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USE OF REGIONAL CLIMATE MODELS IN IMPACTS ASSESSMENTS AND ADAPTATIONS STUDIES FROM CONTINENTAL TO REGIONAL AND LOCAL SCALES

The CREAS (Regional Climate Change Scenarios for South America) initiative in South America

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Introduction

Regional Climate Models (RCMs) are useful tools for generating high resolution climate change scenarios for use in climate impacts and adaptation studies. Coupled Atmosphere-Ocean Global Climate Models (AOGCMs) are the modeling tools traditionally used for generating climate change projections and scenarios. However, the horizontal atmospheric resolution of present day AOGCMs is still relatively coarse, order of 300 km, and regional climate is often affected by forcing and circulations that occur at smaller scales. As a result, AOGCMs cannot explicitly capture the fine scale structure that characterizes climatic variables in many regions of the world and that is needed for many impact assessment studies.

The issue of the spatial resolution in scenarios must be put in the context of other uncertainties of climate change. Studies and analyses of climate change impact and adaptation assessments recognize that there are a number of sources of uncertainty in such studies which contribute to uncertainty in the final assessment. The importance of high resolution climate scenarios for impacts and adaptation studies remains to be thoroughly explored in Brazil and South America. High resolution scenarios developed from regional climate model results have been applied to impacts assessments only in the past five years in various parts of the world, as in North America and Europe as part of international projects. Most of these activities have linked to implementation of scenarios for the UNFCC National Communications on Climate Change at the country level. In studies so far, mainly concerning agriculture and water resources, significant differences in the estimated impacts based on spatial resolution are found. Therefore, there is a need for regional climate change scenarios in South America.

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Regional Modeling Strategy

This section presents an overall discussion of the principles, objectives and assumptions underlying the different techniques today available for deriving regional climate change information. The horizontal atmospheric resolution of present day AOGCMs is still relatively coarse, order of 300 km, and regional climate is often affected by forcing and circulations that occur at smaller scales (Giorgi and Mearns 1991). As a result, AOGCMs cannot explicitly capture the fine scale structure that characterizes climatic variables in many regions of the world and that is needed for many impact assessment studies. Therefore, different "regionalization" techniques have been developed to enhance the regional information provided by AGCMs and AOGCMs and to provide fine scale climate information. To date, most impact studies have used climate change information provided by equilibrium AGCMs or coupled AOGCM simulations without any further regionalization processing. This is primarily because of the ready availability of this information and the relatively recent development of regionalization techniques.

For some applications, the regional information provided by AOGCMs may be sufficient, for example when sub-grid scale variations are weak or when assessments are global in scale. In fact, from the theoretical view point, the main advantage of obtaining regional climate information directly from AOGCMs is the knowledge that internal physical consistency is maintained. The "added value" provided by the regionalization techniques depend on the spatial and temporal scales of interest, as well as on the variables concerned and on the climate statistics required.

What is commonly known as dynamic downscaling refers to as nested RCM model into a AOGCM. The AOGCM provide initial conditions and time-dependent lateral meteorological boundary conditions to drive high-resolution RCM simulations for selected time periods of the global model run (e.g. Dickinson et al. 1989; Giorgi 1990). Sea surface temperature (SST), sea ice, greenhouse gases

(GHG) and aerosol forcing, as well as initial soil conditions, are also provided by the driving AOGCM. Some variations of this technique include forcing of the large scale component of the solution throughout the entire RCM domain (Zorita von Storch, 1999)

To date, this technique has been used only in one-way mode, i.e. with no feedback from the RCM simulation to the driving AOGCM. The basic strategy underlying this one-way nesting approach is that the AOGCM is used to simulate the response of the global circulation to large scale forcing and the RCM is used: 1) to account for sub-AOGCM grid scale forcing (e.g. complex topographical features and land cover inhomogeneity) in a physically-based way, and 2) to enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales. The nested regional modeling technique essentially originated from numerical weather prediction, but is by now extensively used in a wide range of climate applications, ranging from paleoclimate to anthropogenic climate change studies. Over the last decade, regional climate models have proven to be flexible tools, capable of reaching high resolution (down to 10-20 km or less) and multi-decadal simulation times and capable of describing climate feedback mechanisms acting at the regional scale.

An additional consideration is that in order to run a RCM experiment, high frequency (e.g. 6-hourly) time dependent AOGCM fields are needed. These are not routinely stored because of the implied mass-storage requirements, so that careful coordination between global and regional modelers is needed to design nested RCM experiments.

The study of future impacts necessarily requires scenarios of climatic change, and, since the worst impacts of any future climate change are likely to arise from fine scale extremes in weather phenomena, these scenarios should also contain a high level of regional detail. Additional key science issues need to be investigated such as the importance of compatible physics in the nested and nesting models. Measures of uncertainty across the multiple runs will be developed by geophysical statisticians

Applying regional climate change scenarios to impact studies: Experiences in South America: The CREAS project

While results from regional model experiments of climate change have been available for about ten years, and regional climate modelers claim use in impacts assessments as one of their important applications, it is only quite recently that scenarios developed using these techniques have actually been applied in a variety of impacts assessments such as temperature extremes (Hennessy et al., 1998; Mearns, 1999); water resources (Wang et al., 1999; Stone et al., 2001, 2003; Wilby et al., 1997, Parnell and Barnett, 2004); agriculture (Mearns et al., 2000, 2001) and forest fires (Wotton et al. 1998). Prior to the past few years, these techniques were mainly used in pilot studies focused on increasing the temporal resolution and spatial scale (e.g., Mearns et al., 1997; Semenov and Barrow, 1997).

One of the most important aspects of this work is determining whether the high resolution scenarios actually lead to significantly different calculations of impacts compared to the coarser resolution GCM from which the high resolution scenario was partially derived. This aspect is related to the issue of uncertainty in climate scenarios, an issue not explicitly addressed by all of the studies cited above. In many articles the authors adopted the high resolution (RCM) scenarios without comments regarding the use of high resolution versus low resolution information.

An initiative from Brazil has been the implementation of CREAS (Regional Climate Change Scenarios for South America – Marengo, 2004). CREAS is being established as consequence of a GEF-Ministry of Environment/PROBIO lead by CPTEC in Brazil for studies on impacts of climate change in natural ecosystems in Brazil (PROBIO). Additional funding for CREAS comes from the GOF CLIMATE CHANGE & ENERGY PROGRAMME: BRAZIL: Using Regional Climate Change Scenarios for Studies on Vulnerability and Adaptation in Brazil and South America. This project aims to provide high resolution climate change scenarios in the three most populated basins in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures.

The downscaling of climate change scenarios follows the methodology developed by the Hadley Centre (Jones et al. 2004). This centre has developed a regional climate model HadRM3 that can be run on a PC and can be applied easily to any area of the globe to generate detailed climate-change predictions. This modeling system, PRECIS (Providing Regional Climates for Impacts Studies) is freely available to groups of developing countries so that they can develop climate-change scenarios at national centers of expertise (Jones et al. 2004).

The global models to be used are the Hadley Centre HadAM3P (Gordon et al. 2000, Cox et al.

1999, Pope et al. 2000). The HaDAM3P model included the atmospheric version of the Hadley Centre HadAM3P forced with the SST anomalies generated by the oceanic component of the HadCM3 coupled model, and the runs are available for the periods 1961-90 (present climate) and 2071-2100 for the IPCC TAR SRES A2 and B2 scenarios.

For the first task of CREAS (to be completed in May 2006), we used the HadAM3P AOGCM and three regional models (Eta/CPTEC, RegCM3, and HadRM3-PRECIS) that are being run at this time at CPTEC and USP. The RAMS models is going to be used at FUNCEME for downscaling of climate Change Scenarios in Northeast Brazil. The MM5 regional model is being run at the CIMA/UBA in Argentina for South America South of 20^{o}S also using the HadAM3P. This effort is part of the Argentinean contribution for the National Communication on Climate Change. The REMO regional model is being run at the Max Planck Institute in Germany using the ECHAM 5 AOGCM as boundary condition, and this effort is part of the EU-CLARIS project. All of this is illustrated in Fig. 1.

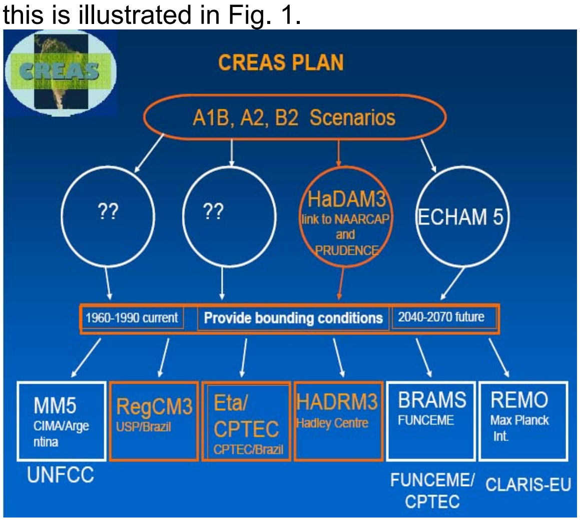

Fig.1: Schematic view of CREAS Phase I Circles shown the global models used, and squares show the regional models used for CREAS (in orange) and also as part of other initiatives from Argentina and the EU-CLARIS project (Marengo 2004).

The analysis of the global and regional models constitutes a multi-model approach that includes the analysis of each regional model and then using cluster analyses to identify groups with similar patterns, and additional techniques for weighting the influence of the different models. Statistical techniques such as empirical orthogonal function, correlation, and cluster analyses, etc., will be applied to model simulations as well as to observed data. Additional key science issues will be investigated such as the importance of compatible physics in the nested and nesting models. Measures of uncertainty across the multiple runs will be developed by geophysical statisticians.

Since much more of the uncertainty in regional climate change is derived from the global models than the regional models, the project would also concentrate its resources on fewer regional models and should get data from more global models. After tests we have selected 3 regional models for vulnerability and impact studies. Fig. 2 shows the strategy for CREAS. Detection studies are implemented from the regional climate change scenarios, and that includes validation, assessments and trends analyses for mean variables and extremes. After that, maps, CDs and other products will be produced. The climate change scenarios will also be used for development and applications, such as impacts of climate change in various sectors of society, vulnerability assessments and adaptation and mitigation measures. All these products will be then available to the society and the government.

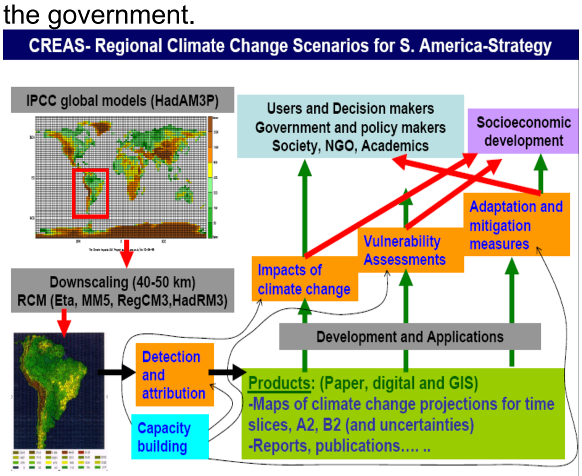

Fig. 2: Schematic view of CREAS project for regionalization of future climate change scenarios in South America and applications to various sectors of society (Marengo 2004).

Programs Exploring Regional Climate Change Scenarios and Multiple Uncertainties in other regions

Various international projects are already working with regional climate scenarios for studies of detection, and assessments of impacts and vulnerability. In Europe, the PRUDENCE-*Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects* (PRUDENCE 2004) and its successor ENSEMBLES projects and in North America, by the NARCCAP-*North American Regional Climate Change for Assessment Program* (Mearns et al. 2004). Both PRUDENCE/ENSEMBLES and NARCCAP use the HAdAM3P as global model that forces

various regional models from meteorological services and research institutions. Typically, a present day (e.g. 1960-1990) and a future climate (2070-2100) time slices are simulated to calculate changes in relevant climatic variables, and can be up-scaled to other time slices. Phase II of CREAS will use the HadGEM1 and ECHAM5 models on a revised and improved version of the Eta/CPTEC model, at 40 km resolution and RegCM3/USP model.
CREAS has strong links with NARCCAP and we are currently coordinating runs and analyses so we can compare and complement climate projections for the Americas. Various institutions in Brazil and South America have confirmed interests in the regional model output from CREAS. We expect collaboration from other institutions in Brazil and from universities and research centers from other countries in South America. Interactions are also expected with various sectors of the government that would need future climate change scenarios for applications and assessments studies (agriculture, human health, tourism, generation of hydroelectricity, etc).

CREAS Objectives:

1. To produce high resolution climate change scenarios for 2071-2100 for South America
2. To assess the uncertainty in South American regional climate change scenarios produced by various regional climate models.
3. To quantitatively assess the risks arising from changes in regional climate over South America,
4. To estimate changes in extremes like intense rainfall, heat waves, flooding and wind storms, by providing a robust estimation of the likelihood and magnitude of the changes
5. To demonstrate the value of the wide-ranging scenarios by applying them to impacts models focusing on effects on adaptation and mitigation strategies for key sectors (agriculture, conservation, hydroelectricity, health, tourism, etc.)
6. To provide climatic information usable to assess socio-economic and policy related decisions for which such improved scenarios could be beneficial, and to interact with government agencies, policy makers and stake holders for assessments of vulnerability

Policy-oriented research can address various questions, but will usually be aimed at providing advice on the range of possible climate change impacts on a system so that possible adaptations may be planned. Because the output of such research is linked to decision-making (clients will be mainly government and industry), it is very important that the climate scenarios be plausible and that key uncertainties be represented in the output. In such cases, use of high resolution may be considered essential if coarse resolution scenarios are a priori implausible (e.g., due to topographic effects or the inability to resolve extreme events), or may be considered not important if coarse resolution scenarios are plausible and the uncertainty in outcome associated with resolution is considered small relative to other uncertainties.
Perhaps the major contribution of the future regional climate change scenarios generated by CREAS will be the possibility of developing indices of vulnerability for key sector of the economy in Brazil to climate change, as well as the identification of socioeconomic indicators or climate change impacts. The major goal is to provide input for the development of a national policy of environmental and socioeconomic assessments of climate change impacts in key regions, such as natural ecosystems, large cities and economically important regions of Brazil and South America.

Some preliminary results of CREAS Phase I:

The HAdRM3 was run for the A2 scenario for the region south of 10S in Brazil, for 30 years, for the base line 1961-90 and the future 2071-2100 at annual time scale (de Mello and Marengo 2006). The maps shown in Fig. 3 exhibit a large warming in 2071-2100 for southern Amazonia and in the west central region of Brazil, up to 6^o C, while the rainfall anomaly maps shows that for the 2071-2100 period there is a tendency for a drier eastern Amazonia and Northeast Brazil, while regions such as southeastern and southern Brazil and parts of western Amazonia along the Andes show rainfall reduction.
This possible future climate scenarios would have a strong negative impact in most of the agriculture production especially in western central Amazonia, that is the region where major growing of soybean is detected, being this commodity one of the major exports in Brazil.
It is clear that maps like this could be used for the assessment of climate change impact on agricultural production, that at the end would be useful for assessments of vulnerability in food production and public policies of economic development, and food security.

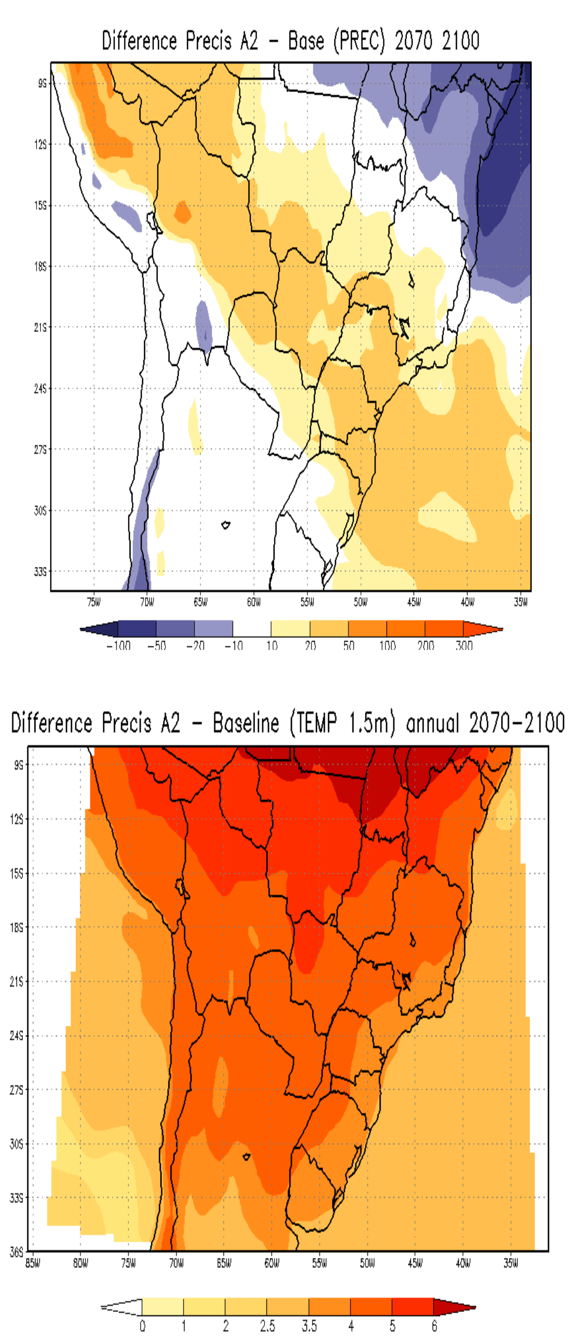

Fig. 3: Annual anomalies of rainfall (above) and air temperature (below) for South America south of 10 S, for the A2 scenario. The maps represent anomalies for the period 2071-2100 in relation to the baseline 1961-90. The scenarios were derived from the HadRM3 regional model. Color bars in the lower side of each panel indicate the anomalies of rainfall and temperature (de Mello Machado and Marengo 2006)

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References:

Cox, P., R. Betts, C. Bunton, R. Essery, P.R. Rowntree, and J. Smith, 1999: The impact of new land surface physics on the GCM simulation of climate and climate sensitivity. *Climate Dynamics* 15: 183-203.

De Mello, M.A. Marengo, J, 2006: Mudanças climáticas globais e seus prováveis efeitos sobre a agricultura brasileira. Submitted to Revista Brasileira de Meteorologia.

Dickinson, R.E., R.M. Errico, F. Giorgi and G.T. Bates, 1989: A regional climate model for western United States. *Clim. Change*, 15, 383-422.

Giorgi, F., 1990: Simulation of regional climate using a limited area model nested in a general circulation model. *J. Climate*, 3, 941-963.

Giorgi, F. and L.O. Mearns, 1991: Approaches to the simulation of regional climate change: a review. *Rev. Geophys.*, 29, 191-216.

Giorgi, F. and L.O. Mearns, 1999: Regional climate modelling revisited. An introduction to the special issue. *J. Geophys. Res.*, 104, 6335-6352.

Gordon, C., C. Cooper, C.A. Senior, H. Banks, J.M. Gregory, T.C. Johns, J.F.B. Mitchell and R.A. Wood, 2000: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics* 16: 147-168.

Hennessey, K.J., P.H. Whetton, J.J. Katzfey, J.L. McGregor, R.N. Jones, C.M. Page, and K.C. Nguyen, 1998: Fine Resolution Climate Change Scenarios for New South Wales. Annual mReport, 1997/98, CSIRO, Australia, 48pp.

Jones, R., Noguer, M., Hassell, D., Hudson, D., Wilson, S, Jenkins G., Mitchell, J (2004) Generating high resolution climate change scenarios using PRECIS. Met Office Hadley Centre, Exeter UK, 40 pp.

Mearns, L. (2004) NARCCAP North American Regional Climate Change Assessment Program A Multiple AOGCM and RCM Climate Scenario Project over North America. 12/17/2004. AGU Fall Meeting, San Francisco, USA.

Marengo, J (2004) Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade-

Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do Século XXI: CREAS (Cenários REgionalizados de Clima para América do Sul). Encontro dos coordenadores dos subprojetos apoiados pelo PROBIO, Brasilia, DF, 27 a 29 de Outubro 2004.

Mearns, L.O., T. Mavromatis, E. Tsvetsinskaya, C. Hays, and W. Easterling, 1999: Comparative responses of EPIC and CERES crop models to high and low resolution climate change scenarios. *J. Geophys. Res.*, 104(D6), 6623-6646.

Mearns, L. O., W. Easterling, C. Hays, and D. Marx, 2001: Comparison of agricultural impacts of climate change calculated from high and low resolution climate model scenarios: Part I. The uncertainty due to spatial scale. *Climatic Change*, 51, 131-172.

Parnell, W. P., and T. P. Barnett, (eds.) 2004: Special Issue of Climatic Change on The Department of Energy's Accelerated Climate Prediction Demonstration Project. *Climatic Change* (accepted, to appear 2004).

PRUDENCE (2004) Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects. Description of work. Available from http://prudence.dmi.dk.

Pope, V. D., M. L. Gallani, P. R. Rowntree and R. A. Stratton, 2000: The impact of new physical parametrizations in the Hadley Centre climate model -- HadAM3. *Climate Dynamics*, 16: 123-146.

Semenov, M.A. and E. Barrow, 1997: Use of a stochastic weather generator in the development of climate change scenarios. *Clim. Change*, 35, 397-414.

Stone, M. C., R. H. Hotchkiss, C. M. Hubbard, T. A. Fontaine, L. O. Mearns, and J. G. Arnold, 2001: Impacts of Climate Change on Missouri River Basin Water Yield. *J. of American Water Resources Association,* 37(5), 1119--1130.

Stone, M. C., R. H. Hotchkiss, and L. O. Mearns, 2003: Water yield responses to high and low spatial resolution climate change scenarios in the Missouri River Basin. *Geophys. Res. Lett.,* 30, 1186-1189.

Wang, Q.J., R.J. Nathan, R.J. Moran, and B. James, 1999: *Impact of climate Changes on the Security of the Water Supply of the Campaspe System*. Proceedings of the 25th Hydrology and Water Resources Symposium, Vol. 1, 6-8 July 1999, Brisbane, Institution of Engineers, Australia, Water99 Joint Congress, pp. 135-140.

Wilby, R.L. and T.M.L. Wigley, 1997: Downscaling general circulation model output: a review of methods and limitations. *Prog. Phys. Geography*, 21, 530-548.

Wotton, B.M., B.J. Stocks, M.D. Flannigan, R. LaPrise, and J-P Blanchet, 1998: Estimating future 2xCO2 fire climates in the boreal forest of Canada using a regional climate model. In: *Proceedings of Third International Conference on Forest Fire Research and the 14th Conference in Fire and Forest Meteorology*. University of Coimbra, Portugal, pp. 1207-1221.

Zorita, E. and H. von Storch, 1999. The analog method as a simple statistical downscaling technique: comparison with more complicated methods. *Journal of Climate*, 12, 2474-2489.