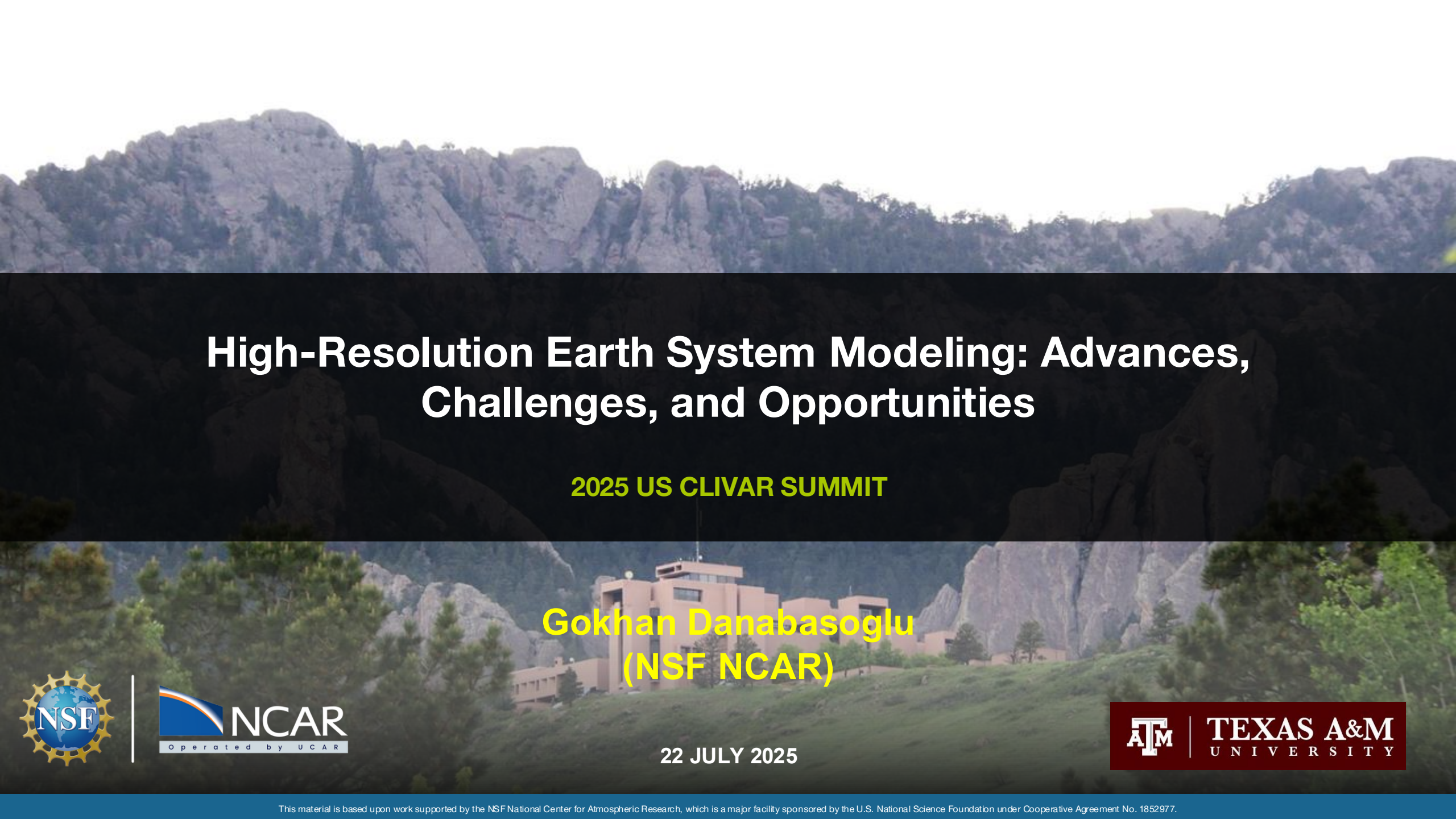

High-Resolution Earth System Modeling: Advances, Challenges, and Opportunities

2025 US CLIVAR SUMMIT

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(NSF NCAR)

22 JULY 2025

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CESM-HR Simulations (CESM1.3; 0.1º ocn; 0.25º atm)

500-year PI control;

80-year 1%CO_2; 150-year 4xCO_2;

10-member (1850) 1920-2005 historical;

10-member 2006-2100 transient w/ RCP8.5;

10-member 2006-2100 transient w/ RCP6.0;

1-member 2006-2100 transient w/ RCP4.5;

1-member 2006-2100 transient w/ RCP2.6;

3-member 1970-2020 Ozone withholding;

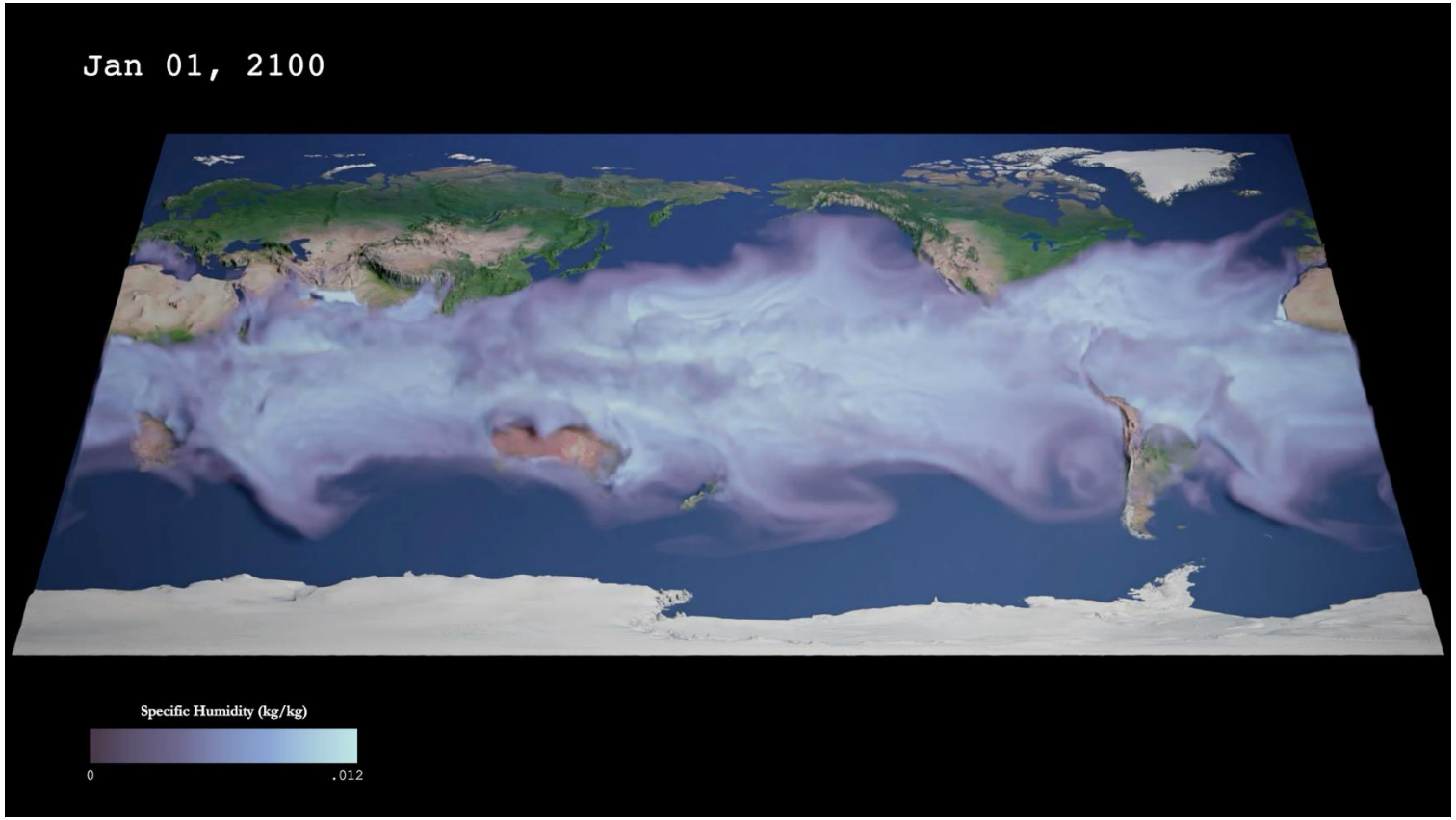
3-member 1950-2014 AMIP;

All HighResMIP coupled and AMIP;

5 cycles of 1958-2018 OMIP (w/ BGC);

Decadal Predictions (1980-2023; HRDP); and

Corresponding low-res (~1º) simulations



Visualization Credit: Matt Rehme, Visualization Services and Research Group, NSF NCAR CISL

Chang et al. (2020, JAMES)

Datasets are available to the community

project.cgd.ucar.edu/projects/MESACLIP/

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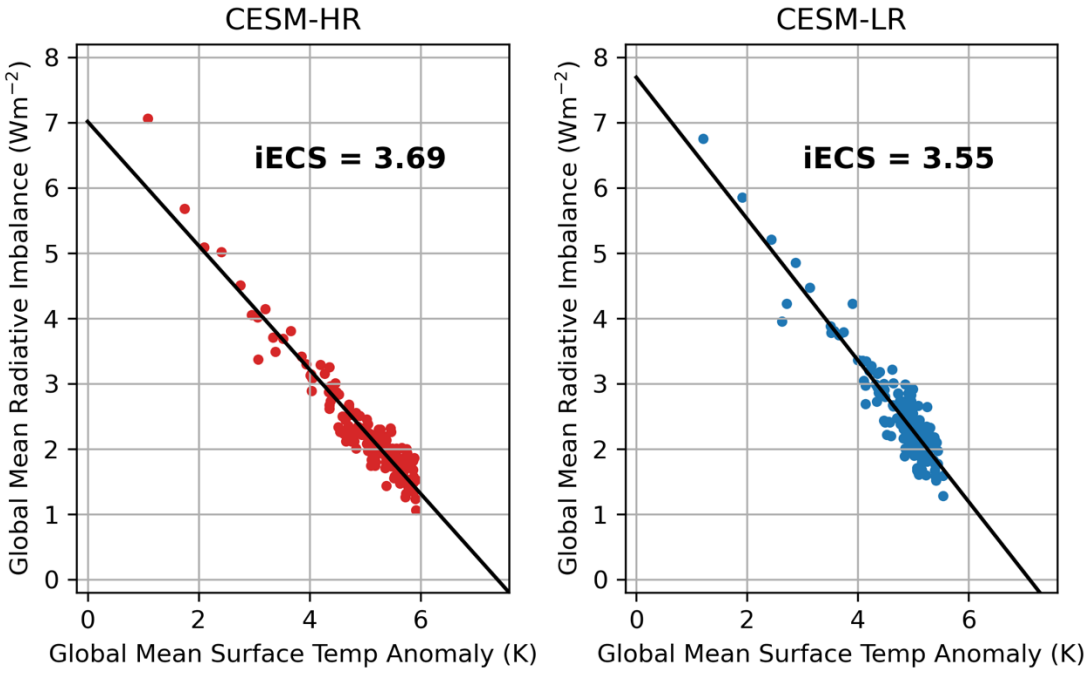
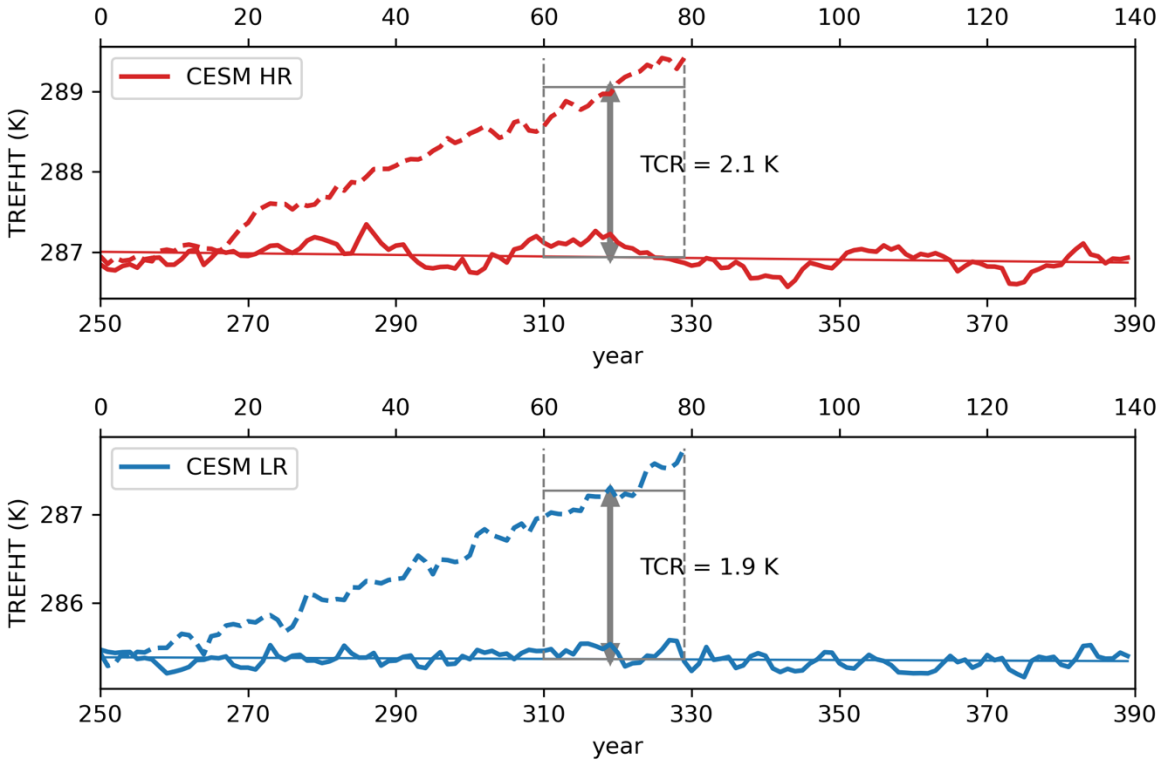
NSF NCAR Operated by UCAR

4xCO_2 inferred Equilibrium Climate Sensitivity (iECS)

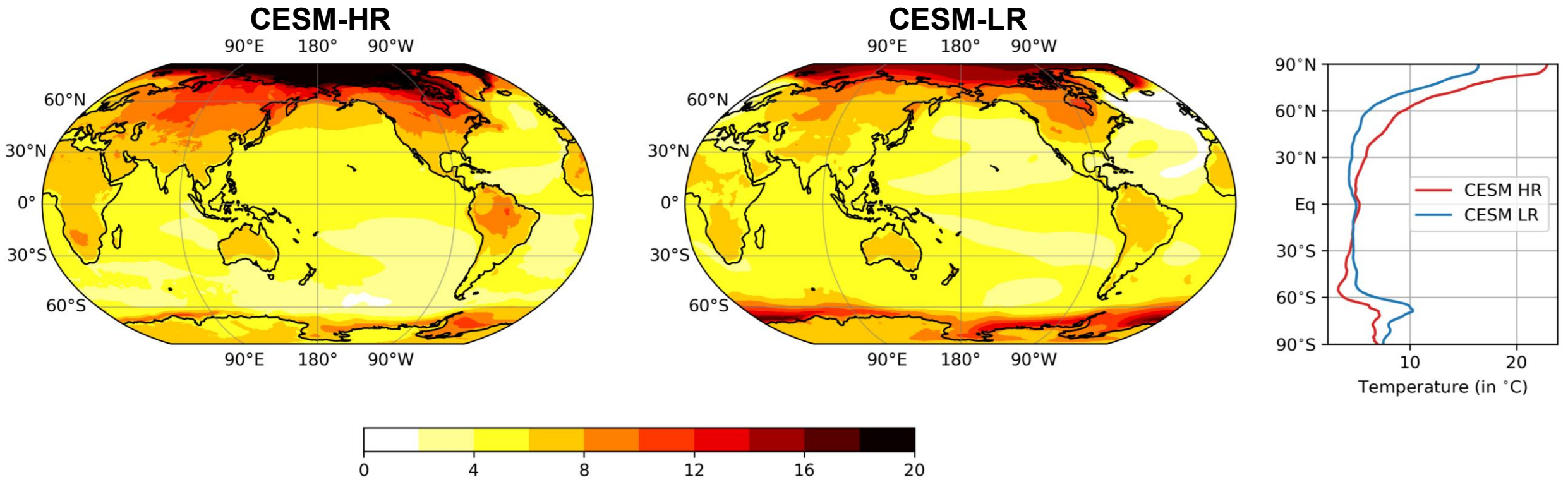


1%CO_2 Transient Climate Response (TCR)



Courtesy of Fred Castruccio

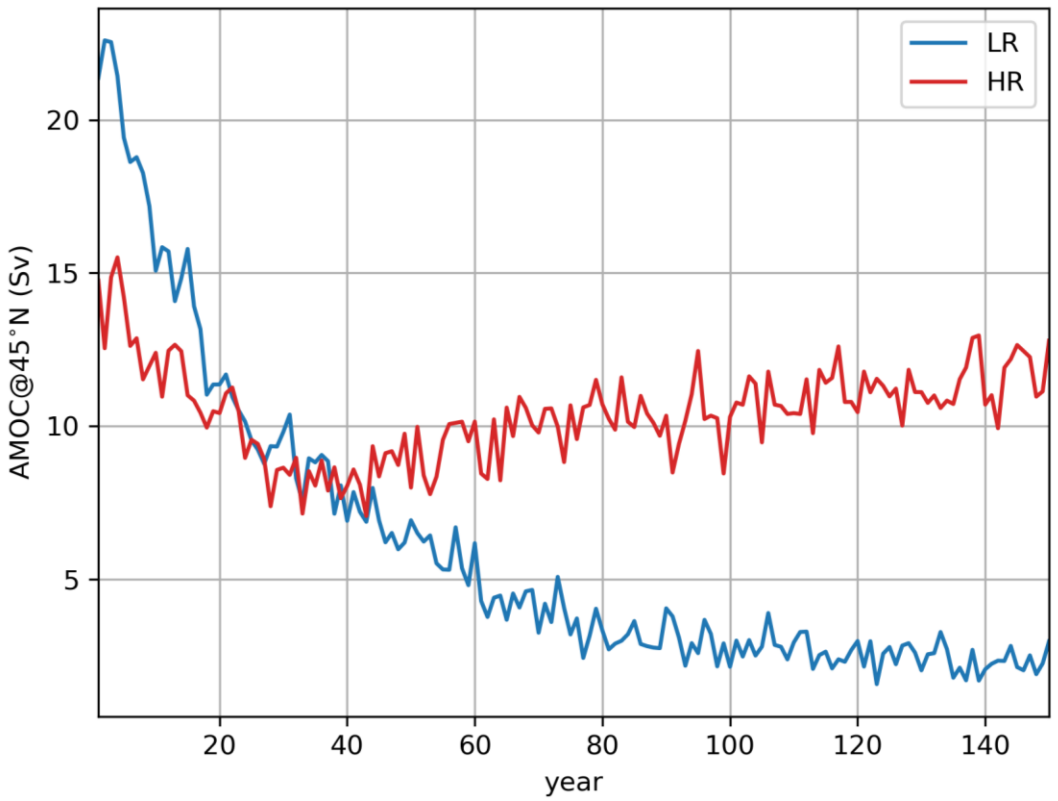
4xCO_2 Surface Warming



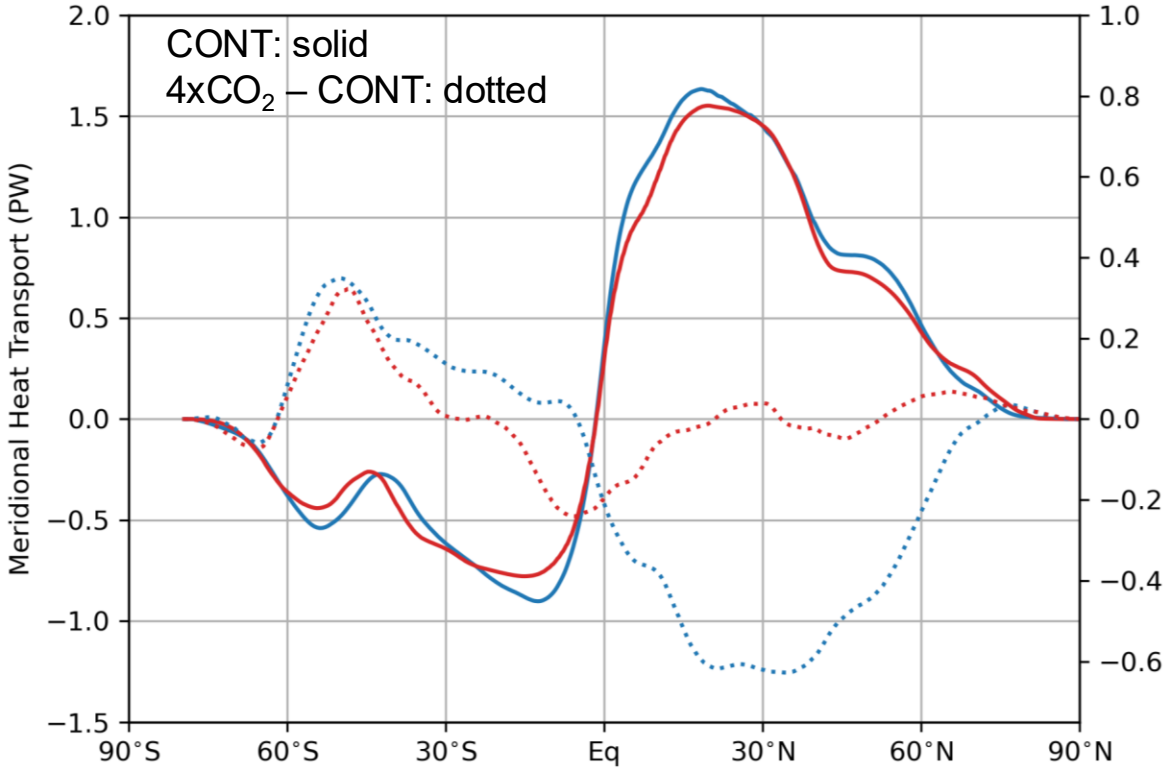
Courtesy of Fred Castruccio

Ocean Response under Abrupt 4xCO_2

Annual mean AMOC at 45°N

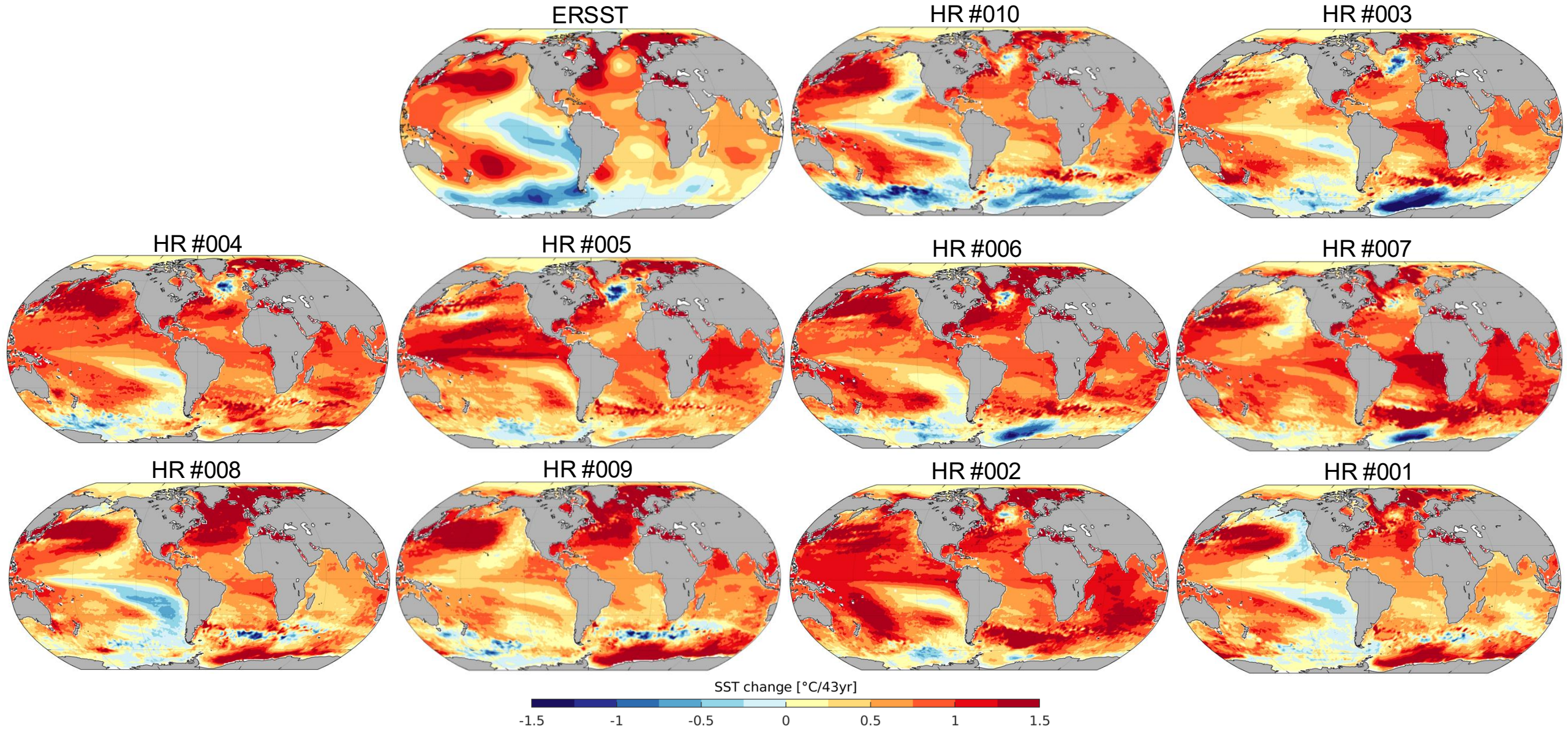


Mean Meridional Ocean Heat Transport

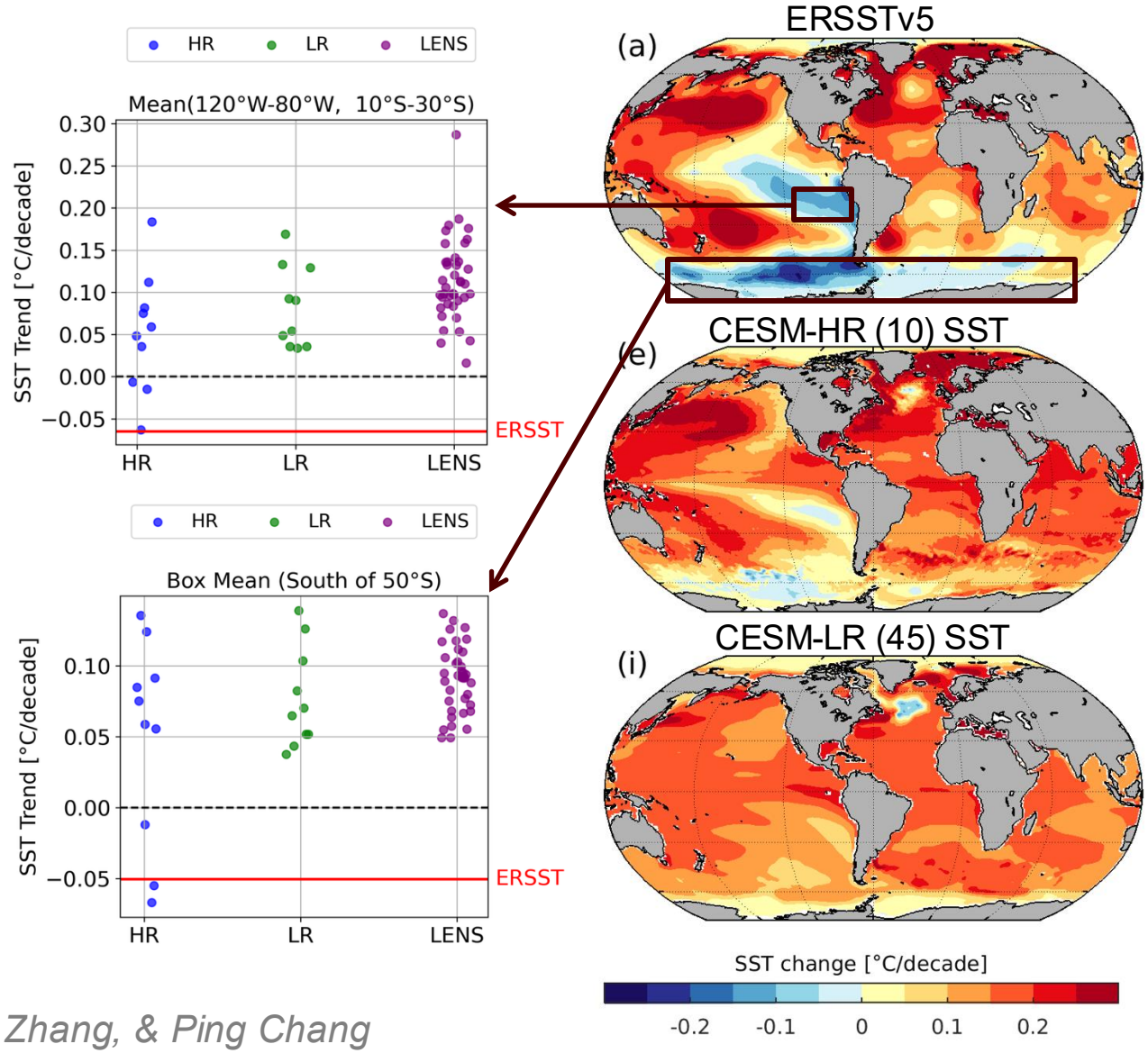


Courtesy of Fred Castruccio

SST Linear Trend (1980-2022) in Each Ensemble Member

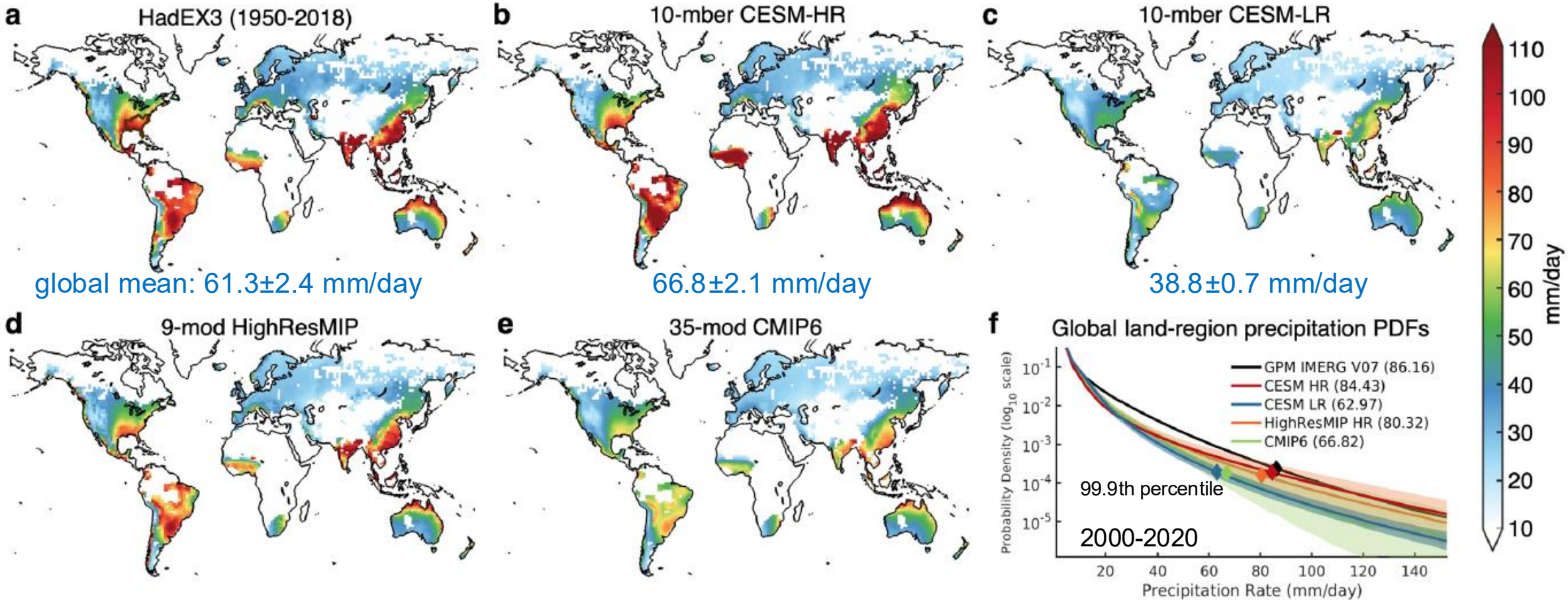


Linear Trends (1980-2022)



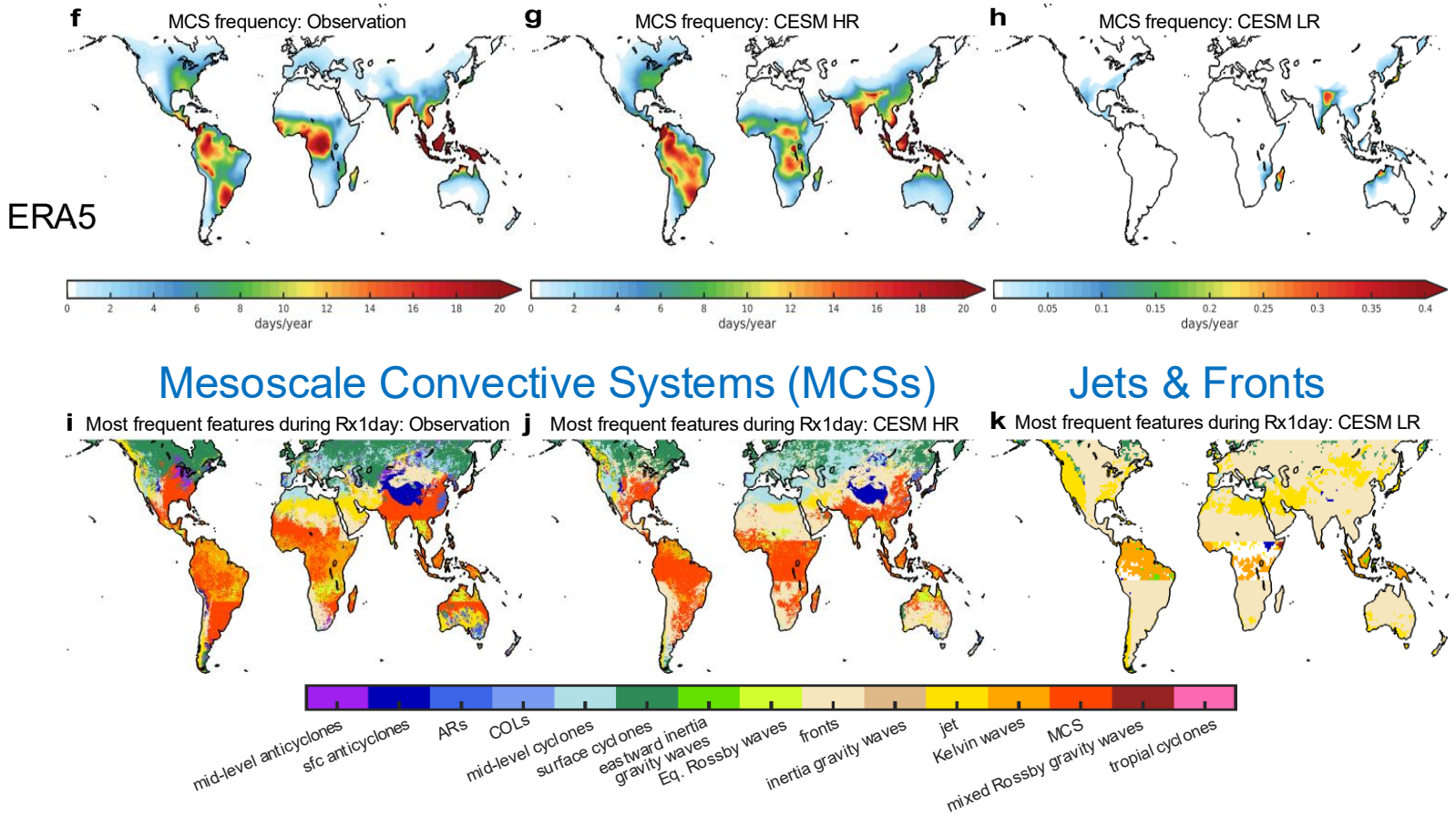
Courtesy of Xue Liu, Qiuying Zhang, & Ping Chang

Observed and Simulated Annual Maximum Daily Precipitation (Rx1day)



Chang et al. (2025, Nature Geoscience, in review)

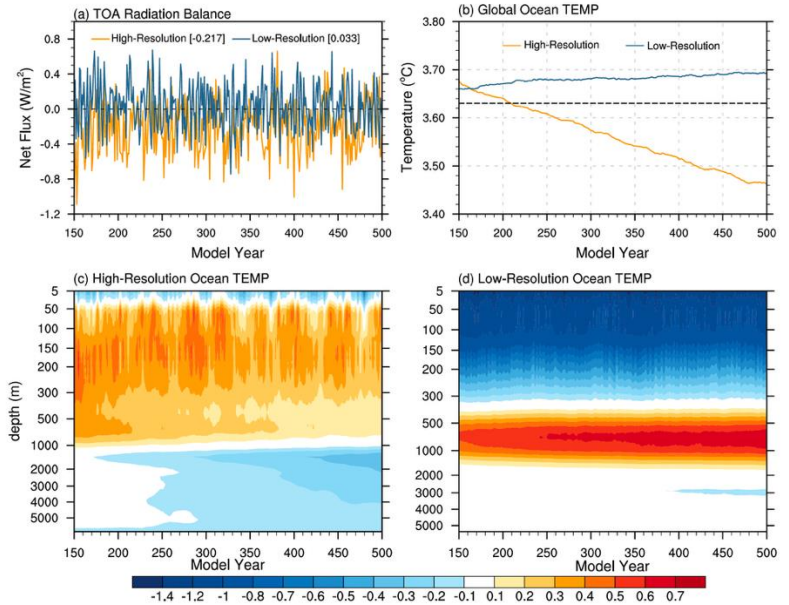
Most frequently Occurring Atmospheric Phenomenon Driving Extreme Precipitation



Detected by the Multi Object Analysis of Atmospheric Phenomenon (MOAAP; Prein et al. 2023) algorithm during Rx1day events over global land

Chang et al. (2025, Nature Geoscience, in review)

Some Challenges



Chang et al. (2020, JAMES)

- Tuning
- Spin up (recent GFDL experience)
- High resolution does not cure all the problems
- Computational resources

  CESM-HR achieves ~5 simulated years per day on 28 544 Derecho cores

  CESM-HR / CESM-LR cost ration is ~100

  ~6500 years of CESM simulations with 7 PB data volume
- Space for storage and serving to the community
- Social aspect: peer pressure; useful and usable simulations

Some Opportunities

- Optimize code and take advantage of new / emerging computational resources, e.g., running on GPUs w/ C++ code
- Explore lossy compression
- Learn from HR vs LR solution comparisons to advance our understanding of processes and use that information to advance simulations across scales in a hierarchical modeling approach
- Large datasets offer an unprecedented opportunity for AI/ML training
- Explore AI/ML techniques to understand HR and LR differences in representation of processes
- Explore efficient / reduced-cost AI/ML methods for parameterization replacement and parameter estimation (long time scales in the ocean)

A worry is reliability / fidelity of LR simulations and findings