# =enter title here=

**D. Kennedy[1,2], D. M. Lawrence[1], and I. R. Simpson[1]**

[1]Climate and Global Dynamics Laboratory, NSF National Center for Atmospheric Research, Boulder, CO
[2]Earth Research Institute, University of California Santa Barbara, Santa Barbara, CA

## Key Points:

- enter point 1 here
- enter point 2 here
- enter point 3 here

Corresponding author: Daniel Kennedy, djk2120@ucar.edu

**Abstract**

[ enter your Abstract here ]

## Plain Language Summary

Enter your Plain Language Summary here or delete this section. Here are instructions on writing a Plain Language Summary: https://www.agu.org/Share-and-Advocate/Share/Community/Plain-language-summary

## 1 Introduction

The 2020 Southwest U.S. drought was the driest summer of the instrumented record and part of a 20-year megadrought with severe consequences for water resources.

Coupled ESMs have not captured humidity trends in semi-arid ecosystems (Simpson et al., 2024).

Though ESMs show a slight increase in spring precipitation in the region, there does not seem to be an attributable influence of climate change on NAM precipitation. Previous work indicates that the 2020 SWUS drought was not exacerbated by climate change, but was rather a result of internal atmospheric variability (Seager et al., 2022).

## 2 Methods

## 3 Results and Discussion

### 3.1 Simulating the 2020 SWUS drought

### 3.2 Porting the 2020 circulation to past and future climates

### 3.3 Similarities and differences between the CCE and the CESM2-LE

ET∼SM looks the same. But P∼ET looks a bit different. The CCE mean looks to be in a reasonable spot, roughly speaking, but the partial response of P to varying ET (via land initialization) looks much smaller than in the fully coupled model. This would seem to indicate that the coupling of SM-¿ET is agnostic to the broader circulation, whereas P is not simply determined by the local ET. In the coupled model we tend to see an 18mm reduction in P for a 10mm reduction in ET, but in the CCE it looks more like 5mm P per 10mm ET. In the coupled model the circulation associated with 140mm ET may be quite different from the circulation that results in 120mm ET, in addition to any differences in the initial conditions. In the CCE, only the initial conditions are different, and the large-scale circulation is following observations. When CCE goes from ET of 120 to 100, the broader circulation still provides a relatively equivalent flux of water to the region (in fact slightly higher), which helps support the precipitation from falling drastically. In the coupled model, when ET goes from 140 to 120mm, it is probably largely driven by a change to a more diverging circulation, whereby the precip is robbed of the convergence flux as well as the associated reductions in ET flux.

Does this invalidate inference from the CCE? No, it just means that any takeaways are conditional to the given circulation pattern. In the case of understanding sensitivity to initial conditions in the 2020 ensemble, the experimental framework is probably quite helpful. In the case of the analogue simulations, it's slightly more complicated, because warmer or colder climates may not be able to develop this circulation pattern. Towards this end, the fact that the 2090 ensemble is so much drier than anything seen in the fully coupled model is hard to overlook. This would seem to indicate that CESM2 predicts changes in circulation that would disallow the droughts we are simulating in the

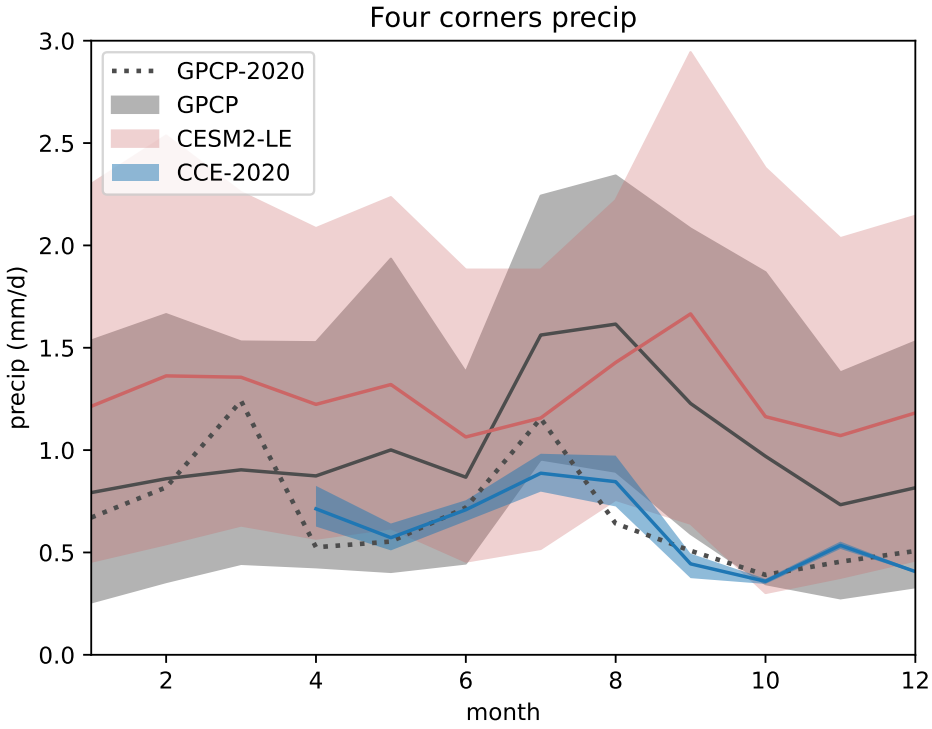


**Figure 1.** The constrained circulation ensemble provides a reasonable match for precipitation observations during the 2020 SWUS drought, despite biases in the fully coupled model. Shaded areas span the 5th to 95th percentiles across pooled ensemble-years (CESM2: 1980-2020, CCE: 2020 only), or in the case of the GPCP observational product, simply across years (1980-2020). Solid lines denote the climatological averages. The GPCP observed precipitation during 2020 is shown as the dotted line. Additional panel with experimental protocol and perhaps some dynamical notion tk.

2090 CCE. Further work to understand the mechanisms underpinning may be interesting, especially given the tendency across many coupled models to produce aberrant VP trends in semi-arid ecosystems.

Why is the CCE drier than the LE in 2090?

### 3.4 Inference capabilities for extreme droughts

## 4 Conclusions

## Open Research Section

This section MUST contain a statement that describes where the data supporting the conclusions can be obtained. Data cannot be listed as "Available from authors" or stored solely in supporting information. Citations to archived data should be included in your reference list. Wiley will publish it as a separate section on the paper's page. Examples and complete information are here: https://www.agu.org/Publish with AGU/Publish/Author Resources/Data for Authors

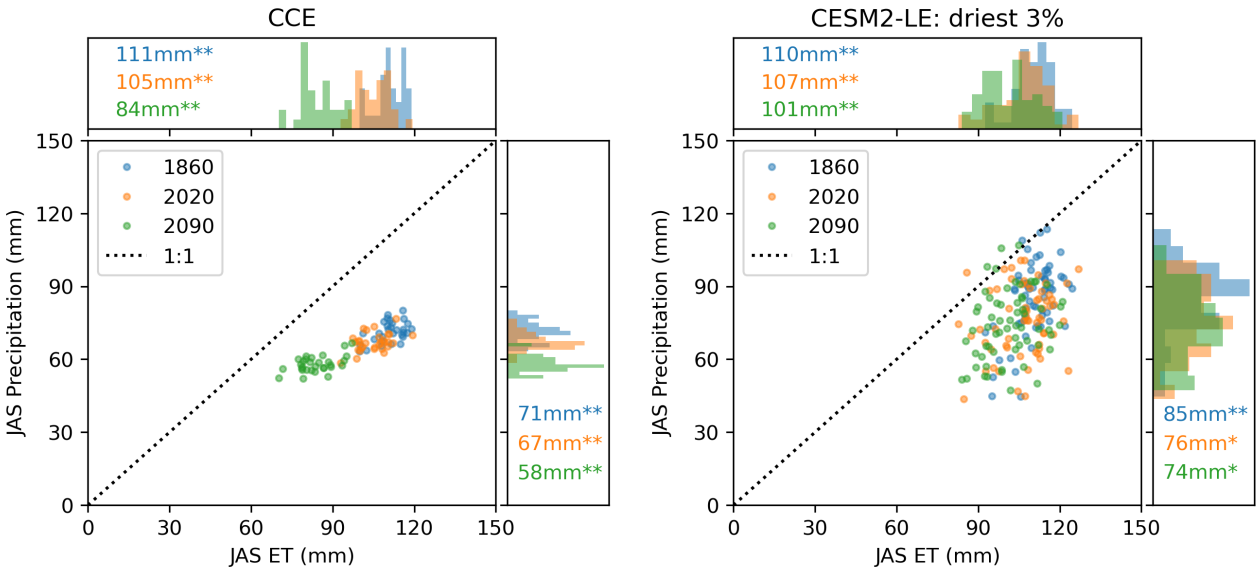


**Figure 2.** Monsoon period precipitation vs. ET in the CCE and a dry subset of the CESM2-LE from three different time periods. ET and Precip seem to decline in both ensembles in response to climate change forcing. Printed numbers indicate the various ensemble means. Two asterisks indicate a given ensemble mean is distinguishable from both the other time period means at the p<0.05 level. One asterisk indicates it is distinguishable from just one of the other time periods. The dry subset of the CESM2-LE is defined as the 3% driest ensemble years from the given time period based on JAS 10cm soil moisture (see methods). Relabeled as 1850 tk.

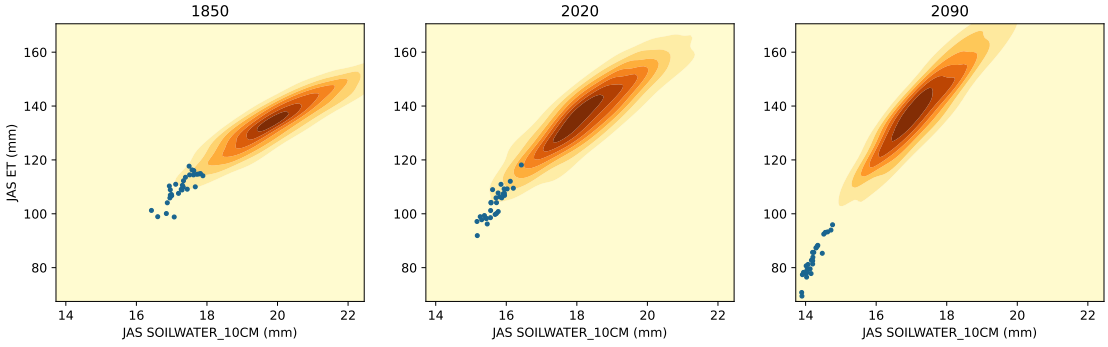


**Figure 3.** Soil moisture (10cm) vs. ET in the CCE (dots) and the CESM2-LE (scatter density heat map) for three time periods. The CCE appears fully consistent with the coupled model with regard to this relationship, demonstrating an intensification of the hydrological cycle in the region. Note that the CCE does however appear significantly drier relative to the LE in 2090 as compared to 1850 or 2020. A second set of plots with something less clean looking potentially tk.

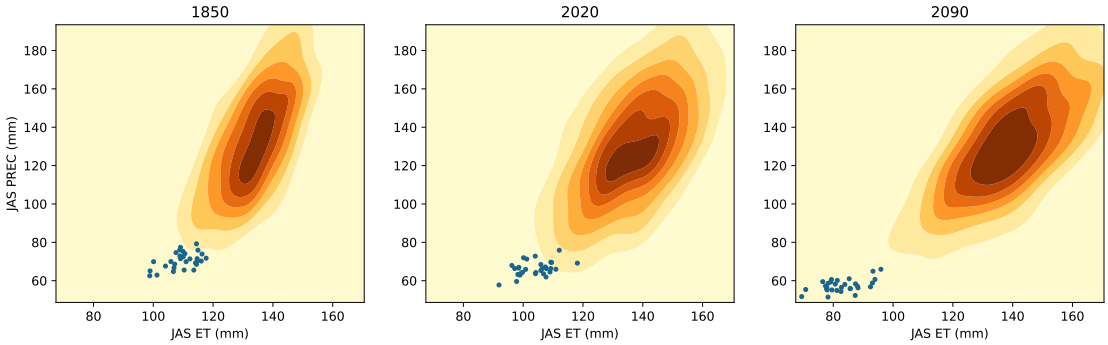


**Figure 4.** Soil moisture (10cm) vs. ET in the CCE (dots) and the CESM2-LE (scatter density heat map) for three time periods. The CCE appears fully consistent with the coupled model with regard to this relationship, demonstrating an intensification of the hydrological cycle in the region. Note that the CCE does however appear significantly drier relative to the LE in 2090 as compared to 1850 or 2020. A second set of plots with something less clean looking potentially tk.

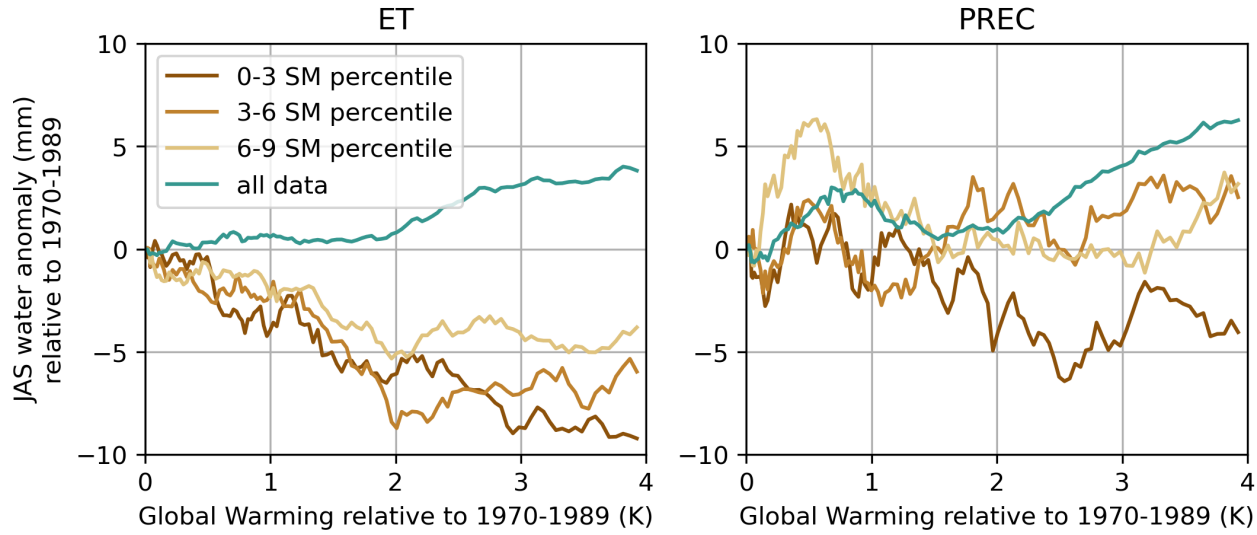


**Figure 5.** Monsoon period precipitation and ET anomalies (relative to 1970-1989) from the CESM2-LE from various ensemble subsets delineated based on 10cm soil moisture. Whereas the ensemble mean (turquoise) shows increases in precipitation and ET, the drier subsets can feature decreases. For reference, CESM2 climatological precipitation and ET are XX and YYmm. Refigured with non-overlapping composites tk.

## Acknowledgments

Enter acknowledgments here. This section is to acknowledge funding, thank colleagues, enter any secondary affiliations, and so on.


## References


Seager, R., Ting, M., Alexander, P., Nakamura, J., Liu, H., Li, C., & Simpson, I. R. (2022). Mechanisms of a meteorological drought onset: Summer 2020 to spring 2021 in southwestern north america. *Journal of Climate*, *35*(22), 7367 - 7385. doi: 10.1175/JCLI-D-22-0314.1

Simpson, I. R., McKinnon, K. A., Kennedy, D., Lawrence, D. M., Lehner, F., & Seager, R. (2024). Observed humidity trends in dry regions contradict climate models. *Proceedings of the National Academy of Sciences*, *121*(1), e2302480120. Retrieved from `https://www.pnas.org/doi/abs/10.1073/pnas.2302480120` doi: 10.1073/pnas.2302480120