Effects of the regional-local circulation on precipitation development in the tropical Andes (Rio Santa Basin)

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Abstract

The Cordillera Blanca (central Andes of Peru) represents the largest concentration of tropical glaciers in the world although the atmospheric processes are still little studied in this region. The main objective of this study is to understand the atmospheric processes of interaction between local and regional scales controlling the diurnal precipitation cycle over the Santa River basin between the Cordillera Blanca and the Cordillera Negra. The rainy season (DJFM) of 2012-2013 is chosen to perform simulations with the WRF (Weather Research and Forecasting) model, with two domains at 6 km (WRF-6km) and 2 km (WRF-2km) of horizontal resolution, forced by ERA5. WRF-2km precipitation outputs show a clear improvement over WRF-6km in terms of the diurnal cycle compared to in situ observations. Three hours of the afternoon (13 LT, 16 LT, and 19 LT) are identified as associated with the triggering precipitation processes over the Santa basin. In addition, WRF-2km shows that the moisture from the Pacific Ocean is a crucial process modulating the diurnal cycle of precipitation over the Santa basin in interaction with moisture fluxes from the Amazon basin.

Methods

- We use precipitation data from 19 in situ meteorological stations from the Peruvian National Meteorology and Hydrology Service (SENAMHI) and 15 meteorological stations from the Universidad Nacional Santiago Antúnez de Mayolo (UNASAM) of Huaraz to validate the model outputs.
- In addition, precipitation products, such as CHIRPS, TRMM, PISCO, and CMORPH, were used in validation.

Table 1. Characteristics of the WRF simulations at the three different spatial grids.

	D01 (WRF-6KM)	D02 (WRF-2KM)
DOMAIN	Tropical Andes	Rio Santa region
CONFIGURATION	Regional simulation	One-way nesting
HORIZONTAL GRID SPACING (KM)	6	2
NUMBER OF GRID POINTS	391x397	187x172
VERTICAL RESOLUTION	38 sigma levels	38 sigma levels
FORCING	ERA5	WRF6
RUN TIME STEP (S)	12	4
OUTPUT TIME RESOLUTION (H)	1	1
PERIOD	Dec 2012 – March 2013	Dec 2012 – March 2013

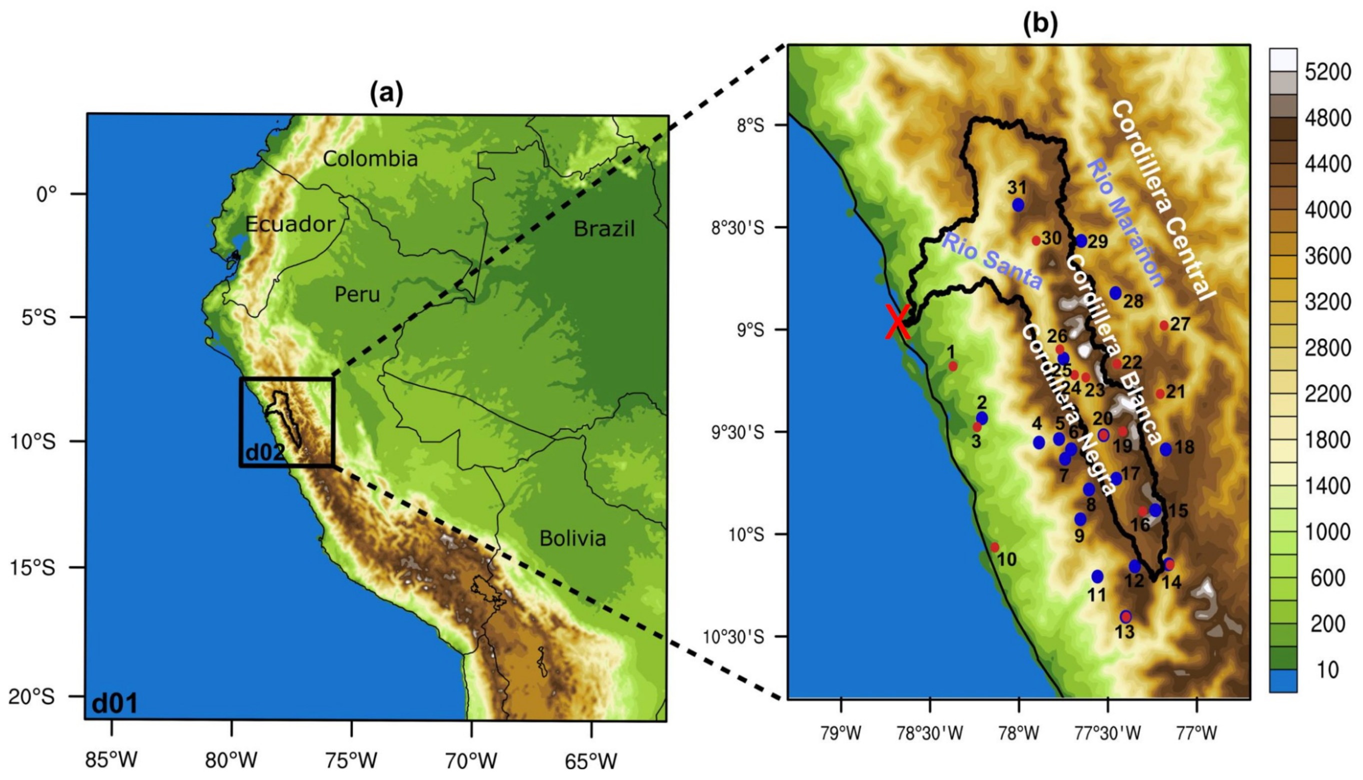

Fig 1. Location of the Santa River basin in central Peruvian Andes and WRF domains for WRF-6km (d01) and WRF-2km (d02) with corresponding WRF topography (shaded; m.asl). b Geographical details of d02. In both panel the location of the upper Santa River basin is indicated in bold black line. In b color dots indicate the meteorological station positions with their respective reference number. Blue and orange dots correspond to SENAMHI and UNASAM stations respectively. The red cross indicates the outlet of the basin.

Table 2. Physical parameterizations used in the sensitivity WRF simulation tests.

	Parameterization	Reference
Planetary boundary layer	Mellor-Yamada Nakanishi and Niino Level 2.5 (MYNN2)	Nakanishi & Niino (2006)
Surface layer	MYNN	Nakanishi & Niino (2004, 2006)
Land Surface	Noah-MP (multi-physics) with precipitation partitioning between snow and rain (option 2)	Niu et al. (2011); (Yang et al., 2011)
Cumulus parameterization	Betts-Miller-Janjic	Betts, 1986; Betts & Miller, 1986; Janjić, 1994
Microphysics	Goddard	Tao et al. (1989)
Radiation	Longwave:Rapid Radiative Transfer Model (RRTM)	Iacono et al. (2008)
	Shortwave: Dudhia scheme	Dudhia (1988)

- We analyze the diurnal cycle of precipitation through the following equation:

$$prep\ (\%) = \frac{Pe_{hour}}{Pe_{day}} * 100\%$$

$prep\ (\%)$: Percentage of precipitation for each hour;

Pe_{hour}: Mean precipitation each hour;

Pe_{day}: Accumulated rainfall during 24 hours or daily rainfall.

Results

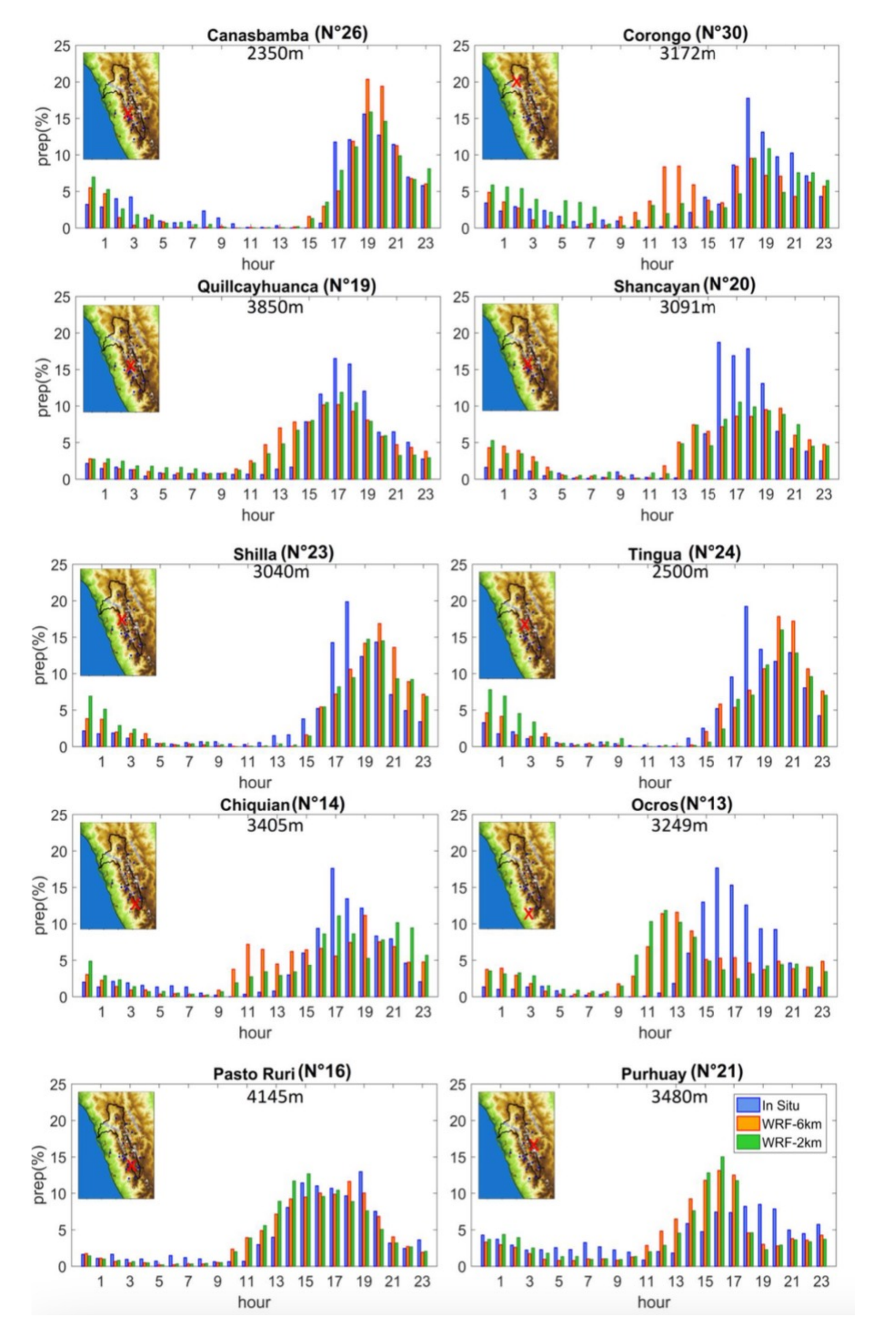

Figure 2. Histogram of the mean diurnal cycle of precipitation in percent (%) of the total daily mean of the summer season (December 2012- March 2013; DJFM) along the Santa River basin, for ten automatic in situ stations (blue bars), and the corresponding grid-point from WRF-6km hourly (orange bars) and WRF- 2km hourly (green bars). The location of the station and other geographical details are indicated in each inset panel.

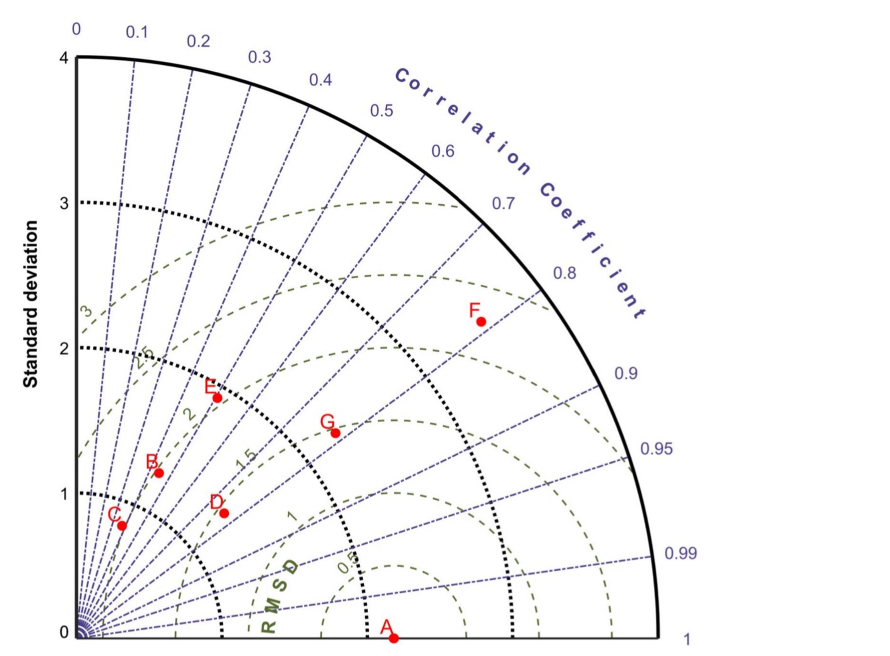

Figure 3. Taylor Diagram of DJFM precipitation mean (mm/day) of TRMM3B42 (B), CMORPH (C), CHIRPS (D), PISCO (E), WRF-6km (F), and WRF-2km (G) compared to the in situ precipitation data (A).

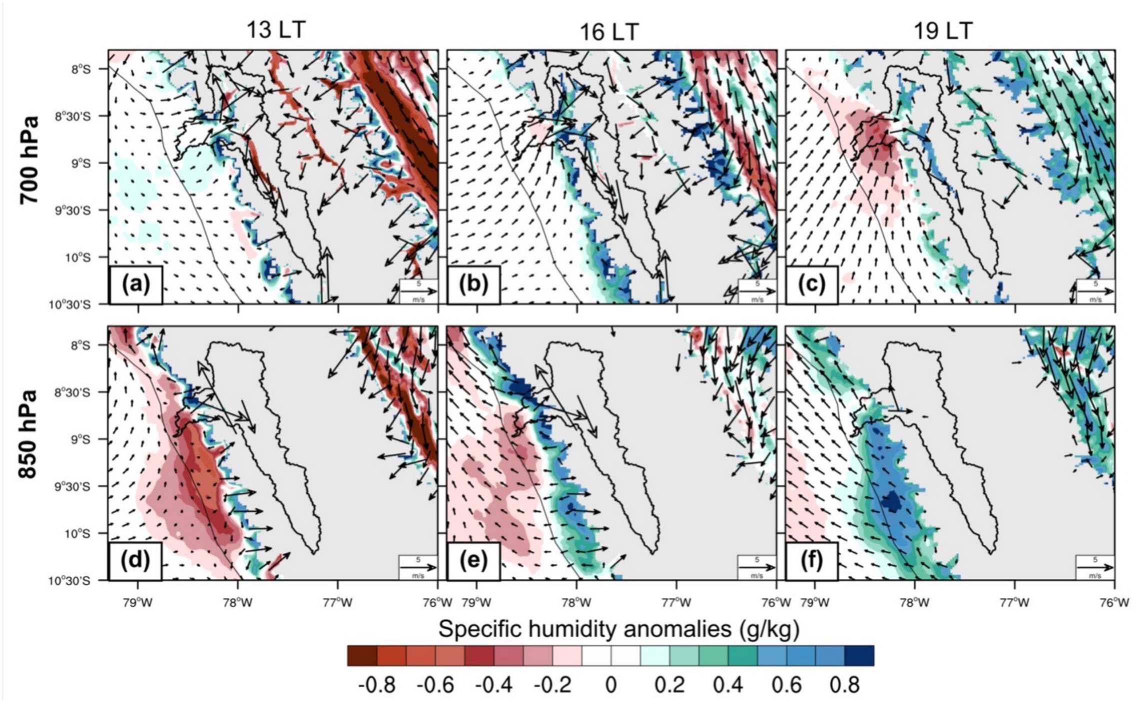

Figure 4. DJFM mean of horizontal wind (arrows, m s^{-1}) and anomalous specific humidity (color shaded, g kg^{-1}) from WRF-2km for hourly means according to each time-step title minus all times step mean at a, b, c 700 hPa and d, e, f 850 hPa. Delimitation of the Santa River basin and the coastline are indicated in black lines.

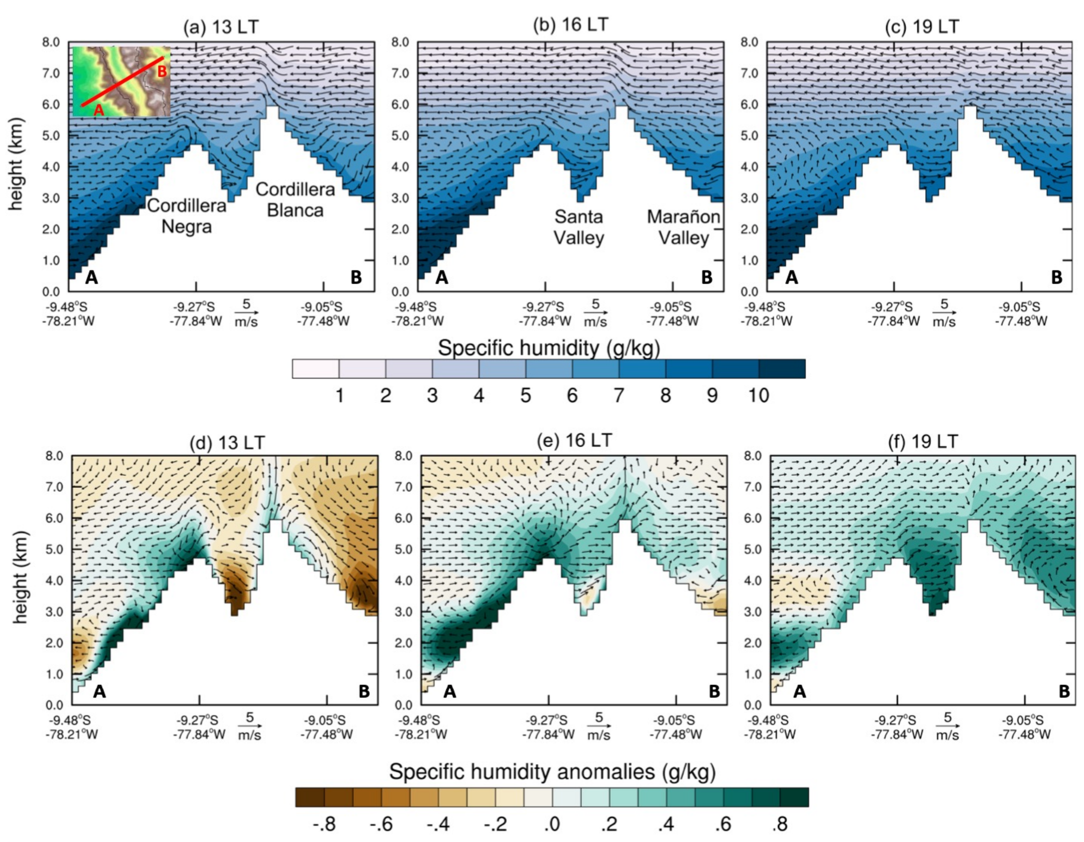

Figure 5. DJFM mean of the vertical cross-section of the meridional-vertical moisture flux (qv;qw) and specific humidity (colors; g kg^{-1}) a, b, c means and d, e, f anomalies (each time-step title minus all times step mean) from the WRF-2 km. The section is (78.2°W, 9.49°S)—(77.33° W, 8.9°S). Reference vector in g kg $^{-1}$ m s^{-1} is displayed at the bottom. The location of the cross-section and other geographical details are indicated in the inset panel (a).

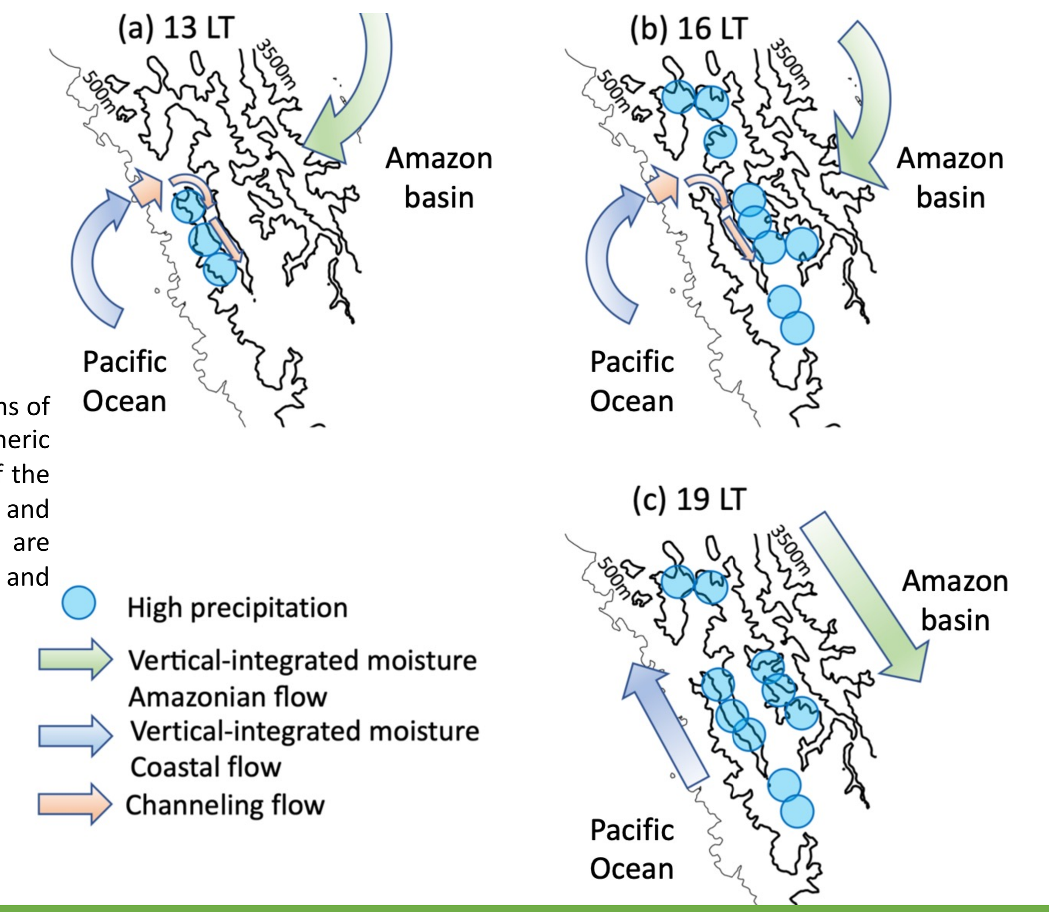

Figure 6. Schematic diagrams of the main atmospheric circulations in the region of the Santa River basin. The thin and bold black contours are topography limits at 500 m and 3500 m respectively.

Conclusions

- Statistical analysis showed a clear improvement of WRF-2km over WRF-6km to simulate the daily mean and diurnal cycle of precipitation in greater agreement with *in situ* observations.
- WRF-2km improves the diurnal cycle of precipitation by decreasing the time delay in triggering convection.
- The main precipitation patterns over the summits in the Cordilleras Negra and Blanca are strongly controlled by the entrance of regional winds alongshore. Therefore, the afternoon precipitation along the Santa valley is associated with an atmospheric circulation triggered by a channeling flow between 13 LT and 16 LT.
- The Pacific Ocean stands out as a source of moisture for the Cordillera Blanca and the Santa basin precipitation through the establishment of channeling flow. Therefore, the moisture from the Pacific Ocean is a key process modulating diurnal cycle of precipitation over the Santa Basin, in interaction with moisture fluxes from the Amazon basin.

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