RACER-WWF Report on Climate Change Scenarios

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Introduction

The present document provides a brief overview of the work done over the one-month contract between WWF and Ouranos for the RACER project. Files and figures created for the project are available on the project web site hosted by Ouranos. This document does not describe nor analyze the results of the study, but rather provides details about the analysis used to generate the results. In particular, it describes the structure of files holding the raw results and presents examples of the figures created for the project.

The bulk of the project was carried out from April to May 2010, but initial work started as soon as december 2009. The projet's main deliverable that are adressed in this report are the following:

1. Collate and manage available data (e.g., climatological and meterological data, and modeled geo-physical variables) from various external sources, from approximately 5 General Circulation Models (GCM), to include Community Climate System Model (CCSM).
2. Confirm with RACER project team and Experts Advisory Group the suite of key variables and specific scenarios for analyses.
3. Extract modeled projections for at least two decadal timelines up to mid 21st Century, and compile these in tabular form averaged for each ecoregion, for all key variables and greenhouse gases (GHG) scenarios.

Selection of Global Climate Models

The general recommendations of the IPCC 2007 documentation is to use as many models as possible to draw conclusions about projected climate change. The IPCC AR4 includes 24 GCMs driven by a set of GHG scenarios, for which a number of different realizations (runs) are available. It was decided early on to limit the study to a subset of models to keep the amount of results manageable given the time constraints.

This decision was validated a posteriori by conclusions from a yet unpublished chapter of the SWIPA Science Assessment (Snow, Water, Ice and Permafrost in the Arctic) reviewed by my colleague Ross Brown (Environment Canada/Ouranos). The work authored by Overland, Wang, Kattsov, Christensen, Chapman and Walsh argues that composite averages for key climatic variables in the Arctic attain optimal performances when they include the top 5-7 models; adding additional models degrade performance. Their top-ranked models for Arctic scenario development are CCSM3, CNRM, ECHO-G/MIUB, and UKMO-HadGEM1. These four models were selected for the racer study. The SWIPA chapter is expected to be published in 2011.

GHG Scenario Selection

Following a meeting with Bruno Tremblay and Peter Ewins, the emission scenario initially selected was A1B. This scenario was regarded as the business as usual scenario, and has the advantage that all 24 IPCC models provide runs for it.

Following discussions with partners, WWF elected to rather focus on the A2 scenario, which projects stronger warming trends at the end of the 21st century, and matches more closely the current observations. Although this scenario was used by 19 participating climate models, all four selected models provide at least one run using A2.

Variable Selection

A subset of 20 variables was identified as relevant for the RACER project. Their name, definition and availability among the four selected models is shown in the following table. Data at the monthly or yearly scale was downloaded from the IPCC AR4 ftp site from two GHG scenarios: `20C3M` for the period 1961-2000 and SRESA2 for the period 2000-2100. Only one run per model per variable is used.

Selected IPCC variables

Variable	Description	Availability
cdd (yearly)	Maximum Number of Consecutive Dry Days	2
etr (yearly)	Intra-Annual Extreme Temperature Range	2
gsl (yearly)	Growing Season Length	2
tas	Surface Air Temperature	1,2,3,4
tasmax	Maximum Daily Surface Air Temperature	1
tasmin	Minimum Daily Surface Air Temperature	1
snc	Snow Area Fraction	1
snd	Snow Depth	1,2,3
snm	Snow Melt	1,2,3,4
snw	Snow Amount	1,2,3,4
pr	Precipitation	1,2,3,4
mrfso	Soil Frozen Water Content	1,4
mrro	Surface and Subsurface Runoff	1,2,3,4
mrros	Surface Runoff	1,2,3,4
mrso	Total Soil Moisture Content	1,3,4
sic	Sea Ice Concentration	1,2,3,4
sit	Sea Ice Thickness	1,2,3,4
so	Ocean Salinity	1,2,3
tos	Sea Surface Temperature	1,2,3,4
zmlo	Ocean Mixed Layer Thickness	2

Availability of the 20 selected variables among the four models: CCSM3 (1), CNRM (2), ECHO (3) and UKMO HADGEM 1 (4).

Data Preparation

Datasets are archived by the IPCC in netCDF format. Each dataset contains meta data describing the grid, source and units. Data coverage is global and to reduce computational time and memory footprint, all datasets were cropped below 40°N. Also, for variables split into multiple files (for instance one file per decade), multiples files were concatenated to facilitate processing. Also, some errors and inconsistencies were corrected in the original files.

Mask Definition

The main project deliverable is a set of tables holding monthly decadal means for all 50 eco-regions defined by the RACER team. To compute the mean over some region, a mask delineating the region is needed. The mask is an array with the same dimension as the original model grid containing values that are proportional to the grid area intersecting the region; we will refer to this array as the weighted mask. To compute the area of intersection, the first step is to map the model grid and region polygon coordinates on a Lambert azymuthal equal area projection. This projection has the property to preserve areas. The next step is to convert the mapped model grid into an ensemble of individual polygons, one for each grid cell. Each grid cell polygon is then intersected with the set of polygons forming one eco-region to find the total eco-region area covered by the grid cell. Once this is done for all grid cells, the values are scaled such that they sum to one and saved as the weighted mask. This procedure is performed for all four models, four domains (ice, atmosphere, land and ocean) and 50 ecoregions. Using those weighted masks, the regional mean can be found simply by multiplying it with the variable field and summing over the entire grid. These weighted masks are saved in HDF5 format and are available on demand.

Regional Decadal Monthly Means

Typically, netCDF variables are shaped as 3D or 4D grids with dimensions (time, latitude, longitude) or (time, level, latitude, longitude), where the level can be the depth or the height. To compute a monthly mean over a region, the procedure followed is

1. Identify the time indices corresponding to one decade (2000-2009, 2010-2019, .., 2090-2099).
2. Among the selected dates, find those for a given month (January, February, ..., December).
3. Select the surface level if applicable.
4. Compute the temporal mean over selected indices.
5. Mutliply the monthly decadal mean by the region weighted mask and sum the resulting array to estimate the regional mean.

These steps are repeated for each decade and month to generate a 10 by 12 table (decade, month) of regional decadal monthly means. One such table is created for all four models, 50 regions and available variables.

A similar procedure is used to compute the annual mean. In this case, the temporal mean is computed over all months before being multiplied by the region mask. The tables for the monthly and annual means are saved in HDF5 format in files named <model>_regional_means.h5, where <model> can be cnrm_cm3, ncar_ccsm3_0, miub_echo_g and ukmo_hadgem1. All files follow this structure, where region folders (*groups* in HDF5 parlance) hold variable groups each holding three tables: `mdm`, `am` and `decades`.

- r0
- r1
  - snw
  - sic
    - mdm
    - am
    - decades
  - pr
  - ...
- r3
- ...

The `mdm` table stands for monthly decadal mean, the `am` table stands for annual mean, and the `decades` table is simply a list of decade names.

Figures plotting the monthly decadal means are provided for two variables in each domain:

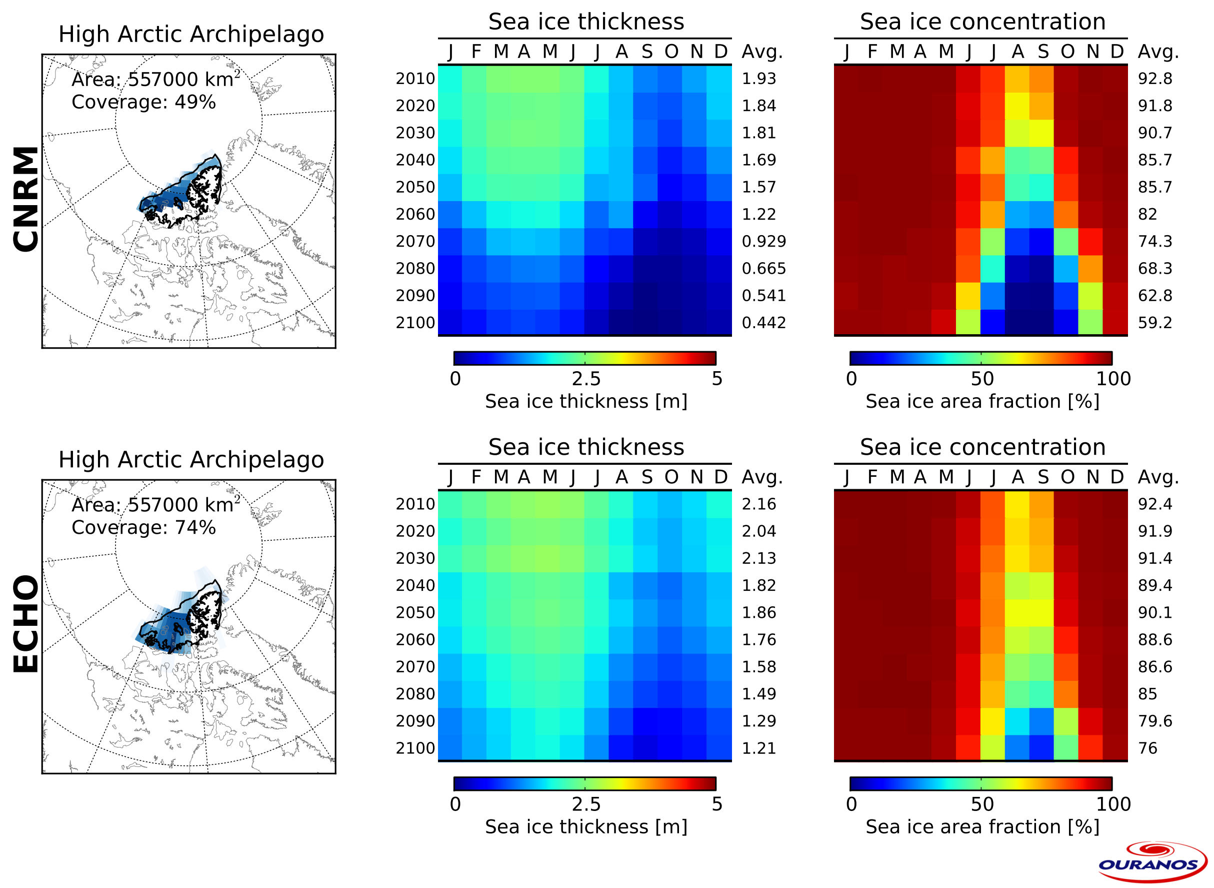
• summary_atm.pdf: precipitation and surface temperature,

• summary_land.pdf: soil moisture content and amount of snow,

• summary_ice.pdf: sea ice thickness and concentration,

• summmary_ocn.pdf: ocean surface salinity and temperature.

In each figure, the leftmost subplot shows a map of the ecoregion with an overlay presenting the weighted mask. A value for coverage is given, whose meaning is the percentage of the eco-region area for which data is present. Missing values occur frequently in coastal regions, reducing the amount of data available for averaging. Results for regions with a coverage of 50% are hence only representative of half the region.



Example of summary figure displaying the regional monthly decadal means.

The subplots on the right of the map show 10x12 data grids (decade, month) of color-coded regional monthly decadal means. The decadal average is printed at the right of each grid. The color scale is the same for all models to facilitate comparisons. White squares indicate missing values.

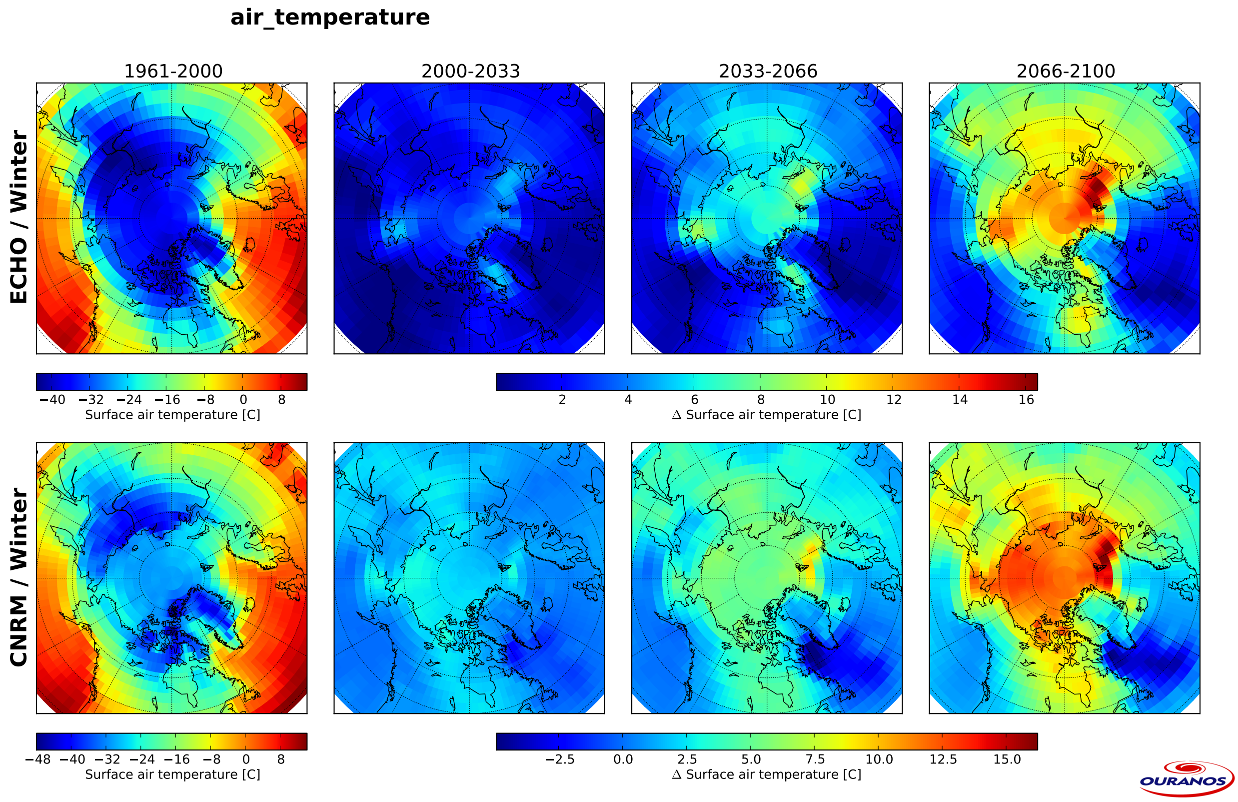
Note

The average decadal monthly means over a decade is not always equal to the annual mean over the same decade. Differences are due to how missing values are handled. The mask of missing cells for a given temporal mean (monthly or annual) is imposed on the weighted mask which is then renormalized. For monthly means, we might hence have 12 different weighted masks, one for each month, while the annual mean has only one weighted mask.

Seasonal Means

To provide an overview of changes in the Arctic, seasonal means (DJF, MAM, JJA, SON) were computed over the periods 1961-2000, 2001-2033, 2034-2066 and 2067-2099. The mean seasonal values over the entire model grid are saved in netCDF format in files named `<model>/<var>_seasonal_means.nc`. Inside the netCDF file, fields are placed in chronological order starting with the winter mean of period 1961-2000 (index 1) to the automnn mean of period 2066-2100 (index 12).

Figures were created showing the mean field for the reference period (1961-2000) and projected differences (deltas) for the three future periods. These figures are available under the names: `seasonal_delta_maps_<var>.pdf` where <var> stands for the variable name. These figures show well the spatial variability of expected changes in the Arctic.



Example of mean seasonal changes figure.

Caveats

As with any study using climate change projections generated by global climate models, it is worth underlining a major *caveat*: climate projections are not predictions. A given climate run is at best a plausible climatic scenario. Accuracy and realism are hampered by the crude representation of certain processes and the shear complexity of all interactions giving rise to what we call climate. For the Arctic, this is even more true since the current representation of glaciers and ice sheets is relatively immature compared to atmospheric phenomena. The message is that analyzes should be conducted on heavy trends affecting large areas over extended periods of time, corroborated by an ensemble of models. This is important to keep in mind when analyzing the results for the smalled ecoregions, spanning only a handful of model grid cells.