



GENERAL ATMOSPHERIC CIRCULATION AND PRECIPITATION EVALUATION OF NEXT-GENERATION EARTH SYSTEM MODELS



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Introduction

- Climate model evaluation is essential for understanding the strengths and limitations of model components (Eyring et al. 2019)
- Precipitation is exceedingly difficult to represent due to:
 - Coarse-resolution (Legates, 2014; Räisänen, 2007)
 - Parameterization of sub-grid-scale physical processes (Pieri et al. 2015)
 - General atmospheric circulation affects precipitation patterns (ITCZ, storm tracks, etc.) (Held, 2019)
- OptimESM aims to develop the next generation of ESMs with increased resolution and process realism.

Methodology

- MSPAEF metric used to evaluate the spatial distribution of precipitation:

$$\text{MSPAEF} = 1 - \frac{1}{\sqrt{4}} \sqrt{(\alpha - 1)^2 + (\beta)^2 + (\gamma)^2 + (\delta)^2}$$

with:

$$\alpha = \rho(M, O), \beta = \text{NRMSE}, \gamma = \frac{|\bar{M} - \bar{O}|}{\text{IQR}_O}, \delta = \sqrt{(\sigma^2 - 1)^2 + \left(\frac{\sigma^2 - 1}{\sigma^2}\right)^2}$$

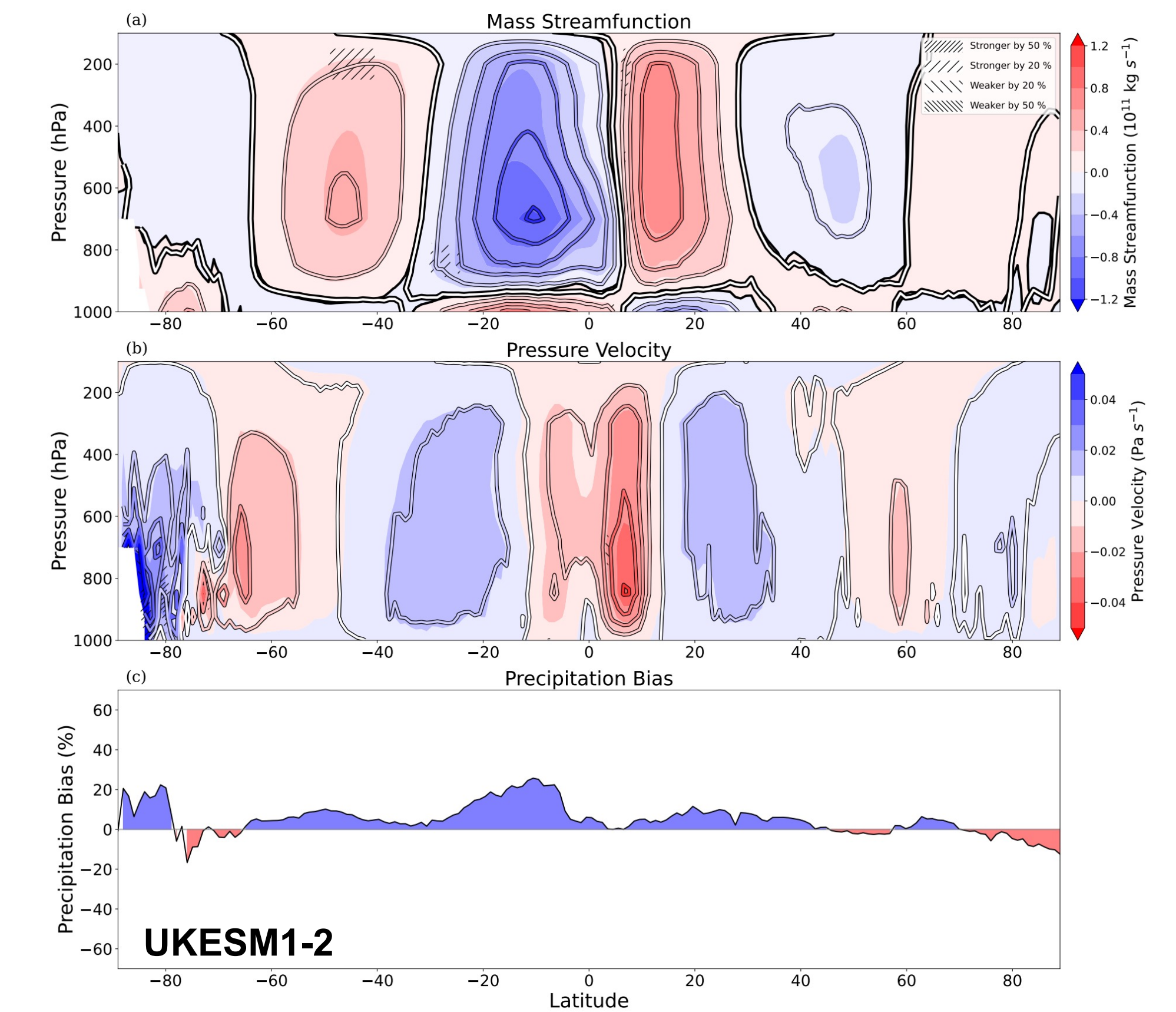
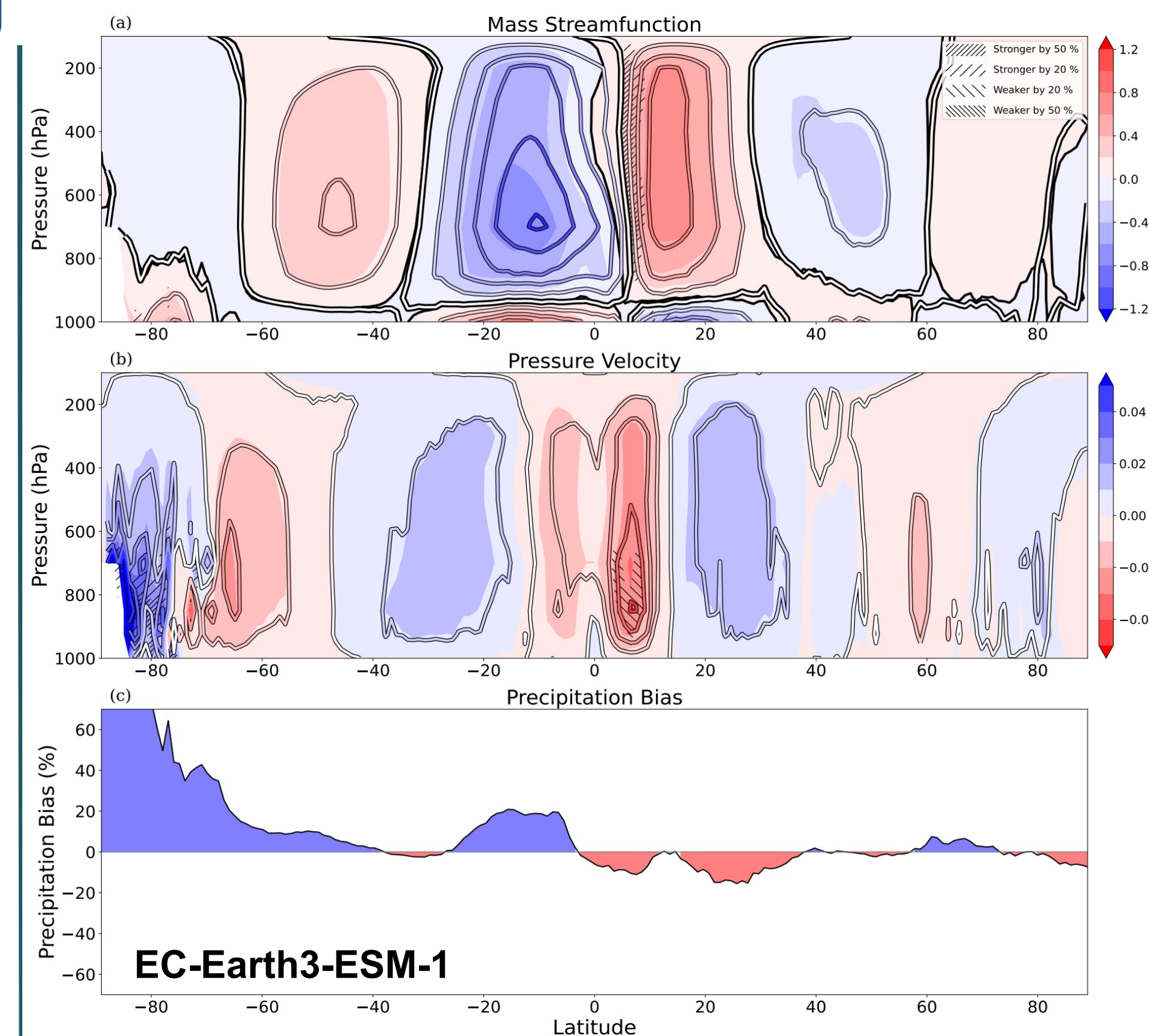
also:

$$\text{NRMSE} = \frac{1}{\text{IQR}_O} \sqrt{\frac{\sum_i^n (M_i - O_i)^2}{n}} \text{ and } \sigma = \frac{\sigma_M}{\sigma_O}$$

- Zonal mean mass stream-function:

$$\Psi_M = \frac{2\pi a \cos \varphi}{g} \int_0^p v dp$$

Zonal Mass Streamfunction and Pressure Velocity

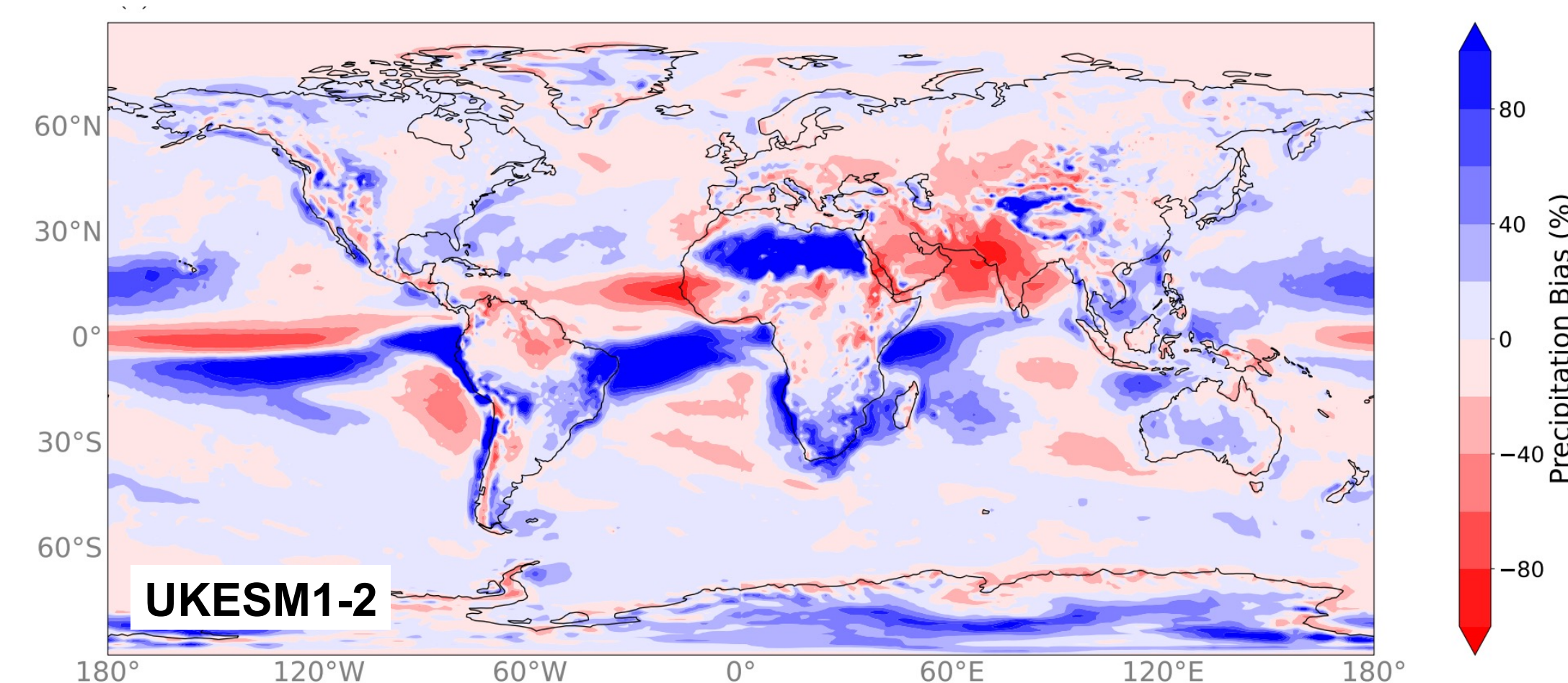
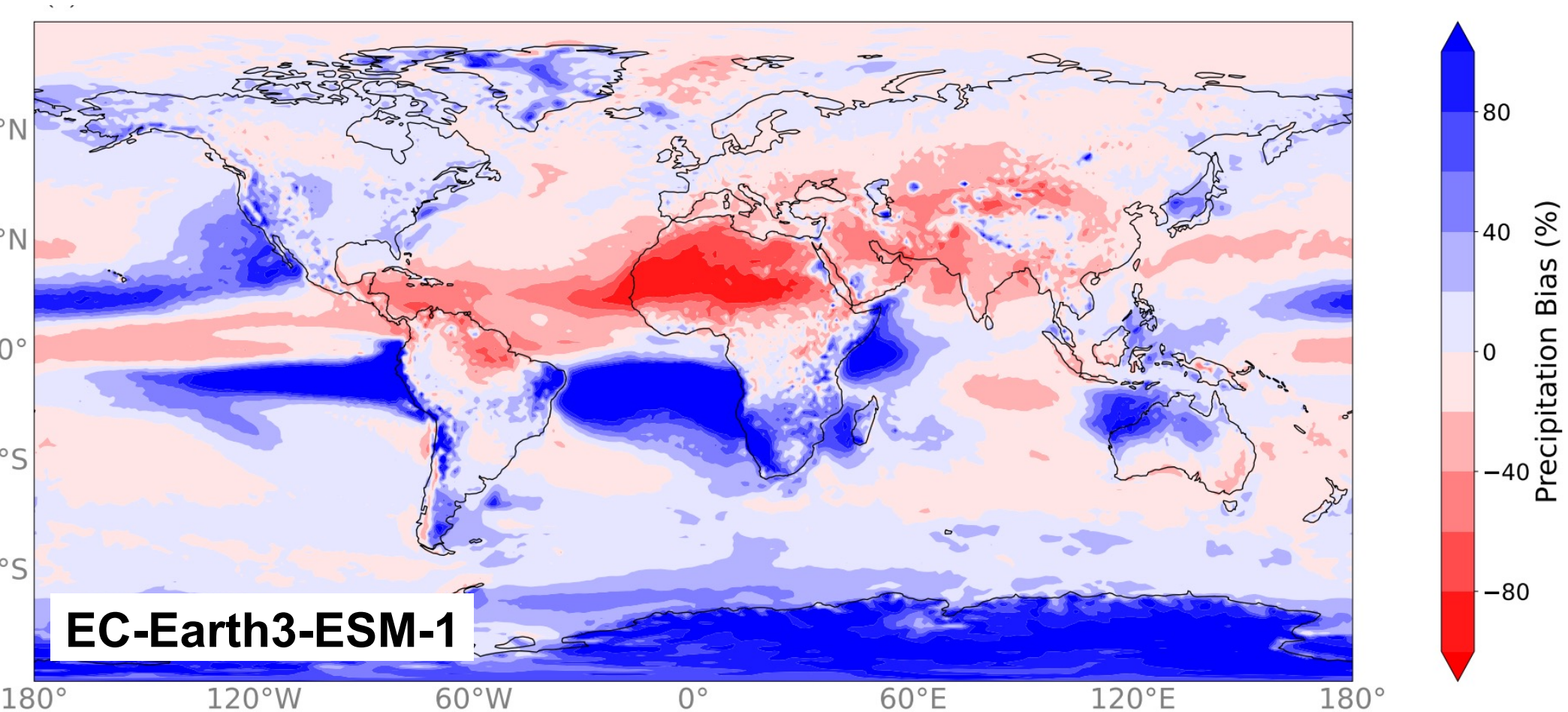


- Annual averaged southern Hemisphere Hadley cell shifted a bit to the south and weaker than ERA5. ITCZ also shifted a bit to the south. Northern hemisphere Hadley cell very well represented.
- Weaker updrafts north of the equator. Stronger and more broad updrafts south of the equator.
- Corresponds to precipitation bias dipole (positive just south of the equator, negative just north of the equator)

- Southern Hemisphere Hadley cell location well represented, but intensity is slightly weaker. ITCZ location matches that of ERA5. Northern hemisphere Hadley cell location and intensity very well represented.
- Slightly weaker updrafts north of the equator, and slightly stronger updrafts south of the equator.
- Positive precipitation bias north and south of the equator. Almost no precipitation bias at the mean ITCZ location (just north of equator).

Results

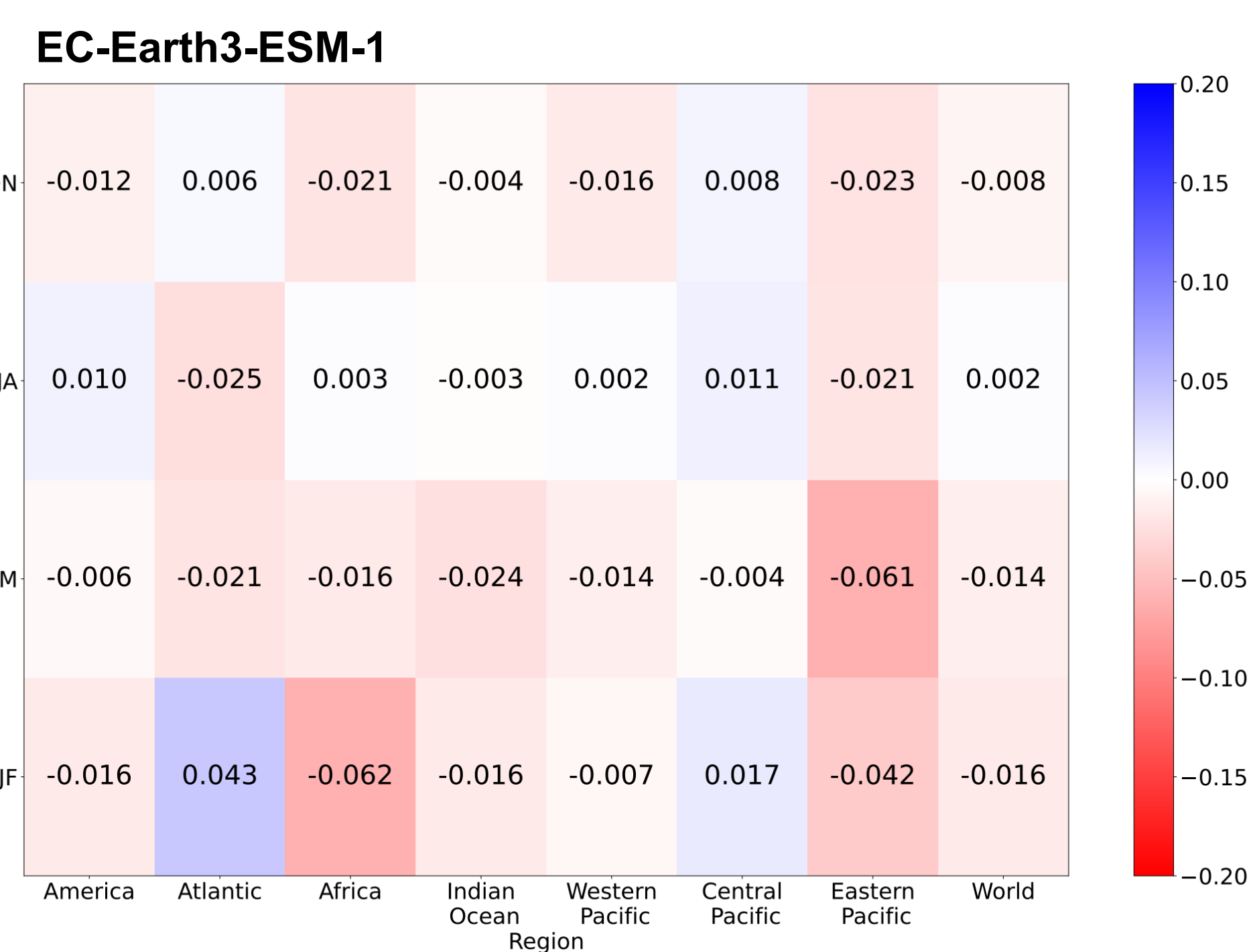
Precipitation biases



- Large precipitation biases in many tropical regions
- Atlantic and Eastern Pacific: ITCZ shifted southwards
- Central Pacific: ITCZ shifted northwards

- Smaller and more confined precipitation biases in the tropics
- Atlantic and Eastern Pacific: ITCZ shifted southwards
- Central Pacific: ITCZ shifted northwards

Added value of new ESMs based on the MSPAEF metric



- Similar performance compared to the EC-Earth3 CMIP6 version, in the tropical and subtropical regions.
- Performs slightly better in the Central Pacific, and a bit worse in the Eastern Pacific, for all seasons.



- Performs slightly worse than its CMIP6 counterpart for many regions and seasons.
- For SON, it performs worse for all regions, while for DJF it performs better for Western and Central Pacific.

Conclusions

- The current version of ESMs performs similarly to their CMIP6 counterparts in representing global precipitation patterns.
- The “double ITCZ bias” in the Eastern Pacific, which has affected many generations of climate models is more evident in the EC-Earth3-ESM-1 than in the UKESM1-2.

- Both models represent well the northern hemisphere annual mean Hadley cell. However, they struggle to represent the southern hemisphere annual mean Hadley cell (EC-Earth3-ESM-1: location and intensity, UKESM1-2: intensity)

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Scan here for more details:

