Sea state bias in SAR mode altimetry: results from observations

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SAR mode altimetry and SSB

- SAR altimetry footprint is strongly asymmetric
 - $_{\odot}$ Across-track ~ O(2-10 km) & along-track ~ O(300 m)
 - uncertainty as to possible effects on SAR mode waveforms by ocean swell and swell direction



EUMETSAT study on SAR SSB

- Dedicated study funded by EUMETSAT on SSB in SAR mode altimetry
 - Focus on SSB correction for Jason-CS/Sentinel-6
 - 12 months project, nearing completion
 - Coordinated with parallel ESA-funded activity (SCOOP) on swell effects for Sentinel-3 SAR mode data
 - Technical Officer at EUMETSAT: Remko Scharroo



Scientific investigations of swell effects

- Effect of swell and swell direction on SAR mode
 - Theoretical considerations
 - Empirical investigations with Cryosat-2 SAR mode data
 - Extend preliminary analyses of Cryosat-2 SAR waveform shape in swell/noswell conditions by Gommenginger et al (2013)
 - Impact of SAR Mode processing & retracking choices
 - Impact on Level 2 SSH



Theoretical considerations



- Rectangular box illustrates asymmetric SAR footprint
 - \circ L x d, with L >> d
 - typically L ~ 2-7km, d ~ 300m
- Swell crests/troughs as dashed lines
 - \circ Wavelength λ
 - \circ $\lambda \sim O(d)$ typically 100-400m
- N = number of crests/troughs per footprint

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Theoretical considerations



Empirical investigations

- Collocate Cryosat-2 SAR mode with Envisat ASAR
 - Cryosat-2 L1B 20Hz waveforms
 - ESA operational products (Baseline B)
 - L1B and L2 from SARvatore processor
 - ASAR (dominant) swell length, direction & height
 - 300km; 24 h
 - Collocate with RADS 1Hz (Cryosat-2 PLRM)
- Cryosat-2/Envisat overlap:
 - $_{\circ}$ $\,$ July 2010 May 2012 $\,$
 - July 2010: first Cryosat-2 data
 - May 2012: Envisat end-of-life
- Three oceanic regions
 - Cryosat-2 operates in SAR mode over ocean, away from sea ice and land
 - Cryosat-2 Pacific box only from May 2012







Swell direction classification





- Cryosat-2 inclination is 92 deg
 - ascending/descending tracks aligned almost North-South
- Parallel swell
 - $_{\circ}$ Crests // footprint
 - $_{\circ}$ Swell travels // track
- Perpendicular swell
 - Crests ⊥footprint
 - Swell travel \perp track
- In practice...
 - any swell travelling within ± α of exact parallel or perpendicular directions

Swell conditions in collocated dataset



Two 20Hz Cryosat-2 SAR waveforms



Same region, same groundtrack orientation, same swell height, same swell direction but ≠ swell wavelength

Short swell wavelength (100 – 200m) Wave height < 1m Wave direction parallel to altimeter

Long swell wavelength (400+ m) Wave height < 1m Wave direction parallel to altimeter





Average waveforms v swell



Average over 100 waveforms

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Average waveforms v swell





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Mean waveform v swell categories ESA operational L0->L1B processing

Perp (9)

Oblique (123)

- Para (19)

100

100

Perp (11)

- Oblique (42

120

- Perp (3)

Oblique (5

120



Parallel Perpendicular Oblique

 No reliable evidence of swell effect

Mean waveform v swell categories SARvatore L0->L1B processing

-Para (52)

Perp (9)

80

80

80

100

100

100

Para (19)

Perp (11)

Oblique (52)

120

Para (19)

- Oblique (5)

120

Perp (3)

Oblique (123

120



Parallel Perpendicular Oblique

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Impact on L2 SSH bias v PLRM?

Parallel Perpendicular Oblique

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- SARvatore Cryosat-2 L2 SAR SSH
- Uncorrected 1Hz SAR SSH v Uncorrected 1Hz PLRM SSH (RADS)
- No discernible ranging bias in SAR mode against PLRM linked to swell
 - Not with swell direction, swell height nor swell length

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Impact on L2 SSH SSH precision v PLRM?

Parallel Perpendicular Oblique

- SARvatore Cryosat-2 L2 SAR SSH
- Uncorrected SAR SSH precision (std)
 ~ 1cm @ Hs = 2m
- No discernible change linked to swell
 - Not with swell direction, swell height or nor swell length



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Impact on L2 SSH SSH precision v PLRM?

Parallel Perpendicular Oblique

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Summary & Conclusions

- EUMETSAT study on SSB in SAR mode nearing completion
 - Theoretical considerations and empirical investigations with Cryosat-2 SAR data (L1B & L2) collocated with Envisat ASAR
- Theoretical analyses indicate swell effect could distort waveforms

 when swell height > 4 metres, which is rare
- Empirical investigations find no evidence of swell effects

 not in L1B waveforms, not in L2 SSH
- Based on the analyses and dataset in this study, we find no convincing evidence of swell effects in Cryosat-2 SAR mode data
 Note that:
 - Absence of evidence ≠ Evidence of absence
 - parallel swell cases had swell height < 2m in this dataset</p>



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