ROLE OF COLD FRONTS IN SOUTH AMERICAN MONSOON ONSET

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1. Introduction:

This study evaluates the impact of cold fronts on the onset of the South American Monsoon (SAMS). Nieto Ferreira and Rickenbach (2010, *Submitted to the Int. J. Clim.*) proposed a three-stage model for SAMS onset. The first stage of onset starts around pentad 58 (13-17 Oct) when precipitation begins in the northwestern part of the continent and slowly progresses southeastward (region I in Fig. 2a). The second stage is marked by the abrupt onset of the South Atlantic convergence zone (SACZ, region II in Fig. 2a) around pentad 61 (28 Oct-1 Nov). The third stage of monsoon onset involves the late arrival of the monsoon to the mouth of the Amazon River. This three-stage conceptual model of onset provides a useful framework for the study of regional differences in monsoon onset mechanisms.

In this study a composite analysis of the structure, intensity and propagation of cold fronts that occur before, during, and after monsoon onset is used to study the effect of cold fronts on monsoon onset in the Amazon basin and on the abrupt onset of the monsoon season in the region of the SACZ.

Our working hypothesis is that cold fronts provide a dynamical trigger for monsoon onset in parts of the South American Monsoon region.

2. Data and Methods:

Datasets:

The study period is 1 January 1998 to 31 December 2007. Two main datasets are used:

- NCEP/NCAR daily reanalysis data at 2.5 horizontal resolution (Kalnay et al., *Bull. Amer. Met. Soc.* 1996)
- Global Precipitation Climatology Project (GPCP) daily rainfall data at 1 resolution (Adler et al., *Hydrometeor.*, 2003).

Cold Front Definition:

The NCEP/NCAR Reanalysis sea level pressure was used to determine the dates of all cold fronts that occurred during 1998-2007 using the following definition:

A cold front event is defined when the box centered at 23.75 S, 58.75 W registers a 1.5 mb increase in sea-level pressure over a period of one day, for sea-level pressure greater than 1010 mb (based on Garreaud 2000, Mon. Wea. Rev.). Cold fronts that persisted for several days were only counted once"

SACZ Onset Definition:

Given the structure of the SACZ and the abruptness of its onset we center our cold front composites around the date of onset in the SACZ. For each year, the SACZ onset pentad was determined using a rotated empirical orthogonal function (REOF) analysis of the GPCP rainfall pentads. The third mode of the REOF analysis (REOF3, Fig. 2a) has strong loadings in the SACZ region (region II in Fig. 2a). For each year SACZ onset was defined as the time when the principal component timeseries (Fig. 2b) for REOF3 becomes negative and stays negative for at least four of the next 5 pentads. REOF1 captures the variability of convection in the Amazon Basin (region I) and is used in a similar fashion to determine onset in the Amazon Basin.

3. Cold Front Climatology:

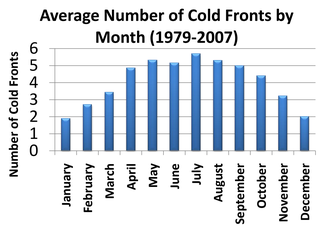


Figure 1: Average number of cold fronts during 1979-2007 by month.

In good agreement with previous studies (e.g., *Lupo et al. 2001, Mon. Wea. Rev.*) the frequency of cold fronts is highest in the winter months, with a peak of 5.5 events per month in July. The number of cold front events drops off sharply to about two per month during the summer.

4. SACZ Onset Dates:

Our results show that on average, onset in the SACZ region (region II of Fig. 2a) occurred on pentad 61 (28 October – 1 November), about 2 pentads later than onset in the Amazon Basin (region I of Fig. 2a). This suggests a role for Amazon convection in setting the stage for SACZ onset.

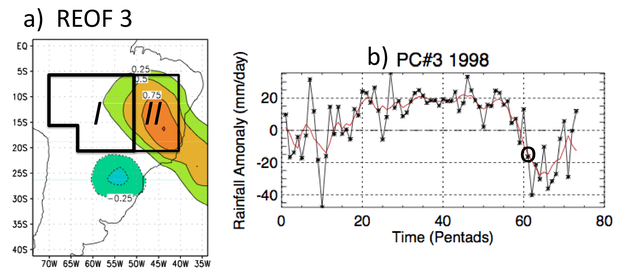


Figure 2: a) REOF 3. b) PC3 timeseries for 1998 with onset pentad marked with an 'O'.

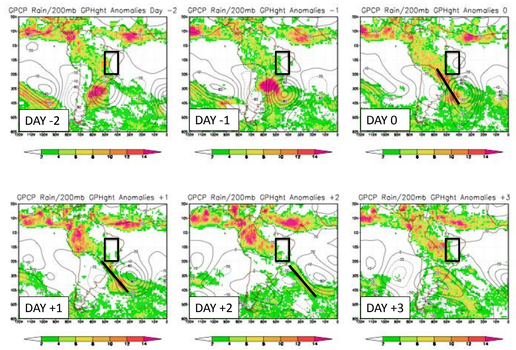
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Onset Pentad	61	59	61	59	61	62	64	61	58	66
Onset Date	28 Oct-1 Nov	18-22 Oct	28 Oct-1 Nov	18-22 Oct	28 Oct-1 Nov	2 - 6 Nov	12 - 16 Nov	28 Oct- 1 Nov	13 - 17 Oct	22 - 26 Nov

Table 1: REOF onset pentads from 1998-2007.

5. Cold Front Composites:

Monsoon onset pentad dates in the SACZ region were used to select for each year the cold fronts that preceded onset ("*pre-onset*"), occurred during the onset pentad ("*onset*"), and followed onset ("*post-onset*"). "Post-onset" composites (not shown) were very similar to "onset" composites.

1998-2007 PRE-ONSET Composites Based on PC3 Onset



1998-2007 ONSET Composites Based on PC3 Onset

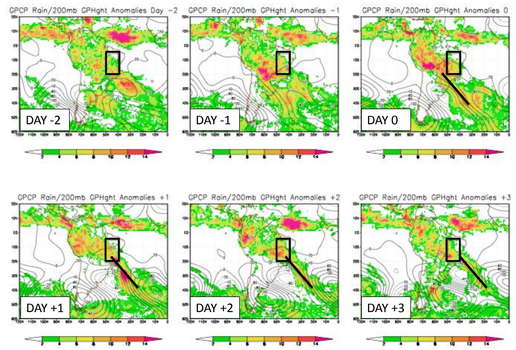


Figure 2: Ten year composites of GPCP rain and 200 mb height anomalies at "pre-onset" (left panel) and "onset" (right panel). DAY0 is the date when the cold front event is defined, with DAY–n (DAY+n) representing *n* days before (after) that date. The box outlines SACZ region and the black lines indicate the position of the cold front.

Pre-onset:

- Amazon Basin onset has already occurred at this time.
- A mesoscale convective complex occurs in Uruguay/Southern Brazil one or two days before DAY0 and likely participates in cyclogenesis and frontogenesis (*Velasco and Fritsch 1987, J. Geophys. Res.*).
- On DAY0 the cold front organizes a band of rainfall that extends from the Western Amazon Basin southeastward toward the coast of São Paulo and into the Atlantic Ocean.
- No rainfall occurs within the SACZ region during the "*pre-onset*" cold front lifecycle.
- The cold front moves out into the Atlantic Ocean by DAY+2

Onset:

- On DAY0 the distribution of convection is very similar to that of the pre-onset DAY0 composite.
- The cold front becomes stationary and is present across the SACZ region at least until day +5 (not shown).
- Upper-level negative geopotential height anomalies are not only stronger but also more zonally oriented during the "onset" cold surges indicating a transition to a new regime with more strongly anticyclonically sheared midlatitude cyclones as the SACZ becomes established (*Thorncroft et al. 1993, Q. J. Roy. Met. Soc.)*.

In summary, the composite analysis confirms that SACZ onset occurs after onset has occurred in the Amazon basin. Moreover, the composites for "pre-onset", "onset", and "post-onset" cold fronts showed significant differences in propagation, duration and strength of the convection associated with cold fronts. In particular, the "pre-onset" cold fronts moved across southern South America quickly and did not reach the SACZ region whereas "onset" and "post-onset" cold fronts became stationary in the SACZ region for at least a few days.

6. Conclusions:

- Maximum number of cold fronts occur during wintertime
- Onset in the SACZ region occurs after onset in the Amazon Basin
- "Pre-onset" – quick, eastward propagating cold fronts that do not reach SACZ region.
- "Onset" – slow propagating cold fronts that become stationary in the SACZ region.
- Changes in the structure and propagation of cold fronts lead to the onset of the SACZ.

7. Future Work:

- Identify mechanisms that allow fronts to become stationary at monsoon onset.

8. Acknowledgments:

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