On the Assimilation of Wide Swath Significant Wave Height and Directional Wave Observations in Wave Model : Perspective for Operational Use

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ON THE ASSIMILATION OF WIDE SWATH SIGNIFICANT WAVE HEIGHT AND DIRECTIONAL WAVE OBSERVATIONS IN WAVE MODEL : PERSPECTIVE FOR OPERATIONAL USE

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ABSTRACT

The availability of wide swath Significant wave heights (SWH) such as those retrieved in the frame of CFOSAT and HY2B satellite missions opens important perspectives for the improvement of operational wave forecasting. The objective of this work is to analyze the impact of the combined assimilation of wide swath SWH and directional wave spectra on the integrated wave parameters in the analysis and forecast periods. The results show a significant improvement of the SWH estimate in different ocean regions. We clearly showed the persistency of the assimilation up to 3 days in the forecast period. Most striking is the ability of the combined assimilation to effectively correct swell tracking for storm events, such as Hurricane Pablo in 2019.

Index Terms— Swath, SWH, wave spectra, forecast, assimilation

1. INTRODUCTION

Satellite wave observations are of crucial importance for the reliability of operational wave forecasting. Wave models are often facing with uncertainties caused by the quality of the wind forcing and also by wave physics approximation such as the source term of non-linear wave interactions. Directional wave spectra from Sentinel-1 have been assimilated in the global wave reanalysis WAVERYS of the Copernicus Marine Service (CMEMS) [1]. This has shown a significant improvement of swell directional properties, particularly those generated by storms in the Southern Ocean. Recently the arrival of the SWIM instrument on the CFOSAT satellite allows to provide directional wave spectra covering wave wavelengths from 60 to 500 m. The assimilation of such directional observations has shown the correction of wind -waves during the growth phase and a better description of the swell that propagates over long distances [3]. Since February 2021, CFOSAT directional wave spectra are assimilated in Météo-France operational wave model MFWAM. The global wave products from this system are distributed in the frame of Copernicus Marine Service (CMEMS) with grid resolution of 10 km. The SWIM instrument also provides Significant Wave Height (SWH) on the 6, 8 or 10° incidence angles. Using deep learning techniques, SWH were also retrieved from the CFOSAT's wind Scatterometer (SCAT) over a wide swath described in [3]. SWH are then provided over a 200 km swath, spaced with a resolution of 25 km. The same method was used to retrieve SWH over a 200 km wide swath for the HY-2B mission. This work consists in analyzing the impact of the combined assimilation of wide swath SWH of the two missions CFOSAT and HY2B, and of the directional wave spectra provided by CFOSAT and also Sentinel-1. We will also examine the complementary use of the directional wave spectra from CFOSAT's SWIM and S1's SAR instruments. We recall that SAR of S1 is able to detect waves of wavelengths from 150 to 800 m in the azimuth direction.

2. METHODOLOGY

The assimilation system implented in the MFWAM model can use both SWH and directional wave spectra provided by SWIM and SAR. The assimilation scheme is composed of two parts. The first part consists in using an optimal interpolation on SWH retrieved from the wide swath of scatterometer (200 km) and the nadir altimeter. Then empirical laws are applied to correct the model wave spectrum. The second part of the assimilation scheme performs an optimal interpolation on the wavenumber components of wave partitions provided by the SWIM or SAR directional wave spectra. This takes place in several steps. First, a partitioning algorithm is applied to split dominant wave trains in modeled and observed wave spectra. Then a cross-assignment between the model partitions and those of the observations is developed, and afterward an optimal interpolation of wavenumber components is performed on the selected wave partitions. The last step consists in reconstructing an analyzed wave spectrum by superimposing the analyzed wave partitions corrected by the optimal interpolation. The assimilation system of Météo-France has been updated in February 2021 to account the difference in wavelength cut-off of the wave spectra provided by CFOSAT's SWIM and S1's SAR.

For this study, a global configuration of the MFWAM model with a resolution of 25 km was used. The resolution of the wave spectrum is 24 directions and 30 frequencies ranging from 0.035 Hz with a geometric increment of 1.1. The MFWAM model is driven by 6-hourly wind and ice fraction forcing provided by IFS-ECMWF atmospheric system. We conducted long term combined assimilation experiments from October 2019 to October 2020 to assess the impact on wave forecasting. Run A stand for the assimilation of both wide swath SWH and directional wave spectra from CFOSAT and Sentinel-1, while run B indicates the assimilation of wide swath SWH only. Run C is performed as a control run without assimilation. Validation of the results has been performed with SWH provided by independent altimeters and also with wave parameters from buoys.

3. RESULTS

Comparison with SWH of the altimeters (Jason-3, Saral and Sentinel-3) showed an overall reduction in bias. Figures 1 and 2 indicate the bias maps of SWH during Austral winter from May to August 2020 for runs A and C, respectively. We can clearly see significant reduction of SWH bias, especially for the Southern Ocean and the Atlantic and North Pacific during the hurricane and typhoon seasons, as illustrated in figure 1. This reveals a better tracking of swell during the propagation from local storm areas. The statistical analysis of the comparison with the altimeters also shows significant improvement of normalized scatter index of SWH (SI, see appendix) with the assimilation of wide swath SWH over the different ocean regions, as shown in Table 1. For example, for run B, we note an improvement of about 10% for mid-latitudes and tropical ocean regions compared to run C. When the assimilation of directional wave spectra (run A) is included, the impact is more pronounced compared to experiment B. The improvement of SI increases to about 16% for the three ocean regions compared to run C. Most striking is observed for the high latitudes ocean region where the reduction of SI for run A is about 3 times that of run B.

Furthermore, we analyzed the evolution of the impact in the forecast period when we stop assimilating wide swath SWH and SWIM and SAR wave spectra. Figure 3 shows the difference between the mean wave period of run A after three days of forecast and run C. It is clearly indicated that the impact on the mean wave period remains significant with differences exceeding roughly 1.2 second, as illustrated in Figure 3. The impact is localized on the storm tracks generating the swell, such as in the Southern Ocean (between Australia and Antarctica), the North-East and North-West Pacific, and the Tropical and Northeast Atlantic during Hurricane Pablo (end of October 2019). In addition, we can point out that the impact of run A affects significantly coastal regions because of better capturing of swell initial conditions and propagation.

Validation of SWH with the altimeters during the forecast period emphasizes that the impact of the assimilation remains positive and effective after 3-day forecast, as shown in Figure 4. This also indicates that when the assimilation of the wave spectra is included the impact on SWH during the forecast period is significantly enhanced.

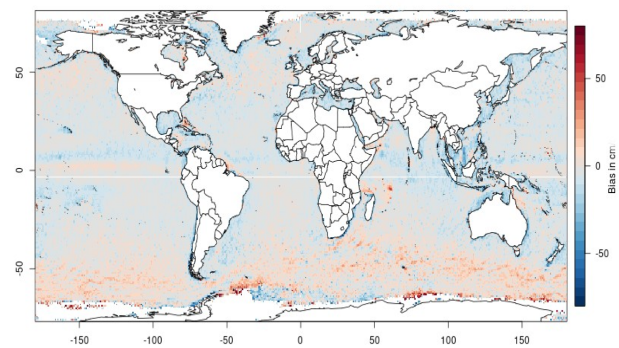

Figure 1 : bias map (in centimeters) of SWH from run A during Austral winter (May-August 2020). The comparison has been performed with altimeters Jason-3, Saral and Sentinel-3.

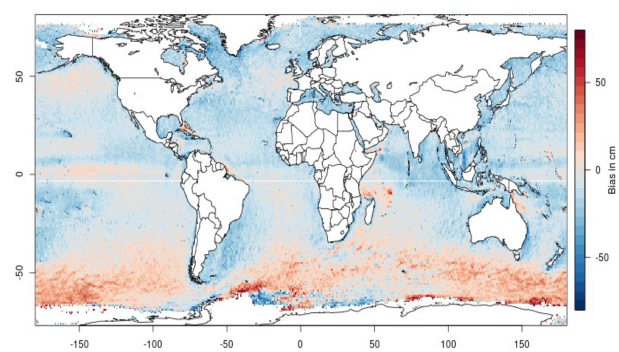

Figure 2 : Same as Figure 1, but for run C.

	Scatter Index (%)		
	High Lats.	Mid Lats	Tropics
Run A	10,5	9,5	8,2
Run B	11,0	9,7	8,8
Run C	12,5	10,8	9,8

Table 1 : Normalized scatter index (in %) of SWH in different ocean regions from August to October 2020. High and Mid Lats stand for latitudes greater than |50°| and between |20°| and |50°|, respectively. Tropics stand for latitudes smaller than |20°|.

4. CONCLUSIONS

The combined assimilation of wide swath SWH and directional wave spectra has been examined for long term run. The impact of such assimilation is assessed and indicates a significant improvement of sea state parameters in the analysis and forecast periods. Expectations for operational use in terms of reliability of wave submersion warning are strongly relevant for storms and hazards events in coastal areas. The operational production of the wide swath SWH is under development by the French and Chinese space agencies CNES and NSOAS, respectively. This will allow to better correct the integrated wave parameters during storm events and to ensure a better correction of the swell propagation from the beginning in the generation area. Further, the combined assimilation of such satellite wave observations will induce the better description of wave forcing parameters such as surface stress, Stokes drift and turbulence by wave breaking in ocean mixed layer, which are needed for the coupling with ocean models.

5. APPENDIX

The scatter index of SWH (SI) is computed by the following relation :

$$SI (\%)=100*STD/MO$$

Where STD is the standard deviation of difference between modeled and observed SWH. MO is the mean of SWH from observations.

6. REFERENCES

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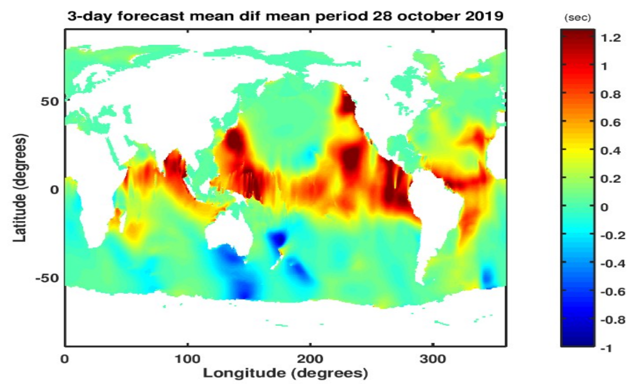

Figure 3 : Average of 3-hourly difference of mean wave period (in seconds) between run A after 3-day forecast and run C during 28 October 2019. Positive and negative values stand for underestimation and overestimation of model mean wave period.

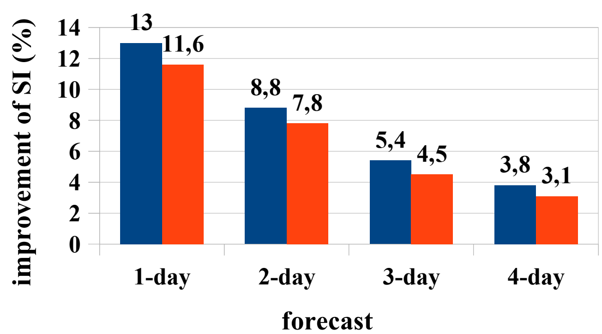

Figure 3 : Reduction of scatter index (in %) of SWH in the forecast period compared to control run C. Blue and red bars stand for run A and B, respectively.