Causal drivers of central Amazon precipitation variability during austral summer

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Research Question

Identifying causal drivers of the South American Monsoon System at monthly time scales

Focus on Central Amazonia, with the Central Amazon Basin (CAB) with the coordinates 0°-10°S, 55°-70°W as region for rainfall

Analysis of drivers of the peak rainy season in December, January, February [1]

Data

ERA5 reanalysis monthly averages of 3 different fields with data for the period 1950-2020 and the period 1979-2020

Data for the period 1979-2020 more reliable [2]

- **Precipitation (precip)** to describe the monthly mean of the precipitation above the CAB
- **Sea surface temperatures (SST)** to describe the Tropical North Atlantic (TNA) and the El Niño Southern Oscillation in the regions 1+2 and 3.4 (ENSO12, ENSO34)
- **Mean Sea Level Pressure (MSLP)** to describe the Southern Annular Mode (SAM) and the Amundsen Sea Low (ASL)

Correlation maps

Correlation maps of precipitation in CAB to MSLP and SST with 3 different lags=$-1, -2, -3$ months are shown in Figure 1

Potential drivers are identified in the maps

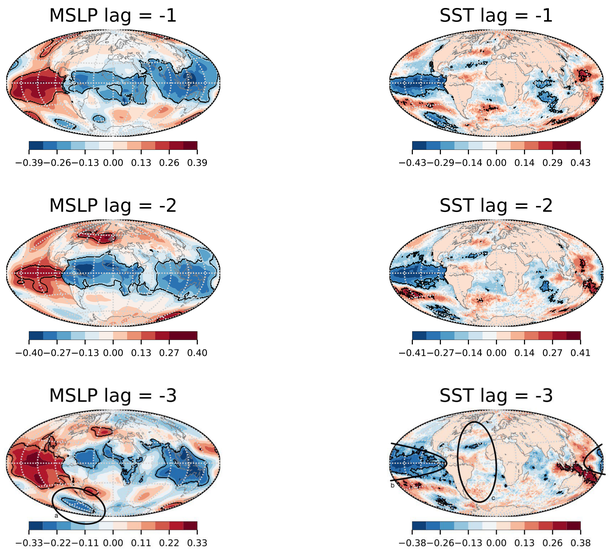

Figure 1. Correlations maps with the correlation between the CAB precipitation time series and the MSLP (left) and SST (right) fields are shown. The lag ranges from -1 month (top) to a -3 months (bottom)

Regions with strong correlation:

- Strong positive correlation to MSLP and negative correlation to SST in tropical Pacific, **ENSO region** (region b in Figure 1)
- Correlated regions with alternating sign over **Atlantic** (region c in Figure 1), sign indicates positive or negative correlation coefficient
- Negative correlation to MSLP and SST in the **Amundsen Sea** (region a in Figure 1)

Causal Effect Networks I

Causal Effect Networks (CEN) created using a **PCMCI algorithm** [3]

Parameters are three different **significance levels** $\alpha = 0.05, 0.1, 0.2$, two different **maximum lags** $\text{lag}_{max}= -2, -3$ months and both time periods 1950-2020 and 1979-2020

CEN for $\alpha = 0.05$, $\text{lag}_{max} = -3$ months and both time periods are shown in Figures 2 to 4, each with different potential drivers (SAM and ASL, ENSO12/ENSO34 and TNA)

CEN with selected potential drivers

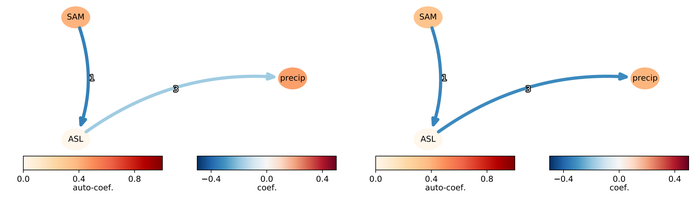

Figure 2. CEN with CAB precipitation, SAM and ASL with a $\alpha = 0.05$, $\text{lag}_{max} = -3$ months and data for the periods 1950-2020 (left) and 1979-2020 (right)

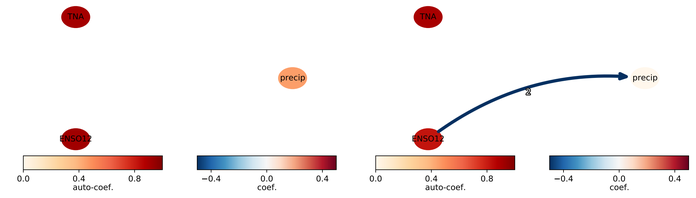

Figure 3. CEN with CAB precipitation, ENSO12 and TNA with a $\alpha = 0.05$, $\text{lag}_{max} = -3$ months and data for the periods 1950-2020 (left) and 1979-2020 (right)

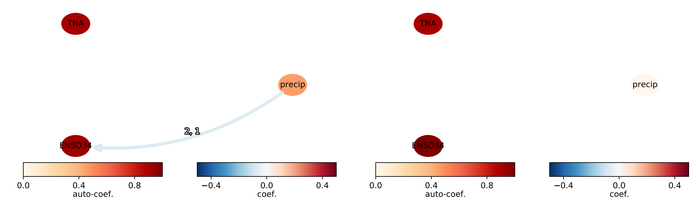

Figure 4. CEN with CAB precipitation, ENSO34 and TNA with a $\alpha = 0.05$, $\text{lag}_{max} = -3$ months and data for the periods 1950-2020 (left) and 1979-2020 (right)

Significant causal links:

- ASL driven by SAM (causal effect strength $\beta = -0.3$, lag $= -1$ month)
- **Negative link** from **ASL** to precip with lag $= -3$ months, stronger during 1979-2020 ($\beta_{1950} = -0.2, \beta_{1979} = -0.3$)
- Strong **negative link** from **ENSO12** to precip when using data for the period 1979-2020 ($\beta = -0.5$, lag $= -2$ months)
- **No causal connection** found from **ENSO34** towards precipitation, weak link from precip to ENSO34 ($\beta = -0.1$, lag $= -2, -1$ months)
- **No causal connection** between precip and **TNA**

Causal Effect Networks II

CEN with all potential drivers

CEN with CAB precipitation and potential drivers SAM, ASL, TNA and either ENSO12 or ENSO34

ENSO34 does not show causal connection to precip, therefore not shown

Two different **significance levels** $\alpha= 0.05, 0.2$ displayed

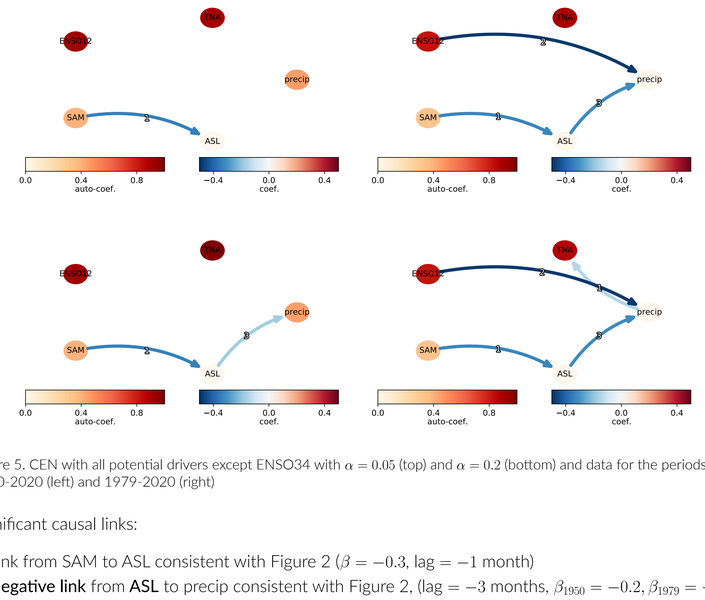

Figure 5. CEN with all potential drivers except ENSO34 with $\alpha = 0.05$ (top) and $\alpha = 0.2$ (bottom) and data for the periods 1950-2020 (left) and 1979-2020 (right)

Significant causal links:

- Link from SAM to ASL consistent with Figure 2 ($\beta = -0.3$, lag $= -1$ month)
- **Negative link** from **ASL** to precip consistent with Figure 2, (lag $= -3$ months, $\beta_{1950} = -0.2$, $\beta_{1979} = -0.3$)
- Strong **negtive link** from **ENSO12** to precip from time period 1979-2020 with lag$= -2$ months, $\beta = -0.5$, consistent to Figure 3 on the right
- Weak **negative link** from precip to **TNA** detected when using $\alpha = 0.2$ and 1979-2020 ($\beta = -0.15$, lag $= -1$ month)

Conclusions

SAM causally modulates ASL, the ASL shows a negative causal link to precipitation with lag of 3 months

SST field in ENSO region 1+2 in eastern tropical Pacific close to South American coast shows strong negative causal link to rainfall in CAB

SST field in ENSO region 3.4 in central tropical Pacific does not show a causal connection to rainfall in any CEN but correlation

SST field in tropical North Atlantic does not show a causal influence on the precipitation

References

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[2] Bill Bell, Hans Hersbach, Adrian Simmons, Paul Berrisford, Per Dahlgren, András Horányi, Joaquín Muñoz-Sabater, Julien Nicolas, Raluca Radu, Dinand Schepers, Cornel Soci, Sebastien Villaume, Jean-Raymond Bidlot, Leo Haimberger, Jack Woollen, Carlo Buontempo, and Jean-Noël Thépaut. The era5 global reanalysis: Preliminary extension to 1950. Quarterly Journal of the Royal Meteorological Society, 147(741):4186–4227, 2021.

[3] Jakob Runge, Peer Nowack, Marlene Kretschmer, Seth Flaxman, and Dino Sejdinovic. Detecting and quantifying causal associations in large nonlinear time series datasets. Science Advances, 5(11):eaau4996, 2019.

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