National Aeronautics and Space Administration

SEA STATE BIAS IN SATELLITE RADAR ALTIMETRY - REVISITED

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INTRODUCTION

Sea state bias (SSB) is an effect that causes sea surface height (SSH) measured with radar altimeters to be lower than the true SSH due to instrument properties and wave troughs being better reflectors of the radar signals than wave crests.
The classical way to solve for SSB is

$$SSH'_2 - SSH'_1 = (SSB_2 - SSB_1) + \varepsilon, \quad (1)$$

where 1 and 2 indicate measurements taken at time t_1 and t_2 at the same geographical location. SSH′ is the sea surface height above the ellipsoid that has not been corrected for SSB and ε is an error term that includes residual geophysical correction errors, altimetric measurement errors and dynamic topography variation between times (Gaspar et al. 2002). Equation 1 can be solved parametrically (Gaspar et al. 1994) or nonparametrically (Gaspar and Florens 1998, Gaspar et al. 2002, Labroue et al. 2004). In most studies SSB is solved as SSH'_2 - <SSH′>, where <> is a long term time mean.

Two key assumptions with this method is:

1. There are enough data that any oceanographic signal at all wave lengths and periods cancel out of the SSB estimate.
2. That <SSH′> itself has no SSB in it.

Here we explore the implications of the first assumption.

To investigate this we calculate SSB parametrically and nonparametrically using significant wave height (SWH) and wind speed (U) from altimetric measurements and SSH from ECCO2 (http://ecco2.org), a high-resolution ocean general circulation (numerical) model and ran with no data assimilation. Since SSH comes from a model it has no SSB except for random noise. We will estimate SSB by using the difference between SSH'_2 from a time mean ("Direct" method) and from collinear consecutive cycle differences (CCD). Since CCD has a short time period (~10 days, the time difference between cycles) most oceanographic signals (ENSO, etc.) cancel out of SSH'_2-SSH'_1, the Direct method assumes these signals will cancel out in the mean.

FIGURES

Figure 1. Correlation of SWH vs. SSH for CCD.

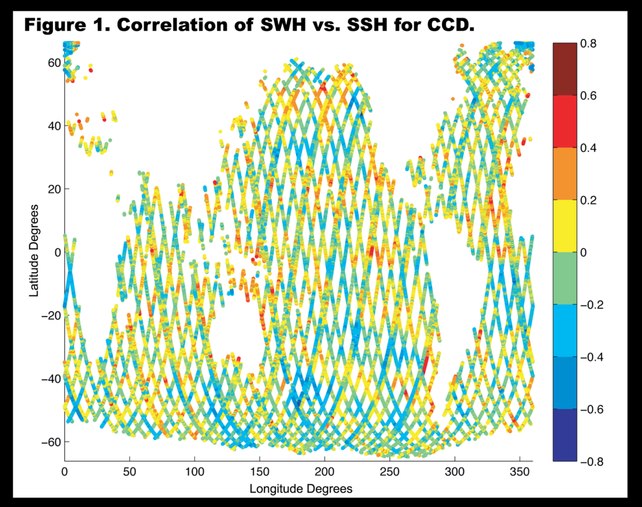


Figure 2. Correlation of SWH vs. SSH for Direct.

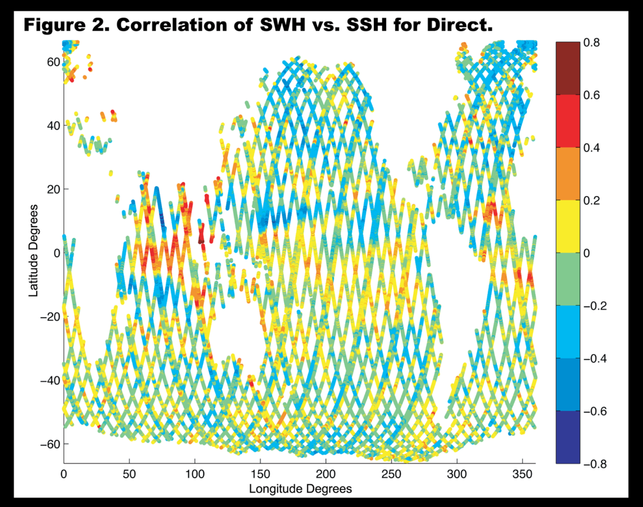


Figure 5. SSB Direct nonparametric solution in millimeters (a) and log of the amount of points used (b).

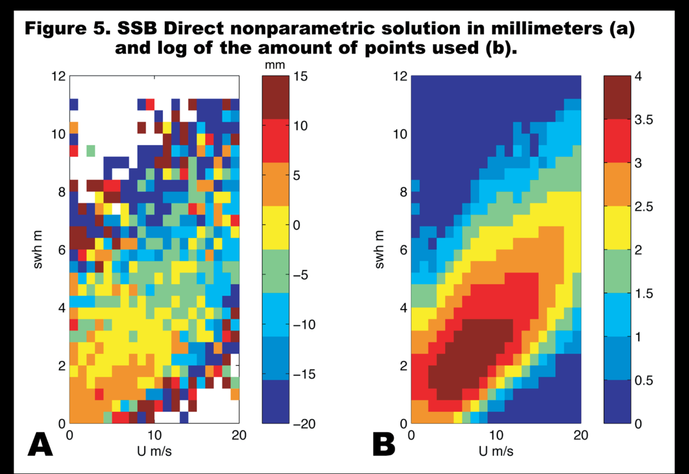


Figure 3. SSB CCD parametric solution in millimeters.

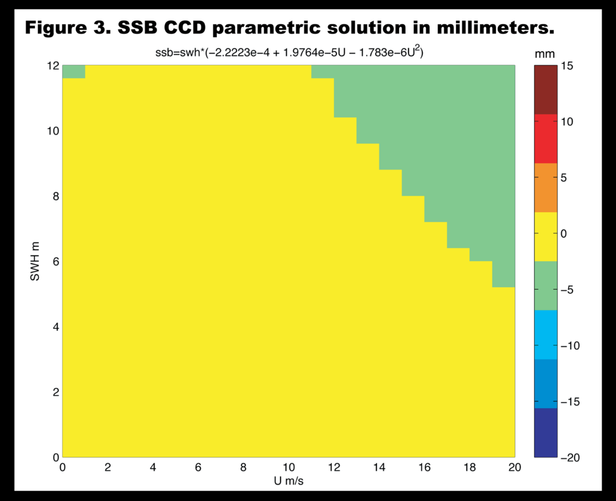


Figure 4. SSSB Direct parametric solution in millimeters.

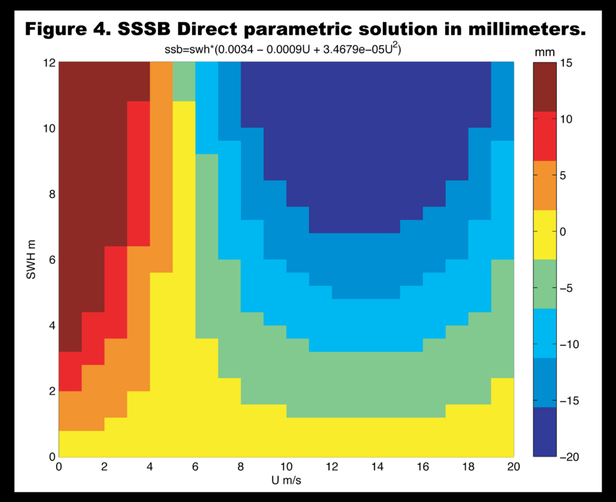
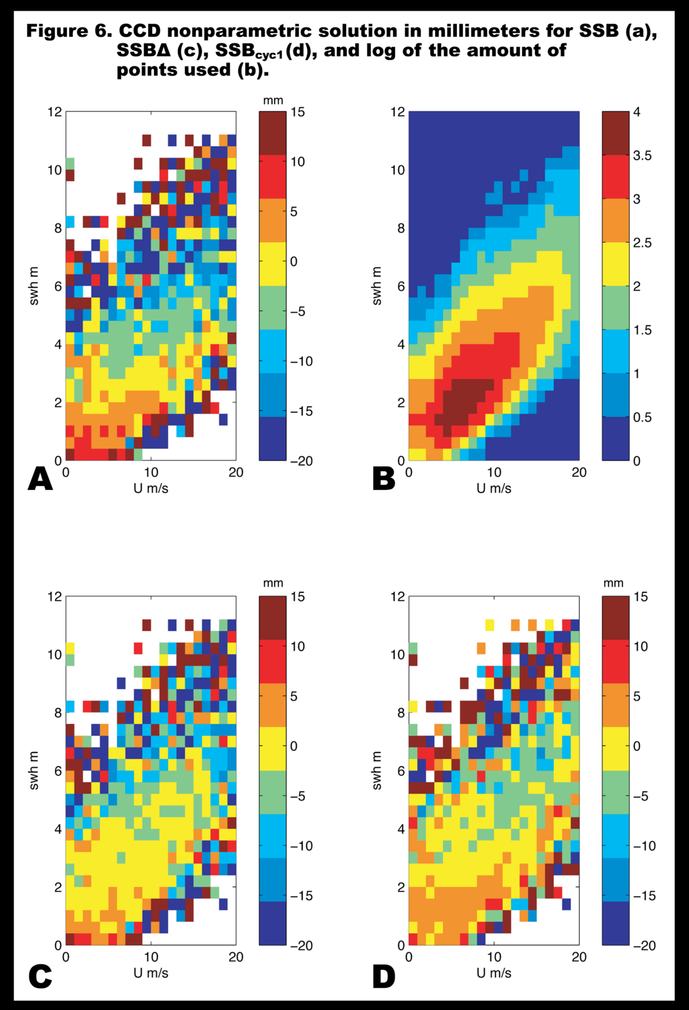


Figure 6. CCD nonparametric solution in millimeters for SSB (a), SSBΔ (c), SSB_{cyc1} (d), and log of the amount of points used (b).



METHODS

Data

Data were obtained for the years 2003-2004. SWH and U were obtained from Jason-1 GDR version B data. SSH output was obtained from ECCO2, cube 65. The data were then gridded to have consistent locations.
Direct will be solved as SSH - <SSH>, where <> is the time mean between 2003 and 2004. No difference is taken with U or SWH. CCD will be solved as $t_2 - t_1$, where there are no repeating cycles, i.e. cycle 37 – cycle 38, cycle 40 – cycle 41, …

Parametric

The parametric method solves equation 1 through linear regression to obtain, for example

$$SSB = SWH(\alpha + \beta U + \gamma U^2), \quad (2)$$

where α, β and γ are constants solved for through least squares (Gaspar et al. 1994).

Nonparametric

Using the nonparametric method equation 1 becomes

$$SSB = \sum_{i=1}^{n} \Delta SSH_i \, \alpha_n(x_{1j}, x_{2i}) + \sum_{i=1}^{n} SSB(x_{1i}) \, \alpha_n(x_{1j}, x_{2i}), \quad (3)$$

where i and j denote location, 1 and 2 are times, ΔSSH is the CCD or Direct difference of SSH at location i, x=(U, SWH), and $\alpha_n()$ is a weighting function. The first summation in equation 3 will be known as SSBΔ and the second summation as SSB_{cyc1}. In this study, the weighting function is determined by using a normalized Kronecker delta (ΔU=1 m/s, ΔSWH=0.4 m) as the kernel. Every 50 points were taken to reduce the calculation time. An offset was applied to the entire SSB CCD surface to be the same height as Direct so the two would be comparable.

RESULTS

Correlations

Correlations were made of SWH vs. SSH for the two methods. Figure 1 shows the correlation using CCD and has no pattern of strong correlations. Direct (fig. 2) shows areas of localized strong correlations. SSH and SWH should not depend on one another given that SSH is from ECCO2, but that is what Direct shows. This suggests that Direct may be introducing bias that does not exist.

Parametric Sea State Bias

The parametric solution for CCD has smaller SSB values than Direct (fig. 3). The solution for equation 2 using CCD is

$$SSB = SWH(-2.2223\times10^{-4} + 1.9764\times10^{-5}U - 1.783\times10^{-6}U^2). \quad (4)$$ see fig. 3 CCD

The Direct solution for equation 2 is

$$SSB = SWH(0.0034 - 0.0009U + 3.4679\times10^{-5}U^2). \quad (5)$$ see fig. 4 Direct

The α term in equation 4 for CCD is an order of magnitude smaller than Direct, resulting in SSB near zero for CCD, while Direct has larger values (fig. 4). Since the SSH has no SSB, the CCD method is the better choice here.

Nonparametric Sea State Bias

SSB estimates for Direct (fig. 5) are smaller than CCD (fig. 6). For CCD SSBΔ is equal to the SSB of cycle2-cycle1 and SSB_{cyc1} is equal to the SSB of cycle1. Since Direct uses <SSH′> instead of cycle1 and assumes the mean has no SSB, SSB_{cyc1} is zero for Direct. Therefore, Direct's SSB is only equal to SSBΔ. Comparing SSBΔ of CCD to Direct's SSBΔ CCD has smaller values. The only reason why SSB of CCD is larger than SSB of Direct is CCD's SSB_{cyc1}. A reason why CCD's SSB_{cyc1} is so large is fewer points were used in CCD than Direct because CCD uses cycle pairs. If one cycle is missing a value then the value in the corresponding location in the paired cycle is ignored, and since it is the difference between two cycles that are calculated you automatically reduce your data set to half. This results in a coarser resolution for CCD that might not have been able to accurately estimate SSB_{cyc1}.

CONCLUSIONS

According to the correlations and parametric solutions, it appears that the Direct method is introducing bias. Since SSH comes from ECCO2 and its SSB=0, there should be no correlations between SWH and SSH and parametric SSB values should be near zero, which is what CCD shows. For the nonparametric solution, it is difficult to determine which method is better. Since the nonparametric solution forces SSB to be zero at a constrained location (U=8 m/s, SWH=2.7 m) the larger the field around that constrained value is zero the better the solution. The SSBΔ of CCD has a larger zero field around the constrained value than Direct's SSBΔ, so for SSBΔ CCD is better. The problem with CCD is its SSB_{cyc1}. The reason why it is so large is there may not have been enough data resolution for an accurate calculation for this method.

ACKNOWLEDGEMENTS

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