Transient Holocene Model Simulations: Initial Conditions, Forcings and Feedbacks Analysis

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ABSTRACT: Using MoBidiC, a climate model of intermediate complexity, several transient simulations have been performed in order to reconstruct the long-term climate variability during the last 9 thousands of years. The global response to combined CO_2 and insolation changes is analysed, individual contributions of the forcings and feedbacks being also discussed. The simulated Holocene climate signal shows the Northern Hemisphere cooling but the amplitude of the temperature changes remains lower than in several data reconstructions. Albedo effect associated to vegetation changes is of critical importance in these model results. As the small amplitude of the simulated Holocene climate evolution remains mostly within the model internal variability, transient results are somewhat hidden in model noise.

KEY WORDS: climate model, Holocene, feedback, insolation forcing, CO_2 forcing.

Introduction to the model

The MoBidiC model belongs to the so called intermediate complexity climate models. It is extensively described in Crucifix et al. (2000). The atmospheric dynamics is computed with a zonally averaged, two-level, quasi-geostrophic model, which includes a parameterisation for the meridional transport of quasi-geostrophic potential vorticity and a parameterisation for the sensible-heat transport by the Hadley cell (Gallée et al., 1991). The atmosphere interacts with the other components of the climate system on a latitude-altitude grid and a sectorial representation of the Earth surface longitudes. Each zonal band is divided into sectors associated with continents, ice sheets or ocean basins. In addition to the zonally averaged thermal and dynamical variables, vertical fluxes of momentum, heat, and water vapour are computed over every sector considered at all latitudes. The atmosphere model incorporates detailed radiative transfer schemes (up to 15 layers are considered), surface energy and moisture balances and a snow-mass budget. It also includes a simplified representation of the hydrological cycle. Albedo changes due to biosphere evolution is represented following Brovkin at al. (1997). The atmosphere is coupled to a three-basins dynamical zonally averaged ocean sea-ice model based on Hovine and Fichefet (1994) and Tulkens (1998). The latitudinal resolution is of 5°, no flux adjustment is added in our present or past climate simulation and ice sheet evolution is not taken into account in this study.

Such a model allows to study the climate variability on times scales from hundred to several thousands of years. Feedbacks associated with sea ice, snow or vegetation changes are represented, but variations linked to short term climate variability (i.e. decadal) are not represented as zonal averages are performed on the atmosphere dynamics and in each ocean basin. The main advantage of this model is that it computes the main dynamical and physical climate processes at a low computational cost. This allows to perform numerous simulations over several thousands of years.

Experimental setup

A reference state and three main simulations have been performed in order to analyse the processes involved in long-term climate variability during the last 9 ka. The reference initial state is a climate equilibrium computed with the 9 ka BP insolation and a 261 ppmv CO_2 concentration. The results referred to as EQUIL represent the continuation of this reference state for 9 ka with identical constant CO_2 and insolation forcing. The transient simulations setup summarise as follows:

- Simulation HOL attempts to reconstruct the Holocene climate evolution. The model is integrated from the 9 ka BP equilibrium state until present day with insolation forcing computed as in (Berger, 1978), prescribed CO_2 concentration based on Indermühle et al. (1999) and a dynamic vegetation responding to the evolving climate conditions.
- FIXCO2 simulation is a sensitivity experiment with the same setup as above except that CO_2 concentration is kept fixed at its initial level (261 ppmv). This simulation allows to evaluate the combined impact of insolation change and vegetation feedback on the simulated climate.
- In FIXVEG simulation, insolation and CO_2 concentration evolve as in the HOL simulation, but the vegetation distribution is maintained fixed to its initial equilibrium pattern. This simulation allows to evaluate the impact of vegetation feedbacks in our model. Note that all simulations have been performed prescribing present day ice sheets distribution and configuration.

Forcing description

Insolation change is the initial cause for climate fluctuations during Holocene. During this period, the annual mean global insolation remained unchanged but the latitudes poleward from 40° in both hemispheres received progressively less energy from the sun. From the equator to the tropics, the annual mean solar energy input increased very slightly. On an annual mean, the insolation changes over the Holocene where very weak and appear similar in each hemisphere.

The seasonal insolation pattern was however considerably modified. In the Northern Hemisphere (NH), summer insolation decreases (by 6% from 9 ka BP to present) and winter insolation increases with a similar amplitude. Insolation change is mainly distributed over mid and high latitudes. In the Southern Hemisphere (SH) the insolation seasonal distribution evolves in the opposite way but with a similar amplitude, i.e. from 9 ka BP to present, summer insolation increases and winter insolation decreases. Therefore, the seasonal contrast is expected to be reduced in the NH and to be enhanced in the SH through the Holocene.

The CO_2 increase during this period is from 260 to 280 ppmv, the fastest increase occurring from 7000 to 3000 years

BP. In our simulation, a non-linear fit on CO_2 data from Indermühle et al. (1999) is used as forcing in order to avoid additional noise inclusion associated with short time scale variations in data records. The MoBidiC model exhibits a low sensitivity to CO_2 variations (+2.1 °C in global mean temperature for a CO_2 concentration doubling), this may partially determine the relative sensitivity to the different forcings and feedbacks in the simulations.

Results and analyses

Our results show that when insolation, CO_2 and vegetation changes are considered, the NH annual mean surface temperature remains rather constant, a slight cooling trend of 0.15 °C appearing during the last 3 ka (Fig. 1, HOL curve and EQUIL curve for the reference). The NH sea ice coverage (not shown) increases by roughly 10% through the simulation and North Atlantic Deep Water circulation does not show a discernible change beyond internal variability fluctuations. Locally, surface temperature changes are more pronounced. In the 70–75 N latitude band, a 3 °C surface temperature decrease over the American continent appears and the NH sea surface temperature maximal cooling is of 1.2 °C over the nine thousands of years simulated. The almost *no trend* global result can be explained by compensating effects of feedbacks and forcing shown up with the other sensitivity simulations performed.

The simulation with fixed CO_2 concentration reveals a more pronounced cooling trend (Fig. 1, FIXCO2 curve). Our model simulates a cooling of 0.35 °C in the NH annual mean surface temperature. Indeed, the NH mid and high latitudes experience a progressive surface cooling initiated by summer insolation reduction and amplified through vegetation and snow-albedo feedbacks. This means that the effect of summer insolation reduction dominates the impact of winter increase and induces an hemispheric cooling. The most representative latitude band for temperature variations is the 60–75 N area. Insolation reduction cools the local temperature, tree fraction decreases significantly and continental snow cover extends. Therefore, the continental albedo increases (Fig. 2, FIXCO2 curve). Such an effect corresponds to the well documented taiga-tundra vegetation feedback which here, in association with snow coverage extension, leads the hemispheric cooling.

By contrast, the CO_2 concentration increase over the Holocene induces a temperature rise. The amplitude of such greenhouse effect - which counteracts the insolation reduction- is revealed in the simulation where vegetation distribution is kept constant (Fig. 1, FIXVEG curve). In this simulation, the NH surface temperature rises by nearly 0.2 °C, most of the change occurring during the last 5 ka. Such trend reveals the critical importance of albedo effect associated with vegetation distribution changes in our model. Moreover, a simulation (not shown) with insolation variation but with constant CO_2 concentration and fixed vegetation distribution induces an almost insignificant cooling only. As the vegetation representation is highly simplified (with three vegetation types only represented), such a large effect might be unrealistic, this remains to be investigated.

Conclusions

MoBidiC simulated a NH cooling during the Holocene. This cooling is initiated by the reduction of summer insolation in the mid and high latitudes and is not compensated by the winter insolation increase. Vegetation distribution changes amplify the variation of solar energy input and induce, through synergism with snow and sea-ice albedo feedbacks, a discernible temperature cooling on the whole hemisphere. Carbon dioxide concentration increase tends to counteract the cooling trend. Although discernible signals and processes could be identified, the magnitude of this model internal variability hides partially the simulated Holocene climate variations. This reduces the significance of the quantitative climate trends estimations.

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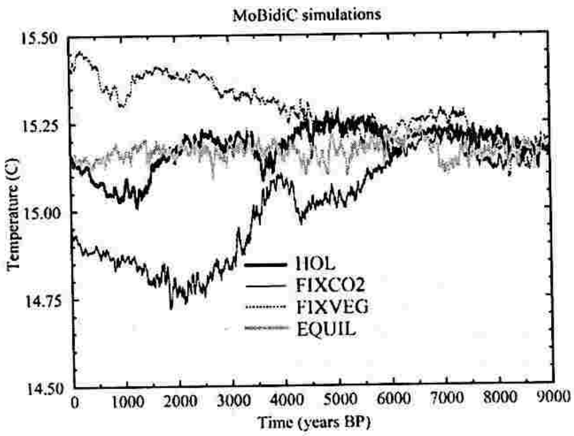

Fig. 1. Time evolution of the Northern Hemisphere annual mean surface temperature (50 years averages are plotted, units are °C) for the four simulations discussed.

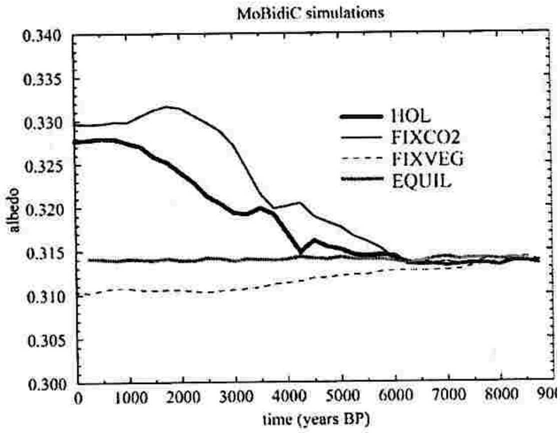

Fig. 2. Continental albedo evolution in the 60–70 latitudinal band for the four simulations presente

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Global Warming – Does it Always Mean Regional Warming?

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ABSTRACT. Proxy data obtained for warm epochs of the last 125 ka permitted to estimate global paleotemperatures at the last interglacial optimum (5e oxygen isotope stage) at 1.8–2 °C above the present one, and at the Holocene optimum (stage 1) at 0.7 to 1 °C higher than at present. Those values are of particular interest as they are approximately equal to temperature growth to be expected in the 21st century due to the greenhouse effect. As follows from spatial paleoclimatic reconstructions for the mentioned epochs, the warming would be most pronounced in high latitudes (compared with today, at the interglacial optimum Eurasian Arctic regions were 8–12 °C warmer in winter and 6–8 °C in summer; at the Holocene optimum the warming amounted to 4 and 3 °C, respectively). The positive deviations, however, gradually decreased towards mid-latitudes, and many regions south of 30–40°N show either negligible or even slightly negative deviations. According to preliminary data, proportion of such regions in the last interglacial could be about 25% of the whole Northern Hemisphere area. As for annual precipitation, reconstructions showed general increase in rainfall amount at the last interglacial optimum, with potential evaporation in high and middle latitudes increasing accordingly. At the Holocene optimum rainfall amount was locally lower than now, though subtropical and tropical regions show a considerable increase in moisture supply.

KEY WORDS: paleoclimatic reconstructions, spatial differentiation, climatic optima.

Introduction

According to generally accepted estimates of the global temperature changes due to human impact, the temperature is expected to rise by 1 °C in the first half of the 21st century and by ~2 °C in the 2nd half (Hougton et al., 1996). Paleogeographic reconstructions based on data obtained in the course of multidisciplinary research, show with fair degree of certainty, that during the last natural macro-cycle there were warm epochs when mean values of the global annual temperature were close to those expected in the near future. Among them, of particular interest are the Holocene optimum (~ 6–5 ka BP) and the last interglacial (Eemian, Sangamon, Mikulino) optimum marked by global temperature rise by 0.8–1 °C and 1.8–2 °C, respectively. Both epochs have been thoroughly studied using an integrated approach; the results obtained permit to visualize spatial differentiation of paleoclimatic parameters which, in its turn, opens the way to forecast regional environmental responses to the predicted climatic changes (Frenzel et al., 1992).

Paleoclimatic reconstructions of the Holocene Optimum

Spatial paleoclimatic reconstructions for the Holocene optimum were based on pollen data processed using information-statistic method (Klimanov, 1985). It appears that a rise in the near-surface air temperature by 1 °C leads to essential redistribution in heat and moisture supply. General increase in thermal level can be assigned to considerable warming of high latitudes. Maps of both summer and winter isotherms show temperatures in the arctic coastal regions to exceed those of today by at least 3 °C; warming in subpolar regions in North America and Eurasia amounted to 2 °C (Velichko et al., 1997), but did not exceed 1 °C over major part of mid-latitudes. Positive deviations continue to decrease southward and become negligible between 40 and 35°N. Still further south, to the equator, deviation values do not exceed 1 °C and are negative locally (in North America and Africa). Positive deviations up to 2 °C are reconstructed for coastal regions of China and Japan (presumably as a result