

PREDICTION OF INTRASEASONAL VARIABILITY IN THE AMERICAS

NOAA Award NA10OAR4310161

FINAL Report

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I: Overview and Research Results:

The research endeavor has centered on diagnostics and modeling of the intraseasonal variability in the Americas. The results from the three years of funding are described in detail below.

(i) ISV in the Americas

Figure 1a shows the global distribution of intraseasonal variability (ISV) during the boreal winter. Maxima exist in a number of locations: the South Pacific Convergence zone (SPCZ), the South Atlantic Convergence Zone (SACZ) and in the tropical Indian Ocean which possesses the highest amplitude variance. The October-March period is chosen because that is the period of highest precipitation in the South America (Figure 1b). Figure 1c shows the spectra of out-going long-wave radiation (OLR) in the Amazon and the SACZ. Clearly both zones are strongly influenced by processes on ISV time scales.

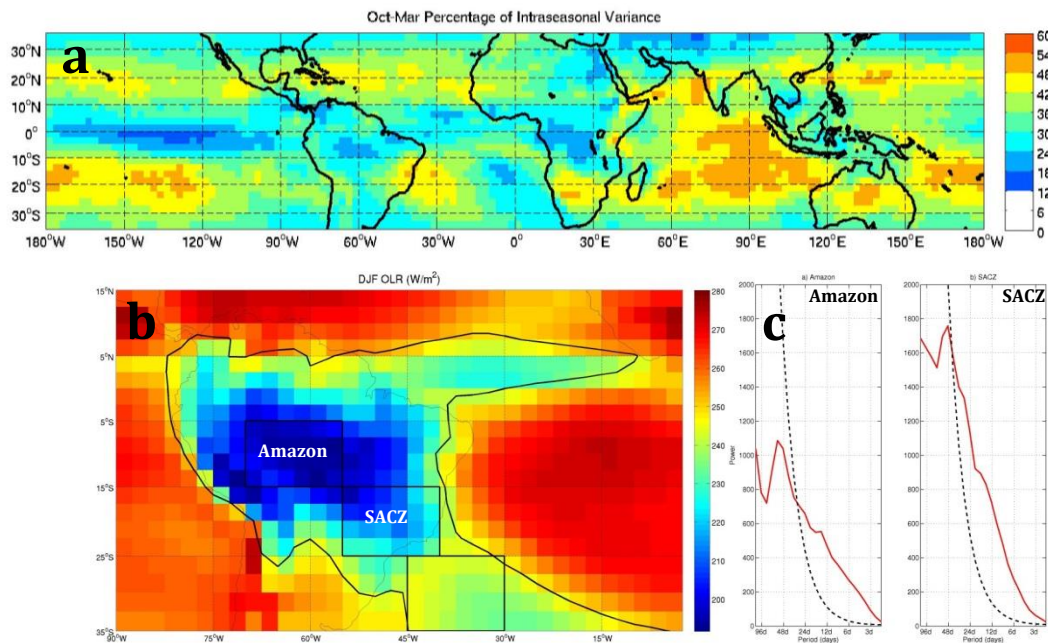


Figure 1. (a) Percentage of OLR intraseasonal variance (relative to total variance) for October to March 1979-2010. (b) DJF climatological OLR from 1979-2010. The black contour indicates $245 W m^{-2}$. (c) OLR spectra for the two regions labeled in (b).

(ii) Formation regions of ISV

Here we show the results of detailed diagnostics of the ISV relative to both major convection centers occurring over the Indian Ocean and over the tropical Central-South American regions. The reason for the study is to determine the major predictors for intraseasonal variability over South America.

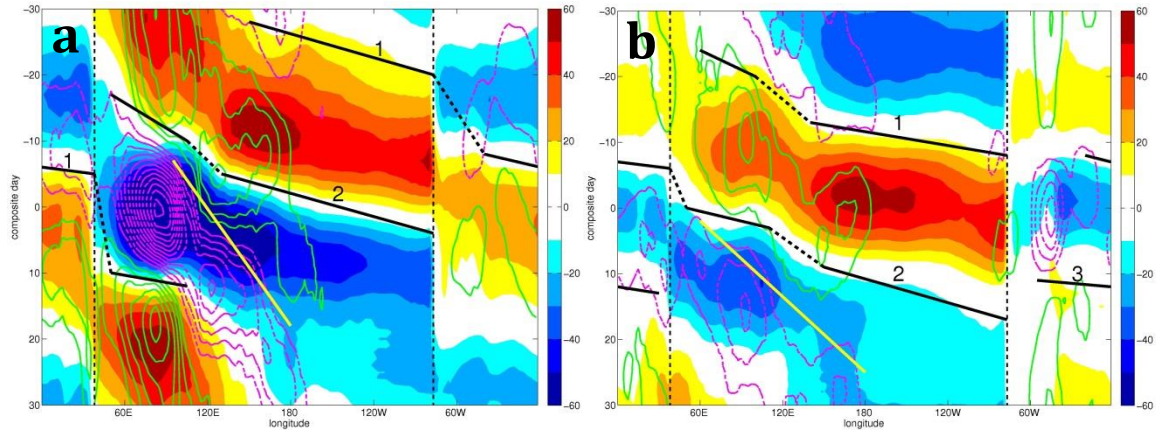


Figure 2. Oct-Mar surface pressure (shading) and OLR (contours) in the 20-60 day band about composite day 0 (maximum convection) in (a) the Indian Ocean and (b) the Amazon. Vertical dashed lines indicate the position of the Andes and the East African Highlands. Black lines signify the pressure propagation speed and yellow lines, convective propagation speed.

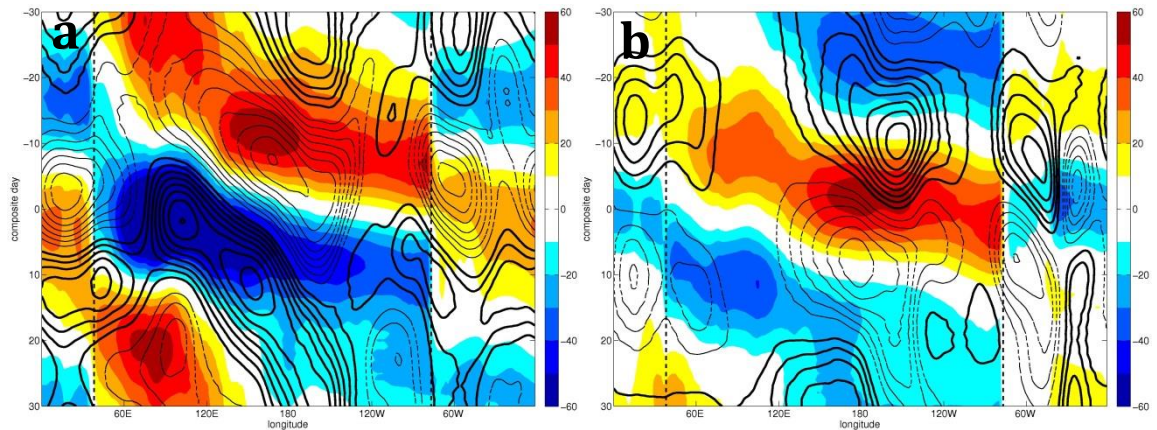
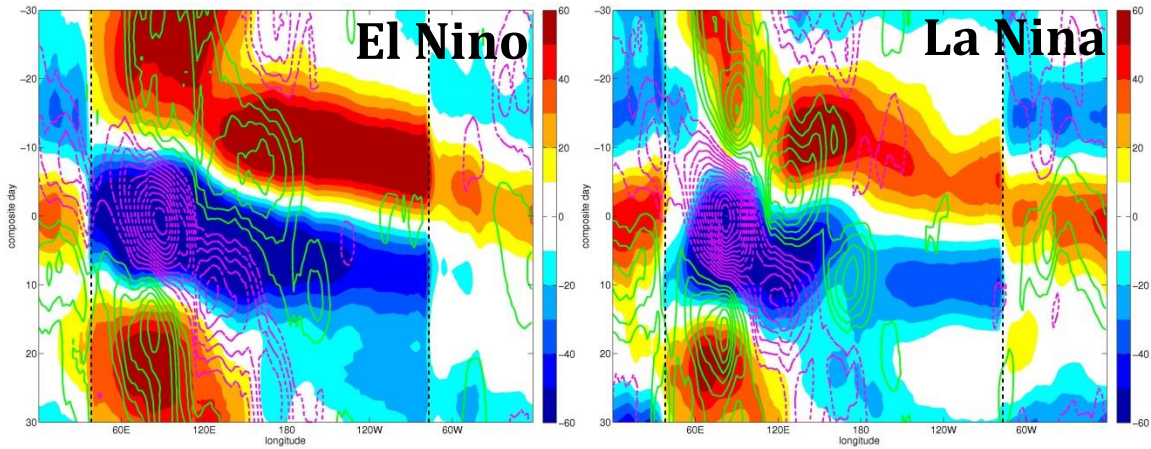


Figure 3. Same as Figure 2, but with surface pressure (shading) 200 hPa geopotential anomalies (contours). (a) Indian Ocean. (b) Amazon.

The traditional view of tropical ISV follows two major ideas: The oscillation propagates globally continually along the equator and reasserts itself in the Indian Ocean intensifying and then moving eastward. Alternatively, the oscillation is thought to grow in situ in the Indian Ocean region from where it propagates eastward. In both of these theories, the ISV occurring over the Americas is thought to be the “remnant” of the propagating mode. There are two offshoots of this theory. The ISV mode, thought to be a combination of Kelvin and Rossby modes, propagates directly along the equator so that 20 days after formation in the Indian Ocean, the mode moves over Central and South America influencing precipitation patterns. An alternative teleconnection theory has the influence of the growing convection in the Indian-western Pacific ocean warm pool promoting

Rossby wave-trains that enter the Atlantic via a northern hemisphere route in the boreal summer (Lin and Burnet 2011) or a southern hemisphere route in the boreal winter (Widlansky, Webster and Hoyos, 2010). The tropical route would suggest a very predictable passage along the equator. Yet, the relationship between convection in the Indian Ocean and the Americas is not as simple as the canonical ISV (e.g., Madden and Julian, 1972) would suggest.

(a) Indian Ocean composite



(b) South American composite

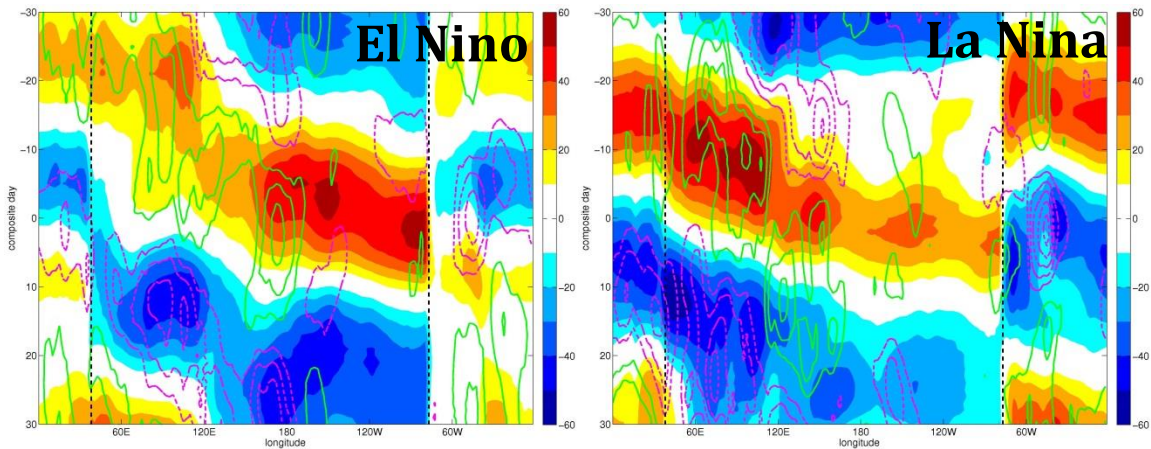


Figure 4. Intraseasonal composite of convective and surface pressure variations for (a) Indian Ocean and (b) South America during El Niño (left column) and La Niña (right column) years. See text for details and explanations.

Given that the mid-latitudes are more variable, the reduced coherence of the signal in the Americas would suggest, perhaps, that the extratropical route is preferred. There are also two other explanations, however. First, the ISV generated (or growing) in the tropical Indian Ocean possesses considerable variance from event to event. This has been established in earlier studies (e.g., Lawrence and Webster 2001, 2002) where it was found that the classical ISV progression only explains about half of the variance observed. These studies found that while a proportion of 20-60 day events moved eastward, some stayed in the Indian Ocean where they eventually decayed and a small proportion even moved westward. The second possible explanation of the decrease in coherence is that there are possible other locations of the formation of an ISV: In addition

to the Indian Ocean ISVs may form in situ in the Amazon region during the austral summer.

This latter suggestion has come from the PhD thesis work of Fernando Hirata, a PhD candidate in our group and will appear in subsequent papers that are in final preparation (Hirata and Webster 2012a,b). Figure 2 shows two figures composited about the maximum convection in the 20-60 day band in (a) the tropical Indian Ocean and (b) the Amazon basin. The period October-March is chosen, as this constitutes maximum ISV precipitation in the Central-tropical South American region. The colored contours (shaded) signify surface pressure anomalies with blue and red shading signifying anomalously low and high pressure. The colored contours indicate OLR with the purple contours showing deep convection and the green contours subsidence (absence of convection). There are a number of points that need to be made about the plots

- (a) In Figure 2a, there are two major time scales: the surface pressure moves eastward very rapidly with phase/group speed matching the equatorially trapped Kelvin wave. The convection, on the other hand, moves slowly to the east and dies out by the time it reaches the date line.
- (b) The modes are well constrained within the African Highland-Andes region (Fig. 2a). On either side of the mountains, a distinct phase shift occurs. (Note, especially, that in Figure 2a there is no continuity of the low-pressure pulse across the Andes into the Amazon region).
- (c) Figure 2b (the composite around maximum convection over equatorial South America) shows very different results. Maximum convection is now associated with low pressure that appears to be detached from the Indian Ocean convection. Thus, Figure 2b suggests that either there is in situ development of ISV over South-Central America or there is a southern hemisphere route. Note the westward propagation of sea-level pressure out of Africa. We will discuss the “peculiarity” presently.
- (d) Figure 3 shows the upper-tropospheric height field superimposed on the surface pressure patterns. Here it is clear that the upper-tropospheric field is attached to the convection (see Fig. 2b) and not the surface pressure wave. We note also that the geopotential structure is entirely different between the Indian Ocean composite and the South American composite, suggesting perhaps that the onset of convection over South America is only casually linked to the ISV over the Indian Ocean.

These signals also show strong interannual variability associated with the ENSO (El Nino-Southern Oscillation). Figure 4 shows the variability of the signals of Figure 2 during El Nino and La Nina conditions. Clearly, in the South American sector, the influence of ENSO is very strong through the boreal winter. With El Nino, convection over Brazil/SACZ is weaker but stronger during La Nina.

The importance of the ENSO cycle allows a clear predictor for the summer rains over South America. The extremes of ENSO occur near the end of the calendar year and possess strong predictability five months in advance. This is because ENSO possesses strong persistence from the previous May/June period through the October-March period in question.

Of particular interest coming from the preceding research is the possibility of there being more than one genesis region for the ISV. This has led to a speculation of the importance of orography (specifically the Andes and the East African highlands). This discussion is part of the publication:

Hirata F. and Webster P.J. (2012a): Source regions of Intraseasonal Variance and the role of major orographic barriers. *J. Clim.*, final preparation.

In the coming year we will continue with the diagnostic studies described above.

(iii) The search for the “southern route”

In the previous section we have noted that the ISV variability in the summer South American sector is not merely an equatorial propagation along the equator following ISV initiation in the Indian Ocean. We have suggested that one possibility is that the Brazilian basin is a region where further initiation can take place. There is a further explanation that we have started to explore. This is the influence of teleconnection patterns via the southern hemisphere extratropics.

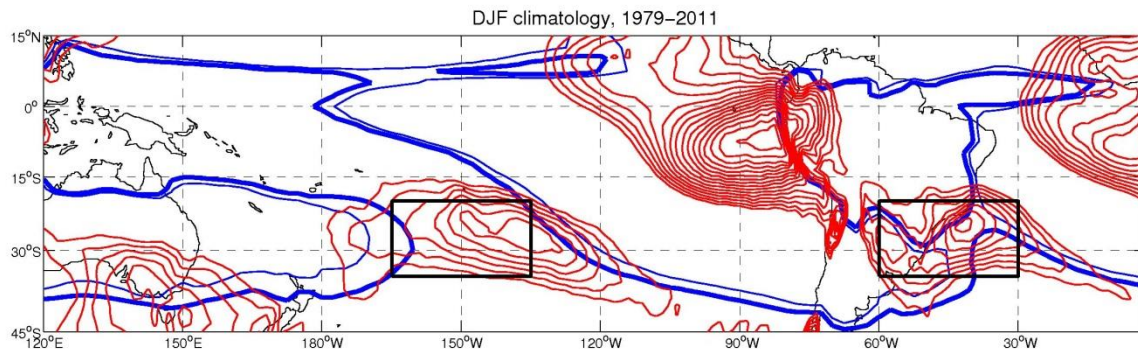


Figure 5. Regions of negative stretching deformation ($dU/dx < 0$) shown by Webster and Chang (1997) to “accumulate” transient wave energy. Note the two middle latitude maxima associated with the SPCZ (Widlansky et al., 2010) and the SACZ.

Lin and Burnet (2011) have suggested through modeling studies that ISV in the Indian Ocean-West Pacific warm pool promotes the excitation of Rossby waves that propagate through the northern hemisphere extratropics to the Atlantic Ocean. Figure 6 presents further evidence of the existence of a “southern route”. The plot is of the 200 hPa geopotential height field and shows a series of negative and positive centers stretching from the equatorial West Pacific to the Atlantic. The composite is made for day +6 following maximum convection in the Indian Ocean. Figures 6b,c show the structure of 200 hPa zonal stretching deformation during SACZ events with strong teleconnection with the MJO (Figure 6b) and without teleconnection with the MJO (Figure 6c).

Widlansky et al. (2010) found similar influences to the South Pacific (specifically the SPCZ) through the accumulation of wave energy. Webster and Chang (1997) have shown that transient wave energy can be accumulated in regions where the stretching deformation of the zonal wind is negative (i.e., $dU/dx < 0$). Figure 5 shows a plot of the stretching deformation. The red contours show that regions of $dU/dx < 0$ exist in the SPCZ

(as shown by Widlansky et al. 2011) and the SACZ. Thus, the SACZ stands as a potential location for wave accumulation and the creation of a disturbed and precipitation region.

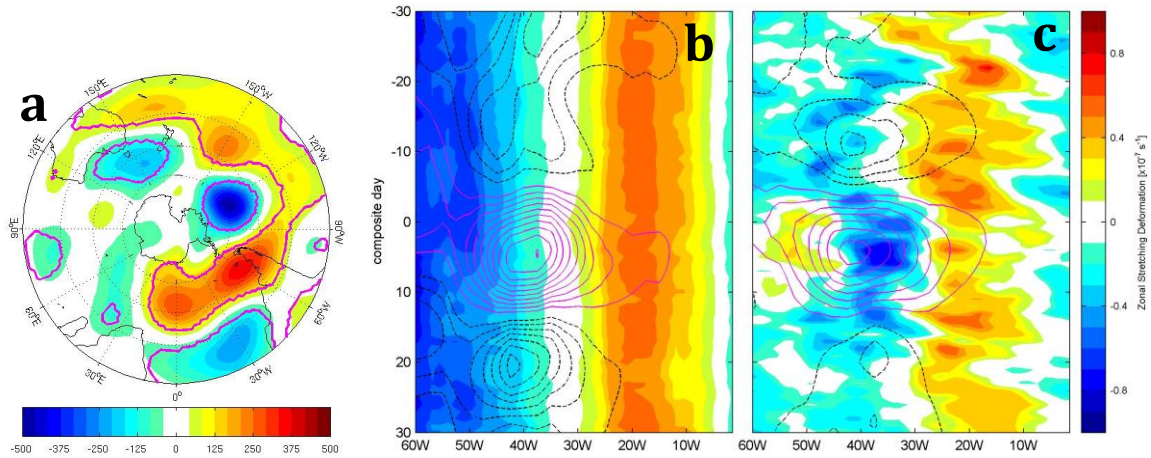


Figure 6. (a) 200 hPa geopotential anomalies for day -6 of the composites for intraseasonal convection over South America. Note teleconnection pattern extending from the western Pacific warm pool to the SACZ. (b) Time-longitude diagram showing negative/positive intraseasonal OLR (magenta/black contours) and unfiltered 200 hPa dU/dx anomalies for SACZ events within the MJO cycle (average from 15°S to 22°S). (c) Same as (b) but for SACZ events independent of the MJO.

Event-to-event intraseasonal convection is found to be significantly different from a canonical Madden-Julian Oscillation (MJO). Nearly half of all austral summer events (40%) do not show the same initiation or propagation characteristics of canonical MJOs, although they meet some MJO criteria during their life cycles. Variations of intraseasonal convection fall within three distinct forms: the canonical MJO, an *eastward decaying* (ED) mode, and an *eastward intensifying* (EI) mode (Figure 7).

Large-scale convection during ED events is similar to the MJO during early stages of their life cycles but fail to propagate as far east as canonical events. During EI events, convection is weaker or even absent over most of the Indian Ocean but grow over the Maritime Continent. This distinction offers important insights into the overall dynamics and predictability of tropical intraseasonal variability.

Sea surface temperature anomalies generated during convective breaks are fundamental for canonical propagation and result from radiative forcing whose modulation is a consequence of large-scale wave dynamics. Eastward propagation seems to rely more on the state of the tropical atmosphere-ocean system before convective triggering than on the trigger itself. ED events exhibit weaker wave-related anomalies. Alternatively, mechanisms driving intensification over Indonesia are very different from the first two categories and deserve further attention.

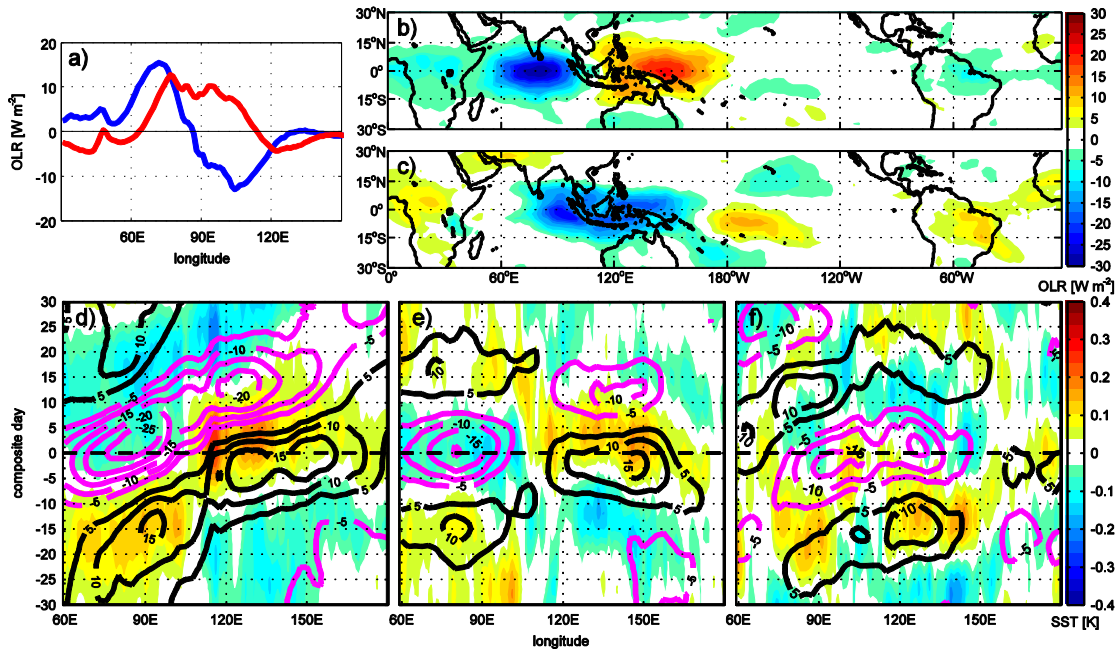


Figure 7. a) Austral summer EOF modes of averaged (5°N to 5°S) intraseasonal OLR. b) Composite day 0 for PC1 events with minimum below -1 standard deviation. c) Composite day 0 for PC2 events with minimum below -1 standard deviation. The bottom panels are longitude-time diagrams of composite life cycles for d) MJO, e) ED, and f) EI events. Shading (contours): band-passed SST (OLR) anomalies averaged between 5°N and 10°S to highlight stronger SST anomalies south of the equator in the surroundings of the Maritime Continent.

These results are discussed in an article accepted for publication in the *Geophysical Research Letters*:

Hirata, F.E., P.J. Webster, and V.E. Toma (2013), Distinct Manifestations of Austral Summer Tropical Intraseasonal Oscillations, *Geophys. Res. Lett.*: *Atmospheres* (accepted).

The categorization of intraseasonal events is also helpful to clarify teleconnection patterns associated with each of these modes of tropical intraseasonal variability. For instance, the MJO influences convection over South America as it propagates eastward along the tropical belt and through the excitation of extratropical Rossby wave trains bridging the Pacific and eastern South America, inducing the formation of the South Atlantic Convergence Zone (SACZ). However, a strong MJO does not lead to strong convection over South America and vice-versa. SACZ events are more common than all intraseasonal events over the warm pool combined and strong SACZ events are also able to influence the initiation of MJO events. When the SACZ occurs independently of the MJO, there is a deepening of upper-level negative zonal stretching deformation off eastern Brazil that is indicative of synoptic wave energy accumulation. Therefore, local wave energy accumulation induces the formation of the SACZ even in the absence of defined intraseasonal teleconnection patterns from the warm pool.

A major emphasis for Year 3 will be the exploration of the teleconnection patterns. We plan a series of modeling studies to determine the hemispheric response relative to the different forms of the ISV and the magnitude of the response over South America and the SACZ.

V. Toma, F. Hirata, and Webster P.J., (2012): Austral summer teleconnection patterns between the Indian Ocean-western Pacific warm pool on intraseasonal time scales. *Geophys. Res. Lett.*, *final preparation*.

(iv) A curious precursor to precipitation in the Americas

So far we have identified two possible routes preceding ISV activity over the Americas: equatorial teleconnections and southern hemisphere teleconnections. There may be a third! Figure 8 concentrates on the Atlantic sector during warm pool composites for days -30 to -23 (i.e., a week prior to the maximum convection over Central/South America) and shows a *westward* propagation of sea-level pressure originating in the African sector. This observation is contrary to most ISV theories, which suggest the influence is transmitted by eastward propagating Kelvin wave families. So this is a curious result suggesting that possibly the large-scale mixed-Rossby gravity waves may be important. Irrespective, the study provides a strong candidate for an ISV predictor. This observation will be highlighted in the following publication:

Hirata F. and Webster P.J. (2012b): Westward propagation of sea-level pressure on intraseasonal time scales. *Geophys. Res. Lett.*, *final preparation*.

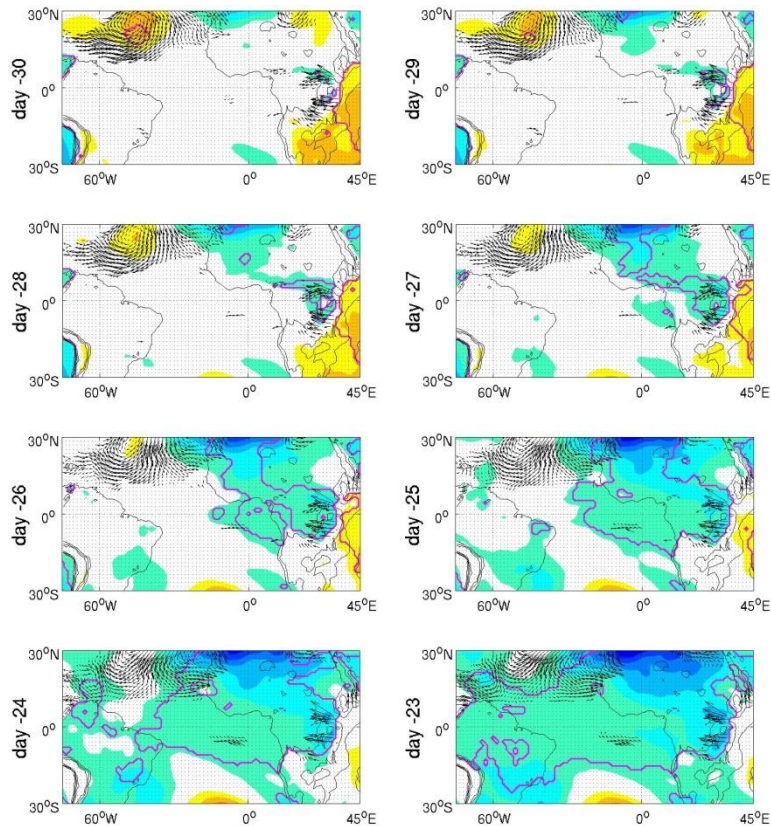


Figure 8. Composites of sea level pressure and 850 hPa winds for the African-Atlantic Ocean- South American sector for days -30 to -23. Magenta contour indicates significant pressure anomalies. Only significant vectors are shown. This retrograde propagation can be seen in Figure 3a,b.

(v) Predictability studies

During the last year, Dr. Hyemi Kim has started to develop a scheme for the prediction of ISV over the Americas. The study entails the use of a multi-model seasonal prediction system: The NOAA CFS and the ECMWF System 4 both of which produce operational multi-month forecasts. The following technique, used successfully for seasonal tropical cyclone forecasts in the Atlantic and the West Pacific and the monsoon (Kim et al. 2010, 2012a, 2012b), will be employed to generate probabilistic forecasts of the ISV. The method is a statistical-dynamical hybrid scheme. With the precursors determined in the studies described above, a linear regression system is developed. The intraseasonal models (CFS and System 4) are then used to determine the probabilities of the occurrence of the predictors. These are then used in the regression system to determine a probabilistic forecast of the ISV activity.

(vi) Long-term variability of South American rainfall

During the process of compiling the statistics, it became apparent that there was a long-term variability of precipitation patterns associated with the SACZ and hence rainfall over South America. Analysis of rainfall variations during the last decades of the past century reveal a trend toward wetter summer conditions to the south of the SACZ climatological position and drier conditions to the north. These long-term variations are described as a weakening and southward shift of the SACZ associated with a tendency to stronger El Niño-like teleconnections from 1979 to 1999. Similarities with the see-saw pattern of intraseasonal and interannual rainfall variability over South America are not coincidental. A Rossby wave pattern along the Pacific basin midlatitudes appear as a trend in the upper-level geopotential during the period, attaining significance in the SACZ region and is accompanied by significant anticyclonic trends in circulation, as it is usually observed during El Niño events. Enhanced teleconnectivity may result from interactions of El Niños and the Pacific Decadal Oscillation (PDO). Without the strong eastern Pacific El Niño forcing after 1999 and with a relaxation of the PDO warm phase, wave-like teleconnections change and precipitation trends over South America level off.

Hirata F. and P. J. Webster (2012c): Summertime trends and long-term variations of rainfall associated with the South Atlantic Convergence Zone, *to be submitted to J. Clim.*

(vii) Outreach, personnel, diversity and education issues

Drs. Carlos Hoyos, initially co-PI on the grant returned to Colombia along with Dr. Paula Agudelo. I became soul PI on the grant. During the last year, Dr. Hyemi Kim has taken a faculty position at SNYU Stony Brook. However, she has remained as a collaborator on the grant.

During the third year of the grant, PhD candidate Fernando Hirata, an underrepresented minority has neared the completion of his PhD. Much of the work described above is part of his dissertation. He will graduate in the fall of 2013. Dr. Hyemi Kim, a female scientist, has worked on the project. Her work is described in section (v), above. To

replace Dr. Carlos Hoyos and maintain the momentum in the project, Dr. Violeta Toma was added to help with the modeling studies relating to the “southern route” together with predictability studies. .

During the last year, we have made six presentations on ISV research at the American Meteorological Society and the American Geophysical Union annual meetings in New Orleans and San Francisco, respectively, and the AMS Hurricane and Tropical Meteorology meeting in Jacksonville, Florida.

(viii) Conference Presentations

Hirata, F., C.D. Hoyos e P.J. Webster (2010). Seasonal differences in tropical intraseasonal variability over South America from the NCEP Reanalysis. 90th American Meteorological Society Annual Meeting, Atlanta (USA).

Hirata, F., C.D. Hoyos e P.J. Webster (2010). Interannual variations and predictability of intraseasonal convective events over South America. 29th AMS Conference on Hurricanes and Tropical Meteorology, Tucson (USA).

Hirata, F., C.D. Hoyos e P.J. Webster (2010). Tropical and extratropical impacts on the South American Monsoon. 2010 AGU Meeting of the Americas, Foz do Iguazú, PR (Brazil).

Hirata, F., C.D. Hoyos e P.J. Webster (2010). Predictors for extreme summertime precipitation events over South America: the importance of intraseasonal forcing. 2010 AGU Fall Meeting, San Francisco (USA).

Hirata, F., P.J. Webster, H. Kim e C.D. Hoyos (2011). Wave accumulation and the formation of the South Atlantic Convergence Zone. 2011 AGU Fall Meeting, San Francisco (USA).

Hirata, F. e P.J. Webster (2012). The role of South American convective cycles on tropical intraseasonal oscillations. 30th AMS Conference on Hurricanes and Tropical Meteorology, Jacksonville (USA).

Hirata, F., P.J. Webster e V.E. Toma (2012). MJO concept, eastward propagation, teleconnections, and South American rainfall. 2012 AGU Fall Meeting, San Francisco (USA).

Hirata, F., P.J. Webster, V.E. Toma e H. Kim (2013). The importance of the Atlantic basin and the extratropics to MJO initiation and eastward propagation. MJO Field Data and Science Workshop, Kohala Coast (USA).

References (*relating to work under NOAA grant)

- *Hirata, F.E., P.J. Webster, and V.E. Toma (2013), Distinct Manifestations of Austral Summer Tropical Intraseasonal Oscillations, *Geophys. Res. Lett.: Atmospheres (accepted)*.
 - *Hirata, F.E. and P.J. Webster (2013), The Importance of Wave Accumulation for the Formation of the South Atlantic Convergence Zone, *J. Clim., final preparation*.
 - *Hirata F. and Webster P.J., (2012a): Source regions of Intraseasonal Variance and the role of major orographic barriers, *J. Clim., final preparation*.
 - *Hirata F. and Webster P.J., (2012b): Westward propagation of sea-level pressure on intraseasonal time scales, *Geophys. Res. Lett., final preparation*.
 - *Hirata F. and P. J. Webster, (2012c): Summertime trends and long-term variations of rainfall associated with the South Atlantic Convergence Zone, *J. Clim., final preparation*.
 - * Toma, V., F. Hirata, and P.J. Webster (2012): Austral summer teleconnection patterns between the Indian Ocean-western Pacific warm pool of intraseasonal time scales. *Geophys. Res. Lett., final preparation*.
- Hoyos, C. D. and P. J. Webster (2007): The Role of Intraseasonal Variability in the Nature of Asian Monsoon Precipitation. *J. Clim.*, 20 (17), 4402-4424.
- Kim, H. M. and P.J. Webster, (2010): Extended-range seasonal hurricane forecasts for the North Atlantic with hybrid dynamical-statistical model, *Geophys. Res. Lett.*, 37, L21705, doi:10.1029/2010GL044792.
- Kim, H. M., P. J. Webster, J. A. Curry, and V. Toma (2012): Asian summer monsoon prediction in ECMWF System 4 and NCEP CFSv2 retrospective seasonal forecasts, *Clim. Dyn.*, DOI: 10.1007/s00382-012-1470-5.
- Kim, H. M., P. J. Webster, and J. A. Curry (2012): Seasonal prediction skill of ECMWF System 4 and NCEP CFSv2 retrospective forecast for the Northern Hemisphere Winter, *Clim. Dyn.*, DOI: 10.1007/s00382-012-1364-6.
- Lawrence, D. and P. J. Webster (2002): The boreal summer intraseasonal oscillation and the South Asian monsoon. *J. Atmos. Sci.*, 59, 1593-1606.
- Lawrence D. and P. J. Webster (2001): Interannual Variations of the Intraseasonal Oscillation in the South Asian Summer Monsoon Region, *J. Clim.*, 14(3), 2910-2922.
- Lin H. and G. Brunet (2011): Impact of the North Atlantic Oscillation on the forecast skill of the Madden-Julian Oscillation. *Geophys. Res. Lett.*, 38, L02802, DOI:10.1029/2010GL046131
- Molteni, F. (2003) Atmospheric simulations using a GCM with simplified physical parametrizations. I: model climatology and variability in multi-decadal experiments. *Clim. Dyn.*, 20:175–191.

Widlansky, M., P. J. Webster, and C. D. Hoyos (2010): On the location and orientation of the South Pacific Convergence Zone. *Clim. Dyn.*, DOI: 10.1007/s00382-010-0871-6.