Variable Resolution CESM (VR-CESM) for Polar Science

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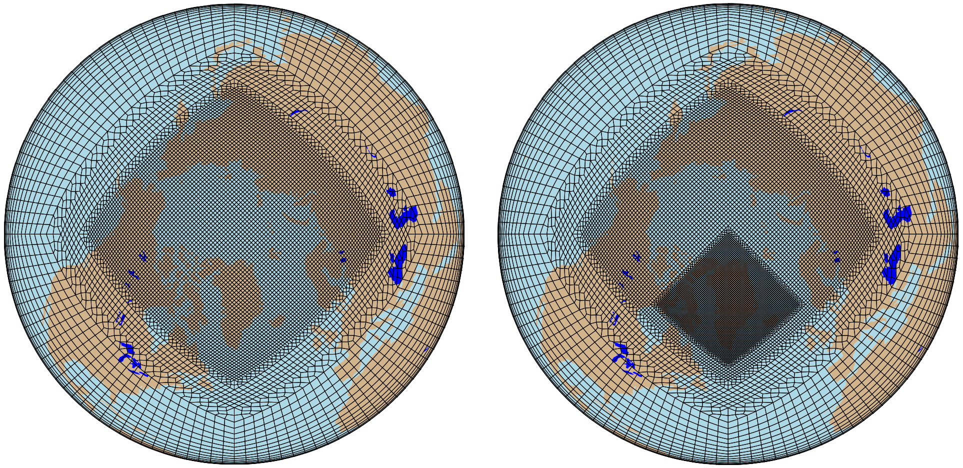
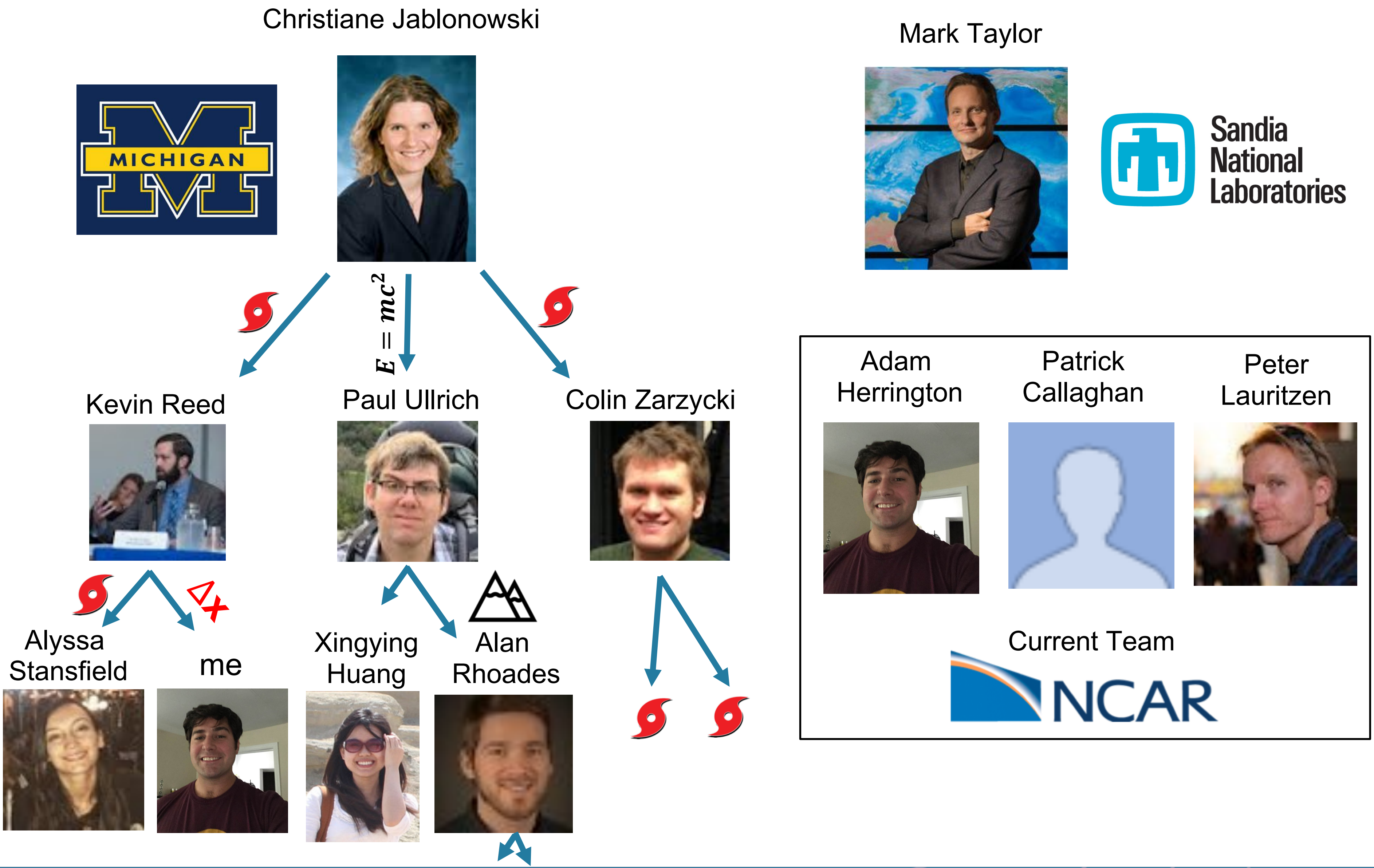
Winter LIWG/PaleoWG Meeting, 2020



"Horizontal grid sizes in GCMs and EMICs are typically several hundred km, and are inadequate to resolve the steep topography around ice-sheet margins that are important in determining ablation." –Pollard, 2010

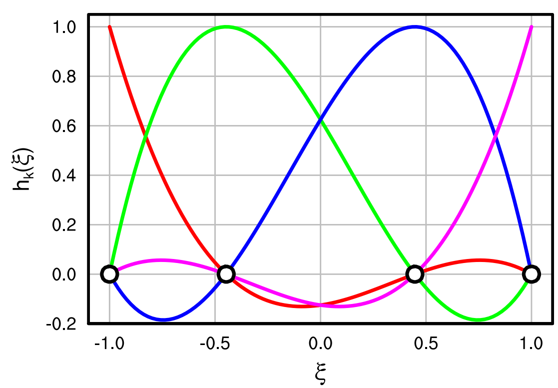
Second Wave of Variable Resolution CAM-SE

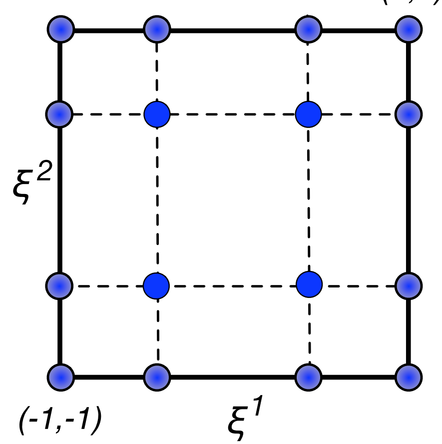


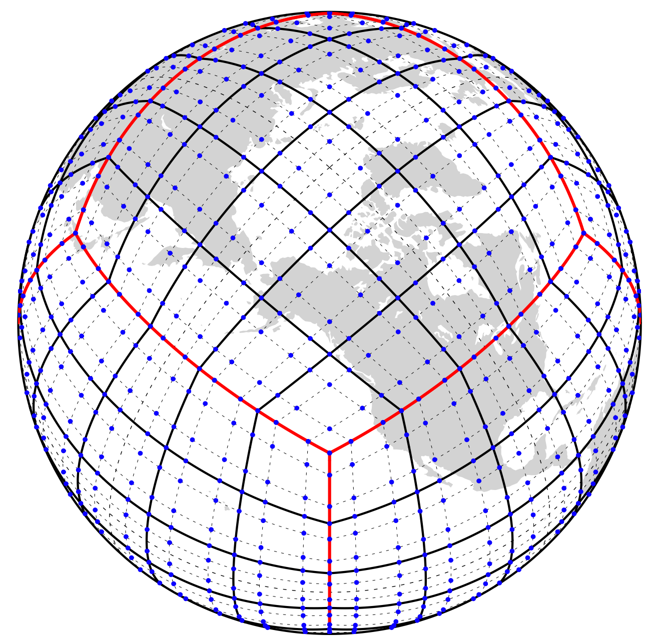
Spectral Element Dycore (CAM-SE, E3SM)

- High-order CG Method on cubed-sphere, unstructured grid (AKA flexible)
- Denote grid with an ‘ne’ followed by the number of elements on the edge of a panel
- We would call this grid **ne5** (element grid)
- Each element contains 16 Gauss-Lobatto Legendre nodes (computational grid)

Degree N=3 Lagrange basis set
(puts the ‘spectral’ in ‘spectral-element’)



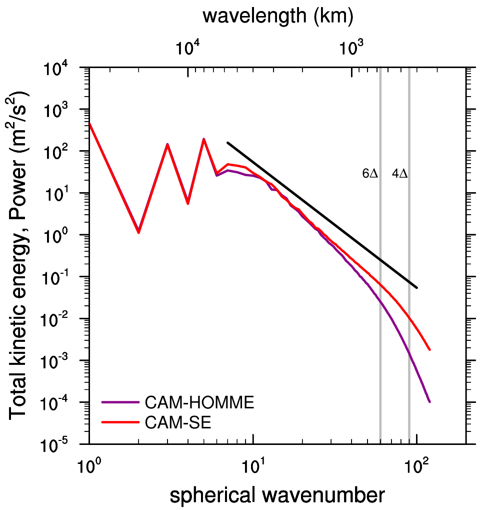


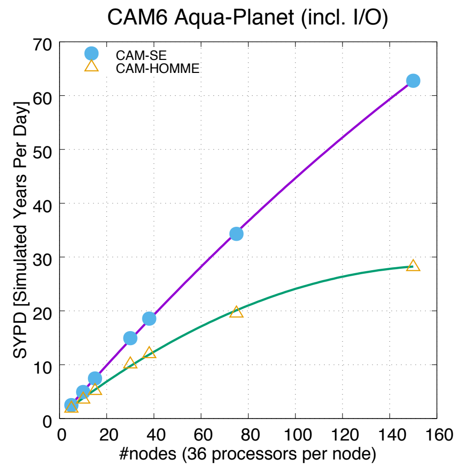


Figures courtesy of Ram Nair

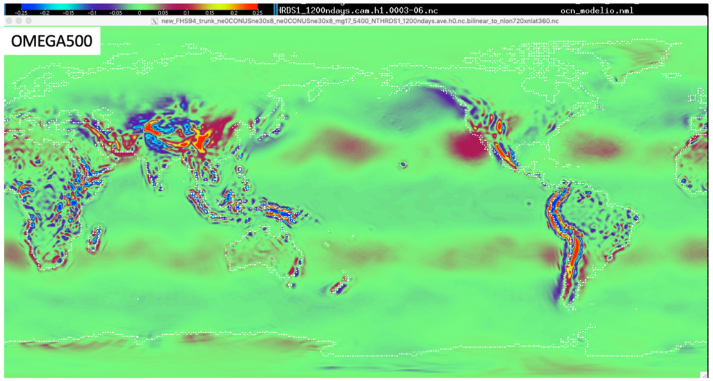
CESM2.2 Spectral Element Dycore

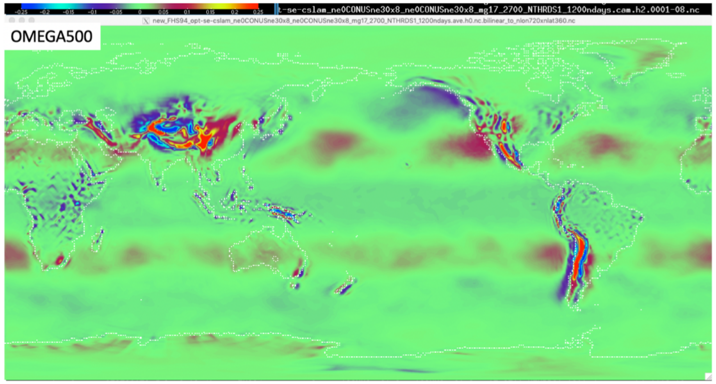
- Dry mass vertical coordinate
- Comprehensive treatment of condensates/energy
- Improved pressure gradient formulation (DOE)
- Improved accuracy in vertical remapping (DOE)
- Fixes conservation issue w/ physics tendencies
- Improved kinetic energy spectrum
- Faster!





Held-Suarez w/ topo stress test

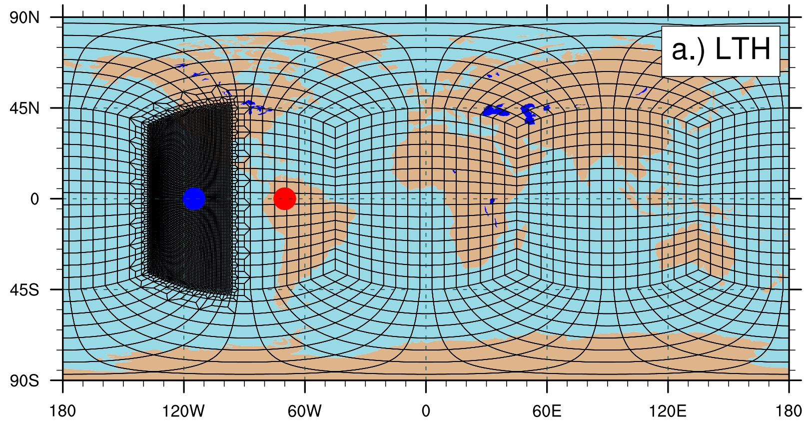




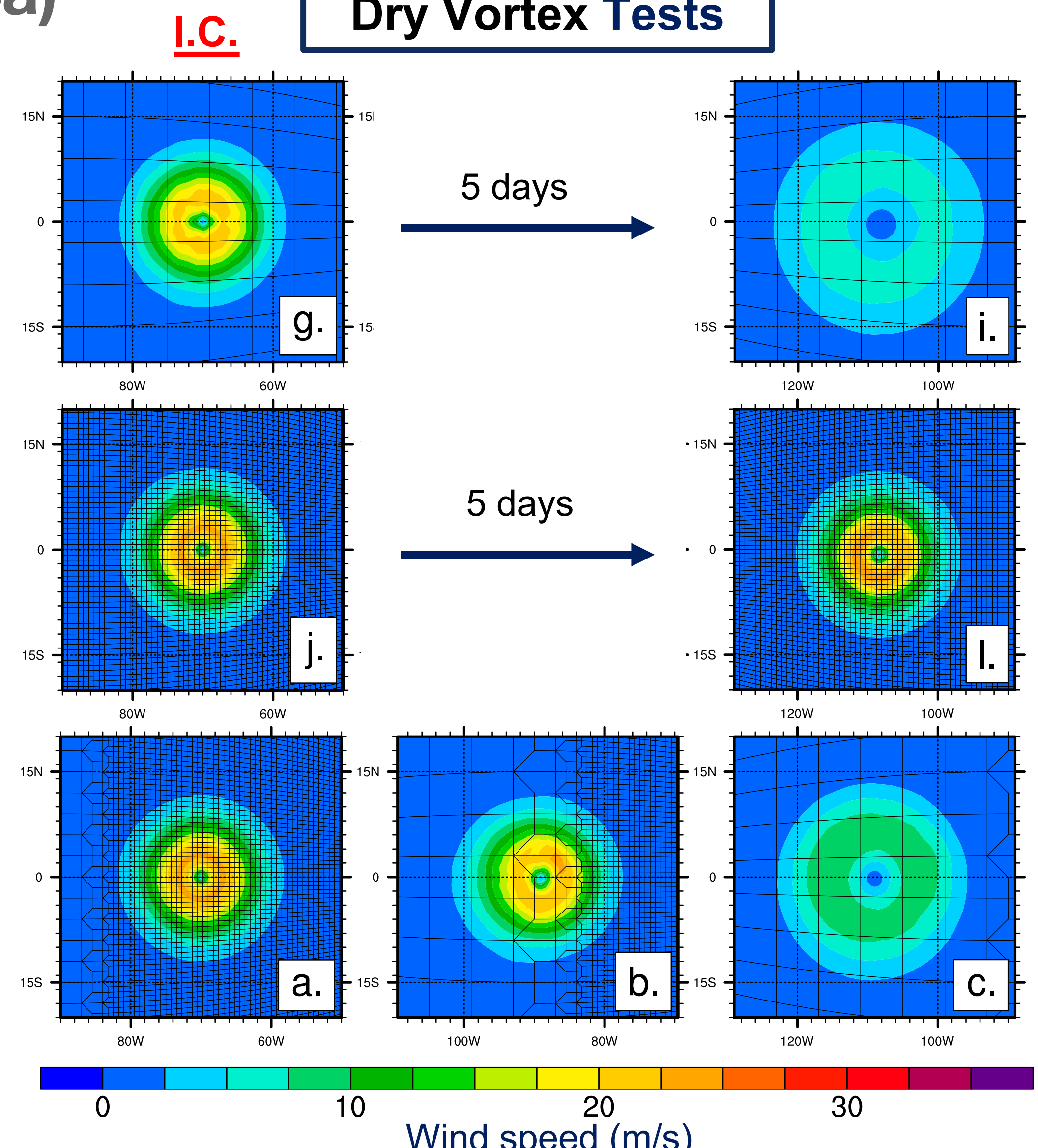
Lauritzen et al. 2018

How do features behave across the transition? (Zarzycki et al. 2014a)

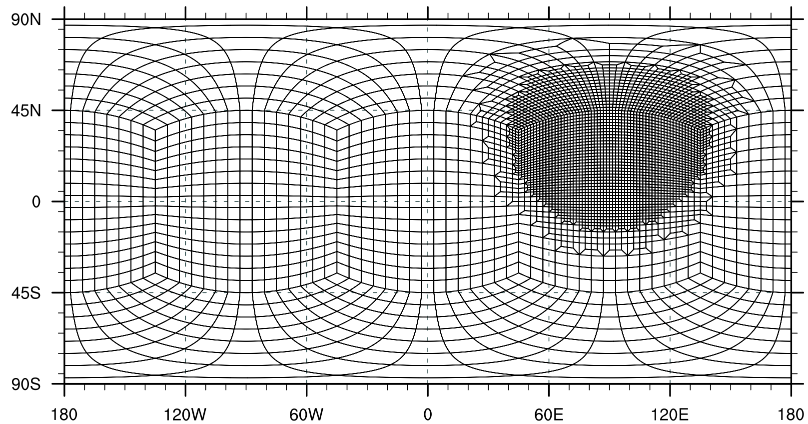
Dry Vortex Tests



*CAM-SE uses higher-order numerics, which avoids large errors that might typically arise from the transition region



Tropical Cyclone Permitting (Zarzycki et al. 2014a)



Tropical Cyclone incl. physics

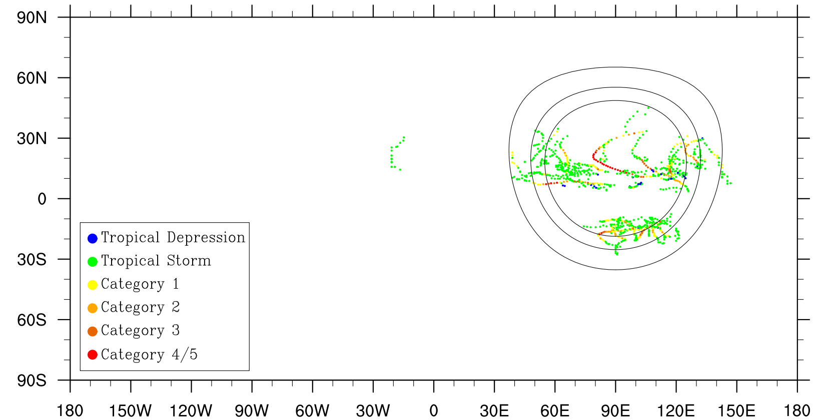
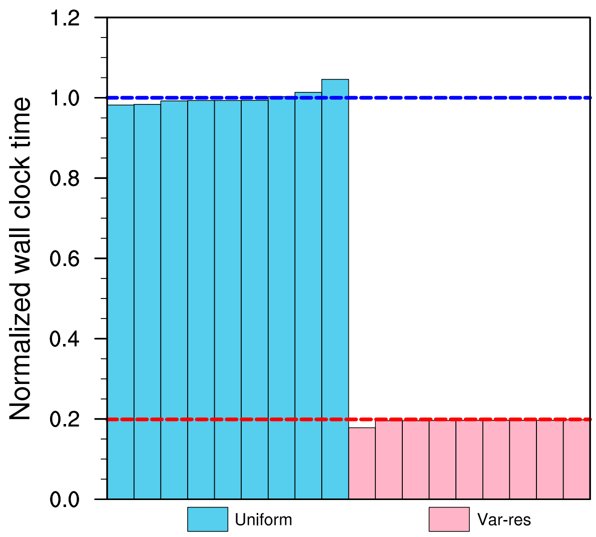


FIG. 12. Trajectories of tropical storms in aquaplanet simulation. Colors indicate intensity on the Saffir–Simpson scale.



Led to quite a few hurricane forecast studies using VR-CESM, e.g.,

Forecasted attribution of the human influence on Hurricane Florence

K. A. Reed[1]*, A. M. Stansfield[1], M. F. Wehner[2], C. M. Zarzycki[3,4]

No refinement (55 km)
4X refinement (222 km -> 55 km)

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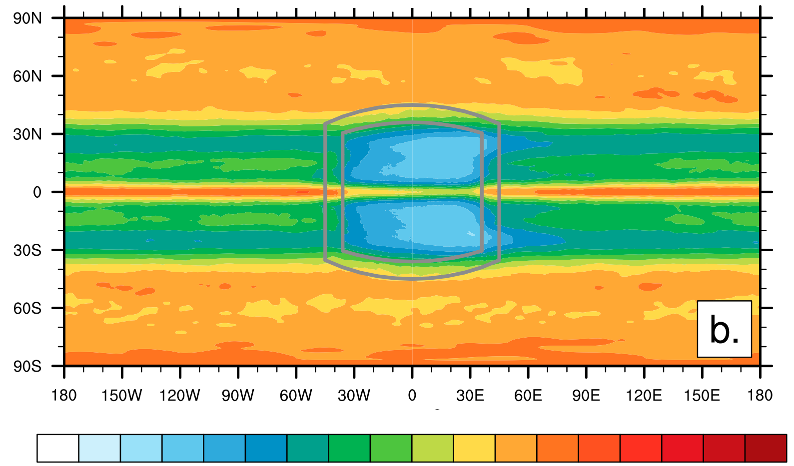
AGCMs exhibit weak- or non-converging solutions

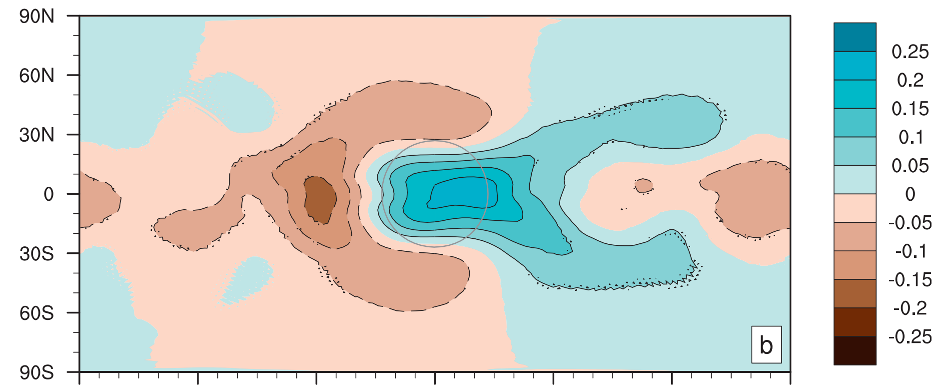
CAM4 Physics

Zarzycki et al. 2014b



Total Cloud Fraction

MPAS, Rauscher et al. 2013

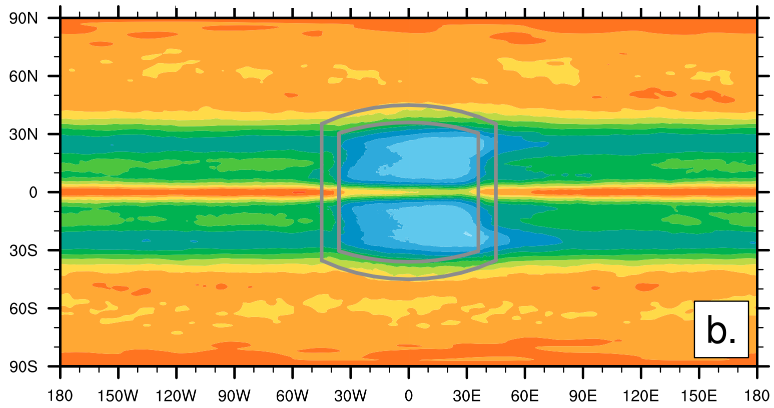


200-hPa Eddy Velocity Potential ($x10^{-7}$ m^2/s)

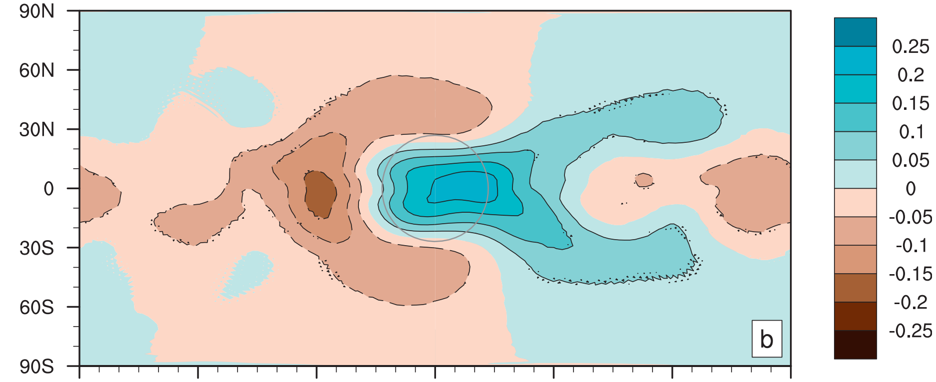
AGCMs exhibit weak- or non-converging solutions

CAM4 Physics

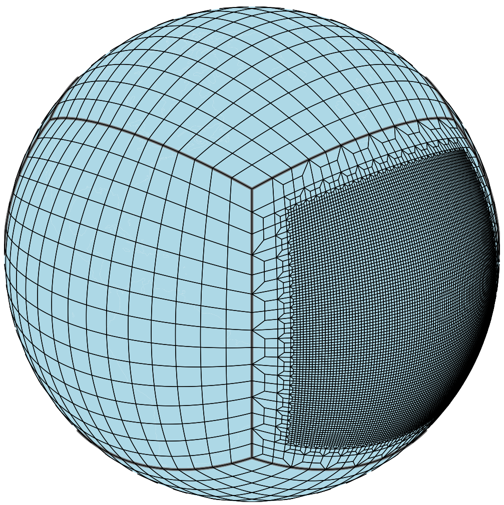
Zarzycki et al. 2014b



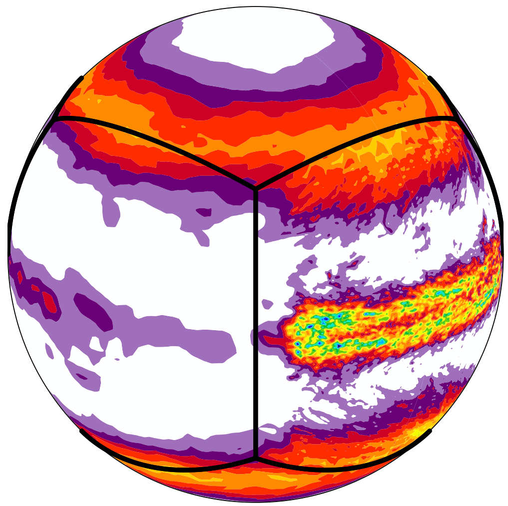
MPAS, Rauscher et al. 2013



CAM6 Physics



PRECL



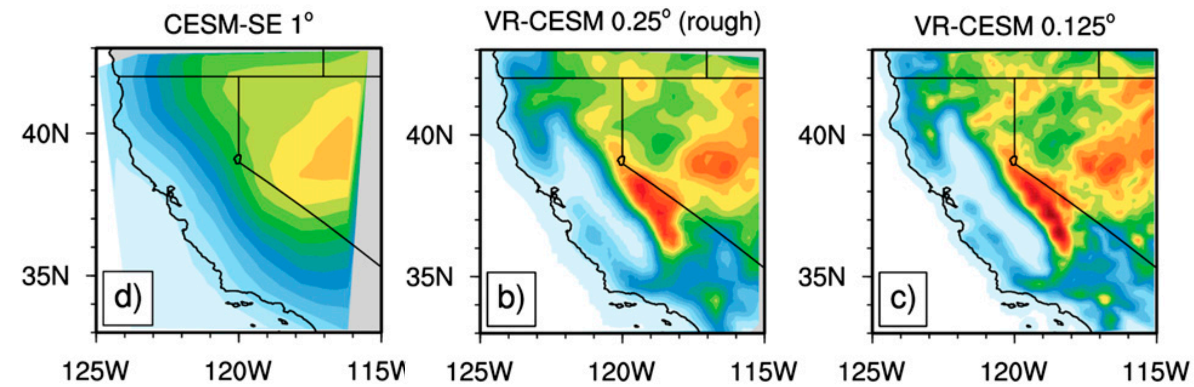
***Conservative advice**: shy away from refining the ITCZ in climate simulations until we solve the convergence problem

Herrington and Reed, *in review*

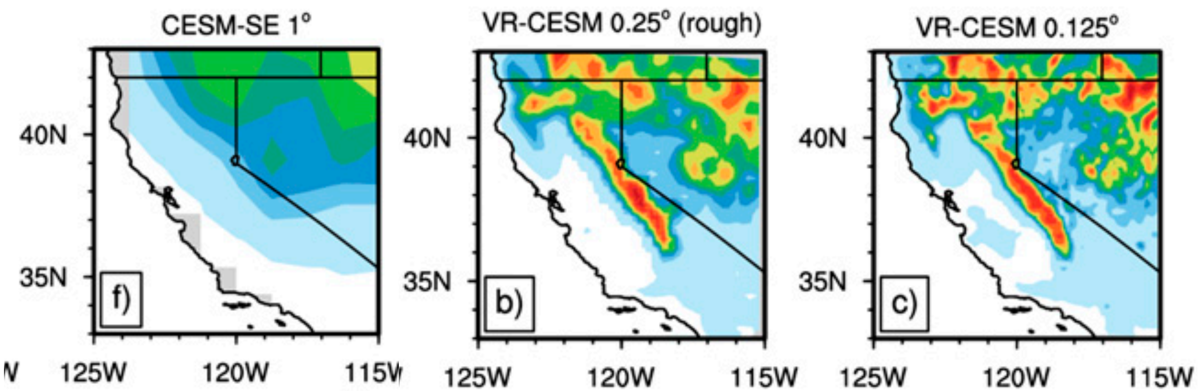
Rhoades: Orographic Precipitation

Characterizing Sierra-Nevada Snowpack, Rhoades et al. 2014

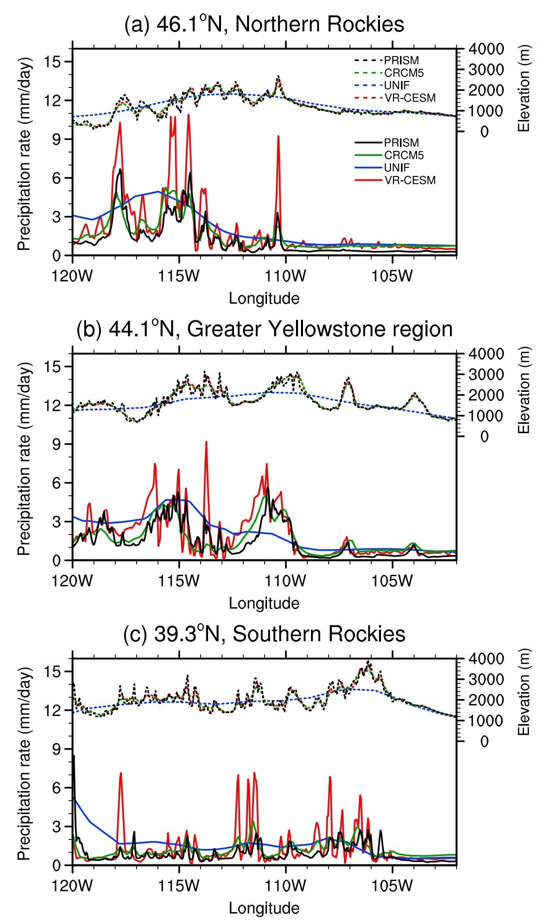
TOPOGRAPHY



SNOW COVER

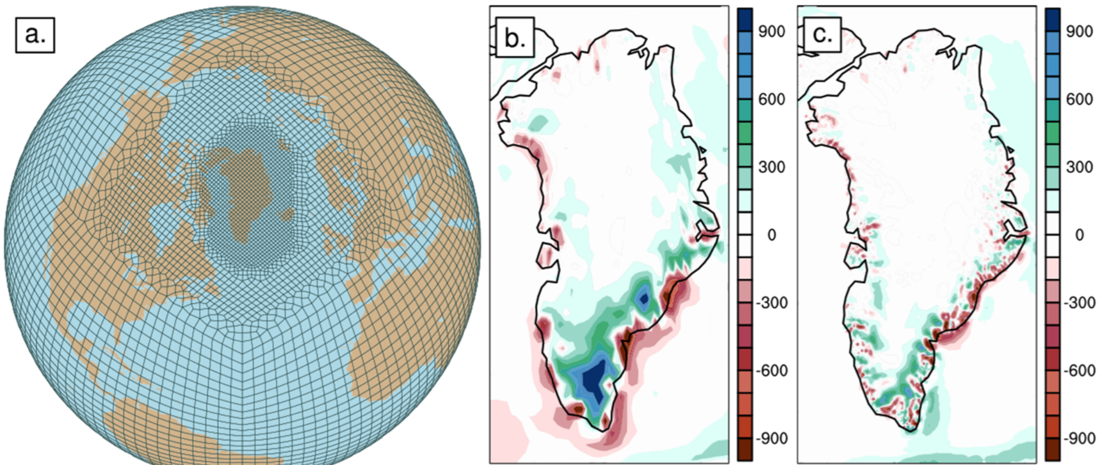


Rocky Mountains, Xu et al. 2014

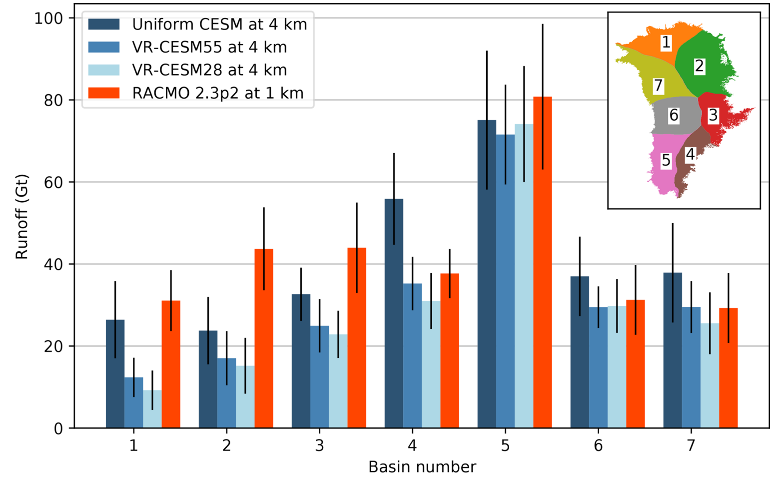


…so to Greenland we go (van Kampenhout et al. 2019)

Case minus RACMO (1980-1999)
Annual Accumulation

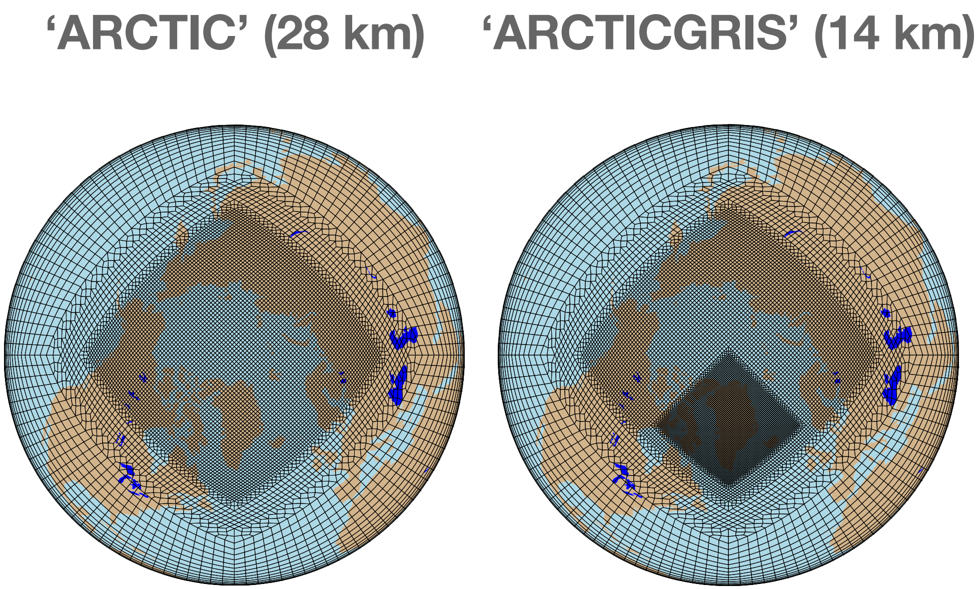


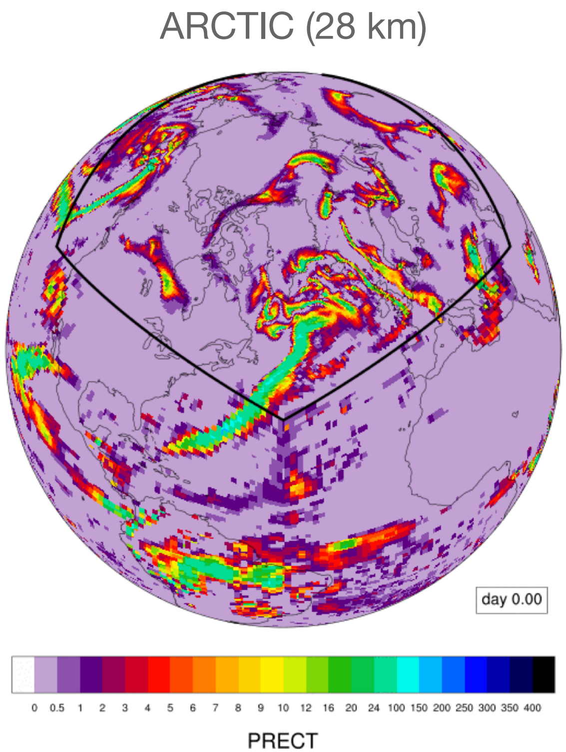
ne30 vr



- Yay on precip!
- BUT yet again with this stubborn low melt bias in N.E. Greenland … exists at all resolutions
- I'll be discussing some progress I've made on this issue in the vr-meeting

ARCTIC-VR (CESM2.2)





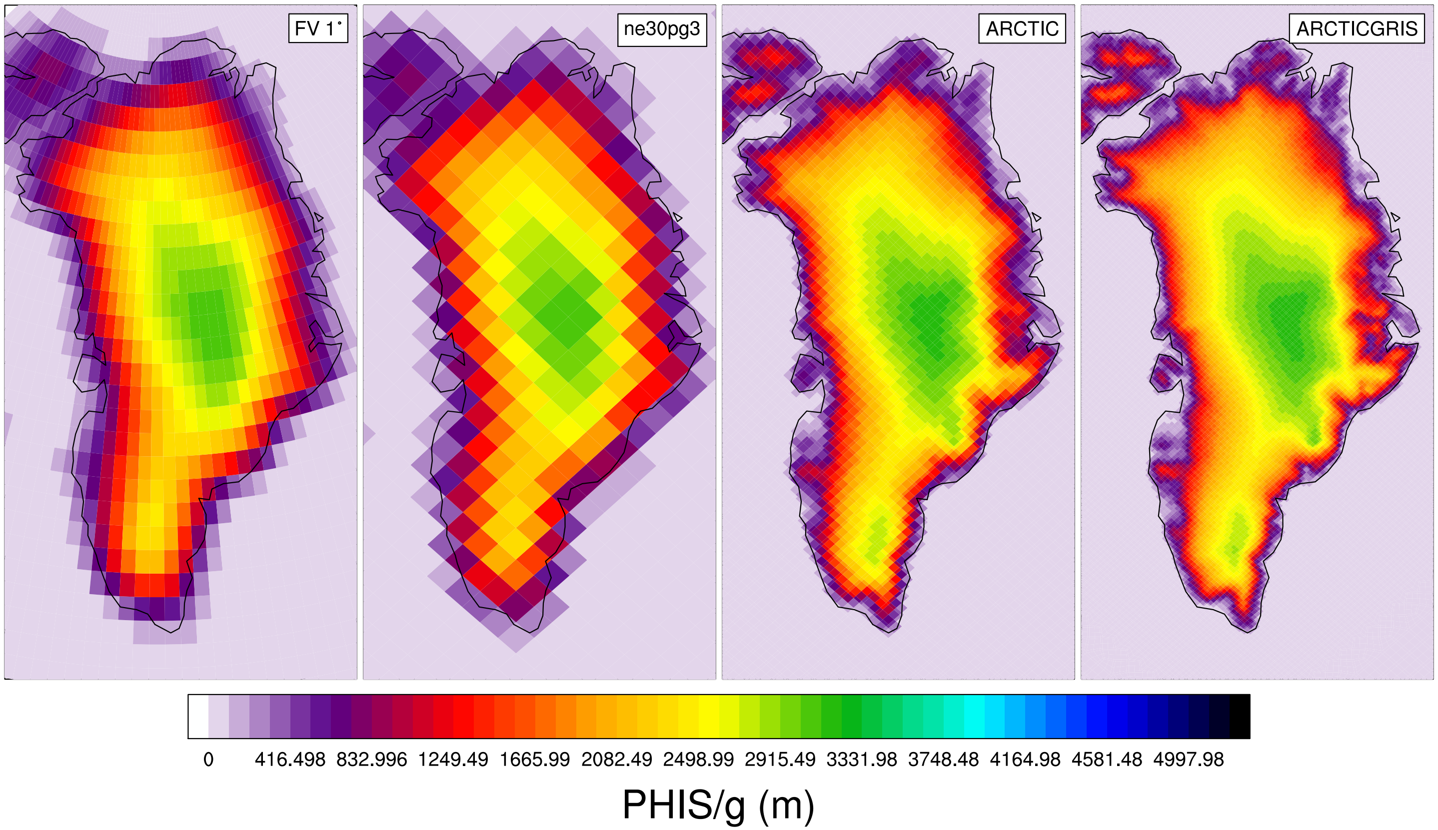
- Lots of enhancements to the spectral-element dycore!
- Variable-resolution (VR) topography
- Scale-aware tensor hyper-viscosity
- MG3 microphysics with improved ice phase

- **Substantial improvement in GrIS SMB over the standard 1° model** (van Kampenhout et al. 2019)
- **2-way coupling with CISM for comprehensive GrIS sea-level study** (come to vr-discussion to learn more)

Historical F-compset (data ocn) simulations

Similar to the experiments carried out in van Kampenhout et al. 2019, but using CAM6

Greenland Ice Sheet (GrIS) Topography



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Historical F-compset (data ocn) simulations

NARES STRAIT FLOW

Strong low-level winds are a common cold-season feature in Nares Strait, located between the high terrain of Greenland and Ellesmere Island (Samelson and Barbour 2008). The strong ageostrophic winds are due to orographic channeling down the pressure gradient between high pressure over the Arctic Ocean (Lincoln Sea) and low pressure over Baffin Bay. They may play a key role in generating the persistent winter North Water polynya in northern Baffin Bay. Samelson and Barbour (2008) modeled these winds with Polar MM5 (predecessor to Polar WRF) with a resolution of 6 km. Figure SB1 shows an example of these events that occurred on 9 February 2007 captured by the ASRv1 and ASRv2. The 15-km ASRv2 does a much better job resolving the orography of Nares Strait, and thus the winds are much stronger (>20 m s^{-1}) and more continuous than at the 30-km resolution (~15 m s^{-1}). The katabatic winds over Greenland feed into the wind flow at two locations in ASRv2. Notice the multiple centers in the low over Baffin Bay compared to the single center in ASRv1. The high over the Arctic Ocean is more clearly captured by the 15-km ASRv2. This case illustrates that topographically forced winds are much better captured by the finer resolution of ASRv2.

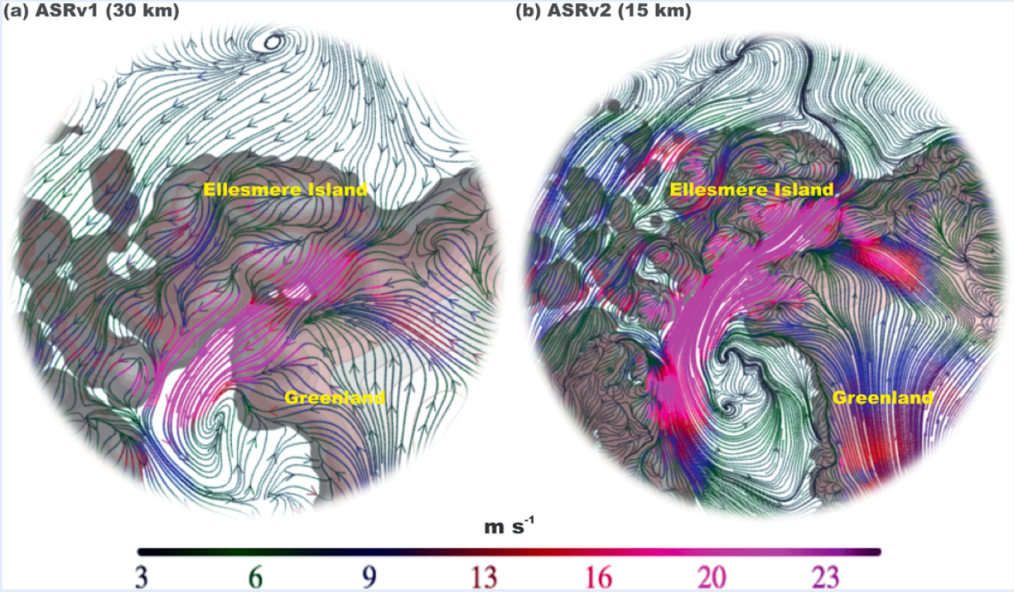
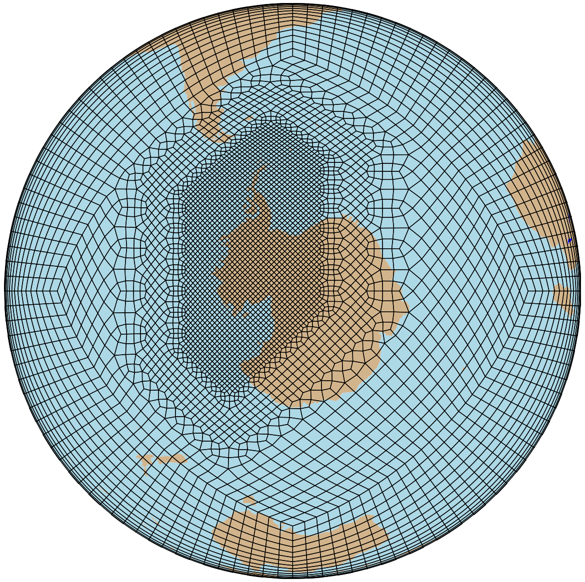


Fig. SB1. Streamlines and wind speeds (colors) at 10-m for an intense orographically channeled wind event in Nares Strait on 9 Feb 2007 as captured by (a) ASRv1 and (b) ASRv2.

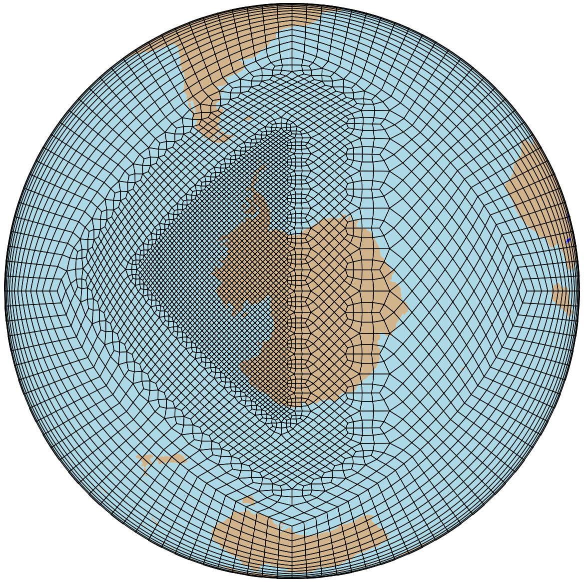
Bromwich et al. 2012, Arctic System Reanalysis

West Antarctic Grids

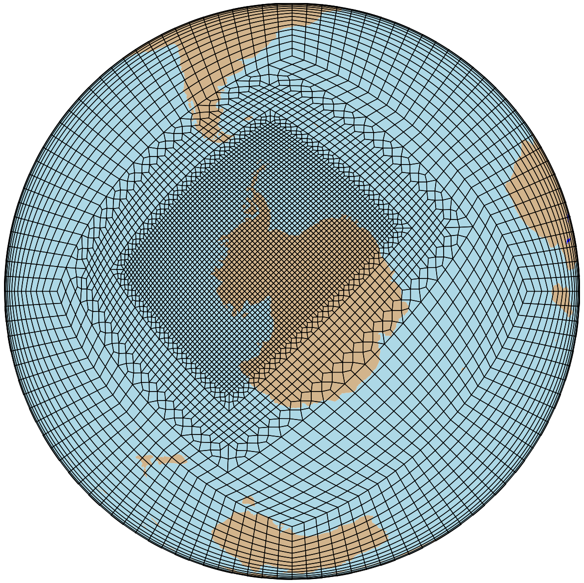
WAIS-S



WAIS-M



WAIS-L



What are the costs of all these grids?

Grids created for Jan Lenearts group

Model Costs

*Includes 6-hourly i/o

Grid	NCOLS	dt_dyn	Core hours p/ sim. yr.
NE30 (global 1 deg)	48602	300 s	2073
NE120 (global 1/4 deg)	777632	75 s	110000
WAIS-S	77024	75 s	10133
WAIS-M	78095	75 s	10091
WAIS-L	85430	75 s	11290
ARCTIC	117398	75 s	20000
ARCTICGRIS	152390	37.5 s	45000

What if you want your own variable resolution grid?

- For now, need to contact VR team at NCAR
- Making/Installing a new grid into CESM is not a trivial task
- We are working with software engineers to simplify the process
- The VR-toolkit is being developed to provide a user friendly means for CESM users to make/install their own grids, and will eventually become part of a release