Assessment of the Sentinel-6 Michael Freilich extension to the TOPEX/Jason Sea Surface Height Climate Data Record referenced to ITRF2020

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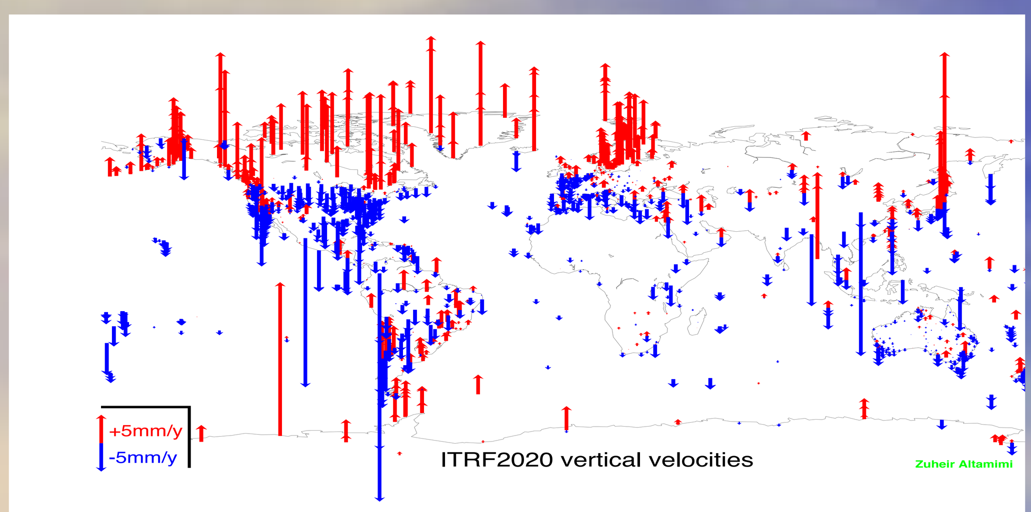
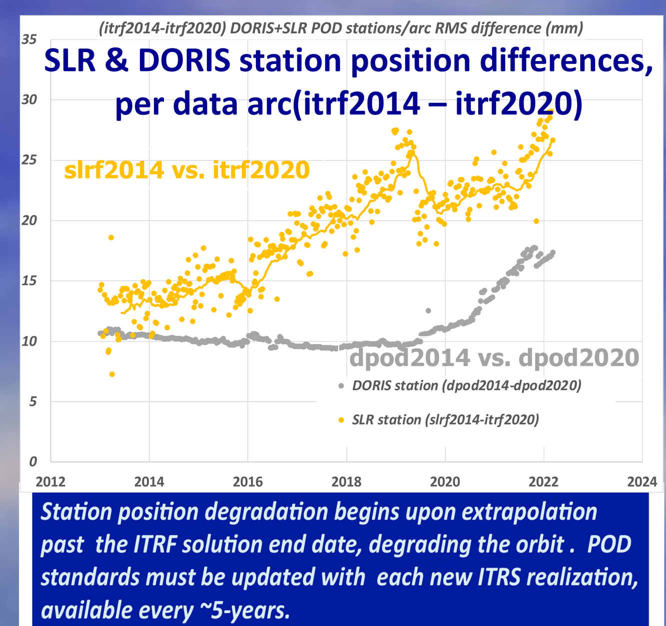
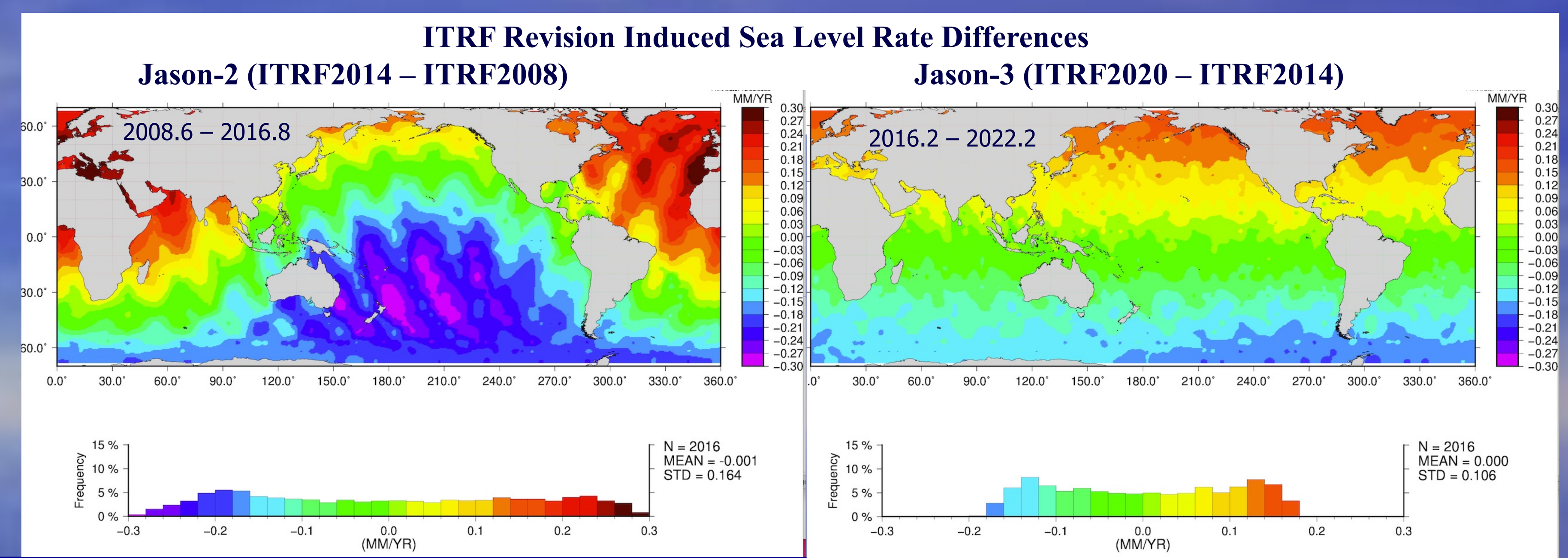
Abstract: The terrestrial reference frame is the foundation for analysis and interpretation of Earth science observations, especially for data from ocean radar altimeter satellites. The accuracy of the coordinates as well as the consistency of the technique solutions within an ITRF affect the accuracy with which orbits are computed, and map into the accuracy of the estimates for global mean sea level (GMSL). The launch of Sentinel-6 Michael Freilich (S6_MF) offers the possibility of continuing GMSL monitoring well into the decade. In order to provide a consistent altimeter sea surface height (SSH) time series and seamless transition to S6-MF, we have generated orbits for the entire time span based on the revised ITRF2020 terrestrial reference frame, improved gravity field and solar-radiation models. We report the efficacy of the revised orbits via tide gauge analyses, assessment of verification phase J3/S6-MF agreement and evaluate the subsequent impact on current global and regional mean sea level estimates.

Improved Orbit Determinations based on ITRF2020 for TOPEX/Poseidon, Jason-1, 2, & 3, and Sentinel-6 Michael Freilich Altimetry



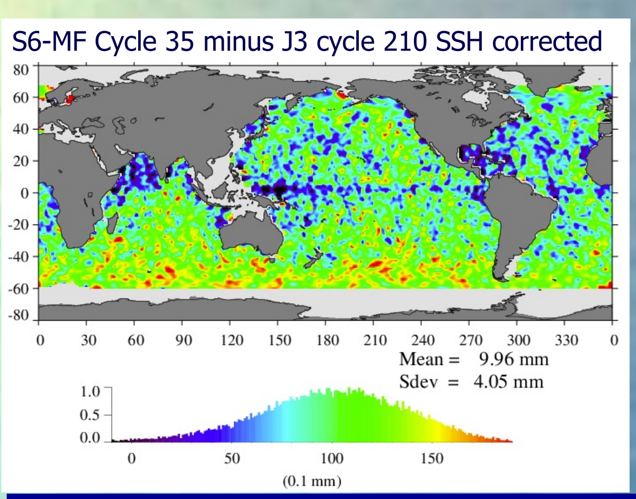
Revised preliminary GSFC replacement orbits (dpod2020_cmitrf2020) have been generated for the TOPEX/Jason/S6-MF altimetric time series based on a new release of the International Terrestrial Reference Frame ITRF2020. Improvements over the prior ITRF2014 is realized by the "extended observation history of the four space geodetic techniques VLBI, SLR, GNSS, and DORIS" (*Altamimi et al., 2016*). Image above left (from *Altamimi et al., 2022*) show the tracking stations vertical velocities with formal error less than 0.2 mm/y.

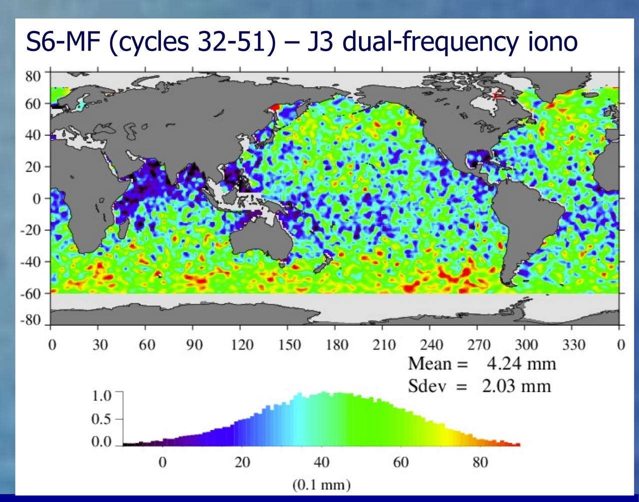




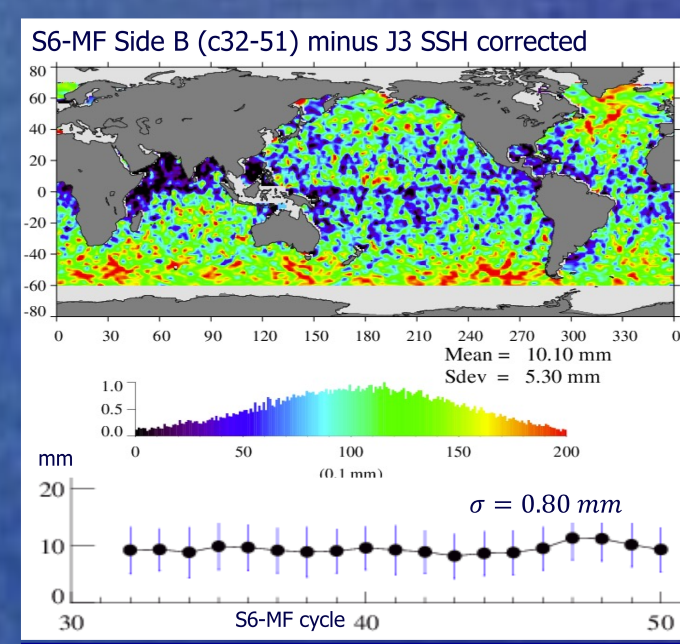
For altimetric satellite POD outside the "station solution interval" (1979 to 2014 for ITRF2014), the tracking station coordinates must be extrapolated. It is in this "extrapolation period" that we can see increasing degradation in tracking data fits and the resultant orbits based on ITRF2014, which can include potential drift error. We have evaluated ITRF2020 and compared its performance to ITRF2014. We see an improvement in the Satellite Laser Ranging Data RMS of fits per 10-day arc for ITRF2020 after 2015 (left figure). The right image (note $\pm$ 0.3 mm/y color scale) shows expected Jason-3 regional sea level trend differences over the period when orbits are based on ITRF2014 versus ITRF2020. A stronger impact was seen on Jason-2 regional sea level rates when transitioning from ITRF2008 to ITRF2014 (*Zelensky et al., 2017*). A standard deviation of 0.1 mm/y provides a stability metric for the most recent ITRF.

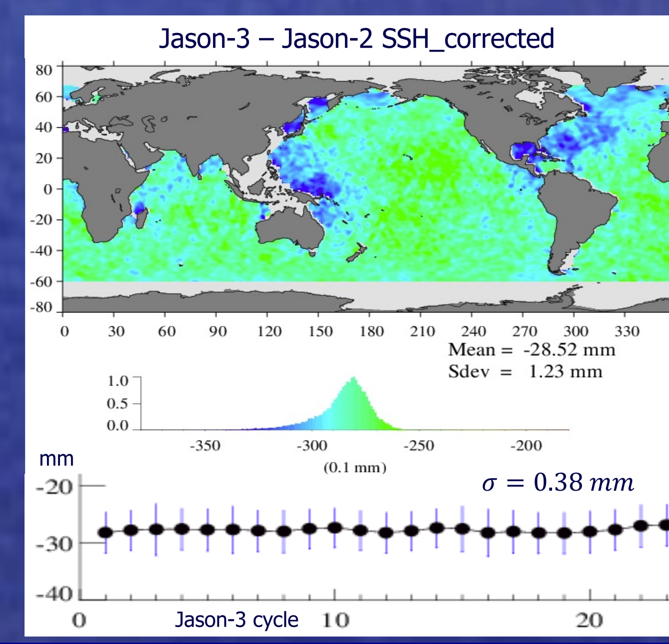
Assessment of S6-MF/Jason-3 Verification Phase Sea Surface Height Differences



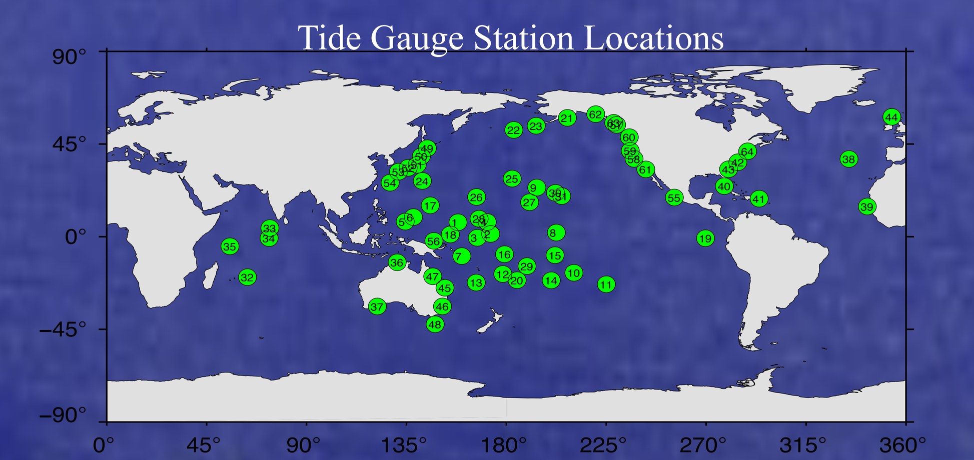


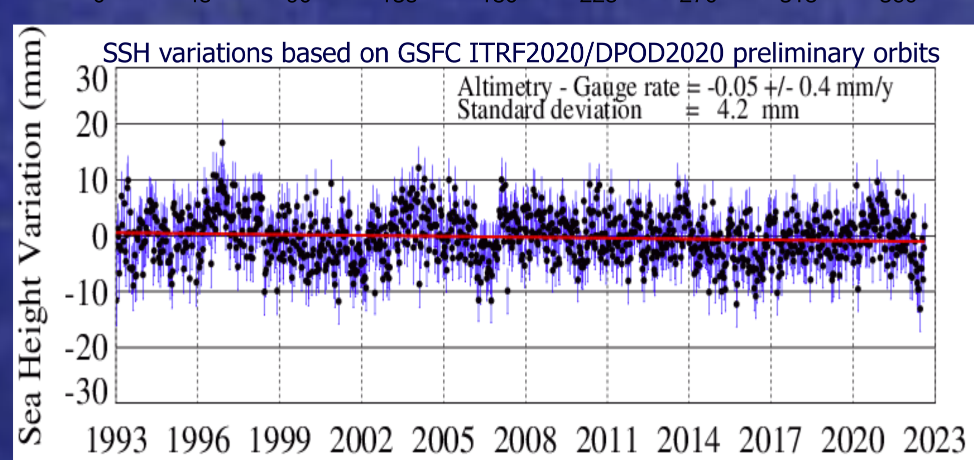
Left figure: Global S6-MF (Side B cycle 35) minus Jason-3 colinear SSH residuals show significant regional differences geographically correlated to significant wave height. Most of the disparity can be attributed to the S6-MF dual frequency range correction (right figure) that is estimated from Ku and C band range (corrected for sea state bias) differences. Reprocessing by the project is underway to retrack C band and re-evaluate sea state bias models for both Ku and C band.

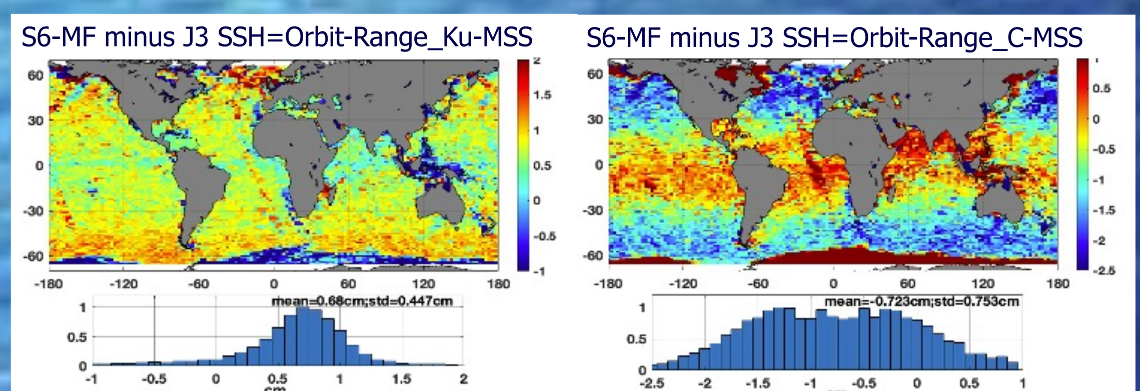


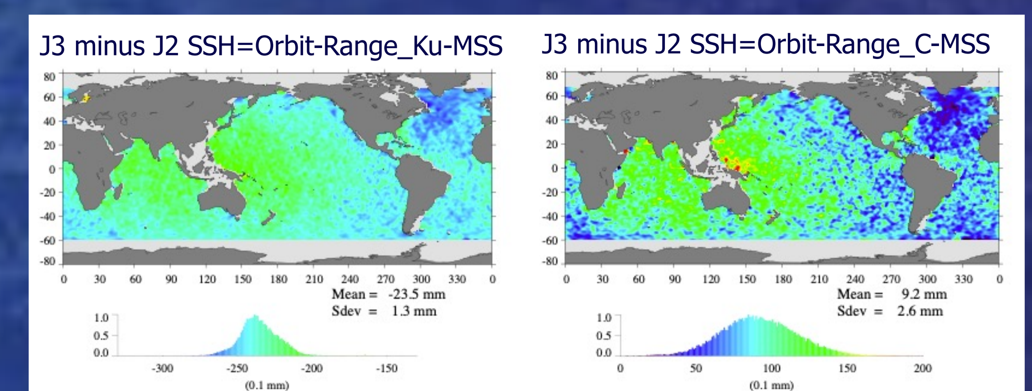


Accurate measures of GMSL derived from multi-mission altimetry requires accurate estimates of global inter-mission biases. The S6-MF/Jason-3 verification phase mean SSH differences (left figure) show significantly higher regional biases in contrast to the J3/J2 verification phase comparison. Cycle to cycle mean SSH differences however are stable and show a variance of less than 1 mm, enabling good agreement of GMSL estimates (at least during verification phase period, figure below right).

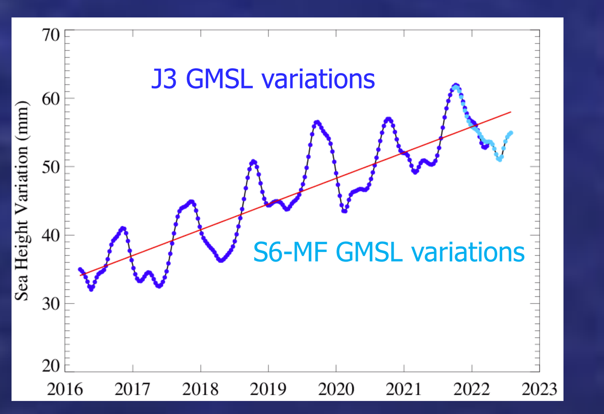


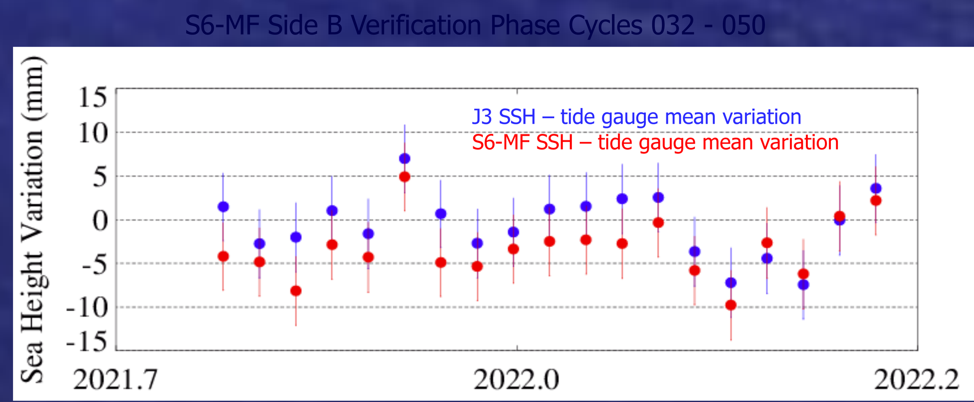






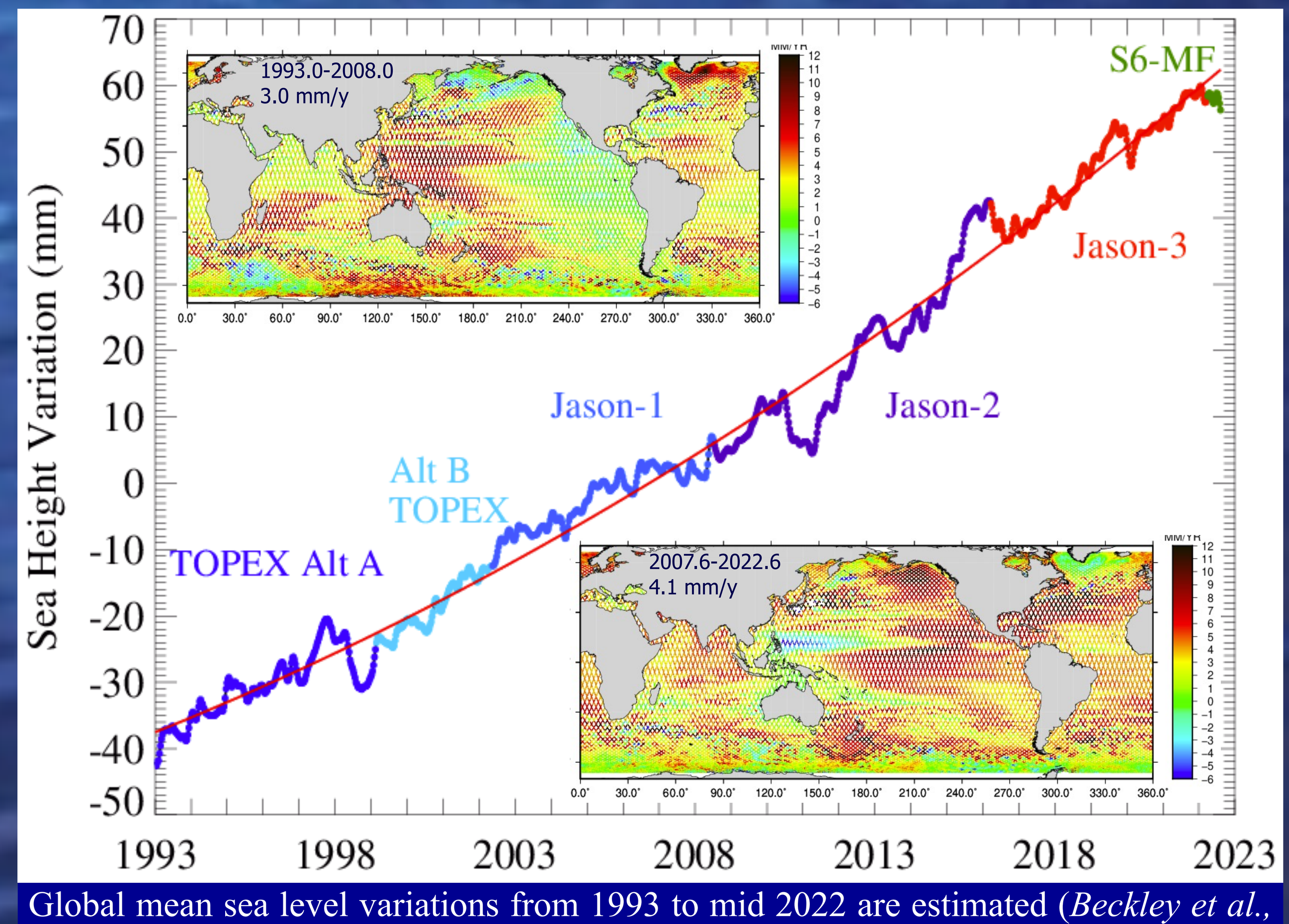
S6-MF/Jason-3 range biases are evaluated for both Ku and C band (left figure). The significantly higher zonal signatures are in contrast to the Jason-3/Jason-2 verification phase (right figure) that revealed smaller east/west geographically correlated differences due to differing POD.



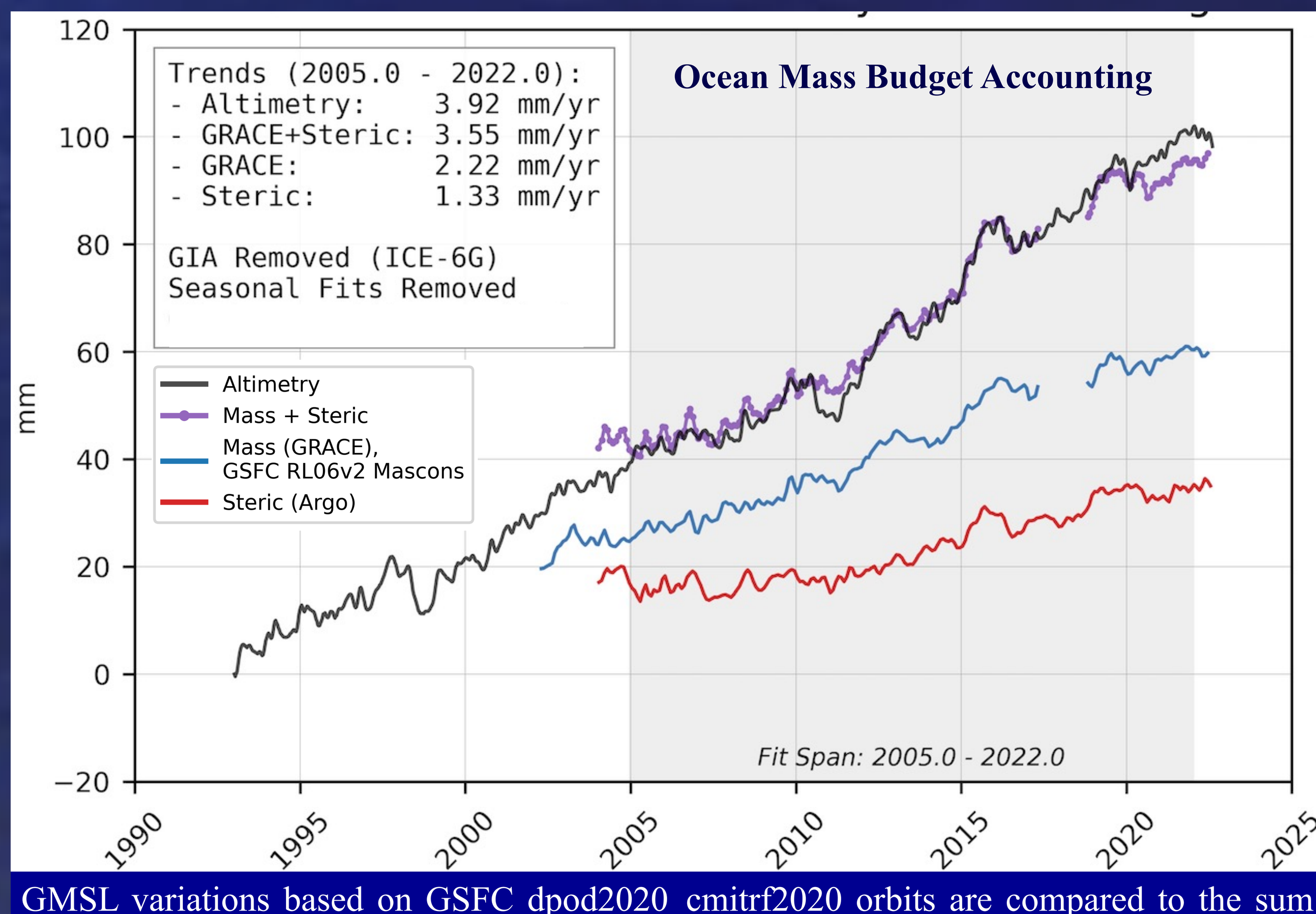


The TOPEX/Jason/S6-MF SSH variations are compared to a 64-site (top figure) global tide gauge network. The drift estimated (middle figure, *Mitchum, 2000*) is less than 0.1 mm/y with a variance of 4.2 mm. Jason-3 and S6-MF (Side B) mean altimeter-tide gauge residuals during the verification phase are shown in above figure.

Global and Regional Mean Sea Level Estimates Referenced to ITRF2020



Global mean sea level variations from 1993 to mid 2022 are estimated (*Beckley et al., 2017*) from TOPEX, Jason, and S6-MF altimetry referenced to ITRF2020 using SLR & DORIS-based GSFC dpod2020_cmitrf2020 orbits. The red line is the quadratic fit to the SSH variations after removal of annual and semi-annual signal and application of GIA. The linear sea level rate is estimated at 3.4 mm/y $\pm$ 0.04 mm/y with an acceleration of 0.080 mm/y^2 $\pm$ 0.025 mm/y^2. Regional sea level rates are shown above (left inset) for the first 15-years and last 15-years (right inset) of the TOPEX/Jason/S6-MF sea surface height time series. Two signatures of note are the reversal of the Pacific Decadal Oscillation (PDO) bringing significantly higher sea level rates to the U.S. West coast, and the rate reversal along southern Greenland coast as a result of ice mass loss post gravitational attraction effects with accelerated rates along U.S. East coast.



GMSL variations based on GSFC dpod2020_cmitrf2020 orbits are compared to the sum total of ocean mass+steric variations in an accounting towards ocean mass budget closure. The above image shows the total ocean mass variations derived from GRACE GSFC RL06v2 Mascons (*Loomis et al., 2019*) and the steric component derived from the SIO RG climatology (https://sio-argo.ucsd.edu/RG_Climatology.html). A visible mis-closure is evident in the global ocean mass budget post 2017. Recent articles (*Chen et al., 2020* and *Barnoud et al., 2021*) point to possible errors in the GRACE Follow On ocean mass estimates, and/or the Argo float derived steric estimates contributing to the mis-closure. The budget misclosure is still present when using thermosteric estimates from Argo, indicating that other sources remain to be found.

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