4DVarNet : Data-driven mapping of Ocean Surface Topography using SWOT altimetry

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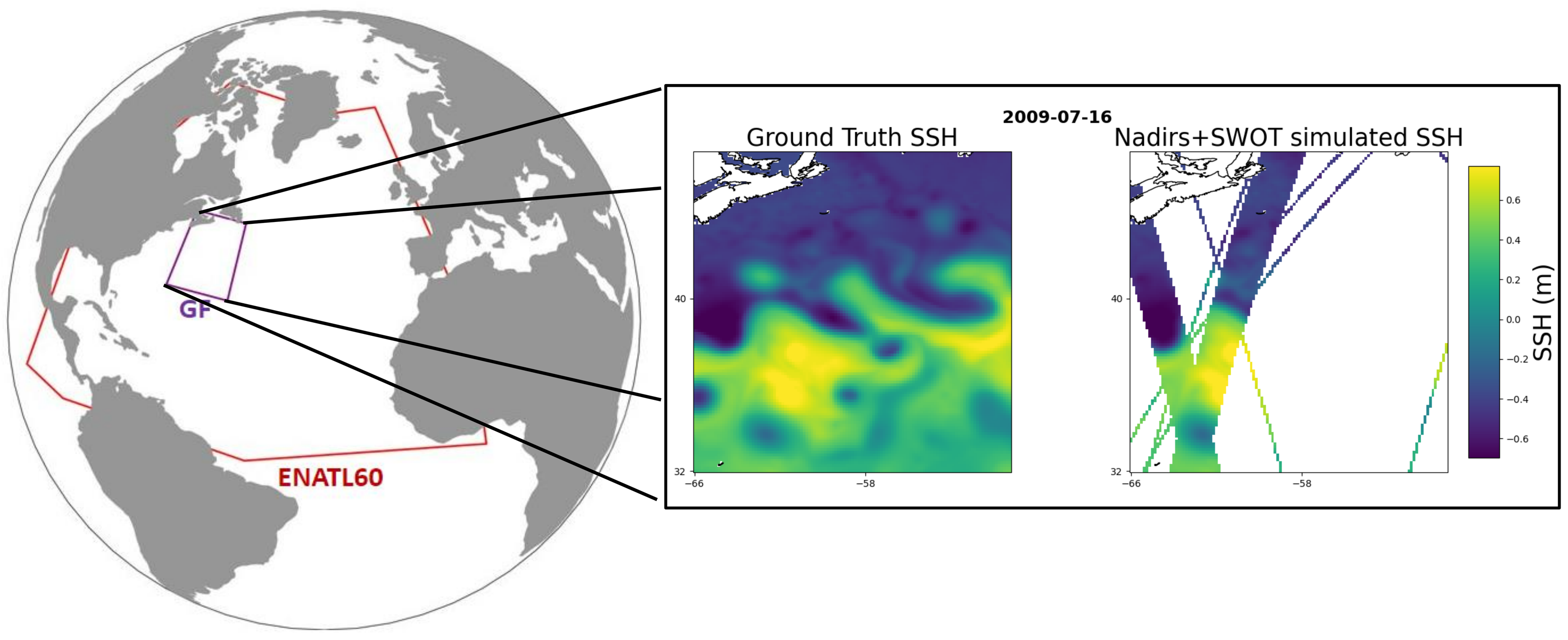
Introduction & Context

Until now, only **OSSEs** have been used to assess and refine the **impacts** of **Karin** data in **mapping systems**. These assessments included various mapping algorithms such as DUACS (Le Traon et al., 1998), MIOST (Ubelmann et al. 2021), DYMOST (Ubelmann et al. 2015), BFN-QG (Le Guillou et al. , 2021) and 4DVarNet (Fablet et al.,2021). Here we present the **first mapping** studies conducted using **real SWOT Karin** observations with **4DVarNet** and **MIOST** methods. The main objectives of these studies were to **assess** the **performance** of mapping systems with **real SWOT data**, especially on **fine scale** ocean structures, and to quantify the contribution of SWOT Karin during the CalVal phase in experimental mapping method 4DVarNet . The altimetry **constellation** used in this study spans from **March 2023 to July 2023** and includes **7 nadirs** (Cryosat-2, Haiyang-2B, Sentinel-3A, Sentinel-3B, Sentinel-6, Jason 3, SWOT nadir) and **1 Karin** instrument (SWOT).

Input data & Methods

Supervised training of 4DVarNet using eNATL60 data

In this study, we use the **4DVarNet framework** introduced by Fablet et al. (2021) relying on a **neural network** architecture backed on a **variational formulation**. This framework consists in an end-to-end **trainable architecture** to which we apply a **supervised learning** strategy. This involves to **minimize** a **training loss** between the true state (ground truth) and its reconstruction made by the neural network. We use the same 4DVarNet-SSH parameterization and learning settings as those presented by Beauchamp et al. (2023).

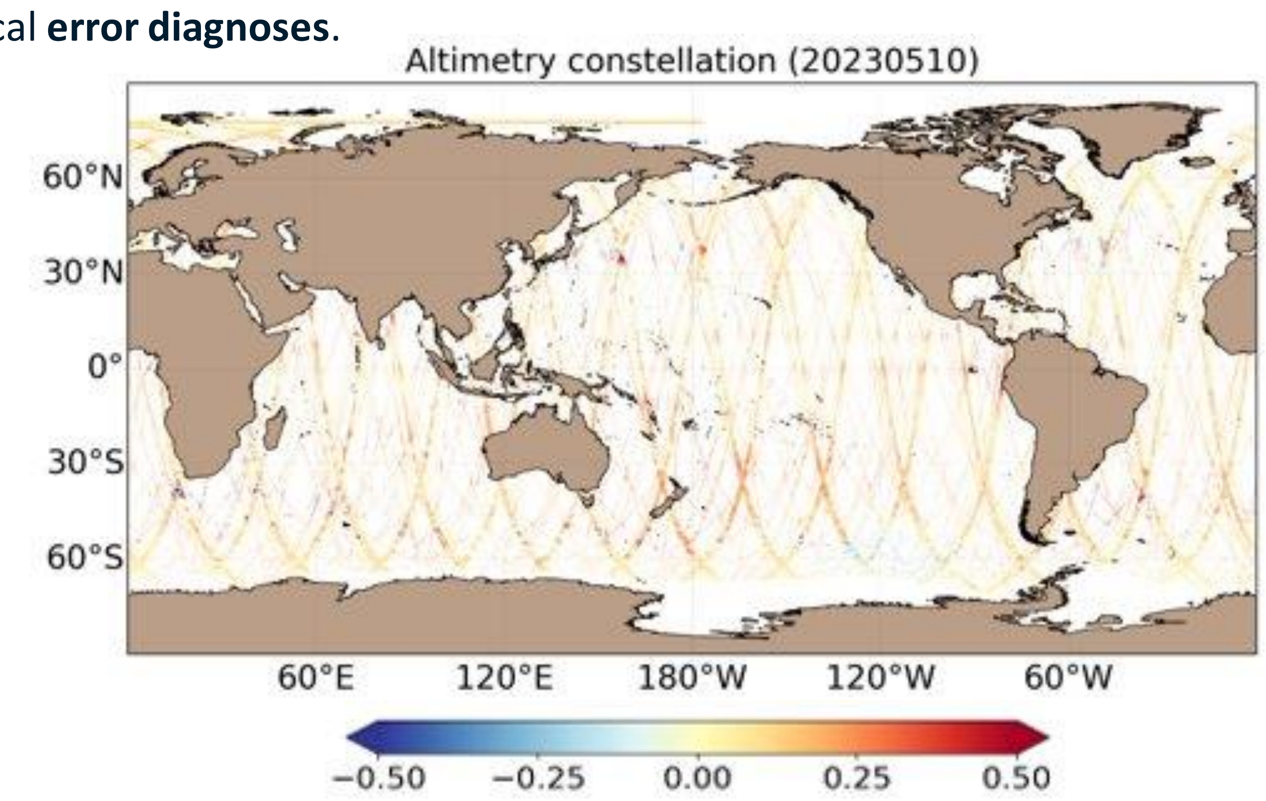


Enatl60 modelled SSH over the GF training domain for a day (16/07/2009) of the training period : ground truth (left), Nadirs + SWOT simulated observations (right). Right panel serves as input of 4DVarNet while left is the target. Simulated constellation includes 5 nadirs (H2B, Jason 3, Sentinel 3A & 3B, and Sentinel 6) and SWOT (nadir + Karin). GF: latitude=[32.°, 46.875°] & longitude=[-66.°, -51.125°] , ENATL60: latitude=[2°,78°] & longitude=[-100°,0°].

In the present study, we use the **eNATL60** modelled **SSH** as the **ground truth**, and 4DVarNet takes as input the **simulated altimetric data** created by interpolating the ocean model on the coordinates from the ground tracks of **5 nadirs** and **1 SWOT**. We consider a **five months** long **training period** from 01/07/2009 to 31/12/2009, and the modelled SSH is downgraded to the resolution of **1/8°** on a 2D regular grid. The model is **trained** on a relatively **small region** of 14.875°x14.875° in the **Gulf Stream current** (GF domain). As we aim to latter **generalize** this model to the **North Atlantic basin** (ENATL60 domain) using real altimetric data, we train the model with **normalized SLA** to enable more **homogeneous** ocean **dynamics** across the basin.

Inference on real altimetric dataset

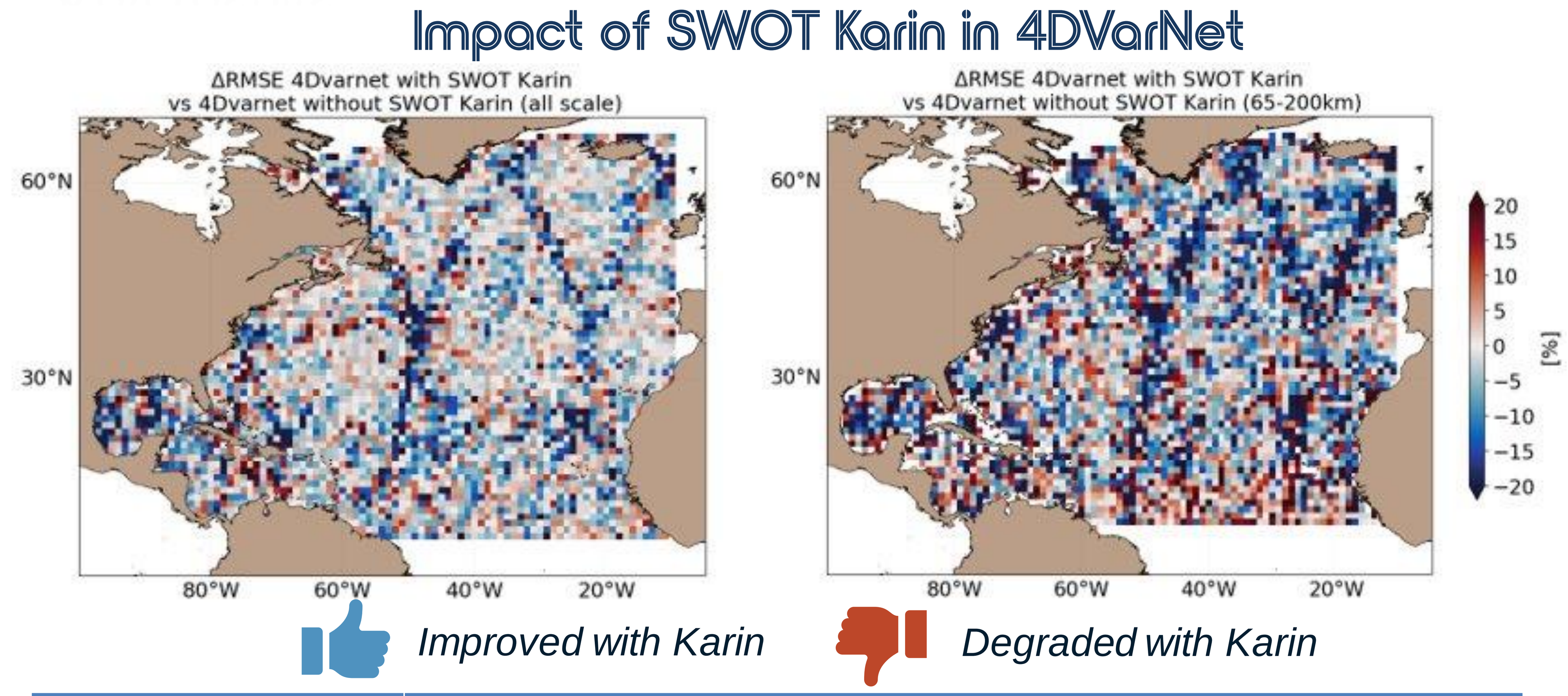
The **trained 4DVarNet** model is ready to be used to perform SSH **reconstructions** with **real altimetric** data as input. 4DVarNet reconstructions are solely generated over the ENATL60 domain as the algorithm is still in development and not yet ready for global use. We also compute the **MIOST** reconstructions (Ubelmann et al. 2021) over the same domain. As **3 months** of **Level-3 SWOT Karin** (1-day repeat orbit) have been processed in the **L3-DUACS system** (see SWOT L3 overview poster, Y. Faugère), we use a constellation spanning from **March 2023 to July 2023**, and including **7 nadirs** (CS-2, H2B, S3A, S3B, S6, J3, SWOT nadir) and **1 Karin** (SWOT) . **Saral/Altika** is kept as **independent** data to compute statistical **error diagnoses**.



Real constellation SLA measurements used as input of trained 4DVarNet and MIOST mapping algorithms, on 10/05/2023.

Key results

Impact of SWOT Karin in 4DVarNet

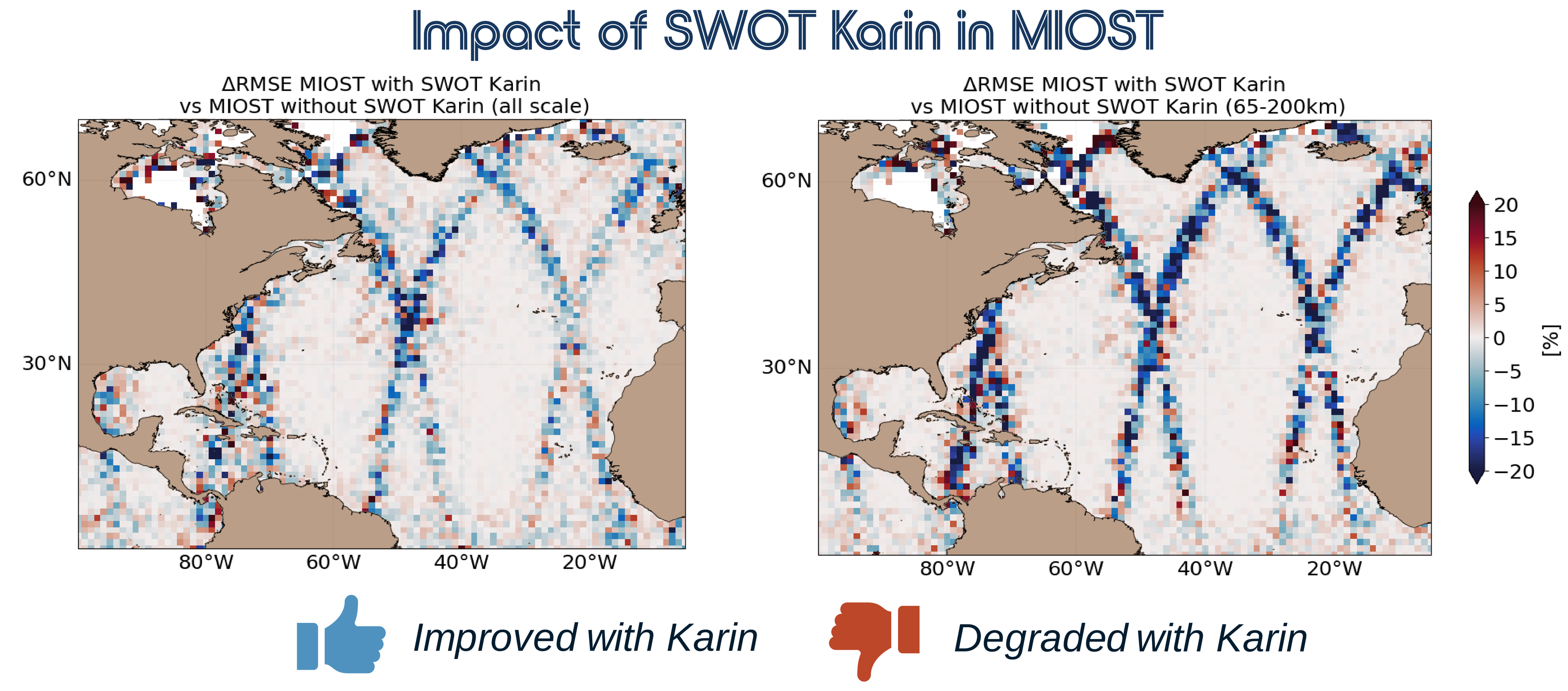


	Off shore(>200km) low variability (<0.02m²)		
	In swath [%]	Near swath [%]	Outside swath [%]
All Scale	-5.34	-3.92	-1.67
65-500 km	-7.13	-7.12	-1.89
65-200 km	-6.79	-6.74	-1.36

	Off shore(>200km) high variability (>0.02m²)		
	In swath [%]	Near swath [%]	Outside swath [%]
All Scale	-17.46	-4.79	-0.07
65-500 km	-17.88	-3.12	0.37
65-200 km	-18.09	-6.45	-0.77

Average loss or gain (%) of RMSE in 4DVarNet reconstructions when adding the SWOT Karin instrument to the constellation, over the ENATL60 domain, from 30/04/2023 to 01/07/2023. Loss of RMSE means that Karin improves the reconstructions.

Impact of SWOT Karin in MIOST



	Off shore(>200km) low variability (<0.02m²)		
	In swath [%]	Near swath [%]	Outside swath [%]
All Scale	-3.44	-2.34	-0.12
65-500 km	-8.45	-4.7	0.22
65-200 km	-8.15	-5.12	0.04

	Off shore(>200km) high variability (>0.02m²)		
	In swath [%]	Near swath [%]	Outside swath [%]
All Scale	-14.51	-7.44	-0.23
65-500 km	-17.46	-9.91	-0.24
65-200 km	-16.85	-10.4	-0.14

Average loss (-) or gain (+) of RMSE (%) in MIOST reconstructions when adding the SWOT Karin instrument to the constellation, over the ENATL60 domain, from 30/04/2023 to 01/07/2023. Loss of RMSE means that Karin improves the reconstructions.

Conclusion & Perspectives

As the first **3 months** of **Level-3 SWOT Karin** (1-day repeat orbit) have been processed in the **L3-DUACS system**, we were able to produce the **first SSH mappings** using **real SWOT Karin** observations. Two **experimental mapping** methods were tested to reconstruct the ocean surface topography using SWOT data. The experiments indicate that the systems are **ready** to **assimilate Karin** data in addition to the current nadir constellation. Even though 4DVarNet reconstructions could only be carried out at the scale of the **North Atlantic basin** (the algorithm is still in development and not yet ready for global use), we can draw common initial conclusions regarding the impact of Karin. For both **MIOST** and **4DVarNet** methods, Karin data enables a **reduction** of **15-20%** in **RMSE** (Root Mean Square Error) in **energetic regions**, and approximately **5%** reduction **elsewhere**. As the SWOT satellite transitions to a **21-day mode**, it will offer **swath** data **coverage** across **all regions** within the basin (with, however, a reduced revisit rate). Consequently, it is reasonable to anticipate that the 21-day SWOT data will lead to a **more consistent enhancement** in the **basin-scale** performance of the mapping algorithm such as 4DVarNet or MIOST. Moreover, **developments** are currently underway to apply 4DVarNet at a **global scale** in the near future, later allowing for the quantification of SWOT's contribution to this method on a global scale. This will also help address an ongoing question that remains unanswered: **which method** of mapping ocean height will be the **most suitable** to make the best use of the **revolutionary swath data** provided by the SWOT satellite's Karin instrument. It could be considered to structure **data challenges** focusing on the **contribution** of **Karin** data in regional and global **mappings** so that **different working groups** on mapping methods can compare their approaches (see for example CMEMS and CNES funded projects : https://ocean-data-challenges.github.io/).

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