Climate of the Past Discussions, 1, 1–16, 2005
www.climate-of-the-past.net/cpd/1/1/
SRef-ID: 1814-9359/cpd/2005-1-1
European Geosciences Union

Climate of the Past Discussions

Climate of the Past Discussions is the access reviewed discussion forum of *Climate of the Past*

Quantifying the effect of vegetation dynamics on the climate of the Last Glacial Maximum

A. Jahn[1,*], **M. Claussen**[1,2], **A. Ganopolski**[1], **and V. Brovkin**[1]

[1]Potsdam Institute for Climate Impact Research (PIK), P.O. Box 601203, 14412 Potsdam, Germany
[2]Institute of Physics, Potsdam University, P.O. Box 601543, 14415 Potsdam, Germany
[*]now at: Department of Atmospheric and Oceanic Sciences, McGill University, Burnside Hall Room 945, 805 Sherbrooke Street West, Montreal, Quebec, H3A 2K6, Canada

Received: 13 June 2005 – Accepted: 16 June 2005 – Published: 23 June 2005

Correspondence to: A. Jahn (ajahn@po-box.mcgill.ca)

Abstract

The importance of the biogeophysical atmosphere-vegetation feedback in comparison with the radiative effect of lower atmospheric CO_2 concentrations and the presence of ice sheets at the last glacial maximum (LGM) is investigated with the climate system model CLIMBER-2. Equilibrium experiments reveal that most of the global cooling at the LGM (−5.1°C) relative to present-day conditions is caused by the introduction of ice sheets into the model (−3.0°C, 59%), followed by the effect of lower atmospheric CO_2 levels at the LGM (−1.5°C, 29%). The biogeophysical effects of changes in vegetation cover are found to cool the LGM climate by 0.6°C (12%). They are most pronounced in the northern high latitudes, where the taiga-tundra feedback causes annually averaged temperature changes of up to −2°C, while the radiative effect of lower atmospheric CO_2 in this region only produces a cooling of 1.5°C. Hence, in this region, the temperature changes caused by vegetation dynamics at the LGM exceed the cooling due to lower atmospheric CO_2 concentrations.

1. Introduction

The climate at the Last Glacial Maximum (LGM) around 21 kyr BP has already been modeled extensively in the past (e.g., PMIP, 2000). In most of these studies, the vegetation distribution was prescribed, either to proxy-based reconstructions or to the present-day potential vegetation distribution. In difference to the potential present-day vegetation cover, vegetation reconstructions for the LGM show that forests were absent north of 55° N, allowing herbaceous vegetation to dominate these areas (Bigelow et al., 2003). Tropical forests in Asia, Africa, and Australia were also decreased, while it is still debated if also the tropical forest in South America was depleted during the LGM (Harrison and Prentice, 2003). In recent years, it has been shown that these differences in vegetation cover between present-day and the LGM played an important role in the climate system during the LGM. Crowley and Baum (1997) showed that a reconstructed vegetation distribution instead of a present-day vegetation cover led to changes large enough to reconcile model results with proxy data in some places. Lewis et al. (1999) showed that the regional vegetation effect on climate is comparable to the radiative effect of a lowered CO_2 level during the LGM. Kubatzki and Claussen (1998) explored the role of an interactive vegetation versus a prescribed present-day potential vegetation distribution during the LGM with a coupled atmosphere-vegetation model and showed that the interactive vegetation led to additional cooling over northern high latitudes. Wyputta and McAvaney (2001) compared the climatic effect of a prescribed modern day vegetation cover to that of a vegetation reconstruction for the LGM. They found that the use of the LGM reconstruction led to a widespread cooling in the northern high latitudes as well as in Australia and northern Africa, and to a warming over Alaska. The role of the physiological effect of lower atmospheric CO_2 concentrations on climate during the LGM was investigated by Harrison and Prentice (2003). They could show that forest cover was overestimated in LGM simulations when this effect was not included, especially in the tropics. However, feedbacks with the thermohaline circulation were missing in all of the above studies. Recently, Ganopolski (2003) performed a full atmosphere-ocean-vegetation (AOV) simulation for the LGM, showing that changes in ice sheets, atmospheric CO_2 concentration, and vegetation cover, as well as the reorganization of the thermohaline circulation are important factors in understanding the glacial climate. Ganopolski (2003) included only the biogeophysical vegetation feedback while Brovkin et al. (2002b) analyzed the effect of an interactive vegetation on the carbon cycle during the LGM with the same model.

Since the LGM climate has been simulated before with CLIMBER-2 (Ganopolski et al., 1998; Ganopolski, 2003), the goal of this study is to investigate the role of the dynamic vegetation in comparison with the roles played by prescribed changes in ice-sheet cover and the radiative effect of a lower atmospheric CO_2 concentration in the simulation of the LGM. We analyze the influence of these prescribed changes in comparison with the biogeophysical vegetation feedback to determine their individual contribution to the cooling at the LGM; however, we do not account for biogeochemical effects. The individual effects of ice sheet and CO_2 changes on the global annual surface air temperature are then compared to the results in Berger et al. (1996), who performed experiments with a 1-D radiative convective climate model in order to separate astronomical-albedo effects from the effect of CO_2 changes. The comparison of vegetation feedbacks with ocean feedbacks will be the subject of a complementary study.

2. Methods

2.1. Model

CLIMBER-2 is a coarse resolution climate system model of intermediate complexity. It has a resolution of 10° in latitude and 51° in longitude. The atmospheric module is a 2.5 dimensional statistical-dynamical model and the ocean module is a multi-basin, zonally averaged ocean model with 20 uneven vertical layers that also includes a sea-ice model. The terrestrial vegetation model VECODE within CLIMBER-2 is a reduced-form dynamic global vegetation model (see Cramer et al., 2001), which simulates the dynamics of two plant functional types (PFTs), trees and grass, in response to changes in climate. The PFT fractions are parameterized as a continuous function of growing degree days (sum of mean daily temperature for days with a temperature above a certain threshold, here 0°C) and annual precipitation. A more detailed description of CLIMBER-2 and its performance can be found in Petoukhov et al. (2000), Ganopolski et al. (2001), and Brovkin et al. (2002a).

2.2. Factor separation and feedback analysis

To quantify the individual contributions of the prescribed changes in CO_2 concentration and ice sheet cover, a factor separation was performed following Stein and Alpert (1993). They developed this factor separation technique to separate pure contributions of different processes in a climate change signal from synergistic effects that result from non-linear processes in the climate system (Berger, 2001). In order to separate the pure contribution of n factors from the synergies between them, 2^n simulations are necessary. Therefore four simulations were performed: a present-day reference run (REF); a simulation with LGM ice sheets but reference CO_2 concentration (LGM_I); a simulation with LGM CO_2 concentration but reference ice cover (LGM_C); and a run with both LGM ice sheets and LGM CO_2 concentration (LGM_{CI}) (see Sect. 2.3 and Table 1 for their setup). From the surface air temperatures at the end of these simulations (T_0, T_I, T_C, T_{CI}, respectively), the two factors and the synergy term (caused by simultaneous changes in CO_2 concentration and ice sheet cover) were calculated following Stein and Alpert (1993), i.e. $f_I = T_I - T_0$, $f_C = T_C - T_0$, and $f_{CI} = T_{CI} - T_C - T_I + T_0$.

To compare the temperature changes due to the changes in CO_2 concentration and ice sheet cover with the temperature change caused by the vegetation feedback to their cooling, a feedback analysis was performed. For this feedback analysis, three more experiments were necessary: a simulation with LGM CO_2 concentration and interactive vegetation (LGM_{CV}); a run with LGM ice sheets and interactive vegetation (LGM_{IV}); and a simulation with LGM ice sheets, LGM CO_2, and interactive vegetation (LGM_{CIV}) (see Sect. 2.3 and Table 1 for their setup). These simulations provided the surface air temperatures T_{CV}, T_{IV}, and T_{CIV}, respectively. The feedback factors f_I^V, f_C^V, and f_{CI}^V were then calculated as follows: $f_C^V = T_{CV} - T_C$, $f_I^V = T_{IV} - T_I$, and $f_{CI}^V = T_{CIV} - T_{CI} - (T_{CV} - T_C) - (T_{IV} - T_I)$.

2.3. LGM boundary conditions

Following Peltier (1994), continental ice sheets and a sea level drop of 115 m were prescribed for all simulations using LGM geography (i.e., LGM_I, LGM_{CI}, LGM_{IV}, and LGM_{CIV}, see also Table 1 for the setup of all runs). Sea level and land-ocean distribution as well as a parametrization of gyres in the North Atlantic (due to the closure of the Canadian Archipelago during the LGM) are altered consistently with changes in ice sheet cover, although, in the following, only the changes in ice sheets are mentioned explicitly. The CO_2 was lowered from 280 ppm to 190 ppm for all runs using LGM CO_2 concentrations (Petit et al., 1999). Orbital parameters were fixed to present-day values in all simulations. However, sensitivity studies reveal that using LGM orbital parameters instead does not cause any significant changes. For the vegetation, either the modeled present-day equilibrium vegetation distribution from simulation REF was used or the vegetation model was used interactively, allowing it to adjust to the climatic effect of the respective changes in CO_2 or ice sheets.

3. Results

The LGM climate simulated in the full LGM experiment shows a global annual mean surface air temperature of 8.9°C, which is 5.1°C lower than in the present-day reference run (REF). This temperature decrease is in the range of simulated changes from AOGCMs that find a LGM cooling between 3.8°C (Hewitt et al., 2003) and 10°C (Kim et al., 2003). The cooling is centered over the ice sheets of the northern hemisphere (NH) and is much weaker over the southern hemisphere (SH) (Fig. 1).

This global LGM cooling of 5.1°C can be attributed to the ice sheet and CO_2 factors, their synergy, and the vegetation feedback to each of them by factor separation and feedback analysis. The largest part of the global cooling is due to the presence of LGM ice sheets (f_I), which leads to a global cooling of 3.0°C, followed by the effect of the CO_2 drop to 190 ppm (f_C), which results in a global temperature decrease of 1.5°C. The term f_I^V, describing the temperature change caused by the vegetation feedback to the cooling produced by the LGM ice sheets, leads to an additional global temperature decrease of 0.5°C. The vegetation feedback to the cooling caused by the lower CO_2 (f_C^V) produces a cooling of 0.1°C, which is the same amount of cooling as generated by f_{CI} (the synergy between CO_2 and ice sheet forcing). The vegetation feedback to the cooling caused by the synergy between CO_2 and ice sheet forcing (f_{CI}^V) leads to a global temperature decrease of substantially less than 0.1°C.

As shown in Fig. 2, there is considerable variation in the regional distribution of the cooling due to each of these factors/feedback terms. The presence of ice sheets causes a cooling mainly over the ice covered regions of the NH due to the increase in albedo and altitude (Fig. 2a). The cooling in the NH leads to an increase in the Atlantic overturning circulation by 7 Sv; this increases the northward heat transport by 0.2 PW, thereby cooling the Southern Ocean. As a consequence, sea-ice cover in the SH increases, which further decreases the temperature in southern high latitudes due to the sea-ice-albedo effect. The CO_2 factor f_C generates the strongest cooling in the high latitudes of both hemispheres; however, the cooling is larger in the SH than in the NH (Fig. 2b). The stronger cooling in the high latitudes ("polar amplification") is caused by a number of positive feedbacks, especially the sea-ice-albedo and snow-albedo feedbacks operating in both hemispheres. At the same time, a strengthening of northward oceanic heat transport at lower atmospheric CO_2 concentrations serves as a negative feedback in the NH, and as additional positive feedback in the SH. This explains a stronger cooling in the high latitudes of the SH compared to the NH. The synergy factor f_{CI} produces a strong cooling over the North Atlantic and a warming over the Southern Ocean (Fig. 2c). This temperature change is caused by a decrease in northward heat transport in the ocean and a displacement of the deep water formation site to the south, which means that the ocean circulation changes from its "warm" glacial mode to its "cold" glacial mode (see Ganopolski and Rahmstorf, 2001, Fig. 2).

The change of the ocean circulation into another mode is a threshold process, which means that in our study the combined climate change caused by CO_2 decrease and presence of ice sheets is large enough to pass this threshold. As intended by Stein and Alpert (1993), the effect of this non-linear climate response is captured by the synergy term f_{CI}. However, sensitivity studies show that the combined cooling due to CO_2 decrease and presence of ice sheets is just large enough to trigger the change in the ocean circulation. A slightly smaller cooling, as caused for example by a CO_2 concentration of 200 ppm instead of 190 ppm in combination with ice sheets, does not cause this change in the ocean circulation mode. In this case, the additional cooling produced by the vegetation feedback triggers the change in the ocean circulation, and the large temperature change associated with it is then included in the term f_{CI}^{V}. This comprises the danger of misinterpretation, since the large temperature change is not produced by vegetation feedbacks per se, but by a nonlinear process that is only triggered by the effect of vegetation feedbacks. Therefore, care has to be taken to not confuse the effect of non-linear processes with the effect of climate feedbacks when calculating individual contributions of feedbacks close to bifurcation points in the climate system.

The cooling effect of f_{I}^{V} is strongest over land in the northern high latitudes (Fig. 2d). It is due to the replacement of forest by herbaceous vegetation in response to the cooling caused by f_I, which decreases the albedo of these regions especially in winter and spring when the surface is snow covered (see Brovkin et al., 2003). In addition, this so called taiga-tundra feedback is amplified by an increase in snow coverage over these regions. The cooling generated by f_{C}^{V} is strongest over North America (Fig. 2e), as a result of the taiga-tundra feedback in this region. As seen in Fig. 2f, f_{CI}^{V} causes the strongest cooling over the North Atlantic and northern latitudes of Eurasia, combined with a warming of the Southern Ocean. The cooling over the North Atlantic is a result of a further decrease of the northward heat transport and an associated increase in sea-ice cover. The decrease in northward heat transport is also responsible for the warming in the SH. In the northern latitudes of Eurasia, f_{CI}^{V} shows a cooling over regions where tree cover decreases, again due to the taiga-tundra feedback.

To compare the cooling caused by the total vegetation feedback with the radiative effect of lowered atmospheric CO_2 concentrations, the temperature changes of all three vegetation feedback terms are added (Fig. 3a). Over the land areas of northern Siberia, the combined effect of the vegetation changes leads to a cooling of about 2°C, while the CO_2 reduction to 190 ppm in $\hat{f}_C$ (Fig. 2b) causes a temperature decrease of 1.5°C in this region. This strong cooling by the vegetation occurs exactly in those regions with the greatest decrease in tree cover (as shown in Fig. 3b). Hence, even though the cooling effect of the CO_2 factor makes up 29% of the global cooling, while the total vegetation feedback only causes 12% of the global temperature change, the cooling

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Print Version
Interactive Discussion

due to the vegetation feedback in the high latitudes of eastern Eurasia is larger than the CO_2 induced cooling in this region.

To evaluate the results of this study, the temperature changes caused by the factors f_l and f_C are compared with the factors calculated by Berger et al. (1996). They found that the increase in albedo due to the presence of an LGM ice sheet, combined with the changed orbital parameters, leads to a cooling of 3.0°C at the LGM, while the lowering of the CO_2 level by 136 ppm cooled the climate by 1.6°C. In CLIMBER-2, the presence of an ice sheet causes a temperature change of −3.0°C, while the lowering of the CO_2 level by 90 ppm to 190 ppm produces a cooling of 1.5°C. Together with the small positive synergy factor between these two factors, Berger et al. (1996) found a LGM cooling of 4.5°C. This is the same cooling as found in the CLIMBER-2 simulation with fixed present-day vegetation (i.e., experiment LGM_{Cl}). The larger CO_2 decrease of 136 ppm in Berger et al. (1996) caused a temperature change for the CO_2 factor that is only slightly larger than the one found in CLIMBER-2 with a CO_2 reduction of only 90 ppm. This is consistent with the smaller sensitivity of the model of Berger et al. (1996) to a doubling of CO_2 (1.8°C), as compared with the CO_2 sensitivity of CLIMBER-2 (2.6°C). Therefore, it can be concluded that the individual effects of the factors f_l and f_C compare well with the results of Berger et al. (1996).

4. Conclusions

Although globally the biogeophysical effect of vegetation dynamics on air temperature is less important for the LGM climate than the impact of CO_2 changes and the presence of ice sheets, it was shown that in the northern high latitudes of Eurasia the interactive vegetation has a cooling effect that exceeds the temperature decrease due to the CO_2 decrease in this region. Hence, the use of a dynamic vegetation module instead of a prescribed present-day vegetation distribution is important as it causes significant temperature changes on a regional scale. This is especially important for the LGM, since Brovkin et al. (2003) showed that climate-vegetation interaction in the northern

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Print Version
Interactive Discussion

high latitudes is stronger in colder climates than in warmer climates.

Furthermore, the factor separation showed that in CLIMBER-2 the influence of the CO_2 drop at the LGM is distributed over both hemispheres but stronger over the SH. The cooling caused by the ice sheets is strongest over the ice covered regions of the NH. A comparison of the globally averaged cooling caused by the presence of ice sheets and CO_2 reduction at the LGM with the results of Berger et al. (1996) shows that these two factors are in good agreement.

In a forthcoming study, complementary experiments will be performed in order to separate the effects caused by vegetation feedbacks from those due to oceanic feedbacks. This will then allow for the separation of the taiga-tundra feedback from the sea-ice-albedo feedback and an assessment of the unique influence of the vegetation on climate.

Acknowledgement. The authors would like to thank C. Kubatzki for constructive discussions.

References

Berger, A.: The role of CO_2, sea-level and vegetation during the Milankovitch-forced glacial-interglacial cycles, in: Geosphere-Biosphere Interactions and Climate, Proceedings of the workshop held at Pontifical Academy of Science, edited by: Bengtsson, L. O. and Hammer, C. U., pp. 119–146, Cambridge University Press, 2001. 5

Berger, A., Dutrieux, A., Loutre, M. F., and Tricot, C.: Paleoclimate sensitivity to CO_2 and insolation, Scientific Report 1996/6, Institut d'Astronomie et Géophysique Georges Lemaître, Université Catholique de Louvain, Louvain-la-Neuve, 1996. 4, 9, 10

Bigelow, N. H., Brubaker, L. B., Edwards, M. E., Harrison, S. P., Prentice, I. C., Anderson, P. M., Andreev, A. A., Bartlein, P. J., Christensen, T. R., Cramer, W., Kaplan, J. O., Lozhkin, A. V., Matveyeva, N. V., Murray, D. F., McGuire, A. D., Gajewski, K., Wolf, V., Holmqvist, B. H., Igarashi, Y., Kremenetskii, K., Paus, A., Pisaric, M. F. J., and Volkova, V. S.: Climate change and Arctic ecosystems: 1. Vegetation changes north of 55° N between the last glacial maximum, mid-Holocene, and present, J. Geophys. Res., 108, doi:10.1029/2002JD002558, 2003. 2

Brovkin, V., Claussen, M., Ganopolski, A., Bendtsen, J., Kubatzki, C., Petoukhov, V., and Andreev, A.: Carbon Cycle, vegetation and climate dynamics in the Holocene: Experiments with the CLIMBER-2 model, Global Geochemical Cycles, 16, 1139, doi:10.1029/2001GB001662, 2002a. 4

Brovkin, V., Hoffmann, M., Bendtsen, J., and Ganopolski, A.: Ocean biology could control atmospheric δ^{13}C during glacial-interglacial cycle, Geochem., Geophys. Geosyst., 3, doi:10.1029/2001GC000270, 2002b. 3

Brovkin, V., Levis, S., Loutre, M.-F., Crucifix, M., Claussen, M., Ganopolski, A., and C. Kubatzki, V. P.: Stability analysis of the climate-vegetation system in the northern high latitudes, Clim. Change, 57, 119–138, 2003. 8, 9

Cramer, W., Bondeau, A., Woodward, F. I., Prentice, I. C., Betts, R. A., Brovkin, V., Cox, P. M., Fisher, V., Foley, J., Friend, A. D., Kucharik, C., Lomas, M. R., Ramankutty, N., Sitch, S., Smith, B., White, A., and Young-Molling, C.: Dynamic responses of global terrestrial ecosystems to changes in CO_2 and climate, Global Change Biol., 7, 357–373, 2001. 4

Crowley, T. J. and Baum, S.: Effect of vegetation on an ice-age climate model simulation, J. Geophys. Res., 102, 463–480, 1997. 2

Ganopolski, A.: Glacial integrative modelling, Phil. Trans. Royal. Soc. Lond., 361, 1871–1884, 2003. 3

Ganopolski, A. and Rahmstorf, S.: Rapid changes of glacial climate simulated in a coupled climate model, Nature, 409, 153–158, 2001. 7

Ganopolski, A., Rahmstorf, S., Petoukhov, V., and Claussen, M.: Simulation of modern and glacial climates with a coupled global model of intermediate complexity, Nature, 391, 351–356, 1998. 3

Ganopolski, A., Petoukhov, V., Rahmstorf, S., Brovkin, V., Claussen, M., Eliseev, A., and Kubatzki, C.: CLIMBER-2: a climate system model of intermediate complexity. Part II: model sensitivity, Clim. Dyn., 17, 735–751, 2001. 4

Harrison, S. P. and Prentice, C. I.: Climate and CO_2 controls on global vegetation distribution at the last glacial maximum: analysis based on palaeovegetation data, biome modelling and palaeoclimate simulations, Global Change Biol., 9, 983–1004, 2003. 2, 3

Hewitt, C. D., Stouffer, R. J., Broccoli, A. J., Mitchell, J. F. B., and Valdes, P. J.: The effect of ocean dynamics in a coupled GCM simulation of the Last Glacial Maximum, Clim. Dyn., 20, 203–218, 2003. 6

Kim, S.-J., Flato, G. M., and Boer, G. J.: A coupled climate model simulation of the Last Glacial

Maximum, Part 2: approach to equilibrium, Clim. Dyn., 20, 635–661, 2003. 6

Kubatzki, C. and Claussen, M.: Simulation of the global bio-geophysical interactions during the Last Glacial Maximum, Clim. Dyn., 14, 461–471, 1998. 3

Lewis, S., Foley, J. A., and Pollard, D.: CO_2, climate, and vegetation feedbacks at the Last Glacial Maximum, J. Geophys. Res., 104, 191–198, 1999. 3

Peltier, W. R.: Ice Age Paleotopography, Science, 256, 195–201, 1994. 5, 13

Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V. M., Legrand, M., Lipenkov, V. Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E., and Stievenard, M.: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, Nature, 399, 429–436, 1999. 6

Petoukhov, V., Ganopolski, A., Brovkin, V., Claussen, M., Eliseev, A., Kubatzki, C., and Rahmstorf, S.: CLIMBER-2: a climate system model of intermediate complexity. Part I: model description and performance for present climate, Clim. Dyn., 16, 1–17, 2000. 4

PMIP: Paleoclimate Modeling Intercomparison Project (PMIP), in: Proceedings of the third PMIP workshop, edited by: Braconnot, P., vol. WCRP-111, WMO/TD-1007, p. 271, Canada, 2000. 2

Stein, U. and Alpert, P.: Factor Separation in numerical simulations, J. Atmos. Sci., 50, 2107–2115, 1993. 4, 5, 7

Wyputta, U. and McAvaney, B. J.: Influence of vegetation changes during the Last Glacial Maximum using the BMRC atmospheric general circulation model, Clim. Dyn., 17, 923–932, 2001. 3

Table 1. Setup for all simulations. "PD" stands for present-day ice sheet forcing, "LGM" for LGM ice sheet forcing according to Peltier (1994). "280" and "190" stand for pre-industrial (i.e., "natural" present-day) and LGM atmospheric CO_2 levels, respectively. "REF" stands for the use of a prescribed modeled present-day vegetation distribution as simulated in REF while "interactive" stands for the use of the interactive vegetation model.

Simulation	Ice sheets	CO_2	Vegetation
REF	PD	280	interactive
LGM_I	LGM	280	REF
LGM_C	PD	190	REF
LGM_{CI}	LGM	190	REF
LGM_{IV}	LGM	280	interactive
LGM_{CV}	PD	190	interactive
LGM_{CIV}	LGM	190	interactive

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀▮ | ▶▮
◀ | ▶
Back | Close
Full Screen / Esc
Print Version
Interactive Discussion
EGU

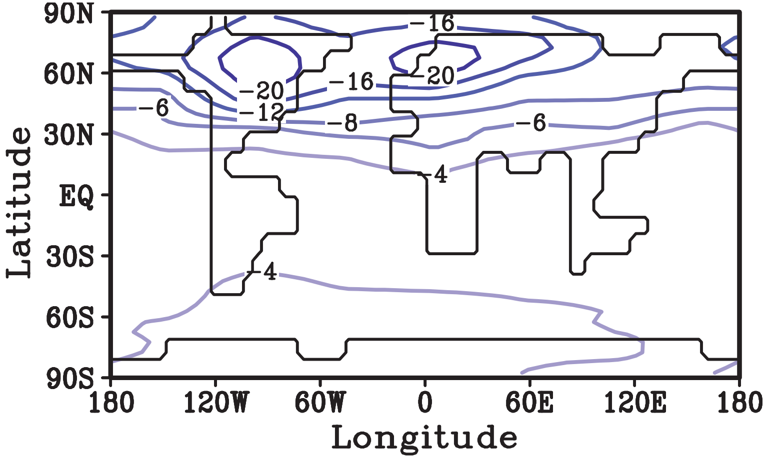

Fig. 1. Annually averaged surface air temperature differences [in °C] between the full LGM simulation (LGM_{CIV}) and the present-day reference run REF.

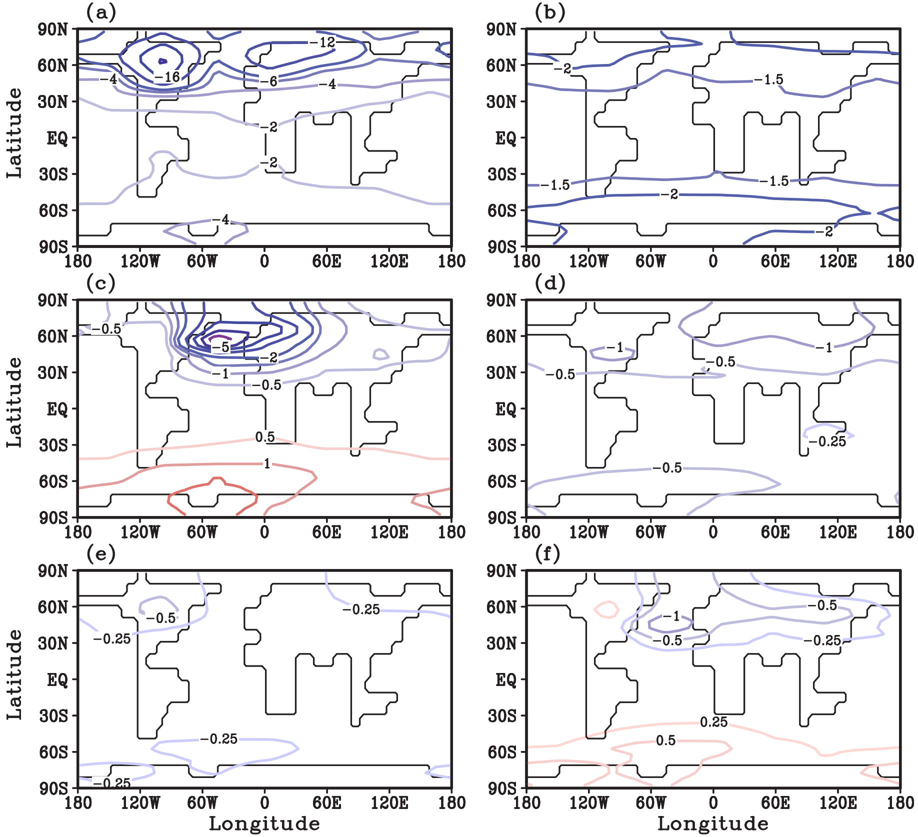

Fig. 2. Annually averaged surface air temperature changes [in °C] caused by **(a)** the presence of an ice sheet (f_I), **(b)** lowering of CO_2 to 190 ppm (f_C), **(c)** synergy between ice sheets and CO_2 decrease (f_{CI}), **(d)** vegetation change in response to an ice sheet (f_I^V), **(e)** vegetation change in response to the lowered CO_2 (f_C^V), and **(f)** vegetation change in response to the synergy between presence of ice sheets and CO_2 lowering (f_{CI}^V).

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀ ▶
Back Close
Full Screen / Esc
Print Version
Interactive Discussion

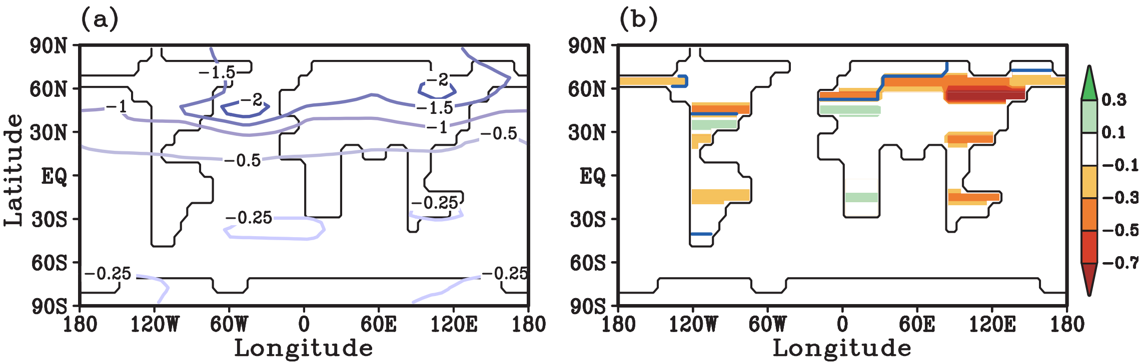

Fig. 3. **(a)** Change in the annually averaged surface air temperature due to the biogeophysical vegetation feedbacks [in °C] and **(b)** the associated change in fractional tree coverage compared to the prescribed potential present-day vegetation cover (in LGM_{CI}). The blue line in (b) is the 60% inland ice border.