SAR mode altimetry and sea state bias

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Motivation

- Sea State Bias (SSB) is the largest remaining error in ocean altimeter data
 - $_{\odot}~$ SSB = ϵ Hs where Hs is the significant wave height and ϵ ~ 3-4%
 - ε usually estimated empirically for each satellite mission e.g. with Look-Up Tables (LUT) based on SSH residuals at cross-overs for large amount of globally-distributed altimeter data
 - In this case, ε includes SSH biases due to sea state effects (e.g. electromagnetic bias) and instrument effects (e.g. retracker bias)
 - So that the ε LUT is different for each satellite mission
 - $_{\circ}$ Various forms of ϵ LUT:
 - ε (Hs, U10) where U10 is the wind speed at 10m
 - $\epsilon(Hs, \sigma 0)$ where $\sigma 0$ is the backscattered power
 - More recently, ε(Hs, U10, T) where T is a the wave period (usually from a numerical wave model)
- No SSB model currently available for SAR mode altimetry



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SAR mode altimetry and SSB

- SAR altimetry provides demonstrated advantages
 - Improved precision for SSH, Hs and wind speed
 - Finer spatial resolution in along-track direction
 - improved description of short-scale ocean variability
 - Improved performance in coastal and sea ice covered oceans
 - All demonstrated in-orbit with Cryosat-2 SAR mode data over ocean
 - SAR Mode adopted for Sentinel-3 and Jason-CS/Sentinel-6
- But insufficient amount of Cryosat-2 SAR mode ocean data to develop reliable SAR SSB correction



Cryosat-2 mode mask v3.5 (since July 2014) SAR Mode in green

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SAR mode altimetry and SSB

- SAR altimetry footprint is strongly asymmetric
 - LXT ~ O(2-10 km) & dAT ~ O(300 m)
 - introduces uncertainty as to possible effects on SAR mode waveforms by ocean swell and swell direction, and possible swell induced biases in SSH.



Context of this work

- Dedicated study on SAR mode SSB funded by EUMETSAT
 - Focus on SAR mode SSB correction for Jason-CS/Sentinel-6
 - 8 months study started 21 September 2015
 - Coordinated with parallel ESA-funded activity (SCOOP) on swell effects for Sentinel-3 SAR mode data
 - Technical Officer at EUMETSAT: Remko Scharroo





Content of the study

- Literature review and scientific investigations
 - Comprehensive review of methods to estimate SSB for conventional (LRM) altimetry
 - Empirical, experimental and theoretical methods
 - $_{\odot}~$ Effect of swell and swell direction on SAR mode data
 - Extend preliminary analysis by Gommenginger et al (2013) of Cryosat-2 SAR waveforms in swell/no-swell conditions
 - Impact of SAR Mode processing & retracking choices
- Algorithm Basis for SAR Mode SSB Correction
- Methods for calibration and validation of SAR Mode SSB



Approach & Datasets

DATA	2010					2011						2012						2013						2014						2015					L1B 20Hz waveforms	L2 20Hz retracked parameters	L2 1 Hz parameters	Availability of p-URM or RDSAR	collocated geophysical corrections		
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ESA Cryosat-2 L1b	П					П	П	П	П	П	П	П	П	П	П	П							П	П					П	П	П	П	П			Ш					
ESA Cryosat-2 L2 20 Hz (IOP)						Π	Π	Π	Π	Π	Π	Π	Π	Π	Π	П							Π	Π			П		П	П	Π	Π	П			Ш					
ESA Cryosat-2 L2 20 Hz (GOP)	П					П	П	Π	Π	Π	Π	Π	Π	Π	Π	П					Π	П	Π	Π		П	П		П	Π	Π	Π	Π	Π		Π					
ESA Cryosat-2 L2 1 Hz (RADS)	П			Ш		Π	П	Π	П	Π	Π	Π	Π	П	Π	П							Π	Π			П		П	Π	Π	Π	Π	П		Ш			x		x
Cryosat-2 CNES CPP	П			Ш	П	П	П	П	П	П	П	П	П	П	П	П	Т			П	Ш	П	П				П		П		П	П	П	Ш		Ш			×		
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- Cryosat-2 L1B waveforms (different sources)
- Ocean swell data from imaging SAR (e.g. Envisat ASAR), numerical wave model (WW3) and buoys
- Comparisons with contemporary LRM missions and Cryosat-2 Pseudo-LRM



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Collocating Cryosat-2 SAR & Envisat ASAR Preliminary results: Jan-April 2012





Frequency of significant wave beights

6

Histogram of Envisat ASAR dominant and second dominant swell wavelength

Initially selected extreme wavelengths (100-200 m and 400+ m)

Histogram of wave heights.

Project will categorize similar physical conditions

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ASAR secondary swell height (m)

3000

2500

2800

1500

1000 500

0

Swell cases in the South Atlantic

Location of Cryosat-2 SAR mode (blue) and Envisat ASAR (red) in Jan-April 2012



Two Cryosat-2 SAR waveforms in same conditions but different swell length



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



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Two Cryosat-2 SAR waveforms in same conditions but different swell length



CS_OFFL_SIR_\$AR_1B_20120203T211535_20120203T211723_B001.DBL; DWL= 424.2m; DWH= 0.591m; DWD= 138.2



Same region, same ground-track orientation, same swell height, same swell direction but ≠ swell wavelength

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

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



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Next

- Complete review of LRM SSB estimation methods
- Analyse and synthesize the impact of swell and swell direction on SAR waveforms for full Cryosat-2 SAR/Envisat ASAR collocated dataset (July'10-Apr'12)
- Repeat analyses with swell data from wave models
- Assess magnitude of the impact in different Cryosat-2 L1 products
- Assess impact on retracking and retrieved SSH
- Recommendation for SAR SSB estimation

