# Acquisition of the Significant Wave Height from CFOSAT SWIM Spectra through a Deep Neural Network and its Impact on Wave Model Assimilation

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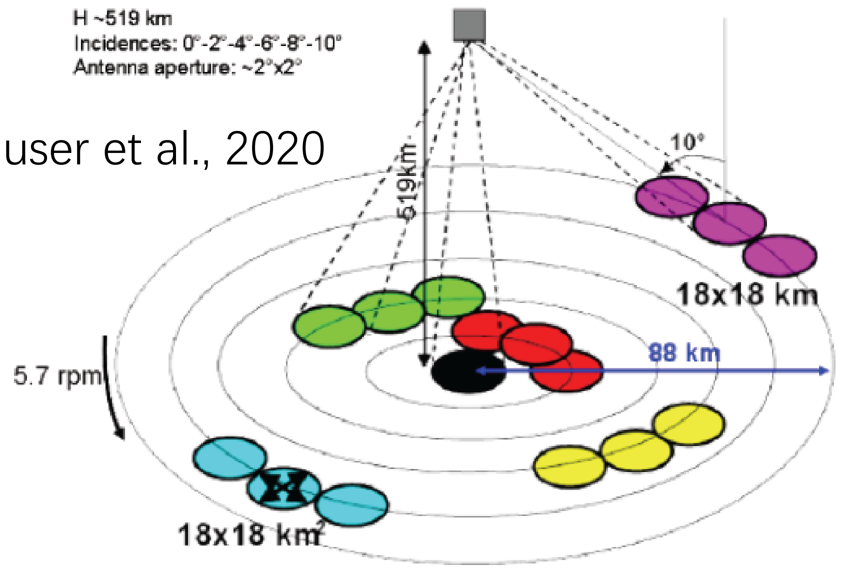
# Introductions

- The accuracy of wave model simulations can be **effectively improved** by **assimilating** all available observations, such as those from spaceborne altimeters.
- Due to the essential characteristics of waves, the impact of wave assimilation is **highly related to the amount of data.**
- A unique wave monitoring instrument, the **SWIM onboard CFOSAT can provide 2 columns of 'boxes'** of wave directional spectra within the wavelength limits of **70m and 500 m wavelengths** in addition to nadir observations. Thus, SWIM has the **potential to provide more positive** impacts on wave assimilation by providing more observations from these boxes.
- The SWIM boxes obtain only partial wave energy within certain wavelengths. **A model based on a deep neural network (DNN)** is constructed in this study to **retrieve the total SWH** from these SWIM box observations. And investigate the impacts to wave assimilations

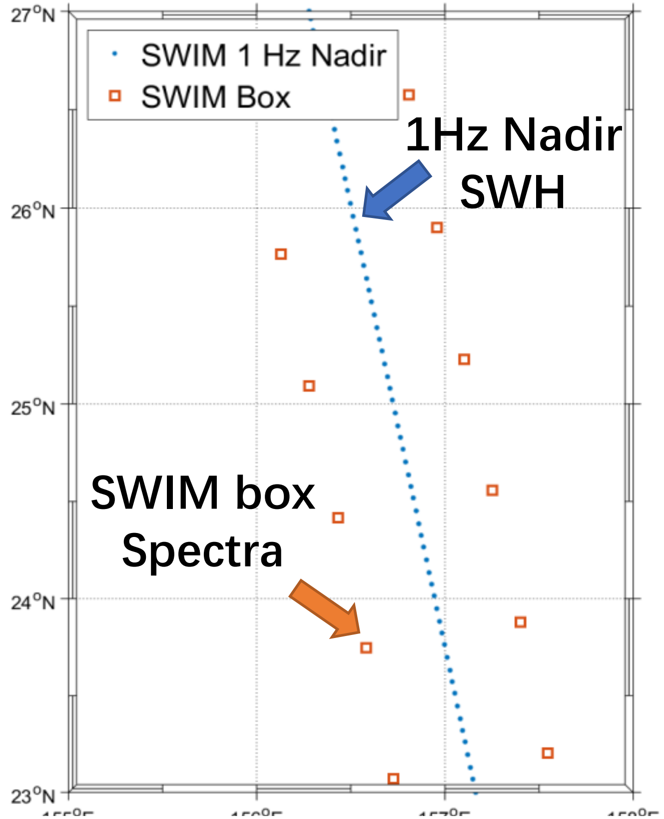
# SWIM Observation setups and Main Objective

Hauser et al., 2020




SWIM beam rotation and incidence angles.

**Setups of SWIM observations: 3 beams with incidence angle of 6°, 8° and 10°**

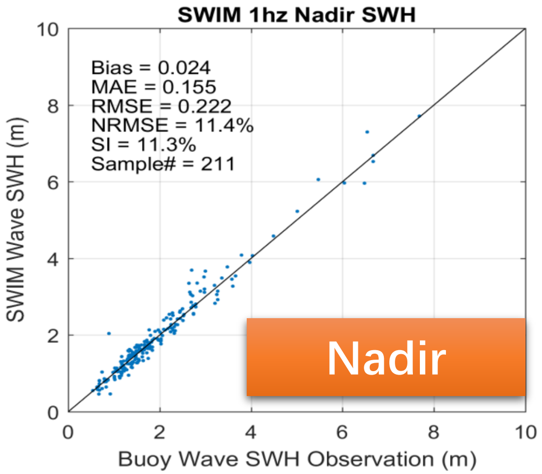


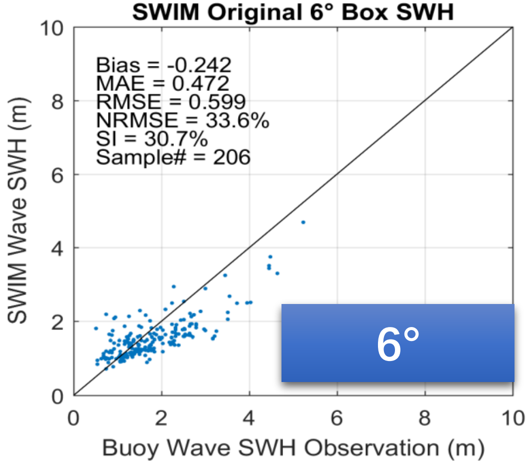

**Objective:**

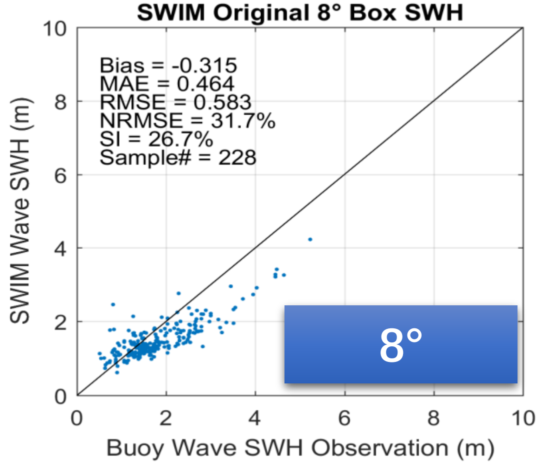
**SWIM Spectra Energy**
(wavelength 70 to 500m)

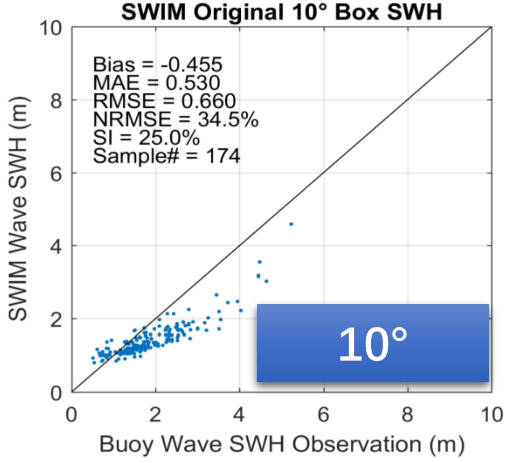
**Total SWH**

**Which Beam is the best?**

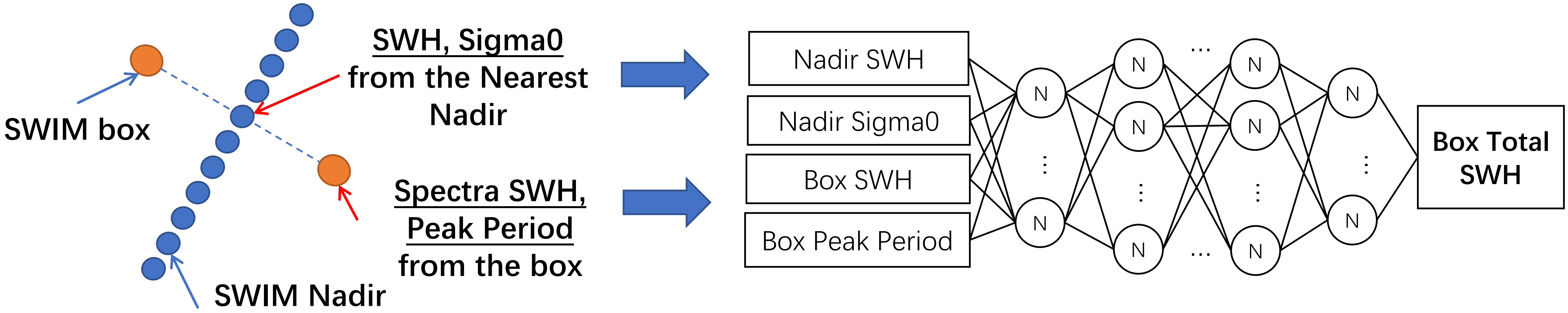


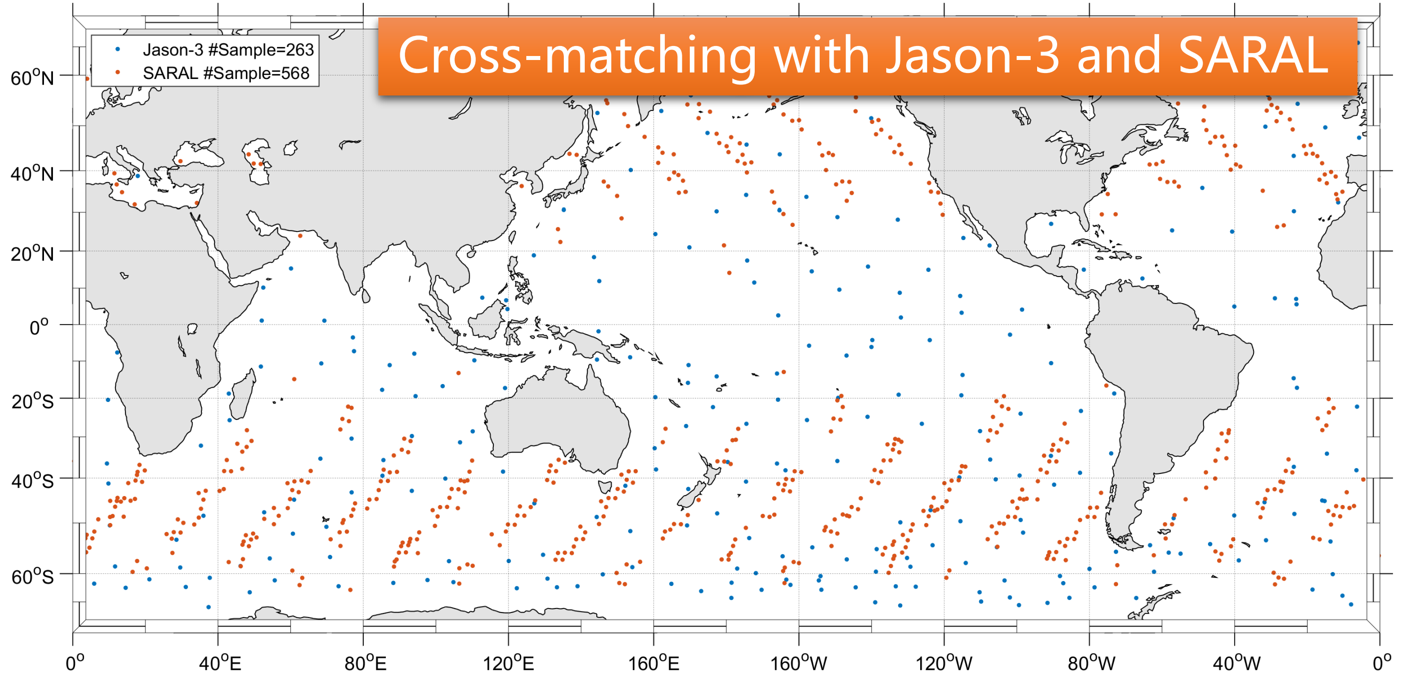



# Methodology of DNN of retrieving the SWH from SWIM box

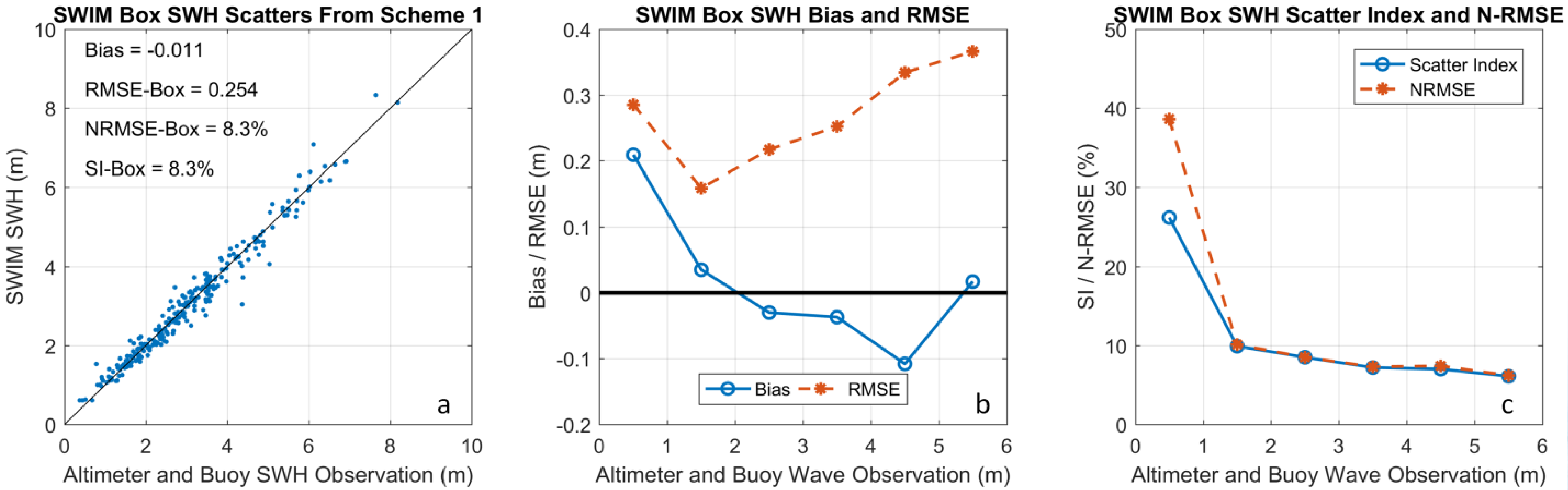



- With the **SWH from the integrated spectra energy** and **peak period** from the SWIM boxes and the **SWH and sigma0** from the nearest nadir points as inputs, the DNN model is trained using cross-matched SWH observations with Jason-3, SARAL and NDBC buoys as the reference.
- We use **75%** of the 1005 matchups for the **training data** and the other **25%** randomly selected matchups as **independent validation data** to verify the trained DNN model.

# Different Accuracies of DNN models with Different Inputs

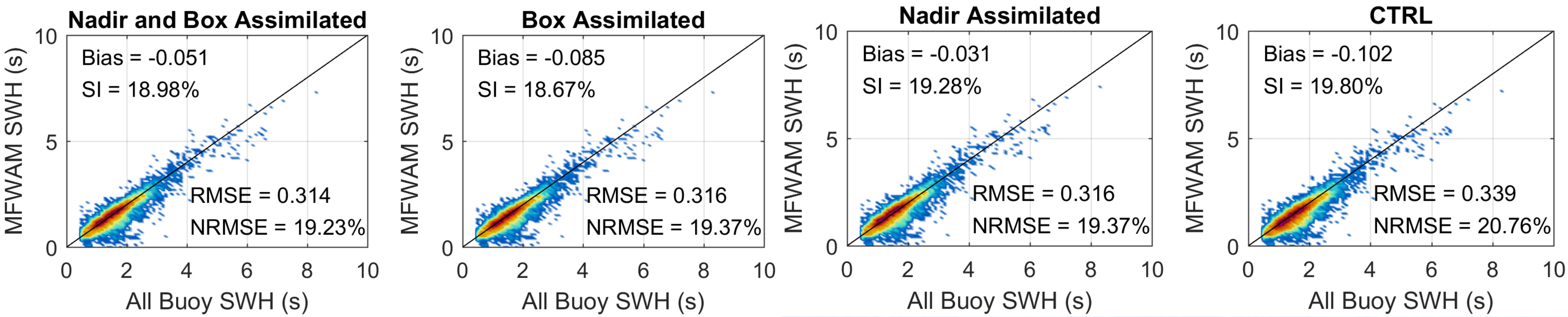
| Schemes | Inputs of DNN | Bias (m) | RMSE(m) | N-RMSE(%) | Scatter Index(%) |
|---|---|---|---|---|---|
| 1 | Nadir SWH, Nadir sigma0, Box SWH, Box peak period | -0.011 | 0.254 | 8.3 | 8.3 |
| 2 | Box SWH, Box peak period | 0.057 | 0.266 | 8.7 | 8.5 |



# Schemes of Assimilation experiments (NDBC / French Buoys)

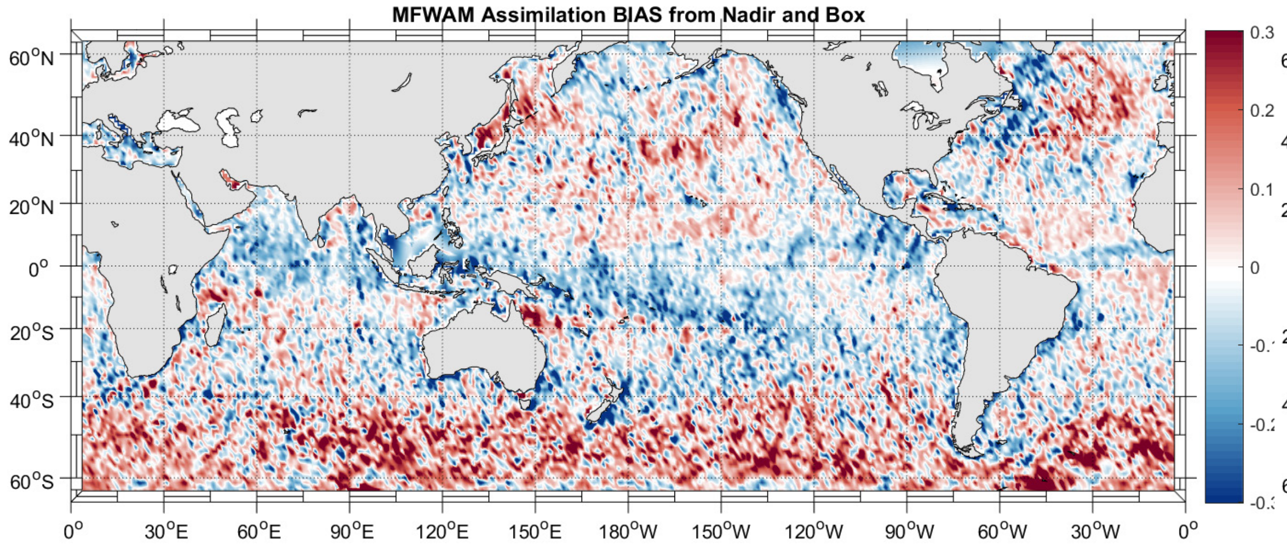
$$bias = \frac{\sum_{i=1}^{N}(Hs_i - Hs_{Ni})}{N} \qquad RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Hs_i - Hs_{Ni})^2}{N}} \qquad NRMSE = 100\% \cdot \frac{\sqrt{\sum_{i=1}^{N}(Hs_i - Hs_{Ni})^2 / N}}{\overline{Hs_{Ni}}} \qquad SI = 100\% \cdot \frac{\sqrt{\sum_{i=1}^{N}[(Hs_i - \bar{Hs}) - (Hs_{Ni} - \bar{Hs}_N)]^2 / N}}{\overline{Hs_N}}$$

| Scheme | Assimilated | BIAS | RMSE | N-RMSE | Scatter Index |
|---|---|---|---|---|---|
| A | Nadir SWH, **Box SWH from DNN** | -0.051 | 0.314 | 19.23 | 18.98 |
| B | **Box SWH from DNN** | -0.085 | 0.316 | 19.37 | 18.67 |
| C | Nadir SWH | -0.031 | 0.316 | 19.37 | 19.28 |
| CTRL | No Assimilation (Control Run) | -0.102 | 0.339 | 20.76 | 19.80 |

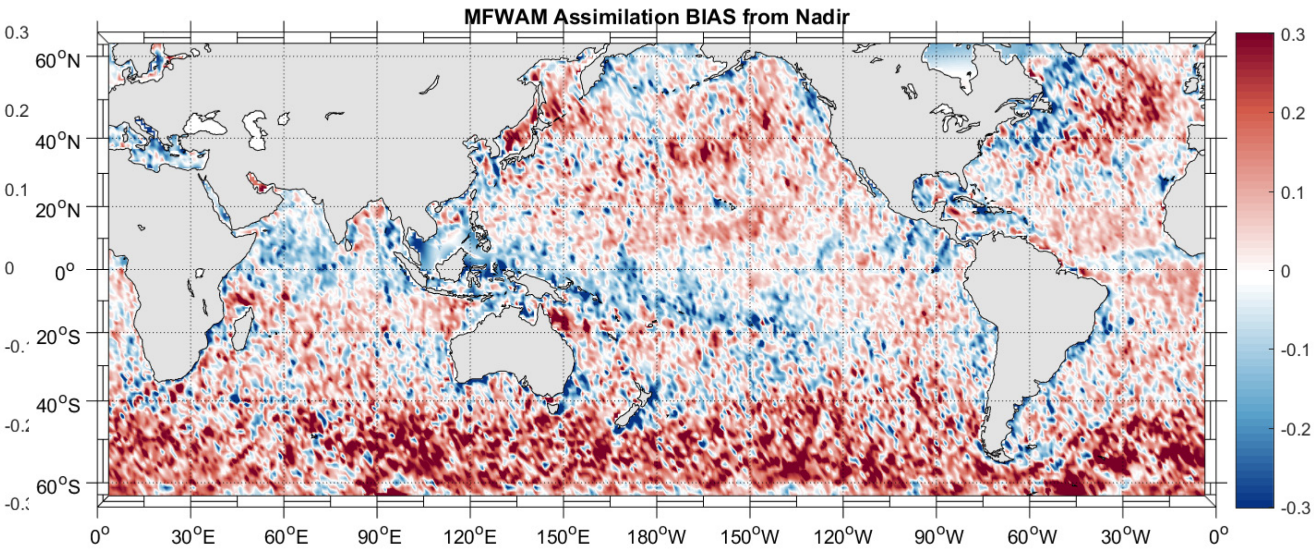



The NDBC and French buoys' SWH observations are used as the reference to assess the accuracy of each run.

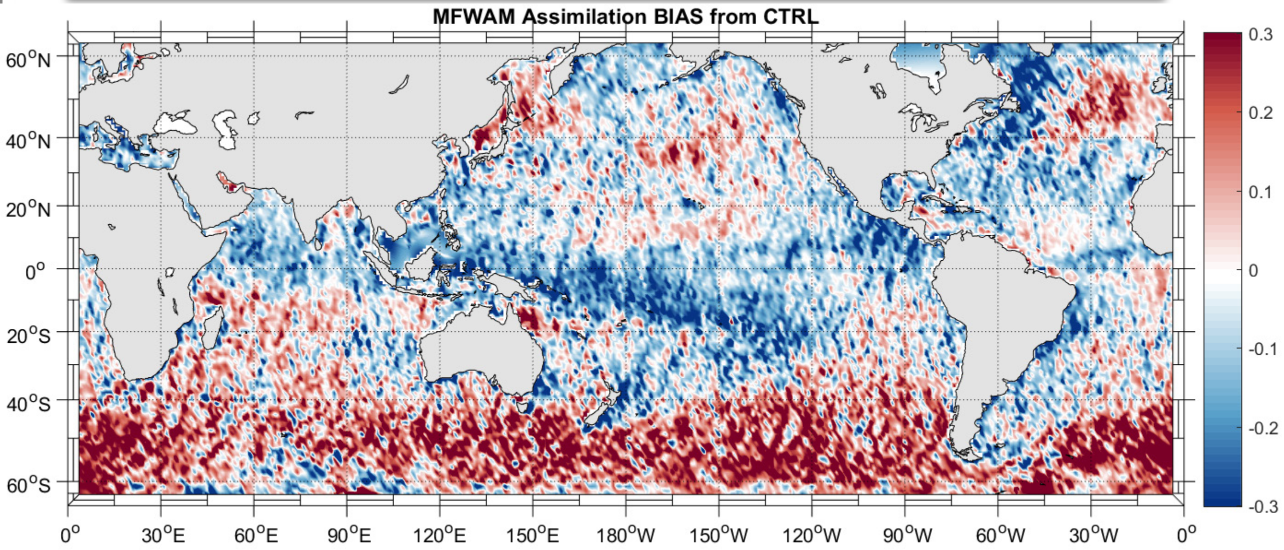
# BIAS of Assimilation Experiments (Jason-3/SARAL as the Reference)




Run A: DNN box SWH + Nadir SWH



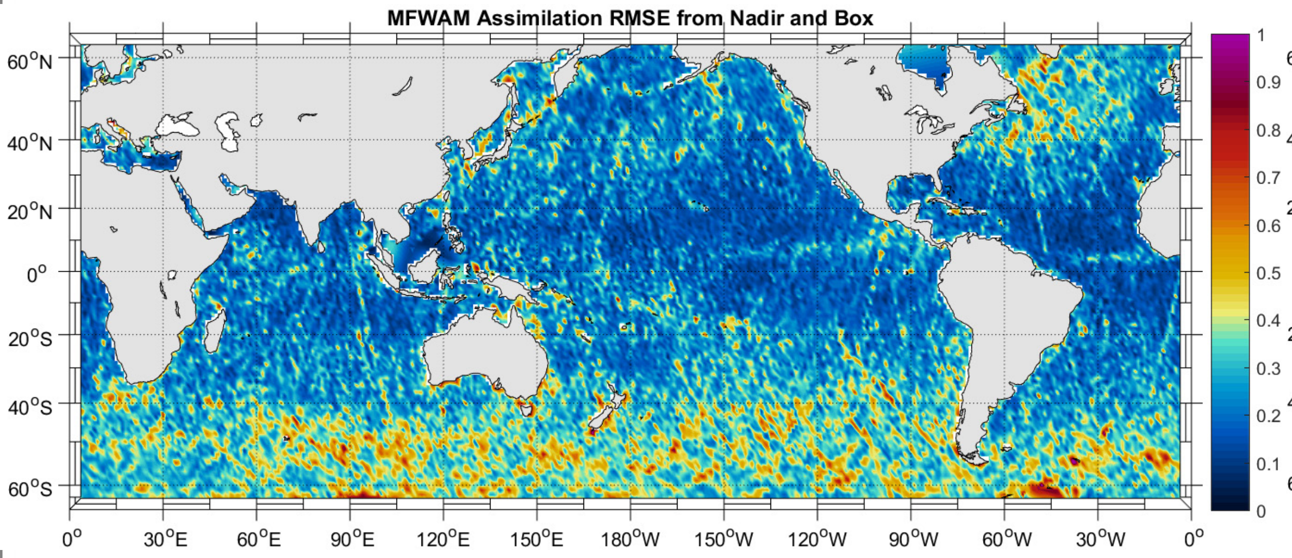

Run C: Nadir SWH



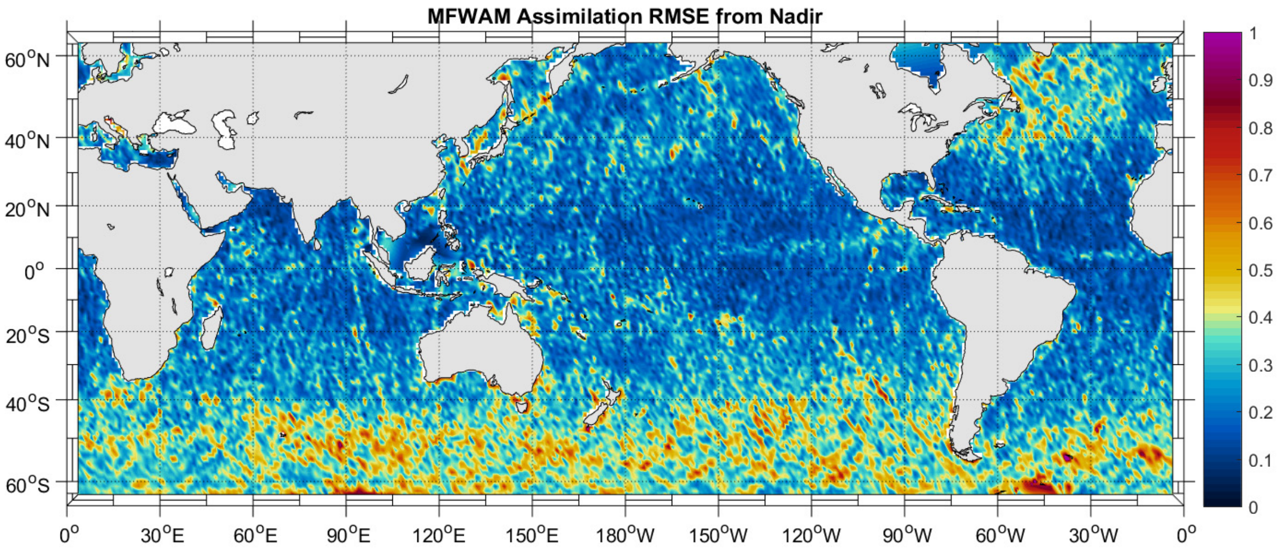

CTRL Run

- To investigate the assimilation impact on global wave systems, the observations from Jason-3 and SARAL in May 2019 are used as the reference to perform a global validation.
- We pay more attention to the difference between runs A and C, which constitute the assimilation of nadir SWH and box SWH and the assimilation of nadir SWH only, respectively.

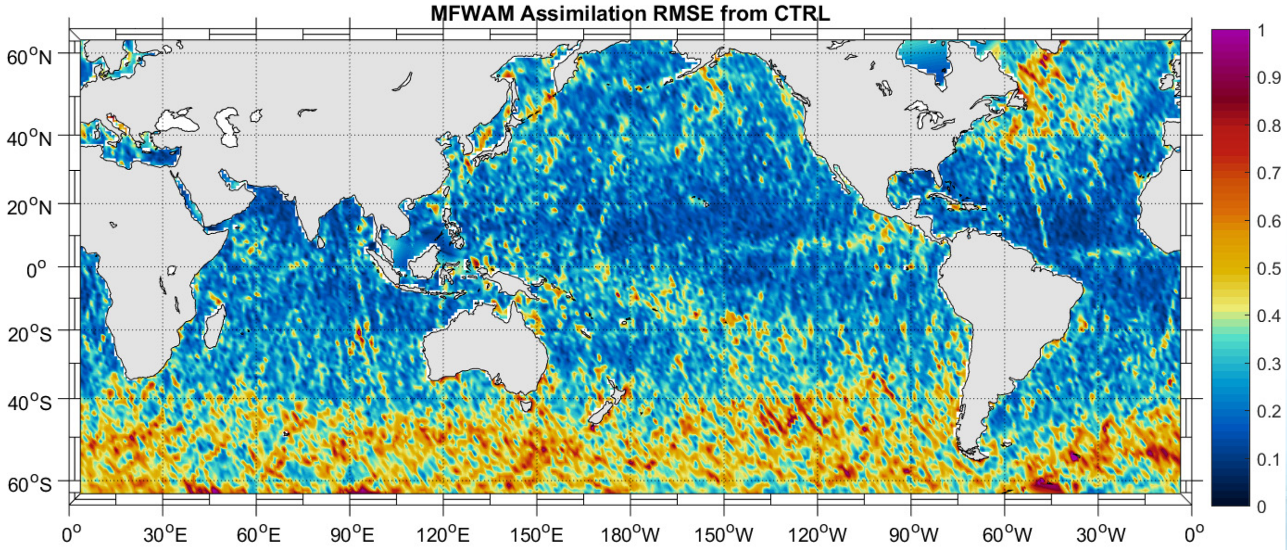
# RMSE of Assimilation experiments (Jason-3/SARAL as the Reference)




Run A: DNN box SWH + Nadir SWH




Run C: Nadir SWH




CTRL Run

■ Relatively high RMSEs are found in the oceans of the Southern Hemisphere and the Northwest Atlantic. Good reductions in the RMSE in these 2 regions are observed, which demonstrate the positive impacts of assimilation.

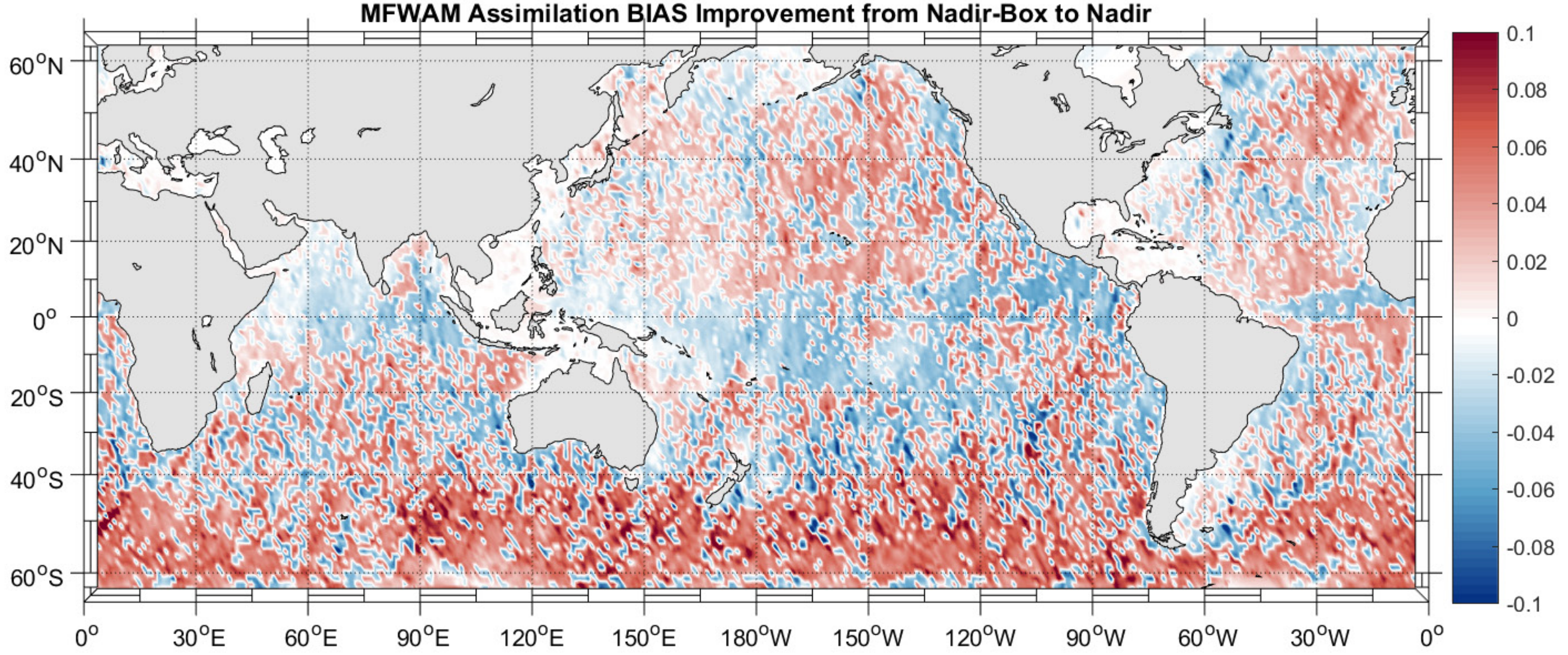
■ When Run A and Run C are compared, with the additional SWIM box SWH data assimilated into the wave model, the RMSE in the North Atlantic and Southern Ocean in run A are lower than those in run C.

# Assimilation Improvements brought by the SWIM DNN SWH

To more clearly show the positive assimilation effect of adding the SWIM box SWH, the improvements in the bias, RMSE and scatter index are defined as follows:

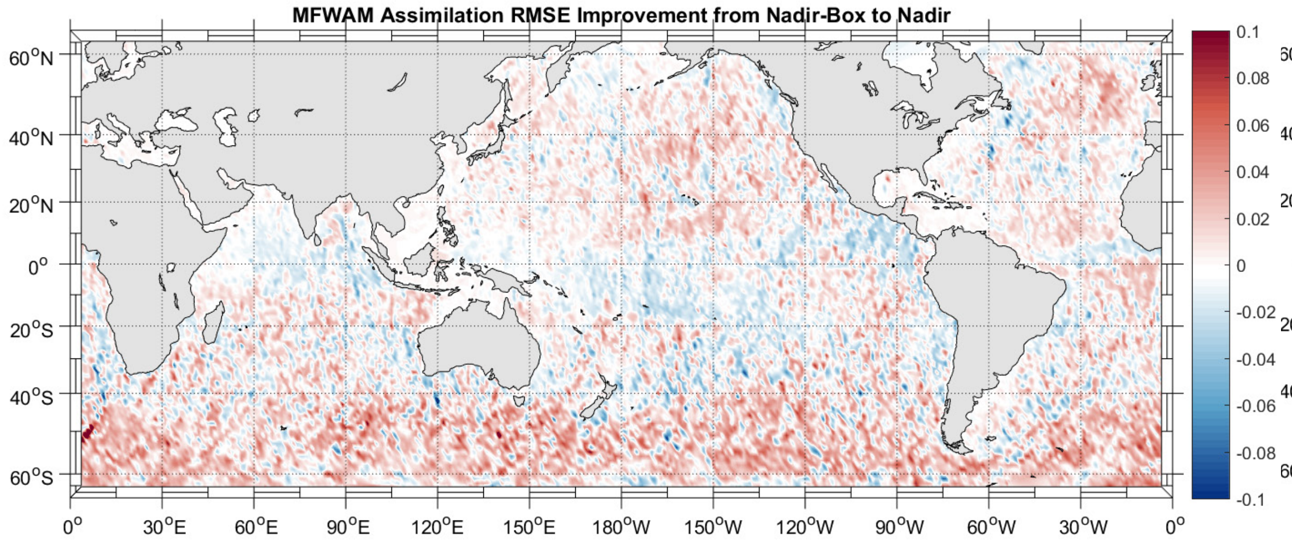
$$bias_{imp} = |bias_{s3}| - |bias_{s1}| \qquad RMSE_{imp} = RMSE_{s3} - RMSE_{s1} \qquad SI_{imp} = \frac{SI_{s3} - SI_{s1}}{SI_{s3}} \times 100\%$$

when run A gives lower values of the bias, RMSE and scatter index, the improved parameter value is positive (shown in more red color); otherwise, degradation of these parameters would lead to negative values (more blue color).

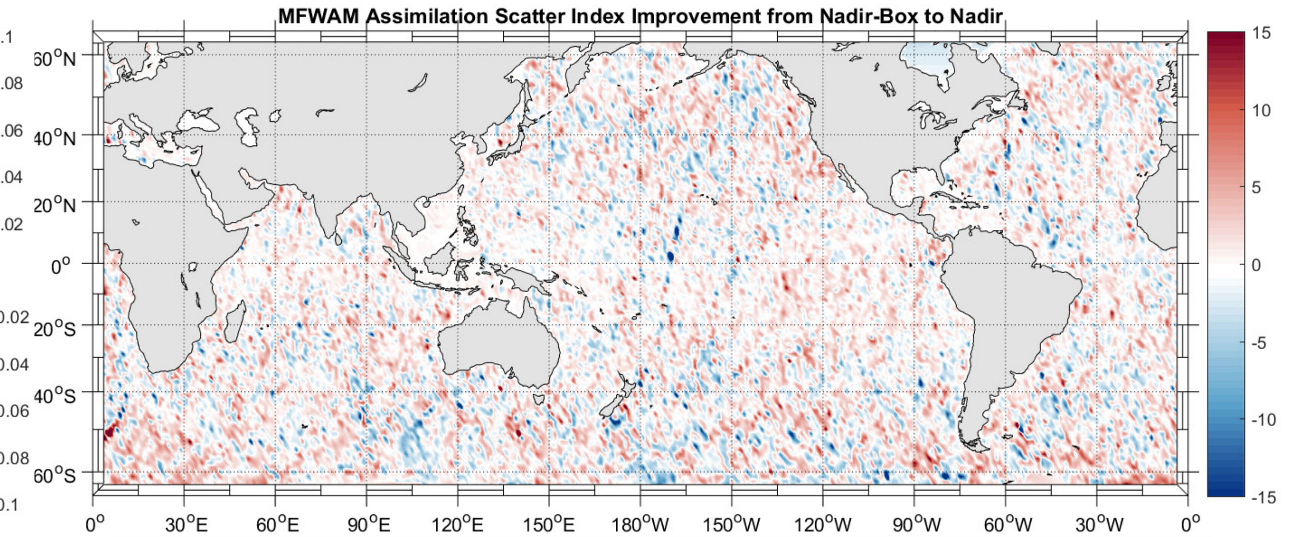



■ Improvement (a decrease in the bias) occurs in most of the global oceans, especially with significant reductions in the mid-latitude regions, such as the North Pacific and North Atlantic, and in the oceans of the Southern Hemisphere between 40°S to 60°S, where the improvement reaches an average reduction of 0.1 m in the bias

# RMSE and SI Improvement of Box-and-Nadir to Nadir-Only



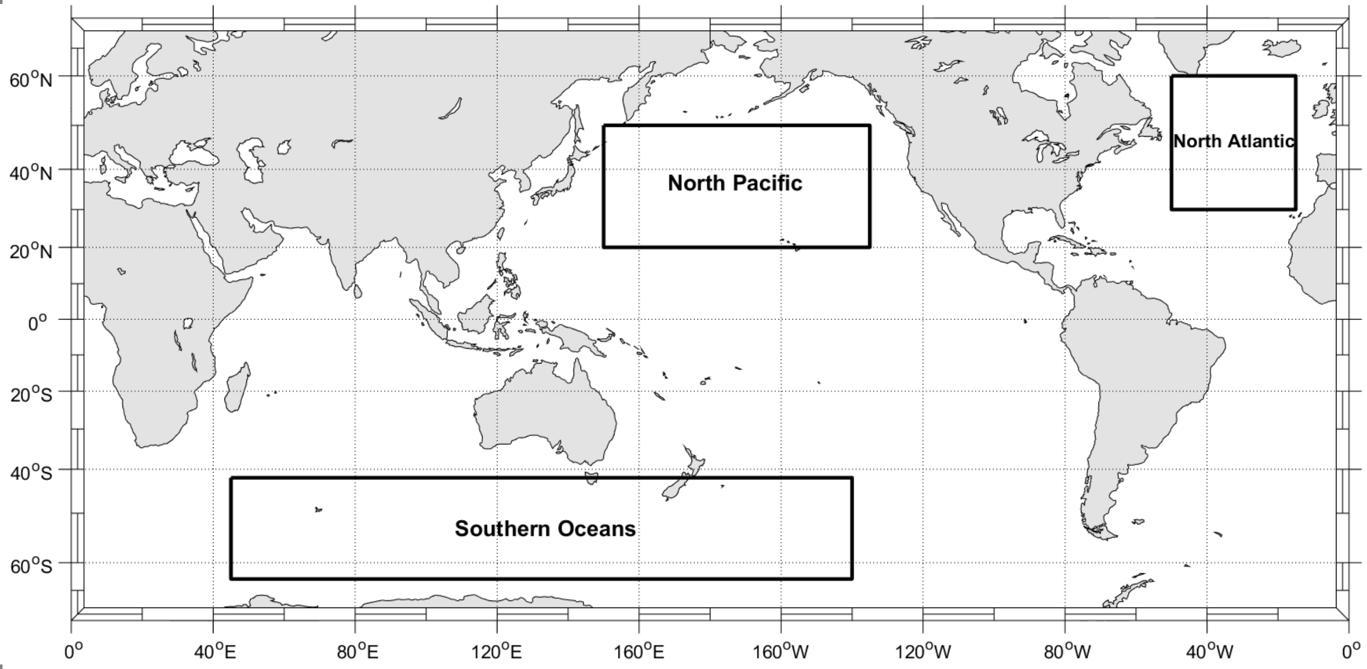

RMSE



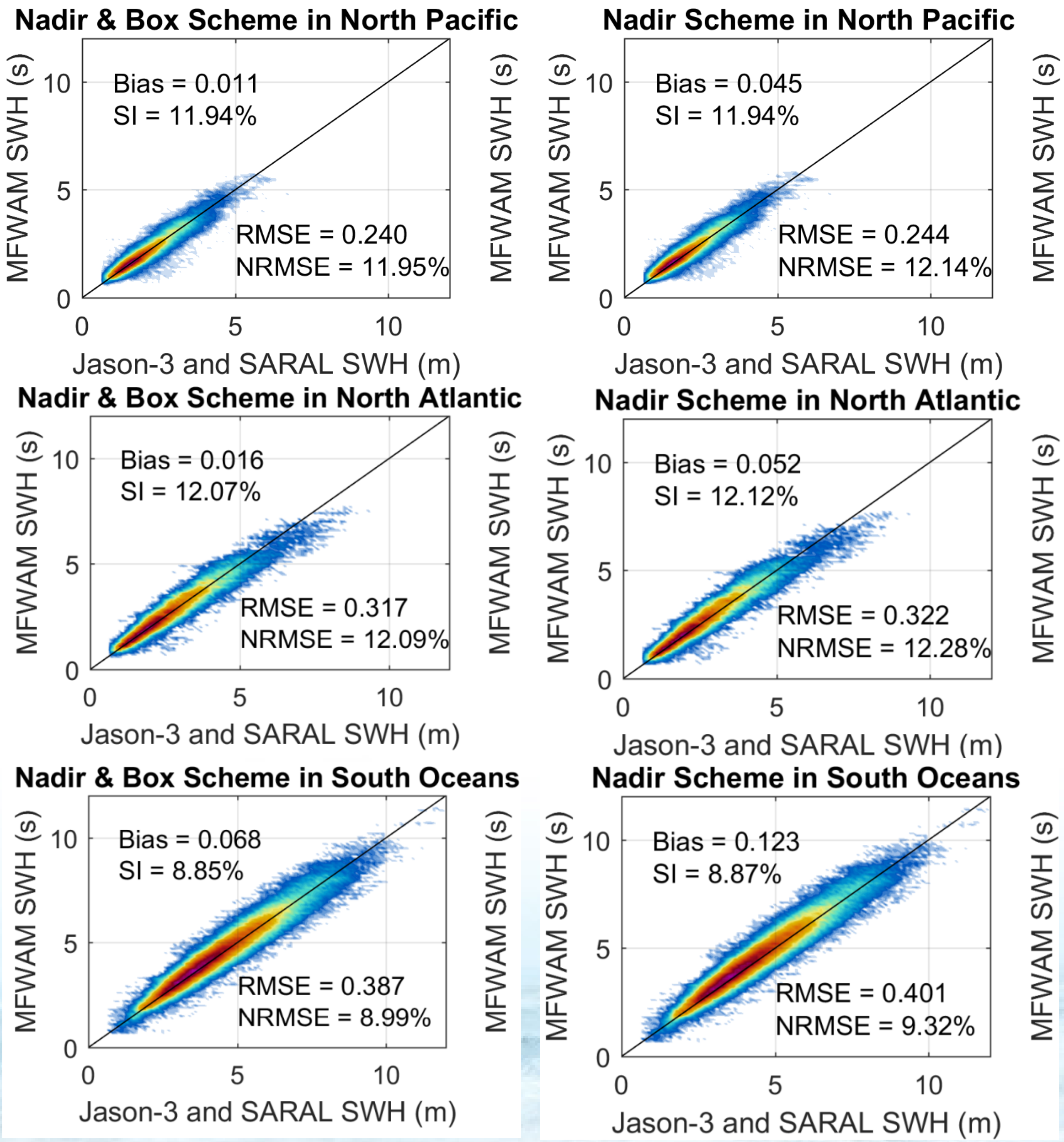

Scatter Index

- The pattern of the improved RMSE distribution is similar to that of the bias. General improvements can be noted globally, as indicated in red in left figure. Relatively significant decreases are also found in the Southern Ocean. Slight degradation appears mainly in the tropical oceans with negligible values, where the SWH is lower than in the subtropical and mid-latitude oceans.
- The global distribution of the improvement in the scatter index also shows promise, as presented in right figure. Among the differences between the SI of runs A and C, a positive impact from the addition of SWIM boxes can be obtained in 53.1% of the global ocean area.
- The assimilation of the SWIM box SWH also reduces the dispersion of the wave model, although not as significantly as the reductions in the bias and RMSE.

# Comparison of Schemes in Sections




- Further detailed assessments of the major oceans are carried out in addition to the global oceans. Three sections are defined, as indicated in the figure
- Among the runs, run A, which assimilates both the SWIM nadir and the SWIM box SWH, achieves the smallest bias, RMSE, NRMSE and SI. When compared to the assessment result of run C, in which only the nadir SWH is assimilated, all the error statistics of run A are improved to a certain extent.



# Conclusion and Discussions

- SWIM onboard CFOSAT can provide **2 columns of 'boxes'** of wave directional spectra within the wavelength limits of 70m and 500 m wavelengths in addition to nadir observations. Thus, SWIM has the potential to provide more positive impacts on wave assimilation by providing more observations from these boxes.

- A model based on a **deep neural network (DNN)** is constructed in this study to retrieve the total SWH from these SWIM box observations.

- Assimilation runs of the box SWH in the MFWAM model are performed to evaluate the assimilation impact on the wave forecast. It is promising to see that the addition of the SWIM box SWH **enhances the positive impact of the assimilation** than the nadir SWH only.

- We note that the performance of jointly using the SWIM nadir and box SWHs is **as good as the use of two altimeters**, which leads to interesting prospects for the next generation of altimeter missions.

# Thanks for Viewing!

# Suggestions and Comments are Welcome!

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