Hybrid Sea–state Bias Models and Their Impact on Sea Level Change Studies

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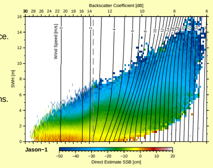
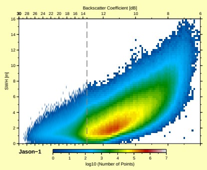
Hybrid SSB Model Formation (Jason–1)

Form direct estimate of SSB from height residuals

- Apply all geophysical corrections **except** SSB.
- Compute height residuals relative to CLS MSS01 mean sea surface.
- Average residuals in 0.10 dB by 0.25 m backscatter/wave bins.
- Height residuals field shows underlying SSB (bias removed in graphs).
- SSB can be estimated with small amount of data (like at fringes).
- Note that horizontal scale is different on left and right side of graphs.





Relationship to wind speed

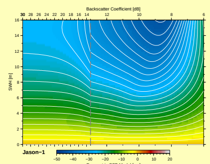
- The f_1 two-parameter wind speed algorithm [*Gourrion et al., 2002*] is shown by contours.
- Note how linear trend in SWH follows lines of equal wind speed rather than equal backscatter.
- To avoid dependency on wind model and backscatter bias, we use backscatter in stead of wind speed as coordinate.

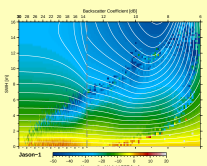
Evaluate parametric fit to direct estimates

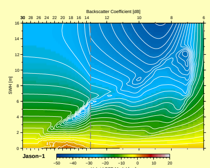
$$SSB = [a0] + SWH \times (a1 + a2 \times SWH + a3 \times U + a4 \times U^2)$$

- Weighted residuals by RMS and nr of points in bin when fitting.
- Bias coefficient, $a0$, is **not** restituted.
- Polynomial function now satisfies $SSB = 0$ when $SWH = 0$.

Altimeter	a_0	a_1	a_2	a_3	a_4
ERS-1 (OPRv6)	0.054265	−0.075043	0.001413	−0.001790	0.000098
ERS-2	0.107618	−0.068219	0.001465	−0.001701	0.000082
GFO	0.092034	−0.055742	0.002743	−0.003756	0.000153
Poseidon	0.015731	−0.062778	0.001894	−0.001194	0.000057
TOPEX (Side A)	0.012450	−0.030578	0.002776	−0.002962	0.000127
TOPEX (Side B)	0.028889	−0.032113	0.002992	−0.002780	0.000101
Jason-1	0.110106	−0.034376	0.001145	−0.001969	0.000083
Envisat	0.026530	−0.052849	0.001746	−0.001713	0.000068
Geosat (GDR)	0.701944	−0.013700	0.001617	−0.003411	0.000111
Geosat (retr.)	−0.218421	−0.028708	0.000311	−0.001748	0.000080

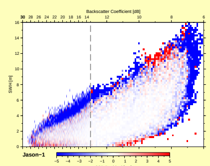






Blend direct and parametric grids to form hybrid model

- Remove BM4 from direct estimate to form SSB residuals.
- Assign zero residual to poorly covered regions.
- Smooth SSB residuals, weighting by RMS and nr of points.
- Final hybrid model is sum of smoothed residuals and BM4 (without $a0$).



Examine differences between direct and hybrid model

- Large differences along fringe (data poor regions).
- Small differences in data rich regions, ...
- **Except** occasional bands caused by discretization.

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Summary

The direct estimation of Sea State Bias (SSB) from sea height residuals [*Vandemark et al., 2002*] is extended with a parametric fitting process and a successive smoothing of the remaining residuals. This hybrid method essentially produces a non-parametric SSB model in the form of a smooth grid in a 2-dimensional space determined by Significant Wave Height (SWH) and backscatter coefficient (σ_0).

The hybrid method allows a much higher resolution than parametric models, without the disadvantage of the direct method's limited $\sigma0$/SWH range [*Labroue et al., 2004*]. The use of sea height residuals as input data allows estimation of a realistic SSB model with only a few month of data.

With state-of-the-art geophysical corrections the hybrid SSB model can be constructed with a high level of accuracy. The impact of errors in the mean sea surface model and tide models appears marginal. Errors in the ionospheric correction, which has a geographical distribution similar to wind speed and wave height, tend to leak into the SSB model.

Although SSB models for different altimeters have much in common, there are also marked differences:

- Many altimeters suffer from discretization effects in either wave height or backscatter, which subsequently show up in the SSB model.
- SSB percentages of wave height differ widely. Also the dependance on backscatter is variable, with a general tendency to flatten SSB at higher winds and waves.
- The *"young seas"* region present in the ERS SSB models, with a significantly positive SSB value.

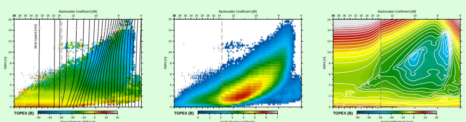
The wave height and backscatter both show trends as a function of time. Wave heights appear to drop over time, but backscatter shows trends either way. This results in trends in SSB and hence sea level that may not be "real". The different trends in SSB between TOPEX Side A and Side B, as well as between the CSR SSB model and our hybrid model, poses challenges on the estimation of sea level change to better than 0.2 mm/yr.

References

Gourrion, J., D. Vandemark, S. Bailey, B. Chapron, G. P. Gommenginger, P. G. Challenor and M. A. Srokosz, Two-parameter wind speed algorithm for Ku-band altimeters, *J. Atmos. Oceanic Technol.*, *19*, 2003-2048, 2002.

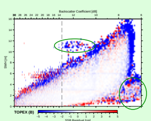
Labroue, S., P. Gaspar, J. Dorandeu, O.-Z. Zanifé, F. Mertz, P. Vincent, and D. Choquet, Non-parametric estimates of the Sea State Bias for the Jason-1 radar altimeter, *Marine Geodesy*, in press, 2004.

Vandemark, D., N. Tran, B. Beckley, B. Chapron and P. Gaspar, Direct estimation of sea state impacts on radar altimeter sea level measurements, *Geophys. Res. Lett.*, *29(24)*, 2148, 2002.



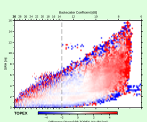
TOPEX Side A and B

- SWH bias (-3.2 cm for Side B) applied before analysis.
- Backscatter bias corrections applied.
- Odd one out, since some "tracker bias" was removed *a priori*.
- Strong discretization is wave height.
- Conspicuous disconnected data at *"young seas"* as well as *"old seas"*.
- Much smaller percentage of wave height than all other altimeters.
- Extreme flattening of SSB at high winds and above-average waves.



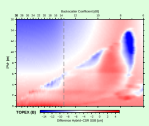
TOPEX Side A *versus* Side B

- Differences (Side A - Side B) of up to -5 cm in high wind region.
- Differences (Side A - Side B) of up to +1 cm at low wave height.
- No significant differences in most densely populated region.
- Disconnected distribution at *"young seas"* less present in Side A.



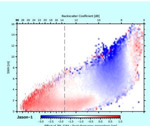
Hybrid versus CSR model

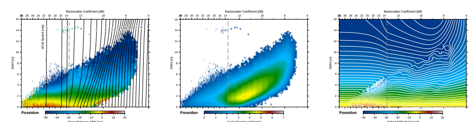
- Mean offset of about 4 cm.
- Some features poorly captured in parametric model.
- Discrepancies particualrly at low wave and high wind.



Sensitivity to choice of geophysical corrections

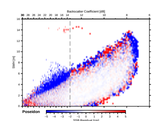
- Direct estimation technique may be sensitive to geographically correlated correction errors.
- Compare direct estimates of SSB with alternative geophysical corrections models.
- Choice of mean sea surface or tide model has virtually no impact on SSB models.
- JPL GIM ionospheric delay in stead of dual-frequency correction produces large region of significant difference over a range between –3 and +1 cm.

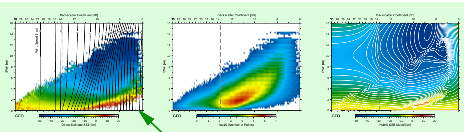




Poseidon

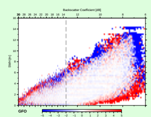
- The most classical example of SSB dependency on wind and wave.
- Very similar to Envisat, ERS-1, ERS-2 and GFO.
- Higher SWH dependancy than its successor, Jason-1.
- Poseidon: approx. 6% of SWH; Jason-1: approx. 3% of SWH.
- Minor discretization in low wind (high backscatter) region.
- *"Young seas"* area effectively edited out.





GFO

- Marked discretization in wave height.
  - Only some 20 levels of SWH in 10-Hz data.
  - Shows also up in residuals.
- Marked increase toward *"young seas"* region (high wind / low wave).
  - Effectively removed by limiting attitude from waveform.



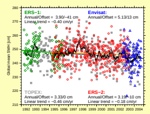
Impact of Sea State Bias on Sea Level Change Estimates

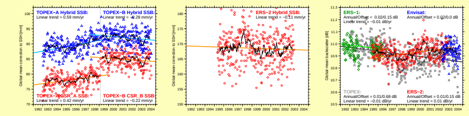
Trends of wave height and backscatter

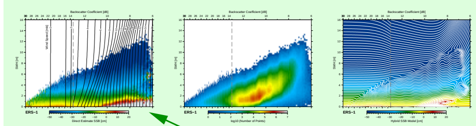
- Wave height TOPEX is corrected for degradation and Side B bias.
- Significant wave heights decrease by 2 mm/yr to 4 mm/yr.
- Backscatter coefficients change over time by –0.01 to +0.01 dB/yr.
- Offsets between various missions removed.

Impact on sea level change estimates

- **Trends of up to 0.6 mm/yr** depending on SSB model and altimeter.
- SSB is important contributor to uncertainty in sea level change.

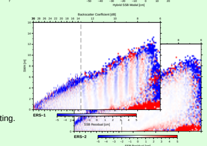


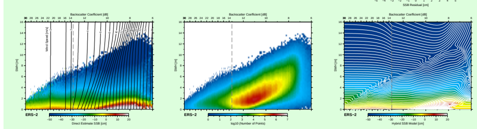


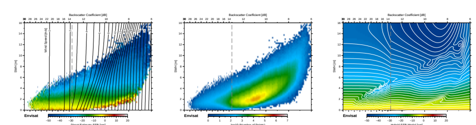


ERS-1 and ERS-2, OPR v6

- ERS-1 has large discretization in backscatter.
  - Shows also up in direct SSB estimation.
  - Somewhat smoothed out in hybrid model.
  - Not as strong in ERS-2 as in ERS-1.
- Strong positive SSB in *"young seas"* region (high wind / low wave).
  - May be caused by ice and/or rain.
  - No altimeter rain/ice flag or attitude from waveform available for editing.
  - **However,** this tendency is systematic among altimeters.

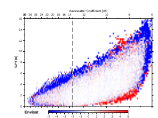






Envisat

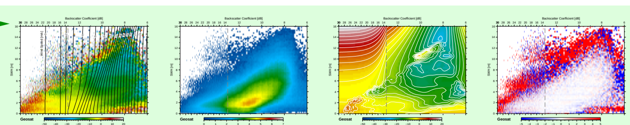
- Added 409.2 mm range bias and USO drift correction.
- Biased earlier Ku-band backscatter up by 0.65 dB to current level.
- More like Poseidon than like ERS-1 and ERS-2.
- No *"young seas"* region.
- No detectible discretization effects.
- Extremely "clean" data set.



Hot from the Press!

One reason to retrack Geosat altimeter data

Geosat (GDR)



Geosat (GDR and retracked)

- NOAA and USCD are developping retracked data for the Geosat Geodetic Mission.
- **See poster by Walter Smith**.
- Retracked significant wave heights are smoothed
  - Results in a cut-off both at the lower end (about 1 m) and higher end (about 11 m)
- Retracking removes a lot of the rogue data, particularly at high waves and low wind.
- Discretization effects are evident in the GDR data, absent in the retracked data.
- The new SSB model looks much closer to Jason-1.
- Retracked data are much *cleaner* than the GDR data.

Geosat (Retracked)