Permafrost modelling with CLASS and CRCM/CLASS

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INTRODUCTION

Recent studies by Alexeev et al. (2007) and Nicolsky et al. (2007) have shown that using shallow soil models with zero flux bottom boundary conditions to study near-surface permafrost and its evolution in future climate can give inaccurate assessments. Their offline study with deep and shallow soil model configurations suggests that near-surface permafrost degradation occurs at an accelerated rate in shallow configurations compared to deep configurations. However, Lawrence et al. (2008) using offline simulations with the Community Climate Model showed that the global area covered by near-surface permafrost converged to practically the same amount at the end of the 21st century for deep and shallow configurations. Many initiatives are underway in different climate modelling groups to better represent near-surface permafrost in climate models. Selected results based on offline simulations performed with the latest version of the Canadian LAnd Surface Scheme (CLASS; Verseghy, 1991, Verseghy et al., 1993) looking at the thermal and hydrologic regimes of permafrost regions are presented in this paper. CLASS is highly suited for permafrost studies due to its very flexible soil configuration, both in terms of the depth of the soil model and the thickness of soil layers. CLASS is also the land surface scheme used in the fifth generation of the Canadian Regional Climate Model (CRCM5; Zandra et al., 2008). Some results based on CRCM5/CLASS, with different configurations of CLASS, are also discussed in this paper.

RESULTS

Results from CLASS offline simulations, driven by CRCM outputs, for the 1961–2100 period suggest that the use of a deeper soil configuration (i.e., 100 m deep with a total of 20 layers) compared to a shallow configuration (i.e., 4.1 m with 3 or 10 layers), as well as organic matter instead of mineral soil when appropriate, delays permafrost degradation by adding thermal inertia to the soil.

Figure 1a shows CLASS simulated temperatures for deep and shallow configurations, which suggest warmer (cooler) temperatures in summer and fall (winter and spring) for the shallow configuration. Overall, the evolution of the soil temperature difference suggests that the shallow configuration accumulates more energy from year to year, which translates into a greater temperature difference over time. The offline simulations, however, do not capture the land-atmosphere feedback and currently efforts are underway to study soil thermal and moisture regimes in permafrost underlain regions using CRCM5 with interactive permafrost (i.e., CRCM5 with the deeper version of CLASS for the LSS). Preliminary results with CRCM5/CLASS current climate simulations (1975-2002) also suggest similar results as obtained with the offline CLASS simulations. Figures. 1b and 1c show the difference in the CRCM5/CLASS simulated temperature for the first 10 cm of soil and at 4.1 m, respectively, for the deep vs. shallow configurations for the month of November, which suggests higher temperatures simulated with CRCM5 with the shallow CLASS configuration. However, the soil temperature differences in these coupled simulations are larger than those obtained with the offline simulations of CLASS and could be partly due to the soil-atmosphere feedbacks, as suggested by the fact that the difference in air temperature difference for the two configurations is positively correlated with the soil temperature difference of the first layer. Important differences in other surface fields (snow cover, albedo, runoff, etc) have also been noticed for the CRCM5/CLASS simulations with different configurations. The most important is snow cover, with onset of snow and snow-melt occurring during the periods when the maximum difference in soil temperature between the two configurations is noted.

CONCLUSIONS

Important differences in the soil thermal and moisture regimes are noted for shallow and deep soil model configurations in the offline CLASS and coupled CRCM5/CLASS simulations. The use of a shallow soil model, especially with a zero flux bottom boundary condition, as used in many climate models, can lead to unrealistic energy distribution and can affect the quality of model simulated soil thermal and moisture regimes. It is hoped that the coupled CRCM5/CLASS with deep soil configuration will provide better estimates of permafrost evolution when applied to future climate.

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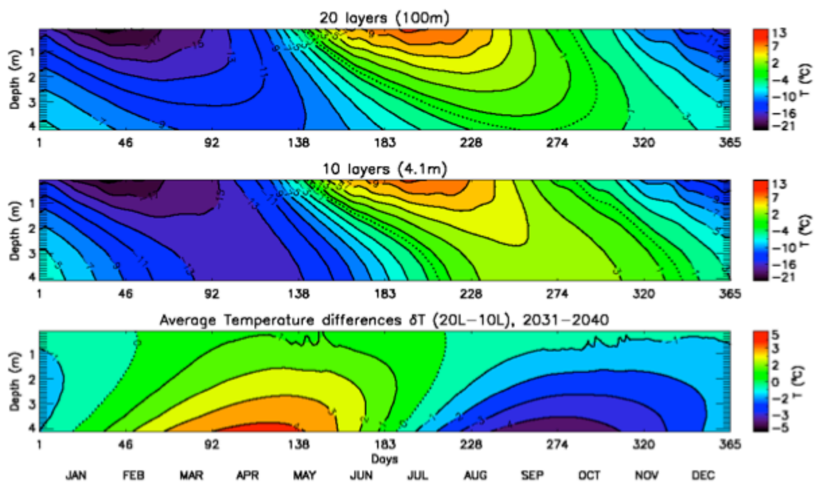
(a)



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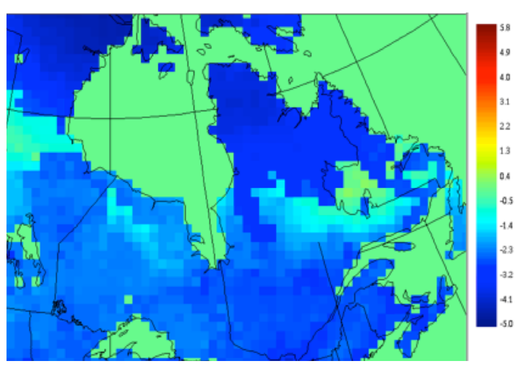

(c)

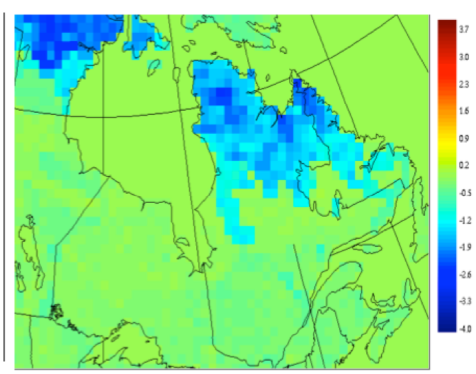

Figure 1. a) Ten-year (2031-2040) mean annual cycle of soil temperature for the first 4.1m, for the deep (top panel; 100 m deep with 20 layers) and shallow (middle panel; 4.1 m deep with 10 layers) soil model configurations, and their differences (bottom panel) from the offline simulations. Dashed lines correspond to 0°C isotherm. b) Difference in the CRCM5/CLASS simulated first soil layer (10 cm) temperature, for the month of November, for the deep and shallow configurations; The deep configuration is up to around 2°C cooler at this time of the year, compared to 0.5°C with offline simulations. c) as in b), but at 4.1m with differences as high as 5°C.