Multi-mission sea state bias modeling: development and assessment

H. Feng[1], **D. Vandemark**[1], N. Tran[2] , B. Beckley[3], and B. Chapron[4]

[1]*University of New Hampshire, Durham, NH*

[2]*CLS / Space Oceanography Division, Ramonville St-Agne, France*

[3]*SGT Inc, GSFC/NASA, USA*

[4]*IFREMER / Centre de Brest, Plouzane, France*

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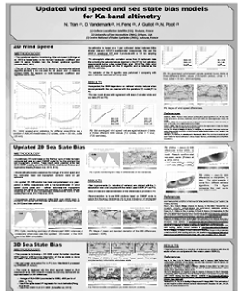
2014 Goals and Progress

Goals

1. Provide best multi-mission sea state bias (SSB) correction models for altimeter Climate Data Record generation

2. Nimble and robust SSB & wind modeling supporting new missions



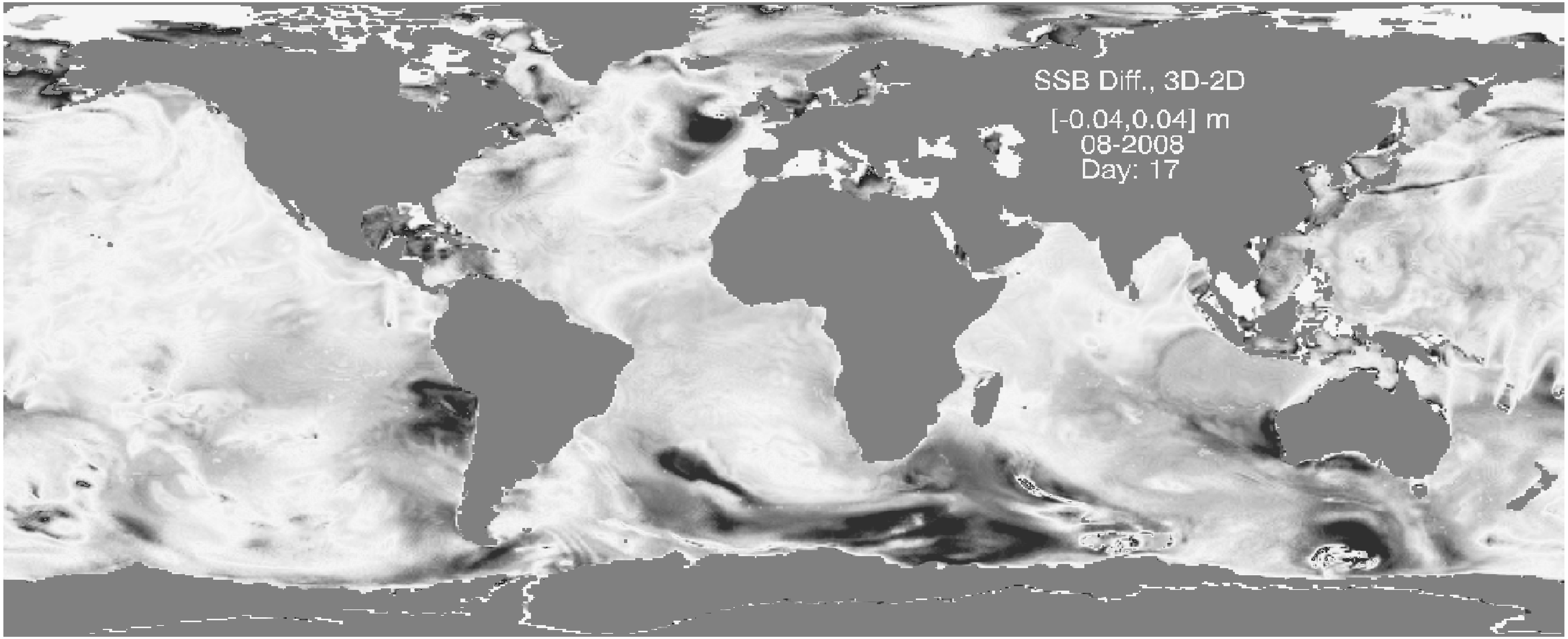
Progress

Refined AltiKa SSB and wind speed – see Tran et al. poster

Develop database and tools to compute 2D & 3D SSB models going backward and forward (T/P -> present) for any mission segment

Codify metrics to verify enhanced SSB model skill

Motivation: 1-2 cm^2 of gain still possible in sea state geophysical corrections (SSB) ?



- Example here: SSB with Wavewatch III global model input
- Difference Above = enhanced_SSB - GDR_SSB

Motivation 2: SSB is an ever? shifting 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, AltiKa, J3)

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

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

GDR updates

Other Geophysical Range Corrections:
stability
accuracy
spurious correlations

Need for
recomputation

Review: SSB direct use of residual sea level anomaly (SLA) method

• Cautions about the use of SLA averaging for sea state bias work presented (e.g. Hausman et al., 2011; Labroue et al., 2009)

• Issues in SLA containing sea level rise signals not related to sea state that should be removed (see next slide)

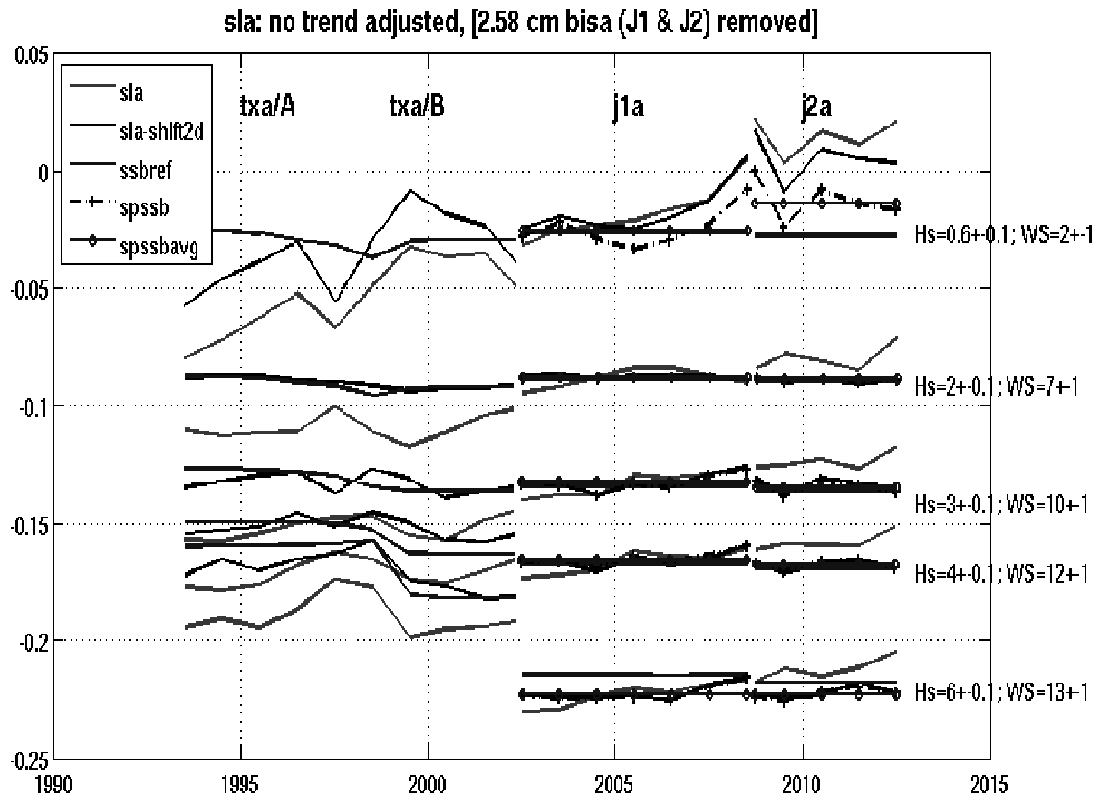
• True that there is spatial variability in the correlation strength for <SWH SLA>. This however does not necessarily translate into the global multivariate solutions if handled correctly.

• To date, still using the direct method for preliminary models and collinear data for GDR solutions, CCI metrics question added value

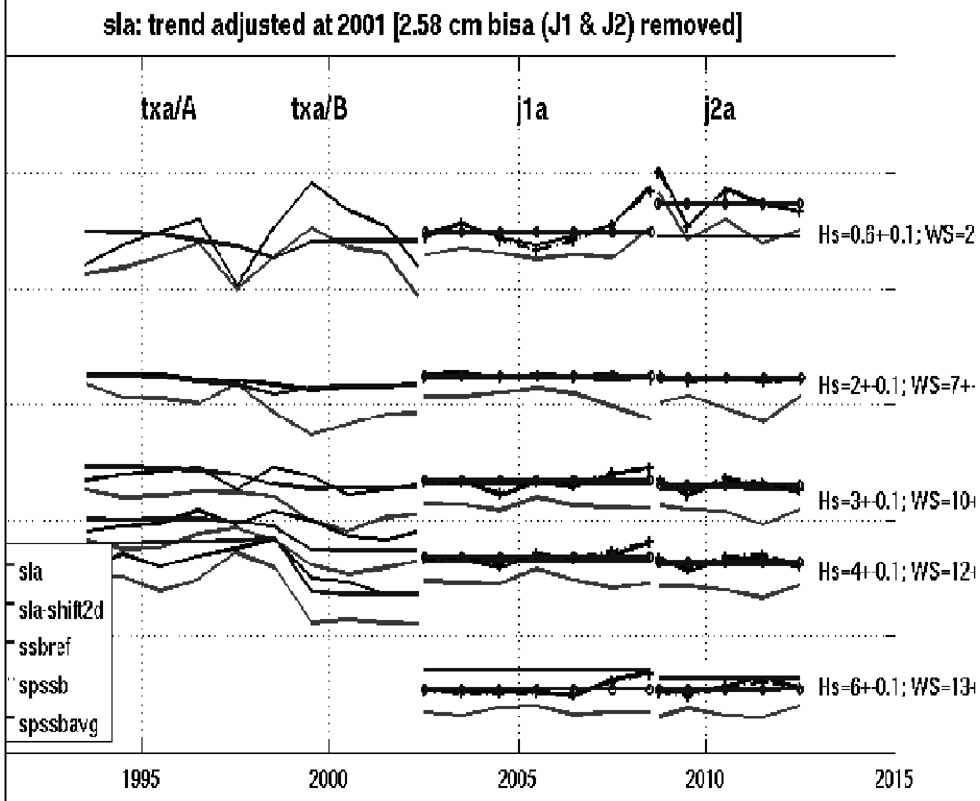
•Need to quantify uncertainty

Sea level rise (not related to SSB) in direct SLA SSB compensated before modeling – dependent on MSS base period, in this case DUT2010

Before removal

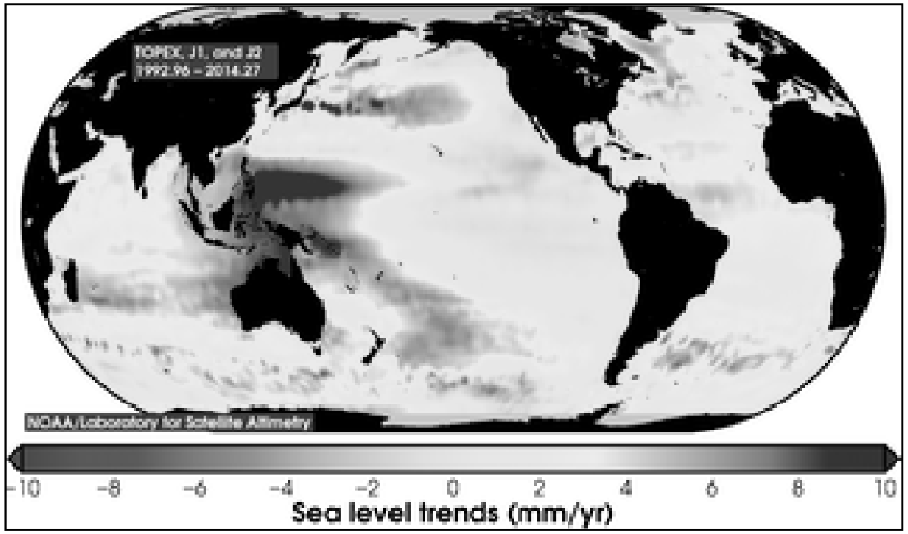


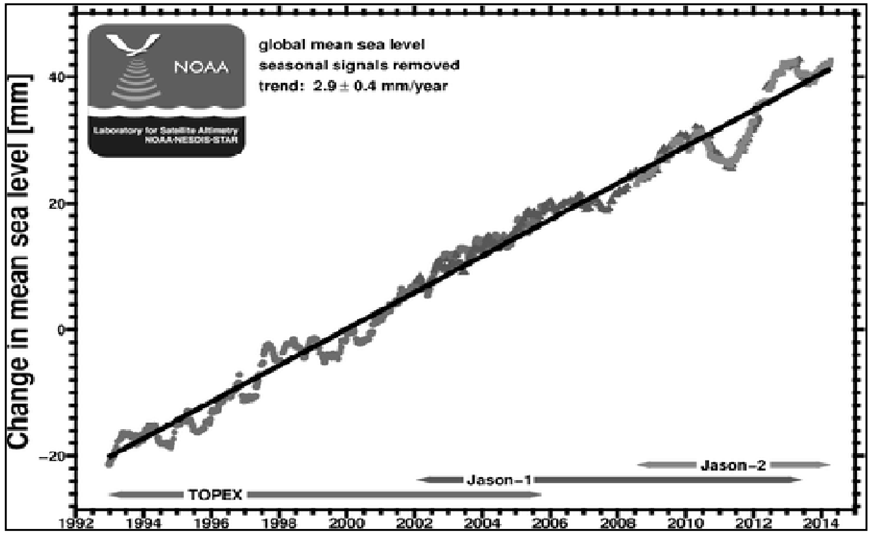
After removal



Preprocessing direct SLA data

• First, remove temporal trend signal in SLA (geolocation specific) is removed using the NOAA sea level rise prediction signal; http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise)





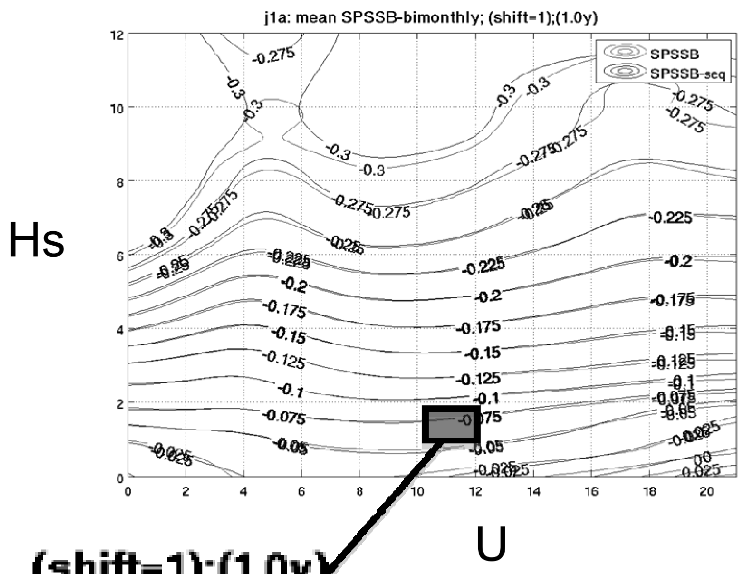
• Second, apply a single shift, related to a reference SSB (e.g. CLS-2dSSB) at mode Hs and U10, to SLA

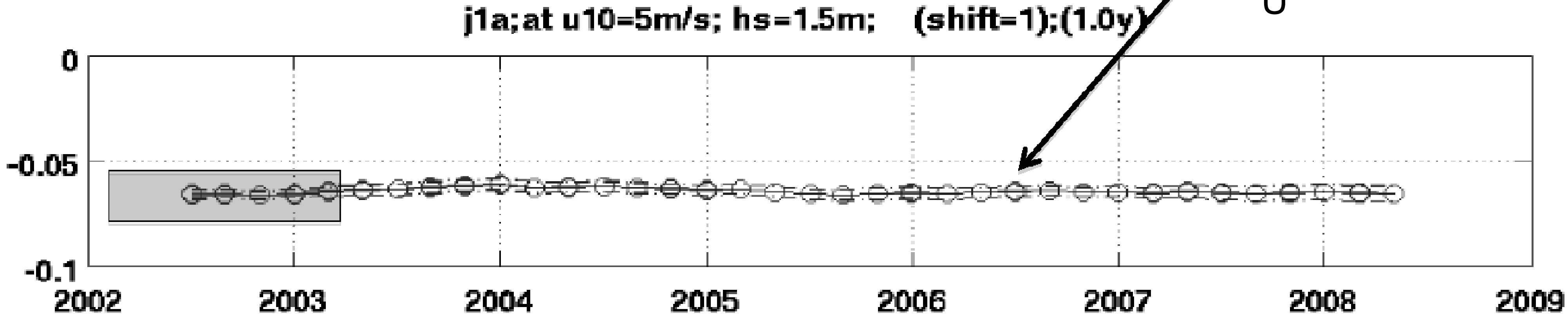
Addressing uncertainty in direct SSB determination, Jason-1 example

N one year SSB solutions, bimonthly 2002-2008

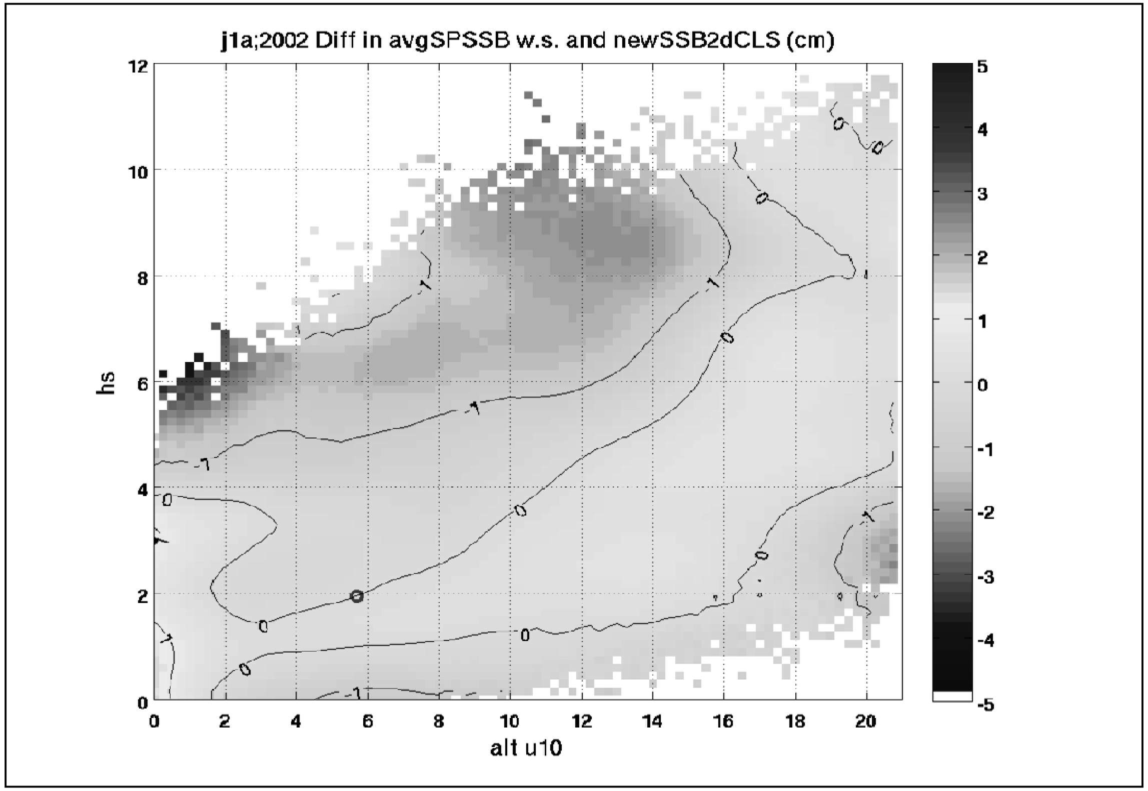
Example SSB for one bin in the 2D space

Temporal variation << 1 cm over 36 solutions





Jason-1 2D SSB, direct - collinear



Overall, sub-cm agreement, slightly more SSB wind dependence at low and high winds in direct SSB solutions – ready to address T/P-> ALtiKa

Direct method SSB can now with defined uncertainty bounds, appears quite valid for 2D or 3D SSB work for GDR application – easier tool to work with

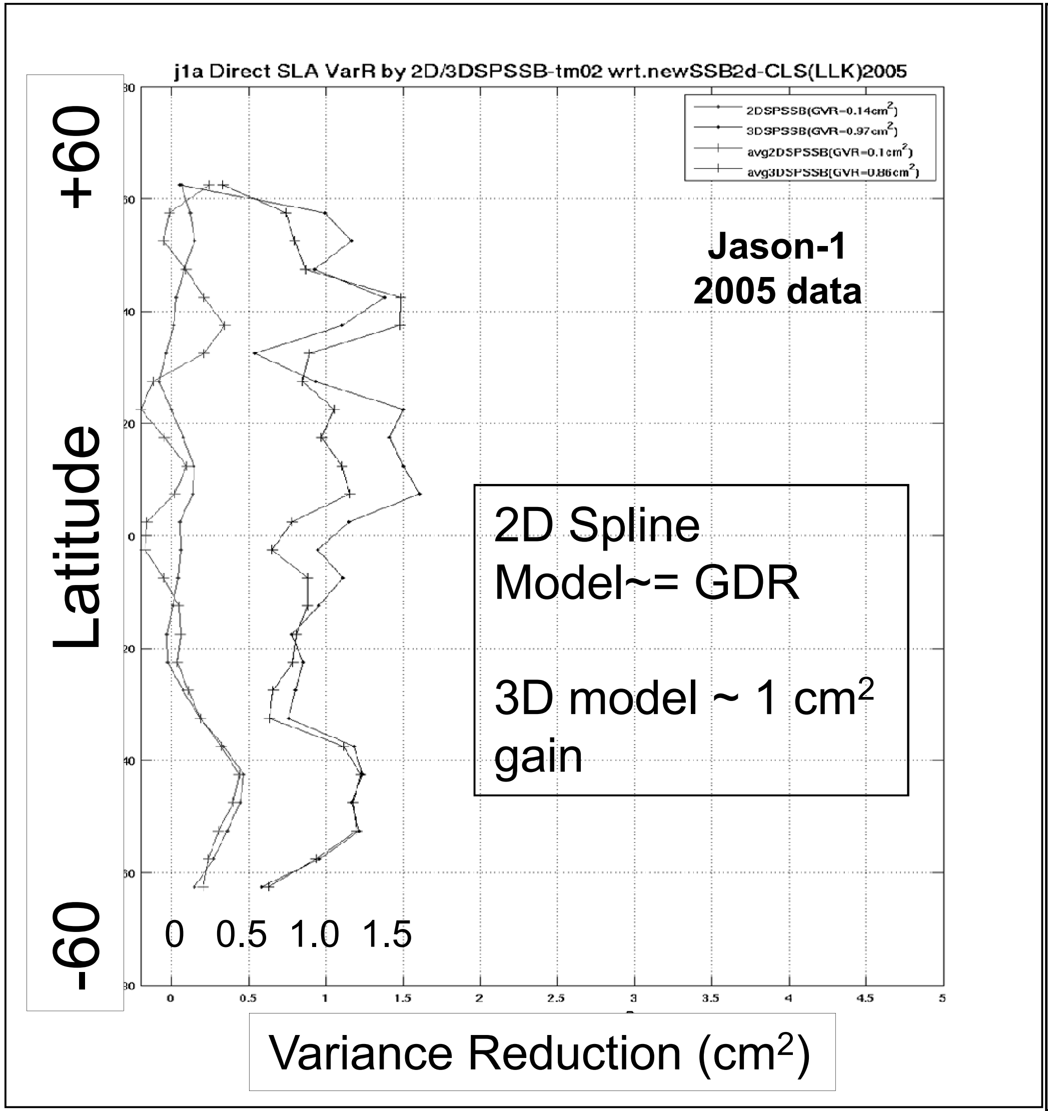
SSB Performance metrics

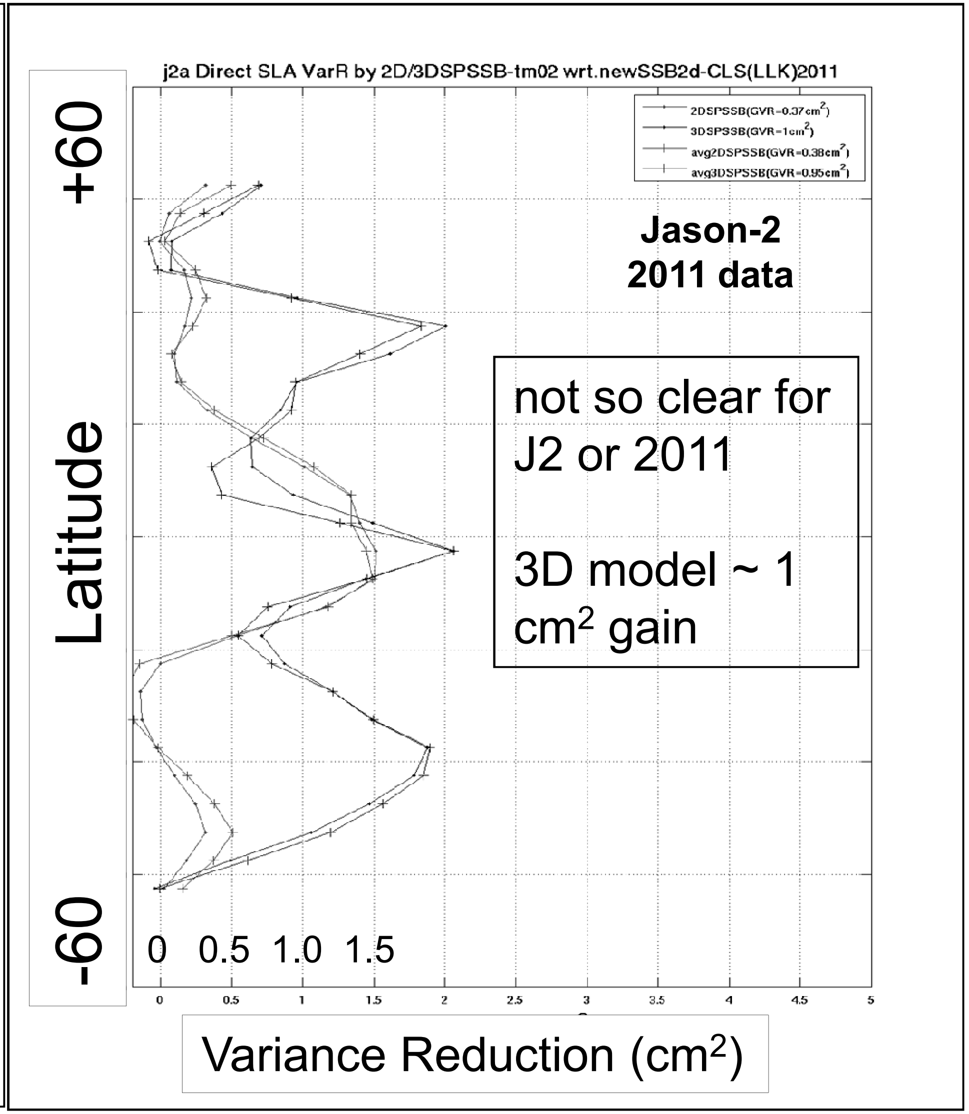
Variance reduction measure: applied to the following

- direct residual sea level anomaly (SLA)
- collinear difference
- crossover differences (gold standard?)

SSB model comparisons across these tests have been difficult to trust

J1 & J2: test by SLA var. reduction, obtained using 2D and 3D SSB models relative to the 2D GDR SSB





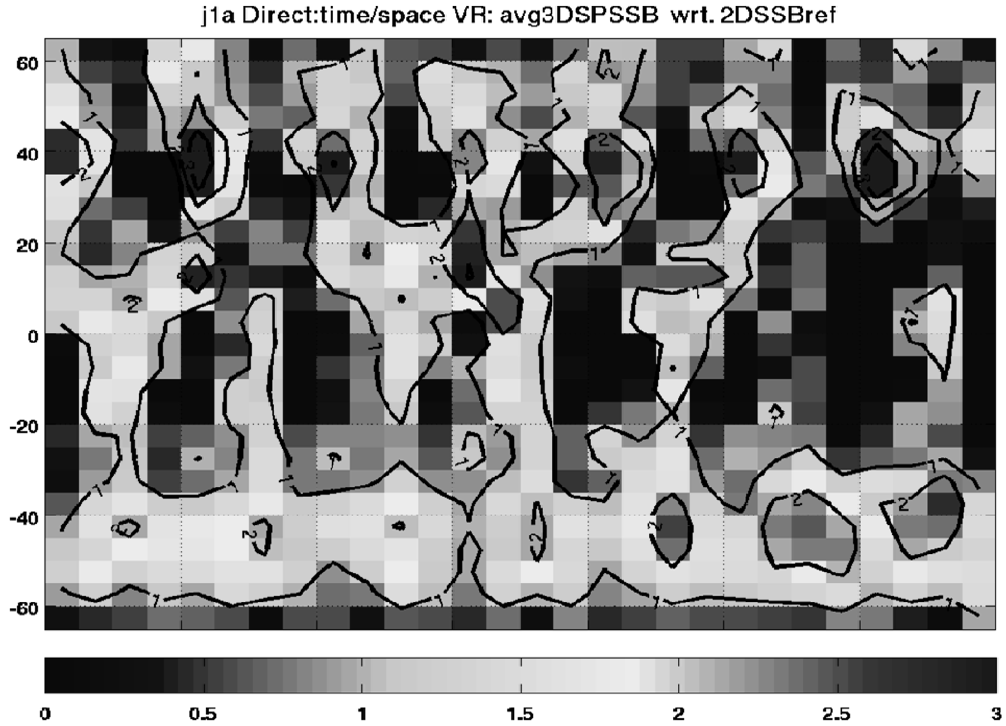
Black lines : 3D_SSB vs. GDR SSB (2D)
Red lines: UNH_2D_SSB vs. GDR SSB (2D)
(The corresponding global variance deduction GVD values are showed in the legend)

Jason-1 – space/time eval. of 3D SSB model

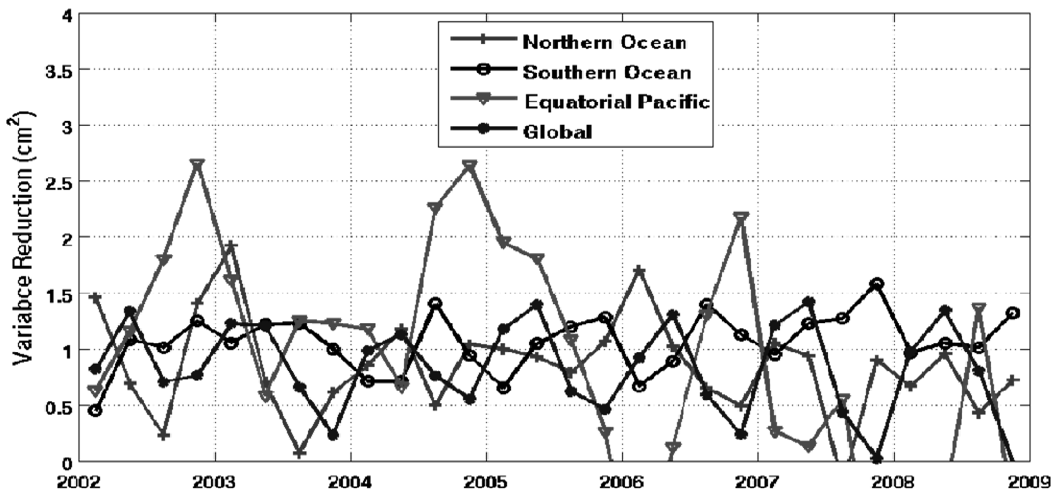
Spatial/temporal variance reduction in **Direct SLA test** in cm^2 (positive values indicating performance gain) relative to a updated 2D CLS_SSB

(a) Temporal/Latitude variation; (b) Temporal variation in selected regions and (c) the 2002 map

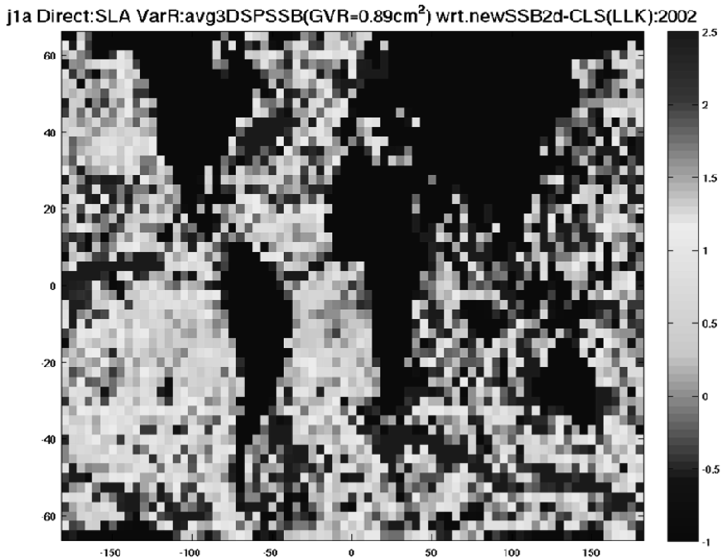
(a)



(b)



(c)



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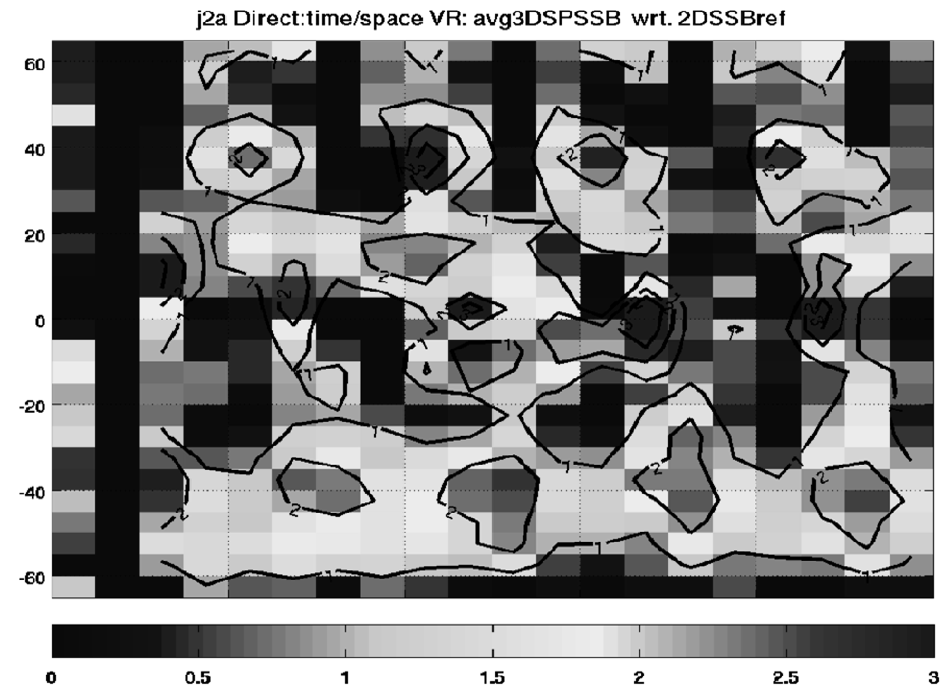
Jason2 – same view

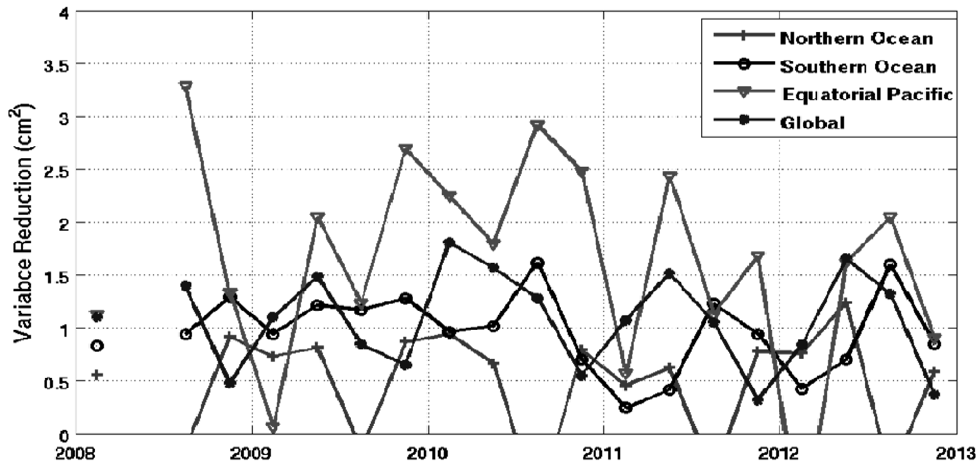
Spatial/temporal Variance Reduction in **Direct SLA test** in cm2 (positive values indicating performance gain) obtained using avg 3DSPSSB(U10,Hs,tm02) model relative to a 2D CLSSSB(best up to date)

(a) Temporal/Latitude variation; (b) Temporal variation in selected regions and (c) the 2002 map

(a)

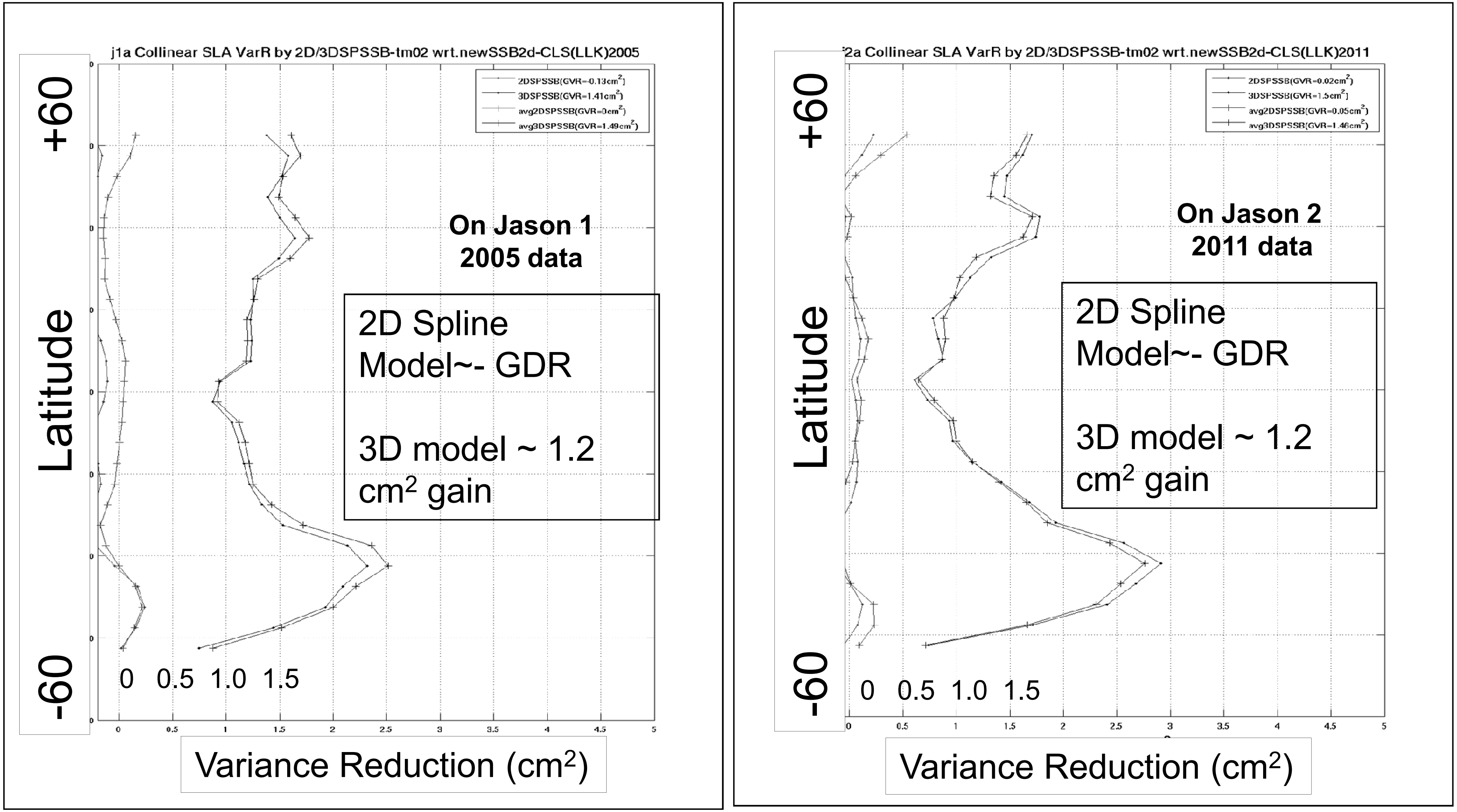


(b)



(c)

J1a/J2a: Collinear difference test : Variance Reduction (positives indicate performance gain) varying with latitude, obtained using the 2D and 3D SSB models relative to a 2D CLSSSB



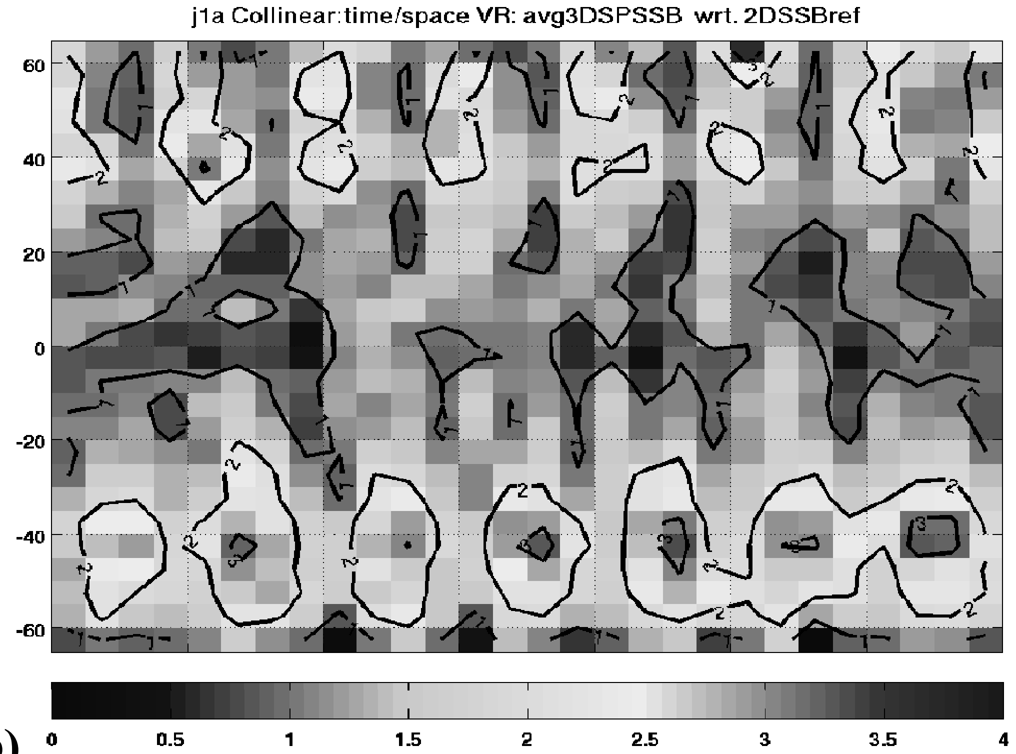
Black lies : Variance Reduction: 3DSPSSB vs. 2DCLSSSB
Red lines: Variance Reduction: 2DSPSSB vs. 2DCLSSSB
(The corresponding global variance deduction GVD values are showed in the legend)

Jason1 – 3D eval with collinear differences

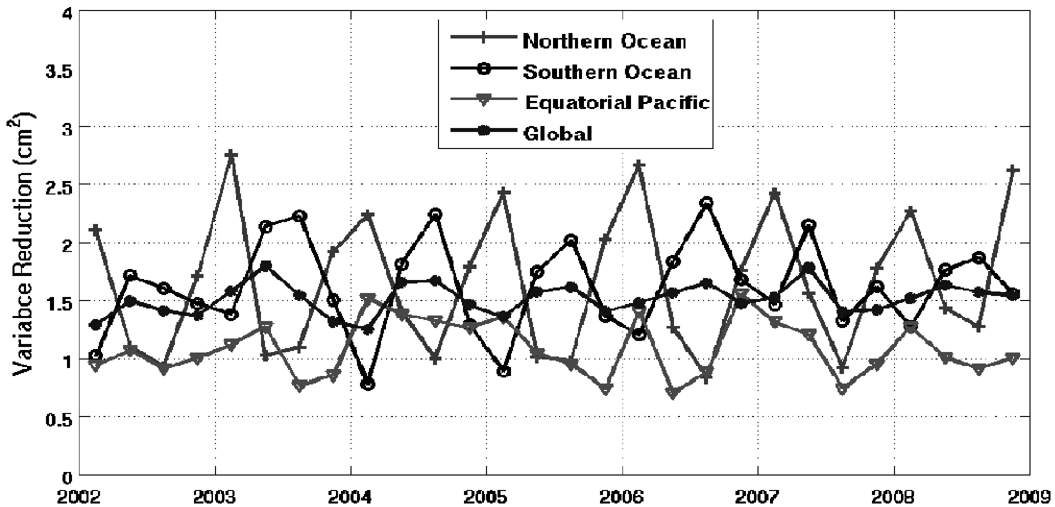
Spatial/temporal var. reduction in cm^2 (positive values indicating performance gain) obtained using avg 3DSPSSB(U10,Hs,tm02) model relative to a 2D CLSSSB(best up to date)

(a) Temporal/Latitude variation; (b) Temporal variation in selected regions and (c) the 2002 map

(a)



(b)



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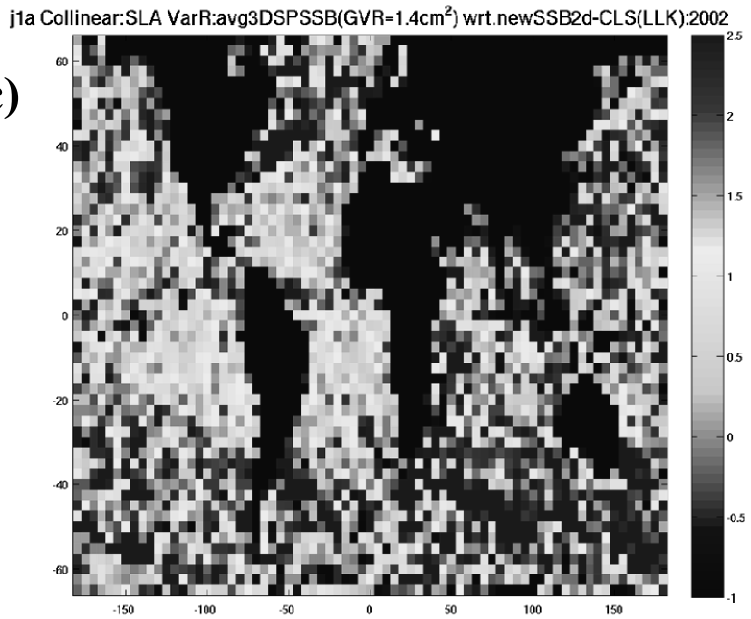
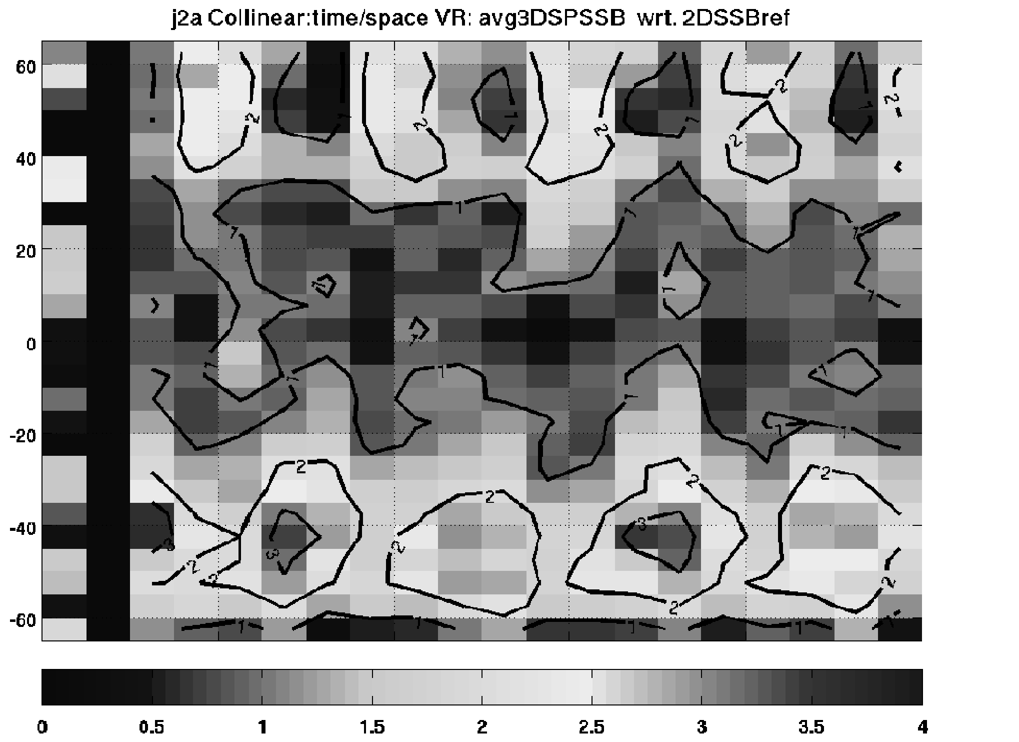


Jason1 – 3D eval with collinear differences

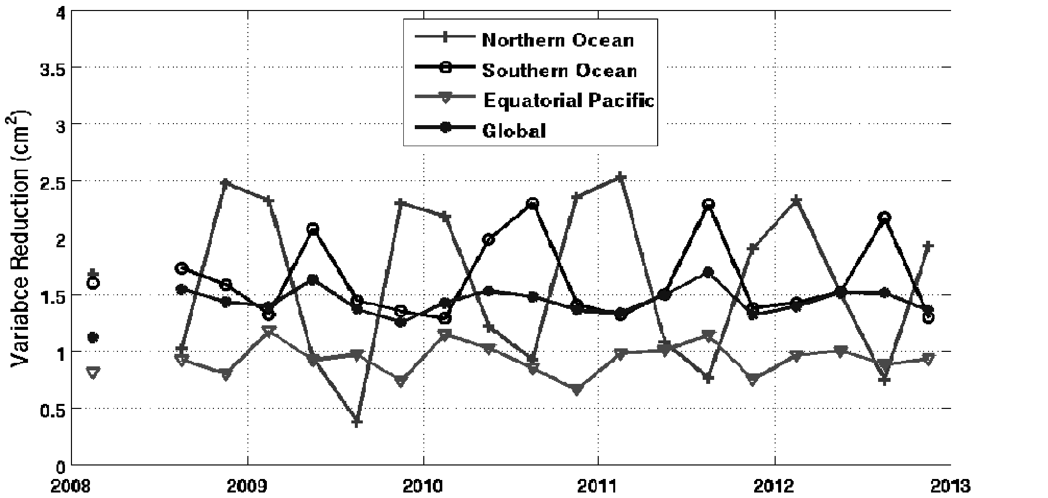
Spatial/temporal var. reduction in cm^2 (positive values indicating performance gain) obtained using avg 3DSPSSB(U10,Hs,tm02) model relative to a 2D CLSSSB(best up to date)

(a) Temporal/Latitude variation; (b) Temporal variation in selected regions and (c) the 2002 map

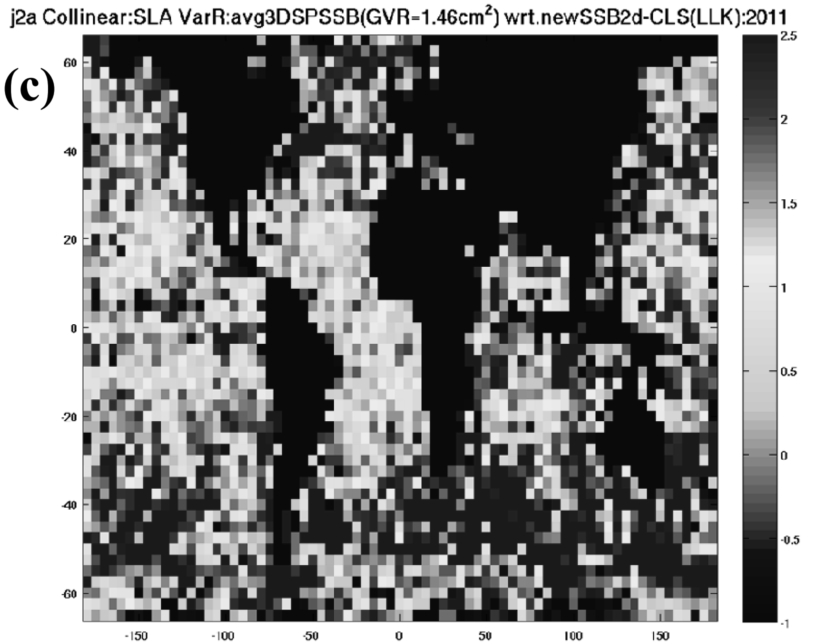
(a)



(b)



(c)

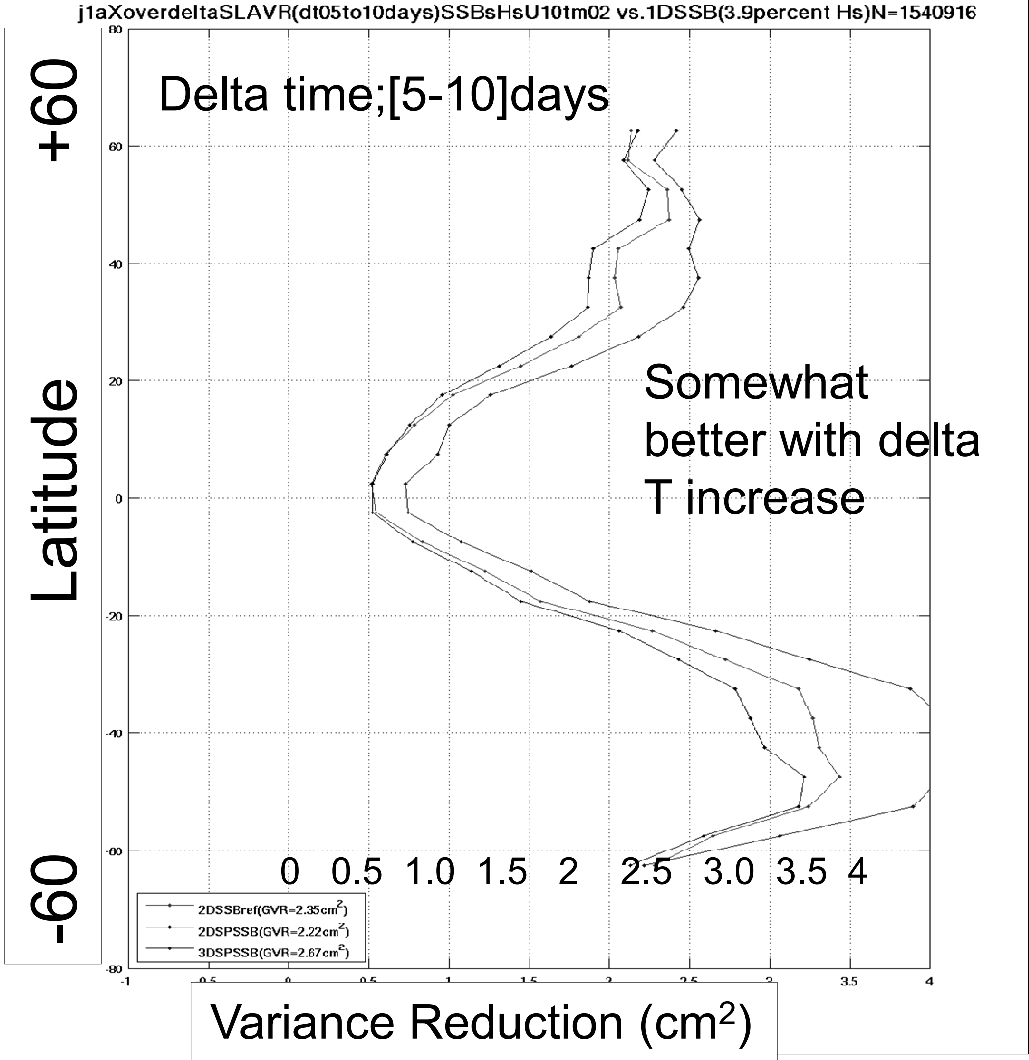


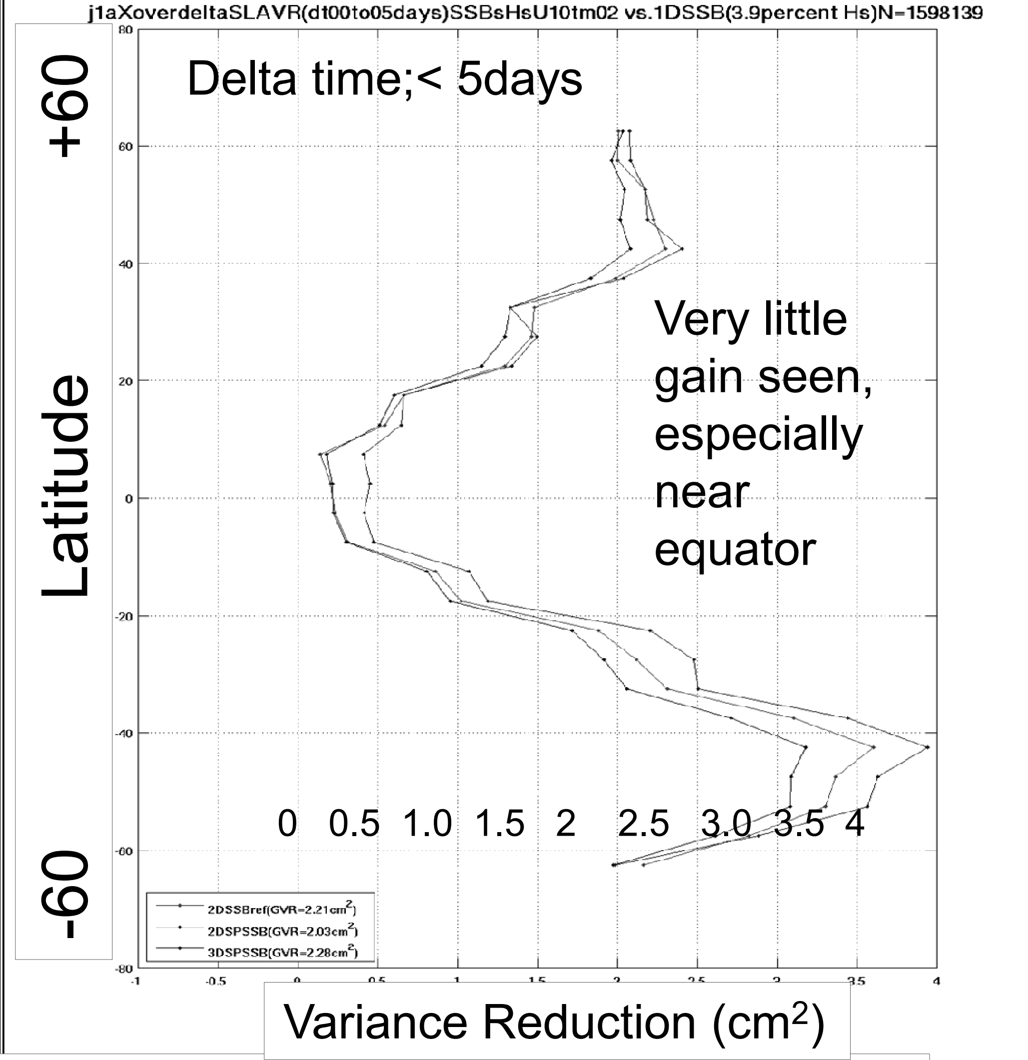
The patterns are all very similar to J1a

Now crossovers

J1: crossover difference, SSHA Variance Reduction, obtained using the 2D/ 3D SSBs relative to a 1DSSB

(positives indicate performance gain)





Black lies : Variance Reduction: 2DSPSSB vs. 1D SSB

Red lines: Variance Reduction: 2DCLSSSB vs. 1D SSB

Blue lines : Variance Reduction: 3DSPSSB vs. 1D SSB

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vssha0: var[(ssha w.o.SSB)] = total variance incl. SSB

vssha1: vssha0 –var [ssha w. SSB1d-(-3.9Hs)] = variance reduction

vssha2: vssha0 –var [ssha w. SSB2d-CLS-LK (colinear) (Best up to date)]

vssha3: vssha0 –var [ssha w. SSB2d-UNH-SP (direct)]

vssha4: vssha0 –var [ssha w. SSB3d-UNH-SP (direct) (U10, Hs, & tm01 or tm02)]

vssha5: vssha4-vssha3 = further variance reduction due to 3D model

vssha6: vssha4-vssha2 = “ “

Collinear Analysis

********* averaged SPSSB-2d/3d models built on data 2002to2008**

******* SPSSB-2d/3d models are multi-yr avg

	vssha0	vssha1	vssha2	vssha3	vssha4	vssha5	vssha6
2002 N=14918612	89.371	21.404	23.034	23.086	24.436	1.351	1.402
2003 N=14361636	98.341	20.627	22.459	22.459	24.036	1.578	1.578
2004 N=14771912	89.429	20.270	22.111	22.126	23.644	1.518	1.533
2005 N=14444116	89.682	21.675	23.398	23.402	24.897	1.494	1.498
2006 N=14416069	87.995	21.112	22.893	22.916	24.448	1.532	1.554
2007 N=15492259	91.521	21.237	23.090	23.087	24.630	1.543	1.541
2008 N=14035511	90.106	21.021	22.895	22.869	24.468	1.599	1.573

Crossover Analysis

********* averaged SPSSB-2d/3d models built on data 2002to2008**

******* SPSSB-2d/3d models are multi-yr avg

Time difference : **< 5 days** at the cross-over points of descending/ascending tracks

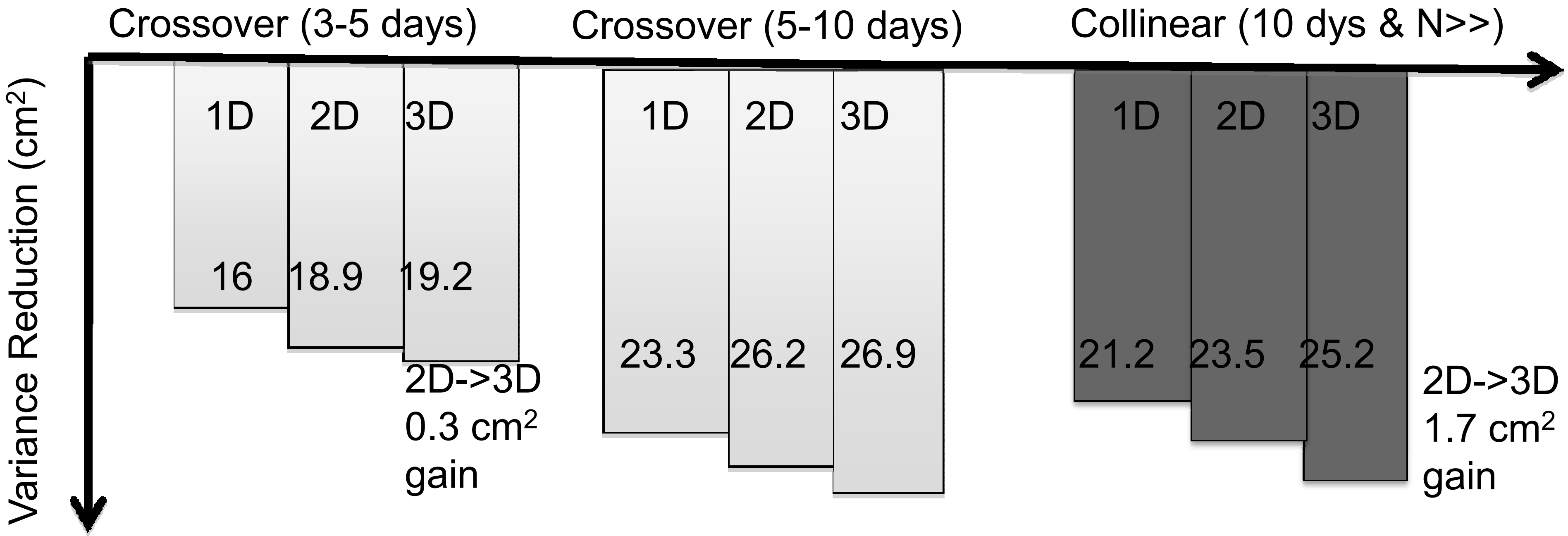
	vssha0	vssha1	vssha2	vssha3	vssha4	vssha5	
2002to2008; N=1598139	47.869	16.634	18.839	18.667	18.911	0.244	0.071
2002; N=223537	46.585	16.865	18.919	18.750	18.862	0.112	-0.057
2003; N=221250	53.137	16.072	18.280	18.136	18.329	0.193	0.048
2004; N=223833	47.499	16.866	19.071	18.939	19.145	0.206	0.074
2005; N=228262	46.524	16.993	19.092	18.921	19.185	0.265	0.094
2006; N=224434	47.293	16.640	18.860	18.683	18.970	0.287	0.110
2007; N=232612	47.079	16.664	18.990	18.784	19.106	0.321	0.115
2008; N=215863	47.131	16.239	18.591	18.389	18.708	0.319	0.117

Time difference: **5 -10 days** at the cross-over points of descending/ascending tracks

2002to2008; N=1540916	80.033	23.424	25.778	25.641	26.090	0.449	0.312
2002; N=214730	78.323	23.808	25.935	25.844	26.134	0.291	0.199
2003; N=208649	87.851	23.108	25.455	25.305	25.765	0.460	0.310
2004; N=212704	77.930	22.742	25.208	25.073	25.451	0.378	0.243
2005; N=217232	77.335	24.249	26.521	26.390	26.818	0.428	0.297
2006; N=212638	78.925	23.325	25.658	25.550	26.006	0.456	0.348
2007; N=224097	81.383	23.688	26.186	26.022	26.586	0.564	0.400
2008; N=203277	79.619	23.110	25.650	25.462	26.062	0.600	0.412

NOTE: Big decrease for 1D SSB model explained variance between collinear and (<5day crossover datasets (~21 vs. 16 cm^2); we attribute to less SWH decorrelation at 3 vs. 10 days

SSB metrics - single global measures for crossovers vs. collinear from 1D-> 3D



Conclude:

- Crossovers are masking SSB model differences due to SWH & wave period decorrelation time scales that exceed 3-5 days
- **Cleanest metric for SSB model tests is collinear**

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Summary on metrics: J1/J2

Metric example shows 3D SSB models consistently show the best overall performance for all the VR measures. Specifically:

- **Direct SLA data evaluation** shows that in terms of variance reduction the 3D SSB outperforms 2D SSB in the range of **0.5-1.5cm^2.** There is spatial variation (noisier) in the observed zonal variance reduction that is likely tied to cross-correlation between dynamic topography (i.e. ocean signal) and sea state/wind, but the temporal pattern in variance reduction does appear more or less. Thus, this evaluation test may be not related only to SSB model performance.

- **Collinear difference data evaluation** shows the largest absolute variance reduction measures for 3D, with 3D SSB outperforming 2D SSB in the range of **1-2.5cm^2**, very stable from year to year and in zonal evaluation. We view this as the best evaluation test even though a 10 day difference may yet be sub-optimal (see crossovers below)

- **Crossover difference data evaluation** shows much less variance reduction gain in the 3D vs. 2D evaluation. In this test, two crossover time difference criteria, [0-5] and [5-10] day are attempted. VR gain in the 5-10 day case, times <5 days are perhaps long enough for wind to de-correlate, but not sea state. Thus this test is sub-optimal for evaluating SSB performance. Further evidence is the relative decrease in 1D SSB reduction seen between crossover and collinear SSB evaluation results. The crossover test might be useful for many geophysical corrections, but it is a relative measure at best for sea state dependent SSB performance testing.

AltiKa vs. J2Ku SSB

First spaceborne altimeter at 36 GHZ

Some ground work in advance for EMB/SSB at Ka:

Melville,W. K., R. H. Stewart,W. C. Keller, J. A. Kong, D. V. Arnold, A. T. Jessup, M. R. Loewen, and A. M. Slinn (1991), Measurements of electromagnetic bias in radar altimetry.

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., D. W. Hancock, D. E. Hines, and J. E. Kenney (1984), Electromagnetic bias of 36-GHz radar altimeter measurements of MSL, Mar. Geod.

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

AltiKa

Field work suggested 1% (Walsh91) to 3% (V2005) SSB at Ka

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?)

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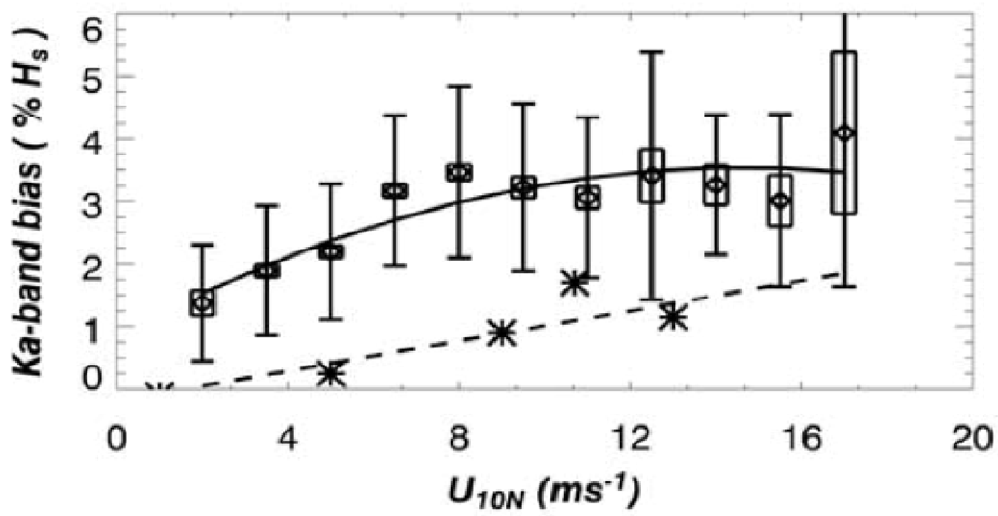
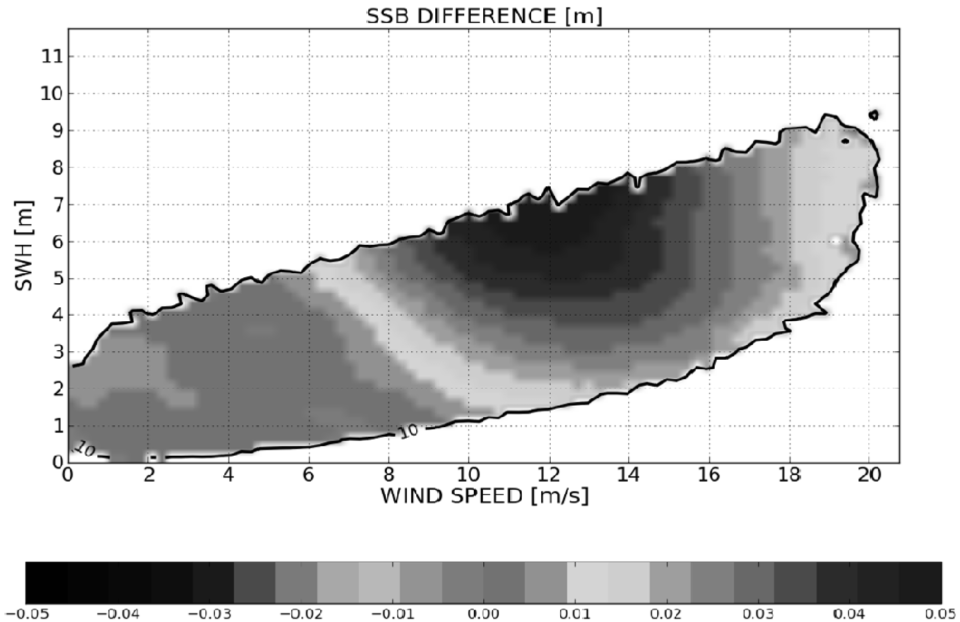


Figure 4. Relative radar bias measurements versus wind speed. The symbols are the observed relative electromagnetic bias (β_r) for a Ka-band radar. Points represent averages over 1.5 m s^{-1} wind speed bins and the whisker plot provides 50% and 95% confidence intervals. The solid curve represents a quadratic fit through the data. The lower curve (dashed line) represents a linear model obtained from the Ka-band data (∗) of *Walsh et al.* [1991].

Ku- vs. Ka-band SSB, main difference at wind > 8 m/s

AltiKa vs. Jason-2 SSB (Tran poster)
High wind speed difference (> U= 8m/s)
Ku > Ka *O*(2-4 cm) at 2-4 m = ~0.5-1%



Aircraft and tower EM bias data
Melville et al. 2004 (Ku)
Vandemark et al. 2005 (Ka)

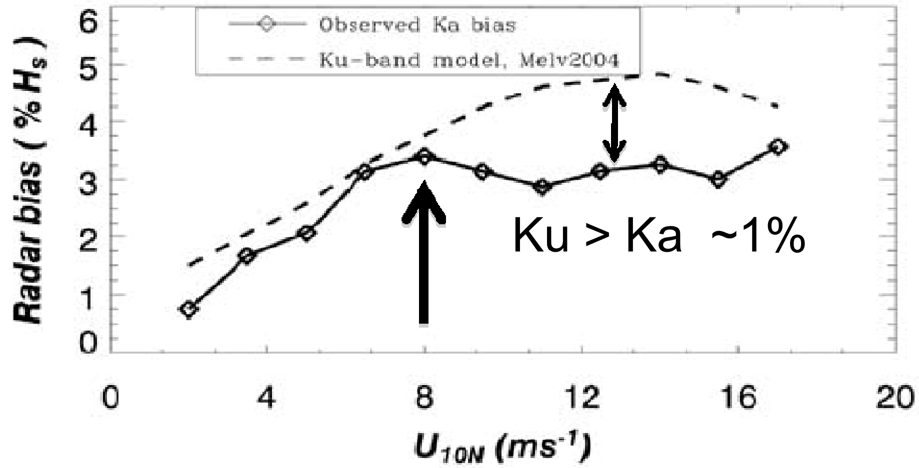


Figure 8. Ka-band bias results as seen in Figure 4 and experiment-derived Ku-band model results using equation (16) of *Melville et al.* [2004].

- Good accord with observed relative 1% EM bias difference
- Physical explanation? – perhaps hydrodynamics of bound cm-scale waves at high winds (V et al., 2005)

Next steps

• Paper in preparation to document details related to multi-mission SSB modeling and verification incl. latest J2 SSB model from CLS

• Models being applied & evaluated under JPL/Measures (B. Beckley)

• Wave model datasets for 1993- present
- 1990 – 2013 Ifremer-Global CFSR run
- Discussions with IFREMER and Meteo-France re: wave model data for 2014-forward = MFWAM

• Additional missions: T/P side A & B improvements?, J3, 35-day missions

• TBD – Bookkeeping to archive/manage SSB models and documentation for OSTST at UNH

Review: SSB collinear difference method

Along-track collinear differencing SSB model approach	
Advantages	Disadvantages
• 10 day difference cancels time invariant as well as small and slowly (> 20 day) time varying contributions to ΔSSHA • Ability to develop large drift-free training datasets using multiple years of measurements • Much larger spatial and data domain sample population than for the crossover differencing dataset • 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	• 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 • Differencing approach imposes significant uncertainty (5-10 mm) in the absolute single bias or shift value for each given P or NP solution • Requires/assumes all SSHA variation in 10 days is solely due to SSB • Assumes linearity or at least a continuous derivative in order to work in difference space • Potential issue of incongruous NP solutions if one reverse the differencing process, T12 ≠ T21

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