Refined Sentinel 6 sea state bias corrections and a multi-frequency EM bias assessment using C-, Ku-, and Ka-band data

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Outline

Flip order –

1. Multi-frequency sea state bias evaluation
2. Brief update on Sentinel-6 Ku- and C-band range and SSB issues

Motivating a three frequency EM bias assessment

- There is a need to characterize the Ka-band sea state bias in advance of SWOT
  - How critical is wind speed variation at short scales to SSB corrections?
  - Is there a need for additional wave spectra information in Ka-band SSB correction?

- An extensive on-orbit comparison of C-, Ku-, and Ka-band sea state bias (~EM bias) has not yet been performed, nor compared back to EM bias field data. Is there something new to learn?

- SWOT will have all three frequencies on board with near-nadir range and NRCS

Study Goals

Objective 1: Independent check of Ka-band SSB model (anticipating SWOT use)

Objective 2: Assess Ka-band SSB (and EM bias) behavior in comparison to the familiar lower frequency Ku-band data - and add in C-band…

Question 1: What is the mean level of SSB reduction between Ku- and Ka-band? Does it follow expectations?

Question 2: Is the observed wind speed influence on SSB similar?

Question 3: Is the observed long wave steepness influence similar?

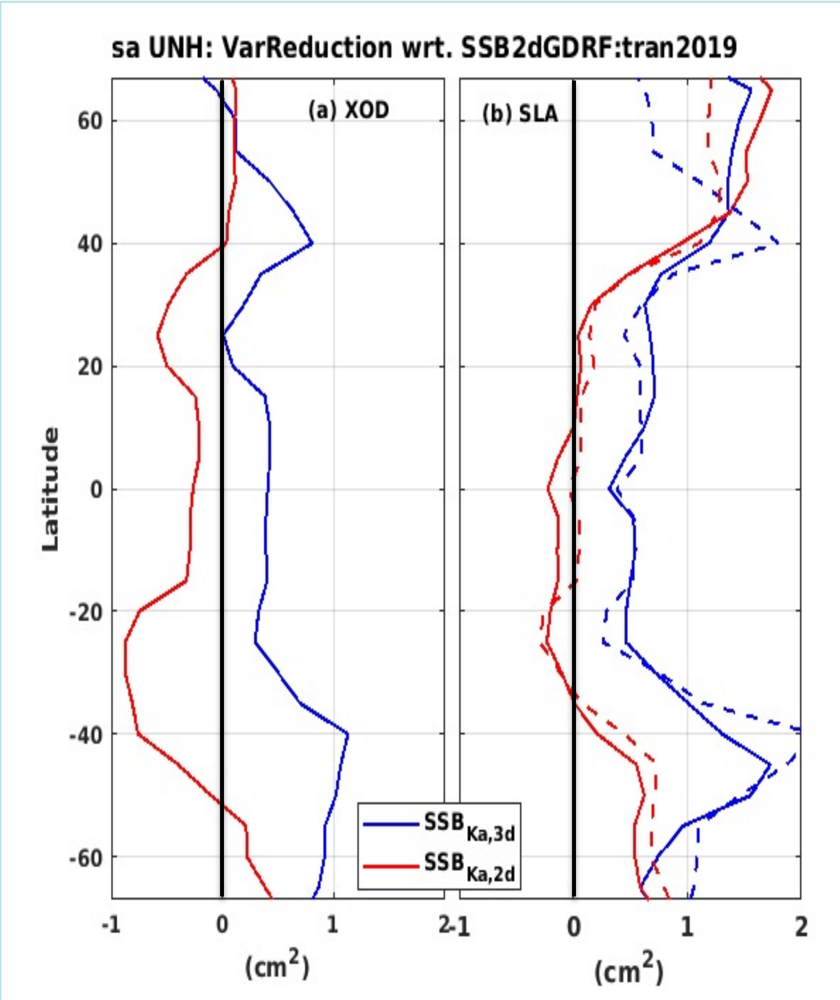
Approach: Use new J3 and AltiKa SSB data and models with same NP approach and in same time frame

1. Independent check of the GDR-F AltiKa/SARAL SSB models

Model 1: UNH 2D (SWH, wind) vs. 2D GDRF

Model 2: 3D (SWH,wind,wave model Tm) GDRF and UNH

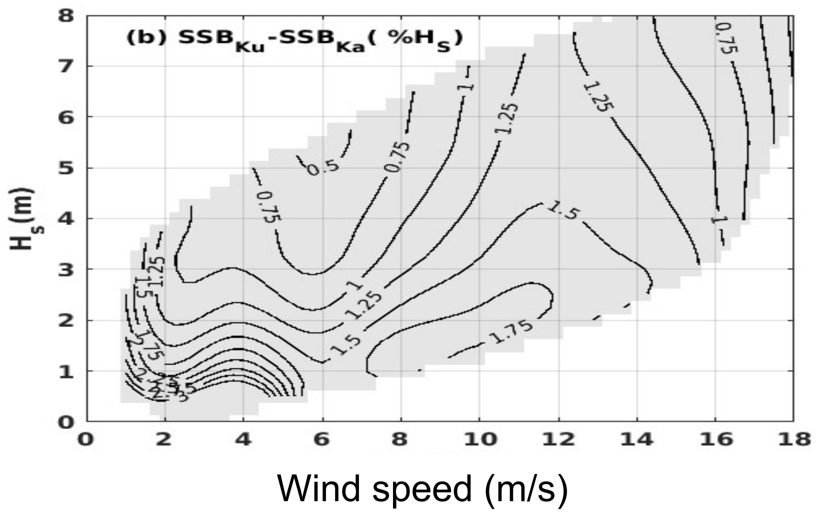
Positive is model gain

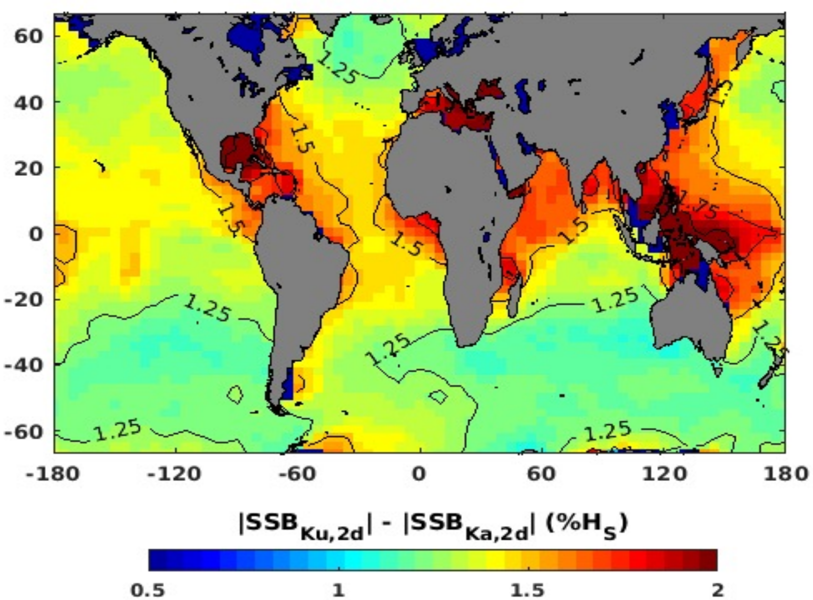


Two variance reduction comparisons vs. latitude

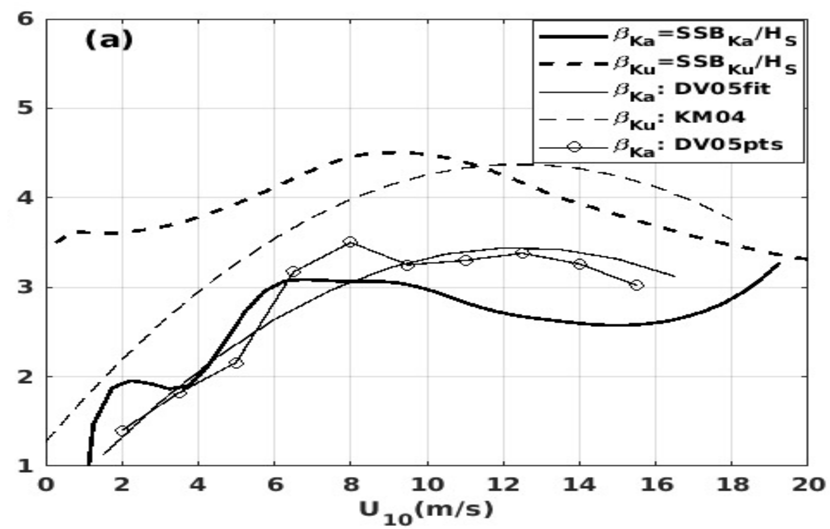
- Crossover (XOD, at left) shows 2D GDRF model slightly outperforms UNH, while UNH 3D outperforms the GDRF
- UNH models outperform GDRF in the SLA tests (at right)
- **In general, similar and solid performance for all 4 SSB models**

Mean SSB difference between Ka- and Ku-band altimeters



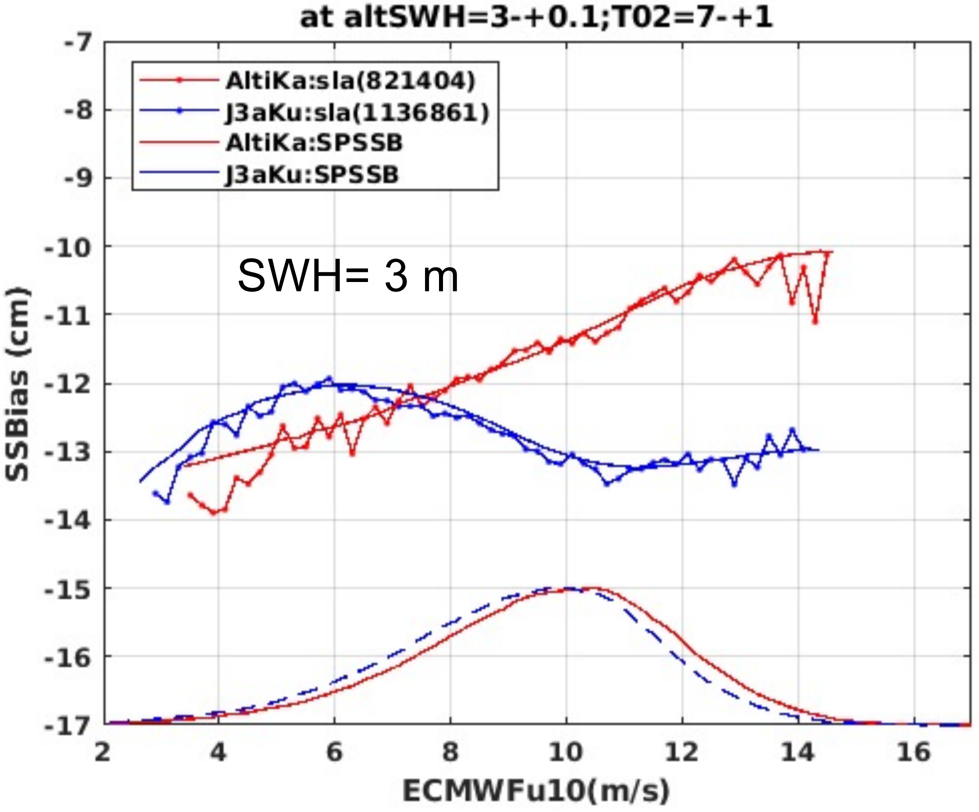


- Ka-band SSB is on avg. 1.2%*SWH **lower** than Ku-band
- Significant regional spatial variation in that value in a global avg. difference
- Ka-band matches V. et al. (2005) aircraft data quite well



Q2: Wind impacts at Ka vs. Ku-band

Data with fixed wave period and SWH; compare AltiKa and J3



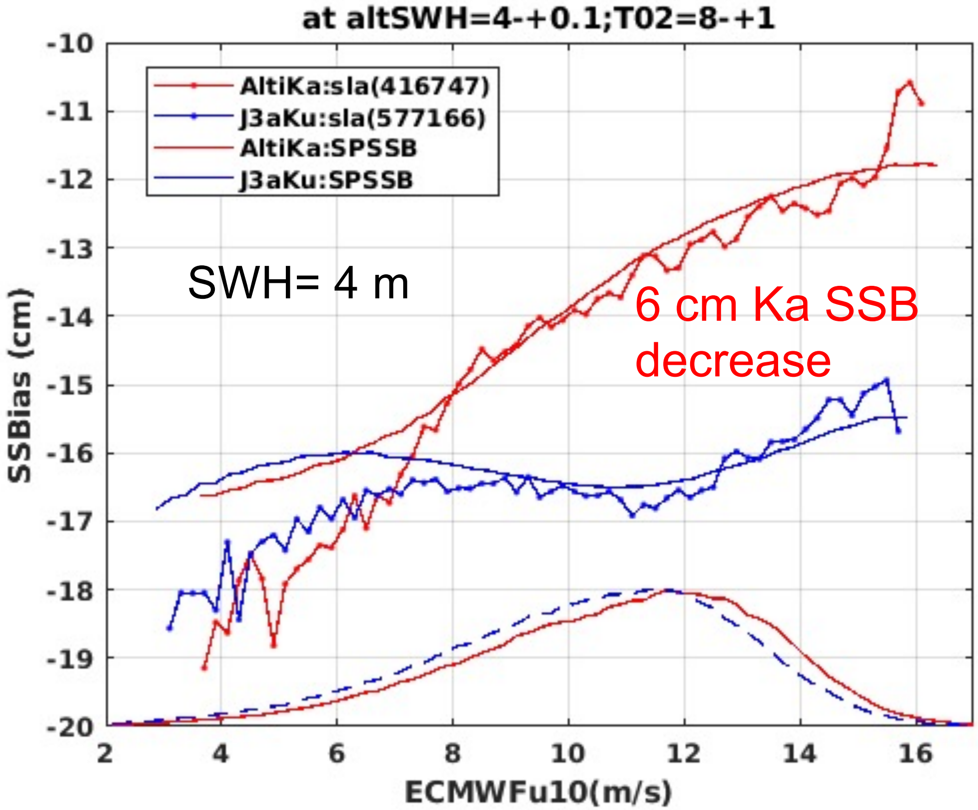
Ka-band SSB weakens linearly as wind increases

Ku-band relatively flat with wind change, but opposite in sign

Expect significant cm-level differences in range change between SWOT and the nadir altimeter with along track wind change….

Q2: Wind impacts at Ka vs. Ku-band

Use fixed wave period and SWH, compare AltiKa and J3



Ka-band SSB change with wind is even more dramatic with higher SWH (4m)

Suggests short wind waves are attenuating the larger effective EM bias seen at Ku-band as U10 increases

Expect significant cm-level differences in range change between SWOT and the nadir altimeter with along track wind change….

Q3. What is Ka-band sensitivity to long wave steepness change in comparison to Ku-band?

A. Examine using the NP 3d vs, 2D SSB models differences

Model difference indicates the relative impact of at a given frequency

B. Examine the analytical expectation against long wave steepness using bin-average data; λ refers to the radar wavelength

$$\mathbf{SSB} = \boldsymbol{\beta}_{\lambda} = \boldsymbol{\beta}_{skew} + \boldsymbol{\beta}_{EM} \quad \text{and} \quad \boldsymbol{\beta}_{EM}(\lambda) = a_{\lambda} * \Delta_{12} * SWH$$

where Δ_{12} = height-slope cross skewness ~ < a k > ~ $\sigma^2_{orbital\ vel.}$

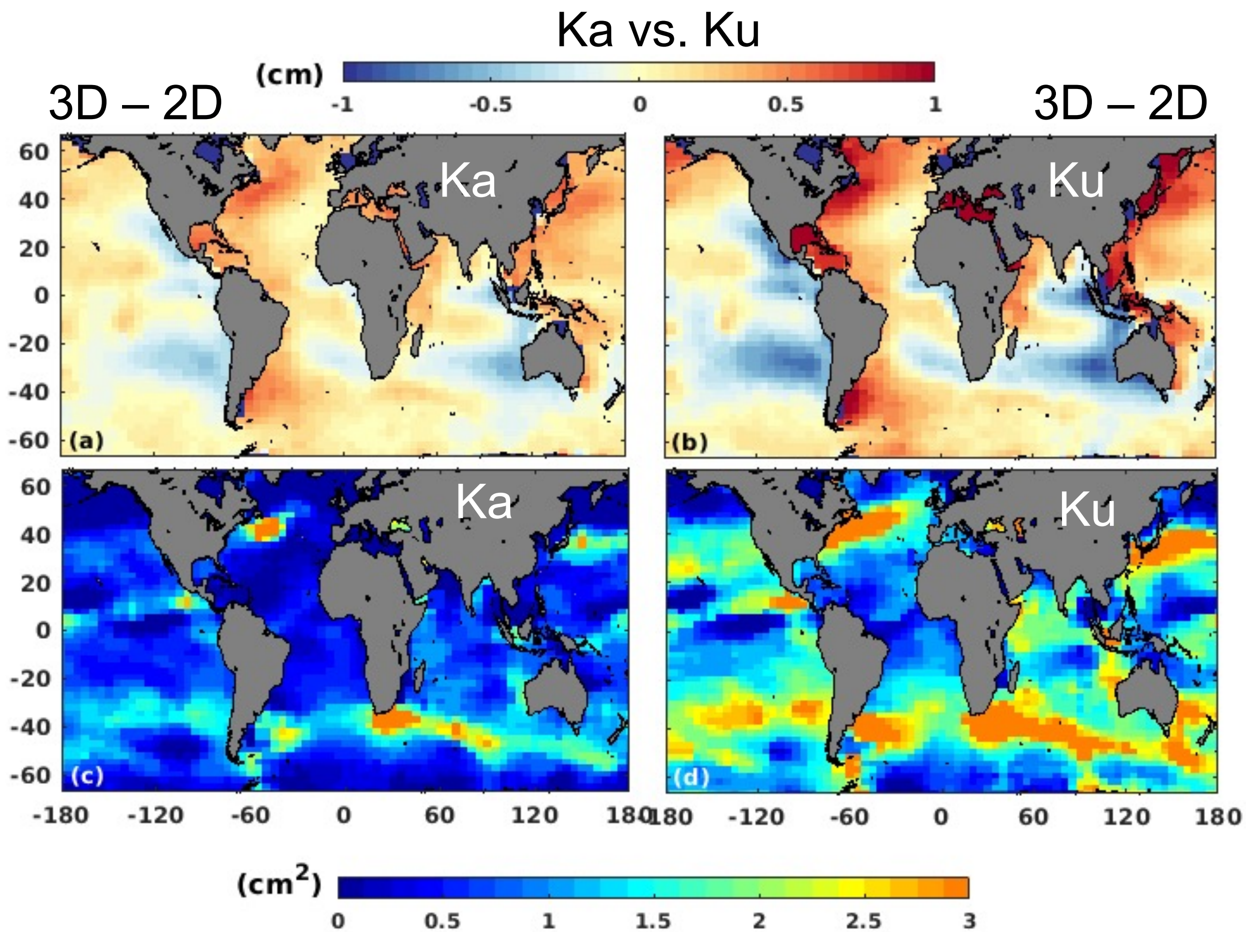
and where <a k > ~ significant slope = steepness = $(\pi^2/g)SWH * T_{02}^{-2}$

Frequency differences primarily enter via $a_{\lambda} = f(NRCS_{\lambda}, mss)$

Q3. Sensitivity to steepness change - Examine using the NP 3D vs. 2D SSB models differences; indirect measure of wave period influence

Mean |SSB| model diff. 3D – 2D

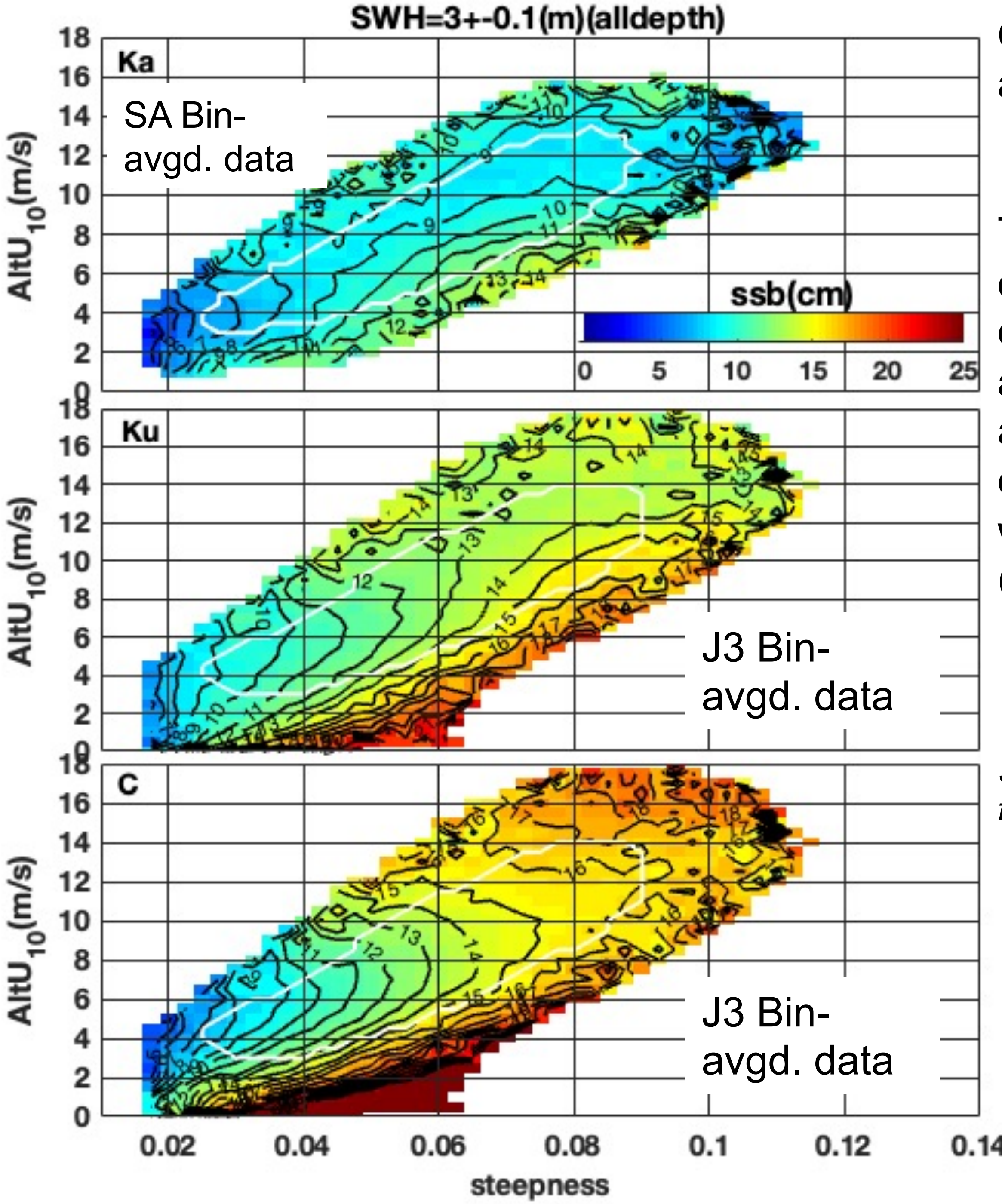
Variance reduction 3D – 2D



In red areas the 3D |SSB| prediction is higher

Variance reduction due to 3D SSB Ku >> Ka

The empirical NP SSB models suggest a much greater wave steepness influence at Ku- than at Ka-band

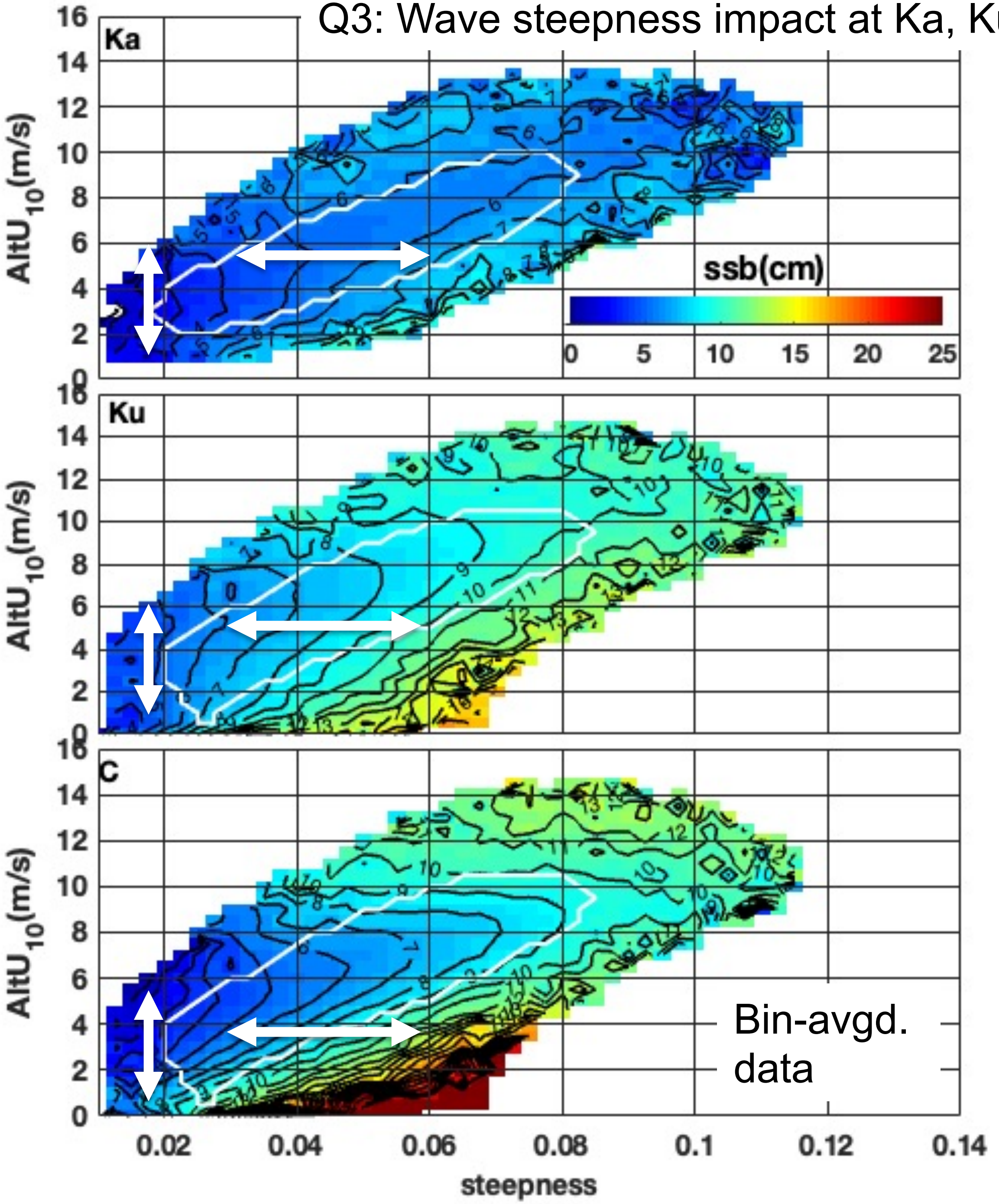


Q3: Wave steepness impact at Ka-, Ku- and C-band

The relative frequency impact of the wave steepness control of EM bias is more clearly seen at three freq. using global AltiKa and Jason-3 and range error data against steepness and wind speed…
(all iono. model corrected)

Steepness = significant slope using T_{02} from wave model

Q3: Wave steepness impact at Ka, Ku and C-band



SWH = 2m

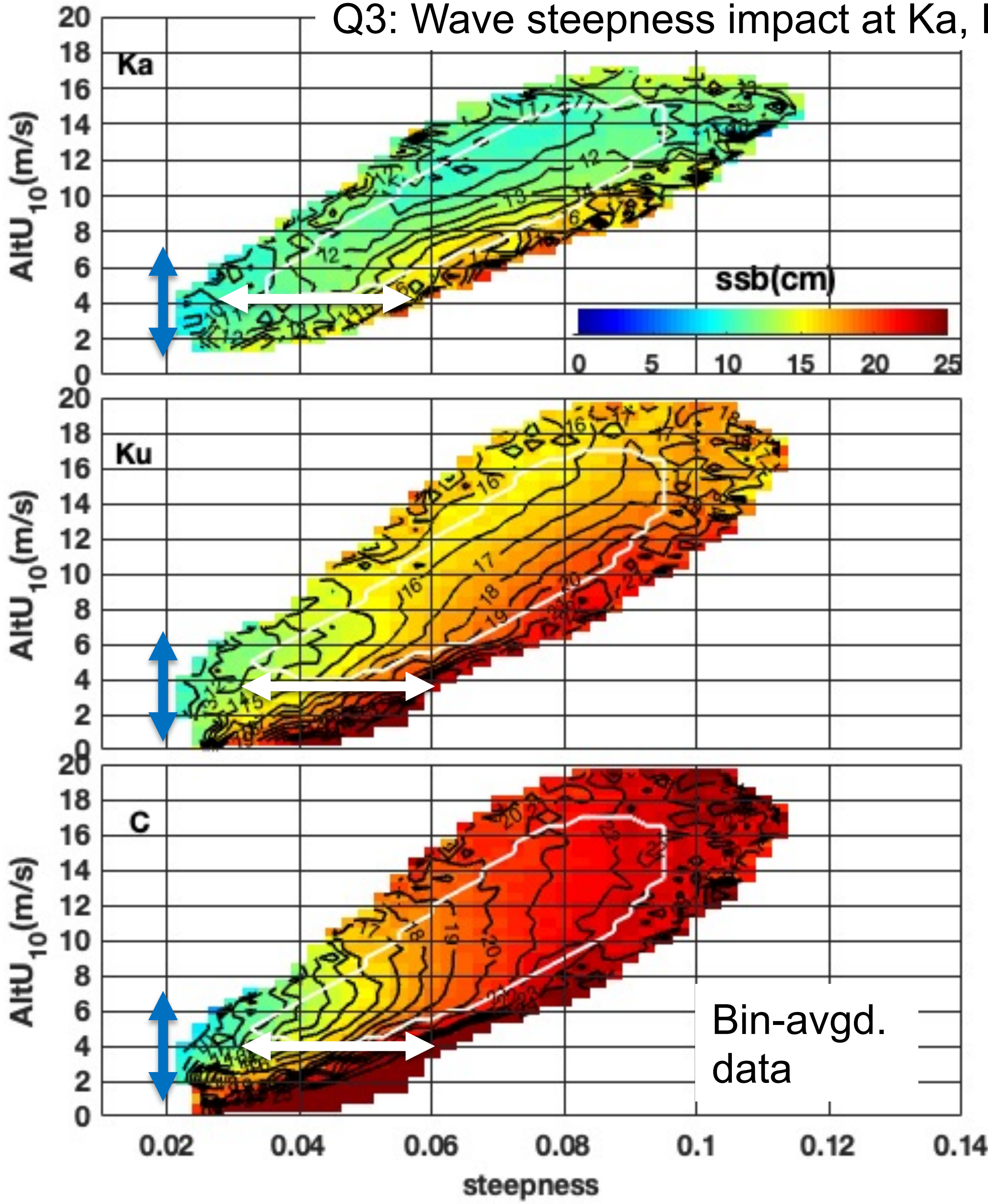
Similar low SSB at lowest steepness level of 0.015 for all three freq.

C-band shows stronger correlation with steepness at wind < 8 m/s

Ka-band shows very weak sensitivity

For low wind regime (U= 2-6 m/s) – C-band sensitivity is 3 times > Ka-band

Q3: Wave steepness impact at Ka, Ku and C-band



SWH = 4m

Similar low SSB at lowest steepness level of 0.015 for all three freq.

C-band shows strongest and clearest linear correlation with steepness at any wind

For low wind regime (U= 2-6 m/s) – C-band sensitivity is 3 times > Ka-band

Ka- and Ku-band relationship with steepness and wind are coupled

Ka-band and multi-frequency SSB summary

- SLA-derived SSB correction tables agree well with the SARAL/AltiKa GDR-F two and three-input SSB models
- The Ka-band SSB levels are 0.5-2%SWH below Ku-band, but with significant regional variation, with a different dependence on wind speed
- Results are consistent with idea that short wind waves act to attenuate the long wave nonlinearity, attenuating the effective EM bias as frequency goes up
- Wave steepness control of the EM bias is weakest at Ka-band and more clearly seen when adding C-band data where the impact is strongest
- SWOT will be the first to have NRCS and range data at C-, Ku- and Ka-band; quite different SSB correction models but also new opportunities to examine the EM bias?

Examining Sentinel-6/MF range error in version GDR-F06 data

Objectives

- Develop S6A 2d and 3d Sea State Bias (SSB) correction models for LR mode Ku-band data with the latest release data
- Provide SSB evaluations for the newly developed models versus the S6 SSB2d correction based on the Jason-3 model (Tran et al., 2020)

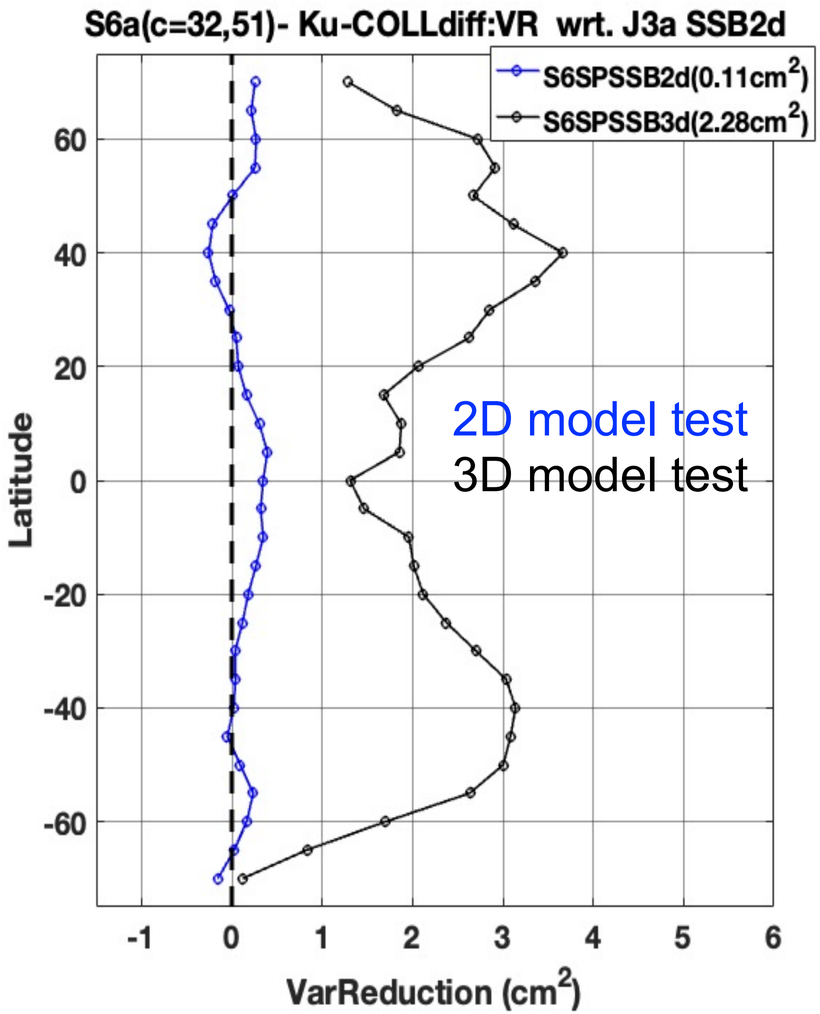
- Prepare to re-estimate S6A SSBs once the new reprocessed S6A datasets available -> CNES/CLS Sentinel-A Processing Prototype (S6PP)

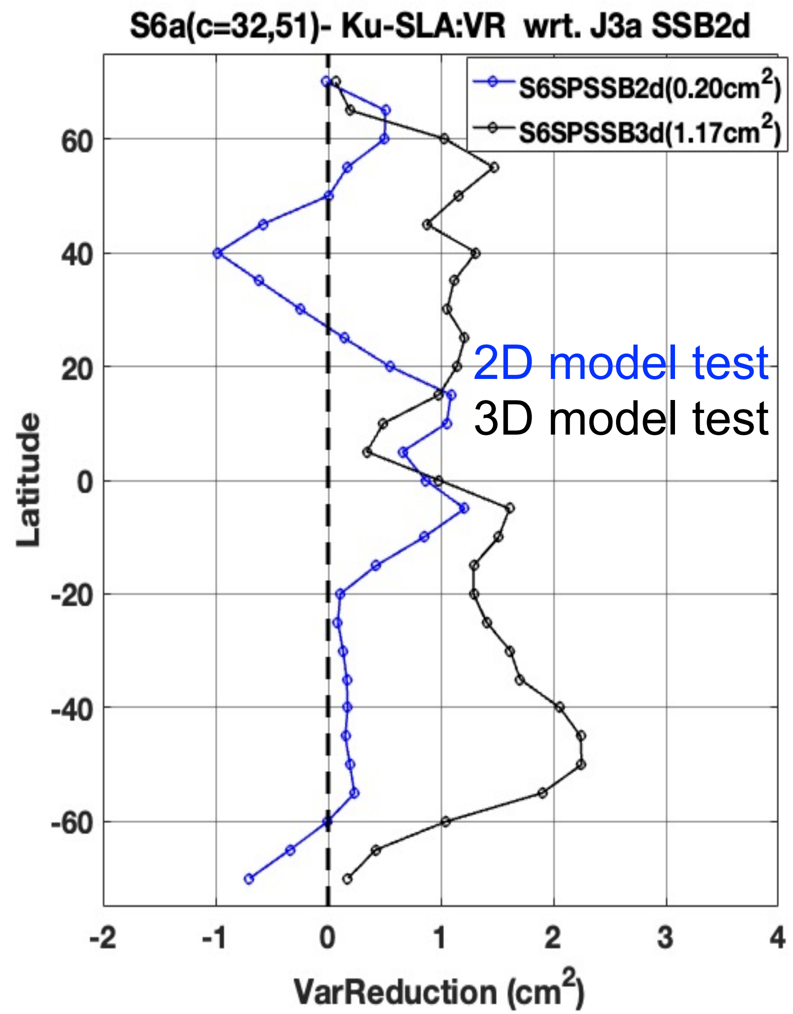
S6 UNH SSB model assessment vs. the S6 F07 model (from J3)

Latitude dependent of variance reduction (**cm²**) where positive = performance gain

Collinear differences new UNH SSB models vs. J3

SLA





- New S6A SSB2d performs slightly better than S6 SSB2d
- New S6A SSB3d outperforms the S6 SSB2d (as expected)

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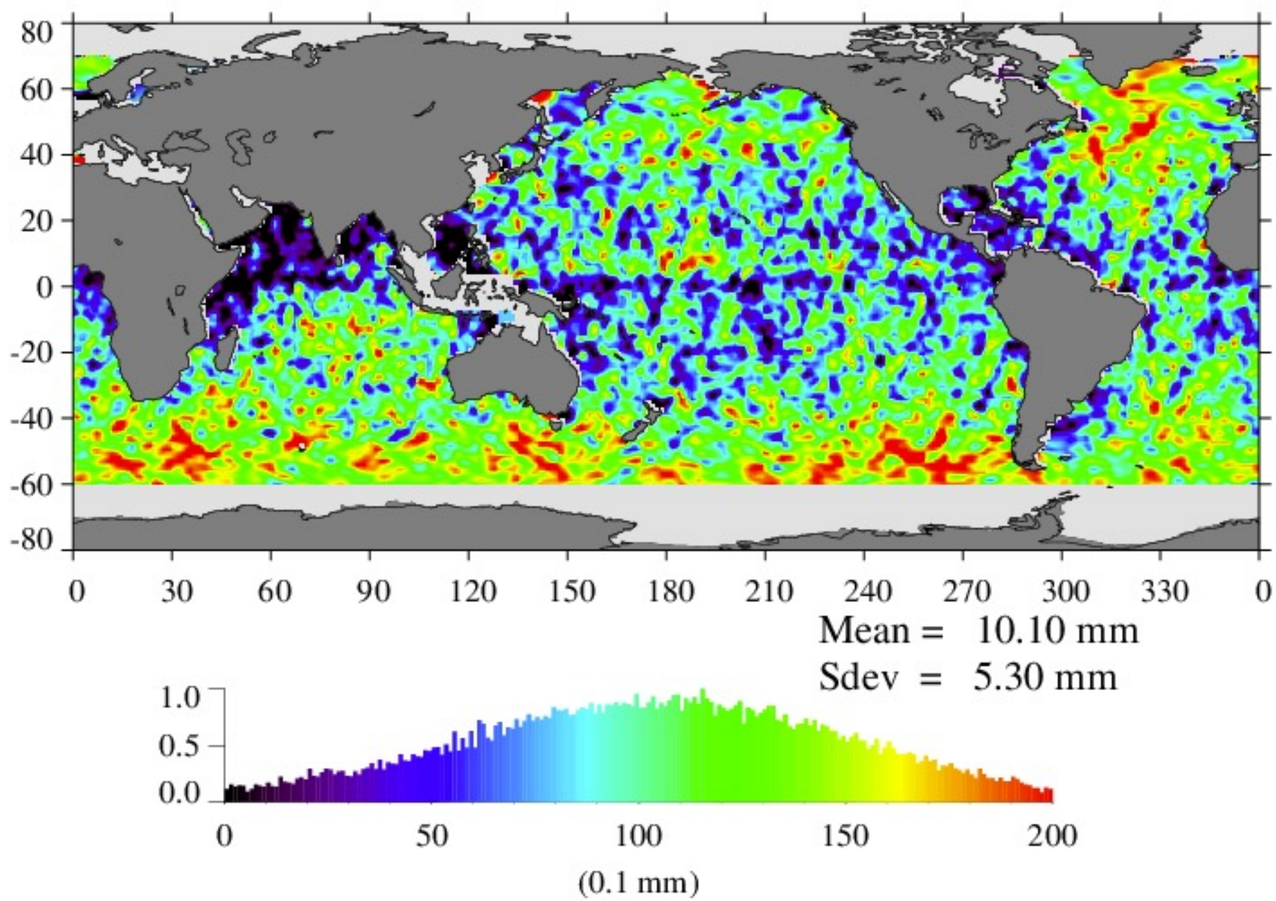
Assessing S6-J3 differences – per plot below from B. Beckley

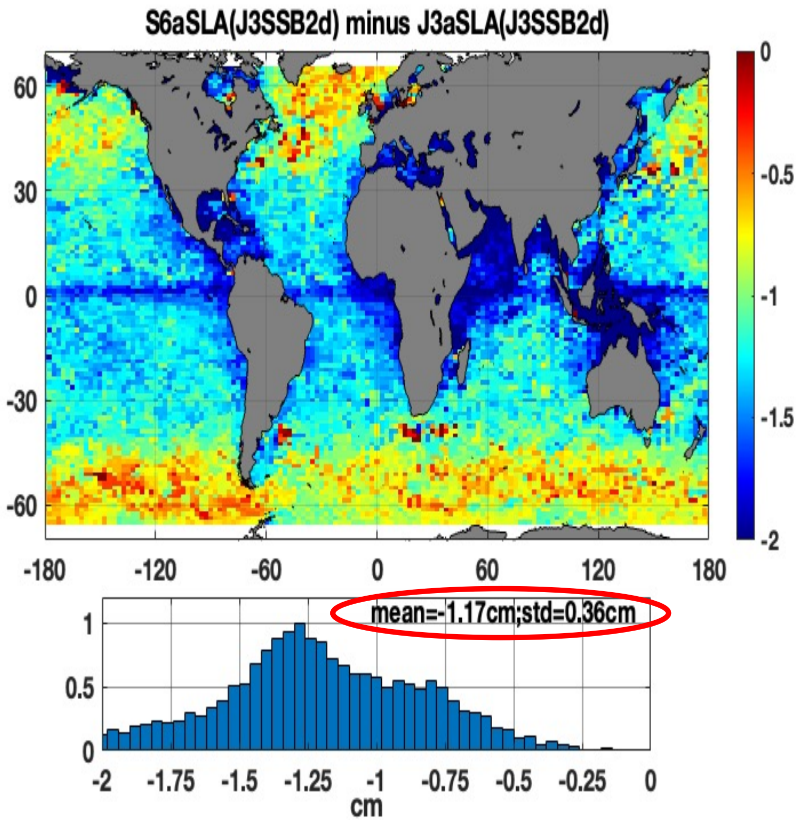
Q: Is this an S6 sea state bias, ionospheric, or range data quality issue?

S6 Side B GDR_F06 LR c032-c050 minus Jason-3 Measures v5.1



Does replacing the S6 2D SSB model with the new UNH S6 model help?

S6A – Jason3 SLA
SSB = project model
Ionosph. = dual-freq. correction



S6A – Jason3 SLA
SSB = new UNH 2D SSB model
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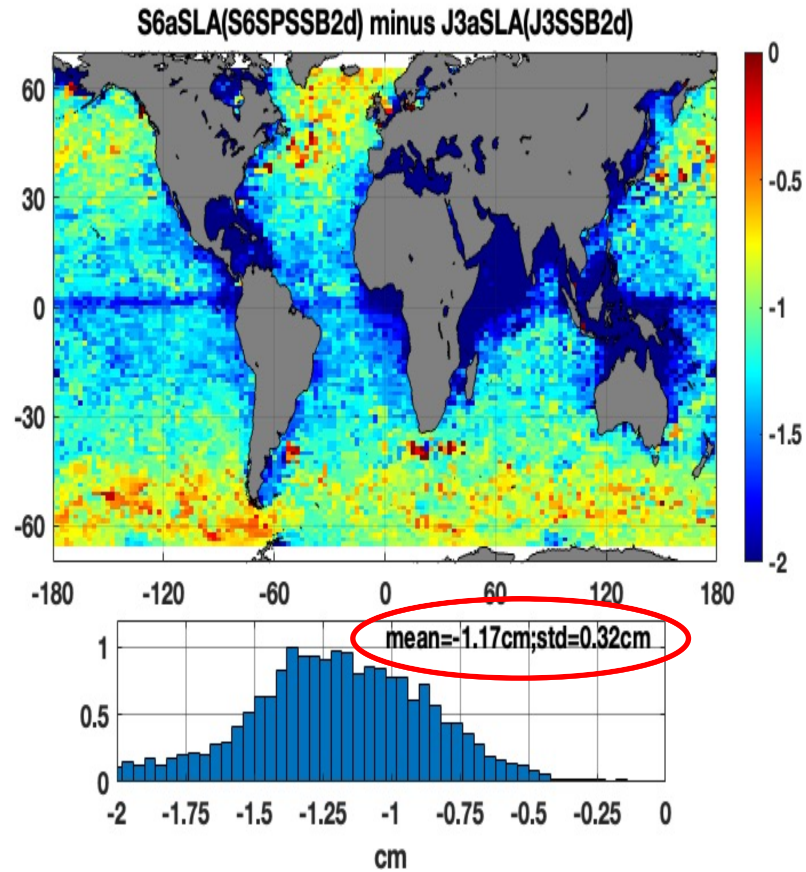
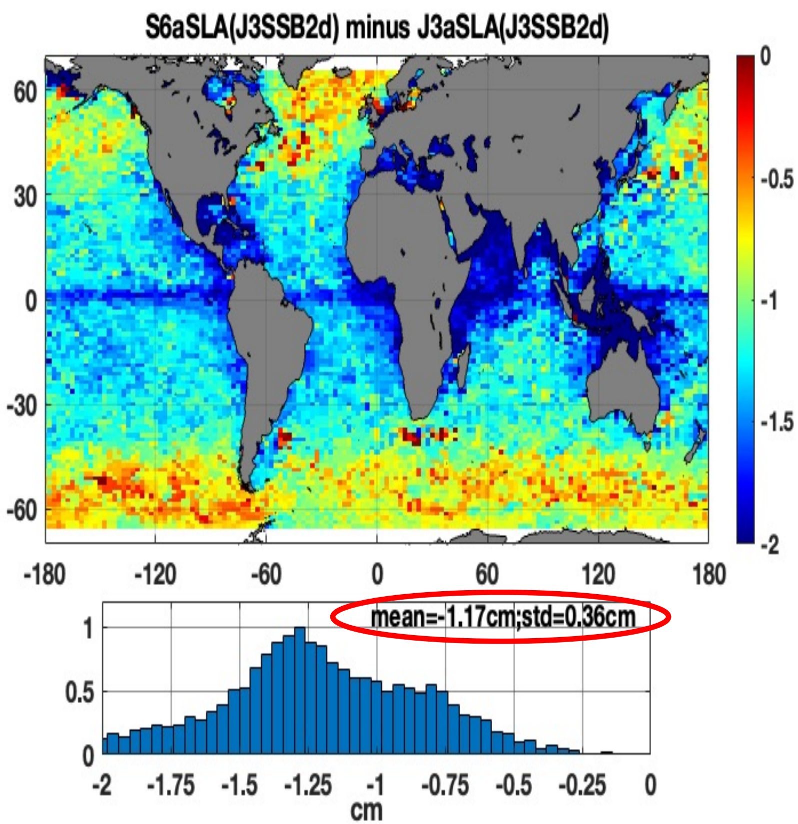


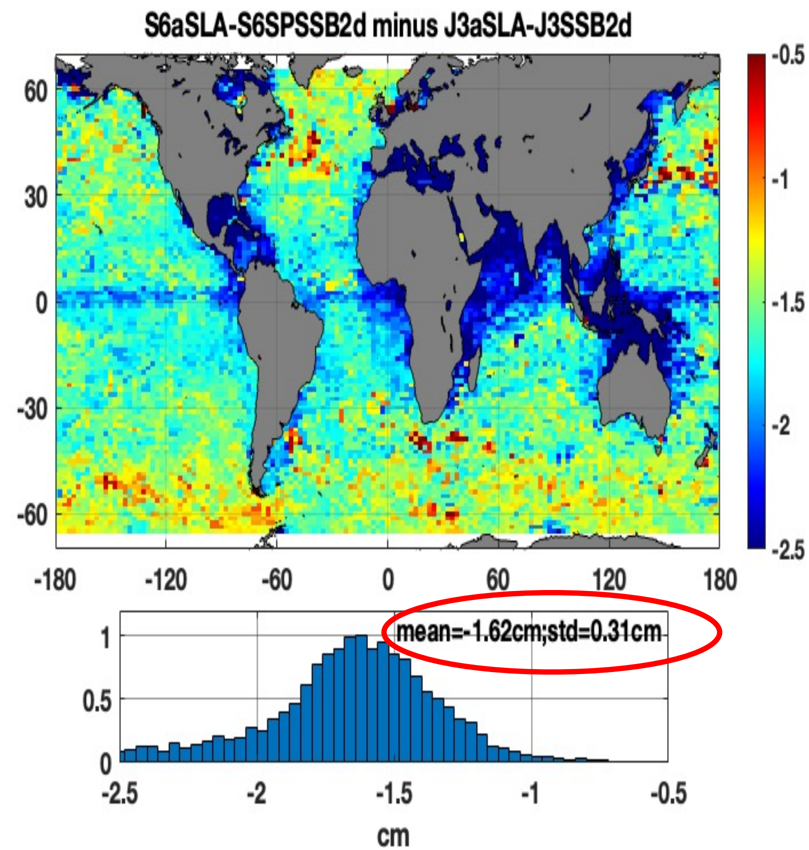
NO; Spatial error is similar as are mean statistics
Slight change in the error distribution PDF

Does replacing the ionospheric correction model help? Ans: A bit…

S6A – Jason3 SLA
SSB = project model
Ionosph. = dual-freq. correction



S6A – Jason3 SLA
SSB = project model
Ionosph. = GIM-based correction



- Spatial error map changes, slight improvements
- Slightly improved rms
- Tighter error distribution PDF
- Likely tie to C-band range error

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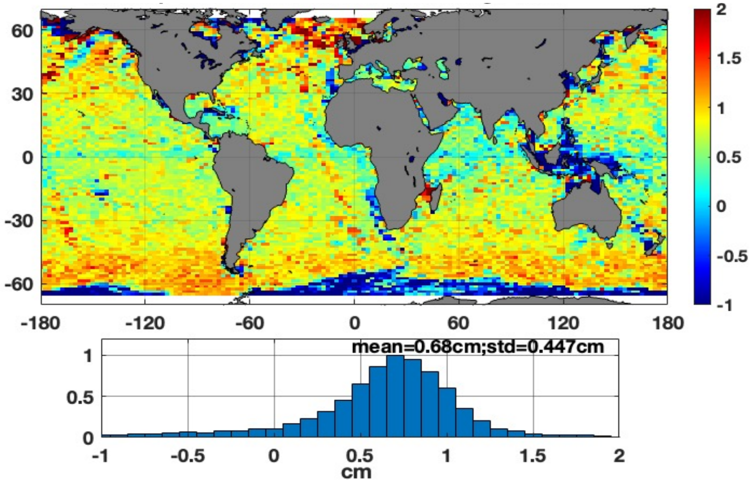
S6-J3 diff maps for SLA Ku- and C-, without geophys corr.

S6A- J3 (SLA'=altH-Range'(no geophy. corrections) -MSS(dtu15))

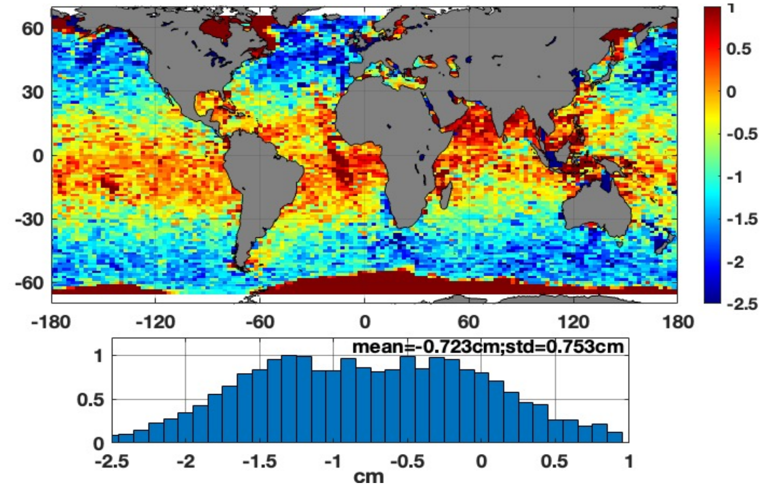
S6-J3 Ku-band

Diff maps : S6A-J3 in Ku SLA'=H-Range'-MSS



S6-J3 C-band

Diff map :S6A-J3 in C SLA'=H-Range'-MSS



- Significant Sentinel 6 C-band range error is apparent versus Jason-3
- Latitude change in difference suggests sea state dependence
- Consistent with the GIM vs. dual-freq. ionospheric results

S-6 range error summary using F06 data and tandem J-3 matchups

Not too much new to conclude prior to refined CNES/CLS S6PP data product that addresses both Ku- and C-band range data quality issues…

- Affirm an apparent geospatial error in range and SSHA between Jason-3 and S6 in tandem phase
- Affirming that the S6/Poseidon-4 C-band altimeter range data are problematic when compared with Jason-3
- New Ku-band SSB models for the present S6 data (rather than using J3) are developed, but this does not harmonize J3 and S6 low resolution mode range or SSHA data

Questions?

We thank NOAA/NESDIS/STAR Laboratory for Satellite Altimetry for support of this OSTST research project.

Backup slides…..

ONE OTHER STUDY IMPLICATION TIED TO WNL STEEPNESS CONTROL

Should there be more focus on improving the dual-frequency ionospheric correction?

The iono_corr_alt_ku correction approach assumes that the range difference is all due to ionospheric delay.

iono_corr_alt_ku = range_corr_ku_noIono - range_corr_c_noIono

Any wet tropo. delay and sea state dependent differences in the range are minimal and taken care of by the mean path delay and 2D Ku- and C-band SSB models.

But what if the residual Ku-C band wave-related range error is systematically different after 2D SSB model corrections?

In this case, resid iono error = ***f*** (wave field)…

a) Should be apparent in GIM vs. iono_corr_alt_ku difference on spatial map vs. Tz map – or effectively in a GIM-corrected SSHA diff = Ku-C SSHA map after 2D SSB correction (i.e they should but won't be the same)
b) Can use of the C-band altimeter data be further optimized?