Climate changes in a global-storm resolving model (GSRM)

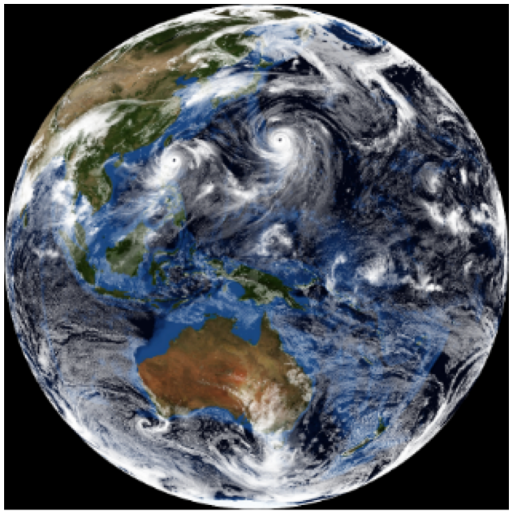
Timothy M. Merlis, Kai-Yuan Cheng, Lucas Harris, Stephan Fueglistaler, Chris Bretherton, Maximilien Bolot, Linjiong Zhou, Alex Kaltenbaugh, Spencer Clark
(Princeton University, GFDL, & Allen Institute for AI)

Cheng et al. 2022, Impact of warmer SST on the global pattern of intense convection: insights from a global-storm resolving model. GRL, accepted.

Pan-GASS Understanding and Modeling Atmospheric Processes 2022

XSHiELD Overview

eXperimental System for High-resolution prediction on Earth-to-Local Domains



- GFDL-developed GSRM based on NOAA's FV3GFS weather forecast model
- ~3 km horizontal resolution, 79 vertical levels, no deep convection parameterization
- Mixed-layer ocean nudged to analyzed ECMWF SSTs
- Performed on Princeton University's CIMES Stellar cluster

XSHiELD Overview

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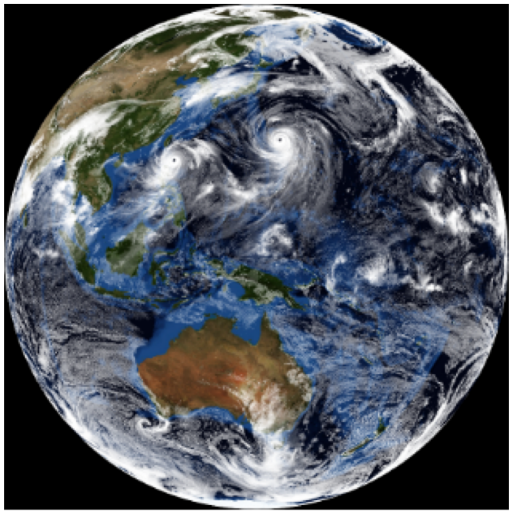
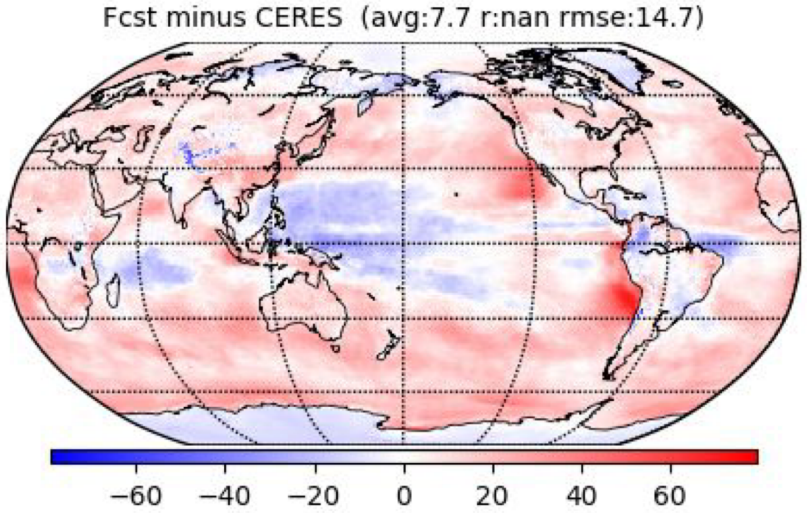


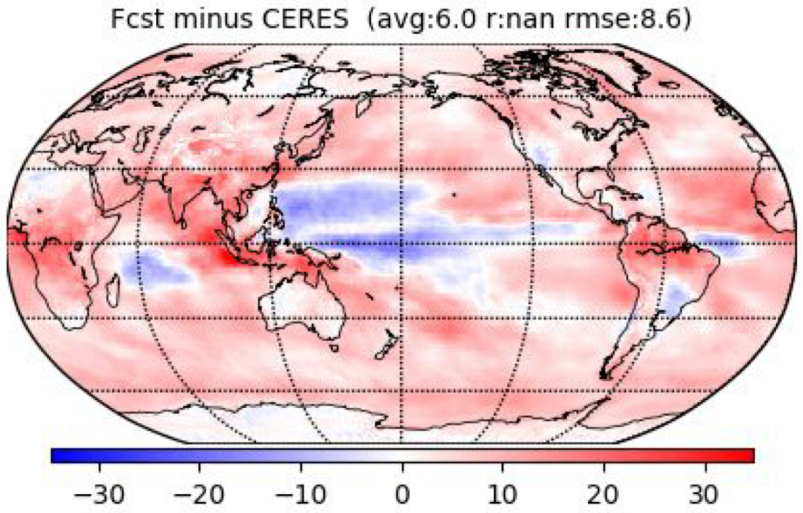
- 1-year long simulations: control, +4K SST warming, 4xCO_2, and both
- Caveats: these are *long* GSRM simulations (full seasonal cycle! 10x DYAMOND length) and *short* compared to GCM AMIP (~1/30x length), so internal variability is not well sampled
- Uniform SST warming eliminates known roles of patterned warming on tropical stratification, large-scale circulation changes, climate feedbacks

XSHiELD Climatology

TOA biases: ASR



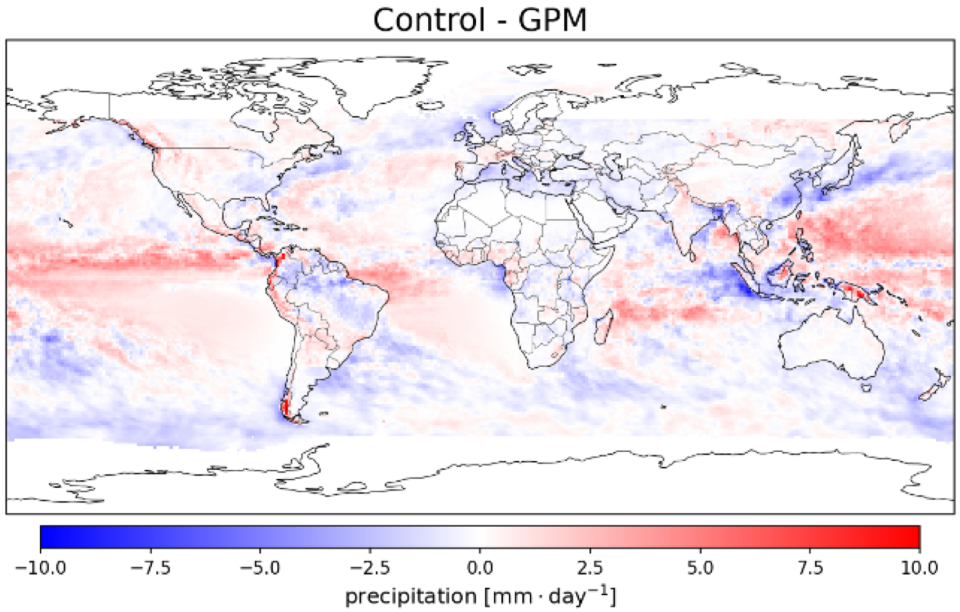
OLR



- Comparable to CMIP GCMs
- Too little extratropical, marine stratocumulus cloud; too much tropical high cloud

XSHiELD Climatology

Annual-mean precipitation bias



- Regional biases are comparable to CMIP GCMs, small global-mean bias

What do you do with several incredible, beautiful simulations of a moist turbulent flow?

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$$0 = \mathcal{F} + \lambda \Delta T_s$$

Global Average!?!

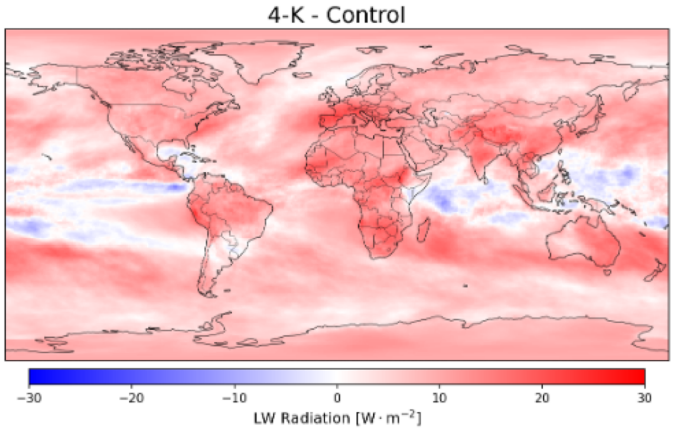
What do you do with several incredible, beautiful simulations of a moist turbulent flow?

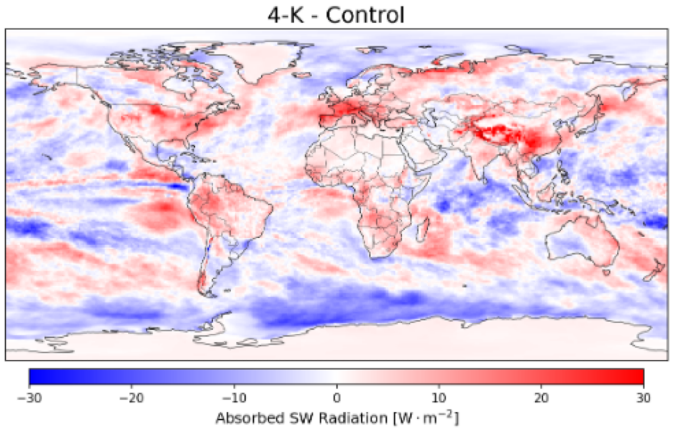
$$0 = \mathcal{F} + \lambda \Delta T_s$$

Global Average!?!
This *is* the trillion dollar question.

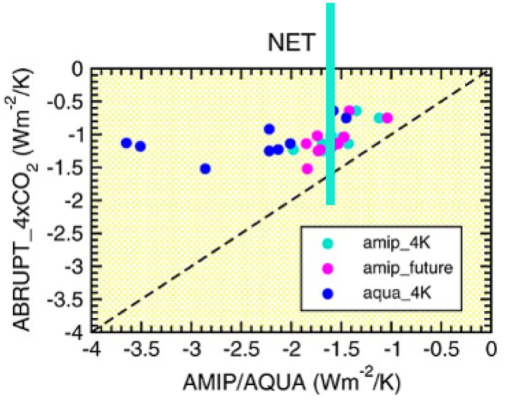
Climate Sensitivity

‘Cess’ sensitivity: TOA flux changes from uniform SST warming





XSHiELD

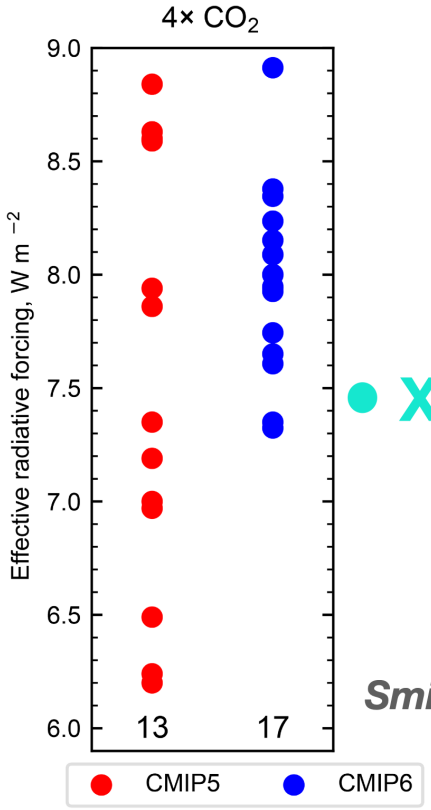


Ringler et al. (2014)

- The net feedback of 1.6 $Wm^{-2}K^{-1}$ ($\Longrightarrow$ CS of 2.3 K for $2xCO_2$) is in range of GCMs

Adjusted Radiative Forcing

TOA flux changes from increased CO_2 with unchanged SST

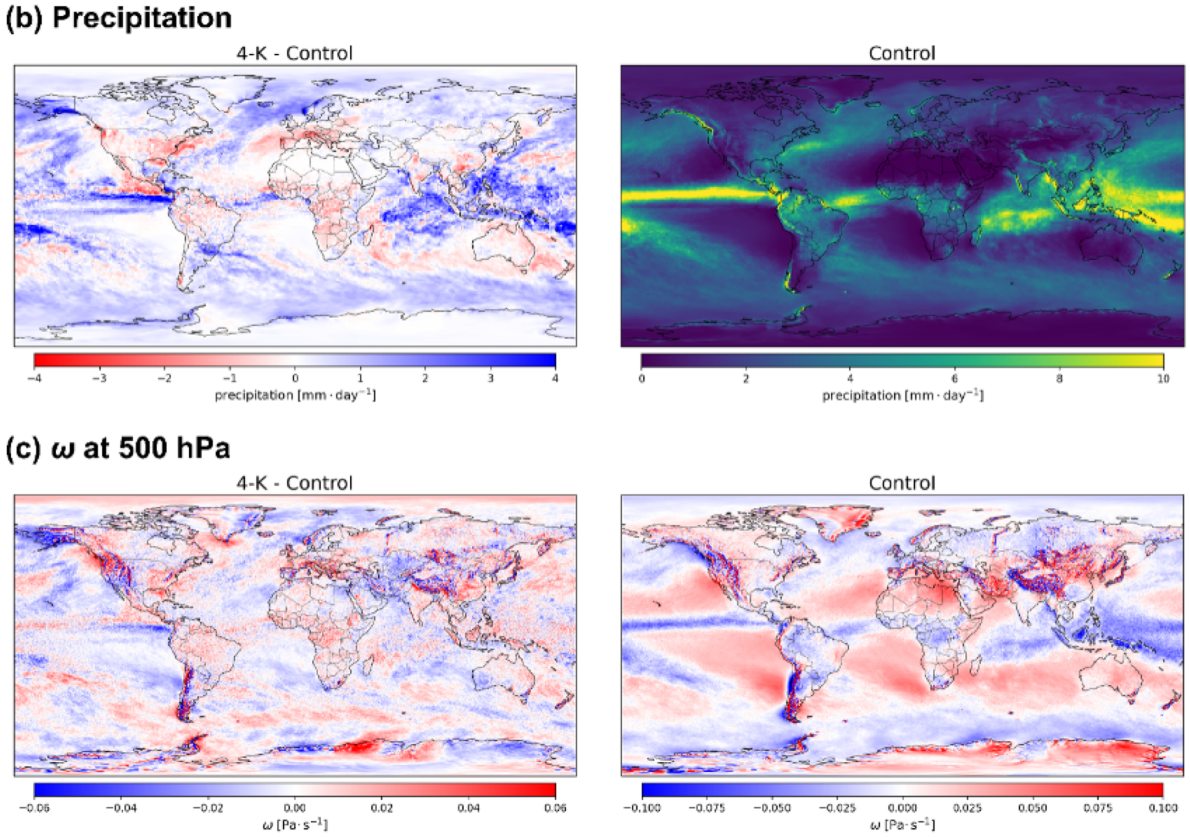


● XSHiELD

Smith et al. (2020)

- The adjusted forcing of 7.45 Wm^{-2} for 4xCO_2 is on the low end of CMIP6 GCMs, but would have been in the middle of CMIP5
- About 1.5 Wm^{-2} is from SW, i.e., cloud adjustments

Annual-mean response to warming

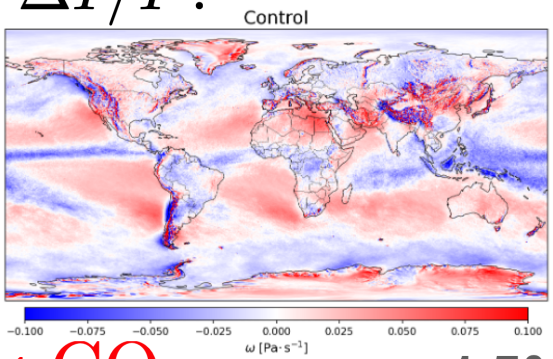


Cheng et al. (2022)

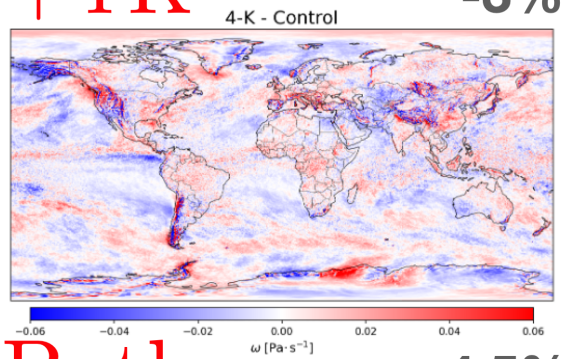
- Global-mean increase in P, modulated regionally by circulation changes

Mean Tropical Overturning Circulation

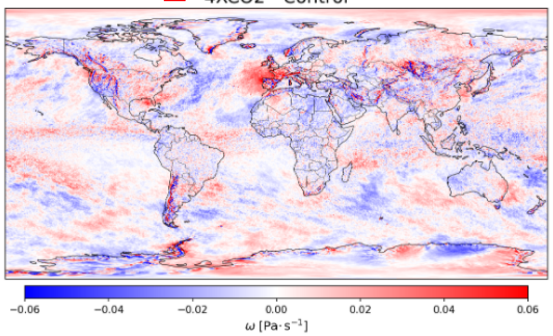
$I = \overline{\omega}^{\downarrow} - \overline{\omega}^{\uparrow}, \ \Delta I / I$:



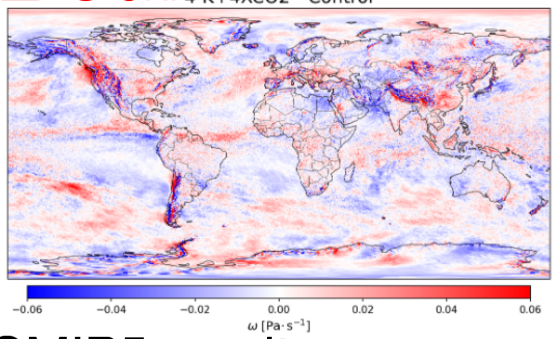
$+4\,\mathrm{K}$ **-3%**



$4 \times \mathrm{CO_2}$ **-1.5%**



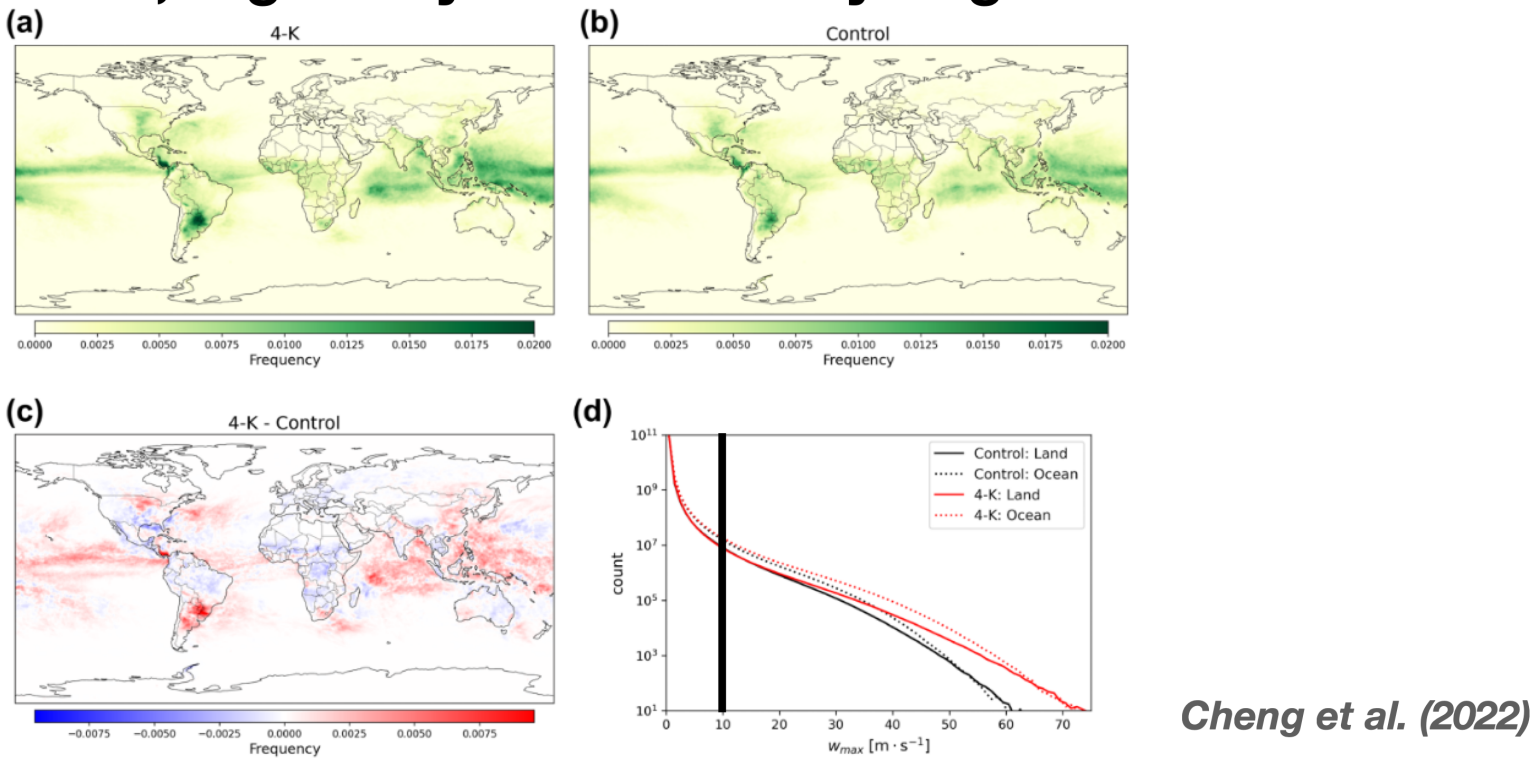
Both **-4.5%**



- Warming response appears weaker than CMIP5 results *Bony et al. (2013)*
- Direct CO2 response in line with GCMs and theory *Bony et al. (2013), Merlis (2015)*

Frequency of Intense Convection

~20% increases, regionally modulated by large-scale circulation

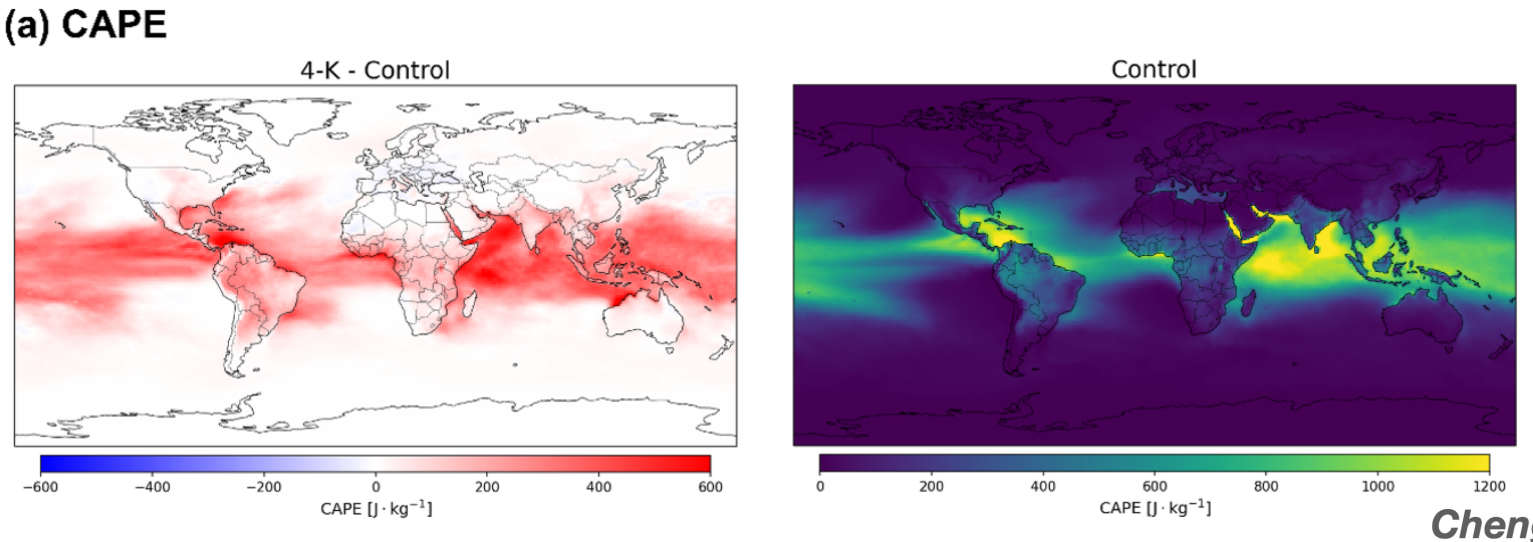


Cheng et al. (2022)

- CO_2 direct response is an increase frequency of intense w_{max} over land, moderating total change

Environmental Proxies?

What could be assessed in GCMs vs explicit simulations of convection

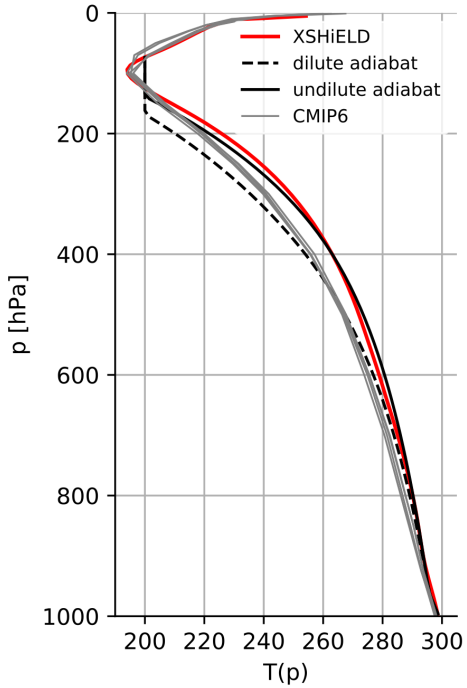


Cheng et al. (2022)

- Some regional discrepancies between CAPE expectations and w_{max}
- Substantial ~40% increases in CAPE, larger than GCMs
- Does tropical stratification change different from GCMs?

Tropical-mean Temperature

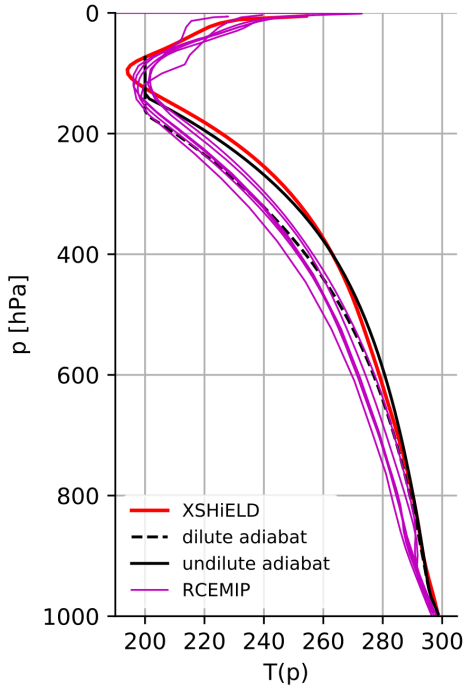
Climatology vs. CMIP6 and adiabats



- XSHiELD's free troposphere is substantially warmer than CMIP6 simulations and dilute adiabat ***Romps (2016)***
- It's actually close to an undilute adiabat

Tropical-mean Temperature

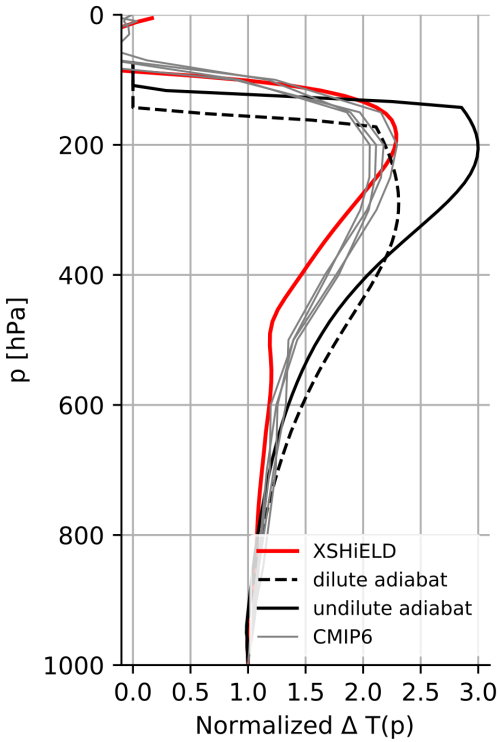
Climatology vs. RCEMIP and adiabats



- RCEMIP are broadly similar to dilute adiabat and colder than XSHiELD's free troposphere

Tropical-mean Temperature Response

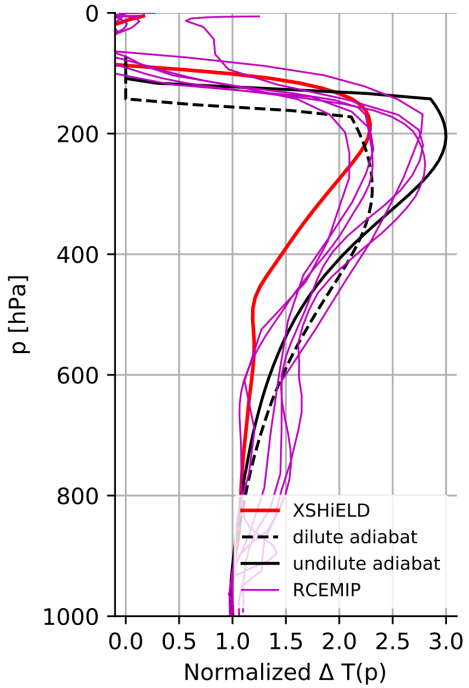
to +4K SST: XSHiELD vs CMIP6 and adiabats



- XSHiELD's mid-troposphere has less warming than CMIP6 AMIP +4K simulations
- But it's upper troposphere has relatively more warming
- Differences in effective entrainment rate, cloud radiative effects, or organization?

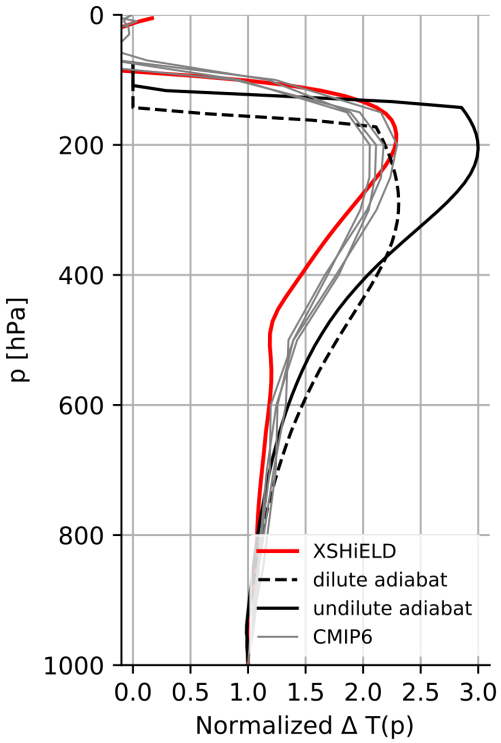
Tropical-mean Temperature Response

to +4K or +5K SST: XSHiELD vs RCEMIP and adiabats



- Some RCEMIP models have more vertical amplification

Tropical-mean Temperature Response
to +4K SST



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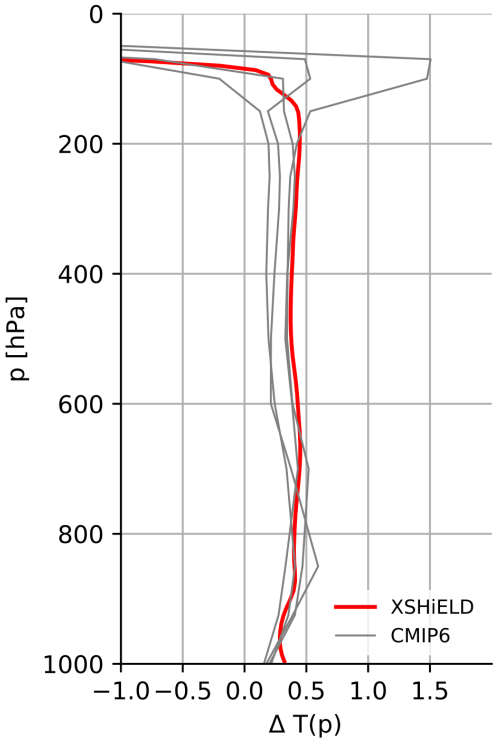
Tropical-mean Temperature Response

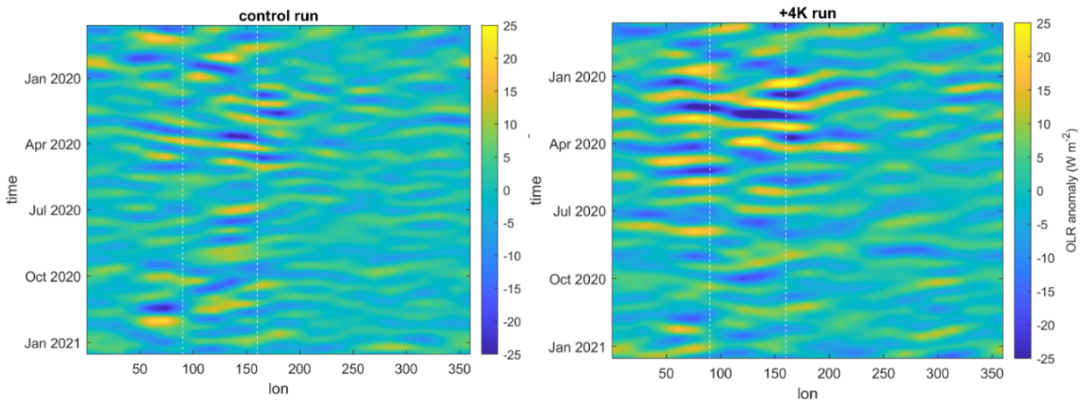
to 4xCO_2



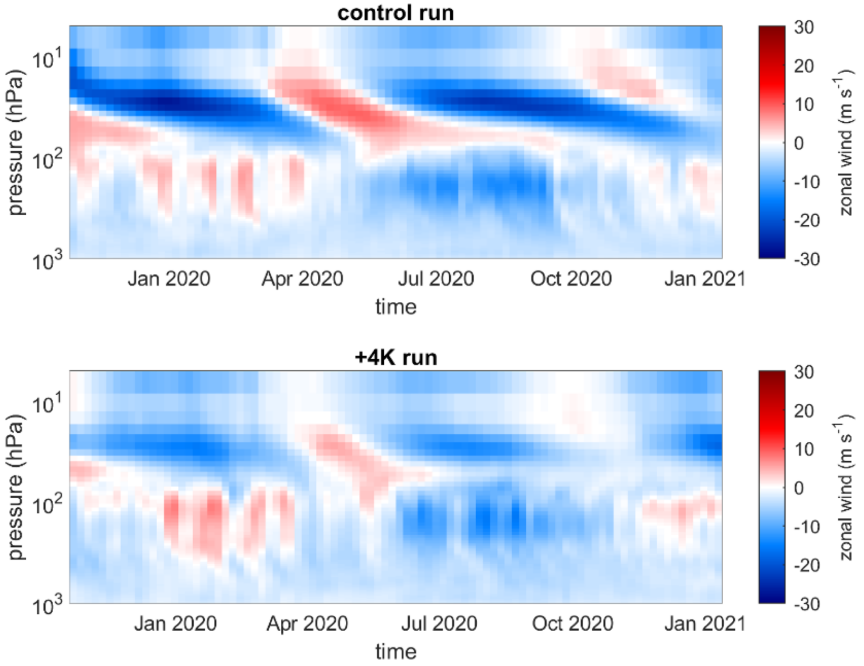
- XSHiELD is more vertically uniform vs. ‘bottom heavy’ CMIP6 tropospheric temperature adjustment
- These don’t look like adiabats: I don’t think there’s a conventional mechanism that explains this

MJO & QBO

Tropical OLR



Zonal-mean zonal wind



- MJO strengthens & propagates faster with warming
- ‘QBO’ (short period) weakens with warming

Conclusions

Climate Changes in a GSRM

- XSHiELD control and +4K SST warming simiulations allow explicit simulation of extreme vertical velocities, their connection to large-scale thermodynamic and dynamic changes *Cheng et al. (2022)*
- Many of the simulated changes are broadly in line with conventional GCMs: good news! Some of the most fundamental aspects of the simulated changes (radiative forcing, tropical temperature changes) are at the edge of CMIP ensemble…
- Open question: how comparable are SHiELD climate changes at ~GCM resolution to GSRM resolution? (model physics vs resolution)
- QBO, MJO and additional analyses to come

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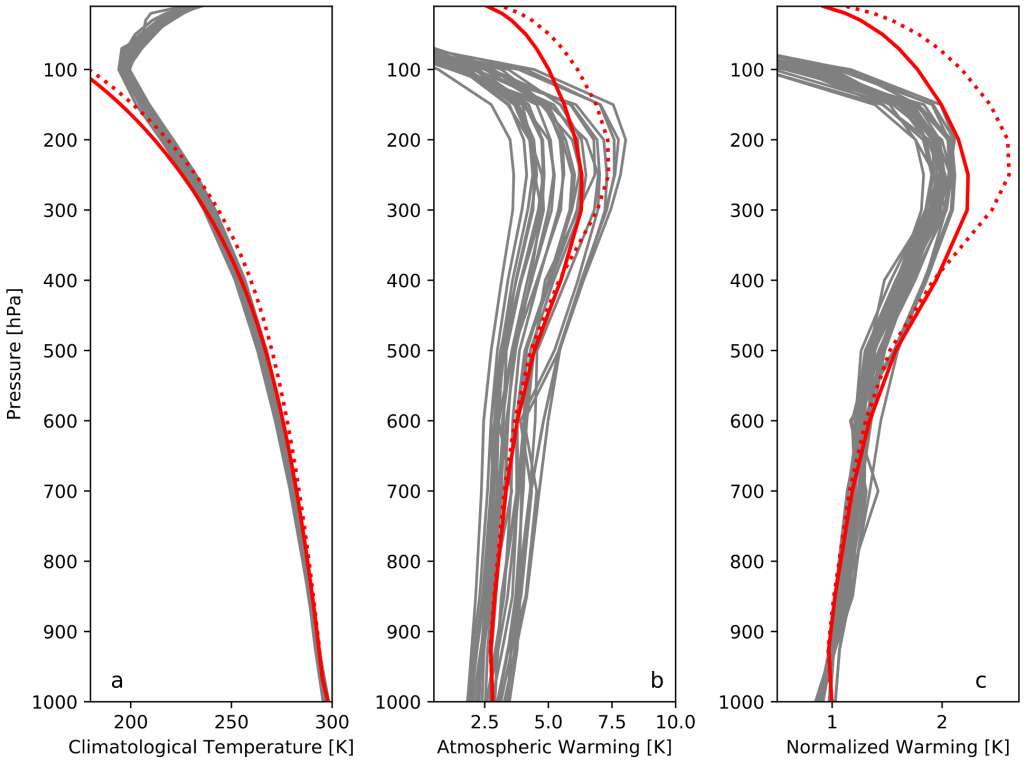
Thank you!

CMIP5 RCP8.5



Po-Chedley et al. (2019)