MERCATOR OCEAN INTERNATIONAL

From Waves to Oceans

Assessing the impact of MF-WAM wave forcing data on Physical and Biogeochemical dynamics of the GLO12 ocean system

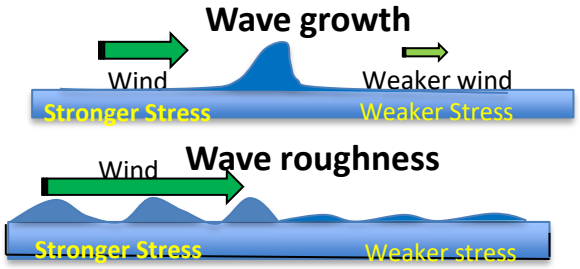
Stéphane Law Chune
Julien Lamouroux, Lotfi Aouf, et al

Wave-induced effects at the ocean surface

Waves…

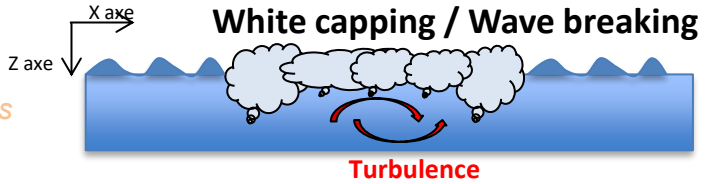
1/ Modify the atmospheric turbulent fluxes at the ocean surface

- → *Waves consume or release wind stress*
- → *Waves are a direct source of roughness / drag*



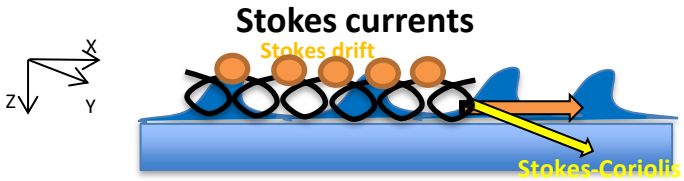
2/ Introduce turbulent energy (TKE) in the surface layer

- → *Wave breaking injects turbulent energy*
- → *Wave height acts as a characteristic length scale for mixing (roughness length)*



3/ Add dynamic coupling with Stokes drift

- → *Stokes drift contributes to shear production in theTKE equation*
- → *Stokes drift interacts with the Coriolis force : Stokes-Coriolis forcing*
- → *Stokes drift transports tracers and mass*
- → *Stokes drift vorticity contributes to the ocean dynamics*



Global ocean / wave **near-real-time** systems in Copernicus Marine

10 days of **forecasts** and 2 years **analyzed** archive

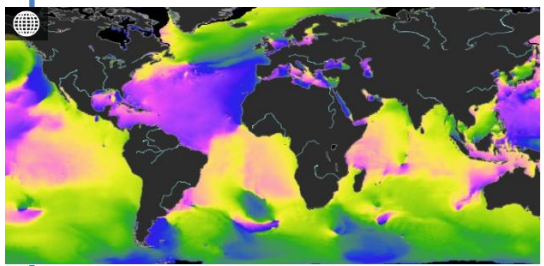
https://data.marine.copernicus.eu/

U_o, V_o → ocean current diffraction

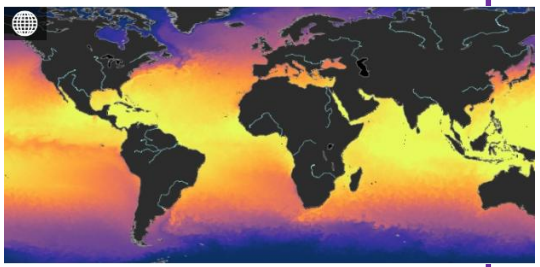
*1/10° **MF-WAM***

- *Forced by 1h IFS atmospheric/ice*
- *Forced by GLO12 daily currents*
- *ST4 physics + in house parameterizations*
- *Assimilates*
  - *Alti Hs*
  - *Wave Spectra (Sentinel, CFOSAT)*

GLOWAVE (waves)



GLO12 (ocean)



*1/12° ORCA **NEMO3.6***

- *Forced by 1h IFS forecasts*
- *IFS Bulk, GLS vertical model, 5 bands light penetration scheme, etc.*
- *Assimilates*
  - *in situ T,S*
  - *Alti SLA alti*
  - *Odysea SST*
  - *OSISAF sea ice*

Wave forcing planned for March 2026

$C_{d\,wave}^{N}$, $\frac{\tau_{oc}}{\tau_a}$ → Surface stress

ϕ_{oc} , H_{sww} → Surface mixing

U_{sd}, V_{sd}, W_{sd} → Stokes drift interactions

See Law-chune et al 2018 + NEMO Manual

Questions and Protocols

Questions ?

- How does wave forcing interact with data assimilation ? over 10-day forecasts ?
- What is the impact on Biology ?

Protocols

- One year (2024) of twin simulations with the full GLO12 system
  - **REF :** 10 m wind parametrizations for waves
  - **WAVES**: forced by GLOWAVE wave-to-ocean parameters

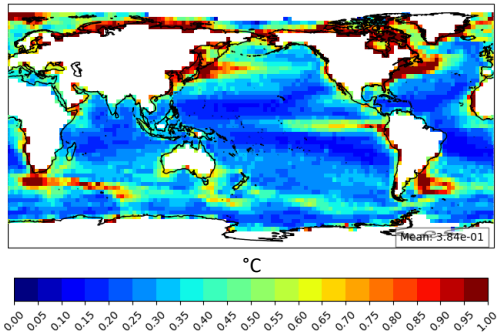
  Assimilation increments are spread over the entire cycle (7 days)

- Validation has been performed with assimilation diagnostics (obs-model)
  - → *how much the data assimilation system rejects/accepts observations*
  - → *no validation with independent data yet (planned)*

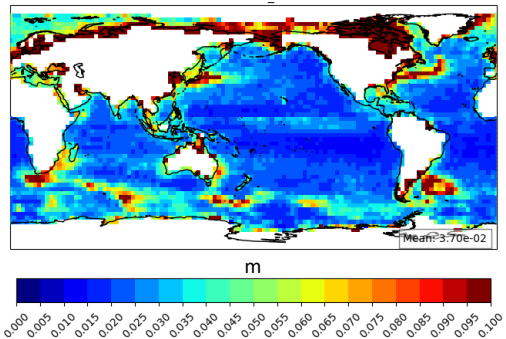
Average yearly impact on SST and SSH : ANA

RMSE for REF

SST



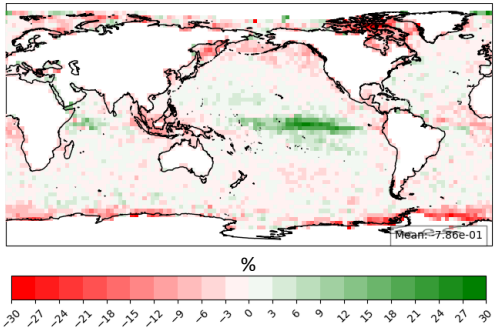
SSH



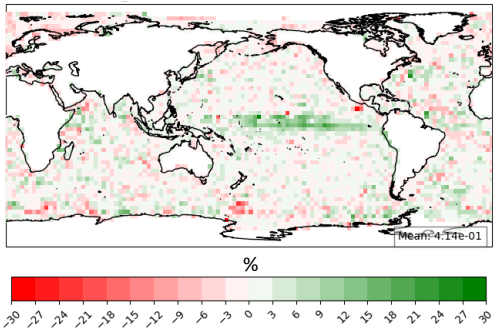
RMSE % Score WAVES

Green : improvement
Red : degradation
Hatched : > obs error

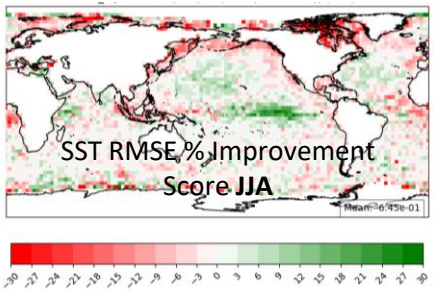
SST



SSH



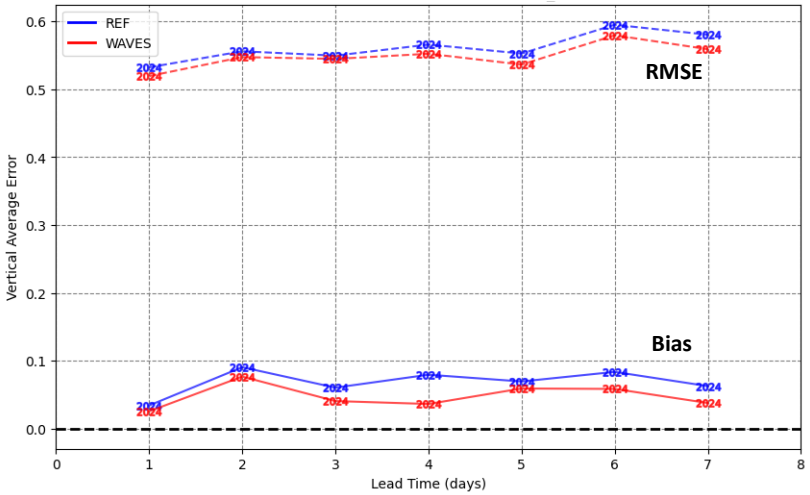
- **Wave forcing improves equatorial Pacific** (cold bias correction), slight degradation elsewhere
- **Differences remain small** (< obs error)
- Main mechanisms :
  - Equator: reduction of wind drag → cold bias correction + reduction of currents
  - Mid latitudes : seasonal correction (wave breaking during NH summer)



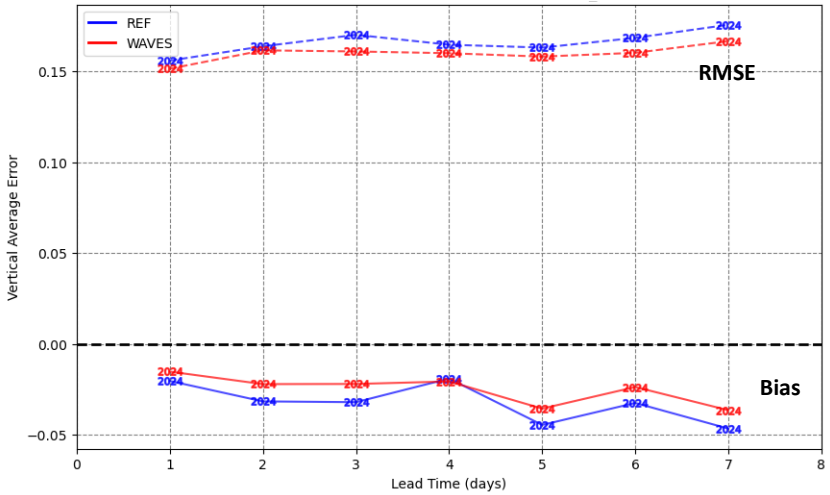
0-300 m average errors vs FCST time (IN-SITU data)

Equatorial band 0-300 m errors

Temperature (°C)

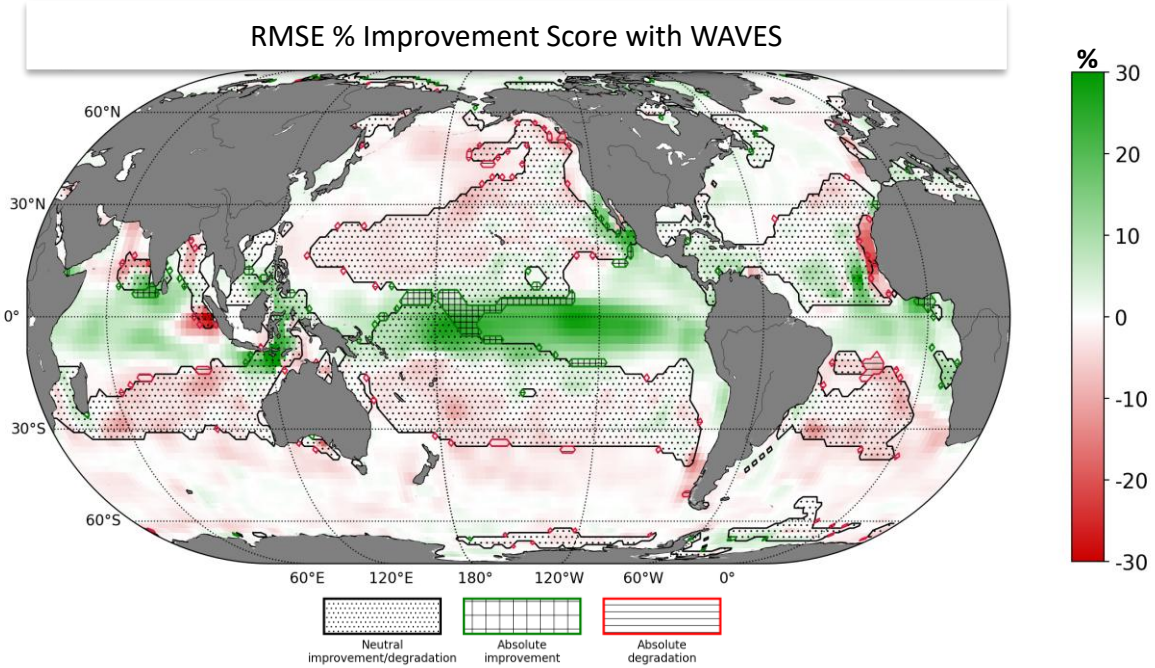


Salinity (psu)



- **Only small improvements** in bias and RMSE (also seen at global scale)
- **Wave forcing impact grows with forecast lead time**

Impact on BIO : Ocean Color (ANA)



1/4° BIO system forced by GLO12 dynamics : *U,V,W* & Kz

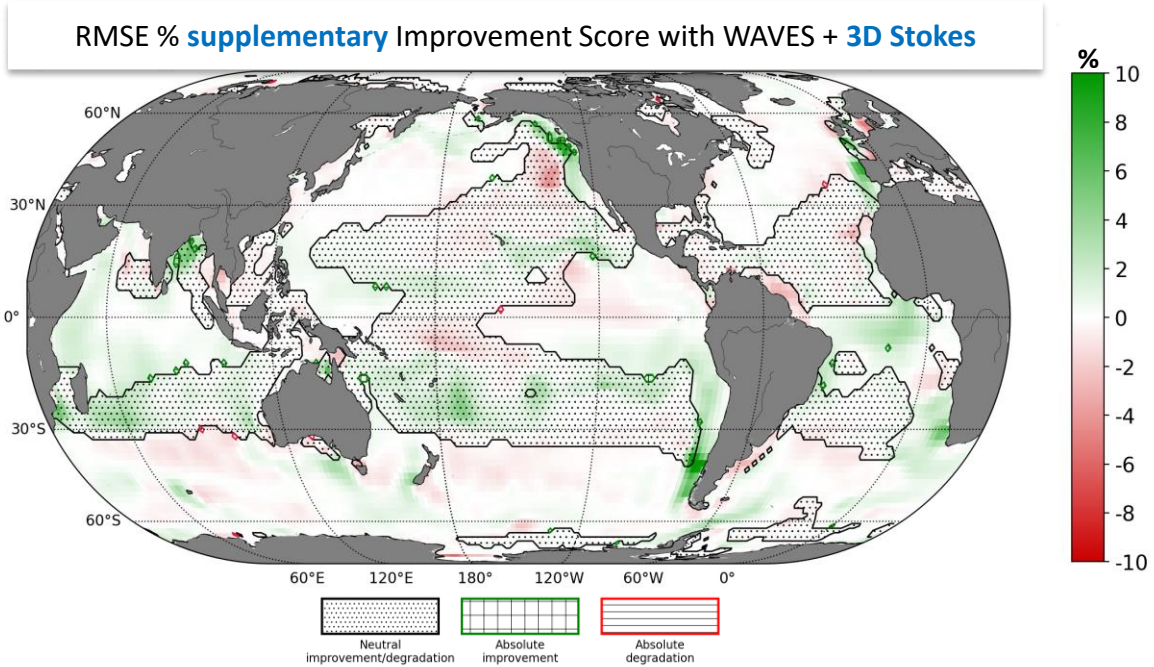
- At the Equator: improved stress → better nutrient and organic matter circulation

→ Upwelling margins (Peru, California, Benguela, Mauritania,) : modified Cd/mixing change upwelling dynamics

→ Mid/high latitudes : slight degradation possibly due to light limitation due to enhanced mixing

Wave forcing tangibly impact BIO !

Impact on BIO : Ocean Color (ANA)



1/4° BIO system forced by GLO12 dynamics : *U,V,W* & Kz + 3D Stokes

→ Coastal upwellings : U+Us improves transversal transport

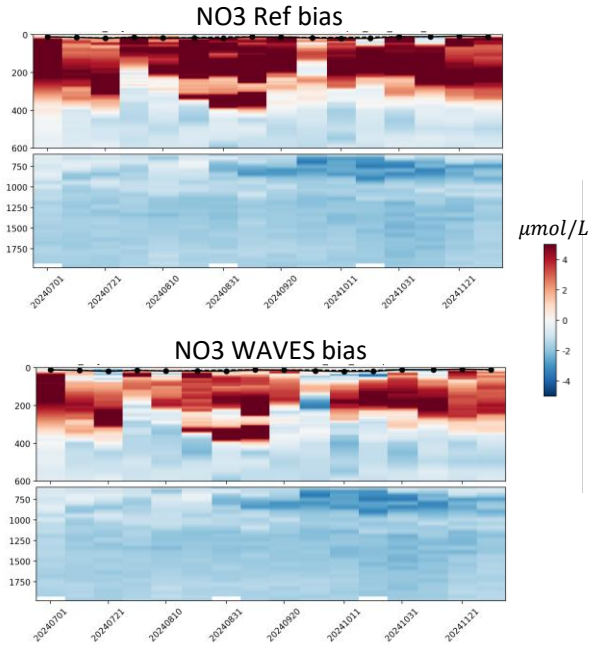
→ Bay of Bengal : improved summer moonson bloom response (to be investigated)

Does adding Stokes drift to Eulerian currents could be relevant for BIO ?

Impact on BIO : NO3 (ANA)

NO3: comparison to BGC Argo (float n°7902102)

jul-dec 2024, south of Costa Rica



- NO3 are constrained by Ocean Color in the Mixed Layer, but “free” below
- Better nitrate representation in the subsurface, corrections down to 200 m

But this improvement is not systematic — work in progress.

Conclusions

- MFWAM wave forcing has measurable but small impact on GLO12 ocean system

→ *Already well-calibrated system (wave parametrizations + data assimilation)*

- ANA/FCST : improvements in the Equatorial Pacific, degradations in other regions
- In FCST, wave forcing improves the results as the lead time grows
- For BIO : Corrections at the equator and upwellings
  Adding 3D Stokes drift forcing appears relevant

Perspectives

- Validation with independent data: drifters with 3D Stokes currents + HF coastal radars

- Additional processes and datasets: tides, new MDT, SWOT 5 Hz altimetry

- Additional wave-related processes: Langmuir mixing, Bernoulli head

- Two-way coupling

Operational implementation planned for March 2026

MERCATOR OCEAN INTERNATIONAL

Appendix

Waves in stand-alone ocean circulation models

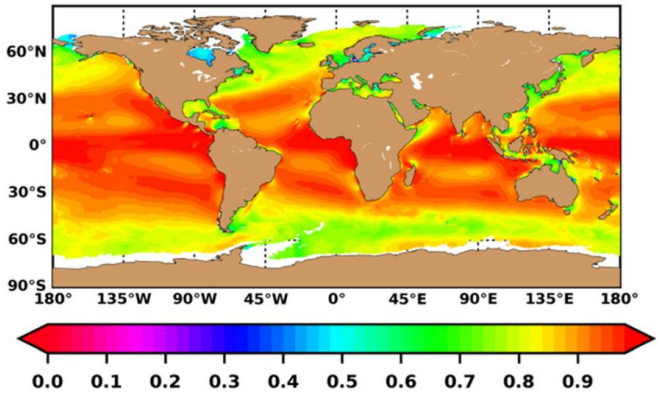
In stand-alone ocean model (like NEMO):

Surface waves effects = 10 m wind parametrizations : ***wind stress*** in BULK algorithms, ***surface mixing boundary conditions*** in TKE, *etc.*

What is the benefit of using a wave model forcing instead ?

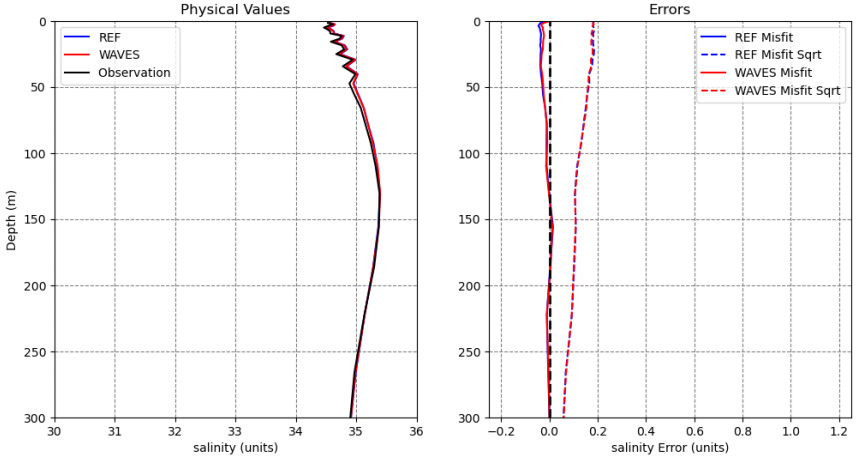
- *Accounts for "non-local-wind" effect (swell)*
- *More realistic wave physics (growth, propagation, interactions)*
- *Inclusion of Stokes drift effects*
- *Enables coupling capacity*

Ratio between total swell / total sea for 2014-16

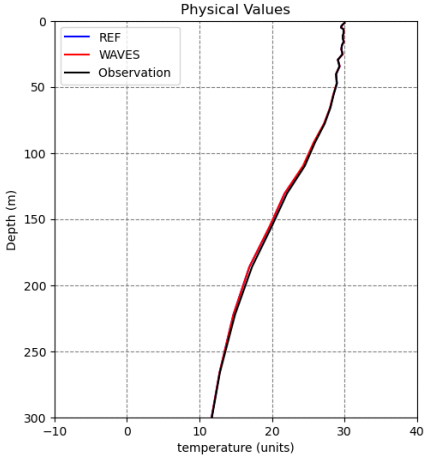


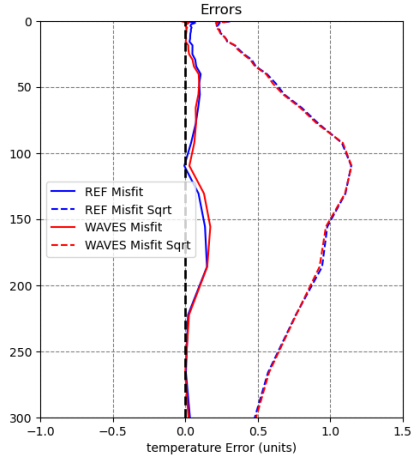
We study the impact on the ocean of ***replacing existing*** ***10 m wind parameterizations*** ***with forcing derived from a wave model***

Vertical Profiles - VP_GEN_INSITU ANA salinity - Equatorial_Band - years=2024



Vertical Profiles - VP_GEN_INSITU ANA temperature - Equatorial_Band - years=2024

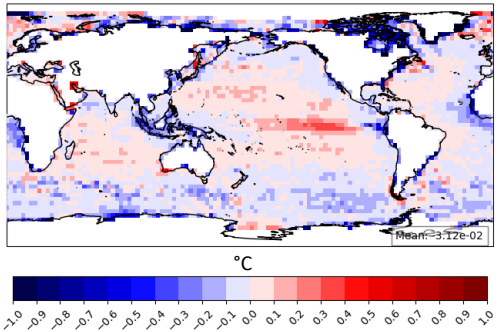




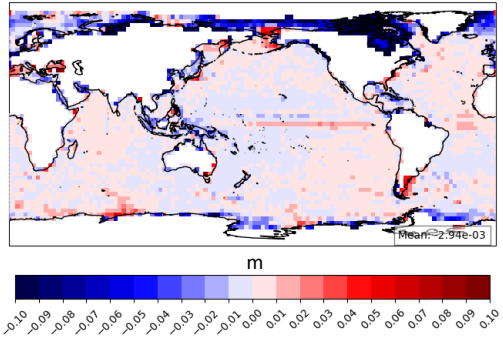
Average impact on SST and SSH : 2024 ANA

BIAS for REF

SST



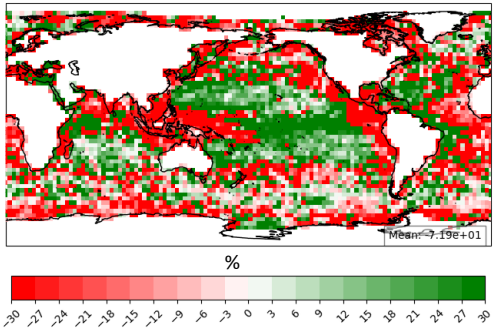
SSH



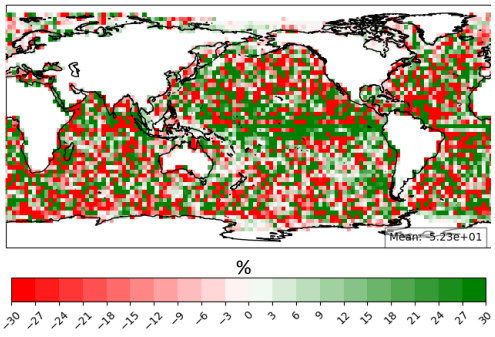
BIAS % Improvement Score

Green : improvement
Red : degradation
Hatched : > obs error

SST



SSH



SST OSTIA 2024 yearly : FCST BIAS

GLO12 delivers 10-day forecasts

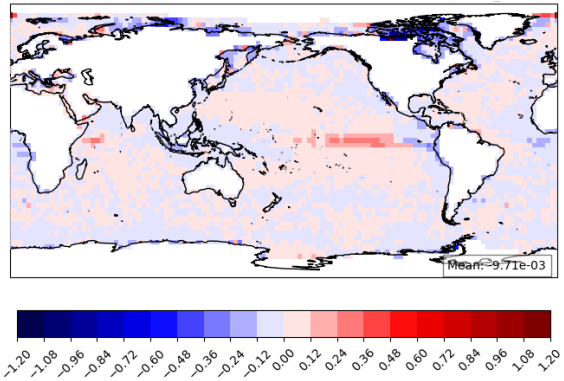
How does wave forcing perform with respect to forecast lead time?

→ Improvement in the equatorial Pacific intensifies with increasing lead time.

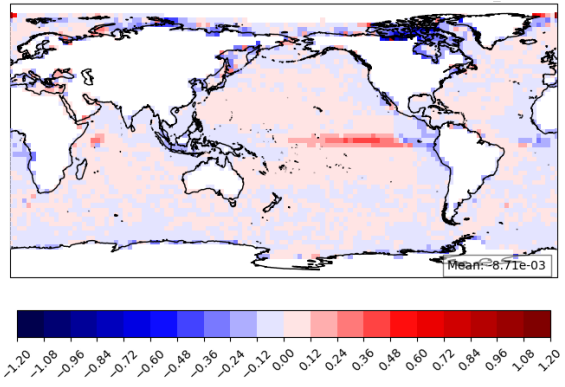
→ On global average, the degradation weakens as lead time increases (from -9.71×10^{-3} to -5.23×10^{-3} °C).

Score / (obs error)

Lead Time **1d**

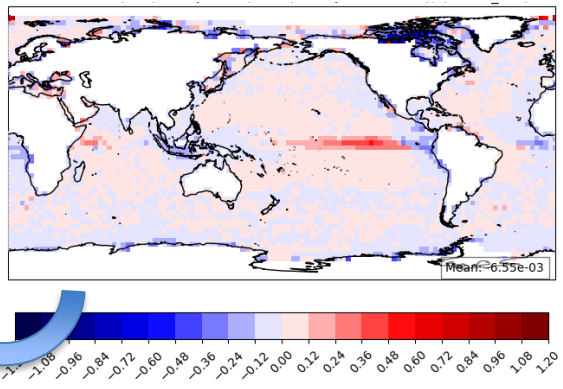


Lead Time **3d**

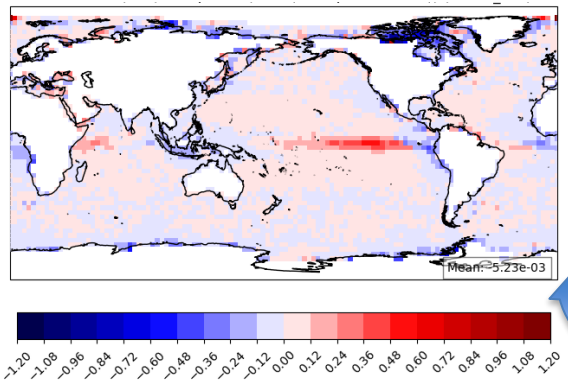


Red : improvement
Blue : degradation

Lead Time **5d**

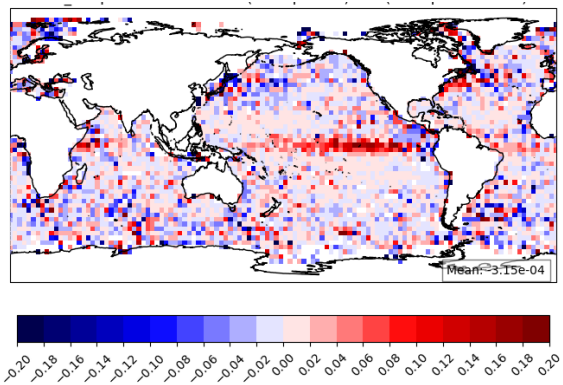


Lead Time **7d**

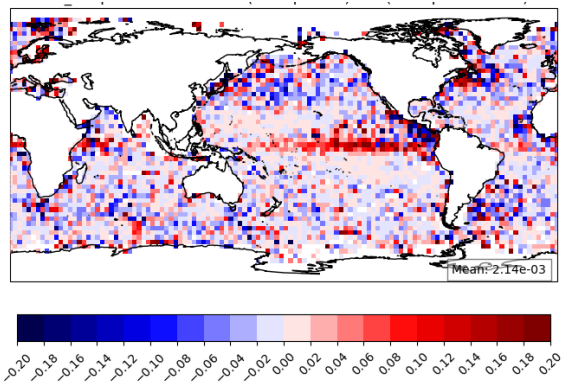


T in-situ profiles: horizontal cross-section at different depths (2024)

Score 15m

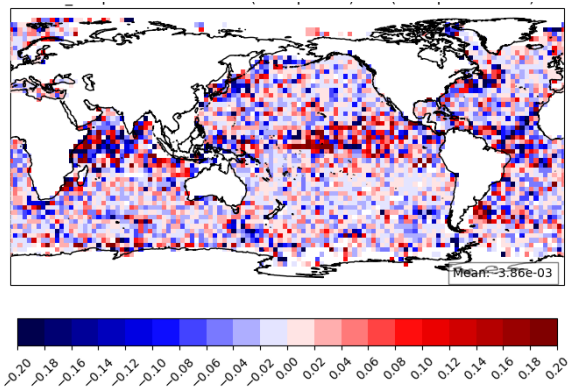


Score 30 m

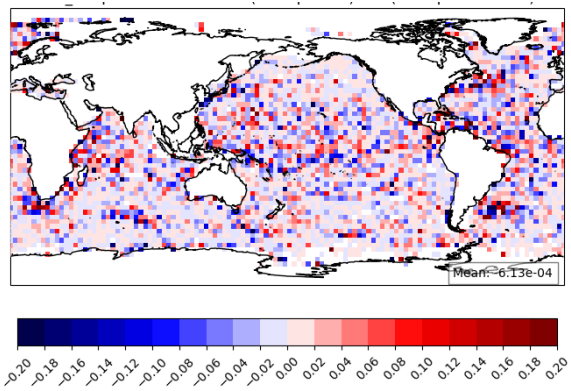


Red : improvement
Blue : degradation

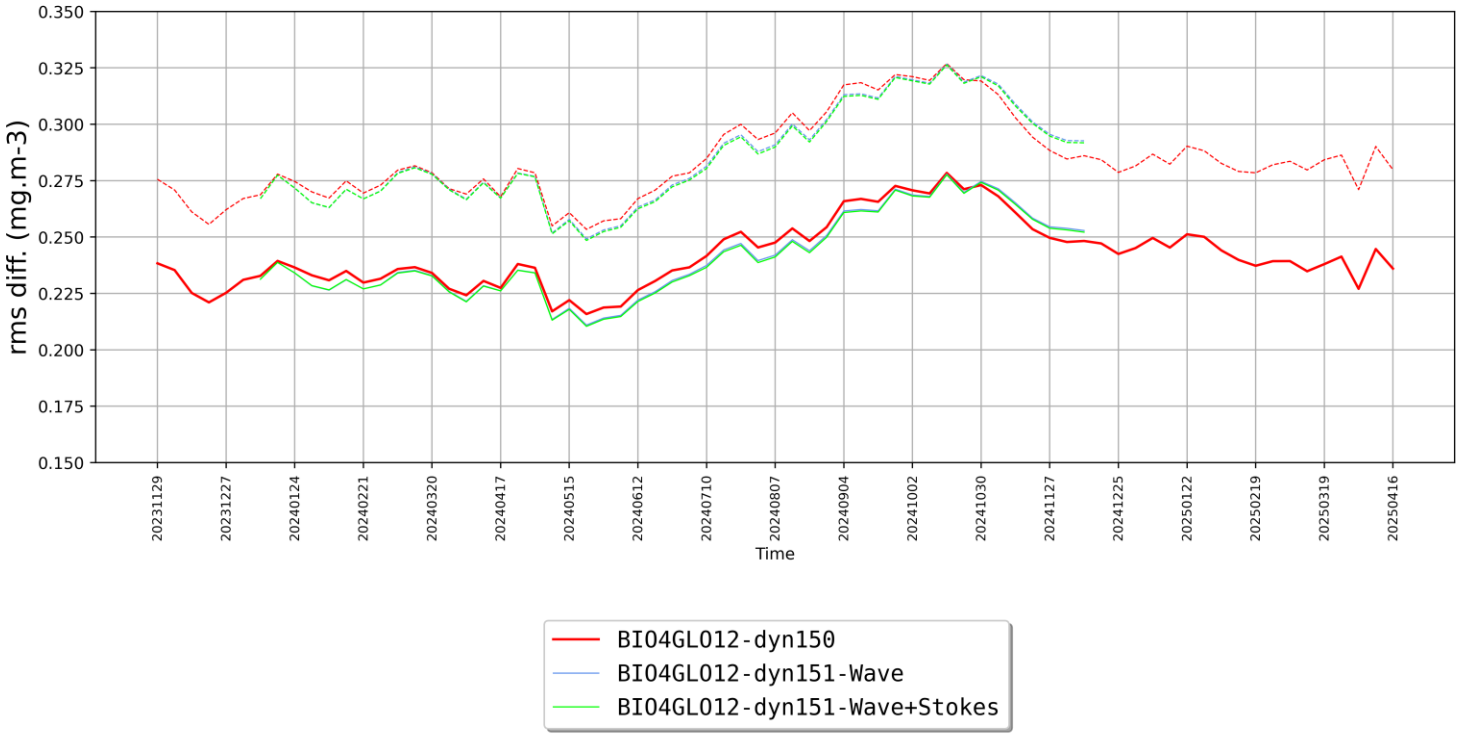
Score 100 m



Score 300 m



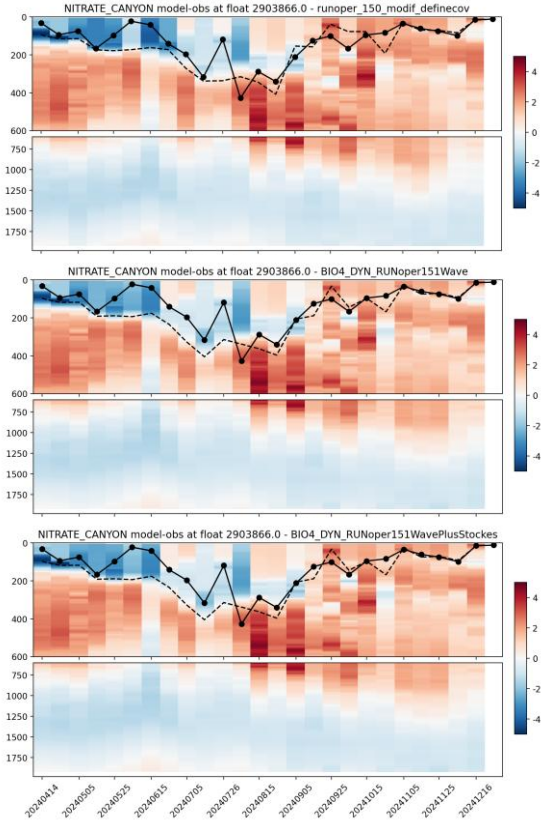
- Improvement observed in the tropical Pacific throughout the entire mixed layer.
- Below 100 m, differences are dominated by non-physical noise


0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
rms diff. (mg.m-3)
20231129
20231227
20240124
20240221
20240320
20240417
20240515
20240612
20240710
20240807
20240904
20241002
20241030
20241127
20241225
20250122
20250219
20250319
20250416
Time
BIO4GLO12-dyn150
BIO4GLO12-dyn151-Wave
BIO4GLO12-dyn151-Wave+Stokes

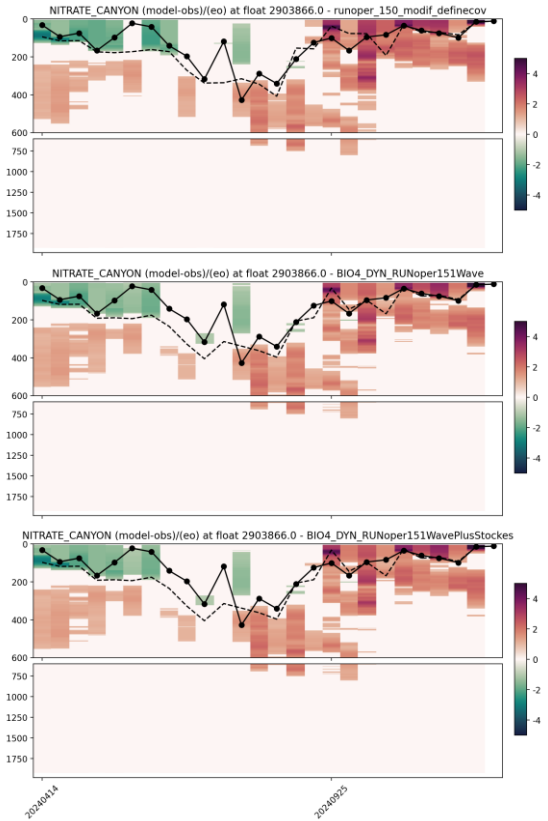
NO3 comparison in Austral Ocean

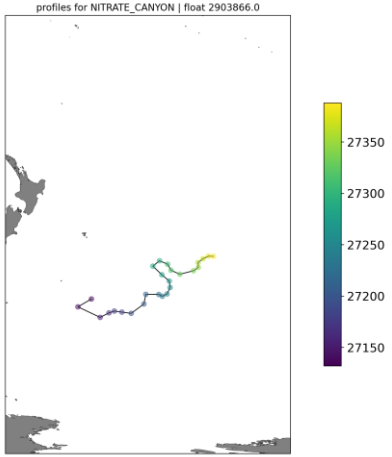
NO3: comparison to BGCArgo

$model - obs.$



$\frac{model - obs.}{obs.error}$





Work in progress, but some improvements already spotted on the vertical distribution of NO3