

WAVEs

southWestern Atlantic climate Variability Experiment

A working proposal outline for a new research program over the SW Atlantic and South America

Paulo Nobre – INPE
August 2008

WAVEs Statement:

Field experiment and ocean-atmos-biosphere coupled modeling research program to study ocean-atmosphere-land coupled phenomena leading to South Western tropical Atlantic-South American climate variability and change;

Proposed project time span: 20010-2013;

INTRODUCTION

South Atlantic Convergence Zone - SACZ: an integration target of opportunity?

The concept of the sea surface temperature (SST) driving large scale atmospheric circulation time means is an established corner stone of climate predictability thinking, which emerged from the work of J. Shukla in the early 1980's (Shukla, 1981a; Shukla, 1981b). Such revolutionary paradigm lead to the use of the same kind of numerical models used for numerical weather predictions, which Lorenz (1963) had previously demonstrated had its limit of deterministic predictability on the order of a few weeks, to predict time mean behavior of atmospheric features with months in advance. The basic thought behind Shukla's proposal was the dominant effect of surface boundary conditions on tropical atmospheric mean circulation, where geostrophy played a second role. Such approach led to the development of truly successful set of applications to predict seasonal climate variability around the world, such as those associated with the El Niño-Southern Oscillation (ENSO) phenomena (Cane et al., 1986; Ropelewski and Halpert, 1987; Philander, 1992).

However, more recent works have suggested that there is a portion of the seasonal climate variability, which can be at least in part attributed to coupled ocean-atmosphere variability. The South Atlantic Convergence Zone (SACZ) is an example of large-scale atmospheric phenomena that global General Circulation Models (AGCM) can neither simulate (Marengo et al., 2003) nor predict (Barreiro et al., 2005). Such are the results of two tier AGCM approaches.

Robertson and Mechoso (2000) showed that the SACZ developed predominantly over cooler ocean temperatures, suggesting that the zone could be the result of atmospheric circulation pattern reinforced by monsoon-type surface temperature gradient between the continent and the ocean. Chaves and Nobre (2004) were the first to suggest that the negative correlations between SACZ and SST anomalies documented by Robertson and Mechoso (2000) could in fact be a consequence of reduced solar radiation due to the enhanced cloudiness associated with the formation of the SACZ.

Following on the pioneering work of Chaves and Nobre (2004), Nobre et al (personal comm., 2008) used a fully coupled ocean-atmosphere GCM to gauge the importance of ocean-atmosphere coupling to predict SACZ variability. Their results indicated that there is some predictability of the SACZ during Southern Hemisphere Summer (i.e. DJF) when coupled ocean-atmosphere interactions are taken into consideration.

Therefore, from the point of view of seasonal climate predictions, the SACZ phenomena constitutes a challenging science target to organize a comprehensive oceanic and atmospheric research program to study this novel branch of climate research, which is the predictability of coupled ocean-atmosphere modes of variability.

Following are some conclusions from the SACOS Workshop (Angra dos Reis, February 2003), which put the main science question of WAVES into context:

“Modeling the coupled ocean/atmosphere system: in order to understand and predict S. Atlantic climate variability in seasonal to decadal time scales, it seems fundamental to first study the annual cycle of the system, especially in the Atlantic, where atmos-ocean-land coupled models are failing.”

Recommended actions from the SACOS Workshop:

- ✓ To develop studies, based on analyses of historical data, numerical modeling and observations, with the purpose of generating a better estimate of the meridional heat flux in the South Atlantic.
- ✓ To carry out observational diagnostic studies and numerical simulations to better understand the land-air-sea interactions in different regions of the South Atlantic basin.
- ✓ To design and implement a sustained monitoring system for the South Atlantic, which could be maintained in by South Atlantic countries in cooperation with North American and European counterparts.

This write up [in draft form as of September 2nd, 2008] points to some science questions that have already been raised about seasonal climate predictability over the Southwestern Tropical Atlantic, and which remain unresolved up until today. It proposes the establishment of a coordinated research program over the SW tropical Atlantic to contribute clarifying such questions.

WAVES Topics:

Coupled o-a variability associated with the SACZ: The following processes constitute elements or patches with which a more comprehensive picture of the SACZ dynamics and its interactions with SST and continental rainfall shall be built.

- ∇ SST-Solar Radiation-Rainfall feedback processes:
 - Suggested by Chaves and Nobre (2004) as an important mechanism affecting the surface heat balance over the SW tropical Atlantic and, therefore, affecting SST anomalies over the region.
 - Modeling investigation: SACZ modulation of underlying SST, surface heat fluxes and precipitation variability to detail the initial processes of SACZ formation and development. The numerical experiments are aimed at diagnosing the largest deviations between observed and simulated surface flux fields over the experiment domain. Two classes of experiments are envisioned: One in which observed atmospheric initial conditions (IC) and climatological SST are used; and one which uses

random atmospheric IC and observed SSTs. For both classes of experiment, the following structure shall be done:

- computing hourly surface fluxes (momentum, heat, p-e) with both AGCM and CGCM in ensemble mode;
 - computing oceanic circulation and temperature-salinity advection, with both OGCM and CGCM;
- ∇ Barrier layers due to SACZ rainfall over the ocean and river discharges
- Based on previous results that indicate 1-D surface heat budget is a first order contribution to determining SSTA variability over the extra-equatorial Atlantic (Foltz et al., 2003), study the effectiveness of barrier layers to generate horizontal gradients of SST under intense solar flux.
 - Modeling experiment design: use of a mixed-layer slab ocean model with horizontal advection to gauge the effect of horizontal SST gradients emerging from salinity non homogeneities exposed to solar radiation diurnal cycle;
- ∇ Amazon soil moisture-rainfall memory: ITCZ-SACZ-LLJ interactions?
- Another empirical result that must be thoroughly investigated is the role of South America deep cumulus convection over the Amazon as a (major) player to organize large scale atmospheric circulation patterns favorable to the formation of the SACZ. There are observational and model results indicating that moisture transport from the Amazon can either feed the SACZ or be transported southward through the Low Level Jet (LLJ) along the andean slopes, to feed deep convection over the La Plata river basin (e.g., results of the SALJETS experiment). On the other hand, the marine Atlantic ITCZ modulates annual rainfall cycle over the Amazon region. Although the Amazon forest function as a climate regulator, in the sense that it evapotranspires even during dry periods [LBA experiment results cited here], it is possible that variations of soil moisture or otherwise total convection over the Amazon might contribute to modulate SACZ related climate variability over the SW Atlantic/South America region, and therefore SSTA variability over the SW Atlantic.
 - The influence of the Amazon rainfall/evapotranspiration/soil moisture on the SACZ variability should be investigated through the assembly of high temporal resolution field campaign to resolve the diurnal variations of rainfall, surface heat and momentum fluxes, along with coupled ocean-atmosphere-biosphere model experiments to test the importance of proper initialization of soil moisture, atmospheric and oceanic conditions.
- ∇ Remote influences from the eastern equatorial Atlantic:
- the slope of the equatorial thermocline along the Atlantic Ocean is a concurrent problem in most if not all fully coupled o-a GCMs. It reverses the zonal gradient of SST over the equatorial Atlantic, generating the warm pool over the eastern, rather in the western, part of the basin. Such erroneous SST field generates spurious atmospheric deep convection over the eastern Atlantic, completely distorting the marine ITCZ behavior over the whole equatorial Atlantic and, therefore, obliterating CGCM predictability of ITCZ-related climate variations.
 - The proposed numerical experiments use fully coupled eddy-resolving ocean model (e.g. 1/12th of degree lat-lon grid spacing) aimed at computing the zonal advection of heat by the EUC and its impact on the equatorial Atlantic thermocline slope on the CGCM results.

- The use of lagrangean tracers shall be used with the CGCM results to map the origin of the model water masses feeding into the EUC.
- Observations shall come from cross-equatorial shipboard ADCP and XCTD profiles over the eastern and western Atlantic, which is a by-product of scheduled PIRATA maintenance cruises. The use of TACE planned cruises crossing the equator could be used as well, to increase the sampling of EUC velocities on the eastern and western sides of the basin.
- ▽ Teleconnections from the SPCZ
 - A further mechanism that should also be investigated is the possible remote influence of the South Pacific Convergence Zone (SPCZ) to set up atmospheric circulation patterns favorable to the development of the SACZ over the SW Atlantic. Such remote influence should be studied through the use of CGCM and AGCM idealized sets of experiments, with observed and idealized SST initial states prescribed over both the South Atlantic and the Pacific basins.

SW tropical Atlantic ocean circulation: In addition to the atmospheric processes that contribute to modulate SST variability over the SW tropical Atlantic, there are also oceanic phenomena that imprint SST variability locally (e.g. density anomaly advection by the SEC), or remote influence (e.g. zonal redistribution of heat done by the SEC and EUC). In addition, on longer time scales, the working of the meridional overturning cell – MOC and the subtropics-tropics cell – STC modulates the meridional heat transport across the equatorial Atlantic. Such meridional heat transport is a key element of global climate stability and change. The topics below highlight the advection of ocean properties (e.g. temperature and salinity) by the current system on the region, constituting an important component of the total heat balance on the region [to be developed].

- ▽ Density anomaly (T-S) advection by the SEC
- ▽ SEC bifurcation
- ▽ MOC-STC modulation of meridional heat transport

Observational Framework: Observations are among the most needed and most difficult aspect of the research proposal to achieve. One, because it depends on the scientific problem to be studied; two, because of the inherent difficulty and cost to design, implement, and operate a comprehensive observational framework over both the ocean and the land. Therefore, the proposed observational framework for the WAVES initiative shall constitute the use of complementary observational techniques aimed at providing oceanic and atmospheric data necessary to test the hypothesis being tested.

- ▽ Array of moored ATLAS buoys (extended PIRATA Array) to estimate upper ocean heat storage and fluxes at the surface layer. The white paper on the scientific rational to establishing the SW extension of the PIRATA Array (e.g. Nobre et al., 2004) depict the overall scientific questions to be studied with the establishment of an array of moored ATLAS systems. In addition, the VAMOS panel has suggested the enhancement of the PIRATA SWE with an extra mooring, to the south of the southernmost PIRATA SWE mooring (at approximately 25°S, 34°W), to encompass the area of maxima variability of the SACZ. The ATLAS systems sample the following variables at 2-minute interval:
 - rainfall;
 - solar radiation;
 - outgoing longwave radiation;

WAVES draft straw man proposal V.1.0

- wind speed and direction;
 - air temperature and humidity;
 - surface atmospheric pressure;
 - water temperature in 10 levels and
 - salinity in four levels at the first 500m of the ocean surface layer.
- ▽ High density of XBT/CTD, ADCP lines: in addition to the array of moored ATLAS systems, high density XBT and ADCP profiles are deemed necessary to study meso-scale eddy activity along the Brazil and North Brazil Current system. Such eddy activity is an integral part of the meridional heat transport over the region, which an array of spaced moored systems is not designed/capable to capture/describe. The use of repeated ADCP and CTD along the 38°W led to the rediscovery of a new feature of the North Atlantic current system by Urbano et al. (2007).
- The proposed high density T-S and velocity profiles over the SW Atlantic are instrumental to document the eddy-modulated density advection over the region.
- ▽ Drifters and Argo floats array: As part of an ongoing global effort to monitoring the upper ocean temperature and velocities, the region shall be periodically reseeded with drifters, to complement the picture compiled from the array of moored systems and repeated XBT/XCTD-ADCP lines.
- ▽ Twice daily radiosonde profiles on two islands (Fernando de Noronha and Trindade), four coastal cities (Recife, Salvador, Rio de Janeiro, and Paranaguá), and four inland stations (Brasília, Manaus, Belo Horizonte, and São Paulo), in addition to the radiosonde profiling done during the yearly maintenance cruises of the PIRATA array. Such atmospheric T, UR, winds profiling shall be used to draw a 4-D picture of the evolution of atmospheric circulation over the region, both over the continent and the ocean, during the occurrences of SACZ formation;
- ▽ Installation and operation of automatic meteorological and tide gauge stations at Fernando de Noronha and Trindade Islands, as well as at the four coastal cities (Recife, Salvador, Rio de Janeiro and Paranagua) listed above. Fernando de Noronha already counts with an automatic met station with a continuous record of hourly data since 2004.
- ▽ Satellite altimetry and infra red data are to be collected and made readily available along with the remaining WAVES datasets in order to foster the studies of total heat stored locally in the surface layers of the SW Atlantic.

References

- Barreiro, M., P. Chang, and R. Saravanan, 2005: Simulated precipitation response to SST forcing and potential predictability in the region of the South Atlantic convergence zone. *Climate Dynamics*,
- Cane, M., S. E. Zebiak, and S. C. Dolan, 1986: Experimental forecasts of El Niño. *Nature*, **321**, 827-832.
- Chaves, R. R., and P. Nobre, 2004: Interactions between the South Atlantic Ocean and the atmospheric circulation over South America. *Geophys. Res. Lett.*, **31**, doi:10.1029/2003GL018647.
- Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. *J. G. R - Oceans*, 3146-.
- Lorenz, E. N., 1963: Deterministic non-periodic flow. *J. Atmos. Sci.*, **20**, 130-141.
- Marengo, J. A., I. F. A. Cavalcanti, P. Satyamurty, C. A. Nobre, J. P. Bonatti, A. O. Manzi, I. Trosnikov, G. Sampaio, H. Camargo, M. B. Sanches, C. A. C. Cunningham, C. D'Almeida, and L. P. Pezzi, 2003: Ensemble simulation of regional rainfall features in the CPTEC/COLA atmospheric GCM. Skill and Predictability assessment and applications to climate predictions. *Climate Dynamics*, **21**, 459-475.
- Nobre, P., E. Campos, P. S. Polito, O. T. Sato, and J. Lorenzetti, 2004: PIRATA Western Extension Scientific Rational Report. INPE,
- Philander, S. G. H., 1992: Ocean-atmosphere interactions in the tropics: a review of recent theories and models. *J. Appl. Meteor.*, **31**, 938-946.
- Robertson, A. W., and C. R. Mechoso, 2000: Interannual and Interdecadal Variability of the South Atlantic Convergence Zone. *Mon. Wea. Rev.*, **128**, 2947-2957.
- Ropelewski, C. F., and M. S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillations. *Mon. Wea. Rev.*, **115**, 1606-1626.
- Shukla, J., 1981a: Dynamical predictability of monthly means. *J. Atmos. Sci.*, **38**, 2547-2572.
- Shukla, J., 1981b: Predictability of the tropical atmosphere. NASA Tech. Memo. 83829, 51 pp., 1981.
- Urbano, D. F., R. d. Almeida, and P. Nobre, 2007: The upper ocean circulation and water masses in the western PIRATA sites from 1999 to 2005. *J. G. R*, Accepted.