Exploring High Mountain Asia with VR-CESM

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IRREVERSIBLE CLIMATE CHANGE RESEARCH CENTER

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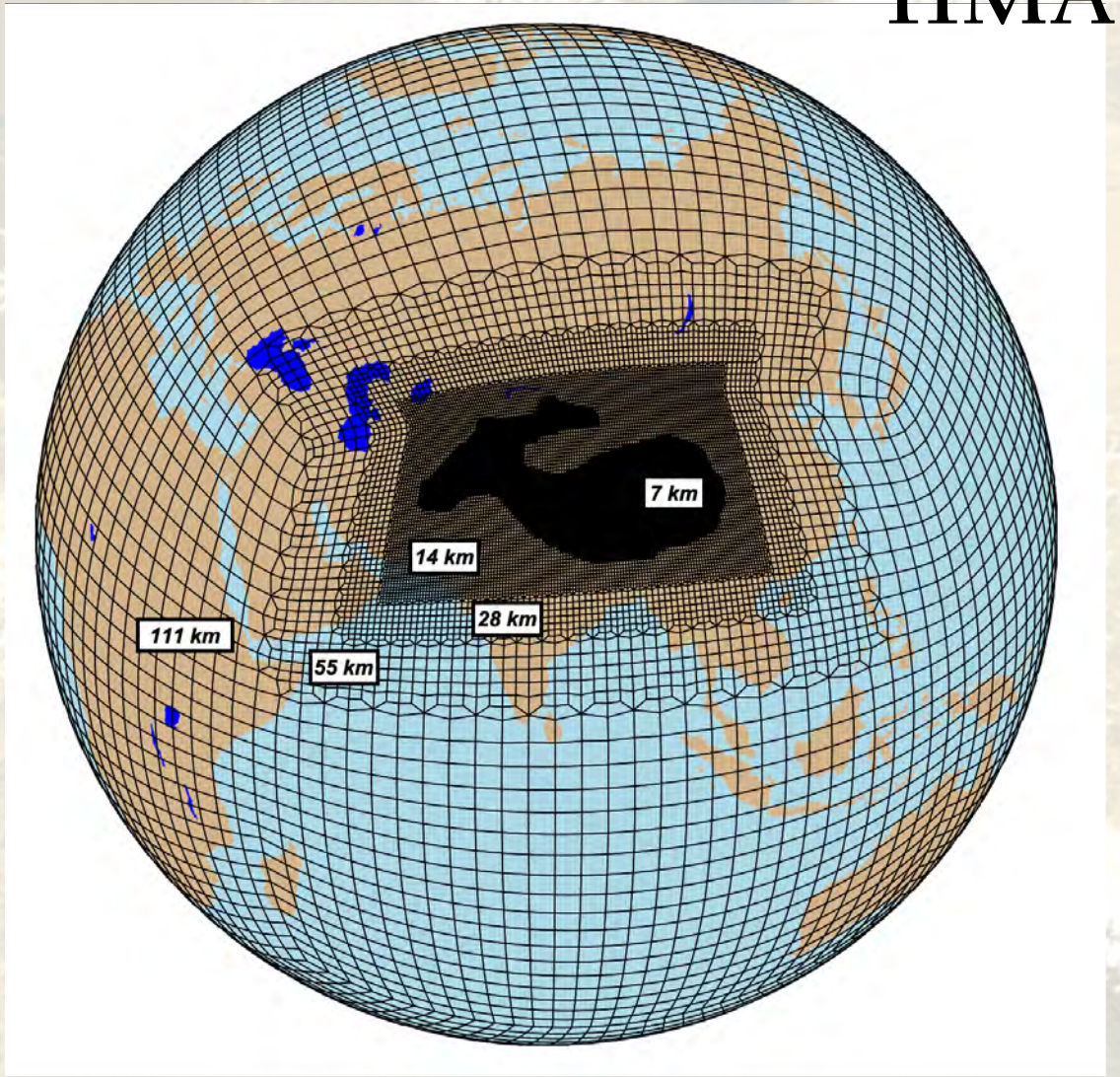
HMA-VR7



Model Setup:

- CESM2 with active atmosphere and land surface components + prescribed sea-ice and SST (AMIP config)
- CAM6-SE + CLM5+diagnostic CISM
- Elevation class (EC) downscaling scheme (Lipscomb et al., 2013) over glacier land units → 36 (200m) ECs (up to 10 000 m altitude)

HMA-VR7 grid time stepping & performance:

- CAM physics (dynamics) time step: 225s (18.75s).
- Model cost: ~90,000 core hours per simulated year.
- Model throughput: ~0.3 simulated years per actual day (~1600 CPU, NCAR Cheyenne) → 10 years/actual month

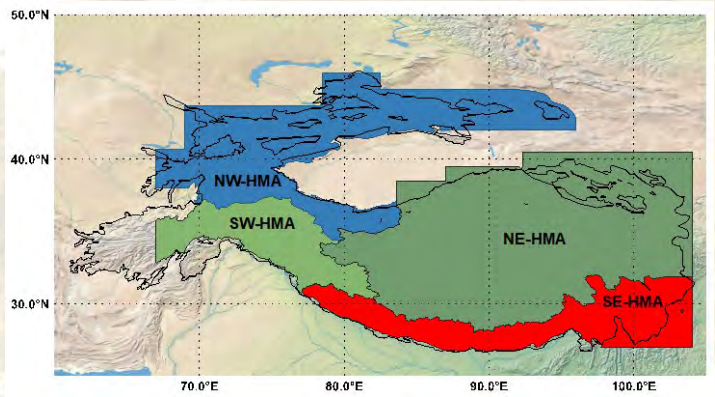
Model Simulations

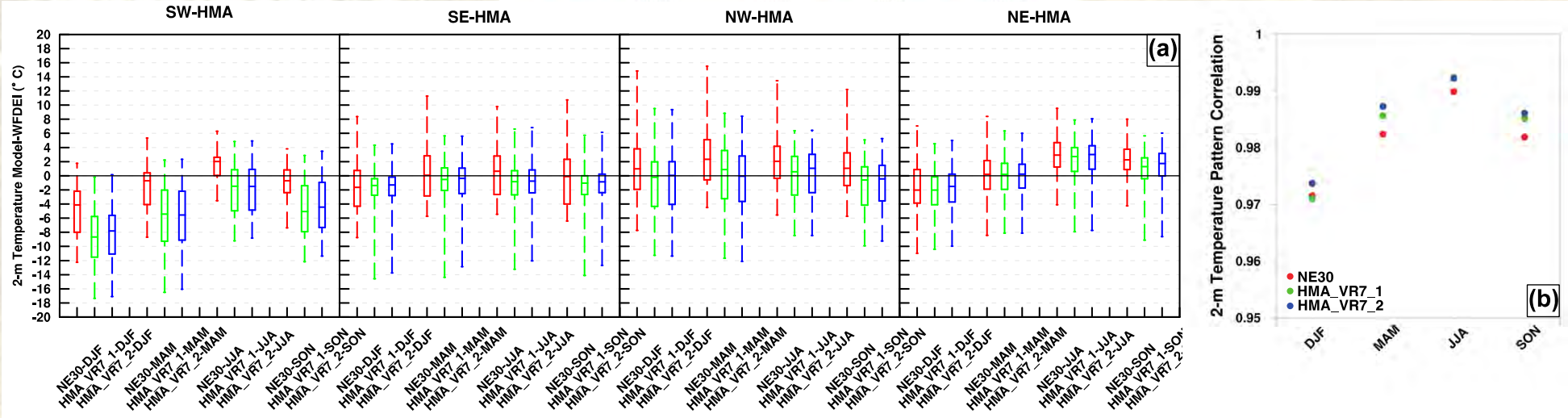
Simulation 1 (HMA-VR7_1):	Simulation 2 (HMA-VR7_2):
Spinup: 1 year	10 years atmospheric component + 50 years land surface component
Maximum snow depth: 1 m w.e. (default CESM1)	Maximum snow depth: 5 m w.e.
0.5 (0.3) for visible (nir) ice albedo (default CESM2)	0.6 (0.4) for visible (nir) ice albedo (default CESM1)
Longwave downscaling	No longwave downscaling
Rain/snow repartitioning: -2 °C (snow)/ +2 °C (rain)	Rain/snow repartitioning: 0 °C (snow)/ +4 °C (rain)
	Tunings on cloud cover and sea ice (incl. MG3 cloud microphysics)
	Updated glacier cover dataset

Outputs 20 years simulation runs (1979/1980-1998) evaluated by comparing with:

- Gridded outputs derived from globally uniform 1° SE grids.
- Reanalysis- and satellite derived products:
  - Watch Forcing Data ERA-Interim (WFDEI, 1980-1998, Weedon et al., 2014) → 2mT, PR
  - JRA55 (1980-1998): Snow Depth
  - MODIS, 2001-2010, Hall & Riggs, 2015): Snow Cover
  - ERA5 (1980-1998): Geopotential Height, Air Temperature
- RCM-based outcomes:
  - WRF based glacier SMB (1980-1998, de Kok et al., 2020)

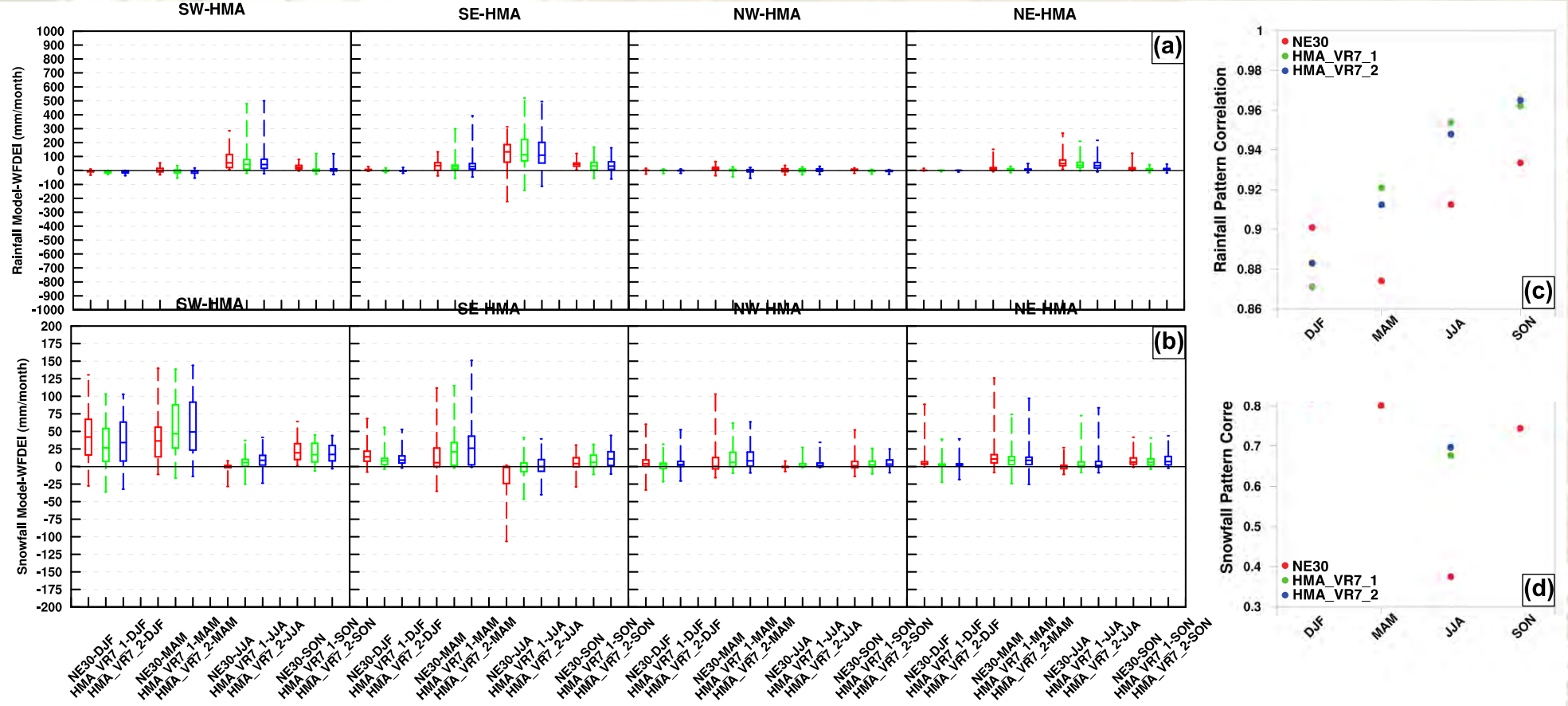
Results: 2m Temperature (TSA)





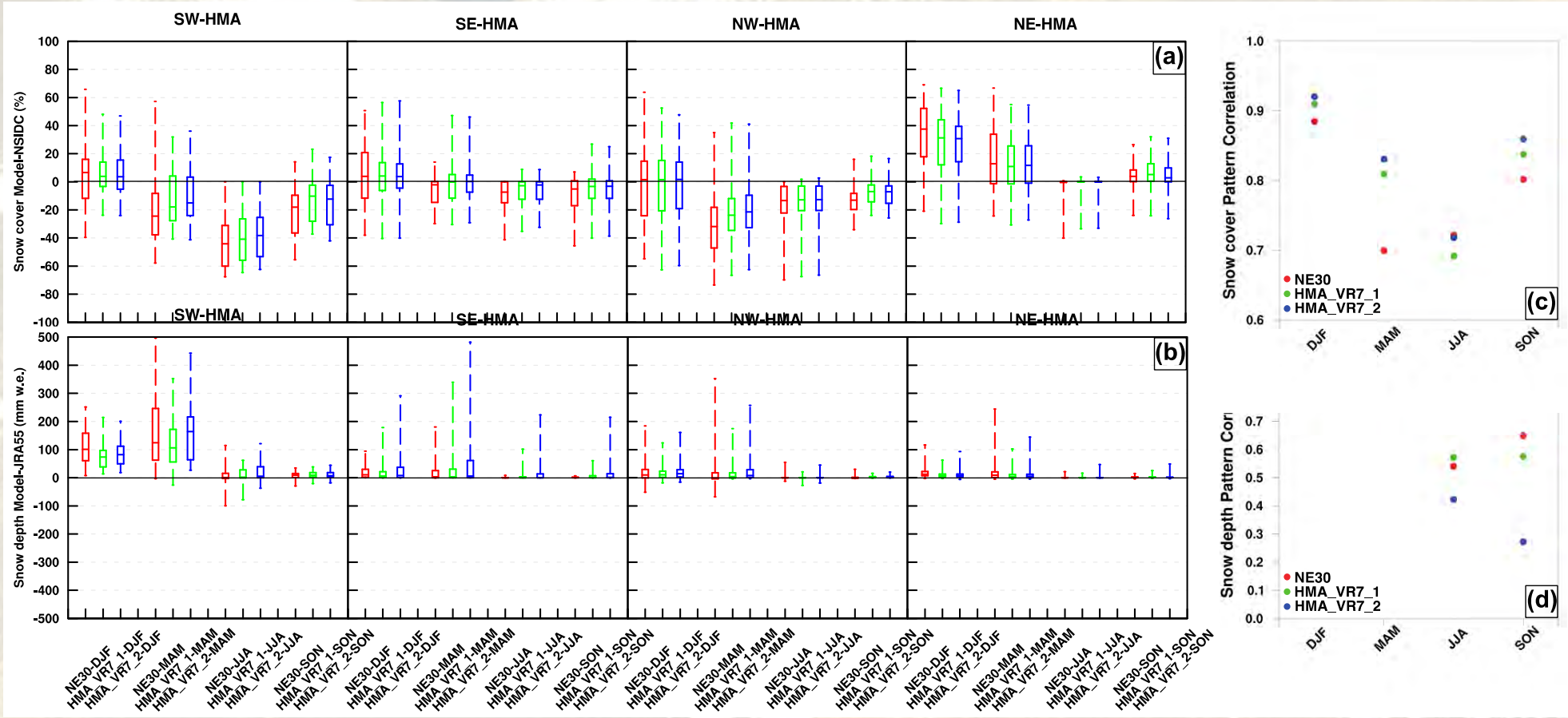
- Warm biases during JJA over Central Asian RGI regions 3 and 4 (i.e., including the Tibetan Plateau). Warm biases becomes generally smaller with increasing resolution.
- In contrast, during DJF, MAM, and SON cold biases over RGI region 1 (i.e., Karakoram and Hindu Kush) become larger with increasing resolution.

Results: Rainfall (RAIN) & Snowfall (SNOW)



- Rainfall is overestimated in RGI region 2 (i.e., monsoon-dominated region) during JJA (i.e., monsoon season). The bias is largest for HMA-VR7, followed by NE30.
- Snowfall is mainly overestimated in RGI region 1 during DJF and MAM --> most likely linked to the cold bias and changed rain/snow repartitioning in HMA-VR7_2. Snowfall bias is largest for HMA-VR7_2 followed by HMA-VR7_1 and the globally uniform SE grids.

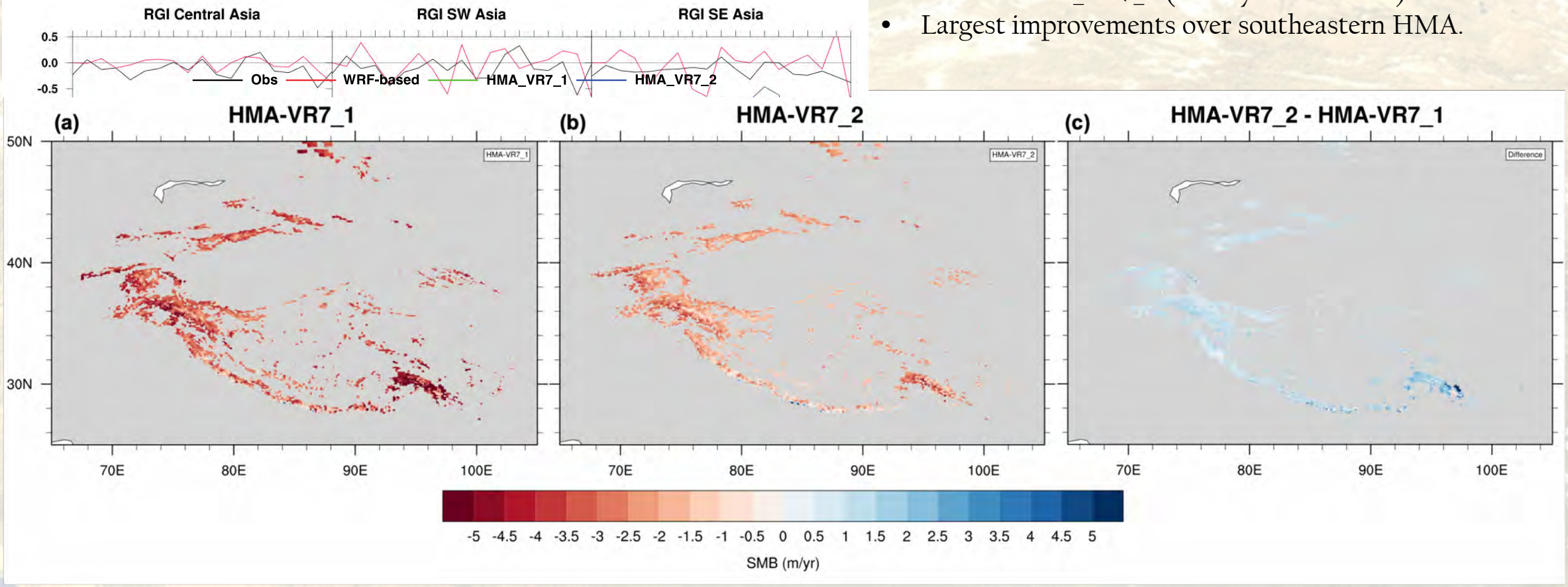
Results: Snow Cover (FSNO) and Snow Depth (H2OSNO)



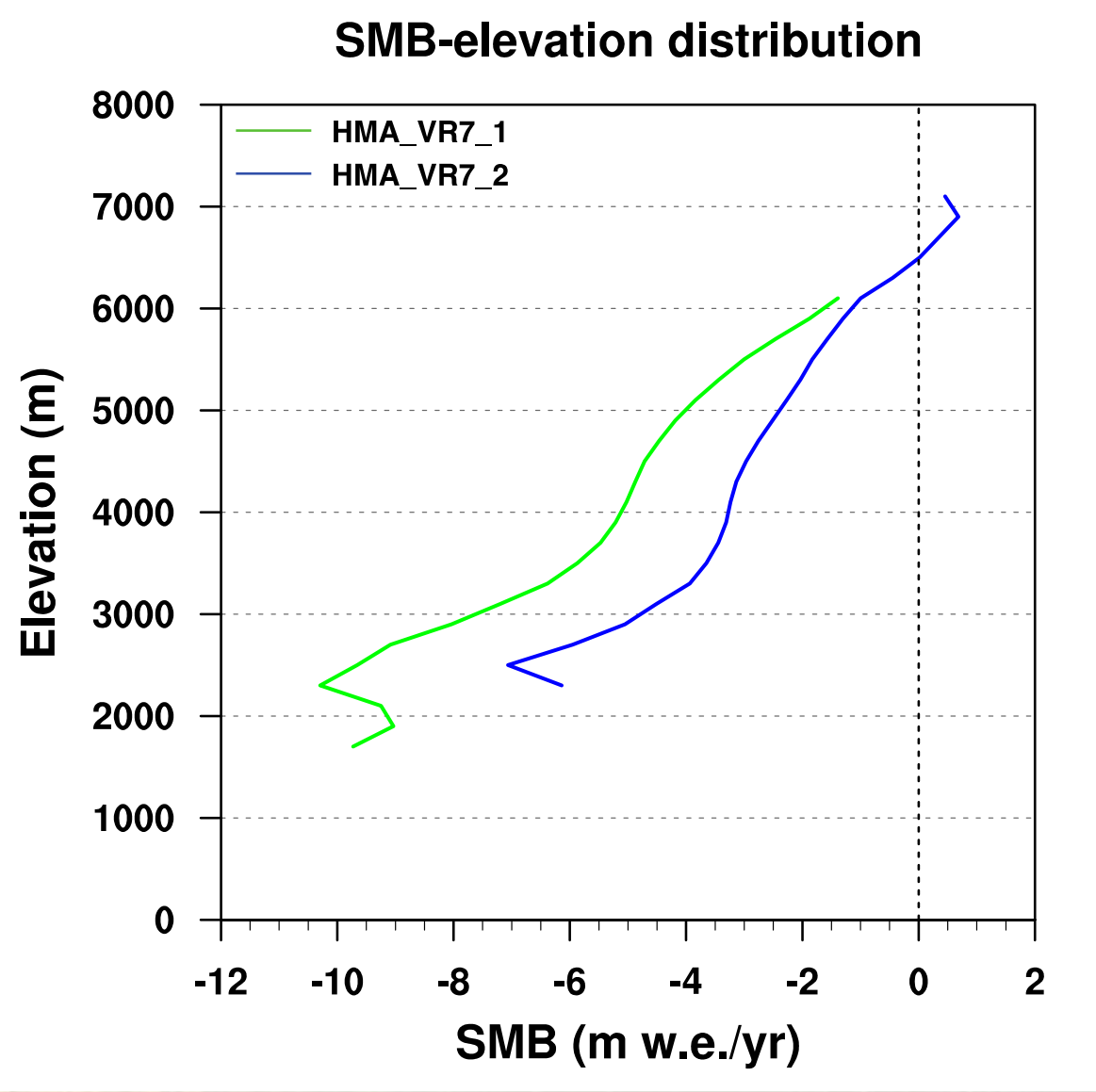
- Snow cover is overestimated (slightly underestimated) during winter (summer). The HMA-VR7 simulations show some improvement compared to NE30. The simulated snow cover shows the best match with satellite-based observations during autumn.
- Compared to JRA55, the snow depth is mainly overestimated in RGI region 1 → partly attributable to the cold bias and snow model modifications in HMA-VR7_2 (e.g., higher maximum snow depth and changed rain/snow repartitioning).

Results: Glaciological SMB

- SMB HMA_VR7 underestimated compared to OBS/RCM-based outcomes
- SMB HMA_VR7_2 significantly improved compared to SMB HMA_VR7_1.
- Number of grid cells where a positive SMB is simulated at the end of a run triples from 105 for HMA_VR7_1 to 299 for HMA_VR7_2 (mainly in the south).
- Largest improvements over southeastern HMA.



Results: Glaciological SMB



Discussion

The negative SMB bias can most likely be attributed to several factors:

- Cloud cover bias + Warm temperature bias over Central Asia, particularly over the Tibetan Plateau. → A potential olution: Nudging CAM with ERA-Interim/ERA5

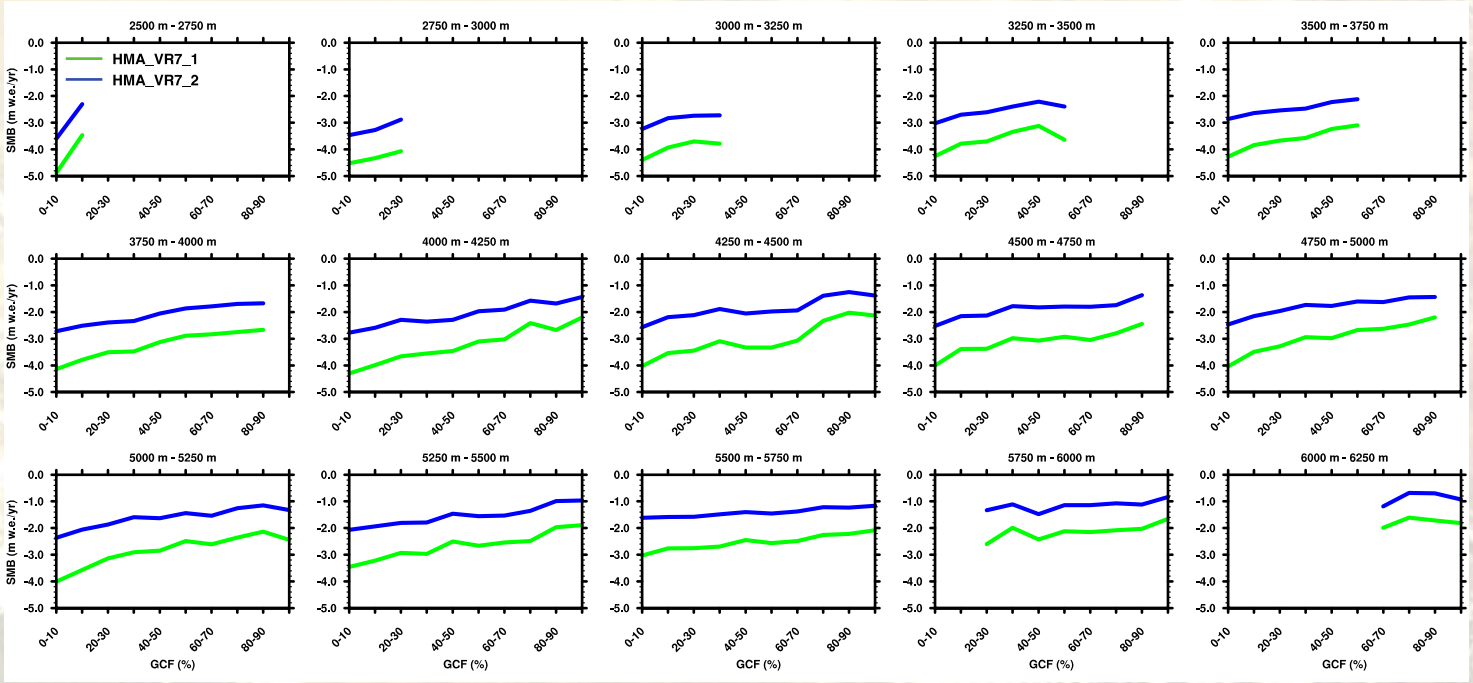
- Missing physics:

-Solar radiation downscaling (i.e., taking into account hillslope aspect and orientation, e.g. Swenson et al., 2019).

- Precipitation downscaling (e.g., elevation ratio weighted method (EWRM), Tesfa et al., 2020).

- Debris cover.

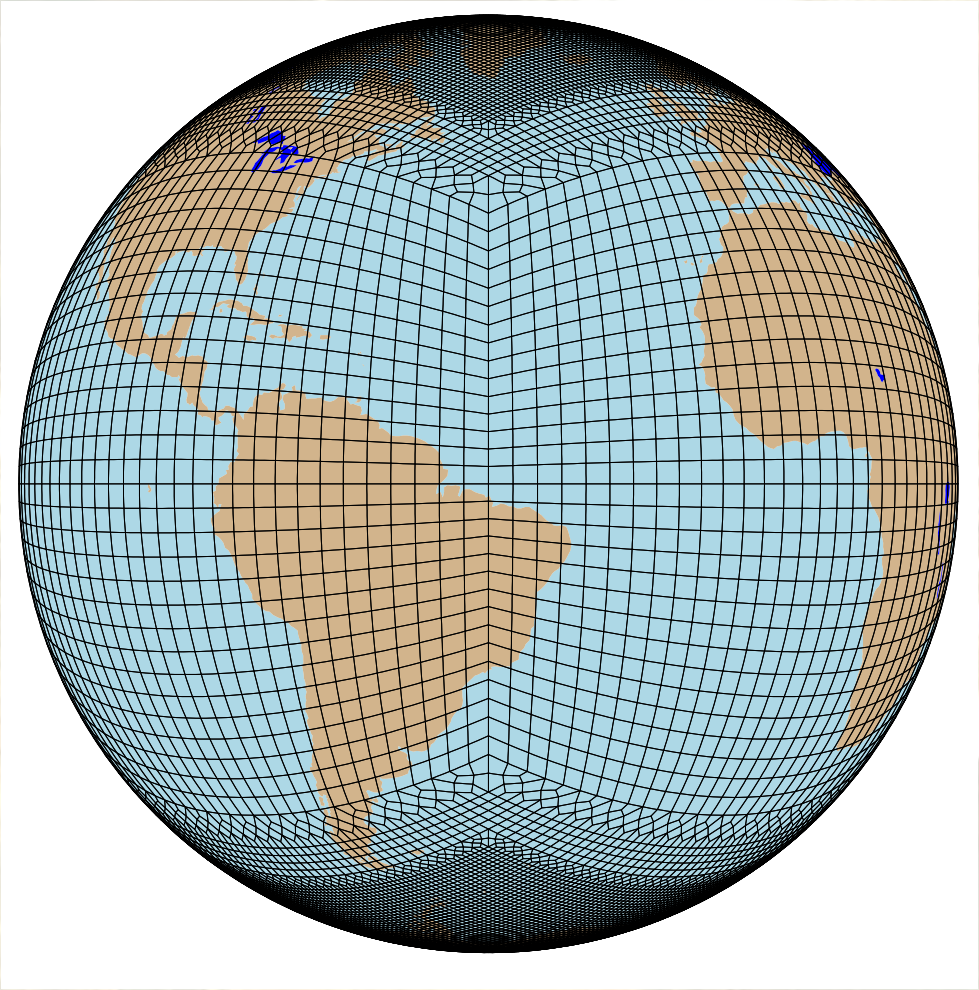
- Elevation downscaling CLM --› elevation zones are currently only applied to glacier land units, but ideally should be applied for the entire grid cell. This might be beneficial for gridcells where the ice fraction is small and will improve the CLM-CAM interaction.



Summary

- HMA-VR7 grid shows temperature (cold for winter and warm for summer) and precipitation (rainfall for monsoon and snowfall for winter/spring) biases, but shows improvements compared to NE30.
- Relative to snow cover observations, the HMA-VR7 grid shows a better agreement than NE30.
- Snow depth is mainly overestimated over western HMA during winter/spring, where HMA-VR7_1 is showing a better agreement than HMA-VR7_2, most likely due to snow model modifications in HMA-VR7_2.
- HMA-VR7 grid can simulate a (positive) SMB but is underestimated compared to observation-based glaciological/geodetic mass balances and RCM-based outputs. The HMA-VR7_2 simulations show a better performance than HMA-VR7_1. The underestimated SMB can most likely be attributed to a combination of a cloud cover/warm temperature bias over Central Asia, lacking model physics and the elevation downscaling in CLM.

Future/Current VR-CESM Work



- Global 1 degree | Polar 0.25 degree
- UU (IMAU) - NCAR AMWG project

AMIP-style simulations with CESM 2.2

1. Active atmosphere (CAM6.3)
   - 58 vertical levels (default: 32 vertical levels) -
   - CAM/CLUBB mods/fixes (incl. CESM-PaleoCalibr mods)
2. Active land surface (CTSM) + 10/18 EC scheme.
3. Non-evolving land ice (CISM_NOEVOLVE)
4. Prescribed daily sea surface temperature and sea ice from ERA5

- Historical (1979-2014) and future simulations (2070/2090 - 2100)
- Unrefined (ne30pg3) and refined (POLARRES)
- Future simulations forced with SST/sea-ice from storylines NH/SH

Thank You!