Ensemble mean of CMIP5 Sea Surface Temperature projections under climate change and their reference climatology*

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Abstract

A software was developed in the framework of the GEOWOW project for computing the mean of the output of an ensemble of climate change models from the World Climate Research Programme (WCRP) Coupled Model Intercomparaison Project Phase 5 (CMIP5). The ensemble mean for the time projections of the Sea Surface Temperature (SST) under climate change and the corresponding climatology were computed: this paper describes the data set and its properties. The generated datasets are of interest for ecologists willing to assess future changes of marine ecosystems, and can be used under Creative Common Attributions license.

Keywords: CMIP5, Ensemble Mean, Time Projection, Climatology, Sea Surface Temperature, Temperature of Surface, SST, TOS, CC-BY

1. INTRODUCTION

The Coupled Model Intercomparison Project Phase 5 (CMIP5, Taylor et al., 2012) is a project of the World Climate Research Programme (WCRP) for providing the

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Intergovernmental Panel on Climate Change (IPCC) with the Fifth Assessment Report (AR5) with time-projected environmental variables (IPCC, 2013). Virtually all climate modelling teams in the world contributed to this work (Taylor et al., 2012). A large repository of outputs, physical variables, and their time series were generated and made available, as a community ensemble is accessible from the Earth System Grid Federation (ESGF) platform (PCMDI, 2014).

The CMIP5 database allows access to the variable outputs for each individual model. The outputs are generally available as a time series with various time steps, including daily, monthly, and yearly time steps, from 2006 to 2100 (some models propose output projections up to 2300).

The models' time-projection variables are computed for different Representative Common Pathways (RCPs) at RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, named after the target energy forcing by 2100 in $W.m^{-2}$. Each RCP contains the same categories of data, but the values vary a great deal, reflecting different emission trajectories over time as determined by the underlying socio-economic assumptions (which are unique to each RCP).

The Transboundary Water Assessment Program (TWAP), a global water assessment program funded by the Global Environment Facility (GEF), requires such model ensemble means to assess the potential future change of essential ocean variables. In particular, the time projection of the Sea Surface Temperature is of highest interest for assessing the potential impact of global warming on the Pacific Warm Pool, the impact of ocean acidification on pteropods and coral reefs on a global scale, or the Cumulative Human Impact projected for 2030 and 2050. The TWAP program is intended for policymakers and is thus aiming to assess the likely future state of the ocean. For this reason, only RCP 8.5 and RCP 4.5 are considered.

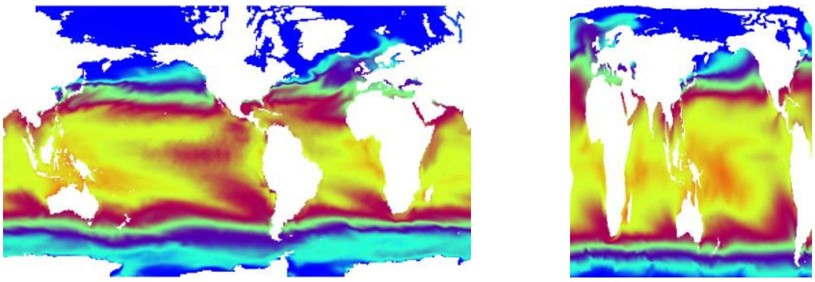
In addition to time-dependent projections of the Sea Surface Temperature, it is often necessary to have climatology representing a reference state, from which deviation (or anomalies) can be stated. The so-called "Reynolds" climatology used in the TWAP report spans the period from 1971 to 2000, with a time resolution of one month and a spatial resolution of 1°x1° (Reynolds et al., 2002). It is based on satellite observation and was corrected on the basis of in-situ measurements. A similar climatology was computed from the models' simulations. Adjusting the model-based climatology to the actual climatology allows for removing model bias and observing only forecasted anomalies.

2. INPUT DATA AND PROCESSING METHOD

Most climate models are run with different sets of input ensemble parameters, numbered r1i1p1, r1i1p2, …, corresponding to different settings of the models, resulting in the domain of variability of each model output. A good practice consists in averaging the output of a model corresponding to the various input ensemble parameters before averaging all the model averages together (Oldenborgh et al., 2013). This procedure avoids giving more weight to a single model because it would have been run against many input ensemble parameters.

The first technical difficulty is related to the different models' grids. The models' outputs are made available with a model grid, depending on each model. Figure 1 shows an example of two different TOS (TOS, or Temperature Of Surface, is the standard name for the sea surface temperature in the CMIP5 dataset) files used by the models for storing their output values; the land masses in white demonstrate the differences between the grid systems. The grids do not have the same resolution, and different areas of the world may have finer resolution than others. The polar regions are not evenly represented, either.

Figure 1. GFDL (Left) and CCSM4 (Right) Output Grids



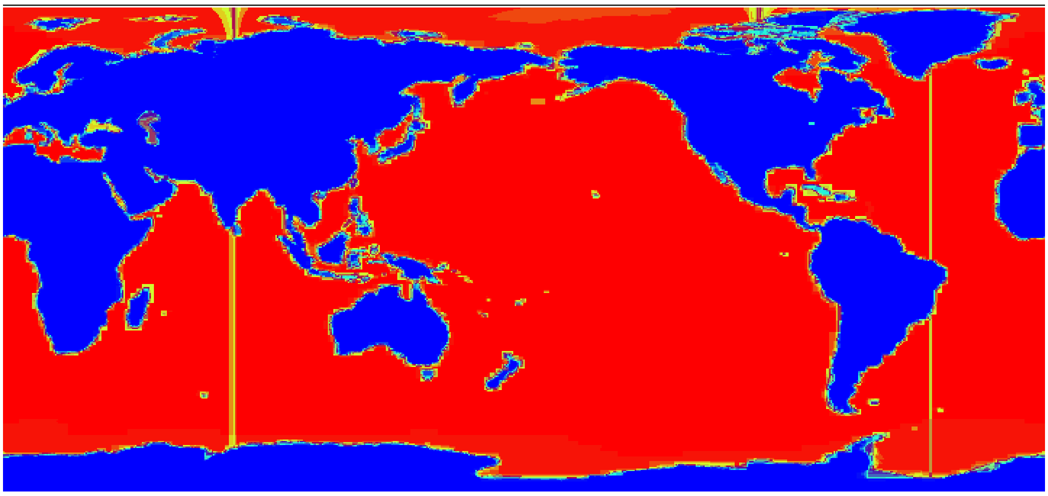
For the TWAP project, the common grid was defined with a spatial resolution of ½° x ½°, with latitude from -85° to 85° and longitude from 0° to 360°.

The horizontal grid was designed with a higher resolution than most average global products found in the literature, which often have a spatial resolution of 1°x1°. The reason is that many CMIP5 models have regions with a resolution better than 1°. A half-degree resolution was found to be a good compromise.

The common grid is thus not evenly covered by all models (Figure 2). Two meridians (around 40°West and 80°East), which correspond to projection limits in several models, are underrepresented. Continents' shores show also large discrepancies due to the significant differences in land mass gridding between the models.

Grid cells with a smaller number of samples for computing the ensemble mean may differ slightly from the neighbouring open ocean. A code (filter_vertical-Lines.py) was written to replace visible boundary seams with linear interpolated values due to under-sampling (https://github.com/IOC-CODE/cmip5_projections/releases/tag/1.0). However, data are provided under their raw format (Combal, 2014a; 2014b; 2014c) to let users apply their favourite filtering operators or analyse the properties of the ensemble mean itself.

Figure 2. Number of Models Providing Contributing to the Ensemble Mean per Grid Element. From 0 (Blue) To 35 (Red)



3. OUTPUT DATASETS: TOS ENSEMBLE MEANS UNDER CLIMATE CHANGE AND TOS CLIMATOLOGY

Two datasets were created. The first one is an ensemble mean for the projection of the sea surface temperature. The second dataset is a climatology based on models output for the period 1971-2000 (the so called historical runs), which is compared to a climatology based on actual observations for the same period: the deviation of the model climatology from the observed climatology corresponds to the correction to bring to the models ensemble mean.

The ensemble mean of the CMIP5 time-projected TOS (Temperature of Surface, equivalent to the Sea Surface Temperature), one value for each of the twelve month of the year, was processed for RCP 4.5 and RCP 8.5 for the time period from 2010 to 2059 (Combal, 2014a). Figure 1 shows the last value in the time series for RCP 8.5, from the file ensemble_tos_rcp85_205912.nc.

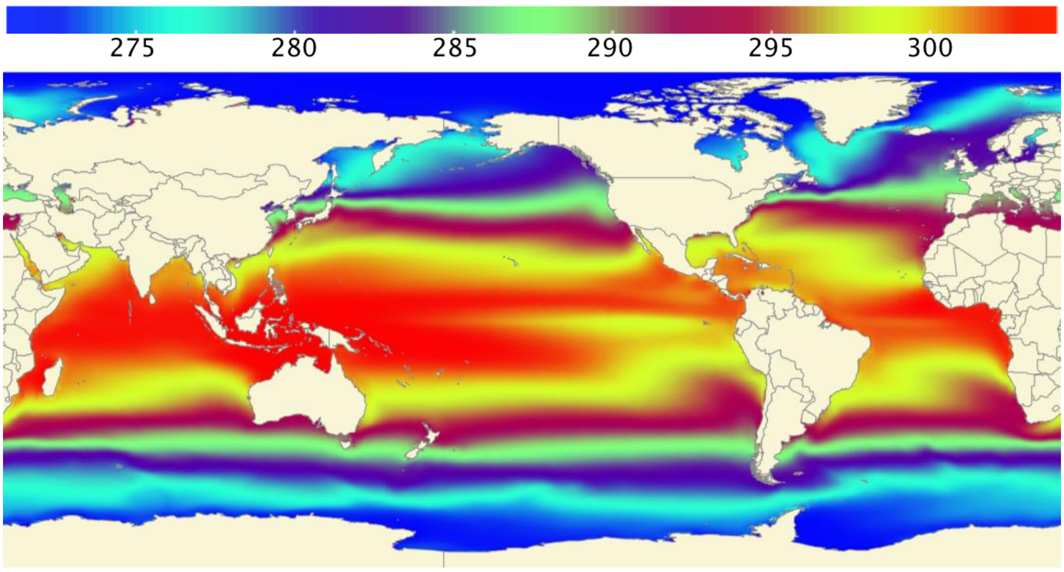
Each NetCDF file is CF-1.0 formatted. It corresponds to a one-month ensemble mean with four variables (Table 2): the TOS ensemble mean (variable "mean_mean_tos"), the count of models used to compute the ensemble mean per grid cell (variable "count"), the minimum of the ensemble mean for this date (variable "minimum"), and the maximum of the ensemble mean for this date (variable "maximum").

The file naming convention is ensemble_tos_rcp[RCP]_[YYYY][MM].nc, where RCP is one of two RCPs (rcp45 or rcp85), YYYY is a year of four digits, and MM is a month of two digits.

Table 2. Variables Available In Ensemble Mean Files

Variable	Units	Missing value
mean_mean_tos	Kelvin	1.10^{20}
count	No unit	999999
minimum	Kelvin	1.10^{20}
maximum	Kelvin	1.10^{20}

Figure 2. Ensemble Mean of Variable TOS for December 2059



The ensemble mean of the historical run does not depend on any RCP and is available for the period from 1971 to 2000 at a monthly time step (Combal, 2014b). Table 3 describes the variables in the CF-1 formatted NetCDF. The file naming convention is modelmean_tos_[YYYY][MM].nc, where YYYY is the four-digit year and MM is the two-digit month. The archive starts on 197101 and ends on 200012.

Table 3. Variables Available In Ensemble Mean Of Historical Run NetCDF Files

Variable	Units	Missing value
tos	Kelvin	1.10^{20}
count_tos	No unit	999999
min tos	Kelvin	1.10^{20}
max tos	Kelvin	1.10^{20}
std tos	Kelvin	1.10^{20}

The TOS climatology (equivalent to the Sea Surface Temperature climatology) was created by computing the monthly average of the former dataset (Combal, 2014c). The files are CF-1.0 formatted and contain only one variable, “TOS”, in Kelvin, with 1.10^{20} for the missing values.

This later dataset allows for computing deviations of the time-projections to the climatology (Figure 6), under scenarios RCP 4.5 and RCP 8.5.

4. POTENTIAL USE

The time series of projected SST values under climate change and their deviations to the climatology is the basis for assessing potential future change in the ecological system. Such an approach is the basis for processing some of the indicators used in the Transboundary Water Assessment Programme (Combal and Fisher, 2016), such as thermal stress on coral reefs (Donner, 2009) or pteropods (see http://onesharedocean.org/open_ocean).

5. LICENSE

The described data set is a contribution to GEOSS Data Core, as a result of the GEOWOW project. Data are licensed under Creative Common CC-BY-4.0 (as defined in http://www.opendefinition.org/licenses/cc-by), which allows re-distribution and re-use on the condition that the creator is appropriately credited. Please use this publication for credits, and Combal (2014a, 2014b or 2014c) to reference the data source.

6. CONCLUSION

This paper explains how to process CMIP5 datasets to obtain an ensemble mean. Writing a general purpose ensemble mean software, as needed in a service, leads to solve the challenges exposed in this paper, in particular to reconcile the grid systems used by the different models.

The described approach is general enough to be applied to most of model outputs (at least for scalar fields, including three-dimensional fields), and it solves common issues found when computing an IPCC-like ensemble mean. An example of processing service, using a cloud computing system, was developed on the basis of the described method (Combal and Caumont, 2016).

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