Regional Analysis of Precipitation in a Community Atmosphere Model (CAM6) Perturbed Physics Ensemble (PPE)

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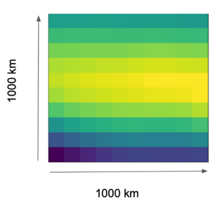
Abstract

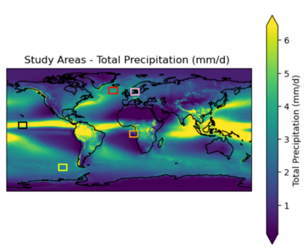
Climate simulations and projections of regional rainfall are important to society, and climate models are one important tool used for such projections. However, because of uncertainties in small-scale physics processes that differ from one region to another, climate models often perform better in some areas relative to others. In order to understand climate model regional projection skill, we need to better understand their present-day rainfall simulation performance across a variety of regions spanning Earth. To begin understanding regional skill, we analyzed a Perturbed Physics Ensemble (PPE) of the CESM2-CAM6 model, and specifically compare the PPE members' rainfall simulations with each other and against ERA5 reanalysis, for five different types of rainfall regimes (as well as globally). We determine which PPE members most skillfully simulate the diverse regimes. The physics parameter settings associated with each of these members are compared to the CAM6 default values to determine whether some parameters exclusively push in one direction relative to the default settings. Our results could inform decisions regarding future parameter auto-calibration efforts in the CESM-CAM model, thus potentially aiding in climate model tuning efforts and possibly enabling improved skill in the model's hydrologic cycle prediction.

1. Introduction

Climate model tuning is essential for improving global climate predictions, yet models often exhibit varying accuracy across different regions. This study focuses on five regions with distinct rainfall regimes to analyze precipitation outputs under varying parameter combinations.

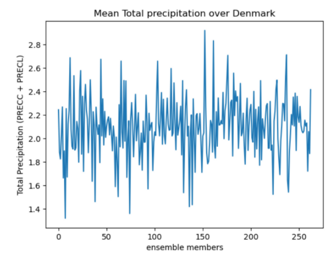
The analysis centers on total precipitation outputs from the CAM6 PPE, combining PRECC (Convective Precipitation Rate) and PRECL (Large-scale Precipitation Rate). Regional accuracy is assessed by comparing ensemble outputs to ERA5 Reanalysis data, identifying parameter combinations that yield the most realistic precipitation. Additionally, the relationship between parameters and regional outputs is examined using predictive models, including linear regression and a neural network, to explore connections and model skill.





2. Methodology

The dataset included 263 ensemble members, each with unique combinations of 45 parameters related to microphysics, turbulence, convection, and aerosol processes. Each member produced 36 monthly precipitation averages from CAM6, spatially and temporally averaged to a single mean value per region. These were compared to ERA5 Reanalysis, with plots showing precipitation (mm/day) against ensemble members. ERA5's mean precipitation was marked with a ±1.5 standard deviation band to identify members closely matching observations. Ensemble member 0, representing CAM6 defaults, was highlighted. The parameter values of ensemble members within the ERA5 band were analyzed for systematic trends relative to CAM6 defaults. Linear regression and neural networks, trained on 210 members and tested on 52, predicted precipitation based on standardized parameter values.



3. Results

The CAM6 default parameter ensemble member matched ERA5 Reanalysis precipitation within the ±1.5 standard deviation band for 2 of 5 regions and globally. Of the 263 ensemble members, only 7 produced precipitation outputs within this band across all regions. For these 7 members, 4 parameters consistently shifted positively and 10 negatively relative to the CAM6 default. These parameters mostly bleonged to the microphysics category.

The linear regression model accurately predicted precipitation outputs across most regions based on parameter values but struggled in the Pacific region. The neural network model performed slightly worse, particularly in the Pacific, near Greenland, and globally. These findings highlight challenges in optimizing parameter settings for all regions, as current ranges may not be universally suitable. This study provides a foundation for refining CAM6 parameter ranges to improve regional performance and enhance the model's hydrological cycle accuracy.

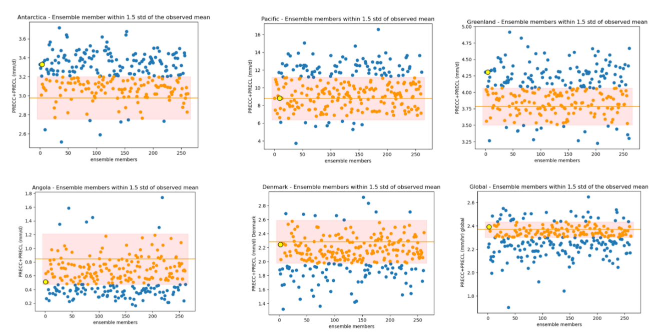


Fig. 1: Total precipitation for each PPE member is show with a blue dot. The orange line is the ERA5 Reanalysis mean.

Linear Regression Results

	Study Area	MSE
0	Global	0.004
1	Antarctica	0.024
2	Pacific	0.752
3	Greenland	0.042
4	Angola	0.030
5	Denmark	0.046

Neural Network Results

	Study Area	MSE
0	Global	0.020
1	Antarctica	0.029
2	Pacific	1.765
3	Greenland	0.104
4	Angola	0.044
5	Denmark	0.070

Fig. 2: The Mean Squared error between the model's precipitation prediction and the value from the CAM6 PPE dataset

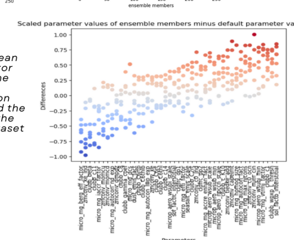


Fig. 3: Difference between the CAM6 default parameters values and the 7 PPE members paramter values. Ordered from most negative differences to positive differences

4. Conclusion

This study highlights the importance of exploring different parameter combinations in CAM6 to improve regional precipitation predictions. These findings suggest that parameter ranges in CAM6 may not be optimal for all regions, emphasizing the need for targeted adjustments. Future work could refine parameter auto-calibration to improve precipitation accuracy across diverse climate regimes.

5. Next Steps

Expanding the analysis of CESM2-CAM6 PPE precipitation outputs to more regions globally could provide a stronger basis for identifying ensemble members that align closely with the ERA5 Reanalysis mean. Additionally, exploring temporal variations rather than averaging over time may reveal new insights into seasonal precipitation differences between the CAM6 PPE and ERA5 Reanalysis datasets.

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