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Anthropogenic climate changes around the Mediterranean basin for several future scenarios

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1. Introduction

It is generally agreed that global coupled ocean-atmosphere general circulation models (CGCMs) are the best tools to predict climate variations at seasonal and interannual scales, and to estimate climate changes at longer time scales, especially those related to the anthropogenic modification of the atmospheric composition. Outputs from such models cannot, however, be directly used in many impact oriented applications because of their relatively coarse spatial scale (typically several hundreds of kilometres) and associated uncertainties. Furthermore, while particular coarse resolution CGCM may be capable of capturing the mean climate behaviour, they are not usually successfull in reproducing higher-order statistics and extreme values. Regional climate modelling plays thus an important role to fill the gap between the global climate models and the growing demand of climate predictions and scenarios on shorter spatio-temporal scales.

As uncertainties related to the future greenhouse-gas emission scenarios and related to the physics in global climate models, the use of regional modelling introduces further uncertainties concerning global-warming issues. The purpose of this study is to estimate future climate changes around the Mediterranean basin and the associated uncertainties.

Projection of climate changes for the end of the 21st century is presented under the IPCC/SRES A2 emission scenario. Mean climate changes and some indicators of extreme events are studied. Several model outputs (IPSL, Météo-France, GFDL, NCAR) for the same A2 emission scenario are used to evaluate uncertainties related to global climate models.

2. Model and simulation

The model used to evaluate the Mediterranean climate change behaviours is the LMDZ-Mediterranean, a global variable-grid atmospheric GCM with zoom over the Mediterranean sea. Figure 1 show the model grid and the grid area. The effective resolution of the model is about 160×160 km2. In this study, the version 4.0 of LMDZ is used. It is derived from the standard version described in Sadourny and Laval (1984). A brief presentation of the current physical parameterization is in Li (1999). The convection schema has been changed, since then, to that developed by K. Emanuel. This version of the LMDZ model is also used in the coupling to a Mediterranean sea general circulation model.

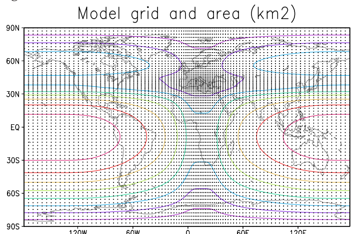

Figure 1: Schematic showing the model grid and grid area (contour, from 20 000 to 160 000 km2) of the LMDZ model with 96 points in longitude, 72 in latitude, 19 in vertical and a zoom over the Mediterranean.

The LMDZ-Mediterranean employs, as boundary conditions and driving forcing, the sea-surface temperature (SST), sea-ice extension and greenhouse-gas concentrations to make regional-oriented simulations. Unlike the nesting approach that need to incorporate a regional model into a large-scale global model, our approach with the variable-grid GCM is operating in a standalone manner. For the control simulation (referred to as exp00, hereafter) dedicated to reproduce the current climate, the observed climatological conditions are used, as in AMIP but without interannual variation.

For the climate at the end of the 21st century, we use outputs from four global climate models (as shown in the Table below): IPSL (exp03), Météo-France (exp04), GFDL (exp05) and NCAR (exp06). All of them give the future climate projection under the hypothesis of SRES-A2 emission scenario.

simulation	period	boundary conditions
exp00	1970/1999	Observed SST and sea-ice
exp03	2070/2099	A2 scenario from IPSL
exp04	2070/2099	A2 scenario from Météo-France
exp05	2070/2099	A2 scenario from GFDL
exp06	2070/2099	A2 scenario from NCAR

In order to correct the bias of global models in reproducing the current climate, we calculate first the simulated changes (anomalies of SST, sea ice and greenhouse gases) and add them to the control simulation. Through such a manipulation, we reduce also the number of necessary simulations since all the scenario runs share a same and unique control simulation.

The manipulation of anomalies is quite easy and straitforward for SST, but sometimes it is not possible to do that for the sea ice whose values are allowed to vary only from 0 to 100%. To overcome this difficulty, we use the analog approach as described in Appendix A.

The following two figures (2 and 3) show the annual-mean changes for SST and sea ice concentration respectively, used as boundary forcing into the LMDZ-Mediterranean.

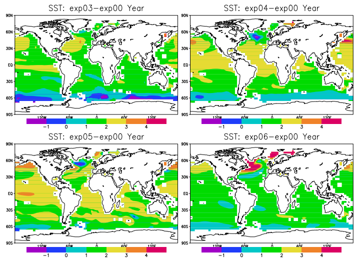

Figure 2: Sea surface temperature anomalies (°C) extracted from SRES-A2 climate scenarios (2070/2099) produced by the global coupled models of IPSL (exp03), Météo-France (exp04), GFDL (exp05) and NCAR (exp06). They are boundary conditions and driving forcing for the LMDZ Mediterranean model.

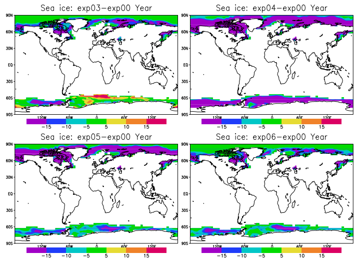

Figure 3: Same as in Fig. 2, but for sea-ice (0 to 100%).

3. Results

Results are only shown for the Mediterranean region where the model's resolution is the highest. After showing important average climate quantities, such as the air temperature and precipitation, we present also a statistic on the extreme events of summer high temperature and winter strong precipitation.

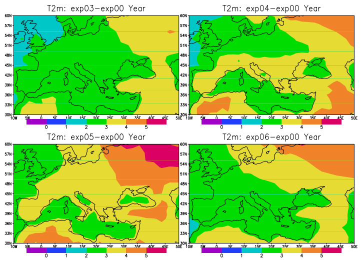

Figure 4: Annual mean surface air temperature changes (°C) predicted for the end of the 21st century for the four SRES-A2 scenarios produced respectively by IPSL (exp03), Météo-France (exp04), GFDL (exp05) and NCAR (exp06) models. Over the Mediterranean sea, the air temperature is warmed by 2 to 3 °C. The surrounding land mass is warmed further, especially in exp04 and exp05.

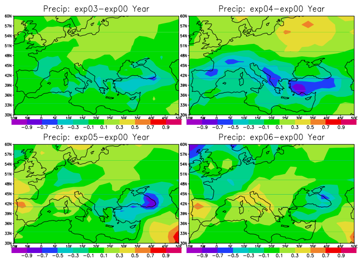

Figure 5: Same as in Fig. 4, but for the annual-mean precipitation (mm/day). The results seem to polarize into two categories. (1) exp03 and exp04 have a general decrease of precipitation, especially for the north coast. They have some spatial resemblance, but the amplitude is much stronger in exp04 than in exp03. (2) exp05 and exp06 share many commun features of spatial distribution, with increased precipitation over the Mediterranean. The increase is larger in exp06 than in exp05. We could eventually assess the uncertainty provided by the four scenarios by calculating the ratio between the multi-model ensemble mean changes and the standard deviation among the four realisations. The same consideration applies also to the temperature of Fig. 4. We can see easily that the temperature changes are much more robust that the precipitation, since $\Delta T/\sigma_{\Delta T}$ is in general larger than $\Delta P/\sigma_{\Delta P}$

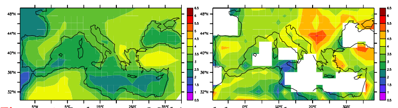

Figure 6: Left panel: Multi-model ensemble mean Summer (JJA) air temperature variations (°C). Right panel: Intensity changes (°C) of Summer heatwaves whose probability of occurence is 14 years, if expressed in terms of return period (see the Appendix B for detailed calculation). The Summer heatwaves are characterized here by the surface maximum temperature during the daytime.

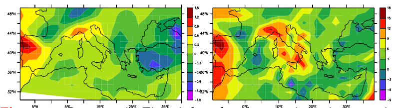

Figure 7: Same as in Fig. 6, but for the precipitation rate in winter (mm/day). Left panel: changes of winter mean precipitations. Right panel: Intensity changes of winter strong rainfall events whose probability of occurence is 14 years, if expressed in terms of return period. We can remark that the strong rainfall events have larger intensity in the future climate almost everywhere for the Mediterranean basin, especially in the middle of the basin. This is certainly related to the fact that strong rainfall events have more energy to develop in a warmer climate.

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GFDL data are obtained from:
"http://data1.gfdl.noaa.gov/nomads/forms/climate.html".
NCAR data are obtained from:
"http://www.ccsm.ucar.edu/experiments/csm1/b030.A2/".

Appendix A: Construction of sea-ice anomalies

In the procedure of using "anomalies" to construct future sea-ice distribution for scenario runs, it is sometimes not possible to do that since the sea-ice concentration is allowed to vary only between 0 and 100%. To overcome this difficulty, we use the analog approach for each hemisphere. The hemispheric ice coverage is first calculated for each month (without consideration of the seasonal cycle) and for the observed period 1979/2002. We obtained thus a look-up table which gives the correspondence between the hemispheric ice coverage extension and the sea-ice geographic distribution. By knowing the hemispheric ice coverages of the observed current climate, simulated current climate and simulated future climate, one can calculate proportionally the optimal value of future ice coverage. This permits us, with the look-up table, to deduce the sea ice geographic distribution to be used as boundary conditions for LMDZ-Mediterranean. When the dynamic range of the sea ice variation offerred by the natural changes of seasonal and inter-annual variations, one has to artificially modify the sea ice extension (progress or retreat) to reach the wanted hemispheric ice coverage. We can also generalize our approach to more than two geographic sectors in order to take into account particular sea ice geographic distribution and temporal variation.

Appendix B: extreme events

Extreme events are defined here in the statistical sens. For each model point of the Mediterranean region, a probability distribution function is estimated and fitted to a Generalized Extreme Value (GEV) distribution. Here the probability P is expressed in terms of return period T. The intensity X_T of such extreme events in function of return period is given by:

$$X_T = \beta + \frac{\alpha}{k}\{1 - [-\ln(1 - \frac{1}{T})]^k\}, k \neq 0,$$

where α, β and k are parameters for the GEV distribution. The following shematic shows the calculating procedure (for each point) to obtain the changes of extreme values.