Impact of grids and dycores in CESM2.2 on the meteorology and climate of the Arctic

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Abstract

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Plain Language Summary

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1 Introduction

General Circulation Models (GCMs) are a powerful tool for understanding the meteorology and climate of the poles, which are among the most sensitive regions on Earth to global and environmental change. Despite their importance, the numerics of GCMs have had to grapple with the *pole-problem* (Williamson, 2007), an economic bottleneck arising from the convergence of meridians into a polar singularity on latitude-longitude grids. In the 1970's this issue was largely defeated through wide-spread adaption of the spectral transform method in GCMs, which transforms grid point fields into an isotropic representation in wave space. But as computing power has increased, local numerical methods have become more desirable for their ability to run efficiently on massively parallel systems. The pole-problem has thus re-emerged in contemporary climate models using latitude-longitude grids, and some combination of reduced grids and polar filters are necessary to subdue this instability (Jablonowski & Williamson, 2011). An alternative approach is to use unstructured grids. Unstructured grids permit quasi-uniform grid spacing globally, thereby eliminating the pole-problem. They allow for more flexible grid-structures than latitude-longitude grids, and can support regional grid refinement that may be used to capture higher resolution in the polar regions. Regional refinement of polar regions may be desirable as latitude-longitude grids, by virtue of the convergence of meridians, have higher horizontal resolution in polar regions compared to quasi-uniform grids containing the same degrees of freedom.

The Community Earth System Model, version 2.2 (CESM; `http://www.cesm.ucar.edu/models/cesm2/`) supports a diverse number of atmospheric dynamical cores (hereafter referred to as *dycores*). These range from dycores using latitude-longitude grids, the finite-volume (FV; Lin, 2004) and eulerian spectral transform (EUL; Collins et al., 2006) models, and dycores built on unstructured grids, the spectral-element (SE; Lauritzen et al., 2018) and finite-volume 3 (FV3; Putman & Lin, 2007) models. The EUL dycore is the oldest dycore in the Community Atmosphere Model (CAM), the atmospheric component of CESM, and is the least supported of all the dycores. FV3 is the newest dycore in CESM, but it was not fully incorporated into the model at the time this work commenced, and so is omitted from this study. The authors instead focus on the two most well supported dycores in CESM, SE and FV. The goal of this study is to characterize the representation of polar regions using the SE and FV dycores, as these models treat the high-latitudes, e.g., the pole-problem, in very different ways.

The Arctic region has unique geography consisting of a polar ocean capped in a layer of sea ice, partially encircled by the northern coasts of the northern hemisphere continents and the large island of Greenland. Greenland is covered in a kilometers thick ice sheet, and receives a substantial portion of its snowfall from synoptic-scale storms traversing up the eastern sea-board of North America, and steered in the direction of the Icelandic low. Katabatic winds accelerate down the steep slopes of the Greenland Ice Sheet (GrIS) in episodic bursts that can clear out sea ice from its fjords and surrounding coastal region. Large volumes of fresh water are drained into the ocean through river outlets in Canada and Russia, ice discharge and melt water runoff from the narrow ablation zones of GrIS. Polar Lows form during the cold season and their gale-speed winds can kick up large waves and pose a hazard to mariners' and coastal communities. These Arctic processes have proven challenging to represent in GCMs, primarily due to the fine-scales in-

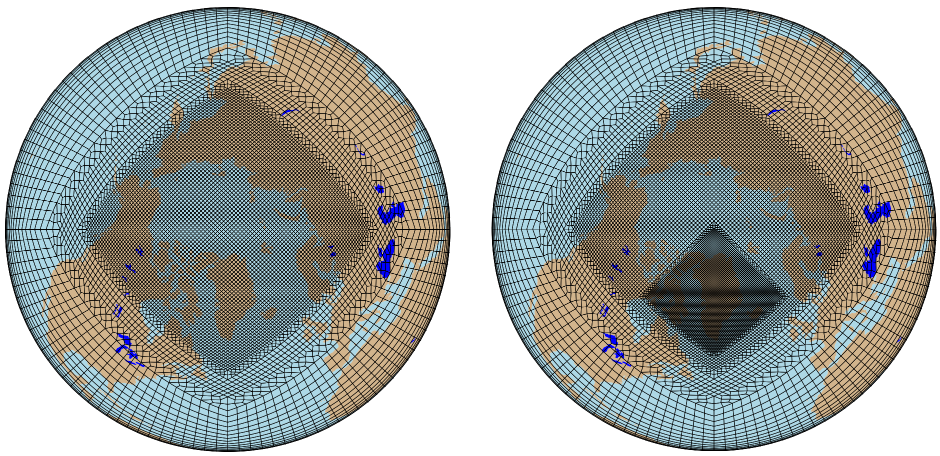

Figure 1. .

volved (Bromwich et al., 2001; Smirnova & Golubkin, 2017; van Kampenhout et al., 2018). As such, the Arctic serves as a challenging test-bed for comparing the simulated meteorology and climate in the SE and FV dycores.

The FV dycore is assessed using grids with Δx of 1° and 2° grid spacing (Δx refers to the average equatorial grid spacing). These are compared to the equivalent 1° SE grid, referred to as ne30pg3. This grid does not refer to the SE dycore proper, but a variant in which the dry dynamics are solved using the SE method, and tracer advection computed using the conservative semi-Lagrangian advection method (SE-CSLAM; Lauritzen et al., 2017). In SE-CSLAM the physical parameterizations are computed on the finite-volume tracer advection grid. Optionally, one can compute the physics on a finite-volume grid that is $\frac{3}{2} \times \Delta x$ of the tracer-advection grid (Herrington et al., 2019). All variants of the SE dycore discussed herein are available as part of the CESM2.2 release. A comparison of the lower-resolution physics grid version of ne30pg3, referred to as ne30pg2, over the Arctic is included in this study.

The SE dycore (not SE-CSLAM) supports regional grid refinement via it's variable resolution configuration. Two variable resolution meshes were developed as part of the CESM2.2 release that contains grid refinement over the Arctic. The ARCTIC grid is a $\Delta x = 1^\circ$ grid with $\Delta x = \frac{1}{4}^\circ$ regional refinement over the broader Arctic region. The ARCTICGRIS grid is similar to the ARCTIC grid, but additionally contains a patch covering the big island of Greenland with $\Delta x = \frac{1}{8}^\circ$ resolution. The Arctic refined grids are depicted in Figure 1, and are available as part of the CESM2.2 release. The surface mass balance of the GrIS is compared across all grids and dycores in this study, and the ARCTCGRIS grid is certainly at an advantage due to its higher resolution.

The study is laid out as follows. Section 2 consists of documentation of the grids, dycores and physical parameterizations used in this study. The Arctic refined grids were developed by the author, and this section serves as their official documentation. Section 2 also contains a description of the experiments along with the observational datasets and post-processing software used for validating the models. Section 3 contains the results of the experiments and Section 4 provides some discussion and conclusions.

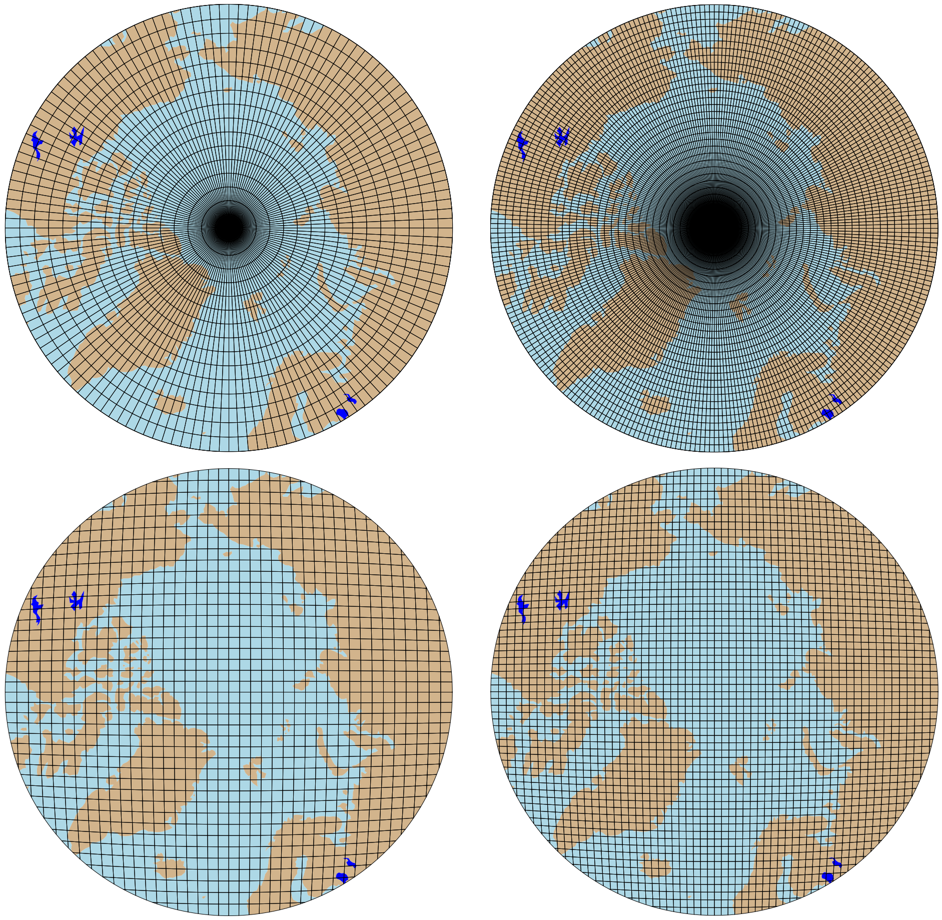

Figure 2. .

2 Methods

2.1 Grids

2.2 Dynamical cores

2.2.1 Finite-volume model

2.2.2 Spectral-element model

2.3 Physical parameterizations

2.4 Experimental desing

2.5 Observational datasets

2.5.1 ERA5

2.5.2 LIVVkit 2.1

2.6 TempestExtremes

2.7 StormCompositer

3 Results

3.1 Tropospheric temperatures

3.2 Inter-annual variability

3.3 Synoptic-scale storm characteristics

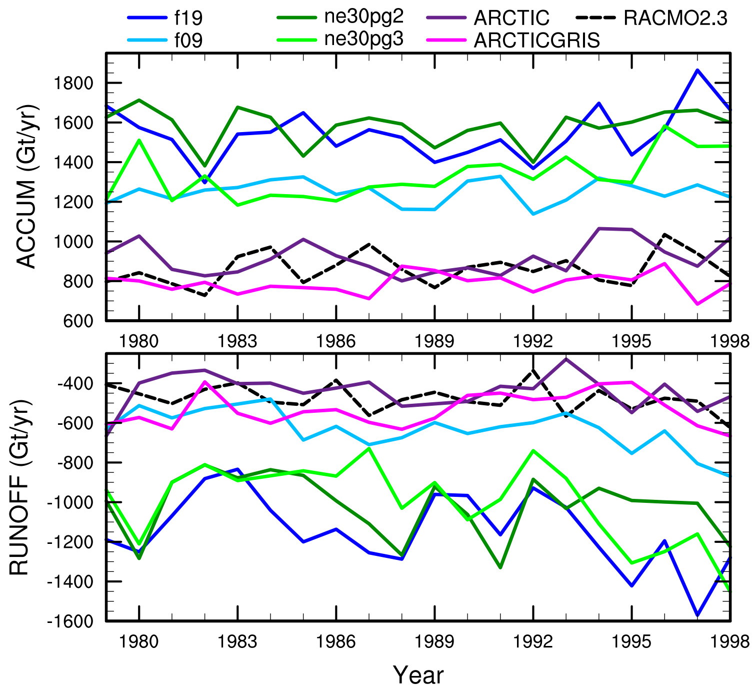

Figure 3. .

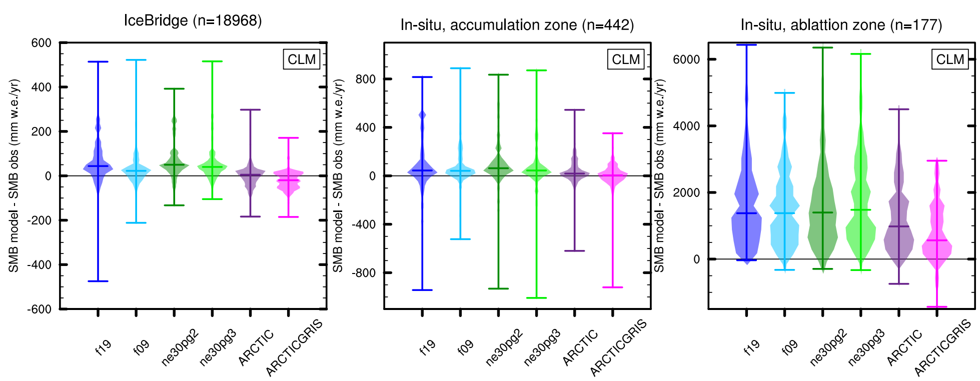

Figure 4. .

ment 1852977. Computing and data storage resources, including the Cheyenne supercomputer (doi:10.5065/D6RX99HX), were provided by the Computational and Information Systems Laboratory (CISL) at NCAR.

The data presented in this manuscript is available at `https://github.com/adamrher/2020-arcticgrids`.

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