Modelling the climate of the last Ice Age

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Abstract

The aim of this project is to use a computer climate model to simulate the changes in the Earth's climate that occurred during the last Ice Age. The simulations will increase our understanding of past climate change and enable its causes to be investigated. Comparison with records of past climate will assist in their interpretation, as well as validating the ability of the model to simulate a range of climate states.

Climate modelling and past climates

Computer models of the Earth's climate consist of numerical representations of the various components of the climate system. General circulation models are the most sophisticated climate models, simulating the global−scale circulations that take place within the atmosphere and the ocean. When an atmosphere model and an ocean model are joined together − a process known as coupling − it becomes possible not only to simulate the behaviour of each of these components, but also the interactions that take place between them.

Climate models are the main tools used to study the processes that occur within the climate system. By simulating past changes in the climate system, models may be used to investigate the mechanisms that drive climate change. As a result, we come to understand these processes better and increase our ability to forecast how the climate will evolve in the future.

Climate models are also the main tools used to forecast future climate change. In order to have confidence in the ability of models to predict future climate states, we must first ensure that they can accurately simulate the present−day climate. However, our confidence is further increased if they can accurately simulate past climates.

This project initially aims to simulate the climate at the height of the last Ice Age, which took place between 18,000 and 21,000 years ago and is a time known as the Last Glacial Maximum. The climate at this time was very different from that of today, with sea levels more than 100m lower than at present, and will provide an extreme test of the model's ability to simulate a change of climate.

Through scientists at the Antarctic CRC and elsewhere, a wide variety of data on past climates is available, from sources such as ice cores and marine sediments. The model simulations will assist in the interpretation of this data, which can also be used to assess the accuracy of the simulations themselves.

The model

This project will use the CSIRO general circulation model, which includes models of both the atmosphere and the ocean. The atmospheric model includes representations of sea ice, vegetation and land snow cover. Although only the atmospheric model is being used initially, the final simulations will be carried out using the coupled atmosphere−ocean model.

As a large number of lengthy simulations are to be carried out, a low resolution is being used, with the Earth's surface divided into a 64x56 grid. This means that each gridbox is nearly 400km across!

The model is being run on both a CRAY SV1 at the University of Tasmania and on the new APAC AlphaServer SC in Canberra. On these machines, a 15−year simulation can be completed in a single day, enabling extended climate simulations to be carried out.

Results

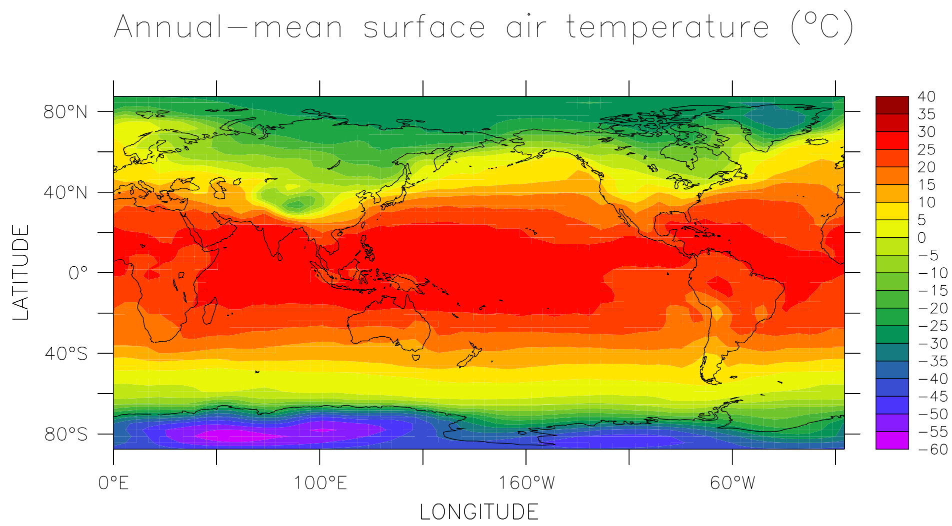
Here we present the results of some simulations that use only the atmospheric component of the model. In these experiments, the temperature of the sea surface is specified using observed values, rather than being simulated by an ocean model. Figure 1 (top right) shows the simulated surface air temperature and rainfall for present−day conditions. Data from the European Centre for Medium−Range Weather Forecasts are shown for comparison. It can be seen that the model successfully simulates the broad−scale features of the global climate, despite the low resolution.

Figures 2 (above) and 3 (right) show the results of an experiment in which the sea surface temperatures were lowered in order to investigate the response of the climate. Three simulations were carried out, in which the sea surface temperatures were lowered uniformally by 2, 4 and 6°C. The upper panels of Figure 2 show the average change in surface air temperature at each latitude, with both the December−January−February (DJF) and June−July−August (JJA) averages being shown. It can be seen that the changes are not uniform, but that much larger decreases occur at high latitudes in winter. The lower panels show that the amount of rainfall also decreases, with the colder atmosphere able to hold less moisture.

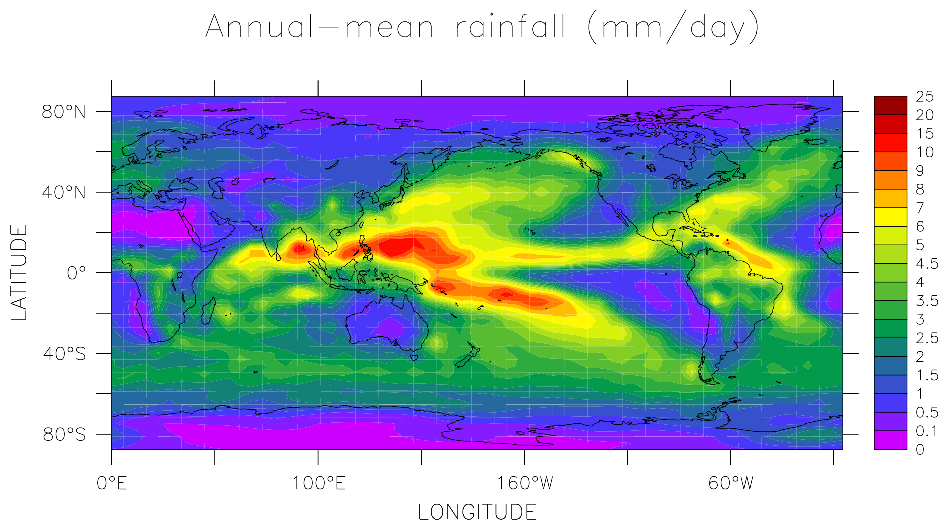
Figure 3 shows the areas covered by sea ice − where the surface of the ocean has frozen over − for each of the simulations. The results shown are for September, when the sea ice in the Southern Hemisphere is at its maximum extent. It can be seen that the areas where the amount of sea ice is increasing are the same regions where the largest temperature changes occur. This is because ice is highly reflective, meaning that much less of the sun's radiation is absorbed, which in turn amplifies the change in temperature. This is an example of one of the many feedbacks that occur within the climate system.

Figure 4 (below left) shows the results of some experiments in which the CO_2 concentration in the atmosphere is decreased. The present−day concentration is about 360ppm; the upper panels show the temperature change which results when the CO_2 concentration is reduced to 280ppm, the value prior to the Industrial Revolution. The lower panels show the changes that result when the concentration is reduced further to 200ppm, the value at the time of the Last Glacial Maximum.

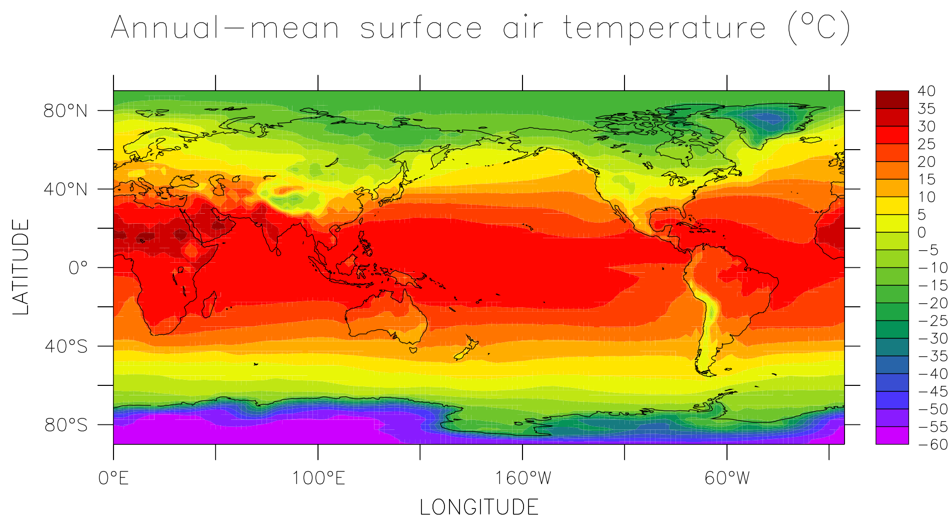
The transitions between glacial and inter−glacial climates are believed to be triggered by small but regular oscillations in the tilt of the Earth's axis and the shape of its orbit, which occur on timescales of tens of thousands of years. As the Earth's orbit changes, the magnitude and timing of the seasonal cycle changes by different amounts at different latitudes. Cold summers in the Northern Hemisphere allow snow on the ground to persist throughout the year and can lead to the onset of glaciation. Figure 5 (below right) shows the results of some experiments in which the Earth's orbital parameters are set to the values of 18,000 and 21,000 years ago. Note the colder temperatures that result at high latitudes during the Northern Hemisphere summer when the orbital parameters of 21,000 years ago are used.



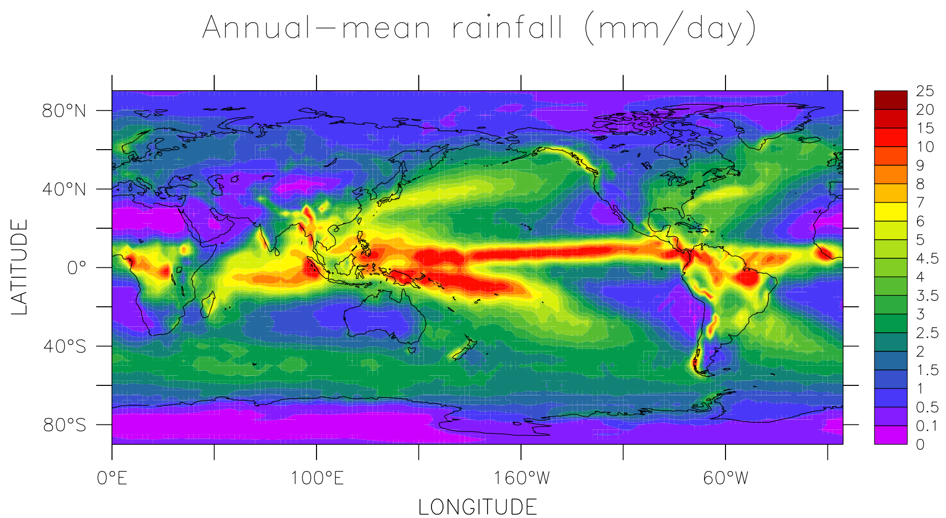
Simulated present−day climate



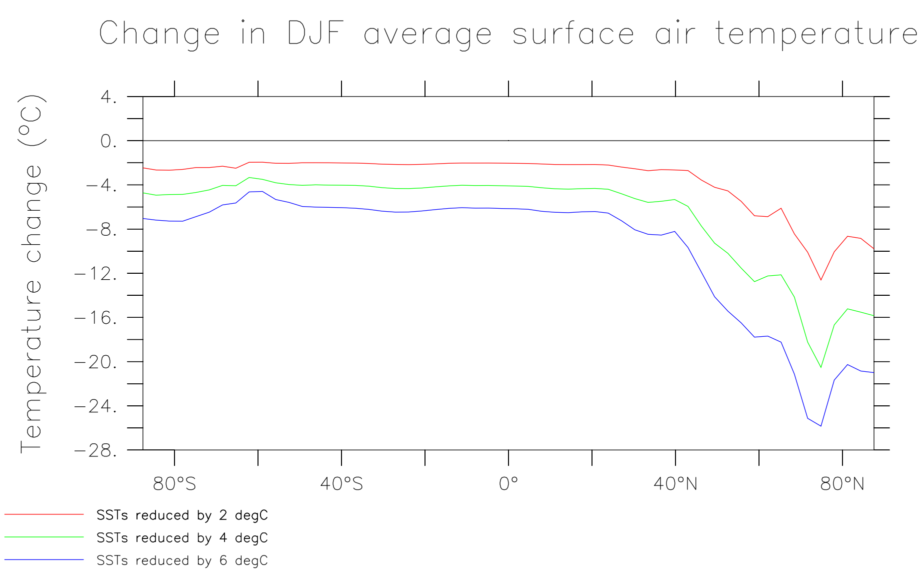
Simulated present−day climate

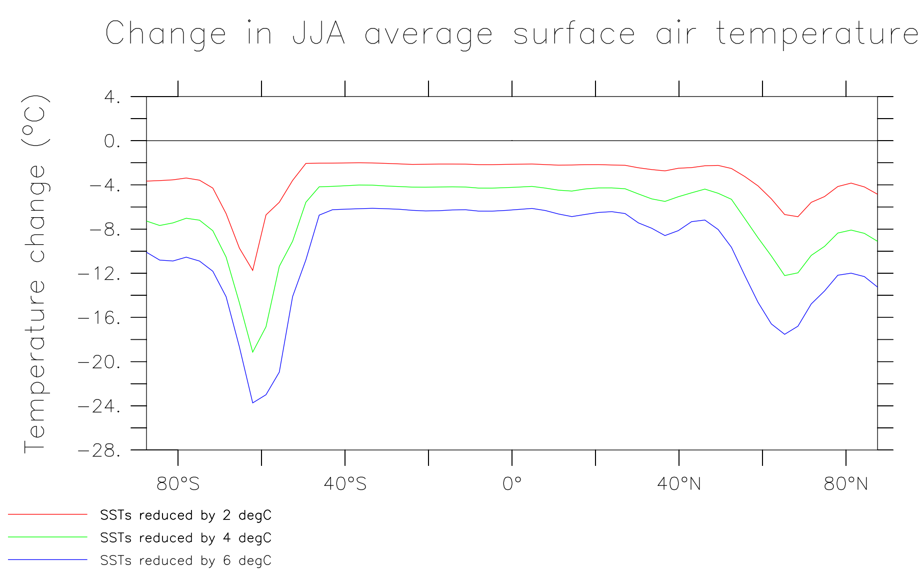


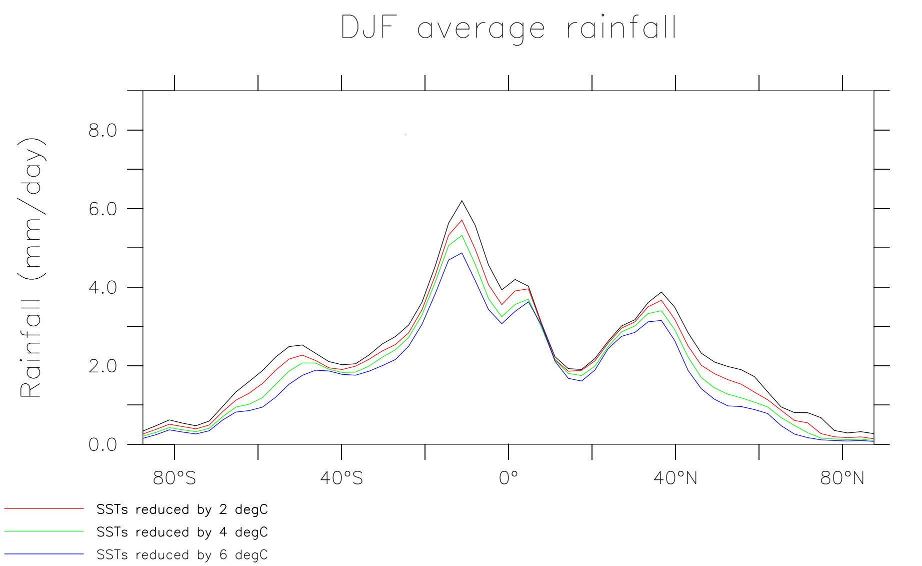
ECMWF data

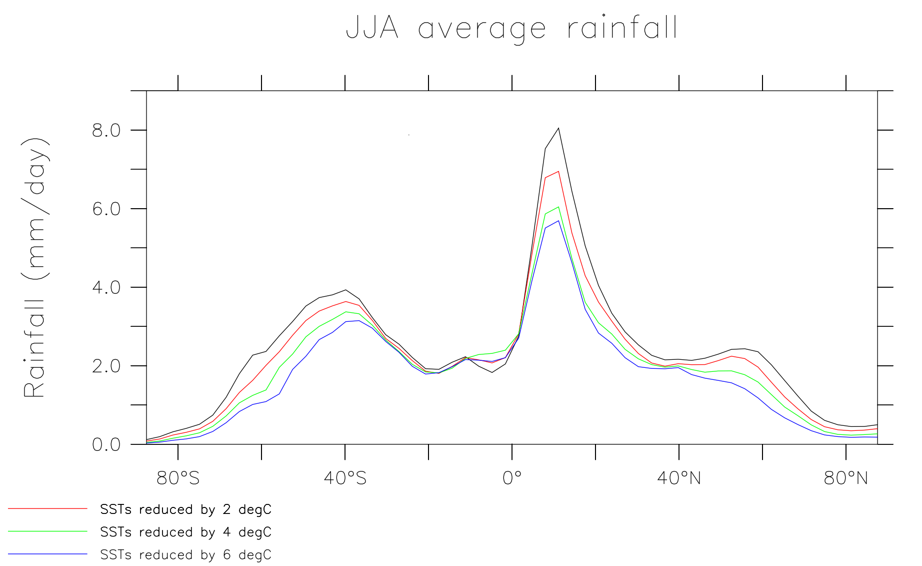


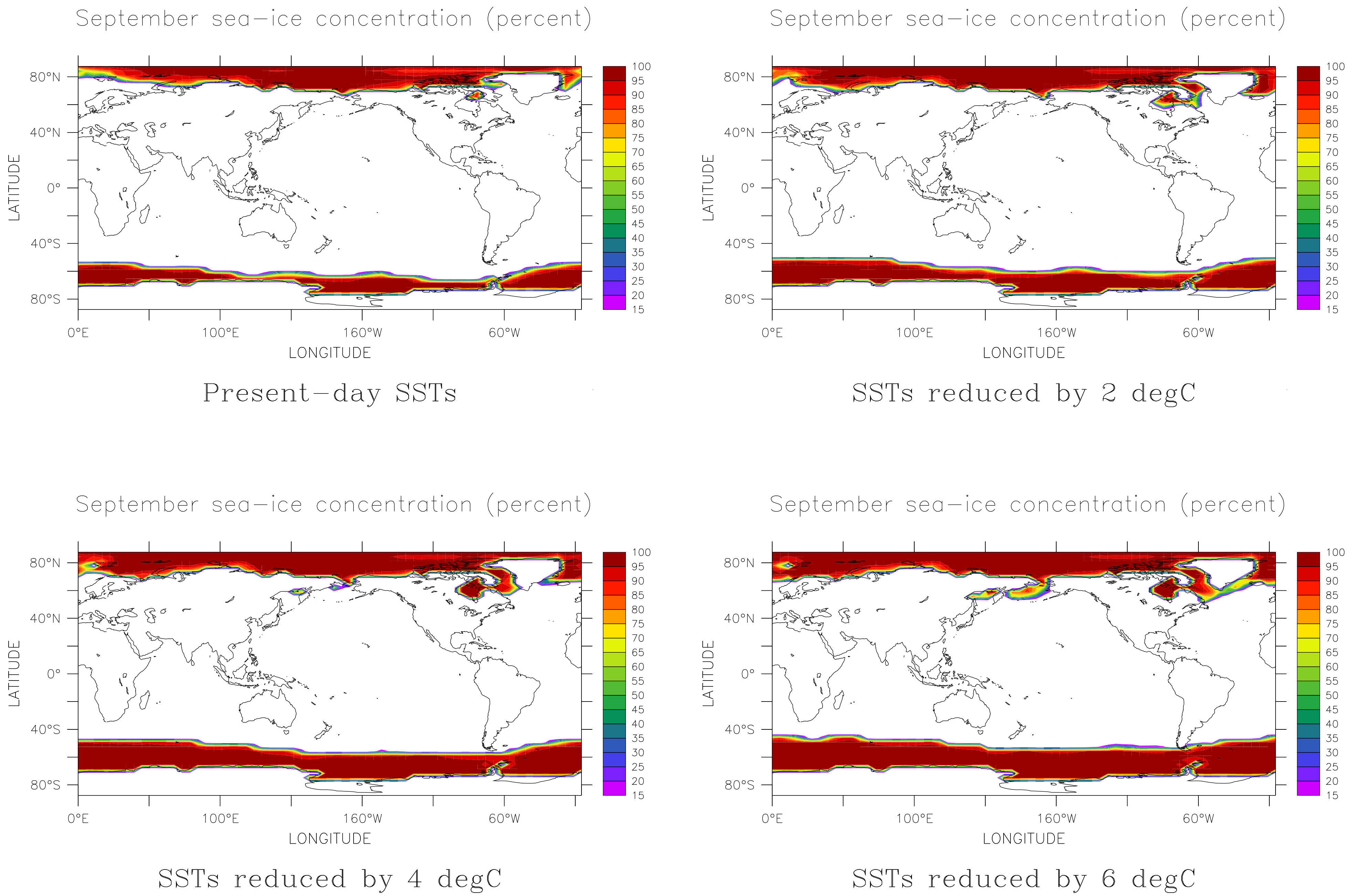
ECMWF data


Change in DJF average surface air temperature
Temperature change (°C)
4.
0.
−4.
−8.
−12.
−16.
−20.
−24.
−28.
80°S
40°S
0°
40°N
80°N
SSTs reduced by 2 degC
SSTs reduced by 4 degC
SSTs reduced by 6 degC

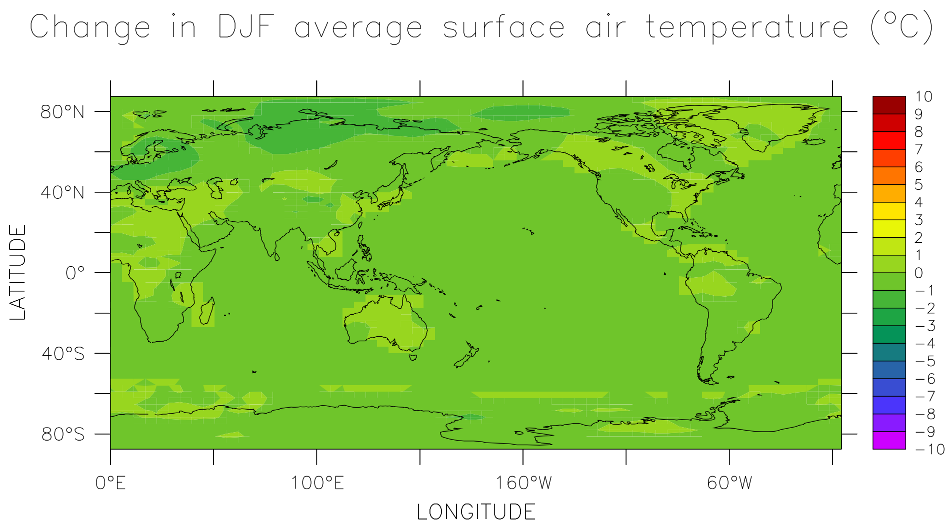

Change in JJA average surface air temperature
Temperature change (°C)
4.
0.
−4.
−8.
−12.
−16.
−20.
−24.
−28.
80°S
40°S
0°
40°N
80°N
SSTs reduced by 2 degC
SSTs reduced by 4 degC
SSTs reduced by 6 degC


DJF average rainfall
Rainfall (mm/day)
8.0
6.0
4.0
2.0
0.0
80°S
40°S
0°
40°N
80°N
SSTs reduced by 2 degC
SSTs reduced by 4 degC
SSTs reduced by 6 degC

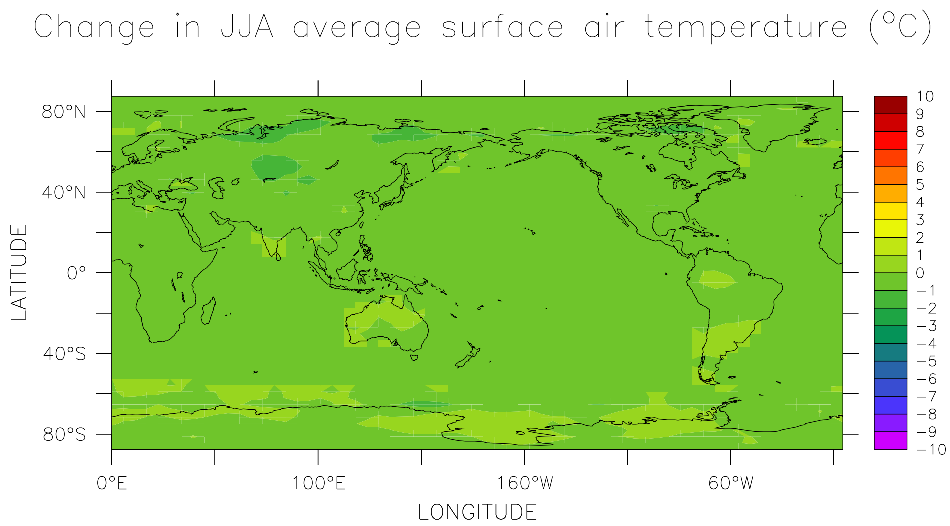

JJA average rainfall
Rainfall (mm/day)
8.0
6.0
4.0
2.0
0.0
80°S
40°S
0°
40°N
80°N
SSTs reduced by 2 degC
SSTs reduced by 4 degC
SSTs reduced by 6 degC



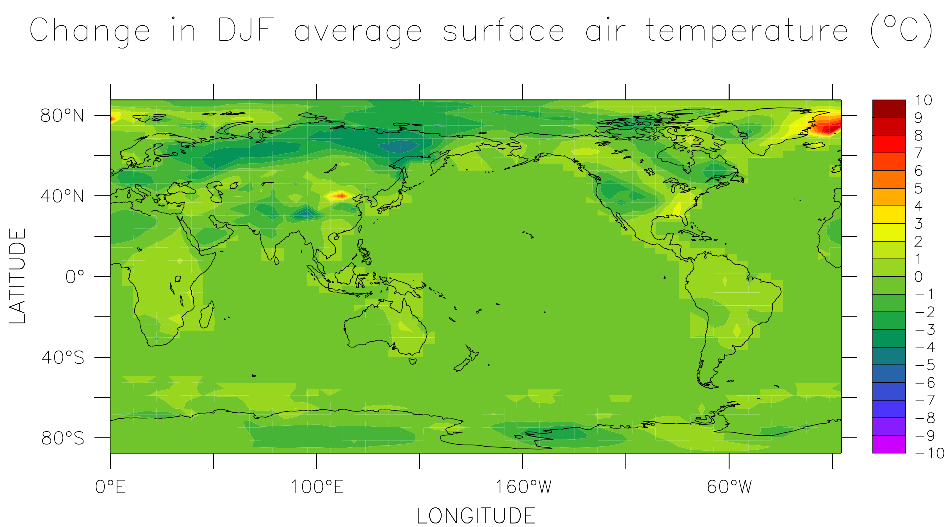
September sea−ice concentration (percent)
Present−day SSTs
September sea−ice concentration (percent)
SSTs reduced by 2 degC
September sea−ice concentration (percent)
SSTs reduced by 4 degC
September sea−ice concentration (percent)
SSTs reduced by 6 degC
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
0°E
100°E
160°W
60°W
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15



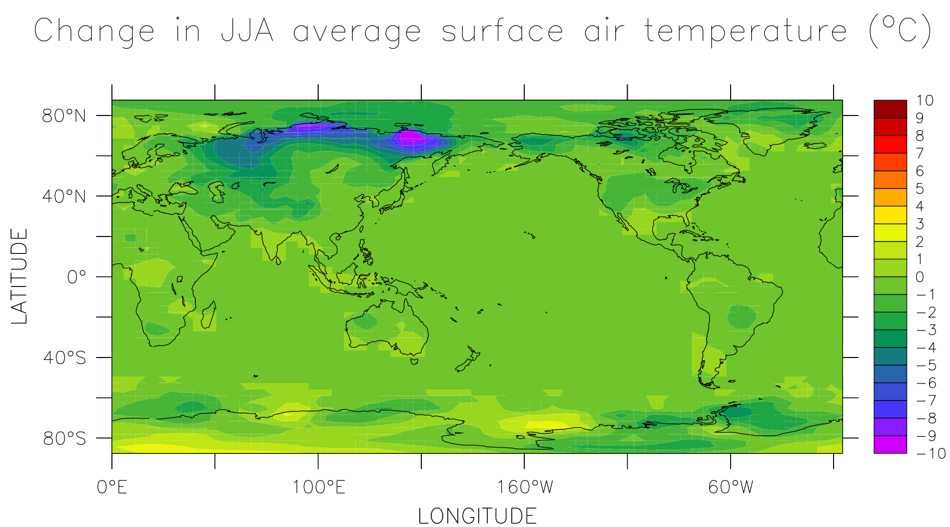
Pre−industrial CO2 concentration



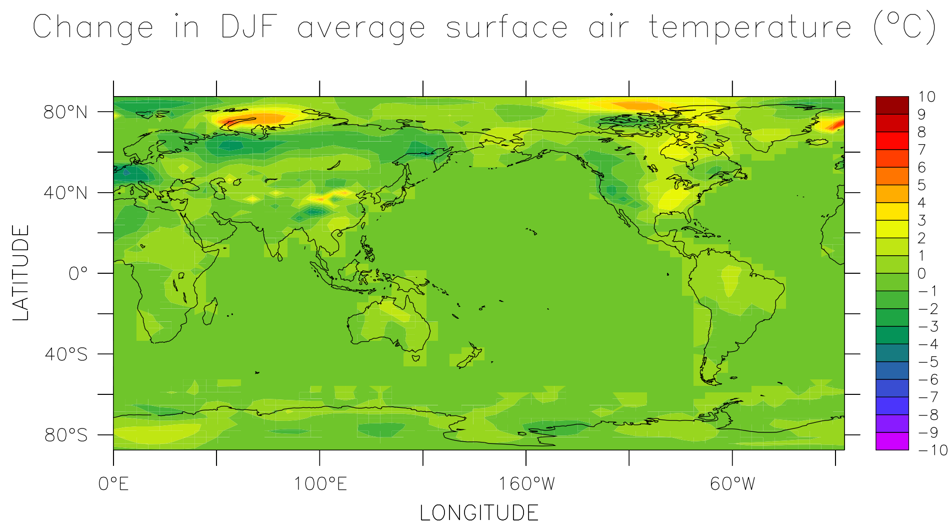
Pre−industrial CO2 concentration



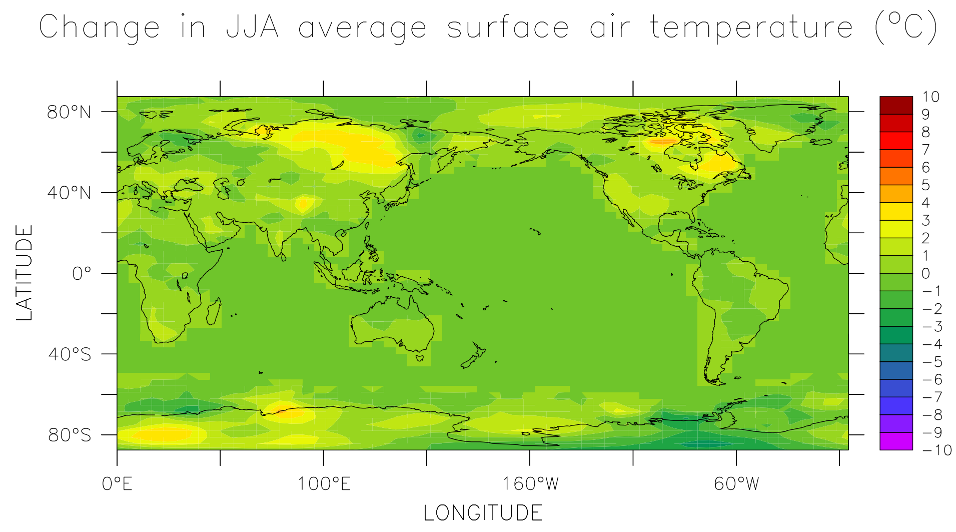
Glacial CO2 concentration



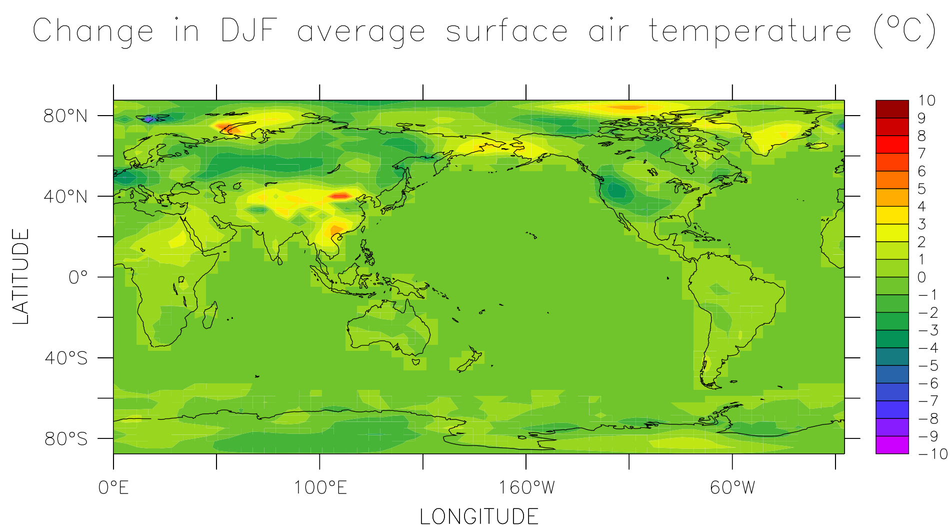
Glacial CO2 concentration



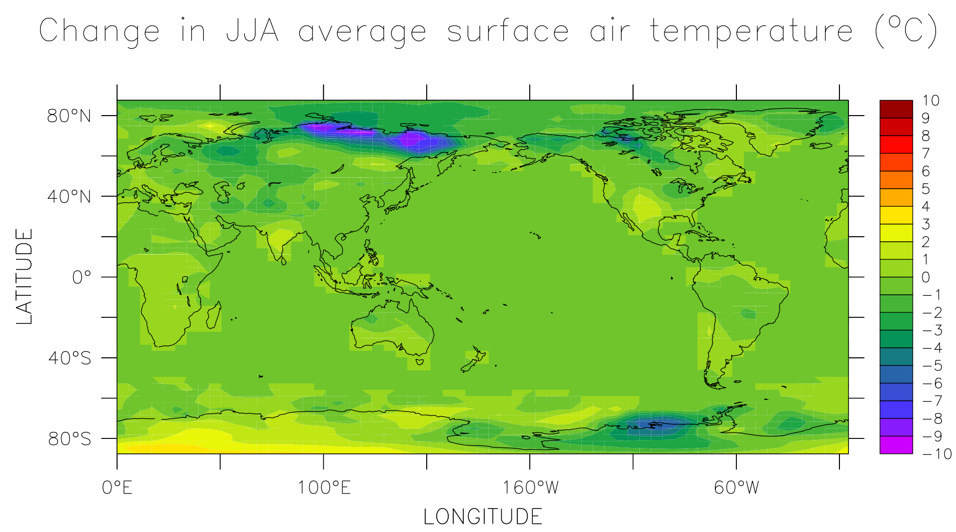
Orbital parameters for 18,000 years ago



Orbital parameters for 18,000 years ago



Orbital parameters for 21,000 years ago



Orbital parameters for 21,000 years ago