# HYBRID PRECIPITATION SEASONAL FORECASTS FOR SOUTH AMERICA

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## 1. INTRODUCTION

Seasonal climate forecasts are forecasts of the expected climatic conditions in the forthcoming 3-6 months. Improvement in seasonal climate forecasts is a key issue for helping countries reduce losses due to weather and climate risks. In South America, seasonal climate forecasts already benefit governmental decision-making in several key areas such as energy production, agriculture, and water resources planning to minimize human and economical losses caused by extreme climate events (e.g. droughts and excessive rainy periods). For example, seasonal forecasts of precipitation are used for decision-making in hydropower electricity production in South America. Hydropower accounts for the major source of electricity production in several South American countries: 60% in Bolivia, Brazil, Colombia, Paraguay and Uruguay; and 40% in Argentina, Chile, Ecuador, Peru and Suriname. Improved seasonal precipitation forecasts can help South American governments to better manage these carbon-friendly electricity production programs – a strategic element in the reduction of global greenhouse gas emissions. In addition, the economies of South American countries also depend heavily on agriculture, an activity which can also benefit from higher quality seasonal climate forecasts. Improved seasonal climate forecasts can thereby clearly benefit the 370 million people who live in South America.

South America seasonal climate forecasts are currently produced using empirical (statistical) and dynamical (physical) models. Given the availability of these two modeling approaches one might question the feasibility of producing a single (hybrid) and well calibrated integrated forecast that gather all available information at the time the forecast is issued. This study illustrates how empirical and dynamical coupled model precipitation seasonal forecasts for South America are currently being integrated (i.e. combined and calibrated) to produce hybrid forecasts at the Centre for Weather Forecasts and Climate Studies (CPTEC). Such a hybrid operational forecasting system, the first to be implemented in South America, has been developed by EUROBRISA (A EURO-BRazilian Initiative for improving South American seasonal forecasts, http://eurobrisa.cptec.inpe.br)* – a multi-institutional cooperation initiative between CPTEC, the European Centre for Medium-Range Weather Forecasts (ECMWF), the United Kingdom Met Office (UKMO), Météo-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 skill of one month lead austral winter (June-July-August or JJA) forecasts is assessed and discussed. To illustrate an operational real time forecast the most recent austral winter forecast for JJA 2008 produced by this system is presented.

## 2. METHODOLOGY

One of the simplest empirical approaches to produce one-month lead austral winter (June-July-August) South America precipitation forecasts use as predictor variable Pacific and Atlantic sea surface temperatures observed in the previous May. 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 precipitation forecasts for winter (June-July-August) are the coupled ocean-atmosphere seasonal prediction models of ECMWF (Anderson *et al.* 2007), known as System 3, and the UK Met Office (UKMO; Graham *et al.* 2005), known as GloSea. The forecast output from these 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 we apply a Bayesian procedure, known as forecast assimilation (Stephenson *et al.* 2005). This procedure allows the spatial calibration and combination of forecasts produced by each individual model. The skill of empirical, ECMWF, UKMO and integrated forecasts obtained with forecast assimilation is assessed and compared over the common hindcasts period 1987-2001. All results were obtained using the cross-validation 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 1a-d shows correlation maps of ECMWF, UKMO, empirical and integrated precipitation anomaly forecasts for the period 1987–2001. Correlation maps show the correlation between observed and mean forecast anomalies at each grid point. Both ECMWF and UKMO forecasts are bias corrected because we are dealing with ensemble mean forecast anomalies with respect to each model climatology. The three individual models show high skill with correlation coefficient generally between 0.4 and 0.8 in tropical South America. ECMWF, UKMO

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and empirical forecasts are also skilful over the south of Brazil, Uruguay and southeast Argentina with correlation coefficient between 0.2 and 0.8. When the forecasts of the three individual models was combined and calibrated to produce integrated forecasts, improved skill was obtained over tropical and southeast South America (Fig. 1d).

Correlation is a deterministic measure of skill that indicates how well associated is the forecast with the corresponding observed anomaly. Correlation, however, only assesses the mean forecast value. In order to assess how well estimated is forecast uncertainty one needs for example to examine scores that evaluate the skill of probabilistic forecasts. Here we examine relative operating characteristic (ROC) skill score maps for the event positive or negative precipitation anomaly (Figs 1e-h). ROC measures the ability of the forecasting system in detecting a particular event. In other words, it measures the ability of the forecasting system in discriminating between different forecast probabilities for a particular event that is being forecast. This ability is known in the forecast verification literature as *forecast resolution*. The ROC skill score is defined as ROCSS = 2A – 1, where A is the area under the ROC curve for forecast probabilities of the event positive or negative precipitation anomaly. A comprehensive review about ROC and other forecast verification scores is found in the book by Jolliffe and Stephenson (2003). No skill forecasts have area A under the ROC curve equals to 0.5 (i.e. null ROCSS). Large positive values of ROCSS indicate increasing ability of the forecasting system in forecasting different forecast probabilities for the event that is being forecast (i.e. increased forecast resolution). Conversely, large negative values of ROCSS indicate increasing inability of the forecasting system in forecasting different forecast probabilities for the event that is being forecast (i.e. poor forecast resolution). In accordance with the correlation map (Fig 1d), integrated forecasts (Fig 1h) have improved (higher) skill in tropical and southeast South America when compared to the three individual forecasts (Figs. 1e-g). This result indicates that not only the estimate of the mean forecast value is improved by calibration and combination of empirical and coupled model forecasts. Uncertainty estimates are also improved by calibration and combination.

Another desirable property of a good probabilistic seasonal forecasting system is *forecast 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 75% for the event occurrence of positive or negative precipitation anomaly, one should observe the occurrence of this event in 75% 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.

Figure 2 shows reliability diagrams for the event positive or negative precipitation anomaly for all South America land grid points for the three individual forecasts (Figs. 2a-c) and integrated forecasts (Fig. 2d) over the period 1987-2001. Perfectly reliable forecasts should have a reliability diagram represented by a diagonal ($45^o$) line. The reliability diagrams for ECMWF and UKMO (Figs. 2a-b) 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. 2c-d) show a signature of well calibrated forecasts with good reliability, which can be noted by the better match between 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 and UKMO forecasts because their forecasts probability density functions are better calibrated. ECMWF and UKMO have overconfident (narrower) forecast probability density functions when compared to empirical and integrated forecast probability density functions.

Figure 3a shows the real-time probability forecast for JJA 2008 for the event negative or positive anomaly issued by the hybrid (integrated) system in May 2008. When issuing a seasonal forecast, it is always good practice to examine and compare the forecast with skill maps to identify regions where the forecasting system has good past performance. Over those regions the real-time forecast is most likely to be successful. The skill maps of Figs. 1d and 1h reveal that integrated forecasts show good skill over northern South America (including northern Brazil) and the central east region of Argentina. Over these regions where integrated forecasts show good past performance Fig. 3a shows a forecast of high probability (above 60%) of above average precipitation in northern Brazil and low probability (between 20 and 40%) of above average precipitation (i.e. high probability of below average precipitation) in central east Argentina. Figure 3b show the observed binary category in JJA 2008. Regions where precipitation was observed to fall in the category below average (i.e. below the long term 1987-2005 climatological mean) are shown in red. Regions where precipitation was observed to fall in the category above average are shown in blue. The comparison of Figs. 1d, 1h, 3a and 3b reveals a generally good agreement between the forecast probability and the observed binary event (above or below average precipitation).

## 4. CONCLUSIONS

This study has illustrated how empirical and dynamical coupled model precipitation seasonal forecasts are currently combined and calibrated in EUROBRISA to produce integrated forecasts for South America. The skill of austral winter precipitation forecasts produced by two coupled ocean-atmosphere models, an empirical model and integrated (i.e. combined and calibrated) forecasts has been assessed and discussed. The main findings can be summarized as follows:

- forecast skill can be improved by calibration and combination;
- the availability of forecasts produced by both empirical and coupled models provide the opportunity to produce objectively integrated, in other words, combined and well calibrated probabilistic forecasts that gather all available information at the time the forecast is issued (i.e. hybrid empirical-dynamical forecasts);
- austral winter precipitation forecasts produced by the empirical-dynamical multi-model integrated system presented here are skilful in tropical and southeast South America.
- integrated forecasts generally provide skill that is equal to or better than that of the best individual model

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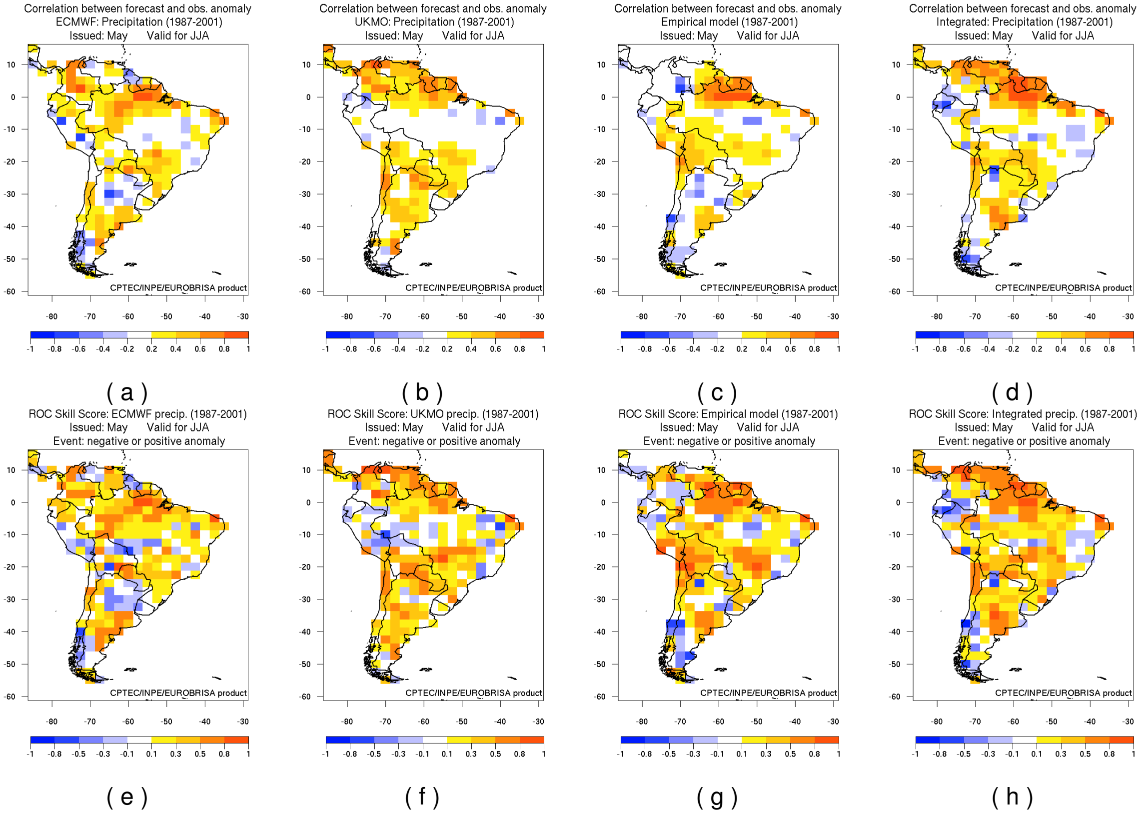

Correlation between forecast and obs. anomaly
ECMWF: Precipitation (1987-2001)
Issued: May Valid for JJA

Correlation between forecast and obs. anomaly
UKMO: Precipitation (1987-2001)
Issued: May Valid for JJA

Correlation between forecast and obs. anomaly
Empirical model (1987-2001)
Issued: May Valid for JJA

Correlation between forecast and obs. anomaly
Integrated: Precipitation (1987-2001)
Issued: May Valid for JJA

ROC Skill Score: ECMWF precip. (1987-2001)
Issued: May Valid for JJA
Event: negative or positive anomaly

ROC Skill Score: UKMO precip. (1987-2001)
Issued: May Valid for JJA
Event: negative or positive anomaly

ROC Skill Score: Empirical model (1987-2001)
Issued: May Valid for JJA
Event: negative or positive anomaly

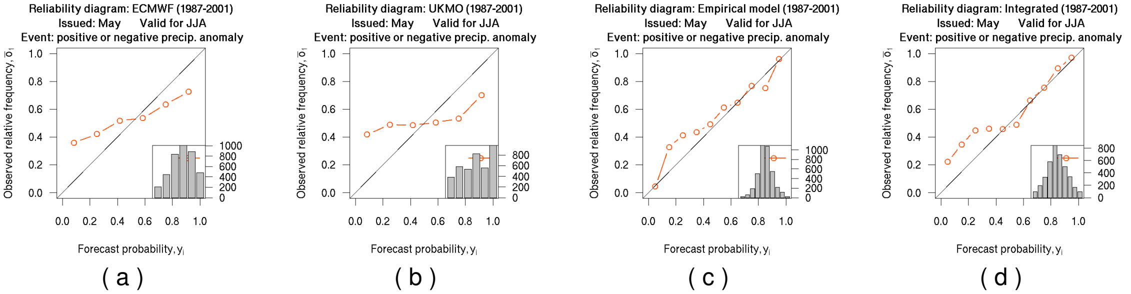
ROC Skill Score: Integrated precip. (1987-2001)
Issued: May Valid for JJA
Event: negative or positive anomaly

CPTEC/INPE/EUROBRISA product

( a ) ( b ) ( c ) ( d )

( e ) ( f ) ( g ) ( h )

Figure 1: Correlation maps (panels a-d) and ROC skill score maps for the event negative or positive anomaly (panels e-h) of ECMWF, UKMO, empirical and integrated one month lead June-July-August precipitation forecasts for the period 1987–2001.


Reliability diagram: ECMWF (1987-2001)
Issued: May Valid for JJA
Event: positive or negative precip. anomaly

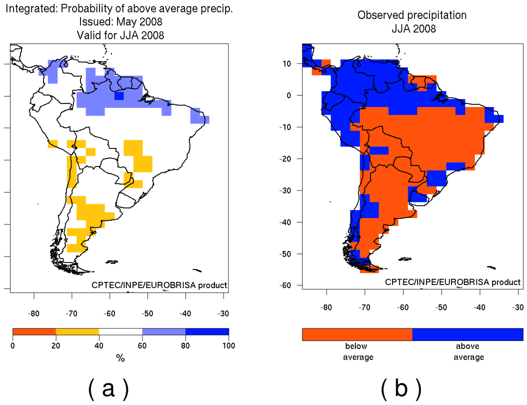
Reliability diagram: UKMO (1987-2001)
Issued: May Valid for JJA
Event: positive or negative precip. anomaly

Reliability diagram: Empirical model (1987-2001)
Issued: May Valid for JJA
Event: positive or negative precip. anomaly

Reliability diagram: Integrated (1987-2001)
Issued: May Valid for JJA
Event: positive or negative precip. anomaly

( a ) ( b ) ( c ) ( d )

Figure 2: Reliability diagrams for the event negative or positive anomaly of ECMWF, UKMO, empirical and integrated one month lead June-July-August precipitation forecasts for the period 1987–2001.


Integrated: Probability of above average precip.
Issued: May 2008
Valid for JJA 2008

Observed precipitation
JJA 2008

CPTEC/INPE/EUROBRISA product

( a ) ( b )

Figure 3: a) Real-time probability forecast for JJA 2008 for the event negative or positive precipitation anomaly issued by the hybrid (integrated) system in May 2008. b) Observed category in JJA 2008: below average (red), above average (blue). The period from 1987 to 2005 is used to compute the long term mean, which is used as the representative value for average conditions.