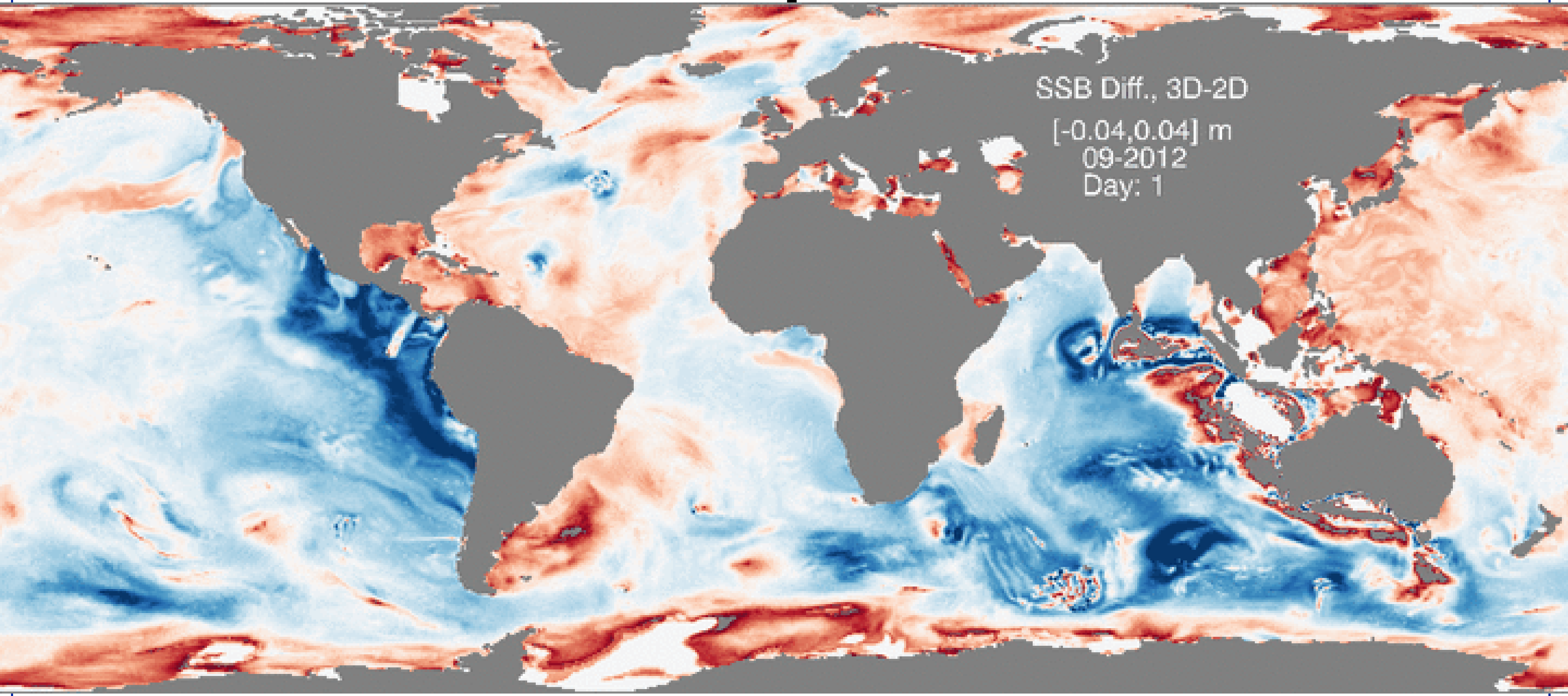
# Assessing sea state bias correction models for differing frequencies and missions

D. Vandemark[1], H. Feng[1], N. Tran[2] , B. Chapron[3]

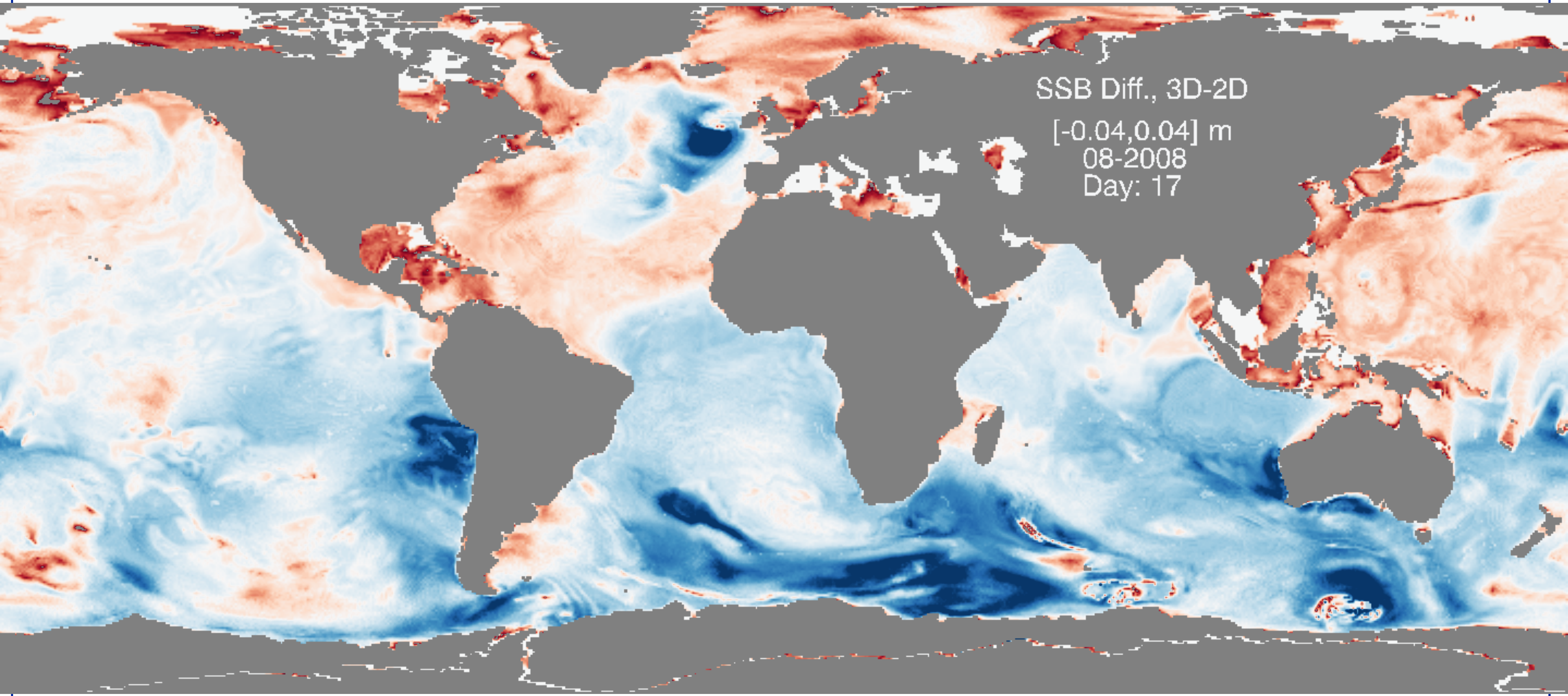
[1]*University of New Hampshire, Durham, NH*
[2]*CLS / Space Oceanography Division, Ramonville St-Agne, France*
[3]*IFREMER / Centre de Brest, Plouzane, France*

# 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: 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

# Outline

- Revisit of 2D sea state bias model approaches to support next steps
- Cross mission comparisons?
- Ka-band  - AltiKA
- Conclusions and future work

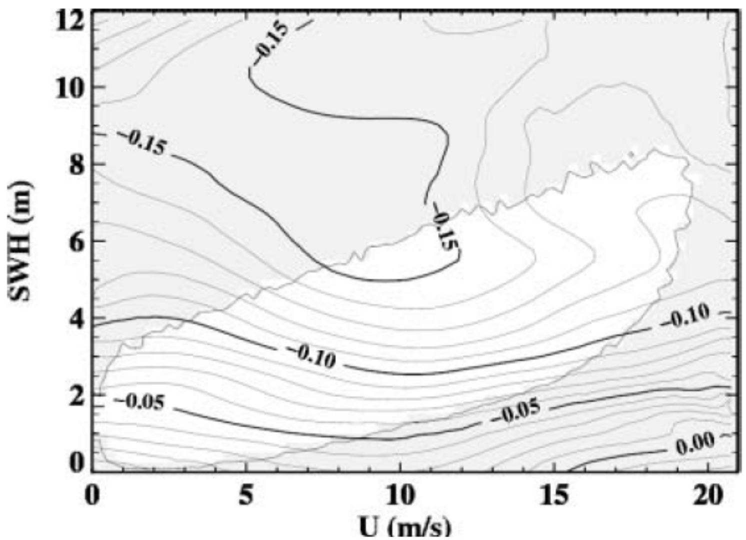
# Step back to 2D models: objectives for optimal ssb

- 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

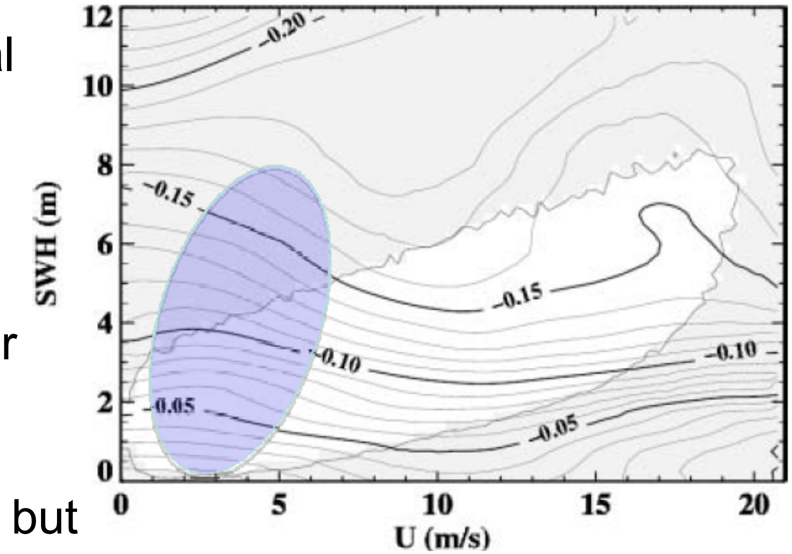
T/P Side A



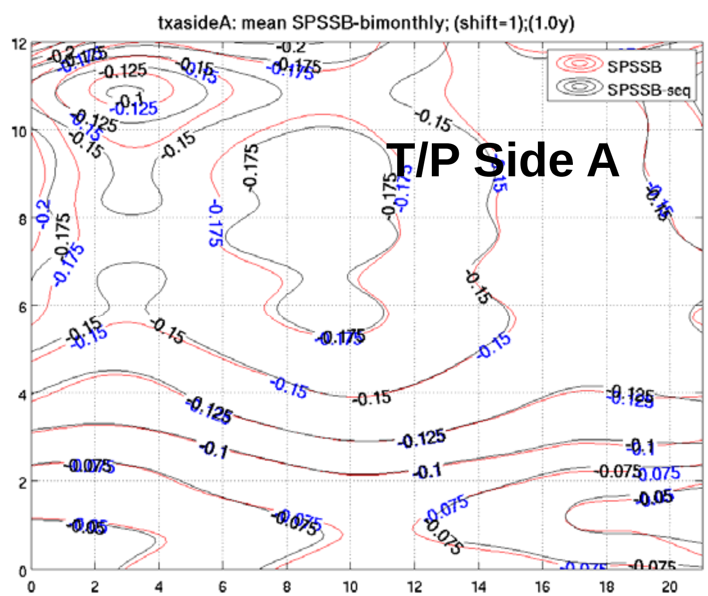

Tran et al 2010 Modified NP LLK

Collinear

T/P Side B

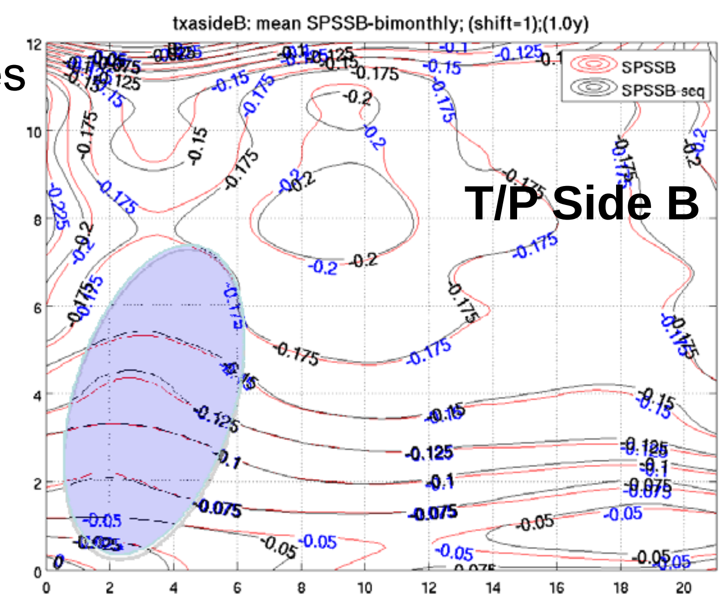



Close, but cm-scale differences




This study NP Spline

Direct



# 2D SSB collinear method revisit

| 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<br>• Ability to develop large drift-free training datasets using multiple years of measurements<br>• Much larger spatial and data domain sample population than for the crossover differencing dataset<br>• 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<br>• Differencing approach imposes significant uncertainty (5-10 mm) in the absolute single bias or shift value for each given P or NP solution<br>• Requires/assumes all SSHA variation in 10 days is solely due to SSB<br>• Assumes linearity or at least a continuous derivative in order to work in difference space<br>• 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

# SSB – collinear dilemma of sorts

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

$$r_{t1} - r_{t2} \neq r_{t2} - r_{t1}$$

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

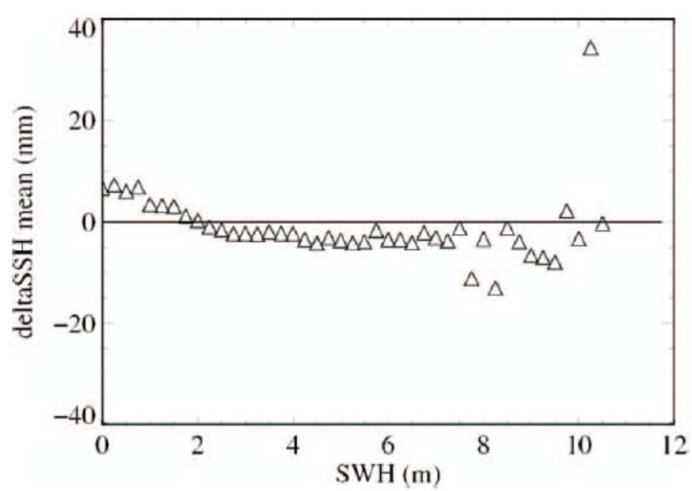



**Figure 2.** Differences of bin-averaged ΔSSH computed with respect to SWH measured at time $t_1$ and at time $t_2$, respectively.

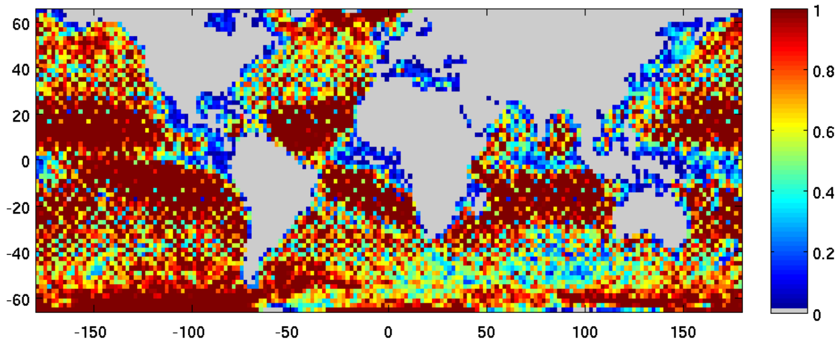
Observed the same for T/P

Solution was to create two NP SSB models and average them

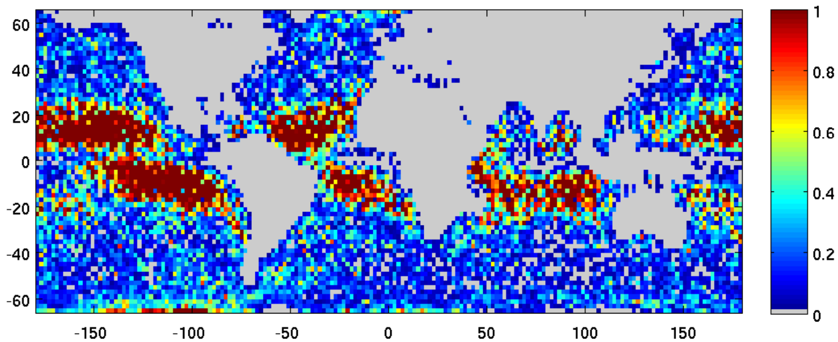
GDR 'standard'

# 2D SSB collinear method revisit - sampling

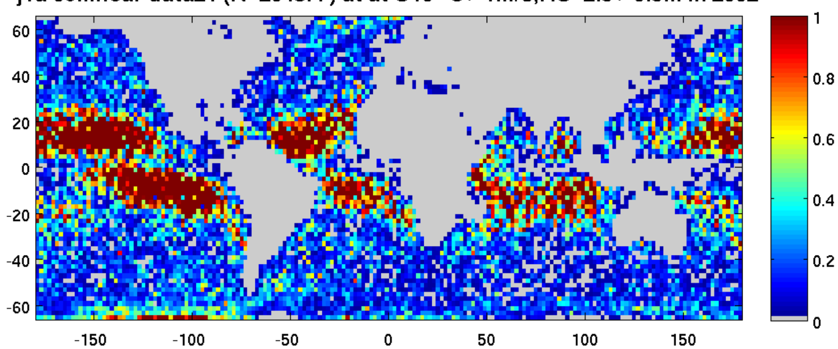
j1a direct data (N=1771639) at at U10 =8+-1m/s,HS=2.5+-0.5m in 2002



j1a collinear data12 (N=264520) at at U10 =8+-1m/s,HS=2.5+-0.5m in 2002



j1a collinear data21 (N=264877) at at U10 =8+-1m/s,HS=2.5+-0.5m in 2002



Example for mode of 2D pdf with maximum data

ONE YEAR OF JASON DATA

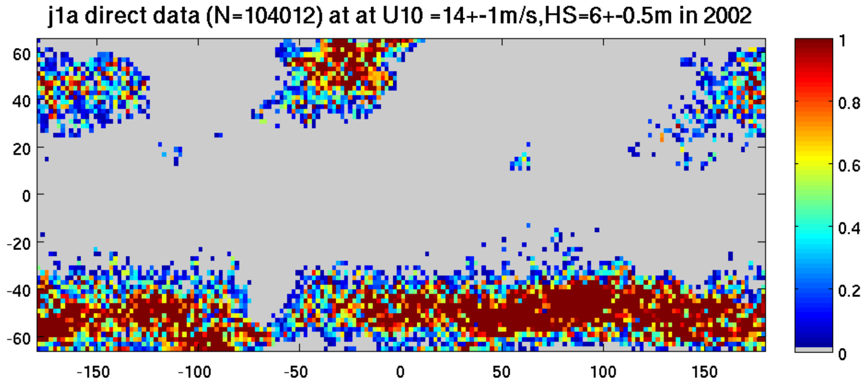
UPPER: SWH, U pair [2.5,8]

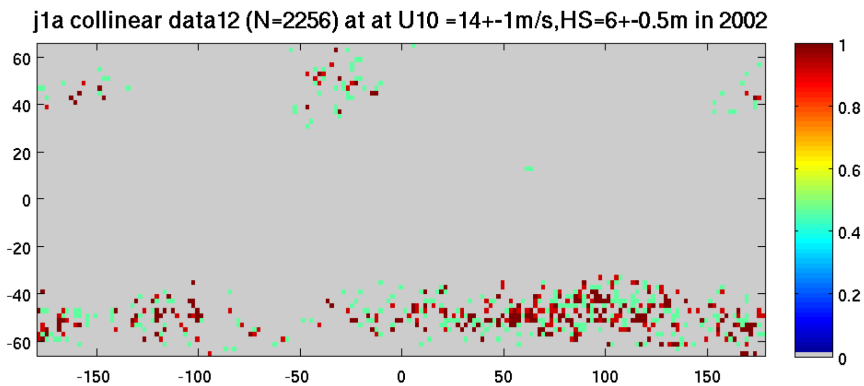
MIDDLE: ΔSWH, ΔU pair (t2-t1)

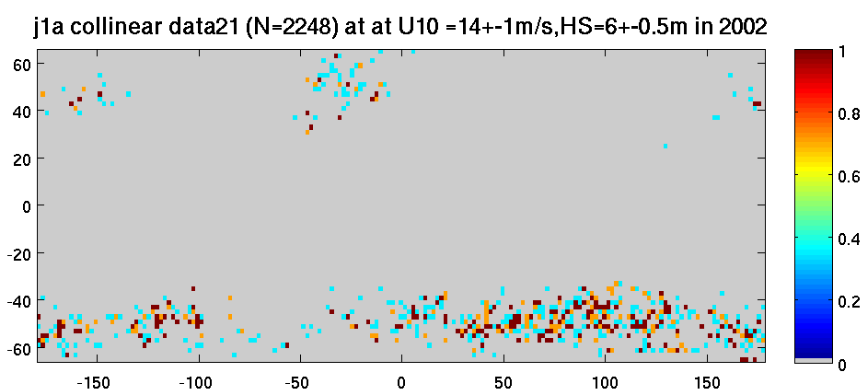
LOWER: ΔSWH, ΔU pair (t1-t2)

- spatial differences apparent
- normalized population differences from upper are obvious

# 2D SSB collinear method revisited - sampling




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

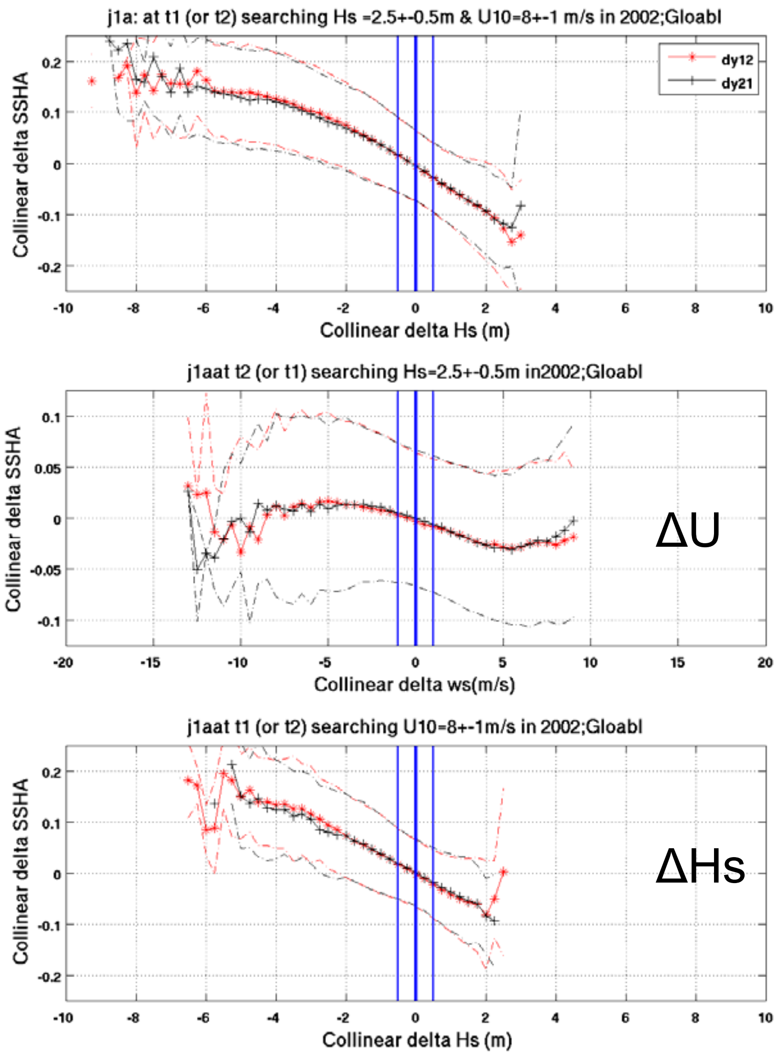


University of New Hampshire

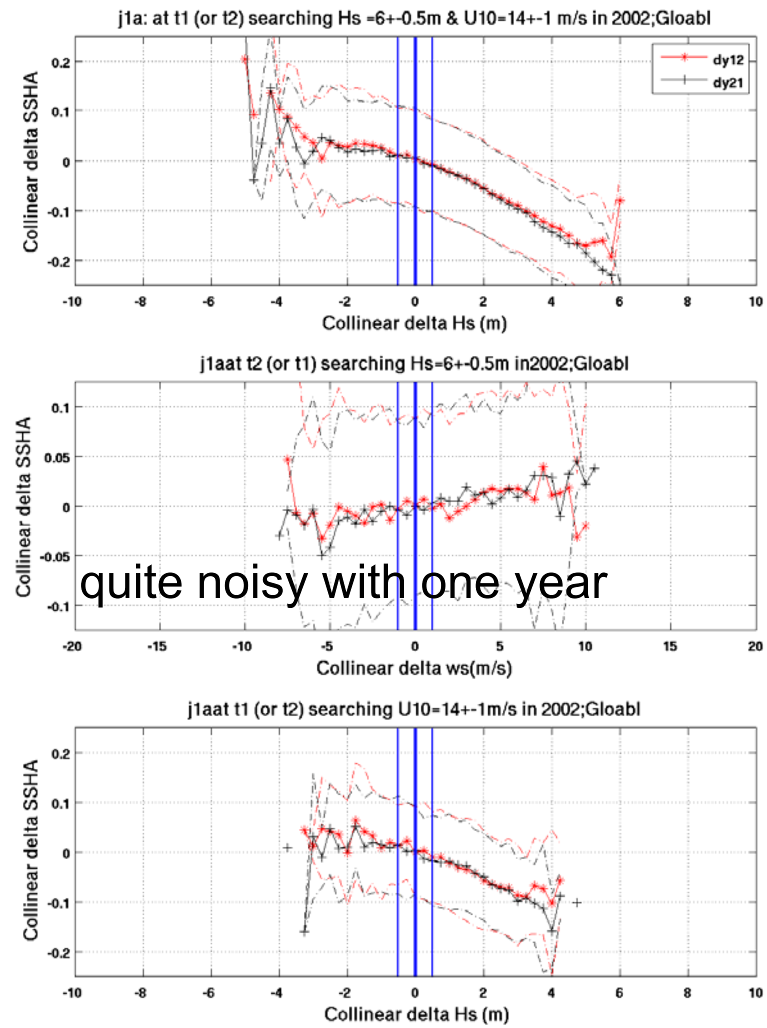
# 2D SSB collinear method revisited - sampling

- 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

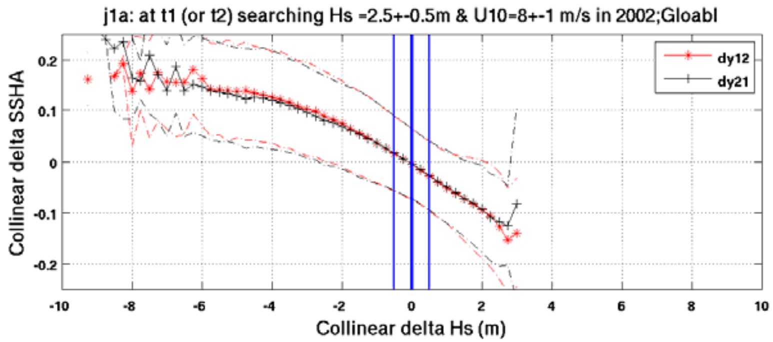


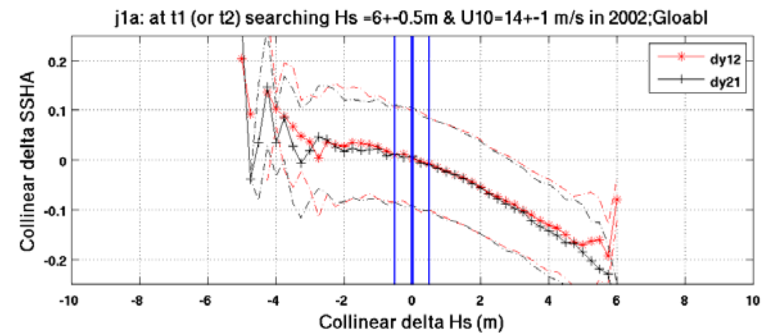
Conclusions re: collinear:

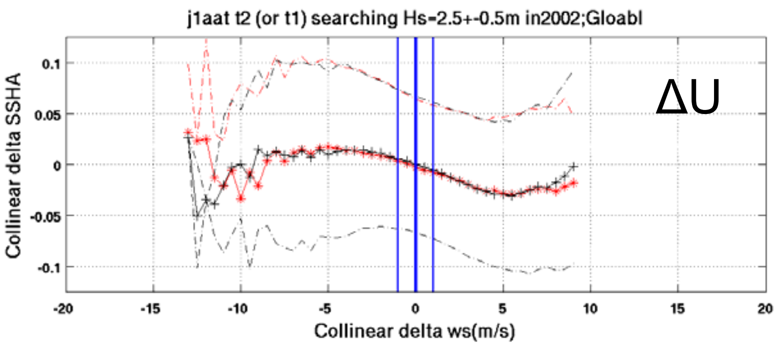
- noisy, sparse data bins will lead to NP SSB smoothing
- we can’t yet duplicate the need for this modified/averaged collinear SSB model
- geolocation not equivalent with direct

Hs = 2.5, U= 8, data rich

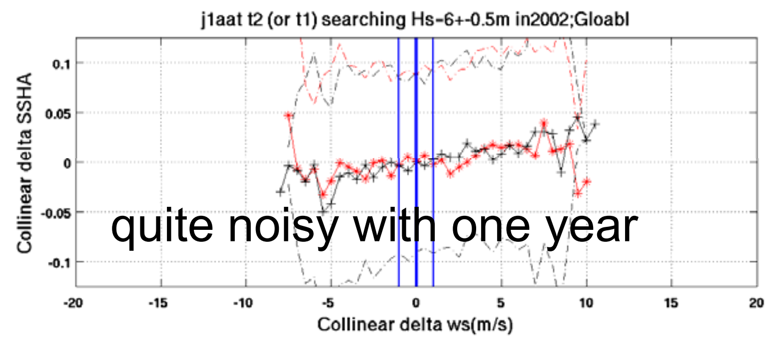
Hs = 6, U= 14



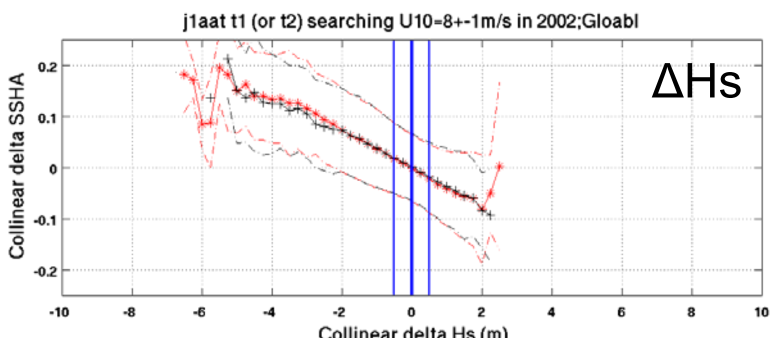



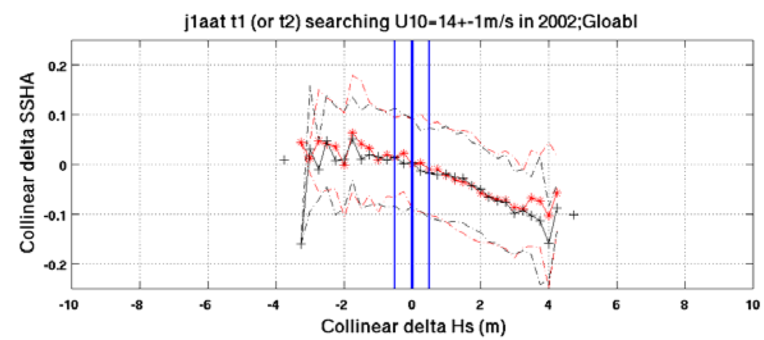

ΔU




quite noisy with one year



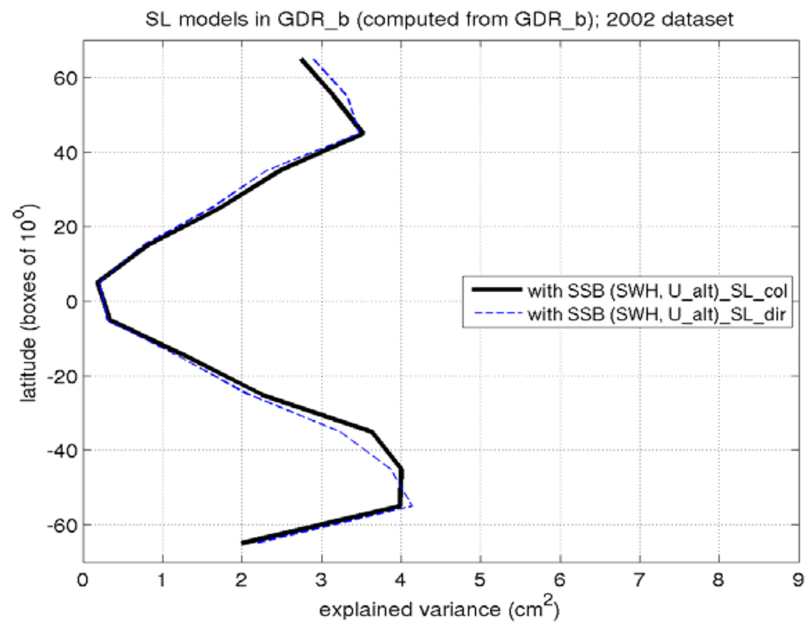

ΔHs



# 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 ΔSSH variance reduction gain from CLS 2D SSB models (BM1 serves as benchmark):
  - 2.45 cm² (collinear solution)
  - 2.40 cm² (direct solution)

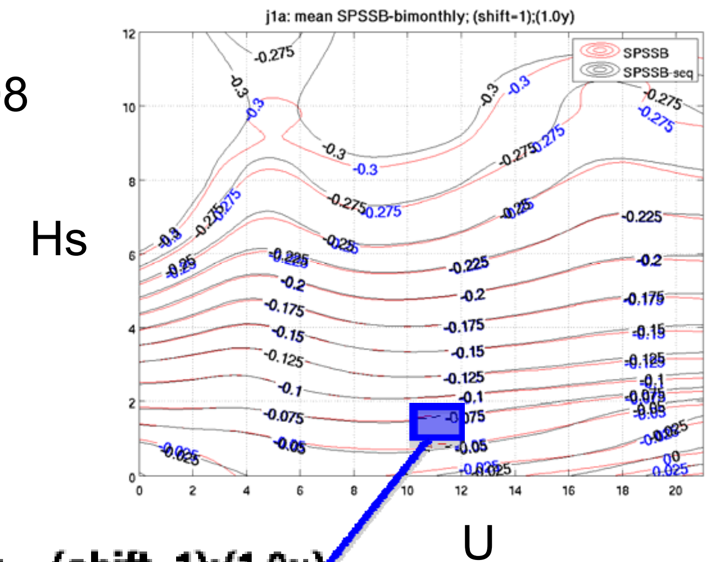


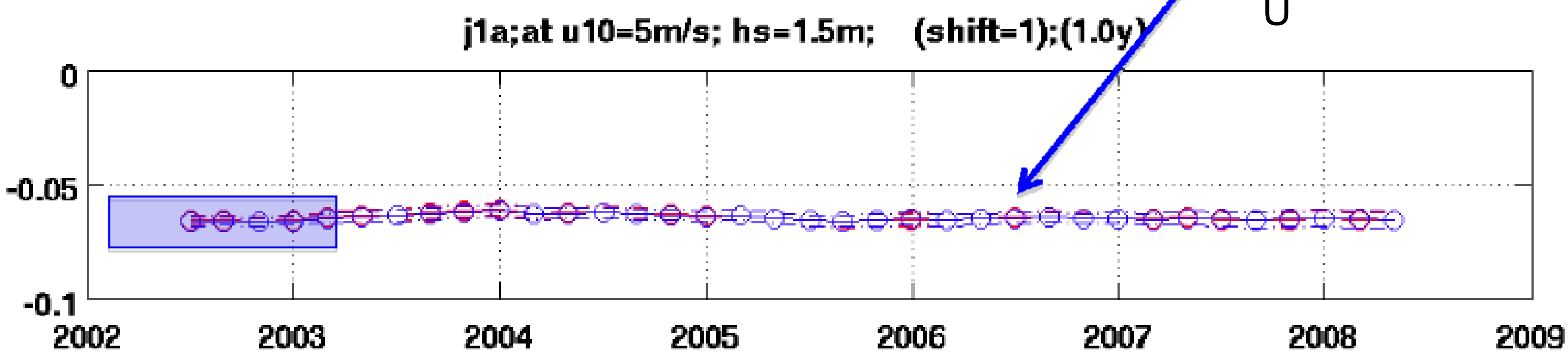
# Addressing uncertainty in direct SSB determination, Jason-1 example

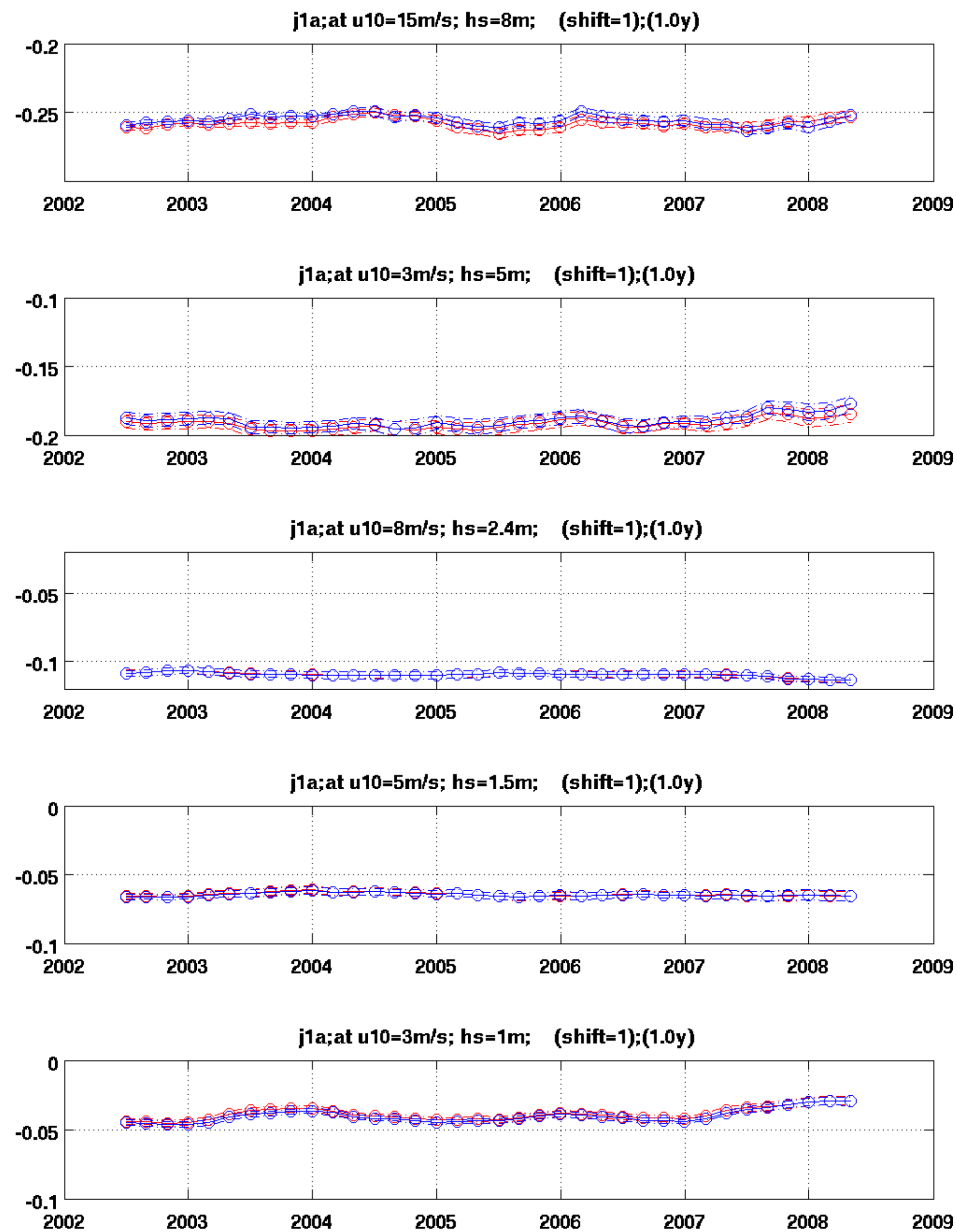
N one year SSB solutions, bimonthly 2002-2008

Example SSB for one bin in the 2D space

Temporal variation << 1 cm over 36 solutions



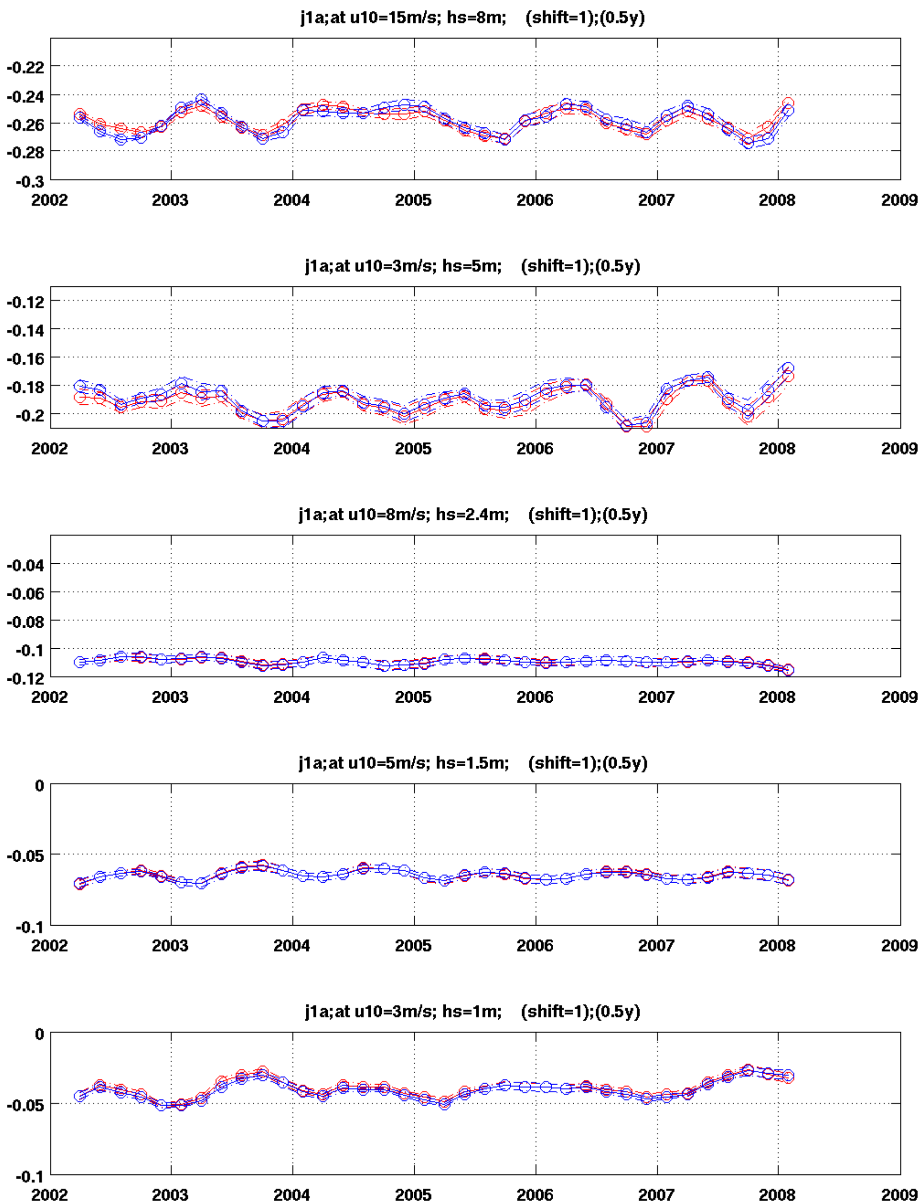



Sliding one year SSB avgs.

Five different bins

Small time variablity in some data poor bins

Can compute STD in each




Sliding **6 month** year SSB avgs.

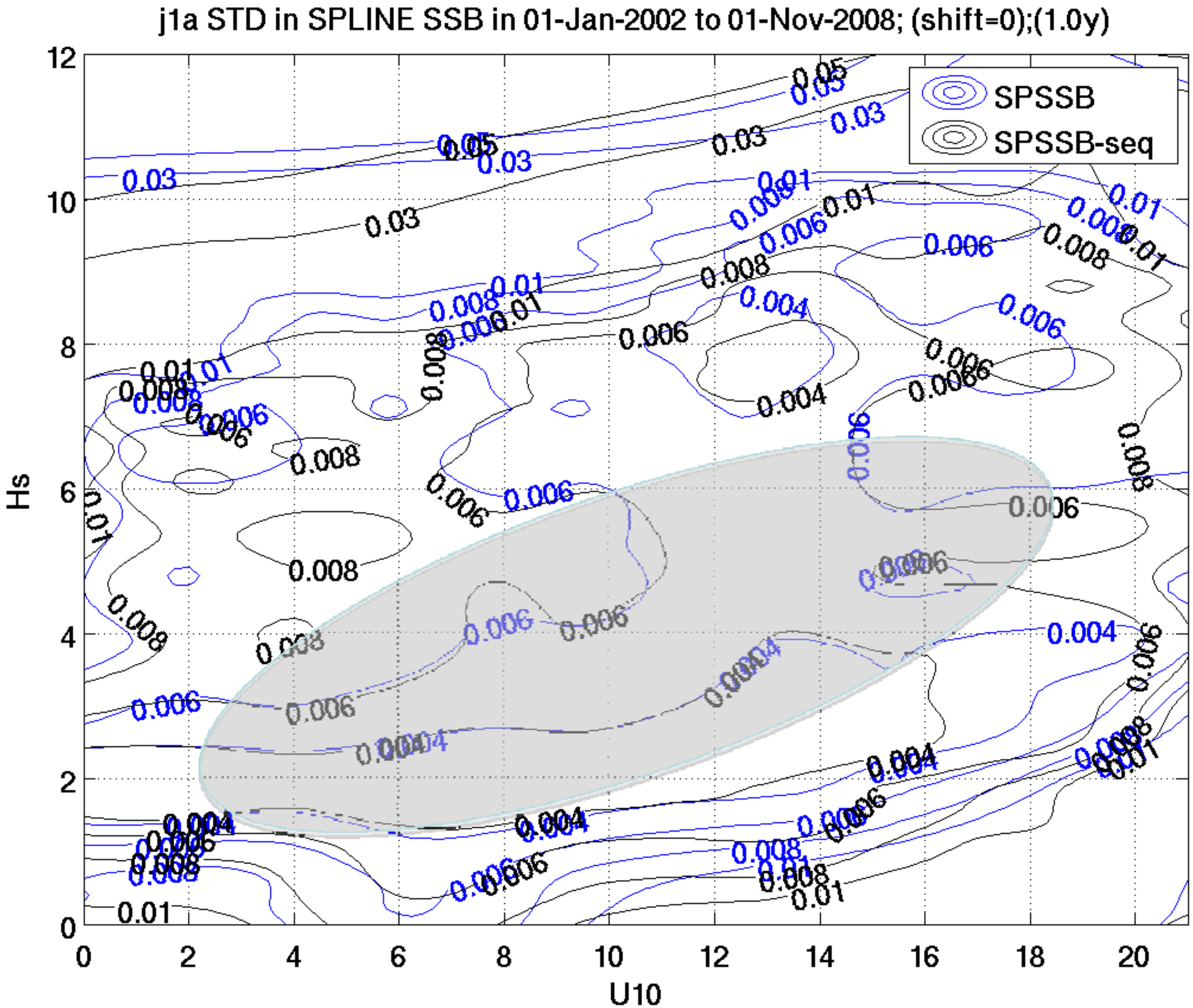
Five different bins

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

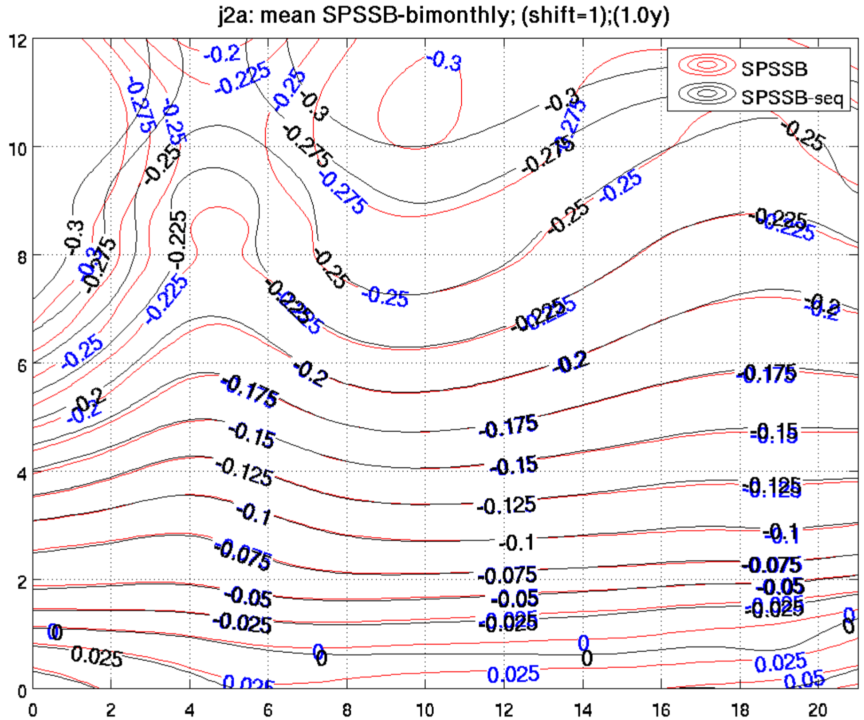
Jason-1 SSB standard deviation estimate < 6 mm in data rich area, < 8 mm
STD_error lower when considering DOF of at least 7

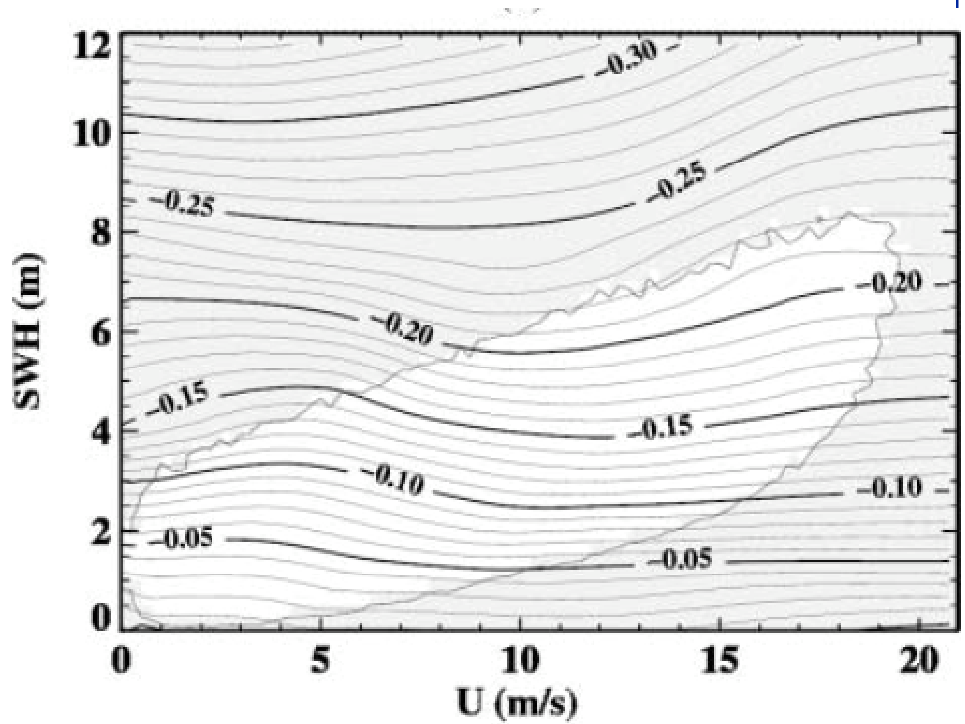



BLUE – all data

BLACK – subset to equally weight data geospatially

# Jason-2 2D SSB, direct vs. collinear




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

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

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

.... and series of SOWEX Ed Walsh Scanning radar altimeter papers for NRCS data

# 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?)



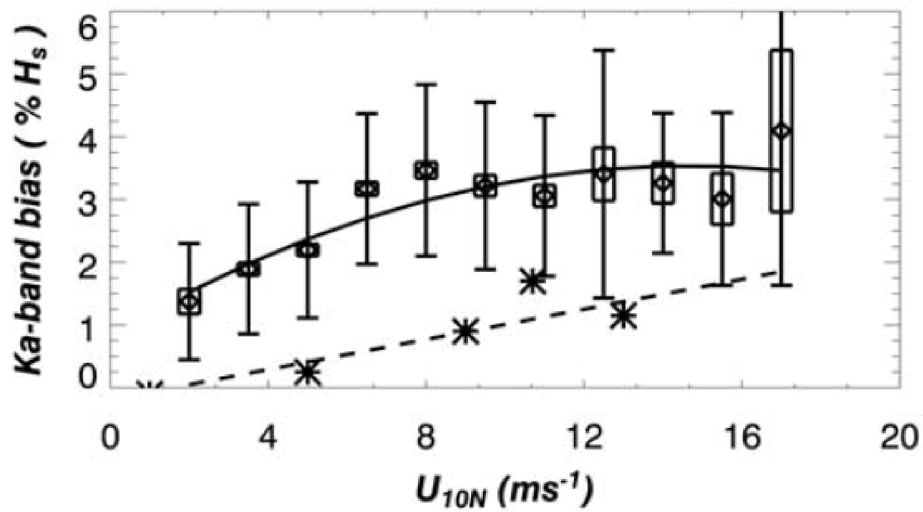
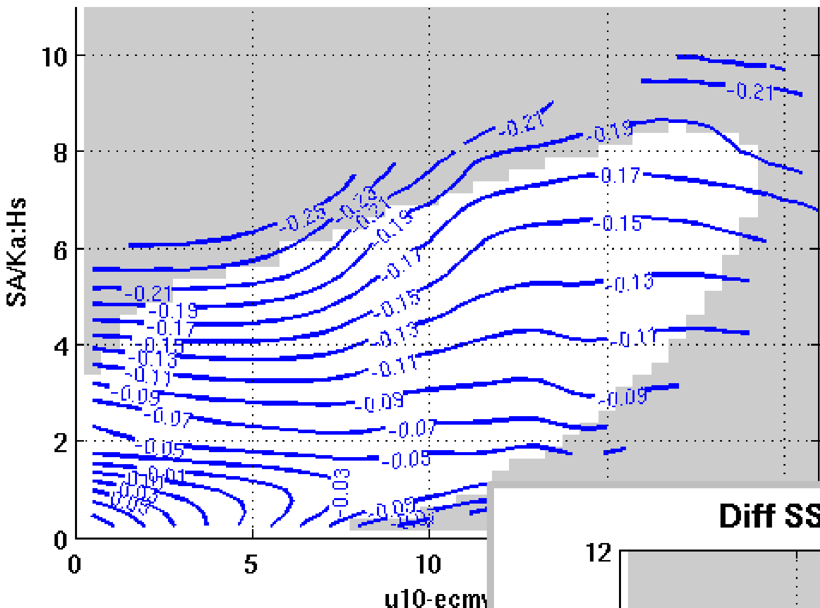


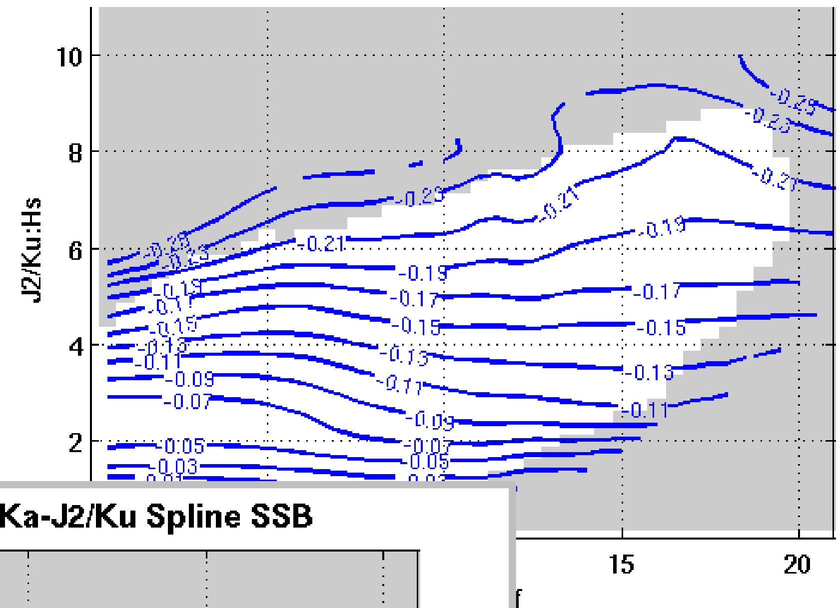

**Figure 4.** Relative radar bias measurements versus wind speed. The symbols are the observed relative electromagnetic bias ($\beta_t$) for a Ka-band radar. Points represent averages over 1.5 m $s^{-1}$ wind speed bins and the whisker plot provides 50% and 95% confidence intervals. The solid curve represents 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].

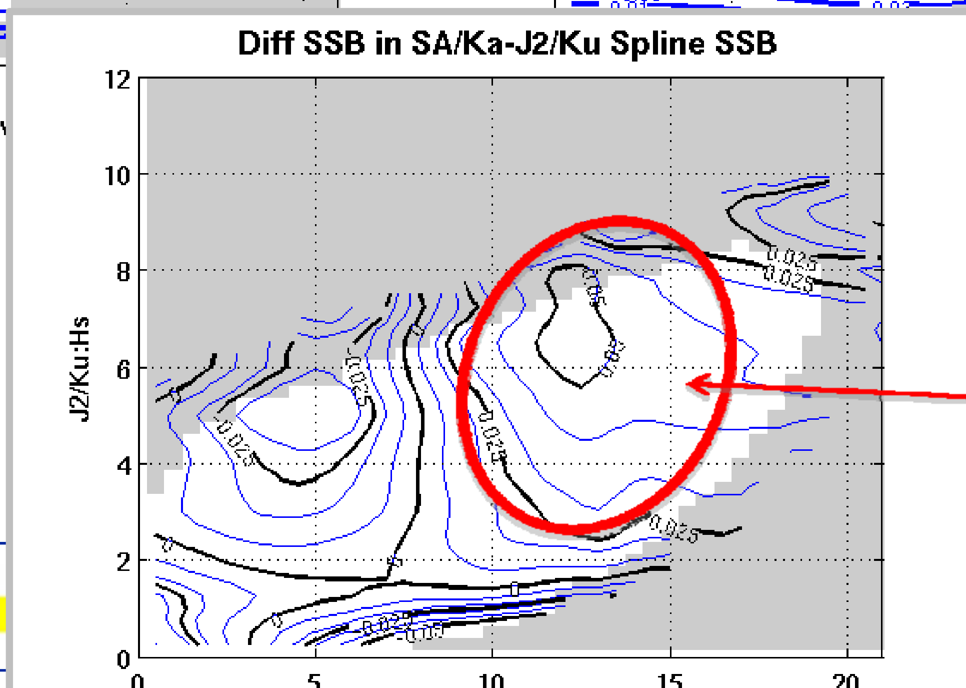
# SSB AltiKa and comparison with Jason-2

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



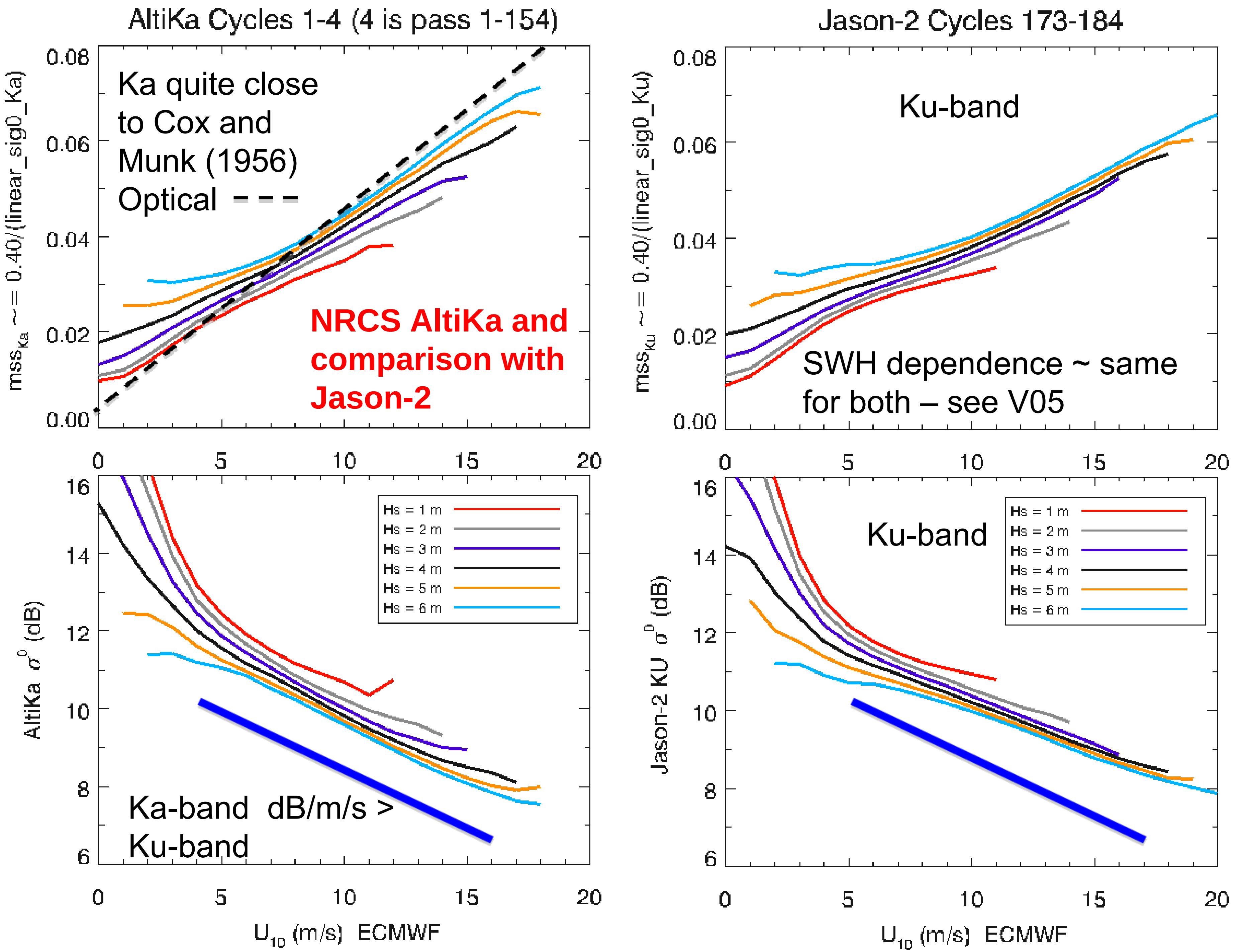




In general
SSB_Ka ~=
SSB_Ku ~ 3 %

Accords with V05

AltiKa SSB >
Jason by 2-5 cm
(0.5-1%) at U >
10 m/s

Agrees with CLS


AltiKa Cycles 1-4 (4 is pass 1-154)
Jason-2 Cycles 173-184
Ka quite close to Cox and Munk (1956) Optical
NRCS AltiKa and comparison with Jason-2
Ku-band
SWH dependence ~ same for both – see V05
$mss_{Ka}$ ~= 0.40/(linear_sig0_Ka)
$mss_{Ku}$ ~= 0.40/(linear_sig0_Ku)
0.00
0.02
0.04
0.06
0.08
0
5
10
15
20
16
14
12
10
8
6
AltiKa $\sigma^0$ (dB)
Jason-2 KU $\sigma^0$ (dB)
Hs = 1 m
Hs = 2 m
Hs = 3 m
Hs = 4 m
Hs = 5 m
Hs = 6 m
Ka-band dB/m/s > Ku-band
Ku-band
$U_{10}$ (m/s) ECMWF
$U_{10}$ (m/s) ECMWF

# 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

We wish to acknowledge NASA OSTST and NASA Measures funding support