Seasonal-to-decadal predictability and prediction of South American climate

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Table of Contents

1. Introduction

South America represents an interesting area concerning seasonal to interannual and longer climate variability. The largest fraction of the continent is within the tropics, where seasonal climate predictability is higher, if compared to mid latitudes, and thus can benefit a large number of people. Also, it encompasses a few important elements of the climate system, like the Amazon rainforest, which covers a considerable fraction of the continental area and represents an important source of upper level mass and heat at lower latitudes; thus contributing both to the general circulation of the atmosphere and to the local climate (Buchmann et al., 1995). It is also subject to and interferes in two convergence zones: the Intertropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone (SACZ). The ITCZ is modulated by surface features, like the interhemispheric gradient of Sea Surface Temperature (SST) anomalies over the equatorial Atlantic (Hastenrath and Druyan, 1993; Wagner, 1996; Chang et al., 2000), and it modulates interannual variability of seasonal rainfall over eastern Amazon and northern Nordeste (Hastenrath and Heller, 1977; Moura and Shukla, 1981; Nobre and Shukla, 1996). Atmospheric general circulation models (AGCM) simulate seasonal rainfall interannual variability over Nordeste strikingly well when observed global tropics SST are prescribed (Goddard and Mason, 2002; Marengo et al., 2003). The SACZ, on the other hand, is also influenced by SST anomalies over the southwestern tropical Atlantic, has a strong impact on the rainfall regime over southern Nordeste, Southeast and Southern Brazil, and contributes to modulate underlying SSTs over the SW tropical Atlantic (Chaves and Nobre, 2004). Differently from the ITCZ, however, the SACZ is observed predominantly over negative SSTA (Robertson and Mechoso, 2000), suggesting that an atmospheric-forcing coupling is operative at zero lag. AGCM experiments using direct SST thermal forcing generates simulations with near zero or even negative skill simulating SACZ (i.e., rainfall) variability (Marengo et al., 2003). The high reproducibility of Nordeste, and to some extent over southern Brazil, seasonal rainfall by AGCMs contrasts with the low reproducibility of seasonal rainfall over southeastern Brazil, indicating that different processes shall be operating to modulate seasonal rainfall over those regions.

The southern region, encompassing southern Brazil, Uruguay, Paraguay and northern Argentina also presents some degree of predictability, which nevertheless is hardly realized during the actual exercise of seasonal climate predictions (Berri et al., 2003). In short, seasonal climate prediction over South America presents two major challenges: first, for the regions in which the mean state of the atmosphere is modulated by external forcing, like SST, effective forecasting tools are needed to predict the future state of the oceans; second, for phenomena that can not be reproduced by the "ocean forcing" paradigm of climate variability, it is necessary to develop coupled models which include not only the ocean and the atmosphere, but also interactions with the biosphere, the cryosphere, and the stratosphere to simulate the complex interactions among these many realms.

On larger time scales, from decades to centennial, South America also plays an important role in the climate system. Primarily, it is believed that the Amazon forest acts as a carbon dioxide sink in today's CO2-rich atmosphere. Yet, recent global climate change research indicates that the capacity of tropical and temperate forests to grow – and therefore extract carbon dioxide from the atmosphere – is limited to a certain amount of temperature increase, beyond which the biological systems reach breakdown, and start liberating large amounts of CO2 to the atmosphere (Cox et al., 2001). It is not yet known to what extent seasonal climate predictability will change on regional scales; whether it will increase (in the case of increased dryness over semi arid regions) or will diminish (e.g., in the case of increased variability of a warmer and more humid atmosphere). In any case, the prospects of regional climate change are robust enough to justify a serious and persistent scientific undertaking to improving the models and monitoring the environment to help society to learn to adapt to a changing climate.

2. Seasonal Predictions and Predictability

Seasonal to interannual and longer climate variability comprise two components: (a) the externally forced component, which is the response to slowly varying external boundary forcing (SST, sea ice, albedo, soil moisture, and snow coverage) and radiative forcing (greenhouse gases and aerosol concentration); (b) the internally forced component, which is the atmospheric variability induced by internal dynamics and the weather noise (Brankovic et al., 1994; Koster et al., 2000; Zheng and Fredericksen, 1999). Climatic variability of a region can be strongly influenced through teleconnection patterns originated by forcing anomalies in distant regions, such as in the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) phenomena.

Over South America, interannual anomalies in rainfall over eastern-central Amazon and Northeast Brazil (Nordeste) appear to be the opposite to regions such as Southern Brazil (Ropelewski and Halpert, 1987), and all of these regions are sensitive to SST anomalies both over the tropical Atlantic and in the equatorial Pacific. On the other hand, tropical Atlantic inter-hemispheric SST anomalies have a strong influence on precipitation in tropical South America, as in Nordeste and Amazonia (Moura and Shukla, 1981; Mechoso et al., 1988; Mechoso et al., 1990; Marengo, 1992; Hastenrath and Greischar, 1993; Uvo et al., 1998; Folland et al., 2001). The SST gradient between tropical North and South Atlantic is the key element associated with rainfall anomalies during summer and autumn in Amazon and Nordeste, while the ENSO signal on precipitation anomalies over southern Brazil seems to be weaker in summer than in spring and it exhibits considerable spatial variability (Grimm et al., 2000). Moreover, there are variations in the precipitation anomalies over all these regions among different ENSO warm events or among different ENSO cold events that cannot be clearly associated with the variability of the tropical Pacific SST anomalies solely (Marengo et al., 1998).

Several modeling studies (Marengo et al. (2003), Cavalcanti et al. (2002), and references quoted in) have been devoted to simulations of the observed interannual variability of rainfall in the Atlantic sector. On these studies, the tropical SST forcing together with the regional land surface processes forcing explain for most of the seasonal to interannual climate variability in tropical South America to the east of the Andes, with the notable exception of southeastern Brazil, where prescribed SST forcing has shown unable to simulate SACZ variability.

2.1. Nordeste and Amazonia:

In the Atlantic sector, tropical Pacific SST forcing correlates well with rainfall and river discharge anomalies in Colombia, the Northern Amazonia-Northeast Brazil region and southern Brazil-Argentina (Marengo, 1992; Poveda and Mesa, 1997; Uvo et al., 1998; Grimm et al., 2000; Marengo et al., 2003). Empirical studies using correlations between rainfall in Amazonia and SST indices in the tropical Pacific (Marengo, 1992) suggests that SST anomalies in the tropical Pacific Ocean explain for less than 40% of the rainfall variability in northern and central Amazonia.

SST anomalies in the equatorial Atlantic Ocean affect the meridional position of the ITCZ and thus the interannual variability of rainfall in Northeast Brazil (Hastenrath and Heller, 1977; Moura and Shukla, 1981; Wagner, 1996; Nobre and Shukla, 1996; Folland et al., 2001) and the Amazon basin (Marengo, 1992; Uvo et al., 1998). Enfield and Mayer (1997) and Enfield and Alfaro (1999) have identified the relative influence of the eastern Pacific (ENSO) and equatorial Atlantic SST over rainfall over the Caribbean and northern South America. Experiments using the CPTEC/COLA AGCM were also performed by Pezzi and Cavalcanti (2001) to analyze the influence of Pacific and Atlantic Ocean on precipitation over South America

Land surface characteristics and processes also serve as slowly varying boundary conditions on climate simulations. Realistic representation of land surface-atmosphere interactions is essential to a realistic simulation and prediction of continental scale climate and hydrology. Experiments on changes in land-surface, such as regional and large scale deforestation in the Amazon basin

(See reviews in Marengo and Nobre (2001) and Costa and Foley (2000)) have identified the sensitivity of rainfall to changes in vegetation and soil moisture conditions in the region. Koster et al. (2000) suggest that both on the real world and the modeling system, the "memory" associated with continental moisture and the limited ability to forecast land-surface moisture state reduces predictability in some regions of South America.

Experiments using the CPTEC COLA AGCM (Marengo et al., 2003) show that the model systematically underestimates rainfall during the January-May peak of the rainy season in Amazonia. The underestimation of rainfall in northern-central Amazonia is found in other global models: Goddard Institute for Space Studies GISS (Marengo and Druyan, 1994), Geophysics Fluid Dynamic Laboratory GFDL (Stern and Miyakoda, 1995); European Centre for Medium Range Weather Forescast ECMWF, (Brankovic and Palmer, 1997); National Center for Atmospheric Research NCAR CCM3 (Hurrel et al. 1998), and the Hadley Centre HadCM3 (P. Cox, personal communication), and deficiencies were linked to the convection and planetary boundary layer schemes in various models.

In the adjacent Northeast Brazil the model tends to overestimate rainfall. Yet, the model depicts a realistic annual cycle and interannual variability of rainfall anomalies. The large scale forcing associated with large SST anomalies in the equatorial Pacific during El Niño determines a quite realistic simulation of rainfall anomalies over Nordeste and eastern Amazonia, while during La Niña or neutral years the models do not always simulate the observed rainfall variability. The model reproduced the low rainfall amounts in those two regions during the El Niños 1982-83, 1986-87 (Marengo et al., 1998; Marengo et al., 2003) and during 1997-98, while in normal years the simulation is not as successful as during the extreme El Nino years. These simulations from the CPTEC/COLA AGCM are comparable to the interannual variability of rainfall in Nordeste with the PROVOST experiments using persisted SST (Folland et al., 2001) and with the original and revised AMIP simulations by Sperber et al. (1999), with all of them showing negative rainfall departures during 1983, 1987 and 1990, and large positive rainfall departures during 1985 and 1989. The deterministic and probabilistic scores presented for this region as derived by Sperber et al. (1999), Goddard et al (2001), and Marengo et al. (2003) also demonstrate a good skill in simulating rainfall anomalies at interannual time scales.

2.2. South/Southeastern Brazil:

The Southern and Southeastern regions of Brazil are highly populated, with large agricultural areas and high hydroelectrical power capacity. These regions are affected by climate anomalies associated with interannual and intraseasonal atmospheric variability. In the interannual scale, the El Nino-Southern Oscillation (ENSO) is related to floods and droughts in the southern region. The anomalous wet or dry ENSO years in Southern Brazil occur with opposite sign of the seasonal rainfall anomalies over the Nordeste (Cavalcanti et al., 2001). Southeastern Brazil, which is a transition area between the tropical Northeast and extratropical Southern region, does not present a clear sign related to ENSO. In some years the Southeast presents the same sign of the tropical Nordeste and some years the same sign of the extratropical South. However, this region is affected by intraseasonal variability which plays a role in the summer season convection (Castro and Cavalcanti, 2003).

The dependence of rainfall variability of these regions to extreme SST forcing in tropical oceans is better documented and established for southern Brazil as compared to Southeast Brazil (see reviews in Marengo et al. (2003)). Southern Brazil exhibits the impacts of El Nino during spring time and model experiences (Marengo et al., 2003) show in southern Brazil a systematic underestimation of rainfall during January-September.

On the interannual variability, in southern Brazil, despite the large scatter among members of the ensemble, the model captures quite well the extremes of the observed interannual rainfall variability; especially the above normal values observed in 1983 and the drought conditions in 1989. The circulation anomalies over southeast Brazil in the spring of El Niño years are mostly due to remote influences from the tropical east Pacific, while in the subsequent summer, when the monsoon-like circulation is enhanced, they are probably due to local influences (Pisciottano et al., 1994) (Cazes-Boezio et al. 2003). Coelho et al. (2002) documented that Southeast Brazil represents a region of a sharp transition between positive and negative SST-rainfall anomalies, defining the boundary from drier conditions in Northeast Brazil and wetter conditions in southern Brazil during El Nino regimes.

Southeast Brazil exhibit a relatively low predictability for seasonal to interannual variability, and it seems that for this region external SST forcing from tropical oceans may be dominated by internal chaotic behavior of the climate system. Chaves and Nobre (2004) used an atmospheric and an oceanic GCMs to study the feedback processes linking SST and SACZ variability. Their results suggest that the frequently observed negative SSTA under the SACZ (Robertson and Mechoso, 2000) is predominantly a ocean response to the reduction of downward solar radiation due to increased cloudiness during the formation of the SACZ. Their results thus support the speculation that the poor performance of AGCM simulations over the SACZ region is the consequence of the lack of coupled interactions between SST and the atmosphere. In this region, AGCMs exhibit a robust inability to simulate interannual rainfall variability, as compared to a relatively better skill in simulating rainfall variability in northern Amazonia, Nordeste, and southern Brazil during the peak of their rainy seasons. Koster et al. (2000) focuses their analyses on precipitation variance, and they analyze the contributions of ocean, atmosphere, and land processes using a simple linear model. The resulting clean separation of the contributions leads to the conclusion that land and ocean processes have essentially different domains of influence, that is, the amplification of precipitation variance by land–atmosphere feedback is most important for regions such as southeast Brazil and the South American monsoon, while for the tropics (Amazonia and Nordeste) rainfall variance is more affected by surface temperatures. This is also true for southern Brazil.

The relative influence of Pacific and Atlantic Ocean on South America precipitation was analyzed in Pezzi and Cavalcanti (2001). Composites of SST from strong ENSO episodes and strong “Atlantic dipole conditions” were combined to integrate the CPTEC/COLA AGCM in order to analyze the influence of Pacific/Atlantic Ocean on the South America precipitation. It was seen that the extreme northern Nordeste is affected by the Atlantic Ocean, when there is anomalous warm water in the tropical South Atlantic, even in a strong El Nino episode (Fig.1), but Southeastern and South Brazil have different behaviour. These regions were not affected by the tropical Atlantic anomalies when the Pacific ocean had warm anomalies, indicating that the Pacific was dominant in inhibiting convection. On the other hand, the Atlantic was dominant in La Nina episodes and the Northeast and northern sector of Southeast changed sign depending on the sign of the SSTA “dipole.” Southern Brazil had also different behavior in this case.

2.3. Northern Argentina and Uruguay:

Much of the skill for the prediction of departures from mean seasonal rainfall totals or temperature averages is based on the boundary conditions at the earth's surface that influence the atmospheric circulation patterns, either because they change slowly or because they are predictable at seasonal scale. Sea surface temperature (SST) and, in some continental regions, soil wetness and snow cover are the more decisive surface conditions affecting climate. The continental area in southern South America (SSA) is relatively narrow compared with the huge oceans that surround it, and thus, the slower timescale of the SST is a potential source of predictability. Consequently, most of the work done to understand interannual climate variability was focused on SST conditions.

On the other hand, though most of Argentina and Uruguay are under the influence of the subtropical circulation, they are frequently reached by westerly disturbances, which might contribute to reduce the seasonal predictability of the region. This could be one of the reasons why the operational prediction systems used both in Argentina and Uruguay have been hardly successful for seasonal prediction, as will be shown in this article. These results seem to contradict the fact that southeastern South America (SESA), which includes subtropical Argentina and Uruguay, is one of the extratropical regions whose climate is most affected by ENSO events, and hence having a potential for seasonal prediction. To address this issue, the ENSO regional signal is briefly revisited in the next section, discussing some aspects of the links between SST and rainfall in SESA.

2.3.1. The tropical Pacific SST

Most of the apparent current ability for the prediction of SSA climate is based on its mean response to ENSO. This average response will be briefly described, but then, emphasis will be put in the inter-event variability of this response.

Aceituno (1988) found significant negative correlations between precipitation at some subtropical Argentine locations and the Southern Oscillation Index (SOI) during November-December, reporting only the sign and the significance of the correlation. However, correlation coefficients between monthly or seasonal precipitation and ENSO indexes in Argentina and Uruguay, although significantly different from zero are, with very few exceptions, not large enough to explain more than a 30 % of the variance (Montecinos et al., 2000) and, therefore, of little help for monthly or seasonal forecasts.

Other approach followed by various authors was to analyze monthly anomalies of El Niño and La Niña with respect to climatology. Kiladis and Diaz (1989) have shown that in a large region, including northeastern Argentina and Uruguay, there is a significant difference between the seasonal precipitation of the spring (0) of El Niño and La Niña. Ropelewski and Halpert (1987; 1989) identified in about the same region, positive rainfall anomalies during spring (0) and summer (+) of El Niño years and below-normal precipitation between June (0) and December (0) of La Niña years. Ropelewski and Halpert (1996) studied the shifts in the precipitation distribution instead of shifts in the mean. This technique is more appropriated to deal with sporadic extreme rainfalls that can alter considerably the mean value. In addition, it is more suitable to make probability forecasts, like those used by IRI and described below. Over most of eastern Argentina and Uruguay, there is a shift in the median precipitation for ENSO events. During the summer of warm events, the shift is towards higher percentiles, and during the winter (0) and spring (0) of cold events there is a more pronounced shift towards lower percentiles. In the second case, the strongest signal is over Uruguay and the neighboring areas of Argentina.

In the three preceding papers, the authors described large scale and broad seasonal features, using a limited number of records and thus, their method overlooked the fact that in this region there is a break in the ENSO relationship with rainfall during high summer (Pisciottano et al., 1994; Grimm et al., 2000).

For Argentina and Uruguay, Grimm et al (2000), using also precipitation distributions, showed that the most significant signal of El Niño events on rainfall in SESA was in spring (0) over the northeast of Argentina and north of Uruguay. In the case of La Niña, the most significant signal was again in spring (0), but displaced southward and westward with respect to that of El Niño, stretching over northeastern and central Argentina and Uruguay. However, when only cases of El Niño lasting until May (+) are considered, their precipitation composite in autumn (+) has also a considerable significant anomaly that reaches more than 300 mm over the area surrounding the common border between Brazil, Argentina and Paraguay. This signal is responsible for the largest floods of the Paraná River in the Argentine territory (Camilloni and Barros, 2003).

Using tropical Pacific SST a season in advance as predictor in a CCA method, Montecinos et al (2000) found that the technique was able to anticipate the rainfall tercile (dry, normal or wet) in more than 45 % of the cases in some seasons of certain stations. However, in most of the seasons, the spatial patterns of skill show that in Argentina and Uruguay stations with such local skill were surrounded by others without any skill, indicating that these results could be obtained by chance. Nevertheless, for spring there is a prevailing pattern of skill over 45 % for Uruguay and the neighboring Argentina that bears spatial significance.

The conclusion from this brief revision is that the ENSO signal on the rainfall in subtropical Argentina and Uruguay can provide some statistical information only in certain regions and in a few seasons. But, even this modest ability for precipitation prediction is hindered by a large inter-event variability, as it will be seen in following paragraphs.

The understanding of the mechanisms that link tropical Pacific SST and precipitation adds confidence to the statistical relationships as potential predictors. It also helps to understand why there is a large variability between inter-El Niño and inter-La Niña events.

Karoly (1989) described the tropospheric structure anomalies of El Niño winter using the composite of three events. He found an equivalent barotropic wavetrain extending from the western subtropical Pacific to the Billingshausen Sea and turning to the northeast into South America and the Atlantic Ocean. This pattern is similar to part of the Pacific-South America (PSA) patterns described by Mo (2000) as the second and third leading modes of the Southern Hemisphere upper troposphere EOF. They are characterized by a wave number 3 structure, extended from the tropics to middle latitudes. The source region of the second leading pattern (PSA1) is to the east of the dateline and that of the third leading pattern (PSA2) is in the vicinity of eastern Australia. Mo (2000) showed that the PSA1 is associated with the variability of the ENSO with dominant periods of around 40-48 months, while the PSA2 is associated with the quasi-biennial component of the ENSO variability with periods of around 26 months.

Although with different phases in the western and central Pacific, both PSA modes, although with certain differences, tend to configure an anomalous circulation with a sort of double dipole structure over southern South America and the contiguous Pacific and Atlantic oceans. Thus, Grimm et al (2000) found that during El Niño (La Niña) there is a pattern of anomalies over the eastern Pacific, with cyclonic (anticyclonic) circulation at the subtropics and an anticyclonic (cyclonic) center at mid latitudes. Over the Atlantic Ocean, they found a tendency toward an inverse dipole pattern. Although this pattern varies along each ENSO phase, with changes in the position and intensity of its centers, the general effect is an enhancement (decrease) of the subtropical upper-level westerly circulation and of the cyclonic advection over eastern SESA, which is consistent with the general pattern of rainfall during El Niño (La Niña).

Although in some seasons, in certain regions of SESA, the statistical response of rainfall to El Niño (La Niña) is significant, there is a great difference from one event to another. Since most of the present ability for the prediction of SESA climate is based on its response to ENSO, this issue needs to be carefully considered in order to assess the limitations of the regional climate predictability.

The austral spring is the season with the most robust signals in the precipitation field during El Niño and La Niña events. However, although in most of Argentina and Uruguay the rainfall response to El Niño (La Niña) events is significant from the statistical point of view, the rainfall response from one event to another is sometimes larger than the mean difference between El Niño and La Niña cases, Fig. 2a (fromBarros and Silvestri, 2002). Fig. 2a also shows that the relationship between the spring precipitation in the region stretching over northeastern Argentina and southern Brazil and SST in the equatorial Pacific is not linear. Similar results hold for eastern

Argentina and Uruguay. In fact, during the austral spring, SSTs in El Niño regions are not correlated with seasonal precipitation in the SST range corresponding to El Niño or La Niña events. On the other hand, the SST in the subtropical south-central Pacific (SSCP) modulates the spring rainfall over most of SESA among El Niño events, Fig. 2b (fromBarros and Silvestri, 2002). Cold (warm) SST anomalies at SSCP are associated with positive (negative) rainfall anomalies in SESA. In the case of La Niña, SST in SSCP does not modulate rainfall in SESA, but this is done by the SST at the Atlantic, near South America (Barros and Silvestri, 2002).

The differences in the response to El Niño over the Southern Hemisphere were analysed by Vera et al. (2004). Cases with cold SST anomalies in the SSCP have an enhanced convection not only in the ITCZ over the central Equatorial Pacific, but also in the SPCZ, which is extended into the southeastern Pacific Ocean. The circulation anomaly field in the central south Pacific presents a well-defined PSA1-like pattern, while this pattern is not present during El Niño events associated with warm surface ocean conditions in the SSCP. The lagged correlations between the SPCZ index and the SST anomalies over SSCP during El Niño events are larger and significant when the SPCZ activity index leads, indicating that the differences in El Niño response over the Southern Hemisphere might be driven by atmospheric changes, which induces extratropical SST anomalies. Nevertheless, the processes that conduct to SST anomalies in the SSCP and to the high-tropospheric circulation features that characterize the more rainy springs (0) in SESA are already present during winter (0) (Silvestri et al., 2003). Thus, the SSCP SST is an additional source of information for the prediction of spring precipitation during El Niño events.

In the case of the winter (0), Silvestri and Barros (2004) identified two groups of El Niño events. In one group, the precipitation in most of SESA, including northeastern Argentina and Uruguay, was significantly higher than in neutral cases. The other group does not show precipitation signals, except in the Buenos Aires province. Both cases have different circulation patterns resulting primary from dissimilar conditions for the propagation of stationary meridional Rossby waves in mid latitudes. The first group shows an anomaly field with a PSA1-like wavetrain pattern ending over eastern South America and favoring the cyclonic vorticity advection over SESA. In the second group, there is a barrier to the meridional propagation in mid latitudes of the southeastern Pacific and thus, the wavetrain is deflected northeastward, far from Argentina and Uruguay. Thus, the predictability of the circulation features that develops such barrier is a precondition for the predictability of precipitation in SESA during El Niño winter. These circulation features are properties of the meridional gradient of the zonal flow, whose predictability results then of practical interest.

Cazes et al (2003), analyzing Uruguay rainfall teleconnections, pointed out to another source of interannual variability, the intraseasonal variability of the tropospheric circulation over the southern Pacific. The predictability of such variability is another issue of importance for the predictability of rainfall in SESA.

Finally, SESA is one of the world regions with frequent Meso Convective Systems (MCS), (Velasco and Fritsch, 1987). Unlike other subtropical regions, their occurrence extends until the autumn and the percentage of precipitation caused by them is determinant for the total seasonal amounts. MCS annual frequency, south of 20°S, ranges from about 20 to more than 50 cases, being enhanced by El Niño occurrence. However, their location and trajectory varies from one El Niño event to another, hence contributing to very different precipitation seasonal fields and making predictions based on statistical properties rather uncertain. Fig. 3 shows the monthly rainfall anomalies for seven April (+) of El Niño events and their composition. Although there is a consistent positive signal over most of the region, there is an important spatial variability of the centers of maximum positive anomalies. The size of the monthly anomalies reflects the occurrence in each case of one or two MCS. The importance of MCS in the monthly and even seasonal precipitation is likely one of the reasons for the poor skill that atmospheric and ocean coupled models show for seasonal prediction over Argentina and Uruguay. It remains to understand if this limitation is an intrinsic feature of an unpredictable system or can be removed by further knowledge of the MCS and their behavior in the region.

There are considerably less publications about the ENSO relationship with surface temperature over Argentina and Uruguay, as compared with those with precipitation. Aceituno (1988) calculated correlations between the SOI and air temperatures at land stations in South America. In SSA, the correlations were generally not significant, except for the positive correlations in the southernmost Argentina during September-October.

Kiladis and Diaz (1989) calculated the difference between temperature anomalies during El Niño and La Niña events. They found positive differences in the South America subtropics during the winter (0), which weaken considerably during austral spring (0). East of the Andes there is very little geographic congruity in the temperature anomalies of the warm and cold events in the summer, but the positive differences appear again in the autumn (+).

Halpert and Ropelewski (1992) found that in the northern part of Argentina, the warm event composite has above-normal temperatures from May (0) through April (+). The composite of the cold events has below-normal temperatures from October (0) through May (+) in the same region, but more extended to the south and including Uruguay and central Argentina. However, significant positive (negative) anomalies are only observed during the winter (0) of El Niño (La Niña) composites over Uruguay and northern and central Argentina (Barros and Silvestri, 2002). These anomalies are caused by an enhanced (diminished) low-level advection of temperature from the tropical continent (Barros and Silvestri, 2002).

In Argentina, the ENSO phases influence the probability of occurrence of persistent extreme temperatures, but this effect is more constant along La Niña events than in El Niño events (Rusticucci and Vargas, 2002). During La Niña, extreme and persistent cold anomalies have a high probability of occurrence in almost every time of the year, while in the case of El Niño, extreme and persistent warm anomalies have high probability only in winter (Rusticucci and Vargas, 2002).

2.3.2. The South Atlantic SST

The connection between South Atlantic SST anomalies and precipitation in SESA has deserved less attention than the ENSO link. However, it abounds the literature with respect to South Atlantic Convergence Zone (SACZ). Since interannual variability of rainfall in subtropical Argentina and Uruguay during summertime is closely related to this system (Doyle and Barros, 2002), it is convenient to briefly introduce some aspects of the SACZ

The SACZ is one important climatological feature of the austral summer in South America. This band of intense convective activity emanates from the Amazon region extending from the tropical South America southeastward into the South Atlantic Ocean (Kodama, 1992; Figueroa et al., 1995). What matters, here, is its connection with rainfall in Argentina and Uruguay. Nogués-Paegle and Mo (1997) found evidence of a seesaw pattern in the convection over the SACZ, with each phase lasting no more than 10 days and that the intensification (weakening) of the SACZ is associated with rainfall deficit (abundance) over the subtropical plains of South America, including eastern Argentina and Uruguay. Doyle and Barros (2002) showed that this dipole behavior appears also as a distinctive feature of the interannual variability of rainfall, and that in western Argentina, precipitation tends to vary in phase with SACZ rainfall. Gandu and Silva Dias (1998) explored the physics of this dipole with numerical experiments, showing that a strong SACZ activity is associated with enhanced subsidence to the south of it.

Barros et al. (2000) found that, during summer, both the intensity and position of the SACZ are related to the SST to the south of it, being displaced northward (southward) and more intense (weaker) with cold (warm) SST anomalies. However, this relation does not mean that SST governs the SACZ variability. There are evidences that the phases of SACZ respond to Rossby wave activity (Liebmann et al., 1999; Robertson and Mechoso, 2000) and to the MJO (Carvalho et al., 2004). However, a numerical experiment shows that there is a positive feedback between cold SST in the subtropical South Atlantic and intense SACZ activity (Robertson et al., 2003), and therefore the SST influence on the SACZ, and consequently on the subtropical rainfall cannot be discarded.

The SACZ connection between SST and rainfall in subtropical Argentina and Uruguay could be one of the mechanisms that relate the interannual variability of SST in the South Atlantic with precipitation in those countries. This relation was studied by Díaz et al (1998), finding the existence of an association between wet (dry) rainfall anomalies in the northern sector of Uruguay and southern Brazil and warm (cold) SST anomalies in the SACZ region and the equatorial Atlantic in the November-February period. Barros et al (2000) found that during summer, SESA rainfall is related to both the intensity and position of the SACZ, but also independently of the SACZ, to the SST of the neighboring Atlantic Ocean. Doyle and Barros (2002) found that the midsummer interannual variability of the low-level tropospheric circulation and of the precipitation field in subtropical South America are associated to the SST anomalies in the western subtropical South Atlantic Ocean. Composites corresponding to extreme SSTs in the area 20ºS-30ºS and 30ºW-50ºW show two different low-level circulation and precipitation patterns.

The aforementioned studies reveal the potential importance of the South Atlantic in the SESA climate variability. However, since the SACZ also responds to remote atmospheric forcings, the predictability of the regional climate based on South Atlantic SSTs is still an issue that requires further research.

2.3.3. Seasonal forecast skill

Since 1997, the International Research Institute for Climate Prediction (IRI) elaborates global seasonal forecasts of temperature and precipitation anomalies containing an outlook for the coming 3-month season and an extended one for six months in advance. The IRI's operational climate forecasts are issued every month for the globe (http://iri.columbia.edu/climate/forecast/net_asmt/). Model skill estimates based on hindcast simulations with prescribed SST are also available. The outlook is prepared using coupled ocean-atmosphere model predictions of tropical Pacific SST, forecasts of the tropical Indian ocean using a statistical model and global atmospheric general circulation model (GCM) predictions of the atmospheric response to the present and predicted sea-surface temperature patterns. Seasonal outlooks provide the probability that average temperature and total accumulated precipitation fall into each of three categories. These categories are defined as the lower, middle, and upper thirds of the climatological distribution. When forecasts with probabilities for the three categories are the same, namely a third each, they are designated as climatology (CL). For each location and season, the terciles correspond to temperature and precipitation ranges based on a set of historical observations. Consequently, when using tercile forecasts, users need to know the ranges to which the terciles refer.

Berri et al. (2003) made an evaluation of the IRI´s seasonal precipitation forecasts for SESA, issued between 1998 and 2002. They showed that the regional IRI´s forecasts have a small positive Ranked Probability Skill Scores (RPSS) in northwestern Uruguay and some part of northeastern Argentina, a region with strong ENSO signal, Fig. 4. The small positive RPSS means that forecasts were better than climatology though rather modest, a result that might be expected according to the arguments shown in section 2.1. On the other hand, results in western Argentina are worst than climatology. This is a semiarid region with strong interannual variability where in general, GCM have difficulties to simulate rainfall (Camilloni and Bidegain, 2002).

Other source for predictions of seasonal average temperatures and precipitations for Uruguay and Argentina, available at the web, is the NASA's Seasonal-to-Interannual Prediction Project (NSIPP) (http://nsipp.gsfc.nasa.gov/main.html). NSIPP runs its coupled global ocean-atmosphere-land model to produce 12-month forecasts with NSIPP SSTs and with NCEP/IRI SSTs inputs, issuing three types of forecasts. The first type presents the precipitation anomaly from a 18 member ensemble mean. Anomalies are calculated with respect to the 1993-2001 model climatology. The second one is the raw category forecast, based on the individual ensemble member forecasts. The three categories are above normal, normal and below normal according to the model climatology. The numbers presented in the forecast are the percentage of the ensemble members that fall in each category. Finally, the calibrated category forecast is based on the ensemble mean of the forecast and reflects the past performance of the model in the three above-mentioned categories. Areas with no forecast skill are also indicated. In this case, numbers represent the probability in percent that forecast will verify.

Since December 1997, 18 climate outlook fora (COF) for SESA were convened to produce seasonal climate forecasts for temperature and precipitation anomalies in the region bounded by 20°S, 40°S, the Atlantic coast, and the Andes. These COFs were organized by governmental organizations of Argentina, Brazil, Paraguay, and Uruguay. The participants were climate experts and operational forecasters, which reach a consensus to forecast the coming 3-month season. The COF also discuss the implications of probable climate outcomes for climate-sensitive sectors. Following the IRI's methodology, the COF estimates the probability of the seasonal mean of precipitation and temperature to be in the lower, middle, and upper thirds of the climatological distribution.

Berri et al (2003) evaluate the COF´s forecasts with the same method used with the IRI's outlooks. Over most of the region, the COF´s seasonal forecasts have a very small negative RPSSs, being therefore slightly worst than climatology. As in the case of the IRI's forecasts, there is a region with positive RPSSs in northwestern Uruguay, but with even lower skill and in a smaller area, Fig. 5. The fact that RPSS are very near zero all over the domain, both in their positive and negative values, reflects the worthless of the consensus method in this case. These consensuses generally tended to smooth out the different opinions, and thus, forecasts resulted not very different from climatology.

Misra (2004) studied the predictability of the austral summer seasonal precipitation over South America using the atmospheric general circulation model of the Center for Ocean-Land-Atmosphere Studies (AGCM-COLA). The AGCM-COLA was run with prescribed observed SST. Consequently, the estimated skill represents the upper bound or the potential skill that can be attained by using predicted SST. The potential skill in predicting the interannual variability of mean January-February-March is lower in central Argentina than over the tropical areas of Northeastern Brazil, the Amazon River Basin and the SACZ, suggesting a lack of skill in the tropical-extra-tropical interactions. The AGCM-COLA underestimates the mean seasonal precipitation over central Argentina by almost a 50% in some areas, but it does better over Uruguay. The root mean square error of the seasonal totals over central Argentina is so large that it can be inferred that the AGCM-COLA has no predictable skill in this region.

2.3.4. Conclusions

Over Argentina and Uruguay, the skill of the operational seasonal forecasts ranges from modest, but better than climatology, to useless. The skill is confined to the northeast of Argentina and north of Uruguay, a region with an important ENSO signal.

There is a number of reasons for such humble result. First, models and statistical tools used for seasonal prediction relay primary on the SST slow changes or their predictability. In spite of the well-known mean regional climate response to ENSO, this indeed is limited to only some areas and some months. But still in these months and areas, there is a large inter-event variability that may hinder predictions based on statistical mean response or even model ability since in some cases, it is not clear that this variability obey to predictable causes.

The importance of MCS in the total seasonal precipitation is likely one of the reasons for the poor skill that atmospheric and ocean coupled models show for seasonal prediction over subtropical Argentina and Uruguay. Though the frequency of these systems seems to respond to ENSO, the locations where they occur are extremely variable. It remains to understand to what extent the contribution of these systems to seasonal precipitation is unpredictable over this region.

There is a connection between SESA precipitation and the South Atlantic SST, as well as with the SACZ, at least during summertime. However, since the SACZ also responds to remote atmospheric forcings, the predictability of the regional climate based on South Atlantic SSTs is still an issue that requires further research.

The Antarctic oscillation index is correlated with precipitation in Argentina and Uruguay during part of the year (Silvestri and Vera, 2004). Since this oscillation is suspected of being unpredictable, at certain frequencies, an understanding of the mechanisms, which relates it to SESA rainfall, is required.

3. Scenarios of global climate change over South America

Climate modeling has proven to be extremely useful in building projections for climate change and scenarios of future climate under different forcings. General circulation models have demonstrated their ability to simulate realistically the large-scale features of observed climate; hence, they are widely used to assess the impact that increased loading of the atmosphere with greenhouse and other gases might have on the climate system. Although there are differences among models with regard to the way they represent the climate system processes, all of them yield comparable results on a global basis. However, they have difficulty in reproducing regional climate patterns, and large discrepancies exist among models. In several regions of the world, distributions of surface variables such as temperature and rainfall often are influenced by the local effects of topography and other thermal contrasts, and the coarse spatial resolution of GCMs cannot resolve these effects. Furthermore, the intrinsic limitation of not-resolving clouds in GCMs is a major limitation to predict the changes on the frequency of extreme events on a CO2-rich atmosphere. Consequently, large-scale GCM scenarios should not be used directly for impact studies, especially at the regional and local levels (Von Storch, 1994); downscaling techniques are required.

Analysis of climate variations during the instrumental period and evidence suggested by paleoclimatic and other proxy climate information suggests that climate variations and change have been found in several regions in Latin America. Most climate records cover the past century; at this time scale, there have been indications of multidecadal and interannual variability, some linked to extremes of the Southern Oscillation. The lack of continuous and long-term records from the past does not allow one to identify climate patterns with a high degree of confidence to determine whether these climates were similar to or much different from that of present times—particularly with respect to the frequency and intensity of extreme events such as drought, floods, freezes, heat waves, and especially hurricanes and tropical storms. However, multidecadal variations have been identified in rainfall and streamflow records in the region, although no clear unidirectional trend indicators of climate change have been identified (IPCC 2001 and references quoted in).

The predictions of future climate change, while differing in details from model to model, consistently indicate that global changes of the current climate state are going to materialize. Due to the inertia of the climate system, even if we were able to stabilize greenhouse-gas concentrations today (what means an overnight reduction in global carbon dioxide emissions of about 70%), a further 1 °C of additional global warming, and around one metre of sea-level rise would occur from emissions that have already taken place over the last 100 years. As shown in previous Hadley Center reports, sea level will go on rising for many hundreds of years after greenhouse-gas concentrations have been stabilized (http://www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/B2000/predictions.html).

Results of a coupled atmosphere-biosphere model simulation by Cox et al. (2001), which included some form of feedback of climate on the carbon cycle, suggests that after a certain threshold of global warming, carbon kept in the soil and the biomas of tropical forests, like the Amazon, would be partially released through respiration as carbon dioxide into the atmosphere, with the inflection point between CO2 sink becoming a CO2 source by mid 21st century. These results, if confirmed by further research and diagnostics, represent the most alarming indication of the seriousness and magnitude of global climate change for the earth system.

3.1. Is climate variability likely change regionally?

There are many more AOGCM projections of future climate available than was the case for the IPCC Second Assessment Report (IPCC, 1996). We concentrate on the IS92a and draft SRES A2 and B2 scenarios of the IPCC Third Assessment Report (2001). Results of experiments using those climate change scenarios show that most tropical areas have increased mean precipitation, most of the sub-tropical areas have decreased mean precipitation, and in the high latitudes the mean precipitation increases. In addition, there is a general drying of the mid-continental areas during summer (decreases in soil moisture). This is ascribed to a combination of increased temperature and potential evaporation that is not balanced by increases in precipitation.

The capability of models to simulate the large-scale variability of climate, such as the ENSO (a major source of global interannual variability) has improved substantially in recent years, with an increase in the number and quality of coupled ocean-atmosphere models with the running of multi-century experiments and multi-member ensembles of integrations for a given climate forcing. IPCC (2001) indicate that the results from these models must still be treated with caution as they cannot capture the full complexity of these structures, due in part to the coarse resolution in both the atmosphere and oceans of the majority of the models used.

The future mean Pacific climate base state could more resemble an El Niño-like state (i.e., a slackened west to east SST gradient with associated eastward shifts of precipitation). Whilst this is shown in several studies, it is not true of all. Decadal and longer time-scale variability complicates assessment of future changes in individual ENSO event amplitude and frequency. Assessment of such possible changes remains quite difficult. The changes in both the mean and variability of ENSO are still model dependent. Finally there are areas where there is no clear indication of possible changes or no consensus on model predictions.

Although many models show an El Niño-like change in the mean state of tropical Pacific SSTs, the cause is uncertain. In some models it has been related to changes in cloud forcing and/or changes in the evaporative damping of the east-west SST gradient, but the result remains model-dependent. For such an El Niño-like climate change, future seasonal precipitation extremes associated with a given ENSO would be more intense due to the warmer mean base state. There is still a lack of consistency in the analysis techniques used for studying circulation statistics (such as the North Atlantic Oscillation) and it is likely that this is part of the reason for the lack of consensus from the models in predictions of changes in such events.

The possibility that climate change may be expressed as a change in the frequency or structure of naturally occurring modes of low-frequency variability has been raised. If true, this implies that GCMs must be able to simulate such regime transitions to accurately predict the response of the system to climate forcing. This capability has not yet been widely tested in climate models. A few studies (Osborn et al., 1999; Paeth et al., 1999; Ulbrich and Christoph, 1999) have shown increasingly positive trends in the indices of the NAO and the SST interhemispheric gradient in the tropical Atlantic in simulations with increased greenhouse gases; although this is not true in all models, and the magnitude and character of the changes varies across models (see reviews in the IPCC 2001).

One intriguing aspect of climate variability under a scenario of climate change is the likelihood of augmented available potential energy due to a warmer and moister troposphere. There are indications that the number and intensity of tropical storms may increase as a consequence of a warmer troposphere and upper ocean, with deleterious social and economic consequences. One extraordinary example of a phenomenon never heard of before over the South Atlantic is the recent extratropical cyclone that hit the coast of Brazil last March 26th, 2004. It was the first time in the record that such large synoptic system developed over the South Atlantic, reaching proportions of a hurricane. Interestingly, the path of this cyclone coincided with the area of augmented probability of cyclogenesis predicted on climate change scenarios constructed by the Hadley Center, UK. Even though the single realization of a cyclone of such proportions over the South Atlantic may not be statistically significant to suggest that we are experiencing the dawn of a changed climate, it is nevertheless intriguing and shall be very much studied in the months and years to come.

3.2. *Predictability of seasonal climate under global climate change scenarios*

The tropical SST anomalies impact more on the predictability over the Pacific/North America sector than the Atlantic/Eurasia (Cheng and Dool, 1997). In the former sector more significant and positive impacts are found during El Nino and La Nina than during the neutral phase or inactive period. Predictability is significantly higher during El Niño than La Nina phases. This was confirmed by Marengo et al. (2003) for regions in the Atlantic sector such as Northeast Brazil, northern Amazonia and southern Brazil-northern Argentina. The predictability of seasonal means exhibit large seasonality for both warm and cold phases of the ENSO cycle, and during the warm phases a high level of predictability is observed during December to April, where the rainy season peaks in tropical South America east of the Andes. Most of the decadal Pacific variability comes from the western Pacific.

Thus, for regions that show some association with Tropical Pacific SST and El Nino some predictability can be expected, while for regions such as Amazonia and Northeast Brazil this predictability will depend on the characteristics if the tropical Atlantic and becoming higher whenever there is an extreme of the ENSO. At the ends, most of the models show for climate change scenarios more frequent El Nino like conditions, and this would in fact overcome SST anomalies in the tropical Atlantic. One could think that being the Amazon, Northeast Brazil and the Southern Brazil regions very sensitive to ENSO these would actually gain some predictability for rainfall anomalies in global warming scenarios. The Hadley Centre HadCM3 model show El

Nino-like conditions since the 2050, with dryness in Amazonia and Northeast Brazil and rainfall above normal in southern Brazil. However, the degree of uncertainty is not low, and if most of the climate models projection for Northeast Brazil show increases in air temperature and rainfall for the extreme scenario IPCC A2, the Amazon basin shows an unclear signal of rainfall (varying from slightly above to below the normal), there is a detected warming trend 5.8 °C in some models. The observed warming trend in Amazonia since the early 1900's is +0.85 C/100 years.

4. The state of the art of climate prediction over South America

The potentially predictable component of atmospheric interannual variability is assumed to be that due to oceanic forcing, together with the unpredictable internal component. Rowell (1998) concluded that the model-based predictability estimate has large variations throughout the annual cycle. The highest predictability occurs over the tropical oceans, particularly the Atlantic and Pacific, for which a better knowledge of the influence of SST on diabatic heating is important for understanding the variability of teleconnected regions. Land-areas displaying high predictability tend to support existing empirical studies, such as the Amazon basin, while other do not exhibit such high degree of predictability as in the South American monsoon (Marengo et al., 2003). Servain et al. (2000) identify two interannual modes of variability that have the same physics as the annual variability does, which is related to the latitudinal displacement of the ITCZ. Furthermore, it is suggested that the ocean dynamics (as opposed to the thermodynamic processes) is the principal cause of climate variability in the region, and this works also at decadal time scales. The observed decadal changes in the Pacific, detected as changes in the frequency of intensity of ENSO events during the middle 1940's and 1970's (IPCC 2001), as decadal changes identified in the tropical Atlantic also show a possible change in predictability on decadal time scales.

A number of studies have reported the existence of decadal and longer time-scale variability in South American rainfall and river discharge, related to ocean surface changes in those timescales in both Pacific and Atlantic Ocean (Zhou and Lau, 1998; Robertson and Mechoso, 1998; Mehta, 1998). Decadal time scales for the Pacific and Atlantic Oceans have been linked to variations of rainfall in the Amazon and Northeast Brazil regions (Wagner, 1996; Nobre and Shukla, 1996; Mehta, 1998; Robertson and Mechoso, 1998. Mehta [, 1998 #510) suggested a distinct decadal time scale (12-13 year) of SST variations in the tropical South Atlantic, whereas no distinct time scale was found in the tropical North Atlantic SST variations. Previously, Mehta and Delworth (1995) identified in the observations and the GFDL model a multidecadal variability in the SST time series with approximately opposite phases between the tropical North and South Atlantic, exhibiting an inter-hemispheric gradient of SST anomalies. Dommenget and Latif (2000) found that the decadal variability in both tropical North and South Atlantic are uncorrelated, and that this variability of the upper-tropical Atlantic Ocean is forced by the atmosphere while dynamic feedbacks are less important.

The role of the ocean in tropical Atlantic decadal variability is investigated by Seager et al (2001). They suggest that the tropical Atlantic is largely passive and damping, and SST anomalies are largely stationary in the deep tropics. Previously, Carton et al. (1996) and Rao et al. (1996) suggested that decadal time scale variability in the tropical Atlantic is controlled by latent heat flux anomalies and is primarily responsible for SST anomalies off the equator. Ruiz-Barradas et al. (2002) examine the connection between the tropical Atlantic and other basins. They found that ENSO events cause patterns of winds, heating and SST resembling the interhemispheric gradient of anomalous SST and dipole pattern of atmospheric heating.

In southern Brazil and northern Argentina, recent studies (Barros, personal communication) have detected increased rainfall and river discharge in the region since the mid-1970s; these increases are linked to changes in the regional circulation, i.e. the southward displacement of the subtropical Atlantic high. Robertson and Mechoso (1998) suggested some predictability on decadal time scales in the southern Brazil region, associated with a near-decadal oscillation in SST over southeastern South America, and they projected low river discharge values for the Parana River for 2003. However, this prediction was not supported by the observed volumes on this year of 2003.

For the Amazon Basin, decadal variations of rainfall have been identified in both northern and southern Amazonia, with shifts in the mid-1940s and 1970s. After 1975–76, northern Amazonia received less rainfall than before 1975 (Marengo 2004). Changes in the circulation and oceanic fields after 1975 suggest an important role of the warming of the tropical central and eastern Pacific on the decreasing rainfall in northern Amazonia, due to more frequent and intense El Niño events during the relatively dry period 1975–98.

In Northeast Brazil, Folland et al. (2001) study the predictability of rainfall using the HadAM2b model, and they demonstrate a relatively high degree of predictability, with its sources lying mostly in the tropical Atlantic and Pacific SST. On this region, the SST gradient between the northern and southern tropical Atlantic appears to be the most important influence, though El

Nino can be dominant when it is strong. This high predictability is the base of empirical predictions in that region, as the forecasts by Greischar and Hastenrath (2000). Their method used 1921-57, and their performance was validated on the independent record 1958-89. The forecasts were in close agreement with the observed rainfall during the 1990's, with exception of the extreme El Nino 1998. A possible cause of this failure is seen in the lack of comparably extreme Pacific warm, events within the training period 1921-57, and the frequency of intense El Nino has changed from the middle 1970's. This conclusion on predictability can be also applicable to the Amazon basin. So, the notion of a rapidly changing climate represents a major quest for the predictability of climate variations on interannual time scales because most methods and models, both statistical and dynamical ones, based on the presumption of stationarity of the mean state statistics considerably longer than the time span of the predictions.

4.1. Dynamical downscaling of regional climate predictions

The disadvantage of using AGCM for regional climate predictions on intraseasonal to interannual and longer timescales is the inability of present day models to resolve sub-grid atmospheric processes of fundamental importance (e.g. clouds and regional scale inhomogeneities of surface fluxes), which are likely to play a determining role on climate statistics. On interannual climate prediction, for instance, the use of regional atmospheric models have suggested that it might be possible to predict higher statistics of the regional climate like the probability density function (pdf) distribution of daily rainfall over a region. Nobre et al. (2001) obtained encouraging results using a regional model nested on the outputs of an AGCM to predict the daily rainfall pdf and the spatial distribution of consecutive number of days with no rainfall over Nordeste during the period of February to May 1999. Sun et al. (2004) used essentially the same dynamical downscaling technique but over a period of 30 years and demonstrated that the regional model can simulate the interannual variability of daily rainfall pdf over Nordeste, better than the AGCM in which it was nested. These results represent a milestone for seasonal climate prediction, as they point to the possibility of climate predictions beyond seasonal averages of atmospheric variables, first suggested by Shukla (1981).

5. Seasonal climate predictions over South America

Presently, there are several centers in South America and other parts of the world that issue regular seasonal climate assessments and outlooks for South America. On its majority, these centers use two-tier approach to generate the predictions; first using various methods to reach the "best estimate" of global tropics SST prediction for the following four to six months; then the SST forecasts are used to force AGCMs to generate ensembles of individual predictions starting from slightly different atmospheric initial conditions. A detailed explanation of this type of methodology can be found in Goddard et al. (2002) and Marengo et al (2003), for example. Among the centers that currently provide seasonal climate predictions over South America are:

5.1. CPTEC

Uses the CPTEC/COLA spectral AGCM forced with prescribed SST globally. The model horizontal truncation is triangular at wavenumber 62 and 28 sigma levels unevenly spaced in the vertical. Atmosphere-biosphere model is SIB; deep convective cloud parameterization is Kuo. A total of 30 ensemble members are computed every month; 15 atmospheric initial conditions (analysis fields obtained from NCEP) are taken two months prior to the start of the forecast period; soil moisture and snow cover at initial condition are climatological; sea ice is kept climatological throughout the integration. The AGCM is then integrated for two months forced with observed global SST; then two sets of SST predictions are used: one uses a composite of NCEP coupled model SST predictions for the equatorial Pacific and CPTEC canonical correlation analysis (CCA) SST predictions over the tropical Atlantic (Repelli and Nobre, 2004) for the following four months, with persisted SST anomalies over the remaining oceanic areas. The second set of 15 integrations (using the very same set of atmospheric IC as above) uses persisted SST anomalies over all the oceans during the same four months of prediction. Ensemble means of the monthly output fields are then used to generate the consensus forecast.

The International Research Institute for climate prediction (IRI) provides results from a multimodel ensemble, and the same probabilistic analysis considered from the several model results are applied to CPTEC AGCM. Regional three-month predictions, using the Eta model, have been under tests and climatological outputs are being analysed to discuss the systematic errors.

5.2. CCM3.2 -

This model was developed at the National Centers for Atmospheric Research (NCAR) in the United States. The horizontal resolution of the model is T42 and 18 vertical layers.

Initial atmospheric conditions are supplied by restart files from an integration in which CCM3 has been forced with observed SSTA for several years up to the forecast start date. At the beginning of the forecast for the first ensemble member, nine sets of restart files are generated, each for a successive model day, to yield nine additional forecast initial conditions.

5.3. ECHAM3.6 -

The European Community - HAMburg (ECHAM) model was developed at the Max Plank Institut fur Meteorolgie in Germany. The horizontal resolution of the model is T42 with 19 vertical layers (Barnett et al, 1994, Tellus, 46A, 381-397; Bengtsson et al, 1993, Science, 261,1026-29). Initial atmospheric conditions for each forecast ensemble member are supplied by restart files from separate ensemble members of a simulation in which ECHAM has been forced with observed SSTA up through the forecast start date.

5.4. NCEP-MRF9 -

The NCEP-MRF9 atmospheric climate model was developed at the National Centers for Environmental Prediction (NCEP) in the United States, based on a version of the medium range forecast model used by the National Weather Service. The horizontal resolution of the model is T40 with 18 vertical layers. Initial atmospheric conditions are derived as with CCM3 from restart files from an integration in which NCEP has been forced with observed SSTA for several years up to the forecast start date. At the beginning of the forecast for the first ensemble member, nine sets of restart files are generated, each for a successive model day, to yield nine additional forecast initial atmospheric conditions.

5.5. NSIPP

This model was developed at the NASA's Seasonal to Interannual Prediction Project (NSIPP) at Goddard Space Flight Center. The horizontal resolution of the model is 2.5 degrees longitude by 2.5 degrees latitude with 34 vertical layers. Each forecast consists of a 9 member ensemble. Initial atmospheric conditions for the nine ensemble members are supplied by restart files from nine integrations in which NSIPP-1 has been forced with observed SSTs for several years up to the start date.

5.6. MET OFFICE

The products are based on the output from forecasts made using a coupled ocean-atmosphere General Circulation Model (GCM). The atmospheric component is version HadAM3 (see Pope et al, Climate Dynamics (2000) for a description), with a horizontal resolution of 3.75°; east-west and 2.5° north-south, and 19 vertical levels. The oceanic component has 40 vertical levels (compared to 20 in HadCM3), zonal grid spacing at 1.25°, and meridional grid spacing of 0.3°

near the equator increasing to 1.25° poleward of the mid-latitudes (compared to 1.25° resolution east-west and north-south in HadCM3).

Each forecast requires initial ocean, land and atmosphere conditions. The land and atmosphere conditions are specified from atmospheric analyses that are produced separately for weather prediction purposes. The ocean initial conditions are taken from ocean analyses generated specifically for seasonal forecasting, using the ocean GCM component of GloSea. The ocean GCM is run using surface fluxes of momentum, heat and water prescribed from atmospheric analyses, while assimilating sub-surface ocean observational data, with temperatures in the top layers constrained to be close to surface observations.

Each month forecasts are run with starting conditions at the beginning of the month, to create a 40-member ensemble.

5.7. ECMWF

The coupled model consists of the ECMWF atmospheric model (cycle 15r8), coupled to an ocean general circulation model which is a version of the Hamburg Ocean Primitive Equation model (HOPE) developed at the Max-Planck Institute for Meteorology, Hamburg. Currently, the atmospheric model is run at T63 resolution (1.8 x 1.8 degrees) with 31 levels in the vertical. The ocean model has lower resolution in the extratropics but higher resolution in the equatorial region in order to resolve ocean baroclinic waves and processes which are tightly trapped to the equator. The ocean model has 20 levels in the vertical, 8 of which are in the upper 200m.

Every day, the coupled model is integrated forward to make a 6 month forecast. Once a month these forecasts are collected together to create an ensemble forecast with about 30 members. Full coupling is applied between the atmosphere and ocean. Because of model error, a drift occurs after coupling which is not small compared with the size of the signal being predicted. This drift is subtracted from the model fields once the integration is complete. Various forecast products are generated, showing both SST anomalies and the predicted atmosphere response.

5.8. FUNCEME

Over the last 20 years, Ceará State Foundation for Meteorology and Water Resources (FUNCEME), in partnership with National Institute for Space Research (INPE) and other Brazilian and foreign meteorology institutions, has worked on a conceptual model of climate forecast that is supported by several regional and global climatic models. In addition, information about oceanic and atmospheric patterns that have a significant influence on the rainy season quality over Ceará and Northeast Brazil are analyzed too.

Every year, FUNCEME holds a workshop in Fortaleza, which is attended by its technical staff and experts from national and international institutes and universities, to make the analysis of such oceanic and atmospheric variables that are significant for the identification of rainy period, and make forecasts based on the application of several numeric models. At the end of the workshop, the panel of researchers and experts issue a climate forecast for the main rainy period (February-May) in both the State of Ceará and the northern portion of Nordeste.

One particularity of FUNCEME's methodology is the use of NCEP's Regional Spectral Model (RSM) nested on the ECHAM5 AGCM outputs generated by the IRI to predict seasonal rainfall anomalies over Nordeste. An ensemble of ten members is generated with the regional model integrated for a period of six months from December AGCM forecasts. SSTs are persisted global SSTAs. Running in hindcast mode, the regional model generated seasonal rainfall hindcasts which were consistently more accurate than the corresponding AGCM hindcasts.

The forecast is read out publicly on the last day of the workshop at a session attended by the major users (EMATERCE, Civil Defense, COGERH, SEAGRI, agricultural businesspersons, and other stakeholders). Forecasts are usually covered and published by the local media (press and TV). It should also be highlighted that, prior to the public disclosure of forecasts, a team of professionals led by the President of FUNCEME, submits the workshop conclusions to the Governor of the State of Ceará.

Once the first forecast for a particular year is issued, FUNCEME team continues to monitor the oceanic and atmospheric patterns. Eventual changes in forecasts is published in technical releases and informed immediately to the end-users. This remains available in the web site of FUNCEME (http://www.funceme.br).

It should be pointed out that climate forecast issued in December is considered as an initial approach, as it is based on oceanic and atmospheric conditions observed in November. Previous experiences have shown a high forecast reliability when observations made in January-February are used.

This anticipated climate forecast, combined with the daily monitoring of sea and atmosphere conditions, has helped the State of Ceará over all those years to plan actions for agriculture (e.g. Hora de Plantar (Time to Plant) Program), water resources (reservoir management), civil defense (alerts against extreme rainy events in Fortaleza Metropolitan Region), civil construction (best periods for concrete application), etc. General society has also benefited of such forecasts through a range of measures taken by the civil defense, Secretariat of Agriculture, Secretariat of Water Resources, Civil Construction, and other sectors that use meteorological information to carry on their activities.

6. Research and data needs.

As it discussed above, seasonal climate predictions over South America can partly benefit from "ocean-driving" conditions of atmospheric circulation and precipitation patterns. Therefore, slowly varying ocean temperature fields as those associated to the ENSO over the equatorial Pacific and the meridional gradient of SST anomalies over the tropical Atlantic imprint seasonal predictability to the climate. However, model improvements and research quality data are in need to both increase predictions skill and lead time. Furthermore, the evidences pointing to the dynamical limitations of using AGCM forced by prescribed boundary conditions to predict SACZ variability is a major limitation in current prediction techniques used. Yet, due to present limitations of coupled ocean-atmosphere models to predict tropical Atlantic climate and ocean variability, the scientific puzzle ahead of us to predict the coupled variability of the tropical Atlantic basin represents a huge challenge to our ingenuity and resources: human, models, data, financial, and scientific wise.

Future implementations on the atmospheric component of the CPTEC coupled ocean-atmosphere model are related to the improvements of physical parameterizations, new vegetation maps and more realistic soil humidity fields. Other implementations comprise the increase of the models resolutions, optimization of codes, and new methods of model analyses, including superensemble mean, clusters, and predictability.

On the observational side, Brazil recognizes the scientific and practical merit, and is deeply committed, to develop a comprehensive observational ocean-atmosphere network over the equatorial and South Atlantic. The PIRATA project of moored ATLAS buoys in the tropical Atlantic, in which Brazil participates with France and the United States, constitutes the embryo of such observational network.

Acronyms:

CCM3 – Climate Community Model 3

COLA – Center for Ocean-Land-Atmosphere Studies

CPTEC – Centro de Previsão de Tempo e Estudos Climáticos

ECHAM – Max Planck Institut

ECMWF – European Center for Medium-Range Weather Forecasts

ECPC – Experimental Climate Prediction Center

FUNCEME – Fundação Cearense de Meterologia e Recursos Hídricos

INPE – Instituto Nacional de Pesquisas Espaciais

IRI – International Research Institute for Climate Prediction

Met Office – UK's National Meteorological Service

NCEP – National Centers for Environmental Prediction

NSIPP – NASA Seasonal to Interannual Prediction Project

UBA – Universidad de Buenos Aires

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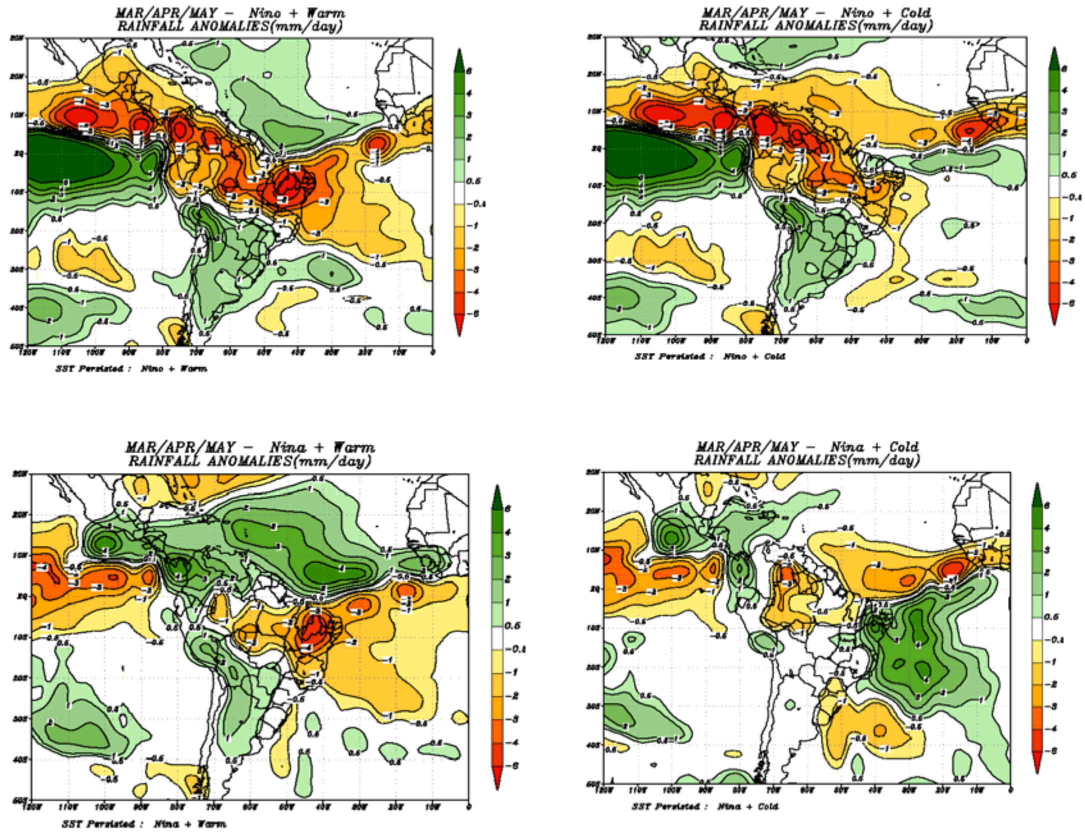
MAR/APR/MAY – Nino + Warm
RAINFALL ANOMALIES(mm/day)
SST Persisted : Nino + Warm
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SST Persisted : Nino + Cold
MAR/APR/MAY – Nina + Warm
RAINFALL ANOMALIES(mm/day)
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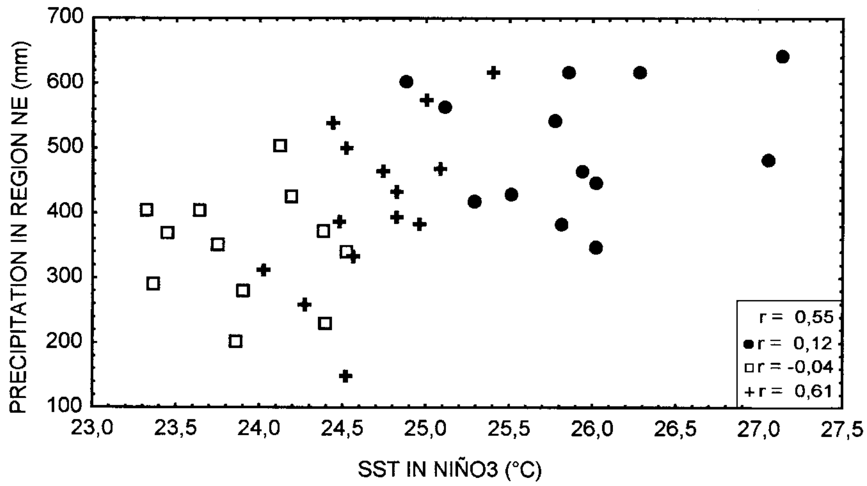
Figure 1 -

a)



b)

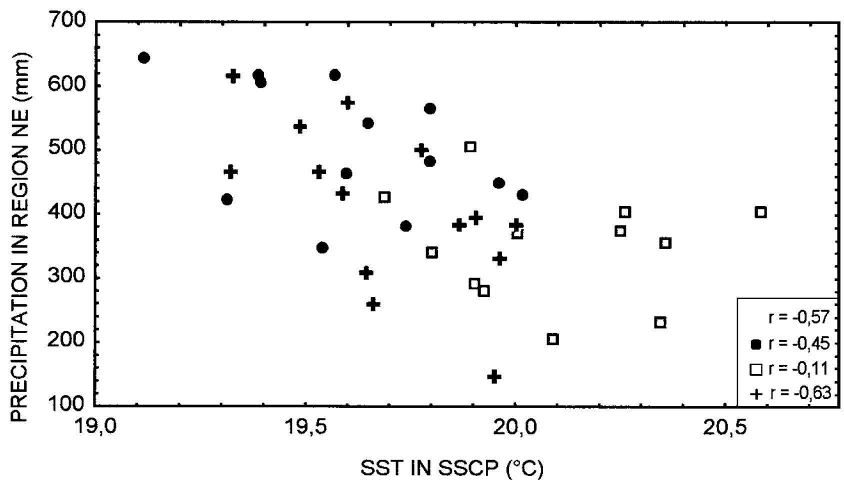


Figure 2 - Scatter diagram between October-November-December precipitation in northeastern Argentina and southern Brazil and SST in (a) El Niño 3 region and (b) the subtropical south-central Pacific (SSCP). El Niño (dots) , and La Niña (empty squares) events and neutral cases (crosses). Correlations for all cases, only El Niño cases (dots), La Niña cases (empty squares) and neutral cases (crosses) are indicated (From Barros and Silvestri 2002).

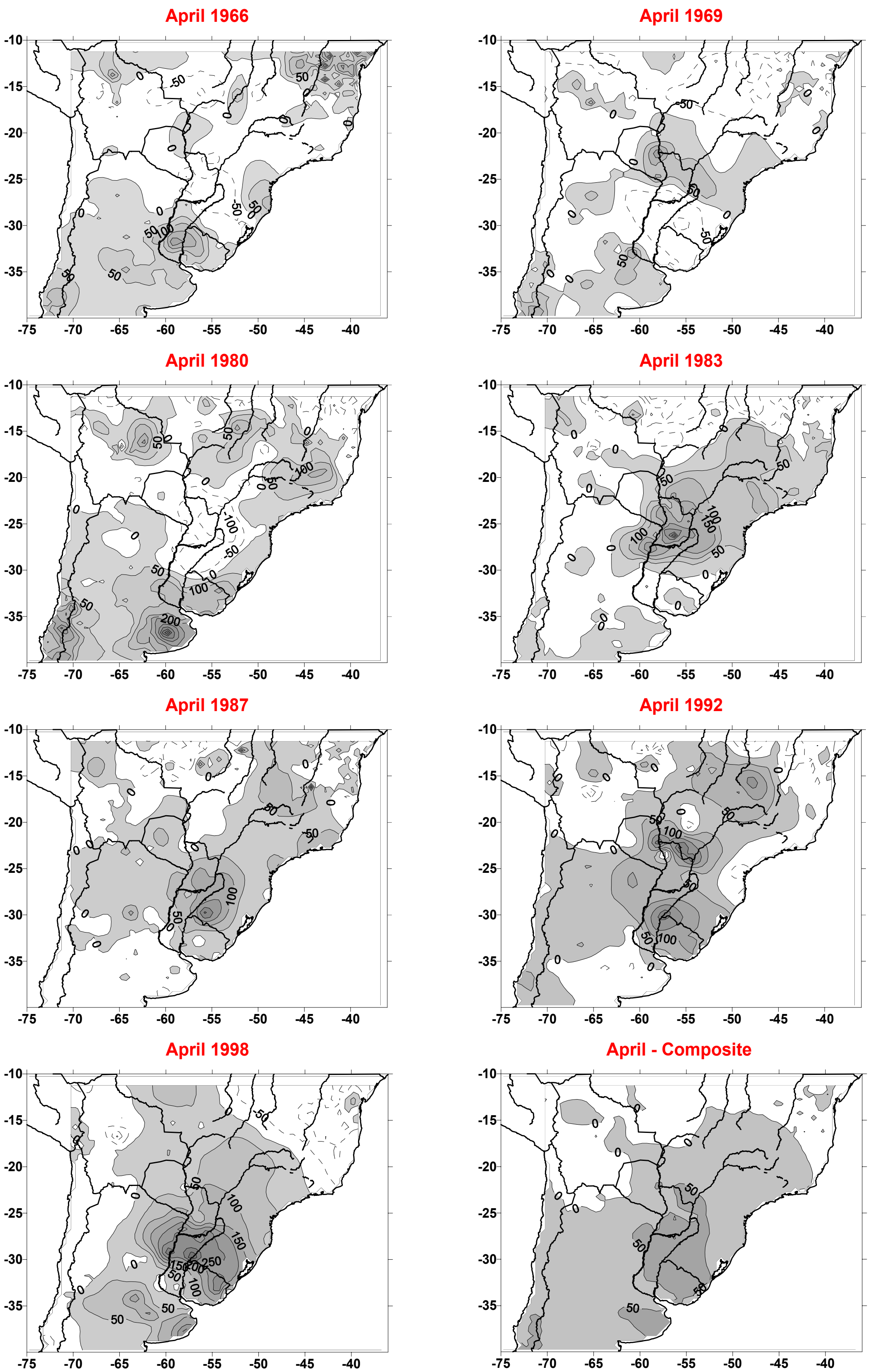

April 1966
April 1969
April 1980
April 1983
April 1987
April 1992
April 1998
April - Composite

Figure 3. Monthly rainfall anomalies for seven April (+) of El Niño events and their composition. (From Barros 2003).

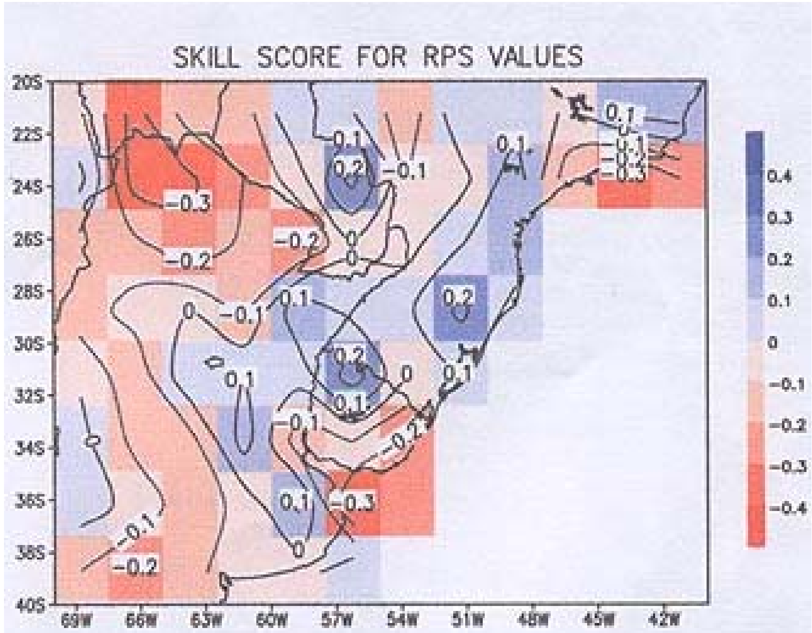


Figure 4. Ranked Probability Skill Scores (RPSS) for sixteen IRI´s seasonal precipitation forecasts for SESA between January 1998 and May 2002. (From Berri et al 2003).

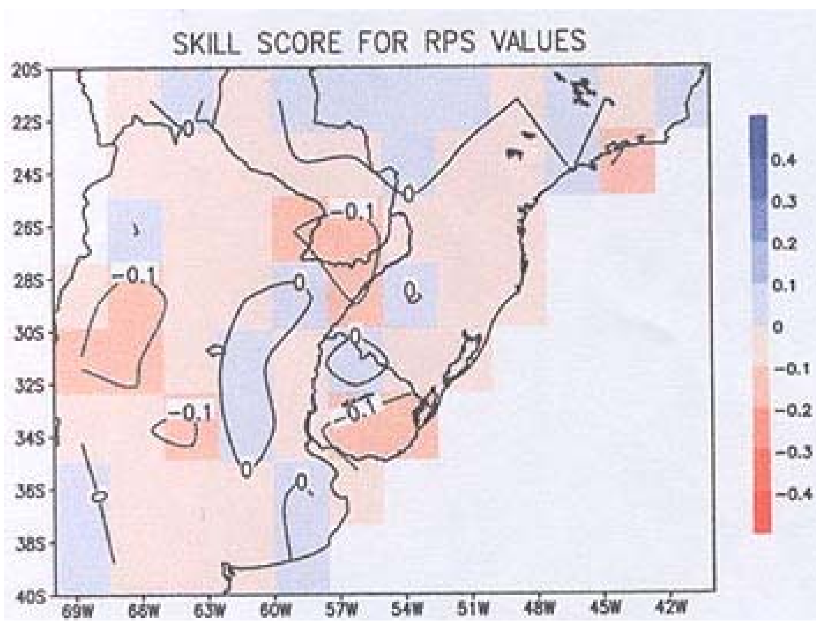


Figure 5. Ranked Probability Skill Scores (RPSS) for sixteen Climate Outlook Fora seasonal precipitation forecasts for SESA between January 1998 and May 2002. (From Berri et al 2003).