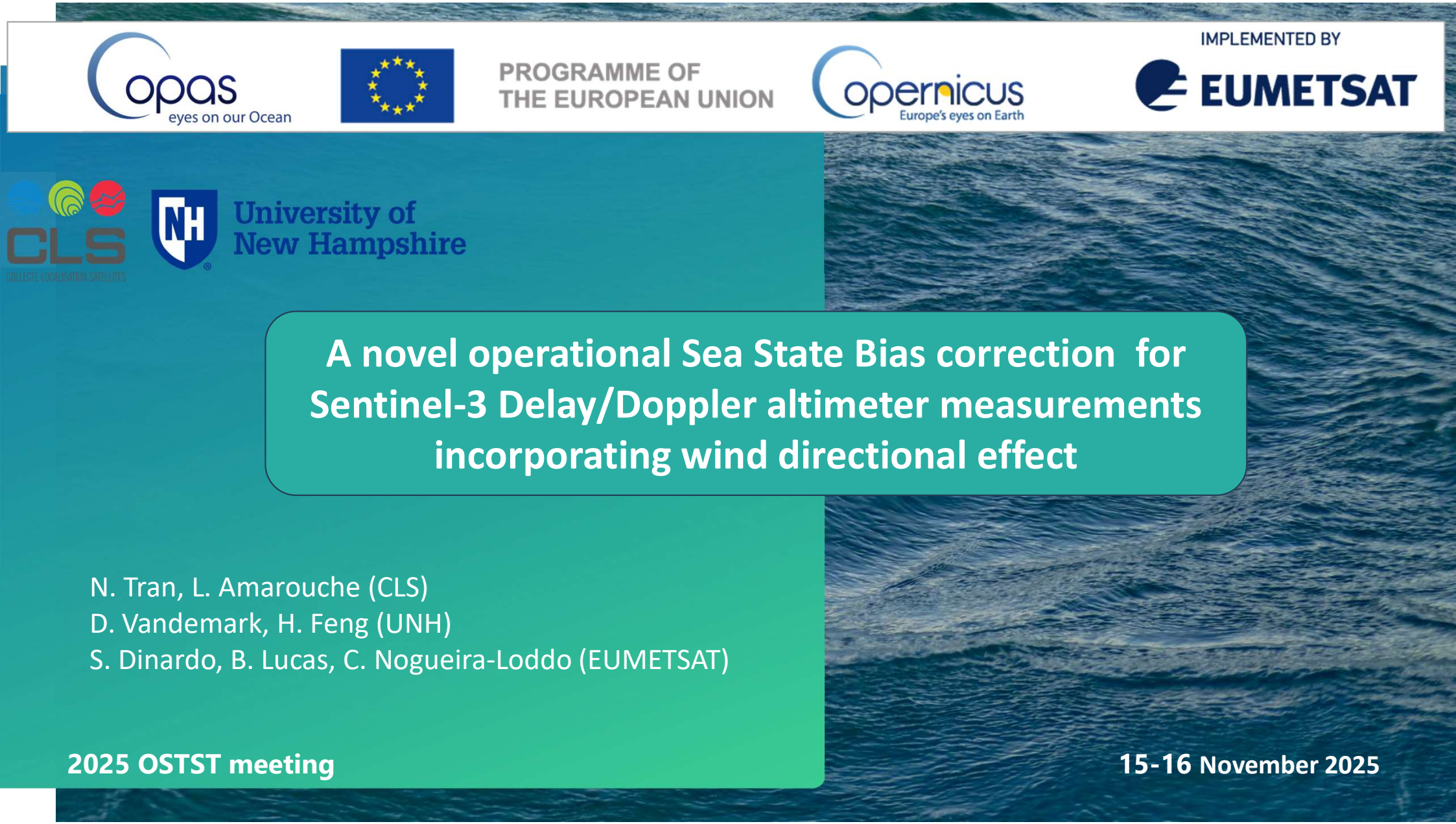


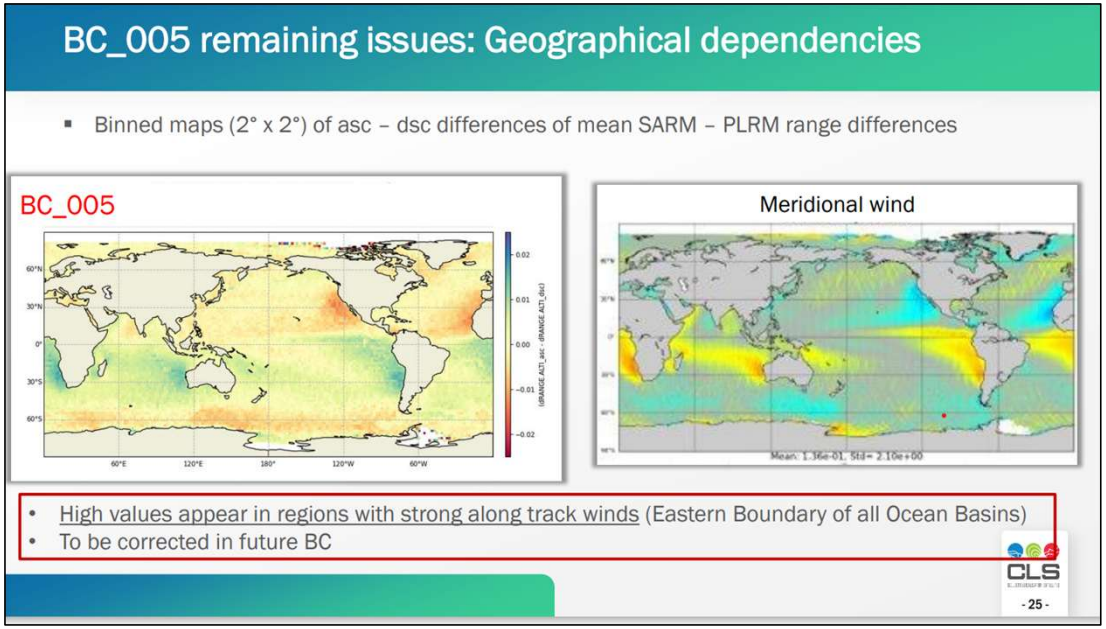
A novel operational Sea State Bias correction for Sentinel-3 Delay/Doppler altimeter measurements incorporating wind directional effect

N. Tran, L. Amarouche (CLS)
D. Vandemark, H. Feng (UNH)
S. Dinardo, B. Lucas, C. Nogueira-Loddo (EUMETSAT)

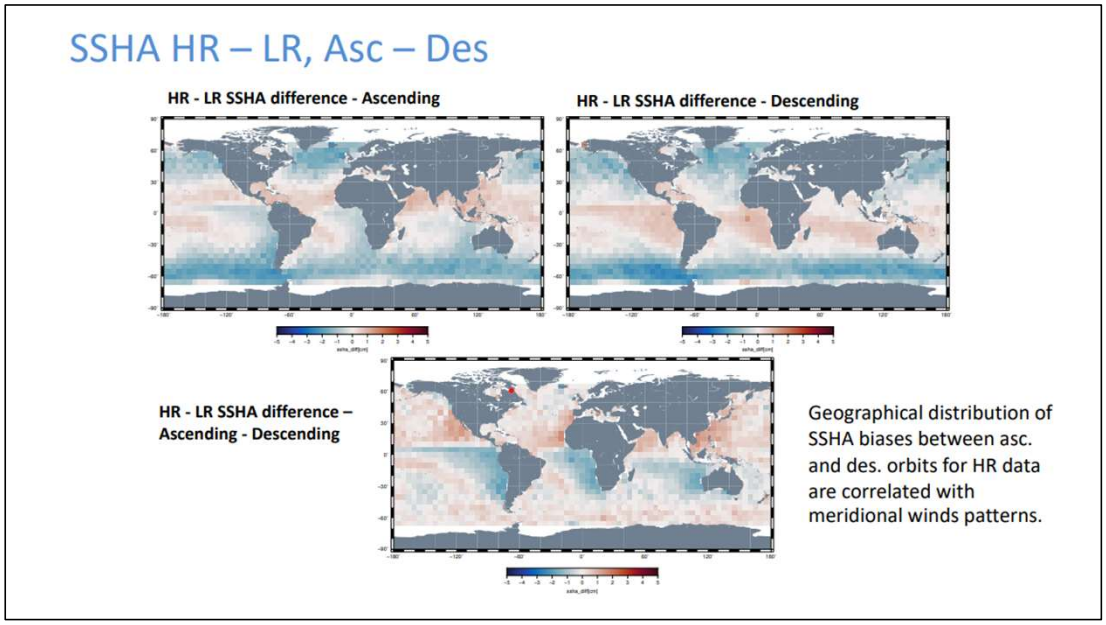
2025 OSTST meeting

15-16 November 2025

Background: Cal/Val observations for S3 and S6_MF



From Raynal et al. [2019]
then Nencioli et al. [2023]



From Egido et al. [2022]

- This bias is now well understood. It results from a Doppler shift caused by the cross-correlation between wave orbital velocity and wave slopes, appearing as an apparent horizontal wave motion that affects the SAR data.

Study Objectives

➢ EUMETSAT statement of work:

“ COPAS work-package WP 2.10 is initiated as response to the recommendation expressed by the altimetry user community at the 8th S3VT meeting during the wrap-up altimetry session (EUMETSAT, 2023):

"***REC: Further investigate and correct geographical Sea Surface Height inconsistencies between PLRM and SAR due to directional wind and waves***"

The recommendation will be implemented evolving the sea state bias (SSB) model in SAR mode for correcting the residual sea state dependency between SAR and PLRM sea surface heights (SSH). “

Content

- Dataset
- Standard 2D SSB model
- Complementary ΔSSB model

$$\Delta SSB = SAR\_(range + 2D\ SSB) - PLRM\_(range + 2D\ SSB)$$

- Total SAR SSB

$$Total\ SSB = 2D\ SSB\ (SWH, WS) + \Delta SSB\ (?)$$

- Validation and performance evaluation results
- Conclusions and way forward

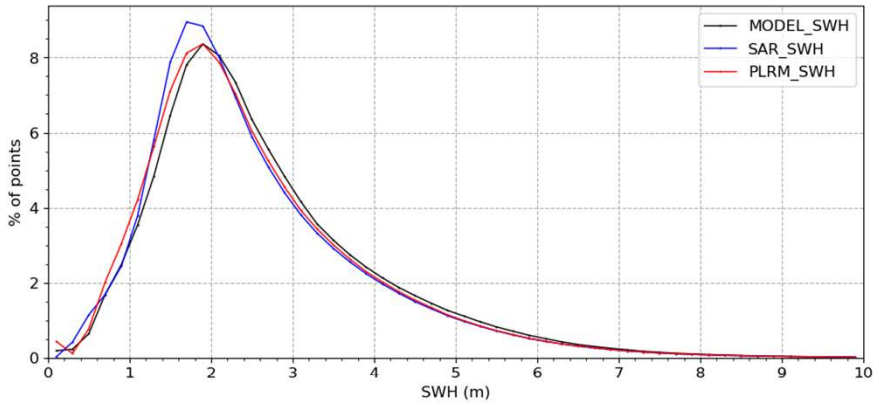
Dataset

- Preliminary BC006 Test Dataset (mid-2020 to mid-2022) from EUMETSAT, used for SSB calibration and validation of updates
- Use of ECMWF wind components from EUMETSAT marine L2 products to characterize wind directional effects (imposed constraint)
- SWH corresponds to the corrected SAR version with the NOAA LUT applied
- Wind speed is computed using Abdalla's algorithm based solely on SAR sigma0

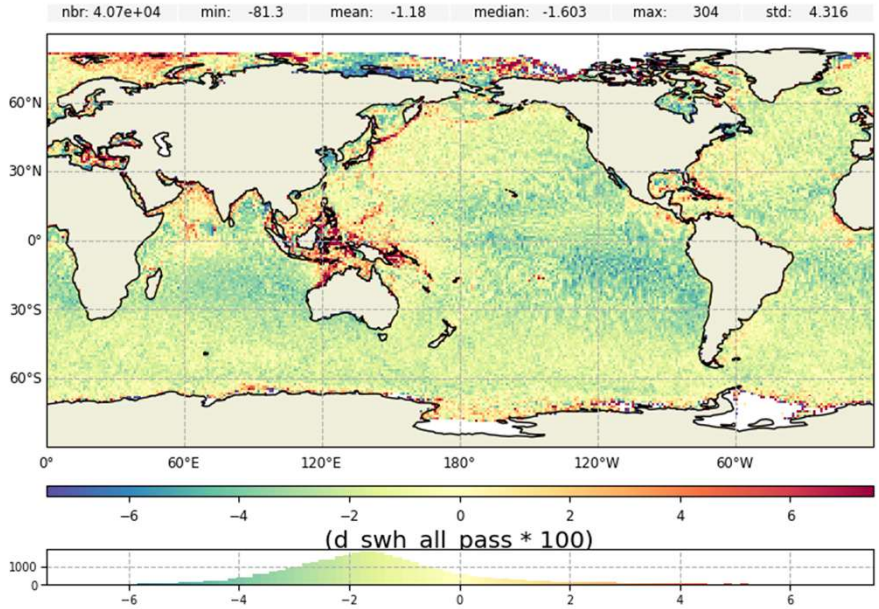
SWH comparison

(MODEL, SAR, PLRM) SWH
S3A; Cycles 59 - 86

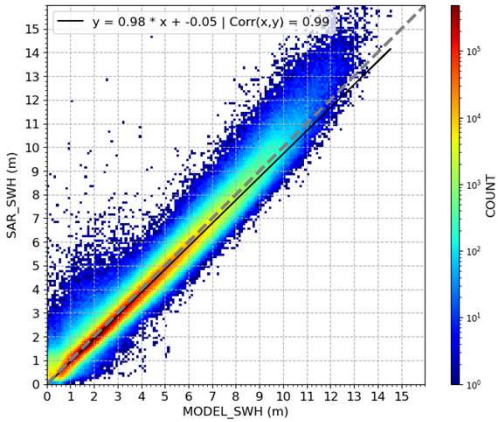
	nbr	min	mean	median	max	std
MODEL_SWH	3.353e+07	0	2.683	2.354	14.63	1.394
SAR_SWH	3.353e+07	-0.023	2.573	2.228	17.83	1.373
PLRM_SWH	3.353e+07	0.181	2.587	2.264	18.78	1.385



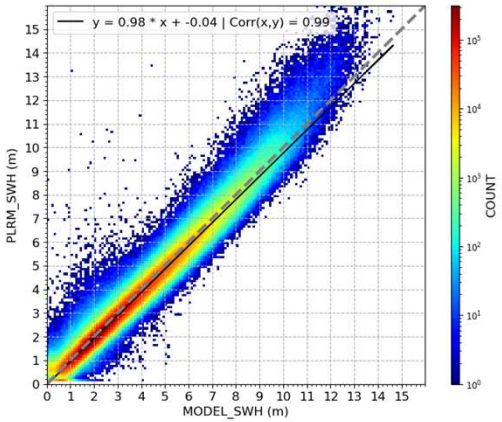
S3A - d_swh_all_pass
(MEAN in SI*100); Cycles 59-86



SAR_SWH (y) vs MODEL_SWH (x)
S3A, Cycles 59 & 86



PLRM_SWH (y) vs MODEL_SWH (x)
S3A, Cycles 59 & 86

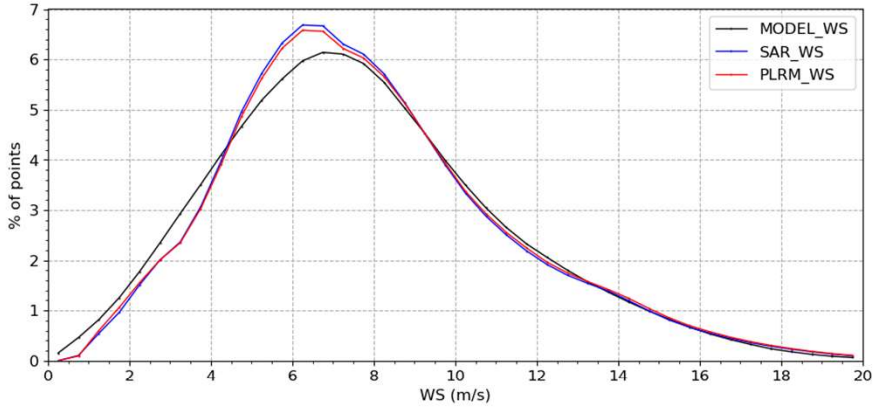


- Estimations in good agreement
- SAR & PLRM overestimate under high waves
- PLRM ~3–4 cm higher than SAR in tropics

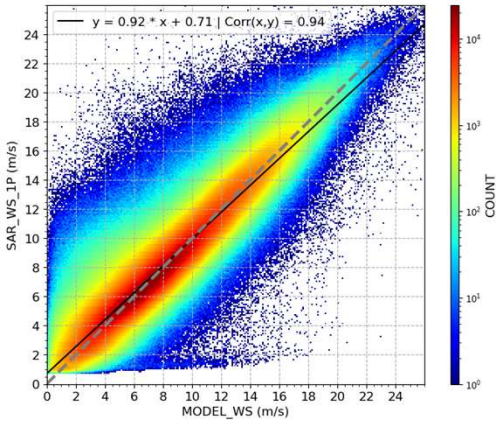
Wind Speed comparison

(MODEL, SAR, PLRM) WS
S3A; Cycles 59 - 86

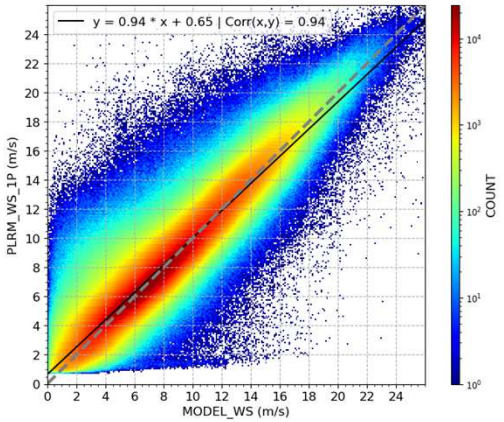
	nbr	min	mean	median	max	std
MODEL_WS	3.378e+07	0	7.792	7.42	31.62	3.508
SAR_WS	3.378e+07	0.75	7.897	7.41	28.37	3.45
PLRM_WS	3.378e+07	0.75	7.942	7.45	28.44	3.495



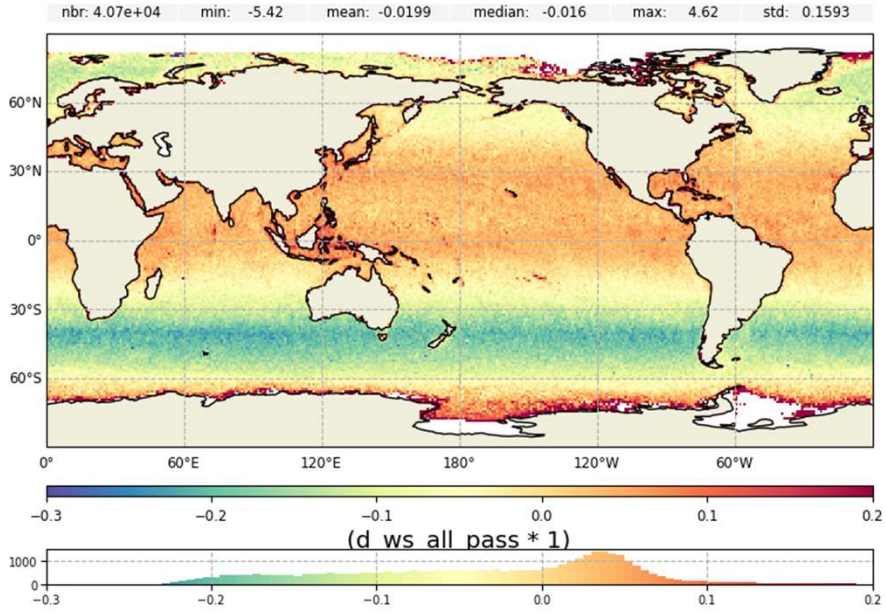
SAR_WS_1P (y) vs MODEL_WS (x)
S3A, Cycles 59 & 86



PLRM_WS_1P (y) vs MODEL_WS (x)
S3A, Cycles 59 & 86



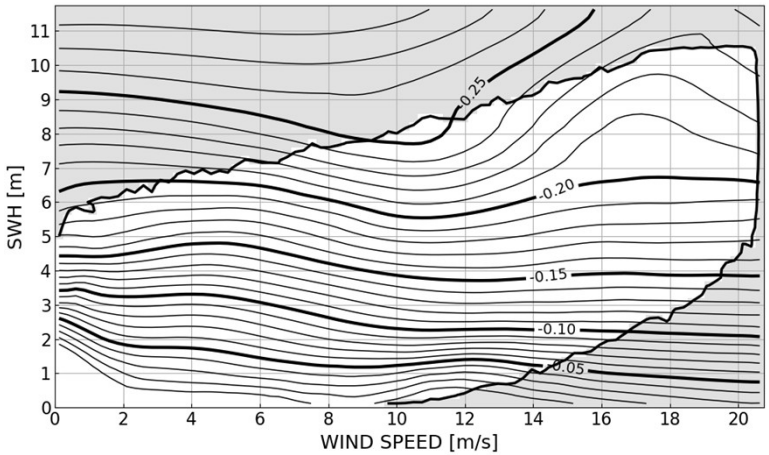
S3A - d_ws_all_pass
(MEAN in SI*1); Cycles 59-86



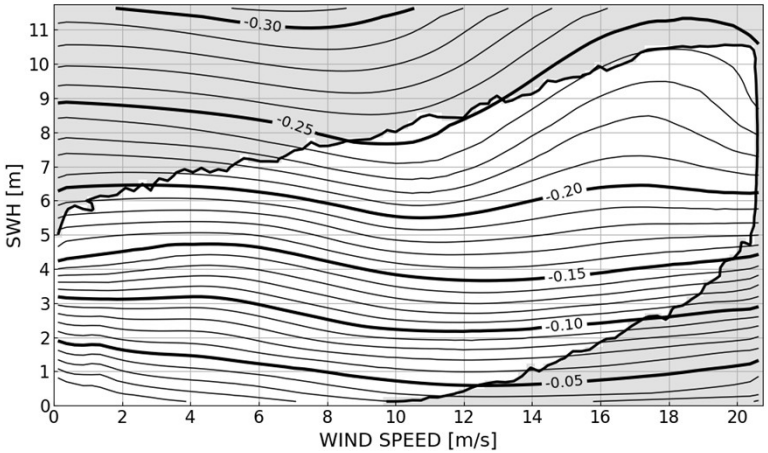
- good overall agreement
- Latitude-dependent differences observed
- PLRM ~0.2 m/s higher than SAR between 60°S and 30°S

S3A SAR 2D SSB models

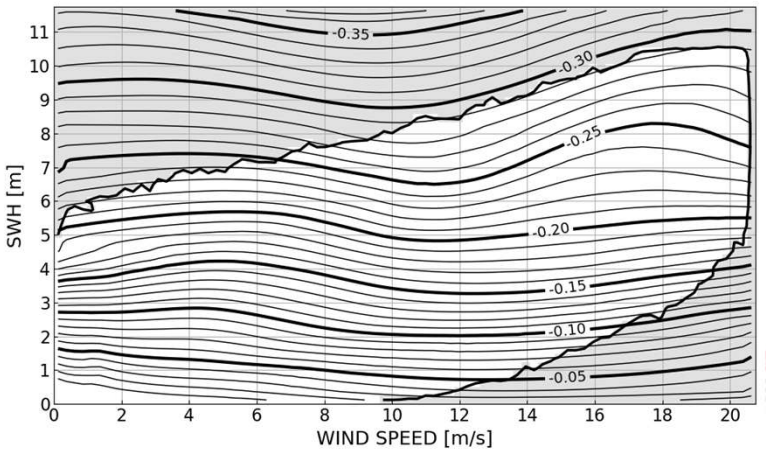
SAR_2D_SSB_2025 from BC006



SAR_2D_SSB_2020 in BC005

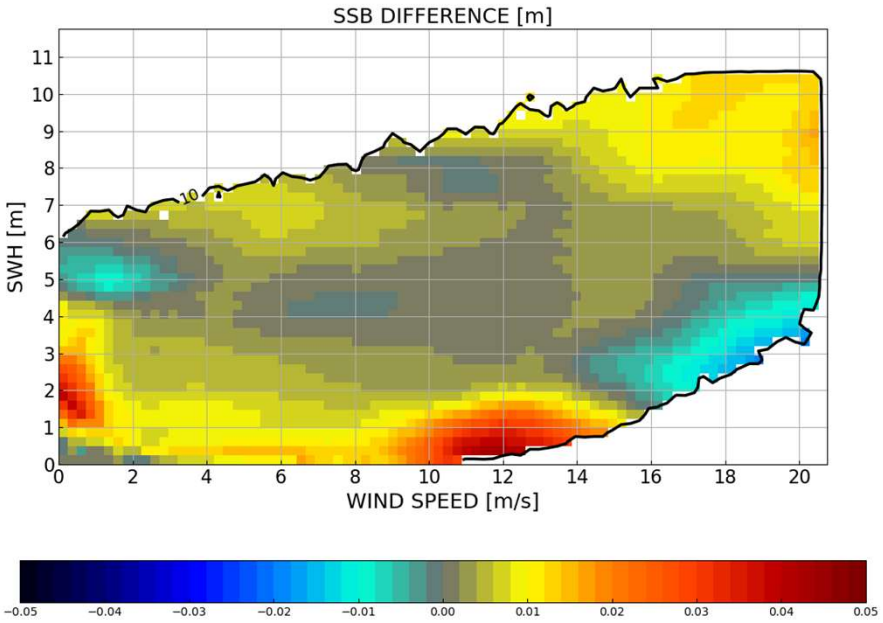


PLRM_2D_SSB_2020 in BC005



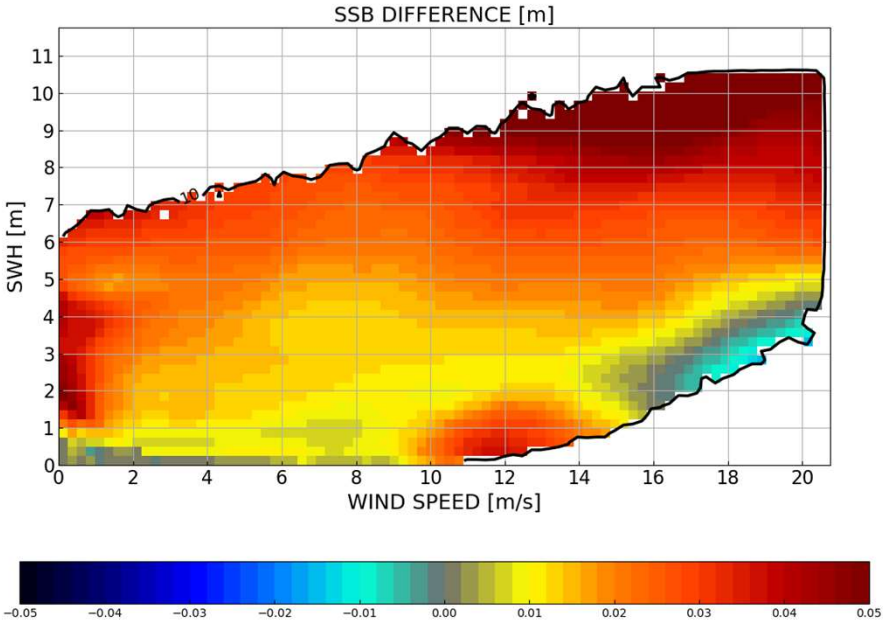
S3A 2D SSB model differences

(SAR_2025 – SAR_2020) SSB



- They’re close. The differences are mostly within 1 cm across the 2D domain.

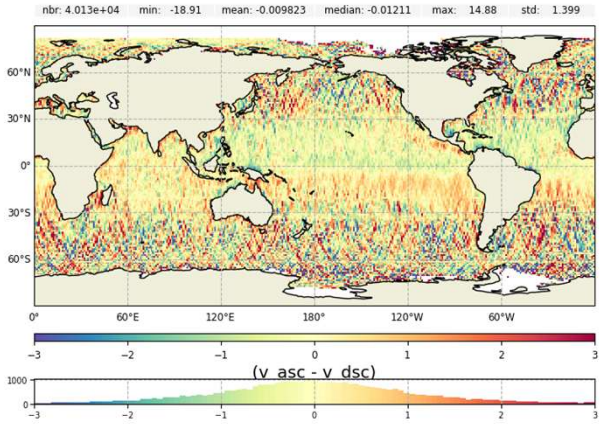
(SAR_2025 – PLRM_2020) SSB



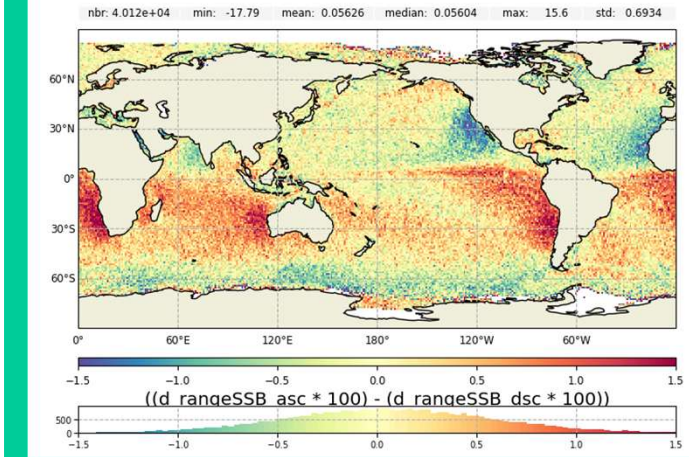
- The differences go up to around 5 cm, with PLRM values generally higher than SAR in magnitude. These differences mainly depend on SWH.

Which regression variable is the more appropriate for ΔSSB modeling?

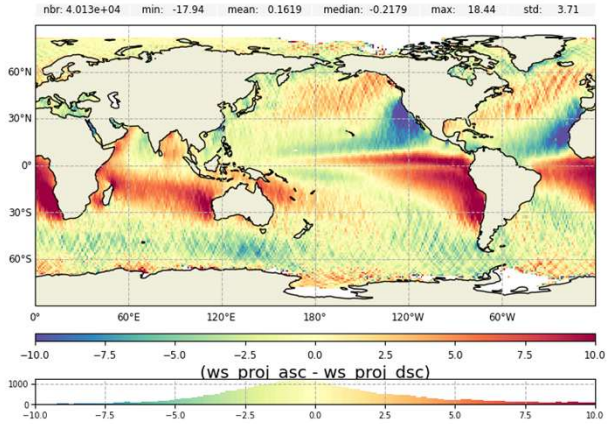
S3A - Wind V-component differences, (ASC-DSC) maps (MEAN in m/s)
Cycles 59 to 86



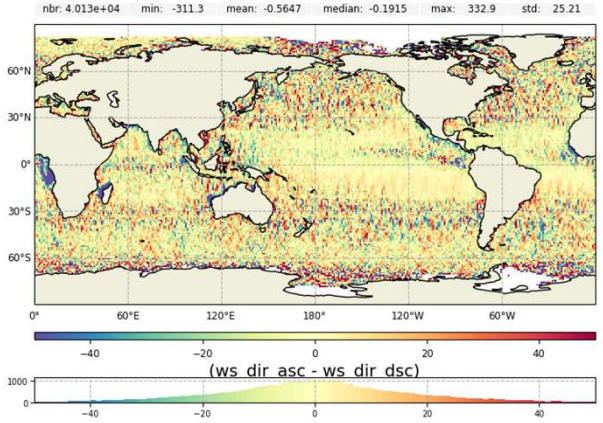
S3A - SARM/PLRM (range+SSB) differences, (ASC-DSC) maps (MEAN in cm)
Cycles 59 to 86



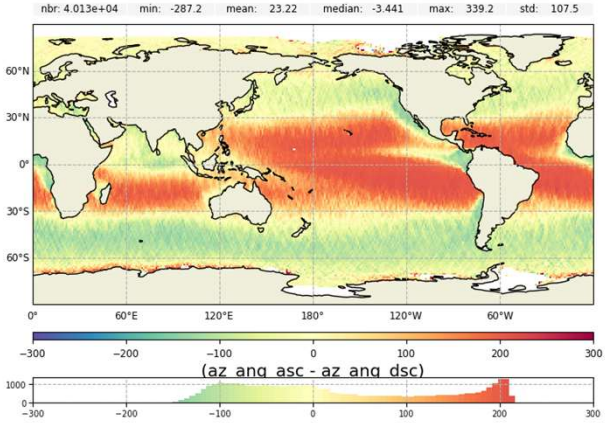
S3A - Along-track Wind projection, (ASC-DSC) maps (MEAN in m/s)
Cycles 59 to 86



S3A - Wind Direction differences, (ASC-DSC) maps (MEAN in degree)
Cycles 59 to 86

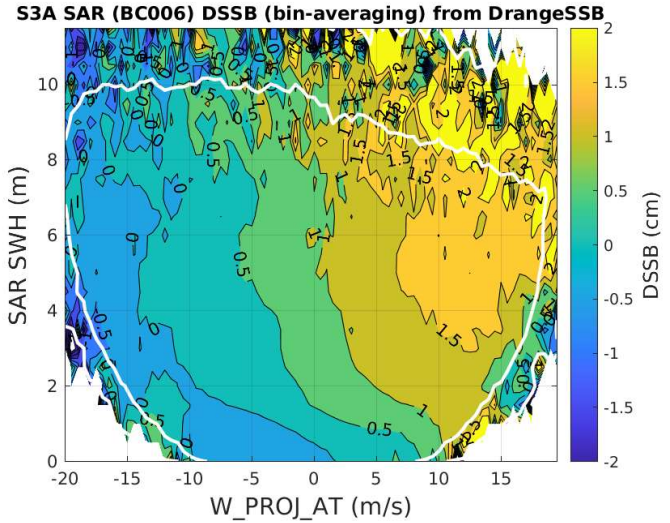


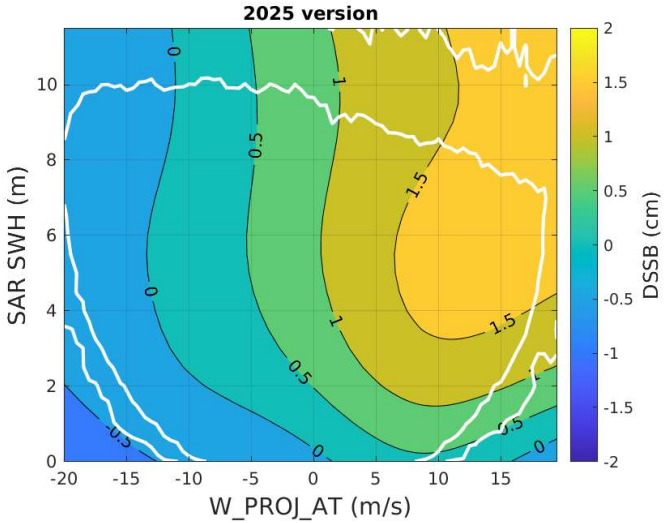
S3A - Azimuth angles differences, (ASC-DSC) maps (MEAN in degree)
Cycles 59 to 86

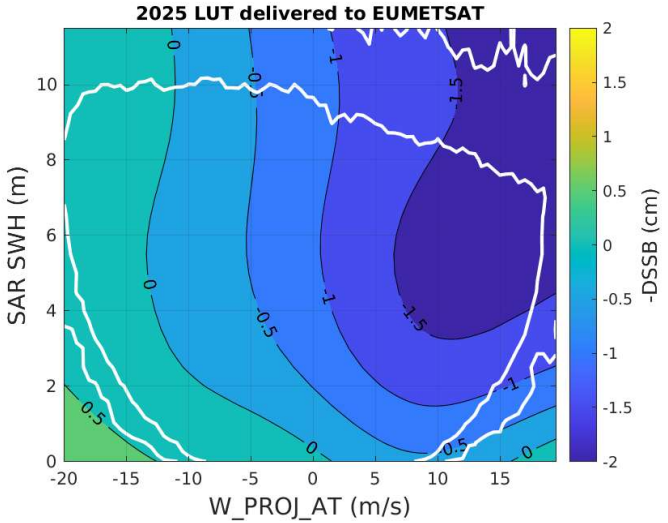


- The main driver is the wind vector projected onto the satellite track (W_PROJ_AT).

SAR ΔSSB 2D models







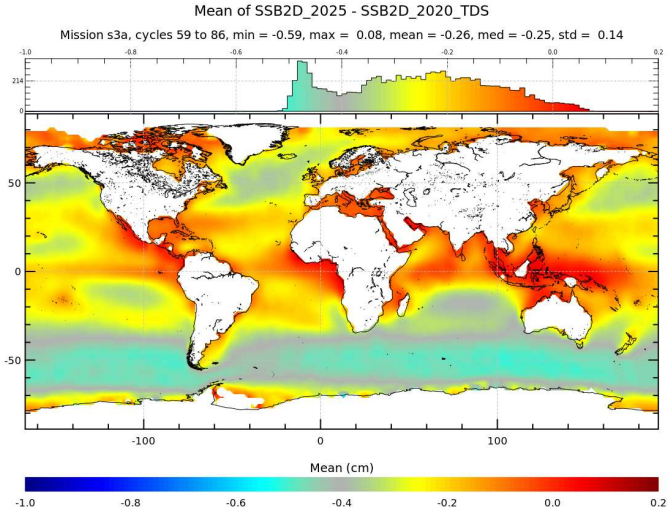
Az angle in]90, 270[° including the upwind situation == 180° (→←)

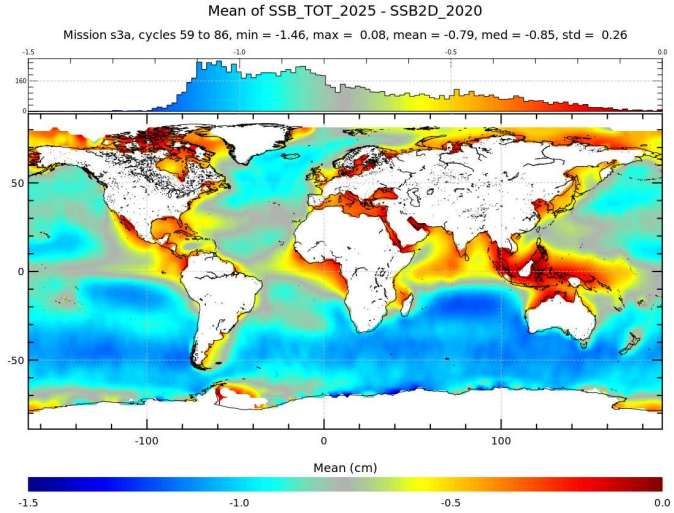
the crosswind situations (↑→)

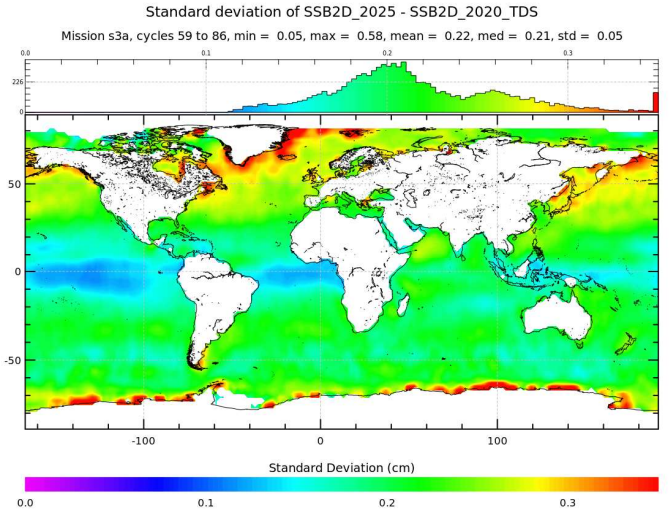
Az angle < 90° or > 270° including the downwind situation ==0° (→→)

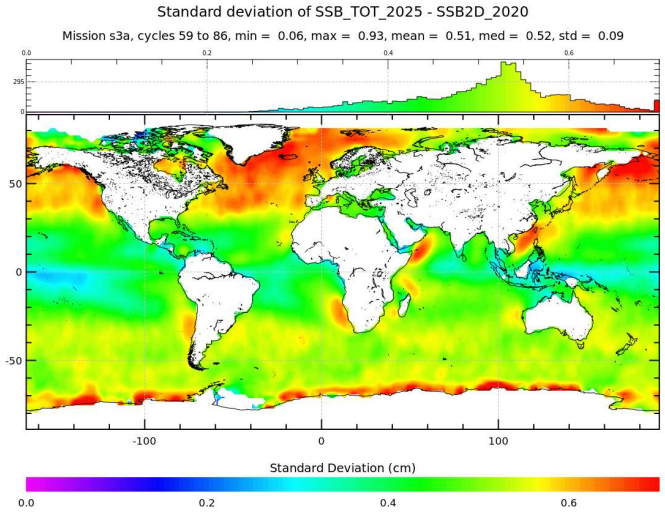
- The model is developed with the Feng et al [2010]'s approach (spline-based non-parametric estimation).
- The final LUT contains (-ΔSSB) to respect the chosen convention : total SSB = standard SSB + ΔSSB

SAR SSB models comparison



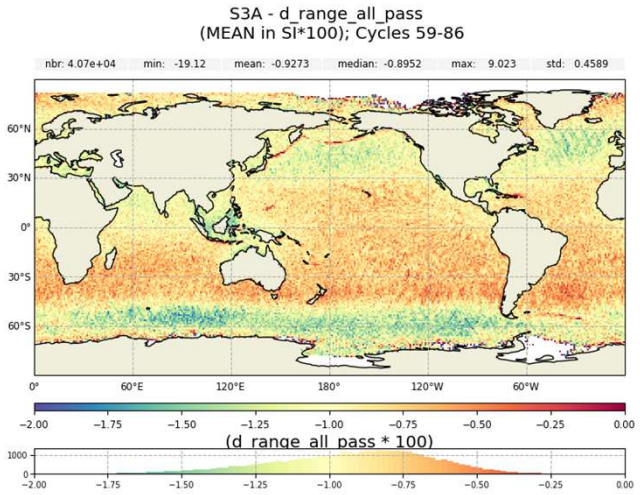


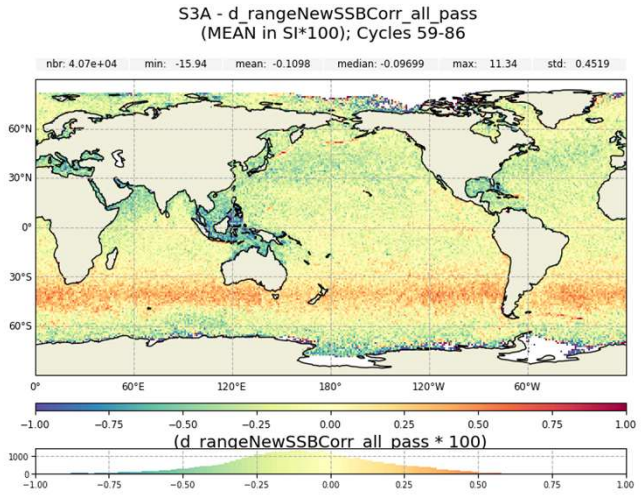


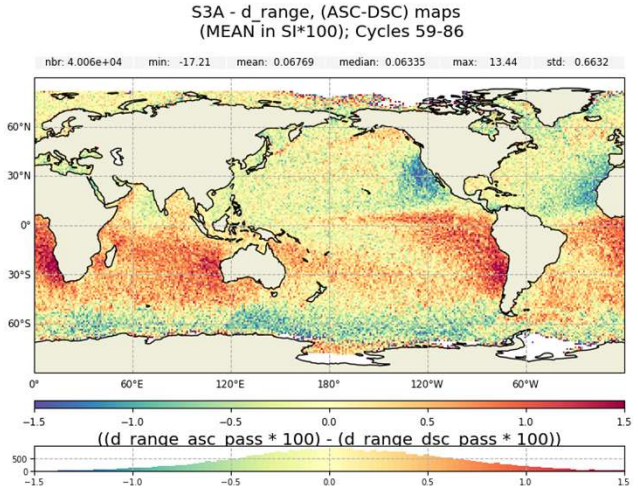


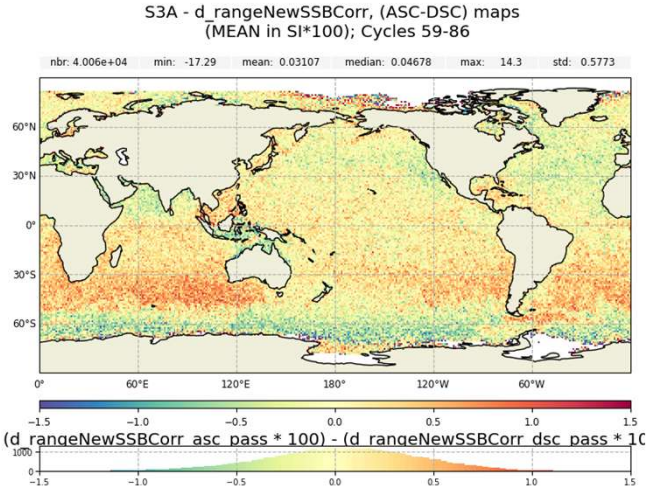
- The geographical patterns in the two maps of average differences are not identical, highlighting the significant influence of the ΔSSB component on the overall SSB update.

SAR – PLRM differences (only range or range+SSB)



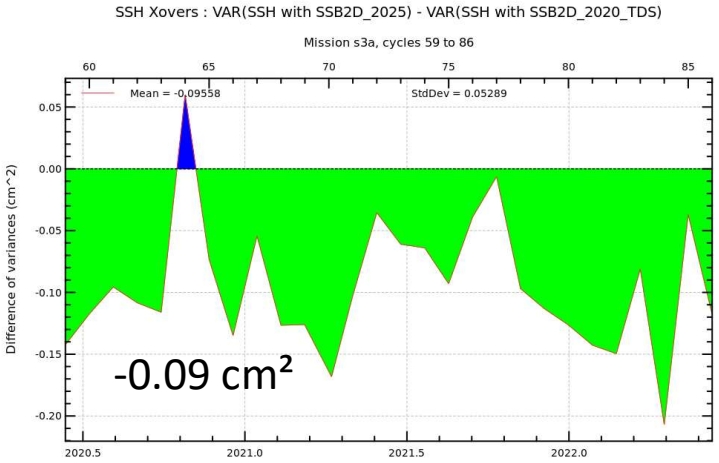


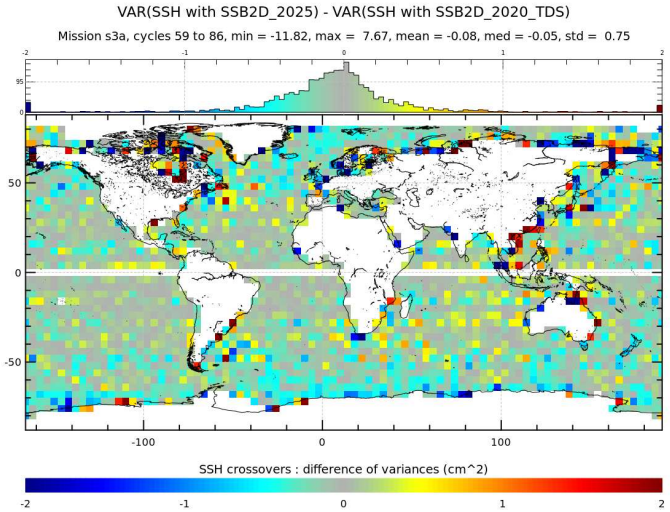




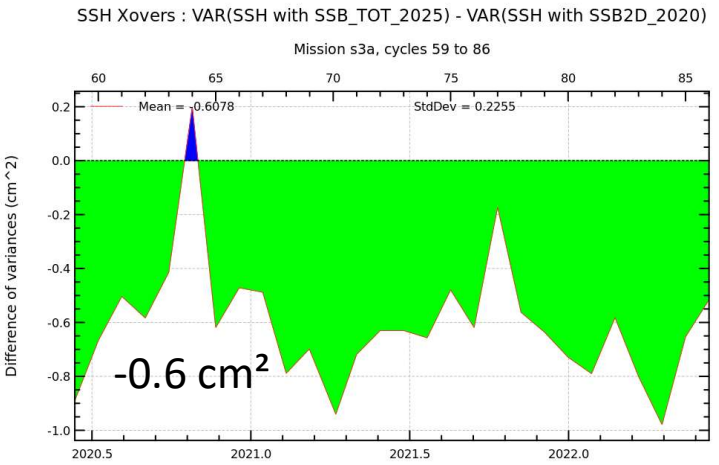
- The total SSB correction removes most patterns, but some inconsistencies persist in the Southern Ocean.

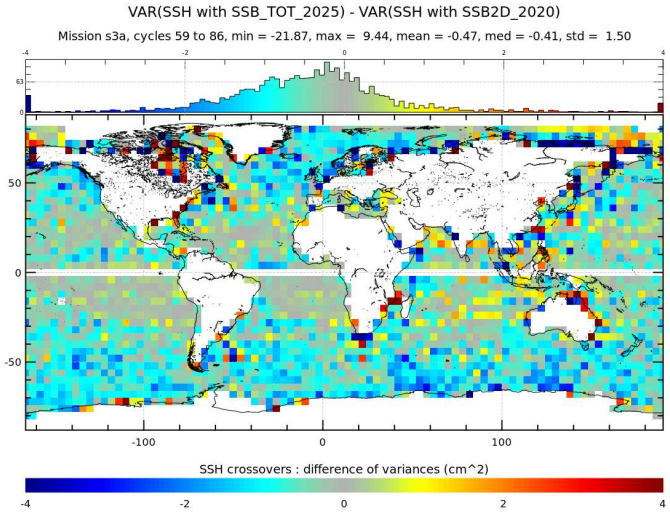
Crossover dataset



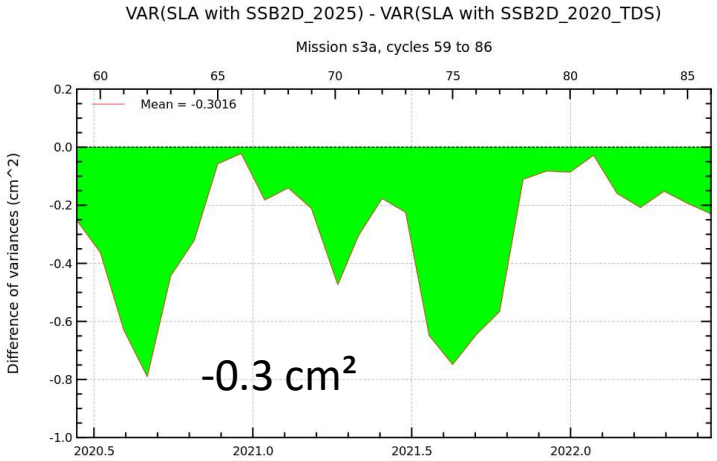


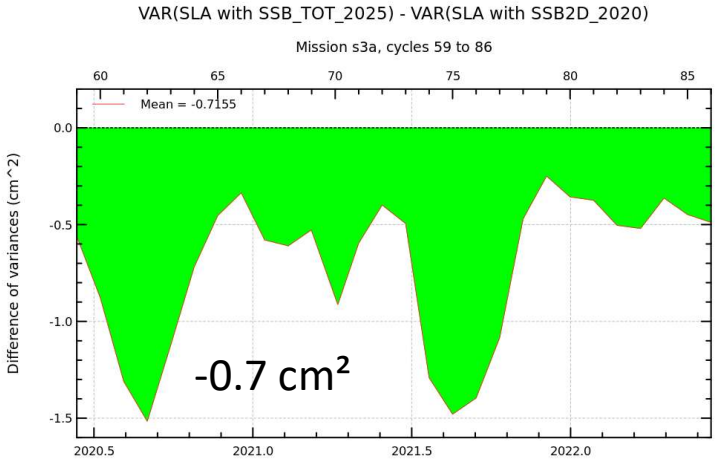
- The new SSB corrections, whether using the 2D SSB or the total SSB, introduce a clear reduction in variance, demonstrating improved precision in Sentinel-3A SAR SLA data.

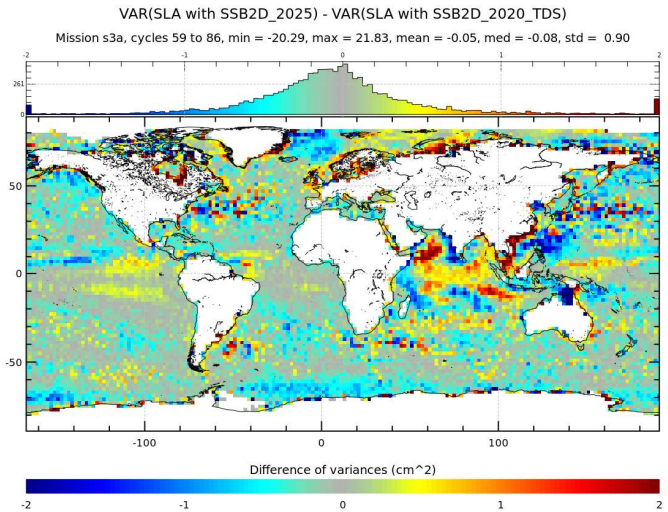


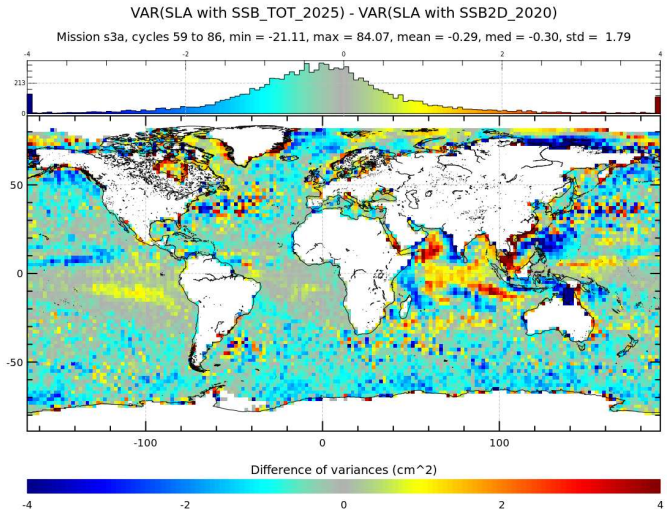


SLA dataset









- Same observation as on the previous slide.

Conclusion

- **New 2D SSB correction**
  Similar to the 2020 version used in BC005, with differences mostly between –0.9 cm and +0.3 cm. Slight improvement in Sentinel-3A SSH precision.
- **ΔSSB correction**
  Significantly reduces wind-directional effects in SAR BC006 data. Improves geographical consistency between SAR and PLRM SSH.
- **Total SAR SSB correction**
  Will replace standard SAR 2D SSB correction in the upcoming Marine Baseline Collection 006 for Sentinel-3.
- **Remaining inconsistency**
  A new discrepancy between SAR and PLRM data is observed, mainly in southern high latitudes. Further investigation is needed to understand this feature. A possible link with orbital height rate was suggested.

Way forward

- Recommendation to compute such additional ΔSSB correction also for Sentinel-6 SAR dataset.

- Recommendation to develop SAR SSB model independently from the PLRM or LRM data to avoid assimilation of imperfections coming from the other dataset.

opas eyes on our Ocean

PROGRAMME OF THE EUROPEAN UNION

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IMPLEMENTED BY EUMETSAT

CLS COLLECTE LOCALISATION SATELLITES

University of New Hampshire

Thank you

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For further information, please see Activity 7 description at:
https://www.eumetsat.int/copernicus-altimetry-services-copas
and associated documents:
https://www.eumetsat.int/media/53046,
https://www.eumetsat.int/media/52425,
https://www.eumetsat.int/media/52426

2025 OSTST meeting

15-16 November 2025