HaiYang-2D data assessment and performance for potential assimilation into DUACS and CMEMS products

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1 CLS

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1 HaiYang-2D overview

The HaiYang-2D (HY-2D) mission has been launched in May 2021 by the China National Space Administration (CNSA). HY-2D is the fourth unit of the HaiYang-2 altimetry Program with similar orbital and instrumental characteristics to HY-2C. Few more units E to H are planned for the future. The National Satellite Ocean Application Service (NSOAS) is responsible for the ground segment processing system as well as distributing collected data and HY-2 Level 2 products. The French contribution performed by the Centre National d'Etudes Spatiales (CNES) on this project mainly consists in supplying the orbit, computed from DORIS, GPS and laser measurements.

1.1 Aim of the study

The past assessments of HY-2B and HY-2C units showed excellent performances [1][2][3][4] that today benefit to the CMEMS Sea Level and Wind&Waves products. This paper aims at presenting the HY-2D data quality and performances over open ocean at global scales. The assessment has been performed by comparison with other altimeters such as Sentinel-3A, Jason-3, Haiyang-2B/C. Performance and stability of the satellite are studied through mono and multi-mission crossover diagnostics and temporal monitoring of several variables such as sea level anomaly, wet tropospheric correction, and significant wave height.

2 HaiYang-2D characteristics

HY-2C has the same orbital and instrumental characteristics as HY-2C summarized on the Table 1 below. There is a 90° phase angle between HY-2C and HY-2D.

Height	957.583 km
Tilt	66°
Cycle period	10 days
Orbit type	Prograde
Sun-synchronous	No
Radiometer	Yes
Bi-frequencies altimeter	Yes
Orbit	GPS + DORIS

Table 1 HY-2D orbital and instruments characteristics

3 HaiYang-2D data

Four cycles of level-2 (L2) short-time critical (STC) NSOAS products have been used for the study, from cycle 50 track 1 to cycle 53 track 274 (from 2022-09-25T07:48:10 to 2022-11-03T22:37:06). From L2 products we made level-2P products (L2P) based on DT21 geophysical standards. The Table 2 show the geophysical corrections used for the sea level anomaly (SLA) computation in L2P products.

Variable	Source
Orbit	CNES MOE-F
Range	L2 NSOAS product
Ionospheric correction	GIM
Dry tropospheric correction	ECMWF
Wet tropospheric correction	L2 NSOAS product radiometer
Ocean tide height correction	FES14b
Pole tide correction	Desai MPL2017
Solid tide correction	Cartwright
Sea state bias	L2 NSOAS product
Dynamical atmospheric correction	MOG2D
Internal tide correction	Zaron2019
Mean sea surface	Scripps combine CNES15 DTU13 on WGS84

Table 2 Corrections used for sea level anomaly computation.

4 HaiYang-2D data quality

4.1 Radiometer performance

The Figure 1 represents the variance gain when the radiometer wet tropospheric correction (WTC) is used instead of the WTC European Centre for Medium-Range Weather Forecasts (ECMWF) model. The SLA variance reduction with radiometer WTC correction is about 5.4% which corresponds to a reduction of 2.3 cm^2. For example, the variance reduction for Sentinel-6A is about 1.8 cm^2. As observed for the HY-2B/C, the radiometer of HY-2D shows good quality even if only one month of data is used, for this raison it has been choose for the SLA calculation.

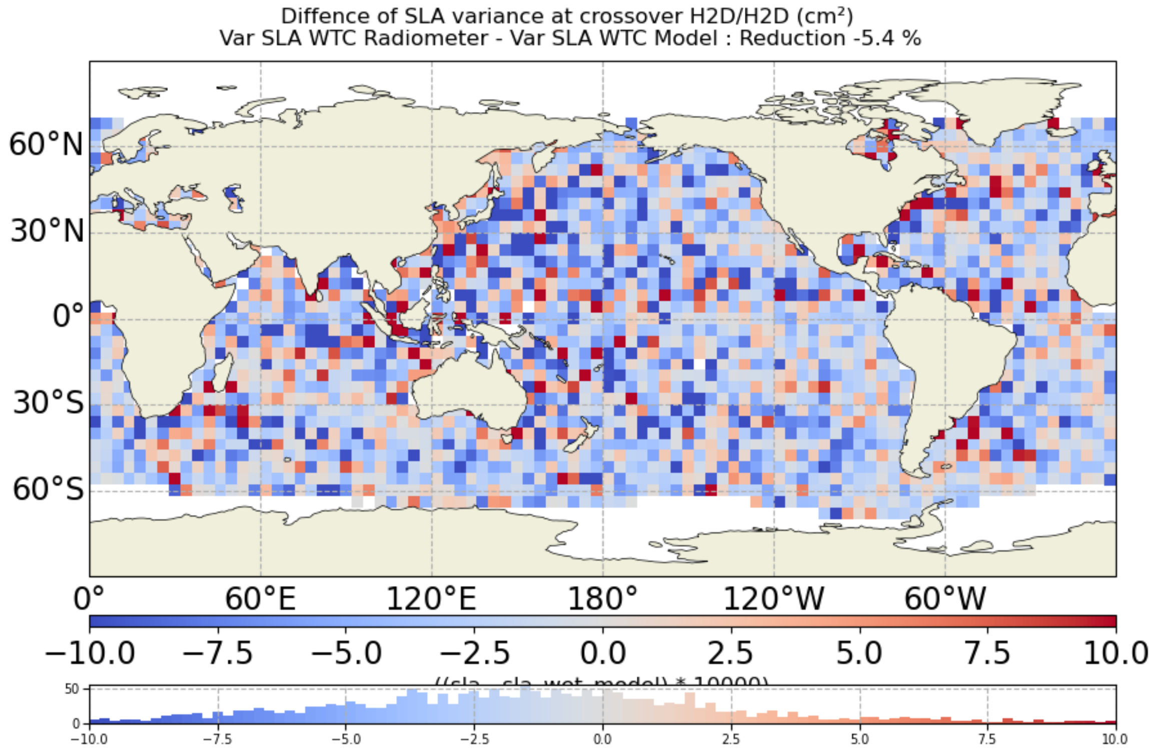
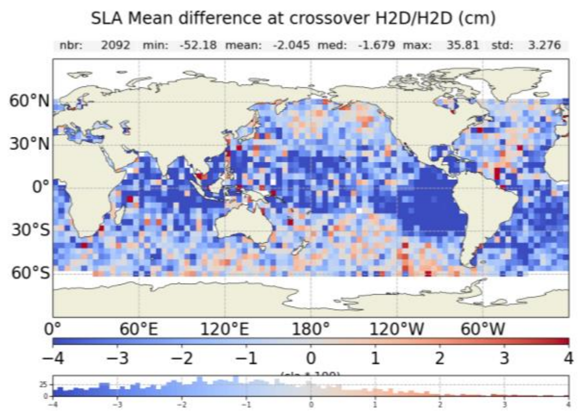


Figure 1 Difference of SLA variance at crossover for HY-2D with WTC radiometer and SLA variance at crossover for HY-2D with WTC ECMWF model.

4.2 Sea level anomaly

The sea level anomaly calculation is based on the Table 2 Corrections used for sea level anomaly computation.. Mean SLA difference at crossover is represented in Figure 2. It shows that HY-2D ascendent/descendent tracks are slightly biased about 2cm in average, which is higher than HY-2B (1.5mm) and HY-2C (5mm) with maximum reach at the geomatic equator. Analyses reveal that this bias is not related to time tag bias (0.1ms) which is in line with other satellites. Global standard deviation (STD) of SLA at crossover point is shown in Table 3. HY-2D SLA STD is about 6.8cm which is in line with HY-2C (6.7cm), HY-2B (6.3cm) and Sentinel-3A/B (6cm). SLA monitoring in Figure 3 shows that the SLA is relatively stable over the time. We notice a little nonstable part around October. The long-term stability should be investigated with longer time series.



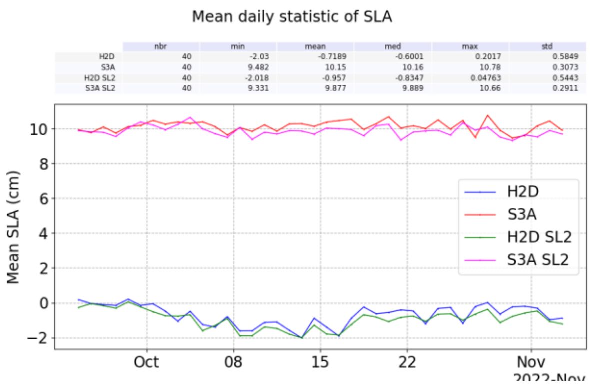


Figure 2 SLA mean difference at crossover. Mono-mission diagnostics HY-2D/HY-2D.

Figure 3 SLA temporal monitoring for open-ocean and with stability selection (SL2: ABS(latitude) >60° and low ocean variability).

Mission	Global standard deviation (cm)
HY-2B	6.3
HY-2C	6.7
HY-2D	6.8
S3A	6
S3B	6

Table 3 Global standard deviation of SLA at crossover points for STC products

Comparison at crossover point with another mission (Figure 4) (here Sentinel-3A) show a global mean bias is around 10,9 cm with differences ranged between -4 and +4 cm only. HY-2D has larger mean bias than the other HY-2 satellites, for example HY-2C has 4 cm mean bias. Geographical patterns are observed with positives values in Indian ocean and negatives values in north pacific and Atlantic oceans. These kinds of pattern have already observed in multi-mission crossover HY-2C/S3A. Mean SLA differences at crossover (Figure 5) shows periodic oscillations around 104 days which is typical for HY-2C and HY-2D orbit characteristics. It could be related to orbit error and especially solar pressure modelling. Oscillations are observed in both CNES (blue line) and NSOAS (red line) orbit solutions. However, CNES orbit solution presents smaller ranges amplitude -1/+1 cm versus -4/+4cm for NSOAS orbit solution. Similar behavior as HY-2C should be confirmed with longer time series of HY-2D. Long wavelength error does not prevent the integration of HY-2C and HY-2D in sea level Copernicus Marine Services thanks to the orbit error correction computed in level 3 SLA products.

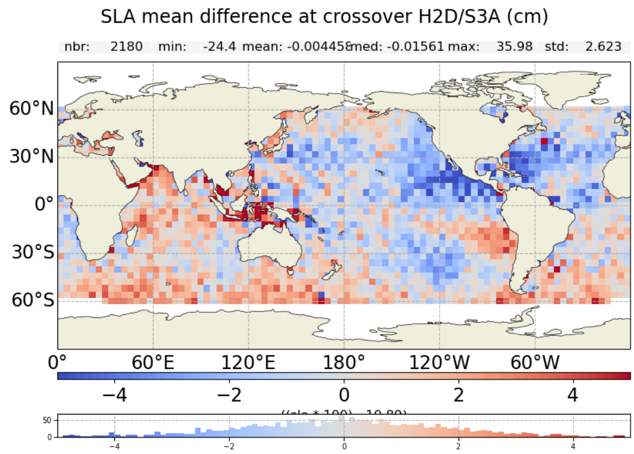


Figure 4 SLA mean difference at crossover for S3A/HY-2D

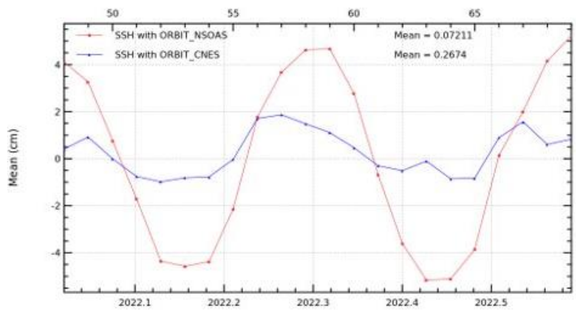


Figure 5 Temporal monitoring of SLA mean difference at crossover for mono-mission HY-2C/HY-2C. Red represents SLA with NSOAS orbit and blue SLA with CNES orbit.

Power spectra are performed for several missions during the same period of HY-2D study. Spectra for high frequency (20Hz) and low frequency (1Hz) are represented in Figure 6 respectively with full line and dashed line. Power recovered by HY-2 satellites (red and grey) is in line with the J3 satellite (blue) for large scales (larger than 100km). There are discrepancies between 1Hz (dashed lines) and 20Hz (full lines) below 100/80km which seems induced by the small time period used because this kind of result are not observed for long time period for HY-2B. However, HY-2D seems to have the same quality of data as HY-2B, spectra red and grey are in line. For high frequency, same order of white noise is observed for HY-2D than HY-2B, which is around 6-7cm. This confirm that HY-2D like the other HY-2 satellites has very good ground segment processing and/or high altimeter performances.

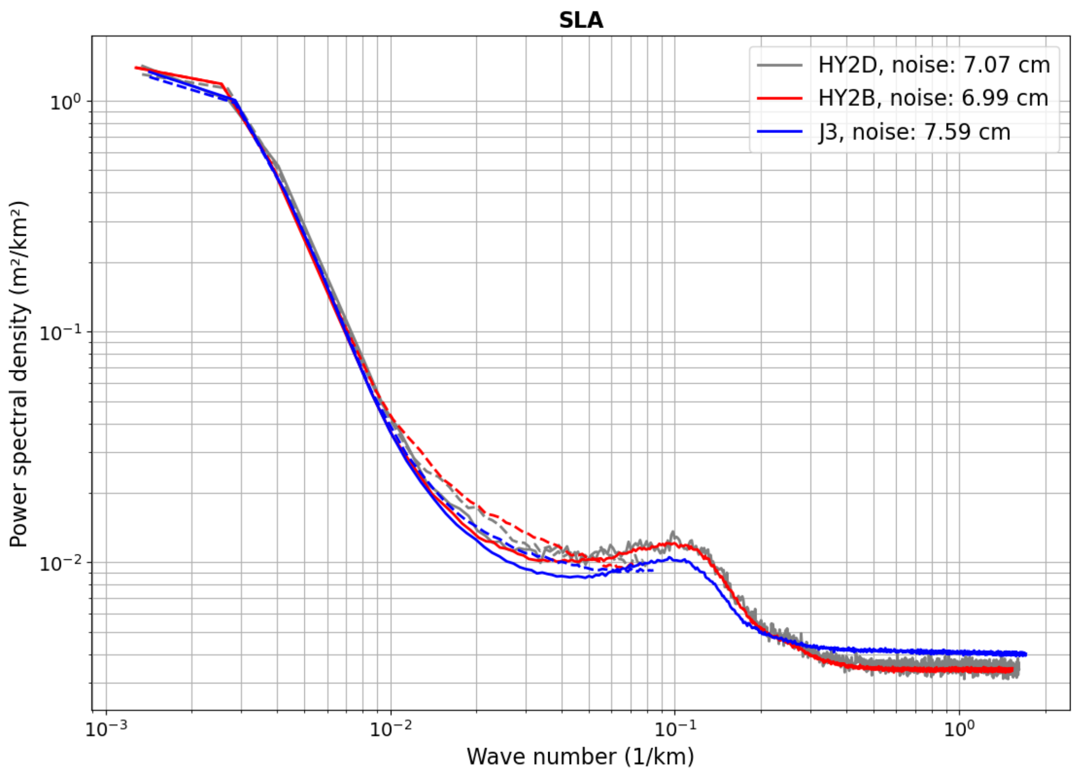
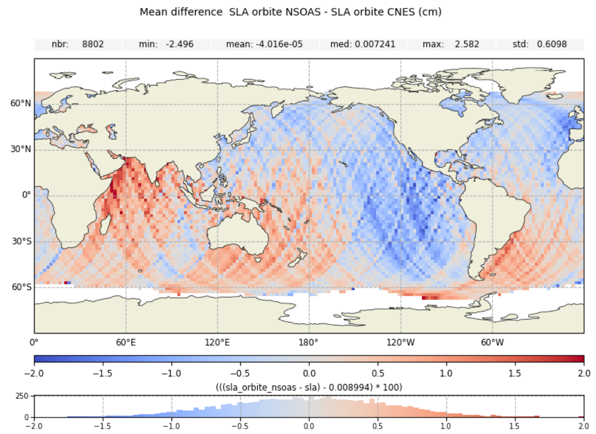


Figure 6 Power spectral density in function of wavelength.

4.3 Orbit quality

In this section we investigate both the CNES and NSOAS orbit solutions. As observed for HY-2B and C satellites, using the NSOAS solution in the SLA calculation induce SLA variance spurius in several passes (not shown). These passes are removed for the study. Geographycal patterns observed in Figure 4 are also observed in SLA difference with NSOAS et CNES orbit solutions (Figure 7). The Figure 8 represents the difference of SLA variance for both orbit solutions. Positive values means that le NSOAS orbit solution increase the SLA variance compared to the CNES orbit. In average, the NSOAS orbit solution increase by 2.2% the SLA variance which correspond to $1cm^2$. For this reason, the CNES orbit solution has been choose for the SLA calculation.



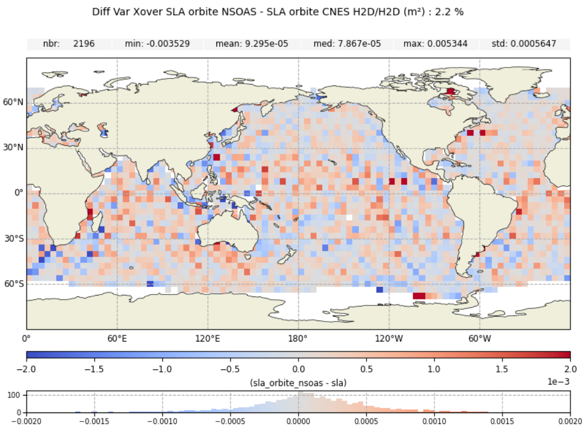
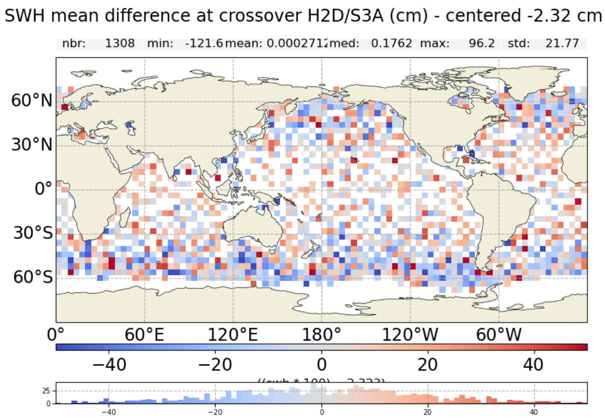


Figure 7 Centered mean difference of SLA with NSOAS orbit and SLA with CNES orbit.

Figure 8 Variance gain: Variance difference at crossover of SLA with NSOAS orbit and SLA with CNES orbit

4.4 Significant Wave Height and wind speed

The prupose of this section is to evaluate the quality of significant wave height (SWH) et wind speed variables provide by the NSOAS level 2 products. Mean difference at 3 hours crossover diagnostics are reprented for SWH and wind speed in Figure 9 and Figure 10 respectively. Mean SWH bias is around 2.3cm) (Figure 9) which is the same order than HY-2B/J3 (not shown). As observed for all HY-2 satellites, geographycal variations are correlated with SWH about 20cm amplitude, under estimated in strong sea states and over estimated in low sea states. Concerning the wind speed (Figure 10), regional bias correlated with wind speed is observed. The HY-2D wind speed is in average biased around 0.25m/s. The wind speed is over estimated in low wind speed areas and under estimated in high wind speed areas. This is also observed for the other HY-2 satellites. HY-2B and HY-2C have been already integrated to the Wind&Waves Copernicus Marine Sevice. In level 2+ W&W product are calibrated over a reference mission. This calibration removes all bias related to SWH, there is no issue to use HY-2 SWH and wind speed data even if strong bias is observed.



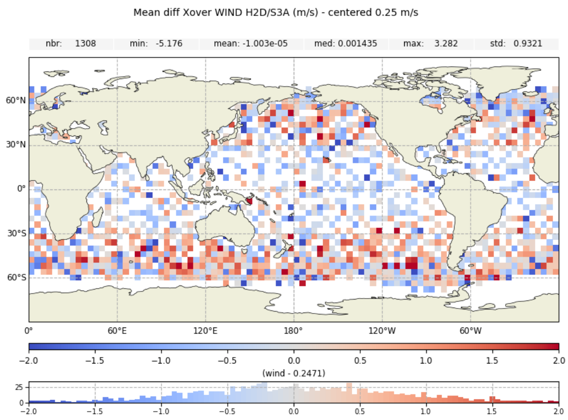


Figure 9 SWH mean difference at crossover for S3A/HY-2D centered à -2.32cm.

Figure 10 Wind speed mean difference at crossover for S3A/HY-2D centered at 0.25m/s

Spectra of SWH for HY-2D (grey), HY-2B (red) and Jason-3 (blue) for 1Hz (dashed line) and 20Hz (full line) are represented in Figure 11. All satellites are in line for larger scales of 100km, we notice discrepancies between J3 and HY-2 satellites below 100km. Both HY-2B and HY-2D spectra are the same for 20Hz spectra and reach about 2.5cm for 2.5m of SWH. This is quite lower than results obtained for J3 which high frequency noise at 2.5m SWH is around 6-7cm. This means that NSOAS ground segment processing for HY-2 satellites is very efficient and/or altimeter performance is excellent. Noise level are summarized in the Table 4. Under 90km, 1Hz and 20Hz spectra are different with lower noise for 1Hz spectra. HY-2D 1Hz spectrum is linear which shows good quality denoising post processing made by the NSOAS agency.

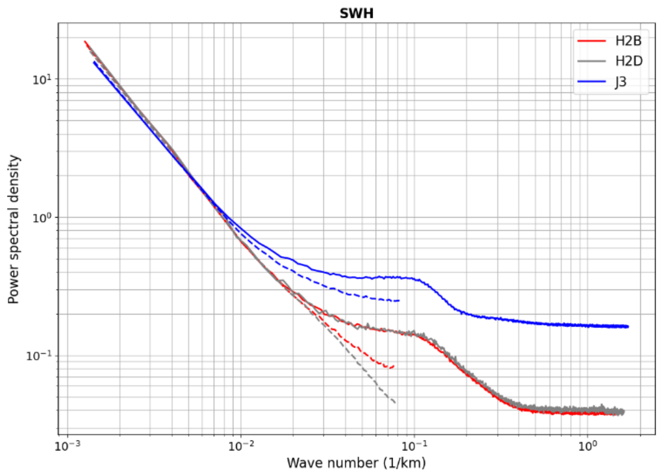


Figure 11 SWH power density spectra for J3, HY-2B and HY-2D respectively in blue, red and grey. 1Hz dashed line and 20Hz full line

	Noise level at 2.5m of SWH (cm)
J3	6-7
HY-2B	2.5
HY-2D	2.5

Table 4 Noise level at 2.5m of SWH

5 Conclusion/future works

HY-2D mission is in overall close to the other HY-2 satellites in terms of qualities and limitations. All results and potential future works are summarized below:

- Good performances of the radiometer wet tropospheric correction. 5.4% of SLA variance reduction is obtained when WTC radiometer is used instead of WTC model, which corresponds to 2.3cm² of SLA variance reduction.
- Ascendent/descendent tracks show in average 2cm bias at crossover points, with maximum values in geomagnetic equator. This is not related to a time tag bias. Further investigation should be done to find the root cause.
- Temporal time series seams stable in time, but this should be validated with larger period.
- Mean standard deviation of SLA (6.8cm) is in line with other missions.
- SLA mean difference at crossover between HY-2D and S3A shows regional bias which could be related to solar modelling. This should be confirmed with further orbit investigations.
- SLA noise level is around 7,1 cm (slightly lower than J3) demonstrating good ground segment anomaly.
- Both NSOAS and CNES orbit solutions have regional bias. SLA variance is reduced when the CNES orbit is used.
- SWH and wind speed are biased correlated to the strong/low SWH wind speed areas. This could be removed by using a look up table bias related to the SWH/wind speed as already made for HY-2B and HY-2C in W&W Copernicus Marine service products.

- SWH noise level is very low, more than twice below J3, which demonstrates very good quality of NSOAS ground segment processing.
- Time tag bias of 3.5ms in high frequency (20Hz) is observed as HY-2C and HY2B (not shown).
- Using ionospheric dual-frequency altimeter instead the ionospheric GIM correction gives promising results: About 0.5cm² of SLA variance reduction which correspond to 0.5% of variance reduction (not shown).

In overall, HY-2D shows good data quality and it will be integrated it into W&W Copernicus Marine Service L3/L4 products during the end of 2024. Good performances of HY-2D reveal a good candidate for potential integration into sea level Copernicus Marine Services.

[1] Philip et al. " Feed-back and contribution after several years of Haiyang-2B data availability" OSTST conference 2022

[2] Philip et al. " Haiyang-2C data assessment, performance and contribution to DUACS Sea Level "Anomaly products" OSTST conference 2022

[3] Faugère et al. "The 2022 Honga Tonga Tsunami monitored by satellite altimetry and SAR" OSTST conference 2022

[4] Philip et al." Hy-2B in DUACS : feedback on performances and contribution to multi-mission products" OSTST conference 2020