Chapter 27. Central and South America

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Executive Summary

Climatic variability and extreme events have been severely affecting Central America (CA) and South America (SA) over the recent years. Increases in warm days and decreases in cold days, and respectively in nights, have been identified in CA, Northern SA, Northeast Brazil, SESA and the West Coast of SA. In addition, changes in rainfall extremes were remarkable in some regions (e.g. Amazonia, Argentina) during 2005 to 2011, although it is difficult to identify the attributions of these changes. [27.1.2.2, 27.2.1.1]

Deforestation rates for the region remain high in spite of a reducing trend in the last decade. Land cover change is a key driver of environmental change for the region with significant impacts that may increase the potential negative impacts from climate change. Deforestation and land degradation are mainly attributed to increased extensive and intensive agriculture, both from traditional export activities such as beef and soy production, but more recently from biomass for biofuel production. Even though deforestation in the Amazon has decreased substantially in the last eight years, other regions like the Cerrado and the Chaco forests still present high levels of deforestation. [27.2.2.1]

Socioeconomic development for the region shows a high level of structural heterogeneity and a very unequal income distribution. There is still a high and persistent poverty level in most countries of the region, in spite of the sustained economic growth observed in the last decade. In terms of human development, the performance of different countries varied greatly from Chile and Argentina at the high end of human development, and Guatemala and Nicaragua with the lowest indices. The economic inequality translates into inequality in access to water, sanitation and adequate housing, particularly for the most vulnerable groups: indigenous peoples, Afro-descendants and women living in poverty. [27.2.2.2]

The projected mean warming for CA and SA by the end of the century, according to different global and regional climate models, ranges from 2°C to 4°C for the SRES emissions scenario B2, and from 4°C to 8°C for scenario A2. Changes in rainfall and in extremes are more uncertain, especially in CA and tropical SA. Projections for the 21st century from CMIP3 global models suggest a weakening of the North American monsoon system and precipitation reduction in June-July, accompanied by projected warming in most of CA. Analyses from global and regional models in SA show common patterns of projected climate in some sectors of the continent, with an increase of precipitation in SESA, Northwest of Peru and Ecuador and western Amazonia, while decreases are projected for northern SA, Eastern Amazonia, central eastern Brazil, Northeast Brazil, the Altiplano and southern Chile. Heavy precipitation is projected to increase in SESA, while dry spell would increase in northeastern South America. [27.2.1.2]

Conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region, and in parallel is also the second largest driver of man-induced climate change on the planet, adding up to 17%-20% of total greenhouse gas emissions. The region has still large extensions of wilderness areas for which the Amazon is the most outstanding example. Nevertheless, some of these areas are precisely the new frontier of economic expansion. Thus, plant species are rapidly declining in CA and SA; the highest percentage of rapidly declining amphibian species occurs also in CA and SA; with Brazil being among the countries with most threatened bird, mammal species and freshwater fish. Climate change will further enhance species decline in the region. [27.3.2.1] Ecosystem-based Adaptation practices, such as payment for environmental services (PES) and community management of natural areas, begin to multiply across the region. [27.3.2.2]

Changes in stream flow and water availability are already evident in many basins in CA and SA, affecting already vulnerable regions. Glaciers (both tropical and extratropical) are retreating and the cryosphere in the Andes is changing in accordance with warming trends. Changes in precipitation are also affecting runoff, with increasing trends in SESA, and reducing trends in the Central Andes (Chile, Argentina) and Central America. No significant trend has been found for the Amazon Basin. [27.3.1.1] Highly vulnerable regions, like the semi-arid zones in Chile-Argentina, North Eastern Brazil and Central America and the tropical Andean communities, are expected to increase in their vulnerability due to climate change. Glacier retreat is expected to continue its trend, and a reduction in water availability due to expected precipitation reduction and increase evapotranspiration demands is expected in the semi-arid regions of CA and SA. Also, a reduction in hydropower generation, the main renewable source of energy in the region, is expected. [27.3.1.1, 27.6.1] Current practices in the optimization of water supply and demand, aimed at reducing current water related vulnerability, could be used to reduce future vulnerability. Constitutional and legal reforms in many countries in the region (e.g. Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia and Mexico) also represent an important adaptation strategy to climate variability and change. [27.3.1.2]

Agricultural responses to climate change are expected to have a great spatial variability and will depend on the implementation of sustainable production systems. In some temperate zones like SESA, average productivity could be sustained or increased until the mid of the century, although interannual and decadal climate variability could considerably modify annual food production. In other zones, such as CA, northeast of Brazil and parts of the Andean region, productivity could be affected in the short-term (before 2025), threatening the food security of large sections of the poorest population. Since SA is a major contributor to global food availability, altering their productive capacities could affect other parts of the world. The great challenge for CA and SA will be to increase the food and bioenergy production, to sustain the environmental quality, and to face climate change. [27.3.4.1]

Renewable energy (RE) has a potential impact on land use change and deforestation, but at the same time will be an important means of adaptation, with the region, especially SA (particularly SESA) being key in this process. Hydropower is the main source of RE in CA and SA, followed by biofuels, notably bioethanol from sugarcane and biodiesel from soy. SESA is one of the main sources of production of the feedstocks for biofuels' production. Sugarcane and soy are likely to respond to the elevation of CO2 and temperature with an increase in growth, which might lead to an increase in productivity and production. However, the drought effects are critical and scientific knowledge has to advance in this area. Advances in second generation bioethanol from sugarcane and other feedstocks will be important as a measure of adaptation, as they have the potential to increase productivity. In spite of the large amount of arable land available in the region, the expansion of sugarcane and soy, related to biofuels production, might have some indirect land use change effects, producing teleconnections that could lead to deforestation in the Amazon and loss of jobs in some countries. This is especially derived from the expansion of soy, which is used for biodiesel production inclusively.

Climate change is affecting human health in CA and SA through morbidity, mortality, disabilities, and the emergence or re-emergence of diseases in previous and non-previous endemic or previously eradicated/controlled areas. Illnesses are associated with excessive heat waves, cold spells, vector- and water-borne diseases, diarrheal diseases, mainly among children, exacerbation of respiratory and cardiovascular diseases owing to air quality and wind-borne dust, environmental toxins, and mental health stress. [27.3.7.1] Multiple factors exacerbate the region's vulnerability to climate change: precarious health systems, malnutrition, socio-economic factors, inadequate water and sanitation services, poor waste collection and treatment systems, air, soil and water pollution, and inadequate governance. Vulnerabilities vary with geography, age, gender, race, ethnicity, and socio-economic status, and are rising in large cities. [27.3.7.2] Adaptation strategies to prevent, cope with and mitigate the highly likely impacts of climate change on human health are urgently needed for the region.

Coastal and marine ecosystems in the region have been undergoing significant transformations that pose threats to fish stocks, corals, mangroves, places for recreation and tourism, and controls of pests and pathogens. Peru and Colombia are two of the eight most vulnerable countries to climate change impacts on fisheries. Frequent coral bleaching events have been reported for the Mesoamerican Coral Reef (1993, 1998, 2005, 2010). In CA and SA, some of the main drivers of mangrove loss are deforestation and land conversion, agriculture and shrimp ponds to an extent that the mangroves of the Atlantic and Pacific coasts of CA are some of the most endangered in the planet. Changes over 2 mm/yr of sea-level rise (SLR) have been found in CA and SA, which is reason for concern since 3/4 of the population of the region lives within 200 km of the coast. [27.3.3.1] In Brazil, fisheries' co-management - a participatory process involving local fishermen communities, government, academia and NGOs - favors a balance between conservation of marine fisheries, coral reefs and mangroves, and the improvement of livelihoods, as well as the cultural survival of traditional populations. [27.3.3.2]

[Placeholder for confidence analyses and adaptation that will be worked out at the LAM3 in Buenos Aires]

27.1. Introduction

27.1.1. The Central and South America Region

The Central America (CA) and South America (SA) region harbours unique ecosystems and maximum biodiversity, has a variety of eco-climatic gradients, and it is rapidly developing. Agricultural and beef production is quickly increasing mostly by expanding agricultural frontiers; accelerated urbanization and demographic changes are remarkable; poverty and inequality are decreasing continuously, but at a low pace; while adaptive capacity is improving related to poverty alleviation.

The region has multiple stressors being climate variability and change and land cover change two of the most remarkable drivers of changes. Climate variability in various time scales has been affecting social and natural systems, and extremes in particular have affected large regions. During 2000-2010 almost 630 weather and climate extreme events ocurred in CA and SA, leaving near to 16,000 fatalities and 46.6 million people affected; and generating economical losses amounting to 208 million US$ (CRED, 2011). Land is facing increasing pressure from competing uses like cattle ranching, food production and bioenergy.

CA and SA are thought as having some key roles in the future. Because some of the countries in the region, especially in SA, are rapidly developing and becoming economically important in the world scenario, the region is bound to be exposed to the pressure related to increasing land use and industrialization. Therefore, it is likely to have to deal with increasing emission potentials. Therefore, science-based decision-making is thought to be an important tool to control innovation and development of the countries in the region.

Two other important contrasting features characterize the region: having the biggest tropical forest of the planet by one side and by another possessing the largest potential for agricultural development during the next 30 years or so. This is so because the large countries of SA, especially, would have a major role in food and bioenergy production in the future, as long as policies towards adaptation to the GCC will be strategically designed. The region is already one of the top producers and user of bioenergy and this experience will serve as an example to other developing regions as well as developed regions.

27.1.2. Summary of the AR4 and SREX Findings

27.1.2.1. AR4 Findings

The principal findings in the AR4 (IPCC, 2007) for the Latin American region comprise:

- Extreme events and climatic variability have been severely affecting the LA region during the last decades. Unusual extreme weather events (droughts, floods, landslides, etc) have occurred in most countries contributing greatly to the heightened vulnerability of human systems to natural disasters.
- Important trends in precipitation were observed with increases in Southeast South America (SESA), northwest Peru and Ecuador; and decreases in southern Chile, southwest Argentina, southern Peru and western Central America (CA). Mean warming was near to 0.1ºC/decade. In some parts of Argentina, the minimum temperature has increased at a rate of 0.8ºC/decade during winter months.
- The glacier-retreat trend has intensified, reaching critical conditions in the Andean countries (Bolivia, Peru, Colombia and Ecuador).
- Rates of deforestation have been continuously increasing mainly due to agricultural expansion. In Brazil, Argentina, Bolivia and Paraguay deforestation was mainly related to soy expansion. Also, land degradation has been intensified for the entire region.
- Other no climatic stressors compromising a sustainable development are: demographic pressures; over-exploitation of natural resources, including aquifers; mismanagement of irrigation systems that cause salinisation of soils and water; as well as sanitation problems.
- According to the GCM projections, mean warming for LA at the end of 21st century could reach 1ºC to 4ºC (SRES B2) or 2ºC to 6ºC (SRES A2). Rainfall anomalies (positive or negative) will be larger for the tropical part of LA. The frequency and intensity of weather and climate extremes is likely to increase.
- Significant species extinctions, mainly in tropical LA, are very likely under future climate conditions. The synergic effect of land use and climate change could lead to the replacement of tropical forest by savannas, and semi-arid vegetation by arid vegetation. Some critical places with high endemic species concentrations are undergoing habitat loss.
- Other future impacts include:
    - Increases in the number of people experiencing water stress.
    - Changes in crops' yield with probable reductions in rice, erratic responses in wheat and maize, and possible increases of soy yield in SESA, together with an increas in crop pests and diseases.
    - Some coastal areas being affected by sea level rise, as well as weather and climatic variability and extremes. Regions and sectors most affected will be: low-lying areas, building and tourism, coastal morphology, drinkable water availability, coral reefs, and fish stocks.
    - A change in the distribution of human diseases as well as the introduction of new diseases is also predicted.
- Some countries have made efforts to adapt to climate change and variability, for example through the conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for avoidance/adaptaion of/to flood, drought and coastal management, and disease surveillance systems. At the same time there are several constraints that outweigh the effectiveness of these efforts like: the lack of basic information, observation and monitoring systems; the lack of capacity-building and appropriate political, institutional and technological frameworks; low income; and settlements in vulnerable areas, to name but a few.

27.1.2.2. SREX Findings

As reported by the IPCC SREX (IPCC, 2012), a changing climate leads to changes in the frequency, intensity, spatial extent or duration of weather and climate extremes, and can result in unprecedented extremes. Levels of confidence in historical changes depend on the availability of high quality and homogeneous data, and relevant model projections. This has been a major problem in CA and SA, where a lack of long-term homogeneous and continuous climate and hydrological records, and of complete studies on trends have not allowed for an identification of trends in extremes, particularly in CA. Recent studies and projections from global and regional models suggest changes in extremes. With medium confidence, increases in warm days and decreases in cold days, as well as increases on warm nights and decreases in cold nights have been identified in CA, Northern SA, Northeast Brazil, SESA and west coast of SA. In CA, there is low confidence that any observed long-term increase in tropical cyclone activity is robust, after accounting for past changes in observing capabilities. In other regions, such as the Amazon region, insufficient evidence, inconsistencies among studies and detected trends result in low confidence of observed rainfall trends. There is evidence that some extremes have changed as a result of anthropogenic increases in atmospheric concentrations of greenhouse gases. While it is likely that there has been an anthropogenic influence on extreme temperature in the region, there is low confidence in attribution of changes in tropical cyclone activity to anthropogenic influences.

Projections for the end of the 21st century for differing emissions scenarios (SRES A2 and A1B) show that for all CA and SA, models project substantial warming in temperature extremes. It is likely that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century on the global scale. With medium-high confidence, it is very likely that the length, frequency and/or intensity of heat waves will experience a large increase over most of SA, with weakear tendency towards increasing in SESA. With low to medium confidence, the models also project an increase of the proportion of total rainfall from heavy falls for SESA and the West coast of SA; while for Amazonia and the rest of SA and CA there are not consistent signal of change. In some regions, there is low confidence in projections of changes in fluvial floods. Confidence is low due to limited evidence and because the causes of regional changes are complex, although there are exceptions to this statement. There is medium confidence that droughts will intensify along the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration in Amazonia and northeast Brazil.

The character and severity of the impacts from climate extremes depend not only on the extremes themselves but also on exposure and vulnerability. These are influenced by a wide range of factors, including anthropogenic climate change, natural climate variability, and socioeconomic development. Disaster risk management and adaptation to climate change focuses on reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot be fully eliminated.

27.2. Major Recent Changes in the Region

27.2.1. Climatic Stressors

27.2.1.1. Climate Trends, Interdecadal Variability, and Extremes

In CA and SA, decadal variability and changes in extremes have been affecting large sectors of the population, especially those more vulnerable and exposed to climate hazards. Observed changes in some regions have been attributed to natural climate variability while human influences (changes in extremes due to urbanization, for instance) have been attributed to land use change. In this section, observed trends in the region's climate are discussed. Table 27-1 summarizes them, indicating the change, period of time, the magnitude of the trend, and the references.

[INSERT TABLE 27-1 HERE
Table 27-1: Regional observed changes in temperature, precipitation, river runoff and climate extremes in various sectors of CA and SA. Additional information on changes in observed extremes can be found in the IPCC SREX (IPCC, 2012).]

Many areas in the Intra American Seas region (IAS- area of the tropical and subtropical western North Atlantic Ocean encompassing the Gulf of Mexico, the Caribbean Sea, the Bahamas and Florida, the northeast coast of SA, and the juxtaposed coastal regions, including the Antillean Islands) show severe anomalies in rainfall- both generalized and storm-related (Magrin *et al*., 2007a). On an annual basis, much of the IAS region experiences the Mid Summer Drought (MSD, also known as *canicula* or *veranillo between July and August*). Dust from the Saharan Desert is also present in the Northern Atlantic and the Caribbean (Prospero and Lamb, 2003) affecting the regional climate in IAS by suppressing tropical cyclogenesis, and/or hurricane formation (Lau and Kim, 2007). In CA and the North American Monsoon System (NAMS), rainfall has been starting increasingly later and has become more irregular in space and time, and the intensity of rainfall has been increasing during the onset season.

In SA, recent studies in the West coast have shown a prominent but localized coastal cooling during the past 30-50 years extending from central Peru down to central Chile, presumably in connection with an increased upwelling of coastal waters favored by the trade winds (Narayan *et al*., 2010). In the extremely arid northern coast of Chile, rainfall, temperature and cloudiness show strong interannual and decadal variability, and since the mid-70s, the minimum daily temperature, cloudiness and precipitation have decreased. These changes are associated with a negative trend in the sea surface temperature (SST) over a large oceanic region off the coast of northern Chile during the same period (Schulz *et al*., 2011). In central Chile, a similar negative trend in precipitation was observed over the period 1935-1976, and an increase after 1976, while further south, the negative trend in rainfall that prevailed since the 1950s has intensified by the end of the 20^{th} century (Quintana and Aceituno, 2012).

Towards the east of the Andes, in the La Plata Basin, various studies have documented interannual and decadal scale changes that have led to changes in the frequency of cold nights in austral summer since the mid-1970s, with a strong influence of the negative phase Southern Annular Mode SAM (Renom *et al*., 2011), and on the frequency of El Niño after 1976. During the austral winter, warm nights and minimum temperatures have shown a significant positive trend during the last 40 years, particularly in Uruguay, northern Argentina and southern Brazil (Marengo *et al*., 2009; Marengo *et al*., 2010; Marengo *et al*., 2011; Penalba and Robledo, 2010; Rusticucci and Renom, 2008; Rusticucci and Tencer, 2008; Rusticucci, 2012; Rusticucci, 2012; Sansigolo and Kayano, 2010). Simultaneously, a reduction in the number of dry months is found since the mid-1970s, especially during the warm season (Barrucand *et al*., 2007; Vargas *et al*., 2011).

The lightning activity has significantly increased with an increasing temperature at various time scales in the state of São Paulo (Pinto and Pinto, 2008), suggesting that the regional decadal lightning activity is in reasonable agreement with an increase in the global lightning activity estimated by most climate models.

In the Andes, positive temperature trends have been detected during 1921-2010, being more pronounced after 1976, while the number of frost days during September-April has increased (Marengo *et al*., 2011). In the central Andes, in the Mantaro Valley (Peru), precipitation show a strong negative trend while warming is also detected (SENAMHI, 2007) . In the southern Andes of Peru, minimum air temperatures have increased during 1964-2006, while there has been no clear signal on precipitation changes (Marengo *et al*., 2009). In the northern Andes (Colombia, Ecuador), changes in temperature and rainfall in 1961-90 have been identified by Villacís (2008). In the Patagonia region, Masiokas *et al*. (2008) and Villalba *et al*. (2003) have identified an increase of temperature together with precipitation reductions during 1950-90.

For the Amazon basin, Marengo (2004), Marengo *et al*. (2009; 2010), Satyamurty *et al*. (2010), and Buarque *et al*. (2010) concluded that no systematic unidirectional long-term trends towards drier or wetter conditions in both the northern and southern Amazon have been identified since the 1920s. Rainfall fluctuations are more characterized by inter-annual scales linked to ENSO or low-frequency variability with a peak at ˜30 years identified in both rainfall and river series in the Amazon. Even though decadal variability is related to natural climate variability, a recent study by Wang *et al*. (2011) suggests the importance of deforestation and vegetation dynamics on decadal variability of rainfall in the region. Analyzing a narrower time period and a larger dataset, Espinoza *et al*. (2009; 2009) found that mean rainfall in the Amazon basin for 1964–2003 has decreased, with stronger amplitude after 1982, consistent with reductions in convection and cloudiness in the same region (Arias *et al*., 2011). An important aspect detected in rainfall variations in the Amazonia since 1950 is a possible delay in the onset of the rainy season (Butt *et al*., 2011), or the extension of the dry season by about a month (Marengo *et al*., 2011; Marengo *et al*., 2011). Previously, numerical experiments by Zhang *et al*. (2009) suggest that biomass-burning aerosols can work against the seasonal monsoon circulation transition, thus re-inforce the dry season rainfall pattern for Southern Amazonia. Regarding seasonal extremes in the Amazon region, two major droughts and two floods have affected the region from 2005 to 2011, although these events have been related to natural climate variability rather than to anthropogenic climate change owing to deforestation (Espinoza *et al*., 2011; Espinoza *et al*., 2012; Lewis *et al*., 2011; Marengo *et al*., 2008b; Marengo *et al*., 2012a).

Regarding the impacts of land use changes on changes in the hydrology of SA, one of the distinctive features to consider is the relation between the hydrological behavior at small and large scales and vegetation atmospheric feedbacks. Collini *et al*. (2008) and Saulo *et al*. (2010) find the SESA precipitation to be more responsive to changes in soil moisture. Although feedback mechanisms are present at all scales, the atmosphere influence is more significant at large scales. Land use change studies in the Brazilian southern Amazonia (Rodriguez *et al.,* 2010) for the last decades showed that the impact on the hydrological response is time lagged at larger scales. Costa and Pires (2010) have suggested a possible decrease in precipitation due to soybean expansion in Amazonia, mainly as a consequence of its very high albedo.

27.2.1.2. Climate Projections

Since the AR4, substantial additional regional analysis has been carried out using the CMIP3 model ensemble. In addition, projections from global models from the IPCC AR5 (placeholder for future climate projections from CMIP5 models- references), the results of the IPCC SREX projections of extremes (IPCC, 2012), and new experiences using regional models (downscaling) have allowed for a better description of future changes in climate and extremes in CA and SA. Table 27-2 summarizes projected climatic changes derived from global and regional models for the region, indicating the projected change, models, emission scenarios, time spans and references.

[INSERT TABLE 27-2 HERE
Table 27-2: Regional projected changes in temperature, precipitation, river runoff and climate extremes in different sectors of CA and SA. Various studies used A2 and B2 scenarios and different time slices from 2010 to 2100. In order to make results comparable, the A2 scenario and the time slice ending in 2100 are included. Additional information on changes in projected extremes can be found in the IPCC SREX (see IPCC, 2012).]

Giorgi (2006), Diffenbaugh *et al*. (2008) and Xu *et al*. (2009) have identified that CA is among the most prominent identified climate change "hot-spots" in terms of a consistent decrease of precipitation projected by most models. Climate change scenarios for the 21st century from CMIP3 global models show a weakening of the NAMS due to a weakening and poleward expansion of the Hadley cell under the A1B emission scenario caused by a warming of about 0.6 ^{o} lat/^{o}K lat by 2100 (Lu *et al*., 2007). According to Rauscher *et al*. (2008, 2011), most of the precipitation reduction could occurr in June-July, with an early onset and an intensification of the MSD. Aguilar *et al*. (2009) project a warming in most of CA by the end of the 21th century. Campbell *et al*. (2011) and Karmalkar *et al*. (2011) performed a downscaling experiment using the PRECIS modeling system, and projected a significantly greater and more consistent warming over land than the ocean, and a tendency for less rainfall in large parts of CA and northern Venezuela. Imbach *et al*. (2012) used CMIP3 models and show reductions of rainfall as well as increases in air temperature and evapotranspiration in CA, indicating that potential vegetation may likely shift from humid to dry types. However, their projection spread is high for future precipitation, and the impacts of climate change on vegetation and water cycle are predicted with relatively low uncertainty (Imbach *et al*., 2012). Projections for rainfall and temperature extremes of both, a 20- and 60-km global model by the Meteorological Research Institute-Japan Meteorological Agency (MRI-JAM) have shown a decrease of precipitation in most of CA and Northern SA by the end of this century, together with an increase in evaporation, and reductions in soil moisture for most of the land during all seasons (Hall *et al*., 2012; Nakaegawa and Vergara, 2010).

Analyses from global and regional models in tropical and subtropical SA show common patterns of projected climate in some sectors of the continent. In present climates, current models are able to reproduce the main features of the seasonal cycle of precipitation, but sometimes fail in reproducing the observed amounts of mean seasonal precipitation due to misrepresentations of the Inter-Tropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone (SACZ) (Bombardi and Carvalho, 2009; Chou *et al.*, 2012; Mizuta R. *et al.*, 2006; Solman *et al.*, 2008). Projections from CMIP3 models show an increase of precipitation in SESA, Northwest of Peru and Ecuador and western Amazonia, while decreases are projected for northern SA, Eastern Amazonia, central eastern Brazil, Northeast Brazil, the Altiplano and southern Chile (Boulanger *et al.*, 2010; Meehl *et al.*, 2007; Minvielle and Garreaud, 2011; Seth *et al.*, 2007; Sörensson *et al.*, 2010; Urrutia and Vuille, 2009; Vera *et al.*, 2006). These future trends identified from low resolution models are also consistent with projections of high resolution global models (Blázquez and Nuñez, 2012; Kitoh *et al.*, 2011), and from downscaling using regional climate models and artificial neural networks for the end of the 21st century for regions such as SESA, Northeast Brazil, and the Northwest coast of Peru and Ecuador, and southern Chile. The CMIP3 models show, however, mixed results in rainfall projections, for the Amazonia and the SA monsoon region (Cabré *et al.*, 2010; Carril *et al.*, 2012; Marengo *et al.*, 2010; Marengo *et al.*, 2011; Mendes and Marengo, 2010; Menendez *et al.*, 2010; Nuñez *et al.*, 2009; Seth *et al.*, 2010). For the Amazon region, Seth *et al.* (2010) suggest that the reduced precipitation along the continental central Amazonia-SACZ region during austral spring for the A2 scenario is due to a southward shift of the maximum precipitation in the convergence zone. This change is consistent with predicted perturbations in the dynamics of the South American Low Level Jet (SALLJ) east of the Andes for the period 2071-2100 {{987 Soares,W.R. 2009;}}. In the extratropical Andes, late 21st century projections of precipitation suggest that the strong reduction of precipitation is possibly associated with the positive trend in the Antarctic Oscillation projected by the CMIP3 models (Quintana and Aceituno, 2012).

As for extremes, CMIP3 models show increases in dry spells are projected for Eastern Amazonia and Northeast Brazil, while rainfall extremes are projected to increase in SESA, as well as increases in warm nights throughout SA by the end of the 21st century (IPCC, 2012; Tebaldi *et al.*, 2006). Projections for rainfall and temperature extremes from the 20- and 60-km MRI-JAM model show similar tendencies to those derived from the CMIP3 models, with some disagreement in rainfall along the South American monsoon regions in Central Brazil (Blázquez and Nuñez, 2012; Kamiguchi *et al.*, 2006). Projections from regional models show an increase in the frequency of rainfall extremes and in the frequency of warm nights in western Amazonia, Northwest Peru and Ecuador and in Southeastern SA, while over southern Amazonia, northeastern Brazil and eastern Amazonia, the maximum number of consecutive dry days tends to augment, suggesting a longer dry season (Marengo *et al.*, 2009; Marengo *et al.*, 2010; Marengo *et al.*, 2011; Marengo *et al.*, 2012a; Menendez and Carril, 2010; Nuñez *et al.*, 2009; Sörensson and Menéndez, 2011).

In SESA, Sörensson and Menéndez (2011), Menendez and Carril (2010) and Seth *et al.* (2010) predict an increase in the future risk of extreme of seasonal precipitation, associated with an increased convergence in the region throughout the warm season, to changes in the Southern Annual mode, and to a Rossby wave train-like anomaly pattern linking the equatorial central Pacific to SESA (Junquas *et al.*, 2011). Shiogama *et al.* (2011) suggest that although the CMIP3 ensemble mean assessment suggested wetting across most of SA, the observational constraints indicate a higher probability of drying in the eastern Amazon River basin.

27.2.2. Non-Climatic Stressors

27.2.2.1. Trends and Projections in Land Use and Land Use Change

Land use and land cover change are key drivers of environmental change for the region with significant impacts that may increase the potential negative impacts from climate change (Lopez-Rodriguez and Blanco-Libreros, 2008; Sampaio *et al.*, 2007). The high levels of deforestation observed in most of the countries have been widely discussed in the literature as a deliberate development strategy based on the expansion of agriculture to satisfy the growing world demand for food and bio-energy (Benhin, 2006; Grau and Aide, 2008; Mueller *et al.*, 2008). Land is facing increasing pressure from competing uses, among them cattle ranching, food production and bioenergy production. The enhanced competition for land increases the risk of land use changes, which may lead to negative environmental and socio-economic impacts. Agricultural expansion has relied in many cases on government subsidies, which have often resulted in lower land productivity and more land speculation (Bulte *et al.*, 2007; Roebeling and Hendrix, 2010). Some of the most affected areas due to the expansion of the agricultural frontier are fragile ecosystems such as the edges of the Amazon forest in Brazil, Colombia, Ecuador and Peru, and the tropical Andes, where activities such as deforestation, agriculture, cattle ranching and informal gold mining are causing severe environmental degradation (ECLAC, 2010b).

Deforestation rates for the region remain high in spite of a reducing trend in the last decade (Fearnside, 2008; Ramankutty *et al*., 2007). Brazil is by far the country with the highest area of forest loss in the world according to the latest FAO statistics (2010): 21,940 km² per year, accounting for 39% of world deforestation for the period 2005-2010 (see Box 27-1 in section 27.3.2.1.). Bolivia, Venezuela and Argentina, in that order, follow in deforested area (see Figure 27-1) with all four countries accounting for 54% of the forest loss in the world for the same period. Together, the countries of CA and SA lost a total of 38,300 km² of forest per year in that period, corresponding to 69% of the total world deforestation (FAO, 2010).

[INSERT FIGURE 27-1 HERE
Figure 27-1: Area deforested per year for selected countries in CA and SA (2005-2010). Notice three countries listed with a positive change in forest cover (based on data from FAO, 2010). Observed rates are: Uruguay 2.79%, Chile 0.23%, Costa Rica 0.90%, Guatemala -1.47%, Nicaragua -2.11%, Honduras -2.16%, Argentina -0.80, Venezuela, -0.61%, Bolivia -0.53%, Brazil, -0.42%).]

Deforestation in the Amazon forest has received much international attention in the last decades, both because of its high rates, but also because of the high biodiversity found in that ecosystem. Brazilian Legal Amazon is now one of the best-monitored ecosystems in terms of deforestation, by the PRODES project, which has been using LANDSAT images to detect deforested areas larger than 6.25 hectares on a yearly basis since 1988 (INPE, 2011; see Figure 27-2). Deforestation rates for this region peaked in 2004 and have steadily declined since then, dropping almost 42% from 2008 to 2009 and to 14% from 2009 to 2010, and currently exhibiting the lowest rates during the entire record. Such reduction results from a series of integrated policies to control illegal deforestation particularly enforcing protected areas, which now shelter 54% of the remaining forests of the Brazilian Amazon (Soares-Filho *et al*., 2010). Deforestation in Brazilian Amazon for the period 2005-2010 accounted for 41% of the total deforestation for that country and showed the lowest rate for all forest biomes in Brazil (0.29%), with the Cerrado forest (drier ecosystem south of Amazon) presenting the forest biome with the highest deforestation rates (1.33%), accounting for 37% of Brazil's total deforestation (FAO, 2009a).

[INSERT FIGURE 27-2 HERE
Figure 27-2: Deforestation rates in the Brazilian Amazonia (km²/year) based on measurements by the PRODES INPE project (see also INPE, 2011).]

The amount of forest loss in CA is considerably less than in SA, owing to smaller country sizes; when deforestation rates are considered, Honduras and Nicaragua show the highest values for the area (Carr *et al*., 2009). At the same time, CA includes three countries where forest cover shows a recovery trend in the last years: Costa Rica, El Salvador and Panama. This forest transition is the result of: (1) economies less dependent on agriculture, and more on industry and services (Wright and Samaniego, 2008); (2) processes of international migration with the associated remittances (Hecht and Saatchi, 2007), and (3) a stronger emphasis on the recognition of environmental services of forest ecosystems (Kaimowitz, 2008). The same positive trend is observed in some SA countries (see Figure 27-1). However, a substantial amount of forest is gained through (single-crop) plantations, most noticeably in Chile (Aguayo *et al*., 2009), which have a much lower ecological value than natural forests (Izquierdo *et al*., 2008).

Besides deforestation, land degradation, which refers to the loss of biological and economic productivity, is also an important process compromising extensive areas of CA and SA very rapidly. According to data from the Global Land Degradation Assessment and Improvement (GLADA) project of the Global Environmental Facility (GEF), additional degraded areas reached 16.4% of the entire territory of Paraguay, 15.3% of Peru and 14.2% of Ecuador for the period 1982-2002. In CA, Guatemala shows the highest proportion of degraded land, currently at 58.9% of the country's territory, followed by Honduras (38.4%) and Costa Rica (29.5%); only El Salvador shows a reversal of the land degradation process, probably due to eased land exploitation following intensive migratory processes (ECLAC, 2010b).

Deforestation and land degradation are mainly attributed to increased extensive and intensive agriculture. Two activities have traditionally dominated the agricultural expansion: beef and soy production; but more recently, biomass for biofuel production has become as important (Nepstad and Stickler, 2008). Deforestation by small farmers, mainly coming from families who migrate in search for land and using shifting agriculture techniques is relatively low. In this line, Oliveira *et al*. (2007) found that only 9% of the deforestation in the Peruvian Amazon between 1999 and 2005 happened in indigenous territories. Pasture for livestock production is the predominant land use in deforested areas of tropical and subtropical Latin America (Wassenaar *et al*., 2007). More than 2/3 of the total deforested areas in Colombia (Etter *et al*., 2006) and in the Brazilian Amazon (Nepstad *et al*., 2006) are converted to cattle ranching. Forest conversion to pasture for livestock is also the major land use change driver in eastern Bolivia (Killeen *et al*., 2008).

In recent years, soybean croplands have expanded continuously in SA, becoming increasingly more important in the agricultural production of the region. Soybean-planted area in Amazonian states (mainly Mato Grosso) in Brazil expanded 12.1% per year during the 1990s, and 16.8% per year from 2000 to 2005 (Costa *et al*., 2007). The southern and eastern parts of the Amazon, known as the Deforestation Arch, have traditionally been the areas of highest deforestation due in part to their higher connectivity to urban centers and markets, but also to more favorable climatic conditions for agriculture in recent years, expressed as a more intense dry season (Aguiar *et al*., 2007). This landscape-scale conversion from forest to soy and other large-scale agriculture can alter substantially the water balance for large areas of the region resulting in important feedbacks to the local climate (Hayhoe *et al*., 2011; Loarie *et al*., 2011) (see also section 27.3.4.1).

Soybean and beef production have also impacted other types of forest ecosystems, such as the Cerrado (Brazil) and the Chaco dry forests (Bolivia, Paraguay, Argentina and Brazil). Gasparri *et al*. (2008) estimated carbon emissions from deforestation in Northern Argentina and concluded that deforestation in the Chaco forest has accelerated in the past decade from agricultural expansion and is now the most important source of carbon emission for that region. In northwest Argentina (Tucumán and Salta provinces) from 1972 to 2007, 1.4 million ha of dry forest was cleared; this process started as a result of technological improvements and increasing rainfall (Gasparri and Grau, 2009). Deforestation continued during the 1980s and 1990s resulting in cropland area covering up to 63% of the region by 2005 (Viglizzo *et al*., 2011). The sustained global demand of soybean accelerated deforestation in the area during the last years as a consequence of increasing commodity prices and favorable exchange rates in the producing countries (Gasparri and Grau, 2009). In central Argentina (northern Córdoba province), an analysis for the period 1969-1999 showed that cultivated lands has increased from 3% to 30%; at the same time, the forest cover has decreased from 52.5% to 8.2%. This high rate of deforestation and agricultural expansion has also been attributed to the synergistic effect of climatic, socioeconomic, and technological factors (Zak *et al*., 2008). Losses in the Atlantic forest are estimated in 29% of the original area in 1960, and in 28% of the Yunga forest area mainly due to cattle ranching migration from the Pampas and Espinal (Viglizzo *et al*., 2011). Even when following good-practice certification schemes, the fast expansion of soy production in SA may enhance the region's deforestation, land degradation, and pollution from pesticides and fertilizers, as a result of low enforcement capabilities and weak institutional arrangements (Tomei *et al*., 2010).

Oil palm is one of the most rapidly expanding crops in the world (Koh and Wilcove, 2008) and a significant biofuel crop linked to recent deforestation in tropical CA and SA. Its magnitude is still small compared with deforestation related to soybean and cattle ranching, but it is considerable for specific countries and expected to increase due to increasing demands for biofuels (Fitzherbert *et al*., 2008). Colombia is the largest oil palm producer in the region (Butler and Laurance, 2009) and it is predominantly planted in medium and large farms. The main forest regions where oil palm has recently expanded are the Chocó region in Colombia and the Sucumbios region of Ecuador. Oil palm production is also important in Brazil (with 75% of the area planted in the state of Bahia) and emerging in the Amazonian region of Peru, where 72% of new plantations expanded into forested areas (Gutiérrez-Vélez *et al*., 2011).

However, forest is not the only important ecosystem threatened in the region. An assessment of threatened ecosystems in SA by Jarvis *et al*. (2010) concluded that grasslands, savannas and shrublands are more threatened than forests, mainly from fires and grazing pressure. An estimation of burned land in Latin America by Chuvieco *et al*. (2008) also concluded that, proportionally, the most affected ecosystems were the savannas of Colombia and

Venezuela. In the Río de la Plata grasslands (Central-East Argentina, southern Brazil, and Uruguay), the area covered by grassland decreased from 67.4% to 61.4% between 1985 and 2004. This decrease was associated with an increase in the area of annual crops, mainly soybean, sunflower, wheat, and maize (Baldi and Paruelo, 2008).

Even with technological changes that might result in agricultural intensification, the expansion of pastures and croplands is expected to continue in the coming years (Kaimowitz and Angelsen, 2008; Wassenaar *et al.*, 2007), particularly fom an increasing global demand for food and biofuels (Gregg and Smith, 2010) with the consequent increase in commodity prices. This agricultural expansion will be limited in the temperate zones already showing a shortage of land suitable for cultivation, but may be more significant in Latin America and Sub-Saharan Africa as these regions hold two-thirds of the global land with potential to expand cultivation (Nepstad and Stickler, 2008). It is important to consider enforceable policy and legal reforms to keep this process of large-scale change under control as much as possible; these reforms should aim to reduce the impact on poor households who depend directly on the natural resources being depleted (Takasaki, 2007). Indigenous groups require particular attention in this respect. Traditionally, they have been denied the rights to their ancestral lands, but there is a growing acknowledgment that recognizing the land ownership and authority of indigenous groups can help central governments to better manage many of the natural areas remaining in the region (Larson, 2010; Oltremari and Jackson, 2006). Many indigenous groups are important drivers of land use change in the region and their well-being should be considered when designing responses to pressures on the land by a globalized economy (Gray *et al.*, 2008; Killeen *et al.*, 2008).

27.2.2.2. Trends and Projections in Socioeconomic Conditions

The population of CA and SA was 435 million in 2011; it is expected to reach 559 million by 2050 and start declining thereafter to 517 million by 2100 (UN, 2011). The countries in the region have experienced profound demographic changes reflected in the decrease in population growth (1.3% in the period from 2005 to 2010), in a rapid fall in fertility and in an aging population (by 2050 one in five persons will be 65 or older) (ECLAC, 2009c) The population has continued to migrate from countryside to the cities; thus, SA is a highly urban region. Seventy-seven percent of the population lives in cities, which increases to almost 90% in the Southern Cone where mega-cities are commonplace (Miguel and Sunkel, 2011).

Development in the region has traditionally displayed four characteristics: low growth rates, high volatility, structural heterogeneity and a very unequal income distribution (Bárcena, 2010; ECLAC, 2008). This combination of factors has generated high and persistent poverty levels, with the rate of poverty being generally higher in rural than urban areas (ECLAC, 2009d). SA has based its economic growth in natural resource exploitation (mining, energy, agricultural), which involves direct and intensive use of land and water, and in energy-intensive and, in many cases, highly polluting natural-resource-based manufactures. Meanwhile, CA has exploited its proximity to the North American market and its relatively low labor costs (ECLAC, 2010d). In terms of productivity, the region's technology gap and the large productivity differences among sectors, within sectors and among companies within a given country, i.e., the structural heterogeneity, complete the picture (ECLAC, 2010g). The GDP per capita in SA is twice that of CA; in addition, in the latter poverty is 50% higher (see Figure 27-3).

[INSERT FIGURE 27-3 HERE
Figure 27-3: Evolution of GDP per capita and poverty from 1990-2011: CA and SA
(US-Dollars per inhabitant at 2005 prices and percentages) (ECLAC on the basis of CEPALSTAT (2012a; 2012b; 2012c) and ECLAC (2011c))]

The financial crisis that broke out in 2008 was transmitted to CA and SA through the traditional channel of exports and credits, with a heavy crunch in foreign trade financing. This was manifested in export volumes and prices, remittances and other items directly associated with the economic activity (Bárcena, 2010; Kacef and López-Monti, 2010). Along with the worsening expectations of consumers and producers, these factors account for the sudden halt for six consecutive years of robust growth and improving social indicators, representing a slight contraction in GDP of some -0.3% in the case of SA and -0.2% in CA in 2009. It was accompanied by a rise in unemployment from 7.5% in 2008 to 8.3% in late 2009, reversing the steady improvements seen in this indicator over a period of five years. All this contributed to higher poverty in 2009, following six years in which it declined by 11 percentage points (from 44% to 33%, which represents 150 million people) while extreme poverty diminished from 19.4% to 12.9% (which represents slightly more than 70 million people), in both cases from 2002 to 2008 (ECLAC, 2010d).

In the second half of 2009, industrial output and exports began to recover and yielded a stronger economic performance (6.4% in SA and 3.9% in CA in 2010) (ECLAC, 2012). SA benefited the most, given the greater relative size of some countries' domestic markets and the greater diversification of their export markets, the orientation of their trade towards raw materials, whose prices are rising, and the greater share of trade accounted for by China in a number of cases. Conversely, slower growth is expected in more open economies with a less diversified portfolio of trading partners and a greater emphasis on manufacturing trade, this being the case with CA (ECLAC, 2010g). Exports of primary products have surged in the 2000s, marking up a growth rate four times as high as the rate for the 1990s, being particularly strong in SA. As mentioned earlier, the stronger showing of exports of natural resources stems from the sharp rise in the prices of these sub regions' main export products, especially in the case of petroleum, copper, soy, coffee, bananas, iron and steel. The region's performance in exports of manufactures marks a sharp contrast with its showing for primary products, with the growth rate for the former falling sharply from one decade to the next (ECLAC, 2010d).

The region is expected to continue to grow in the short term, albeit at a pace that is closer to potential GDP growth, helped by internal demand as credit becomes more available. In SA, this could be boosted by external demand from the Asian economies as they continue to grow at a rapid pace. Beyond the short term, though, the impact could be negative as growth came with unsustainably low real exchange rates. A scenario like the one (with high global liquidity exerting downward pressure on real exchange rates and upward pressure on commodity prices) could lead to overspecialization in the production and export of primary goods. In short, the macroeconomic challenge for the region is to rebuild its capacity to act counter cyclically while continuing to create conditions for productive development that is not based solely on commodity exports (ECLAC, 2010f).

The region also displays high and persistent inequality: most countries have Gini coefficients between 0.5 and 0.6, whereas the equivalent figures in a group of 24 developed countries vary between under 0.25 and around 0.40. The average per capita income of households in the tenth decile is around 17 times that of the poorest 40% of households. Nevertheless, during the first decade of the century, prior to the financial crisis, the region has shown a slight but clear trend towards a lesser concentration of income (ECLAC, 2010g; ECLAC, 2011b; UN, 2010). Latin American countries also reported gains in terms of human development, although the average annual growth rate has slightly fallen over recent years. In comparative terms, the performance of countries varied greatly (from Chile with 0.878 and Argentina with 0.866 to Guatemala -0.704- and Nicaragua -0.699-) although those with lower relative levels of the Human Development Index (HDI) showed notably higher growth rates than countries with the highest HDI (UNDP, 2010).

There is also inequality on the supply side of the economy, since modern production structures coexist with large segments of the economy that have lower productivity and income levels and are excluded from technological modernization. Also associated with inequality are disparities in access to water, sanitation and adequate housing for the most vulnerable groups - for example indigenous peoples, Afro-descendants and women living in poverty- and in their exposure to the effects of environmental degradation. The strong heterogeneity of subnational territorial entities in the region takes the form of high spatial concentration and persistent inequalities in the territorial distribution of wealth (ECLAC, 2010g; ECLAC, 2011b; UN, 2010).

The region faces significant challenges in terms of environmental sustainability, reflecting the specific characteristics of its development: high levels of poverty and inequality among a growing, mostly urban, population that shows increasingly complex migration dynamics; specialization patterns based on primary goods and environmentally sensitive industries, often drawing on static comparative advantages that do nothing to foster the transition towards higher-productivity and higher-value-added sectors; and a significant deficit in infrastructure development. The stakeholders - the State, private sector and civil society- have made progress in incorporating environmental protection into decision-making processes, and particularly in terms of environmental institutions and legislation. Difficulties, however, remain in effectively mainstreaming the environment into sector public policies. While the global economic and financial crises together with climate change impose new challenges, they also provide an opportunity to shift development and growth patterns towards a more environmentally friendly economy (UN, 2010).

27.3. Impacts, Vulnerabilities, and Adaptation Practices

27.3.1. Freshwater Resources

Central America (CA) and South America (SA) are regions with high average but poorly distributed water resources availability (Magrin *et al.*, 2007a). The main user of water is agriculture, accounting for 70% of all withdrawals used to fed the more than 20 million ha of irrigated land that represent 14% of the world's total cultivated area (ECLAC *et al.*, 2010). The second consumptive user of water is composed by the region's 580 million inhabitants (includes the Caribbean countries), of which 86% had access to water supply by 2006 (ECLAC, 2010e). This means an important improvement towards the Milleninum Development Goals (MDGs). However, in rural areas the gap is wider, with only 51% of the population having access to those services. In terms of non-consumptive use of water, the region distinguishes from having the largest relative contribution of hydropower generation to meet its electricity demand. According to the International Energy Agency (IEA) statistics hydropower covers more than 60% of electricity demand in the region. This is by far the largest share in the world with all other regions (and the world average) falling under a 20% contribution (see case study in section 27.6.1).

27.3.1.1. Observed and Projected Impacts

In CA and SA there are many evidences of changing conditions in terms of geophysical variables (cryosphere and runoff) that affect streamflow and finally water availability. For example, García and Mechoso (2005) found for all major rivers in SA (Amazon, Orinoco, Tocantins, San Francisco, Paraná, Paraguay, Uruguay and Negro) an increasing trend in streamflow starting in the 1970s that could be associated to the effect of a large-scale climate change. Their work only distinguishes a change in trend, which however does not qualify the robustness of the trend assessed in other studies as presented below.

The most robust of the trends for major rivers in the region is found in the sub-basins of the La Plata River basin. This basin, second only to the Amazon in size and streamflow (21,500 m^3/s) (Pasquini and Depetris, 2007), has shown a positive trend in streamflow in different sites (Conway and Mahé, 2009; Dai *et al.*, 2009; Dai, 2011; Doyle and Barros, 2011; Krepper *et al.*, 2008; Krepper and Zucarelli, 2010a; Pasquini and Depetris, 2007; Saurral *et al.*, 2008). Two factors have been associated with this increase in runoff: an increase in precipitation, and trends in land use change that have reduced evapotranspiration (Doyle and Barros, 2011; Saurral *et al.*, 2008). According to Doyle and Barros (2011), the precipitation increase factor has been more important in the southern sub-basins, whereas the land use change factor has been more important in the northern ones (see section 27.2.1.).

This positive trend is shared in general with different rivers located in the southeastern region of South America (SESA), which have experienced an increase in precipitation and associated runoff. In Argentina, Pasquini *et al.* (2006) and Troin *et al.* (2010) show this increasing trend in the Laguna Mar Chiquita (a closed lake in central Argentina). A similar trend was found in Santa Fe province (Venencio *et al.,* (2011). This increase in runoff could affect erosion rates, mainly in the lowlands draining to the Atlantic Ocean (Rodrigues Capítulo *et al.*, 2010).

On the other hand, there is no clear long term trend for the Amazon River, which streamflow could be associated with interanual or decadal variability shadowing any distinguishable long-term trend in runoff (Marengo, 2009). Nevertheless, some dry and wet seasonal events have been reflected in anomalously high or low river levels in the Amazon region. Extremely low levels at some rivers were detected during the droughts of 2005 and 2010, while record high levels for the same rivers were detected during the 2009 flood (Marengo *et al.*, 2008a; 2008b; 2011). Espinoza *et al.* (2009; 2011) showed that for the 1974-2004 period an apparent stability in mean discharge at the main stem of the Amazon in Obidos is explained by opposing regional features mainly involving Andean rivers (see section 27.2.1.).

A lack of significant trends has been the signature of all other major critical rivers including the Brazilian North East, and North of SA. Dai *et al*. (2009) performed trend analysis in several rivers, such as the Orinoco, Magdalena and Tocantins, without finding significant trends. The only study done for rivers in CA is that of Dai (2011) who showed a drying trend in this region.

The west Andean river basins fall in a region where it is possible to find robust changes based on recent observations. The most relevant of these changes are those related to the Andes mountains cryosphere, in particular retreating glaciers in tropical and extra-tropical Andes and their effects on snowpack accumulation and melt. River discharges of the most important river basins of Colombia show decreasing trends during the last 30-40 years (Poveda and Pineda, 2009).

The retreat of Andean tropical glaciers has been observed and studied for some decades. However, the level of understanding of these processes has increased noticeably since the IPCC AR4 Report. A summary of the most significant findings of these studies is depicted in Table 27-3a. Recent extensive reviews have demostrated (e.g. Vuille *et al*., 2008a; Jomelli *et al*., 2009; Bradley *et al*., 2009: Poveda and Pineda, 2009), a generalized retreat of tropical glaciers in Venezuela, Colombia, Ecuador, Peru and Bolivia. The rate of retreat is measured using different techniques (e.g. aereal photograph, satellite images, ice coring, lichens) and is presented with different metrics (volume or area loss, length reduction). A synthesis of the studies (Table 27-3 a) recognizes that glaciers retreat, with some fluctuations, started after the Little Ice Age (16^{th} to 19^{th} centuries) but the rate of retreat has accelerated since the middle of the 20^{th} century (Table 27-3a). Depending on the size and phase of glacier retreat there is an expected effect in terms of changes in runoff in basins fed from these glaciers. In an early phase of the glacier retreat runoff tends to increase due to an acceleration of glacier melt, but after a peak in discharge as the glacierized water reservoir gradually empties, while the non-glaciated area increases, runoff tends to decrease. Chevallier *et al*. (2011) have evidenced such dynamics in the Cordillera Blanca in Peru. In general, runoff tends to decrease during the period in the year when precipitation is at its lowest level.

Similarly, glaciers and icefields in the extra tropical Andes located in Central-South Chile and Argentina face significant reductions as presented by different authors (Table 27-3 b). In this region the effect of glacier retreat is compounded with changes in snowpack extent, thus magnifying changes in hydrograph seasonality by reducing flows in dry seasons and increasing ones in wet seasons.

[INSERT TABLE 27-3 HERE
Table 27-3: Observed trends related to Andean cryosphere.
a) Andean tropical glacier trends since the Little Ice Age (LIA) maximum and, particularly, during the last decades
b) Extra tropical Andean cryposphere (glaciers, snowpack, runoff effects) trends]

In conjunction with changes in the accumulation of ice and snow, and observed effects on streamflow, the Central-South region of Chile and Argentina region also faces a significant reduction in precipitation (see section 27.2.1.) that translates into a reduction in runoff that has been observed for the last decades of the 20^{th} century (Rubio-Álvarez and McPhee, 2010; Seoane and López, 2007; Urrutia *et al*., 2011) and contrasted in some cases with long-term records based on dendrochronology assessments (Lara *et al*., 2007; Urrutia *et al*., 2011).

According to the assessment on future impacts (Table 27-4), results show a large range of uncertainty across the spectrum of GCMs. It is hard to make conclusive statements in terms of trends on some particular regions/rivers. Nohara *et al*. (2006) studied the climate change impacts on 24 of the main rivers in the world (considering an uncertainty analysis driven by use of 19 GCMs), and found no robust change for the Parana (La Plata Basin) and Amazon Rivers. Neverthelesss in both cases the average change showed a positive trend consistent at least with observations for the La Plata Basin as discussed earlier. Adding to this climatic uncertainty, future streamflow and water availability projections have the difficulty of considering the influence of deforestation on river discharges, as explored by Moore *et al*. (2007) and Coe *et al*. (2009) for the Amazon river. In terms of future conditions, land use change could also play a significant role on future streamflow trends in a way that could exacerbate or reduce impacts as shown in a next section.

[INSERT TABLE 27-4 HERE
Table 27-4: Synthesis of projected climate change impacts on hydrologic variables in large South American basins and major glaciers.]

CA shows a consistent runoff reduction, based on uncertainty analysis and different scenarios. Maurer *et al.* (2009) studied climate change projections for the Lempa River basin, the largest basin in CA, covering portions of Guatemala, Honduras and El Salvador. They showed that future climate projections imply a reduction of 20% in inflows to major reservoirs in this system. Imbach *et al.* (2012) also found similar results using a modeling approach that also considered potential changes in vegetation. These effects could have large hydropower generation implications as discussed more thoroughly in the case study (see section 27.6.1.).

It is interesting to note the appearance of studies since the AR4 that have tried to associate future climate scenarios with the evolution of glaciers, especially in the tropical Andes. Juen *et al.* (2007) and Chevallier *et al.* (2011) for example developed "regression" type of analysis relating glacier evolution (manifested as downstream streamflow) to changes in temperature. Similarly, Poveda and Pineda (2009) performed linear extrapolations on historic glacier retreat rates to estimate the fate of the remaining glaciers in Colombia. In general, all these studies indicate that glaciers may continue their retreat (Vuille *et al.*, 2008a) as glacier Equilibrium Line Altitudes (ELA) raises. The water contribution of glaciers is more evident during the dry season (Gascoin *et al.*, 2011; Kaser *et al.*, 2010) and hence changes in water availability are more evident in those months. During the glacier retreat process there is a phase were melting contributes to an increase trend in runoff. This is expected to happen in general until the next 20-50 years as shown by Juen *et al.* (Juen *et al.*, 2007) and Chevallier *et al.* (2011). After that period water availability during the dry months is expected to diminish. Once the glaciers completely melt, annual discharge would be lower than present by 2%–30% depending on the watershed as presented by Baraer *et al.* (2012) in a study on the Rio Santa, in the Peruvian Andes. The retreat influence on discharge will be more pronounced during the dry season.

In other regions of the Andes, studies project significant effects associated with energy related (temperature, albedo) changes on the hydrologic conditions. In Central Chile, Vicuña *et al.* (2011) analyze the direct impacts of climate change on the hydrology of the upper watersheds (range in elevation from 1,000 to 5,500 m above sea level) of the snowmelt-driven Limarí River basin (see Table 27-4) projecting changes in seasonality that could be associated with increases in temperature, and reductions in water availability associated with precipitation reduction and temperature enhanced water losses owing to evapotranspiration. A similar situation occurs on the other side of the Andes as presented in a study by Seoane and López (2007) on the Argentinean Limay basin. Projected changes in the cryosphere conditions of the Andes could affect the occurrence of extreme events., such as the Glacial-lake outburst floods (GLOFs) occurring in the icefields of Patagonia (Dussaillant *et al.*, 2010), volcanic collapse and debris flow associated with accelerated glacial melting in some volcanoes in southern Chile and Argentina (Tormey, 2010) or even scenarios of water quality pollution due to glacier receding affecting exposure to contaminants (Fortner *et al.*, 2011).

27.3.1.2. Vulnerability and Adaptation Practices

Vulnerability for the region is assessed taking into account 'future/outcome vulnerability' (related to impacts associated with climate change) and 'actual/contextual vulnerability' (depending on social, political, economic, cultural, and institutional factors) (O´Brien, 2007). Of special relevance are current highly vulnerable regions, such as the semi-arid regions in Chile-Argentina and North East Brazil, certain regions in CA, and communities in the tropical Andes.

Semiarid regions are characterized by pronounced climatic variability and often by water scarcity and related social stress (Krol and Bronstert, 2007). The semiarid regions of Central Chile-Argentina are expected to face reductions in flow and changes in seasonality that could have significant effects on already vulnerable regions which hold large populations (as Santiago, Chile) and extensive agriculture irrigation demands (ECLAC, 2009a; Souvignet *et al.*, 2010). The need to develop special adaptation tools to face the threats of climate change is particularly special for the most vulnerable communities in this region (Young *et al.*, 2010), such as those located in the transition between the semiarid and arid climates (Debels *et al*., 2009). Chile's main hydroelectric basins could also be affected by these changes, reflecting only outcome vulnerability (ECLAC, 2009a; Stehr *et al*., 2010).

Another semiarid region that has been studied thoroughly is the Brazilian North East. De Mello *et al*. (2008), Gondim *et al*. (2008), Souza *et al*. (2010) and Montenegro and Ragab (2010) have shown for different river basins that future climate change scenarios would impact water availability for agriculture irrigation owing to reductions in precipitation and increases in evapotranspiration. Following similar projections, Krol and Bronstert (2007) and Krol *et al*. (2006) presented an integrated modeling work that linked projected impacts on water availability for agriculture to economic impacts that could potentially drive full-scale migrations in the Brazilian northeast region.

In CA, the social and economic implications of the projected drier scenarios for the agricultural sector have been studied by Benegas *et al*. (2009), Manuel-Navarrete *et al*. (2007) and Aguilar *et al*. (2009). Adaptation strategies are suggested in these studies for reducing vulnerability.

An example of how actual vulnerability is exacerbated in the future is represented by the expected changes in tropical glacier extent and effects on water availability (Bradley *et al*., 2006; Casassa *et al*., 2007; Mulligan *et al*., 2010; Vuille *et al*., 2008b). Glacier retreat diminishes the mountains' water regulation capacity, making it more expensive to supply water for human consumption, power generation, or agriculture, as well as for ecosystem integrity in associated basins (Buytaert *et al*., 2011). Impacts on economic activities have been monetized (Vergara *et al*., 2007) and found to represent about US$100 million in the case of water supply for the city of Quito, and a range between US$212 million and US$1.5 billion in the case of the Peruvian power sector due to losses of hydropower generation (see hydropower case study in section 27.6.1.). Andean communities face an increase in their vulnerability (Mark *et al.,* 2010), calling for the need to incorporate with urgency adaptation strategies as suggested by Young and Lipton (2006).

Actual vulnerability to climate variability motivates the development of a series of "adaptation" strategies and/or policies. Potential strategies have been studied in Brazil (mainly in the North East). In 1997, Brazil instituted the National Water Resources Policy and created the National Water Resources Management system under the shared responsibility between states and the federal government. Key to this new regulation has been the promotion of decentralization and social participation through the creation of National Council of Water Resources and their counterparts in the states, the States Water Resources Councils. Extensive study of the challenges and opportunities associated with this type of water resources management in the face of climate variability and climate change have been well studied (Abers, 2007; Engle *et al*., 2011; Kumler and Lemos, 2008; Medema *et al*., 2008). It is interesting to note that several other countries in the region are following similar approaches as the one adopted in Brazil. In the last five years, there have been constitutional and legal reforms in Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia and Mexico; although in many cases, these innovations have not been completely implemented (Hantke – Domas, 2011). Institutional improvements represent a clear win-win adaptation strategy to climate variability and change. More importantly, an effective implementation of most of these adaptation measures require the correct level of adaptation capacity through a right combination of governance and institutions (Engle and Lemos, 2010; Halsnæs and Verhagen, 2007; Lemos *et al*., 2010; Pittock, 2011; Zagonari, 2010).

The particular experience in the Brazilian North East presents some other examples of adaptation strategies. Broad *et al*. (2007) and Sankarasubramanian *et al*. (2009) studied the potential benefits of streamflow forecast in the Brazilian North East as a way to reduce the impacts of climate change and climate variability on water distribution under stress conditions. Water policies to cope with drought in this region have been studied by several authors. An historical review and analysis of drought management in this region is provided by Campos and Carvalho (2008). Souza Filho and Brown (2009) studied different hypothetic water distribution policy scenarios finding that the best option depended on the degree of water scarcity. It is interesting to note the study by Nelson and Finan (2009) who present a critical perspective of drought policies in this region, arguing that they constitute an example of maladaptation via undermining resilience. Tompkins and Lemos (2008) are also critical of risk reduction practices in this region because they have fallen short of addressing the fundamental causes of vulnerability needed for efficient longer-term drought management.

Other types of adaptation options that stem from studies on arid and semiarid regions are related to: a) increase in water supply such as the role of groundwater pumping (Burte *et al*., 2011; Döll, 2009; Kundzewicz and Döll, 2009; Zagonari, 2010); fog interception practices (Holder, 2006; Klemm *et al*., 2012) or the role of infrastructure, reservoirs and irrigation infraestructure (Fry *et al*., 2010; Vicuña *et al*., 2010; 2012); b) improvements in water demand management associated with increased irrigation efficiency and practices (Bell *et al*., 2011; Geerts *et al*., 2010; Montenegro and Ragab, 2010; Van Oel *et al*., 2010) and changing crop patterns towards less demanding crops studied by Montenegro and Ragab (2010).

Flood management practices also provide a suite of options to deal with cases where actual or future vulnerabilities are related to excess water supply. Examples are related to the management of ENSO-related events in Peru via participatory (Warner and Oré, 2006) or risk reduction approaches (Khalil *et al*., 2007), and the role of land use management (Bathurst *et al*., 2010; Bathurst *et al*., 2011; Coe *et al*., 2011) and flood hazard assessment (Mosquera-Machado and Ahmad, 2006).

27.3.2. Terrestrial and Inland Water Systems

27.3.2.1. Observed and Projected Impacts and Vulnerabilities

CA and SA house the largest biological diversity and several of the world's megadiverse countries (Guevara and Laborde, 2008; Mittermeier *et al*., 1997). However, land use change has led to the existence of six biodiversity hotspots, i.e. places with a great species diversity that show high habitat loss and also high levels of species endemism: Mesoamerica, Chocó-Darien-Western Ecuador, Tropical Andes, Central Chile, Brazilian Atlantic forest, and Brazilian Cerrado (Mittermeier *et al*., 2005). Thus, conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region (Ayoo, 2008). This conversion is also the second largest driver of man-induced climate change on the planet, adding up to 17%-20% of total greenhouse gas emissions (Gullison *et al*., 2007; Strassburg *et al*., 2010). In parallel, the region has still large extensions of wilderness areas for which the Amazon is the most outstanding example. Nevertheless, some of these areas are precisely the new frontier of economic expansion. For instance, between 1996 and 2005 Brazil deforested about 19,500 km^2 per year, which represented 2% to 5% of global CO_2 emissions (Nepstad *et al*., 2009). Between 2005 and 2009, deforestation in the Brazilian Amazon dropped by 36%, which is partly related to the network of protected areas that now covers around 1% of the biome (Nepstad *et al*., 2009).

Plant species are rapidly declining in CA, SA, Central and West Africa, and Southeast Asia (Bradshaw *et al*., 2009). Risk estimates of plant species extinction in the Amazon, which do not take into account possible climate change impacts, range from 5%-9% by 2050 with a habitat reduction of 12%-24% (Feeley and Silman, 2009) to 33% by 2030 (Hubbell *et al*., 2008). The highest percentage of rapidly declining amphibian species occurs in CA and SA. Brazil is among the countries with most threatened bird and mammal species (Bradshaw *et al*., 2009).

A similar scenario is found in inland water systems. Among the components of aquatic biodiversity, fish are the best-known organisms (Abell *et al*., 2008) with Brazil accounting for the richest icthyofauna of the planet (Nogueira *et al*., 2010). For instance, the 540 Brazilian small microbasins host 819 fish species with restrict distribution. However, 29% of these microbasins lost more than 70% of their natural vegetation cover and only 26% show a significant overlap with protected areas or indigenous reserves. Moreover, 40% of the microbasins overlap with hydrodams or have few protected areas and high rates of habitat loss (Nogueira *et al*., 2010).

Climate change will further enhance species decline (Brook *et al*., 2008). Vertebrate fauna in North and South America is projected to suffer species losses of at least 10%, as forecasted in over 80% of the climate projections based on low emissions scenario (Lawler *et al*., 2009). Vertebrate species turnover will be as high as 90% in specific areas of CA and the Andes Mountains (Lawler *et al*., 2009). Elevational specialists, i.e. a small proportion of species with small geographic ranges restricted to high mountains, are most frequent in the Americas (e.g. Andes and Sierra Madre) and might be particularly vulnerable to global warming because of their small geographic ranges and high energetic and area requirements, particularly birds and mammals (Laurance *et al*., 2011). In Brazil, projections for Atlantic forest birds (Anciães and Peterson, 2006), endemic bird species (Marini *et al*., 2009), and plant species

(Siqueira and Peterson, 2003) of the cerrado (savannas of central Brazil) indicate that adequate environmental conditions for occurrence will dislocate towards the South and Southeast, precisely where fragmentation and habitat loss are worse. Global climate change is also predicted to increase negative impacts worldwide, including SA, on freshwater fisheries due to alterations in physiology and life histories of fish (Ficke *et al*., 2007).

In addition to climate change impacts at individual species level, biotic interactions will be affected. Modifications in phenology, structure of ecological networks, predator-preys interactions and non-trophic interactions among organisms have been forecasted (Brooker *et al*., 2008; Walther, 2010). The outcome of non-trophic interactions among plants is expected to shift along with variation in climatic parameters, with more facilitative interactions in more stressful environments, and more competitive interactions in more benign environments (Anthelme *et al*., 2012; Brooker *et al*., 2008). These effects are expected to have a strong influence of community and ecosystem (re-) organization given the key engineering role played by plants on the functioning of ecosystems (Callaway, 2007). High Andean ecosystems, especially those within the tropics, are expected to face exceptionally strong warming effects during the 21th century because of their uncommonly high altitude (Bradley *et al*., 2006). At the same time they provide a series of crucial ecosystem services for millions people (Buytaert *et al*., 2011). For these reasons shifts in biotic interactions are expected to be massive in this region, with important, negative consequences on biodiversity and ecosystem services.

Although in the region biodiversity conservation is largely confined to protected areas, with the magnitude of climatic changes projected for the century, it is expected that many species and vegetational types will lose representativeness inside such protected areas (Heller and Zavaleta, 2009).

______START BOX 27-1 HERE______

Box 27-1. The Amazon at an Ecological Tipping Point

Rising greenhouse gases or local deforestation rates drive changes in the regional SA that during this century might lead the Amazon rainforest into crossing a critical threshold at which a relatively small perturbation can qualitatively alter the state or development of a system (Cox *et al*., 2000; Lenton *et al*., 2008; Nobre and Borma, 2009; Salazar *et al*., 2007; Sampaio *et al*., 2007). The surpassing of the threshold or ´tipping point´, marked by a specific extension of the forest cover, in terms of further deforestation, would imply a reduction in rainfall and a consequent increase in the length of the dry season. This in turn would further reduce the rainforest cover and shift the system into a new and drier equilibrium. For instance, Amazonian and Cerrado deforestation contribute to an increase of the duration of the dry season in this region (Costa and Pires, 2010) associated to an increase in near-surface air temperature and a decrease in evapo-transpiration and precipitation. Such conditions in Eastern Amazonia (Malhi *et al*., 2008) will lead to stronger water-stress, which may actually be more appropriate for seasonal forest (more resilient) than for savanna. At the same time, seasonal forests are more vulnerable to fires, which risk may increase under climate change conditions, possibly triggering the transition of these seasonal forests into fire-dominated, low biomass forests, with the risk of reaching a ‘‘tipping point’’ beyond which extensive rainforest would become unsustainable (Justino *et al*., 2010; Malhi *et al*., 2008). In fact, Pueyo *et al*. (2010) found evidence of a critical transition to a megafire regime under extreme drought in rainforests; this phenomenon is likely to determine the time scale of a possible loss of Amazonian rainforest caused by climate change. At a larger scale, Kirilenko and Sedjo (2007) suggest a positive feedback between deforestation, forest fragmentation, wildfire, and increased frequency of droughts that appears to exist in the Amazon basin, in that a warmer and drier regional climate may trigger massive deforestation.

Various models are projecting a risk of reduced rainfall and higher temperatures and water stress, that may lead to an abrupt and irreversible replacement of Amazon forests by savanna-like vegetation for the next several decades(Betts *et al*., 2004; 2008; Cox *et al*., 2004; Malhi *et al*., 2008; Malhi *et al*., 2009; Marengo *et al*., 2011; Nobre and Borma, 2009; Salazar *et al*., 2007; Sampaio *et al*., 2007; Sitch *et al*., 2008). The possible ‘savannization’ or ‘die-back’ of the Amazon region would potentially have large-scale impacts on climate, biodiversity and people in the region. For instance, after crossing a ‘tipping point’ in climate (CO_2 concentration, air temperature) the forest 1) stops behaving as a carbon sink and becomes a carbon source; 2) subsequently enters a state of collapse; and 3) is finally replaced by savanna-type vegetation. The likelihood of this die-back scenario occurring, however, is still an open issue and the uncertainties are still very high (Shiogama *et al*., 2011).

Furthermore, climate change in the Amazon region may also have a critical impact on the yields of commonly cultivated crops. Lapola *et al*. (2011) showed that by 2050 soybean yields would be reduced by 44% in the worst-case scenario (see also section 27.3.4.1). Zero deforestation in the Brazilian Amazon forest by 2020 (and of the Cerrado by 2025) would require either a reduction of 26%–40% in livestock production until 2050 or a doubling of average livestock density from 0.74 to 1.46 head per hectare. Thus, climate change may imply reduction of yields and entail further deforestation.

______END BOX 27-1 HERE______

27.3.2.2. Adaptation Practices: Ecosystem-based Adaptation

The sub-set of practices that are multi-sectoral, multi-scale, and based on the premise that ecosystem services reduce the vulnerability of society to climate change are known as Ecosystem-based Adaptation (EbA) (Vignola *et al*., 2009). Ecosystem (or environmental) services are the aspects of ecosystems actively or passively used to produce human well-being. Such services can be classified in four different types: provisioning services (e.g., food, fiber, freshwater), regulating services (e.g., climate stability, avoidance of outbreaks of disease vectors), supporting services (e.g., soil formation, biomass production) and cultural services (e.g., aesthetic values, linguistic diversity, religious values) (Fisher *et al*., 2009; see also MEA, 2005; Tacconi, 2012). Schemes such as the payment for environmental services (PES) and community management fit the concept of EbA that begins to spread in CA and SA (Vignola *et al*., 2009). The principle behind these schemes is the valuation of ecosystem services that should reflect both the economic and cultural benefits derived from the human-ecosystem interaction and the capacity of ecosystems to secure the flow of these benefits in the future (Abson and Termansen, 2011).

PES consist of transparent schemes for securing a well-defined ecosystem service (or a land use likely to secure that service) through conditional payments to voluntary providers (Engel *et al*., 2008; Tacconi, 2012). Services often include regulation of freshwater flows, carbon storage, provision of habitat for biodiversity, and scenic beauty (De Koning *et al*., 2011; Montagnini and Finney, 2011). Since the ecosystems that provide the services are often privately owned, policies should aim at supporting landowners to maintain the provision of services over time (Kemkes *et al*., 2010). Experiences in Colombia, Costa Rica and Nicaragua show that PES can finance conservation, ecosystem restoration, and better land use practices (Montagnini and Finney, 2011). However, based on examples from Ecuador and Guatemala, Southgate *et al*. (2010) argue that uniformity of payment for beneficiaries can be inefficient if recipients accept less compensation in return for conservation measures, or if recipients that promote greater environmental gains receive only the prevailing payment. Table 27-5 lists examples of PES schemes in Latin America.

[INSERT TABLE 27-5 HERE
Table 27-5: Cases of government-funded PES schemes in CA and SA.]

Ecological restoration can be an important tool for adaptation since it enhances the provision of biodiversity and environmental services by 44% and 25%, respectively, as estimated by Benayas *et al*. (2009) in a meta-analysis of 89 studies, including many in SA. Moreover, ecological restoration increases the potential for carbon sequestration and promotes community organization, economic activities and livelihoods in rural areas (Chazdon, 2008), as seen in examples of the Brazilian Atlantic Forest (Calmon *et al*., 2011; Rodrigues *et al*., 2011).

Community management of natural areas is another efficient tool to adapt to climate change and to conserve biodiversity. Porter-Bolland *et al*. (2012) compared protected areas with areas under community management in different parts of the tropical world, including CA and SA, and found that protected areas have smaller deforestation rates than areas with community management. Similarly, Nelson and Chomitz (2011) found for the region that (i) protected areas of restricted use reduced fire substantially, but multi-use protected areas are even more effective; and that (ii) in indigenous reserves the incidence of forest fire was reduced by 16% as compared to non-protected areas.

Another good example of adaptive community management in the continent are local communities where research and monitoring protocols are in place that pay them for collecting scientific data directly in the field (Luzar *et al.*, 2011).

[placeholder SOD: ecological corridors]

27.3.3. Coastal Systems and Low-Lying Areas

27.3.3.1. Observed and Projected Impacts and Vulnerabilities

Climate change is altering coastal and marine ecosystems (Hoegh-Guldberg and Bruno, 2010). Coral reefs, seagrass beds, mangroves, rocky reefs and shelves, and seamounts have few to no areas anywhere in the world that remain unaffected by human influence (Halpern *et al.*, 2008). Anthropogenic drivers associated with climate change have implied in decreased ocean productivity, altered food web dynamics, reduced abundance of habitat-forming species, shifting species distributions, and a greater incidence of disease (Hoegh-Guldberg and Bruno, 2010). Coastal and marine impact and vulnerability are often associated to collateral effects of climate change such as sea-level rise, ocean warming and ocean acidification. Overfishing, habitat pollution and destruction, and the invasion of species also negatively impact biodiversity and the delivery of ecosystem services (Guarderas *et al.*, 2008; Halpern *et al.*, 2008). Such negative impacts lead to losses that pose significant challenges and costs for societies, particularly in developing countries (Hoegh-Guldberg and Bruno, 2010).

Since the coastal states of Latin America and the Caribbean have a human population of more than 610 million, 3/4 of whom live within 200 km of the coast, marine ecosystems have been undergoing significant transformations (Guarderas *et al.*, 2008). Fish stocks, places for recreation and tourism, and controls of pests and pathogens are all under threat (Guarderas *et al.*, 2008; Mora, 2008). Moreover, changes over 2 mm yr^{-1} of sea-level rise (SLR) have been found in CA and SA. The Western equatorial border, influenced by the ENSO phenomenon, shows a lower variation (of about 1 mm yr^{-1}) and a range of variation under El Niño events of the same order of magnitude that the sustained past changes. The distribution of population is a crucial factor for inundation impact, with coastal areas being non-homogeneously impacted. A scenario of 1m SLR would affect some coastal populations in Brazil and the Caribbean islands (ECLAC, 2011a), (see Figure 27-4).

[INSERT FIGURE 27-4 HERE
Figure 27-4: Current and predicted coastal impacts and coastal dynamics in response to climate change (elaborated by Iñigo Losada, ECLAC)]

The greatest flooding levels (hurricanes not considered) in the region are found in Rio de La Plata area, which combine a 5 mm yr^{-1} change in storm surge with SLR changes in extreme flooding levels (ECLAC, 2011a). Extreme flooding events may become more frequent since return periods are decreasing, and urban coastal areas in the eastern coast will be particularly affected, while at the same time beach erosion is expected to increase in southern Brazil and in scattered areas at the Pacific coast. (ECLAC, 2011a)

Coral reefs are particularly sensitive to climate-induced changes in the physical environment (Baker *et al.*, 2008) to an extent that 1/3 of the more than 700 species of reef-building corals worldwide are already threatened with extinction (Carpenter *et al.*, 2008). Coral bleaching and mortality are often associated to ocean warming and acidification (Baker *et al.*, 2008). If extreme sea surface temperatures are to continue, it is possible that the Mesoamerican coral reef will collapse by mid-century, causing major economic losses (Vergara *et al.*, 2009). Extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of CA and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras and Guatemala (Eakin *et al.*, 2010) The impact of the 1998 bleaching event was unprecedented in the past century, based on measured reduction in skeletal growth rates in the dominant reef builder, massive *Montastraea faveolata* corals, over the past 75–150 years from the Mesoamerican Reef (Carilli *et al.*, 2009). Long-term reductions in coral growth rates have been recorded in Panama (Guzman *et al.*, 2008). In Belize alone, reef and mangrove ecosystems are estimated to contribute approximately $395 - $559 million US dollars in goods and services each year, primarily through marine-based tourism, fisheries and coastal protection (Cooper *et al.*, 2008). In the Eastern Tropical Pacific, seascape trace abundance of cement and elevated nutrients in upwelled waters are factors that help explain high bioerosion rates of local coral reefs (Manzello *et al.*, 2008). In the southwestern Atlantic coast, qualitative observations since the 1980s and regular monitoring since 2001 indicated that coral diseases intensified between 2005 and 2007 to an extent that predictions by Francini-Filho *et al.* (2008) are that eastern Brazilian reefs will suffer a massive coral cover decline in the next 50 years. The same authors predict that ***Mussismilia braziliensis***- a major reef-building coral species that is endemic in Brazil- will be nearly extinct in less than a century if the current rate of mortality due to disease is not reversed (Francini-Filho *et al.*, 2008).

Mangroves are largely affected by anthropogenic activities whether or not they are climate driven. Indeed, estimates are that climate change may lead to a maximum global loss of 10–15% of mangrove forest, which is of secondary importance compared with current average annual rates of 1–2% deforestation (Alongi, 2008). Estimates are that 100% of mangrove forests, along with important ecosystem goods and services, could be lost in the next 100 years if the present rate of loss continues (1-2% a year), (Duke *et al.*, 2007). In CA and SA, some of the main drivers of loss are deforestation and land conversion, agriculture and shrimp ponds (Polidoro *et al.*, 2010). The Atlantic and Pacific coasts of CA are some of the most endangered in the planet with regards to mangroves, since approximately 40% of the present mangroves' species are threatened with extinction (Polidoro *et al.*, 2010). Approximately 75% of the mangrove extension of the planet is concentrated in 15 countries, among which Brazil is included (Giri *et al.*, 2011). In Colombia, the rate of survival of original mangroves lies between 12.8% and 47.6% in the Tumaco Bay, resulting in ecosystem collapse, fisheries reduction and impacts on livelihoods (Lampis, 2010). Gratiot *et al.* (2008) project for the current decade an increase of mean high water levels of 6 cm followed by 90m shoreline retreat implying flooding of thousands of hectares of mangrove forest along the coast of French Guyana.

Peru and Colombia are two of the eight most vulnerable countries to climate change impacts on fisheries, due to the combined effect of observed and projected warming, the relative importance of fisheries to national economies and diets, and limited societal capacity to adapt to potential impacts and opportunities (Allison *et al.*, 2009). Fisheries production systems are already pressured by overfishing, habitat loss, pollution, invasive species, water abstraction and damming (Allison *et al.*, 2009). In Brazil, a decadal rate of 0.16 trophic level decline has been detected through most of the northeastern coast, which is one of the highest rates documented in the world (Freire and Pauly, 2010).

Although the majority of the literature focuses on corals, mangroves and fisheries, there is evidence that other benthic marine invertebrates that provide key services to reef systems, such as nutrient cycling, water quality regulation, and herbivory, are also threatened by climate change (Przeslawski *et al.*, 2008). The same applies for seagrasses for which a worldwide decline has accelerated from a median of 0.9% yr^{-1} before 1940 to 7% yr^{-1} since 1990, which is comparable to rates reported for mangroves, coral reefs, tropical rainforests and place seagrass meadows among the most threatened ecosystems on earth (Waycott *et al.*, 2009).

A major challenge of particular relevance at local and global scales will be to understand how these physical changes will impact the biological environment of the ocean (e.g., Gutierrez *et al.*, 2011b), as the Humboldt Current system -flowing along the west coast of SA- is the most productive upwelling system of the world in terms of fish productivity.

27.3.3.2. Adaptation Practices

Designing marine protected areas (MPAs) that are resilient to climate change is a key adaptation strategy in coastal and marine environments (McLeod *et al.*, 2009). By 2007, Latin America and the Caribbean (which includes CA and SA countries) had over 700 MPAs established covering around 1.5% of the coastal and shelf waters, most of which allow varying levels of extractive activities (Guarderas *et al.*, 2008). This protected area cover, however, is insufficient to preserve important habitats or connectivity among populations at large biogeographic scales (Guarderas *et al.*, 2008).

In Brazil, a protected area type known as "Marine Extractive Reserves" currently benefits 60,000 small-scale fishermen along the coast (Moura *et al*., 2009). Examples of fisheries' co-management, a form of a participatory process envolving local fishermen communities, government, academia and NGOs, are reported to favor a balance between conservation of marine fisheries, coral reefs and mangroves (Francini-Filho and Moura, 2008), and the improvement of livelihoods, as well as the cultural survival of traditional populations (Hastings, 2011; Moura *et al*., 2009).

In addition to marine protected areas that include mangroves and functionally linked ecosystems, Gilman *et al*. (2008) list a number of other relevant adaptation practices: coastal planning to facilitate mangrove migration with sea-level rise, management of activities within the catchment that affect long-term trends in the mangrove sediment elevation, better management of non-climate stressors, and the rehabilitation of degraded areas.

Significant financial and human resources are expended annually in the marine reserves to support reef management efforts. These actions, including the creation of marine reserves to protect from overfishing, improvement of watershed management, and protection or replanting of coastal mangroves, are proven tools to improve ecosystem functioning. However, they may also actually increase the thermal tolerance of corals to bleaching stress and thus the associated likelihood of surviving future warming (Carilli *et al*., 2009).

Adaptations to sea level rise involve redirecting new settlements to better-protected locations and to promote investments in appropriate infrastructure. This shall be required in the low elevation coastal zones (LECZ) of the region, particularly in lower income countries with limited resources, which are likely to be especially vulnerable. Brazil and Mexico rank 7th and 8th worldwide of the total land area in the LECZ. Guyana and Suriname rank 2nd and 5th by the share of population in the LECZ, having respectively 76% and 55% of their populations living in such areas (McGranahan *et al*., 2007). Adaptation will demand effective and enforceable regulations and economic incentives to, all of which require political will as well as financial and human capital (McGranahan *et al*., 2007).

27.3.4. Food Production Systems and Food Security

27.3.4.1. Observed and Projected Impacts and Vulnerabilities

In recent years, the global demand for food, forage, fiber and biofuels promoted a sharp increase in agricultural production in the countries of SA and CA, primarily associated with the expansion of planted areas, and to a lesser extent with increases in productivity. It is predicted that this trend continues and a great part of the increased global demand will be supported by countries in SA, which possess the largest proportions of potential arable land, accounting for more than 40% of the global total (Nellemann *et al*., 2009). Nowadays and in the future, agro-ecosystems are being and will be affected in isolation and synergistically by climate variability and land use changes, which are comparable drivers of environmental change. It is also predicted that SA could lose between 1% and 21% of its arable land due to climate change and population growth (Zhang and Cai, 2011).

In the future, SA will face both the great challenge of fulfilling the growing food and biofuels demand and the impact of climate change, trying to preserve natural resources through sustainable development options. Although optimal land management could combine efficient agricultural and biofuels production with ecosystem preservation under climate change conditions, current practices are far from optimal, leading to a deterioration of ecosystems throughout the continent (see section 27.3.2.). In several countries of SA increases in lands devoted to crops and the trend towards soybean monoculture have contributed to soil deterioration. Current land use changes in the Pampas disrupt water and biogeochemical cycles and may result in soil salinization, altered C and N storage, surface runoff and stream acidification (Berthrong *et al*., 2009; Farley *et al*., 2009; Nosetto *et al*., 2008). In the southern Brazilian Amazonia water yields were near four times higher in soy than forested watersheds, and showed greater seasonal variability (Hayhoe *et al*., 2011). In central Argentina flood extension was associated with the dynamics of groundwater level that, in turn, has been influenced by precipitation and land use change (Viglizzo *et al*., 2009).

SESA (Central Eastern Argentina, Paraguay, Southern Brazil and Uruguay) has shown some of the most significant increases in precipitation during the 20th century (Giorgi, 2002). The rainfall increase has benefited crops (mainly the summer ones) and pastures productivity, partly contributing to a significant expansion of the agricultural area, particularly in climatically marginal regions of the Argentinean's Pampas (Barros, 2010). Comparing the periods 1930-60 and 1970-2000, maize and soybean yields increased, respectively, by 34% and 58 % in Argentina, 49% and 57% in Uruguay, and 12% and 9% in Southern Brazil (Magrin *et al.*, 2007b) mainly due to precipitation increases. It is unclear whether current agricultural production systems, which evolved partly in response to wetter conditions, may or may not remain viable if climate reverts to a drier condition. According to Podestá *et al.* (2009), a trend towards drier conditions may endanger the viability of continuous agriculture in marginal regions of the Argentina's Pampas. During the 1930s-1940s, dry and windy condition together with deforestation, overgrazing, overcropping and non-suitable tillage technology produced devastating results including severe dust storms, cattle mortality, crop failure, farmer bankruptcy and rural migration (Viglizzo and Frank, 2006).

Observed increases in temperature have also altered crop production. At the global scale, warming since 1981 has reduced wheat, maize and barley productivity, although the impacts were small compared with the technological yield gains over the same period (Lobell and Field, 2007). In central Argentina, elevation of temperature altered simulated potential wheat yield, which has been decreasing at increasing rates since 1930 (-28 kg/ha/year between 1930 and 2000, and -53 kg/ha/year between 1970 and 2000) in response to increases in minimum temperature during October-November (+0.4°C/decade during 1930-2000, and 0.6°C/decade between 1970 and 2000) (Magrin *et al.*, 2009).

Lobell *et al.* (2011) showed that the observed changes in the growing season temperature and precipitation have slowed the positive yield trends due to improved genetics of management in Brazilian wheat, maize and soy, as well as Paraguayan soy. In contrast, rice in Brazil and soybean in Argentina have benefited from observed precipitation and temperature trends.

Under future conditions, the IPCC AR4 modeling results (Easterling *et al.*, 2007) suggested that in mid- to high-latitudes moderate to medium increases in temperature (1– 3 °C) associated with CO_2 increases could have slightly beneficial impacts on crop yields. Inversely, in low-latitude regions even moderate temperature increases (1–2 °C) may have negative impacts on yield of major cereals.

In SESA climate change could benefit some crops until the middle of the century, although great uncertainty surrounds the damage that could be caused by greater year-to-year climate variations and interdecadal climatic variability. In Uruguay, agricultural and forestry output is expected to increase steadily until the 2030s (2050s) under the emission scenario A2 (B2) (ECLAC, 2010a). In the Argentinean Pampas average yields of soybean, maize and wheat could remain almost stable or slightly increase. Increases in temperature and precipitation may benefit crops towards the southern and western zone of the Pampas, while conversely some yields in parts of the north and central Pampas's could fall. The higher yields driven by climate change are likely to occur in marginal areas where their fragile soils could constrain crops expansion (ECLAC, 2010a; Magrin *et al.*, 2007c). In South Brazil the CO_2 fertilization effects could increase irrigated rice grain yield, in particular the very early cultivars (Walter *et al.*, 2010). Under ongoing technological advancements and considering CO_2 effects, also bean productivity is expected to increase. If technological improvement is considered, the productivity of common bean and maize is expected to increase between 40% and 90% (Costa *et al.*, 2009). Sugarcane production would benefit as warming could allow the expansion of planted areas towards the south, where currently low temperatures are a limiting factor (Pinto *et al.*, 2008). Increases in crop productivity could reach 6% in São Paulo state towards 2040 (Marin *et al.*, 2009), while in Paraguay the yields of soybean and wheat, and the productivity of beef-raising could remain almost stable or increase slightly until 2030 (ECLAC, 2010c).

In Chile and western Argentina, yields could be affected by water limitation. In the Chilean's basins located between 30ºS and 42ºS the availability of irrigation water may decrease during critical periods, as water flow declines and glaciers gradually disappear (ECLAC, 2010c). Temperature increases, atmospheric warming, water shortages and increased evapotranspiration may reduce productivity of winter crops (wheat, oats and barley), fruit, vines and radiata pine. Deciduous fruit trees (pomes, raspberries, blueberries and cherries) would fare worst because of the reduction in chilling hours. Conversely, rising temperatures, more moderate frosts and more abundant water will benefit all species towards the South (ECLAC, 2010c; Meza and Silva, 2009). In northern Patagonia (Argentina) fruit and and vegetable growing could be affected. The projected drop in rainfall will reduce average flows in the

Neuquén River basin that will affect horticultural activity, including the growing of pip fruits (apples and pears), vines and, to a lesser extent, stone fruits. In the northern part of the Mendoza basin the projected rise in water demand, merely from the population growth estimated for 2030, may compromise the availability of subterranean water for irrigation, pushing up irrigation costs to levels that will force many producers out of farming. In addition, water quality could be reduced by the worsening of existing salinization processes (ECLAC, 2010c).

In CA, northeastern Brazil and parts of the Andean region, climate change could seriously affect not only the local economies but also food security. According to Battisti and Rosamond (2009), and Brown and Funk (2008) it is very likely (>90%) that by the end of the 21st century growing season temperatures in the tropics and subtropics will exceed the extreme seasonal temperatures recorded from 1900 to 2006. Their results suggest that unprecedented seasonal average temperature will affect parts of tropical SA, east of the Andes and CA by 2080-2100, which can be detrimental to regional agricultural productivity and human welfare, as well as to international agricultural markets. For Northeast Brazil, several studies report declining crop yields in subsistence crops such as beans, corn and cassava (Lobell *et al*., 2008; Margulis *et al*., 2010). Increase in air temperature will cause a significant reduction in the areas currently favorable to cowpea bean crop (Silva *et al*., 2010). In addition, land ability to support crops could change. Should no adaptation action is accomplished, the warming up to 5.8 °C foreseen for 2070 could make the coffee crop unfeasible in the Southeast region of Brazil (Minas Gerais and São Paulo States). It has been mentioned that by 2070 the coffee crop may have to be transferred to southern regions, where frost risk will be much lower (Camargo, 2010). In South Brazil a great increase in the production of Arabica coffee (principally in the border with Uruguay and North of Argentina) is expected in the low climatic risks areas with 3ºC increases in the mean temperature (Zullo *et al*., 2011). The impact of future climate on Brazilian potato production will be more important in currently warm areas, which today allow potato production all around the year. In such zones planting will be restricted to a few months. For cooler areas, major drawbacks on potato production are not expected (Lopes *et al*., 2011). Future scenarios showed large losses of suitable environments for the "Pequi" tree (*Caryocar brasiliense*; an economically important Cerrado fruit tree) in 2050, mainly affecting the poorest communities in Central Brazil (Nabout *et al*., 2011).

Teixeira *et al*. (2011) identified hot spots for heat stress towards 2071-2100 under the A1B scenario. Their results suggest that rice in South East Brazil, maize in CA and SA, and soybean in Central Brazil will be the crops and zones most affected by increases in temperature.

In CA current temperatures are close to or slightly higher than the optimum for agriculture. Warming conditions combined with more variable rainfall are expected to reduce the productivity of the agricultural sector (including bean, rice and maize) endangering the food security of large segments of the population and increasing poverty (ECLAC, 2010a). In Panamá maize production could modestly increase over the century because of accelerated development helps the grain-filling period be completed before the worst water stresses occur, resulting in a net increase in yield (Ruane *et al*., 2011). Climate changes are expected to be obscured by the large interannual variations in Panamanian climate that will continue to be the dominant influence on seasonal maize yield into the coming decades (Ruane *et al*., 2011).

One of the uncertainties associated with the impacts of climatic change is the effect of CO_2 on plant physiology. DaMatta *et al*. (2010) reviewed the possible impact of climatic change on crop physiology and food quality, and according to their results, many crops -such as soybean, common bean, maize and sugarcane- will probably respond to the elevation of CO_2, combined with elevation of temperature and a lack or excess of water, with an increasing productivity as a result of higher growth rates related to the fertilization effect and better water use efficiency. However, food quality is likely to change in many cases. As crops respond to elevation of CO_2 by increasing photosynthesis, in general they will uptake more Carbon in relation to Nitrogen. As a consequence, grain and fruits are expected to have higher sugar contents. At the same time this smaller uptake of nitrogen compared to carbon might decrease the protein content of cereals and legumes, therefore decreasing food quality on the overall (DaMatta *et al*., 2010).

Uncertainties associated with climate and crop models, as well as with the uncertainty in human behavior, potentially lead to large error bars on any long-term prediction of food output in SA. However, the trends presented here represent the best current available information (see Table 27-6).

[INSERT TABLE 27-6 HERE
Table 27-6: Impacts on agriculture.]

Climate change may alter the current scenario of plant diseases and their management, and these changes will certainly have effects on productivity (Ghini *et al*., 2011). In Argentina, years with severe infection of late cycle diseases in soybean could increase up to 60% by the end of the century. In the maize-growing segment, severe outbreaks of the Mal de Rio Cuarto virus (MRCV) are expected to become more frequent throughout the endemic area, especially in the northern part (by over 30%). Wheat head fusariosis will increase slightly in the south of the Pampas region (10%) and decrease in the northern part (by up to 20%) (ECLAC, 2010c; Martínez *et al*., 2011). Potato late blight (*Phytophtora infestans*) severity is expected to increase under future conditions in Perú (Giraldo *et al*., 2010). At the same time, there is uncertainty related to how plants will respond to diseases in a world affected by climate change. As plants are expected to increase photosynthesis and accelerate their metabolism under the effect of elevated CO_2 and higher temperature (Sage, 2002), it is possible that such effects will offset many of the diseases' effects in the future.

Related to livestock production, Seo *et al*. (2010) reported that the impacts of climate change would vary by species and climate scenarios. By 2060, under a hot and dry scenario, beef cattle, dairy cattle, pigs and chickens could decrease by 3.2%, 2.3%, 0.5%, and 0.9% respectively, while sheep could increase by 7%. Large changes are expected in the Andean countries. Under this scenario, dairy cattle increase in Uruguay and Argentina, but decrease elsewhere. The increase in sheep occurs mostly in the Andean mountain countries. Under a milder and wetter scenario, beef cattle choice declines in Colombia, Ecuador, and Venezuela, but increases in Argentina and Chile. Sheep increase in Colombia and Venezuela, but decrease in the high mountains of Chile where chickens are chosen more frequently. Future climate could strongly affect milk production and feed intake in dairy cattle in Brazil. Furthermore, it has been suggested that climate change as projected by the A2 and B2 scenarios may lead to substantial modifications in the areas at present suitable for livestock, particularly in the main Pernambuco production regions (Silva *et al*., 2009).

The impact of climate change on regional welfare will depend not only on changes in yield, but also in international trade. By 2030, global cereal price could change between +32% (low-productivity scenario) and -16% (optimistic yield scenario). A rise in prices could benefit net exporting countries like Brazil, where gains from terms of trade shifts could outweigh the losses due to climate change effects. Despite experiencing significant negative yield shocks some countries tend to gain from higher commodity prices (Hertel *et al*., 2010). It has been demonstrated, for instance, that increases in prices during 2007-2009 led to rising poverty in Nicaragua, but decreasing poverty in Peru (see chapter 7 this volume).

27.3.4.2. Adaptation Practices

Suitable soil and technological management, and genetic advances may very likely induce an increase in some crops' yield notwithstanding the unfavorable future climate conditions. In Argentina, genetic techniques, specific scientific knowledge and land-use planning are viewed as promising sources of adaptation (Urcola *et al*., 2010). Anticipating planting dates by 15-30 days could reduce negative impacts in maize and wheat crops in Argentina (Magrin *et al*., 2009; Travasso *et al*., 2009b). In Chile the best alternative for adaptation in maize and wheat correspond to adjustments in sowing dates and fertilization rates (Meza and Silva, 2009). Furthermore, in central Chile and southern Pampas in Argentina warmer climates lead to extended growing seasons and shortens crop cycles, so it would be possible to perform two crops per season increasing productivity per unit land (Meza *et al*., 2008; Monzon *et al*., 2007).

Most adaptation practices have been oriented towards water management (see section 27.3.1), especially in irrigated crops. Adaptive strategies might need to look at the harvest, storage, temporal transfer and efficient use of rainfall water (Quiroga and Gaggioli, 2011). Empirical evidence from the semiarid/sub-humid pampas of Argentina demonstrated that the adaptation to water scarcity can be significantly improved by taking into account a well-known set of agronomic practices that include fallowing, crop sequences, groundwater management, no-till operations, cover-crops and fertilization. In South Brazil, a good option for irrigated rice could be to plant early cultivars (Walter *et al*., 2010). Deficit irrigation could be an effective measure for water savings in dry areas such as the Bolivian Altiplano (quinoa), central Brazil (tomatoes) and northern Argentina (cotton) (Geerts and Raes, 2009).

Adaptation strategies for coffee crops in Brazil include: shading management system (arborization), planting at high densities, vegetated soil, correct irrigation and breeding programs (Camargo, 2010). Shading is also used in Costa Rica and Colombia.

The best way to be prepared to adapt to future climate change is by assisting people to cope with current climate variability (Baethgen, 2010). For example, the use of climatic forecasts in agricultural planning is an adaptation measure to cope with current climatic variability. Increased access to scientific forecasts, and increased availability of improved forecast information relevant to their locality and their current farming strategies would greatly enhance the ability of the farmers in the Brazilian Amazon to cope with El Niño related weather events (Moran *et al*., 2006). In addition, there are other climatic indices related to climate and crops production variability. In Argentina, the SOI (Southern Oscilation Index) for maize and the SSTSA (Sea Surface Temperature South Atlantic) for soybean and sunflower were the best indicators of annual crop yield variability. SOI corresponding to September and May were useful in counties contributing to 71% of the maize production in the pampas region; the SSTSA (June) was the best for soybean in the main producing region; and SSTSA (March) could be useful for sunflower in the northern part of the region (Travasso *et al*., 2009a).

In coping with extreme weather events and climate variability, local and indigenous peoples have developed farming strategies based on traditional and local knowledge that are contributing to food security and have the potential to bring solutions even in the face of rapidly changing climatic conditions (Alteri and Koohafkan, 2008; Folke *et al*., 2002). Crop diversification is a common strategy that communities in the Peruvian Andes use to engender an increased ability to suppress pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios (Lin, 2011). In Honduras, Nicaragua and Guatemala traditional practices such as soil and water conservation, cover cropping, organic fertilizer and integrated pest management have proven more resilient to erosion and renoff and have helped retain more topsoil and moisture during periods of droughts (Holt-Gimenez, 2002).

Increases in precipitation registered in Argentina after 1960 have promoted the expansion of the agricultural frontier to the West and North of the traditional agricultural area. This autonomous adaptation has been generally successful in economic terms for the short time, but is causing environmental damage that could become dangerous, especially if trends in precipitation change towards a drier period (Barros, 2007; República Argentina, 2007). In semi-arid zones of mountain regions of Bolivia farmers have been noticing strong changes in climate since the 1980s, and thus have begun to adjust their production practices: migrating crops towards upper parts, selecting other more resistant varieties and making capture of water (PNCC, 2007).

According to Aguilar *et al*. (2009), in the southeastern and central region of El Salvador, if existing local sustainability efforts continue the future climate vulnerability index (based on climate exposure, resilience and adaptability) could only slightly increase by 2015 due to significant increases in the resilience and adaptability indices.

A controversial, but important issue to be discussed in relation to adaptation to climate change in the future is the use of genetically modified plants to produce food. Usually, the use of these techniques to improve adaptation of crops to the climate variables, takes a fraction of the time needed to produce new varieties using classical genetic breeding. On the other hand, classical breeding is much better developed, mainly because humans have applied it for a much longer period of time. Humanity will need to increase 70% in food productivity to cope with the expected increases in population up to 2040 (FAO, 2009b; Gruskin, 2012). Crop technologies can be divided into conventional, organic, biotech technologies. Biotech crops increased faster than any other technology from 1996 to 2010, which is considered the fastest adopted crop technology during the modern agricultural age (an 87-fold increase). At present, the world plants 1 billion hectares of biotech crops, with Brazil and Argentina being the 2nd and 3rd fastest growing biotech crop producers in the world after the US (Marshall, 2012).

Emissions from the agricultural sector make up 14% of all emissions in the world, with 70% of these occuring in developing countries. Brazil is considered one of the most important, quantitatively, in terms of agriculture production and productivity, being the country where biotech agriculture grew fastest in the world from 1996 to 2010 (Gruskin, 2012). Thus, one of the main actions towards adaptation to the global climate change in CA and SA, with key impacts in the world, will be the development of science and technology in agriculture so that productivity may be increased. If successful, strategies of improving agriculture by development of new varieties by classical and biotech methods have the potential to decrease emissions related to agriculture by lowering the use of fossil fuels, and to decrease impacts on deforestation. Two of the main challenges to maintain food quality and food security in most regions of the world will be 1) the integration of those two types of agriculture with organic strategies and 2) the integration between food and bioenergy production. These two issues have to be addressed necessarily by increasing the production of scientific knowledge in agriculture, which according to Nivia *et al*. (2009) in Ca and SA is the one that receive the lowest investments when compared to the rest of the world, and thus impeding the improvement of decision-making based on increased scientific knowledge of higher quality in the region.

27.3.5. Human Settlements, Industry, and Infrastructure

According to the World Bank database {{1965 The World Bank 2012;}} CA and SA are the geographic regions with the second largest urbanization rate (79%), only behind North America (82%) and clearly above the world average (50%). It is therefore of high relevance the assessment of the literature on climate change impacts and vulnerability of *urban* human settlements in this region as presented in this section. The information provided should be complemented with other sections of the chapter (see 27.2.2.2.; 27.3.1.; 27.3.3; and 27.3.7.)

27.3.5.1. Observed and Projected Impacts and Vulnerabilities

Urban human settlements suffer from many of the vulnerabilities and impacts already presented in several sections of this chapter. The provision of critical resources and services as already discussed in the chapter –water, health and energy– and of adequate infrastructure and housing remain factors of urban vulnerability likely to be enhanced by climate change (Roberts, 2009; Romero-Lankao, 2012; Smolka and Larangeira, 2008; Winchester, 2008).

Water resource management for example (see section 27.3.1.) is a major concern for many cities in view of both controlling flooding while retaining water for other uses (Henríquez, 2009). More than 20% of the population in the region tends to be concentrated in the largest city of each country {{1965 The World Bank 2012}}, and hence water availability for human consumption in the region's megacities (e.g. São Paulo, Santiago, Lima, Buenos Aires) is of great concern. In this regards reduction in glacier and snowmelt related runoff in the Andes poses important adaptation challenges for many cities, e.g. the metropolitan areas of Lima, La Paz/El Alto and Santiago de Chile {{1541 Bradley,R.S. 2006; 1105 Hegglin,Esther 2008; 1617 Melo,O. 2010}}. On the other hand the excess of water is also a preoccupation in cities in the region. In the case of the city of São Paulo for example, according to Marengo *et al*. {{1651 Marengo,J.A. 2009/a; 1809 Marengo,J.A. 2012}} the number of days with rainfall above 50 mm were almost absent during the 1950s and now they occur between 2 to 5 times per year (2000-2010). The increase in precipitation is one of the expected vulnerability issues affecting the city of São Paulo as presented in Box 27-2. Increases in floods have been observed also in the Buenos Aires province and Metropolitan region (Andrade and Scarpati, 2007; Barros *et al*., 2008; Hegglin and Huggel, 2008)). There are also the combined effects of climate change impacts, human settlements' features and other stresses, such as more intense pollution events {{590 Moreno,A.R. 2006; 1861 Nobre,Carlos Afonso 2011; 1932 Nobre,C.A. 2011}} and more intense hydrological cycles from urban heat-island effects.

______START BOX 27-2______

Box 27-2. Vulnerability of South American Megacities to Climate Change: The Case of the Metropolitan Region of São Paulo (MRSP)

The Metropolitan Region of São Paulo (MRSP) developed during 2009-2011, illustrates a very comprehensive and interdisciplinary project on the impacts of climate variability and change, and vulnerability of Brazilian megacities. Studies derived from this project (Marengo *et al.*, 2012b; Nobre *et al.*, 2011) identify the impacts of climate extremes on the occurrence of natural disasters and the impacts on human health by projecting an increase of 38% in the extension of the urban area of the MRSP by 2030, accompanied by a projected increase in rainfall extremes. These may induce an intensification of urban flash floods and land slides, affecting larges areas of the population that is already vulnerable to climate extremes and variability. The urbanization process in the MRSP has been affecting the local climate, and the intensification of the heat island effect to a certain degree may be responsible for the 2°C warming detected in the city during the last 50 years (Nobre *et al.*, 2011). This warming has been further accompanied by an increase in heavy precipitation as well as more frequent warm nights (Marengo *et al.*, 2012b; Silva Dias *et al.*, 2012). By 2100, climate projections show an expected warming between 2-3°C in the MRSP, together with a possible doubling of the number of days with heavy precipitation in comparison to the present (Marengo *et al.*, 2012b; Silva Dias *et al.*, 2012).

With the projected changes in climate and in the extension of the MRSP, more than 20% of the total area of the city could be potentially affected by natural disasters. Related, more frequent floods may increase the risk of leptospirosis, which together with increasing air pollution and worsening environmental conditions that trigger the risk of respiratory diseases would leave the population of the MRSP more vulnerable. Potential adaptation measures include a set of strategies needed to be developed by the MRSP and its institutions to face environmental changes. Among them are a better building control to avoid construction in risk areas, investment in public transportation, protection of the urban basins and the establishment of forest corridors in the collecting basins and slope regions. The lessons learned suggest that the knowledge on the observed and projected environmental changes, as well as on the vulnerability of populations living in risk areas is of great importance on the definition of adaptation policies as a first step towards improving the quality of life and building resilient cities in Brazil.

______END BOX 27-2 HERE______

Changes in prevailing urban climates have led to changing patterns of disease vectors, also water-borne disease issues linked to water availability and subsequent quality (see section 27.3.7.). The influence of climate change on particulate matter and other local contaminants is also relevant in this regard (Moreno, 2006). The relationship between the two factors – water and disease – is important to highlight given the on-going problems of water stress, also intense precipitation events. Both give rise to changing disease risks, as well as wider problems of event-related mortalities and morbidity, and infrastructure and property damage. For low-income groups concentrated in settlements with little or no service provision, e.g. waste collection, piped drinking water, sanitation, these risks are compounded (ECLAC, 2008). Existing cases of flooding, air pollution and heat waves reveal that not only low-income groups are at risk, but also that wealthier sectors are not spared. Factors such as high-density settlement (Barros *et al.*, 2008) and the characteristics of some hazards explain this – e.g., poor and wealthy alike are at risk from air pollution and temperature in Santiago de Chile and Bogota (Romero-Lankao *et al.*, 2012).

There are also other climate change risks in terms of economic activity location and impacts on urban manufacturing and service workers, e.g. thermal stress {{542 Hsiang, Solomon M. 2010}}, and the forms of urban expansion or sprawl into areas where ecosystem services may be compromised and risks enhanced, e.g. floodplains. Both processes are also related to rising motorisation rates; the number of light vehicles is expected to double between 2000 and 2030, and be three times the 2000 figure by 2050 (ECLAC, 2009b).

While urban populations face diverse social, political, economic and environmental risk in daily life, climate change adds a new dimension to these risk settings {{1656 Roberts,N. 2009; 1657 Pielke Jr,R.A. 2003; 1659 Romero-Lankao,Patricia 2011}}. Since urban development remains fragile in many cases, with weak planning responses, climate change is likely to compound existing challenges.

27.3.5.2. Adaptation Practices

Given high regional urbanization rates in CA and SA, the direct (e.g. flooding, heat islands) and indirect effects (e.g. food insecurity, watershed management) of climate change present an urban coin of challenges and opportunities for mainstreaming flood management, warning systems and other adaptation responses with sustainability goals (Bradley *et al.*, 2006; Hardoy and Pandiella, 2009; Hegglin and Huggel, 2008; Romero-Lankao, 2012).

Increasingly the links between adaptation and a wide variety of local development issues are being highlighted and brought into urban and regional planning in SA and CA. These issues include connections with natural hazards and risk assessment, disease transmission, resource availability, land use considerations, poverty linked to vulnerability, and with appropriate governance frameworks. {{1666 Barton,Jonathan R. 2009}}

Population, economic activities and authorities have a long experience of responding to climate related hazards, particularly through disaster risk management (e.g., Tucuman and San Martin, Argentina (Plaza and Pasculi, 2007; Sayago *et al.*, 2010)) and planning to a limited extent (Barton, 2009). Climate policies can build on these. Several adaptation plans have been generated over the last five years in São Paulo, Mexico City, Buenos Aires, Quito and other large cities (Carmin *et al.*, 2009; Romero-Lankao, 2007b; Romero-Lankao, 2012). Local administrations participate in the ICLEI, C40 and other networks demonstrating their engagement towards climate resilient cities. In smaller settlements, there is lower capacity to respond (e.g., climate change and vulnerability information (Hardoy and Romero-Lankao, 2011)). These initiatives are required to reduce social vulnerability, and identify and reduce potential economic effects of climate on the local economy. Rio de Janeiro, for example, with its coastline property and high dependence on tourists (and their perceptions of risk), cannot ignore these longer-term changes (Gasper *et al.*, 2011).

Poverty and vulnerability, as interlinked elements of the adaptation challenge in CA and SA, remain pivotal to understanding urban responses and provoke the need for 'pro-poor' responses that engage with broader development issues and not solely the capacity to respond to climate change (Hardoy and Pandiella, 2009; Hardoy and Romero-Lankao, 2011; Winchester and Szalachman, 2009). These broader links are part of the complexity of defining and operationalizing vulnerability concepts, and the need to develop these alongside more dominant infrastructural responses to adaptation, as with mitigation (Romero-Lankao, 2007a; Romero-Lankao and Qin, 2011). Within these response options, a focus on social assets has been highlighted by Rubin and Rossing (2012), rather than a, purely, physical asset focus.

Much urbanisation involves in-migrating or already resident, low-income groups and their location in risk-prone zones {{1966 Costa Fereira, L.da 2011}}. The need to consider land use arrangements, particularly risk-prone zones, as part of climate change adaptation have highlighted the role of public space in order to increase vegetation, thus mitigate the heat island effect, also to reduce risks from landslides and flooding (Rodríguez Laredo, 2011).

In the case of governance frameworks, there is clear evidence that incorporation into wider city planning is required, and that more inter-sectoral and participative processes should be encouraged where possible for effective applications (Barton, 2009; Puppim de Oliveira, 2009). Several metropolitan adaptation plans have been generated over the last five years, although these have been largely restricted to the largest conglomerations, and are included as an addition to principally mitigation plans, e.g. São Paulo, Mexico City and Buenos Aires.

27.3.6. Renewable Energy

27.3.6.1. Observed and Projected Impacts and Vulnerabilities

Renewable energy (RE) is any source of energy that can be renewed within a reasonable length of time so that, differently from fossil fuels, the accumulation of greenhouse gases in the atmosphere could be avoided. It comprises biomass, solar, wind, water, geothermal, hydrogen and fuel cells. Table 27-7 shows the relevance of RE in the Latin

America energy matrix as compared to the world for 2009 according to the International Energy Agency statistics (IEA, 2012). Hydropower is by far the most representative source of renewable energy in the region and therefore analyzed separately from this section and all other RE sources (see case study in section 27.6.1.). At the same time, geothermal energy will be not discussed as it is assumed that there is no impact of climate change on the effectiveness of this energy type (Arvizu *et al.*, 2011).

[INSERT TABLE 27-7 HERE
Table 27-7: Comparison of consumption of different energetics in Latin America and the world (in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis).]

In Brazil, 47% of the energy in 2007 came from renewable sources. Hydroelectric power plants alone responded for 83% of Brazil's power generation in 2006 (Lucena *et al.*, 2009). Lucena *et al.* (2009) also demonstrated that hydro and wind energy, as well as biodiesel production might be particularly sensitive to climate change in Brazil. With the vital role that RE plays in mitigating the effects of global climate change (GCC), this sensitivity translates into the importance of accounting with knowledge on the implementation of RE projects as well as on the crops providing bioenergy, being by far the most important sources of non-hydro RE in SA and CA.

For historical reasons, CA and SA developed sugarcane as bioenergy feedstock, as sugarcane has been considered advantageous for its high sugar contents. As a result, hundreds of sugar mills have been installed in several countries, especially in Brazil and Cuba. Brazil accounts for the most intensive RE production in the form of bioethanol, which is used by 90% of the cars in the country (Goldemberg, 2008) whereas biodiesel comprises 5% of all diesel nationwide. In 2011, countries like Colombia and Chile have started efforts to increase their bioenergy production from sugarcane and eucalyptus, respectively. With the continent's long latitudinal length, the expected impacts of climate changes on plants are very complex due to a wide variety of climate conditions, imposing the problem of using different crops in different regions. Whereas in Mexico, CA and the Northeast region of Brazil crops like Agave could be used as a bioenergy feedstock (Davis *et al.*, 2011), in the tropical regions of Brazil, Colombia and Peru, grasses (mainly sugarcane) tend to be used (Cardona and Sánchez, 2007; Chum *et al.*, 2011). Other grasses, like sweet sorghum and miscanthus, are already in use or likely to be used in the near future for bioethanol production. For biodiesel, in Brazil 80% is produced from soybeans, but there are promising new sources such as the African palm dendê (Lucena *et al.*, 2009). As mentioned in the section of Non-Climatic Stressors in this chapter (27.2.2), the development of palm oil as well as soybean are important factors that induce land use change, with a potential to influence stability of forests in certain key regions in SA, such as the Amazon.

Biofuels are promising sources of RE that are very likely to help CA and SA to decrease emissions from energy production and use. At the same time, RE might imply potential problems such as those related to positive net emissions of greenhouse gases, threats to biodiversity, an increase in food prices and competition for water resources (see also 27.2.3), all of which can be reverted or attenuated (Koh and Ghazoul, 2008). For example, the sugarcane agro industry in Brazil, besides producing bioethanol, combusts the bagasse to produce electricity, in a process called cogeneration, providing power for the bioethanol industry and increasing sustainability. The excess heat energy is then used to generate bioelectricity, thus allowing the biorefinery to be self-sufficient in energy utilization (Amorim *et al.*, 2011; Dias *et al.*, 2012). In 2005/2006 the production of bioelectricity was estimated to be 9.2 kWh per ton of sugarcane (Macedo *et al.*, 2008), approximately 2% of Brazil's total energy generation production.

Most bioenergy feedstocks at present in production in CA and SA are grasses and display C4 photosynthesis. In the case of sugarcane, the responses to the elevation of CO_2 concentration up to 720ppmv have been shown to be positive in terms of biomass production and principally regarding water use efficiency (Souza *et al.*, 2008). Modeling of sugarcane crop behavior under elevation of CO_2 concentration considering also best practices for sugarcane cropping revealed that bioethanol production might be mildly affected by GCC (Silva *et al.*, 2008). However, it is important to note that other factors such as temperature increase and ozone effects on crops might interfere negatively with plant growth, leading to a decrease instead (Ebrahim *et al.*, 1998; Long, 2012).

The production of energy from renewable sources such as hydro- and wind power are greatly dependant on climatic conditions and therefore may be impacted in the future by the GCC. Vulnerabilities related to renewable energy in

Brazil have been examined by Lucena *et al*. (2010a), who used modeling based on long-term climate projections for the A2 and B2 IPCC emission scenarios from the PRECIS modeling system. The author´s analyses related to liquid biofuels and hydropower suggest an increasing energy vulnerability of the poorest regions of Brazil to GCC together with a likely negative influence on biofuels production and electricity generation, mainly biodiesel and hydropower respectively. It is likely that many regions in CA and SA will respond similarly.

According to Lapola *et al*. (2010) the expansion of biofuel plantations in Brazil might cause both direct and indirect land use changes (e.g., biofuel plantations replacing rangelands, which previously replaced forests) with the former, according to the authors' simulation of the effects for 2020, being found more likely to have a smaller impact on carbon emissions as most biofuel plantations would replace rangeland areas. The same study also shows that sugarcane ethanol and biodiesel derived from soybean each contribute with about one half of the indirect deforestation projected for 2020 (121.970 km^2) (Lapola *et al*., 2010). In this way, indirect land use changes, especially those causing the rangeland frontier to move further into the Amazonian forests, might potentially offset carbon savings from biofuels production.

Although the prospects of energy production by the sugarcane industry are very promising, the increase in global ethanol demand, driven by global concern for addressing climate change, is leading to the development of new hydrolytic processes which aim at converting cellulose and hemicelluloses into ethanol (Santos *et al*., 2011). The expected increase in the hydrolysis technologies is likely to balance the requirement of land for biomass crops. Thus, the development of these technologies has a strong potential to diminish social (e.g. negative health effects due the burning process, poor labor conditions) and environmental impacts (e.g. loss of biodiversity, water and land uses) whereas at the same time it can improve the economic potential of sugarcane. One important adaptation measure will therefore be to increase the productivity of bioenergy crops due to planting in high productivity environments an with highly develop technologies, in order to use less land, thus diminishing the adverse impact on biodiversity and food production. As one of the main centers of biotech agriculture application in the world (Gruskin, 2012), the region accounts with a great potential to achieve this goal.

As the effects previously reported on crops growing in SESA might prevail (see 27.3.4.1), i.e. that an increase in productivity may happen due to increasing precipitation, future uncertainty will have to be dealt with by preparing adapted varieties of soybean in order to maintain food and biodiesel production, mainly in Argentina as it is one of the main producers of biodiesel from soybean in the world (Chum *et al*., 2011).

Other renewable energy sources—such as wind power generation—may also be vulnerable, raising the need for further research. According to Lucena *et al*. (2009; 2010b) the projections of changes in wind power in Brazil, as calculated for for the A2 and B2 emission scenarios results based on the PRECIS modeling system are likely not to negatively influence the use of this kind of energy in the future.

Minimization of the impact of sugarcane on biodiversity and the environment is expected to improve its sustainability. As the demand for bioethanol increases, improvement of productivity will result in a greater demand of land for sugarcane production. In this context, an expansion of land under sugarcane production is likely, especially in Brazil's Central-South region (Lapola *et al*., 2010). Part of the Central-South region of Brazil is occupied with sugarcane and soybean crops. However, this region also includes the cerrado (savannah) biome, which requires protection from expanding agriculture (Sawyer, 2008). It is important to ensure the protection of this unique region of Northern Brazil and Colombia as sugarcane grows into a commodity and policy is formed (Sawyer, 2008).

Initiatives such as the soy moratorium in the Amazon have an inhibitory effect over deforestation rates. Rudorff *et al*. (2011) showed that from 2008 to 2010 soybean was planted only on 0.25% of deforested land, which represents 0.027% of the total soybean cover in Brazil. However, in total, increased demand for agricultural commodities is likely to continue to be a driver behind the conversion of primary and secondary forests in Brazilian tropical forests and savannas (Fargione *et al*., 2010; Sawyer, 2008). Therefore, increased protection of natural areas in these species-rich areas is necessary to preserve biodiversity in the face of these pressures (Brooks *et al*., 2009).

27.3.6.2. Adaptation Practices

According to Fischedick *et al*. (2011) RE will, in general, become increasingly more important over time as this is closely related with the emissions of GHG. Given the fact that the CA and SA region is formed by developing and emerging contries, RE could have an important role as adaptation means to provide sustainable energy for development in the region. However, it has to be noted that the production of RE like bioenergy requires large available areas for agriculture, which is the case of Argentina, Bolivia, Brazil, Chile, Colombia, Peru and Venezuela, that together represent 90% of the total country area of CA and SA region. However, for smalle countries it might not be possible to use bioenergy. Instead, they could benefit in the future of other types of RE, such as geogermical, eolic, photovoltaic etc, depending on policies and investment in different technologies. This is important because economic development is thought to be strongly correlated with an increase in energy use (Smil, 2000), which is itself associated with an increase in emissions (Sathaye *et al*., 2011).

Arvizu *et al*. (2011) highlighted that there is a large undeveloped potential for hydropower in the world, with Latin America alone having a potential of 74%. Developing this potential with the highest possible level of sustainability would be one of the adaptation measures to be adopted for CA and SA. Of the 57% increase in hydropower in the world expected for 2035, Latin America is thought to contribute significantly (7% in Brazil) (Kumar *et al*., 2011). Given the potential of the region, this performance could be better, if undertaken with sustainability.

Latin America is second to Africa in terms of technical potential for bioenergy production from rain-fed lignocellulosic feedstocks on unprotected grassland and woodlands (Chum *et al*., 2011). In this context, some of the most important adaptation measures regarding RE are: (1) management of land use change (LUC); (2) modelling indirect land use change (ILUC); and (3) development of policies for financing and management of science and technology for all types of RE in the region.

If very carefully managed, biofuel crops can be even used as a means to regenerate biodiversity as proposed by Buckeridge *et al*. (2012) who highlight the fact that the technology for tropical forest regeneration has become available to the present, and that forests could share land with biofuel crops (such as sugarcane) taking advantage of forests' mitigating potential. A possible adaptation measure could be to expand the use of reforestation technology to other countries in CA and SA.

One of the main adaptation issues that have been discussed in the literature is the one of food *vs*. fuel, i. e. the possibility that bioenergy crops would compete for land with food crops (Valentine *et al*., 2012). This issue is important for humans because an uncontrolled increase in bioenergy feedstocks might threaten primary food production in a scenario expected to feed future populations with an increase of 50% to 70% in production (Gruskin, 2012; Valentine *et al*., 2012). This issue is particularly important in the region as it has one of the highest percentages of arable land available for food production in the world (Nellemann *et al*., 2009). As CA and SA develop new strategies to produce more RE in the region, LUC may push ILUC so that the pressure for more acreage to produce bioenergy, for instance, might be put forward on food crops on the one hand and on biodiversity and ecosystem services at the other. According to Arvizu *et al*. (2011) bioenergy generates one of the most complex networks of effects. As climate change will affect bioenergy and food crops at the same time, their effects, as well as the adaptation measures related to agriculture will be similar in both cases. The main risks identified by Arvizu *et al*. (2011) are: (1) business as usual; (2) un-reconciled growth, and (3) environment and food *vs*. fuel. Thus, the most important adaptation measures will probably be the ones related to the control of economic growth, environmental management and agriculture production. These three factors will have to be carefully managed so that their sustainability levels should be the highest possible. With this, lower emissions and consequently lower impacts of the GCC will be expected. The choice for lignocellulosic feedstocks (eg. sugarcane second generation technologies) will be quite important because these feedstocks do not compete with food (Arvizu *et al*., 2011). In the case of sugarcane, for instance, an increase of ca. 40% in the production of bioethanol is expected as a result of the implantation of second generation technologies coupled with the first generation ones already existent in Brazil (Buckeridge *et al*., 2012; Dias *et al*., 2012).

Biodiesel production has the lowest costs in Latin America (Chum *et al*., 2011), probably due to the high production of soybean in Brazil and Argentina. The use of biodiesel to complement oil-derived diesel is a productive choice for adaptation measures regarding this bioenergy source. Also, the cost of ethanol, mainly derived from sugarcane, is the lowest in CA, SA and Latin America (Chum *et al.*, 2011) and as an adaptation measure, such costs, as well as the one of bioediesel, should be lowered even more by improving technologies related to agricultural and industrial production of both. Indeed, it has been reported that in LA the use of agricultural budgets by governments for investment in public goods induces faster growth, decreasing poverty and environmental degradation (López and Galinato, 2007). One issue that may become important in the future is that the pressure of soy expansion due to biodiesel demand can lead to land use change and consequently to economic teleconnections, as suggested by Nepstad *et al.* (2006). These teleconnections have as a source of forcing due to the economic growth in China and the avian flu, for instance. The effects of such teleconnections may possibly be a decrease in jobs related to small to big farms in agriculture in Argentina (Tomei and Upham, 2009) on the one hand, and deforestation in the Amazon due to the advance of soybean cropping in the region on the other (Nepstad and Stickler, 2008) (see Figure 27-5).

[INSERT FIGURE 27-5 HERE
Figure 27-5: Soy teleconnections and major effects in SA. Economic growth giant consumers as China pressurize the soy production system in SA, increasing the production of biodiesel, but demanding more energy in general. (partly based on Nepstad and Stickler (2008), and Tomei and Upham (2009)).]

[placeholder for SRREN summary]

27.3.7. Human Health

27.3.7.1. Observed and Projected Impacts and Vulnerability

Climate variability and change are affecting human health in CA and SA (hereafter LA) through morbidity, mortality, disabilities, and the re-emergence of diseases in non-previous endemic or previously eradicated/controlled areas (Rodríguez-Morales, 2011; Winchester and Szalachman, 2009). Heat waves and cold spells are affecting mortality rates in most cities (Bell *et al.*, 2008; Hajat *et al.*, 2010; Hardoy and Pandiella, 2009; McMichael *et al.*, 2006; Muggeo and Hajat, 2009). Outbreaks of leptospirosis, malaria, dengue fever, and cholera were triggered in CA by hurricane Mitch in 1998 (Costello *et al.*, 2009; Rodríguez-Morales *et al.*, 2010). The 2010-2012 floods in Colombia (Poveda *et al.*, 2011a) caused hundreds of deaths and thousands of displaced people. Dengue fever outbreaks followed floods in Brazil in the last decade (Teixeira *et al.*, 2009).

Indices of malaria in Colombia have increased in the last five decades, along with air temperatures (Arevalo-Herrera *et al.*, 2012; Poveda *et al.*, 2011b), as well as in urban and rural areas of Amazonia owing to large environmental changes (Cabral *et al.*, 2010; Da Silva-Nunes *et al.*, 2012; Gil *et al.*, 2007; Tada *et al.*, 2007). Malaria vector densities have increased in northwestern Argentina along with climate variables (2011; Dantur Juri *et al.*, 2010). Besides, El Niño is a major driver of malaria outbreaks in Colombia (Mantilla *et al.*, 2009; Poveda *et al.*, 2011b), amidst drug resistance of the parasite (Restrepo-Pineda *et al.*, 2008), and human migration (Osorio *et al.*, 2007; Rodriguez-Morales *et al.*, 2006). Linkages between ENSO and malaria have been also reported in Ecuador and Peru (Anyamba *et al.*, 2006; Kelly-Hope and Thomson, 2010), French Guiana (Hanf *et al.*, 2011), Amazonia (Olson *et al.*, 2009), and Venezuela (Moreno *et al.*, 2007), including unheard malaria in the Andes up to 2200 m a.s.l. (Benítez and Rodríguez-Morales, 2004).

Dengue fever (DF) and dengue hemorrhagic fever (DHF) have risen in tropical America in the last 25 years, posing an annual toll of US$ 2.1+[1 to 4] billion (Shepard *et al.*, 2011; Tapia-Conyer *et al.*, 2009; Torres and Castro, 2007). Environmental and climatic variability affect DF and DHF incidence in Honduras and Nicaragua (Rodríguez-Morales *et al.*, 2010), in Costa Rica (Fuller *et al.*, 2009; Mena *et al.*, 2011), in French Guiana being concurrent with malaria (Carme *et al.*, 2009; Gharbi *et al.*, 2011), in cities of Colombia (Arboleda *et al.*, 2009) and Venezuela. In Caracas, DF increases (decreases) during La Niña (El Niño) (Herrera-Martinez and Rodríguez-Morales, 2010; Rodríguez-Morales and Herrera-Martinez, 2009). Climate is also associated with DF in southern SA (Costa *et al.*, 2010; De Carvalho-Leandro *et al.*, 2010; Degallier *et al.*, 2010; Honório *et al.*, 2009; Lowe *et al.*, 2011). Despite large vaccination campaigns the risk of major Yellow Fever (YF) outbreaks has increased in tropical America due to climate and environmental conditions (Jentes *et al*., 2011), mainly in densely populated poor urban settings (Gardner and Ryman, 2010).

Schistosomiasis (SCH) is an endemic Neglected Tropical Disease (NTD) in rural areas, including Brazil (Igreja, 2011), Suriname, Venezuela, and the Andean highlands, while uncontrolled peripheral urbanisation and environmental degradation increase its incidence in Brazil (Barbosa *et al*., 2010; Kelly-Hope and Thomson, 2010). Temperatures affect the likely response of SCH to global warming (Lopes *et al*., 2010; Mangal *et al*., 2008; Mas-Coma *et al*., 2009), while vegetation indices are associated with human fascioliasis in the Andes (Fuentes, 2004).

Hantaviruses (HV) have been reported in Honduras, Panama, Cost Rica, Venezuela, Argentina, Chile, Paraguay, Bolivia, Peru, and Brazil (Jonsson *et al*., 2010; MacNeil *et al*., 2011). There is evidence that El Niño and climate change enhance the prevalence of HV (Dearing and Dizney, 2010). Annually, 47,000 children die from climate-driven seasonal rotaviruses (RV) (Linhares *et al*., 2011). In Venezuela, RVs are more frequent, more severe, and more (less) common in cities with minimal (marked) seasonality (Kane *et al*., 2004). The seasonal peak of RV in Guatemala coincides with the dry season, being responsible for 60% of diarrhoea cases (Cortes *et al*., 2012).

In spite of its rapid decline, Chagas disease is still a major public health issue, partly due to climate and environmental changes (Abad-Franch *et al*., 2009; Araújo *et al*., 2009; Moncayo and Silveira, 2009), as in Panama and Argentina (Gottdenker *et al*., 2011; Tourre *et al*., 2008). Ciguatera fish poisoning (CFP) is a tropical disease correlated with water temperature, likely to increase with climate change across the Caribbean (Tester *et al*., 2010). Climate is an important factor of Paracoccidioidomycosis, LA's most prevalent mycosis (Barrozo *et al*., 2009), while ENSO is associated with recent outbreaks of bartonellosis in Peru (Payne and Fitchett, 2010).

Cutaneous leishmaniasis (CL) is correlated with climate in LA, with highest incidence in Bolivia, where it increases (decreases) during La Niña (El Niño) (García *et al*., 2009; Gomez *et al*., 2006). CL is affected in Costa Rica by temperature, forest cover, and ENSO indices (Chaves and Pascual, 2006; Chaves *et al*., 2008). Land use, altitude, and diverse climatic variables are associated with increasing trends of CL in Colombia (Valderrama-Ardila *et al*., 2010), which also increases (decreases) during El Niño (La Niña) (Cárdenas *et al*., 2006; 2008; 2007). The situation of CL in Colombia is aggravated by the internal conflict (Beyrer *et al*., 2007). In Venezuela, CL increased (67%) during a weak La Niña (Cabaniel *et al*., 2005). CL is a seasonal disease in Suriname peaking during the March dry season (35%) (Van der Meide *et al*., 2008), while in French Guiana is intensified after the October-December dry season (Rotureau *et al*., 2007). The incidence rates of visceral leishmaniasis (VL) have been increasing in Brazil (the highest in LA) owing to deforestation (Cascio *et al*., 2011; Sortino-Rachou *et al*., 2011), and its correlation with El Niño (Ready, 2008), as is also the case in Argentina, Paraguay, and Uruguay (Bern *et al*., 2008; Dupnik *et al*., 2011; Fernández *et al*., 2012; Salomón *et al*., 2011). VL transmission in western Venezuela is also associated with the bimodal annual rainfall regime (Feliciangeli *et al*., 2006; Rodríguez-Morales *et al*., 2007). The incidence of cutaneous melanoma in LA is increasing faster than in developed countries (Sortino-Rachou *et al*., 2011). In turn, temperatures are associated with skin cancer in Chile (Salinas *et al*., 2006), and Brazil exhibits the highest rates of non-melanoma skin cancer in the region (Sortino-Rachou *et al*., 2011).

Climate change is responsible for epidemic outbreaks of cutaneous lepidopterism in LA (Paniz-Mondolfi *et al*. (2011). Onchocerciasis (river blindness) is another climate-related disease (Botto *et al*., 2005), whose vector exhibits clear-cut wet-dry seasonal biting rates (Rodríguez-Pérez *et al*., 2011). Global warming and increased rainfall help to explain the re-emergence of leptospirosis in CA and SA (Pappas *et al*., 2008; Valverde *et al*., 2008). Other climate-driven infectious diseases are ascariasis and gram-positive cocci in Venezuela (Benítez *et al*., 2004; Rodríguez-Morales *et al*., 2010), and Carrion's disease in Peru (Huarcaya *et al*., 2004)

Sea water temperature affects the abundance of the bacteria responsible for cholera (Hofstra, 2011; Jutla *et al*., 2010; Koelle, 2009; Marcheggiani *et al*., 2010), and thus high correlations exist between El Niño and cholera in Peru, Ecuador, Colombia, Mexico and Venezuela (Cerda Lorca *et al*., 2008; Gavilán and Martínez-Urtaza, 2011; Holmner *et al*., 2010; Martinez-Urtaza *et al*., 2008; Murugaiah, 2011; Salazar-Lindo *et al*., 2008). Extreme temperatures and changes in rainfall may also increase food safety hazards along the food chain (Sivakumar *et al*., 2005; Tirado *et al*., 2010).

Air pollution and higher temperatures exacerbate chronic respiratory and cardiovascular problems. Dehydration from heatwaves increases hospitalizations for chronic kidney diseases (Kjellstrom *et al*., 2010), mainly affecting construction workers, and CA sugarcane and cotton workers (Crowe *et al*., 2009; 2010; Kjellstrom and Crowe, 2011; Peraza *et al*., 2012). In the region, atmospheric pollutants are associated with artherosclerosis, respiratory and cardiovascular diseases, pregnancy-related outcomes, cancer, cognitive deficit, otitis, and diabetes (Olmo *et al*., 2011). The worsening of air quality in large cities is increasing allergic respiratory diseases, and morbidity from asthma and rhinitis (Grass and Cane, 2008; Gurjar *et al*., 2010; Jasinski *et al*., 2011; Martins and Andrade, 2008; Rodriguez *et al*., 2011).

Climate change affects mental health by exposure to psychological trauma (Berry *et al*., 2010; Higginbotham *et al*., 2006). Drought-prone areas in northeast Brazil are vulnerable to lower socioeconomic and educational levels, in turn associated with depression, psychological distress, and anxiety (Coêlho *et al*., 2004). Hospital admissions for mania and bipolar disorder show climate-driven seasonalities in Brazil. Extreme weather, meager crop yields, and low GDP are also linked with increased violence (McMichael *et al*., 2006). All these problems may be exacerbated by climate change (Schulte and Chun, 2009).

Many factors increase CA and SA's vulnerability to climate change: precarious health systems, socio-economic factors, inadequate water and sanitation services, poor waste collection and treatment systems, air, soil and water pollution, lack of social participation, and inadequate governance (Luber and Prudent, 2009; Rodríguez-Morales, 2011; Sverdlik, 2011). Human health vulnerabilities exhibit serious biases with geography, age (Graham *et al*., 2011; Martiello and Giacchi, 2010; Perera, 2008; Åstrom *et al*., 2011), gender (Oliveira *et al*., 2011), race, ethnicity, and socio-economic status (Diez Roux *et al*., 2007; Martiello and Giacchi, 2010). Malnutrition due to crop failure and drought adds up to vulnerability (Schmidhuber and Tubiello, 2007). NTDs cause 1.5-5.0 million DALYs in LA, many of which are climate-sensitive diseases (Allotey *et al*., 2010; Hotez *et al*., 2008). Vulnerability of mega-cities is increasing due to migration from rural areas forced by environmental degradation and disasters (Borsdorf and Coy, 2009; Campbell-Lendrum and Corvalán, 2007; Hardoy and Pandiella, 2009). Informal settlements are on the rise in the region, on sites at high risk from extreme weather, favoring disease, injury, and premature death. Assesing the vulnerability is necessary to identify better adaptation strategies (Tong *et al*., 2010). Diverse vulnerability assessments to the impacts of climate change were developed in Brazil at national, regional and municipal scales. The approach used was based on composite indicators, which included downscaled climate scenarios, epidemiological variables, economic and demographic projections and the status of natural ecosystens (Barbieri and Confalonieri, 2011; Confalonieri *et al*., 2009; 2011; FIOCRUZ, 2011).

CA and northern SA are vulnerable to intense hurricanes (IPCC, 2007); people from the intra-Andean valleys to intense storms, landslides, and floods; the low-hot and humid tropical Americas to climate-sensitive diseases and their spread to higher altitudes; children to environmental health hazards (Valenzuela *et al*., 2011); large LA cities to limited access to drinking water and energy, to air and water pollution, and to intense storms and flooding (Borsdorf and Coy, 2009). People in the tropical Americas often live at temperatures close to tolerable thresholds. The Andes and CA are among the regions of highest predicted losses [1% to 27%] in labor productivity from future climate scenarios (Kjellstrom *et al*., 2009). Argentina and Chile (under the sub-Antarctic atmospheric circulation) might suffer serious health effects from impacts to water and food availability, and extreme weather (Team and Manderson, 2011).

27.3.7.2. Adaptation Strategies and Practices

Although adaptation strategies are trying to be implemented in CA and SA ((Blashki *et al*., 2007; Costello *et al*., 2011), several factors hamper their effectiveness, such as: a lack of political commitment, gaps in scientific knowledge, and institutional weaknesses of health systems (Keim, 2008; Lesnikowski *et al*., 2011; Olmo *et al*., 2011) (see section 27.4.3.)

Research priorities and current strategies must be reviewed to achieve better disease control (Halsnæs and Verhagen, 2007; Karanja *et al*., 2011; Romero and Boelaert, 2010). The low adaptive capacity of rural communities associated with poor health systems and limited resources exacerbate human health stressors from climate change, and thus regional responsive systems must be put in place in key operational areas (Bell, 2011), involving adaptive capacity building, and implementation of adaptation actions (Huang *et al*., 2011), which in turn require considering the potential magnitude and uncertainty of the hazards, and the effectiveness, costs, and risks of the proposed responses (Campbell-Lendrum and Bertollini, 2010).

Diverse human wellbeing indices must be explicitly stated as climate change policies of adaptation and mitigation in LA, along with the Millennium Development Goals (Franco-Paredes *et al*., 2007; Halsnæs and Verhagen, 2007; Mitra and Rodriguez-Fernandez, 2010). South-south cooperation and multidisciplinary research is required to study the health impacts of climate change and to identify resilience, adaptation, and mitigation strategies (Team and Manderson, 2011; Tirado *et al*., 2010). Colombia is starting to develop a pilot human health adaptation program, to cope with climate-driven changes in malaria transmission and exposure (Poveda *et al*., 2011b). The city of São Paulo has implemented diverse local pollution control measures, with the co-benefit of limiting GHG emissions (Nath and Behera, 2011; Nath and Behera, 2011; Puppim de Oliveira, 2009; Puppim de Oliveira, 2009), benefiting children and adolescents (Jasinski *et al*., 2011). Even if funding for adaptation is available, the overarching problem is the lack of capacity and/or willingness to address the risks, especially those threatening lower income groups (Satterthwaite, 2011). Adaptation to climate change cannot eliminate the extreme weather risks, and thus efforts should focus on disaster preparedness and post-disaster response (Sverdlik, 2011). Migration is the last resort for rural comunities facing water stress problems in CA and SA (Acosta-Michlik *et al*., 2008).

27.4. Adaptation Opportunities, Constraints, and Limits

27.4.1. Adaptation Needs and Gaps

During the last years, the study of adaptation to climate change has progressively switched from an impact-focused approach (mainly climate-driven) to a vulnerability-focused vision (Boulanger *et al*., 2011). While different frameworks and definitions of vulnerability exist and have been published in previous reports, a general tendency aims at studying vulnerability to climate change using a systemic approach (Ison, 2010), where climate drivers are actually few with respect to all other drivers related to human and environment interactions including physical, economic, political and social context, as well as local characteristics such as occupations, resource uses, accessibility to water, etc. (Manuel-Navarrete *et al*., 2007; Young *et al*., 2010).

In developing and emergent countries, there exists a general consensus that the adaptive capacity is low, strengthened by the fact that poverty is a limit to resilience (Pettengell, 2010) leading to a "low human development trap" (UNDP, 2007). Although this is true, Magnan (2009) suggests that this analysis is biased by a "relative immaturity of the science of adaptation to explain what are the processes and the determinants of adaptive capacity". Increasing research efforts on the study of adaptation is therefore of great importance to improve our understanding of the actual societal, economical, community and individual drivers defining the adaptive capacity. Especially, a major focus on traditions and their transmission (Young and Lipton, 2006) may actually indicate potential adaption potentials in remote and economically poor regions of SA and CA. Such a potential does not dismiss the fact that the nature of future challenges may actually not be compared to past climate variability (e.g. glacier retreat in the Andes).

Coping with new situations may require new approaches such as a multilevel risk governance (Corfee-Morlot *et al*., 2011; Young and Lipton, 2006) somehow associated with decentralization in decision-taking and responsibility. While the multilevel risk governance and the local participatory approach are interesting frameworks for strengthening adaptation capacity, their major counterpart is that at all levels it requires (from local to national levels) capacity-building and information transmission on future risks, major challenges and possible methodologies to plan adaptation strategies to climate change. At present, despite an important improvement during the last years, there still exists a certain lack of awareness of environmental changes and mainly their implications for livelihoods and businesses (Young *et al*., 2010). Moreover, considering the limited financial resources of some states in CA and SA, long-term planning and the related human and financial resource needs may be seen as conflicting with present social deficit in the welfare of the population. This situation weakens the importance of adaptation planning to climate change in the political agenda. However, as pointed out by McGray *et al*. (2007), development, adaptation and mitigation issues are not separate issues. Especially, development and adaptation strategies should be tackled together in developing countries, focusing on strategies to reduce vulnerability. The poor level of adaptation of present-day climate in SA and CA countries is characterized by the fact that responses to disasters are mainly reactive rather than preventive. Some early warning systems are being implemented, but the capacity of responding to a warning is often limited, particularly among poor populations. Finally, actions combining public communication (and education), public decision-maker capacity-building and a synergetic development-adaptation funding will be key to sustain the adaptation process that CA and SA require to face future climate change challenges.

27.4.2. Practical Experiences of Adaptation, including Lessons Learned

Adaptation processes have been in many cases initiated a few years ago, and there is still a lack of literature to evaluate their efficiency in reducing vulnerability and building resilience of the society against climate changes. However, some lessons have already been learned on these first experiences (see section 27.3). In CA and SA, many societal issues are strongly connected to development goals and are often considered priority in comparison to adaptation efforts to climate change. However, according to the 135 case studies analyzed by McGray *et al.* (2007), 21 of which were in CA and SA, the synergy between development and adaptation actions allows to ensuring a sustainable result of the development projects.

Vulnerability and disaster risk reduction may not always lead to long-term adaptive capacity (Nelson and Finan, 2009; Tompkins *et al*., 2008), except when structural reforms based on good governance (Tompkins *et al*., 2008) and negotiations (Souza Filho and Brown, 2009) are implemented. While multi-level governance can help to create resilience and reduce vulnerability (Corfee-Morlot *et al*., 2011; Roncoli, 2006; Young and Lipton, 2006), capacity-building (Eakin and Lemos, 2006), good governance and enforcement (Lemos *et al*., 2010; Pittock, 2011) are key components.

Local adaptation to climate and non-climate drivers may undermine long-term resilience of social-ecological systems (Adger *et al*., 2011). Thus, policy should identify the sources of and conditions for local resilience and strengthen their capacities to adapt and learn (Adger *et al*., 2011; Eakin *et al*., 2011), as well as to integrate new adapted tools (Oft, 2010). This sets the question of convergence between the local-scale/short-term and broad scale/long-term visions in terms of perceptions of risks, needs to adapt and appropriate policies to be implemented (Eakin and Wehbe, 2009; Salzmann *et al*., 2009).

Forward-looking learning (anticipatory process), as a contrast to learning by shock (reactive process), has been found as a key element for adaptation and resilience (Tschakert and Dietrich, 2010) and should be promoted as a tool for capacity-building at all levels (stakeholders, local and national governments). Its combination with role-playing game and agent-based models (Rebaudo *et al*., 2011) can strengthen and accelerate the learning process.

27.4.3. Observed and Expected Barriers to Adaptation

It is usually considered that a major barrier to adaptation is the perception of risks and many studies focused on such an issue (Bonatti *et al*., 2012). However, new studies (Adger *et al*., 2009) identified social limits to possible adaptation to climate change in relation with issues of values and ethics, risk, knowledge and culture, even though such limits can evolve in time. Indeed, while being a necessary condition, perception may not be the main driver for initiating an adaptation process. As pointed out by Tucker et al. (2010), exogenous factors (economic, land tenure, cost, etc.) may actually strongly constrain the decision-making process involved in possible adaptation process.

Moreover, it is difficult to describe adaptation without defining at which level it is thought. Indeed, while a lot of efforts are invested in national and regional policy initiatives, most of the final adaptation efforts will be local. National and international (transborder) governance is key to build adaptive capacity (Engle and Lemos, 2010) and therefore to strengthen (or weaken) local adaptation through efficient policies and delivery of resources. At a smaller scale (Agrawal, 2008), local institutions can strongly contribute to vulnerability reduction and adaptation. However, at all levels, the efficiency in national and local adaptation activities strongly depend on the capacity-building and information transmission to decision-makers (Eakin and Lemos, 2006).

27.4.4. Planned and Autonomous Adaptation

As pointed out by McGray *et al*. (2007), 3 types of adaptation can be defined: serendipitous, climate-proofing and discrete. While serendipitous strategies mainly aim at reducing local vulnerability and at attending development issues, climate-proofing strategies aim at integrating present and future climate risks into policies, planning and infrastructures. Finally, discrete strategies aim at undertaking specific actions in direct response to climate change impacts.

Autonomous adaptation strategies are mainly realized at local levels (individual or communitarian), but not always respond to climate forcing. For instance, the agricultural sector adapts rapidly to economic stressors, while, despite a clear perception of climate risks, it may last longer before responding to climate changes (Tucker *et al*., 2010). In certain regions or communities, such as Anchioreta in Brazil (Bonatti *et al*., 2012), adaptation is part of a permanent process and is actually tackled through a clear objective of vulnerability reduction, maintaining and diversifying a large set of natural varieties of corn allowing the farmers to diversify their planting. Another kind of autonomous adaptation is the southward displacement of agriculture activities (e.g. wine, coffee) though the purchase of lands, which will become favorable for such agriculture activities in a warmer climate. In Argentina, the increase of precipitacion observed during the last 30 years contributed to a westward displacement of the crop frontier (Barros, 2008).

Planned adaptation is by definition associated to government policies and planning. During the last years, there has been a growing awareness of CA and SA governments on the need to integrate climate change and future climate risks in their policies. Many countries, such as Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela, have already responded first through their National Communication to the UNFCCC allowing to measure the country's emissions and to assess its present and future vulnerability. Other countries, for instance Argentina, Brazil and Uruguay among others, created specific Secretaries in the government organizations specifically dedicated to climate change in order to coordinate actions between different ministries and secretaries of state. Finally, most of the countries in the region (Keller *et al*., 2011) are now involved in international networks focused on adaptation to climate change, or in international projects aiming at capacity-building and design of adaptation strategies. It is of course too early to evaluate the actual impact of such new initiatives on regional or national adaptation to climate change. However, new tools (Debels *et al*., 2009) or international platforms for CA and SA may help to prioritize adaptation policies according to their efficiency and the limited financial resources in the future.

[placeholder SOD: overview on regional adaptation initiatives]

27.5. Interactions between Adaptation and Mitigation

As demonstrated in 'The SouthSouthNorth Capacity Building Module on Poverty Reduction" (see SSN, 2006), a synergy between adaptation and mitigation strategies can be reached especially when the community organizes itself in a cooperative. In many examples, mitigation strategies based on a cooperative system, which manages recycling or renewable energy production, actually lead to an increase in energy availability, crucial to increase production capacity and thus to create new financial resources for the community. As also pointed out by (Venema and Cisse, 2004), the growth of renewable energy in CA and SA (see also section 27.3.6) should not be limited to large infrastructure projects, and should also encompass the development of decentralized renewable energy solutions. In spite of their smaller size (individual or communitarian), these solutions offer adaptation and mitigation benefits. On one hand, fossil-based energy consumption is reduced, while energy availability is increased. On the other hand, reduction of energy precariousness is key in any development strategy. Thus, it allows local community and individuals to growing socially and economically; and therefore to reducing its vulnerability avoiding the poverty trap (UNDP, 2007), and to initiating an adaptation process based on non-fossil fuel energy sources.

At national and regional scales, CA and SA countries will require the allocation of human and financial resources to adapt to climate change. While resources are limited, too large an economic dependence of these countries to fossil fuels will reduce their adaptive capacity. The reduction in energy consumption and the integration of renewable energies in their energetic matrix is therefore a key issue for all these countries in order to sustain their development and growth and therefore increase their adaptive capacity (see also section 27.3.6).

27.6. Case Studies

27.6.1. Hydropower

Hydropower is the main source of renewable energy available in CA and SA as a whole (see section 27.3.6). The linkages between climate change and hydropower are manyfold and reflect the feedback mechanisms that affect this problem. Hydropower is seen a major contributor to mitigating GHG emissions worldwide, but it is also a climate-related (water) sector, thus making it is likely to be affected from potential impacts of climate change (see section 27.3.1.1).

The CA and SA region constitute a unique example to study these relations According to the Special Report on Renewable Energy Sources and Climate Change Mitigation (see Table 5.1 SRREN; IPCC, 2011) CA and SA are second to Asia in terms energy generation in the world, displaying a 20% share of total annual generation. The quality of water resources availability is the largest in the world with an average regional capacity factor of over 50%. As a result, the region has by far the largest proportion of electricity generated through hydropower facilities. As can be seen in Table 27-7 in section 27.3.6.1, based on data from the IEA (2012), on average Latin America (includes CA and SA and Mexico) has more than 60% of electricity provided by hydropower facilities in contrast to a less than 20% for the world (see section 27.3.6.1). Looking at some specific countries in the region it can be seen that in general hydropower proportion of total electricity production is over 40% and in some cases is near or close to 80% (Brazil, Colombia and Costa Rica for example).

There have been a series of studies that analyzed the potential impacts of climate change on hydropower generation capacity in the region. For CA one example are Maurer *et al.* (2009) who studied future hydrologic conditions for the Lempa River basin, the largest river system in CA covering three countries: El Salvador, Honduras and Guatemala and holding major hydroelectric facilities. Modelling studies involving uncertainty analyes show a reduction in hydropower capacity of 33% to 53% by 2070-2099 (CMIP3 Models; A2, B1 scenarios). A similar loss is expected for the Sinu-Caribe basin in Colombia were, despite a general projection of increased precipitation, losses due to evaporation enhancement reduces inflows to hydroelectric systems reducing electricity generation up to 35% compared to base conditions (four GCMs; A2 scenario, see Table 27-4 in section 27.3.1.1.) (Ospina-Noreña *et al.*, 2009a). Subsequent studies by the same group of authors (Ospina-Noreña *et al.*, 2011a; 2011b) have determined vulnerability indices for the hydropower sector in the same basin and strategies to reduce this vulnerability. Overall reductions in hydropower generation capacity are also expected in Chile for the main hydropower generation river basins: Maule, Laja and Biobio (ECLAC, 2009a; McPhee *et al.*, 2010; Stehr *et al.*, 2010), and also in the Argentinean Limay River basin (Seoane and López, 2007). Ecuador, on the other hand, faces an increase in generation capacity associated with an increment in precipitation on its largest hydroelectric generation Paute River basin (Buytaert *et al.*, 2011). In Brazil, the country with the largest installed hydroelectric capacity in the region, there are continuous efforts to improve the management of the system under variable climatic conditions (Lima and Lall, 2010). There are still unused generation capacity in river basins likes the Amazon (Soito and Freitas, 2011), but future climate conditions plus environmental concerns pose an important challenge for the expansion of the system (Freitas and Soito, 2009). According to Lucena *et al.* (2009) the systems in the south of the country (most significantly the Parana River system) could face a slight increase in energy production under an A2 scenario. However, the rest of the country's hydroelectric system, and especially those located in the North East region, would face a reduction in power generation, reducing the reliability of the whole system (Lucena *et al.*, 2009).

An obvious implication of the mentioned impacts is the need to find replacement for the energy lost due to climate change impacts. In this regards, a typical adaptation measure would be an increase in other forms of generation (see 27.3.6.2). Lower cost of adaptation measures have been studied for the Brazilian case (Lucena *et al*., 2010a), with results implying an increase in natural gas and sugarcane bagasse electricity generation in the order of 300 TWh, increase in operation costs in the order of 7 billion USD annually and 50 billion USD approximate in terms of investment costs by 2035. In the case of Chile, ECLAC (2009a) assumed that the loss in hydropower generation would be compensated by the least operating cost source available (not used probably at full capacity), which is a coal-fired power plant. In this case, the amount of electricity that needs to be replaced in average for the 2011-2040 period is around 18 TWh of electricity, a little over 10% of actual total hydropower generation capacity in the country (ECLAC, 2009a). According to the same study (ECLAC, 2009a), this implies an increase in operating costs of the order of 100 million USD annually and an increase of 2 $MTCO_2e$ (total emissions from the electricity generation subsector in Chile are around 25 $MTCO_2e$ in 2009). Ospina-Noreña (2011a; 2011b) studied some adaptation options, such as changes in water use supply efficiency or demand growth, could mitigate the expected impacts on the operation of hydropower systems in the Colombian Sinú-Caribe River basin.

Some other implications are, for instance, the changes in the seasonality of inflows to hydropower generation systems such as those projected for Peru (Juen *et al*., 2007), Chile (ECLAC, 2009a) or Argentina (Seoane and López, 2007) that could have implications on the relationship between different water users within a basin. In Chile for example, the loss in snowpack accumulation due to temperature increase could reduce significantly spring and summer streamflows affecting water supply to agriculture irrigation that depends on the naturally flowing water through that period. This could introduce future economic and social conflicts on the relation between these two sectors that share the compsumtion of water resources from the same river basin. It is also interesting to note that in those regions which are projected to face an increase in streamflow and associated generation capacity, such as Ecuador or Costa Rica, also share difficulties in managing deforestation, erosion and sedimentation which limits the useful life of reservoirs (see section 27.3.1.1.). In these cases it is important to consider these effects in future infrastructure planning, and also enhance the on-going process of recognizing the value of the relation between ecosystem services and hydropower system operations (Leguía *et al*., 2008) (see more on PES in section 27.3.2.2.).

27.6.2. Case Study II

[placeholder SOD]

27.7. Data and Research Gaps

[to be included in the next version]

27.8. Conclusions

[to be completed in the next version]

[INSERT FIGURE 27-6 HERE
Figure 27-6: Summary of observed changes in CA and SA: changes in climate/hydrology, forest coverage, and glacier retreat.]

[PLACEHOLDER: SOD Figure 27-7: Detection and Attribution of Observed Climate Change Impacts]

Frequently Asked Questions

[provisional FAQs, with answers forthcoming]

- ***FAQ 27.1: What is the impact of receding glaciers on natural and human systems in the tropical Andes?***
- ***FAQ 27.2: Can PES be used as an effective way for helping local communities to adapt to climate change?***
- ***FAQ 27.3: Are there emerging and re emerging human diseases as a consequence of climate variability and change in the region?***
- ***FAQ 27.4: Will biofuels interfere with food security and biodiversity?***
- ***FAQ 27.5: Are there examples in the region of adaptation to observed increases in extreme events?***

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Table 27-1: Regional observed changes in temperature, precipitation, river runoff and climate extremes in various sectors of CA and SA. Additional information on changes in observed extremes can be found in the IPCC SREX (IPCC, 2012).

Region	Period	Observed trends	References
CA and Northern SA			
Increase of precipitation in the North American Monsoon region during the onset season	1943-2002	+0.94 mm/day/58 years	Englehart and Douglas (2006)
Positive runoff trends of the Magdalena river in Colombia	1948-2008	+0.5 mm/day/50 years	Dai *et al*. (2009),
West Coast of SA			
SST and air temperatures off coast of Peru and Chile (15S-35S)	1960-2010	-0.25C/decade	Gutiérrez *et al*. (2011a; 2011b), Falvey and Garreaud (2009)
Cooling, reduction of precipitation, cloud cover, and number of rainy days since the middle 1970´s off coast of Chile (18S-30S)	1920-2009	-1 C/40 years, -1.6 mm/40 years, -2 octs/40 years, and -0.3 days/40 years	Schulz *et al*. (2011)
Reduction in the % of wet days until 1970, increase after that, reduction in the precipitation rate in southern Chile (37S-43S)	1900-2007	-0.34% until 1970 and +0.37 after that, -0.12 %	Quintana and Aceituno (2012)
Increase of warm nights in the coast of Chile	1961-1990	+5 to +9%/31 years	Dufek *et al*. (2008)
Increase dryness as estimated by the Palmer Drought Severity Index (PDSI) for most of the west coast of SA (Chile, Ecuador, Northern Chile)	1950-2008	-2 to -4 / 50 years	Dai (2011)
Decrease in heavy precipitation (R95) in northern and central Chile	1961-1990	-45 to -105 mm/31 years	Dufek *et al*. (2008)
SESA			
Increase in mean annual air temperature in southern Brazil	1913-2006	+1.7 C/100 years	Sansigolo and Kayano (2010)
Decrease in the frequency of cold days and nights, increase in warm days in Argentina and Uruguay	1935-2002	-1.2%/decade, -1%/decade/, +0.2%/decade	Rusticucci end Renom (2008)
Increase in the highest annual maximum temperature and in the lowest annual minimum air temperature in Argentina and Uruguay	1956-2003	+0.8 C/47 years, +0.6C/47 years	Rusticucci and Tencer (2008)
Increase in the frequency of warm nights in Argentina and Uruguay and southern Brazil	1960-2009	10-20%	Rusticucci (2012)
Increase in warm nights in most of the region	1961-1990	+7 to +9%/31 years	Dufek *et al*. (2008)
Decrease in cold nights in most of the region	1961-1990	-5 to -9%/31 years	Dufek *et al*. (2008)
Increase of consecutive dry days (CDD) in northern Argentina, northern Chile, Bolivia and Paraguay and decrease of CDD in SA South of 30 S	1961-1990	+15to +21 days/31 years, -21 to -27 days/31 years	Dufek *et al*. (2008)
Reduction in the number of dry months during the warm season October-March in the Pampas region between 25S-40S	1904-2000	From 2-3 months in 1904-1920 to 1-2 months from 1980-2000	Barrucand *et al*. (2007)
Increase in moister conditions as estimated by the Palmer Drought Severity Index (PDSI) in most of SESA	1950-2008	0 to 4/50 years	Dai (2011)
Positive rainfall trends in the Parana River	1948-2008	+1.5 mm/day/50 years	Dai *et al*. (2009)

Positive rainfall trends in the Parana River Basin	1948-2008	+1.5 mm/day/50 years	Dai *et al*. (2009)
Increase in heavy precipitation (R95) in most of the region	1961-1990	+45 to +135 mm/31 years	Dufek *et al*. (Dufek *et al*., 2008)
Increase in heavy precipitation (R95) in the state of Sao Paulo	1950-1999	+50 to +75 mm/40 years	Dufek and Ambrizzi (2008)
Decrease in consecutive dry days (CDD) in the state of Sao Paulo	1950-1990	-25 to-50 days/40 years	Dufek and Ambrizzi (2008)
Lightning activity increases significantly with increasing temperature in the state of Sao Paulo	1951-2006	+40% per 1_C for daily and monthly timescales and approximately 30% per 1_C for decadal timescale	Pinto and Pinto (2008)
Increase in the number of days with rainfall above 20 mm in the city of Sao Paulo	2005-2011	+5 to +8 days/11 years	Marengo *et al*. (2012a), Silva Dias *et al*. (2012)
Increase in excess rainfall events duration after 1950	1901-2003	+ 21 months/53 yars	Krepper and Zucarelli (2010b)
Decrease in dry events and events of extreme dryness from 1972 to 1996	1900-2005	-29 days/24 years	Vargas *et al*. (2011)
Andes			
Increase in mean maximum temperature along the Andes, and increase in the number of frost dates	1921-2010	+0.10-12 C /decade in 1921-2010, and +0.23-0.24 C/decade during 1976-2010; 8 days/decade during 196-2002	Marengo *et al*. (2011)
Increase in air temperature and changes in precipitation Northern Andes (Colombia, Ecuador)	1961-1990	+0.1 C to +0.22 C/decade, -4 to +4 %/decade years	Villacís (2008)
Increase in temperature and precipitation in northern and central Andes of Peru	1963-2006	+0.2-0.45C/decade, -20 to -30%/40 years	SENAMHI (2005; 2007; 2009a; 2009b; 2009d)
Increase in temperature and changes in precipitation in the southern Andes of Peru	1964-2006	+0.2 to 0.6 C/decade, -11 to +2 mm/decade	SENAMHI (2007; 2009a; 2009b; 2009c; 2009d); Marengo *et al*. (2011)
Increase in air temperature and rainfall reduction Argentinean and Chilean Andes and Patagonia	1950-1990	+0.2 to 0.45 C/decade, -10 to -12%/decade	Falvey and Garreaud (2009), Masiokas *et al*. (2008), Villalba *et al*. (2003)
Increase in dryness in the Andes between 35.65 S-39.9 S using the PDSI	1950-2003	-7 PDSI/53 years	Christie *et al*. (2011)
Strong rainfall decrease in the Mantaro Valley, central Andes of Peru	1970-2005	-44 mm/decade	SENAMHI (2009d)
Increase in air temperature in Colombian Andes	1959-2007	+1 C/20 years	Poveda and Pineda (2009)
Amazon region			
Decadal variability of rainfall in northern and southern Amazonia	1920-2008	-3 STD/30 years in northern Amazonia and +4 STD/30 years in southern Amazonia since the middle 1970's	Marengo *et al*. (2009), Satyamurty *et al*. (2010)(Marengo *et al*., 2009)
Decrease in rainfall in all the region	1975-2003	-0.32 %/28 years	Espinoza *et al*. (2009; 2009)
Delay on the onset of the rainy season in southern Amazonia	1950-2010	-1 month since 1976	Butt *et al*. (2011), Marengo *et al*. (2011)

Spatially varying trends of heavy precipitation (R95), increase in many areas and insufficient evidence in others	1961-1990	+100 mm/31 years in western and extreme eastern Amazonia,	Marengo *et al*. (2009)
Spatially varying trends in dry spells in (CDD), increase in many areas and decrease in others	1961-1990	+15 mm/31 years in western Amazonia, -20 mm/ in southern Amazonia	Marengo *et al*. (2009; 2010)
Negative runoff trends of the Amazon River	1948-1968	-1.5 mmday/50 years	Dai *et al*. (2009), Dai (2011)
Positive runoff trends of the Tocantins River	1948-1968	+0.5 mmday/50 years	Dai *et al*. (2009), Dai (2011)
Positive rainfall trends in most of Amazonia and negative trends in western Amazonia	1948-2008	+1 mm/day/50 years, -1.5 mm/day/50 years	Dai *et al*. (2009), Dai (2011)
Increased dryness as estimated by the Palmer Drought Severity Index PDI in southern Amazonia and moister conditions in western Amazonia	1950-2008	-2 to -4/50 years, +2 to +4 /50 years	Dai (2011)
Decrease of seasonal mean convection and cloudiness	1984-2007	+30 W/m^2/23 years, -8 %/23 years	Arias *et al*. (2011)
Delayed onset of rainy season in southern Amazonia due to land use change	1970-2010	-0.6 days/30 years	Butt *et al*. (2011)
Northeast Brazil			
Negative runoff trends in the Sao Francisco River	1948-2008	-2 mm/day/50 years	Dai *et al*. (2009), Dai (2011)
Negative rainfall trends interior Northeast Brazil and positive trends in northern Northeast Brazil	1948-2008	-0.3 mm/day/50 years, +1.5 mm/day/50 years	Dai *et al*. (2009), Dai (2011)
Positive trends in heavy precipitation (R95) in some areas, negative trends in others in southern Northeast Brazil	1970-2006	-2 mm/24 years to + 6 mm/24 years,	Silva and Azevedo (2008)
Negative trends in consecutive dry days CDD in most of southern Northeast Brazil	1970-2006	-0.99 days/24 years	Silva and Azevedo (2008)
Increase in total annual precipitation in northern Northeast Brazil	1970-2006	+1 to +4 mm/year/24 years	Santos and Brito (2007)
Spatially varying trends in heavy precipitation (R95) in northern Northeast Brazil	1970-2006	-0.1 to +5 mm/yeas/24 years	Santos and Brito (2007)
Spatially varying trends in heavy precipitation (R95) and consecutive dry days (CDD) in northern Northeast Brazil	1935-2006	-0.4 to +2.5 mm/year/69 years, -1.5 to +1.5 days/year/69 years,	Santos *et al*. (2009)
Increase dryness in Southern Northeast Brazil as estimated by the PDSI, and moister conditions in northern Northeast Brazil	1950-2008	-2 to -4/50 years, 0 to +1/50 years	Dai (2011)

Table 27-2: Regional projected changes in temperature, precipitation, river runoff and climate extremes in different sectors of CA and SA. Various studies used A2 and B2 scenarios and different time slices from 2010 to 2100. In order to make results comparable, the A2 scenario and the time slice ending in 2100 are included. Additional information on changes in projected extremes can be found in the IPCC SREX (see IPCC, 2012).

Region	Models and scenarios	Projected changes	References
CA and Northern SA			
Decrease in LAI, increase in evapotranspiration by 2070-2099 in CA	23 CMIP3 models, A2	Evapotransp: +20%; LAI:-20%+0.94 mm/day/58 years	Imbach *et al*. (2012)
Increases in temperature by 2075 and 2100 in CA	9 CMIP3 models, A2	+2.2 C by 2075; +3.3 C by 2100	Aguilar *et al*.. (2009)
Rainfall reductions in CA, and increases in Venezuela. Increase in air temperature in the region	20 km MRI JMA model, A1B	Rainfall decrease/increase of about -10%/+10%, by 2079. Temperature increases of about +2.5-+3.5 C by 2079	Hall *et al*. (2009)
Decrease in precipitation and increase of evaporation was projected to increase in most of the region. Soil moisture in most land areas were projected to decrease in all seasons.	20 km MRI JMA model, A1B	Precipitation decrease of about -5 mm/day, evaporation increase of about +3 to +5 mm/day; soil moisture to decrease by -5 mm/day.	Nakaegawa *et al*. (2012)
Rainfall reductions in Nicaragua, Honduras, Northern Colombia and Northern Venezuela, increases in Costa Rica and Panama. Temperature increases in all region by 2071-2100	PRECIS forced by the HadAM3, A2	Rainfall: -25 to -50%, and +25 to +50%. Temperature: +3 to +6 C	Campbell *et al*. (2011)
Increase of precipitation and temperature in northern SA, decrease in interior Venezuela, temperature increases by 2071-2100	Eta forced with HadCM3, A1B	Increases by +30 to 50%, and reductions between -10 to -20%; temperature: +4 to +5 C;	Marengo *et al*. (2011)
Reduction in precipitation and temperature increases by 2100 in CA	PRECIS forced with HadAM3, A2	Precipitation: -24 to -48%; temperature: +4 to -5 C	Karmalkar *et al*. (2011)
Increase in warm nights, consecutive dry days and reduction in heavy precipitation in Venezuela, by 2100	PRECIS forced with HadAM3, A2	Increase by +12 to _18%, +15 to +25 days and reduction of 75 to 105 days	Marengo *et al*. (2009; 2010)
Increase in temperature, decrease in precipitation by 2100	23 CMIP3 models, A1B	Incfease by +3 to +5 C; reduction by -10 to -30%	Giorgi and Diffenbaugh (2008)
Increase in consecutive dry days and in heavy precipitation by 2099	20 km JMA-MRI model, A1B	Increase by +5 days and bdtwen +2 to +8 %	Kamiguchi *et al*. (2006)
West Coast of SA			
Decrease of precipitation, runoff and increase of temperature at the Limari river basin in semi-arid Chile by 2100	PRECIS forced with HadAM3, A2	Precipitation: -15 % to -25%; runoff: -6 to -27%; temperature: + 3 to +4 C	Vicuña *et al*. (2011)

Warming and increase of surface winds in west coast of SA (Chile) by 2100	15 CMIP3 models, PRECIS forced with HadAM3, A2	Temperature: +1 C; coastal winds: +1.5 m/sec	Garreaud and Falvey (2009)
Precipitation increase in the bands 5N-10S, and 25S-30S, reduction between 10S-25S and 30S-50S; temperature increase between by 2100	Eta model forced with HadCM3, A1B	Increases of 30-40%, rediction of 10-20%; increases of 3-5 C	Marengo *et al*. (2011)
Increase in warm nights, reduction in consecutive dry days, and increase in heavy precipitation in 5N-5S by 2100	PRECIS forced with HadAM3, A2	Increase of +3 to +18%, rediction of -5 to – 8 days, increase by +75 to +105 days	Marengo *et al*. (2009; 2010)
Increase of air temperature, increase of precipitation between 0 and 10S, reduction between 20 and 40S by 2100	23 CMIP3 models, A1B	Increase of -2 to -3 C; increase by 10%, reduction by -10 to -30%	Giorgi and Diffenbaugh (2008)
Increase of consecutive dry days between 5 N and 10 S and south of 30S, increase of heavy precipitation between 5S-20S and south of 20S by 2099	20 km MRI JMA, A1B	Increase by 10 days and between +2 to +10%	Kamiguchi *et al*. (2006)
Decrease of precipitation between 15 and 35 S and increase south of 40S, increase of precipitation by 2100	MM5 forced with HadAM3, A2	Decrease of -2 mm/day, increase of 2 mm/day, increase of +2.5 C	Nuñez *et al*. (2009)
Decrease of precipitation in Panama and Venezuela, increase of heavy precipitation in Panama and reduction in Venezuela, reduction of consecutive dry days over Panama and Colombia by 2099	RCA forced with ECHAM5-MPI OM model, A1B	Reduction of -1 to -3 mm/day,	Sörensson *et al*. (2010)
SESA			
Increase in precipitation and runoff, an in air temperature by 2100	Eta forced with HadCM3, A1B	Precipitation: + 20 to +30%; Runoff: +10 to +20%; air temperature: 2.5 to 3.5 C	Marengo *et al*. (2011)
Increases in precipitation and temperature in the La Plata basin by 2050	MM5 forced with HadAM3, A2	Precipitation: _+0.5 to 1.5 mm/day; temperature: +1.5 C to 2.5 C.	Cabre *et al*. (2010)
Increase in warm nights, consecutive dry days and heavy precipitation by 2100	7 CMIP3 models, A1B	Warm nights: +10 to +30%; Consecutive dry days: +1 to +5 days; Heavy precipitation: +3 to +9 %.	Menendez and Carril (2010)
Increase in precipitation during summer and spring, and reduction in fall and winter by 2100	9 CMIP3 models, A2	Increase pof + 0.4 to +0.6 mm/day, reduction of -0.02 to -0.04 mm/day	Seth *et al*. (2010)
Increase in warm nights, consecutive dray days and heavy precipitation by 2100	PRECIS forced with HadAM3, A2	Increase of +6 to +12%, +5 to +20 days, +75 to +105 days	Marengo *et al*. (2009; 2010)
Increase in temperature and rainfall by 2100	23 CMIP3 models, A1B	Increase by +2 to _+4 C, increase by +20 to +30 %	Giorgi and Diffenbaugh (2008)
Increase in consecutive dry days and in heavy precipitation by 2099	20 km MRI-JMA model, A1B	Increase by +5 to +10% and by +2 to +8 %	Kamiguchi *et al*. (2006)

Increase of precipitation in north central Argentina, decrease in southern Brazil, increase of air temperature by 2100	MM5 forced with HadAM3, A2	Increase of +_0.5 to +1 mm/day, reduction of -0.5 mm/day, increase of +3 to +4.5 C	Nuñez *et al*. (2009)
Increase of precipitation, heavy precipitation, reduction of consecutive dry days in the eastern part of the region, increase in the western part of the region by 2099	RCA forced with the ECHAM5 mode, A1B	Increase of +2 mm/day, of +5 to +15 mm, reduction of -10 days and incrarse of +5 days	Sörensson *et al*. (2010)
Andes			
Reduction of precipitation and temperature, increase by 2100 in the Altiplano	11 CMP3 models, A2	Precipitation: -10 to -30 %; temperature:>3 C	Minvielle and Garreaud (2011)
Precipitation increase at 5N-5S, and 30S-45 S, decrease at 5-25 S; temperature increases by 2100	Eta forced with HadCM3, A1B	Increase between +10 and +30%, decrease by -20 t -30%, increase of +3.5 to 4.5 C	Marengo *et al*. (2011)
Increase in warm nights, reduction of heavy precipitation and consecutive dry days south of 15 S by 2100	PRECIS forced with HadAM3, A2	Increase by +3 to +18%, reduction by -10 to -20 days, and -75 to -105 days	Marengo *et al*. (2009)
Increase in temperature, rainfall increase between 0-10S and reduction between 10-40 S	23 CMIP3 models, A1B	Increase by +3 to +4 C, increase by 10% and reduction by -10%	Giorgi and Diffenbaugh (2008)
Reduction of consecutive dry days and increase of heavy precipitation by 2099	20 km MRI-JMA model, A1B	Reduction by -5 days, increase by +2 to +4 % south of 20S	Kamiguchi *et al*. (2006)
Increase in precipitation, heavy precipitation, and consecutive dry days by 2099	RCA forced with ECHAM5, A1B	Increases of +1 to +3 mm/day, +5 mm and of +5 to +10 days	Sörensson *et al*. (2010)
Amazon region			
Rainfall reduction in central and eastern Amazonia, increase in western Amazonia, warming in all region by 2100	Eta forced with HadCM3, A1B	Precipitation: -20 top -30%, +20 to +30%; temperature: +5 to +7 C	Marengo *et al*. (2011)
Reduction in the intensity of the South Atlantic Convergence Zone and in rainfall in the South American monsoon region, 2081-2100	10 CMIP3 models, A1B	Precipitation: -100 to -200mm/20 years	Bombardi and Carvalho (2009)
Small increases of precipitation in western during summer and decreases in winter in Amazonia by 2100	5 CMIP3 models, A2 and ANN	+1.6% in summer and -1.5% in winter	Mendes and Marengo (2010)
Increase in the number of South American Low Level Jet east of the Andes events (SALLJ), and in the moisture transport from Amazonia to the La Plata basin by 2090	PRECIS forced by HadAM3, A2	+50 events of SALLJ during summer, increase in moisture transport by 50%	Soares and Marengo (2009)
Increase of precipitation in the South American monsoon during summer and spring, and reduction during fall and winter by 2100	9 CMIP3 models, A2	Increase of +0.15 to +0.4 mm/, reductions of -0.10 to -0.26 mm/day	Seth *et al*. (2010)

Increase in warm nights, increase of consecutive dry days in eastern Amazonia, increase of heavy precipitation in western Amazonia and reduction in eastern Amazonia by 2100	PRECIS forced with hadAM3, A2	Increase of +12 to +15%, by 25-30 days in eastern Amazonia, increase in western Amazonia by 75-105 days and rediction by -15 to 75 days in eastern Amazonia	Marengo *et al*. (2009)
Increase in air temperature, rainfall increase in western Amazonia and decrease in eastern Amazonia by 2100	CMIP3 models, A1B	Increase of +4 to +_6 C, increase of +10% and decresase between -10 to -30%	Giorgi and Diffenbaugh (2008)
Reduction of consecutive dry days and increase in heavy precipitation by 2099	20 km MRI-JAM model, A1B	Reduction of -5 to -10 days, increase by +2 to +8 %	Kamiguchi *et al*. (2006)
Increase of precipitation in western Amazonia, reduction of heavy precipitation in northern Amazonia and increase in southern Amazonia, reduction of consecutive dry days in western Amazonia and increase in eastern Amazonia by 2099	RCA forced with the ECHAM5 mode, A1B	Increase of +1 to +_3 mm/day, reduction of -1 to -3 mm, in crease of +5 to _10 mm, decrease of -5 to -10 days, increase by +20 to +30 days	Sörensson *et al*. (2010)
Northeast Brazil			
Rainfall reduction in the entire region, temperature increases by 2100	Eta forced with HadCM3, A1B	Precipitation: -20 to -20%; temperature: +3 to +4 C	Marengo *et al*. (2011)
Increase of warm nights, of consecutive dry days, and reduction of heavy precipitation by 2100	PRECIS forced with HadAM3, A2	Increase by +18 to +24%, by +25 to +30 days and -15 to –75 days	Marengo *et al*. (2009)
Increase in temperature, reductions in precipitation by 2100	23 CMIP3 models, A1B	Increase of +2 to +4 C, reduction of -10 to -30%	Giorgi and Diffenbaugh (2008)
Reduction of consecutive dry days and increase in heavy precipitation by 2099	20 km MRI-JMA model, A1B	Reduction of -5 to -10% and increase of +2 to +6 %	Kamiguchi *et al*. (2006)
Increase of precipitation, in heavy precipitation and consecutive dry days by 2099	RCA foeced with ECHAM5 model, A1B	Increase of +1 to +2 mm/day, increase by +5 to +10 mm, and increase by +10 to +30 days	Sörensson *et al*. (2010)

Table 27-3: Observed trends related to Andean cryosphere.
a) Andean tropical glacier trends since the Little Ice Age (LIA) maximum and, particularly, during the last decades

Country	**Documented massifs (latitude)**	**Significant changes recorded and reference** (dates in AD)	**References**
Venezuela	*Cordillera de Merida (10°N)*	Four glacial advances between 1250 and 1810. Glaciers have been rapidly retreating since at least 1870. ELA raised up by ~300-500m between LIA maximum and today. Accelerated melting since 1972. Remaining glaciers are at risk of disappearing completely in the next years since ELA lies near to the Pico Bolivar summit (4979m).	Polissar *et al*. (2006); Morris *et al*. ((2006)
Colombia	*Parque Los Nevados (4°50N)* *Sierra Nevada del Cocuy 56°30N)* *Sierra Nevada de Santa Marta (10°40N)*	LIA maximum occurred between 1600 and 1850. Loss of 60-84% in glacierized areas during the 1850-2000 period and many small/low elevation glaciers have disappeared. In the past 50yrs, 50% of glacier areas have been lost, and in the past 15yrs 10-50%. Since 2000, glaciers retreated at a rate of 3.0km²/yr. Glacier areas total 45km² in Colombia in 2011.	Ruiz *et al*. (2008); Ceballos *et al*. (2006); Poveda and Pineda (2009)
Ecuador	*Antisana (0°28S)* *Chimborazo and Carihuayrazo (1°S)* *Ecuadorian volcanoes*	LIA maximum occurred in around 1720 and 1830 (Chimborazo). Historical evidences of ELA at 4700±50m in around 1740. ELA raised up 300m between the middle 18th and the last decades of the 20th (~200m during only the 20th century). A slight glacier reduction was reported between 1956 and 1976, but in the 1976-2006 period, glacier areas lost ~45%. Glaciers at low elevation (<5300m) are in process of extinction. Glaciers in Ecuador total less than 50km² in 2011.	Francou (2004); Jordan *et al*. (2005); Jomelli *et al*. (2009); Cáceres *et al*. (2006)
Peru	*Cordillera Blanca (9°S)*	LIA maximum occurred in around 1630±27. Loss of 12-17% of glaciers during the 18th century, and 17-20% during the 19th. Rapid retreat in the 1930s-1940s and from 1976-80. ELA increased by ~100m from the LIA maximum to the beginning of the 20th century, and by more than 150m during only the 20th century. The lost of glacial area reported by several teams since the 1960s to the 2000s converge on a range of 20-35% Physical observations of the Yanamarey glacier show acceleration in frontal retreat at a rate of 8 m decade^{-1} since 1970, accompanied by total volume loss on the order of 0.022 km Increase of 1.6 (± 1.1) percent in the specific discharge of the more glacier-covered catchments (>20 percent glacier area) Seven out of nine watersheds exhibit decreasing dry-season discharge. Median (out of 9 glaciers analyzed) average ice area loss of 0.61% a^{-1}. Glaciers of Coropuna have retreated by 26% between 1962 and 2000	Kaser and Georges (1997); Georges {{1967 Georges,C. 2004/a;}}; Mark and Seltzer (2005); Silverio and Jaquet (2005); Raup *et al*. (2007) Jomelli *et al*. (Jomelli *et al*., 2009); UGRH (2010); Bury *et al*. (2011) Mark *et al*. (2010); Baraer *et al*. (2012)
	Coropuna volcano (15°33S)	Glaciers of Coropuna receded by 26% between 1962 and 2000	Racoviteanu *et al*. (2007)
	Cordillera Vilcanota (13°55S)	Qori Kalis glacier receded in the 1991-2005 period 10 times faster than during the 1963-2005 period	Thompson *et al*. (2006; 2011)

Bolivia	*Cordillera Real and Cordillera Quimza Cruz (16°S)*	On the Telata glacier, strong melting after the maximum extent occurred from 10.8±0.9 to 8.5±0.4kyr ago, followed by a slower retreat until the Little Ice Age, about 200 years ago. The LIA maximum is dated between 1657±20 and 1686±20 in the north of Bolivia. Between the LIA maximum and the late 20th century, the ELA increased by 300m (180-200m during the only 20th century). Proxy of vertical englacial temperature in Bolivia (Illimani, 6340m, 16°S) shows two warming phases from AD 1900 to 1960 (+0.5±0.3 K) starting in 1920-1930 and from 1985 to 1999 (+0.6±0.2K), corresponding to a mean atmospheric temperature rise of 1.1±0.2 K over the 20th century. From 1956 to 1963-1976, glaciers were near the equilibrium, but the recession was very strong after 1976. Small glaciers at low elevation (<5300-5400m) are in process of extinction (Chacaltaya vanished in 2009). Since 1991, Zongo glacier (6000-4900m) has lost a mean of 0.4m we/yr and only 20% of the mass balances measured in the 1991-2011 period have been positive or near the equilibrium. Glaciers of the Cordillera Real have lost 43% of their volume between 1963 and 2006, essentially over the 1976-2006 period, and 48% of their surface area between 1976 and 2006. Studies of sensitivity have shown that during the October-March wet period, crucial for the year mass balance, +1°C temperature increases the ELA by ~200m.	Jomelli *et al*. (2011) Rabatel *et al*. (2005) Rabatel *et al*. (2006; 2008); Gilbert *et al*. (2010); Soruco *et al*. (2009); Lejeune (2007)
	Sur Lipez, Caquella, 21°30S	Evidence of recent degradation of Caquella rock glacier	Francou *et al*. (1999)

b) Extra tropical Andean cryposphere (glaciers, snowpack, runoff effects) trends.

Region	Documented massifs/latitude	Significant changes recorded and reference	References
Andes of Chile, Argentina and Bolivia and Argentinan Patagiona	*Snow cover extent*	The 1979–2006 period shows a sinusoidal like pattern for both snow cover and snow mass, though neither trend is significant at the 95% level.	Foster *et al*. (2009)
Dessert Andes *(17°S-31°S)*	*Review on extra tropical glaciers*	Most areas in the Andes of extratropical SA have experienced a general pattern of glacier recession and significant ice mass losses	Masiokas *et al*. (2009)
	Huasco basin glaciers (29°S)	Glacier mass loss is evident over the study period, with a mean of –0.84m w.e. yr–1 for the period 2003/2004–2007/2008	Nicholson *et al*. (2009); Rabatel *et al*. (2011); Gascoin *et al*. (2011)
Central Andes *(31°S-36°S)*	*Review on extra tropical glaciers*	Most areas in the Andes of extratropical SA have experienced a general pattern of glacier recession and significant ice mass losses	Masiokas *et al*. (2009)
	Piloto/Las Cuevas (32°S)	Within the 24-year period, 67% of the years show negative net annual specific balances, with a cumulative mass balance loss of - 10.50 m w.e.	Leiva *et al*. (2007)
	Aconcagua basin glaciers (33°S)	Reduction in glacier area of 20% (0.63km^2a^{-1}) over last 48 years. Glaciar Juncal Norte, exhibits a smaller reduction (14%) between 1955 and 2006.	Nicholson *et al*. (2009); Bown *et al*. (2008)
	Central Andes glaciers (33–36 °S)	All studied glaciers exhibited a negative trend during the 20th century with mean frontal retreats between –50 and –9my^{-1}, thinning rates between 0.76 and 0.56 my^{-1} and a mean ice area reduction of 3% since 1955.	Le Quesne *et al*. (2009)
	ELA across central Andes	Carrasco *et al*. (2005) Que paso?	Carrasco *et al*. (2005)
	Snowpack (30 °S -37°S)	Marked interannual variability, and a positive, though nonsignificant, linear trend for period (1951–2005)	Masiokas *et al*. (2006)
	Morenas coloradas rock glacier (32 °S -33°S)	A significant change in the active layer and suprapermafrost possibly associated with warming processes.	Trombotto and Borzotta (2009)
	Mendoza river streamflow	Possible link to rising temperatures and snowpack/glacier effects. Not conclusive.	Vich *et al*. (2007)
	Aconcagua basin streamflow	Significant decrease in streamflow that could be explained by a progressive change in glaciers area and volume in the basin.	Pellicciotti *et al*. (2007)
	Streamflow from basins between 28 °S and 47 °S	Not significant increase in February run-off trends for period 1950–2007 that might suggest an increase of glacier melt in the Andes.	Casassa *et al*. (2009)
	Streamflow timing between 30 °S and 40 °S	Significant (95% confidence level) negative trend (CT date shifting towards earlier in the year) for 23 out of the 40 analyzed series. More relevant is precipitation rather than temperature.	Cortés *et al*. (2011)

Patagonian Andes *(36°S-55°S)*	*Review on extra tropical glaciers*	Most areas in the Andes of extratropical SA have experienced a general pattern of glacier recession and significant ice mass losses	Masiokas *et al*. (2009)
	Casa Pangue glacier (41°S)	Between 1961 and 1998, mean thinning rate of -2.3 ± 0.6 m a^{-1}. When ice thinning is computed for the period between 1981 and 1998, the resulting rate is 50%higher (-3.6 ± 0.6 m a^{-1}).	Bown and Rivera (2007)
	North Patagonian Icefield (NPI)	Glacial lake outburst flood (GLOF) interpreted as a delayed paraglacial response to the retreat of Calafate glacier during the twentieth century.	Harrison *et al*. (2006)
	Southern Patagonia Icefield (SPI)	Retreating glaciers with larger rates observed on the west side coinciding with lower elevations of the ELAs (relative to the east side).	Barcaza *et al*. (2009)
	NPI, SPI and the Cordillera Darwin Icefield (CDI)	The majority of glaciers have retreated between 1945 and 2005 with maximum values of 12.2 km for Marinelli Glacier in the CDI, 11.6 km for O'Higgins Glacier in the SPI and 5.7 km for San Rafael Glacier in the NPI	Lopez *et al*. (2010)
	Cordón Martial glaciers (54 °S)	Ice loss rate for the period April 2002-December 2006 of 27.9 ± 11 km3/year, equivalent to an average loss of -1.6 m/year of ice thickness.	Chen *et al*. (2007)
	Gran Campo Nevado (GCN) (53 °S)	Glaciers slowly reciding from Late Little Ice Age (LLIA). Acceleration started 60 years ago	Strelin and Iturraspe (2007)
		All major glaciers of the GCN show a significant glacier retreat during the last 60 yr. Some of the outlet glaciers lost more than 20% of their total area during this period. Overall glacier retreat amounts to 2.8% of glacier length per decade and the glacier area loss is 2.4% per decade in the period from 1942 to 2002.	Schneider *et al*. (2007)
	Proglacial lakes located in Andean Patagonia between ~40°S and ~50°S	Summertime negative trend on lakes with a direct influence of glaciers interpreted as an indication that melt water is decreasing because the ice volume reduction.	Pasquini *et al*. (2008)
	Northwestern Patagonia between ca. 38° and 45°S.	Recession of 6 glaciers based on areal photograph analysis.	Masiokas *et al*. (2008)
	Streamflow from basins between 28 °S and 47 °S	Not significant increase in February run-off trends for period 1950–2007 that might suggest an increase of glacier melt in the Andes.	Casassa *et al*. (2009)

Table 27-4: Synthesis of projected climate change impacts on hydrologic variables in large South American basins and major glaciers.

Region	Basins studied	Flow/glacier changes	Period	GCM	Scenarios	References
La Plata Basin and SESA	Paraná	Average change + 4.9% (not robust) Increase in runoff: +10 to +20%	2081-2100 2100	CMIP3 Eta forced with HadCM3	A1B A1B	Nohara *et al*. (2006) Marengo *et al*. (2011)
	Carcarañá	Increase in ET not compensated with increase in precipitation, slight reduction in recharge.	2010-2030	HadCM3	A2	Venencio and García (2011)
	Grande (Parana)	Range from +20 to -20%	Different periods	7 CMIP3 models	Prescribed temperature changes and emission scenarios	Todd *et al*. (2011) ; Gosling *et al*. (2011); Nóbrega *et al*. (2011)
	Itaipu (Parana)	2010–2040: Left bank: –5 to –15%; Right bank: +30% 2070-2100: 0 to –30%	2010–2040 and 2070-2100	CCCMA-CGCM2	A2	Rivarola *et al*. (2011)
Amazon Basin	Peruvian Amazon–Andes basin	Some basins increased flow, some reduced	Three time slices	BCM2, CSMK3 and MIHR	A1B, B1	Lavado Casimiro *et al*. (2011)
	Ecuador - Tomebamba/Paute	Large uncertainty with increase and reduction	2070-2100	CMIP3	A1B	Buytaert *et al*. (2011)
	Amazon at Obidos	Average change + 5.4% (not robust)	2081-2100	CMIP3	A1B	Nohara *et al*. (2006)
		+6%	2000-2100	ECBilt-CLIO-VECODE	A2	Aerts *et al*. (2006)
	Amazon -Orinoco	-20%	2050s	HadCM3	A2	Palmer *et al*. (2008)
Tropical glaciers	Colombian glaciers	Glacier disappearance by 2020s	linear extrapolation			Poveda and Pineda (2009)
	Cordillera Blanca basins	Runoff increase for next 20-50 years, reduction afterwards	2005-2020	Temperature output only	B2	Chevallier *et al*. (2011)
		2050: Glacier area is reduced by 38 to 60%. Increased seasonality 2080: Glacier area is reduced by 49 to 75%. Increased seasonality	2050 (climatology)	Not specified	A1, A2, B1, B"	Juen *et al*. (2007)
Central Andes	Maipo	Reduction up to 30%	Three periods	HadCM3	A2, B2	Melo *et al*. (2010); ECLAC (2009a)
	Maule, Laja	Reduction up to 30%	Three periods	HadCM3	A2, B2	McPhee *et al*. (2010); ECLAC (2009a)
	Bio Bio					Stehr *et al*. (2010)
	Limari	Reduction range -20 to -40%. Change in seasonality	2070-2100	HadCM3	A2, B2	Vicuña *et al*. (2011)
	Limay	Reduction range -10 to -20%.	2080s (climatology)	HadCM2	Not specified	Seoane and López (2007)

North East Brazil	Brazilian Federal States of Ceara´ and Piauı´	No significant change up to 2025. After 2025: strong runoff reduction with ECHAM4; slight runoff increase with HadCM2.	2000-2100	HadCM2, ECHAM4	Not clear	Krol *et al*. (2006); Krol and Bronstert (2007)
	Paracatu (Sao Francisco)	A2: +31 to +131%; B2: no significant change	2000-2100	HadCM3	A2, B2	De Mello *et al*. (2008)
	Jaguaribe	Increase in demand: +33 to +44%	2040	HadCM3	A2, B2	Gondim *et al*. (2008)
	Parnaiba	-80%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Mimoso catchment	Dry scenario: -25 to -75%; Wet scenario: +40 to + 140%; Similar changes in GW recharge	2010–2039, 2040–2069, and 2070–2099	CSMK3 and HadCM3	A2, B1	Montenegro and Ragab (2010)
	Benguê catchment	-15% reservoir yield	Sensitivity scenario in 2100 selected from TAR and AR4 GCMs with good skill. + 15% PET, -10% Precip			Krol *et al*. (2011)
North SA	Essequibo (Guyana)	-50%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Magdalena (Colombia)	Not significant changes in near future. End of 21st not consistent trend but changes in seasonality.	2015–2035 and 2075–2099	CMIP3 multi-model ensemble (MME)	A1b	Nakaegawa and Vergara (2010)
	Sinu (Colombia)	-2 to -35%	2010-2039	CCSRNIES, CSIROMK2B, CGCM2, HadCM3 (different runs of these models)	A2	Ospina-Noreña *et al*.(2009a; 2009b)
CA	Lempa	Statistically significant reduction of inflows in the order of 13% (B1) and 24% (A2).	2000-2100 (results presented for 2070-2100)	CMIP3	A2, B1	Maurer *et al*. (2009)
	Grande de Matagalpa	-70%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Mesoamerica (6.5-22 N and 76.5-99 W)	Runoff will decrease across the region (different magnitudes and uncertainty associated) even in areas where precipitation increases	2070-2100	CMIP3	A2, A1b, B1	Imbach *et al*. (2012)

Table 27-5: Cases of government-funded PES schemes in CA and SA.

Countries	Level	Start	Name	Benefits	References
Brazil	Sub-national (Amazonas state)	2007	*Bolsa Floresta*	By 2008, 2700 traditional and indigenous families already benefitted: financial compensation and health assistance in exchange for zero deforestation in primary forests.	Viana (2008)
Costa Rica	National	1997	FONAFIFO fund	PES is a strong incentive for reforestation and, for agroforestry ecosystems alone, over 7,000 contracts have been set since 2003, and nearly 2 million trees were planted.	Montagnini and Finney (2011)
Ecuador	National	2008	*Socio-Bosque*	By 2010, the program already included more than half a million hectares of natural ecosystems protected and has over 60,000 beneficiaries.	De Koning *et al*. (2011)
Guatemala	National	1997	Programa de Incentivos Forestales, PINFOR	By 2009, the program included 4,174 beneficiaries who planted 94,151 hectares of forest. In addition, 155,790 hectares of natural forest were under protection with monetary incentives.	Instituto Nacional de Estadística (2011)

Table 27-6: Impacts on agriculture.

Crop	Country	Time slice	SRES	CO2	Temperature	Rainfall	Yield Changes	Source
Maize	CA	2030	A2				0	ECLAC (2010c)
	CA	2050	A2				0	
	CA	2070	A2				-10	
	CA	2100	A2				-30	
	Brazil	2030					0 to -10	Lobell *et al.* (2008)
	Brazil NE						-20 to -30	Margulis *et al.* (2010)
	Argentina	2080	A2	No/Yes			-24 / +1	ECLAC (2010c)
		2080	B2	No/Yes			-15 / 0	
	Paraguay	2020	A2/B2	Yes			+3/+3	ECLAC (2010c)
		2050	A2/B2	Yes			+3/+1	
		2080	A2/B2	Yes			+8/+6	
	Andean Region	2020-2040					0 to -14	Lobell *et al.* (2008)
Soybean	Argentina	2080	A2	No/Yes			-25 / +14	ECLAC (2010c)
		2080	B2	No/Yes			-14 / +19	
	Paraguay	2020	A2/B2	Yes			0/0	ECLAC (2010c)
		2050	A2/B2	Yes			-10 / -15	
		2080	A2/B2	Yes			-15 / -2	
Bean	CA	2030	A2				-4	ECLAC (2010c)
		2050	A2				-19	
		2070	A2				-29	
		2100	A2				-87	
	Brazil NE						-20 to -30	Margulis *et al.* (2010)
	Paraguay	2020	A2	Yes			-1	ECLAC (2010c)
		2050	A2	Yes			+10	
		2080	A2	Yes			+16	
Rice	CA	2030	A2	Yes?			+3	ECLAC (2010c)
		2050	A2	Yes?			-3	
		2070	A2	Yes?			-14	
		2100	A2	Yes?			-63	
	CA	2020-2040					0 to -10	Lobell *et al.* (2008)
	Brazil	2030					-1 to -10	
	Brazil NE						-20 to -30	
Wheat	CA						-1 to -9	Lobell *et al.* (2008)
	Brazil						-1 to -14	Lobell *et al.* (2008)
	Argentina	2080	A2	No/Yes			-16 / +3	ECLAC (2010c)
			B2	No/Yes			-11 / +3	
	Paraguay	2020	A2/B2				+4 / -1	ECLAC (2010c)
		2050	A2/B2				-9 / +1	
		2080	A2/B2				-13 / -5	
	Andean Region	2020-2040					-14 to +2	Lobell *et al.* (2008)

Barley	Andean Region	2020-2040					-1 to -8	Lobell *et al.* (2008)
Potato	Andean Region	2020-2040					0 to -5	Lobell *et al.* (2008)
Cassava	Brazil	2030					0 to -10	Lobell *et al.* (2008)
	Paraguay	2020	A2				+16	ECLAC (2010c)
		2050					+22	
		2080					+22	
Annual Crops	Uruguay	2030	A2/B2				+185 / +92 *	ECLAC (2010c)
		2050	A2/B2				-194 / +169 *	
		2070	A2/B2				-284 / +169 *	
		2100	A2/B2		3.1C / +2.3C	+6% to +8%	-508 / +169 *	
Livestock	Uruguay	2030	A2/B2				+174 / +136	ECLAC (2010c)
		2050	A2/B2				-80 / +182	
		2070	A2/B2				-160 / +182	
		2100	A2/B2		3.1C / +2.3C	+6% to +8%	-287 / +182	
	Paraguay	2020	A2/B2				+4/ -2	ECLAC (2010c)
		2050	A2/B2				-7/-16	
		2080	A2/B2				-27/-22	
Forestry	Uruguay	2030	A2/B2				+15 / +6	ECLAC (2010c)
		2050	A2/B2				+39 / +13	
		2070	A2/B2				+52 / +18	
		2100	A2/B2		3.1C / +2.3C	+6% to +8%	+19 / +18	

* Gross Value of Production (million of US$)

Table 27-7: Comparison of consumption of different energetics in Latin America and the world (in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis).

Energy resource		LATAM						World					
		TFC (non electricity)		TFC (via electricity generation)		Total TFC		TFC (non electricity)		TFC (via electricity generation)		TFC	
Fossil	Coal and Peat	9,008	3%	1,398	2%	10,406	3%	831,897	12%	581,248	40%	1,413,145	17%
	Oil	189,313	55%	8,685	13%	197,998	48%	3,462,133	52%	73,552	5%	3,535,685	44%
	Natural Gas	59,44	17%	9,423	14%	68,863	17%	1,265,862	19%	307,956	21%	1,573,818	19%
Nuclear	Nuclear	0	0%	1,449	2%	1,449	0%	0	0%	193,075	13%	193,075	2%
Renewable	Biofuels and waste	82,997	24%	2,179	3%	85,176	21%	1,080,039	16%	20,63	1%	1,100,669	14%
	Hydro	0	0%	45,92	66%	45,92	11%	0	0%	238,313	17%	238,313	3%
	Geothermal, solar, wind, other renewable	408	0%	364	1%	772	0%	18,265	0%	26,592	2%	44,857	1%
TOTAL		341,166	100%	69,418	100%	410,584	100%	6,658,196	100%	1,441,366	100%	8,099,562	100%

* TFC: Total final consumption

Source: IEA, 2012

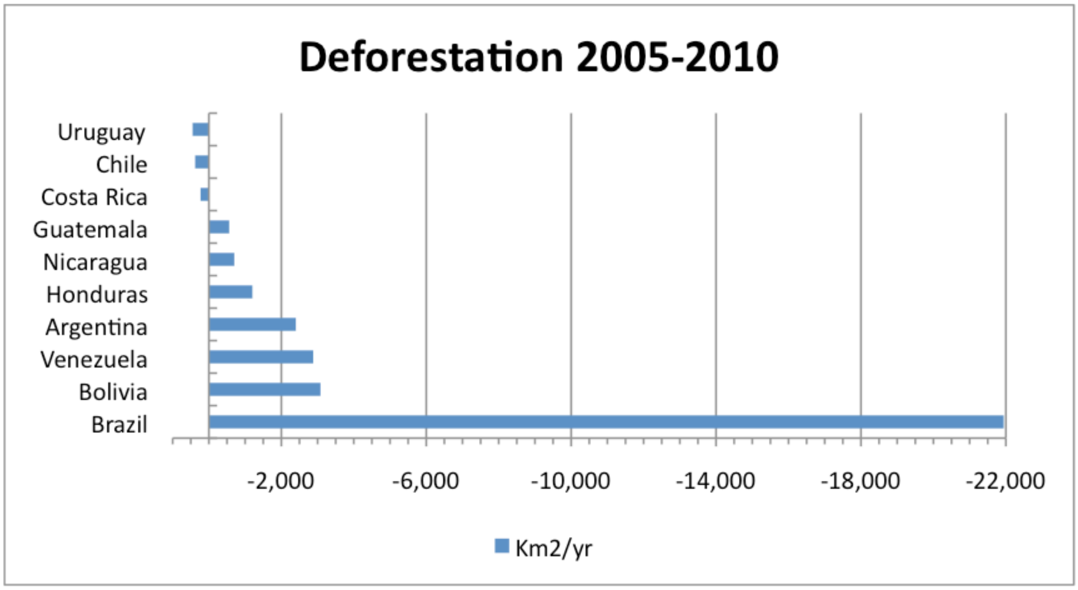

Figure 27-1: Area deforested per year for selected countries in CA and SA (2005-2010). Notice three countries listed with a positive change in forest cover (based on data from FAO, 2010)). Observed rates are: Uruguay 2.79%, Chile 0.23%, Costa Rica 0.90%, Guatemala -1.47%, Nicaragua -2.11%, Honduras -2.16%, Argentina -0.80, Venezuela, -0.61%, Bolivia -0.53%, Brazil, -0.42%).

Figure 27-2: Deforestation rates in the Brazilian Amazonia (km^2/year) based on measurements by the PRODES INPE project (see also INPE, 2011).

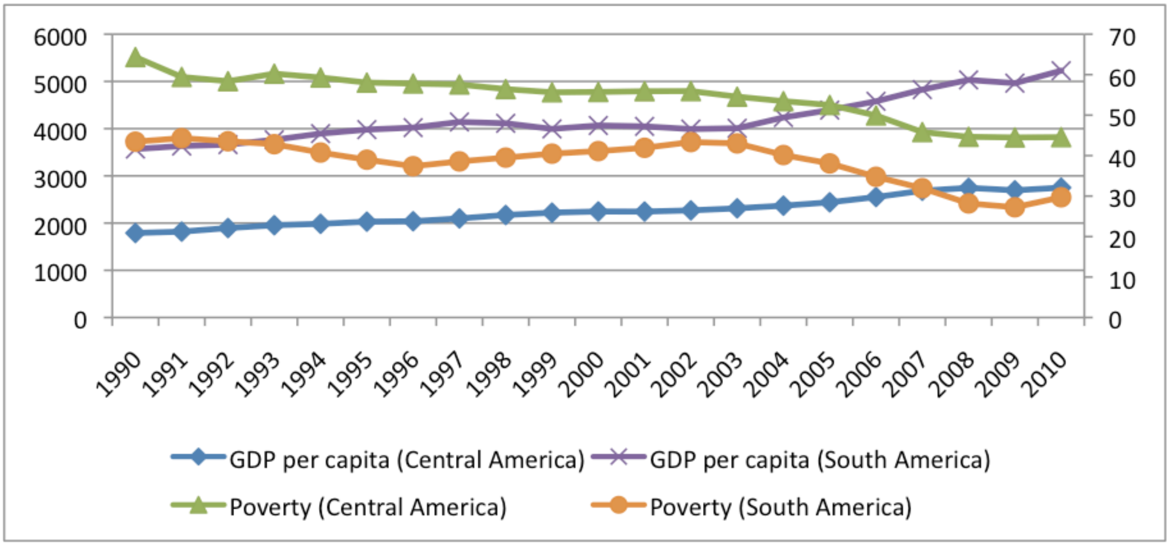

Figure 27-3: Evolution of GDP per capita and poverty from 1990-2011: CA and SA (US-Dollars per inhabitant at 2005 prices and percentages) (ECLAC on the basis of CEPALSTAT {{1961 CEPALSTAT 2012/a;1962 CEPALSTAT 2012/a;1963 CEPALSTAT 2012/a;}} and ECLAC {{1964 ECLAC 2011/a;}})

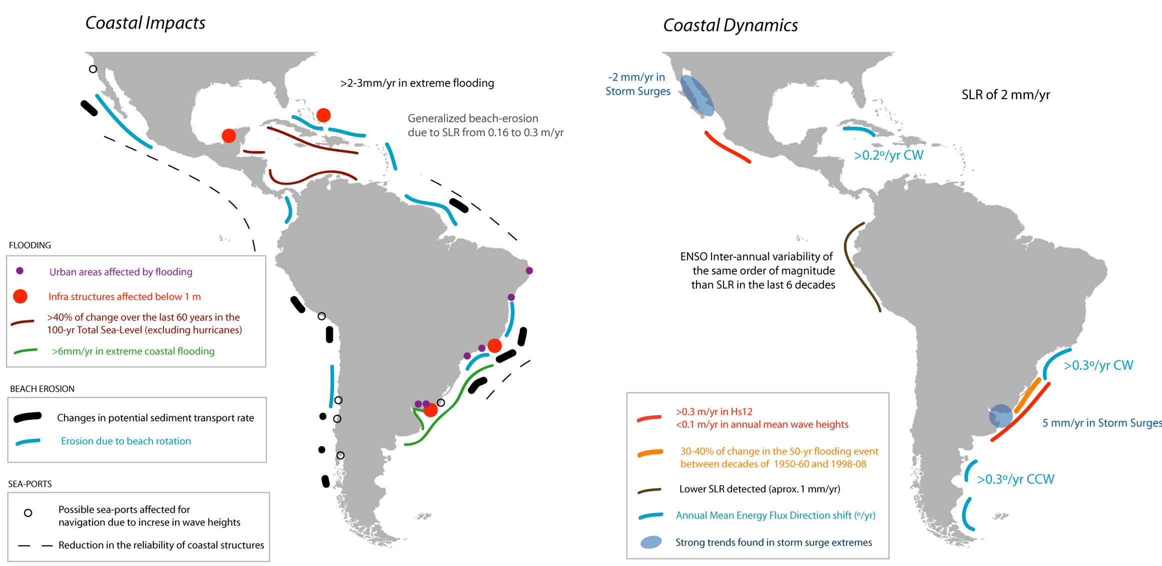

Figure 27-4: Current and predicted coastal impacts and coastal dynamics in response to climate change (elaborated by Iñigo Losada, ECLAC)

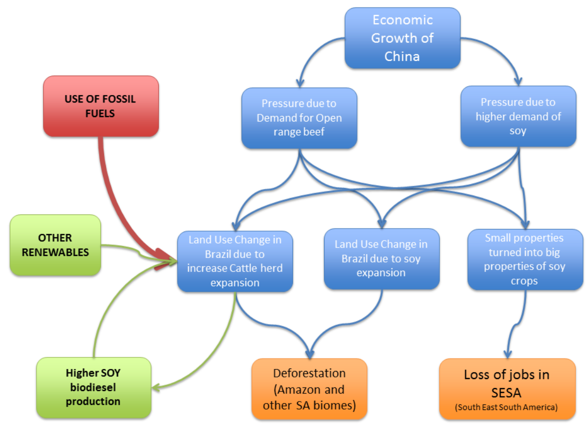

Figure 27-5: Soy teleconnections and major effects in SA. Economic growth giant consumers as China pressurize the soy production system in SA, increasing the production of biodiesel, but demanding more energy in general. (partly based on Nepstad and Stickler (2008), and Tomei and Upham (2009)).

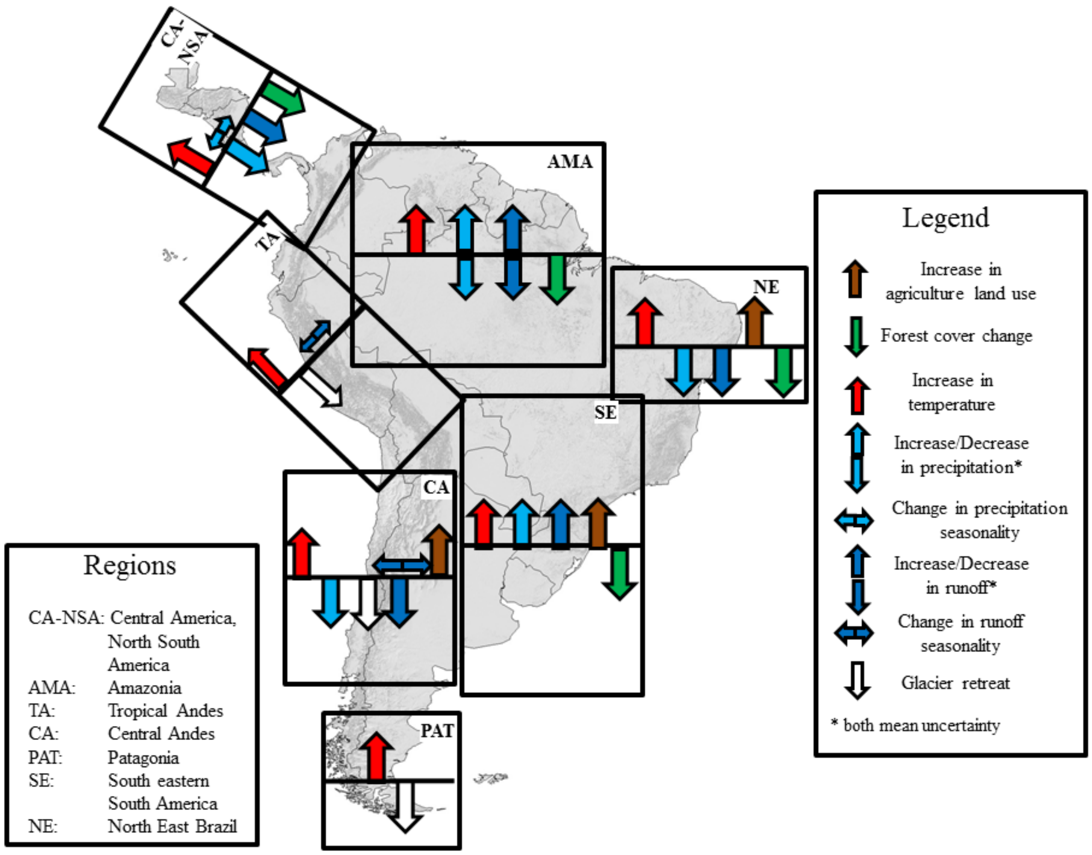

Figure 27-6: Summary of observed changes in CA and SA: changes in climate/hydrology, forest coverage, and glacier retreat.

[PLACEHOLDER: SOD Figure 27-7: Detection and Attribution of Observed Climate Change Impacts]