Progress towards a wave model enhanced SSB correction for multiple missions

and

Spline-based nonparametric estimation for the altimeter SSB correction

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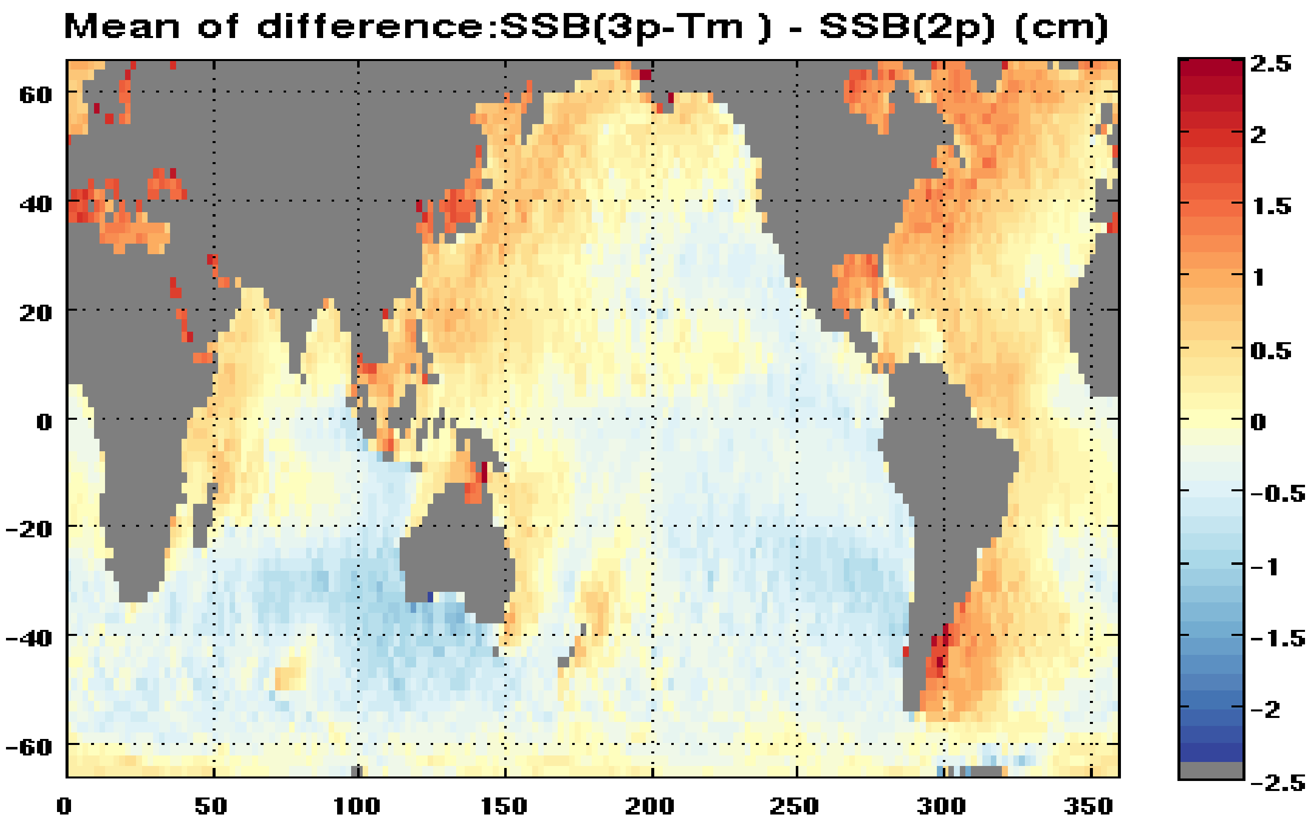
Outline

- Correction model chain
- Alternative/complementary NP solution
- MLE3-MLE4 results related to 3D modeling
- Updates in wave modeling

Premise: Significant improvement (20%) gained in overall error budget with wave model addition to SSB

Tran. N., D. Vandemark, S. Labroue, H. Feng, B. Chapron, H. Tolman, J. Lambin, N. Picot, The sea state bias in altimeter sea level estimates determined by combining wave model and satellite data, J. Geophys. Res., 115, C03020, 10.1029/2009JC2009005534, 2010.



<u>Altimeter Inputs:</u>

SWH
Wind speed (sigma0)

<u>Wave model inputs:</u>

Mean wave period
Elevation of swell
Total slope variance

SSB: a shifting semi-empirical model

SSB model for each Altimeter Mission dataset incl. tracking/retracking impact (SWH, Sigma0, wind speed +? : T/P, J1, J2, RA-2, GFO, ERS)

Training data	Modeling	Validation & Impacts	GDR Application

SSB: a shifting semi-empirical model

SSB model for each Altimeter Mission dataset incl. tracking/retracking impact (SWH, Sigma0, wind speed +? : T/P, J1, J2, RA-2, GFO, ERS)

Training data

Predictors:
SWH,wind
wave model
params.?

Response:
direct SLA or
collinear/
crossover

Moving targets

Modeling

NP models:
Kernel smooting to
date
Alternatives?

Geophysical+ empirical:
known need for
SWH,wind +
intermediate wave
age information

Validation & Impacts

Validation:
global
regional
temporal
uncertainty?
coastal?

Impacts:
sea level rise
cal/val
mdt/mss
mesoscale

GDR Application

Data Inputs:
stability
accuracy
HF response

Moving targets

Multi-mission SSB solutions – 3D+ models

	DONE OR ON-GOING			TO BE DONE		
	Products	**WW3**	**SSB Models**	**Products**	**WW3**	**SSB Models**
TOPEX-B	NASA/GSFC pathfinder	v2 2000-2003	2D per class	-	-	-
JASON-1	GDR_A	v2 2002-2004	2D per class 3D_Tm 3D_Hswell 3D per class	GDR_C	v3.14 2002-2010	3D_Tm
	GDR_C		3D_Tm 3D per class			
JASON-2	GDR_T + CLS reprocessed data*	v3.14 2008-2009	3D_Tm	GDR_C	v3.14 2008-2010	3D_Tm
ENVISAT	GDR_B + GDR_C orbit	v3.14 2006-2007	3D_Tm	Reprocessed GDR	v3.14 2002-2010	3D_Tm

* see N. Tran's presentation

– Use of a stable and consistent source of wave model data : WaveWatch3 v3.14 + ECMWF forcing running at UNH to generate data over 2002-2010 period.

– Development of solutions as SSB (SWH, U, Tm) mainly across the multi-mission datasets.

– Need of long-time series of consistent altimeter products (ex: difference of improvement between GDR_A and GDR_C based models).

SSB – a nonparametric modeling revisit using spline regression

Problem:

Kernel smoothing approach is sensitive to adjustments in set up, costly in computation time, not easy to share method amongst groups, no independent assessment of the CLS kernel approximation method

Approach:

Review of data application and NP methods

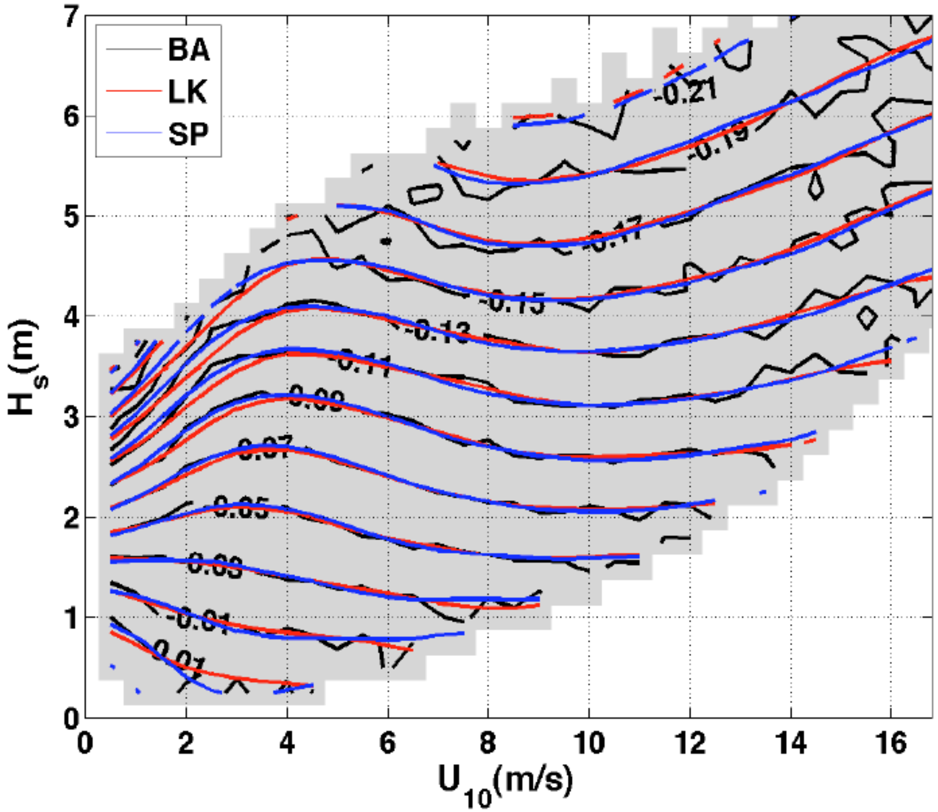
- > spline regression smoothing

- > evaluation of SSB with both NP methods in twin experiment

Expectation:

All 3 NP methods (kernel, spline, wavelets) should yield similar performance. Differences can come in higher dimensional analyses and implementation requirements.

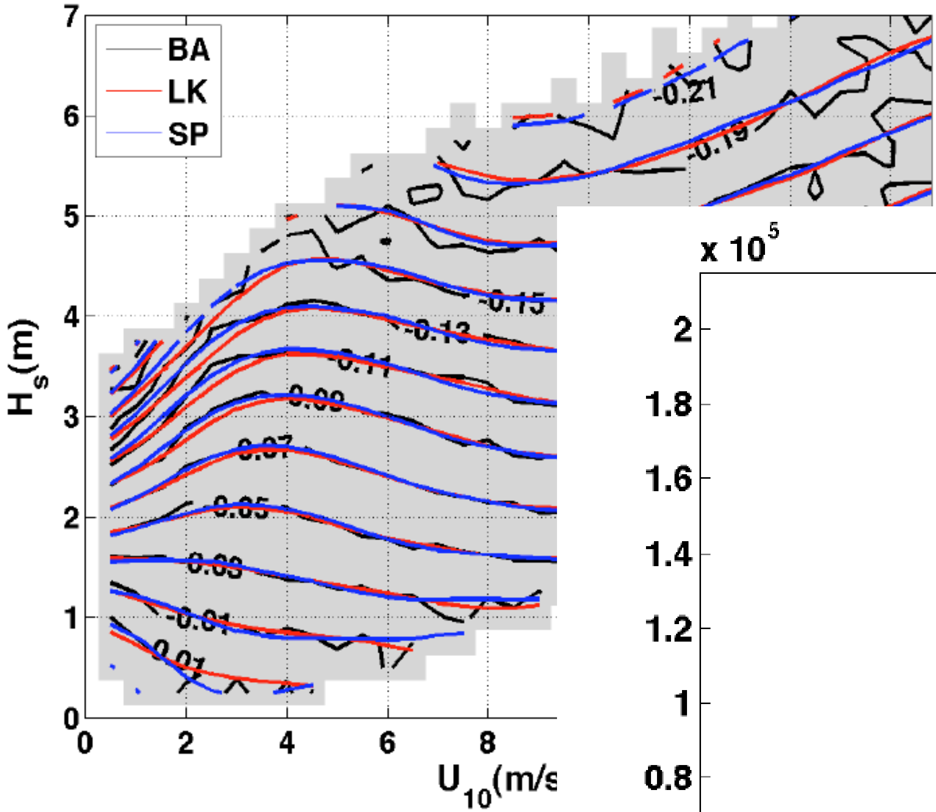
SSB – spline nonparametric modeling experiment using Jason-1 & WAVEWATCH data 2002



Local linear kernel (LK) and spline method (SP) run on same yearlong data sets

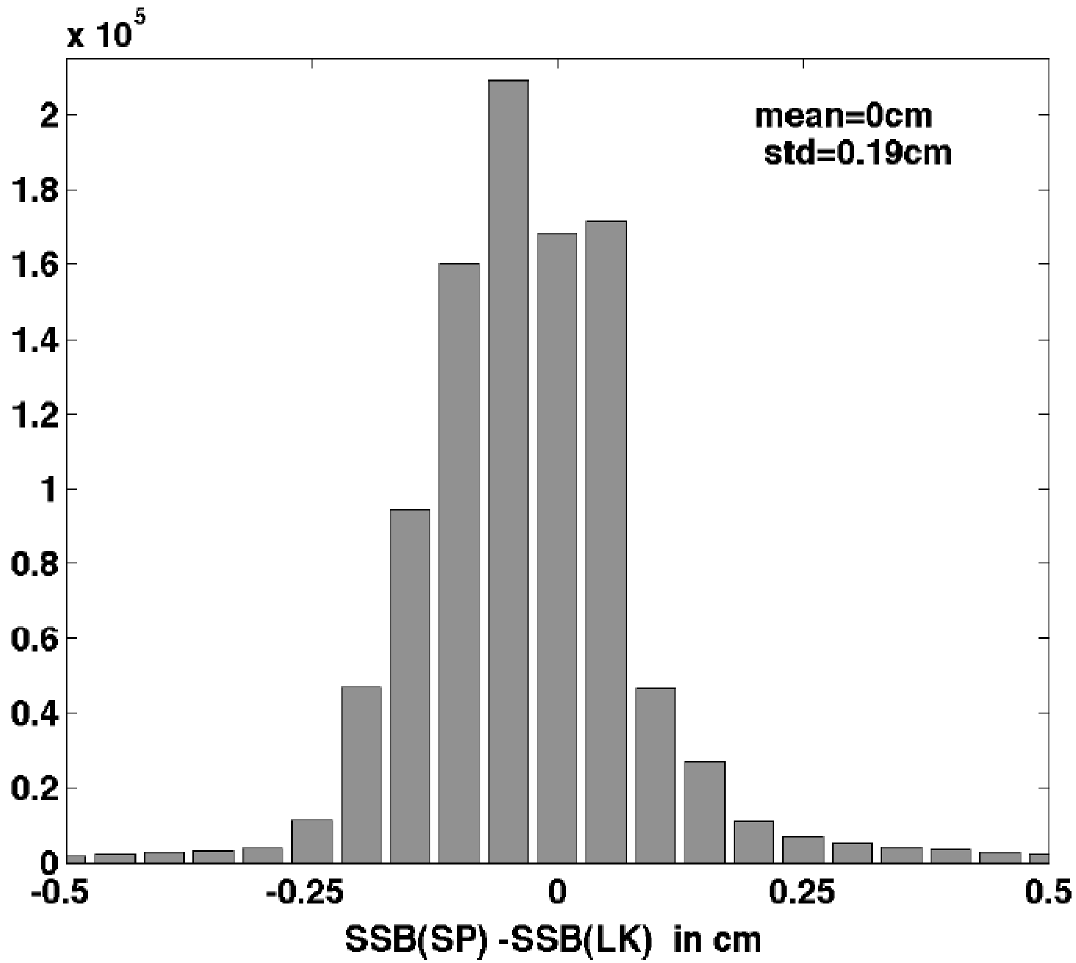
Compared to high resolution bin average response

SSB – spline nonparametric modeling experiment using Jason-1 & WAVEWATCH data 2002



Differences < 2 mm

SP closest to response



SSB – nonparametric modeling using spline regression

Study Summary (see also the poster)

- Demonstrated equivalence to 1 mm in data rich portion of solution space
- This affirms that a robust solution from the CLS local linear kernel models in use now by OSTST
- Spline solution approach bring some benefits – Most notably for higher dimensional (3D, 4D,…) SSB estimators
- Source code developed in R and then Matlab – readily imported (including at CLS)

REFERENCE:

Feng, H., Shan, Y. L. Li, N. Tran, D. Vandemark, S. Labroue, Spline-based nonparametric estimation of the altiemter sea state bias correction, IEEE Geos. And Rem. Sens. Letters, in press.

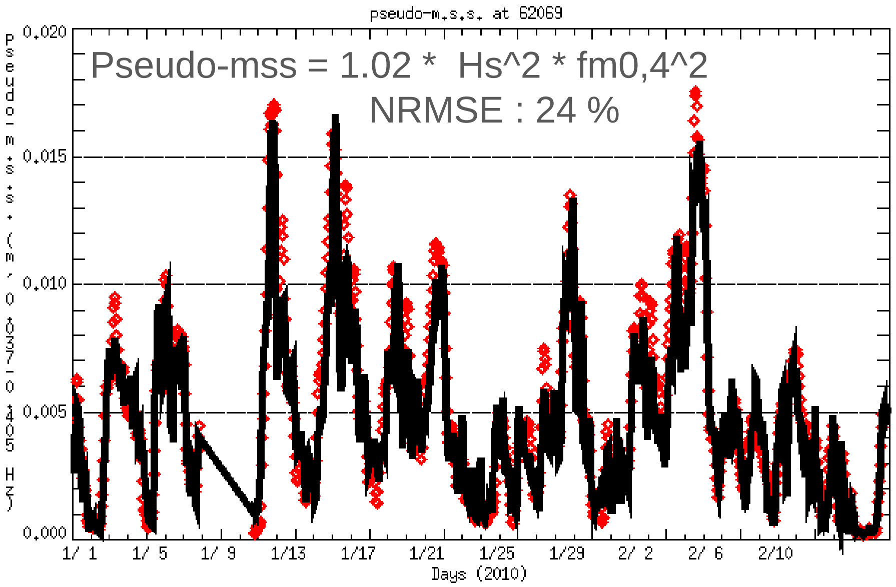
Moving target #1– ocean wave model output for SSB

F. Ardhuin – WAVEWATCH 3

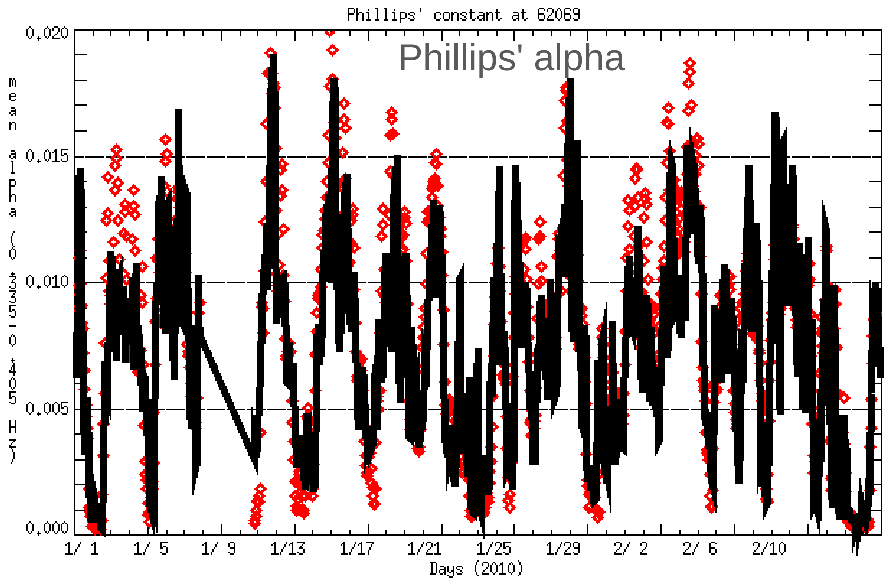
modifications -> improved slopes, Tm

Many different quantities can be estimated from the wave spectrum.
For remote sensing the high frequency tail is very important
(backscatter of radar, brightness temperature ...)
Unlike ECMWF parameterizations, latest wave dissipation functions (Ardhuin et al. JPO 2009, 2010) have a good skill for estimating the higher moments of the frequency spectrum :

Validation in North-East Atlantic (coastal: « Pierres Noires »)



NRMSE (%):	RMSE:	Bias (%):	Corr.(r):	S. I.(%):
23.9	0.001	8.41	0.9409	22.3



NRMSE (%):	RMSE:	Bias (%):	Corr.(r):	S. I.(%):
32.8	0.003	8.55	0.8203	31.6

Cross evaluation of May-2009 wave model outputs from UNH &NCEP WAVEWATCH III and Meteo-France ECMWF-WAM

UNH: Hui Feng and Doug Vandemark
Meteo-France: Lotfi Aouf
NOAA/NCEP: Arun Chawla
CLS: Ngan Tran

OPAL/University of New Hampshire
November, 2009

Conclusions

- **Wind speed U10 (Fig 1a-b)**

  UNH-ww3 uses the same ECMWF wind as MF-WAM; ECMWF wind is slightly higher/lower than NCEP wind in high/low U10 regions (crossing over at ~10 m/s), respectively.

- **Significant wave height, Hs (Fig 2a-b)**

  The three Hs products are quite close. Subtle difference among them will be due to the different winds and/or model physics being used.

- **Wind sea wave height, wHs (Fig 3a-b)**

  MF-WAM wHs differs with UNH-WW3 and NCEP-WW3. This is most likely due to a difference in spectral partitioning where WAM uses wave age < 1.2 and WW3 uses the highest freq. peak of the spectrum. This may be a significant issue related to use of WAM for SSB work as it will likely alter any swell-impacted SSB model (e.g. Tran et al 2006).

- **Mean wave period, Tm (Fig 4a-b)**

  MF-WAM and UNH-WW3 Tm agree well in the mode of their respective distributions, but geographical differences do occur. We anticipate that NCEP-WW3 Tm would agree with UNH-WW3 Tm because their m0 (i.e. Hs) difference is smaller than that of UNH-WW3 and WAM Hs (Fig 2b) and the wind sea of the two WW3 models agrees quite well.

- **Mean square slope, MSS (Fig 5a-b)**

  The considerable differences between UNH-WW3 and MF-WAM MSS are likely due to the fact that energy of high-frequency tail (>0.4 hz) is NOT contained in UNH-WW3 m4 computation but is used in WAM. This is not an immediate concern for SSB work.

Conclusions (Continue)

• **Sea State Bias SSB(U10, Hs,Tm), (Fig 6a-b)**

SSB estimation error induced ONLY by modeled Tm bias (i.e. difference) between UNH-WW3 and MF-WAM falls within [-5 5] and [-10,10] mm in the 60% and 80% monthly data population distributions, respectively. Thus 20% of the data generated with WAM would predict SSB at a level of 1 cm different from that using Wavewatch in this month.

SUMMARY

Slight differences among three products occur due to different winds (ECMWF in UNH-WW3&WAM vs. NCEP in the NCEP-WW3), partitioning (swell and sea between bothWW3 and WAM), and model physics (mean period between bothWW3 and WAM).
In this comparison, UNH-WW3 output is closest to NCEP-WW3 but they are not identical.

The altimeter SSB one would estimate using WAM data will not be essentially the same as for Wavewatch. Differences exceeding 1 cm do occur and are geographically centered within clearly identified ocean regions – primarily associated with mean wave period wave model differences. Which model T_m is correct? Does it matter? (as the SSB model is tuned to WW3).

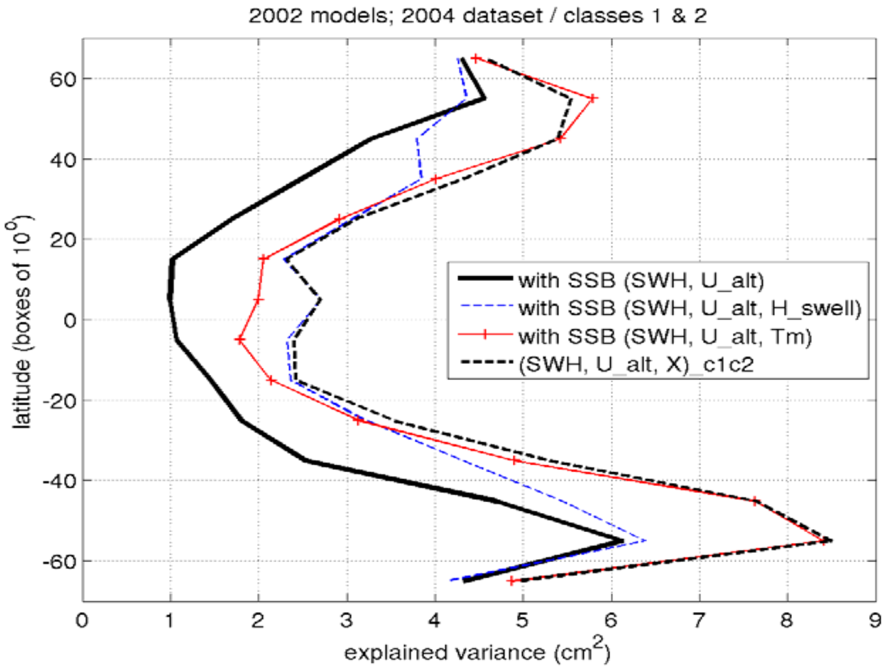
For operational SSB processing, the best choice is still to use the model that created the SSB model, i.e. UNH-WW3. NCEP-WW3 is option 2. To consider WAM - We need to know why WAM mean wave period is differing with WW3.

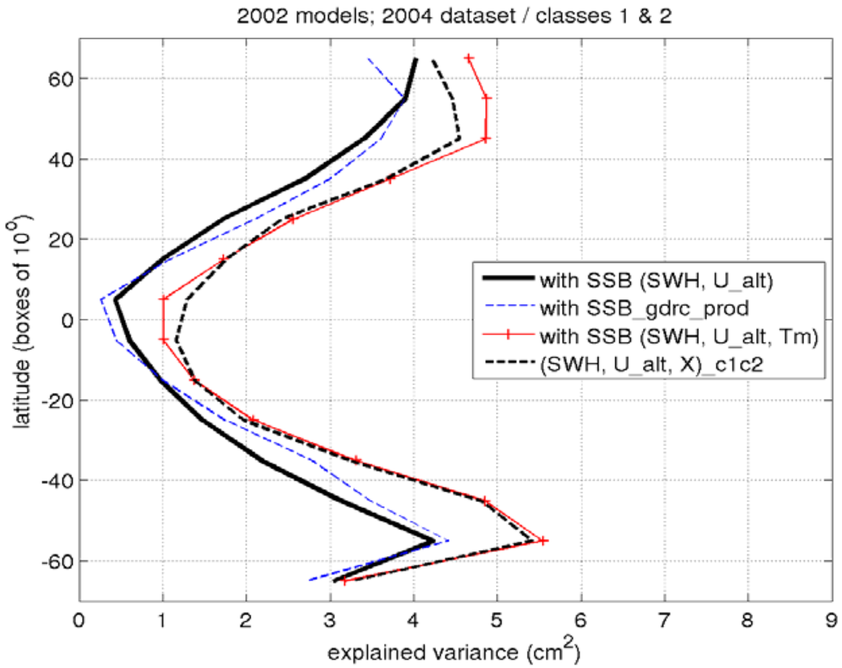
Moving target #2– SWH and wind under MLE3 and MLE4

Improvement Difference

Reduction of collinear ΔSSH variance

Jason-1 (1-year) / WW3 v2



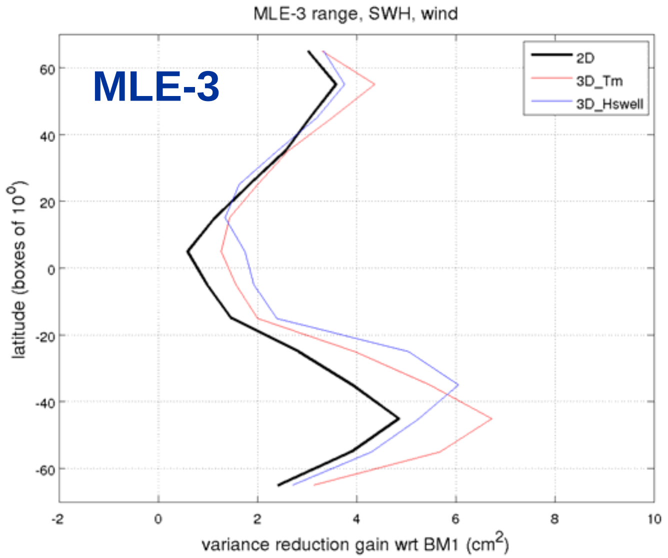


GDR_a → **GDR_c**

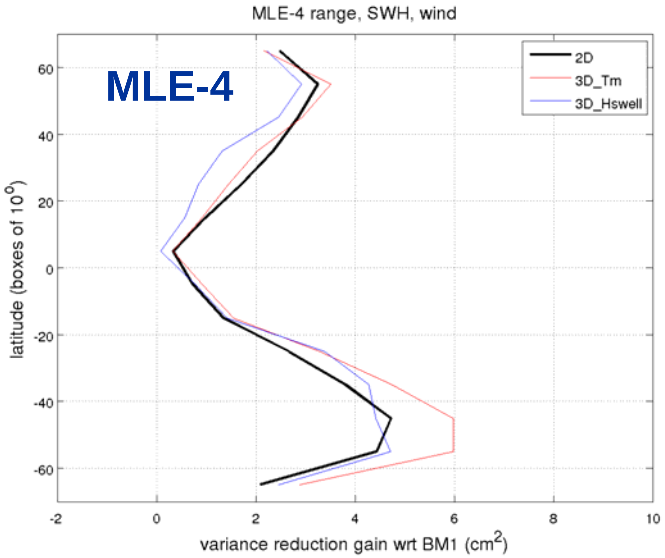
- change of orbit solutions, MLE-3 to MLE-4 retracking algorithms, …
- to be tested: change of WW3 from v2 to v3.14.

Improvement Difference

Reduction of collinear ΔSSH variance

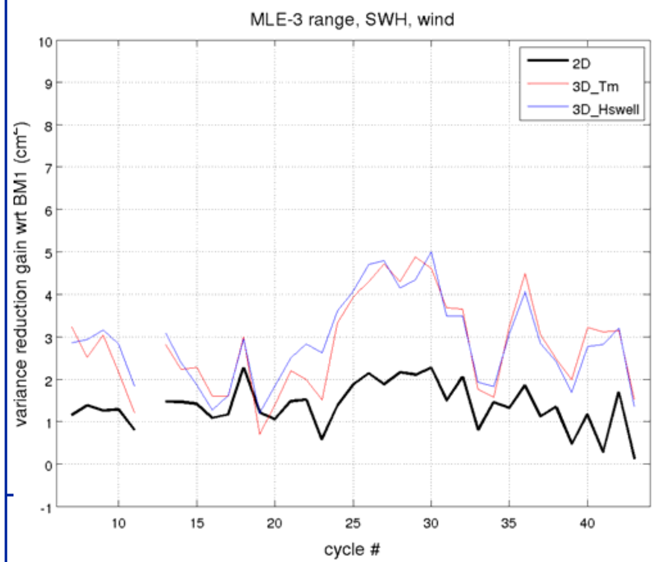


Jason-2 (1-year: cycles 7-43)
WW3 v3.14

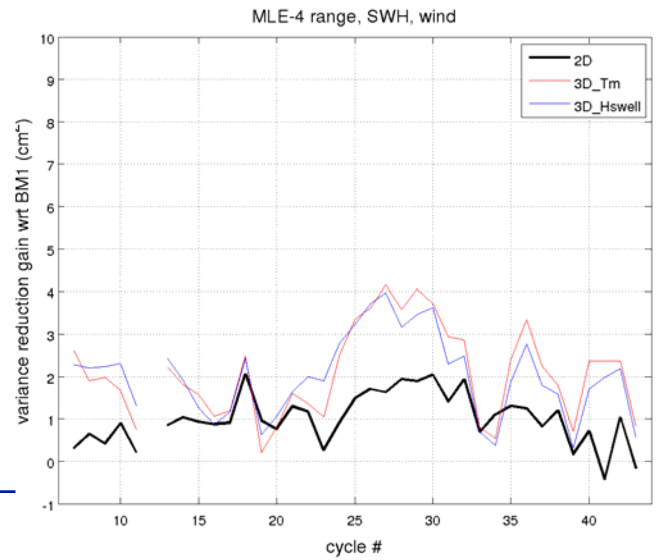


– to be tested: change of WW3 from v2 to v3.14 on Jason-1 data.

$BM1_{mle3} = -3.91\% SWH_{mle3}$

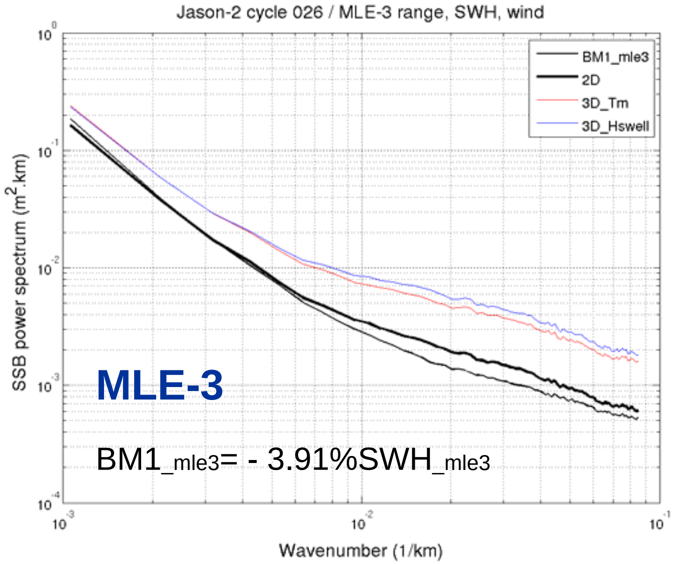


$BM1_{mle4} = -3.85\% SWH_{mle4}$



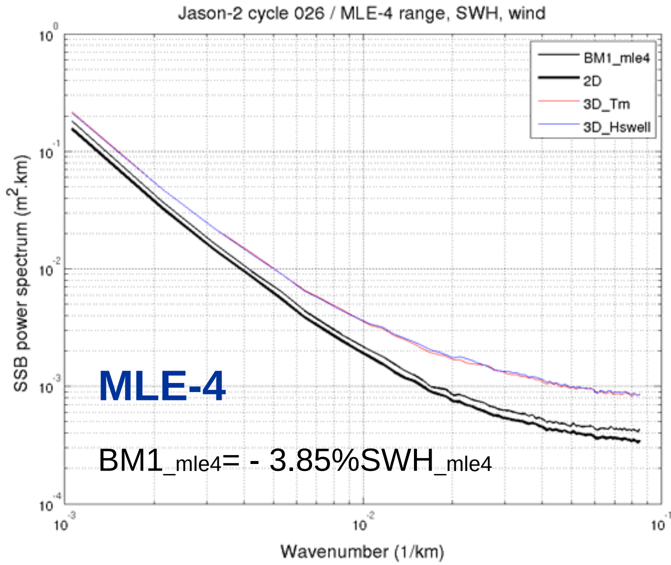
Improvement Difference

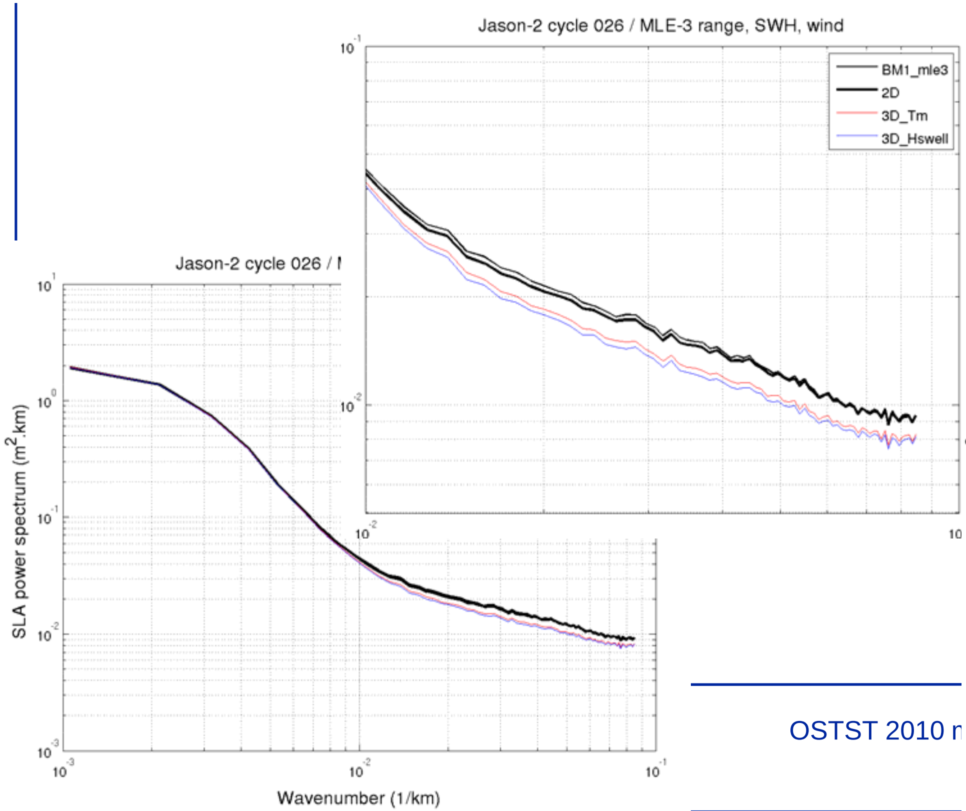
Spectral Analysis

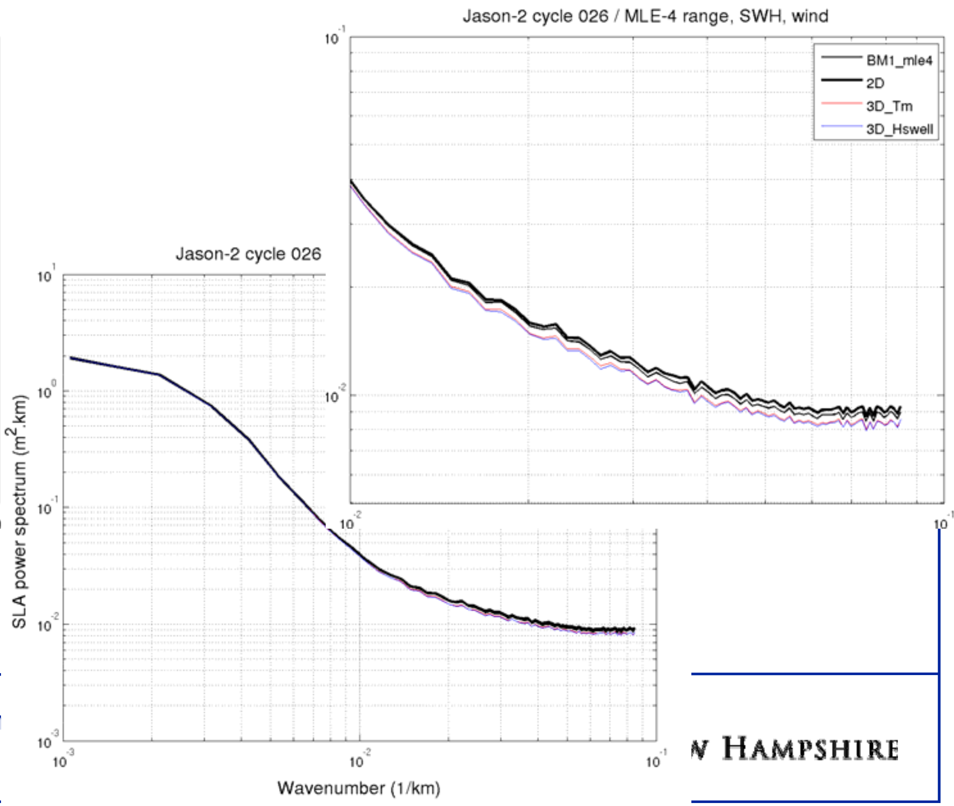


Jason-2 (1-year: cycles 7-43)
WW3 v3.14

– Need to separate impact on large and short wavelengths.







SSB correction progress

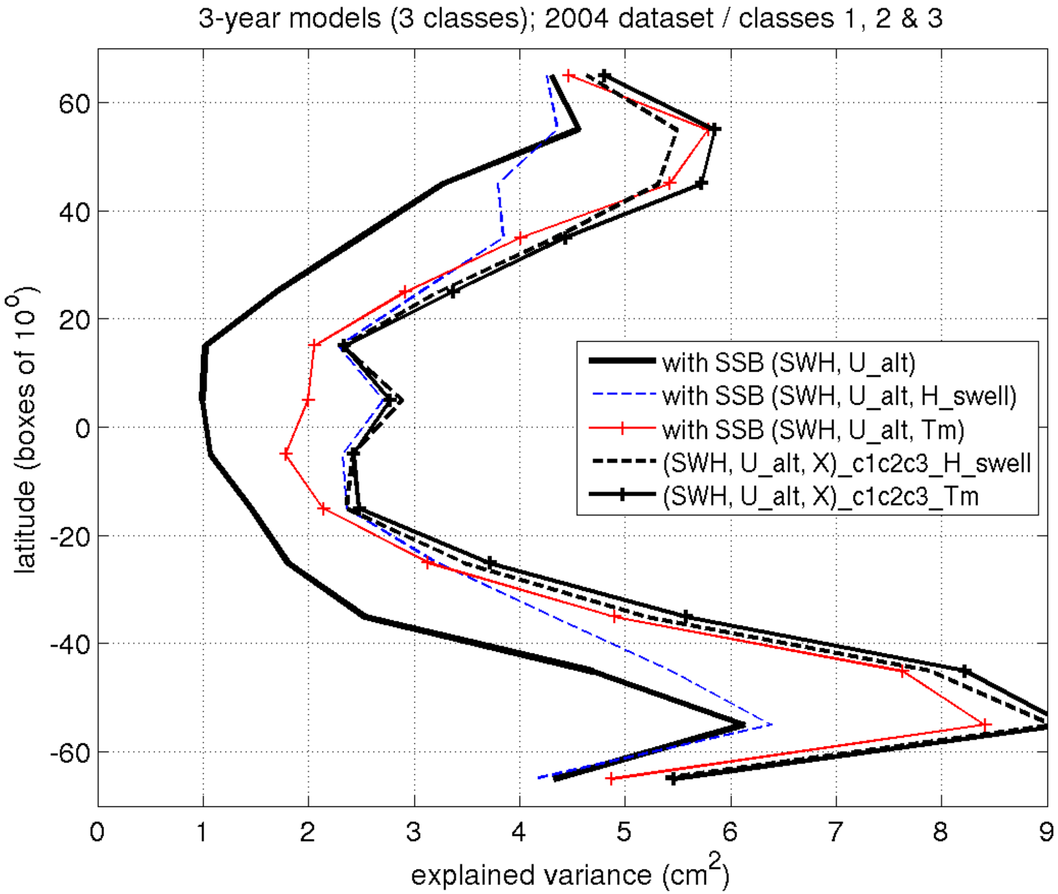
Completed

- Alternative/complementary NP solution method for SSB using spline regression
- Long term stable WAVEWATCH III model run for 2000-2010 with cross model evaluations
- Progress in WAVEWATCH physics modifications (Ardhuin) and in use of wave model data for refined SSB models tied to clustering analyses (CNES/CLS SLOOP project)

Ongoing

- Study to better formalize SSB model impact and validations within and across missions (i.e. best GDR implementations)
- Evaluation of retracking impacts
- Higher dimensional SSB modeling with refined WAVEWATCH data

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 - 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

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