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Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical correction according to observed values

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Abstract

Météo-France atmospheric model ARPEGE/Climate has been used to simulate present climate (1961–1990) and a possible future climate (2071–2100) through two ensembles of three 30-year numerical experiments. In the scenario experiment, the greenhouse gas and aerosol concentrations are prescribed by the so-called SRES-A2 hypotheses, whereas the sea surface temperature and sea ice extent come from an earlier ocean–atmosphere coupled simulation. The model covers the whole globe, with a variable resolution reaching 50 to 60 km over France. Model responses on daily minimum and maximum temperature and precipitation are analyzed over France. The distribution of daily values is compared with observed data from the French climatological network. The extreme cold temperatures and summer heavy precipitations are underestimated by the model. A correction technique is proposed in order to adjust the simulated values according to the observed ones. This process is applied to both reference and scenario simulation. Synthetic indices of extreme events are calculated with corrected simulations. The number of heavy rain (>10 mm) days increases by one quarter in winter. The maximum length of summer dry episodes increases by one half in summer. The number of heat wave days is multiplied by 10. The response in precipitation is less when only the change in the mean is considered. Such a corrected simulation is useful to feed impact models which are sensitive to threshold values, but the correction does not reduce, and may enhance in some cases, the uncertainty about the climate projections. Using several models and scenarios is the appropriate technique to deal with uncertainty.

Keywords: numerical simulation; regional climate; scenario; extreme values

1. Introduction

Which climate will our grand children inherit? A global warming has been observed along the 20th century, especially over land areas of the Northern Hemisphere. It is caused in part by the increase in greenhouse gases (GHG) concentration due to anthropogenic emissions (IPCC, 2001). It is not unreasonable to expect an increase of their concentration along the 21st century. However many parameters are unknown. The projection of future climate change depends partly on the assumptions made about future population or economic growth. In order to anticipate what could occur by the end of the 21st century one can use various scenarios which describe the future development paths in various sectors such as energy, and estimate the emissions of greenhouse gases (IPCC, 2001). The use of complimentary models is necessary to study the impact of these scenarios on living conditions, e.g. in France in the 2080s.

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In the chain of models, general circulation models (GCMs) transform the information about GHG and aerosol concentration fluctuations (or emission if they include a chemistry model) into information about the changes in the atmosphere and ocean conditions and circulation. This information is generally not sufficient enough to feed impact models which are sensitive to local hydrology evolution or extreme temperature distribution. Indeed, due to the high computation requirements of GCMs and the present limitation of scientific computer offer, the horizontal resolution has to be restricted to 200 km or more. In the case of France, this means that the country is represented by a dozen of grid points in a flat area between a mountain over Switzerland–northern Italy and another one centred in the Iberian Peninsula.

Regional climate models (RCM) are therefore introduced in the modelling chain. They generally do not cope with ocean evolution and take the SST and sea ice from GCM simulations. Their horizontal resolution is most generally set up at 50 km for long climate simulations. In the case of France, this means about 300 grid points with an East–West mountain in the south-western border (the Pyrenees), a North–South mountain in the south-eastern part (the Alps) and a mountain in the centre (the Massif Central). This orography representation is able to discriminate coarsely the various climate types over the country. Two kinds of numerical regionalization (or downscaling) techniques have been developed by modellers to generate regional climate information. One can use high-resolution GCMs (Cubasch et al., 1995) or limited area models (LAM) nested in a GCM (Giorgi and Mearns, 1999). In the present study, we use the former method, which offers advantages in providing globally consistent simulations. The latter method is more complex to set up, because of the lateral boundary conditions. The first method is obviously more computer demanding, this is why in the present study, high-resolution was restricted to Europe and the Mediterranean basin (Déqué and Piedelievre, 1995).

The objective of this study is to examine the changes over France in the tails of the distribution of temperature and precipitation in a pair of RCM simulations covering the end of 20th (reference) and 21st (scenario) centuries. The model and the experimental conditions are described in Section 2. The comparison of reference simulation with observed data over France is done in Section 3. The model being a crude simplification of nature, some extreme events are poorly represented. A statistical method for correcting the behaviour of the model is presented in Section 4. This method is applied on scenario data in Section 5 and the model response on a few indices of extreme temperature or precipitation events is examined. Section 6 discusses the role of the correction method. Conclusions are given in Section 7.

2. The model and experiments

Machenhauer et al. (1998) have shown that a variable resolution climate model realistically reproduces seasonal and geographical variations of the main climatological parameters over Europe. Déqué et al. (1998) focused on responses of Version 1 of the ARPEGE-Climate model to a doubling of carbon dioxide concentration. Simulations used here have been performed with Version 3 of the model. Version 3 is described in Gibelin and Déqué (2003); the advection scheme, the horizontal and vertical discretization and most physical parameterizations are different from those used in Version 1. The new model uses semi-Lagrangian advection with a two time-level discretization. The time step is 30 min. The horizontal resolution is based on a T106 spectral truncation. The pole of stretching is in the Tyrrhenian Sea (40°N, 12°E) and the factor of stretching is 3. The grid has 120 pseudo-latitudes and 240 pseudo-longitudes with a reduction near the pseudo-poles to maintain isotropy of the resolution (so-called reduced Gaussian grid). The resolution thus varies from 0.5° in the Mediterranean to 4.5° in the southern Pacific. The vertical resolution is based on the 31 vertical levels of ERA 15 reanalysis (Gibson et al., 1997).

The experimental conditions are described in Gibelin and Déqué (2003), except that the 21st century forcing was SRES-B2. Radiative forcings (GHG and sulfate aerosol concentrations) in the present study are based on observation till 1999, then on SRES-A2 scenario thereafter. SST and sea ice are prescribed to the RCM in the following way: from 1961 through 1990 (reference simulation), monthly mean observed SST is used (Reynolds and Smith 1994). This allows validation of the model by comparing the simulation with observations in the next section. From 2071 through 2100 (scenario simulation), artificial SST and sea ice are constructed by adding to monthly observations a monthly mean anomaly estimated from a former coupled simulation by HadCM3 GCM (Johns et al., 2001). This procedure relies upon the assumption that SST and sea ice interannual variability do not change during the 21st century. This experimental set up is that of the PRUDENCE European project (Christensen et al., 2002) and the simulations used here belong to this project.

Both reference (or control) and scenario experiments consist in fact of three different 30-year numerical