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Climate Prediction from Sub-Seasonal to Decades

1 Introduction

- ❖ The South American Monsoon System (SAMS) is the complex set of interacting atmospheric processes that governs the seasonal rainfall regime over tropical and subtropical South America (Figure 1), characterized by most of the annual precipitation occurring in austral summer and a dry season in winter (Reboita et al., 2025);
- ❖ SAMS is socioeconomically vital, as it sustains rainfed agriculture (about 90% of cultivated land), hydropower generation (around 34% of the continent's electricity supply), freshwater availability, and key ecosystems, directly influencing the region (Carvalho and Nunes, 2025);
- ❖ CMIP5 projections indicate more intense rainfall extremes in southeastern South America and the La Plata Basin, increased dryness in the Amazon (Reboita et al., 2022a,b), and a delayed and shorter monsoon season by the late 21st century (Reboita et al., 2023);
- ❖ This study evaluates future changes in extreme precipitation over the SAMS during austral summer under different climate scenarios, using statistically downscaled CMIP6 projections and ETCCDI indices.

2 Methodology

- ❑ CMIP6 GCMs selection through the Ranking Analysis (Reboita et al., 2024);
- ❑ 3-hourly precipitation projections of eight CMIP6-GCMs (CMCC-CM2-SR5; CMCC-ESM2; EC-Earth3; MIROC6; GFDL-ESM4; IPSL-CM6A-LR; MPI-ESM1-2-LR; MRI-ESM2-0) for the 2020-2099 period, under the SSP-4.5 and SSP5-8.5 scenarios;
- ❑ GCMs' simulations interpolated to the Climate Prediction Center (CPC) reference dataset grid ($0.5^\circ \times 0.5^\circ$) with bilinear interpolation (1995-2014);
- ❑ GCMs' historical simulations and future projections bias-corrected and statistically downscaled (BCSD) with the Quantile Delta Mapping (QDM) technique (Cannon et al., 2015); simulations and projections analyzed individually and as a multi-model ensemble;
- ❑ Extreme events assessed through four ETCCDI indices for the DJF period: Consecutive Dry Days (CDD), Consecutive Wet Days (CWD), 95th Percentile (P95), and the number of days with precipitation above the 95th percentile (R95p).

3 Results

- After applying the QDM technique, CMIP6-GCMs demonstrate good skill in reproducing the spatial and temporal features of the SAMS during the historical period, in comparison with CPC analyses. Remaining biases are mainly concentrated in climatically complex regions, such as the equatorial sector and the continental portion of the South Atlantic Convergence Zone (SACZ).
- **Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD)**
 - By the end of the 21st century, projections indicate an average annual increase of approximately 10 consecutive dry days (CDD) over the central SAMS region (central Brazil) relative to the historical baseline;
 - Both SSP2-4.5 and SSP5-8.5 scenarios show an intensification of CDD, with a stronger and more spatially extensive signal under SSP5-8.5 (Figure 3, top left);
 - Consistent findings with previous dynamically downscaled CMIP5 projections (Reboita et al., 2022a,b);
 - Projections of CWD decrease by about 5 days per year over central Brazil by late century (Figure 3, top right);
- **Extreme Precipitation (P95 and R95p)**
 - The 95th percentile (P95) increases by approximately 10 mm day⁻¹ on average (Figure 3, bottom left), accompanied by roughly one additional heavy precipitation event per year (R95p), particularly over central Brazil (Figure 3, bottom right). Similar increases are also projected for other Brazilian regions, including the South and Southeast;
 - The amplification of extremes is more pronounced and spatially extensive under SSP5-8.5 (Figure 3), and these projections align with earlier dynamically downscaled CMIP5 results (Reboita et al., 2022a,b).

4 Conclusions

- ✓ After applying the QDM technique, CMIP6 models show good skill in reproducing the historical spatial and temporal characteristics of the SAMS; however, considerable intermodel variability persists, and remaining biases are mainly concentrated in climatically complex regions such as the equatorial sector and the continental SACZ;
- ✓ By the end of the 21st century, CDD are projected to increase by about 10 days per year over central Brazil, indicating a substantial intensification of dry spells;
- ✓ CWD are projected to decrease by approximately 5 days per year in the same region, reinforcing the tendency toward longer dry periods and fewer persistent wet episodes;
- ✓ Extreme precipitation intensifies, with the 95th percentile (P95) increasing by around 10 mm day⁻¹ and roughly one additional heavy rainfall event (R95p) per year, especially over central Brazil and parts of southern and southeastern Brazil;
- ✓ Changes are consistently stronger and more spatially extensive under SSP5-8.5 scenario, and overall projections agree with previous dynamically downscaled CMIP5 results.

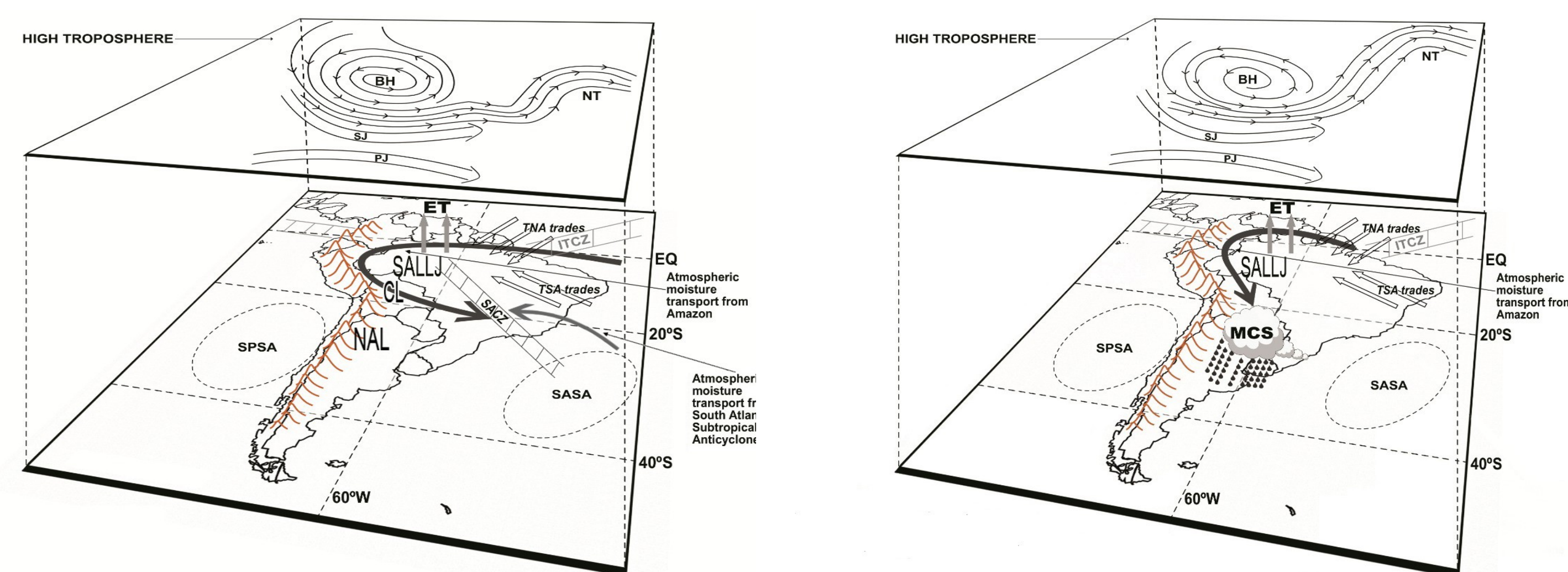


Figure 1. Schematic sketch of important atmospheric circulation features over the South American region, considering events with (left) and without (right) SACZ. SALLJ = South American low-level jet east of the Andes; TNA trades = tropical North Atlantic trade winds; TSA trades = tropical South Atlantic trade winds; ET = evapotranspiration from Amazon forests; MCS = mesoscale convective system; ITCZ = intertropical convergence zone; SPSA = South Pacific subtropical anticyclone; SASA = South Atlantic subtropical anticyclone; CL = Chaco low; NAL = northwestern Argentinean low; NT = northeast trough; BH = Bolivian High; SJ = subtropical jet; PJ = polar jet.

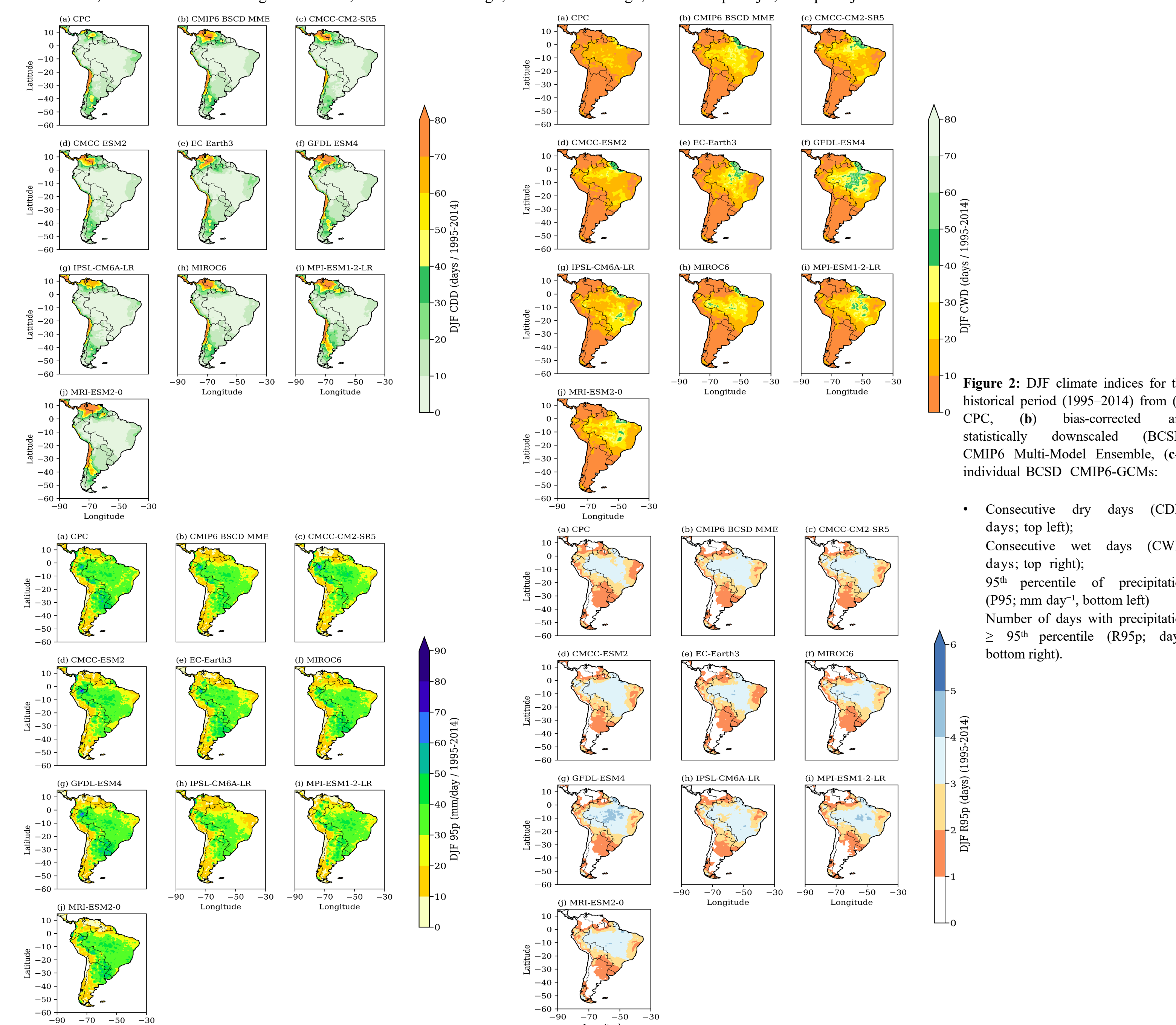


Figure 2. DJF climate indices for the historical period (1995-2014) from (a) CPC, (b) bias-corrected and statistically downscaled (BCSD) CMIP6 Multi-Model Ensemble, and (c) individual GCMs.

- Consecutive dry days (CDD); days; top left);
- Consecutive wet days (CWD); days; top right);
- 95th percentile of precipitation (P95; mm day⁻¹, bottom left);
- Number of days with precipitation $\geq$ 95th percentile (R95p; days, bottom right).

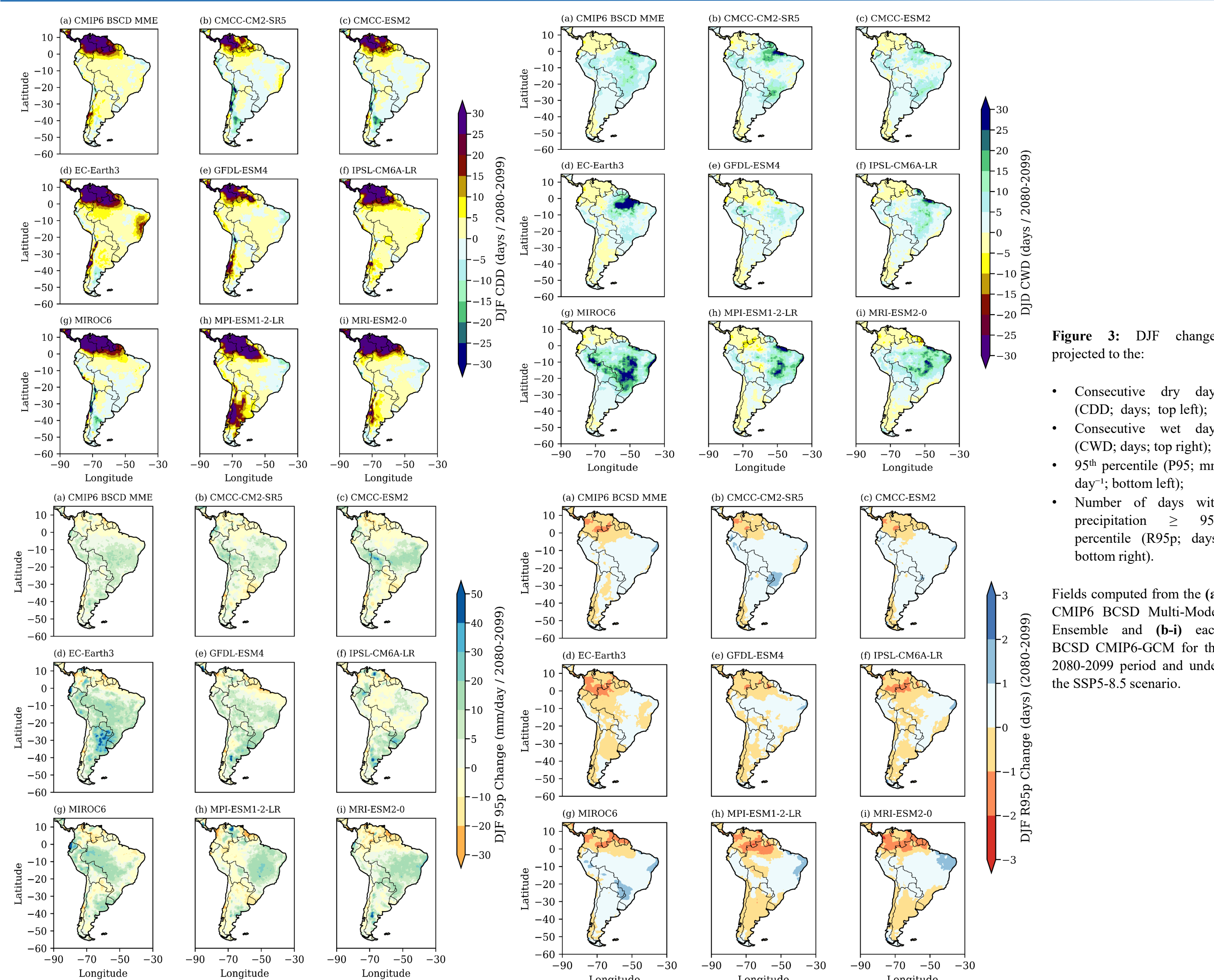


Figure 3. DJF changes projected to the:

- Consecutive dry days (CDD; days; top left);
- Consecutive wet days (CWD; days; top right);
- 95th percentile (P95; mm day⁻¹; bottom left);
- Number of days with precipitation $\geq$ 95th percentile (R95p; days; bottom right).

Fields computed from the (a) CMIP6 BCSD Multi-Model Ensemble, and (b-i) each BCSD CMIP6-GCM for the 2080-2099 period and under the SSP5-8.5 scenario.

4

Conclusions

5

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