Comparing the Response of Climate Models to Freshwater Fingerprints and Hosing

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Introduction / Motivation

The transition from the Bolling Allerod (BA) to the Younger Dryas (YD) was a large amplitude cooling event during the last deglaciation. Traditionally this transition is considered to have been initiated by re-routing of glacial runoff due to deglaciation (Broecker et. Al, 1989). The BA-YD transition has been modelled extensively across varying ranges of Earth system models and generally freshwater injection results in hemisphere wide cooling in the Northern hemisphere. In paleoclimate simulations, freshwater hosing in large bands across the North Atlantic remain frequently used to induce rapid and large scale changes in climate, this transition being one common example. However, results from Condron and Winsor (2012) demonstrate that the distribution of glacial runoff in the open ocean (ie. beyond the Western Boundary Current) does not well agree with the commonly used hosing regions. Furthermore, using realistic glacial discharge routing for injecting glacial runoff in non-eddy permitting climate models introduces biases due to unresolved eddies and coastal boundary currents. We address these issues through use of novel freshwater fingerprint products and further investigation of glacial runoff transport in a glacial ocean simulation.

Method and Models

Condron and Winsor (2012) uses an eddy permitting model configuration for a Last Glacial Maximum (LGM) background climate with associated changes to land-sea mask and model bathymetry. We use the results of these simulations to generate a 'freshwater fingerprint' characterizing the distribution of glacial runoff when it exits the coastal boundary currents and enters the open ocean. The resulting fingerprint for a 5Sv injection at the mount of the Mackenzie river is shown in the bottom panel of **Figure 2** with the typical 50-70N 'hosing' region in the top panel.

Next Generation Fingerprints

Updated fingerprint products are currently in production using a modified configuration of the MITGCM LGM setup of Condron and Winsor (2012). This updated setup involves the same surface boundary conditions but a modified bathymetry to explore the impact of different gateways and shelves in the Arctic Ocean, particularly the Bering Strait and the Barents-Kara sea. The modified bathymetries reflect the relative sea level of the BA-YD transition period with both an open and a closed Bering Strait configuration. As well, these fingerprint products will examine the impact of using smaller injection volumes, ~0.2Sv for a continious Mackenzie river injection, as constrained by the GLAC1D ice sheet reconstruction and different injection locations such as the Fennoscandian ice sheet.

Conclusion and Summary

The use of a freshwater fingerprint instead of a hosing belt results in an appreciably different simulated climate within at least the first years of the injection. This simulated climate displays different characteristics than is expected for a typical freshwater 'hosing experiment'. Longer duration simulations are ongoing to explore the full duration of the freshwater fingerprint method on the simulated climate. Ongoing and future work will incorporate fingerprints generated using more realistic freshwater injection volumes, as constrained by the GLAC1D reconstruction, in both the eddy permitting and the coarse resolution ocean models. As well, exploration of this method with an ensemble of numerical models of varying complexity will be investigated to examine the impact of model complexity and sensitivity on these experimental results.

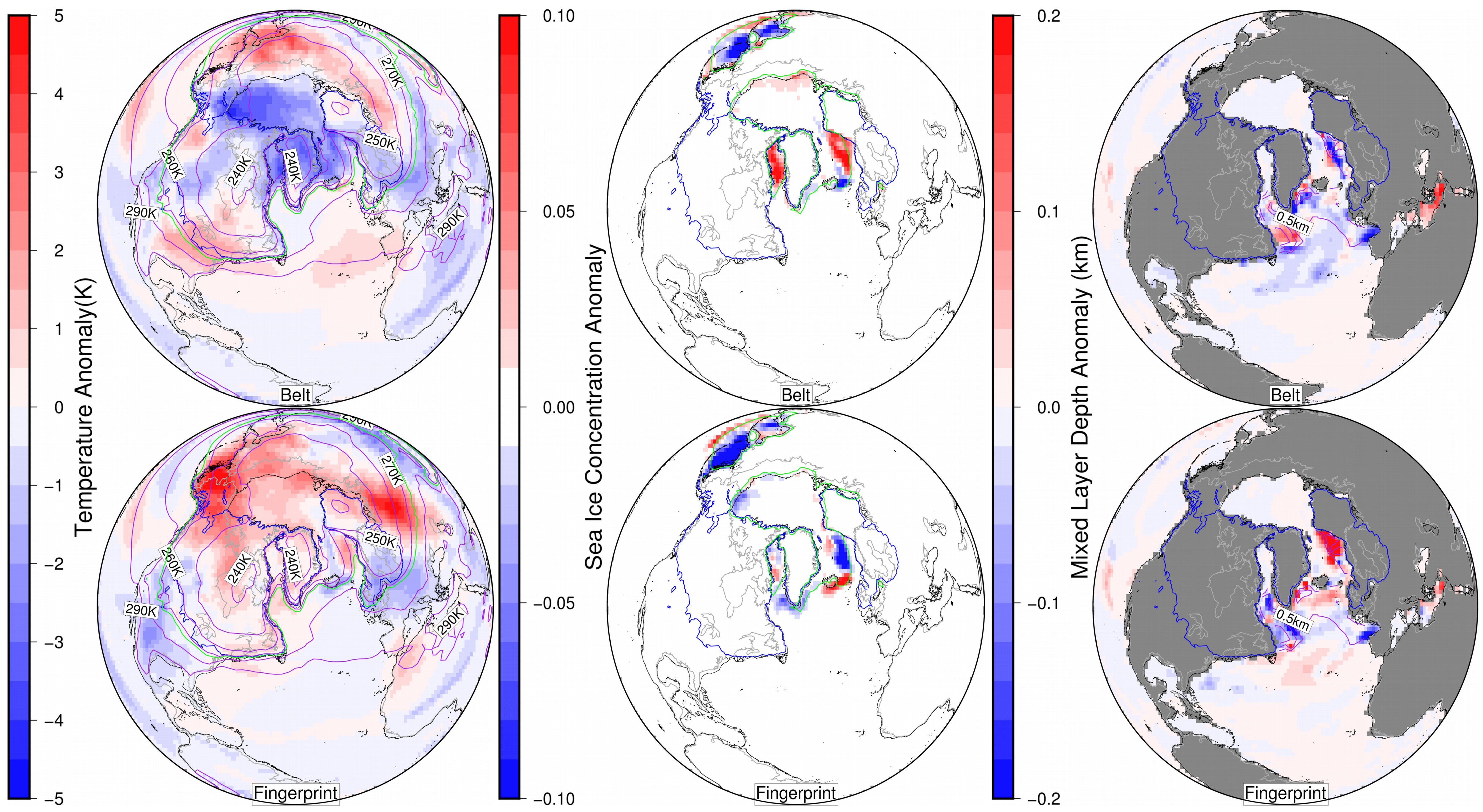

Figure 1: Differences in simulated climate, relative to a control simulation (ie. for surface air temperature anomaly, red is warmer) for both the injection 'belt' and the injection fingerprint methods. Annual means are shown for the surface air temperature and sea ice concentration plots, mixed layer depth is shown for February of the first year of simulation. Purple contours represent the control simulation values and green contours represent 0C and 15% sea ice concentration respectively.

Simulations and Preliminary Results

Our injection simulations are carried out using an LGM configuration of the Community Earth System Model (CESM) according to the Paleoclimate Model Intercomparison Project Phase 4 (PMIP4) LGM boundary condition specifications and the GLAC1D ice sheet reconstruction. The simulation is a fully coupled Atmosphere-Ocean-Sea Ice-Land Surface configuration at ~2 degrees in the atmosphere/land and 1 degree in the ocean. This configuration incorporates the changes in relative sea-level and associated exposed shelved and closed gateways. Furthermore, the surface vegetation is determined by the dynamic vegetation sub-model of CESM equilibrated to the PMIP3 LGM CESM simulation.

Our injection experiments follow those of Condron and Winsor (2012), using an injection volume of 5Sv of freshwater for 1 year for both the belt and the fingerprint injection distributions. **Figure 1** shows the immediate differences in the simulated climate when using the two different freshwater injection schemes. The hosing belt scenario exhibits features in line with previous injection studies, where the northern hemisphere generally cools relative to a control simulation. The fingerprint scenario still shows a cooling over much of Europe, in agreement with proxy records, such as Brauer et. al., (1999), but exhibits a background warming over Siberia, Alaska and much of the Laurentide. The belt simulation results in greater Northward heat transport relative to the fingerprint simulation. The relative sea ice concentration differences are of similar distribution but of opposite signs in the Greenland-Iceland-Norwegian seas, however they are similar in the Pacific around the location of the modern Bering Strait. Thus far there has been little difference between the responses of the simulations when considering the total cloud distribution or precipitation. We have not yet been able to establish the persistance of the resulting climate anomaly as these simulations are ongoing.

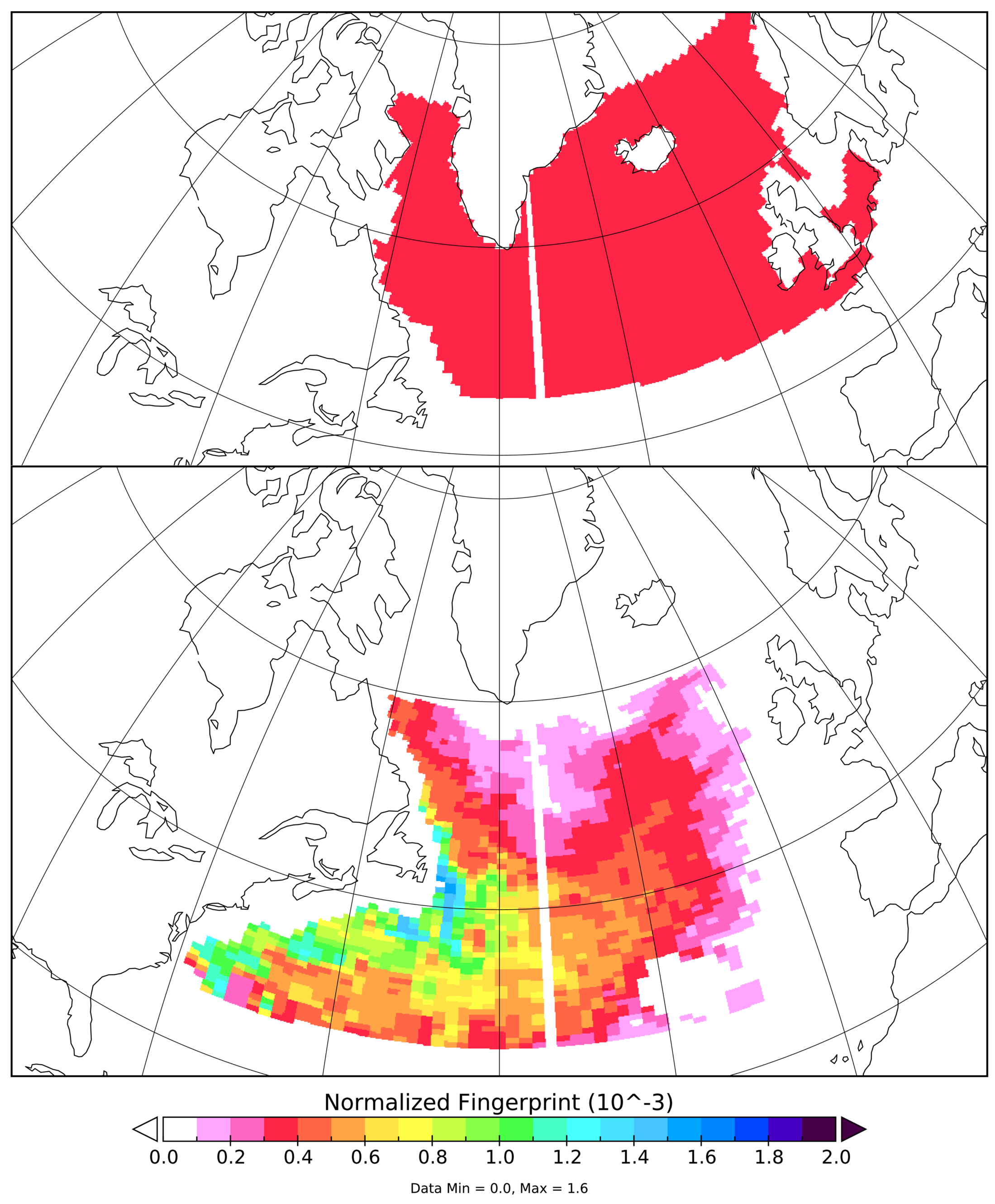

Figure 2: The freshwater injection regions for each of the experiments. The top map shows the commonly used 50-70N region for freshwater injection while the bottom is the fingerprint generated by the 5Sv Mackenzie river injection experiment of Condron and Winsor (2012).

Brauer, A., et. al, High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. QSR, 18 (3), 1999

Broecker, W.S., et. al., Routing of meltwater from the Laurentide Ice Sheet during the Younger Dryas cold episode. Nature, 341 (6240), 318–321, 1989

Condron, A., Winsor, P., Meltwater routing and the younger dryas. 109(49):1992819933, doi:10.1073/pnas.1207381109, 2012