Assessing sea state bias correction models for differing frequencies and missions

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Motivation – SSB ‘error’ simulation using wave model output: one month

- Wavewatch III global model, 3 hour time step
- SSB difference = model-informed 3D SSB - 2D GDR SSB
Motivation – wave model SSB ‘error’ simulation

• Wavewatch III global model, 3 hour time step
• SSB difference = model-informed 3D SSB - 2D GDR SSB

SSB Diff., 3D-2D
[-0.04, 0.04] m
08-2008
Day: 17

OSTST Meeting, Boulder 2013
SSB: ever shifting empirical models?

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

Training data
- Predictors:
  - SWH, wind, wave model params.
  - GDRx?

Response:
- direct SLA or collinear/crossover

Modeling
- NP models:
  - Kernel smoothing
  - Spline smoothing

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
- Other Geophysical Range Corrections:
  - stability
  - accuracy
  - time/space correlations with SSB?

Frequent need for recomputation

OSTST Meeting, Boulder 2013
Outline

• Revisit of 2D sea state bias model approaches to support next steps
• Cross mission comparisons?
• Ka-band - AltiKA
• Conclusions and future work
Step back to 2D models: objectives for optimal ssb

- Variance reduction across climate data records
- Ability to extend SSB to alternate variables at 2-4 dimensions
- Ability to accurately (stably) determine signal for geophysical insight within and across missions (e.g. EM bias, Ku vs. Ka, C, S bands, Cryosat, SWOT etc...)

...but direct and collinear solutions not yet reconciled..
two approaches, 10 day repeat diff. vs. direct

Tran et al 2010
Modified NP LLK
Collinear

This study
NP Spline
Direct

Close, but cm-scale differences
2D SSB collinear method revisit

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>• 10 day difference cancels time invariant as well as small and slowly (&gt; 20 day) time varying contributions to ΔSSHA</td>
<td>• Limited data sampling occurs for the sparsely observed SWH, U pairs. This then leads to a wider NP smoothing kernels and a less precise SSB model</td>
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<tr>
<td>• Ability to develop large drift-free training datasets using multiple years of measurements</td>
<td>• Differences approach imposes significant uncertainty (5-10 mm) in the absolute single bias or shift value for each given P or NP solution</td>
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<td>• Much larger spatial and data domain sample population than for the crossover differencing dataset</td>
<td>• Requires/assumes all SSHA variation in 10 days is solely due to SSB</td>
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<td>• If SSB change is quasi-linear with dependent variables then 10 day differences in SSHA and the 2D input variable differences readily translates to LS model inversion</td>
<td>• Assumes linearity or at least a continuous derivative in order to work in difference space</td>
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<td>• Potential issue of incongruous NP solutions if one reverse the differencing process, T12 ≠ T21</td>
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Issues:

Modified method adopted for SSB GDRs that averages time reversed data solutions – why are they different?

Limited data for sparsely sampled SWH, U pairings

More so if more variables desired

NP not as tractable for additional differenced variables
SSB – collinear dilemma of sorts

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

\[ r_{t1} - r_{t2} \neq r_{t2} - r_{t1} \]

Tran et al 2010... some geophysical information likely left even in the collinear solution approach - this led to a modified collinear NP SSB solution

Observed the same for T/P

Solution was to create two NP SSB models and average them

GDR ‘standard’

Figure 2. Differences of bin-averaged \( \Delta \text{SSH} \) computed with respect to SWH measured at time \( t_1 \) and at time \( t_2 \), respectively.
2D SSB collinear method revisit - sampling

Example for mode of 2D pdf with maximum data

ONE YEAR OF JASON DATA

UPPER: SWH, U pair [2.5,8]

MIDDLE: ΔSWH, ΔU pair (t2-t1)

LOWER: ΔSWH, ΔU pair (t1-t2)

• spatial differences apparent

• normalized population differences from upper are obvious

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Example 2: Limited data for sparse SWH, U pairings

ONE YEAR OF JASON DATA

UPPER: SWH, U pair [6,14]
MIDDLE: ΔSWH, ΔU pair (t2-t1)
LOWER: ΔSWH, ΔU pair (t1-t2)

spatial differences apparent

normalized population differences from upper are obvious

some time reversal differences
2D SSB collinear method revisited - sampling

- 10-day repeat difference data for one year
- little observed difference in reversed data (black and red)

Hs = 2.5, U= 8

Hs = 6, U= 14

quite noisy with one year

ΔHs

ΔU
Conclusions re: collinear:
• noisy, sparse data bins will lead to NP SSB smoothing
• we can’t yet duplicate the need for this modified/averaged collinear SSB model
• geolocation not equivalent with direct

Hs = 2.5, U= 8, data rich

Hs = 6, U= 14

quite noisy with one year
SSB NP methods, direct use of sea level anomaly

- Cautions about the use of SLA averaging for sea state bias work presented (e.g. Hausman et al., 2011; Labroue et al., 2009)
- True that there is spatial variability in the correlation strength for <SWH SLA>. This however does not necessarily translate into the global multivariate solutions if handled correctly.
- To date, still using the direct method for preliminary models and collinear data for GDR solutions
- Need to quantify uncertainty

- Collinear $\Delta$SSH variance reduction gain from CLS 2D SSB models (BM1 serves as benchmark):
  - 2.45 cm² (collinear solution)
  - 2.40 cm² (direct solution)
Addressing uncertainty in direct SSB determination, Jason-1 example

N one year SSB solutions, bimonthly 2002-2008

Example SSB for one bin in the 2D space

Temporal variation $\ll 1$ cm over 36 solutions
Sliding one year SSB avgs.

Five different bins

Small time variability in some data poor bins

Can compute STD in each
Sliding 6 month year SSB avgs.

Five different bins

Larger time variability in some bins – now see Steric height

6 MONTHS IS TOO SHORT!

Direct SSB error depends on avg. time length and time window center
Jason-1 SSB standard deviation estimate < 6 mm in data rich area, < 8 mm
STD_error lower when considering DOF of at least 7

BLUE – all data
BLACK – subset to equally weight data geospatially
Overall, quite close agreement, slightly more SSB wind dependence at low and high winds in direct SSB solutions – ready to address T/P-> ALtiKa

Differences can now be assessed with better defined uncertainty bounds, direct appears quite valid for 3D SSB work for GDR application

TBD – the modified/avgd collinear solution..
AltiKa

First chance to see a mono-freq. spaceborne altimeter at 36 GHZ

Some ground work in advance for sigma0 and SSB at Ka:

Vandemark, D., B. Chapron, T. Elfouhaily, and J. W. Campbell (2005), Impact of high-frequency waves on the ocean altimeter range bias


Walsh, E. J., et al. (1991), Frequency dependence of electromagnetic bias in radar altimeter sea surface range measurements

.... and series of SOWEX Ed Walsh Scanning radar altimeter papers for NRCS data
Overall – V et al 2005 concluded that Ka should act much like a Ku-band signal.

Were also bit puzzled why not more roughness impact in both SSB and NRCS at winds above 10 m/s (limited long wave conditions in field work?)
SSB AltiKa and comparison with Jason-2

SSB AL cycle 1 to 4
Direct method,
with ECMWF Wind and Model Wet Tropo

SSB J2 cycle 1 to 4
Direct method,
with ECMWF Wind and Model Wet Tropo

In general
SSB_Ka ~= SSB_Ku ~ 3 %
Accords with V05

AltiKa SSB > Jason by 2-5 cm (0.5-1%) at U > 10 m/s
Agrees with CLS
NRCS AltiKa and comparison with Jason-2

Ka quite close to Cox and Munk (1956)

Optical

Ku-band dB/m/s > Ka-band

SWH dependence ~ same for both – see V05
Summary

2D SSB model revisit –
Framework in place for quick multi-year assessment of collinear and direct
SSB from each mission
Converging to understand small but systematic SSB model differences and
hopefully to better resolve geophysics in C, Ku and Ka band
Multi-year bootstrapped method readily produces low noise direct-method
SSB with uncertainties; and better footing for 3D,4D extension using
wave model

New Ka-band data
AltiKa SSB quite close to Ku-band, as predicted from field EM bias data

AltiKa sigma0 show same long-wave impacts at Ku as expected

AltiKa sigma0 at higher winds are below K and should prove quite useful to
better solidify active/passive microwave scattering & emission models

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