# Supplementary Information I

# An Integrated Global-to-Regional Scale Workflow for Simulating Climate Change Impacts on Marine Ecosystems

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## Introduction

This Supplementary Information includes the step-by-step instructions needed to perform bias correction of seawater temperature (Step 3) from the GFDL-MOM6-COBALTv2 hindcast and to process the global fishing effort and catch datasets (Step 5) for use in the regional MEMs.

## Step 3: Visualize and extract input variables to see if bias correction is needed

In order to perform bias correction, follow the next sequential sub-steps:

1. Acquire monthly mean sea water temperatures at the depth range of interest (i.e. surface, bottom or depth-resolved) from GFDL-MOM6-COBALTv2, spanning from January 1961 to December 2010 (files are named following this convention: gfdl-mom6-cobalt2_obsclim_thetao_15arcmin for depth-resolved sea temperature). The climate specifier for this dataset is *obsclim*, meaning that climate variability was forced by an atmospheric reanalysis product (JRA-55; Tsujino et al., 2018) and included river nutrient inputs (Liu et al., 2021). The climate data from the ocean model was available on an irregular grid. ISIMIP regridded these outputs to a regular ~0.25° horizontal grid (or 15 arcmin), with a sensitivity scenario specifier of "default" (Table 1, FishMIP3a protocol). Calculate an area-weighted monthly average for sea water temperature over the whole model area for non-spatial models (e.g. Ecosim and therMizer) and over model subregions for spatial models (Atlantis, Ecospace, OSMOSE). Models using more than one depth bin need to calculate an area and depth weighted average for a model subregion and depth layer.
2. Calculate an area-weighted monthly climatology for sea water temperature using the *obsclim* dataset from GFDL-MOM6-COBALTv2 and data from January 1981 to December 2010. Calculate area or area and depth weighted averages depending on the model type as specified in sub-step 3.1.
3. Download the World Ocean Atlas (WOA) 2023 monthly climatologies from January (woa23_decav81B0_t01_04.nc) to December (woa23_decav81B0_t12_04.nc) for the period January 1981 to December 2010. The file name contains important information about the data contained within it. Refer to the WOA23 documentation for further information on the datasets. Regional extractions of the WOA23 climatology are available for download from the Shiny app for all regional models participating in FishMIP.
4. Regrid the spatial domain of WOA23 monthly climatologies to match the GFDL grid. A Python script has been developed to assist modellers with regridding the WOA23 climatologies. The script is publicly available on the FishMIP Github repository. For non-spatial models, calculate an area weighted average over the whole model area (i.e., final product should be one average value per month). For spatial models, calculate the area weighted average for each model subregion (e.g., polygons for Atlantis and grid cells for Ecospace and OSMOSE). If the model is depth-resolved, calculate an area and depth weighted average for a model subregion and depth layer The final product should be a dataset with your specific model dimensions per month. The datasets produced in sub-steps 3.2 and 3.4 will have the same dimensions.
5. Finally, create a bias-corrected temperature time series ($GFDL^{BC}_{1961-2010}$) as follows:

$$GFDL^{BC}_{1961-2010} = (GFDL_{1961-2010} - GFDL_{monthly\ CLIM,1981-2010}) + WOA_{monthly\ CLIM,1981-2010}$$

where $GFDL_{1961-2010}$ was obtained in sub-step 3.1, $GFDL_{monthly\ CLIM,1981-2010}$ represents the monthly climatology for seawater temperature from GFDL-MOM6-COBALTv2 for the 1981-2010 period (sub-step 3.2), and $WOA_{monthly\ CLIM,1981-2010}$ represents the observed monthly climatology for seawater temperature from WOA for the 1981-2010 period (sub-steps 3.3 and 3.4). Using this bias correction method, we correct the systematic biases in the GFDL-MOM6-COBALTv2 model output with respect to the observed monthly mean climatology over the 1981–2010 period. The final temperature retains the observed climatological seasonal cycle, while the interannual variability is derived from the model. Similar approaches to correct the mean historical period of the global climate models are applied in Alexander et al. (2019) and Pozo Buil et al. (2021, 2023).

## Step 5: Match and extract fishing effort groupings to force your model

Fishing effort data can be found in the file "effort_histsoc_1841_2010_regional_models.csv", while catch time series can be found in "calibration_catch_histsoc_1850_2004_regional_models.csv" available in the folders 'ISIMIP3a/InputData/fishing/histsoc/' at the FishMIP THREDDS server. The effort forcing workflow consists of these sequential sub-steps:

1. Filter the effort data to your region of interest (*region*), selecting the sectors (*sector* = 'artisanal', 'industrial') relevant to your model. Filter the effort data based on the Sea Around Us Project (*SAUP*) codes (Pauly et al., 2020) to ensure only the relevant countries fishing within your model area are included in the data. For most areas, only the SAUP code of the country of interest will be used. For instance, 840 for the United States of America was used to filter the effort data for the Hawai'i-based Longline therMizer model. In some areas, such as the Baltic Sea, fishing is done by multiple countries, and therefore the SAUP codes for those countries (e.g., Poland, Denmark and Sweden) were included during data processing for that model region.
2. Select the relevant gears (*Gear*, Table 2) for your model area. The information file 'Codes' contains information on gears, functional groups and taxon needed to map global to regional efforts and functional groups to model species (Watson, 2017; Watson & Tidd, 2018). The mapping of global to regional effort also requires the use of regional time series of effort to inform the mapping of gears, the split of effort and catch from functional groups to species or model groups.
3. Map the selected gears to the target functional groups (*FGroup*, Table 2). As for the gears, use the file 'Codes' and regional time series to advise the allocation of functional groups to specific gears, and model species to functional groups. For instance, the Cape hakes (*Merluccius capensis* and *M. paradoxus*) were allocated to the functional group 'bathydemersal >= 90 cm' and not to 'demersals >=90 cm'. Once the mapping of fleets and functional groups is completed, proceed to filter the effort data to include the gear and functional groups needed for your model.
4. Filter the data based on the *Phase* descriptor, corresponding to the "experiment" phase. The experiment phase spans the years 1961 to 2010. If your model starts before 1961, then relevant data from the transition phase must be extracted. However, most MEMs in FishMIP start after 1961.
5. Apply a similar procedure to the catch data; extracting the region of interest, specific sectors, SAUPs, and functional groups from 1961–2010 based on the decisions made in sub-steps 5.1–5.4 for the effort data.
6. Sub-steps 5.1–5.5 result in two-time series specific to a model area: i) annual catch data (*Reported*) from 1961–2010 for the sector of interest, per functional group to be used for calibration and ii) annual effort (*NomActive*) from 1961–2010 per gear and functional group to force the MEMs.
7. Calculate the average effort per fleet and functional groups using effort data spanning from your model base year (i.e. 1970) until 2004. The latter year is selected because the 3a protocol (Frieler et al., 2024) instructs modellers to use data up to and including 2004 for model calibration/tuning. This average value corresponds to the baseline global effort per fleet (baseline *NomActive*).
8. Calculate a time series of relative effort values by dividing the effort time series from 1961 to 2010 (Annual *NomActive*) by the baseline global effort calculated in sub-step 5.7. Then, multiply this time series of relative effort by the baseline effort or fishing mortality in each regional MEM per fleet as follows:

$$Annual\ Effort = \left(\frac{Annual\ NomActive}{baseline\ NomActive}\right) \times \left(baseline\ effort\ \text{OR}\ fishing\ mortality\right)$$

## References

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