The use of seasonal climate predictions in South America

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1 Introduction

South American seasonal precipitation predictions have been produced since around the mid-nineties using both empirical (statistical) models and physically based dynamical models. Empirical models are entirely based on past (historical) observations for the predictand [e.g. precipitation over South America] and for relevant predictors [e.g. sea surface temperature (SST)]. Dynamical models are based on prognostic physical equations and can either be 2-tier forecasting systems, where SST conditions are first predicted prior to producing relevant climate variable forecasts [e.g. precipitation or temperature], or 1-tier forecasting systems, where the coupled ocean- atmosphere evolution is predicted together.

When comparing statistical and dynamical prediction systems advantages and disadvantages are identified in both systems. Statistical systems have the advantages of being a) entirely based on real-world past climate observations, b) simple to build as many climate relationships are quasi-linear or quasi-Gaussian, and c) cheap (fast) to run. The disadvantages of statistical systems are that they a) depend on quality and length of past climate observations, and b) do not fully account for changes in climate or new climate conditions. Dynamical systems have the advantages of a) using well established laws of physics, and b) potentially being able to reproduce climate conditions never previously observed. The disadvantages of dynamical systems are that a) physical laws must be abbreviated or statistically estimated, leading to errors and biases, and b) these systems are expensive to run requiring powerful computers.

In the conception of EUROBRISA (A EURO-BRazilian Initiative for improving South American seasonal forecast, http://eurobrisa.cptec.inpe.br), given the availability of forecasts produced by these two systems (empirical and dynamical), the following question was raised: Why not combine all available state-of-the-art forecast information from both sources (empirical and dynamical) with the aim of producing a single integrated (combined and calibrated) precipitation seasonal forecasting system for South America? This question motivated the implementation of the EUROBRISA integrated forecasting system for South America.

EUROBRISA has three aims: a) strengthen collaboration and promote exchange of expertise and information between European and South American climate scientists, which has been stimulated through a number of workshops in Brazil and Europe; b) produce improved seasonal climate forecasts for South America using recent scientific advances in both coupled ocean-atmosphere modelling and statistical calibration and combination of multi-model ensemble forecasts; and c) develop forecast products for non-profitable governmental use in South America (e.g. reservoir management, hydropower production, agriculture and health).

The key idea behind EUROBRISA is to improve seasonal forecasts in South America, a region where there is seasonal forecast skill and useful value. Large part of South America is fortunate to be located in the tropics and be influenced by the El Niño Southern-Oscillation (ENSO) atmospheric teleconnections. Such influence makes the seasonal climate over some regions particularly in northern and southeastern South America to be potentially predictable. And a large number of application areas [e.g. hydropower production, agriculture and health] that depend on advanced seasonal climate information can benefit and make good use of improved qualify seasonal forecasts.

2 EUROBRISA forecasting system and its evolution

The first version of the EUROBRISA forecasting system implemented in October 2007 was composed by an empirical model (Coelho et al., 2006) that uses Pacific and Atlantic SST as predictor for South America precipitation, and two coupled ocean-atmosphere dynamical models [ECMWF System 3 (Anderson et al., 2007) and UK Met Office GloSea 3 (Graham et al. 2005)]. For example, for the empirical model the observed SST in the previous October is used as predictor for precipitation in the following December-January-February (DJF) season. Due to the spatial dependence (co-linearity) between neighbouring SST grid points a spatial reduction technique is required to allow empirical model parameter estimation. In order to address this co-linearity problem the empirical model of the EUROBRISA system is based on maximum convariance analysis (MCA), also known as singular value decomposition (SVD), of the cross-covariance matrix between SST and precipitation. Three leading modes of this cross-covariance matrix are used to produce empirical forecasts. Retrospective empirical forecasts for the period 1987-2001 were produced in cross-validation (leave-one-out) mode (Wilks 1995).

For producing the so called integrated forecast (Coelho et al. 2006) that combines and calibrates coupled and empirical model predictions in a single forecast a Bayesian approach known as forecast assimilation (Stephenson et al. 2005) is used. In the same way data assimilation is needed to map the observations into model space to generate initial conditions to run the climate model, a similar and inverse procedure is needed to map model forecasts back into the observational space. This inverse procedure is called forecast assimilation in analogy to the data assimilation procedure. It is in the forecast assimilation procedure that forecasts from different models can be combined and calibrated by comparing past (retrospective) forecasts with past observations. Integrated forecasts obtained with forecast assimilation gather all available information (i.e. dynamical and empirical forecasts) at the time the forecast is issued. In this first version of the EUROBRISA system implemented in 2007 integrated forecasts obtained with the forecast assimilation procedure were hybrid (empirical-dynamical) products combining and calibrating ECMWF System 3, UK Met Office GloSea 3 and empirical model predictions (i.e. two coupled models and one empirical model). Due to the same co-linearity problems mentioned earlier for the empirical model three leading modes of the crosscovariance matrix between past forecasts and past observation were used in the forecast assimilation calibration procedure to produce integrated forecasts. Retrospective integrated forecasts for the period 1987-2001 were produced in cross-validation (leave-one-out) mode (Wilks 1995).

Since its implementation in 2007 the EUROBRISA integrated forecasting system has been updated with the inclusion of additional dynamical coupled ocean-atmosphere models [e.g. Météo-France System 3 (Gueremy et al. 2005) and CPTEC]. Besides when new model versions [e.g. UK Met Office GloSea 4 and ECMWF System 4] have became available they have also been included for updating the EUROBRISA integrated forecasting system. A particular feature worth highlighting is the "on the fly" hindcast production practice adopted by the UK Met Office for GloSea 4. In this practice every month both real time and the corresponding hindcasts are produced so that the calibration equations of EUROBRISA integrated systems in the forecast assimilation procedure needs to be re-computed. Therefore the EUROBRISA integrated forecasting system is re-calibrated every month when new hindcasts from UK Met Office GloSea 4 are made available.

The current version of the EUROBRISA was updated in March 2012 and is now composed by four coupled models [ECMWF System 4, UK Met Office GloSea 3, Meteo-France, CPTEC] and the empirical model described earlier. This version has the flexibility of allowing the inclusion of models with distinct hindcast periods in the forecast assimilation calibration procedure. Retrospective integrated forecasts for this updated system were produced in cross-validation (leave-one-out) mode (Wilks 1995) for the period 1981-2005. Besides, motivated by the fact that coupled models generally produce forecasts in better agreement with the observations over the oceans compared to forecasts over land, in this version the forecast assimilation procedure uses dynamical coupled model precipitation forecasts over the Pacific and South America domain (30oW, 100oE, 60oS, 15 oN), while for the first version of the EUROBRISA integrated system coupled model precipitation forecast were restricted to the South America domain. 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, and the forecast assimilation procedure used to produce EUROBRISA integrated forecasts allows exploiting this possibility.

3 EUROBRISA system performance during La Niña 2007/08 and contribution to seasonal forecasting practice in South America

During 2007/2008 La Niña conditions prevailed in the equatorial Pacific and the the EUROSIP multi-model composed by ECMWF, UK Met Office and Météo-France captured well the onset, amplitude and long duration of La Nina conditions. This section presents a brief review of EUROBRISA integrated precipitation forecasts for South America during 2007/2008 La Niña.

Figure 1 shows EUROBRISA integrated forecast produced with the forecast assimilation procedure by combining and calibrating ECMWF System 3, UK Met Office GloSea 3, Météo-France, CPTEC and empirical model forecasts for a) JJA 2007, b) SON 2007, c) DJF 2007/2008 and d) MAM 2008. In April 2007 early stage La Niña conditions with colder than normal SST started to emerge near the west coast of South America (Figure 1a, top right). In May 2007 the EUROBRISA integrated forecast for JJA 2007 was issued (Figure 1a, bottom left) indicating high probabilities for precipitation in the upper tercile (wetter than normal conditions) in north South America and high probabilities for precipitation in the lower tercile (drier than normal conditions) in southeast and south South America. The observed JJA 2007 precipitation categories are shown in Figure 1a (bottom central image), where regions with precipitation observed in the upper tecile (wetter than normal conditions) are painted in blue, regions with precipitation observed in the lower tercile (drier than normal conditions) are painted in red, and regions with precipitation observed in the central tercile (normal conditions) are painted in white. The bottom right image in Figure 1a shows a skill measure known as Gerrity score for EUROBRISA integrated forecasts over the hindcasts period 1981-2005 for tercile probabilities. This measure accesses the correspondence between the category forecast as most likely and the observed category. Large valued increasing from yellow to orange and red indicate reasonable correspondence between the category forecast as most likely and the observed category. Forecast verification was performed using the version 2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (Adler et al. 2003). Comparing the three bottom panels in Figure 1a it is possible to identify that for those regions where historically the EUROBRISA integrated forecasting system has reasonable skill (e.g. in tropical and southeast South America) there was good correspondence between the category forecast as most likely and the observed category.

Three months later in July 2007 (Figure 1b, top right) La Niña had evolved to a stage where below normal SST conditions prevailed in large part of central and eastern equatorial Pacific. In August 2007 the EUROBRISA integrated forecast for SON 2007 was issued (Figure 1b, bottom left) indicating high probabilities for precipitation in the upper tercile (wetter than normal conditions) in central and north South America and high probabilities for precipitation in the lower tercile (drier than normal conditions) in southeast South America. By comparing Figure 1b (botton left and central images) one can see that this forecast was only partially successful in northern South America with good correspondence between the category forecast as most likely (wetter than normal conditions) and the observed category.

In October 2007 (Figure 1c, top right) La Niña had evolved to a much mature stage with below normal SST conditions prevailing in the entire equatorial Pacific. In November 2007 the EUROBRISA integrated forecast for DJF 2007/2008 was issued (Figure 1c, bottom left) indicating high probabilities for precipitation in the upper tercile (wetter than normal conditions) in northwestern South America and high probabilities for precipitation in the lower tercile (drier than normal conditions) in central Brazil. The comparison of Figure 1c (botton left and central images) reveals that this forecast was successful over these two regions with good correspondence between the category forecast as most likely and the observed category.

Three months later in January 2008 (Figure 1d, top right) La Niña had declined to a stage with below normal SST conditions prevailing mostly in central-west equatorial Pacific. In February 2008 the EUROBRISA integrated forecast for MAM 2008 was issued (Figure 1d, bottom left) indicating high probabilities for precipitation in the upper tercile (wetter than normal conditions) in northern Brazil and high probabilities for precipitation in the lower tercile (drier than normal conditions) in central-south Brazil and parts of Argentina. The comparison of Figure 1d (botton left and central images) reveals that this forecast was successful over northern Brazil, a regions that experiences its wet (rainy) season during MAM, with good correspondence between the category forecast as most likely and the observed category.

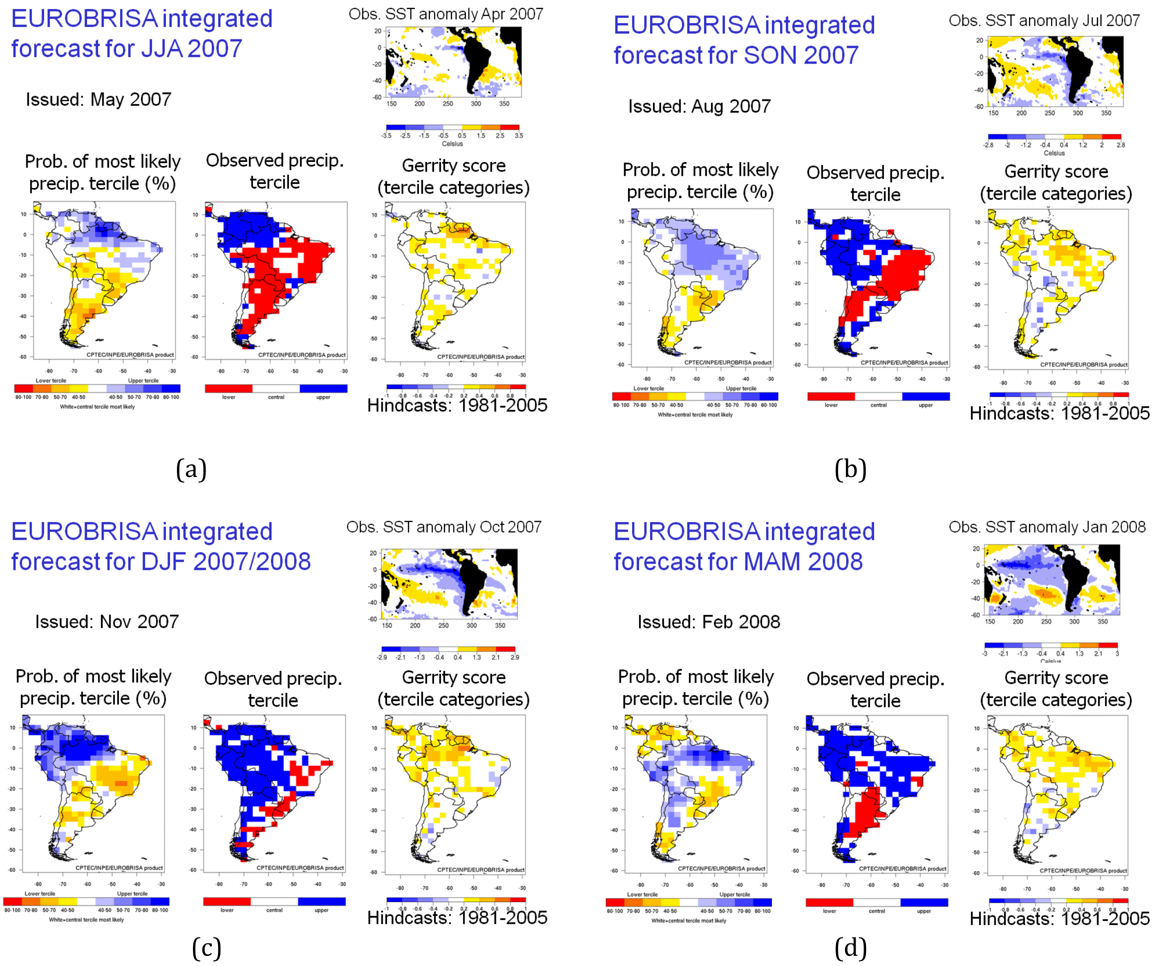


Figure 1: EUROBRISA integrated forecast for a) JJA 2007, b) SON 2007, c) DJF 2007/2008 and d) MAM 2008.

Prior to EUROBRISA several individual precipitation forecasting system have been used in South America, including SST-based empirical models for specific regions, atmospheric dynamical general circulation models (AGCMs) forced with both observed (persisted) and forecast SST, regional dynamical models fed with boundary conditions provided by AGCMs and coupled ocean-atmosphere dynamical general circulation models. With EUROBRISA a single hybrid empirical-dynamical forecasting system was implemented for producing integrated precipitation forecasts for South America by combining and calibrating the forecasts produced by four coupled models and an empirical model. Integrated forecasts produced in EUROBRISA are since 2007 helping and contributing to define the official seasonal forecast for Brazil issued for the general public. EUROBRISA also provided valuable opportunities for exploring the potential for the use of seasonal forecasts in a number of application areas. However, several challenged need to be resolved prior to the successful integration of seasonal forecasts in user applications. The following section illustrates some of these challenges with examples of crop yield predictions in Brazil.

4 Seasonal forecast applications and challenges

A large number of applications particularly in agriculture, water resources management and health require climate information as one the ingredients for the decision making process and seasonal forecasts have the potential to help provide some guidance in this process. However, despite seasonal forecasts being operationally produced at various climate prediction centers around the world, these forecasts are rarely objectively integrated in application models to help the end user decision making process. The reason why seasonal forecasts are rarely objectively integrated in this process is most likely due to a number of challenges that need to be resolved in order to successfully incorporate the forecasts in user applications. Below the challenges for integrating seasonal climate forecast information in user applications within the design of a simplified end-to-end forecasting system framework (Coelho and Costa 2010) is briefly discussed. Two examples of crop (maize) yield forecasts for a location in the south of Brazil produced as part of the EUROBRISA multi-institutional initiative are presented for illustrating some of the challenges.

Figure 1 of Coelho and Costa (2010) presents a simplified end-to-end forecasting system framework. In this framework a number of challenges for making large scale climate forecast information objectively useful for an end user have been highlighted. The first challenge consists in producing seasonal climate forecasts on time scales from 1 to 6 months in advance at course spatial resolution with global climate models. In the two examples that will be presented here this challenge was resolved by using monthly precipitation forecast outputs produced by ECMWF System 3 coupled model and EUROBRISA integrated seasonal forecasts.

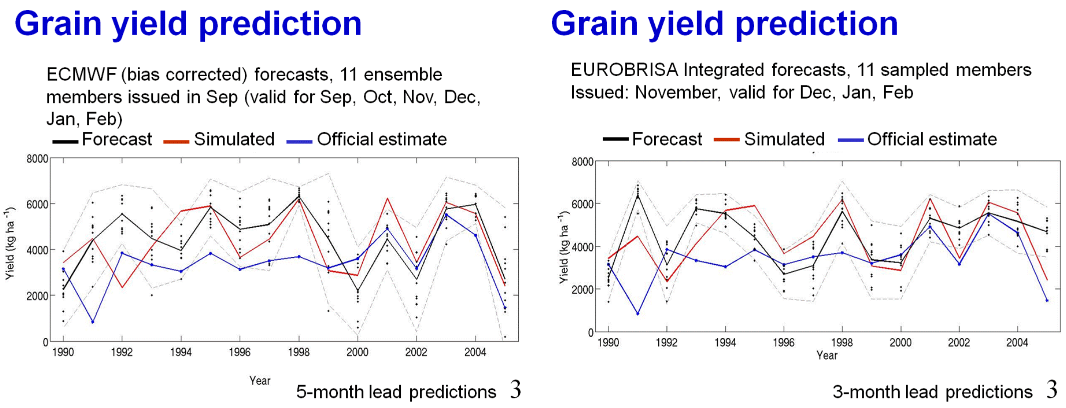
The second challenge consists in producing seasonal forecasts in refined space and time scales for use in application models (e.g. in a crop model). In the examples presented here this challenge was resolved by taking a simplistic approach for the issue of refined space scale, assuming that the forecasts for the nearest grid point of the global model to the location where crop yield was to be forecast was valid as a point forecast for that location. The refined time scale issue arises from the fact that the crop model requires daily precipitation information for estimating crop yield. For resolving this challenge both monthly ECMWF System 3 precipitation forecasts and seasonal (3-month mean) EUROBRISA integrated precipitation forecasts have been disaggregated in daily values using a stochastic weather generator. In this procedure the weather generator takes as inputs historical daily precipitation time series for the locations of interest and also either monthly or seasonal precipitation forecasts from ECMWF System 3 or from the EUROBRISA integrated system. The occurrence of precipitation is defined in terms of a first order Markov chain process and precipitation amount is estimated from the fit of a Gamma distribution based on the observed daily precipitation.

The third challenge consists in the production of information to support decision making based on climate and non-climate related knowledge. The climate related part of this challenge was resolved in the two examples to be discussed here by using a crop model that takes as input daily precipitation forecasts, and daily temperature and radiation, the latter two estimated in terms of climatological values conditioned on wet and dry days. With this information the crop model provides estimates (forecasts) of crop (maize) yield.

Maize in the south of Brazil is sowed around September/October and harvested around February/March. Figure 2a shows the first example of maize yield forecasts. This figure shows maize yield ensemble mean forecast (black line representing the mean of 11 ensemble members indicated by the black dots) produced with a crop model (Challinor et al. 2004) adapted for the conditions of south Brazil (Bergamaschi and Costa, 2007; Costa and Bergamaschi, 2007) fed with time disaggregated bias corrected monthly forecasts produced by ECMWF System 3. These represent 5-month lead forecasts produced in September and valid for the months of September, October, November, December, January and February (i.e. the entire crop cycle) of the period 1989-2005. The dashed lines represent the 95% prediction interval, which is expected to contain 95% of the official estimate crop yield values (blue line). The red line represents the simulated crop obtained when the crop model is fed with the observed daily precipitation. A generally good agreement is observed between the simulate yield (red line), the official yield estimate (blue line) and the forecast yield (black line) for the last six years. For most of these years the observed yield is within the 95 % forecast interval, indicating good reliability of grain yield forecasts.

Figure 2b shows the second example of maize yield forecasts. This figure shows maize yield ensemble mean forecast (black line representing the mean of 11 ensemble members indicated by the black dots) produced with the same crop model fed with time disaggregated EUROBRISA integrated seasonal (3-month mean) forecasts. These represent 3-month lead forecasts produced in November and valid for the months of December, January and February (i.e. the final part of the crop cycle) of the period 1989-2005. The 95% prediction interval for these forecasts is slightly smaller than for the previously discussed forecasts and also the last six years show better agreement between the official yield estimate (blue line) and the forecast yield (black line). The better agreement between forecast, simulated and official yield estimates in the later forecast period compared to the earlier forecast period in both forecasts shown in

Figure 2 is likely to be related to quality improvements in both observed rainfall and yield estimates in latter part of the period. Both examples presented here illustrate the potential for objectively integrating seasonal forecasts in crop yield predictions for a location in the south of Brazil.



(a) (b)

Figure 2: Grain (maize) yield predictions for a location in the south of Brazil (Erechim) produced a) 5-months in advance (issued in September, valid for the following February) using ECMWF System 3 monthly precipitation forecasts and b) 3-months in advance (issued in November, valid for the following February) using EUROBRISA integrated seasonal (3-month mean) forecasts.

5 Summary

Seasonal climate forecasts have been used in South America since around mid-nineties. In recent years the joint effort between Brazilian and European scientists led to the establishment of EUROBRISA, which is an example of a successful initiative bringing together expertise on coupled ocean-atmosphere seasonal forecasting and statistical calibration and combination of multi-model ensemble forecasts. Though this initiative it was possible to developed a novel integrated precipitation seasonal forecasting system that helped improve and advance seasonal forecasting practice in South America by objectively combining empirical and dynamical model seasonal forecasts. The EUROBRISA integrated forecasting system for South America has been showing reasonable performance since its implementation in 2007.

An important aspect in seasonal forecast practice is the objective integration of the forecasts in user application models. However, the success of integrating seasonal climate forecasts in user applications can only be achieved if the entire chain of challenges is thoroughly resolved. In this manuscript two examples of crop yield forecasts produced as part of the EUROBRISA multi-institutional initiative were presented for illustrating some of the challenges. Results demonstrate potential for use of rainfall forecasts produced by EUROBRISA integrated forecast and ECMWF coupled model for producing maize yield predictions for a location in the south of Brazil. There is therefore scope for further advancing the development of procedures for objective use of seasonal forecasts in application models in order to help the decision making process.

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