The 2010-2012 extreme wet season in northern South America: causes and moisture sources

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1. Context

2010: Highest rainfall on record

The record breaking precipitation associated with La Niña events during 2010-2011 affected millions of people in Colombia, and produced property damages of millions of dollars.

The anomalous circulation in northern South America was associated with global circulation anomalies (Trenberth and Fasullo, 2012).

Scientific Questions

- *Where did the excess atmospheric moisture come from?*
- *Which processes could be associated to the anomalous wet season in northern South America during 2010-2012?*

2. Observed rainfall anomalies

Regional rainfall anomalies

- Positive anomalies of precipitation over northern South America were observed between March 2010 and May 2012.
- Strongest anomalies took place between September 2010 and May 2011, and between September 2011 and February 2012.
- Weaker positive anomalies were observed on June-August 2011, during the transition from La Niña 2010-2011 to La Niña 2011-2012.

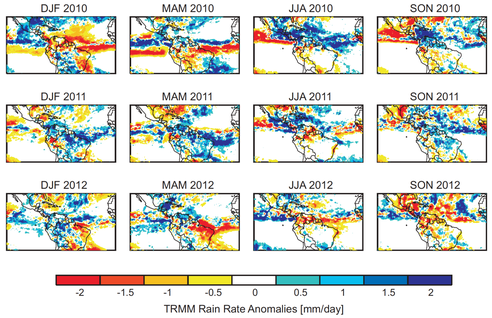
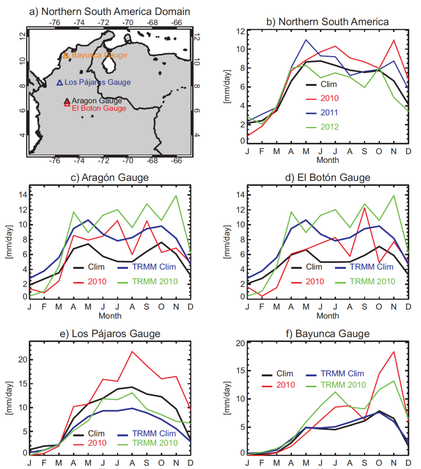


Figure 1. *Seasonal anomalies of precipitation over the tropical Americas between December 2010 and November 2012, estimated from the TRMM monthly data. Base period is 1998-2013.*

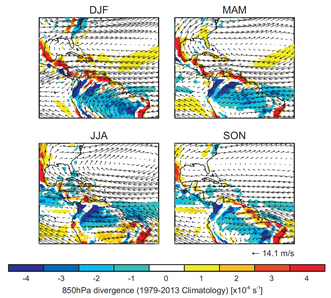


Local rainfall anomalies

- The annual cycle of TRMM precipitation over northern Colombia and Venezuela (Fig. 2ab) exhibits above normal values during 2010 and 2011.
- Observations from rain gauges also show how precipitation was higher than average over northern and central Colombia (Figs. 2c-f).
- TRMM data shows the same type of annual cycle as the observations (e.g. bimodal in Fig. 2d), but with some biases. The sign and timing of deviations during 2010 and 2011 are also well represented by the TRMM data (Figs. 2c-f).

Figure 2. *a) Northern South America region for the TRMM averages in b). c) – f) Annual cycle of precipitation for several sites, using rain-gauge data and the corresponding TRMM pixel values.* In all figures "Clim" refers to the mean annual cycle.

3. Circulation anomalies and water vapor transport



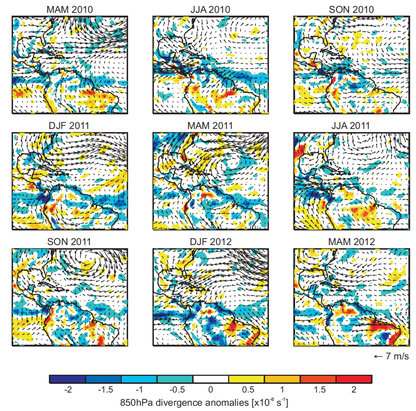


Figure 3. Top: *Seasonal mean of the Vertically Integrated Moisture Flux (VIMF, arrows) and its divergence (VIMFC).* ***Right****: Seasonal anomalies of the VIMF and VIMFC fields during the period March 2010 – May 2012. All fields correspond to ERA-Interim data.*

Anomalies of transport of water vapor

- The **westerly moisture flux** over western Colombia was **enhanced** between March 2010 and February 2011, and again between June 2011 and February 2012. Part of this flux is associated with a westerly jet off the west coast of Colombia, known as the **Choco Jet**.
- The easterly moisture flux over the Caribbean developed a northerly component during most of the period March 2010–February 2012. Part of the easterly flux is due to the **Caribbean Low Level Jet** (CLLJ), which became **weaker and more northeasterly** during 2010-2011.
- A **weaker easterly flux** from the far tropical Atlantic was observed during most of the March 2010 – March 2011 period. This weakening was associated with moisture convergence over northern South America.

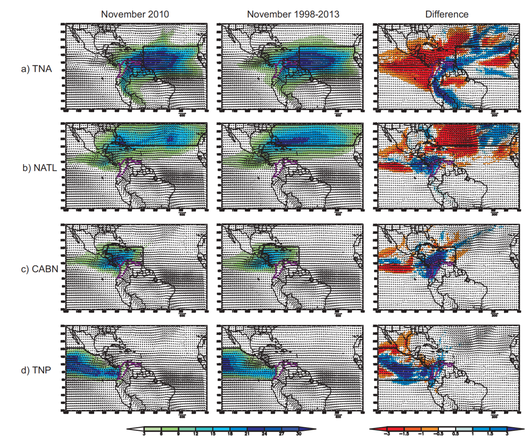


Figure 4. Total precipitable water contributed to Northern South America (NOSA) from a) Tropical North Atlantic (TNA), b) Subtropical North Atlantic (NATL), c) Caribbean Sea (CABN), and d) Tropical North Pacific (TNP) during November 2010 (left panel) and November 1998-2013 (middle panel). Right panel shows the difference between left and middle panel. Black (purple) solid contour indicates the source region (NOSA). Precipitable water contributions are in mm, as indicated by the color scale. Vectors represent VIMF in units of $kg^{-1}\ m^{-1}\ s^{-1}$. Estimations were computed with the Dynamical Recycling Model (DRM).

Sources of Atmospheric Moisture

- Climatologically, most of the precipitable water over northern NOSA comes from the **Atlantic** (52%), followed by **terrestrial sources** (28%, including Orinoco basin, NOSA, northern Amazon, and Guyanas region). The mean annual contribution from the Pacific is 3%, but the contribution is much larger during September-November (almost 10%).
- The excess of moisture during 2010 came from different sources: from **eastern sources** during the first part of the year, from **southern sources** during May-Sep, and from **northern and western sources** from Sep to Dec. The **largest contributions** to the excess moisture during 2010-2011 came from the **Atlantic and eastern Pacific**.

4. Contributing factors

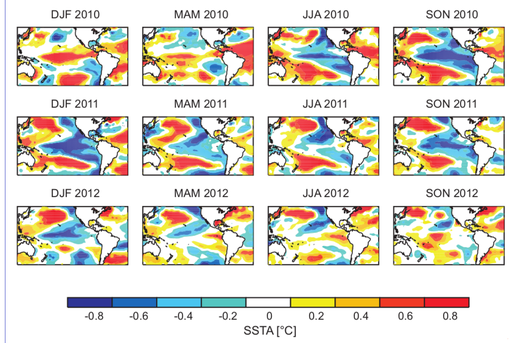


Figure 5. *Seasonal anomalies of SSTs over the tropical Pacific and Atlantic oceans between DJF 2010 and SON 2012. Anomalies are computed using the 1979-2013 base period. SST fields obtained from the Climate Diagnostic Center (CDC).*

Sea Surface Temperature Anomalies (SSTAs)

- The eastern Pacific was warmer than usual between December 2009 and May 2010, corresponding to El Niño conditions.
- Lower temperatures over the eastern Pacific were observed between June 2010 and February 2012, corresponding to La Niña conditions.
- Higher temperatures than average were observed over the Caribbean between 2010 and 2012. The positive anomalies during JJA-2010 were probably due to the 2009-2010 El Niño. The positive anomalies for the rest of the period seem to be associated with the dipolar pattern over the Atlantic, which resembles the *Atlantic Meridional Mode (AMM).*

Schematics of the anomalous circulation

- **Colder** conditions over the **eastern Pacific** led to a **stronger Choco jet**, due to the enhanced land-sea thermal contrast.
- **Warmer** conditions over the **Caribbean** led to a **weaker CLLJ**, due to the weakening of the zonal pressure gradient.
- An **enhanced meridional temperature gradient** over the tropical Atlantic led to **weaker easterlies**.

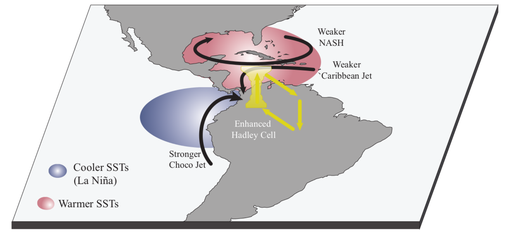


Figure 6. *Schematic diagram of the circulation anomalies observed in northern South America during the wet season of 2010-2012. The cooler eastern Pacific enhanced the Choco Jet. The warmer Caribbean weakened the north Atlantic anticyclone (NASH) and the CLLJ. The enhanced moisture convergence over South America strengthened the regional Hadley cell, promoting subsidence over the Amazon, especially during June-August 2010.*

5. Concluding remarks

- 2010 and 2011 are the rainiest years in Colombia on record. Stronger than average La Niña conditions were observed during both years.
- **Above-average precipitation** over northern South America was observed, mainly between June 2010 and April 2012. This precipitation was associated with **enhanced moisture flux from the Caribbean, the tropical Atlantic, and the eastern Pacific**.
- The anomalous circulation leading to the anomalous transport of moisture to northern South America was associated with the effects of SSTAs. The SSTAs over the Pacific were largely associated with La Niña, but part of the SSTAs over the Caribbean and the Atlantic could also be related to non-ENSO patterns, like the Atlantic Meridional Mode.

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