Climate applications of VR-CESM: from glaciers to convection (using CAM-SE)

Annual CESM Workshop 2023

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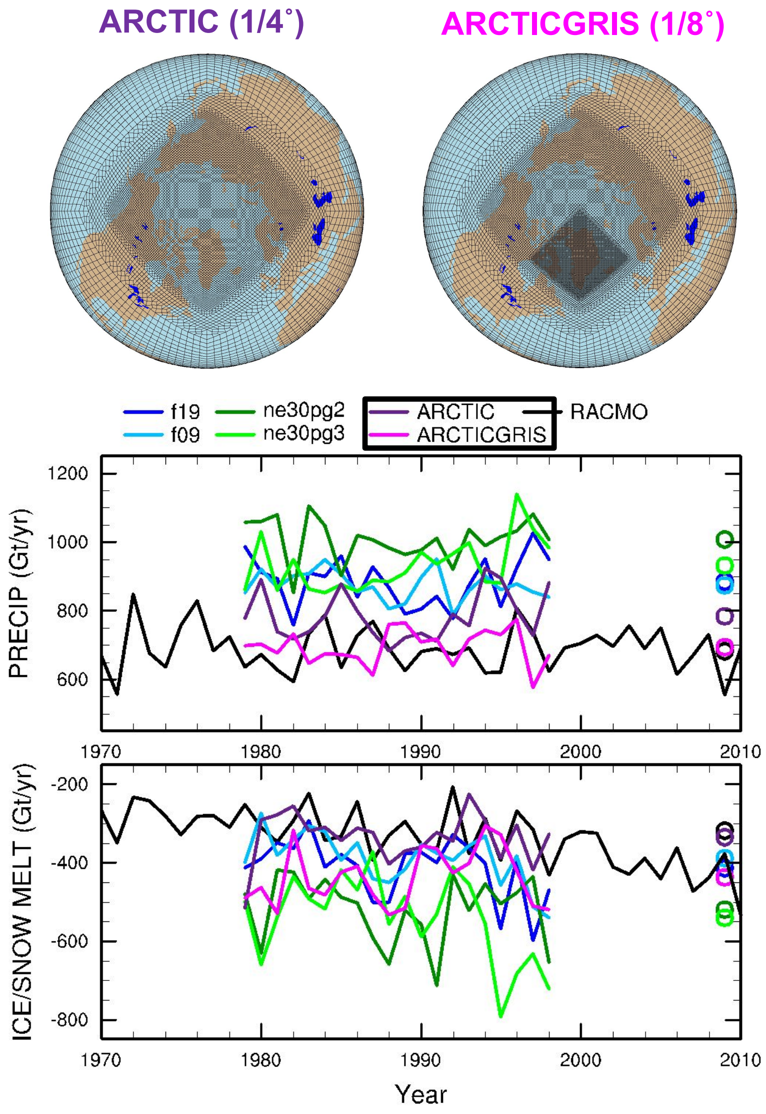
Greenland Surface Mass Balance: AMIP Experiments

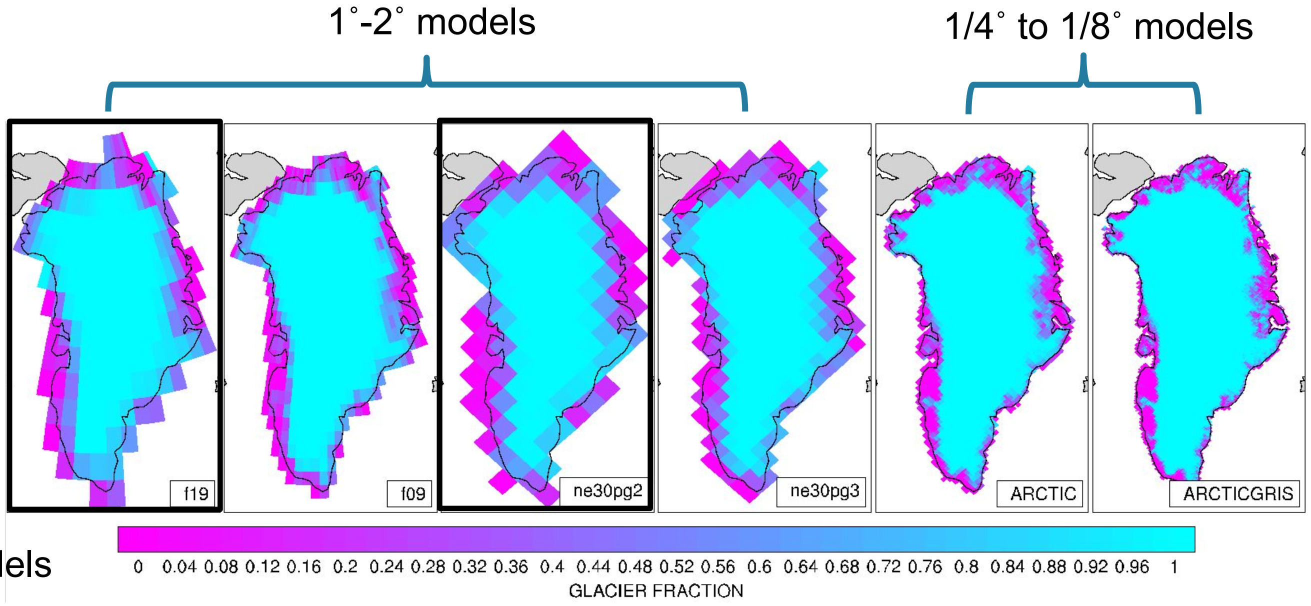
The Greenland Ice Sheet (GrIS) is an important component of the Earth System, but it is challenging to resolve at 1°

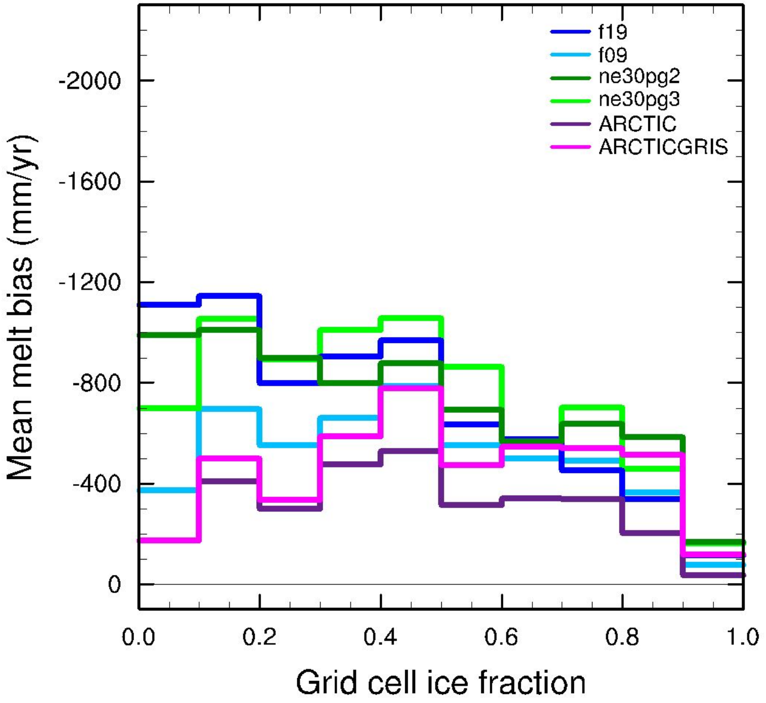
- Large improvements in simulated SMB at ¼° (van Kampenhout et al. 2019)
- Began supporting out-of-the-box functionality for two Arctic grids in CESM2.2 (Herrington et al. 2022)
- Coupled to POP2/CISM2 and run over idealized warming scenarios (Ziqi Yin's talk Wed. at 11am)

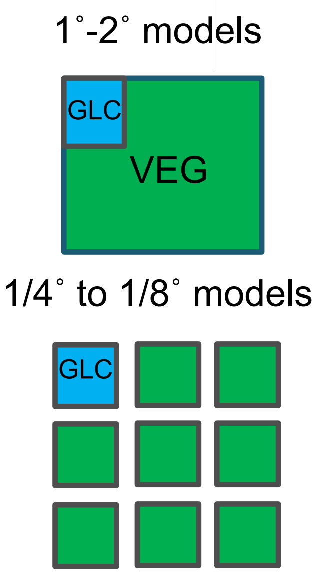


Problems with mixed land surface types: Greenland

- Map climo melt bias map in all grids, to the coarsest grids (f19/ne30pg2)
- Bin melt bias by grid cell ice fraction





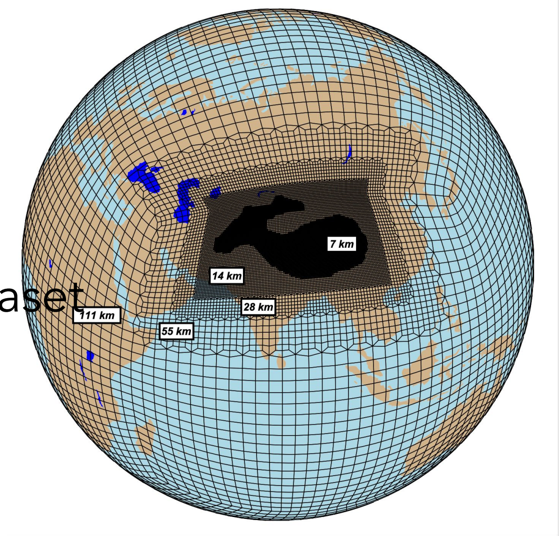


- Smaller grid cell ice fractions have larger (more negative) melt biases
- 1/4° and 1/8° alleviates this dependence of melt bias on ice fraction, because it largely resolves the ice margin

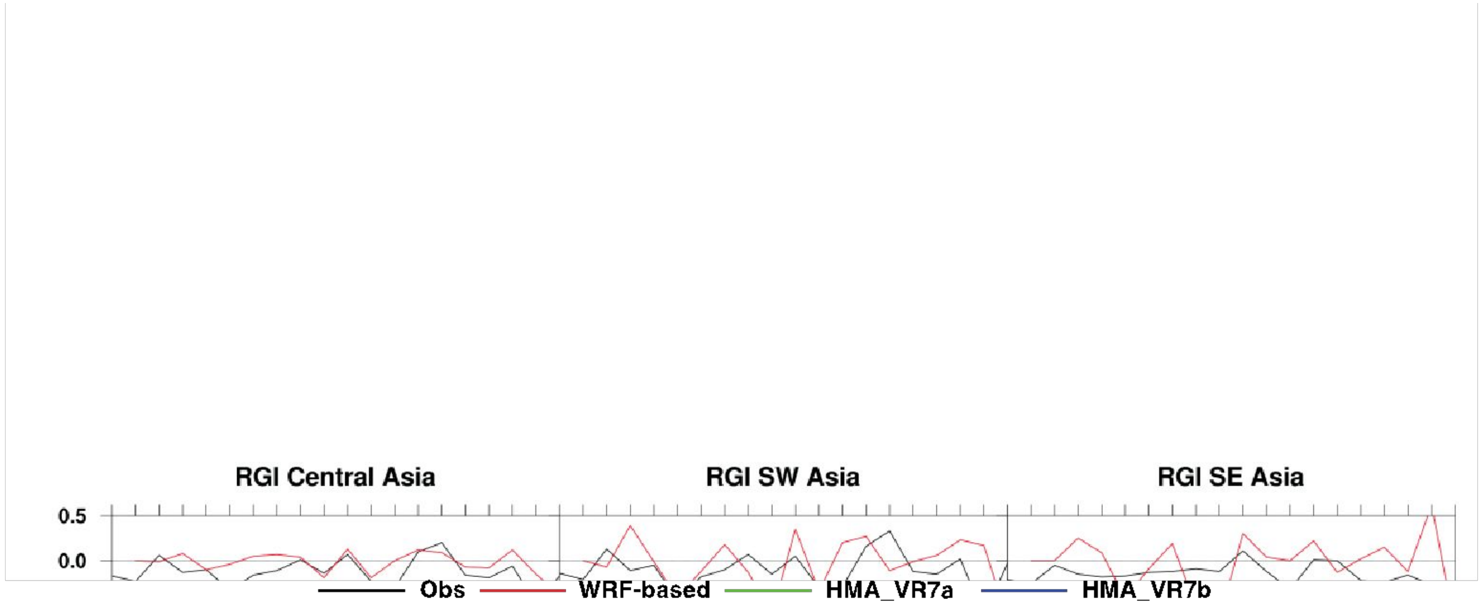
Simulating glacier SMB over High Mountain Asia (HMA)

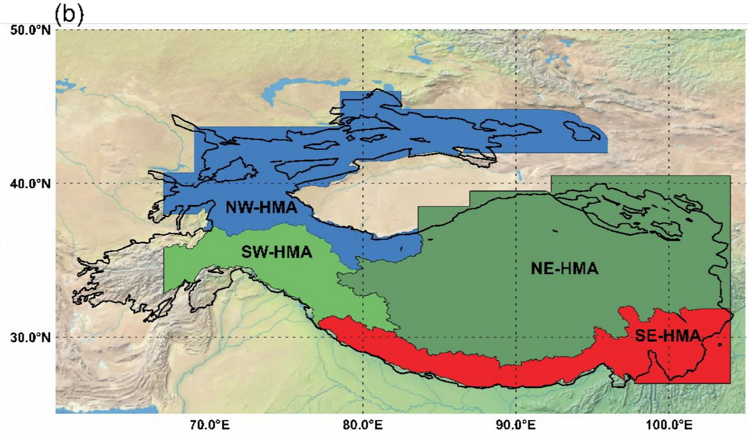
Two coupled land-atmosphere simulations for the period 1979-1998 (HMA_VR7a,b)

- The second simulation (HMA_VR7b) is performed with updated glacier-cover dataset and includes snow and glacier model modifications.
- SMB is underestimated compared to observations (black)
- In HMA_VR7b simulations (blue), SMB improves, but is still underestimated.

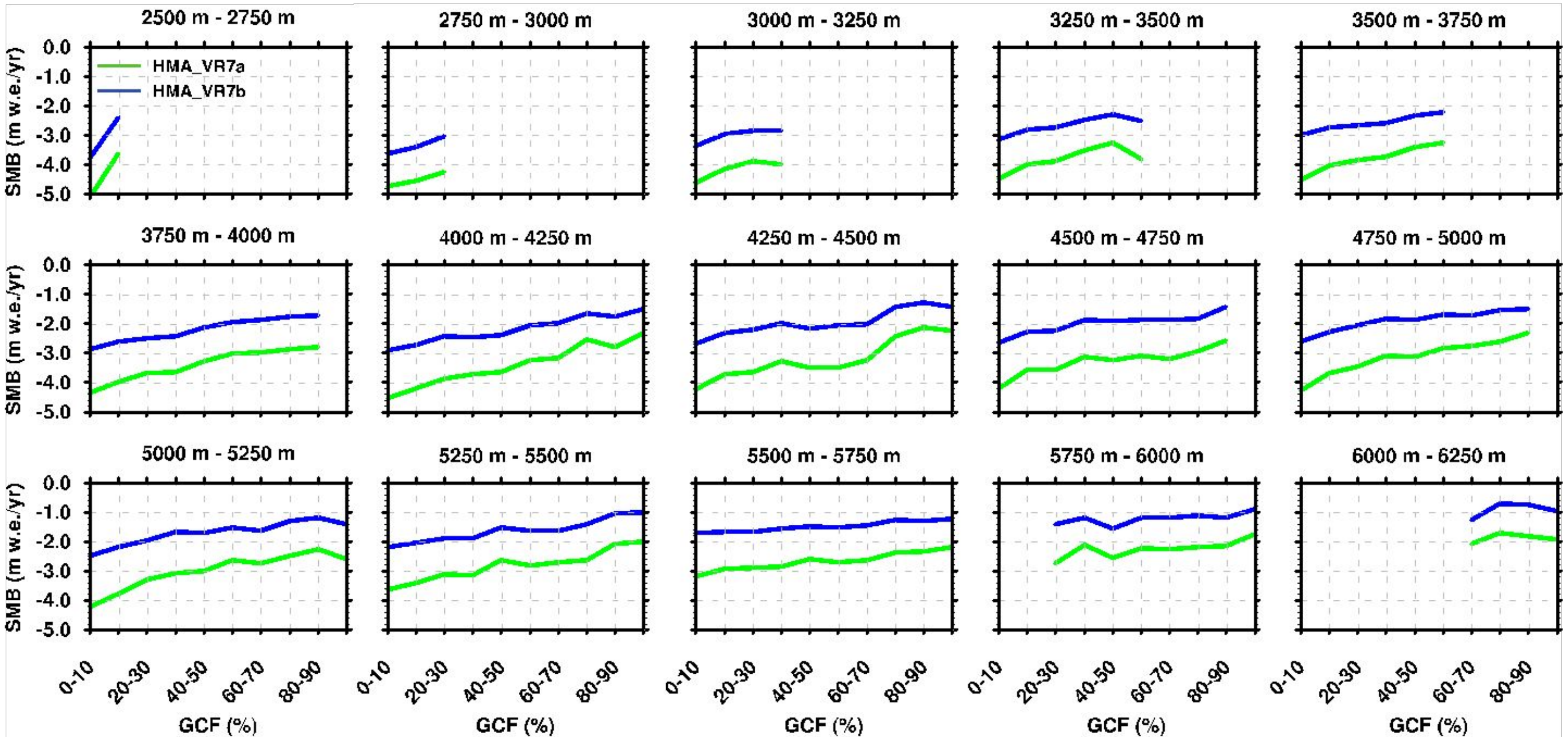


High Mountain Asia VR grid.
Regional refinement up to 7 km.
Model cost: ~90k p. sim. yr.

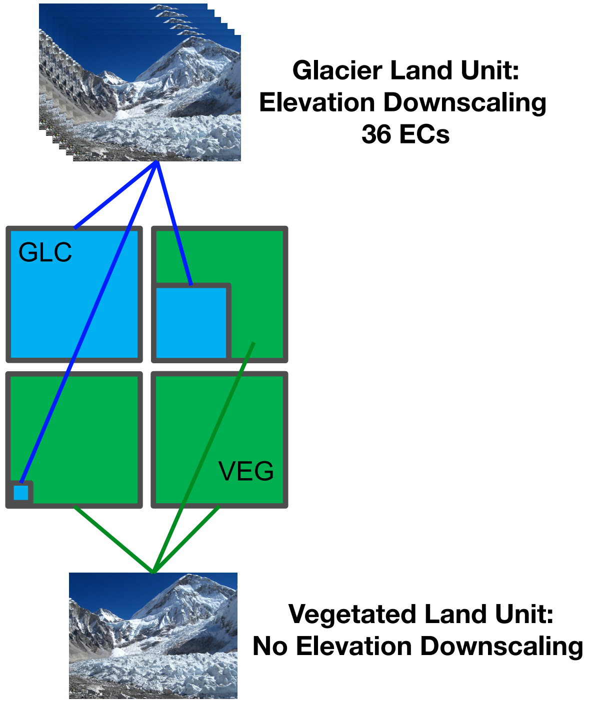




Simulating glacier SMB over High Mountain Asia



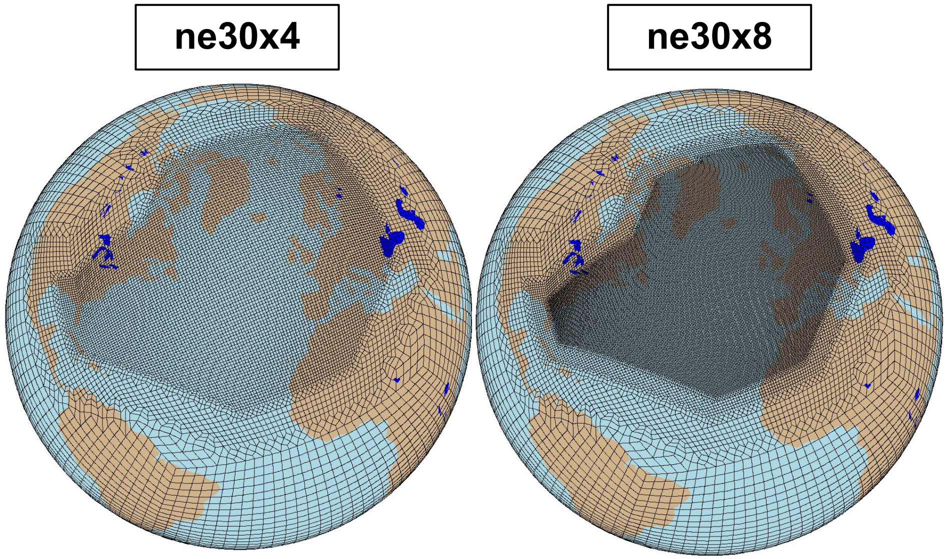
HMA CLM Land Surface + Elevation Downscaling



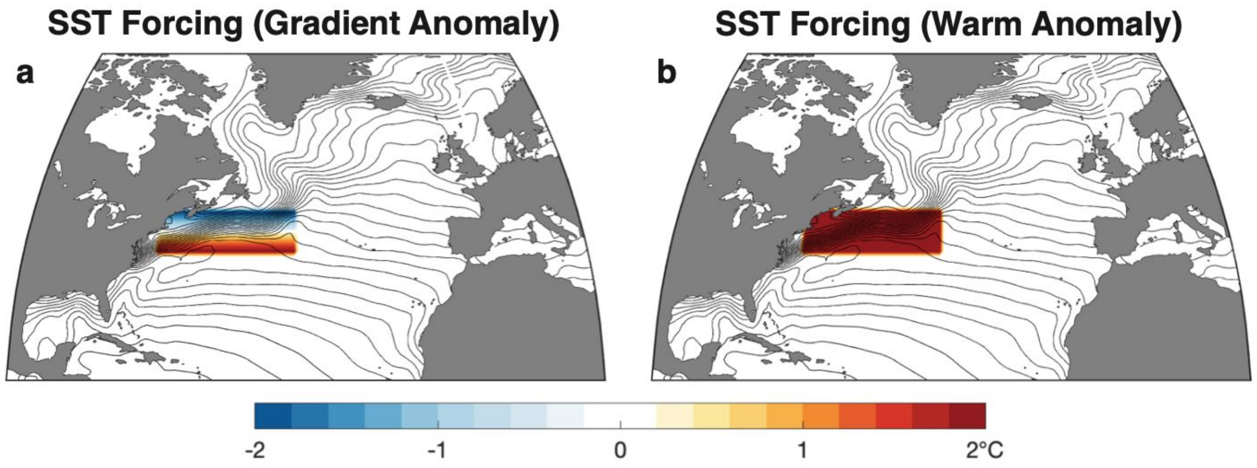
SMB declines with decreasing glacier fraction

- SMB bias partly due to homogeneous land-atmosphere coupling over mixed land surface types and partly due to exclusion of elevation downscaling over vegetation.
- Other explanations SMB bias: reduced cloud cover/warm summer temperature biases.

North Atlantic Grid (1/4° and 1/8°)

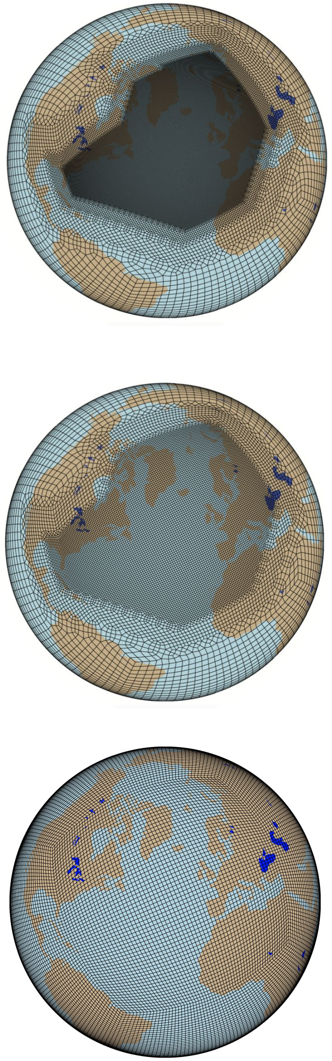


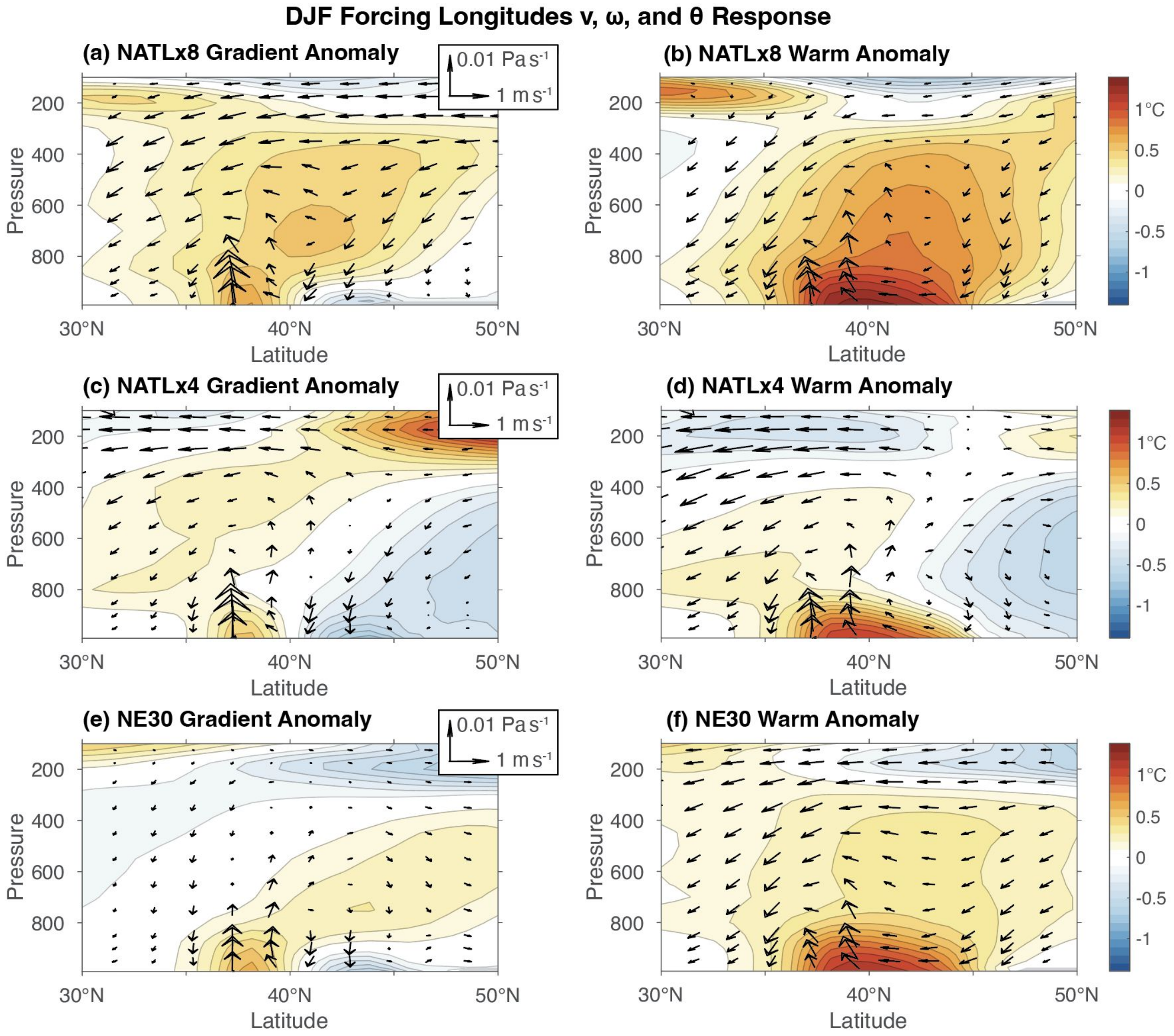
- Reference: Perpetual year 2000-like* seasonally varying (1° resolution) SSTs
  *1995-2005 climatology
- Experiments: Two different SST anomaly patterns in the Gulf Stream
- Each simulation run with the VR-NATL grid and with a 1° reference grid (NE30)



Results show averages over 30 years (VR) or 50 years (NE30)

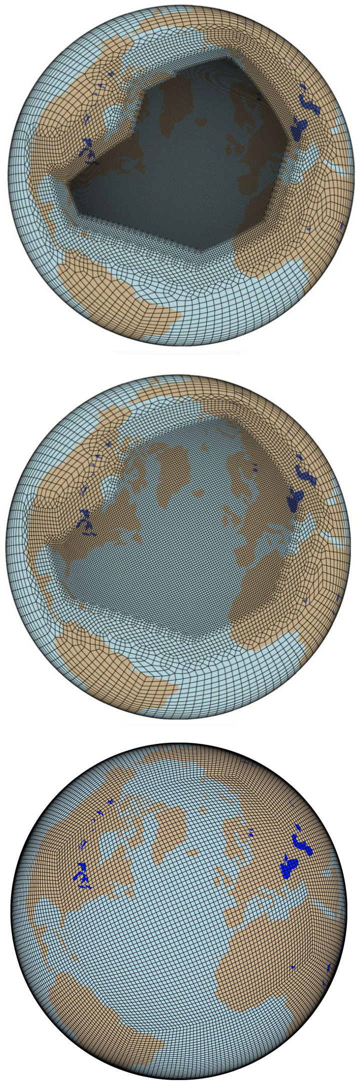
Deeper warm anomaly in forcing region only at 1/8°

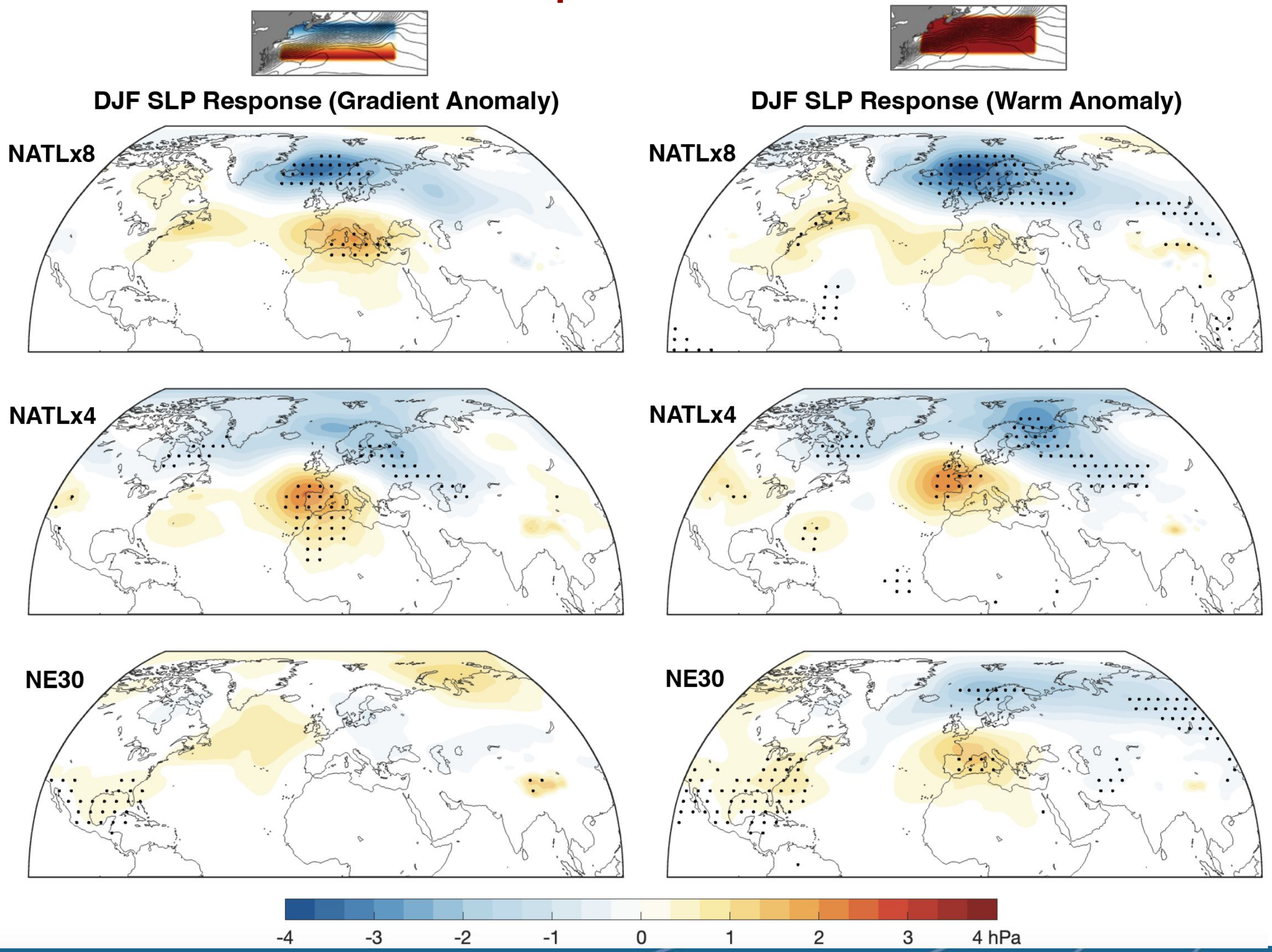




- Updrafts associated with cold-fronts are permitted at 1/4°, but updrafts in warm front aren't permitted occur until 1/8°
- Additional warm front ascent ➡ greater poleward eddy transport

NAO-like large-scale circulation response





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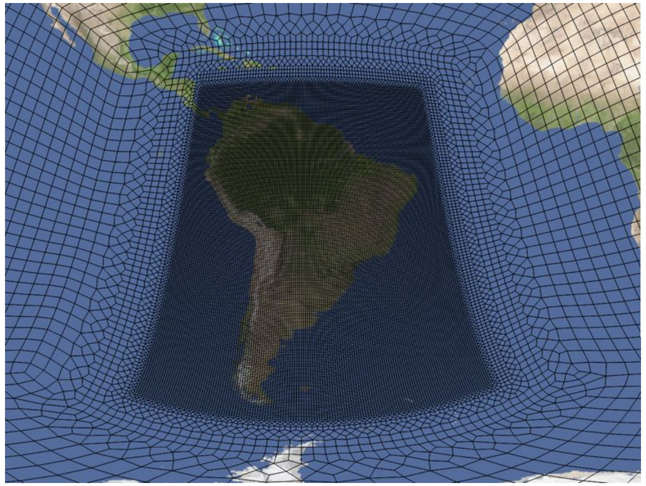
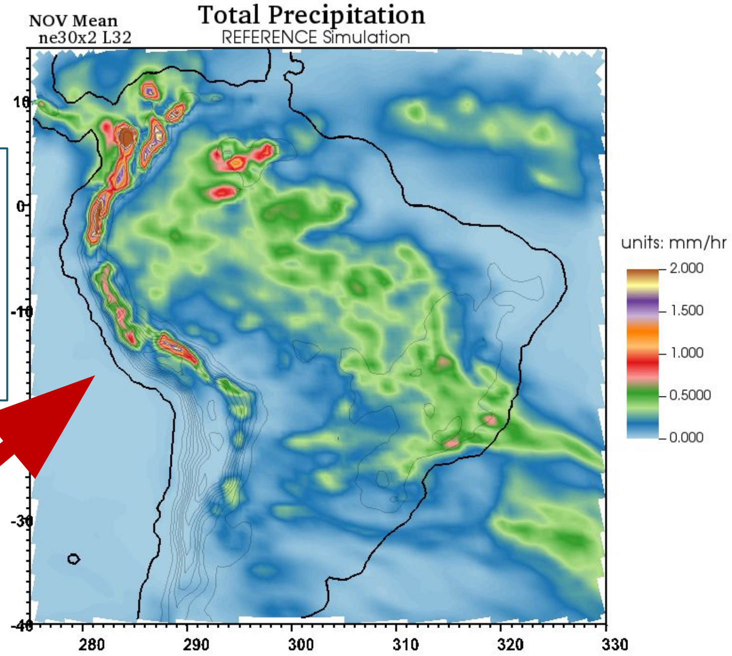
Stippling = significant at 90% confidence level as assessed by bootstrapping of internal variability

Variable Resolution: South American (SAM) Domain

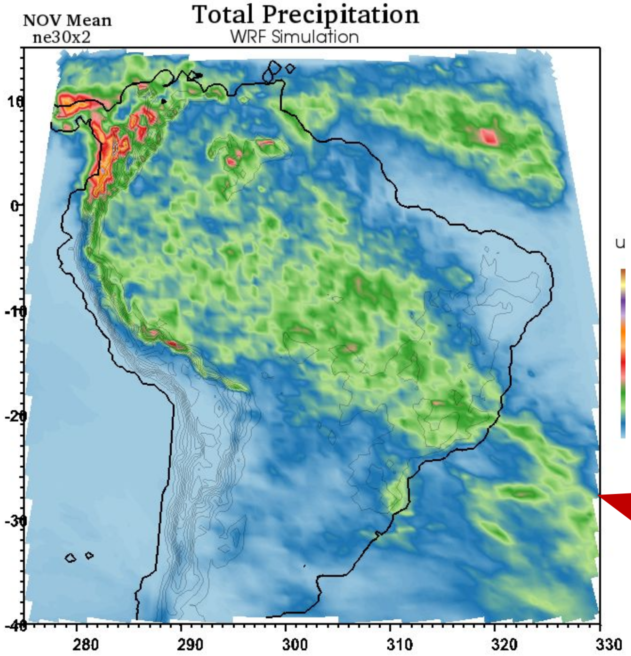


SE Refined resolution	Nominal Grid resolution	Horizontal Grid points
ne30	100km	48,602
ne60	50km	64,766
ne120	25km	116,534
ne240	12km	337,503
ne480	6km	1,167,113

<u>The Domain</u>:
A Hierarchy of grid resolutions coincident with a 4-km WRF domain

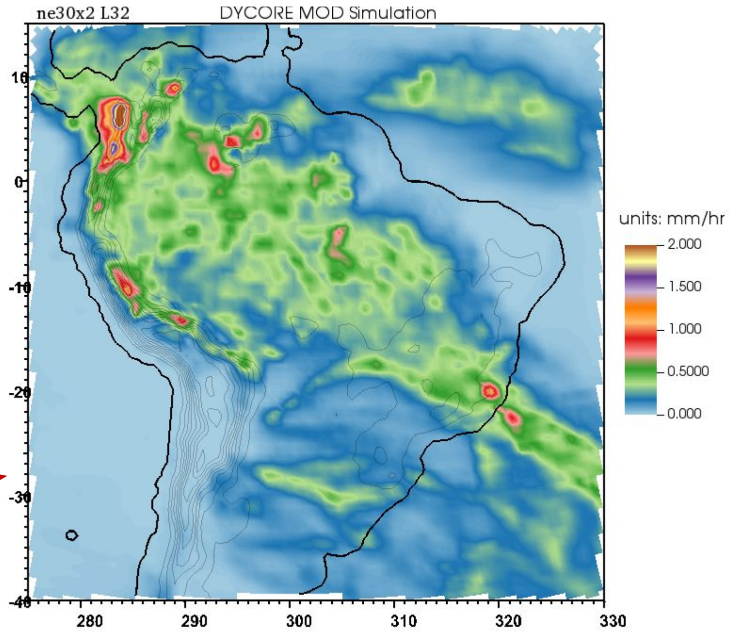


For the SE dycore, the erroneous precipitation over the Andes is caused by the applied hyper-viscosity damping.



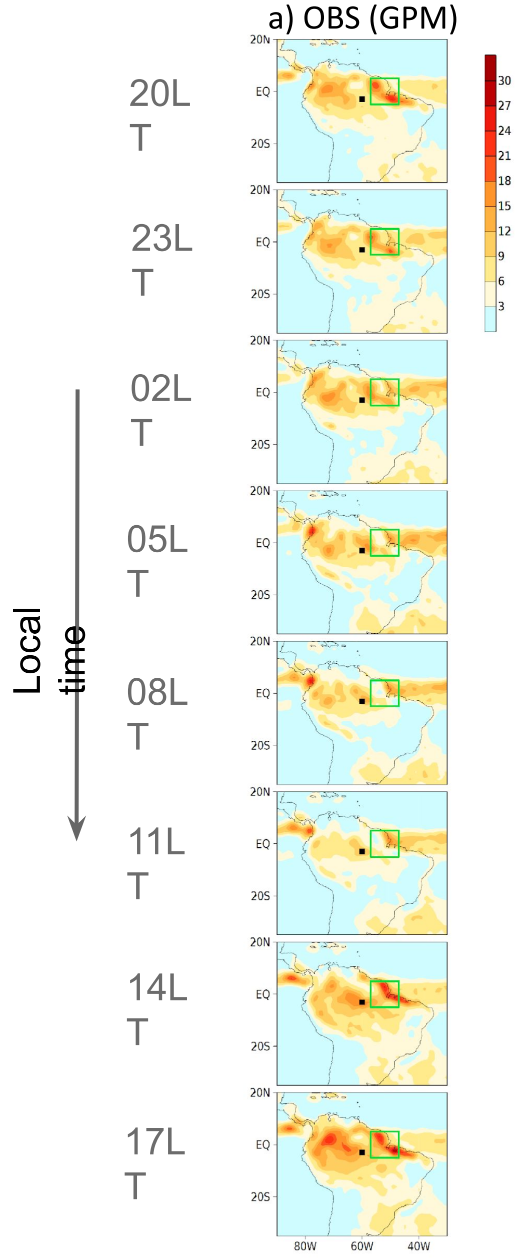
Replacing it with Conservative Damping consistent with terrain following model surfaces:

- The dry halo and heavy precipitation over the ridge has been eliminated.
- The precipitation better resembles the diurnal variations for upscaled WRF results.

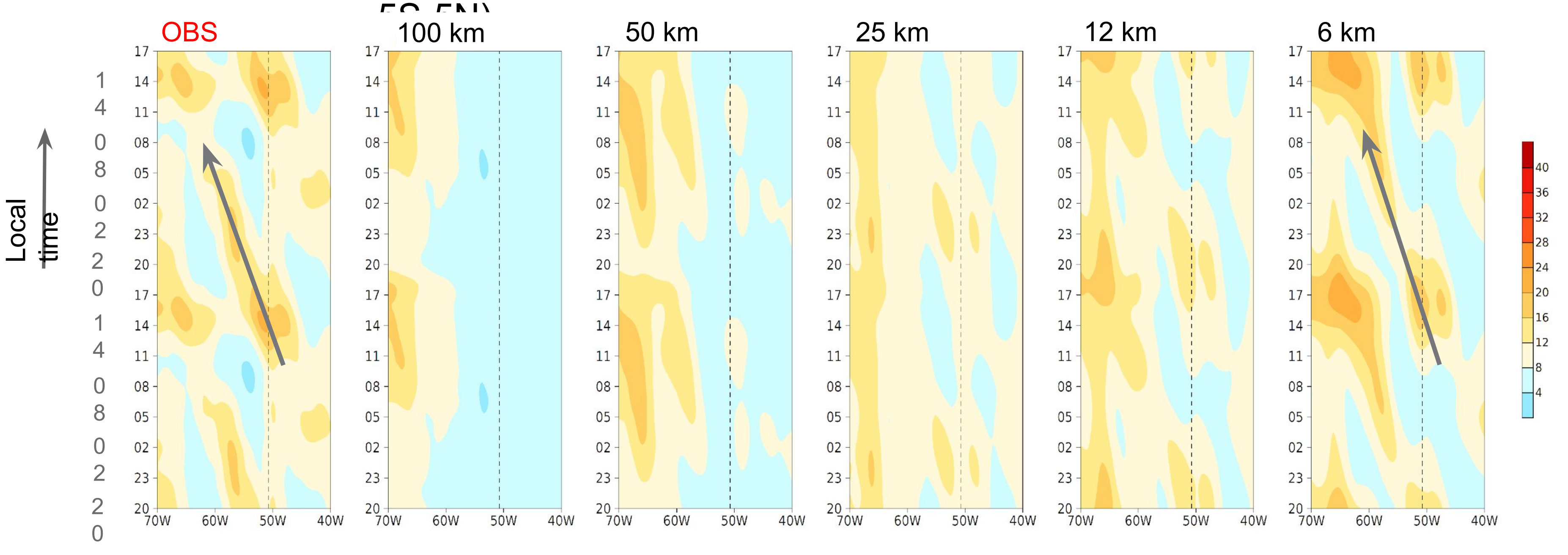


WRF CESM
NOV 2010 Mean for 50km resolution

Climatological diurnal cycle of rainfall in east Amazon (March-May)



The observed precipitation over the east Amazon is closely associated with diurnal westward propagation rainfall events, but is poorly simulated in CAM6 at 1˚



Resolved westward propagation of diurnal rainfall in high resolution runs, particularly in the 6 km experiment

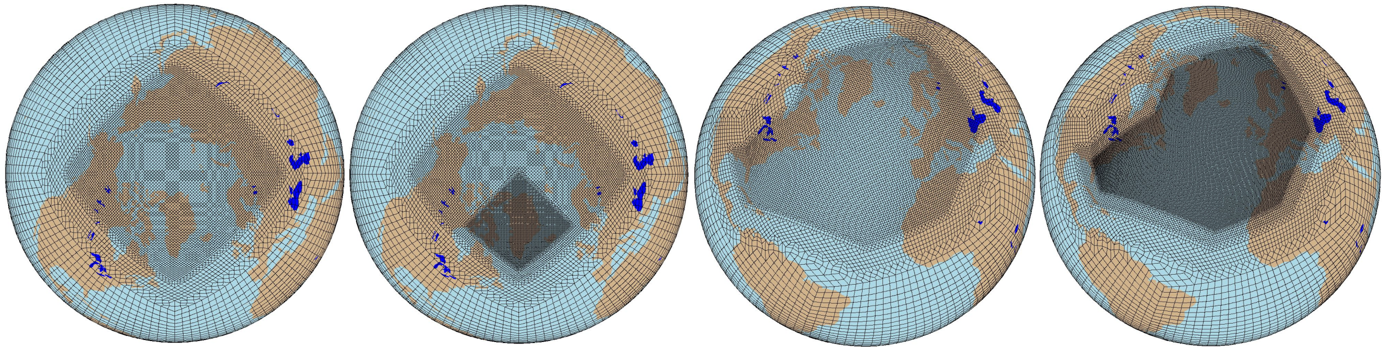
Variable-resolution CAM-SE milestones down to 7 km resolution

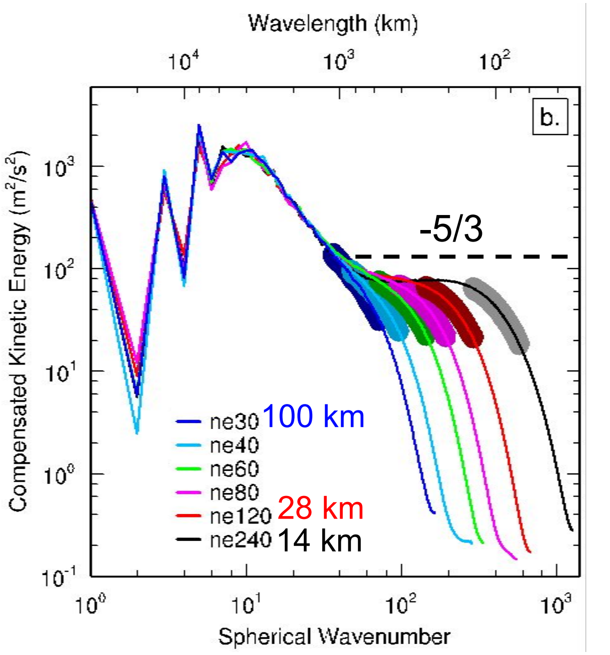
More realistic boundary conditions

- 28 km – Realistic **topography** and orographic precipitation (ice sheets and mountain ranges)
- 28 km – Realistic **land surface-type** (resolves ice sheet margins, but *not* mountain glaciers)
- 14 km – Realistic **surface emissions** for air-quality studies (concentrated sources over urban centers)

Permitting meso-scale motions and convection

- 28 km – **updraft** permitting – 'elements' of TCs, cold-fronts and precipitation extremes
- 14 km – **meso-scale** permitting – meso-scale ascent in warm fronts
- 7 km – **convection** permitting – propagating MCSs and the diurnal cycle over land





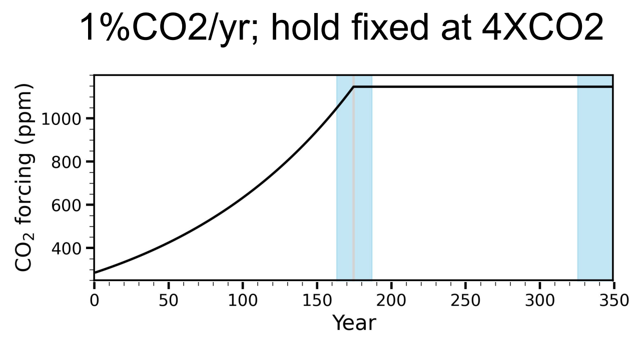
14 km CAM-SE resolves a significant chunk of the meso-scale spectrum

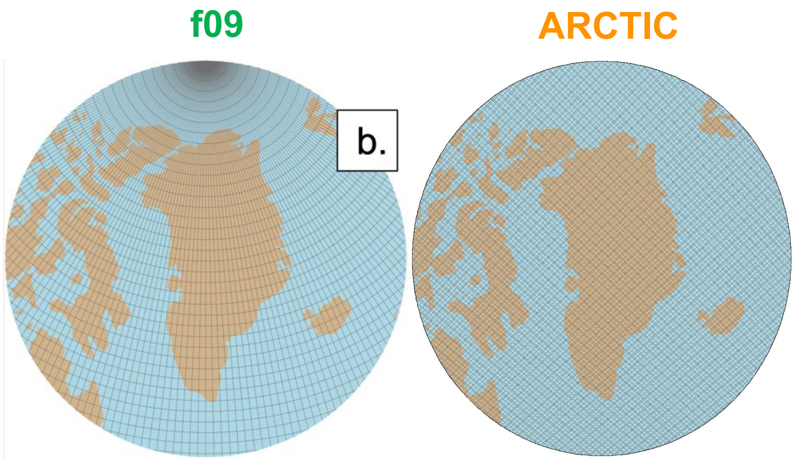
ARCTIC ¼˚ VR grid: Idealized Warming Experiment

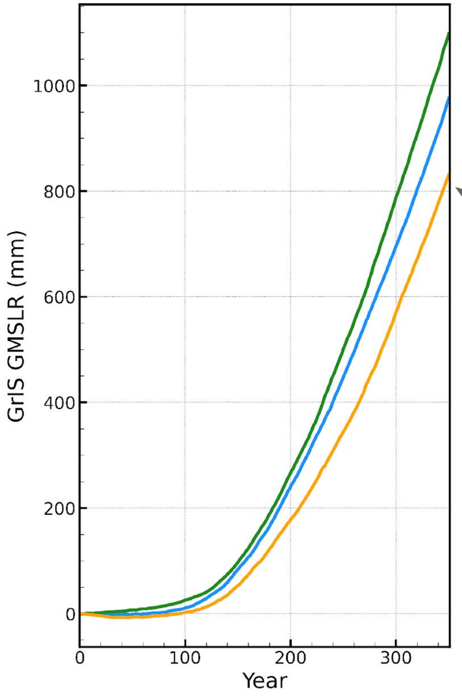
Here, we couple the **ARCTIC** grid to POP2/CISM2, re-tune the model and test:

Is the GrIS *response* different between 1˚ (f09) and 1/4˚ (ARCTIC)?

- **f09** – CESM2.1-CMIP6*
- **f09** – CESM2.1-no hacks**
- **ARCTIC** – CESM2.2

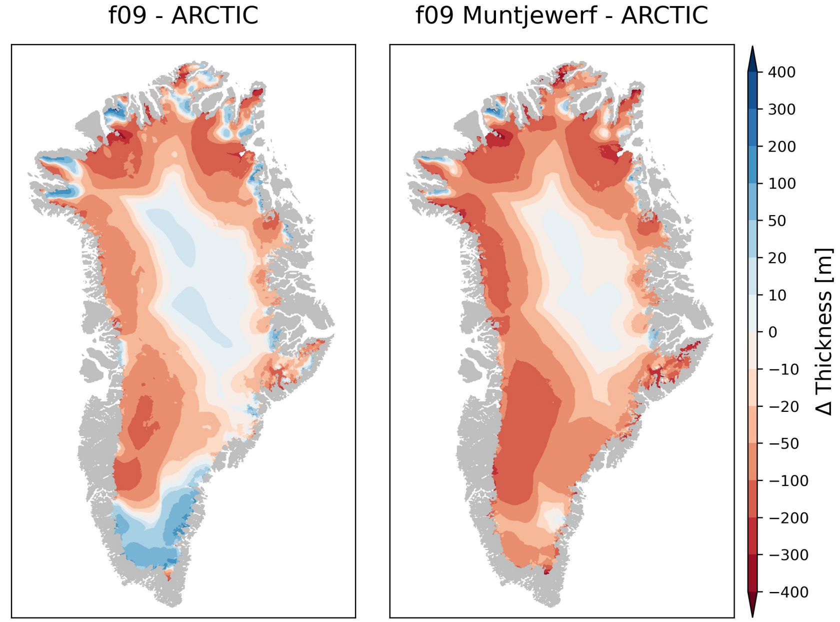






GrIS sea level contribution in the experiments

ARCTIC exhibits a smaller increase in melting, which primarily explains its lower mass loss and sea level rise.



Errors (i.e., 1˚ minus ¼˚) in ice thickness change after 350 years. The 1˚ model melts too much at the ice margins, and this thickness change propagates into the interior via changes in ice flow.

* Muntjewerf et al. 2020
** removes the hacks in CMIP6 runs that reduce GrIS precip biases in f09