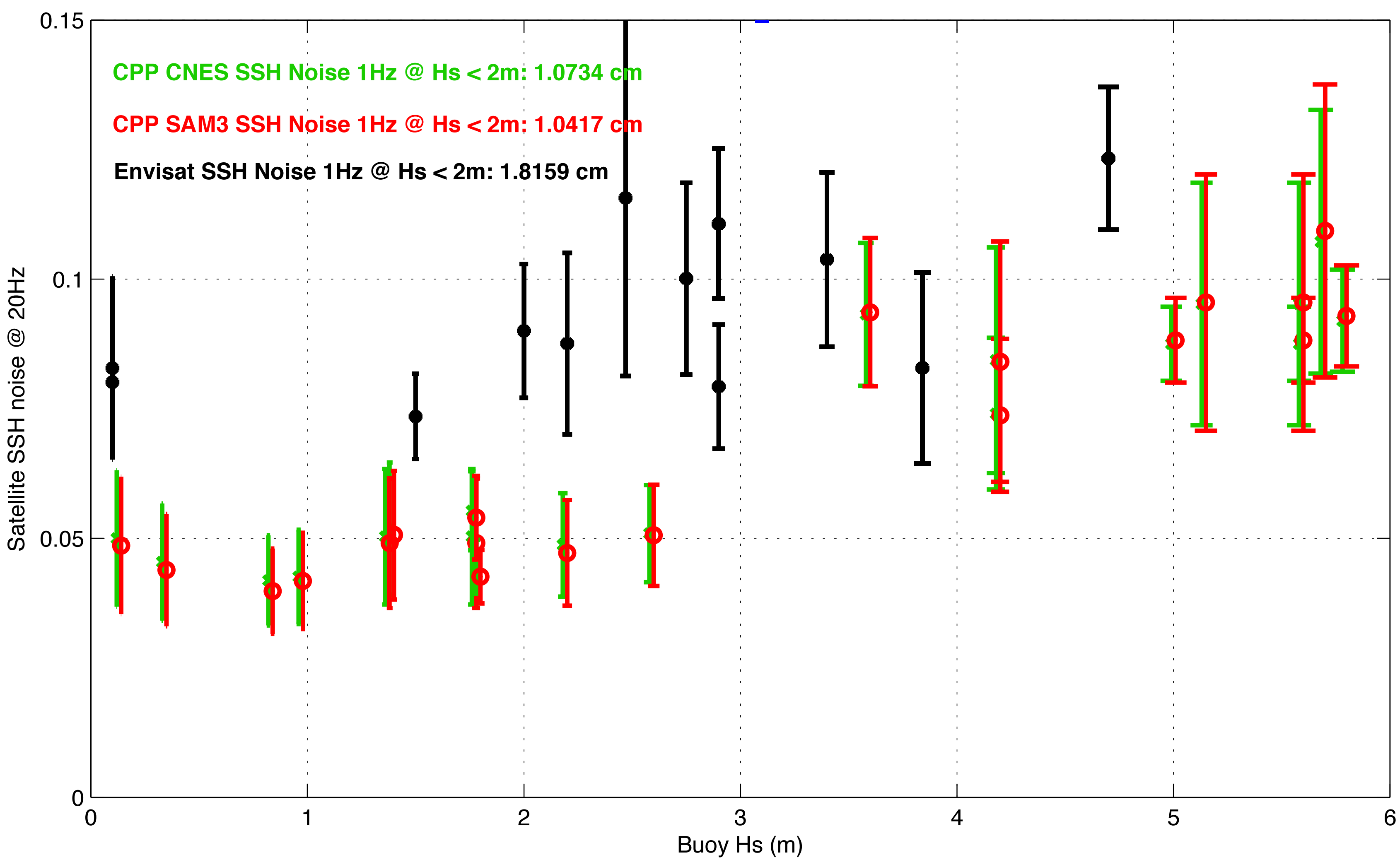
SSH noise v buoy Hs



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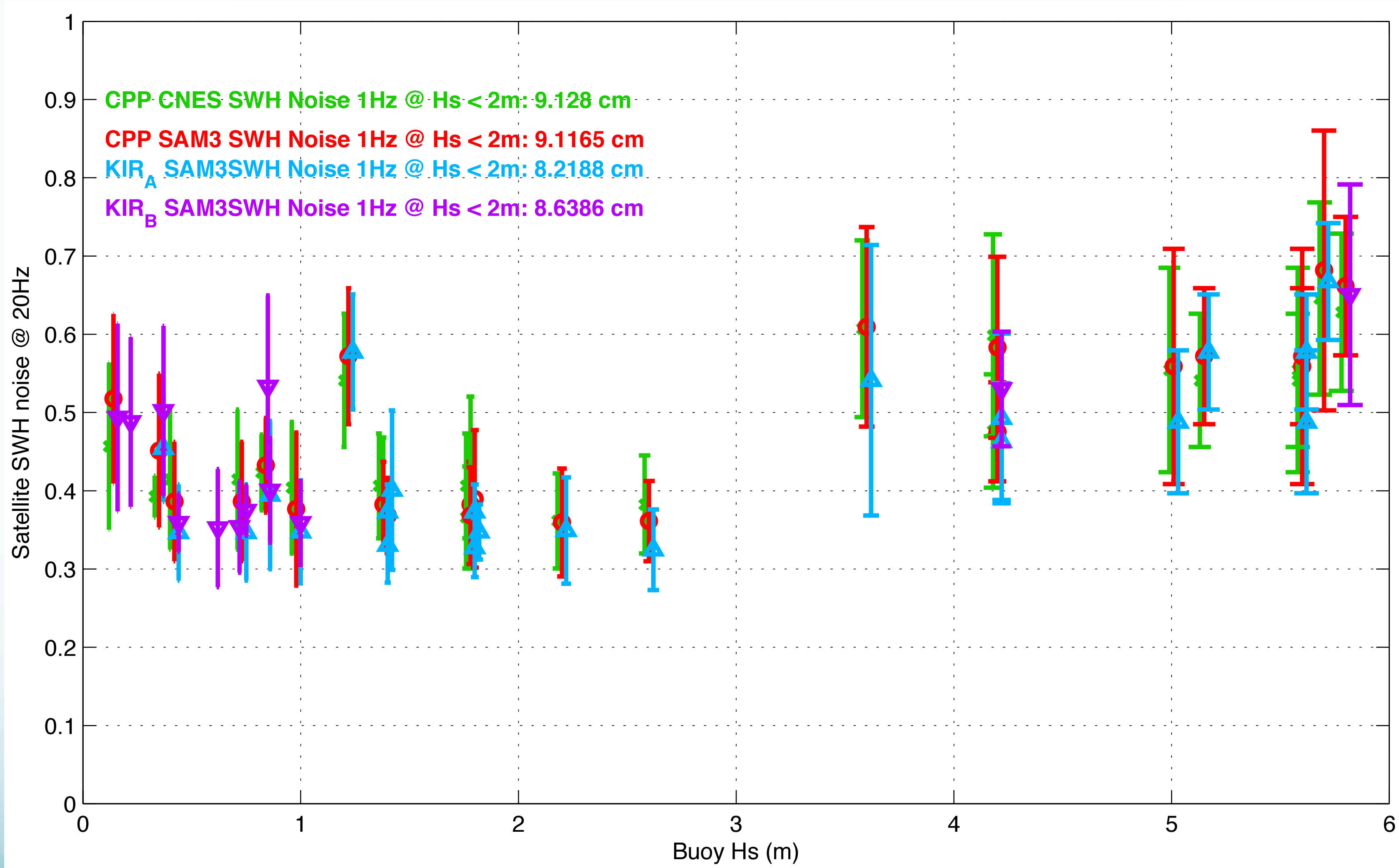
SWH noise v buoy Hs



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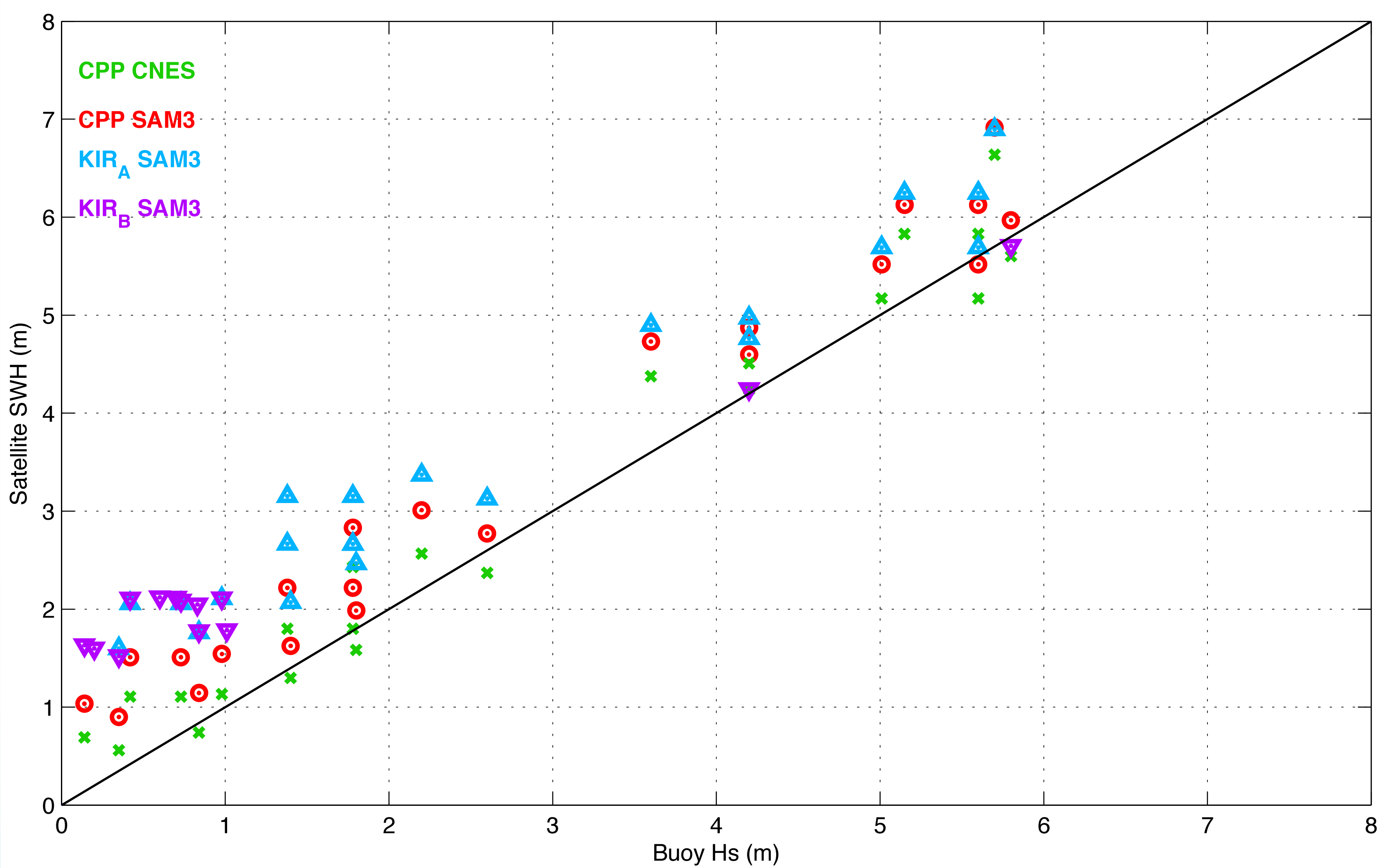
SAR SWH v buoy Hs



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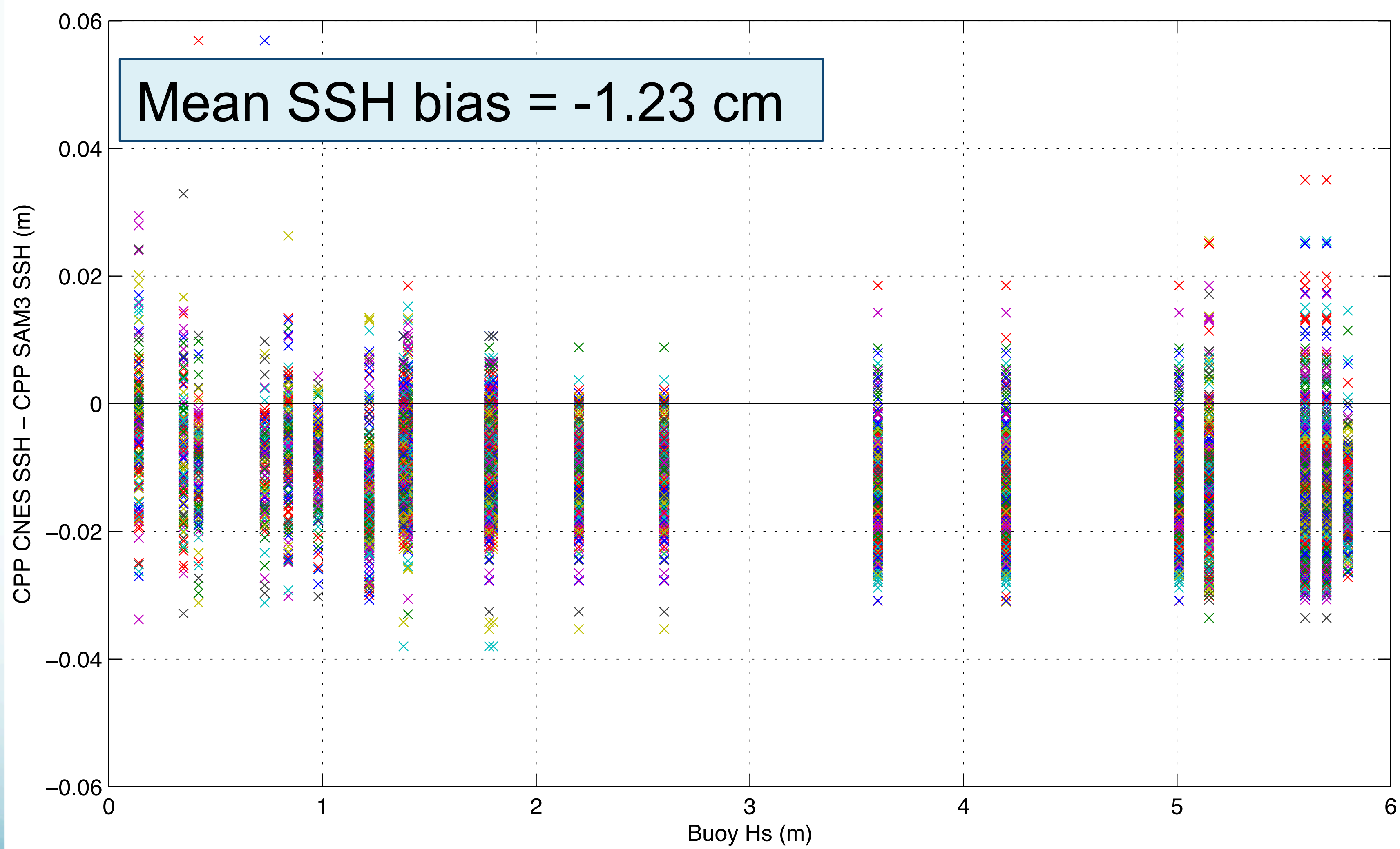
NOC – 26/27 June 2013

CPP CNES – CPP SAM3 SSH bias



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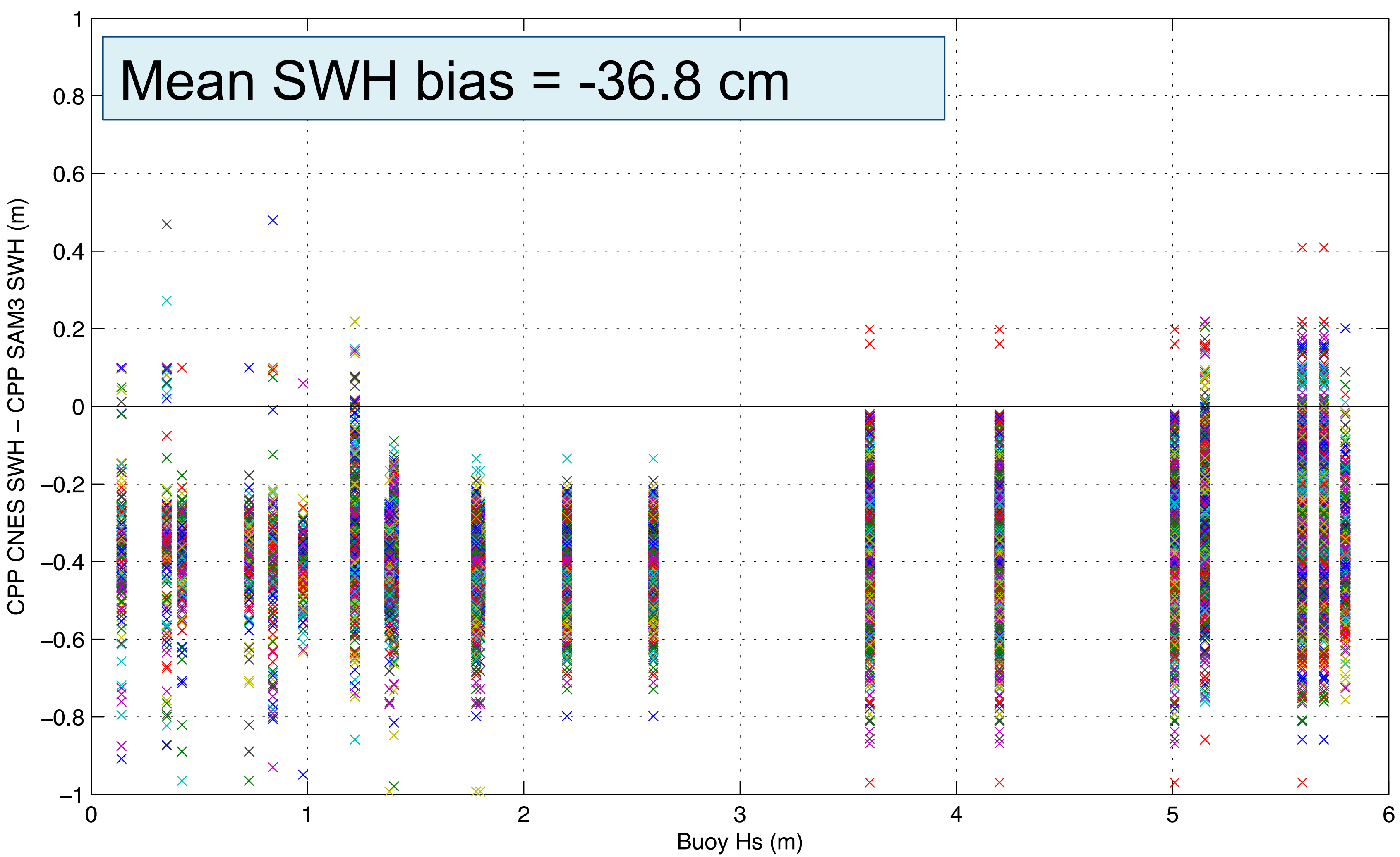
CPP CNES – CPP SAM3 SWH bias



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CP4O outcome (so far)...

- First direct comparisons between SSH and SWH obtained with SAMOSA3 and CNES numerical retracker applied to same (CPP) waveforms, showing that:
    - SAMOSA3 & CNES numerical give equivalent results in terms of noise on SSH and SWH
    - SHW biased slightly high against buoys (especially for Hs < 1m and especially SAM3)
    - CNES v SAM3 bias is ~ 1 cm on SSH and 40cm on SWH, and is independent of SWH !
- SAMOSA3 retracker applied to CPP, ESA Kiruna-A and Kiruna-B ML waveforms show that
    - ESA Kiruna-A and ESA-Kiruna-B equivalent to CPP for SSH and SWH noise
    - ESA Kiruna-A and ESA-Kiruna-B SWH (retracked with SAMOSA3) are biased high against buoys

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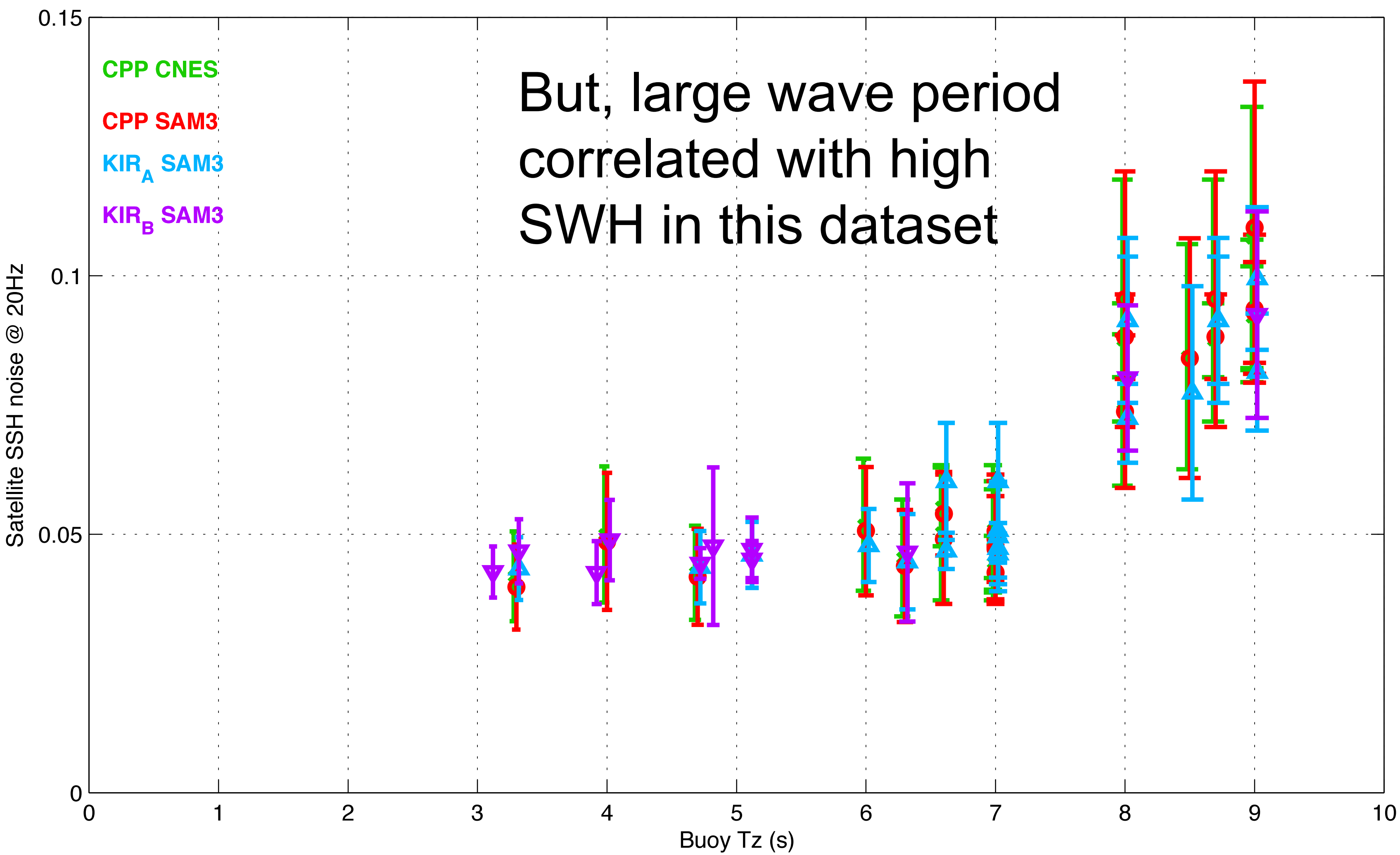
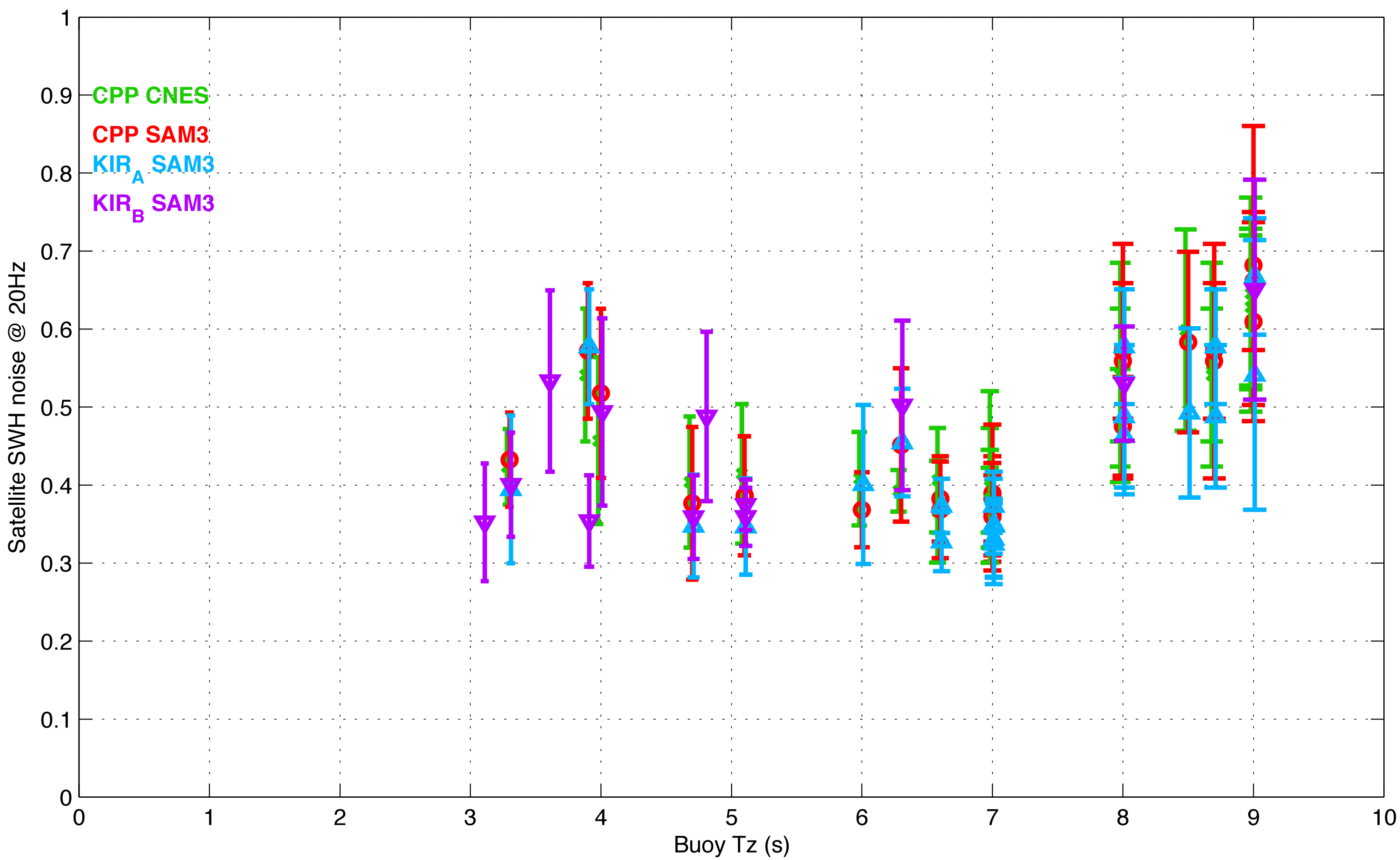
...and open issues

- Effect of swell and direction
  - Some evidence of increased SSH noise in high wave periods

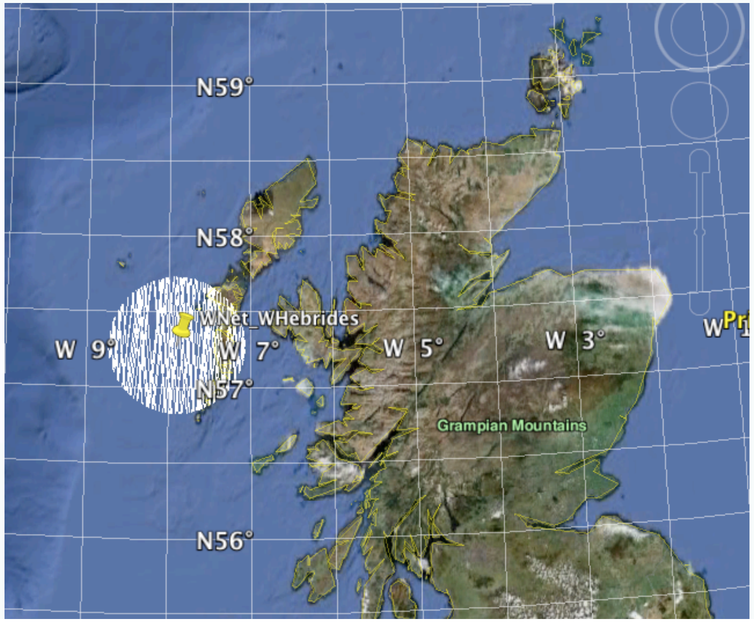
SSH noise v buoy wave period

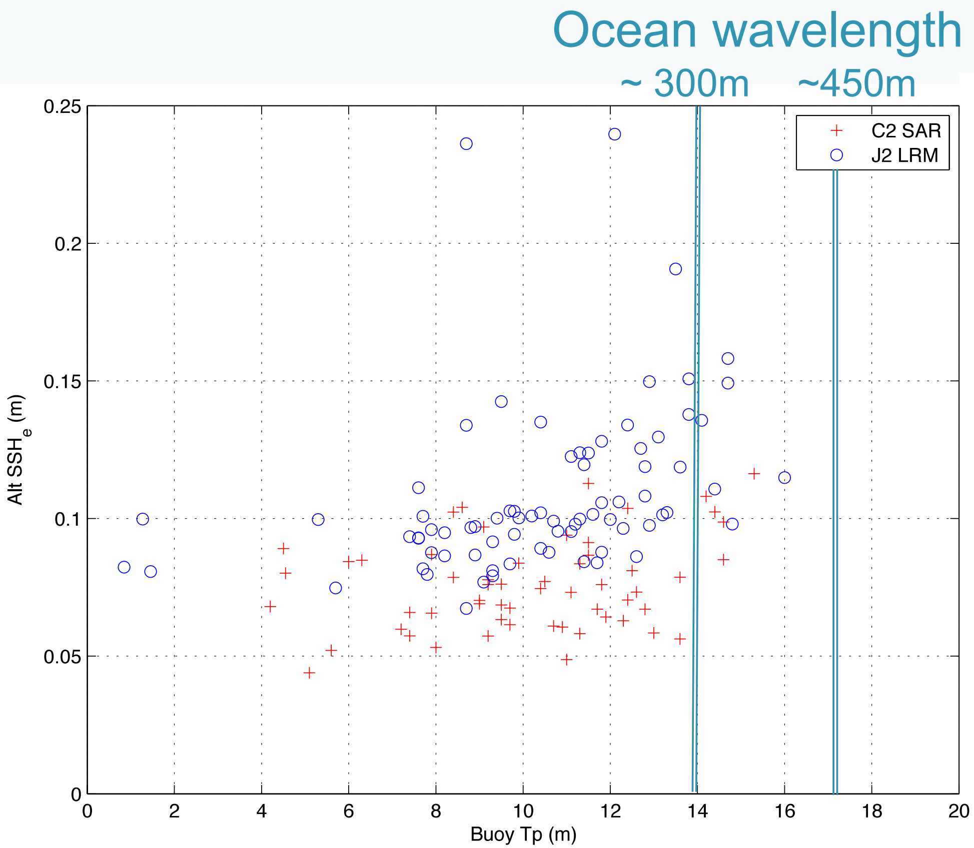


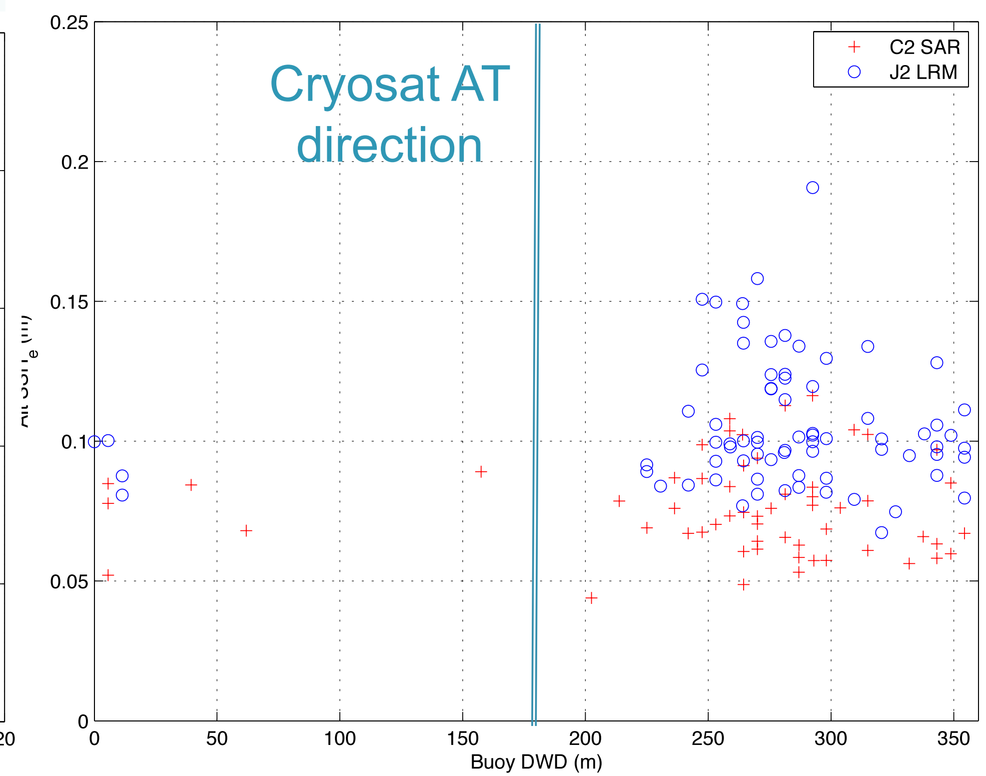
SWH noise v buoy wave period



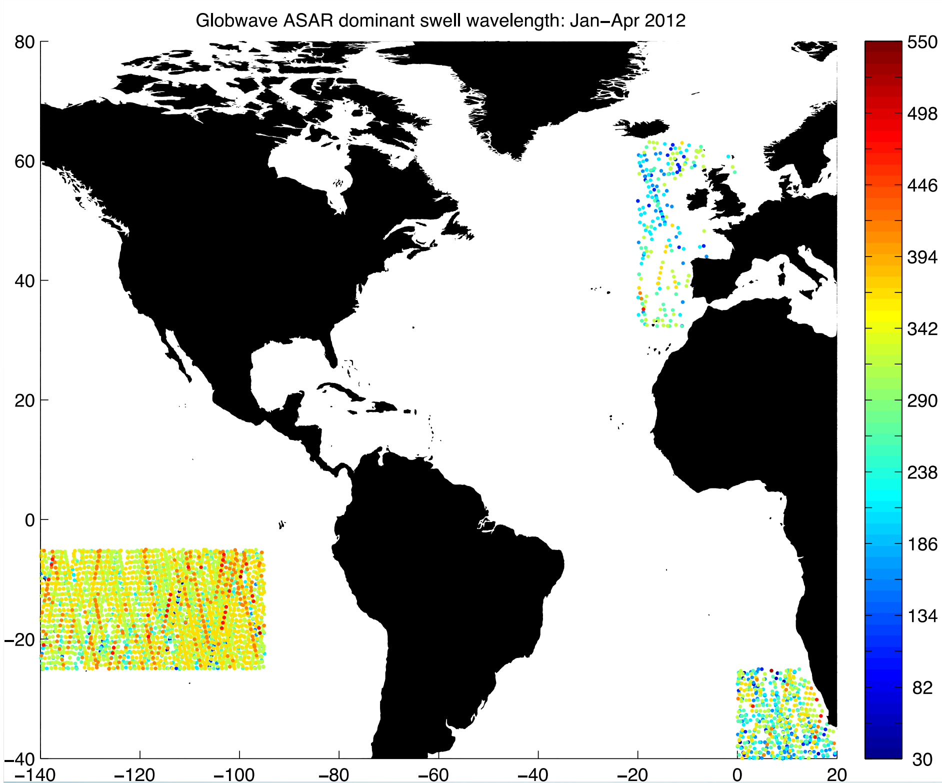
C2 SAR sensitivity to swell and wave direction

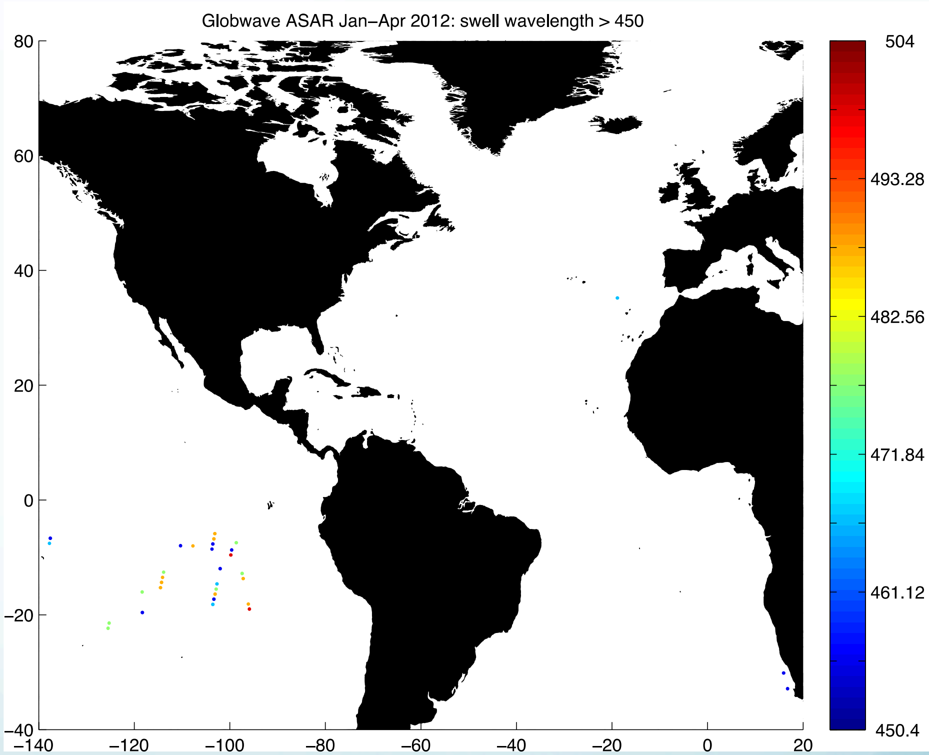






Globwave ASAR swell data





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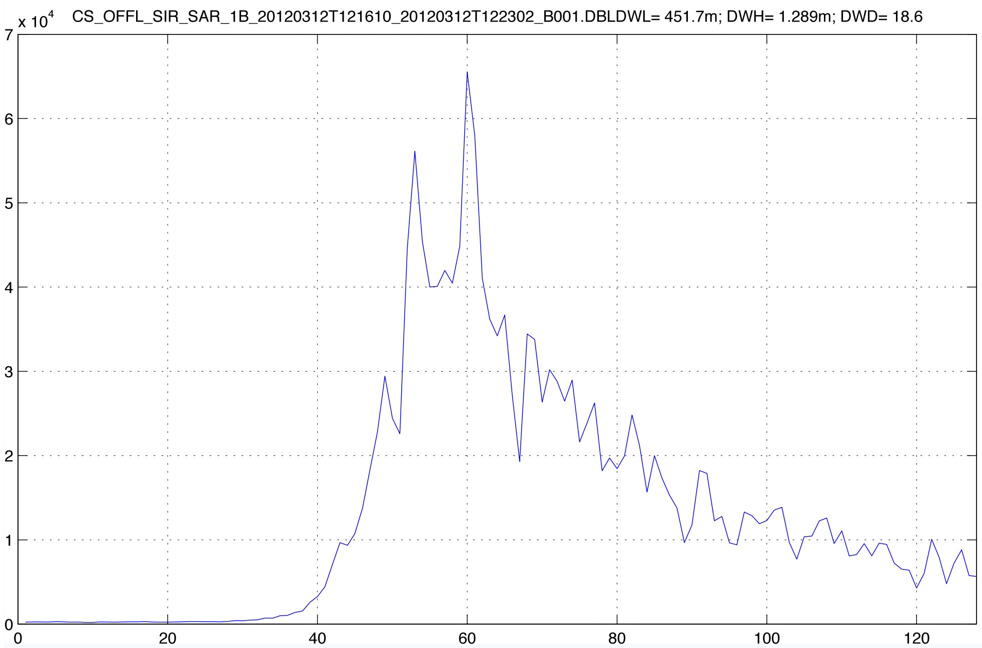
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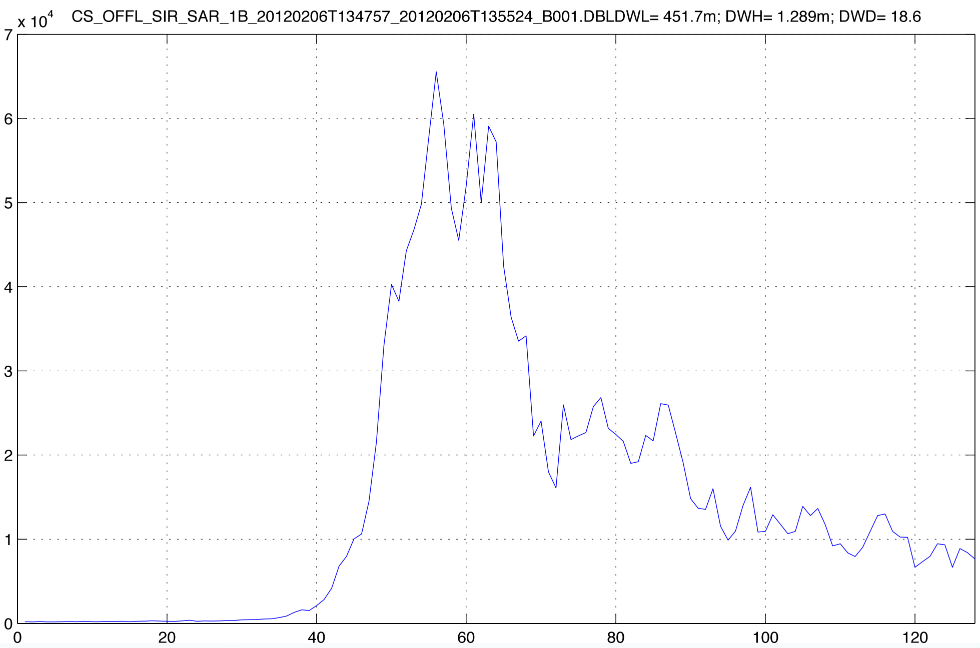
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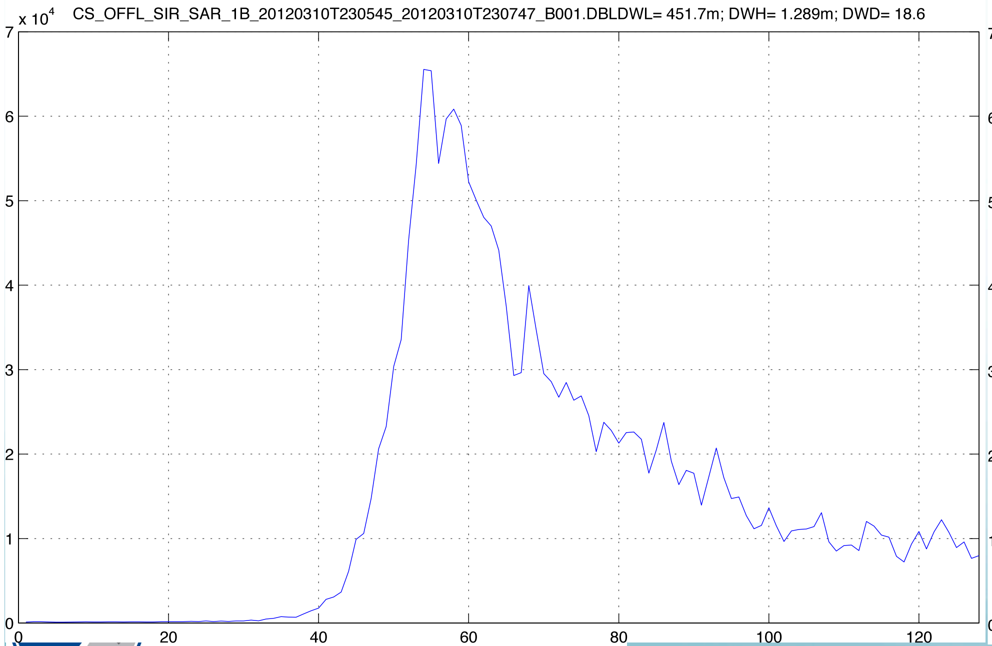
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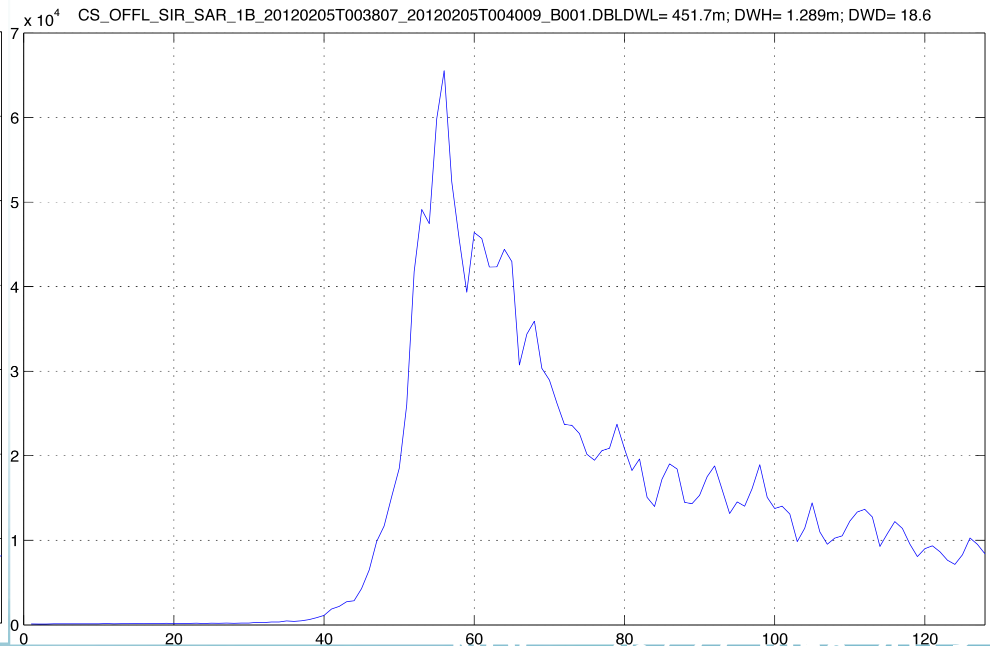
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Next steps

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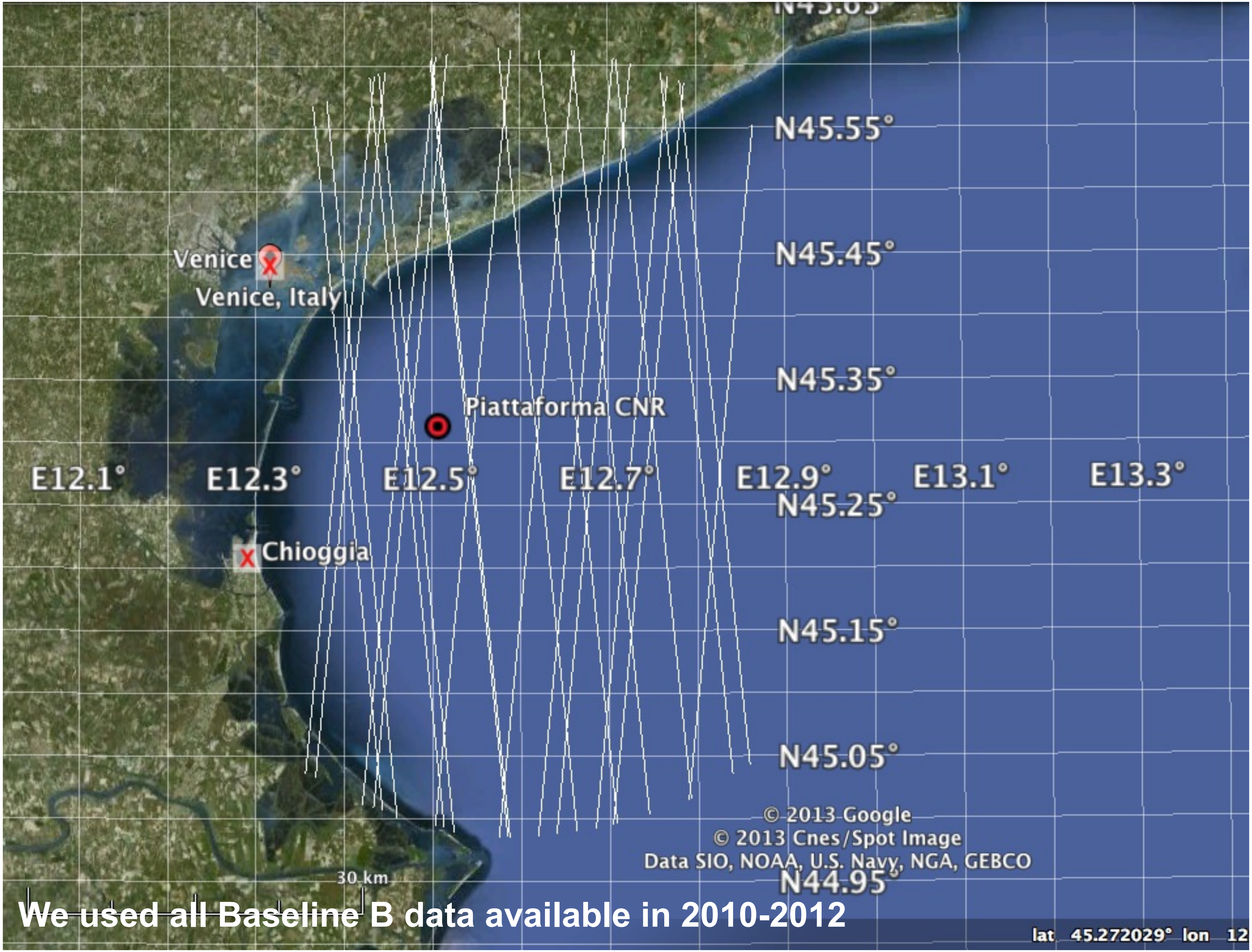
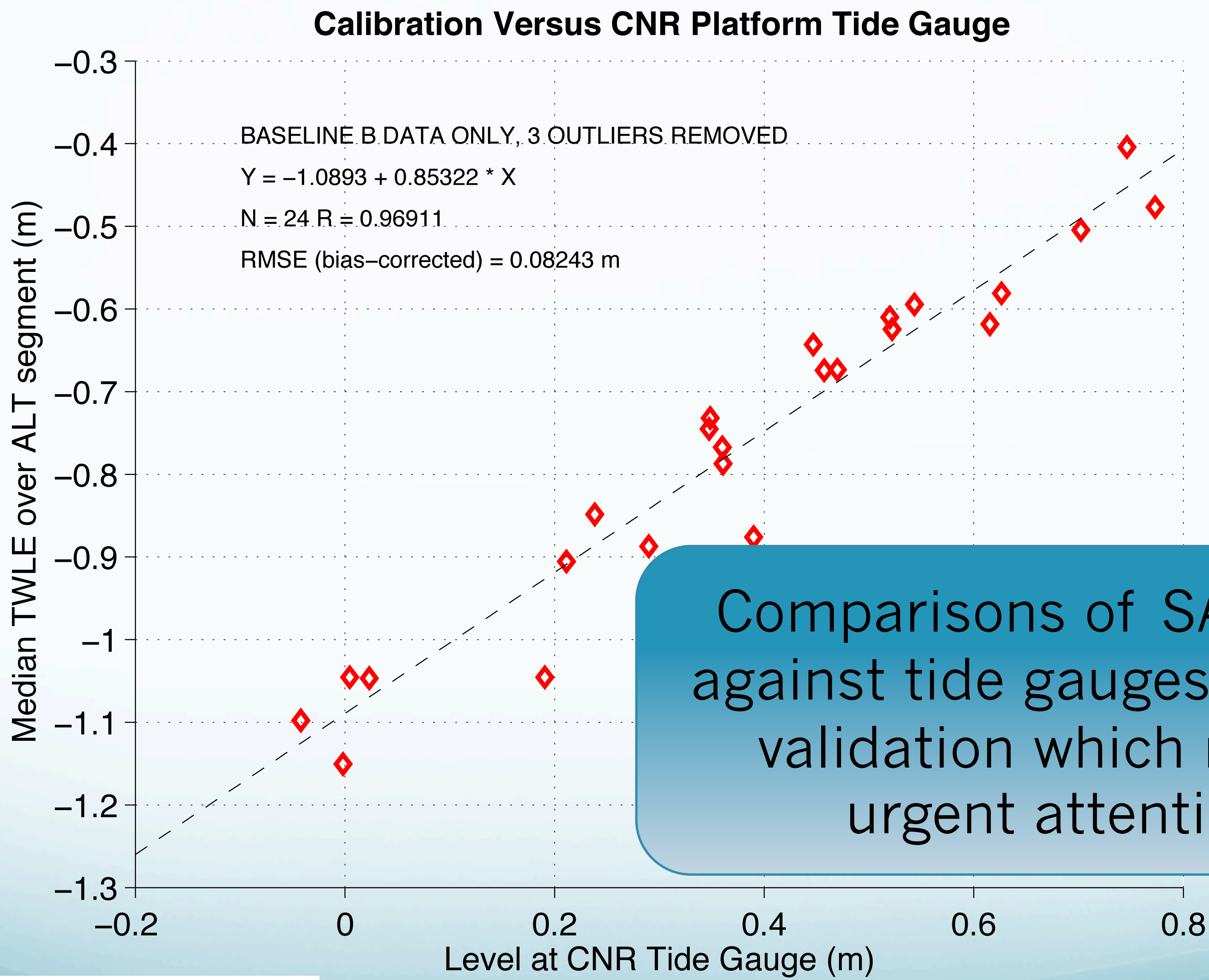
Cryosat-2 SAR in eSurge

- SAMOSA3 implemented in eSurge NRT
- C2 SAR coastal altimetry products in NetCDF
- All fields provided at high rate
- Total Water-level Envelope

eSurge NRT field list	Process	Source
Time	Pass thru	L1B
Latitude	Pass thru	L1B
Longitude	Pass thru	L1B
Satellite Height	Pass thru	L1B
Range	Computed	L1B
Sea Surface Height	Computed	L1B
Significant Wave Height	Computed	L1B
Wet tropospheric	Interpolated	L1B or L2
Dry tropospheric	Interpolated	L1B or L2
Ionospheric (GIM)	Interpolated	L1B or L2
Ionospheric (model)	Interpolated	L1B or L2
Inverse barometric	Interpolated	L1B or L2
Dynamic atmospheric	Interpolated	L1B or L2
Ocean equilibrium tide	Interpolated	L1B or L2
Ocean long period tide	Interpolated	L1B or L2
Geocentric polar tide	Interpolated	L1B or L2
Solid earth tide	Interpolated	L1B or L2
Mean Sea Surface (GEOID)	Interpolated	L2A
Total Water-level Envelope	Computed	L1B & L2A


N45.55°
N45.45°
N45.35°
N45.25°
N45.15°
N45.05°
N44.95°
E12.1°
E12.3°
E12.5°
E12.7°
E12.9°
E13.1°
E13.3°
Venice
Venice, Italy
Piattaforma CNR
Chioggia
© 2013 Google
© 2013 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
30 km
lat 45.272029° lon 12
We used all Baseline B data available in 2010-2012

Tide Gauge data provided by Stefano Vignudelli - CNR



Comparisons of SAR SSH against tide gauges is a key validation which needs urgent attention

Summary & Conclusions

- SAMOSA3 performance on CPP waveforms compared to CNES numerical retracker gives confidence in its validity to retrack SAR waveforms
  - Retrieved SSH and noise on SSH and SWH are comparable
  - Bias in SAMOSA3 SWH against CNES SWH is unexplained
    - Need to understand the processing applied to L1B data to optimise our SAMOSA3 SAR retracker
      - No SWH bias with SAMOSA3 against CPP data in implementation by S. Dinardo (see talk by Luciana Fenoglio-Marc et al.)
- SAMOSA3 now implemented in eSurge operational processor and ready to enter production of Cryosat-2 SAR L2 coastal products in Netcdf format

Recommendations for S-3 and Jason-CS

- Evidence of swell effect on Cryosat-2 SAR waveforms
  - Distorsion of waveforms clearly observed in extreme cases of long swell
    - In SAR mode, there will be an additional bias in SSH linked to swell: SSB_{swell} (in addition to "ordinary" Sea State Bias)
    - The effect has been seen in swell dominated regions e.g. Central pacific, East-European shelf,...
    - Even though these swell conditions are not typical of global conditions, they may be frequent in some regions

- The high sensitivity of SAR SSH and SWH to mispointing (and mispointing bias) is a concern for high-precision sea level measurements