UNCERTAINTY AND PROBABILITY OF TEMPERATURE CHANGE OVER SOUTH AMERICA BY THE END OF THE TWENTY-FIRST CENTURY

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RESUMO: Este estudo analisa as incertezas e probabilidades envolvidas nas projeções de mudanças da temperatura do ar à superfície sobre a América do Sul para o final do século XXI. Simulações e projeções climáticas no cenário futuro de emissões SRES A2 geradas por inúmeros Modelos Globais Climáticos foram utilizados e o método *Reliability Ensemble Averaging* (REA) foi aplicado. O método REA nos permite estimar, através de uma média ponderada de modelos, um intervalo de incerteza e uma avaliação probabilística das projeções climáticas. Os resultados mostram que a temperatura média REA foi ligeiramente menor (~8%) sobre toda América do Sul quando comparado com a média simples (ou seja, quando atribuímos o mesmo peso para todos os membros do conjunto). A probabilidade de um aumento de temperatura acima de 2^{o}C apresenta-se extremamente alta (>80%) para todo o continente e em todas as estações, e uma alta probabilidade (>50%) de exceder 4^{o}C foi encontrada no noroeste da América do Sul, bacia Amazônica e Nordeste brasileiro para 2071-2100.

ABSTRACT: This study assess the uncertainties and probabilities involved in projections of surface air temperature change over the South America by the end of the twenty-first century. Climate simulations and projections in the SRES A2 emission scenarios generated by innumerous Global Climate Models were used and the Reliability Ensemble Averaging (REA) approach was applied. REA allows the estimation, through a weighted mean of models, of an uncertainty range and a probabilistic evaluation of climate outcomes. Results show that the REA mean temperature change was slightly smaller (~8%) over the whole of South America when compared to the simple ensemble mean (i.e. when assigning the same weight to all ensemble members). A temperature increase exceeding 2^{o}C was found to have an extremely high likelihood (>80%) for the entire South America in all seasons, and a high likelihood (>50%) of exceeding 4^{o}C was found over Northwest South America, Amazon basin and Northeast Brazil by 2071-2100.

1. INTRODUCTION

Several factors contribute to uncertainties on climate simulations and projections: stochastic and non-linear climate system processes, random aspects of the natural and anthropogenic forcing, unawareness of the complete system initial and boundary conditions and inability to represent all climate system processes in a model. So, climate change projections possess an intrinsic level of uncertainty, so that probabilistic considerations should always be taken into account.

A common way to synthesize the results of a multi-model ensemble projection is to produce a simple average of its members (i.e. assigning the same weight to all members). Another technique proposed is the use of a probabilistic approach, in which a large results of several models or multiple realizations of a single model are employed. Giorgi and Mearns (2002) proposed a method based on a weighted mean of different Global Climate Models (GCMs) that take into account the "reliability" of each model, called Reliability Ensemble Averaging (REA). This method allows an assessment of the credibility of the ensemble mean climate projection, the calculation of an uncertainty range and the production of probabilistic outcomes.

Based on the complexity of the problems outlined above and the remaining need for detailed information about climate change uncertainties in model projections over South America, this study proposes an assessment of uncertainties in temperature change projections for this part of the world generated by innumerous GCMs. Specifically, this study aims to produce mean and probabilistic projections for changes in mean surface air temperature in the A2 scenario through the REA approach over the entire South America, coping with the involved uncertainties.

2. METHODOLOGY

This study uses simulations and projections of mean surface air temperature generated by nineteen GCMs from the Coupled Model Intercomparison Project Phase 3 (CMIP3) dataset (Table 1). Climate simulations for the twentieth century and projections for the twenty-first century in the SRES A2 emission scenario were used in seasonal averages for the periods 1961-1990 (present time) and 2071-2100 (future time slice). Throughout this work, changes are referenced to the averaged 1961-1990 period. When more than one model run per experiment is available, the mean of all analyzed model runs is used. The GCMs spatial resolutions vary from roughly 1 to 5 degrees (Table 1) and for inter-comparison purposes, model runs and observed data are interpolated to a common 2.5° x 2.5° grid. All models simulations for the twentieth century are compared against observed surface air temperature from the CRU TS 3.0 dataset.

In the REA approach (Giorgi and Mearns 2002), the mean change for a climate variable ξ ($\tilde{\Delta}\xi$) projected by a set of models is given by the weighted average of each ensemble member projected change ($\Delta\xi_i$) as

$$\tilde{\Delta}\xi = \frac{\sum_i R_i \Delta\xi_i}{\sum_i R_i}, \tag{1}$$

where R_i is the reliability factor of the model defined by

$$R_i = R_{B,i} \times R_{D,i} = \left[\frac{\varepsilon_\xi}{abs\left(B_{\xi,i}\right)}\right] \times \left[\frac{\varepsilon_\xi}{abs\left(D_{\xi,i}\right)}\right]. \tag{2}$$

$R_{B,i}$ is a factor that measures the model reliability as a function of its bias ($B_{\xi,i}$) when simulating the variable ξ in the current climate, i.e., the higher the bias, the lower the model reliability. $R_{D,i}$ evaluates the model reliability in terms of the distance ($D_{\xi,i}$) between its projected change and the ensemble REA mean change, i.e., an outlier model result is down weighted. In this study, the natural variability of surface air temperature will be estimated by taking the difference between the highest and minimum value of the observed time series (1901-2000), after removing the linear tendency of the data and applying a running mean filter to retain only climate oscillations with periods greater than 30 years. The uncertainty range around the REA mean change ($\tilde{\delta}_{\Delta\xi}$) can be estimated by

$$\tilde{\delta}_{\Delta\xi} = \left[\frac{\sum_i R_i \left(\Delta\xi_i - \tilde{\Delta}\xi \right)^2}{\sum_i R_i} \right]^{1/2} \tag{3}$$

Additionally, the probability of occurrence of a climate change projection simulated by a model i (P_{m_i}) can be considered to be proportional to the normalized reliability parameter, i.e.

$$P_{m_i} = \frac{R_i}{\sum_{j=1}^{N} R_j}, \tag{4}$$

where N represents the number of different GCMs. In other words, it is assumed that a climate change simulated by a model with higher reliability parameter value is more likely to happen.

Table 1. List of CMIP3 models used, showing the approximate spatial resolution (lat/lon) and number of available run for each model. 20C3m represent the set of climate simulations for the XX century and A2 the simulations for the XXI century under the SRES A2 emission scenario.

Models	Resolution	20C3M	A2	Models	Resolution	20C3M	A2
INM-CM3.0	5^o x 4^o	1	1	GFDL-CM2.0	2.5^o x 2^o	3	1
GISS-ER	5^o x 4^o	9	1	GFDL-CM2.1	2.5^o x 2^o	3	1
CGCM3.1(T47)	3.8^o x 3.8^o	5	5	BCCR-BCM2.0	1.9^o x 1.9^o	1	1
ECHO-G	3.8^o x 3.8^o	5	3	CSIRO-MK3.0	1.9^o x 1.9^o	3	1
UKMO-HadCM3	3.8^o x 2.5^o	2	1	CSIRO-MK3.5	1.9^o x 1.9^o	3	1
IPSL-CM4	3.8^o x 2.5^o	1	1	ECHAM5	1.9^o x 1.9^o	4	3
MRI-CGCM2.3.2	2.8^o x 2.8^o	5	5	UKMO-HadGEM1	1.9^o x 1.3^o	2	1
CNRM-CM3	2.8^o x 2.8^o	1	1	CCSM3	1.4^o x 1.4^o	7	4
MIROC3.2(medres)	2.8^o x 2.8^o	2	3	ECHAM4	1.1^o x 1.1^o	1	1
PCM	2.8^o x 2.8^o	4	4				

3. RESULTS

All CMIP3 models project a temperature increase in all of South America, more intense in its tropical continental portion. According to the simple ensemble mean, the temperature change could reach above 4^{o}C in the Amazon Basin from June to August by 2071-2100 in the A2 scenario (Fig. 1a-d). For the South American continent as a whole, the range of temperature change is between 2-5^{o}C.

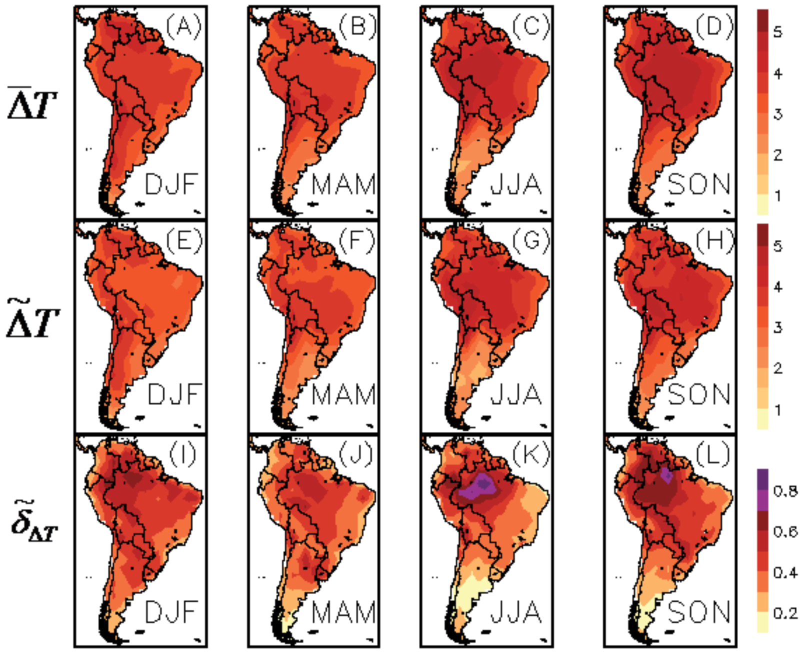

Fig. 1. Simple average ($\bar{\Delta}T$), REA mean ($\tilde{\Delta}T$) and uncertainty range ($\tilde{\delta}_{\Delta T}$) for seasonal surface air temperature change projected for 2071-2100 in the SRE A2 scenario. Units are in ^{o}C.

When comparing the patterns of temperature change obtained by the simple average (Fig.1a-d) and that obtained by the application of REA approach (Fig. 1e-h), it is possible to notice that when we take into account the reliability of models, the magnitude of the temperature change projections decreased in almost all of the domain, more pronounced over the western Amazon basin, where this decrease reaches roughly 0.5^{o}C by the end of this century. The Amazon basin is the region that exhibits the largest disagreements among CMIP3 models on the magnitude of the expected temperature change, as evidenced by the uncertainty range parameter (Fig. 2i-l).

Based on the reliability factor, Figure 2 shows the seasonal probabilities of exceeding some temperature thresholds (2, 3, 4 and 5^{o}C) for 2071-2100 in the A2 emission scenario. As can be seen, there is great probability (> 80%) that the temperature increase will reach more than 2^{o}C for the whole continent in all seasons. A high likelihood (>50%) of exceeding 4^{o}C is found over Northwest South America, Amazon basin, Bolivia, Peru and NEB in JJA and SON.

4. CONCLUSIONS

When taking into account the performance of each model in representing the current climate and the convergence of its projection to the ensemble mean in the ensemble averaging, as proposed by the REA method, it was noted that the REA mean temperature change projection was slightly smaller (roughly 8%) over the whole South America continent when compared to the simple ensemble mean. This indicated that outlier results were down weighted in the ensemble mean, as expected. The temperature change is larger than the corresponding uncertainty range for the entire South America, showing a high reliability of the projected REA mean change for this variable. The probability of a temperature increase exceeding the 2°C threshold was found to be extremely high (>80%) in all seasons of entire South America and a high likelihood (>50%) of exceeding 4°C was found over Northwest South America, the Amazon basin, Bolivia, Peru and NEB from June to November by the end of the twenty-first century.

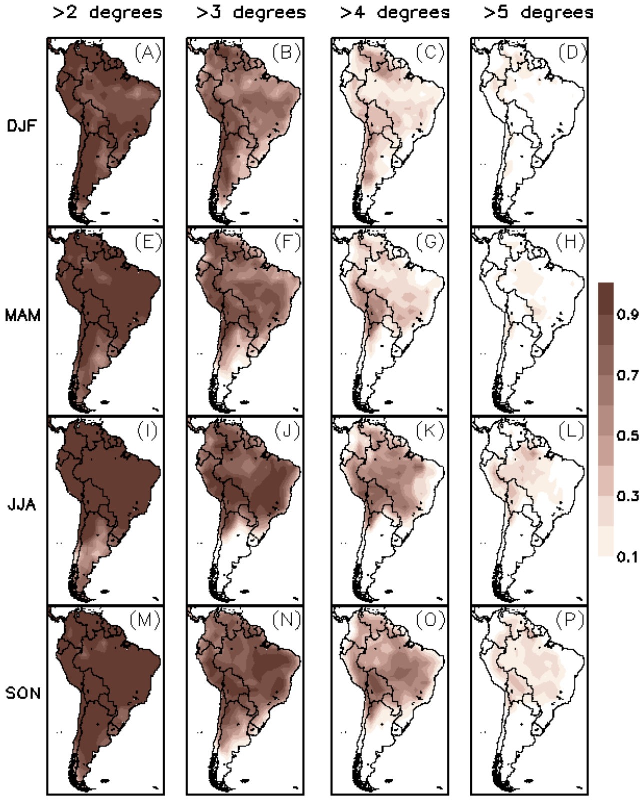

Fig. 2. Seasonal probabilities of exceeding some temperature thresholds (2, 3, 4 and 5 °C) for 2071-2100 in the A2 scenario.

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