A NEW HYBRID PRECIPITATION SEASONAL FORECASTING SYSTEM FOR SOUTH AMERICA

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RESUMO: UMA NOVO SISTEMA HÍBRIDO DE PREVISÃO SAZONAL DE PRECIPITAÇÃO PARA A AMÉRICA DO SUL

Desde Setembro de 2007 o Centro de Previsão de Tempo e Estudos Climáticos (CPTEC) dissemina previsões sazonais empírico-dinâmicas (híbridas) de precipitação para a América do Sul no contexto do EUROBRISA (Uma Iniciativa Euro-Brasileira para a melhoria das previsões sazonais para a América do Sul). A primeira versão desse sistema operacional de previsões híbridas, a primeira desse tipo a ser implementada na América do Sul, foi composta por três modelos; um modelo empírico que utiliza temperatura da superfície do mar observada sobre os oceanos Pacífico e Atlântico como variável preditora para precipitação, e dois modelos dinâmicos acoplados: as versões operacionais do Centro Europeu para Previsões de Tempo de Médio Prazo (ECMWF) e do Serviço Meteorológico do Reino Unido (UKMO). Em dezembro de 2009 uma nova versão do sistema de previsões híbridas do EUROBRISA foi implementada, sendo esse novo sistema composto por cinco modelos: o modelo empírico da primeira versão do EUROBRISA, os modelos dinâmicos acoplados do ECMWF, CPTEC e Meteo-France, e a nova versão do modelo acoplado do UKMO (conhecido como GloSea 4). Para a calibração e combinação das previsões do modelo empírico com as previsões dos modelos dinâmicos acoplados para produzir previsões integradas (híbridas) aplica-se uma metodologia Bayesiana denominada assimilação de previsões. Este estudo ilustra como previsões sazonais de precipitação empíricas (estatísticas) e de modelos dinâmicos acoplados vem atualmente sendo integradas (ou seja, combinadas e calibradas) para produzir previsões híbridas para a América do Sul. A destreza das previsões para o verão (Dezembro-Janeiro-Fevereiro) desde 1981 até 2005 produzidas em Novembro (ou seja, com um mês de antecedência) é avaliada e discutida. Finalmente apresenta-se a previsão operacional em tempo real para o verão 2009/2010 produzida por esse novo sistema em Novembro de 2009.

ABSTRACT: Since September 2007 empirical-dynamical (hybrid) precipitation seasonal forecasts for South America are issued by the Centre for Weather Forecasts and Climate Studies (CPTEC) as part of EUROBRISA: A EURO-BRazilian Initiative for improving South American seasonal forecasts. The first version of such a hybrid operational forecasting system, the first of this kind to be implemented in South America, was composed by three models; an empirical model that uses Pacific and Atlantic sea surface temperature as predictor variable for precipitation, and two coupled dynamical models: the operational versions of the European Centre for Medium-Range Weather Forecasts (ECMWF) and the United Kingdom Met Office (UKMO). In December 2009 a new version of the EUROBRISA hybrid forecasting system was implemented, and the system is now composed by five models: the empirical model of the previous system, ECMWF, CPTEC and Meteo-France coupled dynamical models and the new version of UKMO coupled seasonal forecasting system (known as GloSea 4). A Bayesian approach knows as forecast assimilation is used to combine and calibrate empirical and dynamical coupled model forecasts and produce the so-called integrated (hybrid) forecast. This study illustrates how empirical (statistical) and dynamical coupled model precipitation seasonal forecasts are currently being integrated (i.e. combined and calibrated) to produce hybrid forecasts for South America. The skill of one month lead 1981-2005 austral summer (December-January-February) forecasts is asseesed and discussed. To illustrate an operational real time forecast, the most recent austral summer 2009/2010 forecast issued by this system in early November 2009 is presented.

Key-words: Seasonal forecasts, South America precipitation, empirical and coupled model dynamical forecasts, Bayesian forecast assimilation, forecast calibration, combination and verification.

1. INTRODUCTION

Empirical-dynamical (i.e. hybrid) precipitation seasonal forecasts for South America are issued since September 2007 by the Centre for Weather Forecasts and Climate Studies (CPTEC) as part of EUROBRISA: A EURO-BRazilian Initiative for improving South American seasonal forecasts – a multi-institutional cooperation initiative between Brazilian and European institutions. The following institution are part of this initiative: CPTEC, the European Centre for Medium-Range Weather Forecasts (ECMWF), the United Kingdom Met Office (UKMO), Meteo-France, the Brazilian National Institute of Meteorology (INMET), the University of São Paulo (USP), Federal University of Paraná (UFPR), the Paraná State Meteorological Institute of Technology (SIMEPAR) and the University of Exeter. The first version of such a hybrid operational forecasting system, the first of this kind to be implemented in South America, was composed by three models; an empirical model that uses Pacific and Atlantic sea surface temperature as predictor variable for precipitation, and two coupled dynamical models: the operational versions of ECMWF and UKMO seasonal forecasting systems. In December 2009 a new version of the EUROBRISA hybrid forecasting system was implemented at CPTEC, and the system is now composed by five models: the empirical model of the previous system, ECMWF, CPTEC and Meteo-France coupled dynamical models and the new version of UKMO coupled seasonal forecasting system (known as GloSea 4). This study illustrates how empirical (statistical) and dynamical coupled model precipitation seasonal forecasts are currently being integrated (i.e. combined and calibrated) to produce hybrid forecasts for South America wih this new multi-model system composed by one empirical model and four dynamical coupled models. The skill of one month lead 1981-2005 austral summer (December-January-February, DJF) forecasts is asseesed and discussed. To illustrate an operational real time forecast the most recent austral summer 2009/2010 forecast produced by this system is presented.

2. METHODOLOGY

One of the simplest empirical approaches to produce one-month lead austral summer (December-January-February) South America precipitation forecasts use as predictor variable Pacific and Atlantic sea surface temperatures observed in the previous October. This multivariate regression model (Coelho *et al.* 2006) is used here to produce empirical precipitation forecasts for South America.

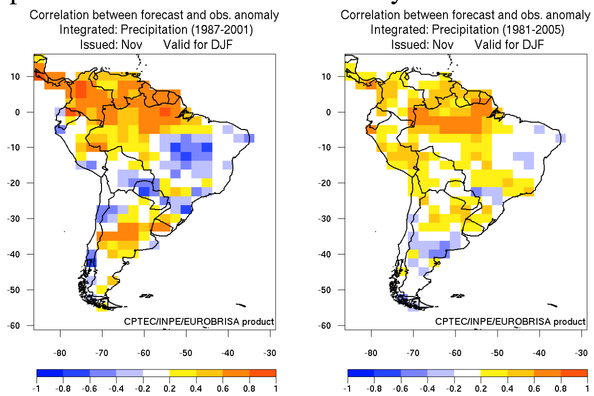
The dynamical systems used in this study to produce one-month lead summer (December-January-February) precipitation forecasts are the coupled ocean-atmosphere seasonal prediction models of ECMWF (Anderson *et al.* 2007), known as System 3, the UK Met Office (UKMO, known as GloSea 4, which is an improved version of the previous UKMO model (Graham *et al.* 2005), Méteo-France which is an improved version of the previous Méteo-France model (Gueremy et al. 2005) and CPTEC (Nobre et al. 2009). The forecast output from ECMWF, UKMO and Méteo-France models is coordinated at ECMWF as part of the European Seasonal to Inter-annual Prediction project (EUROSIP).

To produce empirical-dynamical (i.e. hybrid) multi-model integrated probabilistic forecasts, a Bayesian procedure, known as forecast assimilation (Stephenson *et al.* 2005), is applied. This procedure allows the spatial calibration and combination of forecasts produced by each individual model. In the first version of the EUROBRISA hybrid system implemented in 2007, only precipitation forecasts over South America (30^{o}W, 90^{o}W, 60^{o}S, 15 ^{o}N) were used in the forecast assimilation (calibration and combination) procedure. In the new version of the EURORISA hybrid system implemented in 2009, the forecast assimilation procedure uses dynamical coupled model precipitation forecasts over the Pacific and South America (30^{o}W, 100^{o}E, 60^{o}S, 15 ^{o}N). The reason for using forecasts over the ocean in addition to forecasts over South America is based on the fact that coupled models generally produce forecasts in better agreement with the observations over the oceans compared to forecasts over land. There is therefore scope for improving forecast quality over land by spatially calibrating the forecasts produced by coupled models taking advantage of forecast information over the ocean. The skill of empirical, ECMWF, UKMO, Meteo-France, CPTEC is assessed and compared over the common hindcasts period 1987-2001. The skill of integrated forecasts obtained with forecast assimilation is assessed over the hindcasts period 1981-2005 because the new implementation of the forecast assimilation procedure allows the calibration and combination of forecasts produced by different models with distinct hindcast periods. All results were obtained using the cross-validation leave-one-year-out method (Wilks 1995). Forecast verification is performed using the version 2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (Adler *et al.* 2003).

3. RESULTS AND DISCUSSION

Figure 1 shows correlation maps of hybrid (integrated) precipitation anomaly forecasts for the first version of the EUROBRISA system for the period 1987–2001 (panel a) and for the new version of the EUROBRISA system for the period 1981–2005 (panel b). Correlation maps show the correlation between observed and mean forecast anomalies at each grid point. The first version (Fig. 1a) shows positive correlation over tropical and southeast South America, indicating good association between forecast and observed anomalies. However, a large area of negative correlation is noticeble over parts of central South America. The new version (Fig.1b) that combines and calibrates forecasts from five models (one empirical and four dynamical coupled models) using forecast information over the extended Pacific and South

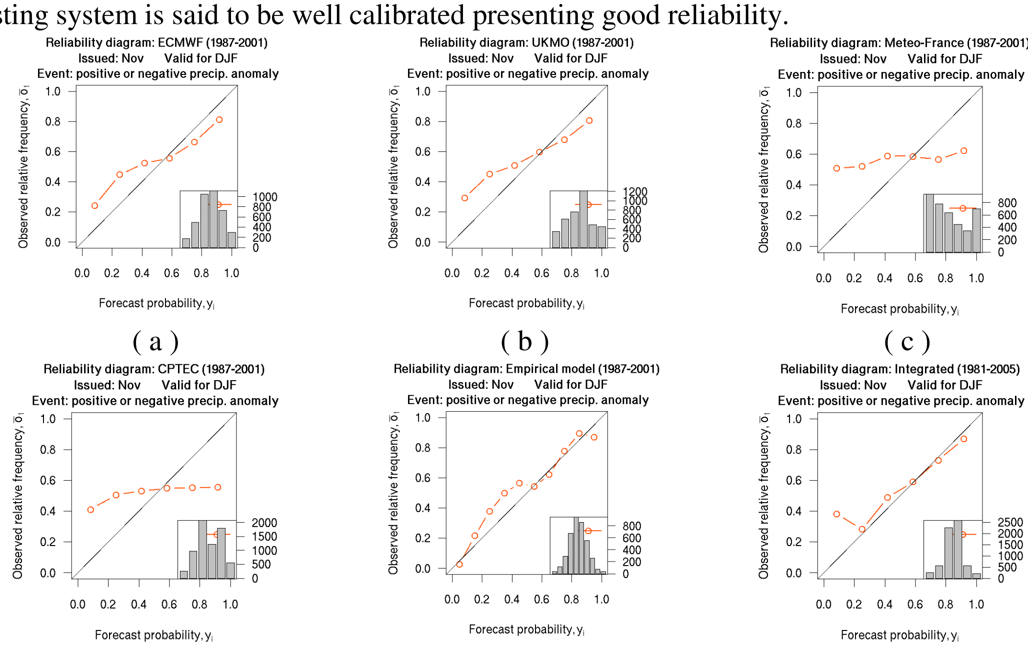
American domain shows a much reduced area of negative correlation over South America. Some areas in central and southeast Brazil now show positive correlation indicating that the new hybrid system produced improved skill over these regions. However, over parts of central Argentina the new hybrid system presents poorer skill when compared to the first version of the system.



(a) (b)

Figure 1: Correlation maps of one month lead December-January-February precipitation forecasts for the first version of the EUROBRISA hybrid system implemented in 2007 (panel a) for the period 1987–2001 and for the new version of the EUROBRISA hybrid system implemented in 2009 (panel b) for the period 1981–2005.

A desirable property of a good probabilistic seasonal forecasting system is *forecats reliability* − a measure of how well calibrated are the forecast probabilities produced by the forecasting system. Forecast reliability can be assessed using the so-called reliability diagram, which is a graph of forecast probabilities against observed relative frequencies of the event being forecast. A well calibrated forecasting system must have its forecast probabilities closely matching the observed relative frequency of the event being forecast. In other words, in a sample of N forecast probabilities for a particular event (for example, occurrence of positive or negative precipitation anomaly), each forecast probability for this event must match the observed frequency n/N, where n is the number of occasions when the event of interest was observed. For example, for a forecast probability of 70% for the event occurence of positive or negative precipitation anomaly, one should observe the occurence of this event in 70% out of the total number N of events forecast. If such correspondence between forecast probabilities and observed frequencies is noted for all forecast probabilities the forecasting system is said to be well calibrated presenting good reliability.



(a) (b) (c)

(d) (e) (f)

Figure 2: Reliability diagrams of one month lead December-January-February precipitation forecasts for the event negative or positive anomaly for ECMWF, UKMO, Meteo-France, CPTEC, empirical and the new version of the EUROBRISA hybrid integrated system.

Figure 2 shows reliability diagrams for the event positive or negative precipitation anomaly for all South America land grid points for the five individual forecasts (Figs. 2a-e) and for the new version of the EUROBRISA hybrid integrated forecasting system (Fig. 2f). Perfectly reliable forecasts should have a reliability diagram represented by a diagonal (45^{o}) line. The reliability diagrams for ECMWF, UKMO, Meteo-France and CPTEC (Figs. 2a-d) show a typical signature of overconfident forecasting systems, with high probabilities being forecast more frequently than observed and low probabilities being forecast less frequently than observed. Empirical and integrated forecasts (Figs. 2e-f) show a signature of well calibrated forecasts with good reliability, which can be noted by the superposition of the red curve and the diagonal black line. The histograms on the bottom right corner of each reliability diagram show the frequencies of each forecast probability. Figure 2 shows that these histograms peak close to the climatological frequency of the event being forecasts (i.e. 50% for the event positive or negative precipitation anomaly). Empirical and integrated forecasts have better reliability than ECMWF, UKMO, Meteo-France and CPTEC forecasts because their forecasts probability density functions are better calibrated. These four models have overconfident (narrower) forecast probability density functions when compared to empirical and integrated forecast probability density functions.

Figure 3 shows one-month lead forecast probabilities for the most likely precipitation tercile for DJF 2009/2010. These forecasts were issued in early November 2009 when a well defined El Niño event was configured in the equatorial Pacific. Consistently with typical El Niño conditions, some of the individual models (e.g. ECMWF and UKMO, Figs. 3a-b) and integrated forecasts produced with the new hybrid system (Fig. 3f) indicate the lower tercile as most likely (i.e. high probabilities for below average precipitation) in northern South American and the upper tercile as most likely (i.e. high probabilities for above average precipitation) in southeastern South America. Examining the forecasts of Fig. 3f and the verification maps of Fig. 1b, which indicates the regions where the hybrid (integrated) forecasts have better quality, more confidence can be attributed for the forecast of below average conditions in northern South America and above avegare conditions in parts of southern Brasil, Uruguay, Paraguay and northeastern Argentina. Figure 3g shows the observed precipitation anomaly in DJF 2009/2010, which is in accordance with the indication of the hybrid (integrated) forecast (Fig. 3f) over northern and southeatern South America, and also over part of northeast Brazil.

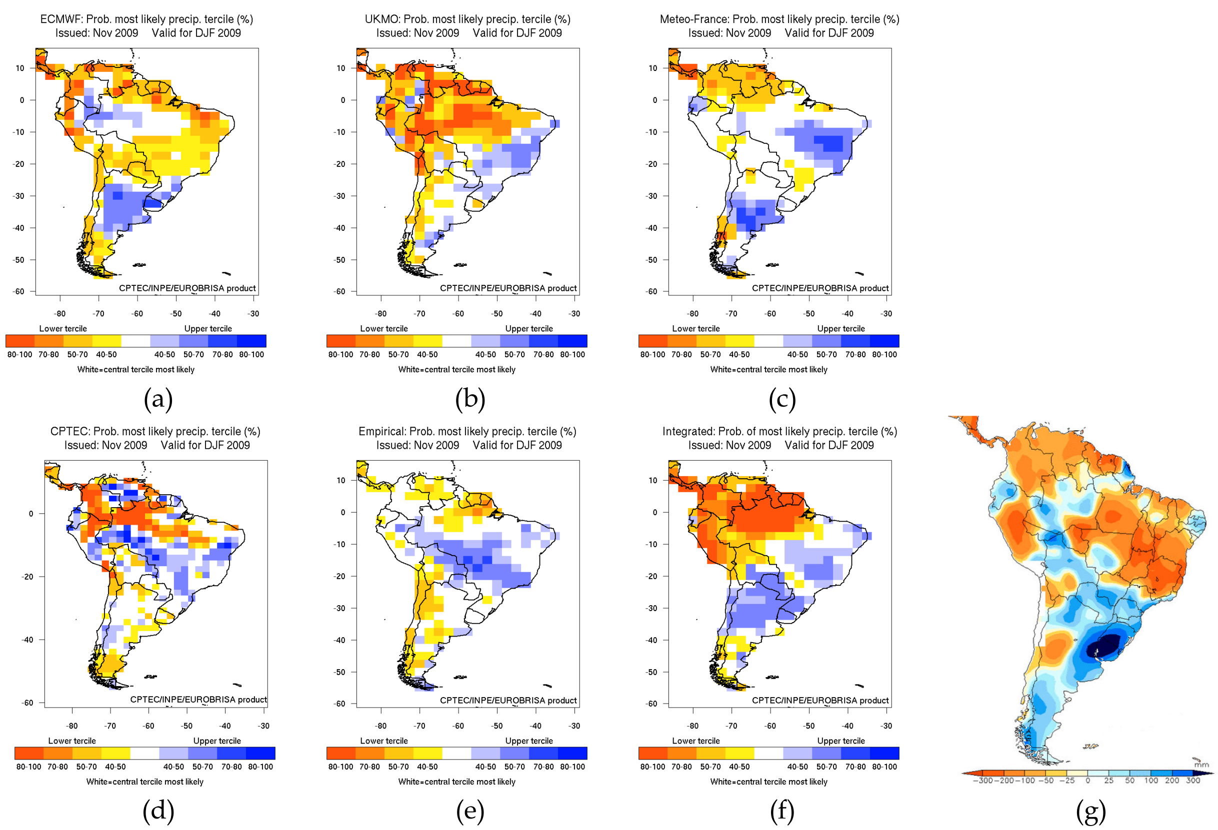


Figure 3: One-month lead DJF 2009/2010 real time ECMWF, UKMO, Meteo-France, CPTEC, empirical and integrated most likely precipitation tercile forecast (panels a-f). Observed precipitation anomaly (mm) in DJF 2009/2010 (panel g).

4. CONCLUSIONS

This study has illustrated how empirical and dynamical coupled model precipitation seasonal forecasts are currently been combined and calibrated in EUROBRISA to produce hybrid (integrated) forecasts for South America with a new multi-model system composed by five models (one empirical and four dynamical coupled models). This new system has been shown to present improve skill in parts of South America when compared to the first system composed by 3 models (one empirical and two dynamical coupled models) implemented in 2007. Skill improvement is likely due to:

a) inclusion of two additional coupled models (CPTEC and Meteo-France);
b) update of UKMO coupled model to a new improved version; and
c) use of forecast information over the Pacific ocean in addition to forecasts over South America in the forecast assimilation (calibration and combination) procedure.

The performance of the new EUROBRISA hybrid forecasting system in forecasting austral summer precipitation during DJF 2009/2010 has been evaluated subjectively and indicates reasonably good agreement between the forecast and observed precipitation signal over the regions where this system has historically moderate to good skill.

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5. REFERENCES

ADLER, R.F.; HUFFMAN, G.J.; CHANG, A.; FERRARO. R.; XIE, P.; JANOWIAK, J.; RUDOLF. B.; SCHNEIDER, U.; CURTIS, S.; BOLVIN, D.; GRUBER, A.; SUSSKIND, J.; ARKIN, P. The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). J. Hydrometeor., 4, 1147-1167, 2003.

ANDERSON, D.; STOCKDALE. T.; BALMASEDA, M.; FERRANTI, L.; VITART, F.; MOLTENI, F.; DOBLAS-REYES, F. J.; MOGENSEN, K.; VIDARD, A. Development of the ECMWF seasonal forecast System 3. ECMWF Technical Memorandum, 503, 2007, 56p.
Available from http://www.ecmwf.int/publications/library/do/references/show?id=87744

COELHO, C.A.S.; STEPHENSON, D. B.; BALMASEDA, M.; DOBLAS-REYES, F. J.; OLDENBORGH, G. J. VAN. Towards an integrated seasonal forecasting system for South America. J. Climate, 19, 3704-3721, 2006.

GUEREMY, J-F.; DEQUE., M.; BRAU, A.; PIEDELIEVRE, J-P. Actual and potential skill of seasonal predictions using the CNRM contribution to DEMETER: coupled versus uncoupled model. Tellus, 57A, 308–319, 2005.

GRAHAM, R.J.; GORDON, M.; MCLEAN, P. J.; INESON, S.; HUDDLESTON, M. R.; DAVEY, M. K.; BROOKSHAW, A.; BARNES, R.T.H. A performance comparison of coupled and uncoupled versions of the Met Office seasonal prediction General Circulation Model. Tellus, 57A, 320-339, 2005.

NOBRE, P.; MALAGUTTI, M.; URBANO, D. F.; ALMEIDA, R. A. F.; GIAROLLA, E. Amazon deforestation and climate change in a coupled model simulation. Journal of Climate, v. 22, p. 5686-5697, 2009.

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