VAMOS and Anthropogenic Climate Change (ACC) in the Americas

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1. INTRODUCTION

The increased recognition of our changing climate has produced a growing demand for climate change information for use in integrated assessments of climate change. Rapid flow of climate-change information from the scientific realm to decision makers and water managers will be critical for planning (Milly *et al.* 2008) and adaptation. In the VAMOS context, the future interplay of societal and scientific aspects of climate change includes the need to identify and understand important processes that control monsoonal climates in the Americas, and how these processes interact with broader societal issues, such as impacts, vulnerability, and adaptation.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) recognized that current atmospheric-ocean general circulation models (GCMs) have some systematic biases, especially in the simulation of regional climate features in areas with complex terrain and in the tropics, both of which typify the American monsoon regions. Therefore, exactly how long-term global warming and changes in large-scale hydroclimatic patterns will manifest at smaller spatial and temporal scales remain as key problems for understanding and preparing for climate change. In this summary the VAMOS Anthropogenic Climate Change (ACC) task force has identified relevant scientific issues that need to be better addressed by the VAMOS community in order to make progress on ACC research and impacts in the Americas. Addressing these issues will hopefully provide a more physical basis for hypothesis testing related to climate change, leading to an increase in the credibility and use of climate change scenarios in the monsoon regions of the Americas. What follows is a summary of these science issues as they pertain to the N. and S. American monsoon systems. Given the early state of the research, this document refrains from drawing firm conclusions about climate change impacts on the American monsoons but, instead, seeks to identify issues requiring further investigation. Future reports by the VAMOS ACC task force will attempt to highlight such conclusions as they emerge from the research community.

2. RELEVANT SCIENTIFIC ISSUES

This summary report addresses the following priority scientific issues as they relate to assessing climate change impacts on the American monsoon systems:

1) Document observed trends in mean and extreme climate conditions (climate extremes will be more fully addressed by the *VAMOS Extremes task force*).
2) Improve simulation and understanding of major tropical and monsoon-related modes of variability including:
    a) Land-sea thermal contrast on monsoon dynamics
    b) Large-scale circulation and precipitation linkages
    c) Variability in mechanisms operating at diurnal (convective activity) and intraseasonal (low-level jets, Madden-Julian oscillation (MJO), tropical cyclones) timescales
    d) Land surface processes (surface energy and water fluxes) and predictability
3) Improve understanding and model simulation of interannual (El Niño/Southern Oscillation (ENSO)) and decadal (i.e., Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO)) climate variability and predictability
4) Improve understanding and simulation of aerosol-cloud interactions, radiative forcing, carbon cycle, and biogeochemical feedbacks, and land-cover and land use change in the monsoon regions
5) Expand the use of detection and attribution studies
6) Evaluate the performance and uncertainties of GCMs in the monsoon regions
7) Improve the use of regional climate model simulations and other climate downscaling techniques:
    a) Synthesize current status and future plans for model regionalization (downscaling) of model projections in the Americas
    b) Improve the open availability of multi-regional model ensembles for the Americas
8) Address needs for integrated information databases for climate change, impacts, and adaptation studies in the Americas

2.1 Document observed trends in mean and extreme climate conditions in the VAMOS regions (Extreme events will be more fully addressed by the *VAMOS Extremes task force*).

Allen and Ingram (2002) suggest that while global annual mean precipitation is constrained by the energy budget of the troposphere, extreme precipitation is constrained by the atmospheric moisture content, as predicted by the Clausius-Clapeyron equation. For a given change in temperature they predict a larger change in extreme precipitation than in mean precipitation. Similarly, Trenberth *et al.* (2005) point out that since the amount of moisture in the atmosphere is likely to rise much faster as a consequence of rising temperatures than the total precipitation, this should lead to an increase in the intensity of storms, offset by decreases in duration or frequency of events. Consistent with these theoretical results, there is early evidence of significant changes in the climate of the monsoon regions of the Americas.

In the NAM region, the annual frequency and annual amount of heavy precipitation increased significantly in the last 25 years of the XX century (Frich *et al.*, 2002; Groisman *et al.*, 2005; Alexander *et al.*, 2006), possibly in association with El Niño events and a positive phase of the PDO after 1976 (Englehart and Douglas, 2001; Hu and Feng, 2002; Gutzler, 2004; Englehart and Douglas, 2006; Zhu *et al*., 2007).

During the summer, the monsoon season has become shorter (Englehart and Douglas, 2006), and while the frequency of heavy precipitation events have not increased, the intensity of 'heavy' events has increased significantly in northwestern Mexico (Groisman *et al*., 2005; Englehart and Douglas, 2006; Cavazos *et al.*, 2008; Kunkel *et al*., 2008). Heavy precipitation in the mountains of the Sierra Madre Occidental (in the core monsoon region) significantly increased at the end of the 20th century largely due to the influence of tropical cyclone (TC) derived extreme rainfall during neutral conditions and La Niña summers, when the land-sea thermal contrast was positive (warmer monsoon region, cooler eastern Pacific) (Cavazos *et al*. 2008). Interestingly, Gochis *et al.* (2007) showed that trends in summer streamflow volumes across parts of western Mexico have been negative over the period of the 1950s and 1960s through the early 2000's, suggesting a complex interplay between different timescales of rainfall variability.

Among the documented temperature changes in the North American monsoon (NAM) region during the last quarter of the 20th century is a statistically significant increase in surface temperatures in the U.S. Southwest and northwest Mexico (Karoly and Wu 2005). Such an increase could potentially affect the land-sea thermal contrast and the monsoon anticyclone, as explained in more detail in Section 2a.

In the South American Monsoon System (SAMS) region, observational data of extreme maximum temperatures during the period 1960-2000 were developed by Vincent *et al.* (2005), Marengo *et al.* (2008), and Rusticucci and Barrucand (2004). At the regional scale, Dufek and Ambrizzi (2005) analyzed data from meteorological stations located in both urban centers in the State of São Paulo and in small cities in the countryside. Their results showed an increase in minimum temperatures associated with the reduction in the number of cold nights and the increase in warm nights during the period 1955-2002. In the Amazon and the south-east and south regions of Brazil, a significant increase in precipitation has been observed over the past 50 years (Marengo *et al.*, 2008a). Groisman *et al.* (2005) also identified systematic increases in mean total rainfall and rainfall extremes in the subtropical region, and in the south and northeast of Brazil Carvalho *et al.* (2002, 2004) noted that in the state of São Paulo more extreme rainfall events were observed during El Niño events, which are sensitive to the intensity of the South Atlantic Convergence Zone (SACZ). More recently, Dufek and Ambrizzi (2007) concluded that the significant increase in total annual precipitation in São Paulo during the period 1950-1999 was associated with an increase in rainfall intensity.

A direct relation between extreme events, particularly the most recent ones, and global warming linked to the atmospheric discharge and or ecosystems changes are not easily demonstrated. Nevertheless, the increase in extreme climate events over S. America that have occurred over the past years (Pezza and Simmonds 2005; Marengo *et al.*, 2008b, c; Zeng *et al.*, 2008, Cox *et al.*, 2008) suggest that the climate might be reacting to the energy increases associated with anthropogenic activities. Combined these initial works underscore the need for additional, mechanistic studies on how humans have influenced global climate and contributed to the divergence of the terrestrial climate system from otherwise ‘natural’ conditions.

2.2 Improve simulation and understanding of major tropical and monsoon-related modes of variability including:

a) Land-sea thermal contrast on monsoon dynamics
b) Large-scale circulation and precipitation linkages
c) Variability in mechanisms operating at diurnal (convective activity) and intraseasonal (low-level jets, Madden-Julian oscillation (MJO), tropical cyclones) timescales

2.2a. Land-sea thermal contrast on monsoon dynamics

As mentioned in Section 2.1a, the NAM region has experienced significant increases in surface temperatures during the last quarter of the 20th century (Karoli and Wu 2005). Observed late 20th century global warming has been attributed primarily to anthropogenic changes in radiative forcing of the climate system, with further warming of approximately 1^{o} to 4^{o} likely to occur in North America (including the NAM and Intra-America Seas regions) at the end of the 21st century (IPCC, 2007). Such an increase could potentially affect the land-sea thermal contrast, which is known to influence the position of the upper-level monsoon anticyclone and hence the onset and intensity of the monsoon rainfall. However, sea surface temperatures have also exhibited significant positive trends in the last quarter of the 20th Century (e.g., Hoyos *et al.*, 2006) which would likely counterbalance the land-sea thermal contrast. To date little is known about the trends in differential heating between the North American continent and the surrounding oceans. Therefore, exactly how increases in continental and ocean temperatures have affected (or will affect) the land-sea thermal contrast and its relation to monsoon dynamics and monsoon rainfall still requires further investigation.

2.2b. Large-scale circulation and precipitation linkages

As global warming is expected to result in more rapid warming over land than over the oceans, the continental-scale land-sea thermal contrast may become larger in summer and smaller in winter. Based on this, a simple idea is that the summer monsoon could be hypothesized to increase in strength while the winter monsoon may weaken in the future compared to the present. However, model results are not as straightforward as this simple consideration (Tanaka *et al.*, 2005) as they show a weakening of the tropical circulations by the late 21st Century as compared to the late 20th Century (IPCC, 2007, Ch. 3). Although, increased atmospheric moisture content associated with warming might be expected to lead to increased global mean precipitation, regional changes in moisture convergence patterns may lead to a drying of the subtropics and parts of the tropics (Kumar *et al.*, 2004; Neelin *et al*., 2006), and a further increase in precipitation in the equatorial regions (Held and Soden, 2006).

For the NAM region, the multi-model ensembles of the IPCC (2007) indicate that by end of the 21st Century mean temperature could increase between 2.5° and 4°C with respect to 1980-1999, if emissions continue at a similar rate as today. For the summer monsoon season it would imply higher maximum temperatures, more evaporation and possibly more intense heat waves

(Meehl and Tebaldi, 2004). With a more intense heating over the continental United States in JJA, the monsoon anticyclone could amplify and migrate farther north possibly influencing areas of Northwestern Mexico and in the Southwest United States. In the US Southwest the projected precipitation changes are small during the summer, but there is a large disagreement among the models on the projected sign, due in part to the different convective parameterizations and the low-resolution and inconsistent representation of topography in global models. Moreover, warmer winter/spring temperatures could produce less snow in the Rocky Mountains, more heavy rainfall, less annual runoff (Milly *et al.*, 2008), and a faster drying of the soil moisture, which may promote droughts and fires. The current hypothesis based on modeled future climate scenarios is that parts of the NAM and the Intra-America Seas regions may become drier and warmer on annual basis than they are today.

2.2c. Variability in mechanisms operating at diurnal (convective activity) and intraseasonal (low-level jets, Madden-Julian oscillation (MJO), tropical cyclones) timescales

Ongoing studies on climate changes in the South American monsoon suggest a weakening of the monsoon by the end of the 21st Century (Chase *et al*., 2003; and Wang and Ding, 2006), while the South American low level jet would be more intense and frequent, producing more frequent and intense rainfall events in southeastern South America (Soares and Marengo 2008, Marengo *et al.*, 2008a).

Simulation of the MJO in contemporary coupled models remains unsatisfactory; models underestimate the strength and coherence of convection and wind variability (Lin *et al.*, 2008). It has been suggested that inadequate representation in climate models of cloud radiative interactions and/or convection-moisture interactions may be responsible for some of the difficulties in simulating the MJO (IPCC, 2007, Chapter 8).

As mentioned above warmer SSTs in the tropics are presently expected and it is well known that El Niño like summers are associated with drier conditions and less tropical cyclones in the North Atlantic and Caribbean basins (e.g., Goldenberg and Shapiro, 1996; Emanuel *et al.*, 2007). However, the impact of global warming on tropical cyclones is still a matter of debate because the spatial resolution of the couple ocean-atmosphere models used in the recent IPCC assessment is generally not high enough to resolve tropical cyclones, and especially to simulate their intensity (IPCC, 2007, Chapter 8). More recent results from dynamical downscaling IPCC AR4 simulations (Emanuel *et al.* 2007) suggest that global warming should reduce the global frequency of hurricanes, though their intensity may increase in some locations. These simulations show potentially large changes in tropical cyclone activity in response to global warming, though the sign and magnitude of the changes vary a great deal from basin to basin and from model to model, reflecting large regional differences in the global model predictions as well as natural multidecadal variability (Emanuel *et al*., 2007).

2.3. Improve understanding and model simulation of interannual (ENSO) and decadal (i.e., PDO, and AMO) climate variability and predictability

The global monsoon systems all involve general circulation connections between the tropics and the subtropics that depend on many factors, from regional air-sea interactions and land processes (e.g., snow cover) to teleconnection influences (e.g., ENSO, PDO, AMO, etc.). In terms of ENSO prediction studies have demonstrated that a multi-model ensemble forecast has better skill than a comparable ensemble based on a single model. These multi-model projections of future climate (IPCC, 2007, Chapter 8) indicate a shift towards mean El Niño like conditions during the 21st century, with the eastern Pacific warming more than the western Pacific. However, there is a wide range of behavior in relation to the El Niño because most models are presently unable to adequately represent the structure and evolution of the Intertropical Convergence Zone (ITCZ), which remains a major source of error in the simulation the annual cycle in the tropics in most GCMs. Also, most models fail to adequately capture the current climatological zonal SST gradient in the equatorial Pacific and many models also have difficulty in capturing the correct phase locking between the annual cycle and ENSO. These shortcomings imply that most models incorrectly represent the dynamics of ENSO (Leloup *et al*., 2008) which ultimately affect the fidelity of predicted ENSO behavior.

Chase et al. (2003) and Wang and Ding (2006) examined changes in several indices of four major tropical monsoonal circulations (not including the S. American monsoon system) for the period 1950-2003 and found a consistent picture of significantly weakening monsoonal circulation. The SAMS is strongly influenced by ENSO (e.g., Lau and Zhou, 2003), and thus future changes in ENSO will induce complementary changes in the region. The relationship between ENSO and the N. American monsoon system for example exhibits marked long-term variability (Hu and Feng, 2002; Gutzler, 2004; Brito-Castillo *et al.*, 2002; Gochis *et al.*, 2007). These changes could possibly be explained by natural climate variability. However, to date few attribution studies have linked long-term, multi-decadal variability (e.g. PDO, NAO) to an increase of concentration of greenhouse gases (Shiogama *et al*., 2005), and simulations suggest that the observed variability includes a conspicuously large trend relative to the natural variation.

2.4. Improve understanding and simulation of aerosol-cloud interactions, radiative forcing, carbon cycle, and biogeochemical feedbacks, and land-cover change and land use in the monsoon regions.

2.4a. Aerosol-cloud interactions and radiative forcing

The Amazonian forest continues to suffer accelerated land use changes spanning over the last 4 decades, which has left 14% of the original forest area deforested. While several Brazilian ecosystems are vulnerable to climate change, Amazonia is a special case as it has been shown to exert significant influence on the climate system and because biomass burning emissions associated with deforestation is responsible for 74% of the Brazilian greenhouse gas emissions (MCT, 2005). Furthermore, Amazonia is a large carbon reservoir, storing around 100-150 tons of carbon per hectare, and the final destination of this carbon is critically important for the global carbon budget. Emissions from biomass burning in Amazonia have been shown to have a very significant climatic impact on large areas of South America because of both direct and indirect effects of aerosols, and the formation of lower tropospheric ozone.

Anthropogenic activities impacting the global concentration of greenhouse gases or changes in land use are apparent over portions of the SAMS region. Recent studies indicate that increased aerosol loading in the atmosphere may have strong impacts on monsoon evolution (Menon *et al*., 2002) through changes in local heating of the atmosphere and the land surface. Moreover, the uncertain role of aerosols in general and carbon aerosols in particular, complicates the nature of future projections of monsoon precipitation, particularly in the Asian and the S. American monsoon systems. If only the direct effect of the aerosol increase is considered, surface temperatures may not warm as much because the aerosols reflect solar radiation (e.g., Knutti, 2008). For this reason, land-sea temperature contrast may become smaller than presently occurs thereby weakening the summer monsoon circulation. However, precisely how regional circulation and rainfall changes will occur over S. America remain unclear. Comparatively, little is known about the impact of aerosols on the structure and evolution of the N. American monsoon.

Presently aerosol impacts on the NAM are unknown. While biomass burning does occur throughout portions of western and southern Mexico prior to monsoon onset, it is not thought to generate aerosol levels similar to those found in S. America or Asia.

2.4b. Land-cover and land use change

Climate change and deforestation affect hydrological cycles on various time and space scales. Brazil is vulnerable to climate change and especially to extreme climate events such as intense droughts and floods (Marengo, 2008). Projected changes in precipitation patterns associated with climate change show a reduction on the order of 10-15 percent of the Amazon River discharge between 2041-2060, under the IPCC's A1B scenario, compared to the period 1900-1970 (Milly *et al*., 2005). In the La Plata Basin, positive tendencies in precipitation patterns have been observed for the past 50 years (Salati *et al.*, 2007), and there exist tendencies towards increased river discharge in the projected climate change scenarios (Milly *et al.,* 2005; UK Met Office, 2005). In the Amazon, the temperature rise is expected to cause greater evapotranspiration, leading to the acceleration of the hydrological cycle (Case, 2006), and greater loss of soil moisture, with potential alterations in the Amazonian biome (Oyama and Nobre, 2003; Salazar *et al*., 2007, IPCC, 2007) and consequences for the regional rainfall regime. There is also the potential for a positive feedback process towards increasing dryness if there will be an increase in the dry season length, as some climate models suggest (Nijseen *et al*., 2001). Rapid changes in land cover in these regions have the potential to exacerbate shifts in regional climate and the regional hydrologic response to monsoon rainfall.

The role of vegetation and land cover is presently thought to play a significant role in modulating the N. American monsoon throughout modulation of land surface fluxes and moisture recycling to the atmosphere. However, it is not yet clear how expected changes in land cover, which are also relatively uncertain, will impact regional precipitation processes.

2.5. Expand the use of detection and attribution studies

Although the terms "detection" and "attribution" are technically linked, they have distinct objectives. The detection of climate change is a process that uses statistical method to show that climate has changed but it does not discuss the causes of this change. Attribution of the climate change is a process that establishes the most probable cause of the detected change with a determined level of confidence. Attribution as well as detection depends directly on observational data and numerical modeling, in particular for the studies of attribution that have great dependence on climate modeling (see Chapter 9, IPCC, 2007).

Practically all over the globe, rates of warming have been observed particularly in the distribution of minimum temperatures throughout the 20th century. The extremes in minimum temperature show a tendency towards warming, albeit inferior to that observed for the maximum temperature (Alexander *et al.,* 2005).

A common conclusion from the variety of studies carried out by means of data analysis or simulations using GCMs (e.g., Stouffer *et al.*,1994) over the past 15 years is that much of the observed warming cannot be explained exclusively by natural factors (Santer *et al*.,1995, 1996a,b,c; Hegerl *et al*., 1996, 1997, 2000; Hasselmann, 1997; Barnett *et al*., 1999; Tett *et al*., 1999; Stott *et al*., 2000). A substantial quantity of anthropogenic influence, in the form of greenhouse gas emissions and land cover change is necessary to explain the warming. However, most existing studies fall short in confidently attributing trends in regional precipitation patterns, where present, particularly in monsoon regions. As such, there has been little if any work published to date on the attribution of specific changes in regional precipitation to climate change or other possible mechanisms.

2.6. Evaluate the performance and uncertainties of GCMs in the monsoon regions (skill and metrics)

The AR4-IPCC recognized that GCMs still possess some systematic biases, especially in the simulation of regional precipitation in areas with complex terrain and in the tropics, such as the monsoon regions. The IPCC report dealt with the problem of inconsistent predictions, resulting from the use of different models, by taking the average of all models as the best estimate for future change (Glecker *et al.*, 2008; Reichler and Kim, 2008). At global scales, the multi-model ensembles outperformed the outcome of any individual climate model possibly because different models have differing strengths and weaknesses (IPCC, 2007). Recently, objective evaluation of regional precipitation trends has exploded with the wide availability of model simulation results of the CMIP3 database (Meehl *et al.*, 2006). One important area of research in this effort is the design of metrics to test the ability of models to simulate well-observed features of the current climate (Brekke *et al.,* 2008; Glecker *et al*., 2008; Leloup *et al*., 2008; Reichler and Kim, 2008). Such metrics can provide guidance about overall strengths and weaknesses of individual models, as well as the general state of modeling.

In the NAM region, only few studies (Ruiz-Barradas and Nigam, 2006; Liang *et al.,* 2008, and Lin *et al.*, 2008; Montero-Martinez and Perez-Lopez, 2008) have evaluated few metrics based on intraseasonal to interannual rainfall variability using several of the IPCC models and these studies found a wide range of skill among models leading to little consensus. Therefore, it is critical that the *VAMOS ACC task force* develops common process-oriented metrics to examine the ability of the GCMs in the N. American monsoon region.

Leloup *et al.* (2008) used self-organizing maps (SOM) also called Kohonen maps to compare models and observations in representing not only ENSO patterns but also its characteristics during the 20th Century. This type of methodology significantly reduces the size of the climate model database, preserving a topological order of the input data. It is currently used to evaluate the performance of GCMs in the SAMS region.

For South America Boulanger *et al.* (2006), Vera *et al.* (2006), and Boulanger *et al.* (2007) analyzed a subset of CMIP3 climate simulations from the IPCC-AR4 to assess their ability in reproducing observed climatological seasonal temperature and precipitation in South America during the second half of the 20th Century. Changes in simulated model climatology for several climate change scenarios (SRESB1, SRESA1B and SRES A2) for the 21st Century were also evaluated. Results showed that the model skill in simulating temperature is relatively poor in the southern tip of South America, along the Chilean and Peruvian coasts, and in the northern coasts of South America, but it quite reasonable in the SAMS region. Moreover, models are able to reproduce the main features of the seasonal cycle of precipitation over South America, although the precipitation in the SACZ region and the precipitation maximum over southeastern South America observed during the cold season are not well- represented. There is a general consensus among models that the temperature changes in the SAMS region will range from 2°C to 4°C with an increase in the seasonal cycle amplitude and that precipitation changes are mainly characterized by: i) an increase of summer precipitation over southeastern subtropical South America; ii) a reduction of winter precipitation over most of the continent; and iii) reduction of precipitation in all seasons along the southern Andes.

2.7. Improve the use of regional climate model simulations and other climate downscaling techniques:

a) Synthesize current status and future plans for model regionalization (downscaling) of model projections in the America
b) Improve the open availability of multi-regional model ensembles for the Americas

2.7a. Synthesize current status and future plans for model regionalization (downscaling) of model projections in the Americas

Within the impacts and adaptation community (e.g. agriculture, water resources management, health, among others) there is a growing move toward integrated assessment, wherein regional climate change projections form a principal factor for decision support systems aimed at reducing vulnerability. At present the regional projections are perhaps the weakest link in this process and the bulk of information readily available for policy and resource managers is largely derived from Global Climate Models (GCMs). Current GCMs have significant limitations due to their coarse spatial resolution, with grid sizes of ~150 km to 350 km. Consequently GCMs are limited in their representation of regional processes, terrain features, clouds, and precipitation, which lead to uncertainties in the magnitude and timing of predicted climate change. 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. For example, there is a need to address the lack of user knowledge in the meaning of assessment of climate projections and uncertainties in GCM fields that will be transmitted to regionalization tools. The cascade of uncertainty in regional climate prediction needs to be understood (WGCM11, 2007) in order to properly establish confidence in climate projections. A 'metrics-based' assessment is needed to quantify GCM skill and identify the errors/uncertainty in the large scale circulation being transferred to the regional scale before using regionalization techniques for climate change (see Section 2.6). Two-tiered approaches have produced interesting results in seasonal forecast projections; this could be a possible solution to perform regional simulations with better skill taking advantage of the high-resolution and physics of regional models. Such an issue is under discussion for South America in the FP7 European Project CLARIS LPB.

In view of the pressing need for regional projections, dynamical and statistical downscaling techniques have been developed to overcome some of the GCM regional biases and their spatial limitations. The "added value" provided by the regionalization techniques will depend on the spatial and temporal scales of interest, as well as on the variables concerned and on the climate statistics required. A review of the different downscaling methods can be found in Wilby and Wigley (1997), and Giorgi *et al*. (2004), as well as in the IPCC Third Assessment Report (Giorgi *et al*., 2001, Mearns *et al*., 2001), and the IPCC Fourth Assessment Report (Christensen *et al.*, 2007b).

Dynamical downscaling in South America has been developed to better understanding of the physical processes in the atmosphere, as well as in weather and climate forecasting (Seluchi and Chou, 2001; Nicolini *et al*., 2002; Chou *et al*., 2002; Seth and Rojas, 2003; Misra *et al*., 2003; Chou *et al*., 2004). The importance of regional climate change scenarios for impacts and adaptation studies remains to be thoroughly explored in South America. High resolution scenarios developed from regional climate models have been obtained in various parts of the world: China (Zhang *et al*., 2006), Pakistan (Islam and Rehman, 2007), Europe (Christensen and Christensen, 2003; Frei *et al.*, 2006), and in South America (Nuñez *et al.*, 2006, Marengo and Ambrizzi 2006, Ambrizzi *et al.*, 2007, Marengo *et al.*, 2007, 2008a; Solman *et al.*, 2007). However, to date, much of the work remains at the level of methodological development. Climate change projections that are tailored to the needs of the impacts community, and which demonstrate convergence of the projections across different forcing GCMs, are only now beginning to become more available.

Recognizing that multiple GCMs are required to provide comprehensive regional climate scenarios, current projects in Europe (ENSEMBLES, Hewitt and Griggs, 2004) and North America (NARCCAP, Mearns *et al*., 2004) have downscaled several GCMs' projections to provide high resolution climate change scenarios for different regions. These are the most advanced regional projects delivering detailed climate scenarios and whilst the output is still not comprehensive it has had a significant impact in raising awareness of the potential seriousness of climate change by providing plausible high resolution projections of future climates, which are being used in impacts models helping to lay the methodological basis for future adaptation studies.

A similar initiative has been recently implemented in South America, CREAS (*Regional Climate Change Scenarios for South America* – Marengo *et al*., 2008a). It aims to provide high resolution climate change scenarios in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures. CREAS runs three regional models nested in HadAM3P (a GCM used in PRUDENCE): Eta for Climate Change Studies – Eta CCS - (Pisnitchenko and Tarasova 2007), RegCM3 (Ambrizzi *et al.*, 2007) and HadRM3P (Jones *et al*., 2004, Marengo *et al*., 2008). CREAS will explore issues such as: the challenge of using regional climate projections to develop plausible scenarios for future changes at daily time scales for extreme events; an assessment of current methods of scenario development for regions where data is available; assessments of vulnerability in regions and key sectors in South America.

PRECIS and its model HadRM3P have been used to develop regional climate change scenarios worldwide (e.g. Tadross *et al*., 2005; Rupa Kumar *et al*., 2006; Xu *et al*., 2006b; Islam and Rehman 2007) including studying extremes (Zhang *et al*., 2007), and in South America (Marengo *et al.*, 2008; Soares and Marengo, 2008). The use of regional climate models in developing countries is also being expanded by the development of portable models for different needs (e.g. ICTP Regional Climate Research NETwork (RegCM), PRECIS, RSM, and the CMIP3-statistical downscaling-California). One recent study using both global and regional models has shown that the northern portions of the N. American monsoon system stand out as a potential 'hot spot' for climate change (Diffenbaugh *et al.*, 2008). In South America downscaling experiments have been performed for the entire continent or for individual countries using the RegCM3, PRECIS, Eta CCS and MM5, enabling local scientists to help formulate future perspectives on climate change by conducting regional climate model experiments. Another statistical downscaling method (CHAC; D'Onofrio *et al*., 2008; Menendez *et al*., 2008) has been developed in the framework of the FP6 European Project CLARIS ("A Europe-South America Network for Climate Change Assessment and Impact Studies"; Boulanger *et al*., 2008). In the framework of the FP7 CLARIS LPB (La Plata Basin) Project, the downscaling technique will soon be available via a web interface for climate change projections at local weather stations.

2.7b. Improve the open availability of multi-regional model ensembles for the Americas

Currently, Ed Maurer in California developed the statistical downscaled WCRP-CMIP3 climate projections over the contiguous United States and Northern Mexico (northward of 25^{o}N at 1/8^{o} spatial resolution (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections). The archive contains fine-resolution translations of 112 contemporary climate projections from the CMIP3 dataset for the 1950-2100 period. Maurer and Lettenmaier have interest in producing CMIP3-statistical downscaled projections for all Mexico.

A dynamical downscaling dataset available for the Intra-America seas region is the PRECIS-CARIBE (http://precis.insmet.cu/Precis-Caribe.htm) that covers all the Caribbean and half of Mexico (from 100W to the Caribbean). Unfortunately, it does not include the core monsoon in Northwestern Mexico. It is necessary that another institution be in charge of the PRECIS output covering the entire NAM region. Ideally, it would be good to have several dynamical downscaling options of the CMIP3 projections to overcome some of the regional model biases, as the CREAS data set in South America.

As explained in Section 2.6, CREAS is a dynamical downscaling dataset available for South America (http://www.cptec.inpe.br/mudancas_climaticas); it uses the A2 and B2 emission scenarios for 2070-2100 from the RegCM3, PRECIS and Eta CCS models. They do include the core monsoon in South America.

One recommended activity for VAMOS is to attempt to synthesize the findings from several of the aforementioned climate downscaling efforts currently underway.

2.8. Needs for integrated information databases for climate change, impacts, and adaptation studies in the Americas

Increased recognition of our changing climate has produced a growing demand for climate change information that can be used in regional integrated assessments. Rapid flow of climate-change information from the scientific realm to decision makers and water managers will be critical for planning (Milly *et al.* 2008), adaptation, and the assessment of impacts and vulnerability. Observations of sufficient detail and scope are required to improve models and to ensure that processes can be elucidated, predicted and projected. Therefore, there is the need to create or improve regional databases that include observations, model simulations, and regional downscaling simulations, for impact assessment studies.

It is worth pointing out that the FP7 European Project CLARIS LPB will address most of the issues described in the present document with a focus on La Plata Basin in S. America. Indeed, the CLARIS LPB Project aims at predicting the regional climate change impacts on La Plata Basin in South America, and at designing adaptation strategies for land-use, agriculture, rural development, hydropower production, river transportation, water resources and ecological systems in wetlands. Although regionally focused, many activities may lead to collaborations with scientists in other VAMOS regions and a transfer of expertise between the different VAMOS regions involving the participation of European scientists.

References

Alexander, L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. R. Kumar, J. Ravedekar, G. Griffiths, L. Vincent, D.B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J.L. Vazquez-Aguirre, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res*., **111**, DO5109.

Allen, M. R., and W. J. Ingram, 2002: Constraints on future changes in climate and the hydrologic cycle. *Nature*, **419**, 224-232.

Ambrizzi, T., R. Rocha, J. A., Marengo, I. Pisnitchenko, L. and Alves, 2007: Cenários regionalizados de clima no Brasil para o Século XXI: Projeções de clima usando três modelos regionais. Relatório 3, MINISTÉRIO DO MEIO AMBIENTE - MMA, SECRETARIA DE BIODIVERSIDADE E FLORESTAS –SBF, DIRETORIA DE CONSERVAÇÃO DA BIODIVERSIDADE – DCBio Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade - Sub projeto: Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do Século XXI. Brasília, Fevereiro 2007.

Boulanger, J.-P., Fernando Martinez, and Enrique C. Segura, year ??. : Projection of future climate change conditions using IPCC simulations, neural networksand Bayesian statistics.Part 2: Precipitation mean state and seasonal cycle in South America. *Clim. Dyn.*, **28**, 255–271, DOI 10.1007/s00382-006-0182-0.

Boulanger, J.-P., Fernando Martinez, and Enrique C. Segura, Year ??: Projection of future climate change conditions using IPCC simulations, neural networks and bayesian statistics.Part 1: Temperature mean state and seasonal cycle in South America. *Clim. Dyn.*, **27**, 233-259, DOI 10.1007/s00382-006-0134-8.

Boulanger, J.-P., G. Brasseur, A. F. Carril, M. Castro, N. Degallier, C. Ereño, J. Marengo, H. Le Treut, C. Menendez, M. Nuñez, O. Penalba, A. Rolla, M. Rusticucci, and R. Terra, 2008: The European CLARIS Project: A Europe-South America Network for Climate Change Assessment and Impact Studies, *Climatic Change*, CLARIS Special issue. *In review*.

Brekke, L.D., M. D. Dettinger, E. P. Maurer y M. Anderson, 2008: Significance of Model Credibility in estimating Climate Projection Distributions for Regional Hydroclimatological Risk Assessments. *Climatic Change*. ***89 (3*****):** 371 -394.

Brito-Castillo L, A. Leyva-Contreras, A. V. Douglas, D. Lluch-Belda, 2002 : Pacific-decadal oscillation and the filled capacity of dams on the rivers of the Gulf of California continental watershed. Atmosfera, 15: 121–138.

Carvalho, L.M.V., C. Jones, and B. Liebmann, 2002: Extreme Precipitation Events in Southeast South America and Large-Scale Convective Patterns in the South Atlantic Convergence Zone. *J. Climate*, **15**, 2377-2394.

Carvalho, L. M. V., C. Jones, and B. Liebmann, 2004: The South Atlantic Convergence Zone: Intensity, Form, Persistence, Relationships with Intraseasonal to Interannual Activity and Extreme Rainfall. *J. Climate*, **17**, 88-108.

Cavazos, T., C. Turrent, and D. P. Lettenmaier, 2008: Extreme precipitation trends associated with tropical cyclones in the core of the North American monsoon. *Geophys. Res. Lett.* doi:10.1029/2008GL035832, **35**, L21703.

Christensen, J.H. and O.B. Christensen, 2003: Climate modeling: severe summertime flooding in Europe. *Nature*, **421**,805-806.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007a: Regional Climate Projections. In: Climate Change 2007:The Physical Science Basis. Chapter 11, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Chou, S. C., J. F. Bustamante, J. L. Gomes, 2004: Previsões sazonais utilizando o modelo Eta/CPTEC sobre América do Sul. Proc. XIII Cong. Bras. de Meteorologia, Fortaleza, Brasil, (in CD-ROM).

Chou, S. C.; C. A. Tanajura, Y. Xue, C. A. Nobre, 2002: Validation of the coupled Eta/CPTEC/SSiB model over South America. *J. Geophys. Res.*, **107**, n. D20, p. doi:10.1029/2000JD000270, Oct. 2002. 34, 37.

Cox, P. M., P. P. Harris, C. Huntingford, R. A. Betts, M. Collins, C. D. Jones, T. E. Jupp, J. A. Marengo, C. A. Nobre, 2008: Increase risk of Amazonian Drought due to decreasing aerosol pollution. *Nature* (London). , v.453, p.212 - 216.

D'onofrio, A., J.-.P Boulanger, and E. C. Segura, 2008 : A weather pattern classification system for regional climate downscaling of daily precipitation and temperature, *Climatic Change*, CLARIS Special issue. *In review*.

Diffenbaugh, N. S., F. Giorgi, and J. Pal, 2008: Climate change hotspots in the United States. *Geophys. Res. Lett*., **35**, L16709, doi:10.1029/2008GL035075.

Dufek, A. S., T. Ambrizzi, 2007: Precipitation variability in Sao Paulo State, Brazil. *Theoretical and Applied Climatology*, **1**, 1-12.

Emanuel, K., R. Sundararajan, and J. Williams, 2007 : Hurricanes and global warming. Results from downscaling IPCC AR4 simulations. *Bull. Amer. Meteor. Soc*., March, 347-367.

Englehart, P.J. and A.V. Douglas, 2001: The role of eastern North Pacific tropical storms in the rainfall climatology of western Mexico. *Int. J. Climatology*, **21**, 1357–1370.

Englehart, P.J., and A.V. Douglas, 2006: Defining Intraseasonal Rainfall Variability within the North American Monsoon. *J. Climate*, **19**, 4243–4253.

Frei, C., R. Scholl, S. Fukutome, J. Schmidli and P. L. Vidal, 2006: Future change of precipitation extremes in Europe, 2006: Intercomparison of scenarios from regional climate models, *J. Geophys. Res*., **111**, D06105, doi:10.1029/2005JD005965.

Frich, P., L.V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. Klein Tank, and T. Peterson, 2002: Observed coherent changes in climate extremes during the second half of the twentieth century. *Clim. Res.*, **19**, 193-212.

Giorgi, F., Bi X, J.S. Pal, 2004: Mean, interannual variability and trends in a regional climate change experiment over Europe. I: present day climate (1961-1990). *Clim. Dyn*. 22:7333-756.

Groisman, P. Y., R.W. Knight, D.R. Easterling, T.R. Karl, G.C. Hegerl, V.N. Razuvaev, and N. Vyacheslav, 2005: Trends in intense precipitation in the climate record. *J. Climate*, **18**, 1326–1350.

Gleckler, P. J., K. E. Taylor, and C. Doutriaux, 2008: Performance metrics for climate models. *J. Geophys. Res*., **113**, D06104.

Gochis D. J., L. Brito-Castillo, and W. J. Shuttleworth, 2007: Correlations between sea-surface temperatures and warm season streamflow in northwest Mexico, *Int. J. Climatol*., **27**, 883-901.

Groissman, P., P. Knight, D., Easterling, T. Karl, G. Hegerl, V. Razuvaek, 2005: Trends in Intense Precipitation in the Climate Record, *J. Climate*, **18**, 1326-1350.

Gutzler D.S, 2004: An index of interannual precipitation variability in the core of the North American monsoon region. *J. Climate,* **17**, 4473–4480.

Held, I. M., and B. J. Soden, 2006 : Robust ressponses of the hydrological cycle to global warming. *J. Climate*, **19,** 5686-5699.

Hewitt C. D. and D. J. Griggs 2004: Ensembles-Based Predictions of Climate Changes and Their Impacts. *Eos Transactions* AGU **85**(52): 566. DOI: 10.1029/2004EO520005

Hoyos, C. D., P. A. Agudelo, P. J. Webster, and J. A. Curry, 2006 : Deconvolution of the factors contributing to the increase in global hurricane intensity. *Science*, **312**, 94-97.

Hu, Q., and S. Feng, 2002: Interannual rainfall variations in the North American summer monsoon region : 1900-98. *J. Climate*, **15**, 1189-1202.

IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of the Working Groups I, II, and III to the Fourth Assessment Report of the IPCC (Pachauri, R.K. and A. Reisinger, A. (Eds.). IPCC, Geneva, Switzerland, 104 pp. (Chapters 3, 8, 9, and 10).

Islam, S and N. Rehman, 2007: Future change in the frequency of warm and cold spells durations over Pakistan simulated by the PRECIS regional climate Model, Submitted, *Climatic Change.*

Jones, R. G., M. Noguer, D. Hassell, D. Hudson, S. Wilson, G. Jenkins, and J. Mitchell, 2004: Generating high resolution climate change scenarios using PRECIS, report, Met Off. Hadley Centre, Exeter, UK.

Karoly, D. J., and Q. Wu, 2005: Detection of regional surface temperature trends, *J. Climate*, 18, 4337-4343.

Knutti, R., 2008 : Why are climate models reproducing the observed global surface warming so well ?. Geophys. Res. Lett., 35, L18704, doi :10.1029/2008GL034932.

Kunkel, K. E., P. D. Bromirski, H. E. Brooks, T. Cavazos, A. V. Douglas, D. R. Easterling, K. A. Emanuel, P. Ya. Groisman, G. J. Holland, T. R. Knutson, J. P. Kossin, P. D. Komar, D. H. Levinson, and R. L. Smith. 2008. Chpater 2. Observed changes in weather and climate extremes, in *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North*

America, Hawaii, Caribbean, and U. S. Pacific Islands. T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray (Eds.). A Report of the U. S. Climate Change Program and the Subcommittee on Global Change Research, D. C.

Leloup, J., M. Lengaigne, and J.-P. Boulanger, 2008: Twentieth Century ENSO characteristics in the IPCC database, *Clim. Dyn.*, **30**, 277-291, DOI 10.1007/s00382-007-0284-3, 2008.

Liang, X.-Z., J. Zhu, K.E. Kunkel, M.Ting, and J.X.L. Wang, 2008: Do CGCMs simulate the North American monsoon precipitation seasonal-interannual variations. *J. Climate*, **21**, 4424–4448.

Lin, J. L., B. E. Mapes, K. M. Weickmann, G. N. Kiladis, S. D. Schubert, M. J. Suarez, J. T. Bacmeister, and M.-I. Lee, 2008: North American monsoon and associated intraseasonal variability simulated by IPCC AR4 coupled GCMs. *J. Climate*, **21**, 2919–2937.

Marengo, J., and T. Ambrizzi, 2006: 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. *Proceedings of 8 ICSHMO*, Foz do Iguaçu, Brazil, April 24-28, 2006, p. 291-296.

Marengo, J. A., L. Alves, M., Valverde, R., Rocha, and R. Laborbe, 2007: *Eventos extremos em cenários regionalizados de clima no Brasil e América do Sul para o Século XXI: Projeções de clima futuro usando três modelos regionais*. ***Relatório 5*,** Ministério do Meio Ambiente - MMA, Secretaria de Biodiversidade e Florestas – SBF, Diretoria de Conservação da Biodiversidade – DCBio Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade - Sub projeto: Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do Século XXI. Brasília, Fevereiro 2007.

Marengo,, J. A., R. Jones, L. Alves, M. Valverde, 2008a: Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. International Journal of Climatology, *In press*, 2008c.

Marengo, J. A., C. Nobre, J. Tomasella, M. Oyama, G. Sampaio, Camargo, Helio, Alves, Lincoln Muniz, R. Oliveira, 2008b: The drought of Amazonia in 2005. *J. Climate*. , v.21, p.495 - 516,

Marengo, J. A., C. Nobre,, J. Tomasella, M. Cardoso, and M. Oyama 2008c: Hydro-climatic and ecological behavior of the drought of Amazonia in 2005. Philosophical *Transactions of the*

Con formato: Inglés Estados Unidos

Royal Society of London. Series A, Mathematical and Physical Sciences, 21B, pp 1-6.

MCT, 2005: Inventário Nacional de emissões de gases de efeito estufa. Ministério de Ciência e Tecnologia, Ministério da Ciência e Tecnologia.

Mearns, L. O., M. Hulme, T. R. Carter, R. Leemans, M. Lal, and P. Whetton, 2001: Climate Scenario Development (Chapter 13). In *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the IPCC [Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson (eds.)]. Cambridge U. Press: Cambridge, pp. 583-638.

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.

Meehl, G. A., J. M. Arblaster, and D. M. Lawrence, 2006: Monsoon regimes in the CCSM3. *J. Climate*, **19**, 2482-2495.

Menéndez, C. G., M. de Castro, J.-P. Boulanger, A. D'Onofrio, E. Sanchez, A.A. Sörensson, J. Blazquez, A. Elizalde, D. Jacob, H. Le Treut, Z.X. Li, M.N. Núñez, S. Pfeiffer, N. Pessacg, A. Rolla, M. Rojas, P. Samuelsson, S.A. Solman, and C. Teichmann, 2008 : Downscaling extreme month-long climate anomalies in southern South America, *Climatic Change*, CLARIS Special issue. *In review*.

Milly, P.C.D., K. A. Dunne,; A. V. Vecchia, 2005: Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438**, 347-350.

Milly, P. C. D., J. Betancourtm M. Falkenmark, R. M. Hirsch, Z. W, Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer, 2008: Stationarity is dead: Whither water management? *Science*, **319**, 573-574.

Misra, V., P. A. Dirmeyer, B. P. Kirtman, 2003: Dynamic Downscaling of Seasonal Simulation over South American. *J. Climate*, 2003, 16, 103-117.

Montero-Martínez, M. and J. L. Pérez-López. 2008. Regionalización de proeyecciones climáticas en México de precipitación y temperatura en superficie usando el método REA para el Siglo XXI. *En Efectos del cambio climático en los recursos hídricos de México, Volumen II*. Polioptro F. Martínez Austria y Ariosto Aguilar Chávez (Eds.), IMTA, México, ISBN: 978-607-7563-01-3, pp 11-21.

Neelin, J. D., M. Muncich, H. Su, J. E. Meyerson, and C. E. Holloway, 2006: Tropical drying trends and global warming models and observations. *Proc. Natl. Acad. Sci.* USA, **103**, 6110-6115.

Nicolini, M., P. Salio, J. J. Katzfey, J. L. McGregor, A. C. Saulo, 2002: January and July regional climate simulation over South American. *J. Geophys. Res*., 2002, 107, NO. D22, 4637.

Nuñez, M. S. Solman and M. F. Cabré, 2006: Mean climate and annual cycle in a regional climate change experiment over Southern South America. II: Climate change scenarios (2081-2090), *Proceedings of 8 ICSHMO*, Foz do Iguaçu, Brazil, April 24-28, 2006, p. 325-331.

Nijssen, B., G. M. O'Donnell, A. F. Hamlet, and D. P. Lettenmaier, 2001: “Hydrologic sensitivity of global rivers to climate change”. *Climate Change*, **50**(1-2), 143-175.

Oyama, M.D., and C.A. Nobre, 2003: A new climate-vegetation equilibrium state for Tropical South America, *Geophys. Res. Lett*., **30**(23), 2199, doi:10.1029/2003GL018600.

Pezza, A. B., I. Simmonds, .2005: The first South Atlantic hurricane: Unprecedented blocking, low shear and climate change.. *Geophys. Res. Lett*., **32**, p. 10.1029/2005GL0.

Pisnitchenko, I.A., T.A. Tarasova, 2007: The new version of the Eta regional model developed for climate-change simulations. Submitted to *Meteorological Applications*.

Reichler, T., and J. Kim, 2008: How Well do Coupled Models Simulate Today's Climate? *Bull. Amer. Meteor. Soc*., **89 (3),** 303-311.

Ruiz-Barradas, A., and S. Nigam, 2006: IPCC's Twentieth-Century climate simulations: Varied representations of North American hydroclimate variability. *J. Climate*, **19**, 4041-4058.

Rupa Kumar, K., A. K. Sahai, K. Krishna Kumar, S. K. Patwardhan, P. K. Mishra, J. V. Revadekar, K. Kamala, and G. B. Pant, 2006 : High-resolution climate change scenarios for India for the 21st century. *Current Science*, **90**, 334-345.

Rusticucci, M and M. Barrucand, 2004: Observed trends and changes in temperature extremes in Argentina. *J. Climate*, **17**, 4099-4107.

Salati, E, T. Campanhol, N. V. Nova, 2007: Tendências de Variações Climáticas para o Brasil no Século XX e Balanços Hídricos para Cenários Climáticos para o Século XXI. In: *Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade*, 2007.

Salazar, L.F., C. A. Nobre, and M. D. Oyama, 2007: “Climatic change consequences on the biome distribution in tropical South America". *Geophys. Res. Letts*, **34**, L09708, doi:10.1029/2007GL029695.

Seluchi, M. E., and S. C. Chou, 2001: Evaluation of two Eta/CPTEC Model versions for weather forecast over South America. *Geofísica Internacional*, 40, 219-237.

Seth, A.; M. Rojas, 2003: Simulation and sensitibity in a nested modeling system for South America. Part I: reanalysis boundary forcing. *J. Climate*, **16**, 2437-2453.

Soares, W.R,, J. Marengo, 2008: Assessments of Moisture Fluxes East of the Andes in South America in a Global Warming Scenario. *Int. J. of Climatology*. *In Press*

Solman, S, M. N. Nuñez, and M. F. Cabre, 2007: Regional climate change experiments over southern South America. I: present climate, *Clim. Dyn.*, DOI 10.1007/s00382-007-0304-3

Tadross M., C. Jack, B and . Hewitson, 2005: On RCM-based projections of change in southern African summer climate, *Geophys. Res. Lett.*, **32**, L23713, doi:10.1029/2005GL024460

Trenberth, K., J. Fasullo, and L. Smith, 2005 : Trends and variability in column integrated atmospheric water vapor. *Clim. Dyn.*, **24**, 741-758.

UK MET OFFICE. Climate change, rivers and rainfall. Recent research on climate change science from the Hadley Centre. UK Met Office, Exeter, December 2005.

Vincent, L. A., T. C. Peterson, V. R. Barros, M. B. Marino, M. Rusticucci, G. Carrasco, E. Ramirez, L.M. Alves, T. Ambrizzi, M.A. Berlato, A.M. Grimm, J.A. Marengo, L. Molion, D.F. Moncunill, E. Rebello, Y.M.T. Anunciação, J. Quintana, J.L. Santos, J. Baez, G. Coronel, J. Garcia, I. Trebejo, M. Bidegain, M.R. Haylock, D. Karoly, 2005: Observed trends in indices of daily temperature extremes in South America 1960-2000. *J. Climate*, **18**, 5011-5023.WCRP, 2007: Future climate change research and observations: GCOS, WCRP and IGBP learning from the IPCC Fourth Assessment Report. Workshop and Survey Report, Sydney, Australia, Jan 2008. GCOS-117, WCRP-127, IGBP Report No. 58, WMO/TD No. 1418.

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

Xu, Y. L., X. Y. Huang, Y. Zhang, W. T. Lin, and E. D. Lin, 2006a: Statistical analyses of climate change scenarios over China in the 21st century, Adv. *Clim. Change Res*., **2**, Suppl. 1, 50– 53.

Xu, Y. L., Y. Zhang, E. D. Lin, W. T. Lin, W. J. Dong, R. Jones, D. Hassell, and S. Wilson, 2006b: Analyses on the climate change responses over China under SRES B2 scenario using PRECIS, *Chin. Sci. Bull*., **51**(18), 2260– 2267.

Zhang, Y., X. Yinlong, D. Wenjie, C. Lijuan and M. Sparrow, 2006: A future climate scenario of regional changes in extreme climate events over China using the PRECIS climate model, *Geophys. Res. Lett*., 33, L24702, doi:10.1029/2006GL027229

Zhu, C., T. Cavazos, and D. P. Lettenmaier, 2007: Role of antecedent land surface conditions in warm season precipitation over Northwestern Mexico. *J. Climate*, **20**, 1774-1791.