SKILL ASSESMENT OF AN INTEGRATED SEASONAL FORECASTING SYSTEM FOR SOUTH AMERICA

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RESUMO – Este trabalho avalia a destreza de um sistema objetivo integrado construído para a produção de previsões climáticas sazonais probabilísticas bem-calibradas para a América do Sul. O sistema é composto por dois componentes: a) um modelo empírico que utiliza a temperatura da superfície do mar dos oceanos Pacífico e Atlântico como preditores para chuva e b) um conjunto de três modelos dinâmicos acoplados. Previsões para o verão austral com um mês de defasagem produzidas por esses dois componentes foram integradas, ou seja, calibradas e combinadas, utilizando-se uma metodologia Bayesiana de assimilação de previsões. A destreza das previsões empíricas, do conjunto de modelos acoplados e das previsões integradas foi examinada e comparada. Assim como na maior parte do globo, a destreza das previsões sobre a América do Sul é baixa. Entretanto, quando as previsões empíricas e do conjunto de modelos foram combinada e calibrada utilizando-se a metodologia Bayesiana, obteve-se previsões integradas com melhor destreza do que ambas previsões empíricas e do conjunto de modelos. Tanto a confiabilidade quanto a resolução das previsões foi melhorada em várias regiões. A região tropical e o sudeste da América do Sul foram identificadas como as regiões mais previsíveis. Previsões de chuva com destreza razoável somente foram possíveis durante anos de El Niño e La Niña.

ABSTRACT – This study assesses the skill an objective integrated seasonal forecasting system designed for producing well-calibrated probabilistic rainfall forecasts for South America. This system has two components: a) an empirical model that uses Pacific and Atlantic sea surface temperature anomalies as predictor for rainfall; and b) a multi-model system composed of three coupled ocean-atmosphere models. One-month lead austral summer rainfall predictions produced by these two components are integrated (i.e. combined and calibrated) using a Bayesian forecast assimilation procedure. The skill of empirical, coupled multi-model and integrated forecasts is assessed and compared. The simple coupled multi-model ensemble has comparable level of skill to empirical forecasts. As for most regions of the globe, seasonal forecast skill for South America is low. However, when empirical and coupled multi-model predictions are combined and calibrated using forecast assimilation, more skillful integrated forecasts are obtained than with either empirical or coupled multi-model predictions alone. Both the reliability and resolution of the forecasts have been improved in several regions of South America. The tropics and the area of southeastern South America have been found to be the two most predictable regions. Skillful rainfall forecasts are generally only possible during El Niño or La Niña years rather than in neutral years.

Palavras-chave – Previsão climática sazonal, calibração e combinação de previsões

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Introduction

Good quality seasonal forecasts are fundamental for local governments to plan their actions to minimize human and economical losses that may be caused by anomalous climate events. In South America these forecasts are useful for civil defence, agriculture, fishery and water resources planning. Brazil, the largest and most populated country of South America, produces around 85% of its electricity with hydropower stations, which are administered by the government (http://www.ons.org.br). This emphasizes the need of good quality seasonal rainfall forecasts.

Seasonal forecast for South America are currently produced using both empirical (statistical) and physically-derived dynamical models (e.g. using a multi-model ensemble). Given the availability of these two modelling approaches it is natural to question the feasibility of producing a single forecast that combines all available forecast information. Dynamical forecasting models, however, show systematic errors (biases) that can be corrected via statistical calibration approaches (e.g. model output statistics) using past (historical) observation and hindcasts (retrospective forecasts produced after the event is observed). The ultimate aim of this study is to produce improved integrated (i.e. combined and calibrated) probability forecasts of seasonal rainfall for South America that incorporates all available forecast information. This study, therefore, introduces and assesses the skill of an objective integrated seasonal forecasting system for producing well-calibrated probabilistic rainfall forecasts for South America. This system has two components: a) an empirical model that uses Pacific and Atlantic sea surface temperature anomalies as predictor for rainfall; and b) a multi-model system composed of three coupled ocean-atmosphere models.

Data and Methods

The multi-model ensemble investigated here is composed of three coupled models (ECMWF, Météo-France and Met Office), and was produced as part of the DEMETER project (http://www.ecmwf.int/research/demeter). Each model provides 9 members to compose the 27 multi-model ensemble. One-month lead 1959-2001 rainfall predictions for December-January (DJF) are investigated. The empirical model uses the previous season August-September-October (ASO) ERA-40 (http://www.ecmwf.int/research/era) sea surface temperature anomalies of the Pacific and Atlantic as predictors for DJF rainfall anomalies for the entire South American continent. Coelho *et al.* 2006 provides the mathematical formulation of this empirical model. Multi-model ensemble predictions are obtained by pooling all 27 ensemble members. All results shown here were obtained using the cross-validation (leave one out) method (Wilks 1995).

Integrated forecasts are produced using a Bayesian methodology that allows the calibration and combination of coupled multi-model with empirical predictions. The Bayesian method (Bayes 1763) is a procedure for updating prior information when new information becomes available.

Coelho 2005, Coelho *et al.* (2004; 2006) and Stephenson et al. (2005) provide more detailed information about the Bayesian methodology, which is referred to as forecast assimilation.

Results and discussion

Figure 1 shows 1959-2001 correlation maps (Figs. 1a, 1e and 1i), Brier Skill Score (BSS) (Wilks, 1995) maps (Figs. 1b, 1f and 1j), as well as the reliability (Figs. 1c, 1g and 1k) and the resolution (Figs. 1d, 1h and 1l) components of the Brier Skill Score for rainfall anomaly predictions of empirical, coupled multi-model ensemble and integrated forecasts obtained with forecast assimilation. Correlation maps show the correlation between observed and predicted anomalies at each grid point. The BSS is for the event ‘rainfall anomaly less than or equal to zero’. The BSS represents the level of improvement of the Brier score (Brier, 1950) compared to the Brier score of the reference/climatological forecast (BSc). The climatological probability of the event ‘rainfall anomaly less than or equal to zero’ is about 50%, and the BSc is about 0.25. The BSS is designed to range from one for perfect predictions, through zero for predictions that provide no improvement over the reference forecast, to negative values for predictions that are worse than the reference forecast. The Guianas region in northern South America, is the most skillful with correlations between 0.6 and 0.8 and BSS between 0.1 and 0.6. The subtropics (southern Brazil, Paraguay, Uruguay and northern Argentina) also show some skill. Correlations between 0.2 and 0.5 are found in this region. These two regions are influenced by ENSO suggesting that most of the skill of South American rainfall predictions is ENSO derived.

Empirical, coupled multi-model ensemble and integrated predictions have similar correlation maps (Figs. 1a, 1e and 1i), indicating that these three approaches have comparable level of deterministic skill. The probabilistic measure of skill (Figs. 1b and 1f) shows that empirical predictions are more skillful than coupled multi-model ensemble predictions, particularly in the tropical region where empirical predictions have higher BSS. Integrated forecasts obtained with forecast assimilation (Fig. 1j) have higher BSS than uncalibrated coupled multi-model ensemble predictions (Fig. 1f). This indicates that the calibration provided by forecast assimilation improves the skill of the multi-model predictions. This increase in BSS is mainly due to improvements in the reliability of the predictions (Fig 1c, 1g and 1k), with the tropical regions also showing improvements in resolution (Fig 1d, 1h and 1l). Integrated predictions obtained with forecast assimilation (Fig. 1j) now have a level of probabilistic skill comparable to empirical predictions (Fig. 1b).

Figure 2 shows the mean anomaly correlation coefficient (ACC) (Jolliffe and Stephenson 2003), sometimes referred to as pattern correlation, for La Niña, neutral and El Niño years occurred during 1959-2001 (Table 1) and all years. The ACC of each year is given by the correlation between the observed and predicted spatial anomaly pattern over the South American domain. The geographic conformity is generally low (c.f. ACC less than 0.31). La Niña and El Niño years have

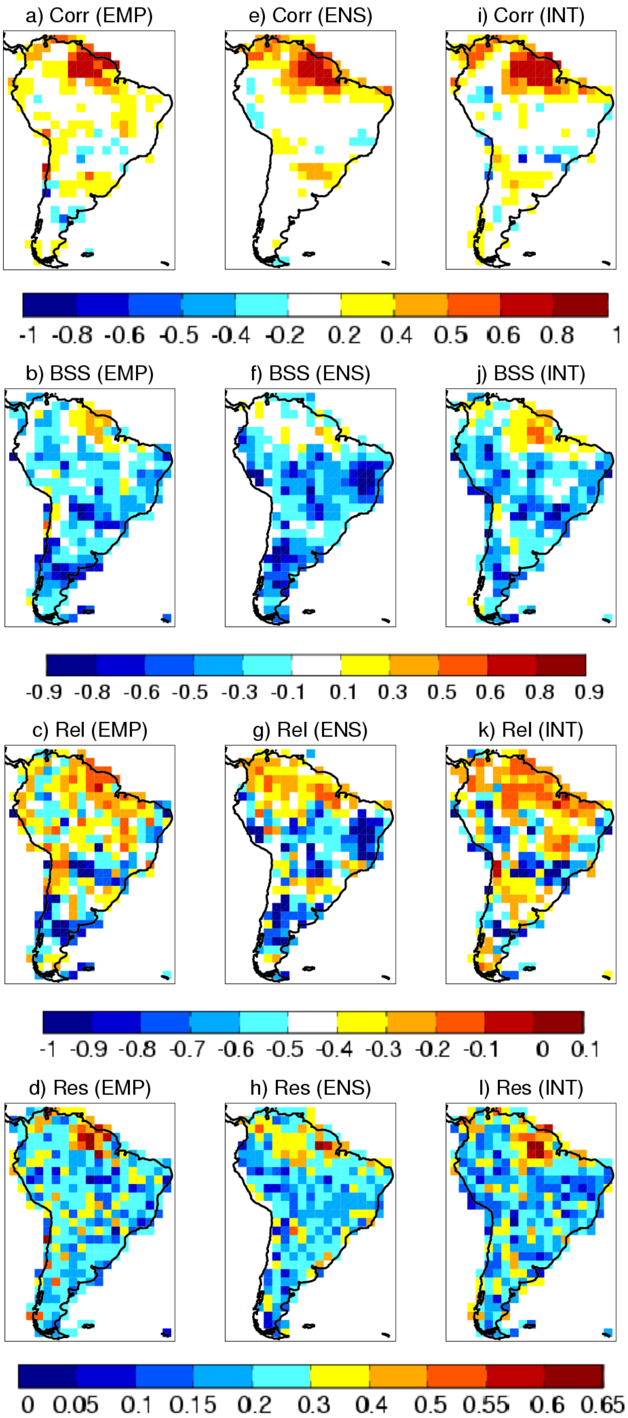

Figure 1. Maps of correlation (first row), BSS (second row) and its reliability (third row) and resolution (fourth row) components for empirical (EMP), coupled multi-model ensemble (ENS), and integrated (INT) forecasts. The BSS is for the event 'rainfall anomaly less than or equal to zero'. The reliability component of the BSS is given by *–Rel/BSc* and the resolution component of the BSS is given by *Res/BSc*, where *BSc* is the Brier Score (Brier, 1950) of the climatological forecast, and *Rel* and *Res* are the reliability and resolution components of the Brier Score shown in panels c, g, and k and d, h and l, respectively.

higher mean ACCs than neutral years, indicating that predictions for ENSO years are more geographically consistent than predictions for neutral years. El Niño and La Niña integrated forecasts obtained with forecast assimilation show an increase in the mean ACC compared to the uncalibrated coupled multi-model ensemble predictions. The mean ACC of El Niño and La Niña integrated forecasts are now comparable to the mean ACC of empirical predictions. Neutral years have nearly null mean ACC, indicating that rainfall anomalies of these years are virtually unpredictable. Figure 2 shows that empirical and integrated forecasts have comparable ACCs when all years (1959-2001) are examined.

Table 1. La Niña, neutral and El Niño years occurred during 1959-2001 as defined by the Climate Prediction Center (http://www.cpc.noaa.gov).

	Years
La Niña	1964/65, 1970/71, 1971/72, 1973/74, 1974/75, 1975/76, 1983/84, 1984/85, 1988/89, 1995/96, 1998/99, 1999/00, 2000/01
Neutral	1959/60, 1960/61, 1961/62, 1962/63, 1966/67, 1967/68, 1978/79, 1980/81, 1981/82, 1985/86, 1989/90, 1993/94, 1996/97, 2001/02
El Niño	1963/64, 1965/66, 1968/69, 1969/70, 1972/73, 1976/77, 1977/78, 1979/80, 1982/83, 1986/87, 1987/88, 1990/91, 1991/92, 1992/93, 1994/95, 1997/98

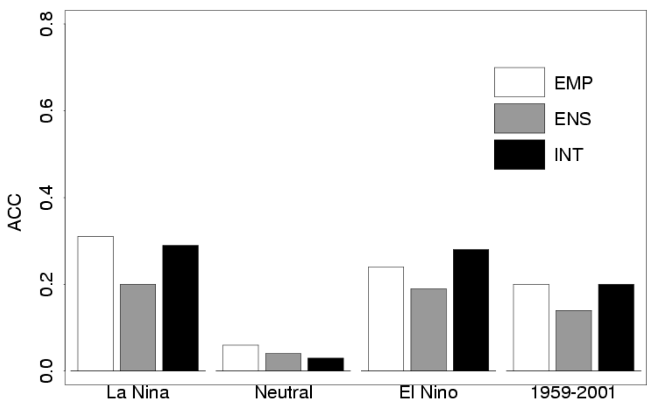

Figure 2. Mean DJF anomaly correlation coefficient (ACC) for empirical (EMP), coupled multi-model ensemble (ENS) and integrated (INT) forecasts of La Nina, neutral, El Nino years (listed in Table 1) and all 1959-2001 years.

Conclusions

This study assessed seasonal predictability of South American summer rainfall by introducing an integrated seasonal forecasting system composed by an empirical model and a coupled multi-model ensemble. The skill of empirical, a coupled multi-model ensemble and integrated forecasts obtained with forecast assimilation has been compared. This comparison revealed that when seasonally forecasting DJF South American rainfall at 1-month lead-time the current generation of coupled models have comparable level of deterministic skill to those obtained using a simplified empirical approach, as illustrated by the correlation maps of Figure 1.

Bayesian forecast assimilation has been shown to be a powerful tool for the calibration and combination of multi-model ensemble and empirical predictions. Integrated predictions obtained with forecast assimilation have been shown to have improved BSS compared to the simple multi-model prediction. This is because forecast assimilation provides better estimates of forecast uncertainty than coupled multi-model. In addition to incorporating well-calibrated empirical predictions, the forecast assimilation procedure used to generate integrated forecasts also corrects biases in the coupled models predictions and shifts multi-model ensemble prediction patterns towards the observed patterns. The tropics and the area of south Brazil, Paraguay, Uruguay and northern Argentina have been found to be the two most predictable regions of South America. South American rainfall is generally only predictable in ENSO years rather than in neutral years, which exhibit very little skill.

This integrated system here introduced will be implemented operationally at the Centre for Weather Prediction and Climate Studies (CPTEC) as part of the EUROBRISA project (A EURO-BRazilian Initiative for improving South American seasonal forecasts, http://www.cptec.inpe.br/~caio/EUROBRISA/index.html) using real-time forecasts.

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References

Bayes, T., 1763: An essay towards solving a problem in the doctrine of chances. Philosophical Transcations of the Royal Society of London, 53, 370-418.

Brier,G.W., 1950:Verification of forecasts expressed in terms of probability.Mon.Wea.Rev.,78, 1-3.

Coelho, C. A. S., 2005: Forecast calibratoin and combination: Bayesian assimilation of seasonal climate predictions. PhD thesis. University of Reading, 178pp.

Coelho, C. A. S., D. B. Stephenson, M.Balmaseda, F. J. Doblas-Reyes and G. J. van Oldenborgh, 2006: Towards an integrated seasonal forecasting system for South America. J.Climate. **19**, 3704-3721.

Coelho, C.A.S., Pezzulli, S., Balmaseda, M., Doblas-Reyes, F.J. and Stephenson, D.B.: Forecast calibration and combination:A simple Bayesian approach for ENSO.J.Climate.,**17**,1504-1516, 2004.

Jolliffe, I. N. and Stephenson, D. B.: Forecast verification: A practitioner’s guide in atmospheric science. Wiley and Sons, First edition. 240pp, 2003.

Stephenson, D.B., Coelho, C.A.S., Doblas-Reyes, F.J. and Balmaseda, M.:Forecast Assimilation:A unified framework for the combination of multi-model weather and climate predictions.Tellus, 57, 253-264, 2005.

Wilks, D. S.: Statistical methods in atmospheric sciences: An introduction. 1st Edition. Academic Press. 467pp, 1995.