Exploring the Moisture Sources and Pathways for South American Rainfall Using Variable-Resolution CESM Simulations

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COLLEGE OF SCIENCE
Geosciences

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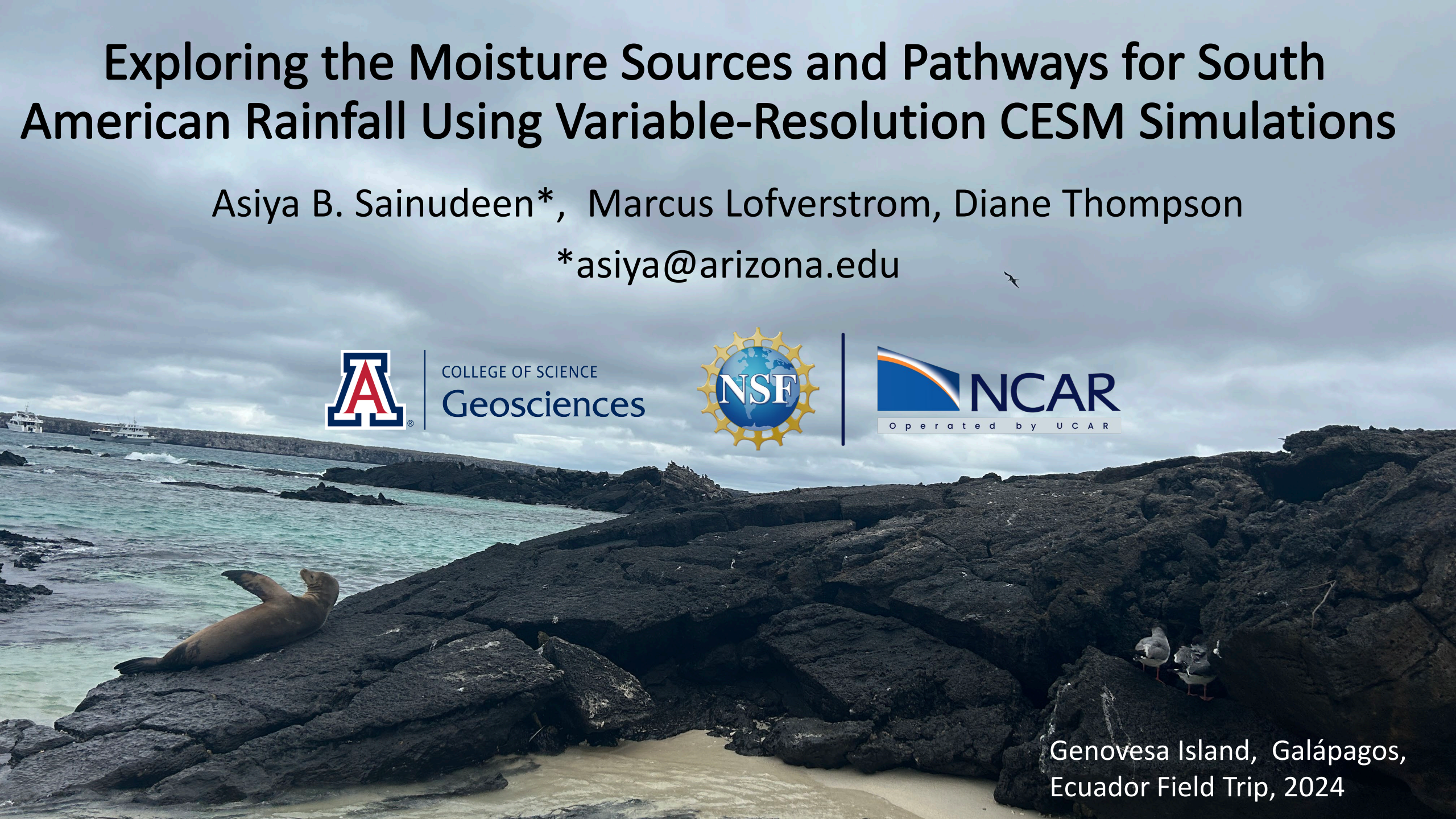
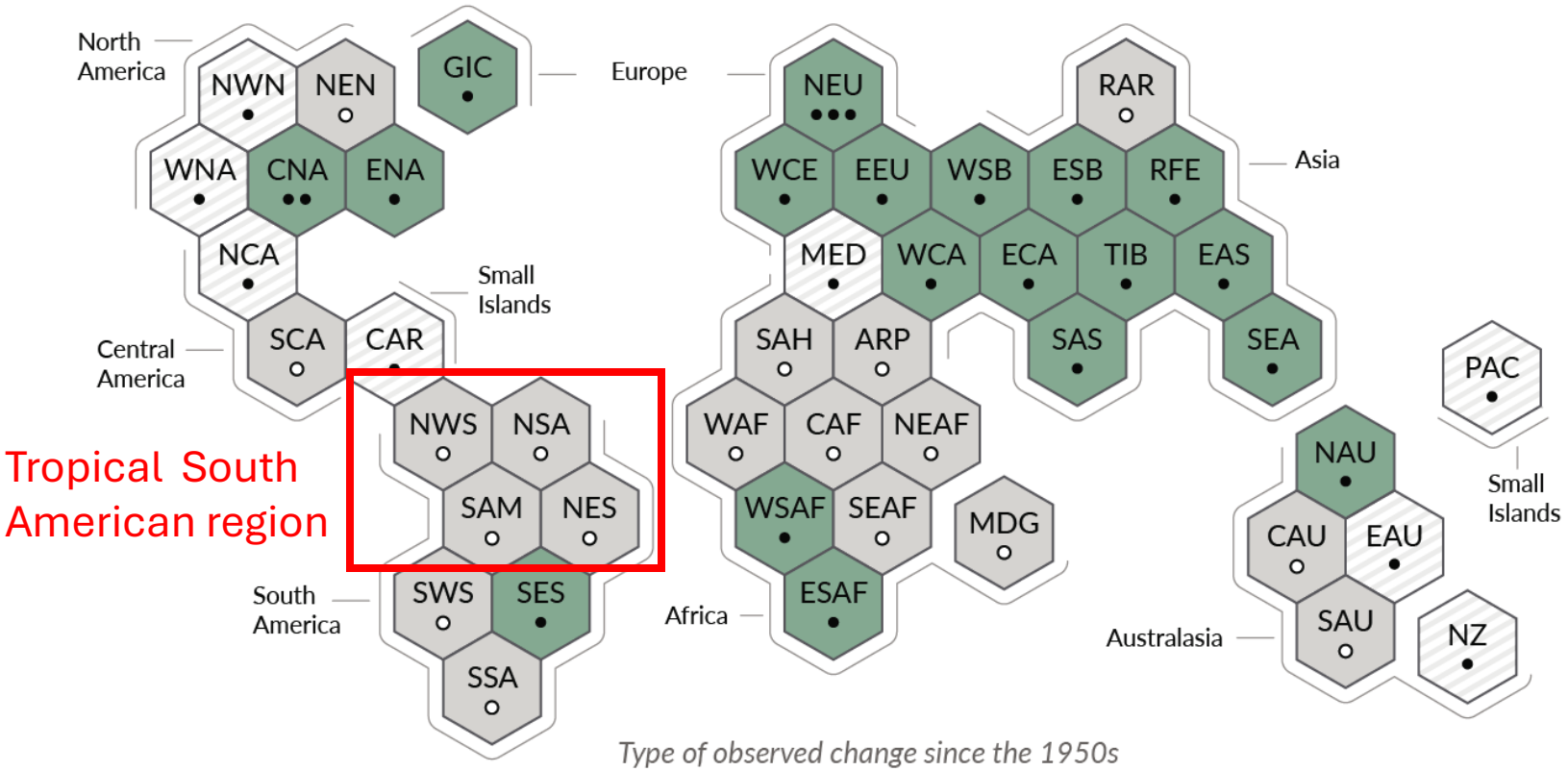


Genovesa Island, Galápagos, Ecuador Field Trip, 2024

Tropical South American hydroclimate



Type of observed change since the 1950s

Type of observed change
in heavy precipitation

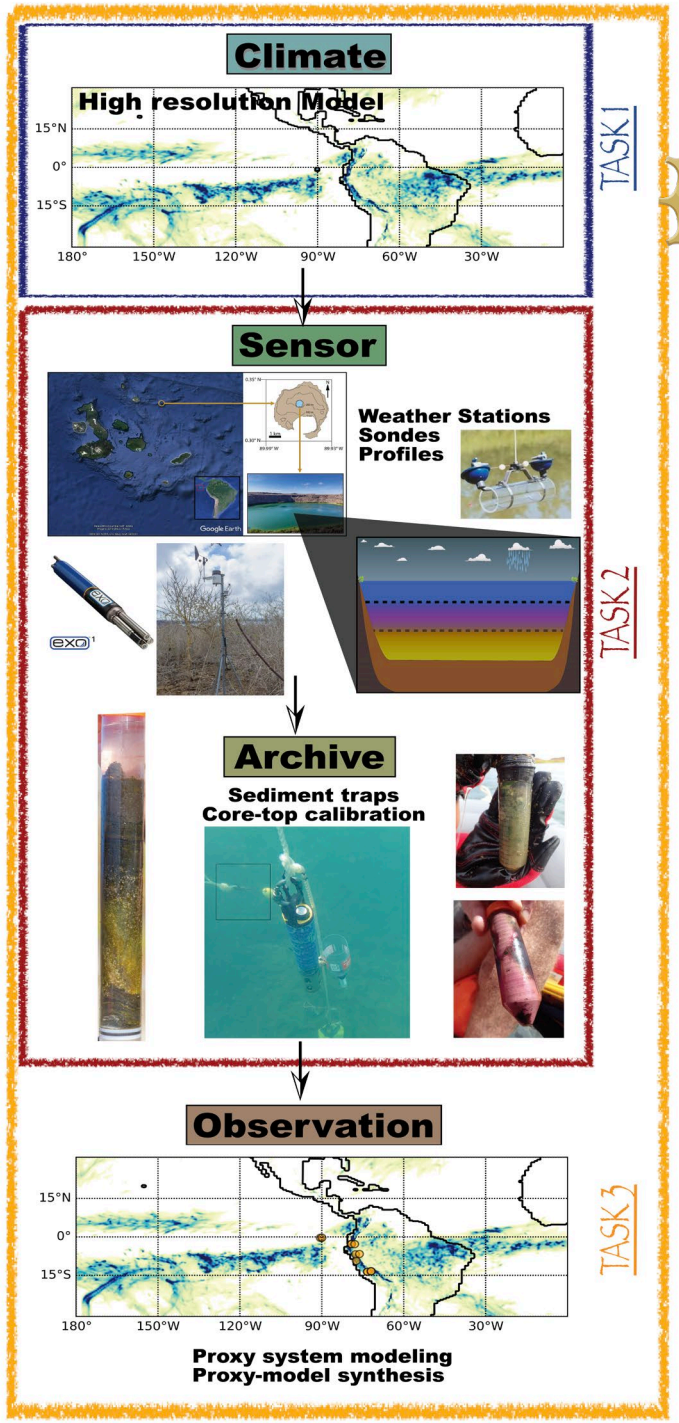
- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

Confidence in human contribution
to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

Technical Summary, AR6

Tropical South American hydroclimate Variability



High-resolution Simulations

- **CESM 2.2 geotrace** enabled with **moisture tagging and Variable resolution** (VR) grids
- CAM5 Physics and prescribed SSTs

~55 km ~28 km

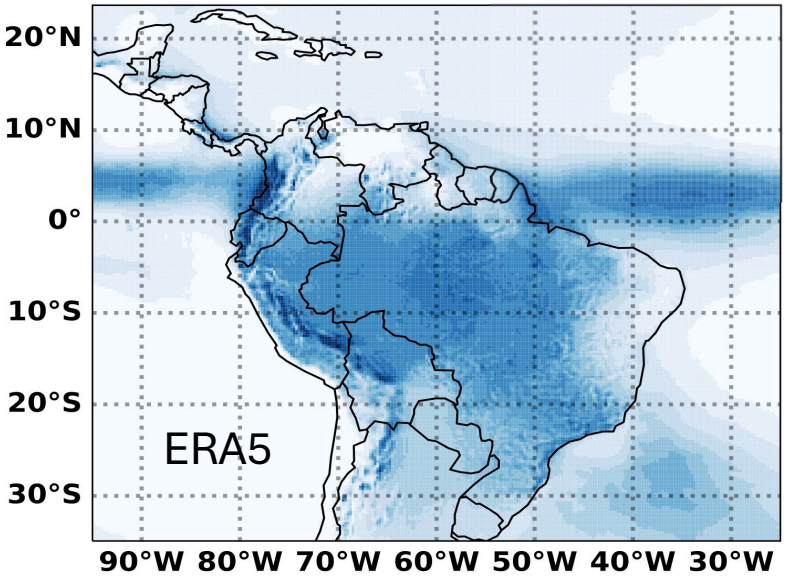
~111 km

  - 50 years of Mid-Holocene (~6 Kya)
  - 50 years of Historic (1991- 2040)
  - 50 years of Mid-Holocene with Green Sahara

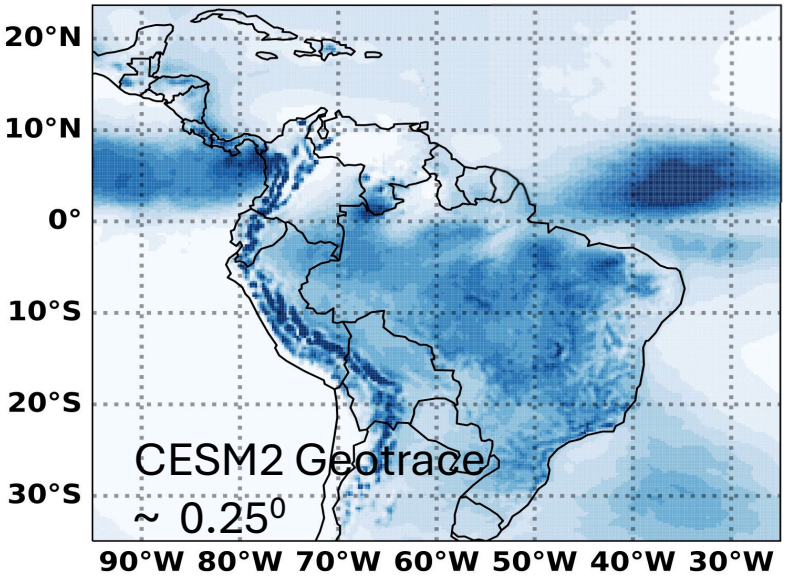
- 23.5 years of Historic (1991-01 – 2013-06)

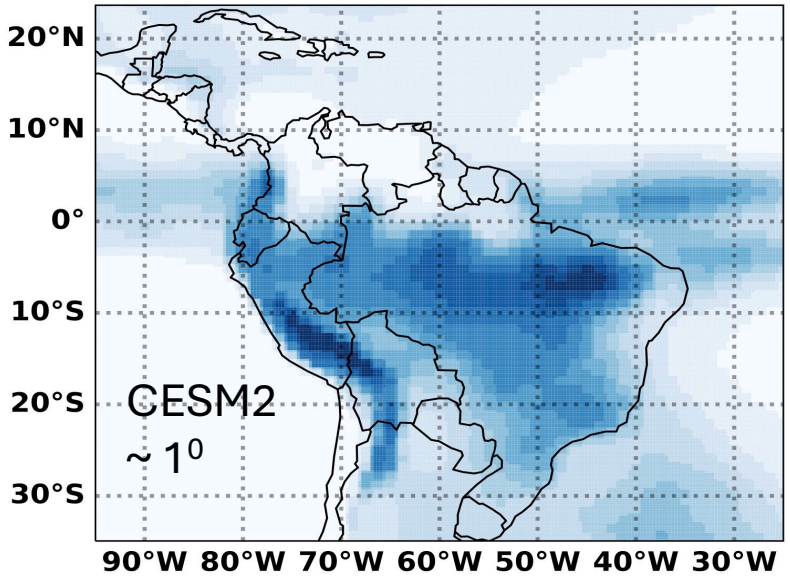
Bambach, N. E., Rhoades, A. M., Hatchett, B. J., Jones, A. D., Ullrich, P. A., & Zarzycki, C. M. (2022). Projecting climate change in South America using variable-resolution community Earth system model: An application to Chile. *International Journal of Climatology*, *42*(4), 2514-2542.

High-resolution Simulations



GPCC





precipitation

DJF mean precipitation

The geotrace simulation, featuring regional refinement (0.25°) over South America, captures more detailed and localized precipitation structures with finer spatial variability, particularly over the Amazon and the Andes, compared to the coarser resolution (0.90° × 1.25°) CESM2 simulations.

Moisture tracking

- The moisture tagging capabilities in CESM enables us to quantify the moisture pathways and the relative contribution of water from different source.

- 17 Source boxes + All land + All Ocean

Tropical South American hydroclimate

Major Source regions contributing to the overall rainfall precipitation

Western tropical Atlantic box

Eastern tropical Atlantic box

Northern South American land box

Southern subtropical Atlantic box

Northern subtropical Atlantic box

Precipitation (%)

Tropical South American hydroclimate Variability

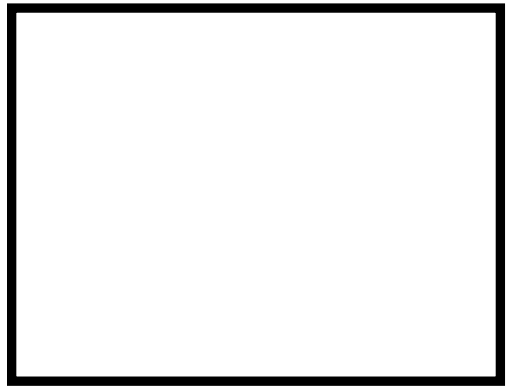
- Interannual variability in the tropical South American rainfall is majorly driven by

1. **El Niño Southern Oscillation (ENSO**
2. Atlantic Niño

*Green dots indicate regions of enhanced convection (ascent), and red crosses indicate subsidence.

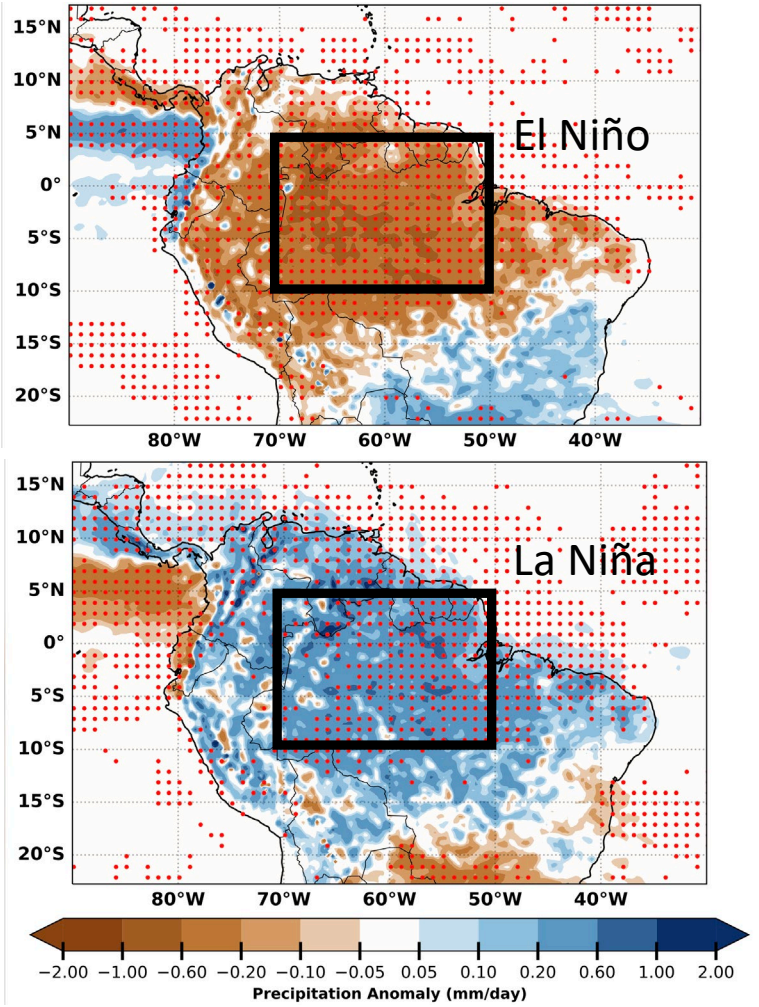
Tropical South American hydroclimate Variability

ENSO



Regression pattern

Tropical South American land box



*Red dots indicate >90 % significance

Tropical South American hydroclimate Variability

Interannual variability -- El Niño Southern Oscillation (ENSO) and Atlantic Niño

- Interannual variability in the tropical South American rainfall is majorly driven by

  1. El Niño Southern Oscillation (ENSO
  2. **Atlantic Niño**

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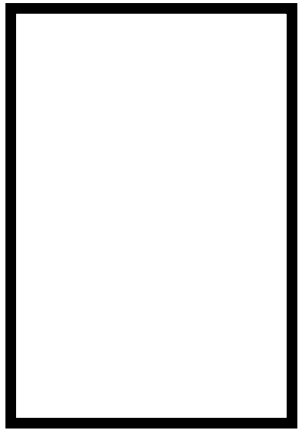
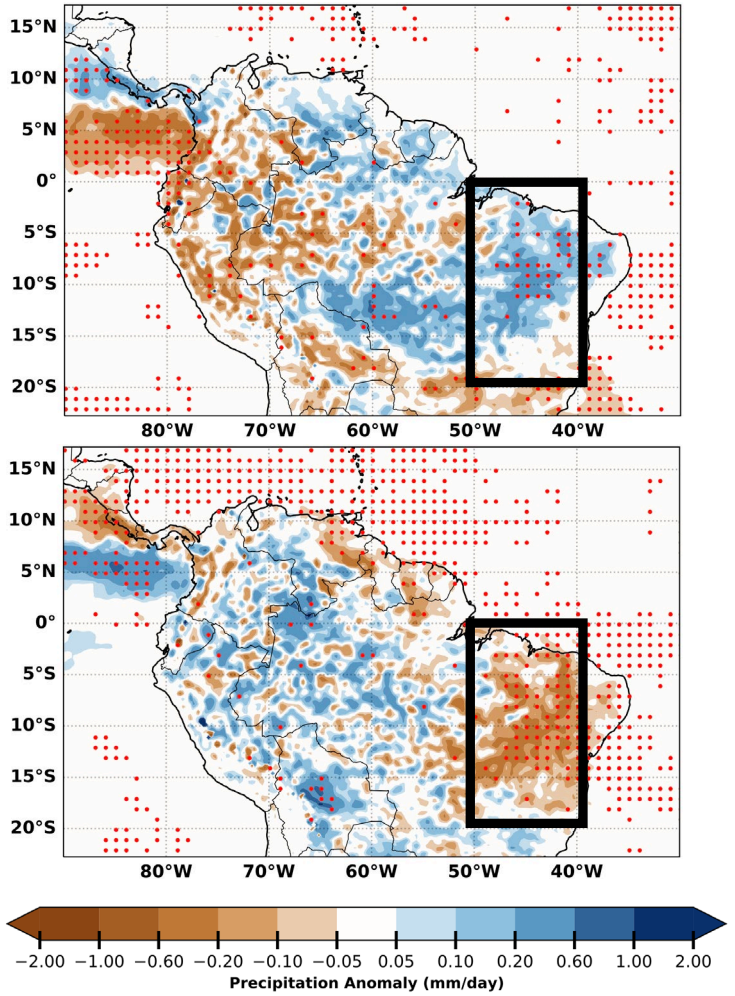
Tropical South American hydroclimate Variability

Atlantic Niño

Regression pattern



Tropical South American land



*Red dots indicate >90 % significance

Key Takeaways

- Moisture tagging enhances our understanding of the sources and pathways shaping the region's hydroclimate.

- The moisture pathways are highly modulated by modes of variability, such as the El Niño Southern Oscillation and Atlantic Niño.

- **Moisture sourced from Amazonian land regions reinforces the influence of ENSO and Atlantic Niño on regional precipitation**

- The findings highlight the complexity of regional precipitation responses and the need to isolate the roles of anthropogenic climate change, land-use change, and variability modes such as ENSO and Atlantic Niño to inform future projections.

Thanks for your attention!

Questions 

Email: asiya@arizona.edu

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Sheela GowriShankaran, University of Arizona

Sulzer Earth Science Scholarship
Melange summer scholarship
William and Clara Sulzer Scholarship

Variable Resolution grid

- The model grid used in this study has a quasi-uniform 1.0^0 (~111 km) global resolution, 0.5^0 (~55 km), and 0.25^0 (~28 km) refinement regions over the broader South American region.

- Variable resolution grids implemented into CESM2 help mitigate the high computational costs associated with running a uniformly high-resolution global model.

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Tropical South American hydroclimate

Local Source contributing to the overall precipitation

Summer **Winter**

Accumulated precipitation (mm/day)

Tropical South American hydroclimate

Local Source contributing to the overall precipitation

$$\frac{PRECT_{nSAmL}\ X\ 100}{PRECT_{All\_land} + PRECTAl_{l\_Ocean}}$$

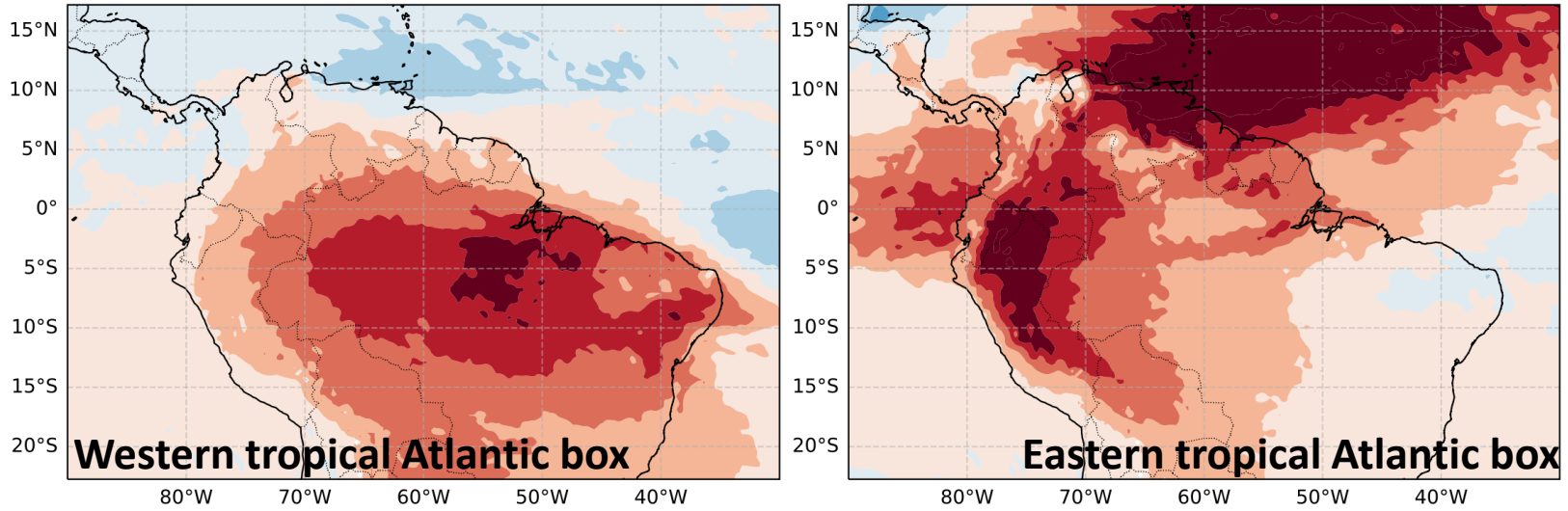
DJF – JJA

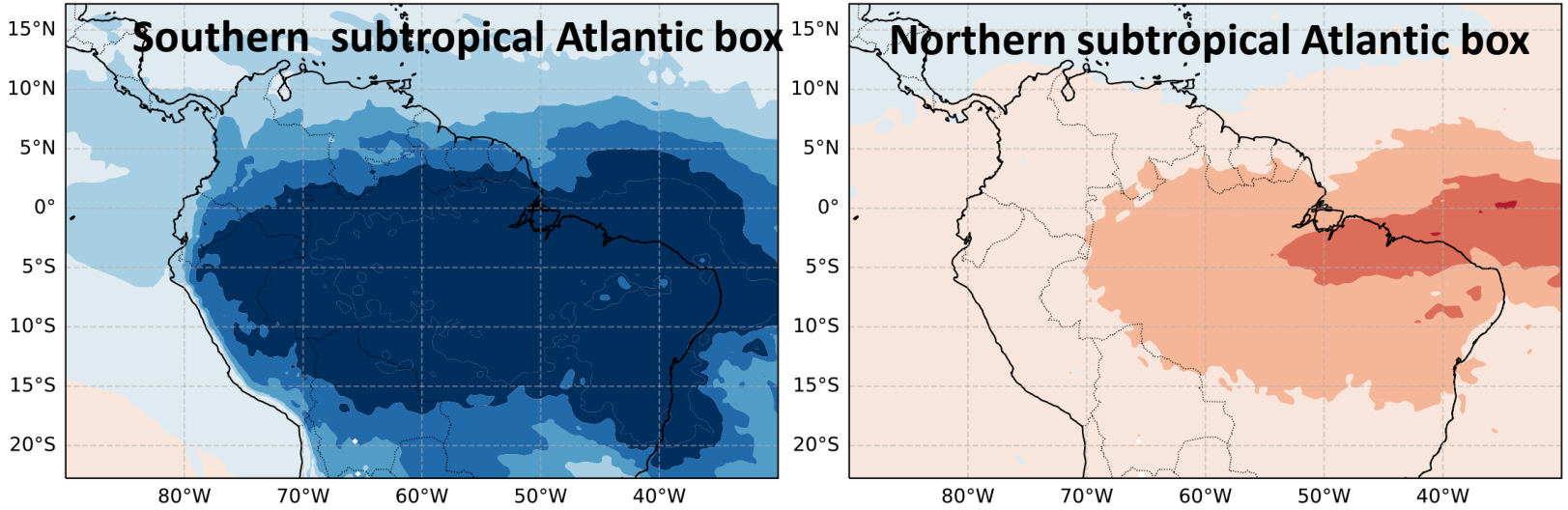
Precipitation (%)

Reduced external moisture inflow during winter leads to a higher fraction of locally recycled rainfall.

Tropical South American hydroclimate

Seasonal variability [DJF - JJA]





Reduced external moisture inflow during winter from three out of four Oceanic source regions!

Tropical South American hydroclimate

Local Source contributing to the overall precipitation

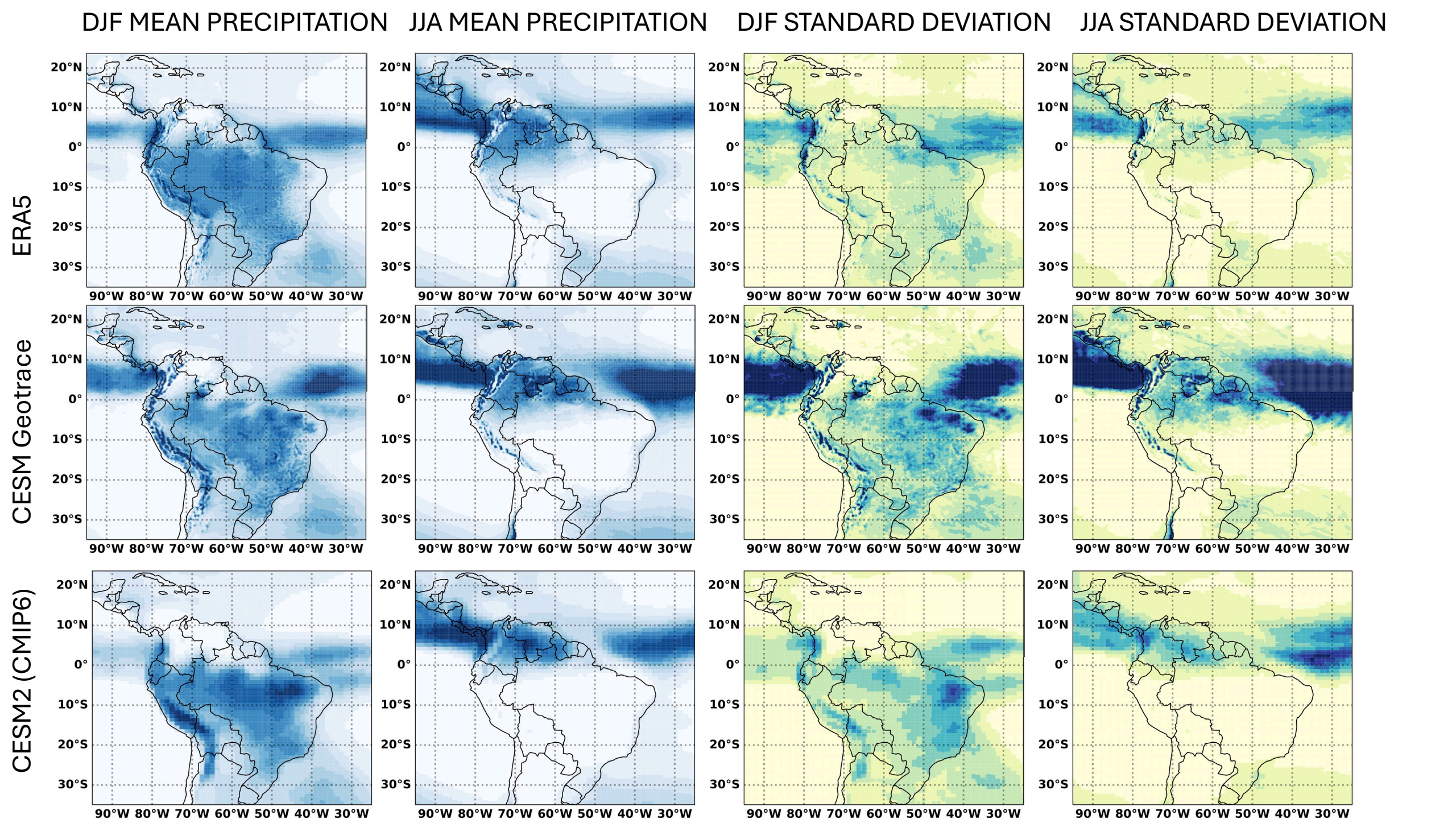
DJF – JJA

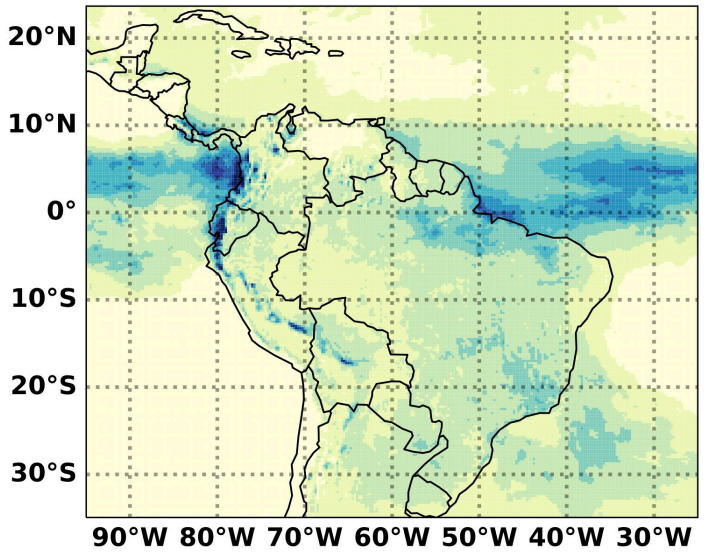
JJA

$$\overline{P}\frac{PRECT_{Source}\ X\ 100}{PRECT_{All\_land} + PRECTAll_{\_ocean}^{ocean}}$$

Precipitation (%)

Reduced external moisture inflow during winter leads to a higher fraction of locally recycled rainfall.


DJF MEAN PRECIPITATION
JJA MEAN PRECIPITATION
DJF STANDARD DEVIATION
JJA STANDARD DEVIATION
ERA5
CESM Geotrace
CESM2 (CMIP6)
20°N
10°N
0°
10°S
20°S
30°S
90°W 80°W 70°W 60°W 50°W 40°W 30°W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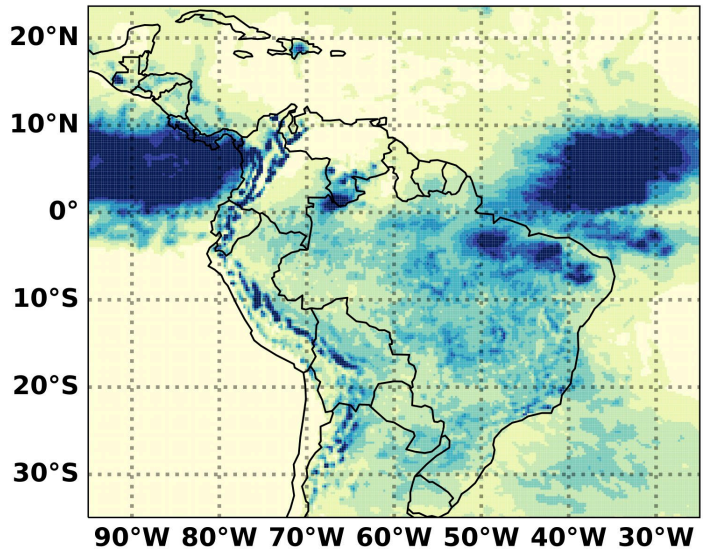
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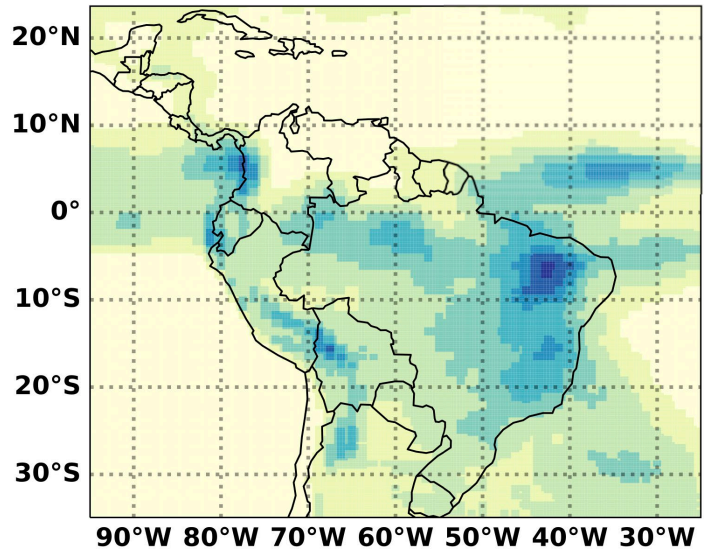
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$$\frac{PRECT_{Source}\ X\ 100}{PRECT_{All\_land} + PRECTAll_{\_ocean}}$$

Precipitation (%)

Tropical South American hydroclimate Variability

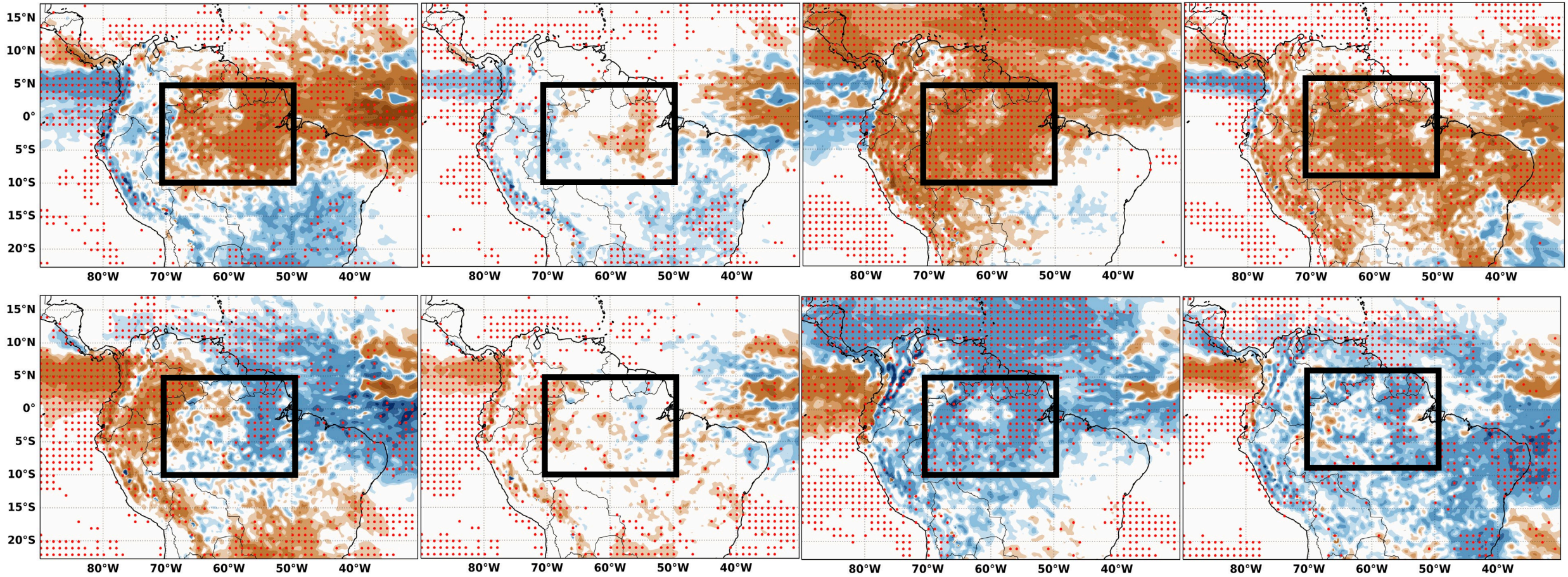
ENSO

Western tropical Atlantic

Eastern tropical Atlantic

Northern subtropical Atlantic

Southern subtropical Atlantic



Tropical South American hydroclimate Variability

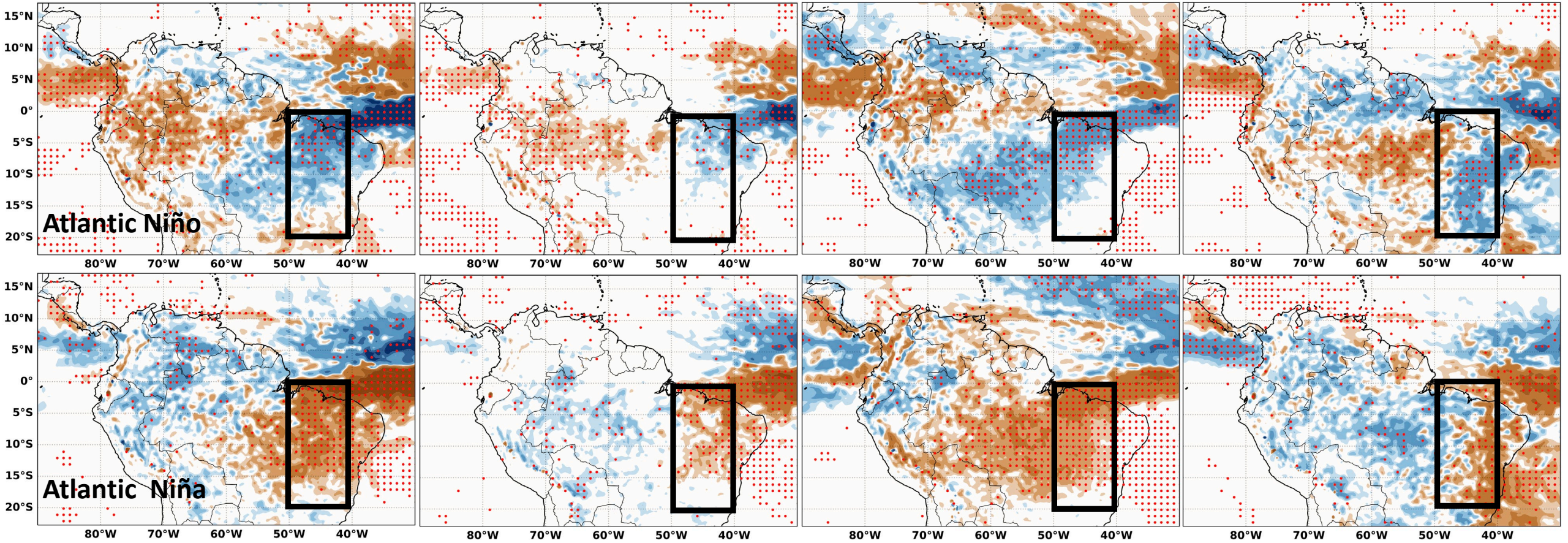
Atlantic Niño Composites

Western tropical Atlantic

Eastern tropical Atlantic

Northern subtropical Atlantic

Southern subtropical Atlantic



Tropical South American hydroclimate Variability

How are precipitation patterns, sources, and pathways modulated by major modes of climate variability?

Article | Published: 28 May 2018

Forest-rainfall cascades buffer against drought across the Amazon

Arie Staal, Obbe A. Tuinenburg, Joyce H. C. Bosmans, Milena Holmgren, Egbert H. van Nes, Marten Scheffer, Delphine Clara Zemp & Stefan C. Dekker

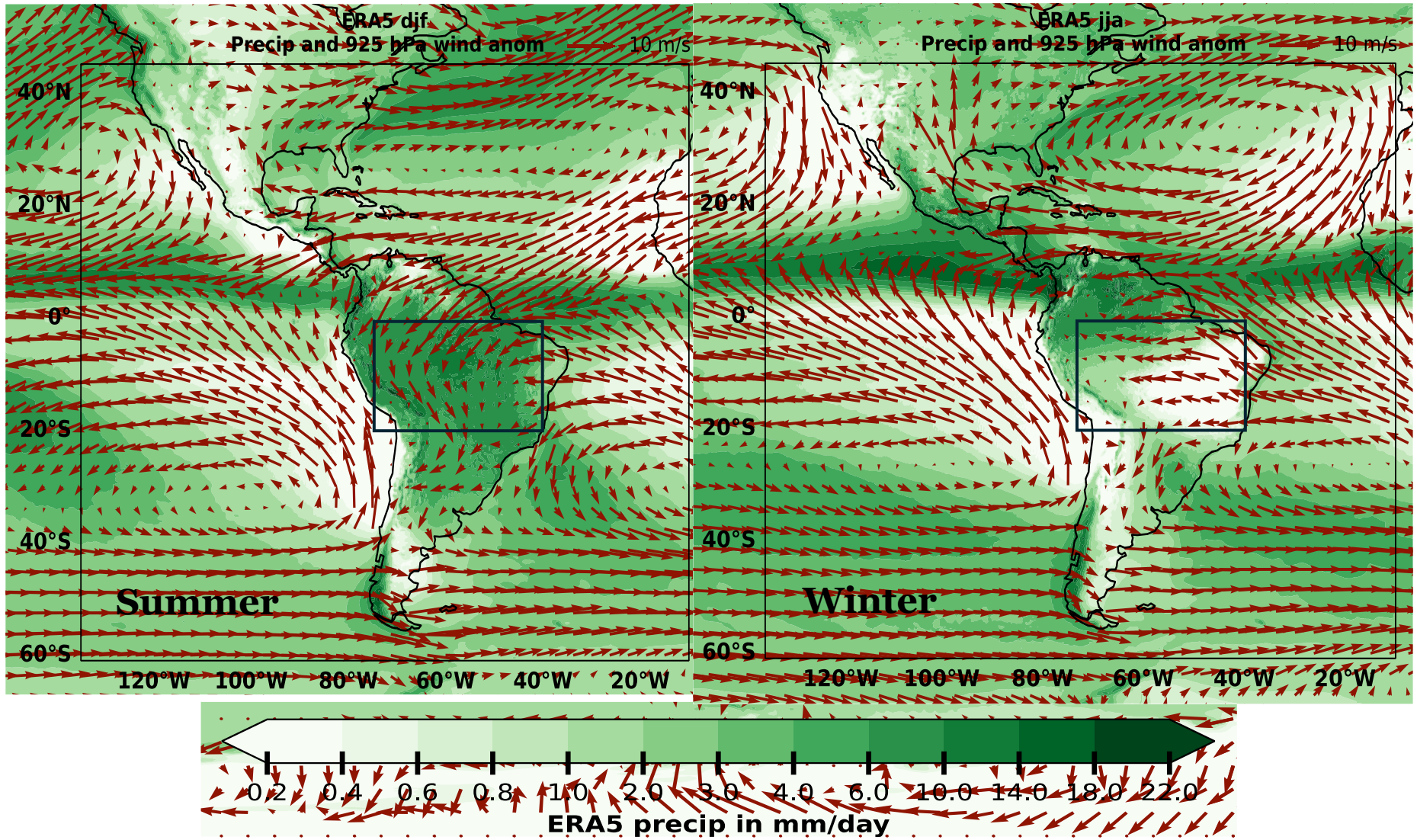
Nature Climate Change **8**, 539–543 (2018) | Cite this article

Study period –> 2003–2014
32% of Amazonian rainfall originates from the basin

Q. What is the relative role of local recycling versus long-range moisture transport in shaping these seasonal and interannual patterns?

Q. How does the interannual variations in source contributions drive or reinforce precipitation teleconnections across tropical South America?

Tropical South American hydroclimate Variability



- The largest contrast between summer and winter rainfall occurs in the central **Amazon** Basin, between 0° and 20°S.
- In this region, precipitation peaks during the austral summer, driven by the monsoon circulation.

Tropical South American hydroclimate Variability

- **Q1.** What are the major source regions contributing to rainfall over the Amazon Basin

  - How much of the moisture is locally recycled within the Amazon (nSAmL box)?
  - How does this local contribution differ between the summer (DJF) and winter (JJA) seasons?

- **Q2.** Which external source regions contribute significantly to Amazon rainfall, and how do their contributions vary seasonally?

- **Q3.** Which moisture source regions show the strongest interannual variability associated with:

  - El Niño (ENSO)
  - Atlantic Niño