Microphysical Sensitivity of Superparameterized Precipitation Extremes in the Continental US Due to Feedbacks on Large-scale Circulation

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Abstract

Superparameterized (SP) global climate models have been shown to better simulate—as compared to conventional models—various features of precipitation, including diurnal timing as well as extreme events. While various studies have looked at the effect of differing microphysics parameterizations on precipitation within limited-area cloud-resolving models, we examine here the effect on continental-US extremes in a global SP model. We vary the number of predicted moments for hydrometeor distributions, the character of the rimed ice species, and the representation of raindrop self-collection and breakup. Using a likelihood ratio test and accounting for the effects of multiple-hypothesis testing, we find that there are some regional differences, both in the current climate and in a warmer climate with uniformly increased sea-surface temperatures. These differences are most statistically significant and widespread when the number of moments is changed. To determine whether these results are due to (fast) local effects of the different microphysics or the (slower) ensuing feedback on the large-scale atmospheric circulation, we run a series of short, 5-day simulations initialized from reanalysis data. We find that the differences largely disappear in these runs and therefore infer that the different parameterizations impact precipitation extremes indirectly via the large-scale circulation. Finally, we compare the present-day results with hourly rain-gauge data and find that, for the model configuration and resolution used, SP underestimates extremes relative to observations regardless of which microphysics scheme is used.

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Introduction

In the context of climate modeling, super-parameterization (SP) refers to the replacement of convective schemes in each grid column with a cloud-resolving model (CRM). Because the CRM has resolutions on the order of a few kilometers, it can more explicitly resolve convective processes and cloud-scale interactions. Super-parameterization has been shown to improve the diurnal timing and the intensity of precipitation. However, additional parameterizations remain in climate models. In particular, different microphysics formulations have been shown in limited-domain CRM studies to impact precipitation structures and statistics. **Here, we investigate the effect of varying microphysics on SP precipitation extremes in both climatological runs and short, 5-day integrations initialized by CFSv2 reanalysis (ILIAD framework developed by O'Brien et al., 2016 [3]).**

Microphysics Experiments

1. **1M_Base** (Khairoutdinov and Randall, 2003) [1]
   - In the 1-moment formulation, only one moment of the hydrometeor size distribution—the mixing ratio—is predicted. The number concentration is diagnosed (from the mixing ratio).
2. **2M_Base** (Morrison et al., 2005) [2]
   - In the 2-moment formulation, two moments of the hydrometeor size distribution—the mixing ratio and the number concentration—are predicted.
3. **2M_Hail**
   - Use hail instead of graupel as the rimed-ice species. Hail particles are bigger, denser, and have a faster terminal velocity.
4. **2M_600**
   - Raindrops combine with a collection efficiency of 1 until the mean diameter in a grid cell reaches a size threshold, at which point the efficiency decreases, representing increased drop breakup. The threshold is altered from the default 300 μm to 600 μm.

SPCAM Simulation Description

- SPCAM version 5.2
- GCM horizontal resolution: 1.9° latitude x 2.5° longitude
- CRM horizontal resolution: 2 km, 32 columns
- 30 vertical levels
- 3-hourly model output
- **Climatological** runs: 7-year run; climatological (1982-2001) SSTs
- **ILIAD** runs: 5 years of 5-day runs; output from fifth day

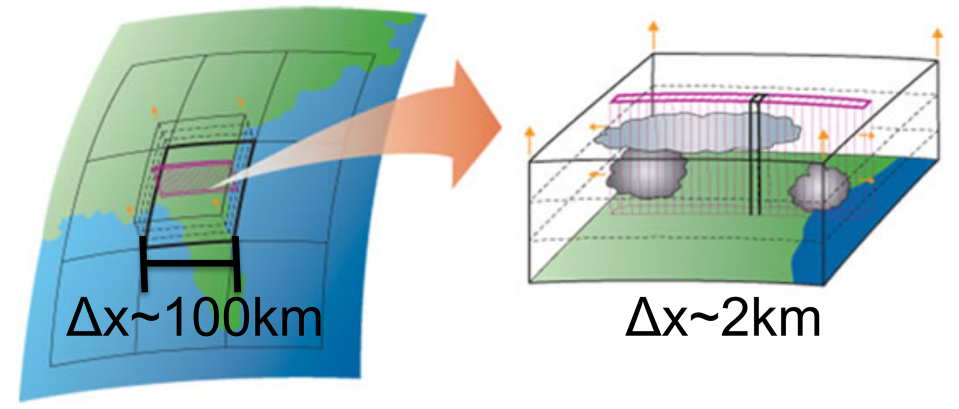

Fig. 1. Schematic representation of super-parameterization. Within a (left) GCM grid column, a (right) CRM is embedded.

Identifying Extremes and Implementing Statistical Test

Within each grid cell and for each season:

1. For each of the four cases, the 98th percentile (including times with zero precipitation) was calculated. The maximum of these four values was taken as the threshold u in the distribution described in step 2.
2. A non-homogeneous point Poisson process was fitted to the extremes. Temporal dependence was accounted for by only taking the maximum in contiguous rain events.

$$\lambda(t,y)=\frac{1}{\sigma}\left[1+\xi\left(\frac{y-\mu}{\sigma}\right)\right]^{-1/\xi-1},\ y\geq u$$

μ - location
σ - scale
ξ - shape

3. A log-likelihood ratio test (comparing two cases) was performed with a significance level of $\alpha = 0.05$.

$$\chi^2(z, df=3)$$

$$z=-2\ln\left(\frac{L_{AB}}{L_A L_B}\right)$$

L = f(λ) denotes the likelihood given a fit of a dataset. L_{AB} fits the combined datasets of A and B.

Results

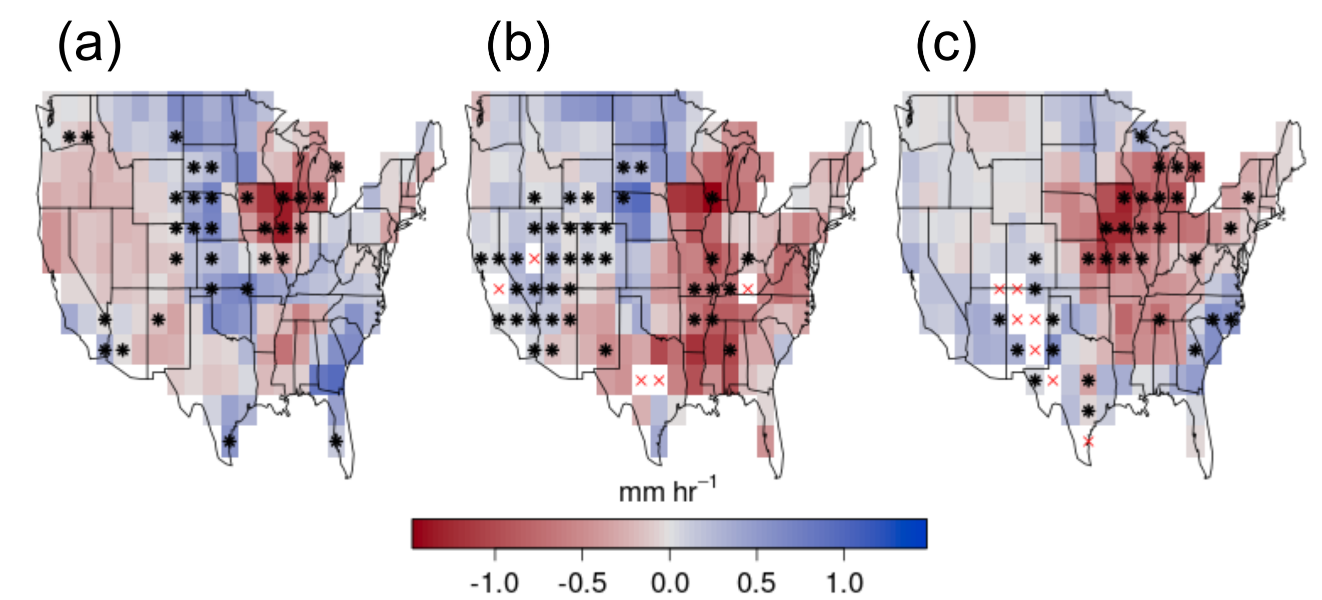

Fig. 2. **Climatological** runs. 2M_Base 1-year return value minus that of (a) 1M_Base in the annual, (b) 1M_Base in JJA, and (c) 2M_600 in MAM. Grid cells with statistically different distributions at the α=0.05 level are denoted by asterisks (*). Grid cells where parameter estimation failed are denoted by a red X.

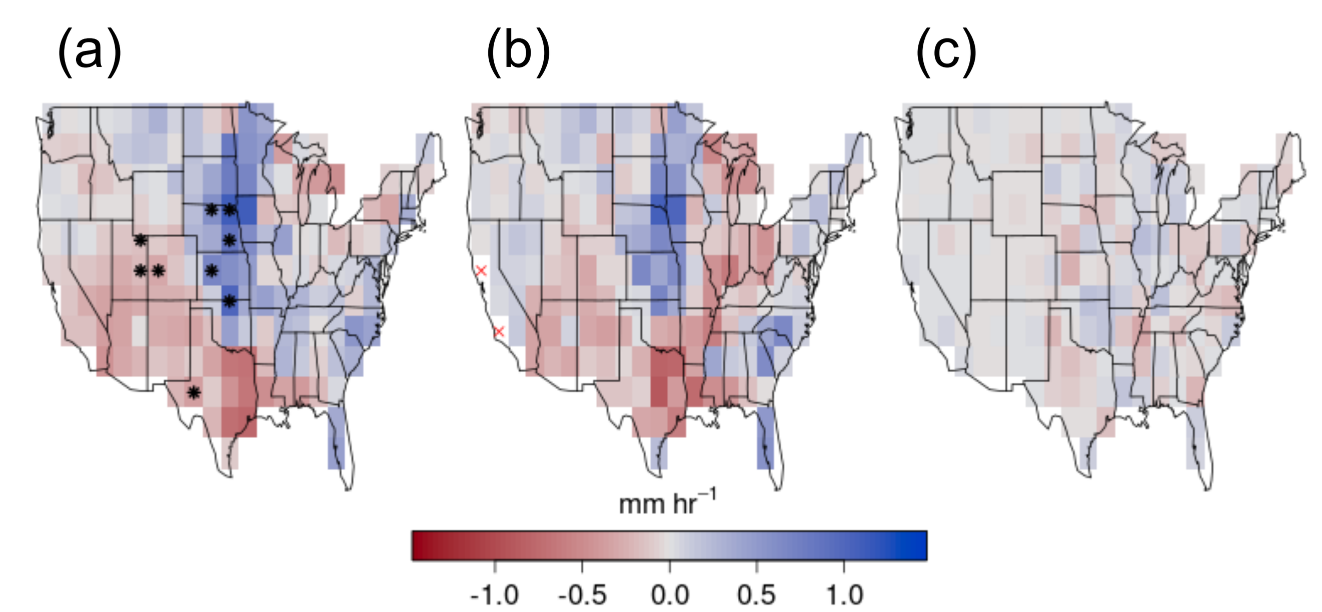

Fig. 3. As in Fig. 2, but for 5-day **ILIAD** simulations.

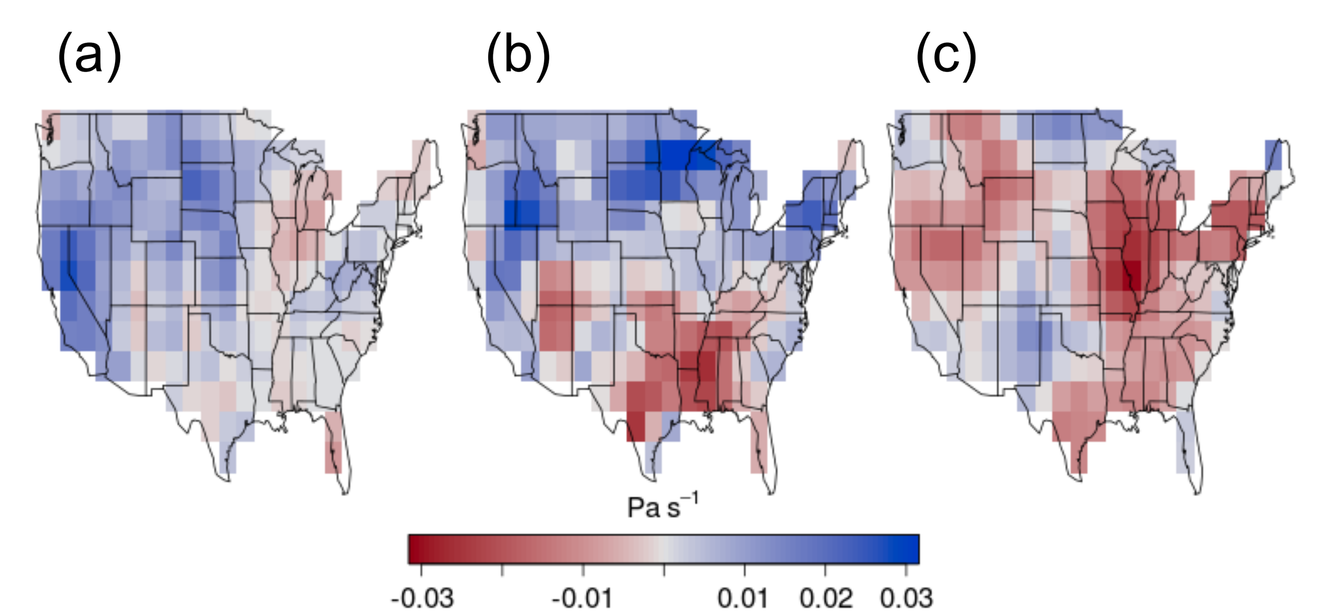

Fig. 4. 2M_Base climatological, daily-mean ω_{500} subtracted from that of (a) 1M_Base in the annual, (b) 1M_Base in JJA, and (c) 2M_600 in MAM.

Summary and Conclusions

- Responses in precipitation extremes differ with variants of microphysics schemes
- Most of the (climatological) signal is due to slower changes in the large-scale circulation, as evidenced by the small response in 5-day integrations, though the existence of any response in these short experiments means local, faster timescale effects are possible
- Evidence of impact on the large-scale circulation can be seen in daily-mean maps of ω_{500}

Appendix

When doing multiple-hypothesis testing, e.g., at individual grid cells, it is important to control the false discovery rate (FDR): the fraction of rejected null hypotheses that are in fact true (Wilks 2016) [4]. We do this by only rejecting p_i:

$$p_i \leq p_{FDR} = \max_{i=1,\ldots,N}\left[p_i : p_i \leq (i/N)\,\alpha_{FDR}\right],\ \alpha_{FDR}=0.05$$

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Acknowledgments

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