Present uncertainties and future refinement of the sea state bias correction

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Content

- Brief introduction
- The error budget
- Path to refinement

SSB - an empirical model

Physically this is an error associated with the radar scattering from waves within the footprint. This skews the range estimate below MSL. But also tied to radar tracking of sea level and waveform retrievals.

$\therefore$ **Empirically** the SSB determined using repeat pass altimeter range measurement differences and wave information (**X**):

$$\Delta\text{range (cm)} = \varepsilon = r_{t1} - r_{t2} = \varepsilon(\mathbf{X}) + \sigma \quad \approx 3\% \text{ SWH}$$

SSB - an empirical model

SSB determined using repeat measurement differences (not geophysics):

$$\Delta\text{range (cm)} = \varepsilon = r_{t1} - r_{t2} = \varepsilon(\mathbf{X}) + \cancelto{0}{\sigma} \approx 3\%\ \text{SWH}$$

Issues and error sources in solving for and applying ε:

A. All models are empirically devised using each satellite's range data to relate altimeter-measured SWH and U (wind speed) to a range correction

- **X** imposed by pragmatic choice
- Inherent dependence between range, SWH, U from retracking of waveforms
- Stability and quality of input SWH and U are first-order issues (GDR_B->C)

B. Statistical method for solving ε

- Polynomials in SWH, U (3 or 4 terms)
- Non-parametric solutions (NP - linear local kernel: Gaspar et al, 2002)

C. Geophysical error due to choice of X - (see WaveModel work)

SSB - an empirical model

SSB determined using repeat measurement differences (not geophysics):

$$\Delta\text{range (cm)} = \varepsilon = r_{t1} - r_{t2} = \varepsilon(X) + \sigma \xrightarrow{} 0 \approx 3\%\ \text{SWH}$$

Issues and error sources in solving for ε:

D. Does σ tend to 0?

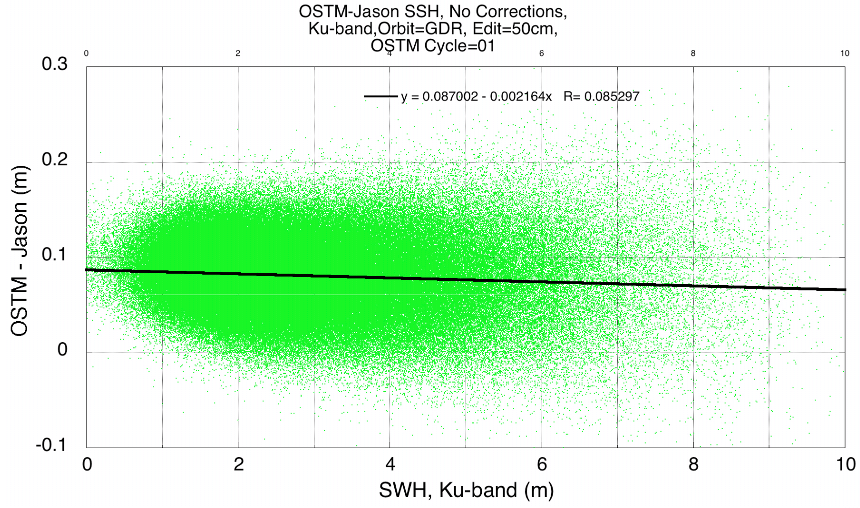
- This error term holds Mission Correction terms such as orbits, HF Barotropic, ionosphere, tides. RESULT -> Possible geographically correlated errors - NEED best models

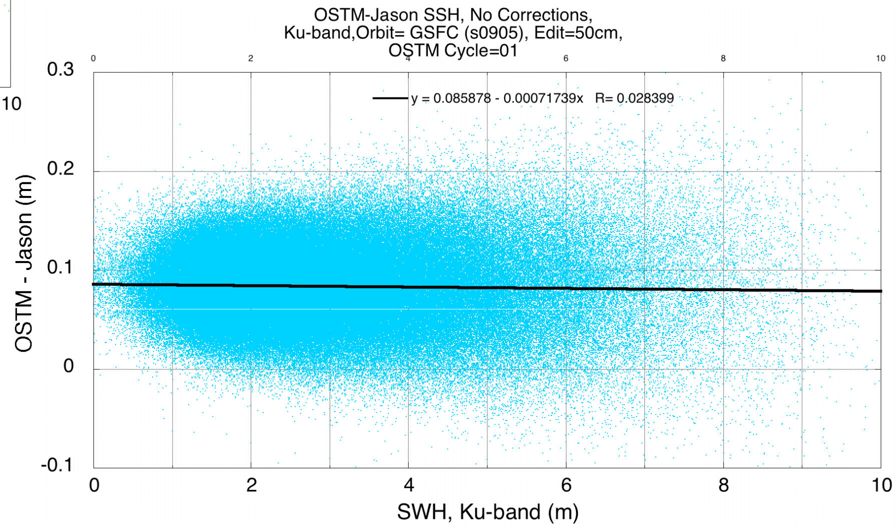
E. Lack of independent ground truth sets this correction apart in terms of computed solutions, error estimation, and metrics for validation

SSB - an empirical model

D. Does σ tend to 0?

- An example related to orbit change…





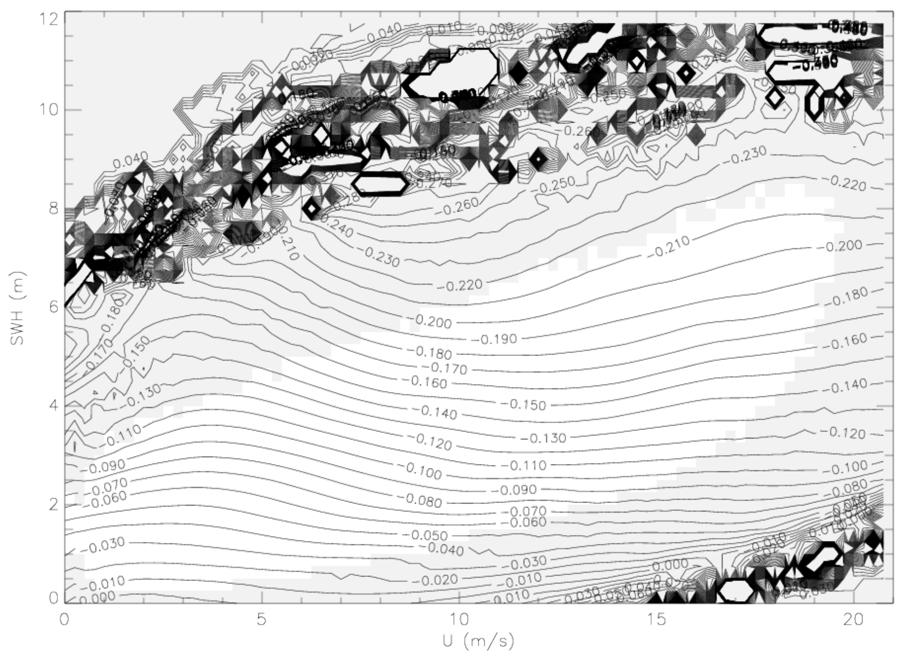
Suite of SSB models across platforms

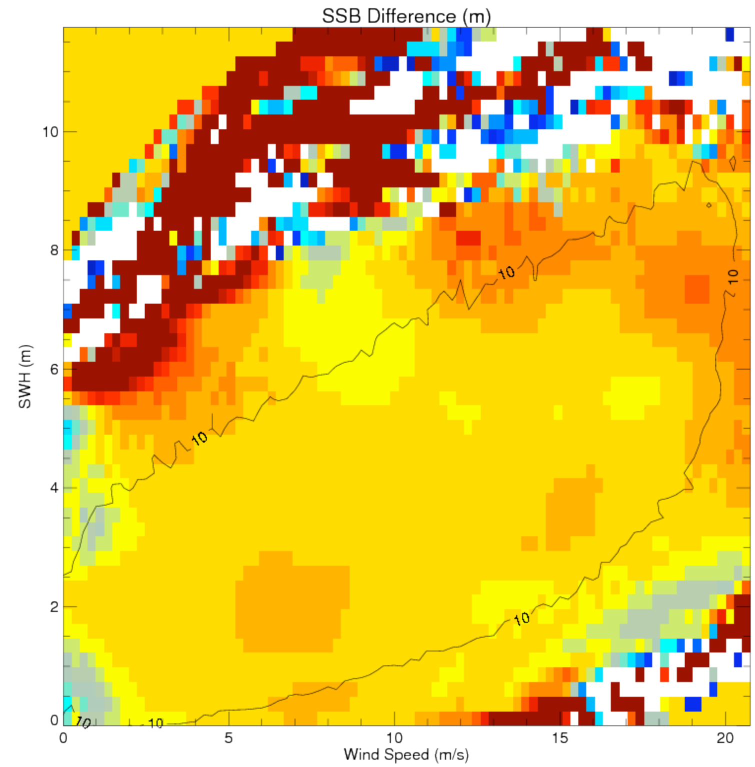
Mission	Data Version	Approach	Input parameters	Wind algorithm	Description	Reference
Jason-2	GDR	Collinear /NP	SWH, U	Collard [2004] / 2D	Empirical model derived from 3 years (cycles 1-111) of Jason-1 GDR_b products	Labroue [2008]
Jason-1	GDR-C	Collinear /NP	SWH, U	Collard [2004] / 2D	Empirical model derived from 3 years (cycles 1-111) of Jason-1 GDR_b products	Labroue [2008]
TP side B	MGDR	Crossover / BM4	SWH, U	Modified Chelton and Wentz [1991] /1D	Empirical model derived from side A data (cycles 2-30)	Gaspar et al [1996]
TP side A	MGDR	Crossover / BM4	SWH, U	Modified Chelton and Wentz [1991] /1D	Empirical model derived from side A data (cycles 2-30)	Gaspar et al [1996]
Envisat	GDR	Crossover /NP	SWH, U	Abdallah [2006] /1D	Empirical model derived from 1 year (cycles 25-35) of data	Labroue [2005]

- All models are empirically derived using the satellite range data to relate altimeter-measured SWH and U (wind speed) to a range correction
- Alternatives available: NP models for TP (CLS), Hybrid models for GFO,Geosat RA-2 and Poseidon (R. Scharrooo), TP A/B (Chambers)
- More consistent retracking leading to closer agreement between TP and Jason models, but empirical nature still warrants satellite-specific models
- **Can pose overall error discussion using J1 or J2 data and models**

Comparison of Jason-1 & Jason-2 SSB

Jason-2 SSB





- J2 and J1 SSB both estimated on the tandem period data (20 cycles / GDR products)
- estimation with collinear approach (10-day differences)

(J2 – J1) SSB

-5 cm **+5 cm**

- very consistent SSB solutions are obtained for J1 and J2, no sea state dependence difference is pointed out here
- the tracker bias for the Jason-2 altimeter appears equivalent to Jason-1

The Error Budget and SSB - 2 Input models

To date: BIAS 1-2 cm; RMS 1% SWH (2.3 cm @ SWH=2.3, Vincent et al 2003)

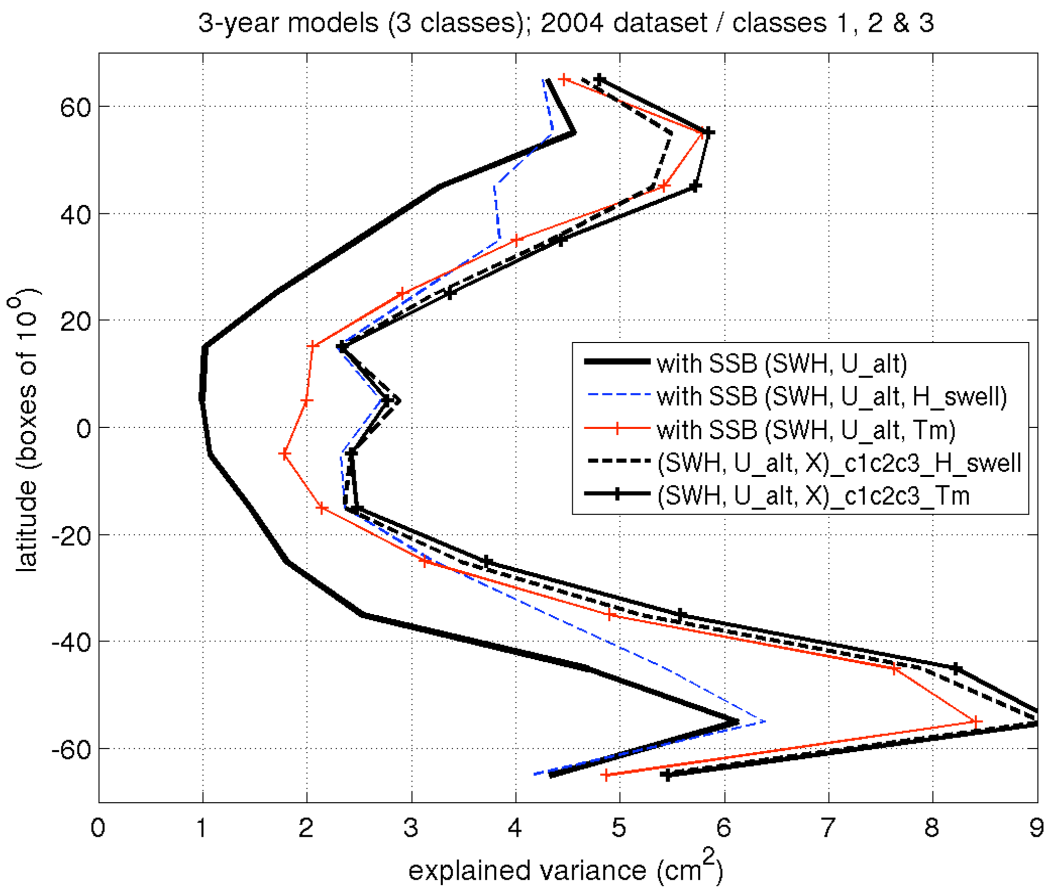
Consensus since T/P: ~ 1% SWH, *O*(1-5 cm)

- obtained via uncertainty in model estimation, not by independent methods. SWH,Wind dependence maps to higher error with increasing latitude.

Quantification of spatial/temporal errors limited and difficult w/o ground truth (TP asc/desc certainly a dramatic issue, but see also Glazman/ Fu work; Kumar et al., 2003; Minster et al, etc…)

Stability of SSB models might be valued as highly as accuracy (e.g. for sea level rise work) - an unresolved absolute bias is intrinsic to all SSB derivations but needs to be handled consistently

New SSB model using added wave model data
- also useful for 2D SSB model error assessment

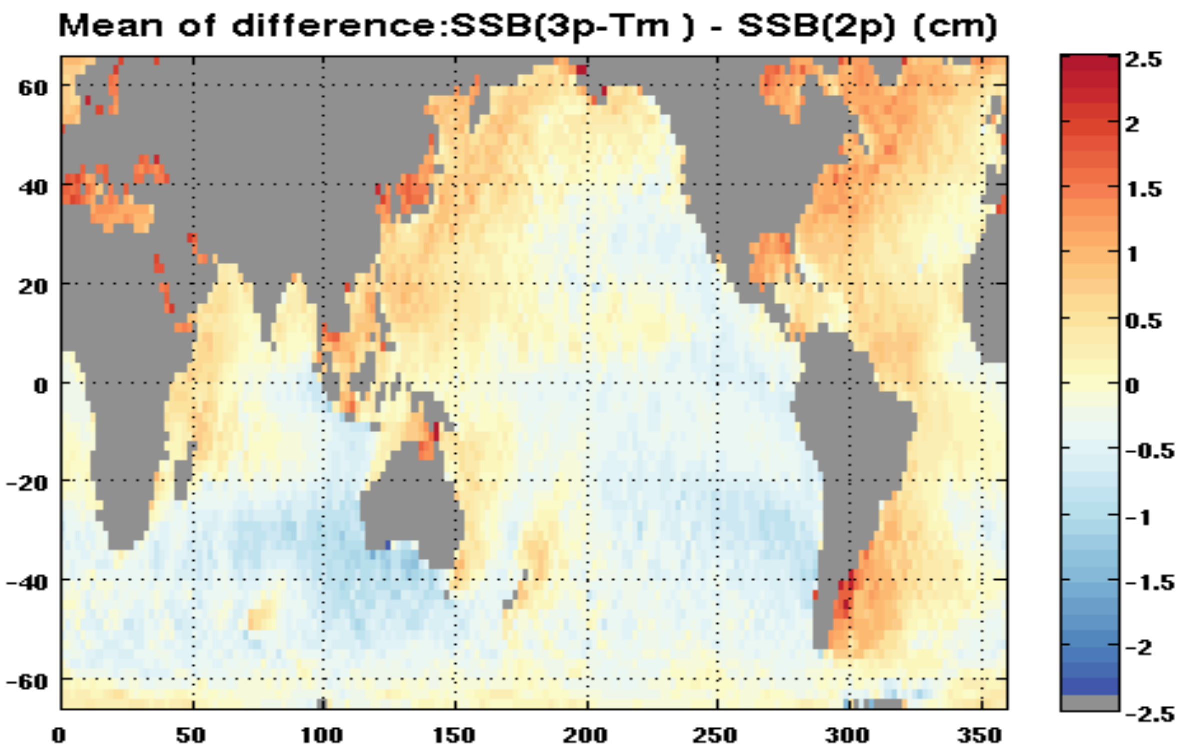


Gain of ~ 0.5% SWH in repeat pass range residual reduction over the NP Jason-1 model

Physically - the new model acts to improve correction associated with wave age change.

The Error Budget and SSB

Recent addition of wave model data to SSB study allowing some refinement by comparison of 2D and 3D models - **assessing unresolved spatial error**

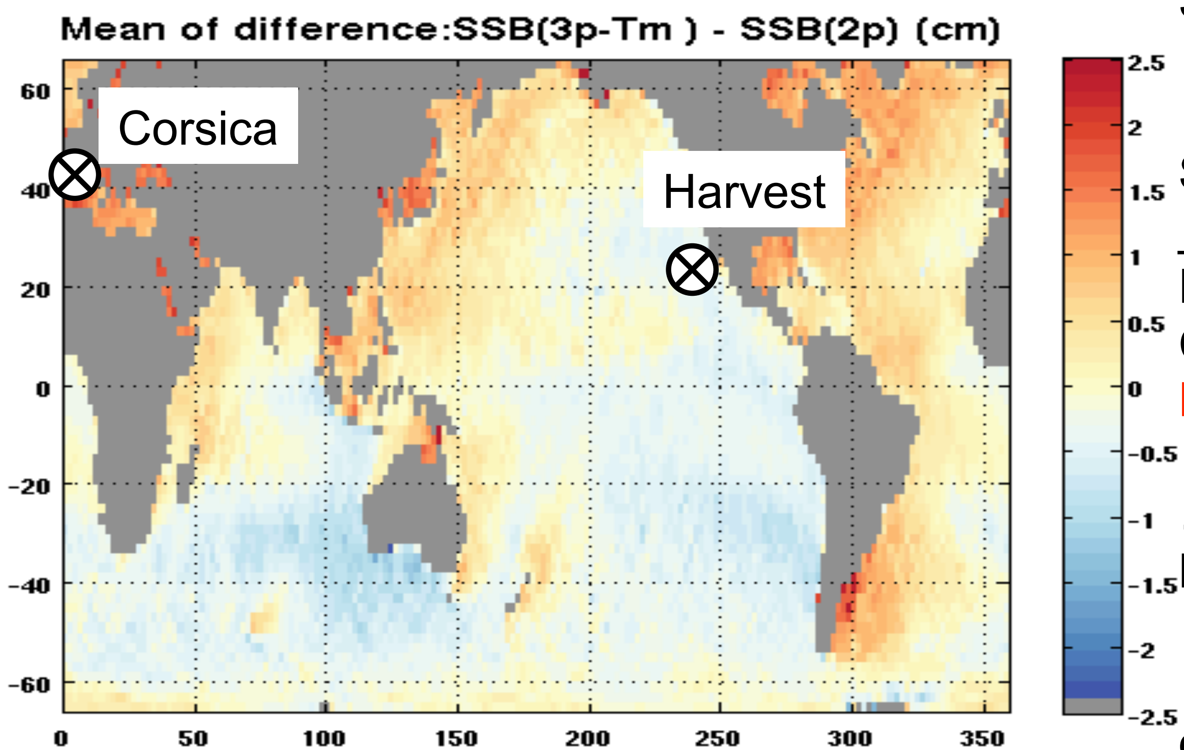


Zonal (cross basin) error in annually averaged model differences is 1-2 cm

Impact on MSS? On MDT? (First look suggests that 1-2 cm is below noise of MDT retrieval methods)

The Error Budget and SSB

Spatial error due to differing wave climates - CalVal Site example : Mediterranean Sea vs. US West Coast Pacific



Sea level cal/val site data
Jason1 - *in situ* (cm)

Site	2DSSB	3D
Harvest	9.9	8.7
Corsica	5.4	7.3
Difference	4.4	1.5

… thanks to Haines and Bonnefond teams…

- one independent estimate example using Jason-1 cycles 1-145

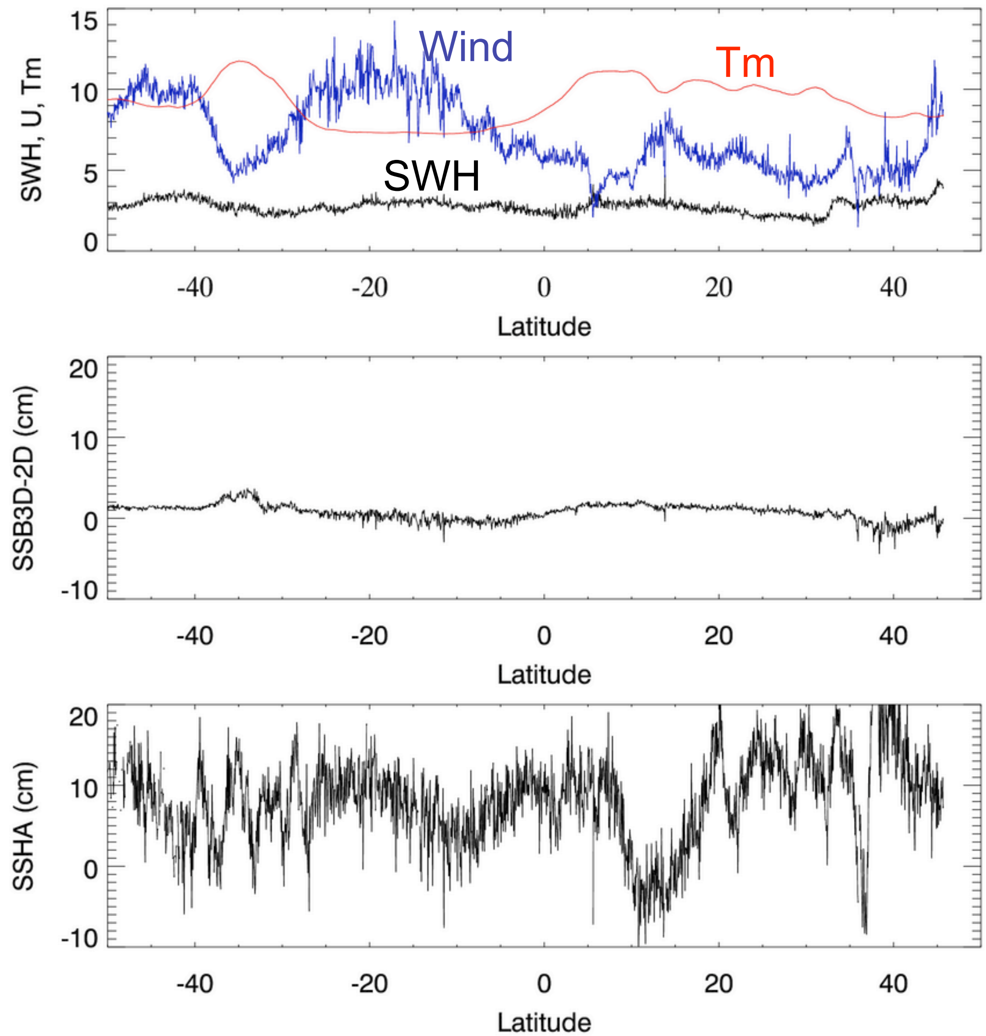
The Error Budget and SSB

Single Pass (54) Example, Jason-1

Spatial scale of mean wave period change > wind speed change

SSB model differences ("EMB error") at the 1-2 cm level and 200-1000 km length scale (SWH ~ 3 m)

Spatial scales of ΔSSB > SSHA dynamics. Same for HF uncertainty magnitude.



The Error Budget and SSB - Jason-1,2 NP

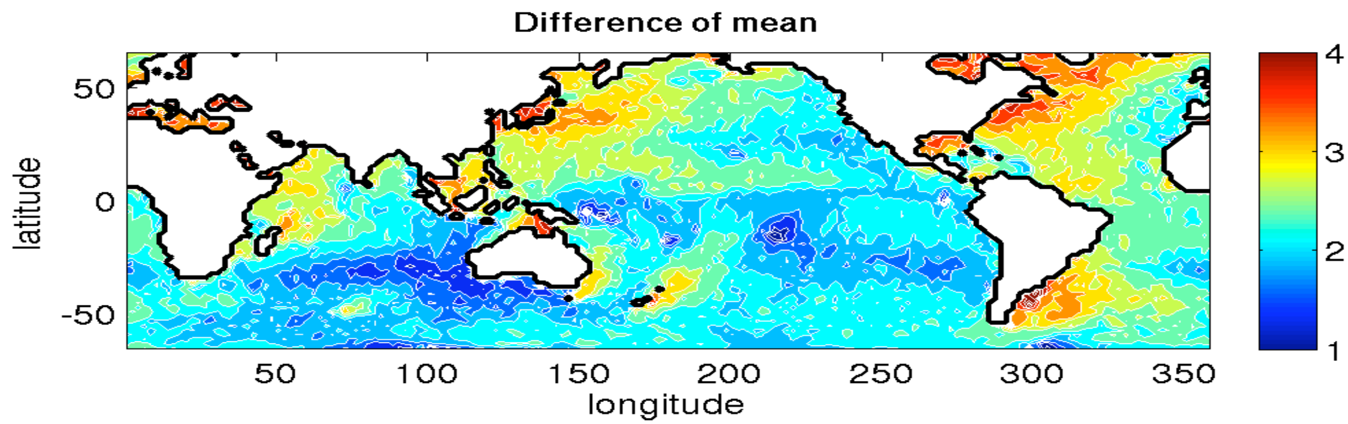
Spatial Uncertainty	Processes	Estimate	Method
a) < 20 km	Input (SWH, U) noise or error	< 1 cm rms	Evaluation of retracking, prefiltering SWH,U
b) 20 to 2000 km	Fronts, coastal waters, swell propagation, wave/current	0.5%-1% SWH Unresolved EM bias	Wave model SSB studies, previous literature
c) >2000 km	Wave age quasi-static spatially (continents and storm tracks)	< 5? cm	3D -2D SSB studies, possibly using cal/val or tide gauge sites
Temporal Uncertainty			
d) < 20 days	Same a) and b) above		
e) > 20 days	As for c), seasonal storm tracks -> swell pools	< 5? cm	
Absolute Bias	inherent to model	1-2 cm	see Gaspar 2002
Drift	Drift in inputs (SWH,U)	1.0 mm SWH 0.2 mm U	5 cm/yr SWH linear 25 cm/s WIND

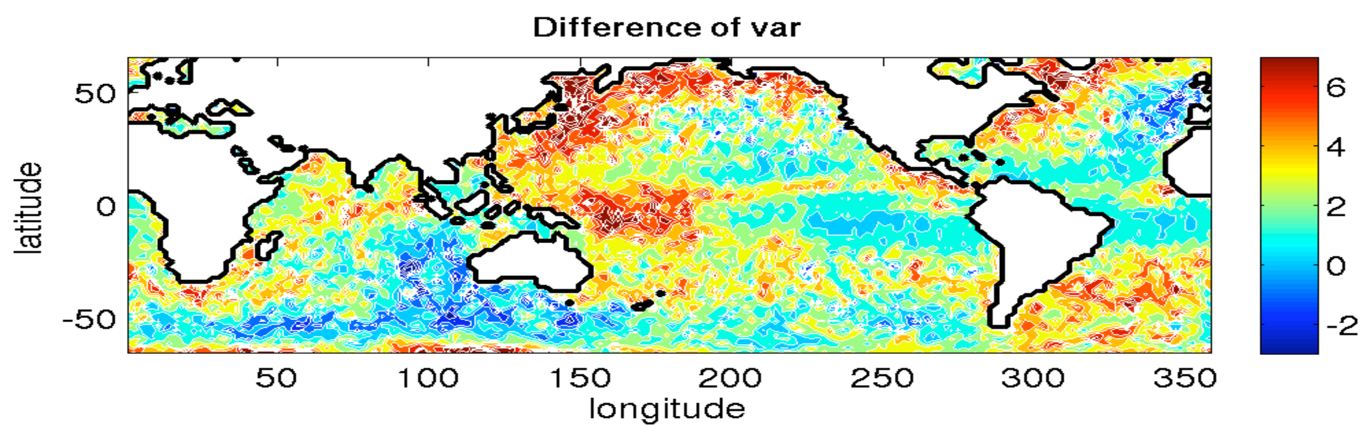
Path for future refinement

- Standard NP SSB: Improved error determination and stable long term models for each platform
  - Do no harm (maintain absolute bias consistency and limit noise due to SWH, U) but remedy MLE3 vs. MLE4 issues
  - Longer-scale spatial error quantification (impacts on MSS, cal/val etc.)
  - Resolve J1 and J2 issues and perhaps go back to TP retracked for NASA Measures project
- 3 Input SSB: Alternative SSB solutions for Jason-1,2 from the SLOOP project
  - Complete refined models and document the expected changes
  - Offer as alternative in GDR and/or RADS databases
  - Tradeoff analysis for benefits vs. cost of implementation
    - Apparent gain in longer wavelength/time corrections order 0.5%SWH
    - Wave model adds another data stream to monitor for stability/accuracy

Thanks

Mean (SSB (SWH, U_alt)) – Mean (SSB (SWH, U_alt, X)_3c)





Var (SSB (SWH, U_alt, X)_3c) – Var (SSB (SWH, U_alt))

Global performances with collinear method data from 2002, 2003 & 2004

Variance explained by different models minus the variance explained by BM1 = -3.8% SWH (cm²)			
	2002	**2003**	**2004**
SSB (SWH, U_alt)	**2.68**	**2.85**	**3.07**
SSB (SWH, U_alt, H_swell)	3.44	3.69	3.97
SSB (SWH, U_alt, Tm)	**3.94**	**4.21**	**4.62**
SSB (SWH, U_alt, X)_3c_Hswell	4.09	4.58	4.98
SSB (SWH, U_alt, X)_3c_Tm	**4.25**	**4.76**	**5.16**

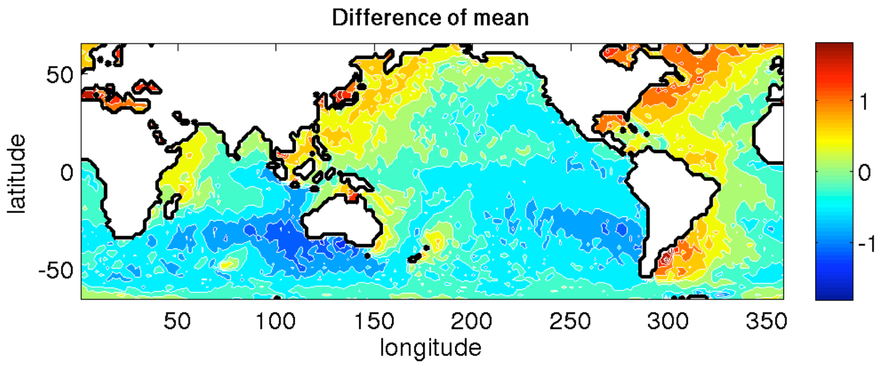
var (ΔSSH_withSSB_BM1) – var (ΔSSH_withSSB_tested)

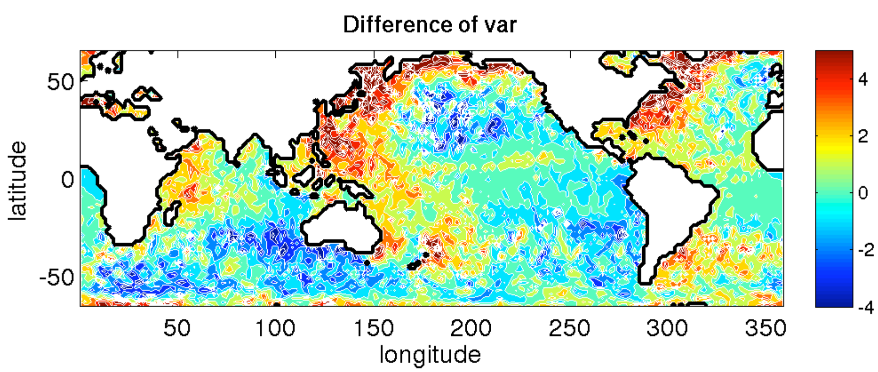
- Differences 3D-2D models : ~1.39 cm²
- Differences class-based-2D models : ~1.86 cm²

Comparison of SSB model features / yearly dataset

SSB (SWH, U_alt, Tm)

Mean (SSB (SWH, U_alt)) – Mean (SSB (SWH, U_alt, Tm))

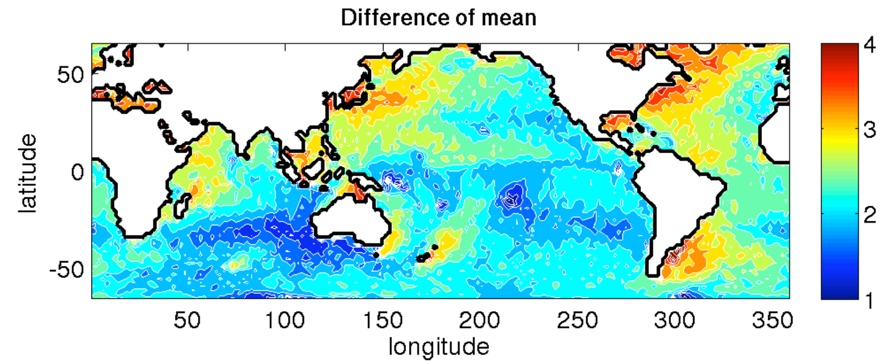


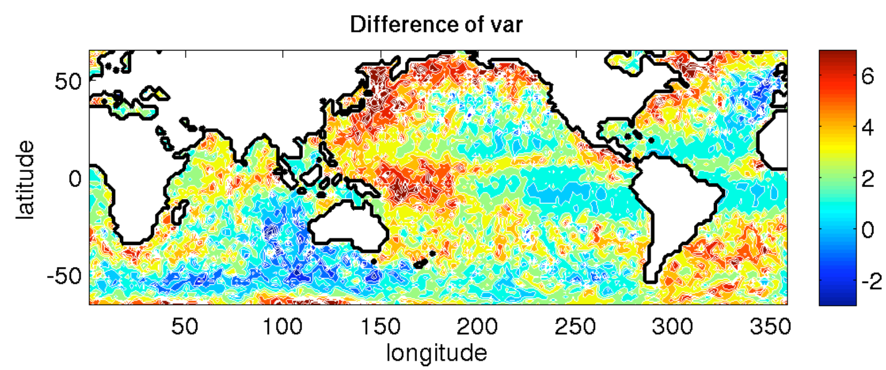


Var (SSB (SWH, U_alt, Tm)) – Var (SSB (SWH, U_alt))

SSB (SWH, U_alt, X)_3c_Tm

Mean (SSB (SWH, U_alt)) – Mean (SSB (SWH, U_alt, X)_3c)



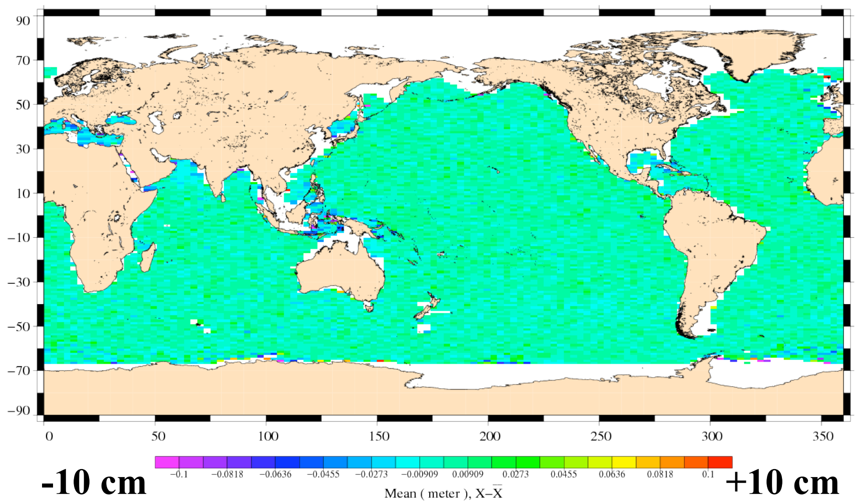


Var (SSB (SWH, U_alt, X)_3c) – Var (SSB (SWH, U_alt))

Comparison of Jason-1 & Jason-2 SWH, Wind Speed

GDR cycles 240-259 / 1-20

SWH differences

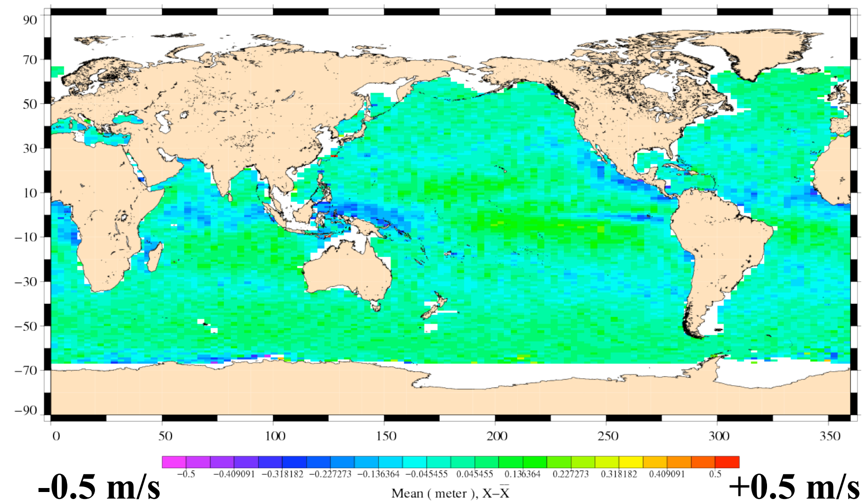


-10 cm **+10 cm**

Nb of data	:	10925	St. Dev	:	0.01190	Skewness	:	−4.46118	Minimum	:	−0.29900
Mean	:	0.01162	Rms	:	0.01663	Kurtosis	:	94.57317	Maximum	:	0.13325

Mean value = 1.16 cm

Wind Speed differences



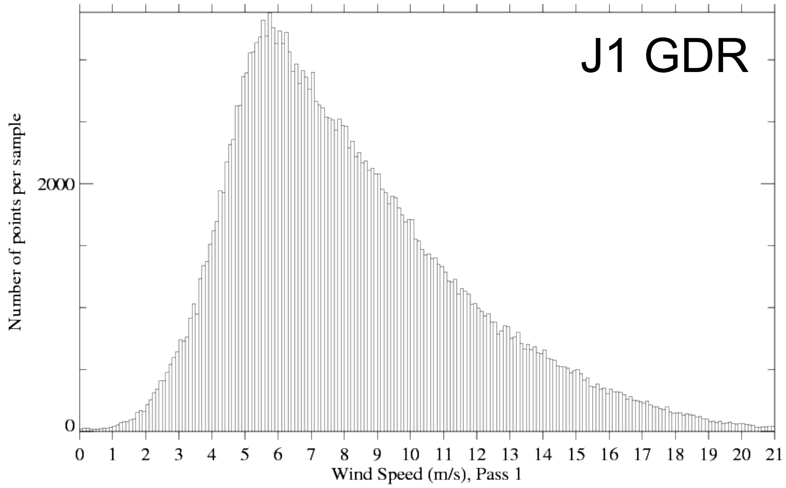
-0.5 m/s **+0.5 m/s**

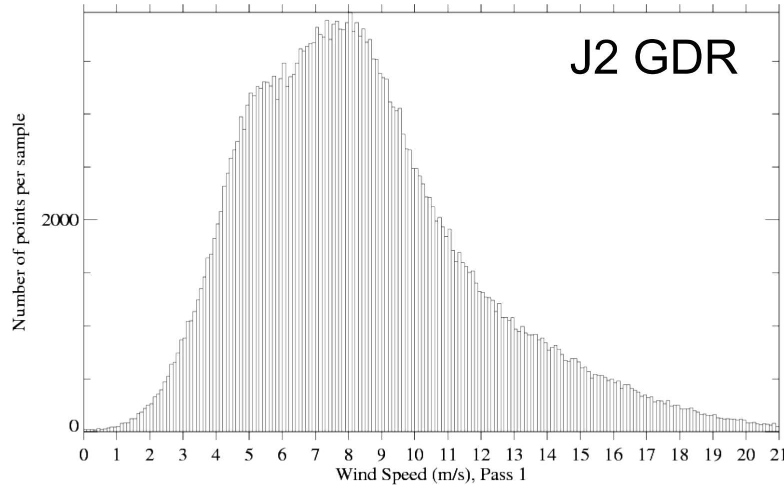
Nb of data	:	10925	St. Dev	:	0.0690457	Skewness	:	−0.2076138	Minimum	:	−0.0165000
Mean	:	0.4801655	Rms	:	0.4851043	Kurtosis	:	8.1879949	Maximum	:	1.5230000

Mean value = 0.48 m/s

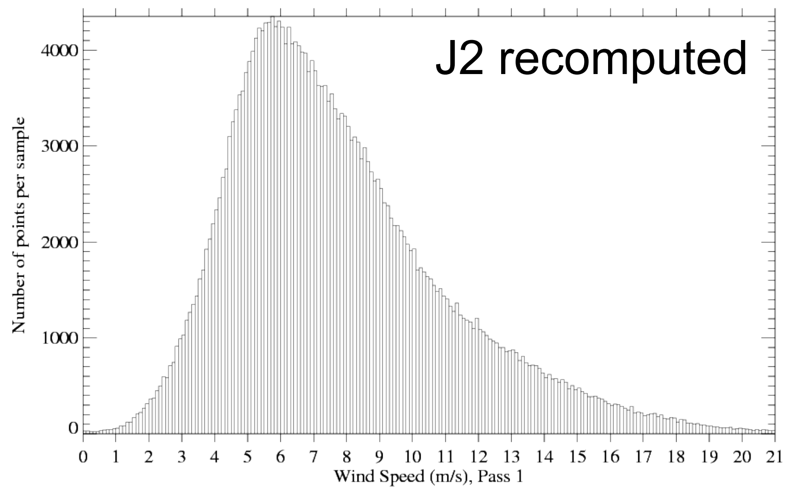
- Some patterns are observed in the tropical area

Finer look at Jason-1 & Jason-2 Wind Speed

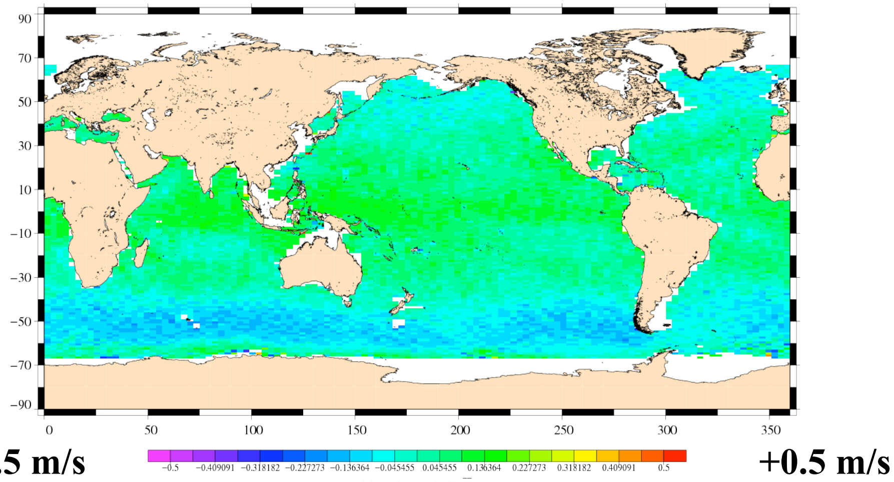




- Differences of shape of the wind speed distribution
- Test of gross linear adjustments of sigma0 and SWH before recomputing the wind speed (S. Phillips)
- J2 recomputed wind speed distribution looks more like the J1 one

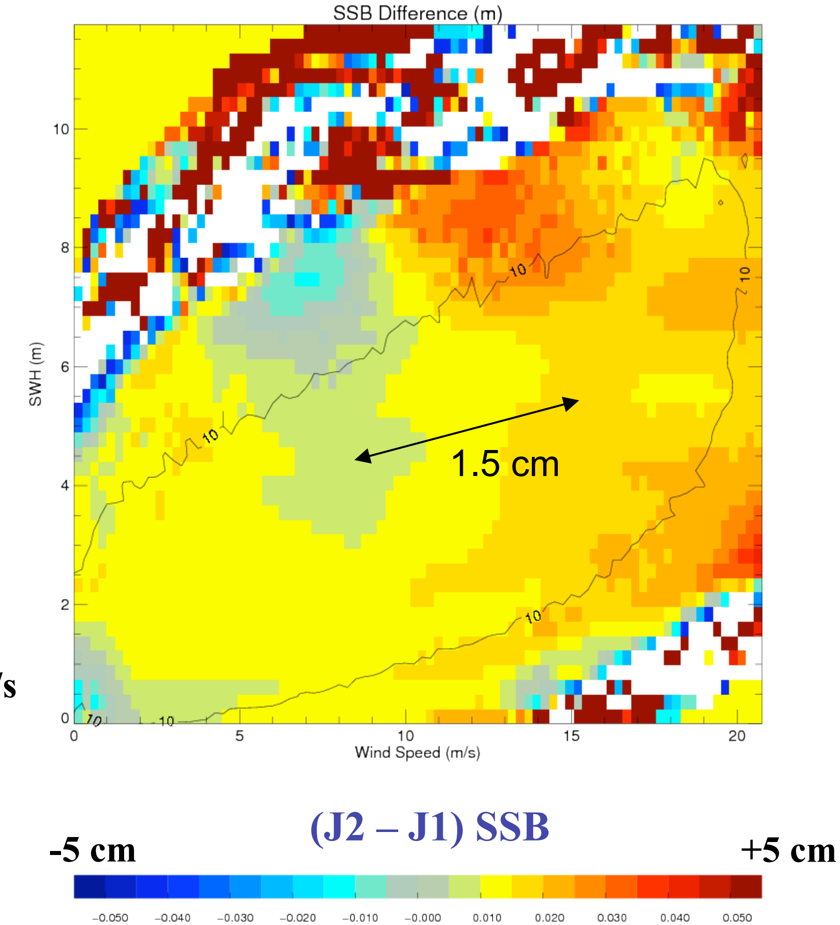


Wind Speed differences (J2 recomputed)



Nb of data	10925	St. Dev	0.074792	Skewness	0.078499	Minimum	−0.548500
Mean	−0.157445	Rms	0.174307	Kurtosis	3.520645	Maximum	0.822000

Mean value = -0.16 m/s



(J2 – J1) SSB

- The previous statement on the tracker bias difference between the two altimeters has to be qualified, a slight difference is displayed.
- Some finer calibration / validation of the J2 wind speed needs to be done before conclusive analysis on the tracker bias difference can be done.