Cess-Potter Experiments with 3-km SCREAM

W. Hannah[1], C. R. Terai[1], N. D. Keen[3], P. M. Caldwell[1], H. Beydoun[1], P. A. Bogenschutz[1], L.-W. Chao[1], H.-Y. Ma[1], M. D. Zelinka[1], L. Bertagna[2], A. M. Bradley[2], T. C. Clevenger[2], A. S. Donahue[1], J. Foucar[2], J.-C. Golaz[1], O. Guba[2], B. R. Hillman[2], J. Lee[1], W. Lin[5], N. Mahfouz[6], J. Mülmenstädt[6], A. Salinger[2], B. Singh[6], S. Sreepathi[7], Y. Qin[6], M. A. Taylor[2], P. A. Ullrich[1], W.-Y. Wu[1], X. Yuan[8], C. Zender[9], Y. Zhang[1]

[1] Lawrence Livermore National Laboratory, Livermore, CA, USA [2] Sandia National Laboratories, Albuquerque, NM, USA [3] Lawrence Berkeley National Laboratory, Berkeley, CA, USA [5] Brookhaven National Laboratory, Upton, NY, USA
[6] Pacific Northwest National Laboratory, Richland, WA, USA [7] Oak Ridge National Laboratory, Oak Ridge, TN, USA [8] Argonne National Lab, Lemont, IL, USA [9] University of California, Irvine, Irvine, CA, USA

Baseline Climate

Experiment Design

The Cess-Potter approach is used to assess SCREAM's response to an abrupt +4K SST warming relative to a control with observed SST on a global 3km grid. The model was **initialized on 1 Aug 2019** and **integrated for 13-months**, with the first month ignored for analysis. This period represents an ENSO-neutral year and the use of a single year is motivated by the results of Qin et al. (2022). An ensemble of coarser 12km runs is used to evaluate the sensitivity to initial condition and simulation period. A single land initial condition was spun up with ERA5 derived forcing and used for all experiments. Aerosols are handled with the Simplified Prescribed Aerosols (SPA) scheme to prescribe droplet number concentration and aerosol radiative properties using aerosol data from a previous E3SM simulation.

	Obs	3km	12km	12km[1]	12km[2]	12km[3]	12km[4]
Net TOA ($W\,m^{-2}$)	1.3	4.3	-2.0	-1.8	-1.7	-1.7	-1.8
Net CRE	-20.2	-19.2	-20.2	-20.2	-20.2	-20.2	-20.2
Net clr-sky	20.7	23.4	21.7	21.7	21.8	21.9	21.8
SW TOA ($W\,m^{-2}$)	242.4	243.1	238.2	238.4	238.5	238.5	238.5
SW CRE	-44.3	-44.2	-48.4	-48.2	-48.2	-48.2	-48.1
SW clr-sky	286.8	287.2	286.6	286.6	286.7	286.7	286.7
LW TOA ($W\,m^{-2}$)	241.1	238.8	240.3	240.2	240.2	240.2	240.4
LW CRE	25.1	25.0	24.6	24.7	24.7	24.7	24.6
LW clr-sky	266.1	263.8	264.9	264.9	264.9	264.8	264.9
Precip ($mm\,d^{-1}$)	2.88	3.03	3.15	3.14	3.14	3.14	3.15

Table 1. Global-mean radiative fluxes at the top of atmosphere (TOA) and precipitation rates at the surface for the simulation period, SCREAM 3km, and SCREAM 12km. Superscripts indicate the SCREAM 12km ensemble members. Observational estimates are used from CERES-EBAF and GPM IMERG.

TOA Radiative Fluxes

The baseline 3km SCREAM does well capturing the basic global mean TOA fluxes (**Table 1**). The net TOA imbalance of +4.3 W/m2 is greater than satellite estimates, but consistent with the use of prescribed SST. 12km SCREAM exhibits a negative net TOA imbalance due to robustly negative global mean CRE.

Figure 1 reveals notable regional SW CRE biases, such as the lacking marine stratocumulus in the Northeastern Pacific and overly bright clouds in the Southern Ocean. The bias pattern is qualitatively similar to other CMIP models (not shown). The LW CRE biases are generally smaller compared to CERES-EBAF.

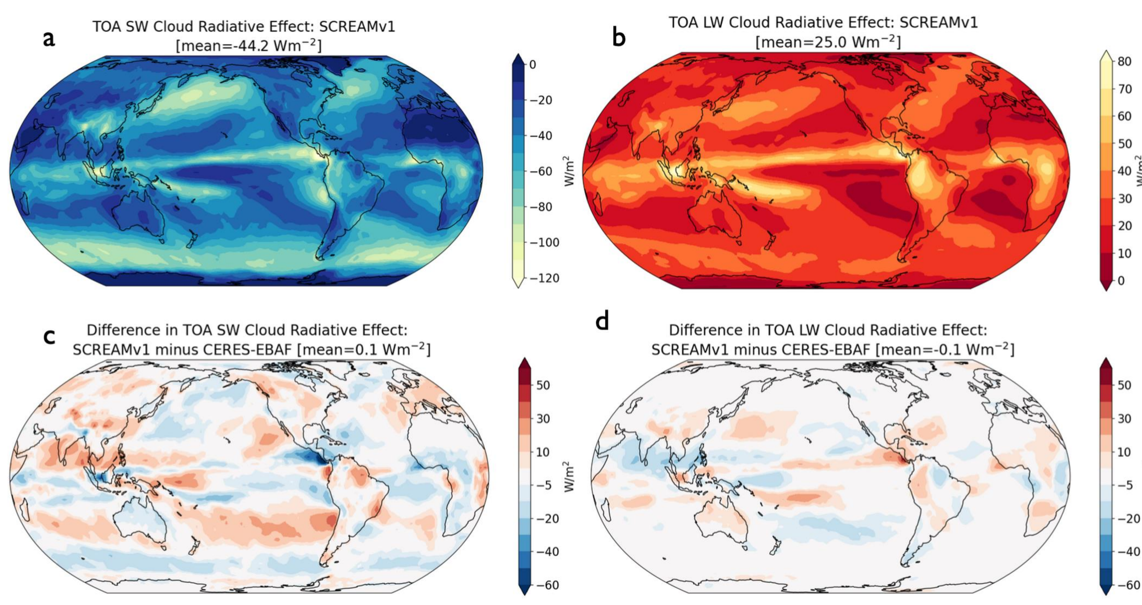

Figure 1. Present-day top-of-atmosphere, cloud radiative effect (CRE) in SCREAM 3km and its difference with CERES-EBAF satellite estimates. a) The baseline shortwave CRE in SCREAM 3km. b) The baseline longwave CRE in SCREAM 3km. c) The difference between CERES-EBAF and SCREAM 3km in shortwave CRE. d) The difference between CERES-EBAF and SCREAM 3km in longwave CRE.

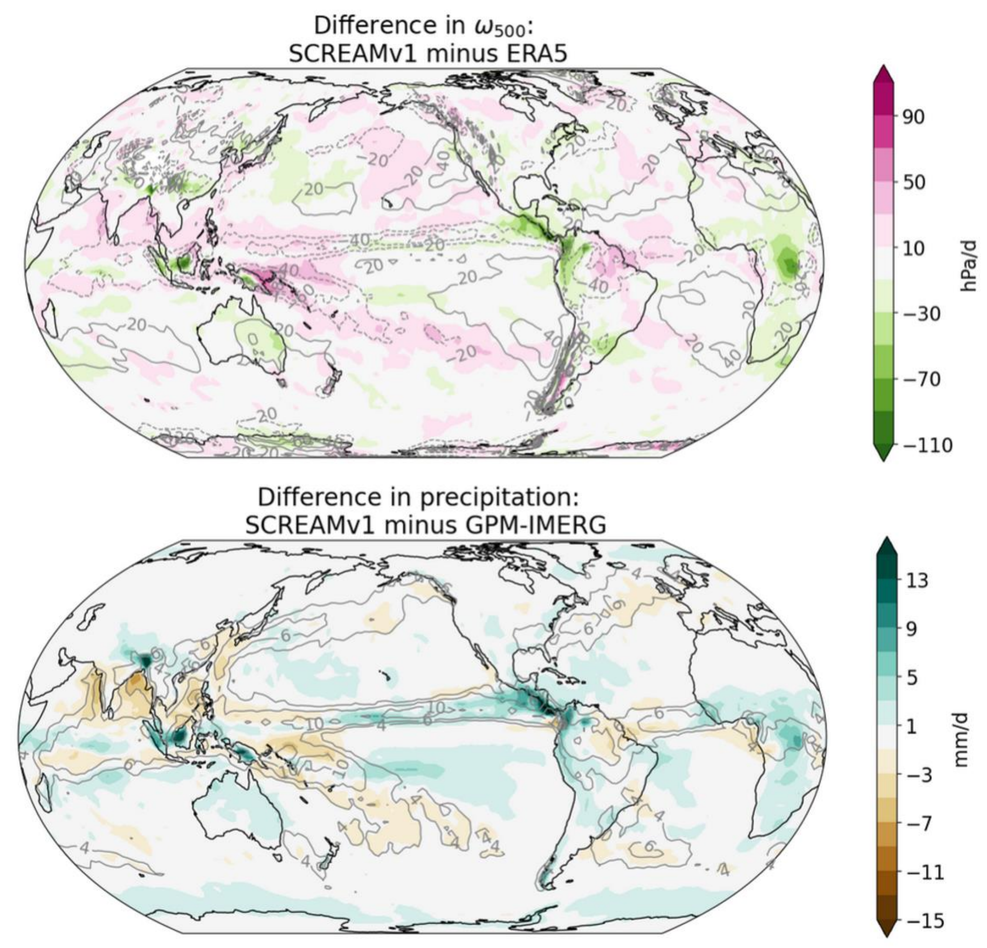

Figure 2. (top) Present-day difference in 500 hPa vertical pressure velocity (ω500) between ERA5 and SCREAM 3km. (bottom) Present-day difference in surface precipitation between IMERG and SCREAM 3km. Contours indicate baseline present-day values from ERA5/IMERG.

Precipitation Biases

Global mean precipitation is systematically higher than observed (**Table 1**) and regional biases coincide with circulation biases indicated by the 500mb vertical pressure velocity (**Figure 2**). The Tropical Western Pacific shows a bias for weak upward motion and overly strong upward motion along the Pacific ITCZ, with corresponding low and high precipitation biases. Other notable regions with a high precipitation bias are over the Andes, Himalayas, the maritime continent, Panama, and Central Africa.

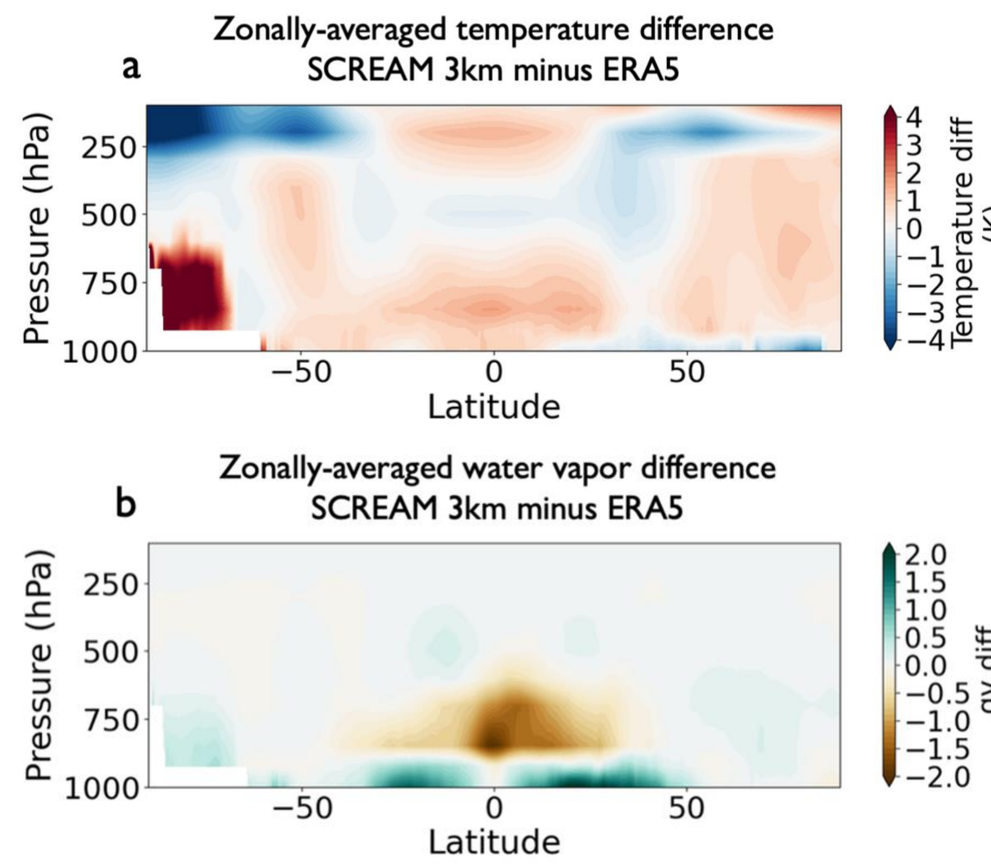

Figure 3. (a) Time- and zonally-averaged difference in the temperature between SCREAM 3km and ERA5 for the simulation period (Sept 2019 to Aug 2020). (b) Same as (a), but for water vapor mixing ratio.

Zonal Mean Biases

Consistent with Donahue et al. (2024) the Tropics shows a warm and dry bias in the lower free troposphere and warm bias aloft, as well as an extra-tropical cold bias around 200mb. These bias patterns, along with a poleward shifted jet (not shown), suggest a potential problem with gravity wave breaking. The dry lower free troposphere and overly humid boundary layer seem related to a lack of mid-level clouds reported by Donahue et al. (2024).

Response to Warming

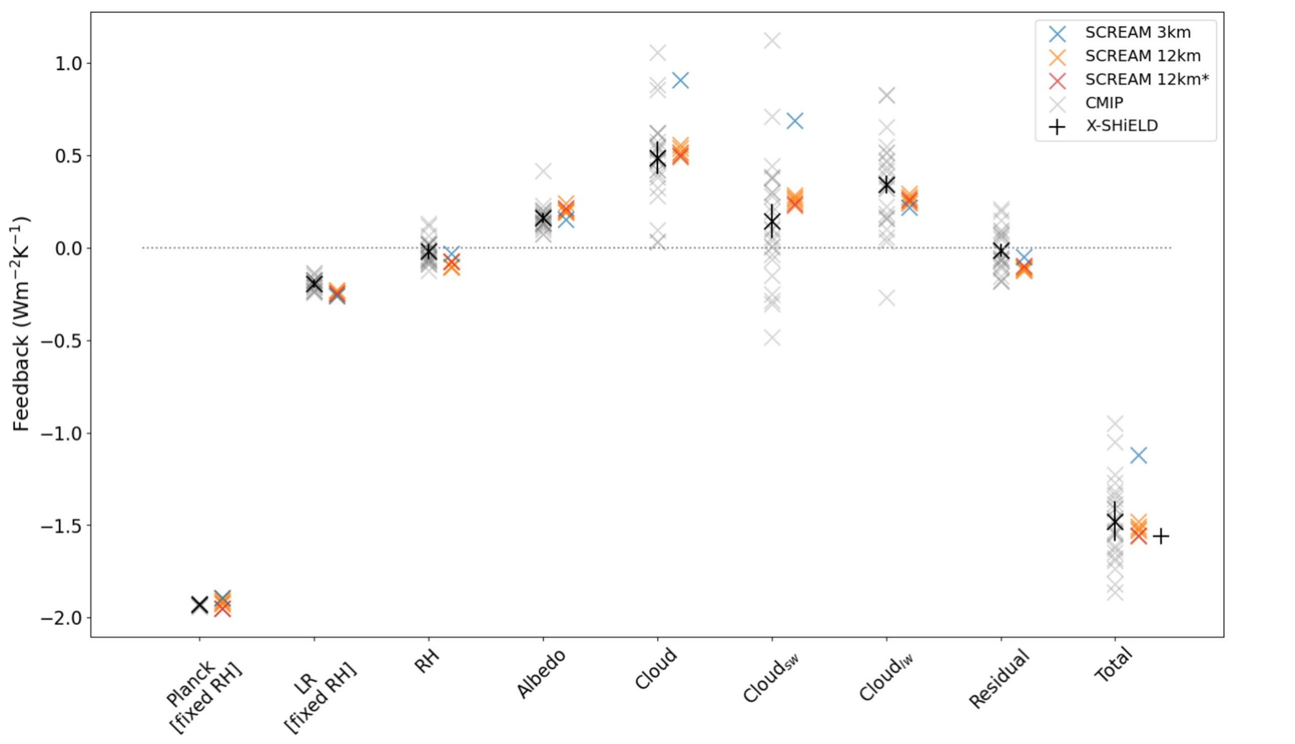

Figure 4. Global-mean radiative feedbacks in SCREAM 3km (blue), SCREAM 12km (orange), SCREAM 12km over Mar 2020 - Feb 2021 (red), X-SHiELD (black plus), CMIP5/6 models (gray), and the CMIP5/6 ensemble mean (black cross).

Global Mean Radiative Feedbacks

The total radiative feedback of 3km SCREAM is within the spread of CMIP5/6 models, but in the top 15th percentile, suggesting a very high Climate Sensitivity **(Figure 4).** We also find a relatively large difference between the total feedback of SCREAM and X-SHiELD as reported by Merlis et al. (2024). These differences are largely driven by an overly positive shortwave cloud feedback. 12km SCREAM shows a total feedback closer to the CMIP ensemble mean. The small spread across the 12km SCREAM ensemble indicates minimal sensitivity to initial condition or time period.

Cloud Feedbacks

Despite notable differences in the global mean cloud feedback, 3km and 12km SCREAM show cloud feedbacks with qualitatively similar spatial patterns (**Figure 5**). The zonal mean feedbacks are also roughly consistent with CMIP models. The largest SW cloud feedback difference between 3km and 12km is found in the Tropics, where 12km SCREAM shows a broader area of negative feedback over the Pacific. The similarity of LW cloud feedbacks between 3km and 12km cases is somewhat surprising given the change in high clouds revealed by **Figure 6**, which shows more ice condensate aloft in 3km SCREAM despite having a similar high cloud fraction to 12km SCREAN. The global mean ice water path also shows different response, with an increase in 3km SCREAM and a slight decrease in 12km SCREAM (not shown). Liquid cloud amount is reduced with warming in all runs, but the reduction is larger in 3km SCREAM (not shown), consistent with stronger SW cloud feedback.

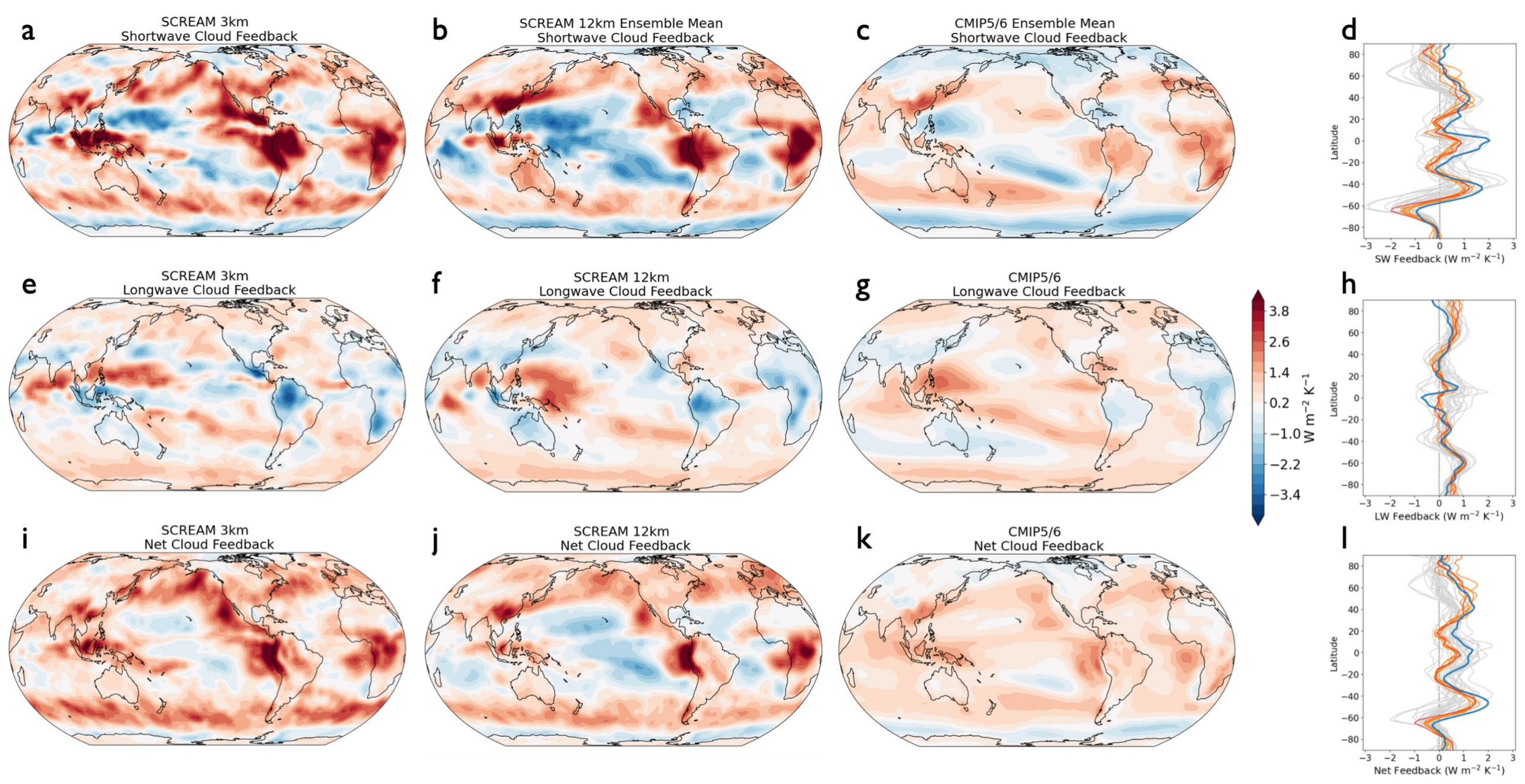

Figure 5. Map of SW and LW cloud feedback components and the combined net cloud feedback in SCREAM 3km (a,e,i), SCREAM 12km ensemble (b,f,j), and CMIP5/6 ensemble (c,g,k). On the far right column (d,h,l) are the zonal means of the cloud feedbacks from SCREAM 3km (blue), SCREAM 12km (orange), CMIP models (gray), and the CMIP ensemble mean (black).

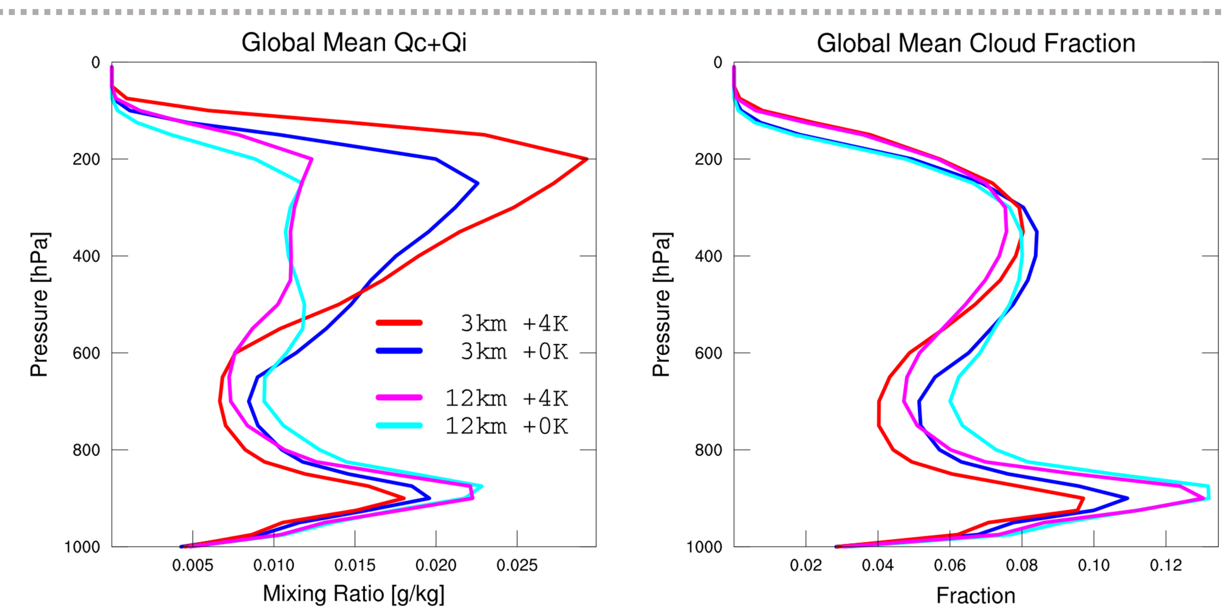

Figure 6. Area weighted global mean profiles of cloud condensate (left) and cloud fraction (right) for the last 3-months of the 13-month simulations for 3km runs and a single 12km ensemble member.

Key Take-Aways

- The total feedback of 3km SCREAM is on the high end of estimates from CMIP models due to a high SW cloud feedback
- Comparison of 3km and 12 km SCREAM reveal a notable resolution sensitivity of cloud feedbacks
- Comparison with X-SHiELD suggests that km-scale models will not inherently reduce the uncertainty of climate sensitivity

E3SM
Energy Exascale Earth System Model

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