Prognostic Schemes for Skin SST in Coupled Regional Modeling

A case study from the Mediterranean Sea

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Outline

Background & Motivation

- SST definitions from GHRSST
- SST in ocean and atmosphere models

Data & Models

- Data used in this study
- System Description: Downscaling Seasonal Forecast

Results

- Validation

Conclusions

- Discussion & future steps

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SST definitions from the GHRSST

- SSTint: right at interface;
- SSTskin (always cooler);
- SSTsubskin diurnal excursions;
- SSTdepth less pronounced;
- SSTfnd no diurnal variations.

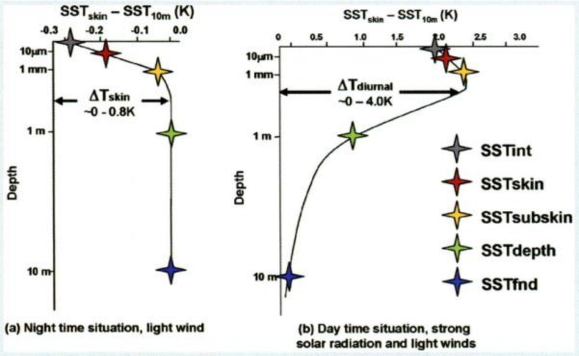
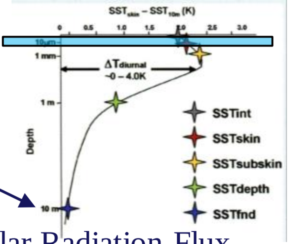


Figure: SST sketch from (Donlon et al., 2007)

Modeling SST diurnal variations: cool skin (Zeng and Beljaars 2005, WRF)



Starting point: 1d heat transfer in the ocean

$$\cancel{\frac{\partial T}{\partial t}} = \frac{\partial}{\partial z}(\cancel{K} + k)\frac{\partial T}{\partial z} + \frac{1}{\rho_w C_p}\frac{\partial R}{\partial z}$$

Turbulent diffusion, Thermal Conductivity, Net Solar Radiation Flux

Cool Skin formulation:

$$\Delta T = \frac{\delta}{\rho_w C_p k}(Q + f_s R_s) \qquad \textit{where} \qquad f_s = \frac{1}{\delta}\int_{-\delta}^{0}\left(1 - \frac{R(z)}{R_s}\right)dz$$

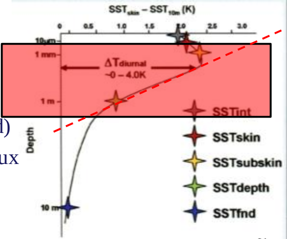
Parameterization of fraction of solar radiation absorbed in the cool skin, and cool skin thickness from Fairall et al. 1996 TOGA COARE data (ship & buoy, December 1992, tropical western pacific)

Modeling SST diurnal variations: warm layer (ZB05)

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}(K + \cancel{k})\frac{\partial T}{\partial z} + \frac{1}{\rho_w C_p}\frac{\partial R}{\partial z}$$

(+ downward)

Turbulent diffusion, Thermal Conductivity, Net Solar Radiation Flux



After some mathematical calculations and scaling assumptions….

We get the prognostic equation for the warm layer:

$$T = T_{-\delta} - \left[\frac{z+\delta}{-d+\delta}\right]^{\nu}$$

$$\frac{\partial}{\partial t}(T_{-\delta} - T{-d}) = \frac{Q + R_s - R(-d)}{d\rho_w C_p \nu/(\nu+1)} - \frac{(\nu+1)\kappa u_*}{d\phi_t(d/L)}(T_{-\delta} - T_{-d})$$

Modification from Artale et al. 2002, Takaya et al. 2010 allow respectively to consider cases of sustained winds, and account for the effect of mixing enhancement from the Langmuir circulation;

Other parameterizations for the Absorption of Solar Radiation exist, but they are calibrated according to chlorophyll variations or consideration of larger waveband division, but still constant in time and space.

Constant in time and space! Soloviev (1982)

Motivation

- Improving the representation of the skin SST diurnal cycle is important to get more accurate representation of air-sea heat fluxes;

- This is very important in coupled ocean-atmosphere modeling, where there's a back-and-forth exchange and computation of air-sea heat fluxes from (skin) SST and viceversa;

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Carrying out validation of results against Copernicus Marine Environmental Service Mediterranean Diurnal Optimally Interpolated subskin SST data of Pisano et al. 2022:

- These are the results of an optimal interpolation between Meteosat-11 SEVIRI data (masked regions where model data exceed 50% of the total available points);

Quality control HR-Drifter from iQuam Star as described by Xu et al. 2014:

- There are five quality levels, #5 stands for highest quality – only quality levels higher than 4 were selected to carry out the comparison;

EN4 Temperature Profiles from MetOffice Hadley Centre observation:

- Objective analyses produced after Gouretski and Reseghetti (2014) XBT correction and Gouretski and Cheng (2020) MBT corrections;

ISMAR MedESM

Atmospheric Model: Weather and Research Forecast (WRF-4.3.3), with a horizontal resolution of about 15km and 41 vertical levels;

Ocean Model: Nucleus European for the Modeling of the Ocean (NEMO 4.0.7), with a horizontal resolution of 7km and 72 vertical levels;

Interactive runoff from Hydrological Discharge model (HD-5.0.1);

Oasis3-mct to Couple the system;

Ocean and Atmosphere bdy from Reanalyses (ORAS5 and ERA5);

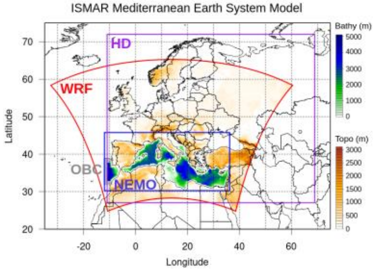

Fig: the model domains composing the system (Courtesy of A. Storto)

Simulated the 2019 with hourly outputs with:

Atm dt -> 1min; Oce dt ->7.5min;
HD dt -> 30 min;
Coupling Frequency -> 30min;

SST and SSTSK from WRF outputs are remapped on a regular grid on the Mediterranean Sea.

Set of simulations

Four simulations were performed:

- A control run in which SST comes from the first ocean model level (about 0.5m), namely using bulk and not skin SST (**ctrlnoskin**);
- A simulation with the scheme as in ZB05, i.e. constant solar extinction coefficients from Soloviev 1982, no Langmuir circulation ocean mixing enhancement effects, valid for low wind conditions (**wrfskin**);
- A simulation with the modifications of Artale et al 2002 for the high wind regimes in the cool skin, and the modifications after Takaya et al 2010 to account for langmuir effects – still constant solar extinction coefficients but with the modification into the 9-band scheme of Gentemann et al. 2009 (**nemoskin**) ;
- As above, but with extinction coefficients dependent on chlorophyll concentration and using the same solar penetration scheme as NEMO (3-band) (**modradnemo**);

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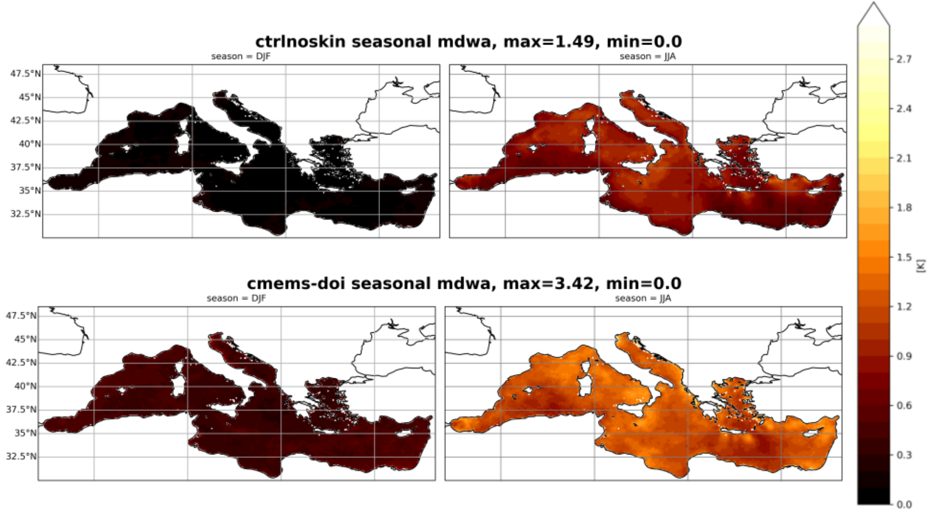
Comparison with CMEMS-MED-DOI MDWA, Seasons



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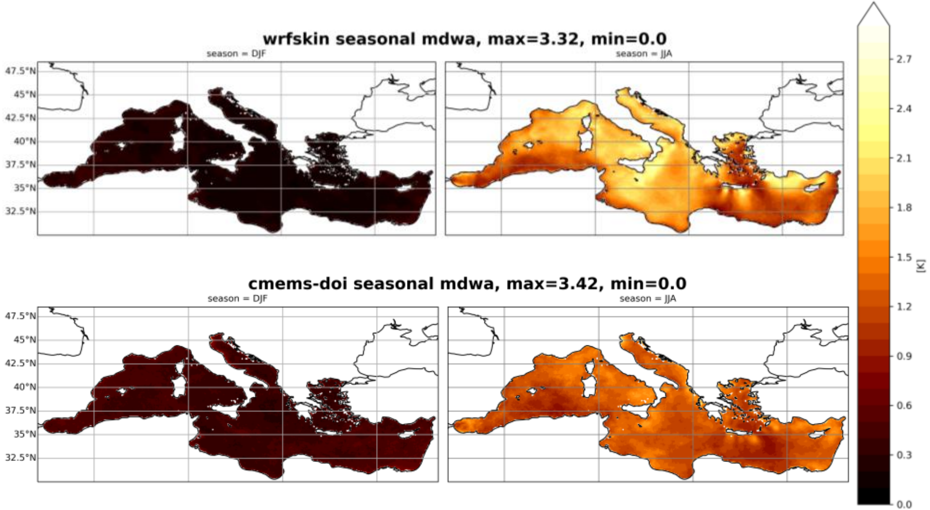
Comparison with CMEMS-MED-DOI MDWA, Seasons



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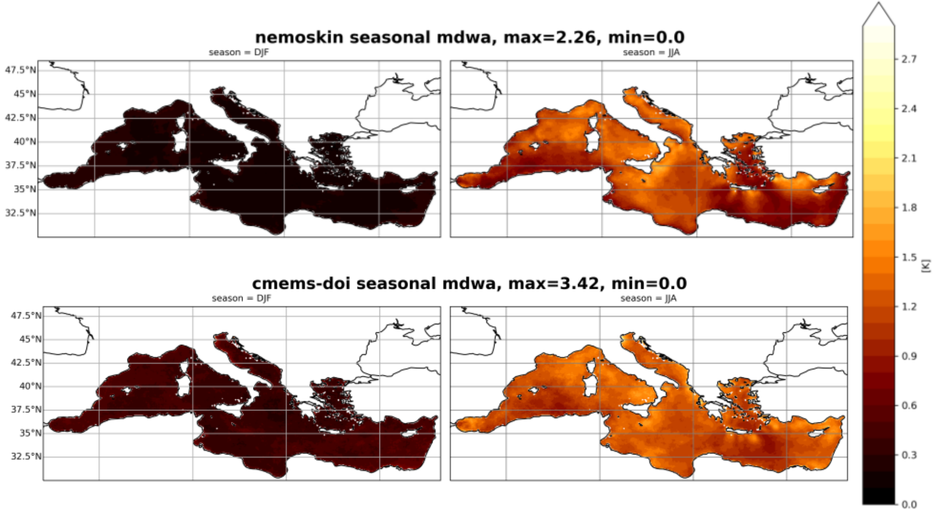

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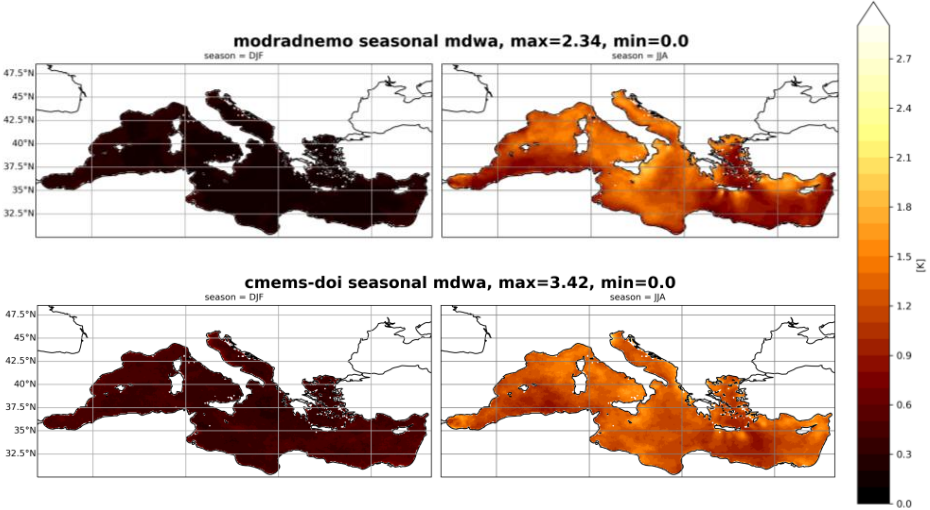

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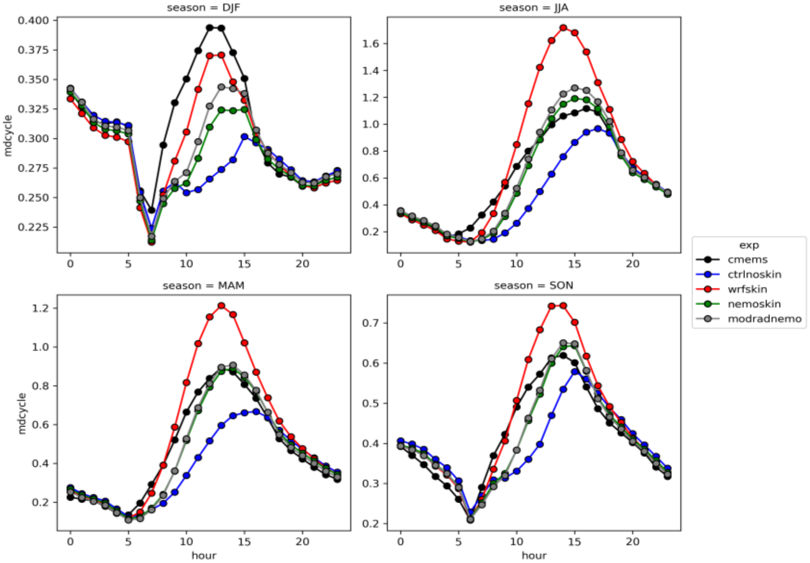
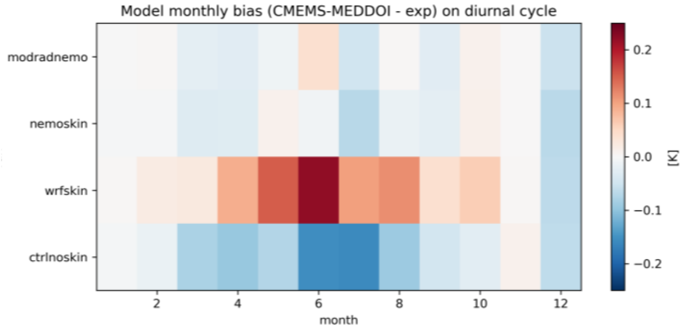
Comparison CMEMS-MED-DOI, Mean Diurnal Cycle, Seasons



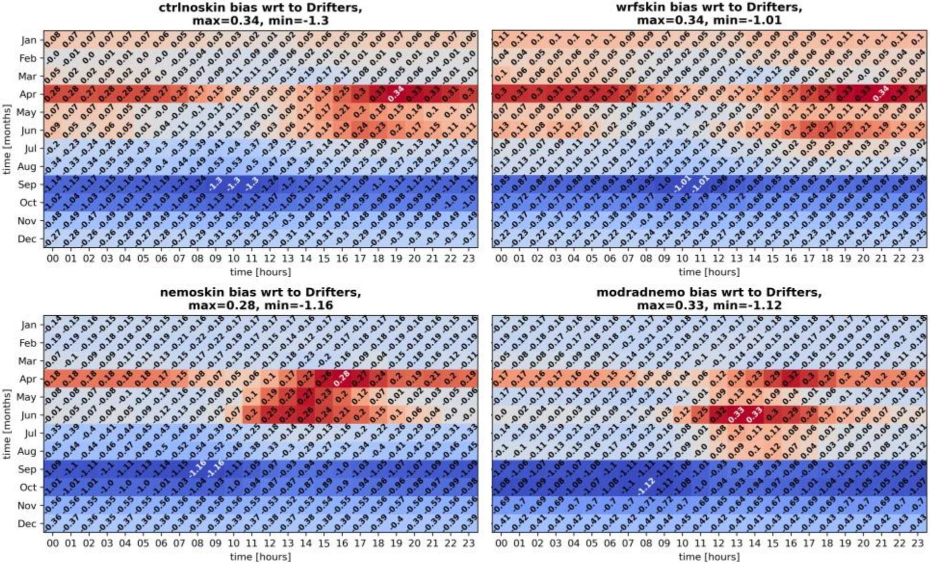
Comparison with CMEMS-MED-DOI MDWA, monthly bias



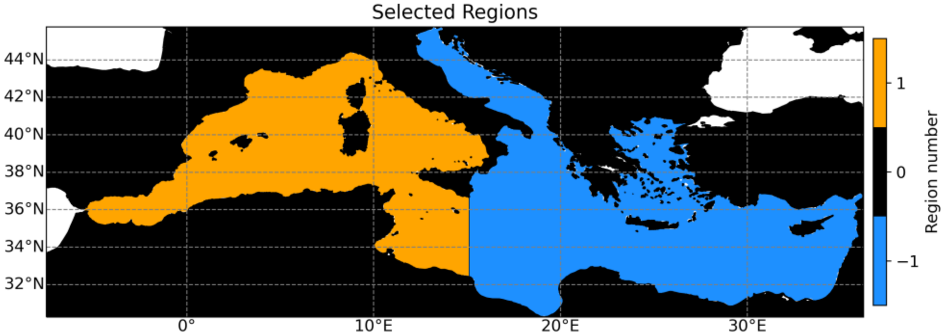
It seems that the modification of the solar radiation extinction coefficients provides a slight improvement on seasonal and monthly timescales mean diurnal warming amplitudes, and on the diurnal cycle representation during Spring and Summer with respect to the wrfskin.

(all the analysis has been carried out masking regions in space-time where the percentage of model data in the optimal interpolation first guess is less than 50%).

Comparison with HR-Drifters: hourly bias vs month (spatial average)

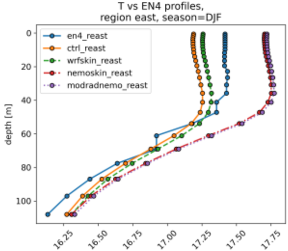


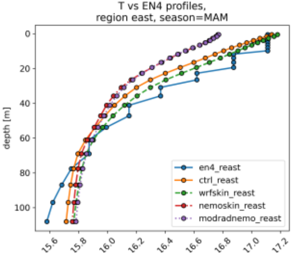
Validation vs EN4 Analysis (bias corrected from GR2010 XBT and GC2020 MBT corrections)

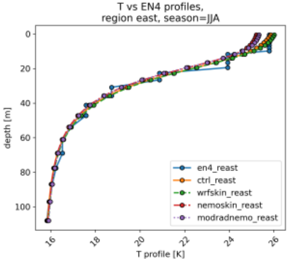


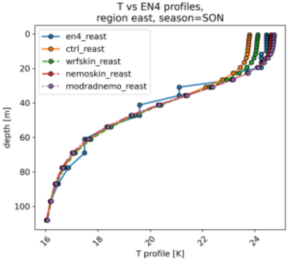
Needing also for a spatial characterization for the validation…
Looking at the vertical profiles averaged over each region which run performs better?
The answer depends on the region and on the time of the year…

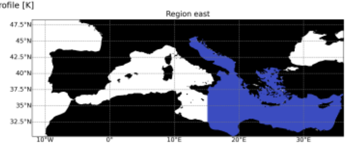
Validation vs EN4 Analysis East Med Sea, Seasonal











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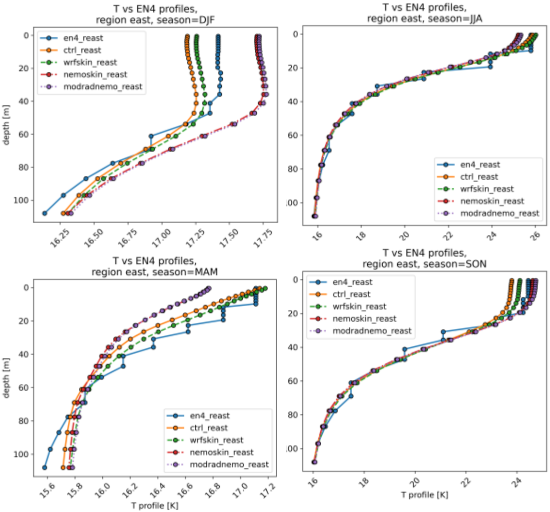
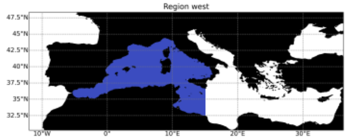
Validation vs EN4 Analysis West Med Sea, Seasonal





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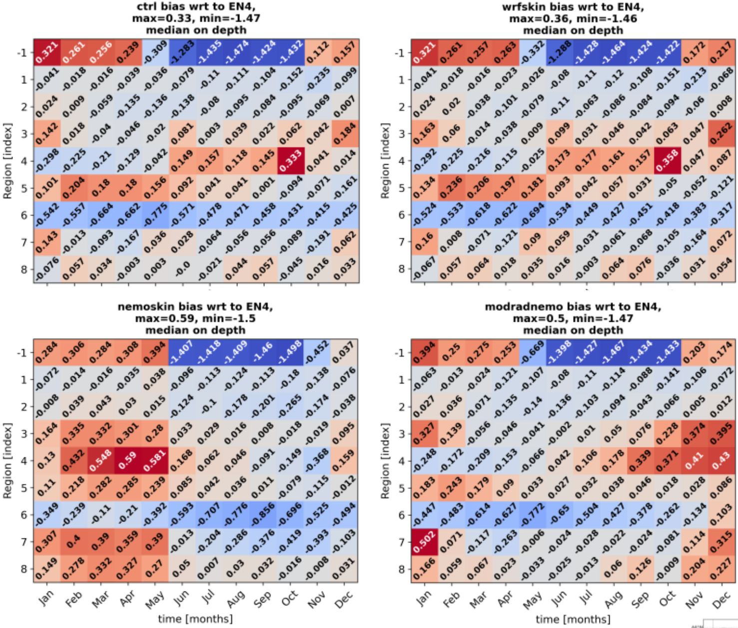
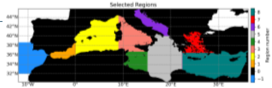


Looking at the median on the vertical it is clear that there's a systematic cold bias with respect to EN4 analysis outside Gibraltar. All the simulation show similar results except in the Tyrrenian Sea: here the bias is reduced when introducing space and time dependent solar extinction.



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Validation vs EN4 Analysis

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Conclusions and future steps

- The comparison with CMEMS-MEDDOI showed that in general, all the simulations except wrfskin tend to underestimate the mean dwa on seasonal timescales during winter and autumn;
- Modifying the solar radiation absorption coefficients slightly improves the situation, depending on the area and timescales of interest (MDWA Seasonal maps):
- Comparison with CMEMS-DOI shows a good performance on seasonal and monthly timescales of the modified solar extinction coefficient simulation;
- Drifters' comparison shows that the peak of overestimation shifts from April to June, and from late to early afternoon; Systematic underestimation in early to late morning in Autumn characterizing all runs;
- Vertical Profiles comparison show better performances of all the methods both in the western and in the eastern mediterranean domain, with marked differences in winter and autumn, when the signal itself gets smaller;
- Looking in more detail, the median profile comparison show systematic underestimation of Autumn and Summertime [0-200m] temperatures in the Atlantic-Mediterranean Area, and the modified solar radiation scheme showed an inversion of the bias' sign in the Tyrrenian Sea from January to July (peak shifting to Nov-Dec);

Acknowledgments

Thanks for the Attention!

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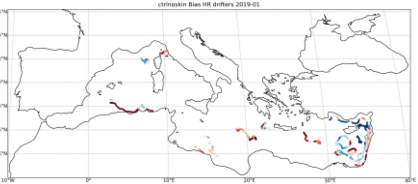
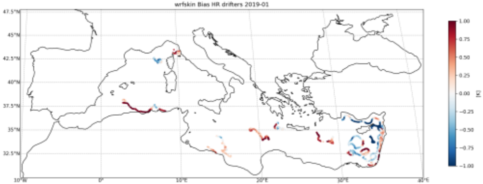
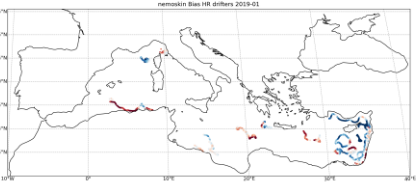
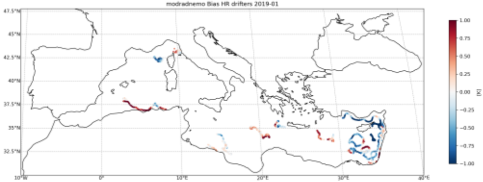
Comparison with HR-Drifters: Monthly averaged mean DWA bias
Winter (Jan)

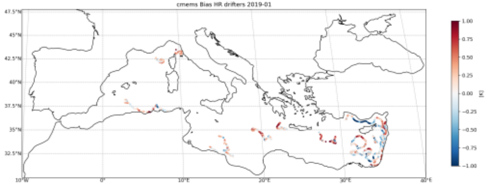






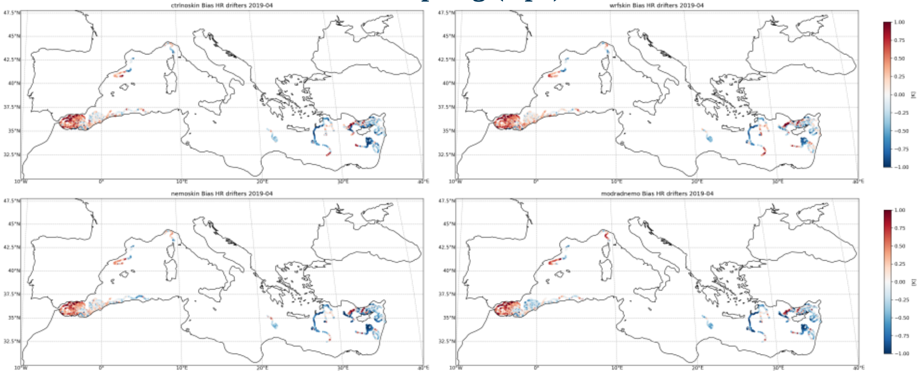


Positive and negative bias, of about 1 degree

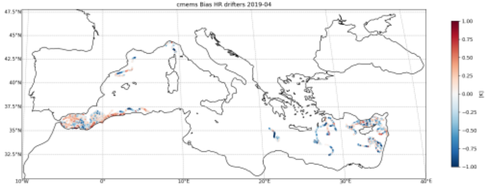


Size of the bias comparable with the signal amplitude

Comparison with HR-Drifters: Monthly averaged mean DWA bias Spring (Apr)



Size of the bias lower then signal amplitude



All simulations generally overestimate in the east and underestimate in the west

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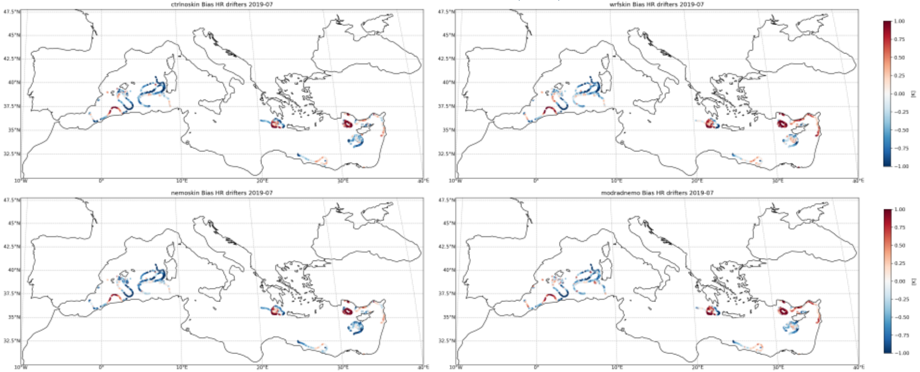
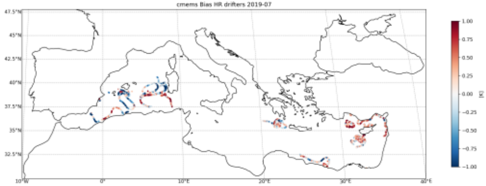
Comparison with HR-Drifters: Monthly averaged mean DWA bias Summer (Jul)



Similar pattern to what the DOI does, less differences across different simulations



Except under Cyprus Island, where the bias is reversed wrt to DOI

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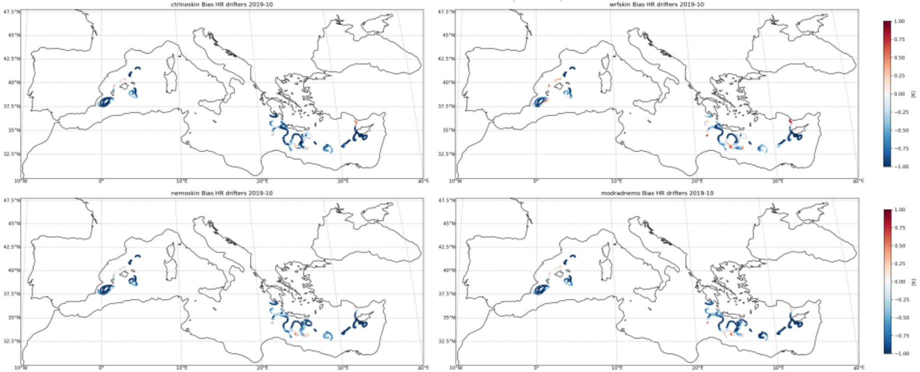
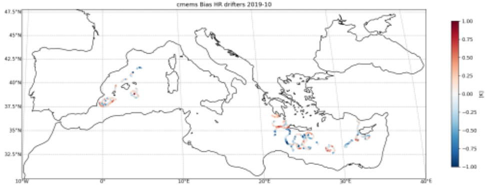
Comparison with HR-Drifters: Monthly averaged mean DWA bias Autumn (Oct)



Systematic underestimation of Mean DWAs in large part of drifter's locations.



Lowest mean Diurnal Warming amplitudes in Autumn!