Crop yield predictions using seasonal climate forecasts

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ABSTRACT: Agriculture is an economic activity that strongly depends on climate and weather information. Dynamical and statistical seasonal climate forecast models have the potential to provide anticipated meteorological information to agricultural decision makers. This study aims to investigate the potential of using monthly mean climate forecasts for producing maize yield predictions in Rio Grande do Sul. A stochastic weather generator was used to disaggregate monthly mean rainfall from the European Centre for Medium-range Weather Forecast (ECMWF) seasonal forecast model (known as System 3) into daily sequences of rainfall. The stochastic model generates daily rainfall based on 16-years of daily observed rainfall. The disaggregated daily rainfall was used as input data to a process-based crop model - GLAM (General Large Area Model) to predict maize crop yield. Preliminary results show promising usefulness of monthly mean rainfall forecasts produced by ECMWF coupled model for producing maize yield predictions for Rio Grande do Sul five months in advance.

RESUMO: Os modelos numéricos e estatísticos de previsão de clima têm o potencial de fornecer informações meteorológicas antecipadas aos órgãos responsáveis pela tomada de decisões das atividades agrícolas. O objetivo deste estudo foi adquirir conhecimentos metodológicos para o acoplamento das previsões climáticas sazonais a um modelo de produtividade agrícola. Neste contexto, previsões médias mensais de chuva do modelo climático acoplado do Centro Europeu de Previsão de Tempo de Médio Prazo foram desagregados em dados diários através de um modelo gerador de tempo, o qual considera a distribuição climatologica de chuva provenientes de dados observados diários. Os dados desagregados foram utilizados para alimentar o modelo de produtividade agrícola GLAM (General Large Area Model) para a cultura do milho no Rio Grande do Sul. Resultados preliminares mostram que as previsões mensais de chuva do modelo acoplado do ECMWF podem ser uteis para prever a produtividade agricola do milho com 5 meses de atencedência.

Key-words: seasonal climate forecast, crop yield prediction, stochastic weather generator.

1 INTRODUCTION

Linking climate and weather forecasts to a crop yield model can provide a useful tool for predicting crop productivity a season or even a longer period ahead. Additionally, it is useful for investigating options for crop management, food and livelihood security. Rainfall forecasts from global circulation models have been used with some success into crop models (Baron et al., 2005; Cantelaube and Terres, 2005, Challinor et al., 2005). Operational climate season forecast generally focus on seasonal mean rainfall (i.e 3 month mean values), while crop models are usually designed to assimilate daily rainfall values. According to Hansen et al. (2006), four different methods for linking crop simulation models to seasonal climate forecast models have been generally used: (1) crop simulation with daily climate model forecast output, (2) use of synthetic daily weather conditioned on climate forecasts, (3) statistical prediction of crop response simulated with historic weather, and (4) classification and analog methods. In this studied, synthetic daily rainfall conditioned to the monthly mean rainfall produced by the European Centre for Medium-range Weather Forecast seasonal forecast model (known as System 3, Anderson et al. 2007) is used as input for a crop model in order to simulate maize (*Zea mays* L.) in Rio Grande do Sul State (RS). Brazil is the third main maize producer in the entire world after USA and China, and RS State is the second greatest producer in Brazil (IBGE, 2006). Interseasonal variability of maize yields is high, mainly due to irregular rainfall during the cropping seasons. Therefore, it is important to predict this yield variability.

2 – MATERIAIS E MÉTODOS

Maize yield was simulated using the General Large Area Model for annual crops (GLAM, Challinor et al., 2003), which has previously been used to simulate groundnut in India (Challinor *et al*., 2004; Osborne *et al*., 2007) and wheat in China (Sanai *et al*., 2007). The model was calibrated for simulating maize based on a comprehensive soil and crop phenology database observed in Rio Grande do Sul (Bergamaschi and Costa, 2007; Costa and Bergamaschi, 2007). GLAM requires daily rainfall, maximum and minimum temperature and surface incident solar radiation. A stochastic weather generator[1] was used to disaggregate the 11 ensemble members of monthly mean rainfall from the ECMWF model into daily rainfall. The weather generator estimates the occurrence of rainfall based on a first-order Markov chain and the rainfall amount based on a gamma distribution fit to 11 years of daily observed rainfall (i.e. daily climatological distribution). Temperature and solar radiation were assumed being monthly daily climatology conditioned on wet and dry conditions. The observed data are from 11 weather stations (Figure 1) that belong to two different official networks: FEPAGRO - Fundação Estadual de Pesquisa Agropecuária (Cruz Alta, Erechim, Ijuí, Julio de Castilhos, Santa Rosa, São Borja, Taquari, and Veranopolis) and INMET - Instituto Nacional de Meteorologia (Irai, Passo Fundo and São Luiz Gonzaga). The shaded area in Fig. 1 is the main maize producer region in RS. Most maize crop in RS is sown from September to October and harvested from January to the beginning of March. For this reason ECMWF monthly mean rainfall forecasts issued in the beginning of September for 0-5 months ahead (i.e. 0-5 month lead predictions, from September up to February of the following year) were used in this study. Rainfall forecasts for the closest grid point to the main maize producer region were used in the study.

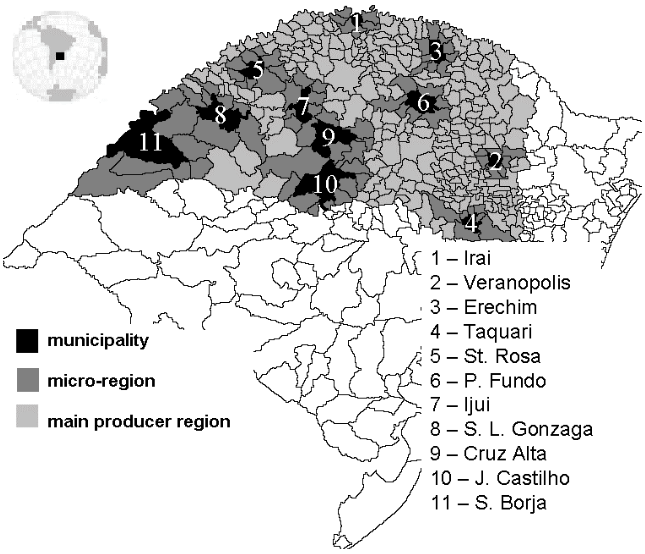

Figure 1 – Map of Rio Grande do Sul State (RS), Brazil showing the main maize producer region and 11 municipalities.

3 – RESULTS

Figure 2 shows the correlation between the ECMWF ensemble mean anomaly forecast and observed rainfall anomaly for the period 1981-2005. The forecast is issued in the beginning of September and is valid for September, October, November, December, January and February (i.e. 0-5 month lead forecast). High positive correlation is noticed over nearly all South America in September, indicating good association

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1 http://portal.iri.columbia.edu/portal/server.pt?open=512&objID=697&PageID=7575&cached=true&mode=2&userID=2

between observed and forecast anomalies. Over Rio Grande do Sul State, positive correlation is observed over all months, except January, when nearly null correlation is noticed. These maps illustrate that ECMWF couple seasonal forecast model does show skill on monthly mean rainfall forecasts during the maize crop cycle, suggesting the potential use this information for crop yield prediction.

Figure 3 shows the observed 1989-2005 daily rainfall histogram for Santa Rosa municipality during the maize yield cycle (September – January, top panel) and the disaggregated daily rainfall histograms using two ensemble members of ECMWF monthly mean rainfall for the same period (lower panels). The disaggregation was performed for all 11 ensemble members, but only two ensemble members are shown her for illustrative purposes. A reasonable agreement is noticed between the observed and disaggregated histograms, indicating that the used weather generator can reproduce the observed daily rainfall distribution accordingly.

Figure 4 shows the maize grain yield prediction for three different municipalities located in the main maize producer region. The red line shows grain maize yield simulated by GLAM using the observed daily rainfall. The black line is the ensemble mean grain yield (i.e. the mean of the eleven dots shown in the figures for each year) using disaggregated daily rainfall. The dashed lines indicate the 95% prediction interval given by the ensemble mean plus or minus 1.96 times the ensemble standard deviation. A generally good agreement is observed between the simulate yield (red line) and the predicted yield (black line), particularly for the last ten years. For most years the observed yield is within the 95 % prediction interval, indicating good reliability of grain yield predictions.

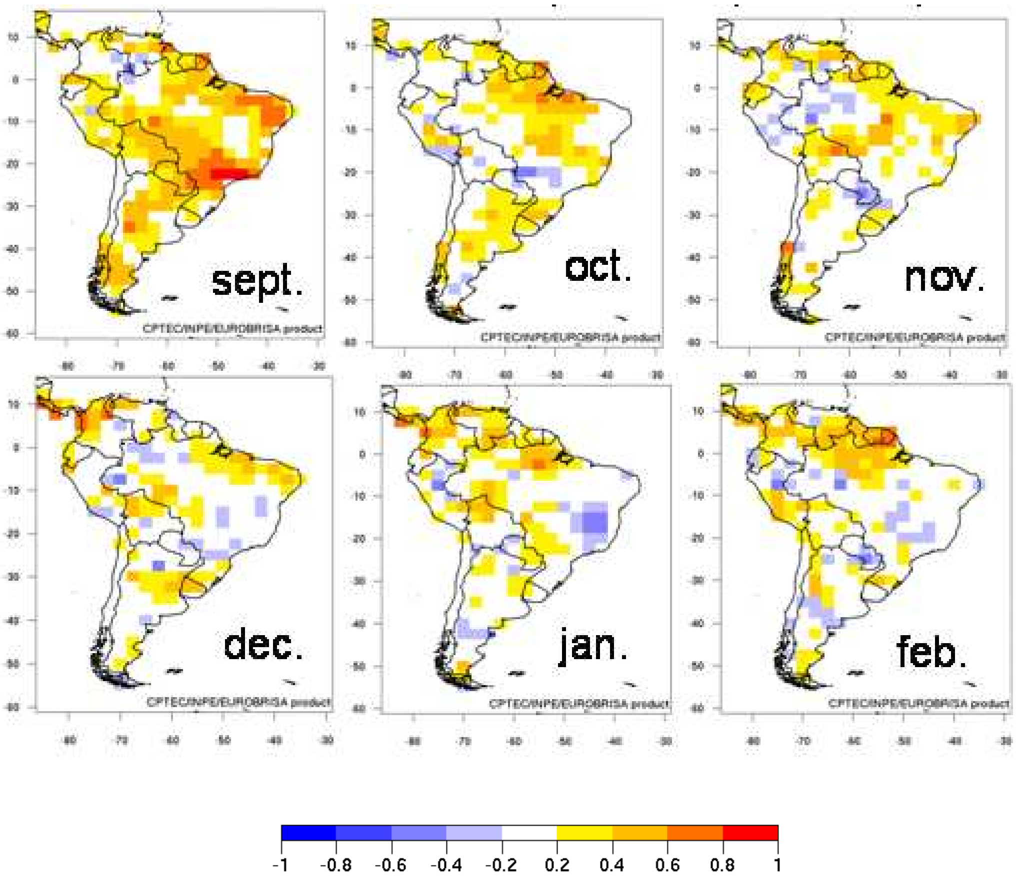

Figure 2 – Correlation between ECMWF monthly mean forecast and observed rainfall anomalies (1981 – 2005), forecast issued in September, valid for September, October, November, December, January and February.

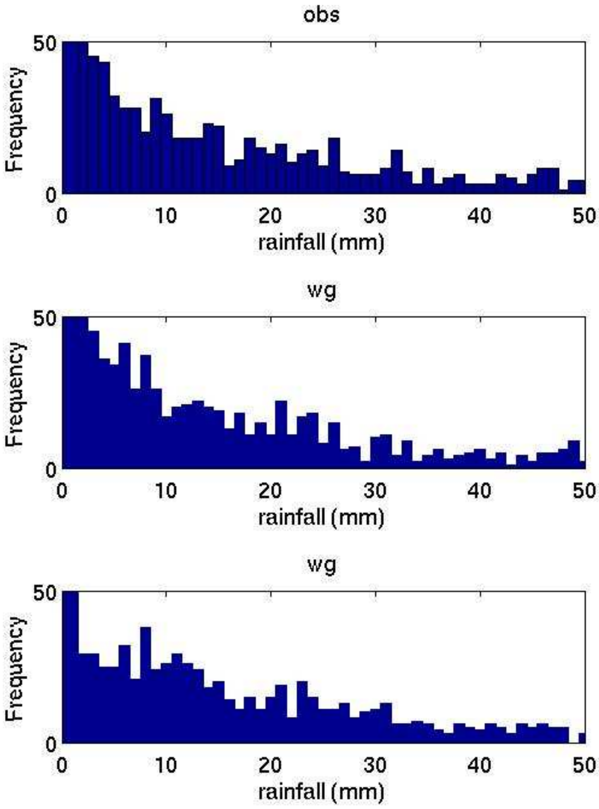

Figure 3 – Daily rainfall histogram for Santa Rosa county for September to February (1989 – 2005) based on observed rainfall and disaggregated rainfall for two of the 11 ECMWF ensemble members.

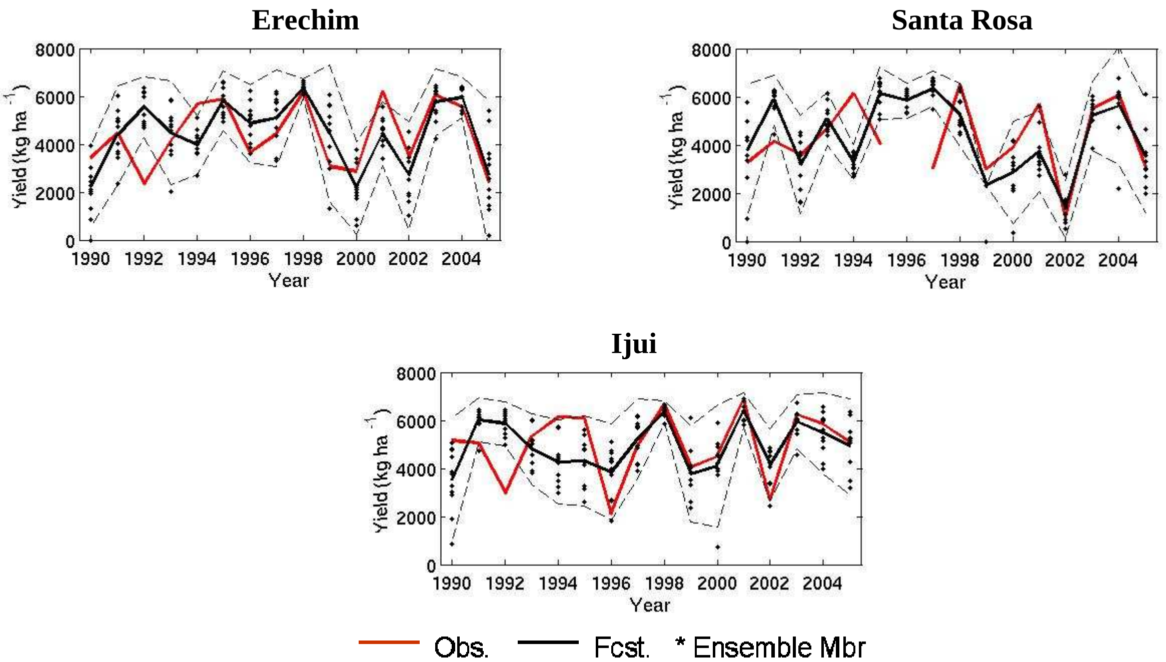

Figure 4 - Grain yield prediction produced five months in advance for three individual Counties.

4- DISCUSSION AND CONCLUSION

The stochastic weather generator is a powerful tool for making use of monthly mean rainfall forecasts from coupled seasonal forecast models for producing crop yield predictions. Preliminary results show promising usefulness of monthly mean rainfall forecasts produced by ECMWF coupled model for producing maize yield predictions for RS five months in advance.

Future work will use monthly mean rainfall forecasts from other coupled models (e.g. CPTEC, UK Met Office and Meteo-France) into the weather generator for use in the maize yield crop model. This will allow skill comparison of crop yield prediction using different coupled model monthly mean rainfall forecasts.

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