Dynamical core in atmospheric model does matter in the simulation of Arctic climate

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1. Introduction

It has been reported that global climate modeling has uncertainties in the Arctic region, including a mean bias with respect to observations and large diversity across models (IPCC, 2014). In particular, a cold winter bias over the Arctic has been found in climate simulations from the Coupled Model Intercomparison Project phase 3 (CMIP3) and phase 5 (CMIP5). It has been suggested that these uncertainties in Arctic climate modeling are mainly linked to observational difficulties and consequent poor understanding of the relevant physical processes (ACIA, 2005).

However, the dynamical cores used in atmospheric models could also play a key role in the uncertainty afflicting Arctic climate research. The latitude-longitude grid system adopted by conventional atmospheric models has unique numerical modeling characteristics associated with polar regions such as pole singularity. Previous studies simply addressed possible problem of pole singularity in using latitude-longitude grid system over the polar region (Dubos, 2009), but the quantitative comparison of the quality of the Arctic climate simulation with other dynamic cores has not been addressed yet. The recent development of dynamical cores using unstructured grid systems, such as cubed-sphere (Choi & Hong, 2016) raise the necessity of evaluating the impact of existing dynamical cores on Arctic region in global simulations. A comparison of global climate simulations between unstructured and latitude-longitude grids give us opportunity to investigate their potential impacts on Arctic climate simulations.

2. Model experiment

We adopted two dynamical cores of the Community Atmosphere Model version 5. The first was the latitude-longitude grid-based finite volume (FV) core, and the second was the cubed-sphere grid-based spectral element (SE) core. Using the FV and SE cores, we carried out two sets of full-physics experiments. First, we conducted simulations using both cores to examine the differences between present climate systems. The physical processes in both dynamical core experiments were set to the same CAM4 physics. Second, we conducted sensitivity experiments to investigate different responses to reduced sea ice by both cores. This experiment set adopts reduced sea ice coverage north of 60 °N compared to present climate simulation. The experiments were performed for 100 years, analyzing the boreal winter of the entire period.

3. Result

The present climate experiments using the SE and FV dynamical cores showed different zonal mean temperature distributions despite using the same physical settings. Compared to the FV core, the SE core simulated a colder troposphere over the subtropics and a warmer near-surface over the Arctic region (Fig. 1a). Especially, warmer temperatures of more than 3 K is observed at the lower troposphere below 850 hPa north of 60 °N in the SE core simulation. Compared to the FV simulation, the altered eddy momentum and heat fluxes of the SE simulation contributed to changes in mean circulation, producing rising motion at about 40 °N and sinking motion north of 60 °N in the troposphere by indirectly forced circulation (Figs. 1b, 1c, and 1d). As a result, the SE core produced an enhanced sinking motion in the troposphere north of 60 °N that enforced a warmer lower troposphere through adiabatic warming.

We also compared the responses of surface air temperature (SAT) and sea level pressure (SLP) as simulated by the FV and SE cores to reduced Arctic sea ice conditions. Both cores showed the same pronounced warming response over the sea ice reduction region in the Arctic. In contrast, the SAT response in the mid-latitude region and the SLP in the north Atlantic showed a statistically significant difference between the two cores. The FV core produced no significant response in mid-latitude SAT or northern mid-latitude SLP, but the SE core produced a significant cold SAT response in North America and lower pressure response in the North Atlantic. Only the SE core seemed able to simulate Warm Arctic, partly Cold Continents response to reduced sea ice cover in this study.

4. Discussion

Various factors such as the grid system, fast-wave handling, and the physics-dynamics coupling process may contribute to this difference between eddy fluxes. Among the factors, fast-wave treatment may be profound contributors. The additional numerical filter for polar regions is a necessary requisite for models using finite method on latitude-longitude grid system. The FV core in this study also applies an additional polar filter to stabilize fast gravity waves over high-latitude regions. Further studies on the influence of the polar filter are needed.

5. References

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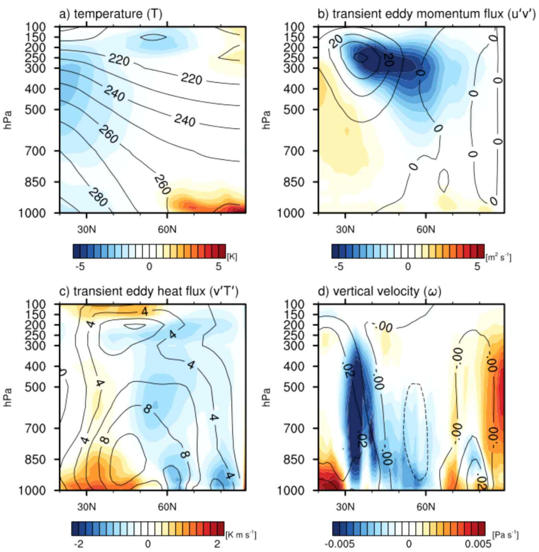

Figure 1 Zonally averaged climate parameters during winter (December-January-February) produced by two full-physics climate simulations, a finite volume dynamical core (contours) and the changes produced by using a spectral element dynamical core (shading): (a) temperature, (b) transient eddy momentum flux, (c) transient eddy heat flux, and (d) vertical velocity