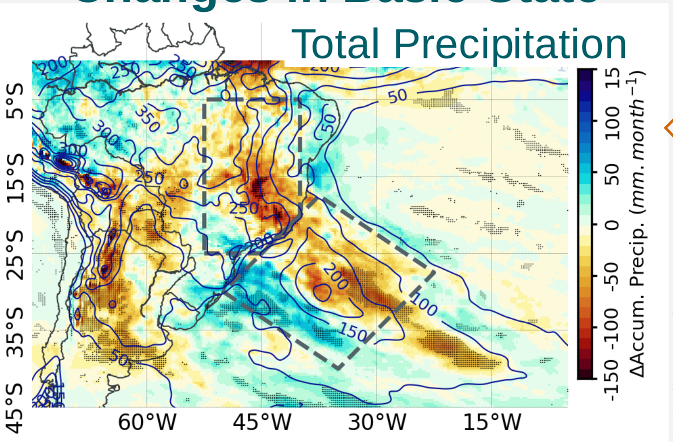
Large-scale circulation changes over South America are impacting synoptic-scale tropical-extratropical interactions and altering rainfall seasonality.

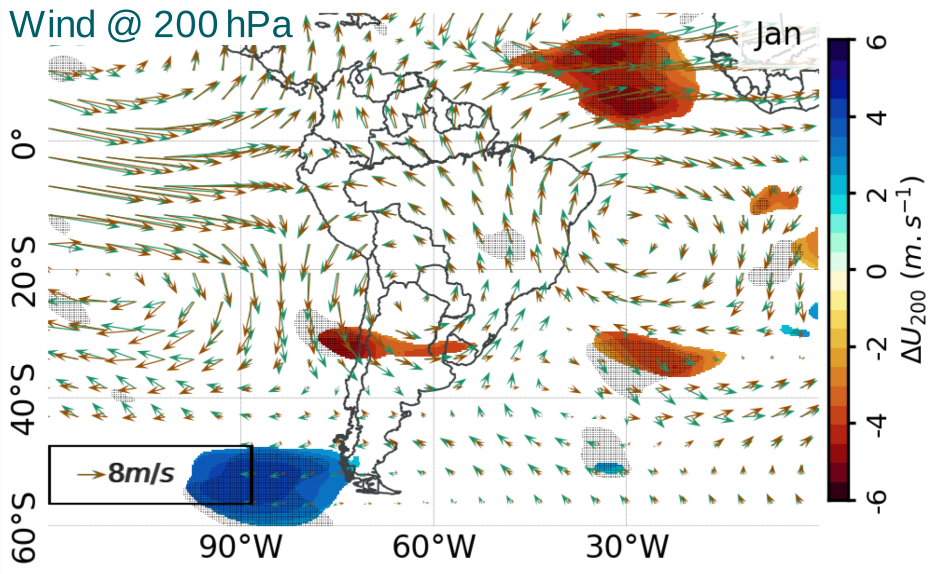
Marcia Zilli and Neil Hart

Met Office · INPE · INPA Instituto Nacional de Pesquisas da Amazônia · Cemaden · Newton Fund · SoGE School of Geography and the Environment · University of Oxford

Changes in Basic State



< January accumulated precipitation (contours each 50 mm.month^{-1}) and the difference between the two periods analysed (shades). Stappling indicates areas with significant difference ($p \leq 0.1$)

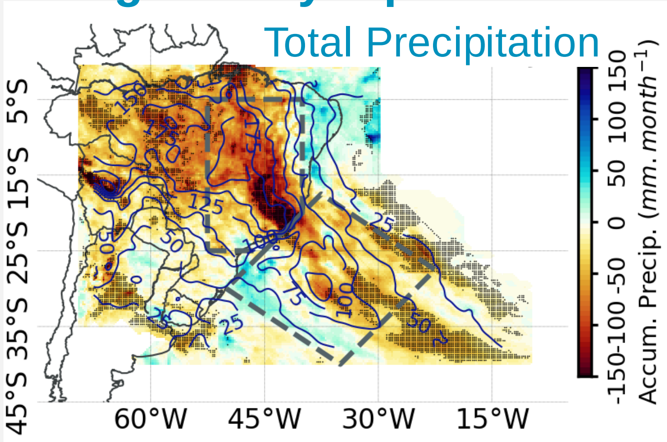


January 200 hPa wind averages (arrows) during the first (green) and last (brown) periods analysed, with the gray stappling indicating areas with significant differences ($p \leq 0.1$). Shades: zonal wind differences between the two periods (only areas with significant difference [$p \leq 0.1$]).

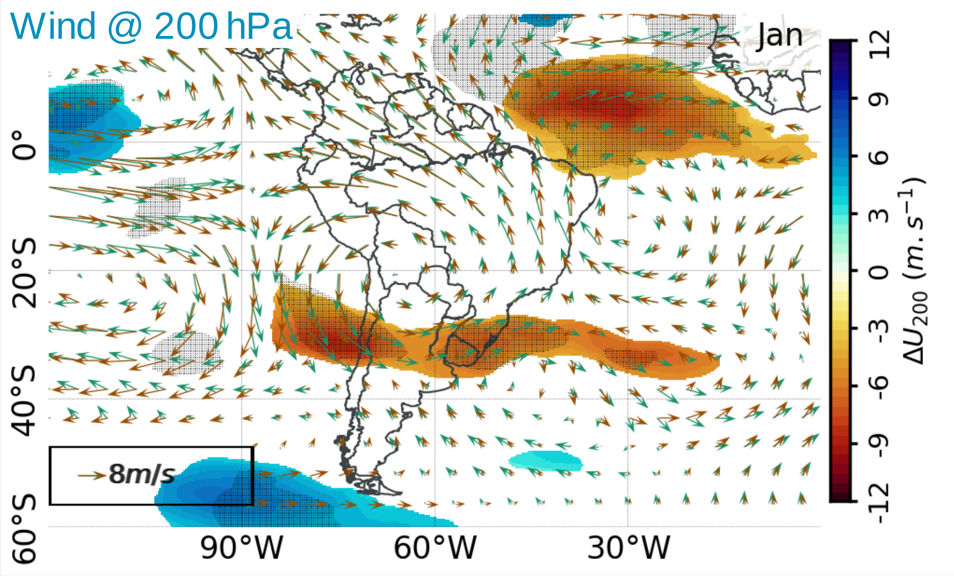
Fewer persistent TE events
Reduction in total precipitation

BH expanding
Easterlies over subtropics
Blocking Rossby waves

Changes in Synoptic-scale



< January accumulated precipitation during persistent TE events (contours each 50 mm.month^{-1}) and the difference between the two periods analysed (shades). Stappling indicates areas with significant difference ($p \leq 0.1$)



January 200 hPa wind averages (arrows) during persistent TE events, considering the first (green) and last ((brown) periods analysed, with the gray stappling indicating areas with significant differences ($p \leq 0.1$). Shades: zonal wind differences between the two periods (only areas with significant difference [$p \leq 0.1$]).

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Authors: Marcia Zilli & Neil Hart

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Recent Precipitation changes over Tropical South America

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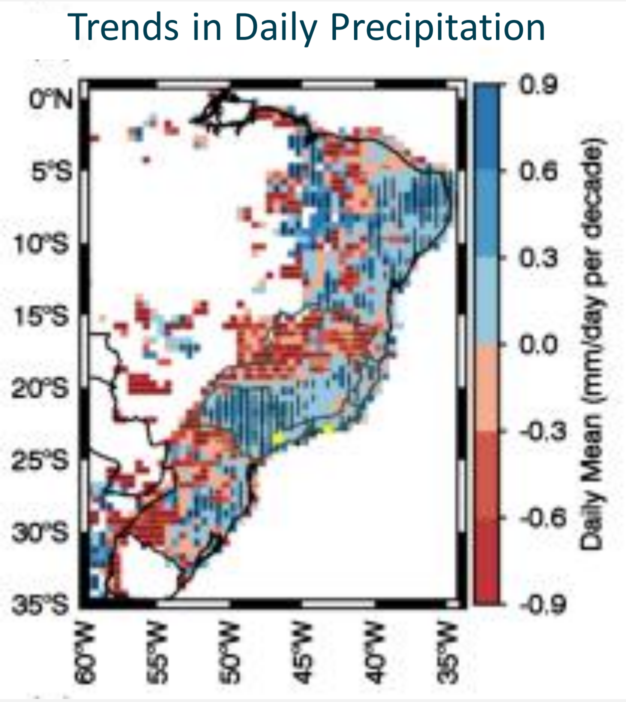
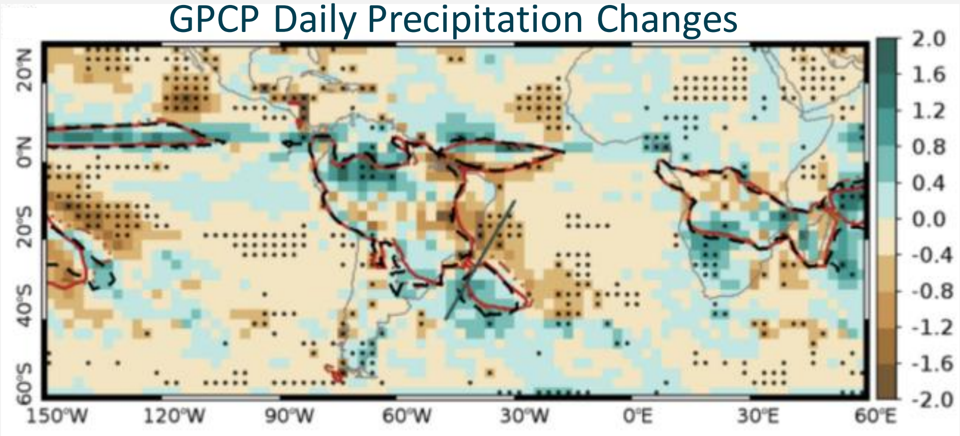


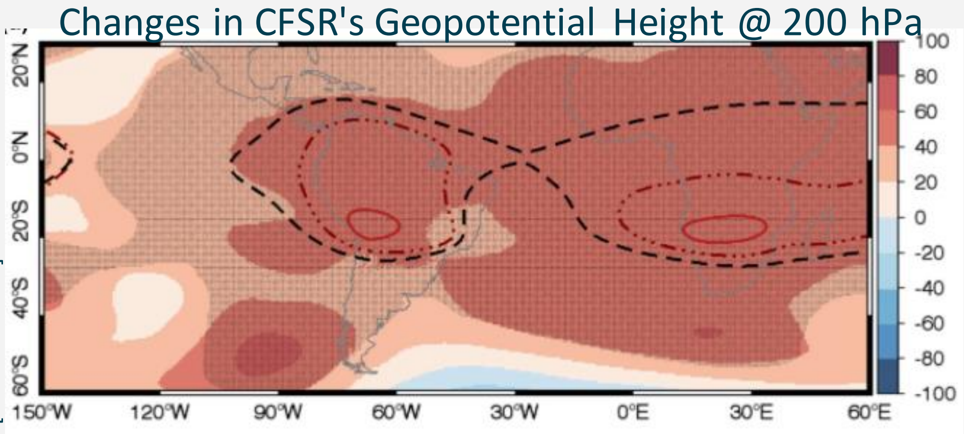
[Zilli et al 2017]

Mann-Kendall trend (shades) in the rainy season (Oct-Mar) daily precipitation rate over Brazil for 1938-2012 period and its significance (hatching) [Source: Zilli et al 2017]

- Spatial pattern of positive and negative precipitation trends over Brazil (left) and along the oceanic SACZ (right, top) suggest a poleward shift of the SACZ over recent decades.
- Changes in the intensity of the Bolivian High (BH; right, bottom) as one of the forcing driving this shift



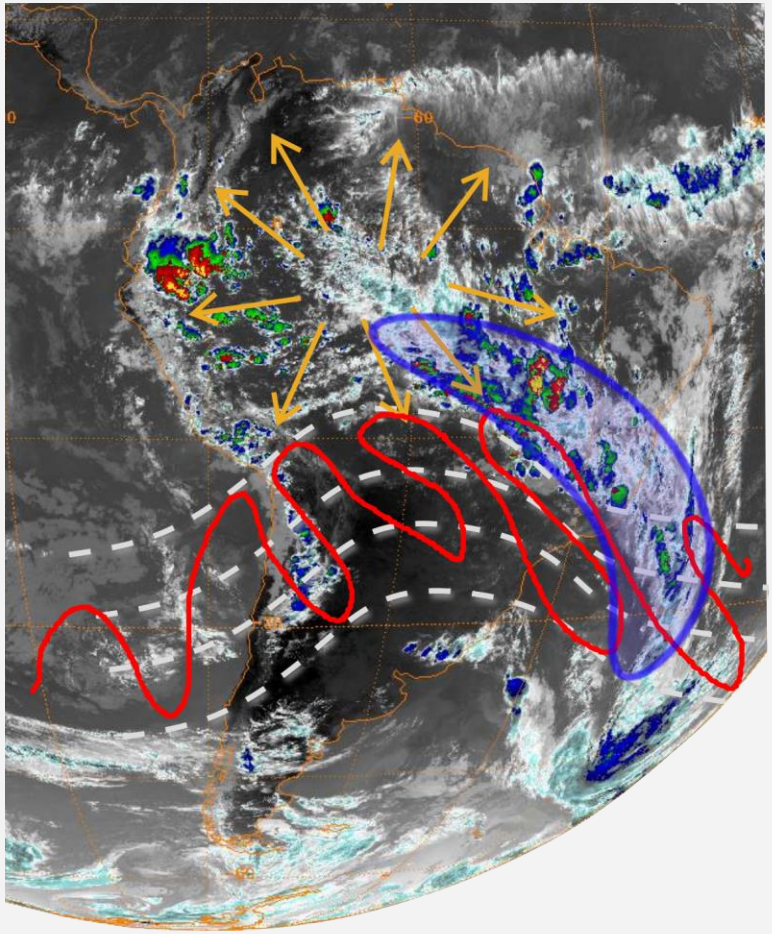
[Zilli et al 2019]



[Zilli et al 2019]

Top: Summer (DJF) daily precipitation rate isohyet at 4 mm.day^{-1} for three subsequent periods (79-91 solid red; 92-04 dot-dashed brown, and 05-14 dashed black; excluding strong ENSO years) and the difference between the first and the last periods (shades). Stippling represents areas where the difference is significant ($p \leq 0.05$). Bottom: and on top but for geopotential height at 200 hPa, with contours at 12,400 gpm. [Source: Zilli et al 2019]

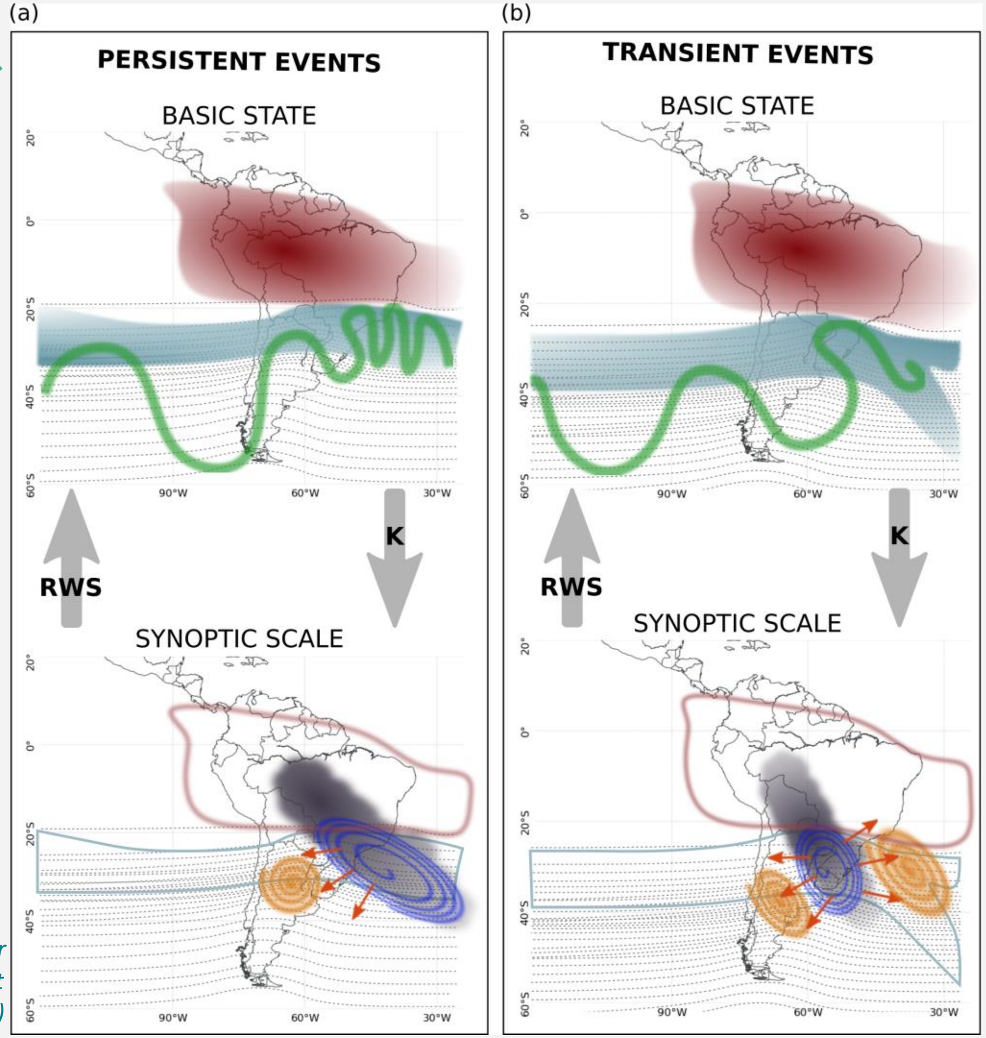
Cloud band Events Framework



TE Events

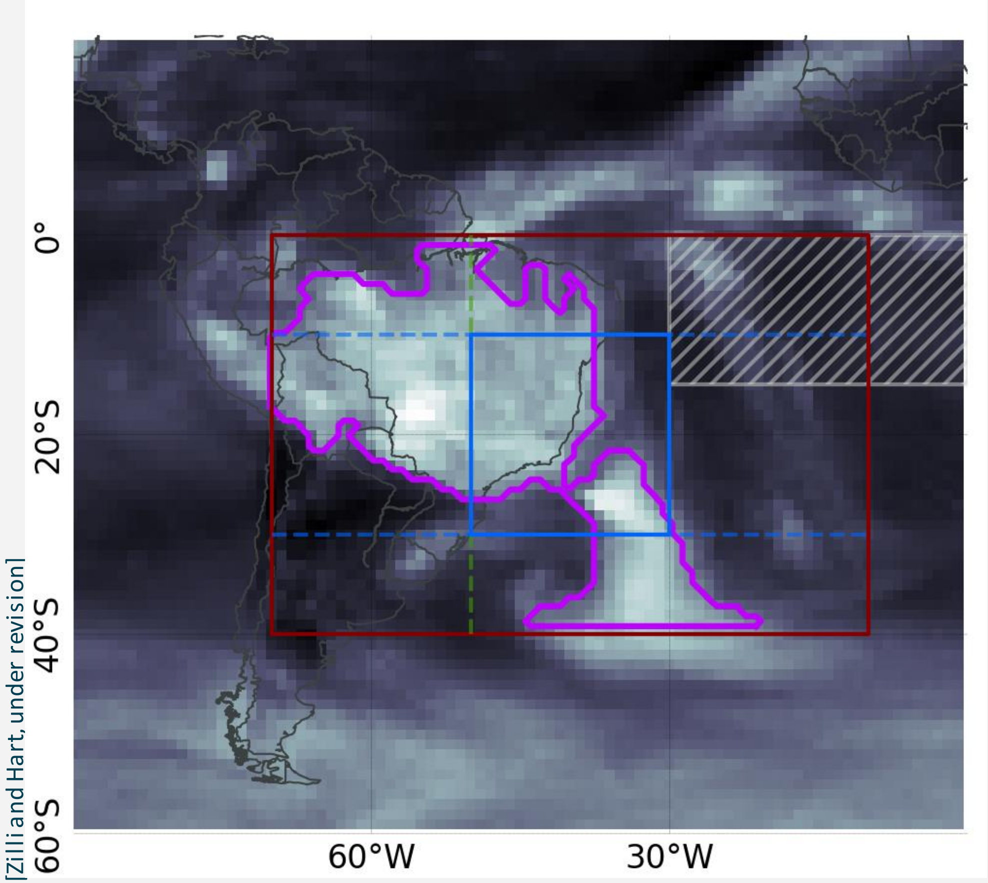
- **Extratropical forcing** – Rossby wave propagation
- **Tropical forcing** – Influence of diabatic heating from the Amazon
- **Local forcing** – land-use change and other regional influences

Schematic of the Rossby wave dynamics over South America during persistent and transient events (Zilli and Hart, under revision)



[Zilli and Hart, under revision]

Methodology



Schematic of the study area: average OLR for 12th January 2011, representing a day with cloudband event (shades) and its signature as identified by the algorithm (magenta contour). Other parameters utilised by the cloudband detection algorithm: region of interest for cloudband occurrences (red square), the minimum latitudinal extension of the cloudbands (dashed blue lines), the area over which the cloudband should be diagonal (blue square), and the meridian defining the minimum eastern limit of the events (green dashed line). The OLR in the hatched area is excluded from the analysis.

- Cloud band detection algorithm developed by Hart et al. (2012, 2013) and adapted to South America [Zilli and Hart 2021, under revision]
- Dataset:
  - OLR – NOAA CDR V1.2
  - Precipitation and Circulation variables – ERA5
- Quantification of changes: comparison between two 9-year periods, excluding EN and LN years:
  - 1979-1996 (excluding 82, 83, 84, 86, 87, 88, 91, 94, 95)
  - 1997-2018 (excluding 97, 98, 99, 00, 02, 06, 07, 09, 10, 11, 15, 17)
- Significance of the differences: Student's T-test and Hotelling's H^2 test

Contribution of the cloudband events to the observed changes in precipitation

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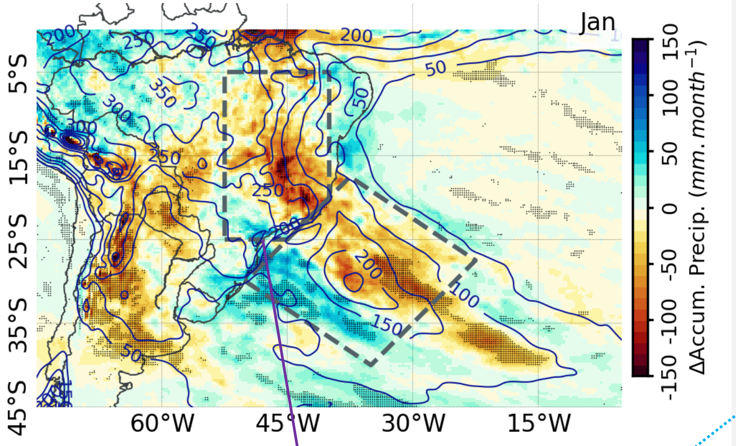
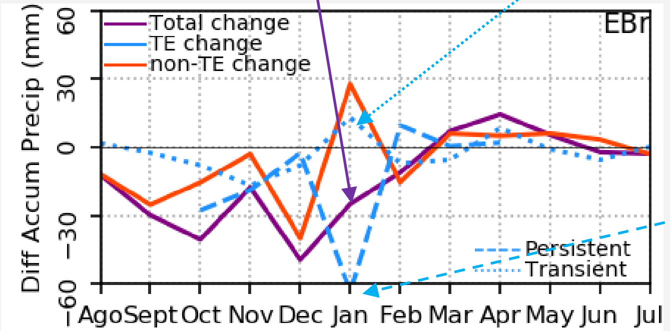
CLIMATOLOGY

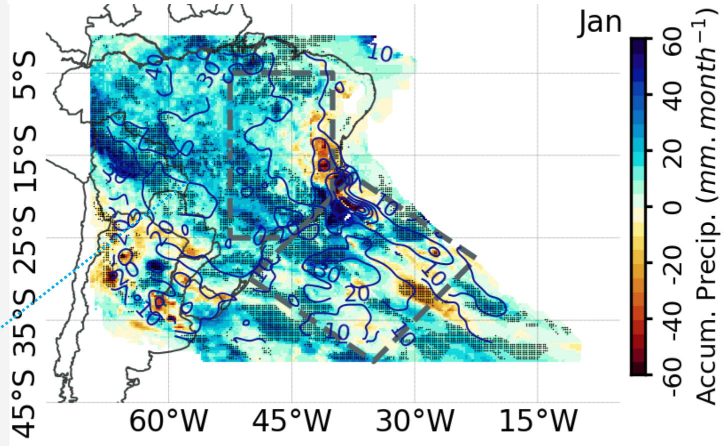


Total precipitation in January (contours in mm.month-1) and the difference between the two periods considered (shades). Gray shading indicates the areas where the difference was significant (p ≤ 0.1). Dashed areas delimits eastern Brazil and the oceanic SACZ.

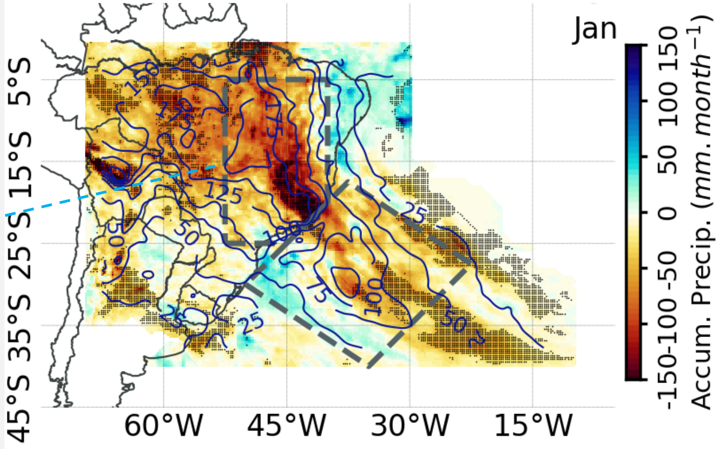


Monthly difference in accumulated precipitation spatially averaged over Eastern Brazil, considering the climatology (purple line), non-TE events (red lines) and persistent (dashed blue line) and transient (dotted blue line) TE events.

TRANSIENT EVENTS (1-3 days)



PERSISTENT EVENTS (≥ 4 days)



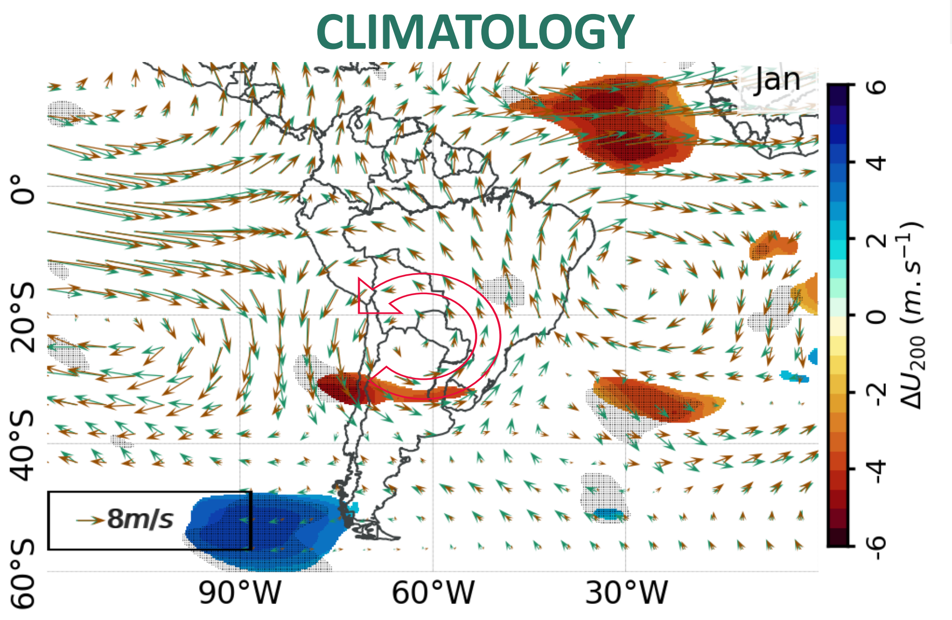
In January:

- Climatology: reduction of the total precipitation over Eastern Brazil
- Fewer persistent events, largely contributing to the reduction in total precipitation.
- More frequent transient events, partially offsetting the reduction in total precipitation

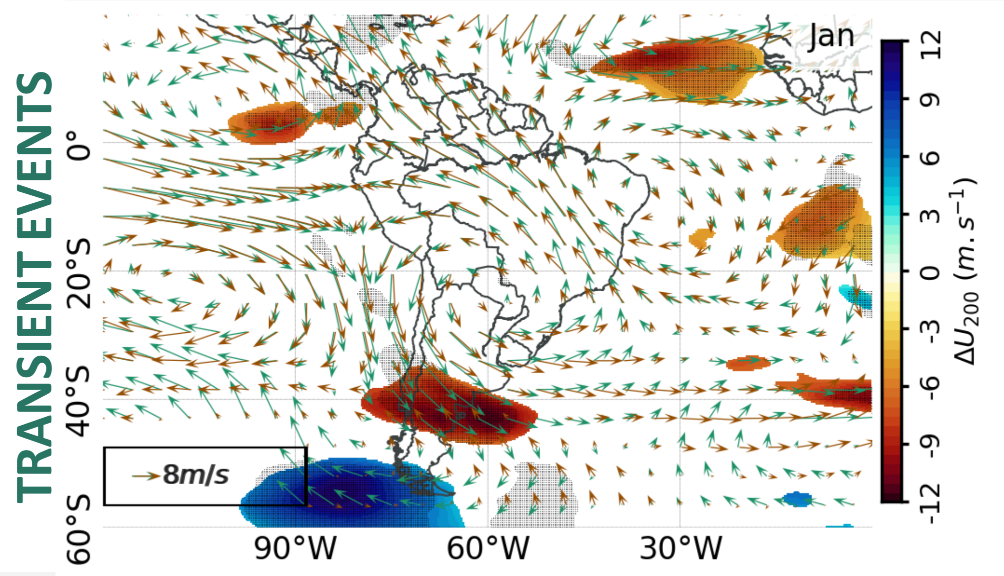
>> What causes this changes in the duration of the events?

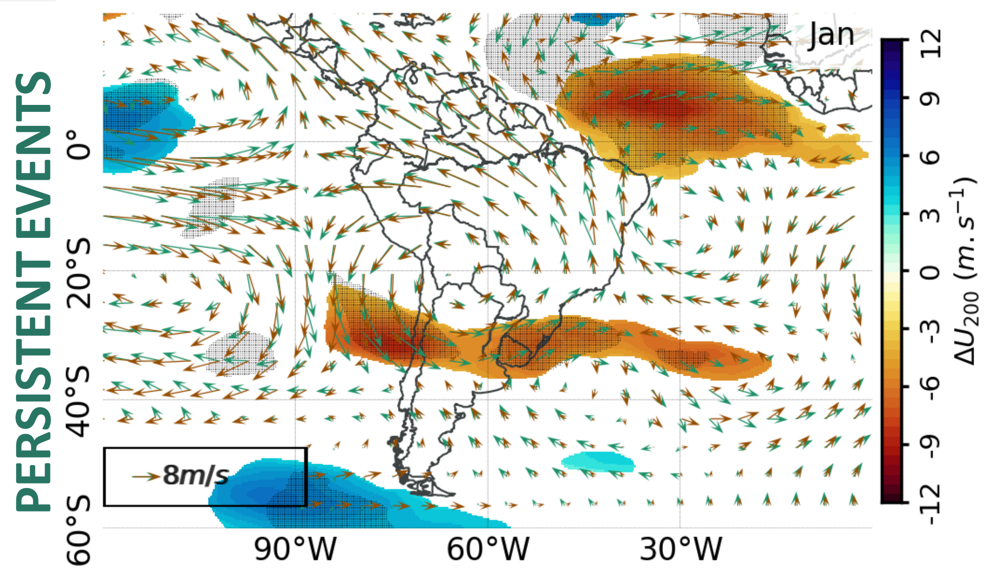
< Total precipitation in January (contours in mm.month^{-1}) and the difference between the two periods (shades) considering ony days with transient (top) and persistent (bottom) TE events. Gray shading indicates the areas where the difference was significant (p ≤ 0.1). Dashed areas delimits eastern Brazil and the oceanic SACZ.

Changes in upper-level circulation



January upper-levels (200 hPa) wind during the first (green arrows) and last (brown arroes) periods analysed and the difference between their zonal component (shades, only significant areas [p ≤ 0.1]). Gray shading indicate areas where the differences in wind are significant (p ≤ 0.1 considering the Hotelling H² test). The red arrow represents the approximate location of the Bolivian High.



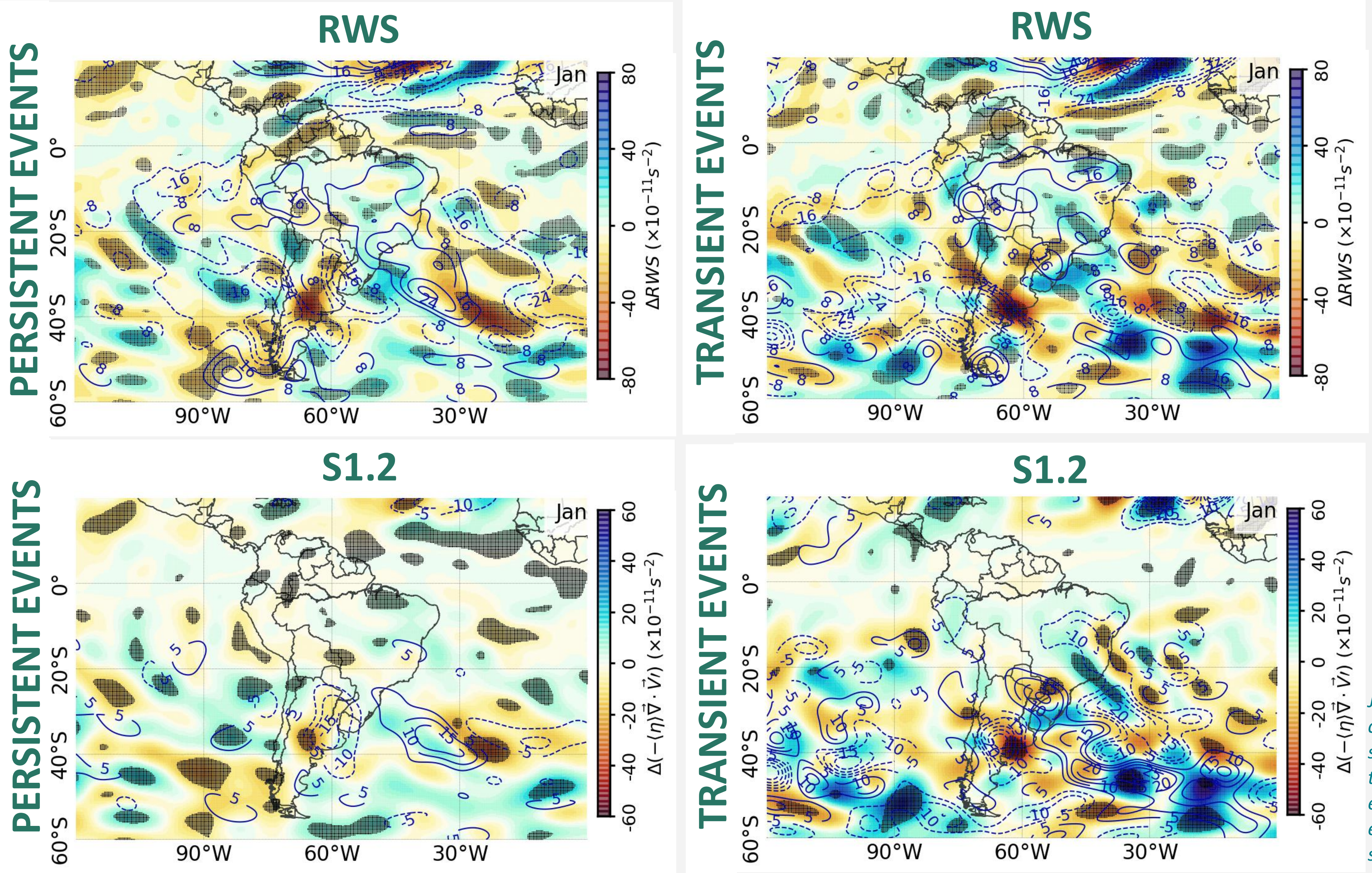


January upper-levels (200 hPa) wind during the first (green arrows) and last (brown arroes) periods analysed and the difference between their zonal component (shades, only significant areas [p ≤ 0.1]), considering only days with transient (top) and persistent (bottom) cloud band events. Gray shading indicate areas where the differences in wind are significant (p ≤ 0.1 considering the Hotellling H2 test).

In January:

- Climatology: deepening and eastward expansion of the Bolivian High increasing the easterlies over subtropical latitudes.
- Similar changes are also observed during transient (top) and persistent (bottom) events.
- Prevents further tropical propagation of the RW reducing the organization and persistence of the events

Consequences of changes in precipitation



$$RWS = \langle RWS \rangle + RWS'$$

$$\langle RWS \rangle = \underbrace{-\langle \eta \rangle \langle \nabla \cdot \mathbf{V} \rangle}_{S1} \underbrace{- \langle \mathbf{V}_\chi \rangle \cdot \langle \nabla \eta \rangle}_{S2}$$

$$RWS' = \underbrace{-\eta' \langle \nabla \cdot \mathbf{V} \rangle}_{S1.1} \boxed{\underbrace{- \langle \eta \rangle \nabla \cdot \mathbf{V}'}_{S1.2}} \underbrace{- \langle \mathbf{V}_\chi \rangle \cdot \nabla \eta'}_{S2.1} \underbrace{- \mathbf{V}_\chi' \cdot \langle \nabla \eta \rangle}_{S2.2}$$

- Reduced RWS along the northern margin of the cloud bands during persistent events
- Transient events: reduction in the organization of the areas of positive and negative RWS

January upper-levels (200 hPa) Rossby wave sources and sinks (top; contours each $x10^{-11}s^{-2}$; calculated as the equations above) and the stretchung of the climatological vorticity by the anomalous divergence term (bottom, contours each $x10^{-11}s^{-2}$, calculated as the term S1.2 in the equations above), considering persistent left) and transient (right) events. Shades indicate the difference between the two periods. Gray shading indicate areas where the differences are significant ($p \leq 0.1$).

Consequences of changes in precipitation

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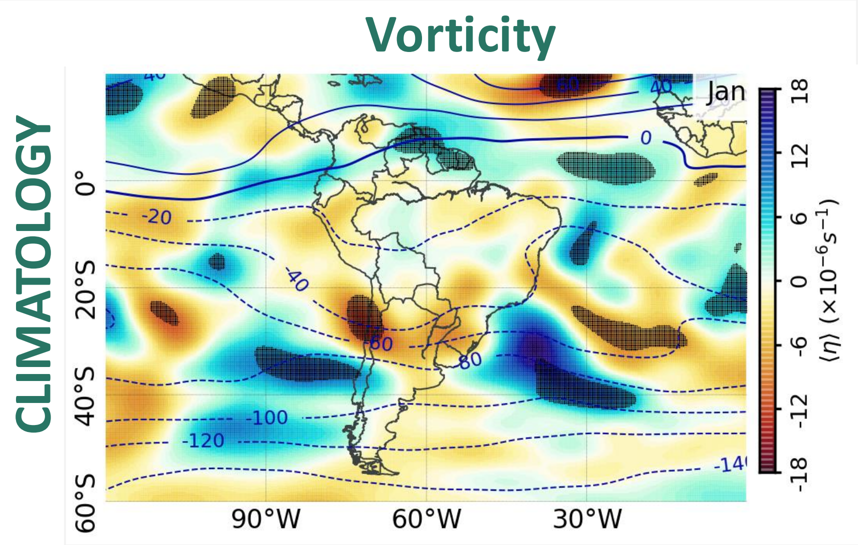
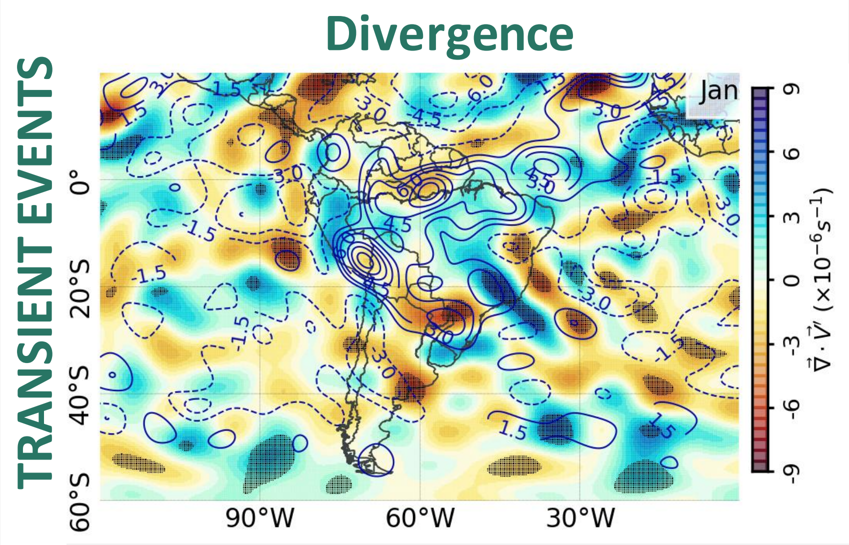
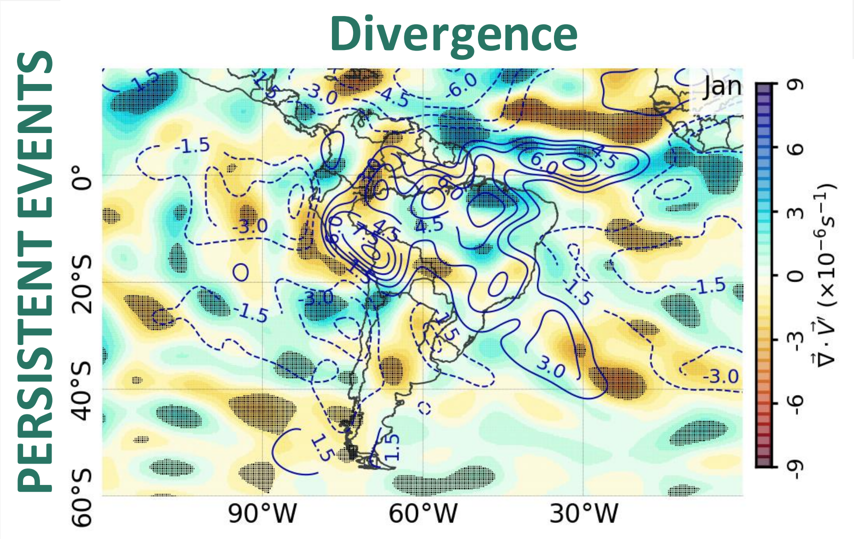


January upper-levels (200 hPa) vorticity (contours each $10^{-6}s^{-1}$) and their differences between the two periods (shades). Gray shading indicate areas where the differences in wind are significant ($p \leq 0.1$)

- Changes on the periphery of the BH
- Southward shift of the trough over SACZ





January upper-levels (200 hPa) divergence (contours each $x10^{-6}s^{-1}$) and their difference between the periods analyzed (shades) considering transient (top) and persistent (bottom) events. Gray shading indicate areas where the differences in wind are significant ($p \leq 0.1$).

$$RWS = \langle RWS \rangle + RWS'$$

$$\langle RWS \rangle = \underbrace{-\langle \eta \rangle \langle \nabla \cdot \mathbf{V} \rangle}_{S1} \underbrace{- \langle \mathbf{V}_\chi \rangle \cdot \langle \nabla \eta \rangle}_{S2}$$

$$RWS' = \underbrace{-\eta' \langle \nabla \cdot \mathbf{V} \rangle}_{S1.1} \boxed{\underbrace{-\langle \eta \rangle \nabla \cdot \mathbf{V}'}_{S1.2}} \underbrace{-\langle \mathbf{V}_\chi \rangle \cdot \nabla \eta'}_{S2.1} \underbrace{-\mathbf{V}_\chi' \cdot \langle \nabla \eta \rangle}_{S2.2}$$

- Transient events: increase in divergence over SE Brazil reflecting the larger number of events
- Persistent events: reduction in the oceanic portion of the cloud band

Final Remarks

- Identification of changes in the frequency of cloud band events leading to a reduction in precipitation along the northern margin of the SACZ
- Changes in climatology affect the dynamic support to the organisation of coherent structures characteristic of the cloud band events
- Framework allows the identification of the main factors involved
- Framework also allows for the identification of possible downstream effects of the observed changes
- This framework is also helpful when evaluating historical and future scenarios simulated by global and regional climate models

Thank you

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References:

Hart N et al (2012) Mon Wea Rev 140, 4005–4016, doi:10.1175/MWR-D-12-00127.1.
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Zilli MT and Hart N (in revision) J Climate