Considering waves in global ocean modeling within the Copernicus Marine Service (CMS) framework: present status and current work

Stéphane Law Chune (1), Guillaume Samson(1), Lotfi Aouf (2), Alice Dalphinet (2)

(1) Mercator Ocean International, France
(2) Météo-France, DirOP/MAR, France

I - INTRODUCTION

In the Copernicus Marine Service (CMS), https://marine.copernicus.eu/, products are intended to be physically homogeneous and balanced between each others, for example by using the same forcing data or by being connected to each other at physical interfaces. In the specific case of physical ocean and wave products, this requires coupling or forcing techniques at the wave/ocean interface. To this end, as a new release of the GLO12 near-real-time physical ocean system will be forced by the global MFWAM system from October 2024. Thanks to NEMO's sbc_wave forcing interface, several wave parameters will be provided as inputs to GLO12, as for instance wave surface roughness or wave breaking energy. The effect of this wave forcing has never been tested for analyses, and the current work checks whether wave forcing gives consistent results with the assimilation system.

II-GLOBAL WAVE AND OCEAN PRODUCTS IN CMS

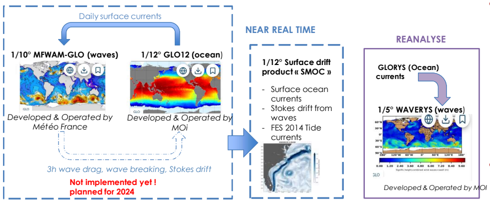


Figure 1 : General diagram of couplings/interactions between ocean and waves in Global CMS models

- GLO12 [1] system provides ocean currents to MFWAM global wave model [2]. The next step is to provided as well to GLO12 wave coupling parameters from MFWAM. Those parameters are linked with sea surface roughness, mixing by wave breaking and Stokes currents
- Waves and surface currents (+ tides) are linearly added offline in a blended surface current product (SMOC) product. The interactions between these components are not considered.

III – CONTEXT

Traditionally, wave effects in OGCM ~ 10 m wind parametrizations in *BULK algorithms* + *surface mixing boundary conditions*

Why is it better to have a wave model ?

→ Proper wave modeling input : wave dynamic, transitory regimes, swell contribution

→ Wave parameters for 3D Stokes currents

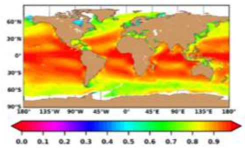
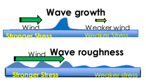


Figure 2 :Ratio between total swell / total sea for 2014-16

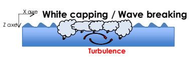
NEMO3.6 sbc_wave routines: wave effects on stress, surface mixing and Stokes drift interactions from wave data, see Breivik et al 2014 [3]

IV – WAVE EFFECTS AT THE OCEAN SURFACE

- Modify the surface stress : *Janssen 1992, 1998*



- Inject surface mixing : *Craig and Banner 2004, Terray et al 1996*



- Stokes current effects : *Hasselman 1970, Polton et al 2004*

+ further more, e.g. see Uchiyama et al 2010, Bennis et al 2011, Couvelard et al 2019 [4]

V - FORCING NEMO 3.6 WITH A WAVE MODEL

NEMO 3.6 sbc_waves routines adapted for 1h IFS BULK atm forcing and GLS vertical scheme **forced by WAVERYSv1**

	Physical process	STAND-ALONE 10 m wind parametrizations (no wave model involved)	WAVE FORCING Coupling parameters with MFWAM
SURFACE STRESS	• *Balanced stress from wave growth or dissipation*	NO	$\tau_{oc} = \tau_a - \tau_w$
	• *Surface drag from Waves*	$z_0 = \frac{\alpha_{ch} u_*^2}{g}$ (Charnok)	$z_0 = z_{10m}\, e^{-\kappa / \sqrt{Cd_{gw}}}$
SURFACE MIXING	• *TKE Wave breaking*	$\phi_{oc} = \rho_w . 100 . u_*^3$ (Craig and Banner 94)	$\phi_{oc} = \rho_w \alpha_{cb} u_*^3$
	• *TKE roughness length as Hs*	$Hs = \frac{665}{0.85g} u_*^2 . 30 \tanh(\frac{0.6}{28u^*})^{3/2}$ (Rascle 08)	Hs from MFWAM
STOKES INTERACTIONS	• *Stokes-Coriolis*	NO	$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho_w}\nabla p + (\mathbf{u} + \mathbf{u_s}) \times f\vec{z} + \frac{1}{\rho_w}\frac{\partial \tau_{oc}}{\partial z}$
	• *Mass + tracer advection due to Stokes drift*	NO	$\frac{\partial \eta}{\partial t} = -\nabla \int_{-H}^{\eta} w.dz - -\nabla \int_{-H}^{\eta} \mathbf{w_s}.dz$ at $z=\eta$ $\frac{\partial T}{\partial t} + \nabla.T + \nabla_s.T = D + F + \cdots$

Table1: how wave coupling parameters are introduced in NEMO

→Law Chune et Aouf 2018 [5], *Wave effects in global ocean modeling: parametrizations vs. forcing from a wave model*

VI –SENSITIVITY SIMULATIONS WITH GLO4 OPERATIONAL SYSTEM

GLO4V4 system (GLO12, but ¼°)

Assimilation of SST, SLA, T/S profiles with **SAM2V1** assimilation scheme

4 sensitivity simulations to study the impact of wave forcing (WF) in Free vs Assim mode

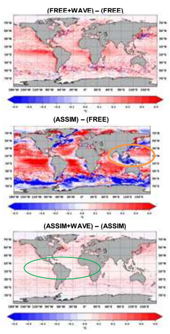
Name	FREE	ASSIM	FREE+WAVE	ASSIM+WAVE
Data Assimilation (DA)	NO	YES	NO	YES
Wave forcing (WF)	NO	NO	YES	YES

Table2: Sensitivity simulations to wave forcing in a data-assimilated context

- Common initial state from 2012 Oct 17 (restart from oper. GLO4)
- Study period from 1st Jan. 2013-> 31 Dec. 2015 (3 years)

VII- RESULTS ON TEMPERATURE

Figure 3 : SST differences , 3-year averaged maps (2013-2015)



- **FREE+WAVE** increases globally SST ~0,1°C ; more intensely in Pacific and Atlantic tropics
- **ASSIM** increases SST much more (vs Free), but with some major large-scale cooling : Indonesia, WBC, ACC, upwellings
- **ASSIM+WAVE** injects same signatures than FREE+WAVE, but they are reduced

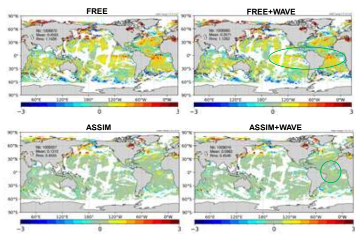


Figure 4: SST innovation maps from Observations Operator for 28th July 2015 (summer NH)

FREE+WAVE: summer mid-latitudes + all the year tropical WF modifications → reduce daily global SST bias ~ 0.1°C

ASSIM+WAVE: WF bias reduction not so significant ~ 0.01°C

→ WF is mainly interesting for forecasts, but helps a bit in an analysis framework

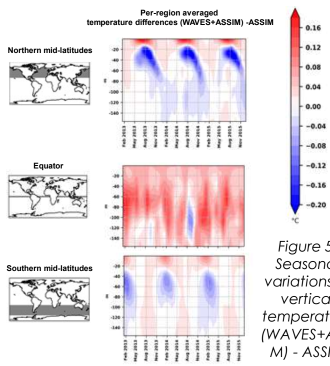


Figure 5: Seasonal variations of vertical temperature (WAVES+ASSIM) - ASSIM

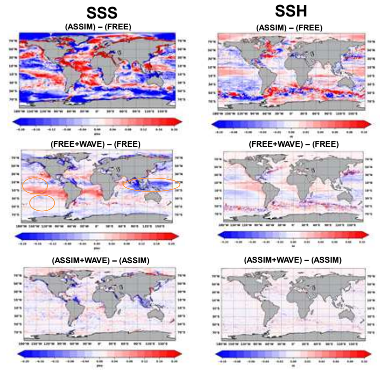
Effects of wave forcing in an assimilated context (in free, same effect, but stronger):

- For mid-latitudes, enhanced summer stratification, **caused by weaker wave-breaking**
- At the equator, increase of 0.2°C up to 200 m all the year, **mainly caused by reduced wave roughness**

→ WF modifies vertical structure of temperature, with marked seasonal variations for mid latitudes

VIII- RESULTS ON SSS AND SSH

Figure 6 : Sea surface salinity (left) and Sea surface height (right) differences, 3-year averaged maps (2013-2015)



- Large scale effects of WF on SSS and SSH are very similar to the one obtained for SST.
- For SSS, WF produces differences that counter the effect of DA, in Indonesia, and off French Guiana and Quebec. This needs further investigation.
- Adding WF with DA doesn't produce much differences on SSH

CONCLUSIONS AND PERSPECTIVES

Wave-forcing in NRT ocean system would benefit mostly for forecasts (free context), as it corrects large-scale structures in accordance with the data assimilation system. Even in presence of DA, some short-scale are still corrected (need further investigations).

We are also working on an OASIS-based NEMO-MFWAM 2 way coupling to prepare CMS post 2026 systems.

REFERENCES:

[1] Lellouche et al. "Recent updates to the Copernicus Marine Service global ocean monitoring and forecasting real-time 1/12° high-resolution system" 2018

[2] Lotfi Aouf & Jean-Michel Lefèvre (2015) On the Impact of the Assimilation of SARAL/AltiKa Wave Data in the Operational Wave Model MFWAM, Marine Geodesy, 38:sup1, 381-395, DOI: 10.1080/01490419.2014.1001050

[3] Breivik, Ø., Mogensen, K., Bidlot, J.-R., Balmaseda, M. A., and Janssen, P. A. E. M. (2015), Surface wave effects in the NEMO ocean model: Forced and coupled experiments, J. Geophys. Res. Oceans, 120, 2973–2992, doi:10.1002/2014JC010565.

[4] Couvelard, X., Lemarié, F., Samson, G., Redelsperger, J.-L., Ardhuin, F., Benshila, R., and Madec, G.: Development of a two-way-coupled ocean–wave model: assessment on a global NEMO(v3.6)–WW3(v6.02) coupled configuration, Geosci. Model Dev., 13, 3067–3090, https://doi.org/10.5194/gmd-13-3067-2020, 2020.

[5] Law Chune, S., Aouf, L. Wave effects in global ocean modeling: parametrizations vs. forcing from a wave model. Ocean Dynamics 68, 1739–1758 (2018). https://doi.org/10.1007/s10236-018-1220-2

Contact :
slawchune@mercator-ocean.fr