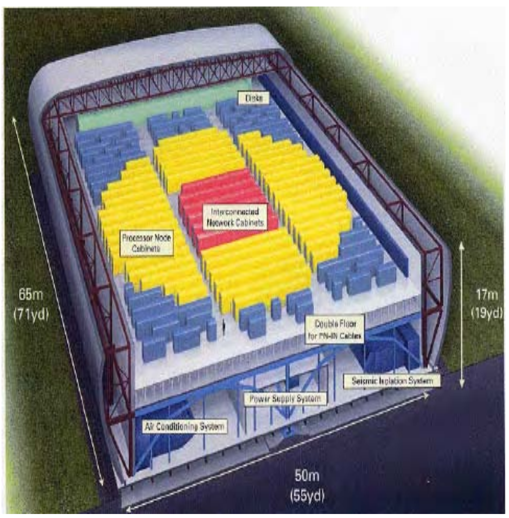
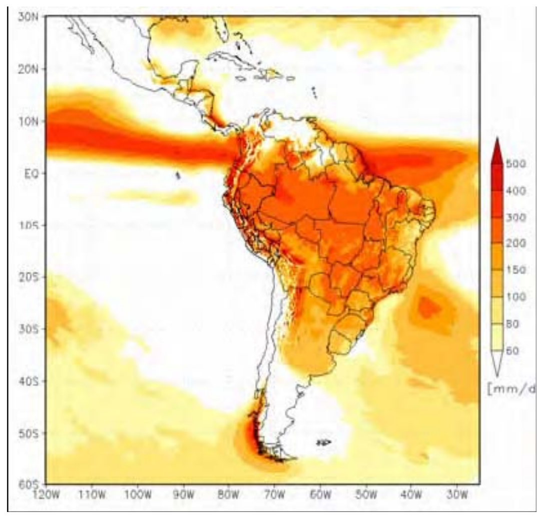
Public Disclosure Authorized

41770

Latin America and Caribbean Region
Sustainable Development Working Paper 30

Visualizing Future Climate in Latin America:
Results from the application of the Earth Simulator





November 2007

By:
World Bank: Walter Vergara
Japan Agency for Marine-Earth Science and Technology: Hiroki Kondo
INE (Mexico): Edgar Pérez Pérez, Juan Matías Méndez Pérez and Victor Magaña Rueda
IDEAM (Colombia): María Constanza Martínez Arango and José Franklyn Ruíz Murcia
SENAMHI (Peru): Grinia Jesús Avalos Roldán
INAMHI (Ecuador): Enrique Palacios

The World Bank

Latin America and the Caribbean Region
Sustainable Development Department (LCSSD)

This summary report is based on data, information, and analysis of the results of work undertaken under a Memorandum of Understanding among the MRI in Japan, IDEAM in Colombia, INAMHI in Ecuador, INE in Mexico, and SENAMHI in Peru, and the World Bank. This report has been made possible thanks to the cooperation of many individuals and institutions, without whose support and hard work the results summarized here would not have been achieved. The authors wish to acknowledge the comments and contributions received from numerous colleagues both inside and outside of the institution. Special thanks are due to Abel Mejía for his useful guidance and advice, and to Adriana Valencia and Janice Molina who assisted with the editing of the report.

Cover art credits:
Left panel: Graphic Representation of the Earth Simulator, MRI-JAMSTEC; right panel: Average precipitation in mm/month during the austral summer for the southern hemisphere of the Americas, as projected by the Earth Simulator

Additional copies may be obtained from Walter Vergara (wvergara@worldbank.org or tel. 202-458-2705), Seraphine Haeussling (shaeussling@worldbank.org or tel. 202-458-9347), or Beatriz Iraheta (airaheta@worldbank.org or tel. 202-473-7778).

41770

Contents

Foreword

There is little doubt now that the Latin America region will experience substantial climate impacts, affecting key ecosystems and the services these provide. Some of the major anticipated changes include the potential collapse of the coral biomes in the Caribbean, intensification of weather patterns and storms, coastal flooding that could displace millions, warming of high mountain ecosystems that could affect water and power supplies, increased exposure to tropical diseases that could increase health delivery and prevention costs, and possibly changes in precipitation patterns that could affect the integrity of the Amazon ecosystem. Combined, these changes make the region particularly vulnerable to climate impacts. All species and human activities will be impacted. In view of these prospects, there is an urgent need to better understand the likelihood of the changes and to prepare suitable adaptation strategies.

This report summarizes the application of Earth Simulator runs to model future climate in Latin America as part of efforts to better understand climate trends.

The Earth Simulator has been used as part of efforts of the IPCC and continues to play a central role in the modeling of future climate scenarios. The results summarized here represent the culmination of activities undertaken under a pioneering partnership with the Earth Simulator, involving the Meteorological Research Institute of Japan (MRI), the Instituto Nacional de Ecología of Mexico (INE), the Instituto Colombiano de Estudios Ambientales y Meteorología (IDEAM) of Colombia, the Servicio Nacional de Meteorología e Hidrología (SENAMHI) of Peru, the Instituto Nacional de Meteorología e Hidrología (INAMHI) of Ecuador, and the Instituto de Hidráulica e Hidrología (IHH) of Bolivia, in collaboration with the World Bank. Under the agreement, the MRI provided the data produced by the fastest available computing tool dedicated to climate modeling today to be used by leading scientists and climate modelers in the region.

As instrumental as modeling is to visualize future climate, it needs to be complemented with vigorous efforts to measure what is taking place today through the implementation of monitoring and sensing networks that can effectively document the dynamics of major changes. Thus, the Bank in the region is also involved in a concerted effort to support climate observing systems. The report also summarizes some of what is known about current observed impacts and the efforts made to structure and implement major observing systems in the Caribbean and the Andes.

This work is only a first step in what needs to be a consistent and dedicated effort to observe climate, its impacts, and the process of change. Through the application of these long-term investments in observation, monitoring, and modeling, decision makers and affected parties would be better positioned to optimize the allocation of resources to adapt, as best as possible, to future climate.

Laura Tuck
Director
Sustainable Development Department
Latin America and the Caribbean Region

Introduction

As indicated in the foreword, this report summarizes the results of the application of Earth Simulator runs to model future climate in Latin America as part of efforts to better understand climate trends. The document begins with an update of observed and impending climate impacts in Latin America, prepared on the basis of recent reports, some of which have been commissioned by the region as part of the work in support of the portfolio of climate change activities, which started as early as 1997. The summary of impacts paints a worrisome picture of ecosystems already under siege by the consequences of climate change. Subsequent chapters provide a brief description of the Earth Simulator and summarize the results of the application of the Earth Simulator data in some of the areas where the Bank is assisting the process of adaptation (Mexico, Colombia, the Tropical Andes).

The data made available by the MRI, a result of the application of scenario A1B, have been compiled and analyzed by scientists and engineers in each country, including some of the leading experts in the region, to produce high-resolution images of the anticipated climate parameters for the period 2080–2099. Thus, a picture of future climate in Latin America has emerged that provides inputs for the visualization of adaptation strategies and measures.

The data produced by the Earth Simulator for Mexico have been analyzed by Edgar Pérez Pérez, Juan Matías Méndez Pérez, and Victor Magaña Rueda of the Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma of Mexico City. The analysis concludes that besides an expectation of significant temperature increase, the model predicts net reductions in rainfall over sections of Mexico's national territory. The 20-km model also produces intense anomalies in the precipitation pattern over the eastern Pacific. Enhanced precipitation on the Pacific coast of Panama results in intense subsidence and negative anomalies in precipitation over northern Mexico.

Climate change projections also indicate that the maximum number of dry days may increase in some parts of central and southern Mexico, but may decrease in parts of northwestern Mexico. Since episodes of consecutive dry days occur mainly during winter, the projected pattern reflects to some extent the response under El Niño conditions.

In the application of the ES data in Colombia, María Constanza Martínez Arango and José Franklyn Ruíz Murcia, of the Instituto de Estudios Ambientales y Meteorología of Colombia (IDEAM) found a good representation of the country's orography. The analysis found a significant temperature anomaly for the Andes region, well in excess of the average anticipated temperature increases over the nation's territory. This is in agreement with other recent projections of temperature increases over the Andes.

Grinia Jesús Avalos Roldán of Peru's National Meteorology and Hydrology Service (SENAMHI) reports that the model realistically represents the configuration and seasonality of synoptic systems as well as topography. In comparing the climatology outcomes of the model with observations (historical data), it was found that the model efficiently represents the seasonality of precipitation. However, there is a tendency to overestimate amounts. In a preliminary basin-level analysis, the model's performance differs in the two basins of interest. A better correlation was found in terms of the annual precipitation cycle in the Urubamba River Basin, at stations below 3,800 masl, and during the dry season.

According to the results of the indexes of extreme events based on the model used by the Earth Simulator, there are indications that in the future extreme events of precipitation and temperature may significantly impact the Amazon and the northern coast of Peru, respectively.

Enrique Palacios of Ecuador's National Institute of Meteorology and Hydrology reports that the application of the data to the basins around the Antisana and Cotopaxi glaciers makes it possible to establish the analysis in the distribution of precipitation and extreme temperatures in the two existing climate periods (rainy and dry periods). In reference to precipitation, the study reports an anticipated marked irregularity and variability in its behavior inside the annual cycle, with greater increments on the western and oriental sides and decreases in the central portion of the study area.

Moreover, with regard to precipitation, a negative rate of change or a decrease in percentages of precipitation in both climate periods is observed (nearly 20% in the rainy period and nearly 30% in the dry period). The model simulates well the spatial precipitation locations (zones of greater, lesser, or no registered quantities). However, the model does not excel in magnitudes, because it overestimates almost 4 times in relation to historical records of the nearest weather control station located in the study area.

The Impacts of Climate Change in Latin America

Walter Vergara
World Bank

The latest Intergovernmental Panel on Climate Change report (IPCC 2007) and other recent assessments (Schellnhuber 2006) conclude that the planet will face dangerous climate change consisting of irreversible and drastic impacts on the biosphere, possibly crossing critical thresholds in the near future. Along with changes in mean climatic conditions, the biosphere potentially faces catastrophic system impacts associated, for example, with the reduction of thermo-haline circulation, the melting of the Greenland ice sheet, the subsidence of small islands and coastal wetlands, the collapse of coral reefs and associated marine ecology, increases in intensity of hurricanes, acidification of oceans, retreat of mountain cryo-spheres and others. Global warming will affect all species and exacerbate the stresses already being experienced by ecosystems. There is now consensus that drastic actions are required to avert these scenarios. Climate change is the most serious challenge being faced by the global ecosystem.

Regional Impacts

In Latin America, climate impacts are very significant and expected to irreversibly affect key ecosystems and the services these provide. Some of the major impacts already observed have been reported in a previous Sustainable Development Working Paper (Vergara 2005). Efforts are also being made, some with World Bank cooperation, to further document these impacts and provide information on the consequences. These activities are being complemented by an analysis of projections, made through the Earth Simulator, of the future climate in the region. Key observation networks (coral systems, sea level rise, sea surface temperature, and glacier dynamics) are also being supported by the World Bank. Together with current observations and analysis of impacts, a route map of priority adaptation efforts can be constructed.

Later chapters in this report summarize the results of the simulation made by the Earth Simulator on key regions of Latin America, selected on the basis of local adaptation efforts, supported by the World Bank. A summary of regional climate impacts as now understood is the scope of this section of the report:

Destruction of the coral ecosystems in the Caribbean Basin. During the summer of 2005, major disruptions to the coral ecosystem and a record hurricane season in the Caribbean Basin contributed to highlight impacts associated with large-scale disruptions of this region's climate system.

The impacts on the coral areas of the basin continue to be assessed, but it seems clear that the loss of coral to heat stress experienced during the season will be very difficult to overcome. A recent assessment of the event indicates that over 80% of coral reefs were affected and in some (Rosario Islands), bleaching reached all coral beds. The implications of the wholesale bleaching of corals are severalfold: a) corals provide a natural protection against storm surges; as they bleach, the reefs disintegrate and thus eliminate this protection; b) coral reefs in the Caribbean are hosts to fish nurseries for an estimated 65% of all species in the region; the collapse of these reefs may have widespread impacts on the ecology of the ocean; and c) corals are also a tourism attraction and as these bleach and disintegrate, they lose any esthetic value.

The first near real-time satellite monitoring of global bleaching and early warning system was developed in 1996 at NOAA's National Environmental Satellite, Data and Information Service (NESDIS), where Coral Reef Watch (CRW) is located (Strong et al. 1997). Strong and Causey (2007) have argued that integration of remote and in situ sensors is essential to coral reef observations. Very few in situ sensing stations are providing near real-time data, and their number and the coverage of critical reef areas need to be increased.

Coral bleaching has been documented under the World Bank-implemented Caribbean Planning for Adaptation to Climate Change. These efforts continue under the follow-up initiative, Mainstreaming Adaptation to Climate Change. As part of these efforts, the Caribbean Community Climate Change Center, with cooperation from NOAA and the World Bank, has installed a CREWS station[1] and several sites have been observed using standard protocols. These observations and those by others are providing solid data on the extent of the crisis for the coral ecosystem in the Caribbean Basin. An analysis of the economic and ecological consequences of coral bleaching is under way.

Hurricane intensification. Recent reviews of hurricane trends (Hoyos et al. 2006; Webster and Curry 2006) point to trends in the intensification of hurricanes in the Caribbean Basin that have major implications for regional ecosystems and human activities. The estimated costs of hurricane impacts in the region are estimated to have increased by two orders of magnitude since the 1970s. While some of this increase is due to the densification of human interventions in coastal zones, the number of higher intensity hurricanes has also contributed to and require urgent actions in coastal zoning and in the strengthening and restoration of coastal ecosystems and coastal infrastructure.

In a recent analysis for the World Bank (Curry et al. 2007), a historical dataset of land-falling tropical cyclones in Mesoamerica has been compiled. This dataset allows for the first time an analysis of the behavior of tropical cyclones in Central America and the Caribbean for over one century. A past peak in activity can be seen from the mid-1930s to the mid-1950s (with a record number of 16 landfalling tropical cyclones in 1933). Of particular interest is the recent increase in Mesoamerican landfalls since 1995 after an extended quiet regime of nearly forty years. Four of the ten most active years for hurricane landfalls have occurred in the last ten years. These datasets are being used to provide information for an assessment of current and potential economic impacts in the region.

1 NOAA developed the Coral Reef Early Warning System (CREWS), an integration of meteorological and in situ oceanographic instrumented arrays (buoys and dynamic pylons) employing artificial intelligence software to monitor corals for conditions theoretically conducive to coral reef bleaching (Hendee et al. 2001).

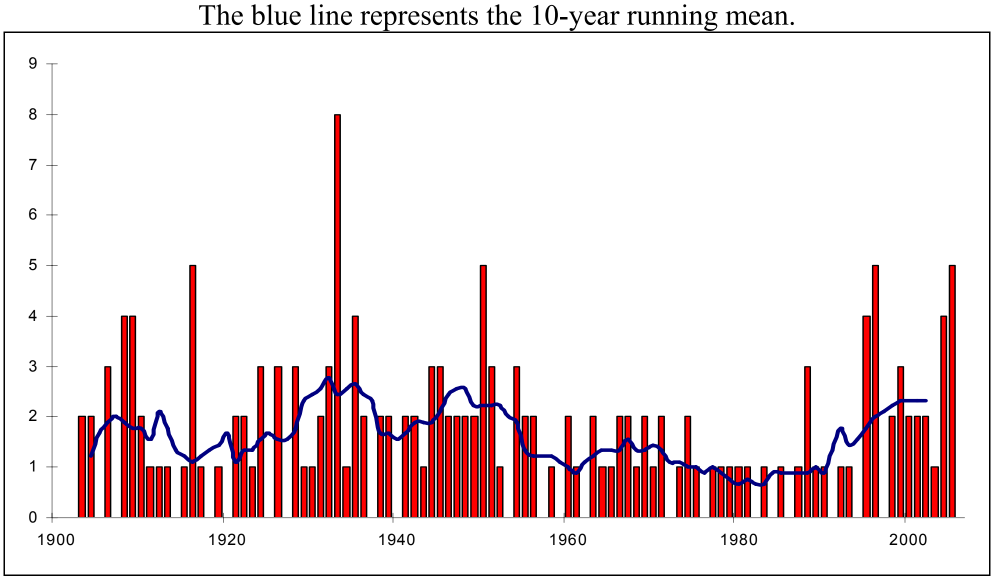
Table 1. Latin America–Strongest Landfalling Hurricanes

Year	Storm	Maximum Landfall Strength	Countries Impacted
2007	Dean and Felix	5	Mexico Yucatán (5), Nicaragua (5)
1988	Gilbert	5	Mexico Yucatán (5), Mexico (3), Jamaica (3)
1992	Andrew	5	Bahamas (5)
1979	David	5	Dominican Republic (5), Lesser Antilles (4), Haiti (2), Bahamas (1)
1971	Edith	5	Nicaragua (5), Honduras (3)
1967	Beulah	5	Mexico (5), Mexico Yucatán (2), Dominican Republic (1)
1947	4	5	Bahamas (5)
1932	4	5	Bahamas (5)
1928	4	5	Puerto Rico (5), Lesser Antilles (4), Bahamas (4)
1960	Donna	4	Lesser Antilles (4), Bahamas (4)
1955	Janet	4	Mexico Yucatán (4), Belize (4), Lesser Antilles (3), Mexico (2)

Source: Curry et al. 2007, complemented by 2007 season data.

Figure 1. Annual total landfalling hurricanes striking the Caribbean and Central America from 1900 to 2006.

The blue line represents the 10-year running mean.



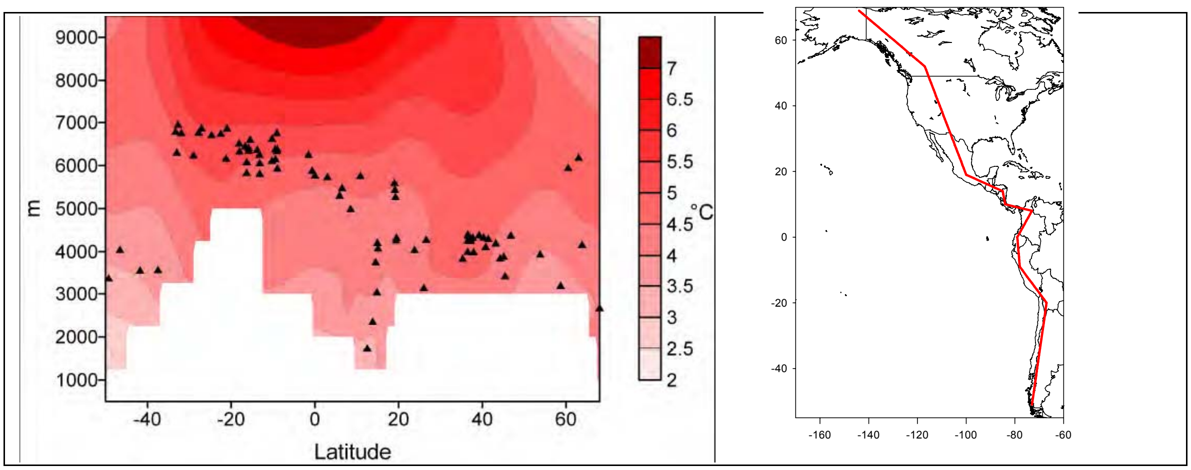
Source: Curry et al. 2007

Impacts on Andean Ecosystems. According to global circulation models**,** the anticipated temperature increases in the Andes will greatly exceed those in surrounding lowlands. The rate of increase is projected at two or more times those projected for average temperature increases. Changes of this magnitude will irreversibly affect the ecology of the Andes (see Figure 2). Most immediately affected are tropical glaciers and other high mountain ecosystems.

41770

Rapid Tropical Glacier Retreat. Field observations and historical records have been used to document the current pace of glacier retreat in the Andes (Francou et al. 2005). This retreat is consistent with upward shifts in the freezing point isotherm and coincides with an overall warming of the Andean troposphere (Kaser 2001; Francou et al. 2003). Modeling work and projections indicate that many of the lower-altitude glaciers in the cordillera could completely disappear during the next 10 to 20 years (Bradley et al. 2006; Ramírez et al. 2001).

Figure 2. Projected changes in temperature for the American Cordillera from Alaska to Southern Chile between 1990–1999 to 2090–2099

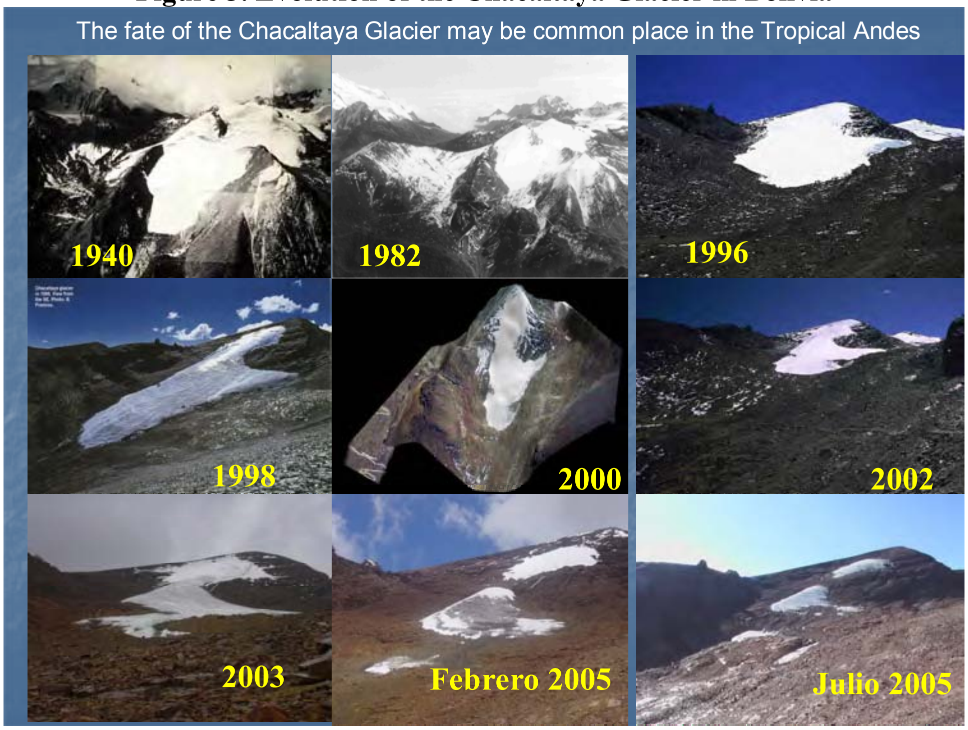


Source: Bradley et al. 2006.

Tropical glaciers (located between Bolivia and Venezuela) covered an area of over 2,940 square kilometers in 1970 but declined to about 2,490 square kilometers by 2002 (Kaser and Osmaston 2002). Many of the smaller glaciers (less than 1 square kilometer in area) have already declined in surface area, and most are likely to disappear within a generation. For example, Bolivia's Chacaltaya glacier has lost most (82%) of its surface area since 1982 and may completely melt by 2013 (Francou et al. 2003). This rapid retreat has resulted in a temporary but unsustainable net increase in hydrological runoffs (Pouyaud et al. 2005).

Recent work on glacier dynamics (Cartier 2007) indicates that many more glaciers will disappear during the century, with major implications for water supply, power generation, and ecosystem integrity. As glaciers retreat, the water regulation function of glaciers (contribution to runoffs during dry, warmer periods and storage of water during wet, colder periods) will be affected and eventually lost. A recent report (Vergara et al. 2007) estimates that the economic consequences of glacier retreat are major, running into billions of dollars for the power sector, and affecting water supply for mountain urban areas, agriculture, and ecosystem integrity. These costs constitute in fact a climate tax imposed on populations that have contributed little to the problem.

Figure 3. Evolution of the Chacaltaya Glacier in Bolivia



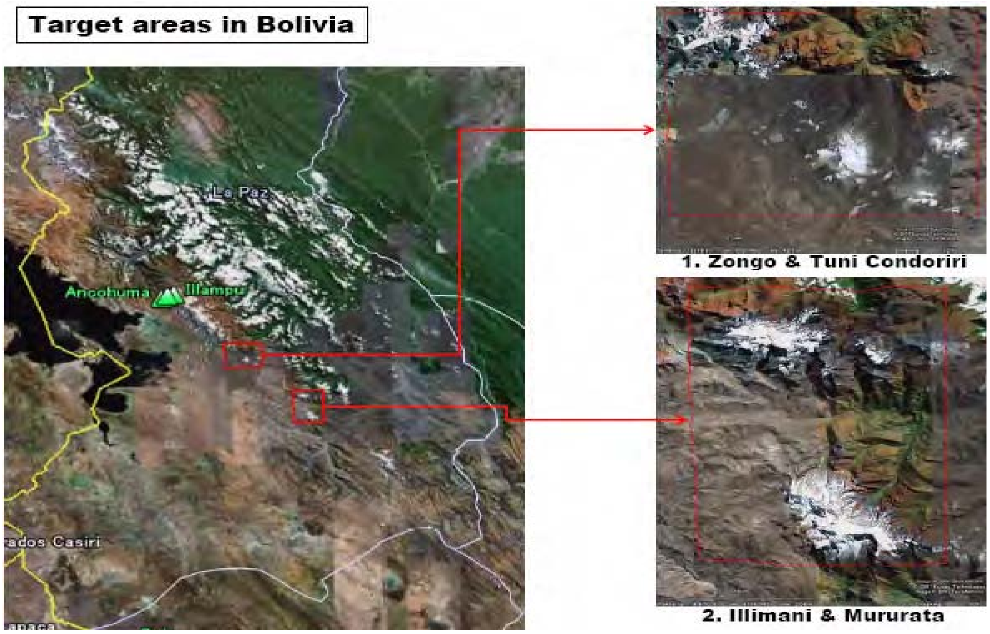
Source: Photographs by B. Francou and E. Ramirez and archive photographs

A network of nine glacier monitoring stations, complemented by satellite images using the ALOS (Advanced Land Observation Satellite), is being implemented with World Bank assistance to aid in the analysis of glacier dynamics. The field stations will continuously monitor weather and hydrology. The ALOS will use its sensors (PRISM, ALVNAR, and PALSAR) to photograph and radiograph the same glacier areas. The network will target glaciers that provide water regulation to major cities or that are of major relevance for agriculture or energy supply. The system will complement existing regional efforts made by IRD and others.

Impact on Mountain Wetlands. High mountain ecosystems, including *páramos* (unique wetlands of the Northern Andes) and snowcapped terrain, are among the environments most sensitive to climate change. These ecosystems have unique endemic flora and provide numerous and valuable environmental goods and services. Although understanding of glacier retreat and its consequences has significantly increased, the consequences of climate change in the functioning of páramos require additional work. Data recently made available (Ruíz et al. 2007) suggest that climate impacts have already altered the circulation patterns responsible for producing and moving water vapor to the region. These striking changes have probably contributed to the disappearance of high altitude water bodies, as well as to the increased occurrence of natural and man-induced mountain fires.

41770

Figure 4. Target glacier areas for remote sensing through ALOS



Source: RESTEC 2007.

These prospects are all the more alarming because major population centers in the region depend on these fragile ecosystems for water supply. Although not yet assessed, the environmental and economic consequences of the loss of these wetlands would be immense. Many urban centers in the northern Andes, including the cities of Bogotá and Quito, are very dependent on páramo ecosystems for their water supply. Under the Bank-supported Integrated National Adaptation Project in Colombia, the water and carbon cycles in páramo ecosystems are being monitored and should result in a better understanding of the consequences of rapid warming.

Figure 5. High altitude water body in the Los Nevados Natural Park, Andean central mountain range, Colombia.

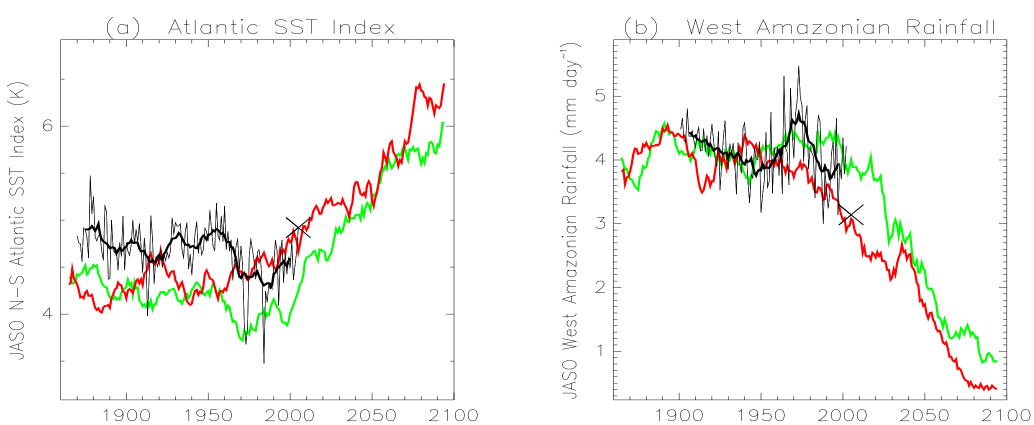
Photo on the left was taken in September 2005; photo on the right, two years later.

Source: Ruiz et al. 2007.

The Risk of Amazonian Dieback. One of the most profound predicted impacts of climate change into the 21st century is the effect on ecosystem integrity of the large Amazon Basin. Temperature increases and disruption in precipitation cycles have the potential to seriously hamper the workings of the Amazon as a forest ecosystem, reducing its capacity to retain carbon, increasing its soil temperature, and eventually forcing the Amazon through a gradual process of "savannization". The issue of Amazonian dieback evolved from computer predictions to global environmental concern with the unexpected Amazonian drought of 2005.

The Amazon is critical to global climate because it helps regulate the amount of carbon dioxide in the global atmosphere by locking away vast quantities of carbon. It also contributes to the global atmospheric circulation that widely affects rainfall patterns. Through the recycling of rainwater back into the atmosphere, the Amazon rainforests also influence their own unique regional climate, which provides a home to a quarter of the world's biodiversity and many indigenous peoples. Moisture injected by the Amazon ecosystem into the atmosphere plays a critical role in South America's precipitation patterns. Serious disruptions in the volumes of moisture coming from the Amazon Basin could also trigger a process of desertification over vast areas.

Figure 6. Observed and Modeled Decadal Variability in the N-S Atlantic SST Index and West Amazonian Rainfall (July–October)



Source: Cox 2007

Modeling done on the prospects of Amazonian dieback (Cox 2007) indicates the possibility of severe drops in total precipitation in the western Amazon Basin, linked to the North-South Atlantic sea surface temperature index. Rainfall reductions of this magnitude would trigger a gradual process of savannization and eventually lead to the loss of ecosystem integrity. The prospect of Amazonian dieback, even if small, needs to be seen as a risk management policy situation that needs to be addressed through better analysis and identification of risk thresholds for action. This could be the most serious climate change impact in Latin America, but its prospects and consequences are still poorly understood. An assessment of the likely prospects and impacts of these changes is under way.

Increased Exposure to Tropical Vector Diseases. Recent work reported under the Integrated National Adaptation Program (INAP) points to a gradual trend in Colombia of exposure to tropical vector diseases (malaria in particular). The increase has been linked to increases in minimal nocturnal temperatures in the Andes piedmont and to changes in the hydrological cycle induced by the El Niño Southern Oscillation (ENSO) phenomenon. A recent analysis has been made (Blanco and Hernandez 2007) of the associated costs to the health sector caused by climate change. This study formally tested the statistical relationship between long-term temperature and precipitation, and the historical levels of malaria and dengue epidemics in 715 municipalities of Colombia. The study found a significant relationship between precipitation and malaria epidemics, and between temperature and dengue epidemics. This relationship is being used to estimate the diagnosis, treatment, and time opportunity costs of the additional epidemics expected to be caused by climate change in Colombia for 50 and 100 years, in an unconstrained scenario. The issue continues to be diagnosed.

Coastal flooding and salinization of coastal aquifers. An analysis of sea level change in coastal zones throughout the Americas (Miller 2006) indicates that the impact of sea level rise will vary regionally. In some coastal areas, there is insufficient evidence on which to base conclusions, with some areas such as the Caribbean Basin and coast of Ecuador apparently more vulnerable than others. The analysis completed at the University of the West Indies (Miller 2006) indicates that a significant fraction of the populations in Latin America lives within the coastal zones (49% in Brazil, 45% in Argentina, 82% in Chile, 30% in Colombia, 24% in Mexico, and practically 100% in the Caribbean Community [CARICOM] countries) and is thus exposed to coastal flooding and to impacts caused by sea level rise on coastal fresh water supplies.

However, in order to undertake a full impact assessment of locations at which sea level rise represents a risk, additional data are required. In many other locations, while measurements have been obtained, these lack sufficient precision and integrity to identify whether rates of sea level rise are changing, or if any increase that may exist in the intensity of storms is having a significant effect on occurrences of flooding and saltwater intrusion. Thus, there is clearly a requirement to improve monitoring systems, and to undertake further research into modeling of meteorological effects on sea level so that adaptation measures can be taken in advance where possible. Under the Bank-supported Mainstreaming Adaptation to Climate Change in the Caribbean, a network of 11 sea level monitoring stations is being implemented. Its long-term operation should assist in providing the data required to identify the best course of action for the area. Similar networks should be considered at other vulnerable locations.

Regional carbon footprint

On the other hand, Latin America is not a major contributor of greenhouse gas emissions (GHG). It accounts for about 6% of global emissions of GHG. Most of the emissions are concentrated in a few countries in the region. Furthermore, most Latin American economies are less CO_2-intensive than the U.S. and several are less intensive than Japan or the European Union. In the case of the Andes region, strong reliance on hydro as a source of power and a transport sector that relies on public transportation contribute to maintain the low carbon footprint of these economies. Even Brazil, despite its large industrial output, manages to have a much lower CO_2-intensive economy. On a per capita basis, the population of the region is a modest contributor to the problem and this is not likely to change significantly in the future. Thus, most countries in the region already have low carbon economies. The contrast between the magnitude of impacts and the low carbon character economies of the countries in the regions highlight the moral imperative of energy intensive nations to accelerate and in some cases to commit to drastic reductions in GHG emissions.

Although emissions of greenhouse gases are modest in the global context, the region does contribute an estimated 25% of all carbon sink losses. Brazil and to a lesser extent Mexico are the principal sources of emissions caused by land-use change, mainly through deforestation. The equivalent CO_2 emissions caused by loss of carbon sinks are estimated at about 2.0 billion tons per year, which is approximately equivalent to the emissions of GHGs. See Table 2 below.

Table 2. Global GHG emissions

Country	**Total (BTA)**	**Ton/GDP ton/$Mpp**	**Ton/cap**
USA	6.9	720	24.6
EU-25	4.7	450	10.5
Japan	1.3	400	10.4
China	4.9	1020	3.9
Mexico	0.5	590	5.2
Brazil	0.8	680	5.0
Argentina	0.3	660	8.1
Colombia	0.1	580	3.4
Peru	0.04	470	1.0
Belize	neg	820	3.1
Chile	0.06	660	3.4
Total	33.6		
LACR	2.1 (6%)		3.4

Unfortunately, some of the impacts caused by climate change are likely to have a negative effect on the ability of these economies to maintain a low carbon profile and in a larger context to develop sustainably. For example, changes in the ecology of the Andes are expected to affect firm hydropower capacity, which could be replaced by the cheapest available alternatives, most likely fossil fuels. The type of impacts anticipated for the Amazon would result in the release of massive amounts of carbon into the atmosphere within a century. Thus, Latin America is a modest carbon emitter but also a region very vulnerable to climate impacts. Therefore, the emphasis of a regional climate strategy clearly must rely on adaptation as a first priority. The regional program on climate change activities, summarized below, reflects this conviction.

Regional strategy on climate change

A regional strategy on climate change was proposed in 2004 (Vergara 2004) and has since been applied to guide regional efforts. The strategy is composed of three lines of activities:

1. In light of the significant and sometimes irreversible anticipated changes, the regional strategy assigns top priority to adaptation efforts focused primarily on the formulation and implementation of specific adaptation measures that illustrate practical options to adapt to climate change effects and that help document the costs and benefits of alternative adaptation approaches.

2. The strategy also proposes to marshal available institutional development resources to strengthen institutional capacity in the region and transfer knowledge, seeking to empower the region to play an active and influential role in the international climate agenda while it acquires the knowledge and tools required to face the challenges imposed by climate change to the sustainable development of the region.

3. Recognizing the comparatively low emissions of the region but also the potential for the Clean Development Mechanism (CDM) and the role that the region plays in global deforestation, the strategy proposes to **maximize the value and synergies of emission reduction (mitigation) activities by tightening the linkage between these and local environmental and social priorities**. Rather than solely commercial transactions, the strategy calls for the involvement in development projects around mitigation activities.

Regional Program on Adaptation

World Bank involvement in adaptation was initiated in the Latin America region with the formulation of the CPACC (Caribbean Planning for Adaptation to Climate Change) Project in 1997, an enabling activity of regional nature. It focused on the vulnerability of the island nations of the Caribbean to the impacts of climate change. These efforts continue with MACC (Mainstreaming Adaptation Measures to Climate Change in the Caribbean) and the Implementation of Adaptation Measures in Coastal Zones (SPACC) Project, now under formulation. To date, work on adaptation in the Caribbean constitutes the most comprehensive approach Bank-wide, from which valuable lessons can be derived. Strategically, the work on adaptation was focused on the promotion of specific adaptation measures that respond to impacts on key ecosystems. It is anticipated that this work could be used as a springboard to incorporate adaptation at a sector level including sector planning and policy making in the region. The total direct investment in adaptation activities is now close to US$100 million but is still far short of the actual needs in the region.

Update on the work on adaptation in Latin America

The objective of the regional **Mainstreaming Adaptation to Climate Change Project** (P073389) is to facilitate the internalization of climate change considerations into decision making and sector planning among CARICOM members and to continue and expand the network of sensing and monitoring stations to document the trends in climate impacts in the region. The project is now in implementation. The project is seen as a stepping stone in support of the design and implementation of specific adaptation measures in the region.

The project development objective of the Colombia **Integrated National Adaptation Program** (INAP; P083075) is to support Colombia's efforts to define and implement specific pilot adaptation measures and policy options in order to meet the anticipated impacts of climate change. These efforts are focused on high mountain ecosystems and insular areas, and on human health concerns related to the expansion of areas for vectors linked to malaria and dengue. The project is now in the process of implementing specific adaptation measures in the health sector, mountain habitats, and coastal zones. The project has become a standard for adaptation work in the region and has influenced the design of adaptation measures under other initiatives. It was approved by the Board in April 2006.

The regional **Implementation of Adaptation Measures in Coastal Zones in the West Indies Project** (P090731) was approved by the Board in August 2006. The project development objective is to support efforts by Dominica, St. Lucia, and St. Vincent and the Grenadines to implement specific (integrated) pilot adaptation measures that primarily address the impacts of climate change on their natural resource base, focused on biodiversity and land degradation along coastal and near-coastal areas. The project is now under implementation by the CCCCC and is off to a good start. The Centre is now a widely recognized center of excellence in the region on issues pertaining to climate in the Caribbean Basin. Specific adaptation measures have been identified and are in the process of detailed design.

The Regional **Adaptation to the Impacts of Rapid Glacier Retreat in the Tropical Andes Project** (Bolivia, Ecuador, Peru; P098248) was approved by the GEF Council in June 2007. The development objective of the proposed project is to implement adaptation measures to meet the anticipated consequences of the catastrophic glacier retreat induced by climate change. This will be achieved by: a) supporting the detailed design of selected adaptation measures; b) implementing regional and strategic adaptation pilots to address key impacts of rapid glacier retreat on selected basins; and c) supporting continuing observation and assessment of glacier retreat and the associated impacts on the region (no GEF resources are requested for this activity). The project is being prepared with the assistance of a multidisciplinary group that includes expertise in glaciology, remote sensing, agriculture, water and power supply, and rural development. This project is expected to be submitted to the Board by the third quarter of FY08.

The Mexico **Adaptation to Climate Impacts in the Coastal Wetlands in the Gulf of Mexico Project** (P100438) has begun its formulation phase. The project is being formulated by the National Institute of Ecology (INE). The objective of the project is to reduce vulnerability to the anticipated impacts of climate change on the country's water resources, with a primary focus on coastal wetlands and associated inland basins. Specifically, the project seeks to identify national policies to address the impacts of climate change on water resources at the national level (global overlay), to evaluate current and anticipated effects of climate change on the integrity and stability of the Gulf of Mexico wetlands, and to implement pilot adaptation measures to protect their environmental services from the impacts of climate change.

The proposed regional **Implementation of Adaptation Measures in Coastal Ecosystems of Global Biological Importance Project** (P107047) is under formulation. The project objective is to incorporate climate change adaptation measures into the conservation and sustainable use of endangered coastal and marine ecosystems of global biodiversity importance. The project seeks to complement ongoing conservation and preservation efforts, developed without due consideration of climate change issues, with a set of specific activities that: (i) address the direct expected impacts of climate change, (ii) expand the traditional scope of preservation initiatives to include adaptation to climate change, and (iii) apply the knowledge generated at project sites to coastal and marine ecosystem management in the wider Caribbean Basin.

Table 3. Portfolio of adaptation activities under execution or preparation

Project	***ID***	***Milestone in FY08***	***Cost (US$ million)***
Regional: Mainstreaming Adaptation to Climate Change Impacts	73389	Completion of sector adaptation assessments	10.0
Colombia: Integrated National Adaptation Program	83075	Midterm review. Adaptation measures under implementation.	14.9
Regional Implementation of Adaptation Measures in Coastal Zones in the West Indies	90731	Adaptation measures designed	5.5
Regional Adaptation to Impacts of Rapid Glacier Retreat in the Tropical Andes	98248	Board Approval	32.5
Mexico: Adaptation to Climate Impacts in the Gulf of Mexico Wetlands	100438	Council Approval	13.5
Regional: Implementation of Adaptation Measures in Coastal Ecosystems of Global Biological Importance	107047	Council Approval	8.3
Guyana: Conservancy Adaptation (*)	103539	Board approval	5.0
Total			89.7

The need for simulation of future climate

There is considerable information in the literature on regional climate impacts, including the data released under the Fourth Assessment, detailing some of these impacts. However, there is comparably less data on modeling and regional simulations of climate at a regional level that could be used to justify and formulate effective adaptation activities. Most GCMs do not have the resolution that would be useful in planning for regional climate impacts.

To address this need, the Meteorological Research Institute (MRI) of Japan, the Institute of Environmental Studies and Meteorology (IDEAM) in Colombia, INE in Mexico, the CCCCC in the CARICOM community, and the National Environmental Council (CONAM) in Peru, with the World Bank, subscribed a Memorandum of Understanding (MOU) for the use, interpretation, and analysis of projected climate data in Latin America, at a resolution of 20 x 20 km. The available Earth Simulator data correspond to a run of the A1B standard IPCC scenario. The MOU has been used to produce detailed climate projections in several geographical areas of interest in the region. A summary of some of this work is presented in this report and corresponds to the involvement of the institution in specific adaptation activities. For example:

a) the work done by Pérez and others, reported here, has been used in the formulation of the proposed adaptation project in the Gulf of Mexico wetlands and to inform the requirements of the proposed National Water and Climate Impacts study. The data provided by the Earth Simulator continue to be analyzed and have been instrumental in the promotion of other regional modeling efforts in Mexico.
b) The simulation work in Colombia, documented by Hernandez and Ruiz, has been used in the preparation of the Second National Communication and is being adopted as a central rationale in support of adaptation efforts in mountain wetlands and coastal zones, under implementation as part of the INAP project.
c) The work in the tropical Andes, included in this report, also responds to the need for information on glacier and mountain ecosystem dynamics as affected by climate change. The results are being used to identify and formulate adaptation measures to these impacts.

Next steps on simulation of future climate

This work with the Earth Simulator continues with the discussion of a follow-up MOU to further detail projected climate in the region, to analyze the likelihood of extreme climate events and to contribute to the analysis of the likelihood of Amazon dieback. The work on simulation is now being complemented by agreements that will allow for field and remote monitoring of key ecosystems using state-of-the-art instruments, including the ALOS (Advanced Land Observing Satellite) of the Japanese Space Agency, and with a recently signed MOU with the National Center for Atmospheric Research (NCAR). Long-term climate monitoring and climate simulation are essential for the work on adaptation. The outputs of these simulations need to be complemented by those from other regional models and with data from other scenarios.

As the need for adaptation becomes more widely recognized, there is an urgency to further strengthen the ability to observe current, and visualize future, climate. This would require the following:

a) a substantial increase in observation systems, scaling up the networks already in place or under implementation. The work under MACC and the Regional Andes Glacier Retreat project, although pioneering in the region, is still insufficient for the demands for accurate and comprehensive information on which future policy decisions can be made. Investing in observation systems, linked to the global observation networks, is an urgent priority;
b) work on regional models that can simulate current and future climate at a basin scale and that could be the basis for feedback to large-scale systems such as the Earth Simulator;
c) the development of carbon-water vegetation-soil dynamic models that could be used as an integral part of current climate simulations; and
d) besides work related to impacts on the availability and variability of ecosystem services, there is a need to estimate impacts on water and power demand induced by climate change, which is a key question for policy makers and development agencies in the region.

References

Blanco, Javier T. and Diana Hernández. 2007. The Costs of Climate Change in Tropical Vector-Borne Diseases – A Case Study of Malaria and Dengue in Colombia. Report to World Bank.

Bradley, R. M. Vuille, H. Díaz, and W. Vergara. 2006. *Science. 312,* 1755. June.

Cadier, Eric, Marcos Villacís, Luis Maisincho, Edgar Ayabaca, Vincent Favier, Bernard Pouyaud, Robert Gallaire, Bernard Francou. 2007. Impactos del cambio climático sobre la disponibilidad de agua de los glaciares andinos. Presentation.

Cox P.M., Betts R.A., Collins M., Harris C., Huntingford C., Jones C.D., 2004. Amazon dieback under climate-carbon cycle projections for the 21st century. *Theoretical and Applied Climatology*, **7**8, 137–156

Curry, J. A., P. J. Webster, M. Jelinek, P. Agudelo, C. Hoyos, A. Suzuki. 2007. Historical dataset of landfalling Tropical Cyclones in Mesoamerica. Report to World Bank. April.

Francou, B. et al. 2003. Tropical climate change recorded by a glacier of the central Andes during the last decades of the 20th century : Chacaltaya, Bolivia, 16°S. *Journal of Geophysical Research*, *108*.

Francou B., et al. 2005. Glaciers of the Tropical Andes, indicators of the global climate variability. In Global Change and Mountain Regions: A State of Knowledge Overview, U. Huber, K.M. Harald & M. A. Reasoner (eds), Springer.

Hendee J.C., et al. 1998. A data-driven expert system for producing coral bleaching alerts. In: Pepper DW, Brebbia CA, Zannetti P (eds) Proc 7th Int. Conf on Development and Application of Computer Techniques to Environmental Studies. Computational Mechanics Publications/WIT Press, Southampton, p 139–147.

Hoyos, C. D., P. A. Agudelo, P. J. Webster, J. A. Curry, 2006. Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity. Science Express. March.

IPCC. 2007. Fourth Assessment Report. IPCC Secretariat. Geneva, Switzerland.

Kaser, G. 2001. Glacier–Climate Interactions at Low Latitudes. *Journal of Glaciology. 47,* 195.

Kaser, G. and H. Osmaston. 2002. *Tropical Glaciers.* Cambridge University Press: Cambridge. *21,* 2281–2282.

Miller, Keith M. 2006. Land Under Siege. Recent Variations in Sea Level through the Americas. Paper delivered on November 7, 2006 at The World Bank's Panel on "Climate Impacts and Adaptation Responses in Latin America."

Pouyaud, B. et al. 2005. Avenir des ressources en eau glaciaire de la Cordillère Blanche. Hydrological Sciences - Journal des Sciences Hydrologiques *50,* 999–1021.

Ramírez et al., 2001. Small glaciers disappearing in the Tropical Andes. A case study in Bolivia; the Chacaltaya Glacier (16° S). *Journal of Glaciology* 47 157. pp. 187–194.

Ramírez E. 2007. Personal communication.

Ruiz, Daniel, Hernán Alonso Moreno, María Elena Gutiérrez, Paula Andrea Zapata, 2007, Changing climate and endangered high mountain ecosystems in Colombia. Exploratory analysis of changes in climatic conditions - Case study: Los Nevados Natural Park, Andean Central Mountain Range

Schellnhuber et al. (eds). 2006. Avoiding Dangerous Climate Change. Cambridge University Press.

Strong and Causey. 2007. *Crisis in the oceans: The impacts of climate on coral reefs and the marine ecosystem, a manager's tools and response.* Written composite version of papers delivered on November 7, 2006 at The World Bank's Panel on "Climate Impacts and Adaptation Responses in Latin America."

41770

RESTEC. 2007. Communication via email on scope of areas to be covered through ALOS.

Vergara, W. 2005. *Adapting to Climate Change. Lessons Learned, Work in Progress and Proposed Next Steps for the World Bank in Latin America.* World Bank Latin America Region. Sustainable Development Series. No. 25. Washington, D.C.

Vergara, W., A. Deeb, A. Valencia, R. S. Bradley, B. Francou, S. Hauessling, A. Grunwaldt and A. Zarzar. 2007. Economic Consequences of Rapid Glacier Retreat in the Andes. *Journal of the American Geophysical Union, EOS*. Vol. 88, No. 25. June.

Webster, P. J. and J. A. Curry. 2006. Climate Impacts and Adaptation Responses in Latin America A Glimpse into the Near Future. Written composite version of papers delivered on November 7, 2006 at The World Bank's Panel on "Climate Impacts and Adaptation Responses in Latin America."

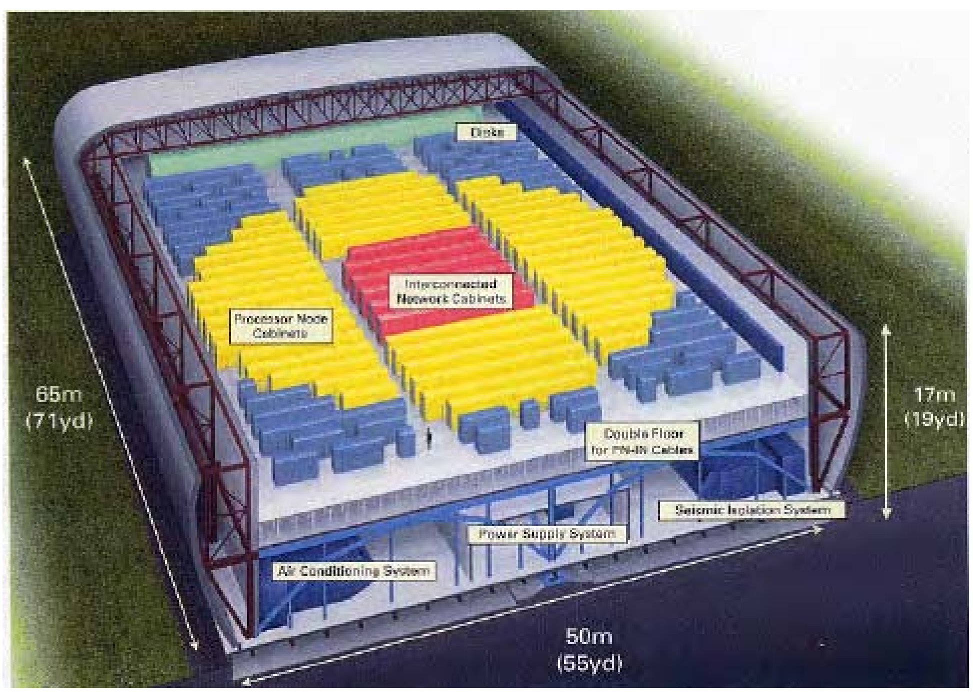
The Earth Simulator: An introduction

Hiroki Kondo

Japan Agency for Marine-Earth Science and Technology (JAMSTEC/FRCGC), Japan

In 1996, a report entitled, "For Realization of the Global Change Prediction,"[2] published by an advisory committee of the Science and Technology Agency of Japan, led to the creation of a highly advanced supercomputer, the Earth Simulator (ES). This supercomputer was recognized as one of the three essential elements—*Simulation,* along with *Observation and Modeling—t*hat had been identified by the above report and has been promoted for attaining better global climate change prediction. See Figure 1 below for a representation.

Figure 1. Graphic representation of the Earth Simulator
(Source: RCCP 2004)



The ES was designed as a parallel vector computer suitable for numerical computation such as climate simulation. The ES uses a super high-resolution model with the time slice method (applied for 10~20 years to present or future climate) and a regional climate model. From its creation, the aim of the ES has been to mainly serve the earth sciences. It

[2] This report was later integrated into the present Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan.

41770

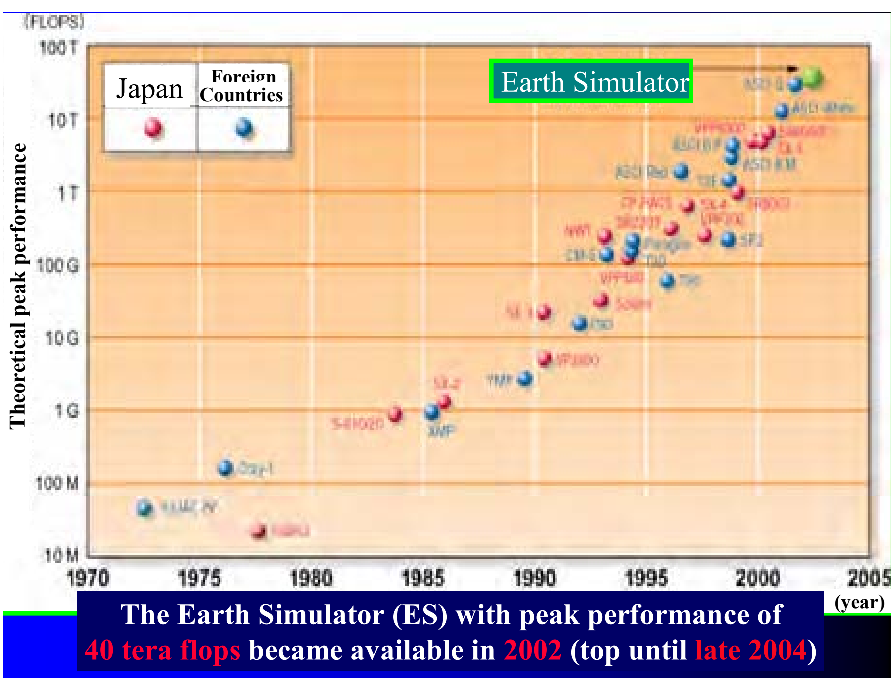
was produced by the NEC Corporation and launched for operation in March 2002, when the IPCC was just starting its activities for the Fourth Assessment Report (AR4).

The ES has a main memory of 10 terabytes and consists of 640 processor nodes, an interconnection network for connecting nodes, system disks, user disks, and other related devices including outer networks. Each processor node has a peak performance of 64 gigaflops and consists of 8 vector processors (each of which has a peak performance of 8 gigaflops). The theoretical peak performance of the ES is 40 teraflops and it has shown a sustained performance of 35.86 teraflops according to the Linpack Benchmark Test. It held the No. 1 position in the world ranking among TOP500 supercomputers from its launch to late 2004 (see Figure 2 below). During this period almost all parts of climate model experiments were conducted to contribute to the IPCC/AR4. Even now, because of its unique mission for the earth sciences, it is still playing a very important role for climate change research.

The ES already has run complex environmental modeling experiments that have returned some startling results. Advanced modeling of the planet by the ES determined that over the next 100 years, a 65% to 80% decrease in Arctic Sea ice melted by global warming will create a 10 cm rise in sea level, causing mass coastal flooding (IT News Australia 2005).

Figure 2. Earth Simulator performance

The green dot in the upper right corner of the graph illustrates
the top rating performance of the Earth Simulator since its launch in 2002.



41770

High Spatial Resolution Climate Change Scenarios for Mexico Based on Experiments Conducted with the Earth Simulator

Edgar Pérez Pérez, Juan Matías Méndez Pérez and Victor Magaña Rueda
Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México
Mexico City 04510

Objective

The need to construct high spatial resolution climate change scenarios for the Gulf of Mexico region under an adaptation project supported through the World Bank led to the visit of two Mexican scientists to the Meteorological Research Institute (MRI) in Tsukuba, Japan. The main objective of their stay at this institution was to examine very high spatial resolution (20-km grid size) simulations of climate change experiments with the Earth Simulator (Mizuta et al. 2006) for the region of Mexico. These high spatial resolution simulations are used to elucidate/design strategies of adaptation over the wetland regions surrounding the Gulf of Mexico under the event of a warmer climate. Climate change scenarios with coarse resolution require downscaling techniques to produce input data for hydrological models. Daily high spatial resolution output from the Earth Simulator represents an opportunity to generate hydrological scenarios in order to examine climate change adaptation options.

The Mexican Climate: Driving mechanisms

Because of its geographic location, Mexico is affected by midlatitude systems in winter such as cold fronts and the *Nortes*—midlatitude waves that penetrate deep into the tropics over the Gulf of Mexico—and by tropical systems during the summer, such as easterly waves and tropical cyclones. Most of these synoptic scale systems are affected by topography, resulting in various climates at the basin level. The study of mechanisms that control climate over Mexico has been focused on air-sea interaction processes that occur mainly over the Americas' warm pools that surround Mesoamerica. In addition, the presence of stationary features, such as the Inter-Tropical Convergence Zone (ITCZ) or low-level jets in the Caribbean or the Gulf of California, result in a monsoon-type climate over Mexico.

The Inter-Tropical Convergence Zone

The location and strength of the ITCZ may result in periods of strong rain or severe drought over Mexico. For instance, during El Niño years, an equatorward shift in the mean meridional position of the ITCZ may result in anomalously intense subsidence over central northern Mexico and at times may even lead to drought episodes (Magaña et al. 2005). On the other hand, the strongest cyclogenetic activity on the planet tends to occur over this zone of the northeastern Pacific. Its role as a rain producer is still to be determined since its effect on precipitation over Mexico depends on how close the trajectory is located to coastal regions.

Tropical systems (hurricanes and easterly waves)
Mexico is located between two very active cyclogenetic regions. These are the northeast part of the tropical Pacific and the Intra-Americas Sea (IAS). Hurricane activity constitutes a fundamental component to explain the summer rainy season over Mexico. The effect of tropical cyclones on the Mexico's summer climate has not been well established. Recent studies indicate that tropical cyclone activity over the IAS may affect the total amount of seasonal precipitation (Magaña and Perez 1998). Most General Circulation Models (GCMs) are unable to produce tropical cyclones due to their coarse spatial resolution. Consequently, more adequate climate change scenarios should include this element of Mexican climate. This is the case of the Earth Simulator Climate Change scenarios.

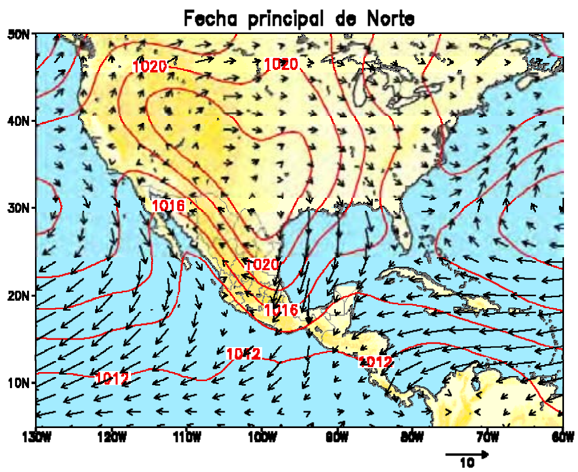
The Mexican monsoon
During the period from June to September, the northwest region of Mexico receives almost 60% of the annual precipitation. Some explanations of this phenomenon tend to suggest that this monsoon is the result of moisture fluxes from the Gulf of California. According to some studies the interaction of a moist flow with topography of the Sierra Madre results in the characteristic pattern of precipitation over Mexico. It is not clear what controls the interannual variability of this system and consequently of northwestern precipitation, since it is not related to ENSO (Koster et al. 2000).

Cold fronts and Nortes
During the winter, the most important precipitation events are due to the passing of midlatitude synoptic-scale systems over the Gulf of Mexico into the tropics. This midlatitude/tropical interaction resembles cold surges in other regions. The presence of moist air over southern Mexico interacting with cold air, plus topographical forcing, results in precipitation over the Gulf of Mexico states, east of the Sierra Madre. The most intense events, known as Nortes, are associated with intense winds over the Gulf of Tehuantepec, due to a strong meridional pressure gradient between the low pressure of the northeastern Pacific and the high pressure of the midlatitude wave.

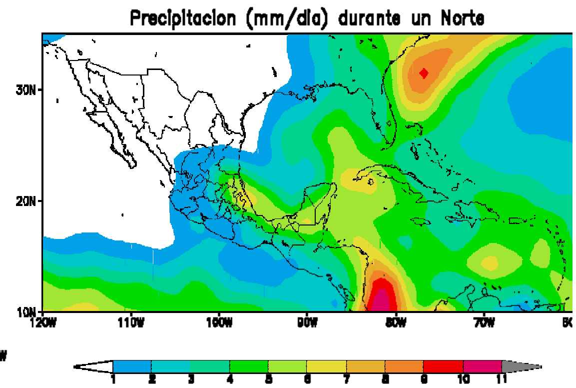
The passing of cold fronts and Nortes over the region can be explained in terms of the location of the subtropical jet stream. That is, Nortes and fronts use the subtropical jet stream to be transported (see Figure 1). The anticyclonic circulation associated with the presence of a Norte tends to give rise to strong northern winds, which may exceed 30 meters per second on the surface. Moreover, surface temperature is also affected, with typical decreases of up to 15ºC in 24 hours in Mexico and Central America (Schultz et al. 1998). Thus, although Mexico's winter season is characterized by dry conditions for most of the country, it is possible to define a winter precipitation regime for the northern region and for the wetlands surrounding the Gulf of Mexico.

Figure 1. a) Composite pattern of surface pressure and winds (in m s^{-1}) at 925mb, and b) precipitation (in mm dy^{-1}) during a Norte event (taken by Vázquez 1999)

a)



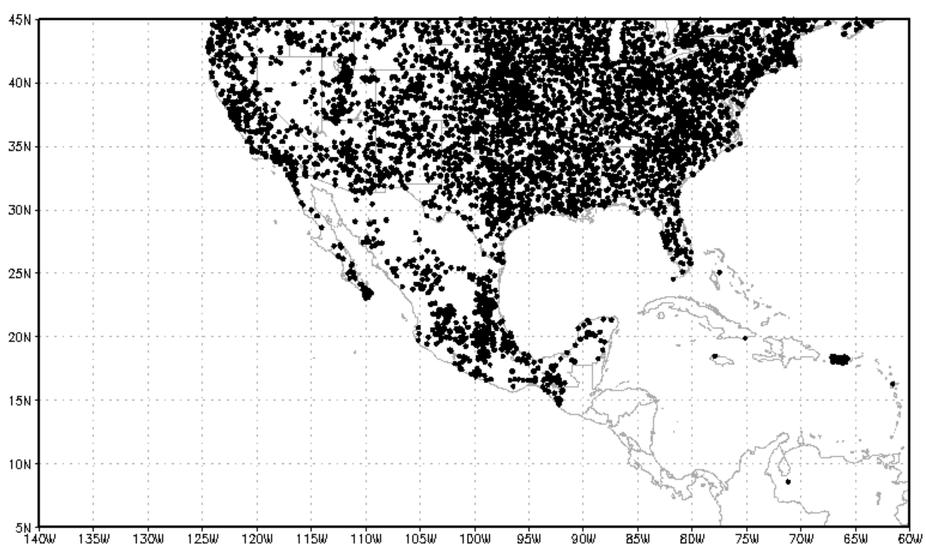
b)



Climate Change Scenarios for Mexico

The first stage of analyses consisted of assessing the skill of the TL959L60 Japanese Atmospheric General Circulation Model (AGCM) in simulating the characteristics of Mexican climate. To this end, daily observational data on precipitation, maximum and minimum temperatures from Mexico and regional stations were used (Figure 2). Selected stations had at least 70% of the daily observational records for the period 1979–1998.

Figure 2. Weather stations used to prepare the observed climatology of Mexico and the region

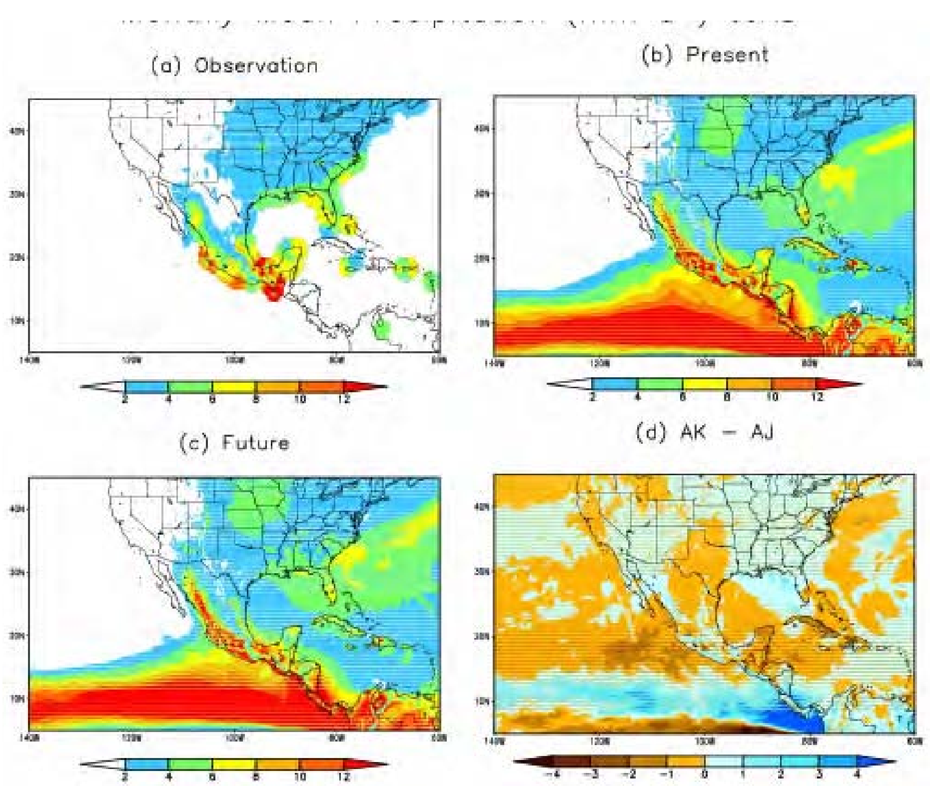


41770

Seasonal Variability of the Mexican Climate

Summer precipitation. A large percentage of Mexican precipitation occurs during the Northern Hemisphere summer months (Figure 3a). The corresponding 20-km model precipitation adequately reproduces most of the characteristics of precipitation patterns in the region with some biases in terms of amounts of precipitation (Figure 3b). However, the fine spatial resolution of the simulation makes it possible to characterize the main climate features such as the North American monsoon rains over northwestern Mexico or the intense precipitation in southern Mexico. Climate change projections maintain the characteristic patterns of summer precipitation over Mexico (Figure 3c) and indicate regions where changes in precipitation may be important with respect to present climate as simulated by the model (Figure 3d). Several GCMs used to produce climate change scenarios have a tendency to enhance an El Niño type of pattern in precipitation anomalies over the eastern Pacific. The 20-km model also produces intense anomalies in the precipitation pattern over the eastern Pacific, but the meridional shift of the ITCZ over this region is less pronounced (Figure 3d). Nevertheless, enhanced precipitation on the Pacific coast of Panama results in intense subsidence and negative anomalies in precipitation over northern Mexico due to a direct Hadley cell effect.

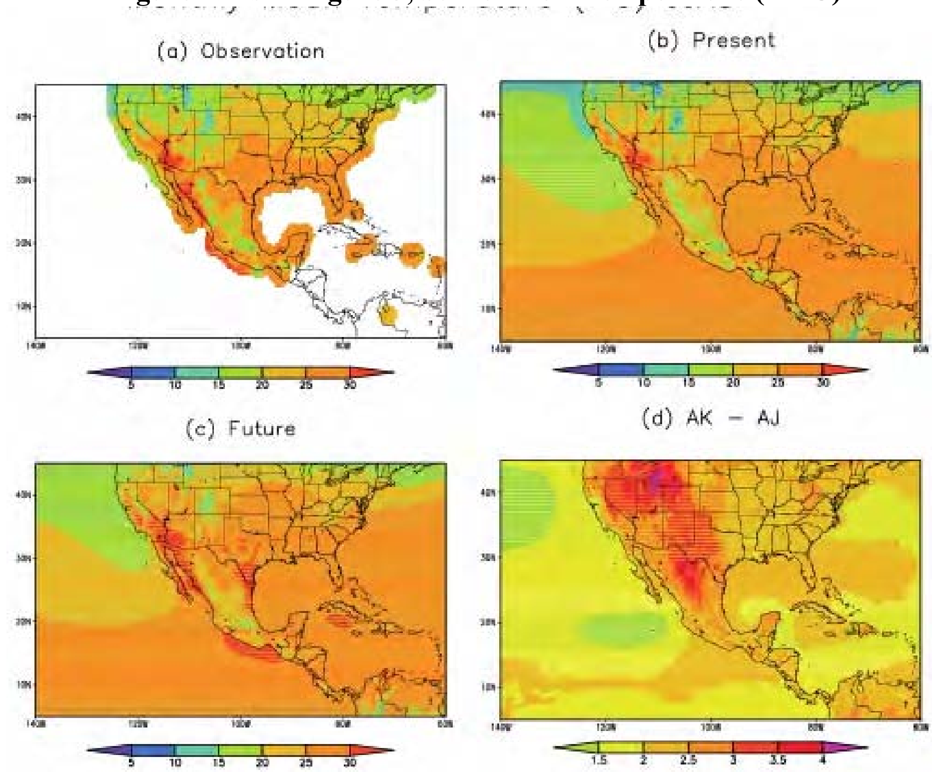
Figure 3. Summer precipitation (in mm dy^{-1}): a) observed climatology (1979–1998), b) present climatology as simulated by the 20-km model, c) future climatology (2080–2099) as simulated by the 20-km model, and d) precipitation difference: future–present



Over most of Mexico, precipitation anomalies projected under the A1B emissions scenario tend to be relatively weak as compared, for instance, with those observed under intense El Niño episodes.

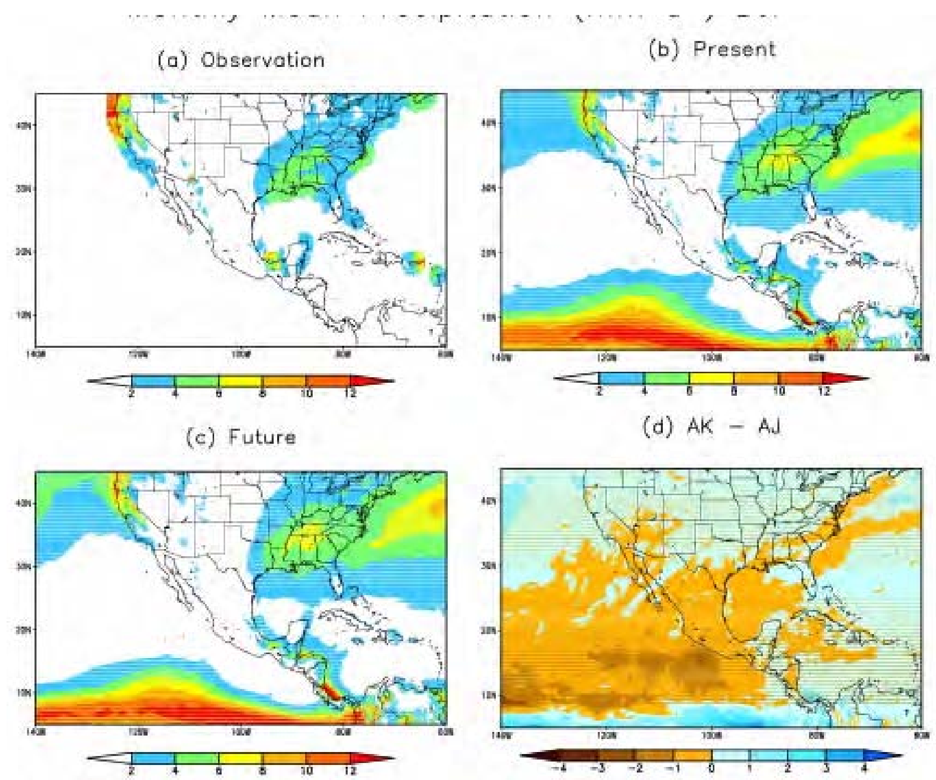
Summer temperature. The highest temperatures in Mexico are observed during the spring–summer period. In the semiarid region of northwestern Mexico, temperatures above 40°C are not unusual (Figure 4a). This pattern is accurately reproduced by the 20-km model present climate simulation (Figure 4b). Climate change projections (Figure 4c) indicate an increase in temperature between 2 and 4°C (Figure 4d), and the future climate simulation appears to suggest a mean increase in surface temperature of approximately 2.5°C over most parts of the country. However, for the central and northern parts of Mexico, increases above 3°C and 4°C are observed.

Figure 4. As in Figure 3, but for mean temperature (in °C)



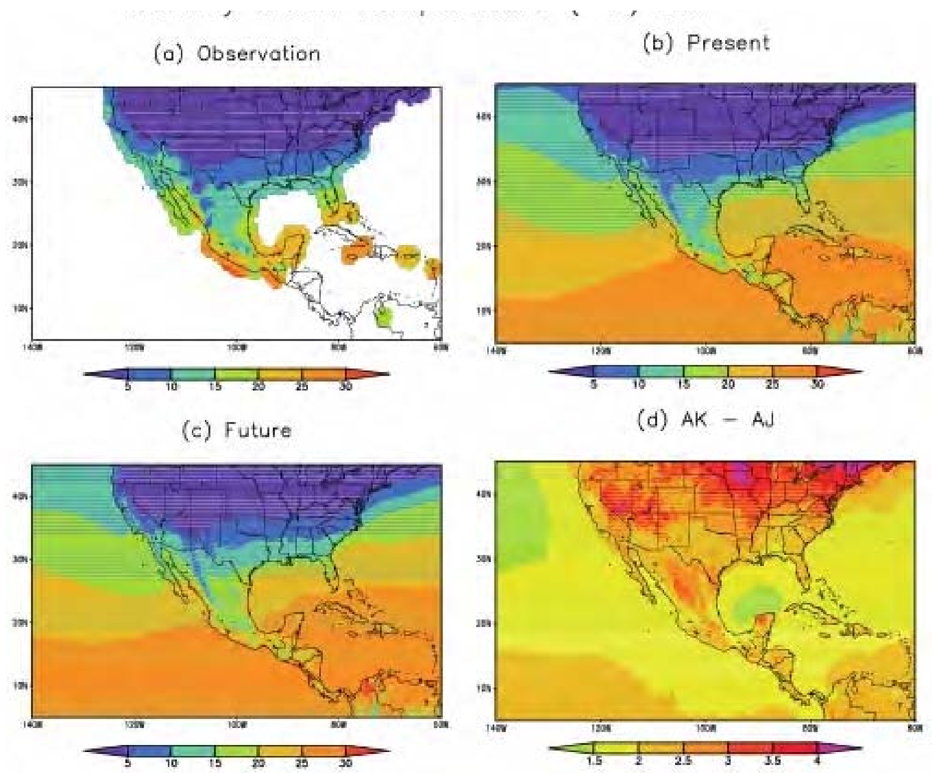
Winter precipitation. Winter is considered the dry season over Mexico. However, midlatitude systems such as cold fronts or Nortes may produce precipitation over northern Mexico or in the states along the Gulf of Mexico (Figure 5a). The 20-km model adequately reproduces the observed winter precipitation patterns over Mexico (Figure 5b), although with some problems in terms of the magnitude. The 20-km model climate change projection for the end of the present century (Figure 5c) indicates changes in the precipitation regime, mainly over the eastern Pacific ITCZ (Figure 5d). For this season, an El Niño-type of pattern may affect the number of Nortes entering the Gulf of Mexico (Magaña et al. 2003). However, the precipitation anomaly under the climate change scenario does not resemble what is observed during winter El Niño conditions. A more in-depth study of Nortes activity is necessary to explain the dynamic mechanisms that modulate changes in precipitation under climate change scenarios.

Figure 5. Winter precipitation (in mm dy^{-1}): a) observed climatology (1979–1998), b) present climatology as simulated by the 20-km model, c) future climatology (2080–2099) as simulated by the 20-km model, and d) precipitation difference: future–present



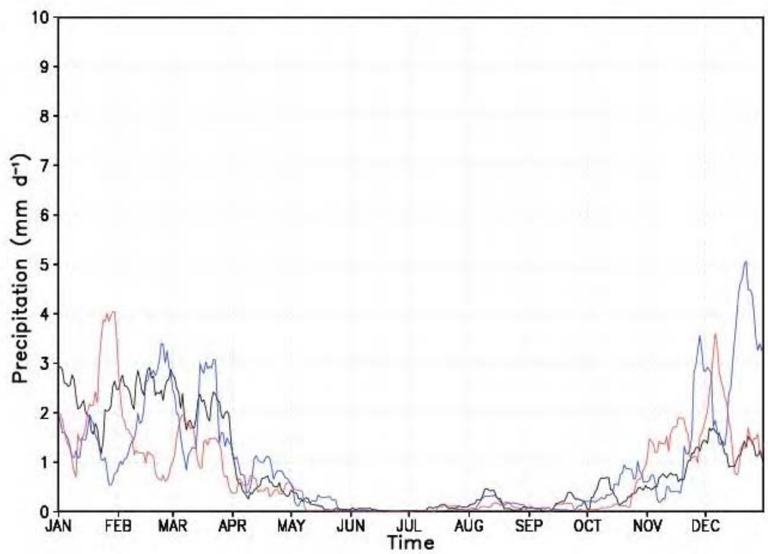
Winter temperature. The lowest temperatures in Mexico are observed during winter (December to February). In the semiarid region of northwestern Mexico, the mean winter temperatures are below 15°C (Figure 6a), but minimum temperatures are below 0°C in some locations. The mean temperature pattern is well reproduced by the model simulation (Figure 6b), except in the southern parts of Mexico, where values are below the observed ones. The mean winter temperature projection for the end of the present century reproduces the average pattern with relatively low temperature in northern Mexico (Figure 6c). For the future climate, an increase in temperature of about 2.5°C for the central, northern, and southern parts of the country is observed. In the region surrounding the Gulf of Mexico and the region adjacent to the Gulf of California, increases only range between 1.5°C and 2.0°C for the end of the present century (Figure 6d).

Figure 6. As in Figure 5, but for mean temperature (in °C)



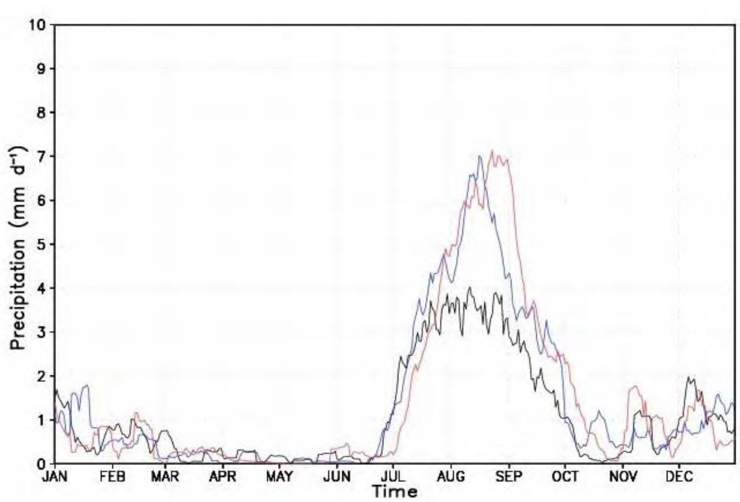
Based on the previous analysis of the mean conditions for summer and winter, using the 20-km model, the entire annual cycle of precipitation and temperature on a daily basis is examined in some locations of Mexico. One of the locations where precipitation is controlled by winter midlatitude meteorological systems is Ensenada, Baja California, in the northwestern part of Mexico (Figure 7). In this particular location there appears to be a slight increase in precipitation but it is more concentrated in the winter months. There is clearly a high uncertainty when one single experiment is considered to evaluate climate change in a particular location.

Figure 7. Observed (black line), present simulated by the 20-km model (blue line) and future climate simulated by the 20-km model (red line) average daily precipitation (in mm dy^{-1}), for Ensenada, Baja California, Mexico



In the northwestern part of Mexico, where the North American monsoon is present, as in Hermosillo, Sonora, the climate change signal suggests a slight increase in precipitation for the latter part of the monsoon (Figure 8). In the model simulation of present climate and the climate change scenario, the annual cycle of precipitation in Hermosillo exhibits a positive bias in magnitude but an adequate phase coincidence of the maximum in precipitation during the summer months.

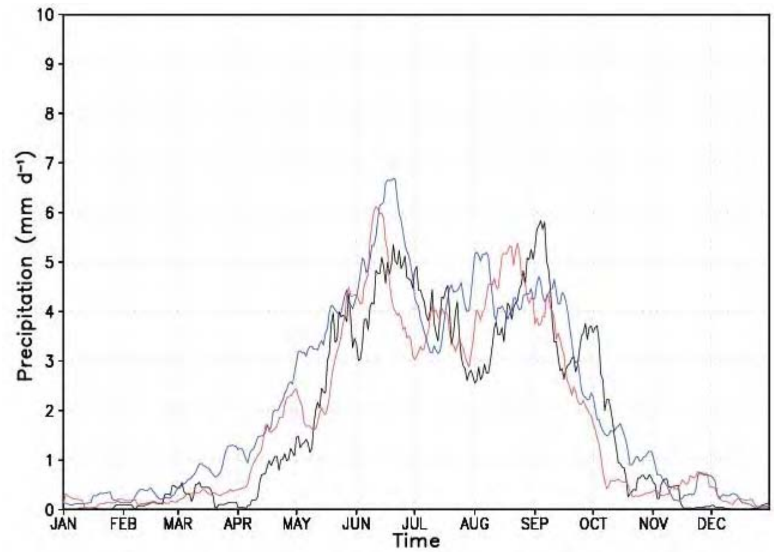
Figure 8. As in Figure 7, but for Hermosillo, Sonora, Mexico



In southern and central Mexico, the precipitation regime is characterized by a relative minimum in precipitation by midsummer (Magaña et al. 1999), locally named the

Canicula, as in Oaxaca (Figure 9). This feature of the summer rains is well captured by the model, except for a minor phase shift. Climate change scenarios with the 20-km model suggest minor changes in the summer precipitation regime for this region.

Figure 9. As in Figure 7, but for Oaxaca, Mexico

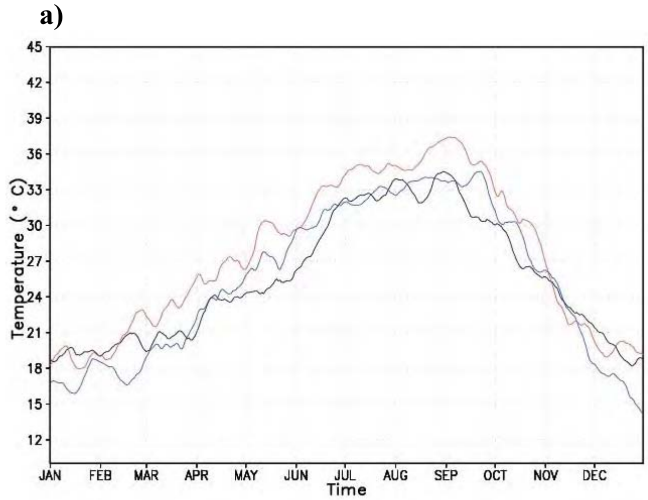


Annual cycle of maximum and minimum temperatures

The annual cycle of the maximum daily temperature is correctly reproduced in most regions of Mexico, as in Ensenada, Hermosillo, and Oaxaca, three characteristic regions (Figures 10a, 10b, and 10c). In all of them, an increase in the projected maximum temperature for the climate at the end of the present century is found to be about 2 to 3°C with respect to present climate.

Figure 10. As in Figure 9, but for maximum temperature (in °C) in a) Ensenada, Baja California, b) Hermosillo, Sonora, and c) Oaxaca

a)



b)

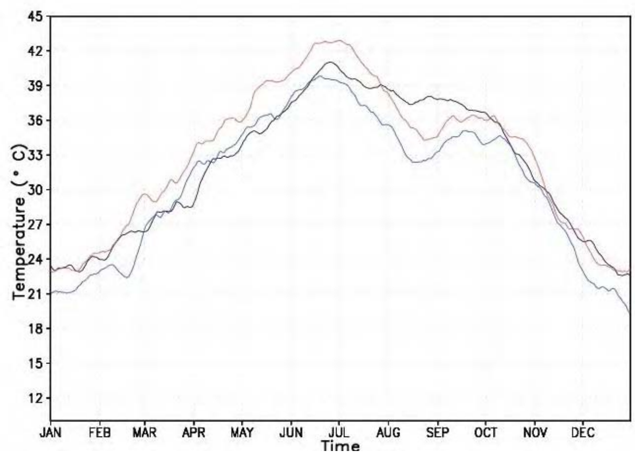
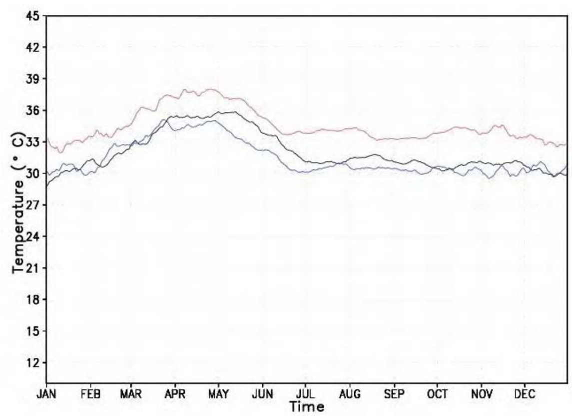


Figure 10, continued

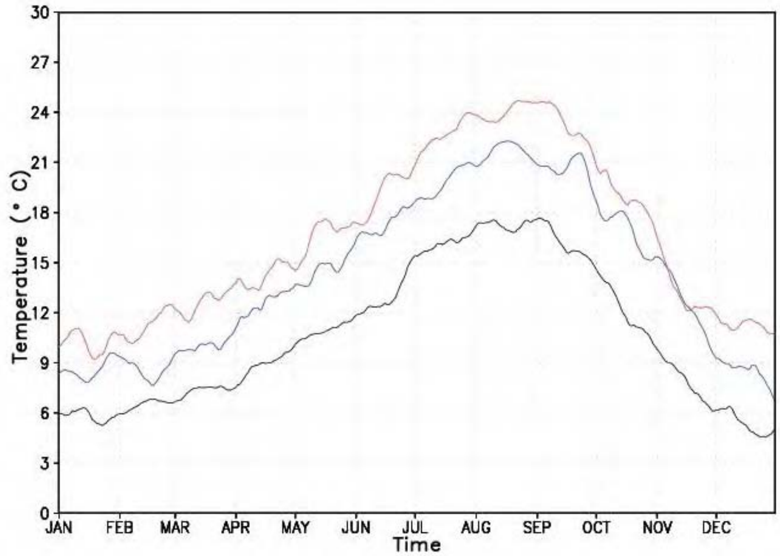
c)



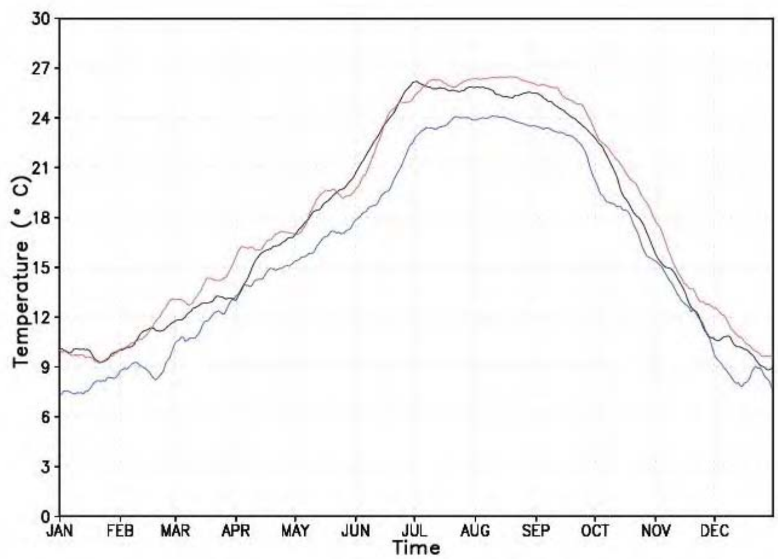
A similar analysis was performed for minimum temperature in Ensenada, Baja California. In this case, the model exhibits a systematic bias toward higher temperature. Even so, a clear increase in minimum temperature is observed for most months (Figure 11a). However, for the case of Hermosillo, Sonora (Figure 11b) and Oaxaca (not shown), the projected changes in minimum temperature are close to 0°C, suggesting that the dry conditions will persist in such a way that radiative cooling in these regions during winter will maintain minimum temperatures as in the present.

Figure 11. As in Figure 10a, but for the annual cycle of minimum temperature (in °C)

a)



b)



Analysis of extreme event

Indexes of precipitation extremes

According to most climate change studies, most regions will experience an increase in temperature but also an enhanced hydrological cycle. This condition will be reflected in heat waves as well as in anomalously dry and wet periods. Mexico has historically experienced severe drought (Mendoza et al. 2005) but also major floods in recent years, suggesting that a more intense hydrological cycle has begun.

The 20-km model may be used to conduct an analysis of extreme climate conditions in order to estimate future changes in frequency and intensity of some meteorological events. There are various ways to analyze changes in extreme events in the hydrological cycle. In the present case, three indexes have been used:

- **Simple daily intensity precipitation index:** Amount of precipitation accumulated during one year, divided by the number of rainy days with precipitation above 1 mm/day.

- **Mean dry spell length index**: Maximum number of days without precipitation events of more than 1 mm/day.

- **Maximum number of consecutive dry days.**

Climate change projections indicate that the intensity of rains will increase moderately in northwestern Mexico as well as in some states along the Pacific coast, such as Michoacán, Guerrero, and Oaxaca. This increase will be more evident in northeastern Mexico (Figure 12). The increased intensity of precipitation events in these regions may well explain the increase in total precipitation on an annual basis projected for the climate at the end of the century. On the other hand, the model projects fewer episodes of intense rain episodes and even fewer rainy days in some parts of southern central Mexico. Consequently, climate change projections in some parts of Mexico may experience less annual precipitation (Figure 12). However, this projection does not appear to correspond with several analyses of extreme precipitation events in some parts of the state of Chiapas, for instance, where the intensity and number of extreme precipitation events have increased since the beginning of the last century.

The mean dry spell length will tend to decrease over most of Mexico, except in some locations of Baja California (Figure 13). This decrease may be related to an increase in water vapor resulting from the warming over most of the world. Under a warmer climate, the Clausius-Clapeyron relationship indicates a potential increase in water vapor pressure.

Figure 12. Changes in the simple daily intensity of precipitation (in mm dy^{-1}) for the end of the present century

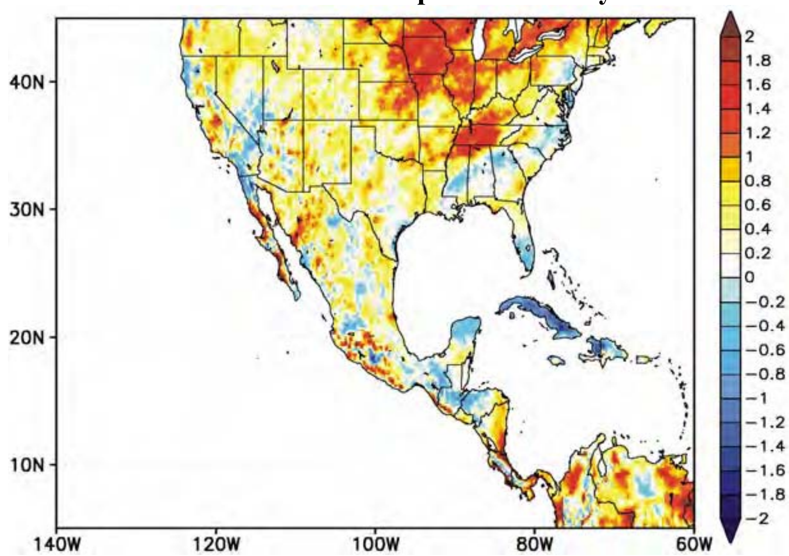
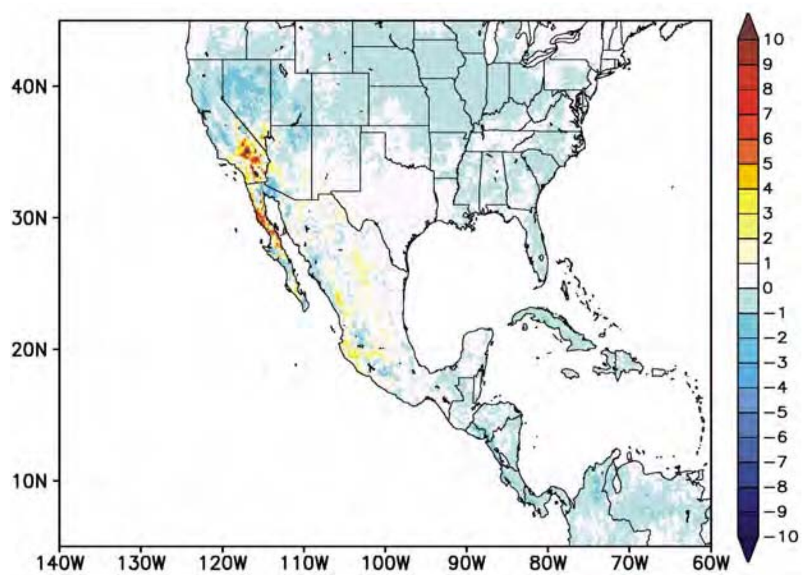


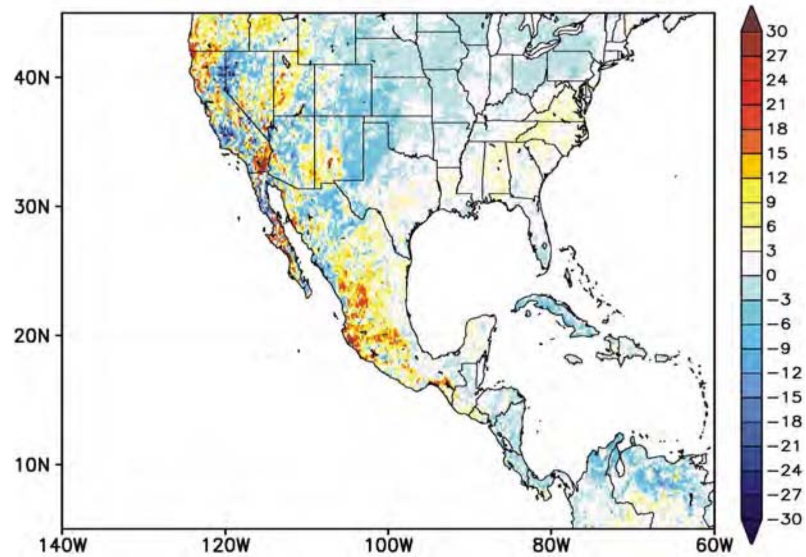
Figure 13. Changes in the mean dry spell length (in days) for the end of the present century



Climate change projections using the 20-km model indicate that the maximum number of dry days may increase in some parts of central and southern Mexico, but may decrease in parts of northwestern Mexico (Figure 14). Since episodes of consecutive dry days occur mainly during winter, the projected pattern reflects to some extent the response under El Niño conditions, in which more rainy days occur mainly in the states of Baja California and Sonora.

41770

Figure 14. Changes in the maximum number of consecutive dry days



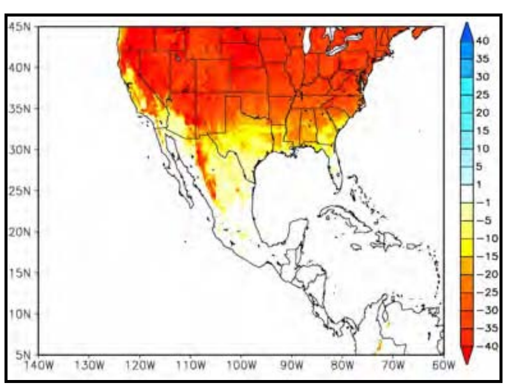
Indexes of temperature extremes

In the case of extreme temperature conditions, indexes have been defined to characterize changes in minimum and maximum temperatures. In this way, three indexes have been used to characterize changes in extreme surface temperatures for the end of the present century (2080–2099):

- **Frost days:** minimum temperatures below 0°C;
- **Tropical nights:** minimum temperatures above 25°C; and
- **Tropical days:** maximum temperatures above 30°C.

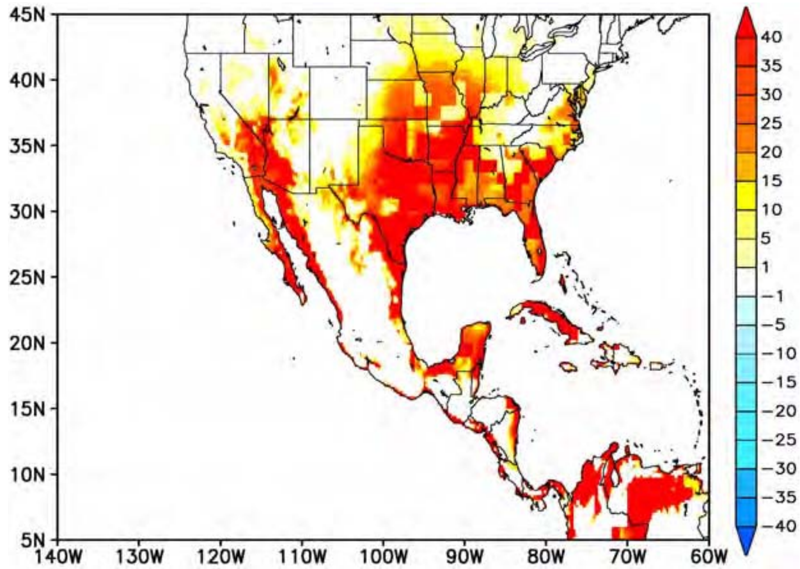
It is clear that a warmer climate will decrease the number of frosts, which essentially occur at high elevations over the Sierra Madre (Figure 15). There are no signs of increase in the number of frosts, suggesting that even radiative frosts may decrease in terms of their frequency.

Figure 15. Changes in the number of days per year with frosts (Tmin < 0°C)



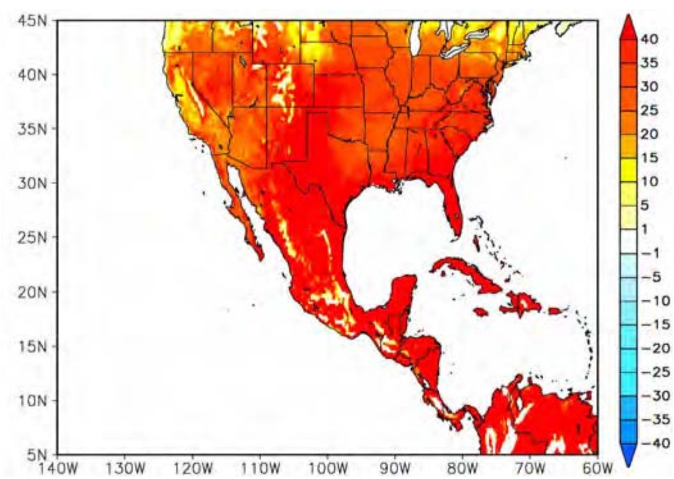
With respect to tropical nights, these events will tend to increase mainly in coastal regions over most of Mexico (Figure 16). The corresponding pattern suggests the effects of El Niño mainly during winter. This is consistent with the fact that at present, tropical nights occur during most of summer.

Figure 16. Changes in the number of days per year with tropical nights (Tmin > 25°C)



Finally, the number of warm days with maximum temperature3 above 30°C will increase over most of North America by more than thirty days (Figure 17). The only regions where this change will not be so dramatic are the high elevations, such as the Sierras and the mountains above southern central Mexico.

Figure 17. Changes in the number of tropical days per year (Tmax > 30°C)



The thresholds used for the present analyses are constant over the entire domain. A more refined analysis will require the determination of extreme events in the statistical sense of probabilities of the variable's distribution.

Conclusions

Climate change scenarios clearly indicate an increase in temperature and an enhanced hydrological cycle over most of the world and in particular over North America. The possibility of examining high-resolution climate scenarios becomes valuable when processes are important to determine potential impacts of climate change.

An analysis of the high spatial resolution (20-km grid size) makes it possible to determine changes in temperature, considering the effects of complex topography such as that existing in Mexico. For instance, climate change and its manifestations at regional level will depend on elevation. Through the use of regional scenarios, it is possible to observe how such changes will vary in distances of a few dozen kilometers. Even more, the role of complex topography and how it affects the projected changes in extreme events may be identified with a high-resolution model such as the one available in the Earth Simulator.

It is clear that at present, most conclusions were obtained from a single climate change experiment, given the difficulty and the demands to obtain more downscaled experiments. Several more experiments, for more time slices, will greatly increase the confidence and value of some of the scenarios for impact assessment and adaptation studies. Nevertheless, the present scenario makes it possible to extend the analysis of climate change, including other forms of extreme events such as tropical cyclones.

Results from the present analysis will focus in the wetlands of the Gulf of Mexico to examine the hydrological cycle in depth. Output with high spatial resolution will be of great use to implement water balance models at the basin level.

References

Koster R.D., M.J. Suarez, M. Heiser. 2000. “Variance and predictability of precipitation at seasonal-to-interannual timescales”. J. Hydrometeor., 1, 26–46.

Magaña V. and J.L. Pérez. 1998. “Variabilidad climática en los Mares Interamericanos”. Proceed. VIII OMMAC Congress. October 28–30, 1998. Veracruz, Mexico.

Magaña V., J.A. Amador, and S. Medina. 1999. “The midsummer drought over México and Central America”. J. Climate, 12, 1577–1588.

Magaña, V., J.L. Vázquez, J.L. Pérez, and J.B. Pérez. 2003. Impact of El Niño on precipitation in Mexico. *Geofísica Internacional*. 42, 313–330.

Mendoza B., E. Jáuregui E., R. Díaz-Sandoval, V. García-Acosta, V. Velasco, and G. Cordero. 2005. “Historical Droughts in Central Mexico and Their Relation with El Niño”. Journal of Applied Meteorology. 44(5), pp. 709–716

Mizuta, R., K. Oouchi, H. Yoshimura, A. Noda, K. Katayama, S. Yukimoto, M. Hosaka, S. Kusunoki, H. Kawai and M. Nakagawa. 2006. “20-km-mesh global climate simulations using JMA-GSM model–mean climate states.” J. Meteor. Soc. Japan, 84, 165–185.

Schultz, D.M., W.E. Bracken, and L.F. Bosart. 1998. “Planetary and Synoptic Scale Signatures Associated with Central American Cold Surges. Monthly Weather Review. 126:5–27.

Vázquez Aguirre, Jorge Luis. 1999. Caracterización objetiva de los Nortes del Golfo de México y su variabilidad interanual. Tesis de Licenciatura en Ciencias Atmosféricas. Fac. de Instrumentación Electrónica y Ciencias Atmosféricas. Universidad Veracruzana. 62 pp.

41770

Report on Activities Performed in MRI-Japan to Simulate Climate in Colombia and the A1B Scenario with the Japanese Model using a Resolution of 20 x 20 Km

María Constanza Martínez Arango and José Franklyn Ruíz Murcia,
Instituto de Estudios Ambientales y Meteorologia de Colombia, IDEAM

Introduction

One of the basic activities performed in the Meteorological Research Institute (MRI) is data analysis, especially on rainfall and precipitation, from four computer simulation runs designed by MRI's Climate Change Laboratory, as shown below:

Table 1. Types of computer simulation runs of the Japanese experimental model, at a resolution of 20 x 20 km

Computer Simulation Runs	SST	Annual variation	Integration time
AJ	Observed	No	10 years
AK	Observed + Anomaly	No	10 years
AM	CGM SST 1979 to 1998	Yes	1979 to 1998 20 years
AN	CGM SST for A1B scenario A1B, 2080 to 2099	Yes	2080 to 2099 20 years

In the AJ simulation run, the annual seasonality in ocean surface temperature (OST) remains constant over the 10 years of integration, while in the AK simulation run the anomaly of this ocean variable is added to the OSM seasonality. The latter run would simulate the climate at the end of the 21^{st} century, maintaining the current CO_2.

The AM run corresponds to climate throughout the 1979–1998 period and is simulated by the CGM 2.3.2 model with seasonal OST variation over those 20 years, while the AN run generates the A1B scenario for the last 20 years of the 21^{st} century, assuming the duplication of CO_2.

The unified model utilizes:

- Semi-Lagrangian integration scheme
- Short-Wave Parameterization by Shibata & Uchiyama
- Long-Wave Parameterization by Shibata & Aoki
- Cumulous Parameterization by Arakawa & Schubert
- In clouds, consideration of large-scale condensation, cumulus, and stratocumulus
- Parameterization of the boundary layer: 2-level closed system of Mellor & Yamada

- Gravity-wave drag: Iwasaki + Rayleigh friction

The ocean surface temperature in the present time is the result of the joint ocean-atmosphere model with the data observed,[3] while the meteorological variables forecasted to the end of the 21st century depend only on the forecast of ocean surface temperature as a boundary condition for the future atmosphere and, in the case of the A1B scenario, also duplicates CO_2 in the atmosphere.

Information Utilized

For the four experimental simulation runs (AJ, AK, AM, and AN), 12 scripts were programmed in Grads under Linux for each variable. The following data were obtained:

1. Spatial seasonality of precipitation and temperature in Colombia
2. Seasonality of precipitation for 30 Colombian cities
3. Seasonality of temperature for 32 Colombian cities
4. Climate variability for 4 Colombian cities in terms of temperature
5. Climate variability for 19 Colombian cities in terms of precipitation

Preliminary Analysis

For the spatial analysis, the 20 x 20 km spatial resolution of Colombia was prepared, using SURFER software in accordance with the coordinates provided by the Earth Simulator:

Table 2. Spatial resolution for Colombia

	MIN	MAX	SPACING	NODES
LONGITUDE	-79.125	-67.125	0.1875	65
LATITUDE	-4.404	12.846	0.1875	93

For a discretization consisting of 6,045 nodes in spatial analyses

Orography. In principle, orography models describe the country's most important landscape features such as the western, central, and eastern mountain ranges as well as the Sierra Nevada de Santa Marta and La Macarena (see Figure 1); small hills on Colombia's plains (*Llanura*) are also detailed.

For a more specific localized analysis, a comparison is made between the altitudes of several stations and the nearest point offered by the model's resolution (see Figure. 2).

[3] The resolution of the atmospheric model for present time conditions is 270 km, while the ocean model is between 50 and 200 km.

Figure 1. Earth Simulator Orography

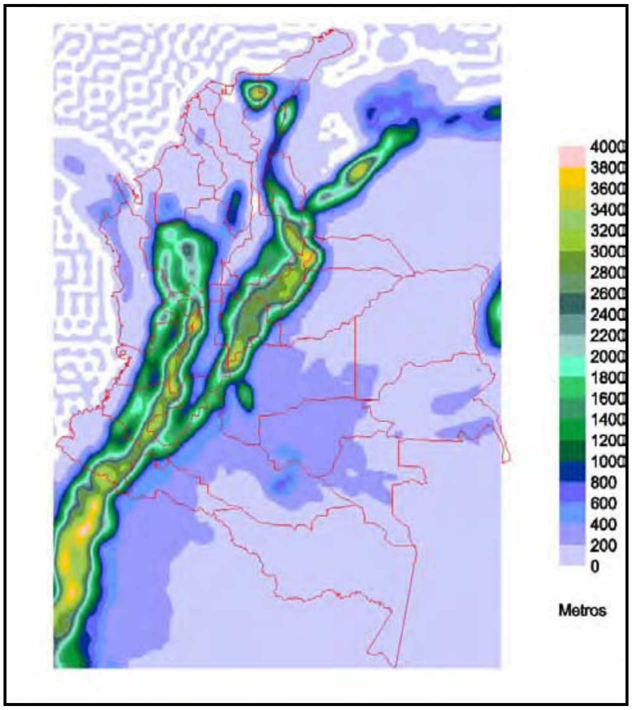
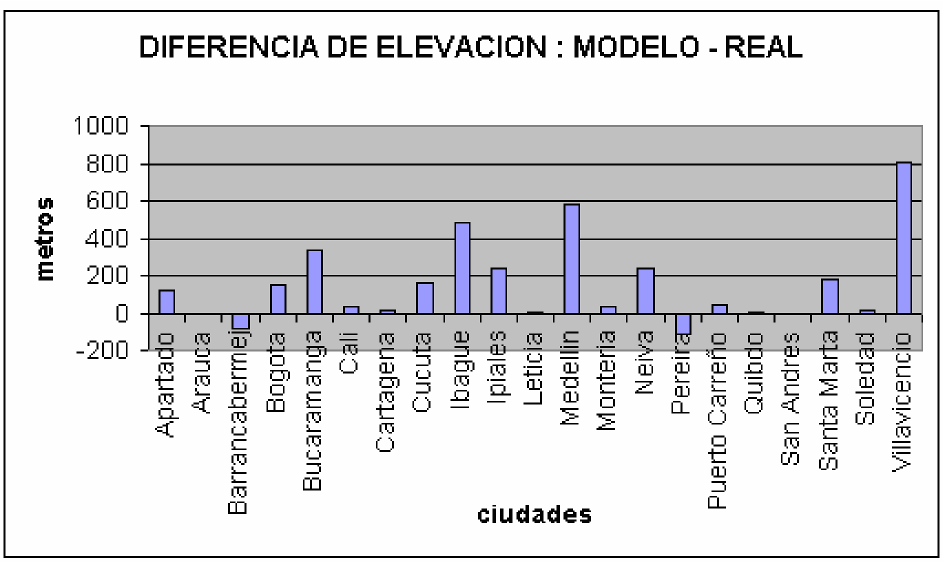


Figure 2. Intercomparison of model altitudes and real altitude for several cities



Precipitation

The seasonal variation of precipitation was analyzed using data from the AJ and AM simulation runs described previously, both spatially and locally. However, present and future climate variability is analyzed using the AK and AN simulation runs designed by MRI.

It should be noted that the common measure used in the AJ and AK runs is the average mm/day. For this reason, our data on total precipitation in mm are carried to this unit by simply dividing the number of days each month has, in order to make the results comparable. In the case of the AM and AK simulation runs, the average daily/monthly precipitation depends on the sum of cumulous precipitation (PPCI) plus large-scale precipitation (PPLI) in $kg/m^2/sec$; the conversion to mm/day was made using the following ratio:

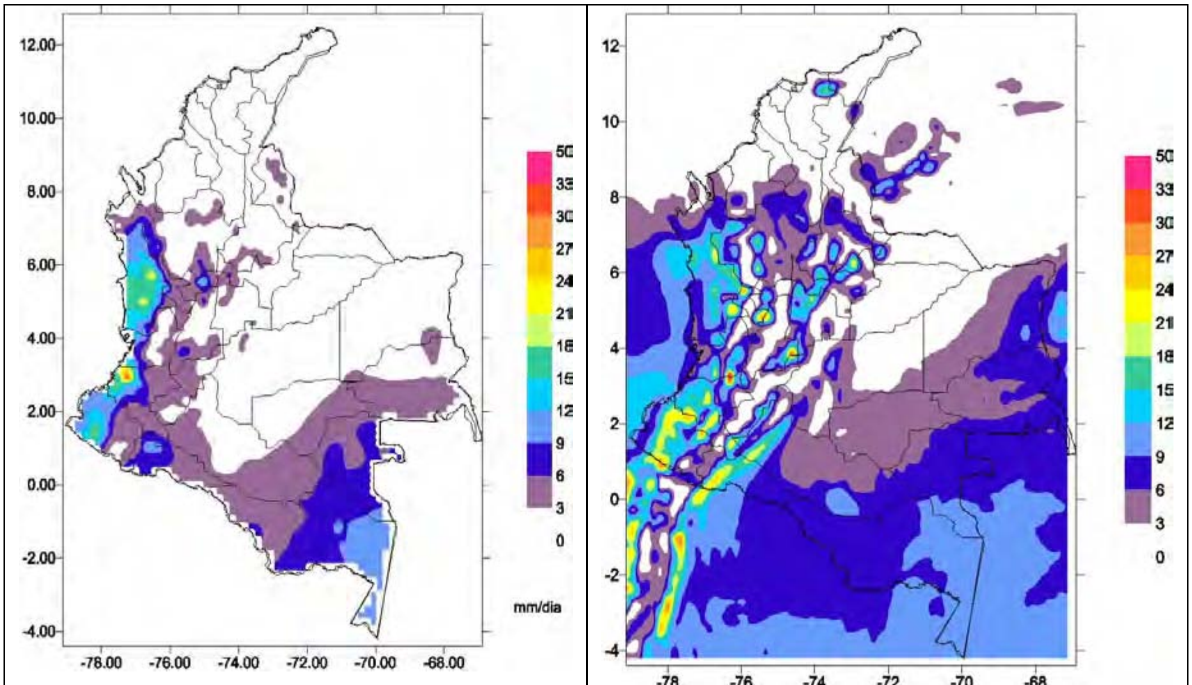
$$[mm/day] = 86400 \times (PPCI + PPCI)$$

As an example, the following shows the four simulation runs that model seasonality in the present time and at the end of the 21st century for a relatively dry month.

In addition, MRI scientists recommend that in the interval where there is no information on future and present climate, linear or logarithmic interpolations may be assumed in the increase or decrease of meteorological variables.

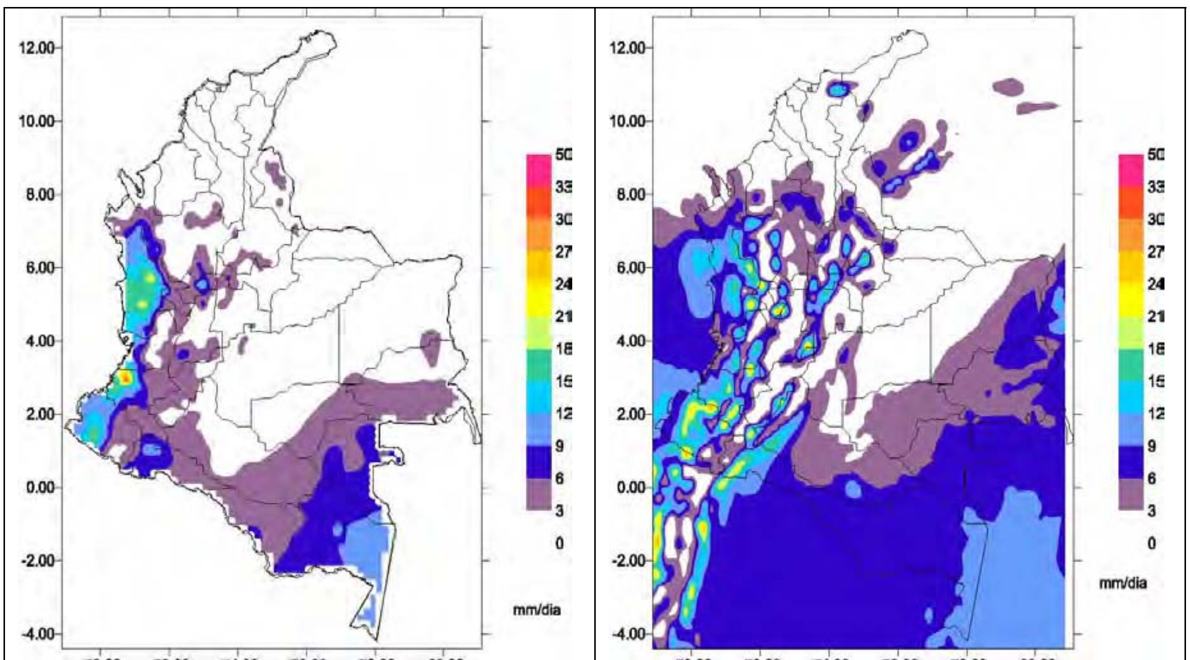
Seasonal variation–present time. In most cases, the AJ and AM simulation runs are well able to consider the general patterns of the overall (synoptic-type) circulation of the atmosphere and thus that of precipitation, even though these runs overestimate rain in the cordilleras, especially for the dry season in central and northern Colombia. For example, Figures 3 and 4 present the particular case of January.

Figure 3. Comparison of observations of the AJ computer simulation run for January



a) 20x20 km interpolation from the 1961–1990 series, with information on seasons	b) AJ computer simulation run

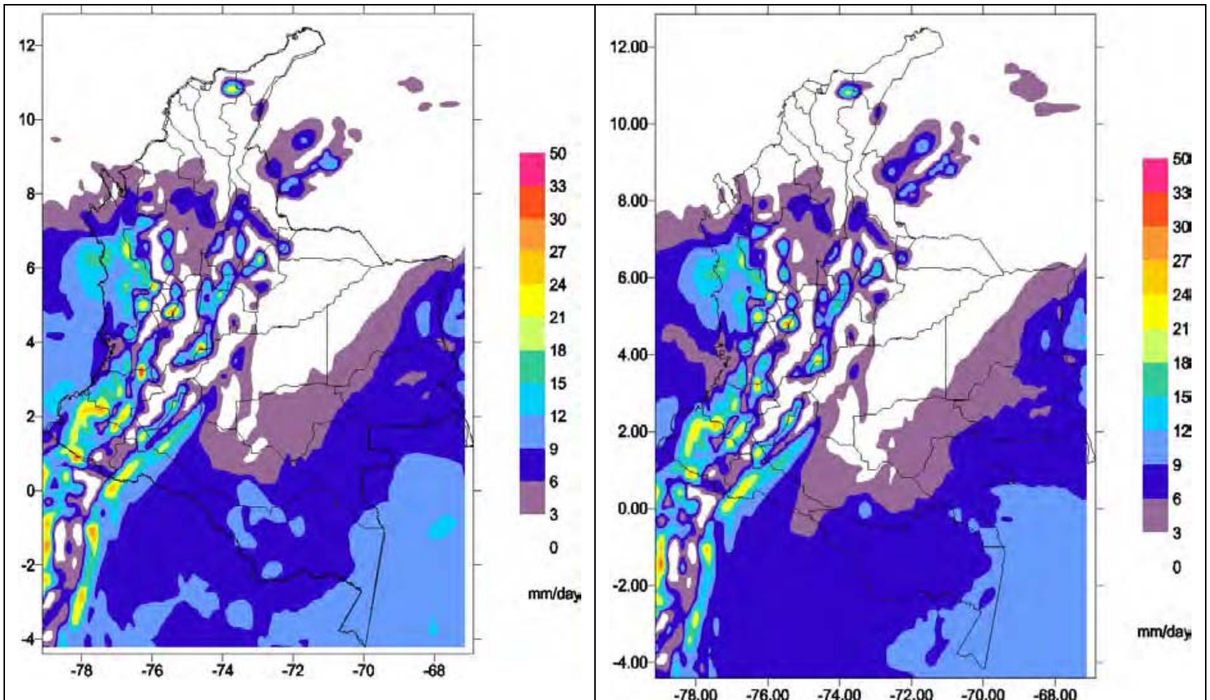
Figure 4. Comparison of observations and the AM computer simulation run for January



a) 20x20 km interpolation from the 1961–1990 series, with information on seasons	b) AM computer simulation run

Seasonal variation–future time. Figure 5 shows the results from model runs for a future climate scenario under AK and of scenario A1B (AN) for precipitation in the month of January.

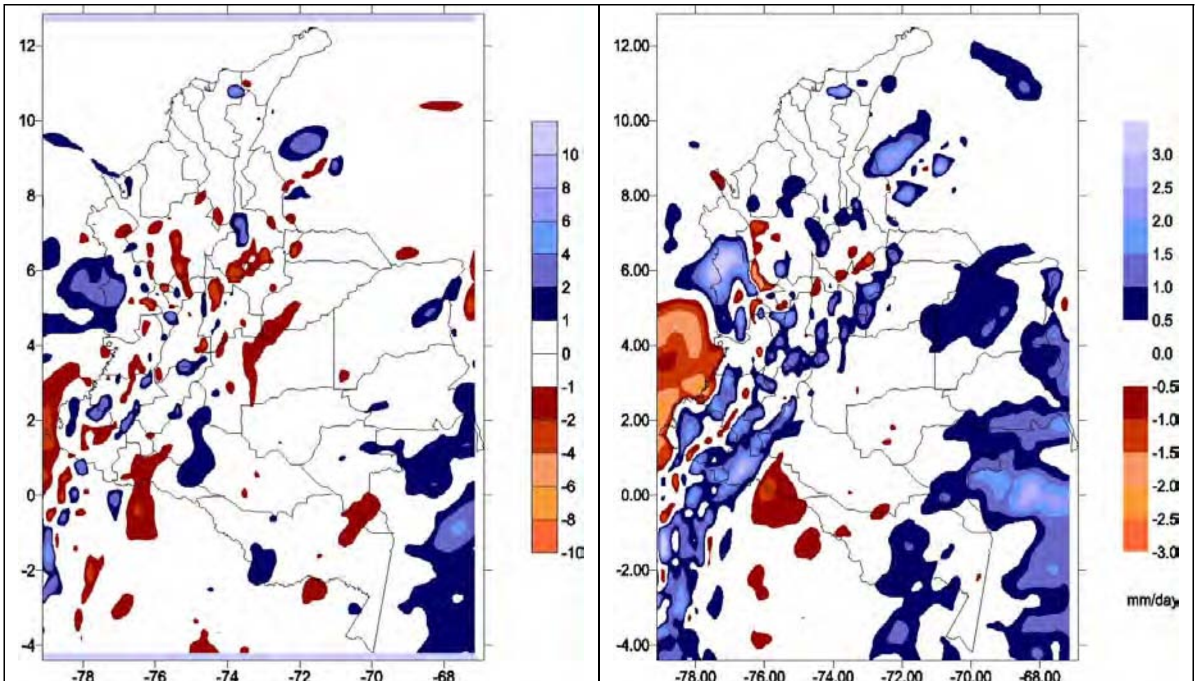
Figure 5. Future climate AK and AN (or scenario A1B) in precipitation for January



AK	AN (Scenario A1B)

The difference between the future status and present status for January, provided by the computer simulation runs, is presented in Figure 6.

Figure 6. Difference between future climate and present climate for January. In the case of AN–AM, the difference between Scenario A1B and the 1979–1998 present climate is simulated.



AK–AJ	AN–AM

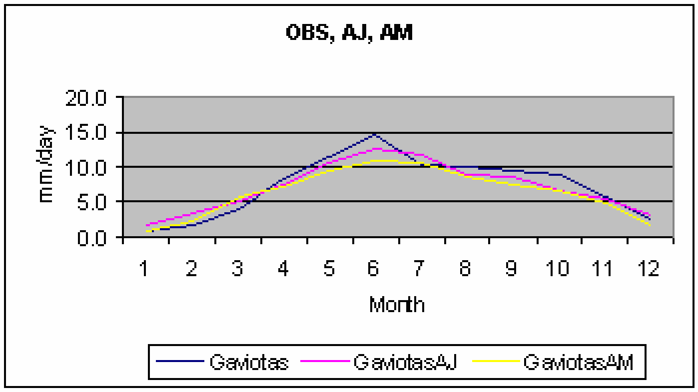
Evaluation of simulations for present climate. From a more local standpoint, the seasonal cycle with the AJ simulation run in the case of precipitation shows a correlation above 0.6 in 17 of the 30 stations evaluated (see Table 3). In this result, good correlations were not obtained between the 20 x 20 run and the Cúcuta, Florencia, Tulúa, Pereira, Cali, and Cenicaña stations. The AM simulation run includes two more stations with a correlation above 0.6 and maintains no significant correlation with those described in the AJ run.

Table 3. Evaluation of simulations for seasonality of precipitation

	CORRELATION		ECM	
STATION	**AJ**	**AM**	**AJ**	**AM**
Santa Marta	0.96	0.97	0.71	0.45
Gaviotas	0.96	0.96	1.72	2.77
Arauca	0.96	0.95	4.73	4.57
Leticia	0.94	0.93	0.70	1.23
Cartagena	0.90	0.91	6.07	2.34
Montería	0.92	0.89	3.80	3.68
Soledad	0.88	0.88	1.38	1.26
Fundación	0.88	0.86	3.12	2.93
Puerto Carreño	0.85	0.85	19.35	16.45
San Andrés	0.87	0.84	3.52	3.21
Pto. Legizamo	0.85	0.83	3.32	3.61
Barrancabermeja	0.84	0.81	51.48	47.01
Providencia	0.83	0.77	3.38	3.69
Medellín	0.83	0.72	164.39	146.93
Villavicencio	0.68	0.67	46.82	45.40
Apartado	0.59	0.66	9.27	9.37
Ipiales	0.69	0.65	1.33	1.16
Quibdo	0.63	0.65	20.77	27.58
Bogotá	0.55	0.60	1.44	0.96
Ibagué	0.48	0.55	16.15	14.33
Valledupar	0.54	0.44	3.58	4.38
Riohacha	0.55	0.43	8.34	9.03
Bucaramanga	0.47	0.43	89.35	61.49
Neiva	0.34	0.27	12.33	12.83
Florencia	0.10	0.14	38.86	47.29
Cúcuta	0.12	0.05	16.72	15.99
Tulúa	-0.17	-0.15	6.86	5.26
Pereira	-0.22	-0.18	40.00	26.51
Cali	-0.26	-0.24	1033.29	730.91
Cenicaña	-0.46	-0.44	1005.49	709.94

For example, Figure 7 presents a case with a major statistical correlation. It should be added that the nearest point that offers resolution of the 20 x 20 km grid was chosen with respect to the place of interest for making correlations.

Figure 7. Comparison of seasonal cycle observed with AJ and AM simulation runs for Gaviotas



Evaluation of seasonal variability. Climate variability was analyzed for 19 synoptic aeronautical stations in the 1979–1998 series (240 months) to make them compatible with the scenario of climate variability in the present climate, under the AM simulation run. Therefore, the methodology suggested by Prof. Daniel Pabón was utilized, which consisted of evaluating the average quadratic error (AQE) and the comparisons proposed by Portman and Sailor (R1, R2). The results are presented in Table 4.

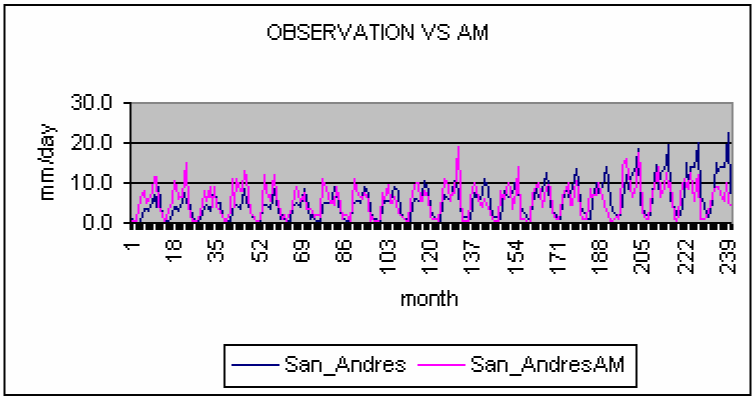
Table 4. Evaluation of simulations for climate variability of precipitation

STATION	CORR	R1	R2	AQE	RAQE
Arauca	0.78	-0.20	1.32	7.58	2.75
Pto. Carreño	0.74	-0.35	1.69	22.05	4.70
Cartagena	0.72	-0.27	1.04	5.52	2.35
Santa Marta	0.67	-0.20	1.05	1.56	1.25
Barranquilla	0.66	-0.14	1.09	3.89	1.97
San Andrés	0.60	-0.05	1.08	13.70	3.70
Leticia	0.57	0.40	1.56	9.66	3.11
Barrancabermeja	0.54	-0.74	0.83	47.51	6.89
Providencia	0.51	-0.07	0.97	12.34	3.51
Villavicencio	0.46	0.99	2.70	79.93	8.94
Bogotá	0.32	-0.01	0.81	2.57	1.60
Quibdo	0.31	0.69	1.20	59.97	7.74
Ipiales	0.30	0.23	0.82	2.53	1.59
Ibagué	0.25	1.16	1.56	19.36	4.40
Bucaramanga	0.13	-1.29	0.32	65.23	8.08
Neiva	0.12	1.09	5.38	16.04	4.00
Cúcuta	0.05	-0.87	0.63	19.51	4.42
Cali	-0.08	-1.55	0.10	754.74	27.47
Pereira	-0.13	-0.31	0.52	38.15	6.18

41770

The results in Table 4 show that climate variability is better represented in the insular sector of San Andrés, the Caribbean coast, and the Eastern Llanos, as shown in Figure 8.

Figure 8. Comparison between the climate variability of San Andrés and the AM simulation run



Temperature

The parameter of air temperature given by the model is in degrees Kelvin, which was converted to degrees Celsius, subtracting 273.15.

This parameter was analyzed using information from 685 stations for the spatial case and information from observations of 32 stations for the specific analysis; only 4 stations were subjected to climate variability analysis.

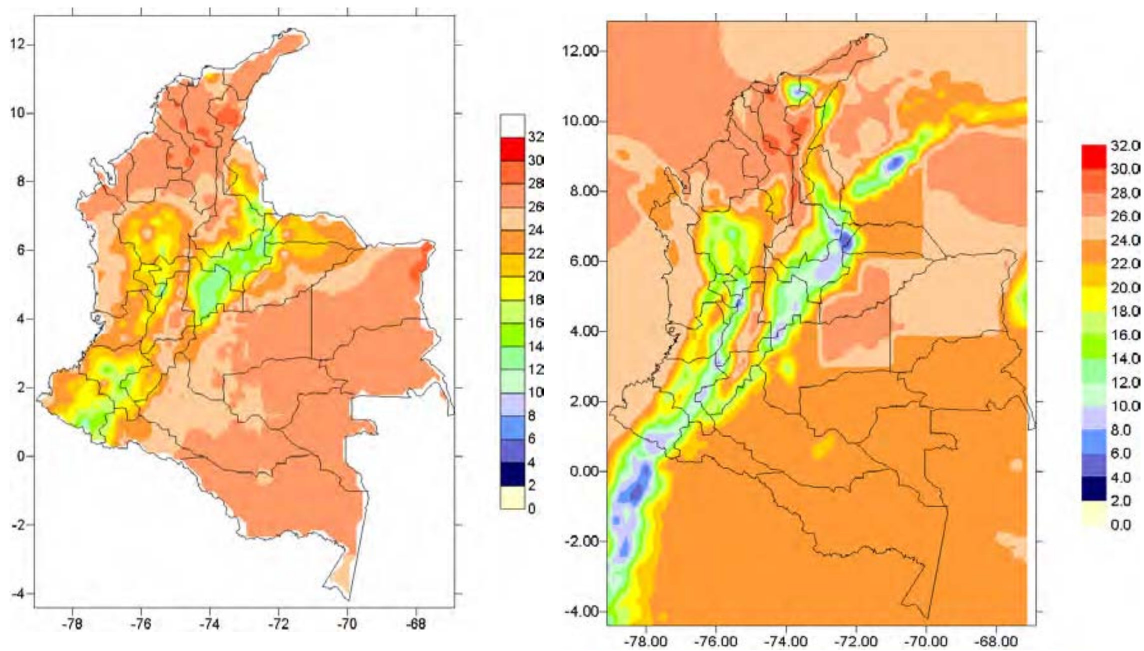
Seasonal variation in present time.
As in the analysis of precipitation, an analysis is made of seasonal representation in the present scenario given by the model (AJ–AM) of air temperature on the surface for January, a month considered to be seasonally dry.

In the AJ and AM simulation runs, the information obtained is rather fine, with details of low temperatures in mountain ranges (*serranías*) and high elevations, as in the cases of Sierra Nevada de Santa Marta, Nevado del Cocuy, Serranía de la Macarena, and Perijá.

In the case of January, if one looks closely at temperature values in observations for the 1961–1990 period in the Andean region, the interpolation assumes that in the mountainous zone temperature ranges are no lower than 12 or 14 degrees, while simulation runs of the models reflect values from 4 to 6 degrees Celsius, which reflects the fact that temperature is a function of altitude.

In general, by comparing the observations in the AJ simulation run, one can infer that the temperature detected by the model is quite acceptable in the Caribbean region, particularly in the Upar Valley (in César), but if one compares it to the AM run, this signal is not detected.

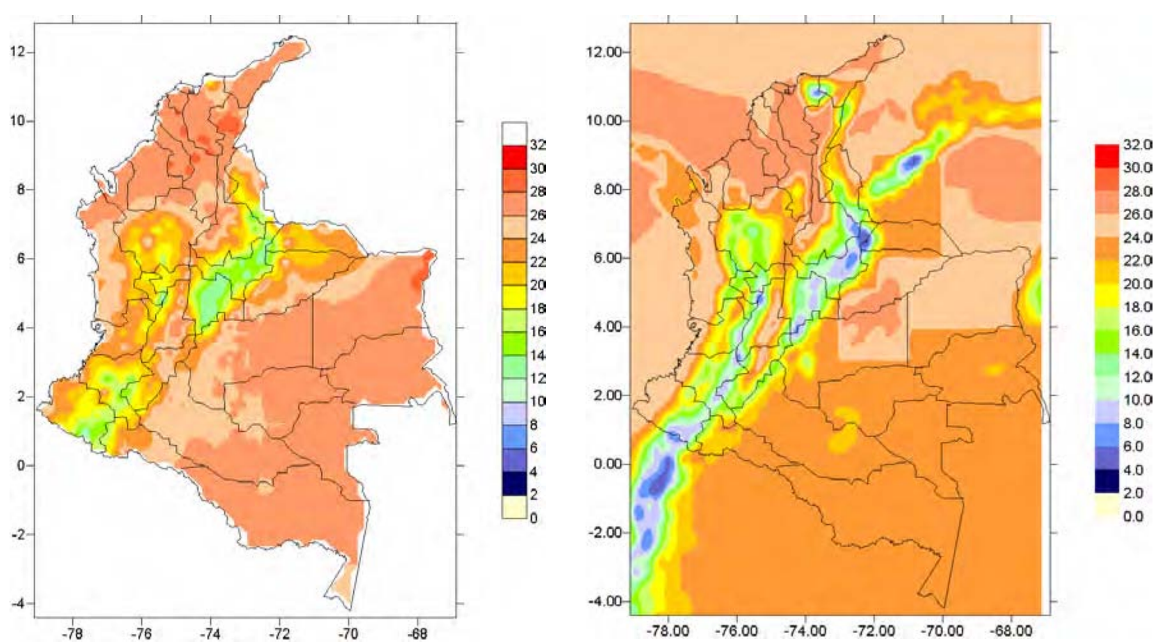
Figure 9. Comparison of observations and AJ simulation run for January



a) Baseline temperature interpolation 61–90 with 685 stations January

b) AJ model simulation run–January

Figure 10. Comparison of observations and AM simulation run for January



a) Baseline temperature interpolation 61–90 with 685 stations-January

b) AM model simulation run-January

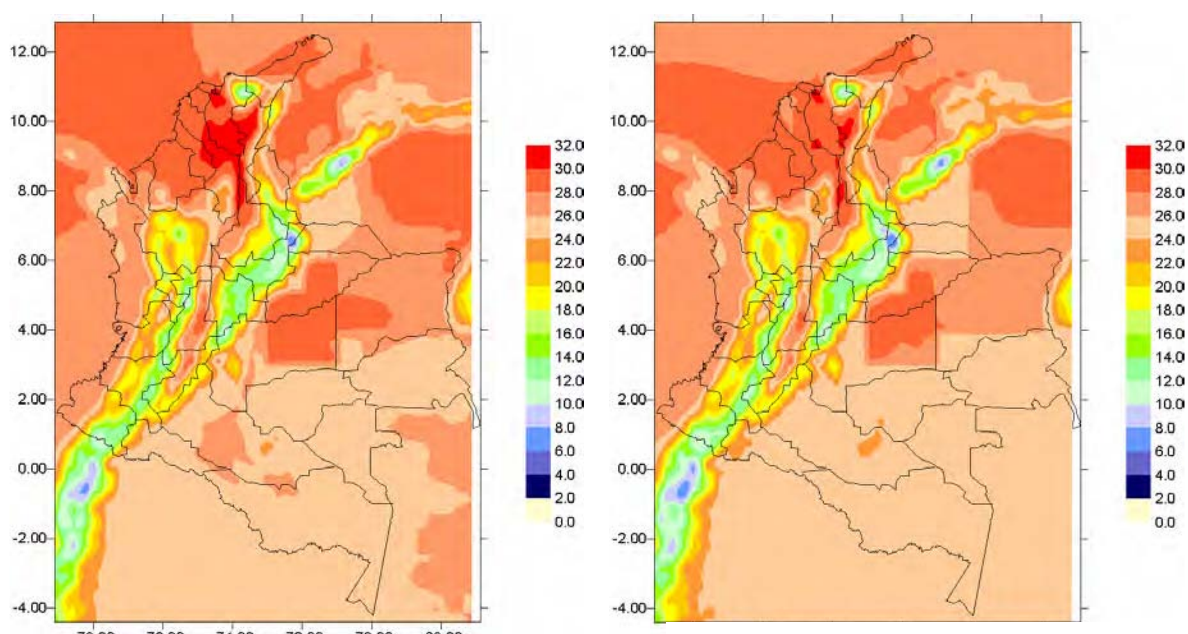
41770

Seasonal variation in future time. Air temperature in the AK–AN runs shows no major differences in most of the country. However, there are some differences in spatial distribution, as in the case of the eastern Llanos and the Caribbean Sea, where temperature has a slight tendency to be higher in the AK run and lower in the AN run.

As in the present in mountainous zones, temperature observations have more observation points and a higher resolution than precipitation records.

In general, the difference between the future and present for AK–AJ and AN–AM is the same, if one notes that the temperature ranges in both cases must be greater than 1.5º C. This means that the model assumes an increase in air temperature both for a scenario without changes in the seasonal cycle, and for a scenario with increased CO_2. Despite this, several cases for the future—2080 to 2099 (AN)—may be highlighted, where the spatial distribution of temperature increases in sectors such as the Llanero and Amazon foothills as well as in mountainous zones.

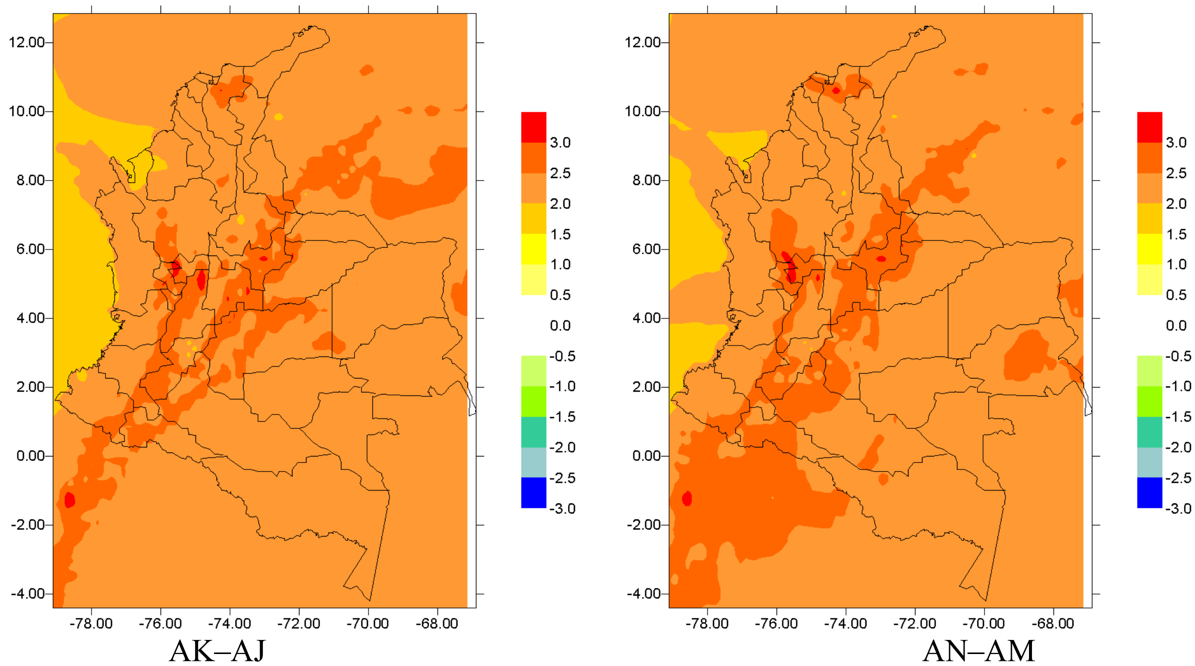
Figure 11. AK and AN future climate (or A1B scenario) in temperature for January



a) AK model simulation run-January

b) AN model simulation run-January

Figure 12. Difference between future climate and present climate for January. In the AN–AM case, the difference between the A1B scenario and the 1979–1998 present climate is simulated



Analysis of present seasonal variability. In Table 5, if one considers only seasons with correlations greater than 0.6, one can see that the AJ run has 62% in proportion (19 stations), while the AM run has only 51%, represented by 16 stations. This ratifies the spatial analysis performed previously, where the AJ details are greater than those of AM, although one cannot dismiss the correlations contributed to the AM run by the Florencia and Leticia stations.

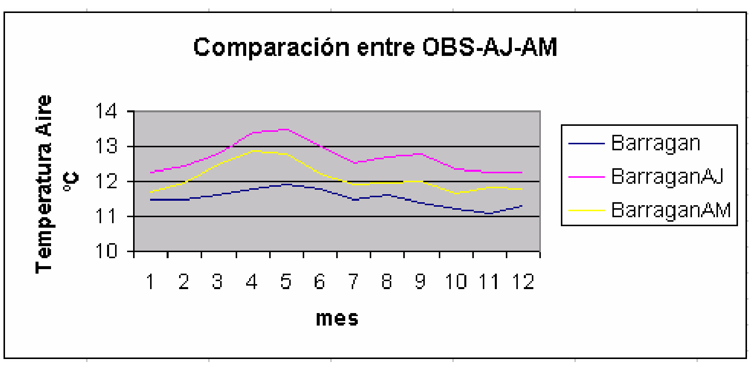
An example is the Barragán station (at an elevation of 3,100 meters), located in the area of influence of Las Hermosas moorland. Air temperature is compared with the AJ and AM simulation runs, which represent a good degree of seasonality. It should be noted that, among the analyses of various stations, it was found that air temperature should be corrected more by extent than by phase.

Table 5. Evaluation of simulations for temperature seasonality

MUNICIPIO	CORRELACION		ECM		RECM	
	AJ	AM	AJ	AM	AJ	AM
Cartagena	0.97	0.45	1.11	2.73	1.05	1.65
San Andres	0.95	0.93	0.54	0.99	0.73	1.00
Gaviotas	0.93	0.95	1.07	1.90	1.04	1.38
Tenerife	0.92	0.84	0.59	0.22	0.77	0.47
Providencia	0.90	0.89	0.58	1.10	0.76	1.05
Ipiales	0.87	0.82	2.26	4.72	1.50	2.17
Puerto Carreño	0.87	0.90	11.63	14.95	3.41	3.87
Barragan	0.85	0.81	1.41	0.39	1.19	0.63
Santa Marta	0.85	0.72	4.53	6.81	2.13	2.61
PtoLegizamo	0.76	0.93	5.64	7.99	2.37	2.83
Quibdo	0.74	0.58	1.15	1.76	1.07	1.32
Barrancabermej	0.74	0.84	1.21	2.48	1.10	1.57
Bucaramanga	0.70	0.67	5.06	7.88	2.25	2.81
Arauca	0.66	0.76	12.09	16.05	3.48	4.01
Medellin	0.64	0.47	26.27	32.74	5.13	5.72
Villavicencio	0.64	0.72	93.53	104.72	9.67	10.23
Valledupar	0.63	0.52	2.94	4.70	1.72	2.17
Bogota	0.61	0.72	0.11	0.57	0.34	0.76
Florencia	0.61	0.76	17.35	22.07	4.17	4.70
Cucuta	0.58	0.46	8.10	11.90	2.85	3.45
Tulua	0.50	0.44	13.26	16.35	3.64	4.04
Leticia	0.45	0.79	4.04	6.31	2.01	2.51
Ibague	0.44	0.40	16.44	23.23	4.05	4.82
Monteria	0.36	0.39	4.31	6.46	2.08	2.54
Pereira	0.33	0.39	1.28	2.96	1.13	1.72
Riohacha	0.22	-0.08	2.51	4.36	1.58	2.09
Cali	0.21	-0.11	5.40	7.02	2.32	2.65
Apartado	0.14	-0.05	3.95	5.90	1.99	2.43
Cenicana	-0.01	-0.34	4.71	6.24	2.17	2.50
Soledad	-0.37	-0.52	1.04	2.07	1.02	1.44
Neiva	-0.38	-0.46	3.29	5.48	1.81	2.34

Note: ECM is the Spanish acronyms used for the average quadratic error, AQE.

Figure 13. Comparison of seasonal cycle observed in the AJ and AM simulation runs for Barragán

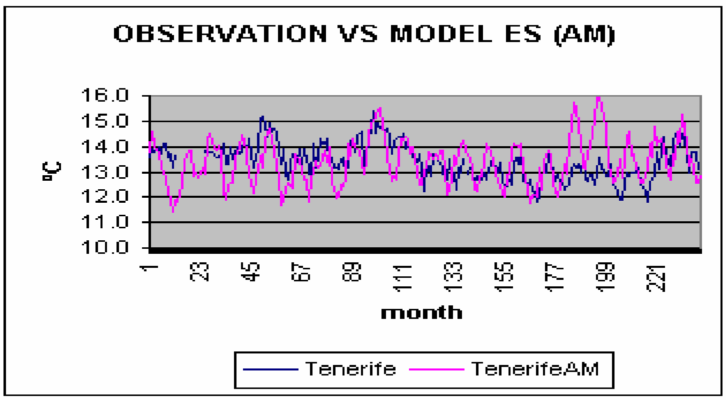


Evaluation of climate variability. The evaluation of climate variability in the AM–AN simulation runs for temperature indicates that the Tenerife station, located in the Cauca Valley at an elevation of about 2,609 meters, has an acceptable level of information in accordance with the index prepared by Portman and Sailor, which was proposed by the methodology for preparing scenarios with an r1 of nearly 0, of 0.02; and an r2 of nearly 1, of 0.80.

Table 6. Evaluation of simulations for the climate variability of temperature

	Portman AJ-AK		Portman AM-AN	
	r1	r2	r1	r2
Tulua_Farfan	4.04	3.23	4.27	1.54
Tenerife	-0.53	1.04	0.02	0.80
Barragan	-1.49	1.30	-0.59	0.91
SanAndres	0.87	1.90	1.35	1.27

Figure 14. Comparison of the climate variability of Tenerife and the AM simulation run



Evaluation of spatial seasonality: Case of Las Hermosas Moorland

Using the seasonal evaluation methodology, the area corresponding to Las Hermosas Moorland was selected, using information from the 20-km model for the present time. Observations were made, using this resolution, both of temperature and precipitation for the month of January, with the AJ–AM runs which simulate the present climate.

Tables 7 and 8 present the selected coordinates as well as the corresponding evaluations.

Table 7. Evaluation of seasonality of precipitation for January in Las Hermosas Moorland

		Topografía 20 km		prec mm/day		
LONGITUD	LATITUD	Modelo	Inf. Colombiana	OBS	AJ	AM
-76.125	3.846	2170,0	1608.47	3.86783	15.1047	16.927
-76.125	3.6585	2436,0	1802.34	3.44307	11.173	14.71031
-76.125	3.471	2421,0	2326.35	3.78609	8.31216	9.991624
-75.9375	3.846	3153,0	1265.45	3.30855	10.44008	1.792875
-75.9375	3.6585	3278,0	1729.17	3.99829	8.58843	1.776315
-75.9375	3.471	3070,0	2021.22	3.81764	5.17815	1.866725
				ECM	44.4300497	56.3810735
				RECM	6.66558697	7.50873315
				CORREL	-0.16754601	-0.02135809

Table 8. Evaluation of seasonality of temperature for January in Las Hermosas Moorland

		Topografía 20 km		temperatura aire		
LONGITUD	LATITUD	Modelo	Inf. Colombiana	OBS	AJ	AM
-76.125	3.846	2170,0	1608.47	20.91	13.6591	13.494
-76.125	3.6585	2436,0	1802.34	20.13	13.2474	12.648
-76.125	3.471	2421,0	2326.35	22.86	13.7793	13.208
-75.9375	3.846	3153,0	1265.45	20.41	10.064	9.586
-75.9375	3.6585	3278,0	1729.17	21.218	9.16772	8.641
-75.9375	3.471	3070,0	2021.22	22.24	10.4539	9.967
				ECM	65.323369	58.2789674
				RECM	8.08228736	7.63406624
				CORREL	-0.05518681	-0.03275715

As shown in Tables 7 and 8, the correlation obtained is not good. In this case, one should consider that the spatial analysis of our observations is the result of an interpolation that does not take the geography into account but instead is the result of the distance and density of data introduced in the interpolator program (SURFER).

Furthermore, Tables 7 and 8 show the elevation generated for the discretization points both of the model and of that obtained by the IDEAM database.

Notes

- Consider that the model's topography (20 x 20 km) at points near the stations must be corrected; for the analyses, the project requires variables that depend on elevation (pressure, temperature, etc.).
- Although in the preliminary analyses and in data downloading San Andrés was considered the representative point for the Caribbean Sea, it should be noted that the model's resolution does not view the island.
- The method utilized to interpolate information was Inverse Distance to a Power.
- Understand that the AJ Present Climate run simulates an ideal atmospheric condition for a 10-year period, while the AM run represents a 20-year variability.
- Understand that the AK Future Climate run corresponds to a period in which CO_2 remains constant, although there is variability in the sea surface temperature as a lower boundary condition. For the AN Future Climate run, the simulation corresponds to the last 20 years (2080–2099) with CO_2 increases thus representing an A1B scenario.
- When comparisons are being made, due consideration must be given to the lag and to the absolute value of the difference between the modeled results and the recorded observations.
- The downloading of information for analysis of the daily cycle is being prepared.
- MRI will provide us with two DVDs containing a total of 9.4 G, with the information required for the INAP project, only for the AJ–AK simulation runs. Thus, we should select the variables that are of most interest for resolving the uncertainties within the project.

Activities performed

- Recognition of the model and distribution of information in MRI's work stations;
- Preliminary analysis of the AJ–AK model, the difference between them, and the observations provided by the low resolution (2.5ºx2.5º) ERA-40, from which a set of prints was obtained;
- Preparation of scripts in Grads under Linux for downloading information on the four simulation runs of the models;
- Preparation of multiannual data and observations;
- Preparation of analysis tools in Surfer and Excel;
- Preparation of first progress report;
- Visit to the meteorological fair planned by MRI scientists;
- Presentation to MRI Director and Dr. Hiroki Kondo;
- Participation in discussions on:
    - Global Warming Projection by an atmospheric general circulation with 20-km grid size—Dr. Shoji Ksunoki
    - Climate modeling for global warming projection at the MRI—Dr. Akira Noda.

Projected Climate Over the Central Andes Countries caused by Global Warming

Grinia Jesús Avalos Roldán
National Meteorology and Hydrology Service–SENAMHI (Peru)

Introduction

The fourth IPCC report confirms that there is observable proof of regional thermal changes in climate and these have affected a wide range of physical and biological systems in many parts of the world. The changes observed include the shrinking of glaciers.

Most of the world's tropical glaciers are located in the mountains of Peru, Bolivia, and Ecuador (Andes Cordillera). In Peru, which currently has 18 mountain glaciers, 22% of the surface of these glaciers has been lost over the past 27 to 35 years, an area equivalent to that of all glaciers in Ecuador.

In light of the above, and under the framework of the subproject entitled Climate Change Scenarios for the Andean Regional Adaptation Project, led by Peru's National Environmental Council (CONAM) under the auspices of the World Bank, the present work presents the results of simulations made by the High-Resolution Atmospheric Global Climate Model (AGCM–TL959L60) developed by the Meteorological Research Institute (MRI) and the Japanese Meteorological Agency (JMA).

This AGCM for global warming experiments has a super-high horizontal resolution of 20 km (TL959) with 60 levels on the vertical plane, and was processed in one of the world's fastest supercomputers, the Earth Simulator. The time-slice method (IPCC 2001) was developed to generate present and future climate scenarios, using as a driver the climatological Sea Surface Temperature (SST) and the anomaly, respectively. The experimental runs are presented in Table 1.

Table 1. Types of model runs

Experiment	SST	Annual Variability	Integration Period
AJ	Present Observed SST (1982 to 1993)	No	20 years
AK	Present Observed + Anomaly	No	10 years
AM	GCCM SST 1979 to 1998	Yes	20 years
AN	GCCM SST A1B for 2080 to 2099	Yes	20 years

The SST anomaly of time-slices is: MRI GCCM 2.3 = SST (2080–2099) – SST (1979–1998)

Where:

AJ is the simulation of present climate with the TL959L60 AGCM model (20x20), using observed climatological SST as a driver, without seasonal variation.
AK is the simulation of future global warming (end of XXI century), with the TL959L60 AGCM model (20x20). The driver is observed climatological SST, without seasonal variation plus the time-slice anomaly.
AM is the simulation of present climate, using SST (1979–1998) as a driver, with seasonal variation and with the MRI-GCCM model 2.3.
AN is the simulation of future global warming (end of XXI century), using SST (2080–2099) as a driver, with seasonal variation under the SRES A1B (assuming the duplication of CO_2) and with MRI-GCCM model 2.3.

Model Outline

Among global atmospheric models, TL959L60 (20-km mesh) is a recent one, the result of cooperation between MRI and JMA. The model is based on the JMA numerical weather forecasting model (JMA-GSM0103) which has been modified and improved.

The model is coded in Fortran90; the integration scheme is Semi-Lagrangian (Yoshimura 2004); the shortwave parameterization is based on the Shibata & Uchicaya scheme (1992); the longwave parameterization is based on Shibata & Auki (1989); the cumulus scheme (convection) is that of Arakawa–Schubert (Randall & Pan 1993); the outer layer is parameterized under the Mellor & Yamada scheme, with a closing level 2, and pull by gravity waves is based on Iwasaki (1989).

Results

Continental-Scale Patterns

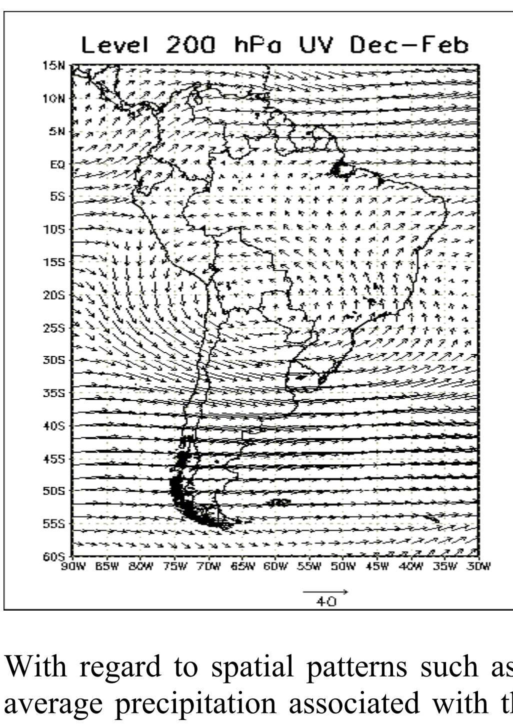
The principal large-scale systems responsible for the variability of precipitation over South America are: the Alta de Bolivia (AB), the South Atlantic Convergence Zone (SACZ), the Intertropical Convergence Zone (ITCZ), the South Pacific Anticyclone (SPA), and the South Atlantic Anticyclone (SAA). The linkage of the first three of these assures a large amount of convective activity in the region during the summer season, while the intensification and configuration of the SPA may block or facilitate during winter the entrance of frontal systems which also bring about rains; the strengthening and location of the SAA favors the advection of warm, humid air from the Amazon Basin which, when it hits the eastern Andes, rises due to the orographic effect, causing a quick cooling of the air mass, thereby reducing much of its capacity to sustain the initial moisture and producing strong precipitation that extends longitudinally over adjacent regions to the east of the Andes (Avalos 2005). The AB and SACZ are typical summer systems, and the ITCZ, SPA, and SAA are quasi-stationary systems with seasonal southerly movements.

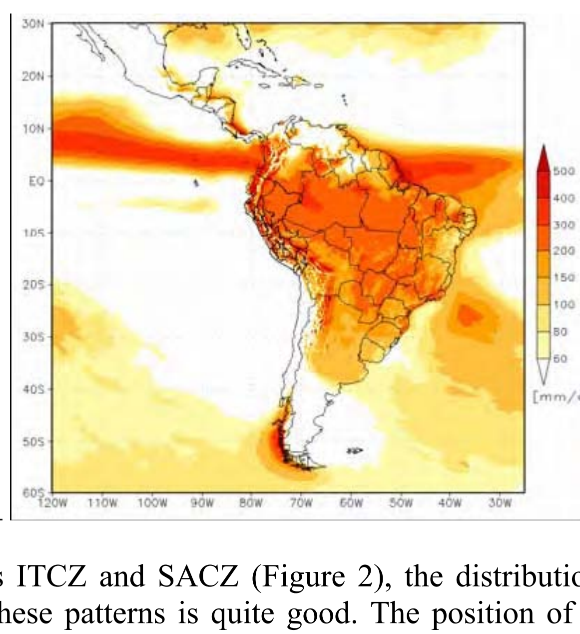
Considering that some global models present certain limitations in the simulation of synoptic systems in the tropical region (SEAMHI 2004), especially during the rainy season, the first exercise of this training session was to determine the skill of the MRI-JMA TL959L60 model (20-km mesh) in simulating the position, configuration, and seasonality of the abovementioned system (especially ITCZ), for the purpose of understanding which of these systems are well characterized by the model and which merit more attention, and finally determining the reliability of the model's projections for climate change studies. The upper troposphere analysis (for the AB) was carried out with the MRI T42GCCM model, since the predominant flow at this level is not affected by local effects.

The following figures show the AJ outcomes of the TL959L60 model during the rainy season of December, January, and February (summer in the southern hemisphere). Figure 1 shows that during this period the AB is centered on average over 19°S and 21°S, showing comparatively more intense winds over the subtropics with a marked anticyclone curve (30°S–40°S). This indicates that the representation of the medium flow in the upper troposphere is quite realistic in the MRI T42GCCM model.

Figure 1. Average wind field in 200hPa in ms^{-1} during the southern hemisphere summer, simulated by the MRI T42CGCM model.

Figure 2. Field average precipitation in mm/month^{-1} during the southern hemisphere summer, simulated by the Japanese high-resolution model MRI-JMA TL959L60.

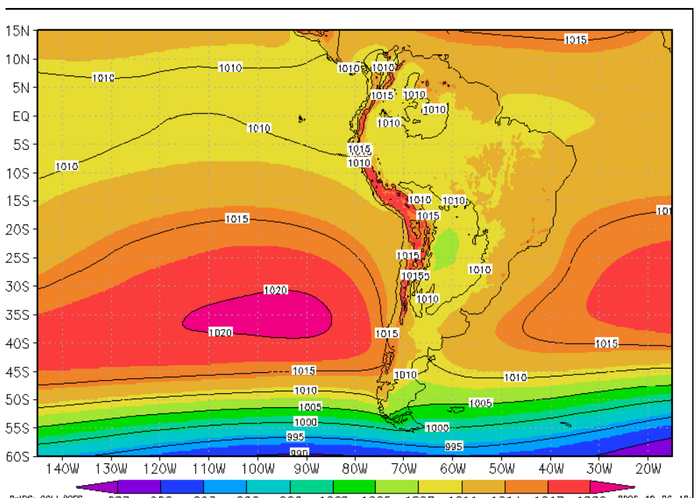




With regard to spatial patterns such as ITCZ and SACZ (Figure 2), the distribution of average precipitation associated with these patterns is quite good. The position of both systems is within their normal range of variability in summer, although it is moved slightly northward in the case of the ITCZ (Satyamurty et al. 1999). In an analysis of various global models, for the generation of climate change scenarios over the Piura River Basin (along the northern coast of Peru), SENAMHI (2004) found that two out of eight models deficiently represented the ITCZ's position, placing it between 5°S and 10°S, nearly in front of the capital city, Lima.

During summer in the southern hemisphere, the average intensity of the SPA varies from 1020 hPa and 1023hPa, and its center from 20°–40°S; 80°–120°W, approximately (Satyamurty 1999). Figure 3 (South American domain) shows that the model coherently simulates its normal variability in terms of intensity and location of the SPA; moreover, the model can correctly simulate the seasonal southerly movement of the system (winter results are not shown).

Figure 3. Field of pressure at sea level during the southern hemisphere summer, simulated by the high-resolution Japanese model MRI-JMA TL959L60



Orography

A numerical forecasting model depends on several constant fields such as orography and surface conditions (albedo, vegetation, etc.). Topographic characteristics play an important role in the determination of local climate, because these portions of land with a particular elevation generate their own climates (Beniston 2000) in terms of the slope, aspect, and exposure of the mountain surface to climate elements.

Considering that the representation of orography is closely tied to the problem of resolution, from our perspective as an Andean country it was particularly interesting to evaluate the topography provided by the MRI-JMA TL959L60 model, since the Andes Cordillera is the planet's longest (10,000 km) and second highest mountain chain. In Figure 4, the colored region corresponds to the Cordillera's domain, and the scale is expressed in meters above sea level (masl). One can see the good approximation of altitudes over Peruvian territory. The Pearson correlation coefficient between the real elevation of 45 stations located above 3,000 masl and the elevation simulated by the model was 0.61 (see Figure 5).

Figure 4. Topography of the Andes Cordillera according to MRI-JMA model TL959L60

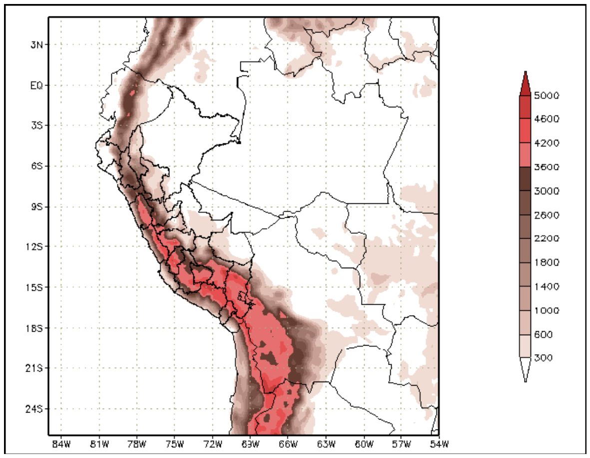
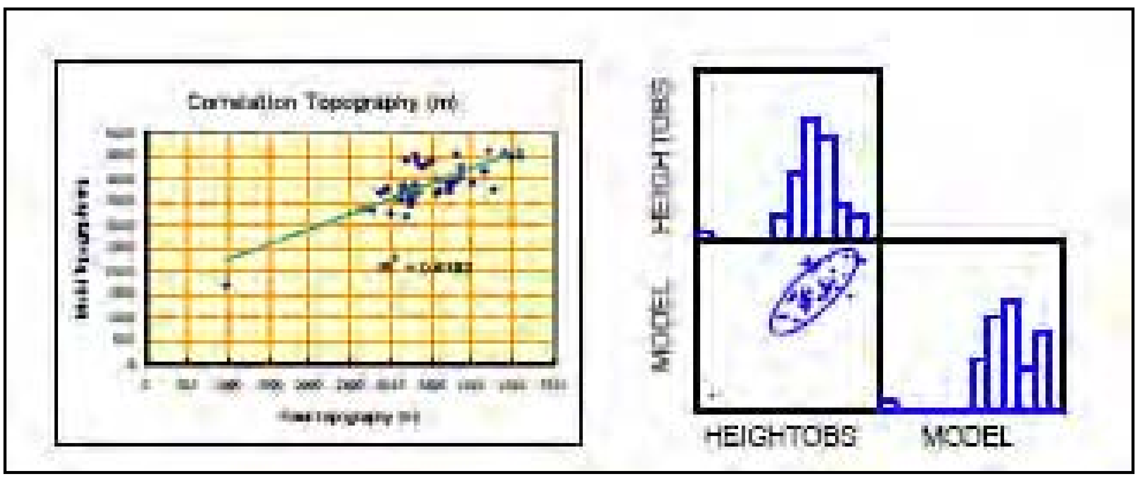


Figure 5. Pearson correlation between real elevation of stations and the model's topography



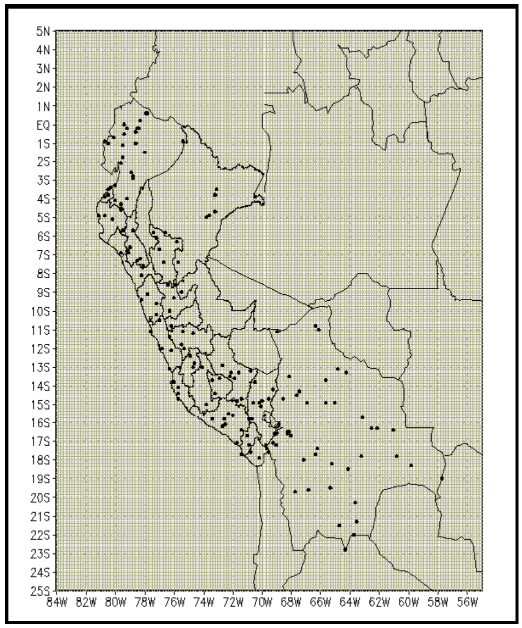
Precipitation

Data and work area. This preliminary evaluation looked at 101 stations with (monthly) precipitation information records for 30 years. The records of nearly 70% of stations correspond to the period from 1970 to 2002. For the case of extreme temperatures (maximum and minimum), 81 stations were considered. The spatial distribution of these stations is shown in Figure 6.

One can see that the spatial coverage of the 101 stations throughout Peru is not uniform; a large part of the Amazon region is not covered, which hinders the evaluation of the model over that region.

41770

Figure 6. Spatial distribution of stations used in the preliminary evaluation of MRI-JMA model TL959L60 (20-km mesh)



The present climate was analyzed using the AJ run of the Japanese model and future climate with the AK run. In the latter run, the AN run is considered because it assumes the duplication of CO_2. The basins where individual analyses of the precipitation variable were made, are the Mantaro River Basin and the Urubamba River Basin, both with a glacier component. It is important to highlight the socioeconomic importance of both basins, since they produce over 50% of the electricity in the country; moreover, the agricultural production of nearby valleys provides food for the city of Lima where 33% of the country's population lives (see Figure 7).

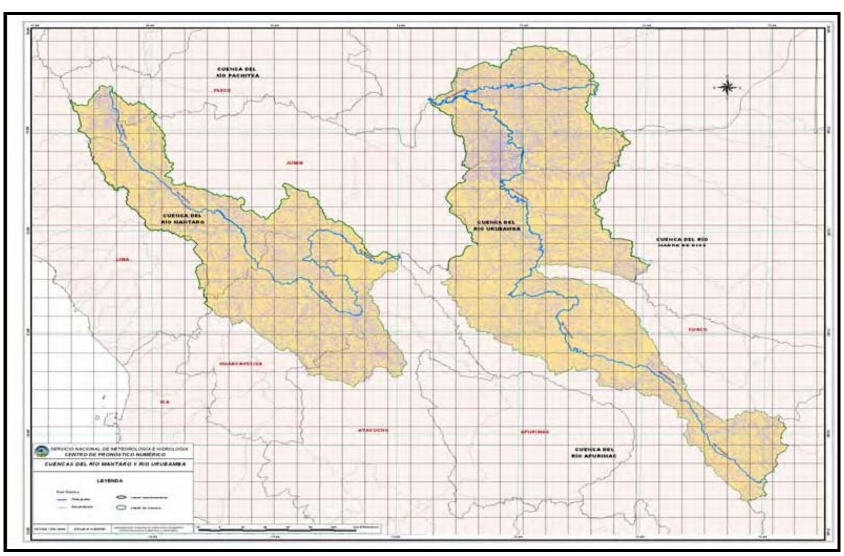
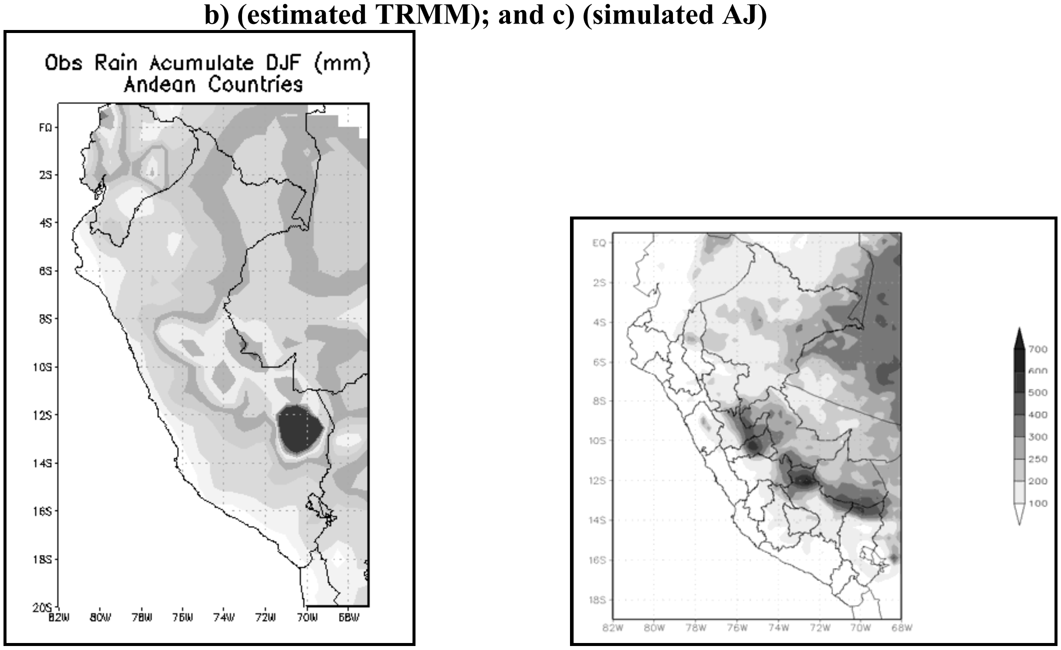


Figure 7. Mantaro River Basin (left) and Urubamba River Basin (right), both located in the central-southern sector of the Andes Cordillera in Peruvian territory. 20-km grid

Seasonality. The seasonality of precipitation was analyzed by comparing real seasonality (with historical information) with the seasonality simulated by the model (AJ run) based on historical SST.

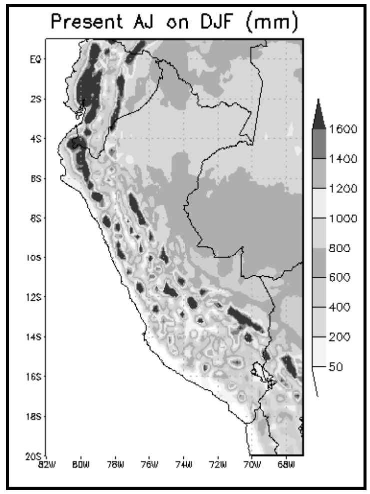
Figure 7a presents real precipitation in the rainy season, corresponding to the months of December, January, and February (DJF). The results indicate that the precipitation patterns simulated by the model are strongly associated with topography (Figure 7c). For another approximation of the real distribution of precipitation, this analysis was complemented by the precipitation estimated by the Tropical Rainfall Measuring Mission (TRMM) satellite for the 2000–2006 period (Figure 7b). One can see that there are differences between observed and estimated amounts; however, spatial distribution is quite similar. According to the personal experience of several forecasters (DMS-SENAMHI), the precipitation estimated by the TRMM offers a good spatial approximation of rains but underestimates the amount of precipitation by at least 40%.

Figure 7a. Accumulated precipitation in the DJF rainy season: a) (real); b) (estimated TRMM); and c) (simulated AJ)



41770

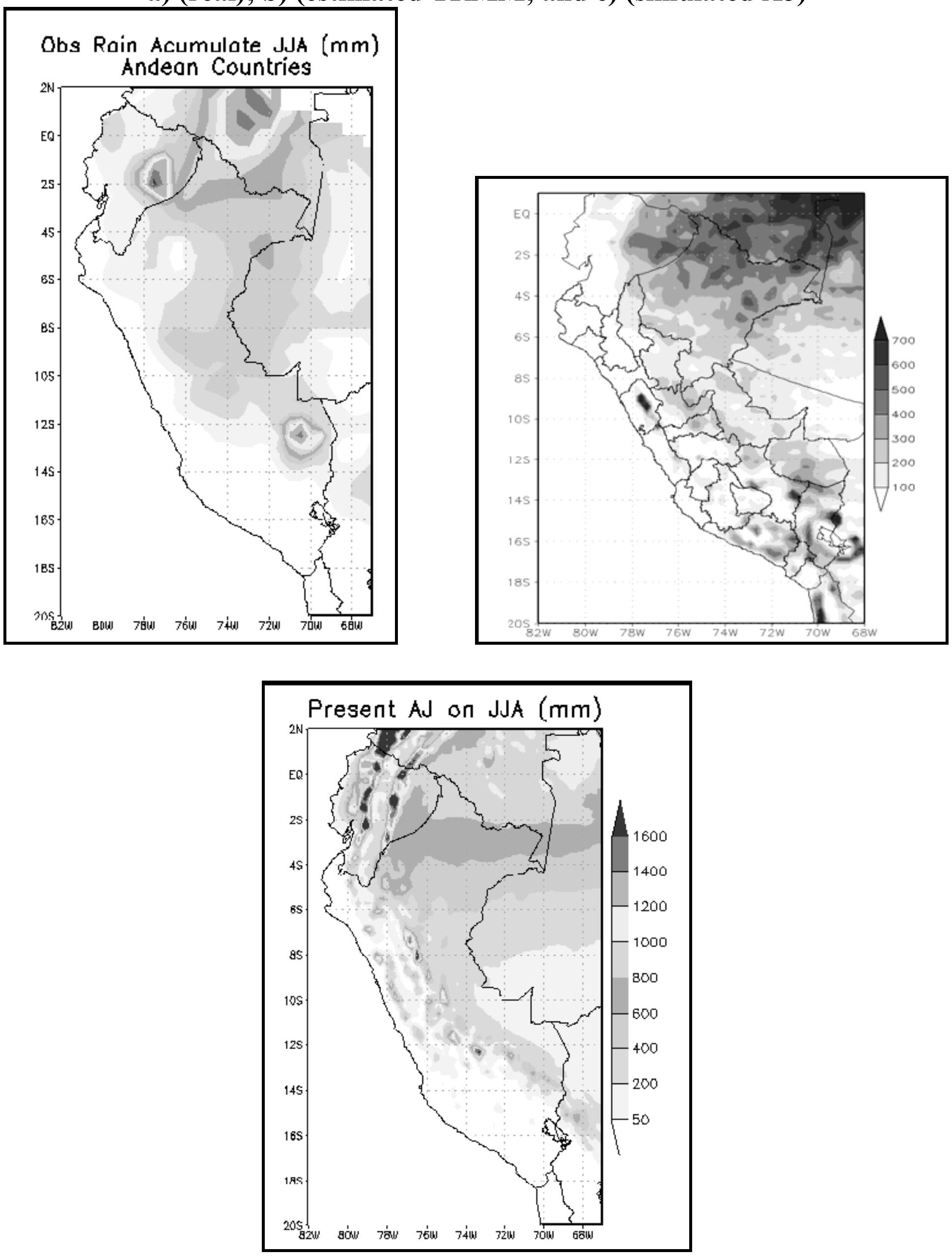
Figure 7b. Accumulated precipitation in the DJF rainy season: a) (real); b) (estimated TRMM); and c) (simulated AJ) (continued)



The model does not differentiate the contrasting amount of accumulated precipitation on both sides of the Cordillera (the eastern side is the rainiest). The amount of precipitation is overestimated on both flanks of the Cordillera and in the more equatorial region. This is consistent with the findings of Mizuta et al. (2006) in an analysis of the global precipitation patterns simulated by the same model; it was found that the model overestimates global annual average precipitation by more than 15% (3.06 mm/day^{-1}) in comparison to observations (2.68 mm/day^{-1}) by the Global Precipitation Climatology Project–GPCP (Huffman et al. 1997). The maximum nucleus (~1600 mm) observed in the southern rainforest of Peru (12^{o}S–70^{o}W) is not well simulated by the model in spatial terms.

With regard to the dry period (June, July, August–JJA), Figure 8a corresponds to the reality and Figure 8c is simulated by the model. This analysis is also complemented by TRMM satellite estimates (Figure 8b). The maximum nucleus observed in Figure 7a remains present in Figure 8a and is also not well simulated by the model; instead, the model tends to overestimate precipitation on the eastern slope of the Andes. One can also see how, over Ecuador, both strips of high precipitation that were observed during the rainy period remain for the dry period.

Figure 8. Accumulated precipitation in the JJA rainy season:
a) (real); b) (estimated TRMM; and c) (simulated AJ)

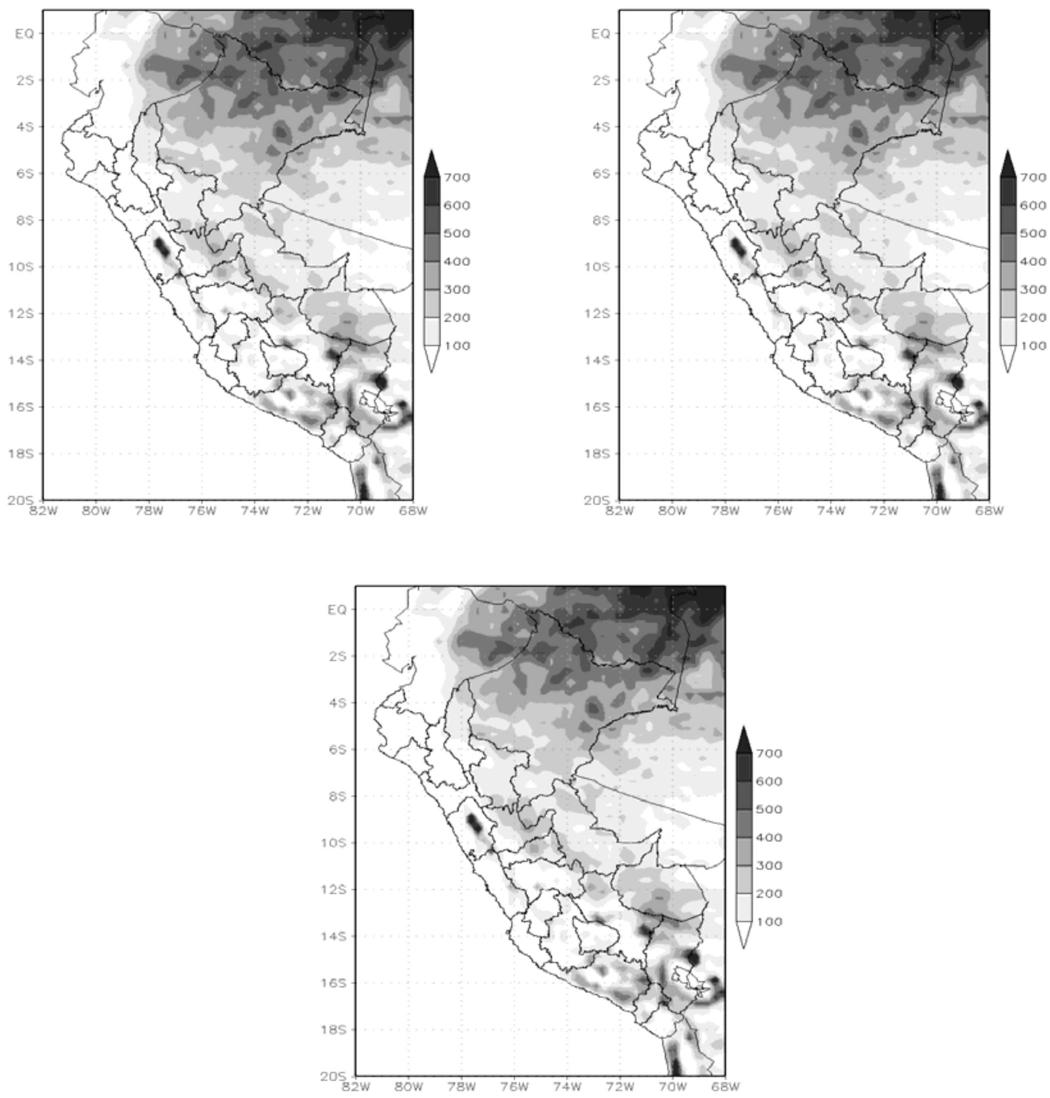


It should be kept in mind that the interpolation made by the Grads visualizer to generate the information observed on a grid point is very thick, especially in regions where the distribution of stations is not very dense. Therefore, these results were complemented by the aid of the TRMM satellite. Moreover, the cumulus parameterization that the model uses to simulate rains may not be the best for our region, which is also not a determinant as is circulation, which according to the analysis of point 2.3 is coherent.

Annual cycle. At basin level, an individual analysis was made, comparing on the same grid point real precipitation and simulated precipitation for the entire annual cycle. Figure

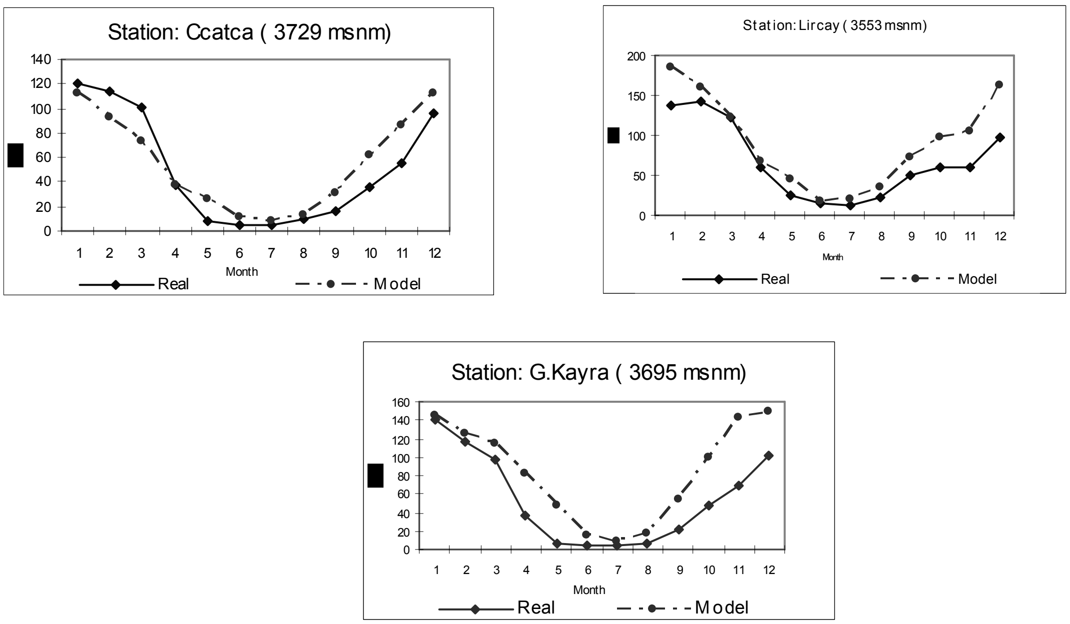
9 shows the results in the stations of Ccatca (3,729 masl), Granja Kayra (3,695 masl), and Lircay (3,553), all belonging to the Urubamba River Basin. We can say at first glance that the model efficiently simulates the annual cycle of precipitation, although it systematically overestimates especially in the rainy period (September–April), except at the Ccatca station where the model underestimates precipitation between January and March.

Figure 9. Skill of high-resolution Japanese model in the Urubamba River Basin



In the Mantaro Basin (Figure 10), the model's performance is ambiguous. At the Huayao station (3,859 masl), the model presents a marked underestimation throughout the entire annual cycle of precipitation, especially during the rainy period, with accumulated values of 20 mm/month, when in reality up to 130 mm/month (February) are recorded. At the Jauja station (4,386 masl), the model's performance was the opposite, i.e., it overestimates precipitation, producing rains of up to 100 mm during the dry season, when in reality accumulations only total about 10 mm/month.

Figure 10. Skill of high-resolution Japanese model in the Mantaro River Basin

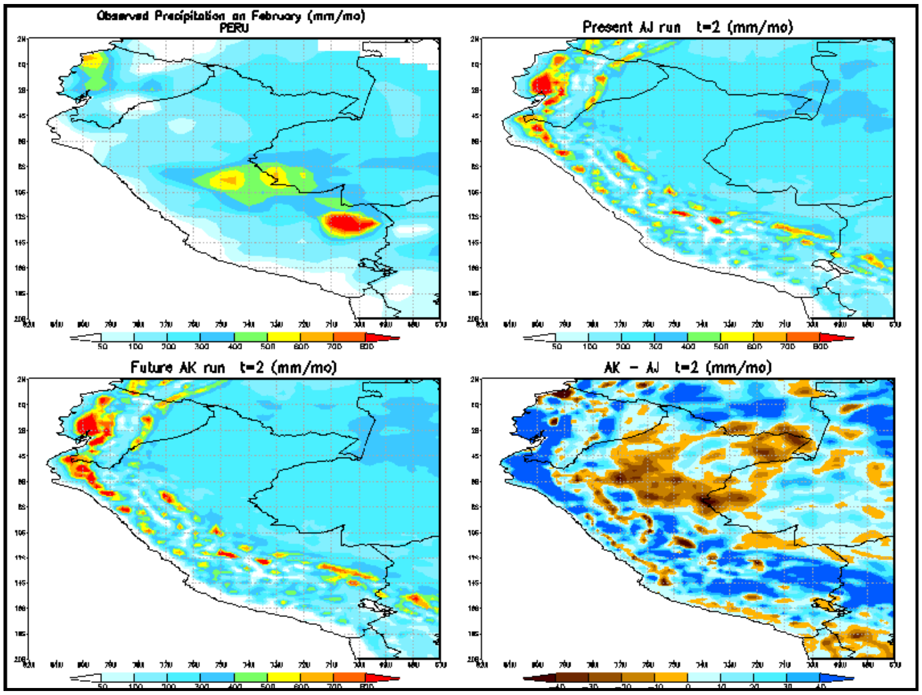


For stations located above 3,800 masl, the model shows certain deficiencies that could be attributed to the orographic effect; in other words, not only does land elevation play an important role but so does its location in light of the predominant flow, so that processes such as the convergence of moisture at low levels may not be well resolved by the convection scheme.

AK Scenarios (future). The following are the results of the output of the Japanese model in the future scenario (AK) for a representative month at each station.

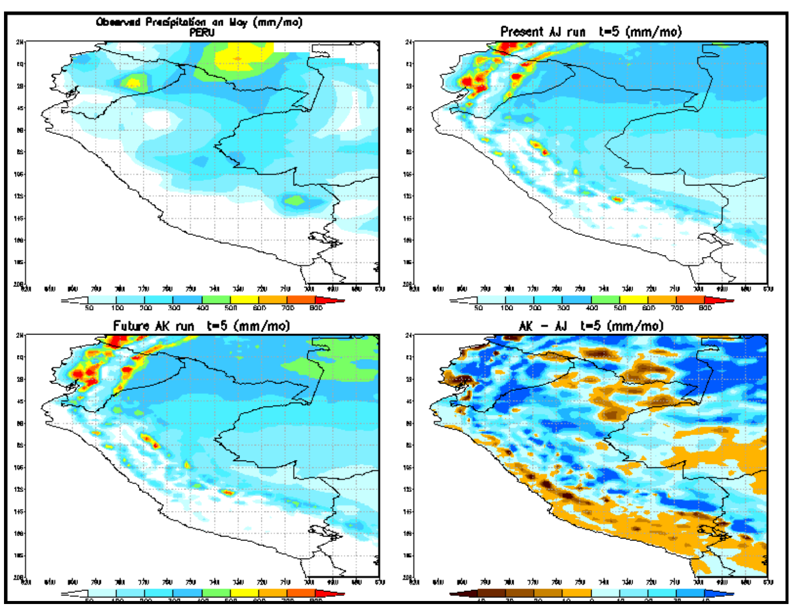
- **Summer**

Figure 11. Spatial distribution of precipitation for February (summer): a) observed; b) AJ scenarios (present model); c) AK scenario (future model); and d) AK-AJ



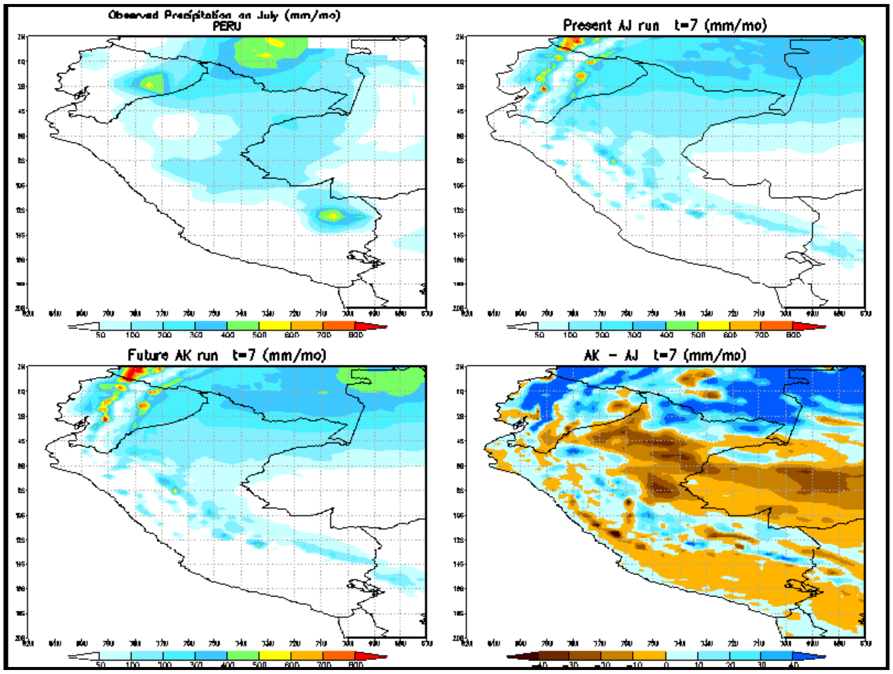
- **Autumn**

Figure 12. Spatial distribution of precipitation for May (autumn): a) observed; b) AJ scenarios (present model); c) AK scenario (future model); and d) AK-AJ



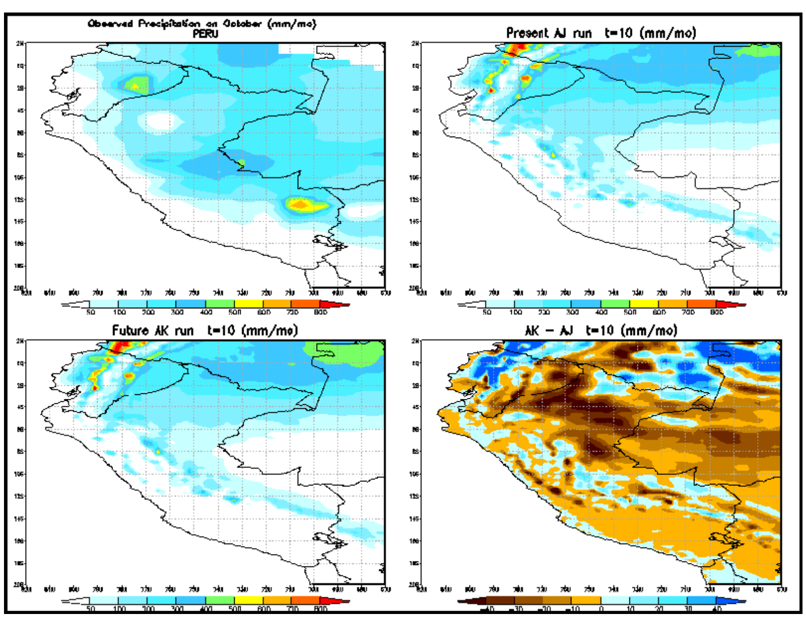
- **Winter**

Figure 13. Spatial distribution of precipitation for July (winter):
a) observed; b) AJ scenarios (present model); c) AK scenario (future model); and d) AK-AJ



- **Spring**

Figure 14. Spatial distribution of precipitation for October (spring):
a) observed; b) AJ scenarios (present model); c) AK scenario (future model); and d) AK-AJ

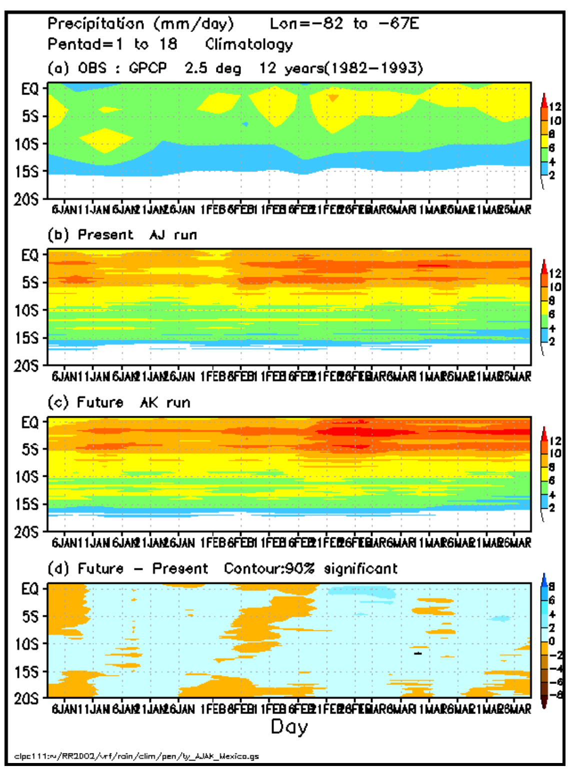


According to the model's projections for the end of this century (Figures 11d, 12d, 13d, and 14d), the region most impacted by possible changes in the rainfall regimen would be the Amazon. This change would be more accentuated in the spring, followed by summer and winter. With regard to the Andean region, the deficiencies would be accentuated mainly on the western side of the central Andes; that is, the Mantaro River Basin would be more vulnerable to these possible changes, mainly in the autumn and spring. Despite the possible future decrease in rains over the Cordillera, it is important to note that during the rainy season (only February is shown), the model projects an increase in precipitation, with centers of excessive rainfall on the western slope (between Ayacucho and Apurimac), as well as in the north of the country (Tumbes and Piura).

With regard to projected precipitation in the Altiplano regions, everything indicates that precipitation would increase, especially in the northeast sector, and would be deficient near Lake Titicaca (see Figure 11d on the rainy season).

Precipitation in pentads. To analyze how episodic rains may be, days were grouped into periods of five (pentads) during the rainy period from January to March. Real data are based on GPCP information with a resolution of 2.5^{o} (Figure 15a). The output of the model was also grouped in pentads for the present rainy period (AJ run [Figure 15b]) and the future rainy period (AK run [Figure 15c]).

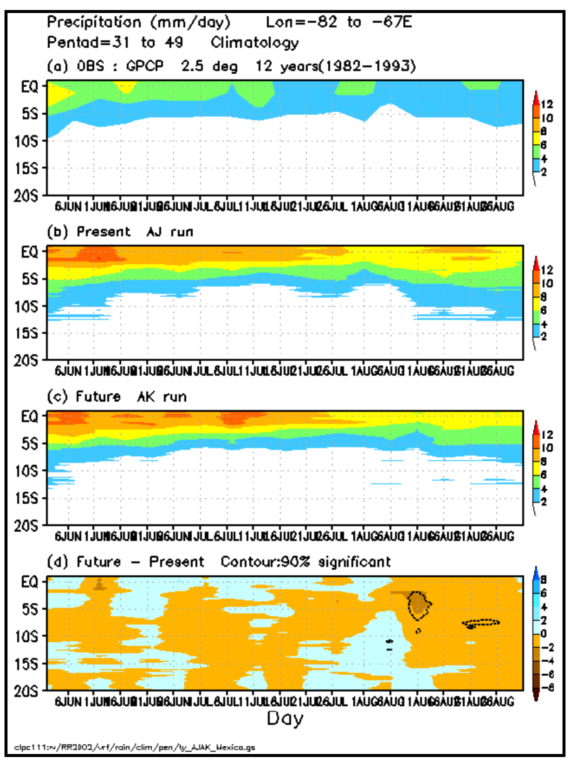
Figure 15. Precipitation in pentads during the January–March rainy season: a) GPCP observation; b) present scenario AJ; c) future scenario AK; and d) difference AK-AJ



The real information shows that the greatest convective activity occurs between February and March, especially in the 0°–10°S belt, with accumulations of up to 10 mm/day^{-1}. However, in the present climate simulation, accumulated values are higher and continuous in comparison to the GPCP observation; there is also a greater increase in volumes of precipitation at latitudes near 15.0°S. This behavior is in line with what was previously mentioned, i.e., the model's overestimation in volumes of precipitation. This behavior is also partly reflected in the AK outcome; however, Figure 15d shows cycles of underestimation (early January and February, late March), both near the equator and in the 15°S–20°S belt, and thus a smaller number of days of precipitation could be inferred.

With regard to the dry period, the pentads between June and August were analyzed. This showed a better connection between the GPCP observations (Figure 16a) and the AJ outcome (Figure 16b). However, the AJ outcome continues to overestimate the amounts of precipitation. One can see a maximum nucleus between the first and second pentads of June with accumulations of up to 12 mm/day^{-1}. The AK future projection (Figure 16c) shows a marked decrease in the volumes of precipitation, especially for August, which is reflected in Figure 16d with periods of lesser volumes of precipitation than the current ones and with a 90% degree of significance between 2°S and 10°S.

Figure 16. Precipitation in pentads during June–August dry season: a) GPCP observation; b) present scenario AJ; c) future scenario AK; and d) difference AK-AJ



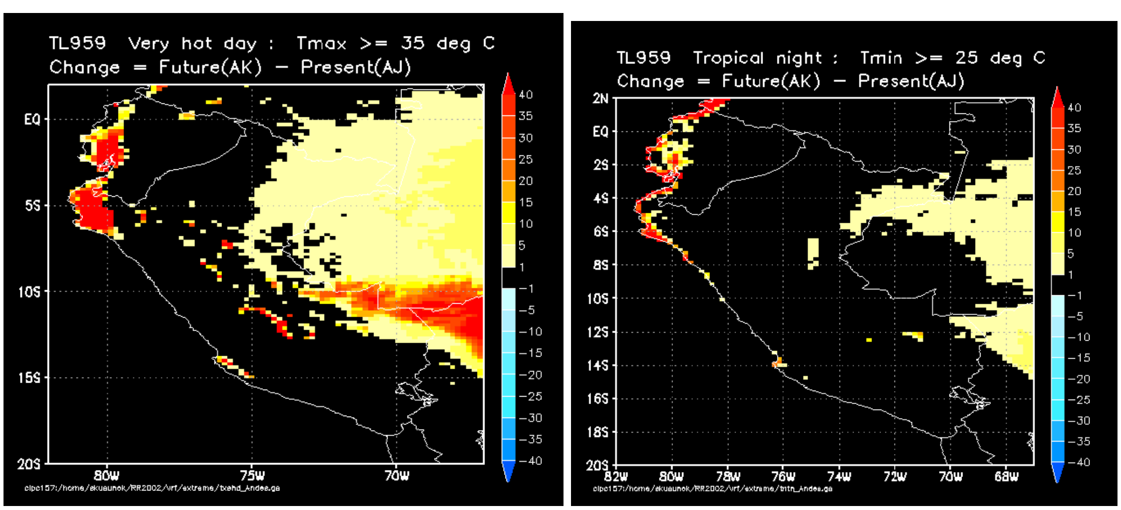
Extreme events

One of the uncertainties associated with climate change projections for the end of this century is how the variability and extreme values of temperature and precipitation will determine the planet's average climate. According to the IPCC (2001), changes in variability and extreme values will affect societies more than changes in average climate. In this regard, MRI researchers (Uchiyama et al. 2006; Kamiguchi et al. 2006) have proposed various extreme indexes of temperature and precipitation as proposed by Frich et al. (2002), based on outcomes of the high-resolution Japanese model, MRI-JMA TL959L60 (20-km mesh), which is considerably finer than many other global-scale models used in climate change studies.

Extreme temperatures. According to the projections of the high-resolution Japanese model, consecutive days with maximum temperatures above 35°C would be expected to occur in arid regions, in the subtropics, and in mountainous regions (Uchiyama et al. 2006). In our country, these hot days would occur on the northern coast (Tumbes–Piura region), in a smaller area on the central coast (Ica region), and at several highly localized points in the central and southern rainforest of Peru (Figure 17a). It is worthwhile to ask if this nucleus of high temperatures on the northern coast may be related to an increasingly recurring presence of the ENOS hot phase.

Not only would the days be hotter, but the nights would also have higher minimum temperatures. According to Figure 17b, nights with temperatures equal to or higher than 25°C would occur on the country's northern coast, but in comparison to Figure 17a, this time the area is more restricted to the coastal zone, and thus we can infer that the adjacent sea may present unusual warming in the future. Once again, we wonder if this is yet another sign of the increasingly frequent or intense occurrence of El Niño. In the Ica region these warm nights would also occur but in a very isolated manner.

Figure 17. Indexes of extreme events of air temperature: a) very hot days; b) hot or tropical nights



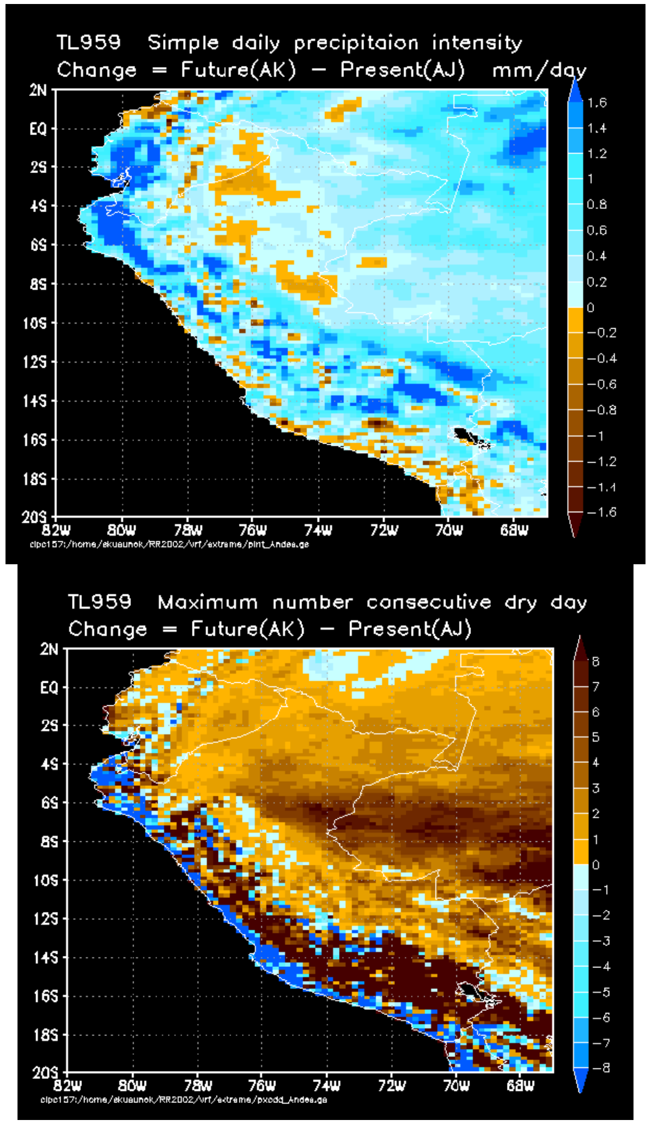
Intense rains and dry periods. The analysis of extreme indexes of the precipitation variable (Kamiguchi et al. 2006) makes it possible to understand the frequency and intensity of extreme events of precipitation such as heavy rains or severe droughts in certain areas, as a consequence of an alteration in water-cycle patterns due to global warming.

Figure 18a corresponds to the index of days of intense precipitation, which is the total annual precipitation divided by the number of days with precipitation higher than or equal to 1 mm/day^{-1}. The results indicate that this index is higher in the middle and upper parts of the Piura region, as well as in a large sector of the southern rainforest (Madre de Dios region). One can also see several sectors of maximums on both slopes of the Andes Cordillera (indexes in blue), which could be attributed to the orographic effect, considering the model's high resolution. In contrast to the above, in several sectors of the northern and central rainforest as well as on southwestern slope of the Cordillera, there could be a precipitation deficit or precipitation events could be less intense or more episodic.

With regard to the index of the maximum number of consecutive dry days (Figure 18b), the region most impacted would be the Amazon, with 3 and 5 consecutive days (precipitation < 1 mm/day^{-1}). One can see that this index is more noticeable south of 5^{o}S. Over the Andes, there would be a predominance of up to 8 consecutive days (brown according to the scale). However, it is suspicious that this value coincides with the presence of the Andes; this could be a "blip" (according to a personal communication by Dr. Kunosoki of the MRI).

The results found by Kamiguchi (2006) indicate that dryness indexes would increase mostly in the southern hemisphere, except in Antarctica, and would decrease in higher latitudes of the northern hemisphere. The same author states that the most drastic changes would occur in the Amazon as a consequence of anomalies in the Walker circulation and the de-intensification of the South Atlantic Anticyclone.

Figure 18. Indexes of extreme precipitation events:
a) days of intense precipitation; and b) maximum number of consecutive dry days



Conclusions

- The model realistically represents the configuration and seasonality of synoptic systems such as the ITCZ, SACZ, SPA, and AB, as well as topography. In the case of Peru there is a correlation of 0.6 between the stations' elevation and the model's topography.
- In comparing the climatology outcomes of the model with observations (historical data), it was found that the model efficiently represents the seasonality of precipitation. However, there is a tendency to overestimate amounts.
- In a preliminary basin-level analysis, the model's performance differs in the two basins of interest. A better correlation was found in terms of the annual precipitation cycle in the Urubamba River Basin, at stations below 3,800 masl, and during the dry season.
- According to the results of the indexes of extreme events based on the MRI-JMA TL959L60 model, there are indications that in the future extreme events of precipitation and temperature may significantly impact the Amazon and the northern coast of Peru, respectively.

Recommendations

- The analyses performed are preliminary. For the construction of climate scenarios over areas of interest (basins), it will be necessary to implement statistical downscaling techniques.
- It has been observed that the performance of the Japanese model is generally good, especially because the representation of topography is more realistic and its high resolution makes it possible to better represent small-scale phenomena and extreme events with greater detail. However, in terms of the amount of estimated precipitation, the results are not good. The model systematically overestimates precipitation and sometimes the annual cycle disappears (at stations located above 3,800 masl). Thus, we stress that techniques need to be developed in order to correct such outcomes, under criteria yet to be determined, since precipitation results are modulated by cumulus parameterization. Nevertheless, the model's dynamic (divergences, convergences, vorticity, average flow, etc.) is good.
- It is plausible that in future simulations the model's resolution (5 km) could be increased, because one of the limitations that we have in developing countries is computer infrastructure. For example, a dynamic downscaling of a global model (280 km) at 60 km with a nesting of 20 km took us (SENAMHI Peru) nearly two years to process. If we have a higher resolution global model (to avoid problems with the boundary conditions and to incorporate interactions between the global and regional scales, explicitly), many studies could be carried out on more specific areas and in less time.
- Technical assistance abroad could also be complemented by researchers' visits to countries undergoing training, through sets of courses or workshops of no more than two weeks' duration. This would ensure the availability in the short term of trained and/or specialized staff.

Acknowledgments

To the World Bank, the Meteorological Research Institute (Japan), the Yobix Agency (Japan), the National Environmental Council–CONAM (Peru), and the National Meteorology and Hydrology Service–SENAMHI (Peru) for their ongoing support during our stay in Tsukuba.

References

Avalos, G. 2000. Validación del pronóstico de precipitación del modelo regional Eta/SENAMHI durante periodos secos y lluviosos. Tésis para optar el título de Ingeniero Meteorólogo. 98 pp., UNALM.

Beniston, M. 2000. Environmental change in mountains and uplands. Eds. Oxford University Press, USA, 172 pp.

IPCC. 2001. Climate change 2201: The Scientific Basis. J. T. Houghton et al. Eds., Cambridge University Press, UK, 881 pp.

Kamiguchi, K. et al. 2005. Changes in precipitation-based extremes indices due to global warming projected by a global 20-km mesh atmospheric model. SOLA, *submitted*.

Kusunoki, S. et al. 2005. Change of Baiu in global warming projection by an atmospheric general circulation model with 20-km grid size. *J. Meteor. Soc. Japan. Submitted.*

Mizuta, R. et al. 2006. 20-km-mesh global climate simulations using JMA-GSM model–mean climate states. *J. Meteor. Soc. Japan*, 84, 165–185.

Satyamurty, P., C. Nobre. 1999. South America. Meteorological Monograph. Vol. 27, 49. 119–139.

SENAMHI. 2005. Climate change scenarios in Peru to 2050: Piura River Basin. Numerical. Rosas G., Díaz A., Avalos G., Oria C., Acuña D., Cornejo A., Metzger L., Fano G., Carrillo M., Miguel R. Eds. SENAMHI Peru, 170 pp.

Uchiyama, T. et al. 2005. Changes in temperature-based extreme indices due to global warming projected by a global 20-km mesh atmospheric model. SOLA, *submitted*.

Climate Simulation in the Papallacta, Blanco Grande or Jeringa, Quijos, and Antisana microcatchments of Ecuador Using the 20 x 20 Km Japanese Model in the A1B Scenario

Enrique Palacios, National Institute of Meteorology and Hydrology, Ecuador

Introduction

The Ministry of Environment of Ecuador, through the Andean Regional Project on Adaptation to Climate Change, and with the specialized support of the National Institute of Meteorology and Hydrology–INAMHI, is carrying out activities aimed at determining climate change scenarios by using outcomes of the Japanese model. These activities include:

- Recognition and use of the outputs of the Japanese model in the study area selected by PRAA/Ecuador (Papallacta, Blanco Grande or Jeringa, Quijos, and Antisana microcatchments) to carry out the study and determine climate change scenarios.

- Analysis of studies performed by regional scientists on the subject of climate change.

- Preparation of instructions (scripts) in Grads under LINUX for downloading information from the model's runs and its AJ (present time) and AK (future time) experiments on the study area.

- Analysis of outputs of the AJ–AK model (present climate–future climate over a ten-year integration period) on the study area.

The Japanese model provides four types of outputs or runs:

- An AJ run (present time) in which the seasonality of SST is constant for the model's ten-year integration period.

- An AK run (future time) in which the SST anomaly is added to the abovementioned seasonality, assuming that the AK experiment simulates future climate for the years 2080 to 2099.

- A third output of the Japanese model uses an AM output and simulates climate during the period from 1979 to 1999 based on the CGM model.

- Finally, the Japanese model incorporates an AN output that provides climate scenarios in terms of the variation of different meteorological parameters at the end of the century, taking into consideration the duplication of carbon dioxide as a key premise.

Information Used

To carry out the present technical report, the basic, key information is related to the results and/or experimental runs of the Japanese model, i.e., AJ, AK, AM, and AN.

This binary information on the experimental outputs is used to carry out the study of the spatial seasonality of precipitation and extreme temperatures over the study area.

Analysis of Outputs of the Japanese Model on the Study Area

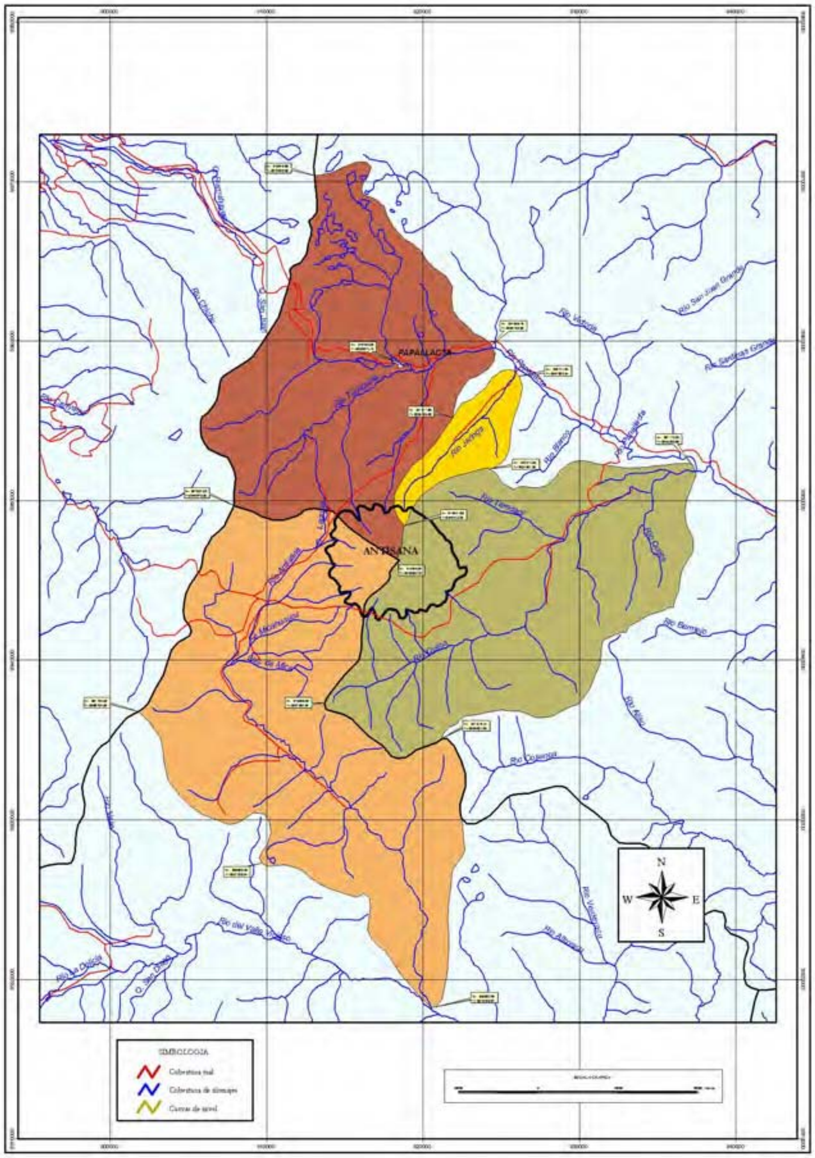
For the spatial analysis, the study area has been covered by a grid from 0.5° latitude South to 0.3° latitude North, and from 77° longitude West to 78.5° West, and with a spacing of 20*20 nodes in the latitude and longitude, respectively.

Orography

On the grid determined for the study over the study area, the model in principle interprets the orographic feature located in the center of the grid, consistent with the presence of the Antisana Volcano, identifying it on the contour lines with a centroid at heights of over 4,000 masl.

The figure below shows the study area with its principal orographic feature (Antisana Volcano) in the center of the Antisana microcatchments, where climate change scenarios will be determined under scenario A1B through the use of the high-resolution 20 x 20 km Japanese model.

Figure 1. Antisana Microcatchments–Case Study



Precipitation

Precipitation is one of the meteorological factors with the most uncertainty regarding its actual determination due to its random occurrence and to the nature and tropical environment where it is generated in Ecuador, in which prevailing conditions favor the presence of convective pluviogenetic systems.

With these special geographic and meteorological conditions of the study grid, the Japanese model experiments are performed to simulate present and future weather and the change in this zone with regard to precipitation.

Seasonal Variation of Precipitation in the Study Area in the Model's Present (AJ) and Future Time

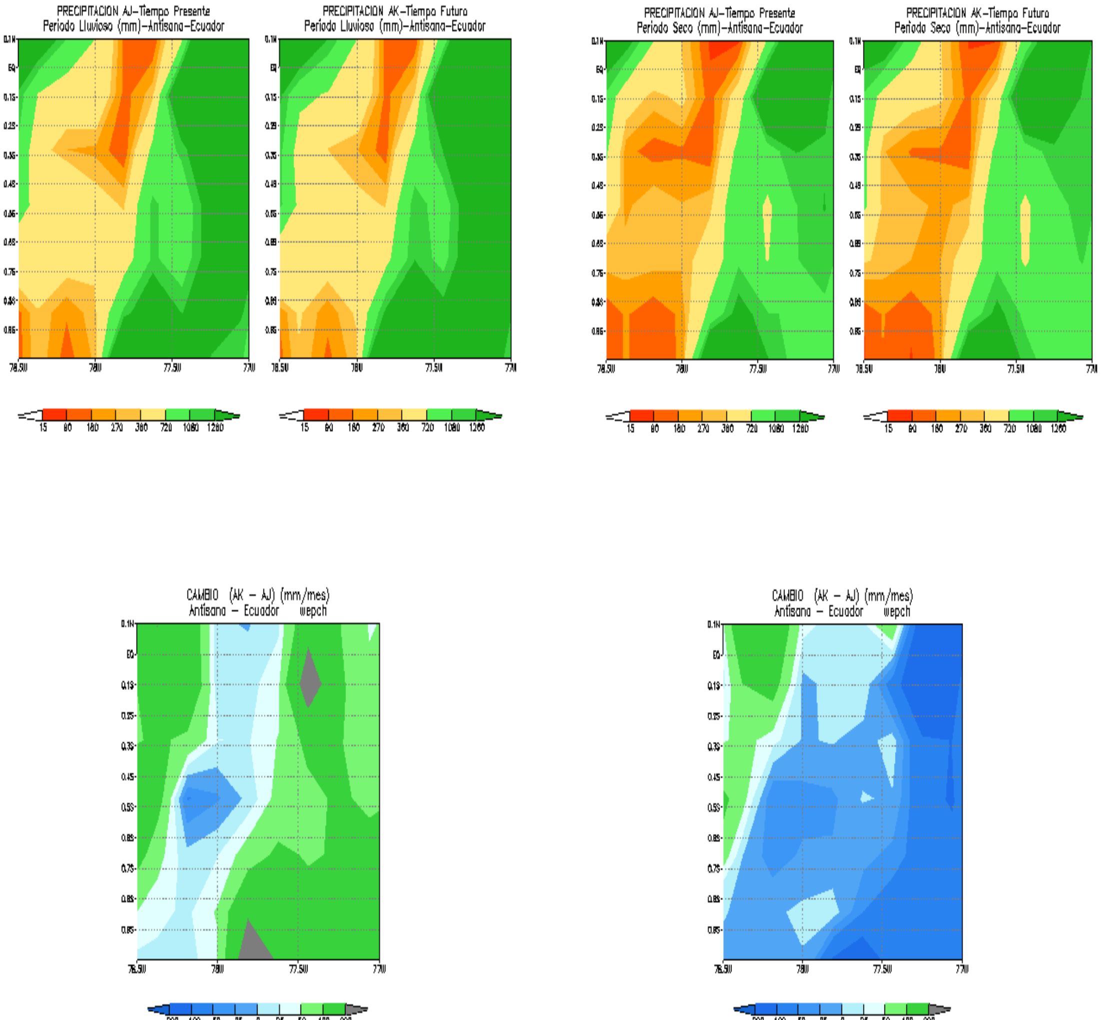
The annual cycle of precipitation in the inter-Andean region of Ecuador shows a bimodal distribution, with a principal maximum in April and a secondary maximum in November. According to information from high-altitude meteorological stations in the study zone maintained by the Quito Municipal Water and Sewer Company–EMAAP-Q (>3000 masl), the distribution in these latitudes is unimodal and left bilateral, skewed to the first four months of the year with a maximum in April, the rainiest month.

The consistency of the model's simulations on the seasonality of precipitation is analyzed by selecting rainfall volumes registered and generated by the model, using AJ and AK experiments during the months of March, April, and May.

Over the study area, the AJ experiment (present time) reproduces quite well the synoptic-scale circulation pattern of the atmosphere and thus that of the spatial distribution of precipitation, with accumulated values during the three-month rainy period totaling 700 and 800 mm on the northeastern and western sides from the Antisana volcano, while a low-precipitation zone is detected right over the study area.

With regard to the AK–AJ rate of change, i.e., the change that can be observed in the future over the study area, a decrease of around 25 to 50 mm is observed in volumes of precipitation, and with percentages of nearly 20% in terms of decreases in the rainy period (see Figures 2a and 2b), while in the dry period (June, July, and August) a very marked trend prevails in the rate of change toward a generalized decrease over the basin and its nearby sub-basins during the dry period.

Figure 2. Distribution of precipitation during the rainy season (Figure 2a, left) and during the dry season (Figure 2b, right)



Seasonal Variation of Maximum and Minimum Temperatures in the Model's Present (AJ) and Future (AK) Times

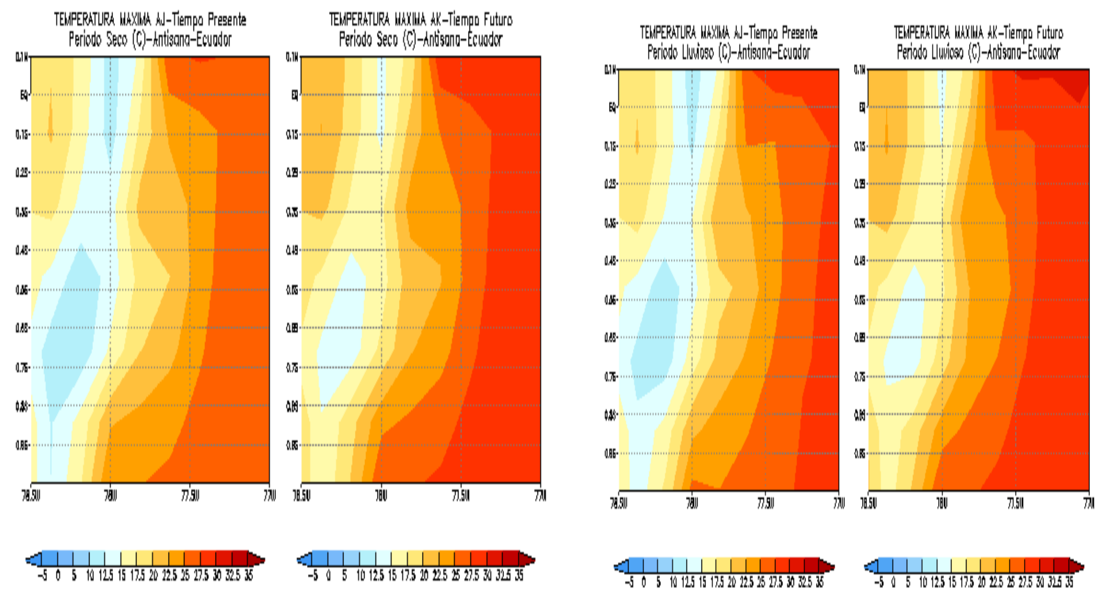
For the rainy and dry periods, the AJ and AK experiments of the model on the study area and on extreme temperatures (maximum and minimum) were analyzed. It was determined that in the dry and rainy periods the AJ experiment adequately simulates the unevenness of the orography, showing differences in minimum and maximum temperature values at each altitude threshold, in accordance with the natural orography.

The rate of change in extreme temperatures over the study area is in accordance with a positive rate of change, that is, both the minimum and maximum temperatures (Figure 3)

41770

in both periods analyzed envision an increase of up to 2.4°C and 3.2°C in the case of maximum temperature, and 1.4°C and 2.2° C in the minimum temperature (Figure 4).

Figure 3. Distribution of maximum temperature (right) in the rainy period and in the dry period (left)



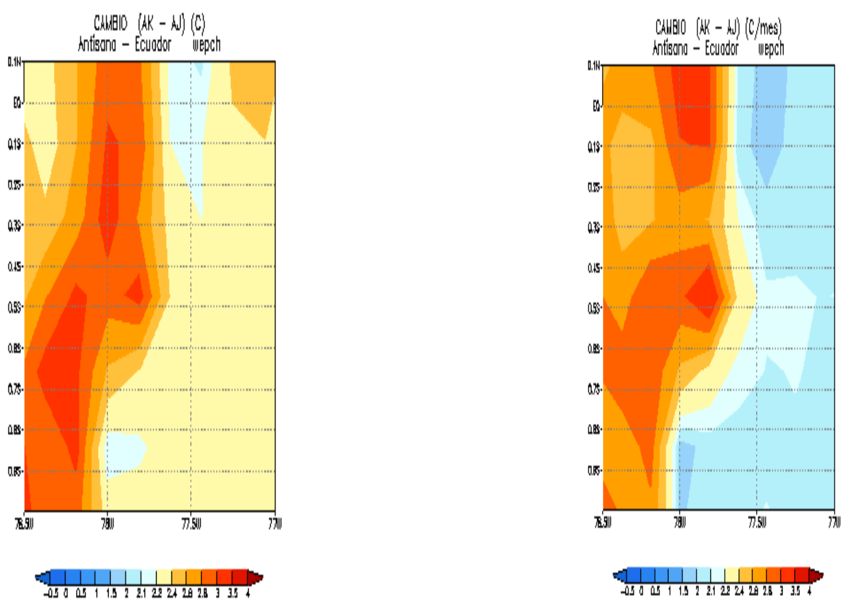
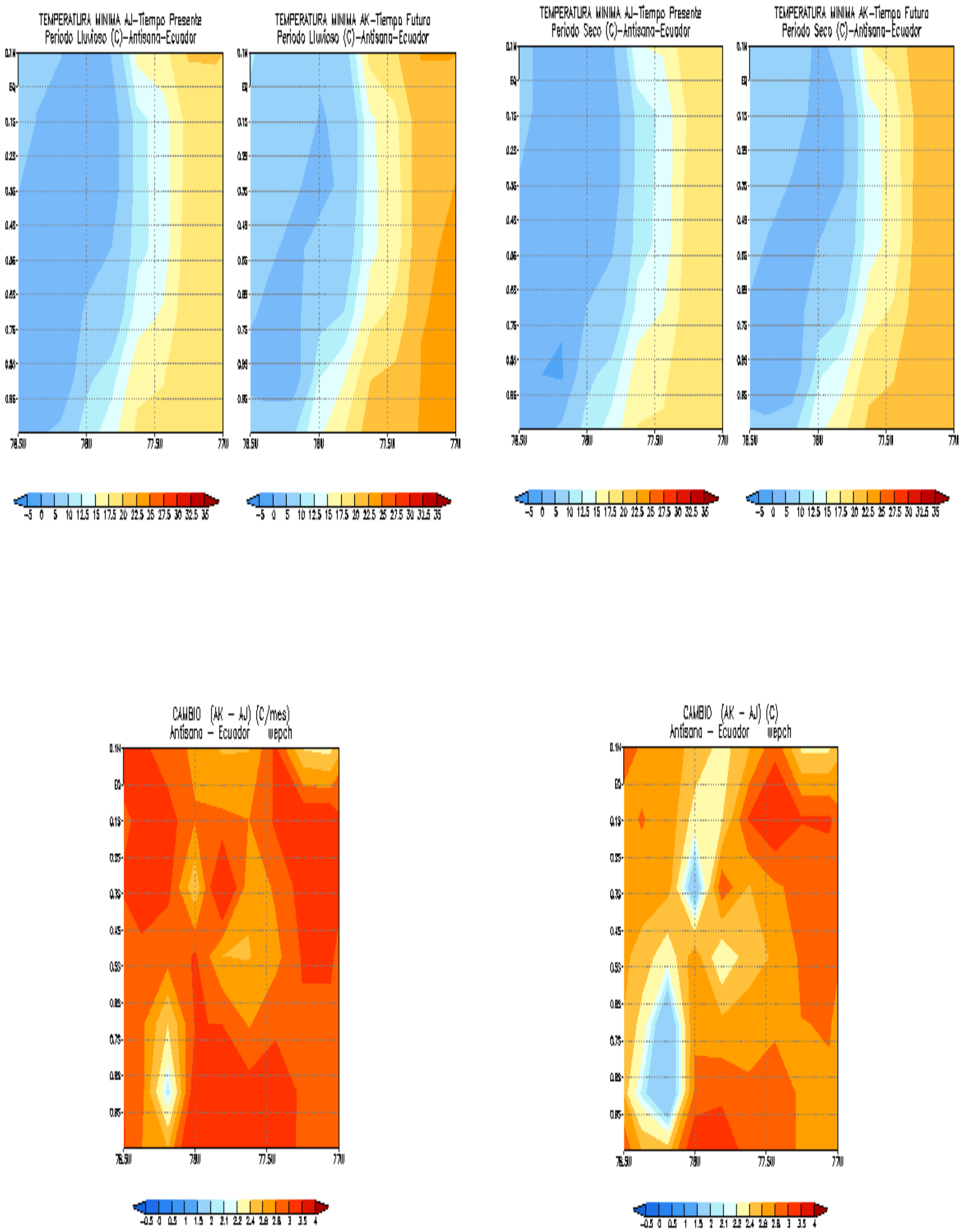


Figure 4. Distribution of minimum temperature in the study area during the dry and rainy periods



Conclusions

- The study makes it possible to establish the analysis on the distribution of precipitation and extreme temperatures in the study area's two existing climate periods (dry and rainy periods).
- In reference to precipitation, the study concludes with the analysis of the Japanese model's experiments in the present and future and the rate of change, obtaining as a result a foreseen marked irregularity and variability in its behavior within the annual cycle, with greater increases on the eastern and western sides and a decrease in the central portion of the study area.
- Over the study area, and toward the end of the period of validity of the projections calculated by the Japanese model in scenario A1B, a negative rate of change or a decrease in percentages of precipitation in both climate periods is observed, ranging from about 20% in the rainy period and about 30% in the dry period.
- The study concludes that the model simulates well the spatial locations of precipitation (zones of greater, lesser, or no registered quantities). However, the model does not excel in terms of magnitudes, because it overestimates almost 4 times in relation to historical records of the nearest weather control station located in the study area.
- It should be kept in mind that the precipitation parameter is random, not continuous, and variable. Therefore, the degree of uncertainty in the trends and projections obtained through the use of any method, increases in function of the time of the predictive experimentation considered. For these reasons, it is valid to consider the trend toward variability throughout the year and the signs (increase or decrease) of precipitation, as well as its spatial location. However, it is not worthwhile to take into account the individual values obtained.
- The study indicates that extreme temperatures (maximum and minimum) tend to increase. The results are relatively consistent and are adjusted to international research and estimates referring to variations or increases in temperature in the region's latitudes.
- The model does not provide parameter outcomes for the period between 2008 and 2080. Therefore, dynamic, statistical processing of lower scale and resolution should be carried out in order to incorporate climate change outputs of the parameters of interest, for the period not considered in the Japanese model.

41770

LCR Sustainable Development Working Papers

For back issues please contact the respective authors

No.	*Title*	*Date*	*Author(s)*
29	Transport and Climate: Lessons from the Partnership between Mexico City and the World Bank	May 2007	Walter Vergara, Seraphine Haeussling
28	Vulnerability to Air Pollution in Latin America and the Caribbean Region	September 2006	Carla Della Maggiora, Juan Andrés López-Silva
27	The Role of Water Policy in Mexico: Sustainability, Equity, and Economic Growth Considerations	September 2006	Musa Asad, Ariel Dinar
26	Using Strategic Assessments for Environmental Mainstreaming in the Water and Sanitation Sector: The Cases of Argentina and Colombia	December 2005	Ernesto Sánchez-Triana, Santiago Enríquez
25	Adapting to Climate Change: Lessons Learned, Work in Progress, and Proposed Next Steps for the World Bank in Latin America	October 2005	Walter Vergara
24	Water Resources Management in Mexico: The Role of the Water Rights Adjustment Program (WRAP) in Water Sustainability and Rural Development	August 2005	Musa Asad, Hector Garduño
23	Centroamérica–La Crisis Cafetalera: Efectos y Estrategias para Hacerle Frente	Noviembre 2004	Felipe Castro, Eduardo Montes, Martin Raine
22	Public Investments in Tourism in Northeast Brazil: Does a Poor-area Strategy Benefit the Poor?	February 2005	Paul B. Siegel, Jeffrey R. Alwang
21	Spatial Analysis of Rural Economic Growth Potential in Guatemala	February 2005	Jeffrey Alwang, Paul B. Siegel, David Wooddall-Gainey
20	Lessons of Indigenous Development in Latin America: The Proceedings of a World Bank Workshop on Indigenous Peoples Development	September 2004	Shelton H. Davis, Jorge E. Uquillas, Melanie A. Eltz
19	Responding to Climate Change: Proposed Action Plan for the World Bank in Latin America	June 2004	Walter Vergara
18	Programas de microcrédito y capital social entre mujeres indígenas	January 2004	Carmen Tene, Guadalupe Tobar, Dolores Bolaños
17	Sistema Participativo de Planificación, Seguimiento y Evaluación de Proyectos con Pueblos Indígenas	January 2004	Gloria Vela, Axel Borchgrevink
16	Good Dams and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects	November 2003	George Ledec, Juan David Quintero
15	Social Capital as a Factor in Indigenous Peoples Development in Ecuador	August 2003	Jorge E. Uquillas, Martien Van Nieuwkoop
14	CFC Markets in Latin America	December 2002	ICF Consulting/World Bank

41770

13	World Bank Approaches to the Brazilian Amazon: The Bumpy Road toward Sustainable Development	November 2002	John Redwood III
12	Microfinance Prospects in Brazil	September 2001	Steven N. Schonberger
11	Local Governments and Sustainable Rural Development: The Rural Municipalities Project (Protierra) in Nicaragua	December 2000	Maurizio Guadagni and others
10	Strengthening Indigenous Organizations: The World Bank's Indigenous Capacity-Building Program in Latin America	December 2000	Jorge E. Uquillas, Teresa Aparicio Gabara
9	La raza y la pobreza: Consulta interagencias sobre afrolatinoamericanos *(available in English)*	November 2000	Proceedings of June 2000 roundtable in Washington
8	Incorporación de aspectos de género y desarrollo en las operaciones del Banco Mundial: Avances y recomendaciones	April 2000 *(published in English in 1998)*	Caroline Moser, Annika Törnqvist, Bernice van Bronkhorst
7	Perceptions of Urban Violence: Participatory Appraisal Techniques *(available in Spanish)*	February 2000	Caroline Moser, Cathy McIlwaine
6	Defining Ethnodevelopment in Operational Terms: The Ecuador Indigenous and Afro-Ecuadoran Dev. Project	January 2000	Martien van Nieuwkoop, Jorge E. Uquillas
5	Violence and Social Capital: Proceedings of the LCSES Seminar Series, 1997–98	August 1999	Caroline Moser, Sarah Lister
4	Youth Gangs and Violence in Latin America and the Caribbean: A Literature Survey	August 1999	Dennis Rodgers
3	Youth Violence in Latin America and the Caribbean: Costs, Causes, and Interventions	August 1999	Caroline Moser, Bernice van Bronkhorst
2	A Conceptual Framework for Violence Reduction *(available in Spanish)*	August 1999	Caroline Moser, Elizabeth Shrader
1	Environmental Guidelines for Social Funds *(available in Spanish)*	December 1998	Douglas J. Graham, Kenneth M. Green, Karla McEvoy