Robustness and sensitivities of central U.S. summer convection in SP-CAM: Multi-model intercomparison with a new regional EOF index

Gabriel J. Kooperman[1], Michael S. Pritchard[2], Richard C. J. Somerville[1]
[1]Scripps Institution of Oceanography, UC San Diego, [2]University of Washington

Most global models do not simulate realistic summer rainfall in the lee of mountains 1

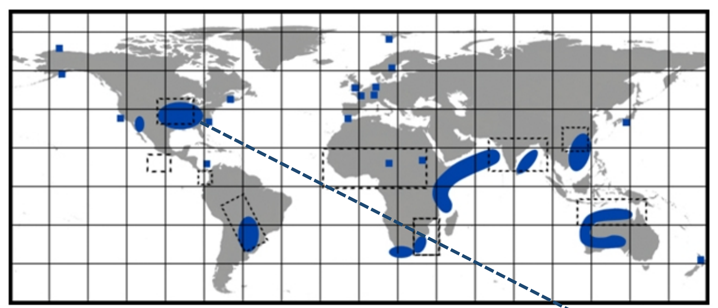


Figure 1. Regions where low-level jets (shaded) and MCSs (boxes) are know to occur from Stensrud [1996] and COMET®.

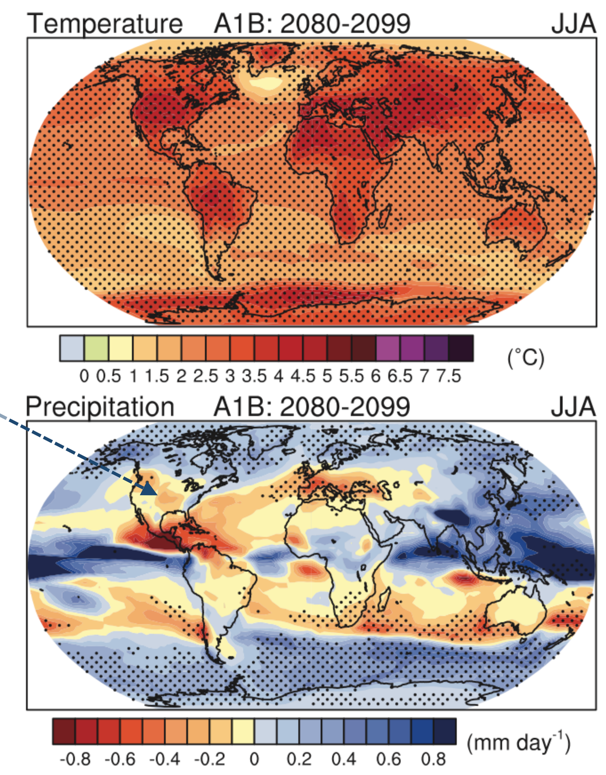


Figure 2. IPCC AR4 multi-model mean change in summer surface temperature (top) and precipitation (bottom) for the A1B scenario. Stippling denotes where models agree on the sign of the change.

- Mesoscale convective systems (MCSs) form on the leeward side of mountains worldwide in regions with low-level jets.
- Most global climate models (GCMs) are unable to simulate MCSs and disagree on the sign of future precipitation trends.
- In the central US these storms can bring 60% of summer rain.
- Improving the simulation of MCSs in GCMs is critical for projections of future climate change and rainfall patterns.

Propagating central US summer convection is captured in an early version of SP-CAM3.5 2

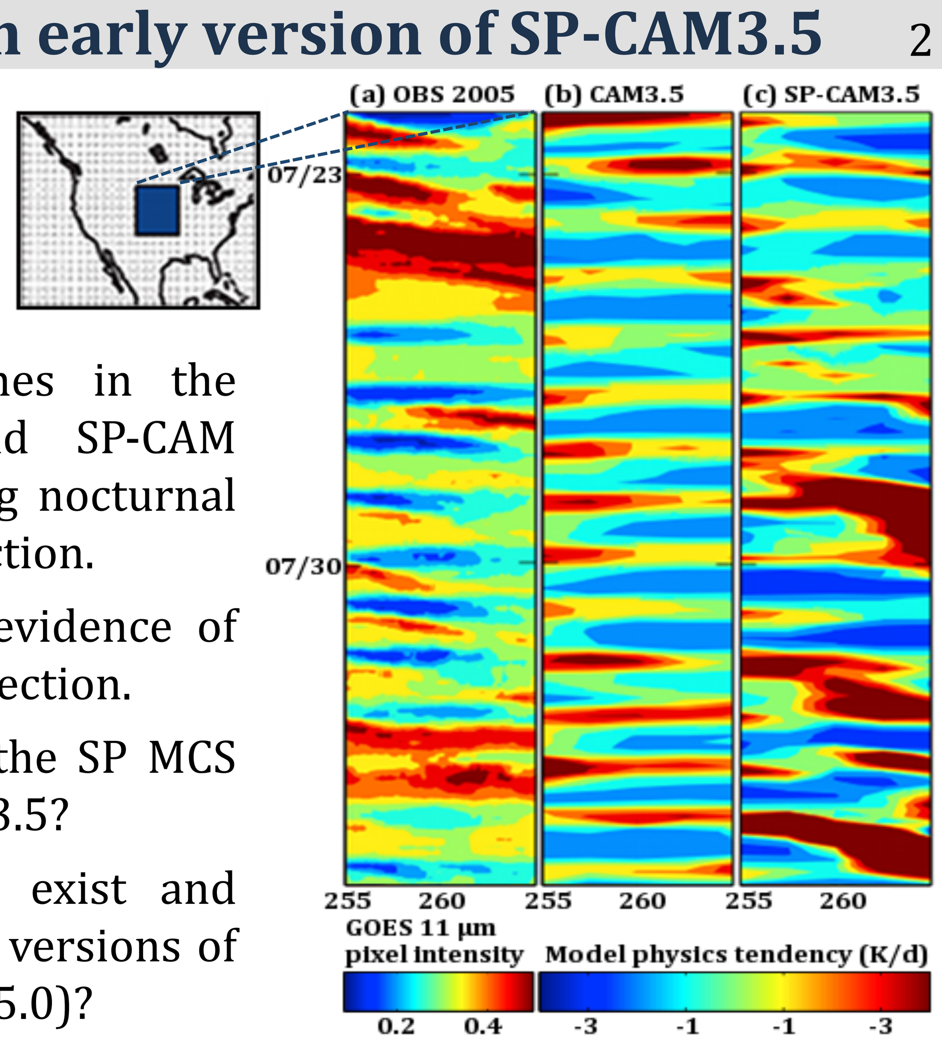
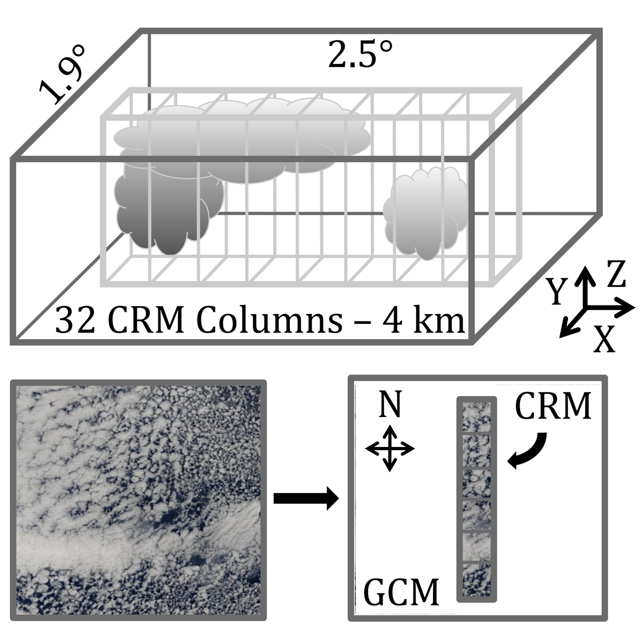


Figure 3. Hovmöller diagram of convection in (a) GOES (b) CAM, and (c) SP-CAM from Pritchard et al. [2011].

- Tilted phase lines in the observations and SP-CAM show propagating nocturnal mesoscale convection.
- CAM shows no evidence of propagating convection.
- How realistic is the SP MCS signal in version 3.5?
- Does the signal exist and improve in other versions of SP-CAM (3.0 and 5.0)?

SP-CAM simultaneously resolves both small- and large-scale processes related to clouds 3

- AKA super-parameterization.
- 2-D cloud-resolving models replace conventional cloud parameterizations.
- Host GCM: NCAR Community Atmosphere Model (CAM).
- 200x more expensive than CAM, but better scalability.
- Developed by CMMAP, an NSF STC, www.cmmap.org.



Multiscale Modeling Framework

Why a Wheeler and Hendon [2004] type EOF index for central US mesoscale convection? 4

- Organized convection in the tropics and mid-latitudes is a major source of variability.
- The convective signal has zonal propagation in both regions.
- An EOF based index has been useful for evaluating the MJO.
- The MJO index isolates eastward propagating convection and, with simple rules, composites MJO events by phase.

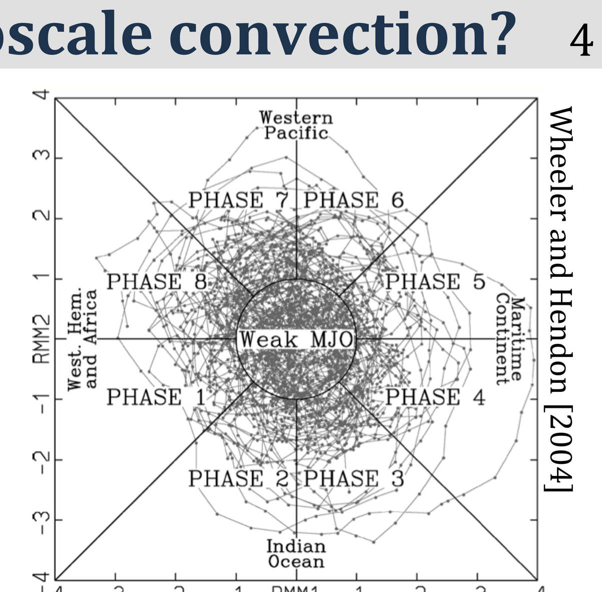


Figure 4. Phase diagram of MJO propagation from PC time series of 850, 200 hPa zonal wind, and OLR.

New MCS index to compare six conventional and super-parameterized versions of CAM 5

- 3 hourly MJJA longwave cloud forcing (LWCF) band-pass filtered for 12 to 48 hours from observations and six model versions is used to develop a new EOF index in the central US.
- Observations are from 23 years (1984–2006) of the NASA GEWEX Surface Radiation Budget (SRB) flux data.
- Hourly accumulated precipitation data from the NCEP Climate Prediction Center (CPC) is also compared in composite events.

Model configurations:

Model	GCM resolution	CRM resolution	Microphysics	Aerosol Physics
CAM3.0	T42, 26 levels	N.A.	1 moment	N.A.
SP-CAM3.0	T42, 26 levels	1x32, 4 km, NS	1 moment	N.A.
CAM3.5	1.9x2.5°, 30 levels	N.A.	1 moment	N.A.
SP-CAM3.5	1.9x2.5°, 30 levels	1x64, 1 km, EW	1 moment	N.A.
CAM5.0	1.9x2.5°, 30 levels	N.A.	2 moment	3 mode, 2 mom
SP-CAM5.0	1.9x2.5°, 30 levels	1x32, 4 km, NS	2 moment	3 mode, 2 mom

A regional LWCF leading EOF pair represents eastward propagating nocturnal convection 6

- Nocturnal variance of LWCF shows the MCS activity zone.
- EOF analysis of meridionally averaged LWCF in white box.
- Leading EOF-pair explains ~ 65% of the variance, 35% from EOF 1, 30% from EOF 2.
- EOFs 1 and 2 have spatial patterns in phase quadrature and high time-lag correlation.

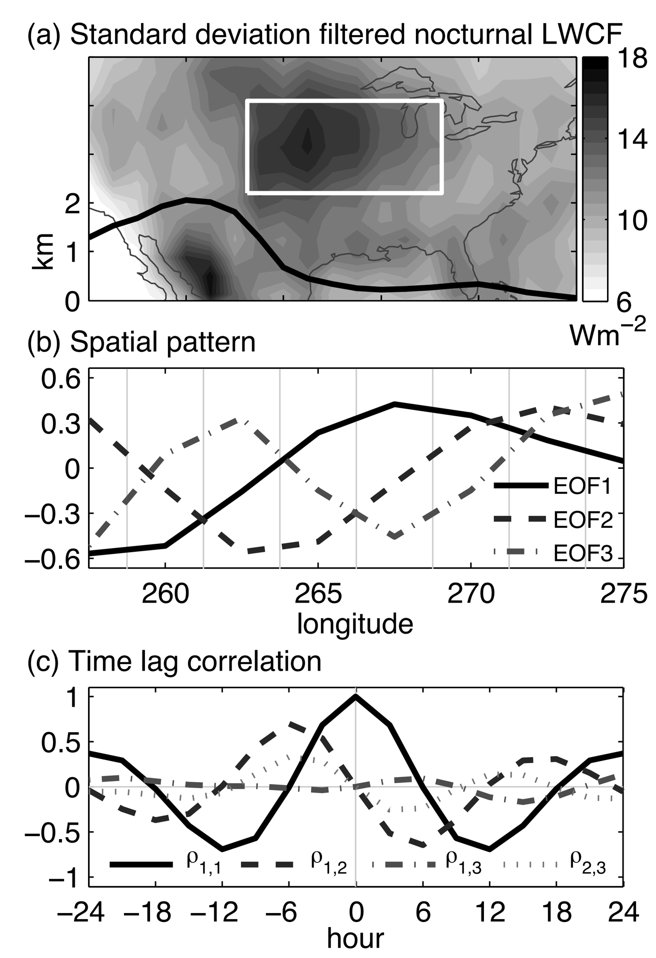


Figure 5. (a) Standard deviation of 12 to 48 hour band-pass filtered nocturnal (00–06 CST) longwave cloud forcing (W/m^2); the white box is the EOF analysis region. (b) Spatial patterns of EOFs. (c) Time-lag correlations between PC time series.

The new EOF index compactly isolates the mid-latitude MCS signal in SRB and SP-CAM 7

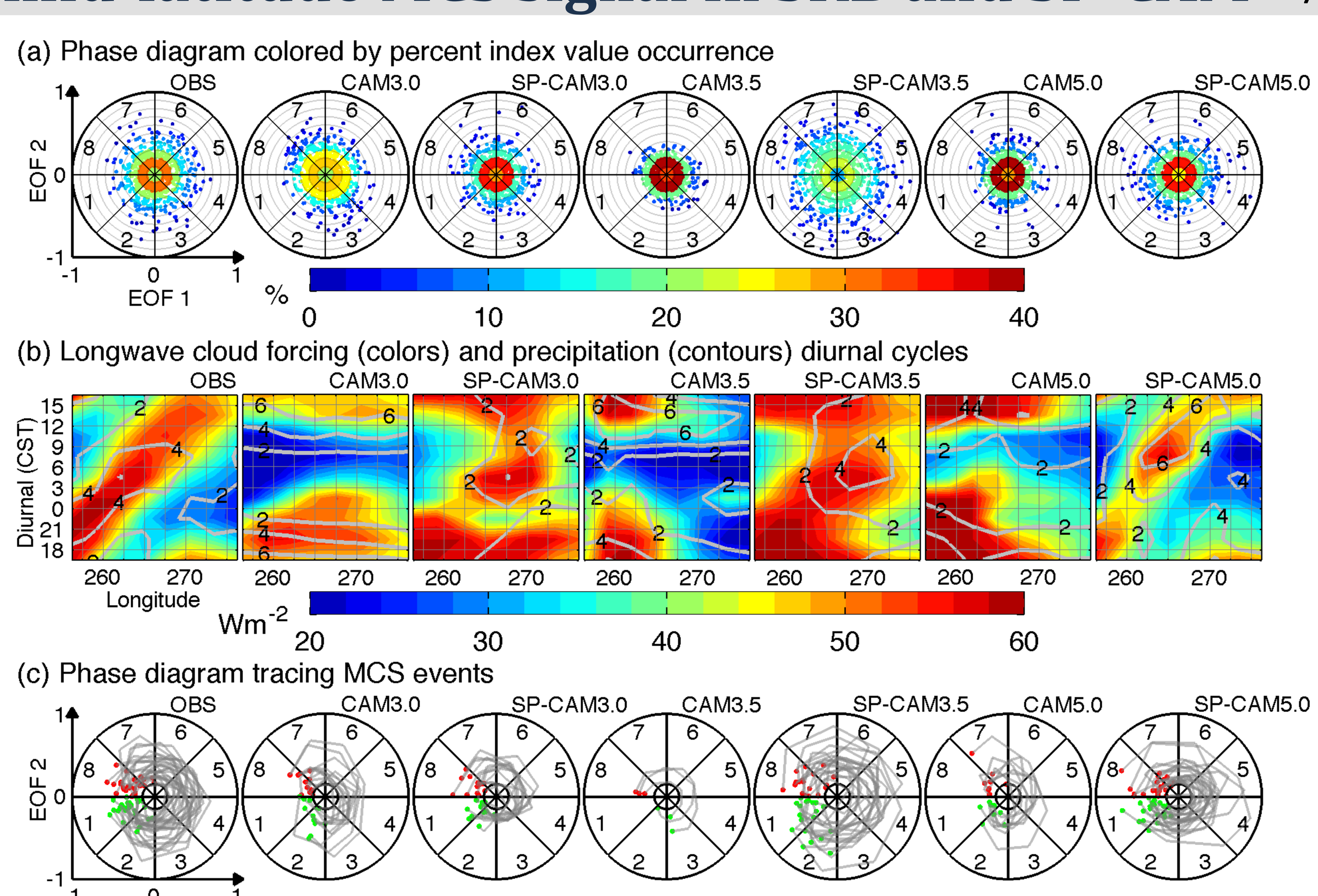


Figure 6. (a) Phase diagram of PC time series colored by percent index value occurrence. (b) Longwave cloud forcing (colors, W/m^2) and precipitation (contours, mm/d) diurnal cycles for index values greater than 0.25. (c) Phase diagram of EOF PC time series tracing MCS events based on selection criteria.

- SP-CAM3.5 has the highest amplitudes, CAM3.5 has the lowest.
- The eastward slant in Figure 6b shows nocturnal propagating convection in SRB and SP-CAM. SP-CAM5.0 agrees the best with the observed width and colocated precipitation.
- 24 events where identified in SRB; 13, 20, and 22 in SP-CAM; and 12, 3, and 9 in CAM for 3.0, 3.5, and 5.0, respectively.

Event selection criteria:

1. At least three (9 h) consecutive index amplitudes greater than 0.15 propagating forward (east) in phase space,
2. spanning at least 70% of the domain (~1200 km), and
3. starting between 18 and 03 local (CST) time.

MCS physics is a robust effect of SP and most realistic in 5.0 with two-mom microphysics 8

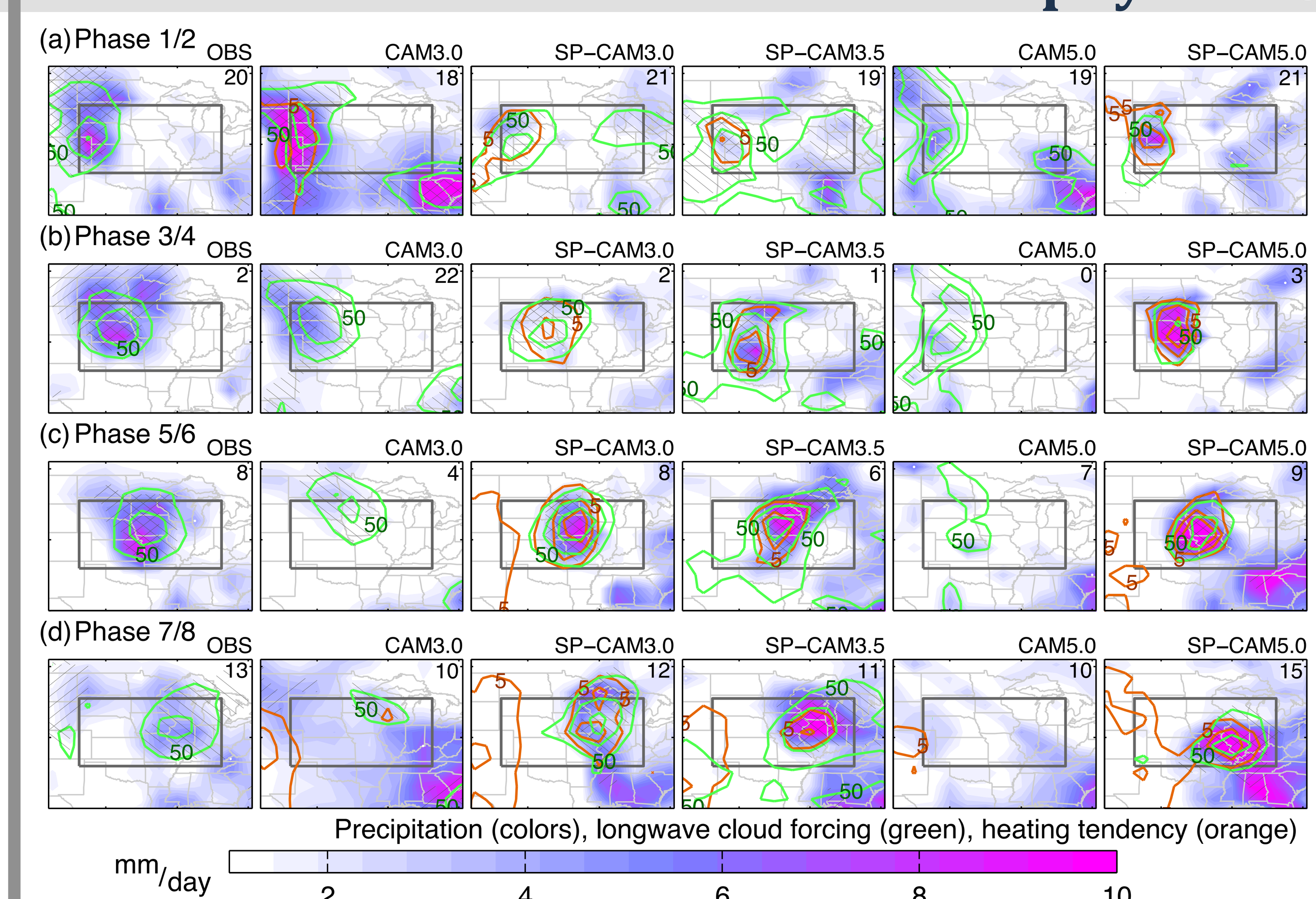


Figure 7. Composite event phase average of precipitation (colors, mm/d), longwave cloud forcing (green, increments of 25 W/m^2), and vertical standard deviation of model heating tendency (orange, increments of 2.5 K/d) in observations and models; right/45 (left/45) slashes indicate that precipitation (longwave cloud forcing) is significant at 95% confidence.

- Strong convective heating and rainfall anomalies overlapping LWCF are seen in all versions of SP-CAM, but not in CAM.
- Magnitude, timing, and extent of LWCF/rainfall improve in 5.0.

SP MCS events may become more intense with climate change in a 4x CO_2 scenario 9

- Boundary and initial conditions for SP-CAM5.0 are from the last 25 years CMIP5 pre-industrial PI & 4x CO_2 CESM experiments.

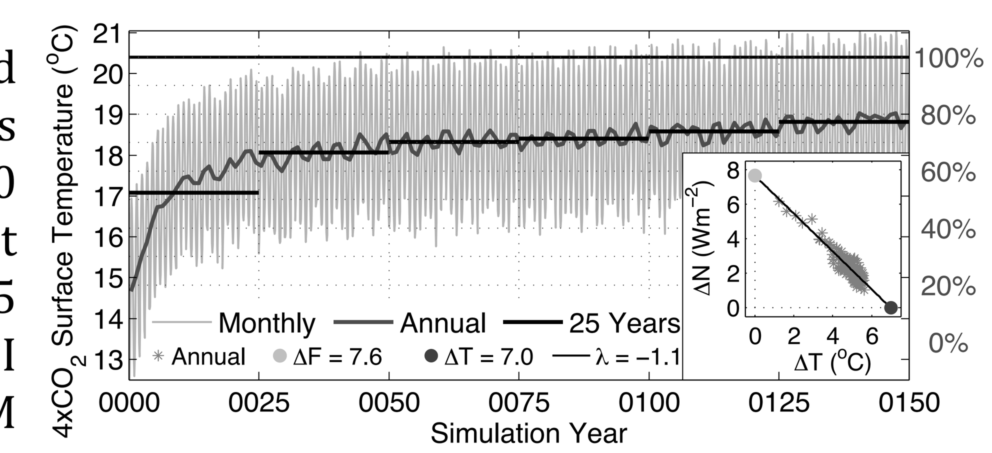


Figure 8. Change in temperature from the 4xCO_2 simulation.

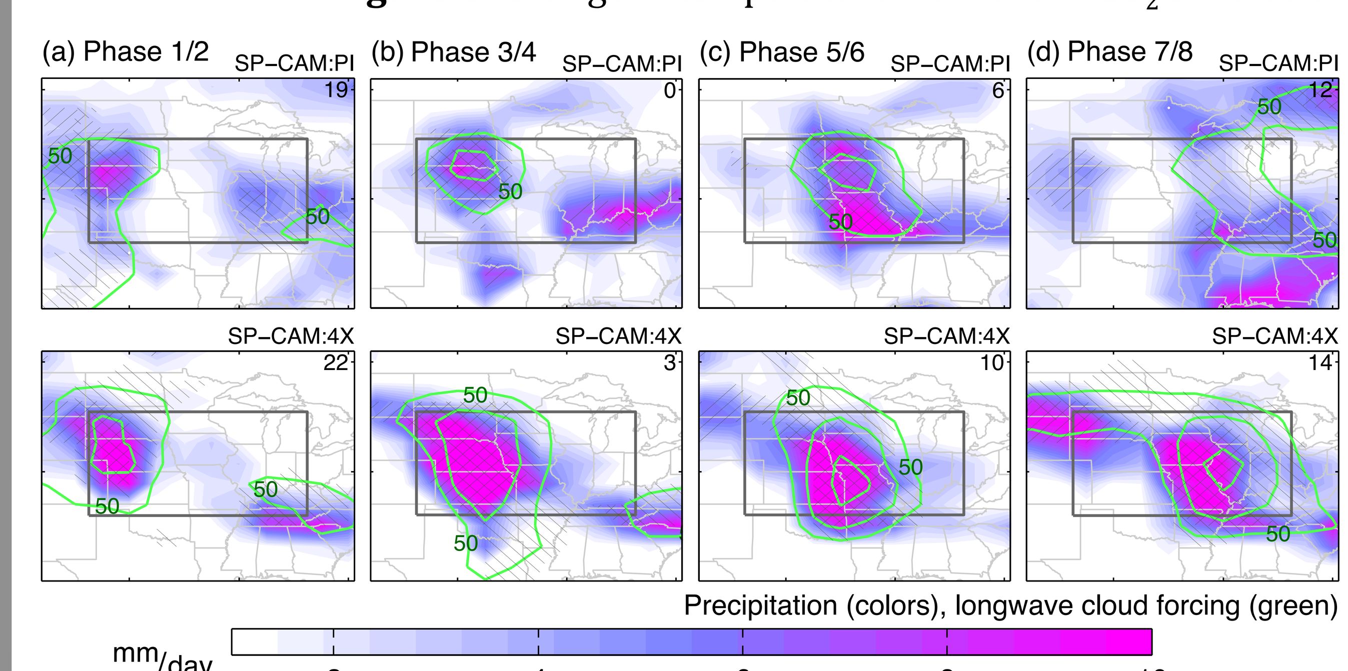


Figure 9. Same as Figure 7, but for SP-CAM5.0 PI and 4x pre-industrial CO_2.

- SSTs and sea-ice BCs are ~80% adjusted to the 4x CO_2 forcing.
- SP-CAM5.0 composite MCS events become more intense with higher CO_2: a 25 W/m^2 increase in LWCF magnitude, greater areal extent, increased precipitation, and persist for longer.

Conclusions: SP is a useful analog to nature 10

- A new EOF based index compactly evaluates the mid-latitude MCS signal in conventional and super-parameterized GCMs.
- US MCS physics is a robust effect of super-parameterization.
- The signal is most realistic in 5.0 with two-mom microphysics.
- MCS events may become more intense with climate change.

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Contact Information. Gabriel J. Kooperman, Scripps Institution of Oceanography, UC San Diego, 9500 Gilman Drive, Dept. 0224, La Jolla, CA 92093. (gkooperman@ucsd.edu).