Chapter 27. Central and South America

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Contents

Executive Summary

Changes in climate variability and in extreme events have been severely affecting Central America (CA) and South America (SA) during the last 60 years. Increases in observed warm days and decreases in cold days and nights have been identified in CA, Northern SA, Northeast Brazil (NEB), Southeastern South America (SESA) and the West Coast of SA (medium-lower confidence). More frequent and intense rainfall extremes in SESA have favored an increase in the occurrence of landslides and flash floods (low confidence). On seasonal scales, it is likely that changes in hydrometeorological extremes in regions such as Amazonia, La Plata basin and Northern South America observed during the last 10 years have been related to changes in natural climate variability, determining changes in extreme streamflow variability in the La Plata and Amazon Rivers (27.1.2.2, 27.2.1.1).

The projected mean warming for CA by the end of the century, according to different global and regional climate models from the CMIP3 and CMIP5 ranges from 1.5°C to 4.0 °C, while rainfall tends to decrease between 5 and 10% by 2100. SA shows a warming between 1.0°C to 5.0 °C, with rainfall reduction up to 10% in tropical SA and an increase of about 10-15% in SESA. Projections for the 21st century from CMIP3 global models suggest a weakening of the North American Monsoon System NAMS and precipitation reduction in June-July, accompanied by projected warming in most of CA (medium confidence). Analyses from global and regional models in SA show common patterns of projected climate in some sectors of the continent, with a very likely 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, NEB, the Altiplano and southern Chile. With lower-medium confidence, heavy precipitation is likely projected to increase in SESA, while dry spells would increase in northeastern South America. Increases in warm days and nights are very likely to occur in most of SA (27.2.1.2).

In CA and SA there is evidence of changing conditions in terms of geophysical variables (cryosphere and runoff) that affect streamflow and finally water availability (high confidence). Since AR4, there is growing evidence that glaciers (both tropical and extratropical) are retreating and the cryosphere in the Andes is changing according to the warming trends. These changes affect streamflow availability in different seasons of the year. Robust trends are apparent associated with changes in precipitation such as increasing runoff in the SESA region (La Plata basin), and reducing runoff in the Central Andes (Chile, Argentina) and Central America. In contrast to these findings, no robust trend in streamflow in the Amazon Basin has been detected (27.3.1.1).

Land cover change is a key driver of environmental change 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. The agricultural expansion has affected fragile ecosystems such as the edges of the Amazon forest and the tropical Andes increasing the vulnerability of communities to extreme climate events, particularly floods, landslides and droughts. Even though deforestation rates in the Amazon have decreased substantially in the last eight years to a current value of 0.29%, the lowest for all forest biomes in Brazil, other regions like the Cerrado and the Chaco forests still present high levels of deforestation with rates as high as 1.33% (27.2.2.1).

Socioeconomic development shows a high level of structural heterogeneity and a very unequal income distribution resulting in high vulnerability of the region to climate change. There is still a high and persistent level of poverty in most countries of the region (45% for CA and 30% for SA for year 2010) 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 which translates into low adaptive capacities to climate change for these groups (27.2.2.2).

Coastal and marine ecosystems have been undergoing significant transformations that pose threats to fish stocks, corals, mangroves, places for recreation and tourism, and controls of pests and pathogens. Frequent coral bleaching events have been recently reported for the Mesoamerican Coral Reef. 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 live within the range of 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).

Conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region, and in parallel is a driver of anthropogenic climate change. 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. However, the region has still large extensions of natural vegetation cover for which the Amazon is the main example. Ecosystem-based Adaptation practices, such as conservation agreements and community management of natural areas, begin to multiply across the region (27.3.2.2).

Although there is high uncertainty in terms of climate change projections for regions with high vulnerability in terms of current water availability, this vulnerability is expected to increase in the future due to climate change impacts (high confidence). Already vulnerable regions in terms of water supply, like the semi-arid zones in Chile-Argentina, North Eastern Brazil and Central America and the tropical Andes, are expected to increase even further their vulnerability due to climate change. Glacier retreat is expected to continue, 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. These scenarios would affect water supply for large cities, small communities, hydropower generation and the agriculture sector (27.3.1.1, 27.3.1.2, 27.6.1). Current practices to reduce the mismatch between water supply and demand could be used to reduce future vulnerability. Constitutional and legal reforms towards more efficient and effective water resources management and coordination among relevant actors in many countries in the region (e.g. Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia and Mexico) also represent an adaptation strategy to climate variability and change (27.3.1.2).

Changes in agricultural productivity attributed to climate change are expected to have a great spatial variability**.** In SESA, where projections indicate more rainfall, average productivity could be sustained or increased until the mid-century (SRES: A2, B2) (medium confidence). In CA, northeast of Brazil and parts of the Andean region increases in temperature and decreases in rainfall could decrease the productivity in the short-term (before 2025), threatening the food security of the poorest population (medium confidence). The great challenge for CA and SA will be to increase the food and bioenergy production and at the same time to sustain the environmental quality in a scenario of 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, mainly SESA being key in this process. Hydropower is currently 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 CO_2 and temperature with an increase in growth, which might lead to an increase in productivity and production. However, the drought effects expected for some regions in CA and SA will be 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 biofuels productivity in the region. 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 employment in some countries. This is especially derived from the expansion of soy, which is used for biodiesel production inclusively (27.3.6.).

Climate variability and climate change are negatively affecting human health in CA and SA, either by increasing morbidity, mortality, and disabilities (very high confidence), and through the emergence of diseases in regions previously non-endemic, or the re-emergence of diseases in areas where they have previously been eradicated or controlled (high confidence). Climate-related drivers have been recognized for respiratory and cardiovascular diseases, vector- and water-borne diseases (malaria, dengue, yellow fever, leishmaniasis, cholera, and other diarrheal diseases), Hantaviruses and Rotaviruses, pregnancy-related outcomes, diabetes, chronic kidney diseases, and psychological trauma (27.3.7.1). Vulnerabilities vary with geography, age, gender, race, ethnicity, and socio-economic status, and are rising in large cities (27.3.7.2). It is very likely that Climate change and variability may exacerbate current and future risks to health, given the region's vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, and pollution.

The best way to be prepared to adapt to future climate change is by assisting people to cope with current climate variability. 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 CA and SA population. Such conditions weaken the importance of adaptation planning to climate change on the political agenda. Various examples demonstrate possible synergies between development, adaptation and mitigation planning, which can help local communities and governments to allocate efficiently available resources in the design of strategies to reduce vulnerability (27.3.4, 27.4.1, 27.4.2, 27.4.3, 27.4.4, 27.5).

27.1. Introduction

27.1.1. The Central and South America Region

The CA and 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/climate change and land cover change two of the most remarkable drivers of changes. Climate variability at 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 US$ 208 million (CRED, 2011). Land is facing increasing pressure from competing uses like cattle ranching, food production and bioenergy.

CA and SA are thought to have some key roles in the future because some countries, 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 on the one side, and possessing the largest potential for agricultural development during the next decades on the other. This is the case 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 global climate change (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

During the last decades of the 20th century, unusual extreme weather events have been severely affecting the LA region contributing greatly to the strengthening of the vulnerability of human systems to natural disasters. In addition, increases in precipitation were observed in SESA, northwest Peru and Ecuador; while decreases were registered in southern Chile, southwest Argentina, southern Peru and western CA since 1960. Mean warming was near to 0.1ºC/decade. The rate of SLR has accelerated over the last 20 years reaching 2-3mm/year. The glacier-retreat trend has intensified, reaching critical conditions in the Andean countries. Rates of deforestation have been continuously increasing mainly due to agricultural expansion, and land degradation has been intensified for the entire region.

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.

Future impacts include: “Significant species extinctions, mainly in tropical LA” (high confidence). “Replacement of tropical forest by savannas, and semi-arid vegetation by arid vegetation” (medium confidence). “Increases in the number of people experiencing water stress” (medium confidence). “Probable reductions in rice yields and possible increases of soy yield in SESA; and increases in crop pests and diseases” (medium confidence). “Some coastal areas affected by sea level rise, weather and climatic variability and extremes” (high confidence).

Some countries have made efforts to adapt to climate change and variability, for example through the conservation of key ecosystems, the use of early warning systems and climate forecast, and the implementation of disease surveillance systems. However, several constraints 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, outweigh the effectiveness of these efforts.

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, NEB, 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. 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 weaker 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 signals 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. 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 NEB.

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 and Projections in the Region

27.2.1. Climatic Stressors

27.2.1.1. Climate Trends, Long-term 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. Table 27-1 summarizes observed trends in the region's climate.

[INSERT TABLE 27-1 HERE
Table 27-1: Regional observed changes in temperature, precipitation and climate extremes in various sectors of CA and SA. Additional information on changes in observed extremes can be found in the IPCC SREX Chapter 3 (IPCC, 2012) and in WGI AR5 [2.4, 2.5, 2.6]]

Many areas in the Intra American Seas region that includes 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. In CA and the North American Monsoon System (NAMS), rainfall has been starting increasingly later and has become more irregular in space and time, while the intensity of rainfall has been increasing during the onset season (see references in Table 27-1) since around 1950. Arias *et al*. (2012) found decadal rainfall variations in NAMS.

In SA, the West coast has shown a prominent but localized coastal cooling during the past 30-50 years extending from central Peru down to central Chile. Presumably, this occurs in connection with an increased upwelling of coastal waters favored by the trade winds (Narayan *et al*., 2010), that 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 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. In central Chile, a 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 20th century (Quintana and Aceituno, 2012).

Towards the east of the Andes, NEB exhibits large interannual rainfall variability and a slight decrease since the 1970s. Although droughts in this region (e.g. 1983, 1987, 1998) have been associated with El Niño, the recent extremely intense drought in 2012-2013 occurred during La Niña (Marengo *et al*., 2013). In the La Plata Basin, various studies have documented interannual and decadal scale circulation changes that have led to decreases in the frequency of cold nights in austral summer, as well as to increases in warm nights and minimum temperatures during the last 40 years (see references in Table 27-1). Simultaneously, a reduction in the number of dry months in the warm season is found since the mid-1970s (see references in Table 27-1). Heavy rain frequency is increasing in SESA (references in Table 27-1).

In the central Andes, in the Mantaro Valley (Peru), precipitation shows 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 the number of frost days during September-April has also increased, but no clear signal on precipitation changes has been detected (Marengo *et al*., 2009a). 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) have identified an increase of temperature together with precipitation reductions during 1950-90.

For the Amazon basin, Marengo (2004), Marengo *et al*. (2009a; 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 decadal variability. Analyzing a narrower time period, Espinoza *et al*. (2009a; 2009b) found that mean rainfall in the Amazon basin for 1964–2003 has decreased, with stronger amplitude after 1982, especially in the Peruvian western Amazonia (Lavado *et al*., 2012), consistent with reductions in convection and cloudiness in the same region (Arias *et al*., 2011). Recents studies by Donat *et al*. (2013) suggest that heavy rains are increasing in frequency in Amazonia. Regarding seasonal extremes in the Amazon region, two major droughts and three floods have affected the region from 2005 to 2012, although these events have been related to natural climate variability rather than to deforestation (Marengo *et al*., 2008; Espinoza *et al*., 2011; Lewis *et al*., 2011; Espinoza *et al*., 2012; Marengo *et al*., 2012a). On the impacts of land use changes on changes in the climate and hydrology of Amazonia, 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, while Wang *et al*. (2011) suggests the importance of deforestation and vegetation dynamics on decadal variability of rainfall in the region. 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.

In the SAMS region in the last 50 or 60 years, positive trends in rainfall extremes have been identified (see Table 27-1). These studies suggest a pattern of increasing frequency and intensity of heavy rainfall events, with a tendency for early onsets and late demise of the rainy season.

Collini *et al*. (2008) and Saulo *et al*. (2010) find the SESA precipitation to be more responsive to changes in soil moisture, and although feedback mechanisms are present at all scales, the atmosphere influence is more significant at large scales. Moreover, land use change studies in the Brazilian southern Amazonia for the last decades showed that the impact on the hydrological response is time lagged at larger scales (Rodriguez *et al*., 2010)

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 CMIP5 models, and new experiences using regional models (downscaling) have allowed for a better description of future changes in climate and extremes in CA and SA. Using CMIP3 and CMIP5 models, Giorgi (2006), Diffenbaugh *et al*. (2008), Xu *et al*. (2009) and Diffenbaugh and Giorgi (2012) have identified areas of CA/western North America and the Amazon as persistent regional climate change hotspots throughout the 21st century of the RCP8.5 and RCP4.5. 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, and climate extremes in different sectors of CA and SA. Various studies used A2 and B2 scenarios from CMIP3 and various RCPs scenarios for CMIP5, and different time slices from 2010 to 2100. In order to make results comparable, the CMIP3 and CMIP5 at 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), and WG1 AR5 Chapter 9 and 14 [9.5, 9.6 and 14.2, 14.7]]

In CA and Northern Venezuela, projections from CMIP3 models and from downscaling expriments suggest precipitation reductions and warming together with an increase in evaporation, and reductions in soil moisture for most of the land during all seasons by the end of the 21th century (see references in Table 27-2). However, the spread of projections is high for future precipitation.

Analyses from global and regional models in tropical and subtropical SA show common patterns of projected climate in some sectors of the continent. Projections from CMIP3 regional and high resolution global models show by the end of the 21st century for a high emission scenario A2, a consistent pattern of 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, NEB, the Altiplano and southern Chile (see references in Table 27-2). For some regions, projections show mixed results in rainfall projections, for the Amazonia and the SA monsoon region (see references in Table 27-2).

As for extremes, CMIP3 models and downscaling experiments show increases in dry spells are projected for Eastern Amazonia and NEB, while rainfall extremes are projected to increase in SESA, in western Amazonia, Northwest Peru and Ecuador, while over southern Amazonia, northeastern Brazil and eastern Amazonia, the maximum number of consecutive dry days tends to augment, suggesting a longer dry season. Increases in warm nights throughout SA are also rojected by the end of the 21st century (see references in Table 27-2). 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 basin.

The CMIP5 models project an even larger expansion of the monsoon regions in NAMS and SAMS in the future scenarios (Kitoh *et al*., 2012; Jones and Carvalho, 2013). A comparison from eight models from CMIP3 and CMIP5 identifies some improvements in the new generation models. For example, CMIP5 inter-model variability of temperature in summer was lower over northeastern Argentina, Paraguay and northern Brazil, in the last decades of the 21st century, as compared to CMIP3. Although no major differences were observed in both precipitation datasets, CMIP5 inter-model variability was lower over northern and eastern Brazil in summer by 2100 (Blázquez and Nuñez, 2012).

The projections from the CMIP5 models at regional level for CA and SA (using the same regions from the IPCC SREX) are shown in Figure 27-1, and update some of these previous projections based on SRES A2 and B2 emission scenarios from CMIP3. Figure 27-1 shows that in relation to the baseline period 1986-2005, for CA and northern South America-Amazonia, temperatures are projected to increase approximately by 1.8 °C and 3 °C for the RCP4.5 scenario, and by 4 C and 5 °C for the RCP8.5 scenario. For the rest of South America, increases by about 1.8 to 2 °C are projected for the RCP4.5 and by about 4 C to 5 C for the RCP8.5 scenario. The observed records show increases of temperature from 1900 to 1986 by about 1 °C. For precipitation, while for CA and northern South America-Amazonia precipitation is projected to decrease by about 10% (with large spread among models). For Northeast Brazil, there is a spread among models between +20 to -20% making hard to identify any projected change. This spread is much lower in the western coast of South America and SESA, where the spread is between +10 and -10%, and in SESA, the tendency is for an increase of precipitation that may reach 30%.

[INSERT FIGURE 27-1 HERE
Figure 27-1: Observed and simulated variations in past and projected future annual average temperature over land areas of the Central and South American "SREX regions". Black lines show several estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.]

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 (Sampaio *et al*., 2007; Lopez-Rodriguez and Blanco-Libreros, 2008). 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, energy and minerals (Benhin, 2006; Grau and Aide, 2008; Mueller *et al*., 2008). Land is facing increasing pressure from competing uses, among them cattle ranching, food 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 gold mining are causing severe environmental degradation (ECLAC, 2010d), and the reduction of environmental services provided by these ecosystems.

Deforestation rates for the region remain high in spite of a reducing trend in the last decade (Ramankutty *et al*., 2007; Fearnside, 2008). 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 km^2 per year -39% of world deforestation for the period 2005-2010. Bolivia, Venezuela and Argentina follow in deforested area (Figure 27-2) with all four countries accounting for 54% of the forest loss in the world for the same period. The countries of CA and SA lost a total of 38,300 km^2 of forest per year in that period (69% of the total world deforestation) (FAO, 2010). These numbers are limited by the fact that many countries do not have comparable information through time, particularly for recent years.

[INSERT FIGURE 27-2 HERE
Figure 27-2: 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).]

Deforestation in the Amazon forest has received much international attention in the last decades, both because of its high rates, and its rich biodiversity. Brazilian Legal Amazon is now one of the best-monitored ecosystems in terms of deforestation since 1988 (INPE, 2011; see Figure 27-3). Deforestation rates for this region peaked in 2004 and have steadily declined since then 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, 2009).

[INSERT FIGURE 27-3 HERE
Figure 27-3: Deforestation rates in the Brazilian Amazonia (km^2/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 (Figure 27-2). However, a substantial amount of forest is gained through (single-crop) plantations, most noticeably in Chile (Aguayo *et al.*, 2009), which has a much lower ecological value than natural forests (Izquierdo *et al.*, 2008).

Land degradation, 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, 2010d).

Deforestation and land degradation are mainly attributed to increased extensive and intensive agriculture. Two activities have traditionally dominated the agricultural expansion: soy production (only in SA) and beef; but more recently, biomass for biofuel production has become as important (Nepstad and Stickler, 2008) with some regions also affected by oil and mining extractions. 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). 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 section 27.3.4.1).

Soybean and beef production have also impacted other ecosystems next to the Amazon, 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) 1.4 Mha of dry forest were cleared from 1972 to 2007 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). In central Argentina (northern Córdoba province), cultivated lands have increased from 3% to 30% (between 1969 and 1999); and the forest cover has decreased from 52.5% to 8.2%. This change 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).

Oil palm is a significant biofuel crop also 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). 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 have expanded into forested areas (Gutiérrez-Vélez *et al*., 2011).

However, forests are not the only important ecosystems 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 region (Central-East Argentina, southern Brazil, and Uruguay), grasslands decreased from 67.4% to 61.4% between 1985 and 2004. This reduction was associated with an increase in 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 (Wassenaar *et al*., 2007; Kaimowitz and Angelsen, 2008), 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 mainly 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; 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 (Oltremari and Jackson, 2006; Larson, 2010). 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

Development in the region has traditionally displayed four characteristics: low growth rates, high volatility, structural heterogeneity and a very unequal income distribution (ECLAC, 2008; Bárcena, 2010). This combination of factors has generated high and persistent poverty levels (45% for CA and 30% for SA for year 2010), with the rate of poverty being generally higher in rural than urban areas (ECLAC, 2009c). 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. In turn, CA has exploited its proximity to the North American market and its relatively low labor costs (ECLAC, 2010e). The region shows a marked structural heterogeneity, where modern production structures coexist with large segments of the population with low productivity and income levels (ECLAC, 2010g). The GDP per capita in SA is twice that of CA; in addition, in the latter poverty is 50% higher (see Figure 27-4).

[INSERT FIGURE 27-4 HERE
Figure 27-4: Evolution of GDP per capita and poverty (income below US$ 2 per day) from 1990-2011: CA and SA (US-Dollars per inhabitant at 2005 prices and percentages) (ECLAC on the basis of CEPALSTAT (2012)and ECLAC (2011c))]

The 2008 financial crisis reached CA and SA through exports and credits, remittances and worsening expectations by consumers and producers (Bárcena, 2010; Kacef and López-Monti, 2010). This resulted in the sudden stop of six consecutive years of robust growth and improving social indicators, which contributed to higher poverty in 2009 after six years where poverty had declined by 11%. Poverty rates fell from 44% to 33% of the total population, leaving 150 million people in this situation while extreme poverty diminished from 19.4% to 12.9% (which represents slightly more than 70 million people) (ECLAC, 2010e).

In the second half of 2009 industrial production and exports began to recover and yielded a stronger economic performance (GDP growth of 6.4% in SA and 3.9% in CA in 2010) (ECLAC, 2012). SA benefited the most because of the larger size of their domestic markets and the greater diversification of export markets. Conversely, slower growth was observed in CA with more open economies and a less diversified portfolio of trading partners and a greater emphasis on manufacturing trade (ECLAC, 2010g).

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 the middle class becomes stronger and 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. The macroeconomic challenge is to act counter cyclically creating conditions for productive development that is not based solely on commodity exports (ECLAC, 2010f).

In spite of its economic growth, the region still 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 richest 10% of households is approximately 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 more equitable distriburion of income and a stronger middle class population resulting in a higher demand for goods (ECLAC, 2010g; UN, 2010; ECLAC, 2011b). Latin American countries also reported gains in terms of human development, although these gains have slowed down slightly over recent years. In comparative terms, the performance of countries as measured by the Human Development Index (HDI) varied greatly (from Chile with 0.878 and Argentina with 0.866 to Guatemala -0.704- and Nicaragua -0.699-) although those with lower levels of HDI showed notably higher improvements than countries with the highest HDI (UNDP, 2010).

Associated with inequality are disparities in access to water, sanitation and adequate housing for the most vulnerable groups - for example indigenous peoples, Afro-descendants, children and women living in poverty- and in their exposure to the effects of climate change. The strong heterogeneity of subnational territorial entities in the region takes the form of high spatial concentration and persistent disparities in the territorial distribution of wealth (ECLAC, 2010g; UN, 2010; ECLAC, 2011b).

The region faces significant challenges in terms of environmental sustainability and adaptability to a changing climate (UN, 2010), reflecting the specific characteristics of its population and economy already discussed and added to 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 public policies (UN, 2010). 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.

27.3. Impacts, Vulnerabilities, and Adaptation Practices

27.3.1. Freshwater Resources

CA and SA are regions with a high average but unevenly distributed water resources availability (Magrin *et al.*, 2007a). The main user of water is agriculture, accounting for 70% of all withdrawals used to feed more than 20 Mha of irrigated land (14% of the world's total cultivated area) (ECLAC *et al.*, 2010). The second use is composed by the region's 580 million inhabitants (including the Caribbean), of which 86% had access to water supply by 2006 (ECLAC, 2010b), although in rural areas only 51% of the population have access to those services. In terms of non-consumptive water uses, according to the International Energy Agency (IEA), the region meets 60% of its electricity demand through hydropower generation, which contrast with the 20% average contribution of other regions (see case study 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 hydro-geophysical variables (cryosphere and runoff) that affect streamflow and finally water availability.

The most robust trend for major rivers is found in the sub-basins of the La Plata River basin (***high agreement, robust evidence***). This basin, second only to the Amazon in size, and third in streamflow (21,500 m^3/s) (Pasquini and Depetris, 2007), shows a positive trend in streamflow in the second half of the 20th century at different sites (Pasquini and Depetris, 2007; Krepper *et al.*, 2008; Saurral *et al.*, 2008; Amsler and Drago, 2009; Conway and Mahé, 2009; Dai *et al.*, 2009; Krepper and Zucarelli, 2010a; Dai, 2011; Doyle and Barros, 2011). An increase in precipitation and a reduction in evapotranspiration from land use changes have been associated with the trend in streamflows (Saurral *et al.*, 2008; Doyle and Barros, 2011), with the former being more important in the southern sub-basins and the latter in the northern ones (Doyle and Barros, 2011) (see section 27.2.1). Increasing trends in streamflows have also been found in the Laguna Mar Chiquita (a closed lake), and in the Santa Fe Province, both in Argentina, with ecological and erosive consequences (Pasquini *et al.*, 2006; Rodrigues Capítulo *et al.*, 2010; Troin *et al.*, 2010; Venencio and García, 2011; Bucher and Curto, 2012). The effect of reservoirs on changing hydrologic conditions has been reported for the San Francisco River basin in Northeast Brazil (Andrade e Santos *et al.*, 2012; Genz and Luz, 2012).

There is no clear long-term trend for the Amazon River, owing to its strong interannual and decadal variability. Extremely low levels were experienced during the droughts of 2005 and 2010, while record high levels for the same rivers were detected during the 2009 and 2012 floods (see section 27.2.1). Espinoza *et al.* (2009a; 2011) showed that the 1974-2004 apparent stability in mean discharge at the main stem of the Amazon in Obidos is explained by opposing regional features of Andean rivers (e.g. increasing trends in the Peruvian Amazons, Lavado *et al.*, 2012) (see section 27.2.1). Major Colombian rivers draining to the Caribbean Sea (Magdalena and Cauca) exhibit decreasing trends along their main channels (Carmona and Poveda, 2011), while significant trends are absent for all other major large rivers in the Brazilian North East, and northern SA (Dai *et al.*, 2009). The only study done for rivers in CA is that of Dai (2011) who showed a drying trend in this region.

Water resources are threatened by the rapid retreat and melting of the Andean cryosphere, which has been further reported following the IPCC AR4, through diverse techniques such as aereal photography, satellite imagery, ice coring, and lichens in the tropical glaciers of Venezuela, Colombia, Ecuador, Peru and Bolivia (see reviews in Vuille *et al.*, 2008a ; Jomelli *et al.*, 2009; Bradley *et al.*, 2009; Poveda and Pineda, 2009; Rabatel *et al.*, 2012) and specific papers in Table 27-3a). A synthesis of the studies recognizes with ***high confidence*** (based on ***high agreement**, and* ***robust evidence***) that tropical glaciers' retreat has accelerated since the middle of the 20th century (Table 27-3a). In early stages of 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, runoff tends to decrease, as evidenced in the Cordillera Blanca of Peru (Chevallier *et al*., 2011; Baraer *et al*., 2012), where seven out nine river basins have probably crossed a critical threshold, exhibiting a decreasing dry-season discharge (Baraer *et al*., 2012). In general, runoff tends to decrease during the period in the year when precipitation is at its lowest level. Likewise, glaciers and icefields in the extra tropical Andes located in Central-South Chile and Argentina face significant reductions (see Table 27-3b), with their effect being compounded by changes in snowpack extent, thus magnifying changes in hydrograph seasonality by reducing flows in dry seasons and increasing them 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]

Some regions in Central-South Chile and Argentina also face significant reductions in precipitation (section 27.2.1), which has contributed to runoff reductions in the last decades of the 20th century (Seoane and López, 2007; Rubio-Álvarez and McPhee, 2010; Urrutia *et al*., 2011), contrasted with long-term trends found through dendrochronology (Lara *et al*., 2007; Urrutia *et al*., 2011). Trends in precipitation and runoff are less evident in the Central-North region in Chile (Fiebig-Wittmaack *et al*., 2012; Souvignet *et al*., 2012).

Assessment on future impacts (see Table 27-4) show a large range of uncertainty across the spectrum of climate models. It is hard to make conclusive statements in terms of trends on some particular regions/rivers. Nohara *et al*. (2006) studied 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 Paraná (La Plata Basin) and Amazon Rivers. Nevertheless, in both cases the average change showed a positive value consistent at least with observations for the La Plata Basin. On top of such climatic uncertainty, future streamflows and water availability projections are confounded by the potential effects of deforestation (Moore *et al*., 2007; Coe *et al*., 2009).

[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, Maurer *et al*. (2009) studied climate change projections for the Lempa River basin, one of the largest basins 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 (see Table 27-4). Imbach *et al*. (2012) found similar results using a modeling approach that also considered potential changes in vegetation. These effects could have large hydropower generation implications as discussed in the case study (see section 27.6.1).

Since the AR4 several studies have been developed to associate future climate scenarios with the evolution of glaciers, especially in the tropical Andes. Juen *et al*. (2007) and Chevallier *et al*. (2011) 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 six remaining glaciers in Colombia. In general, these studies indicate that glaciers may continue their retreat (Vuille *et al*., 2008a) as glacier Equilibrium Line Altitudes rises, with larger hydrological effects during the dry season (Kaser *et al*., 2010; Gascoin *et al*., 2011). This is expected to happen during the next 20-50 years (Juen *et al*., 2007; Chevallier *et al*., 2011) (see Table 27-4). After that period water availability during the dry months is expected to diminish. A forecast, for instance, by Baraer *et al*. (2012) for the Santa River in the Peruvian Andes finds that once the glaciers are completely melt, annual discharge would decrease by 2%–30%, depending on the watershed.

Significant effects are foreseen in the energy balances of the Andes, through changes in temperature and albedo, thus influencing hydrologic regimes. In Central Chile, Vicuña *et al*. (2011) project changes in the seasonality of streamflows of the upper snowmelt-driven watersheds of the Limarí River, associated with temperature increases and reductions in water availability owing to a reduction (increase) in precipitation (evapotranspiration) (see Table 27-4). Similar conclusions are derived across the Andes on the Limay River in Argentina by Seoane and López

(2007). Projected changes in the cryosphere conditions of the Andes could affect the occurrence of extreme events, such as the Glacial-lake outburst floods occurring in the icefields of Patagonia (Dussaillant *et al*., 2010), volcanic collapse and debris flow associated with accelerated glacial melting in the tropical Andes (Carey, 2005; Carey *et al*., 2012b; Fraser, 2012), and with volcanoes in southern Chile and Argentina (Tormey, 2010), as well as scenarios of water quality pollution by exposure to contaminants owing to glaciers retreat (Fortner *et al*., 2011).

27.3.1.2. Vulnerability and Adaptation Practices

Vulnerability for the region considers both '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 *et al*., 2007). Current highly vulnerable regions include the semi-arid regions in Chile-Argentina and North East Brazil, certain regions in CA, and communities along the tropical Andes.

Semiarid regions are characterized by pronounced climatic variability and often by water scarcity and related social stress (Krol and Bronstert, 2007; Scott *et al*., 2012). The semiarid regions of Central Chile-Argentina are expected to face streamflow reductions and changes in seasonality, with potentially significant effects on already vulnerable and highly populated regions (e.g. Santiago, Chile) and extensive agriculture irrigation demands (ECLAC, 2009a; Souvignet *et al*., 2010; Fiebig-Wittmaack *et al*., 2012). 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) (see Table 27-4).

Another semiarid region that has been studied thoroughly is the Northeast Brazilian (Hastenrath, 2012). De Mello *et al*. (2008), Gondim *et al*. (2008), Souza *et al*. (2010) and Montenegro and Ragab (2010) have shown that future climate change scenarios would decrease water availability for agriculture irrigation owing to reductions in precipitation and increases in evapotranspiration. Krol and Bronstert (2007) and Krol *et al*. (2006) presented an integrated modeling study that linked projected impacts on water availability for agriculture with economic impacts that could potentially drive full-scale migrations in the Brazilian northeast region.

In CA, Benegas *et al*. (2009), Manuel-Navarrete *et al*. (2007) and Aguilar *et al*. (2009) provide different frameworks to understand vulnerability and adaptation strategies to climate change and variability in urban and rural contexts, although no specific adaptation strategies are suggested.

The retreat of Andean glaciers can exacerbate water resources vulnerability (Bradley *et al*., 2006; Casassa *et al*., 2007; Vuille *et al*., 2008b; Mulligan *et al*., 2010). Glacier retreat diminishes the mountains' water regulation capacity, making it more expensive and less reliable the supply of water for diverse purposes, as well as for ecosystems integrity (Buytaert *et al*., 2011). Impacts on economic activities associated with conceptual scenarios of glacier melt reduction have been monetized (Vergara *et al*., 2007), representing about US$100 million in the case of water supply for Quito, and between US$212 million to US$ 1.5 billion in the case of the Peruvian electricity sector due to losses of hydropower generation (see case study 27.6.1). Andean communities face an important increase in their vulnerability, as documented by Mark *et al*. (2010), Pérez *et al*. (2010) and Buytaert and De Bièvre (2012). Different issues have been addressed in the assessment of adaptation strategies for these communities such as the role of governance and institutions (Young and Lipton, 2006; Lynch, 2012), technology (Carey *et al*., 2012a), and the dynamics of multiple stressors (McDowell and Hess, 2012).

A series of policies have been developed to reduced vulnerability to climate variability as faced today in different regions and settings of CA and SA. In 1997, Brazil instituted the National Water Resources Policy and created the National Water Resources Management System under the shared responsibility between the 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. The challenges and opportunities dealing with water resources management in Brazil in the face of climate variability and climate change have been well studied (Abers, 2007; Kumler and Lemos, 2008; Medema *et al*., 2008; Engle *et al*., 2011; Lorz *et al*., 2012). Other countries in the region are following similar approaches. In the last five years, there have been constitutional and legal reforms towards more efficient and effective water resources management and coordination among relevant actors in Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia and Mexico; although in many cases, these innovations have not been completely implemented (Hantke –Domas, 2011). Institutional and governance improvements are required to assure an effective implementation of these adaptation measures (e.g. Halsnæs and Verhagen, 2007; Engle and Lemos, 2010; Lemos *et al.*, 2010; Zagonari, 2010; and Pittock, 2011).

The particular experience in Northeast Brazil provides other examples of adaptation strategies. Broad *et al.* (2007) and Sankarasubramanian *et al.* (2009) studied the potential benefits of streamflow forecast in this region as a way to reduce the impacts of climate change and climate variability on water distribution under stress conditions. An historical review and analysis of drought management in this region are provided by Campos and Carvalho (2008). Souza Filho and Brown (2009) studied different water distribution policy scenarios finding that the best option depended on the degree of water scarcity. The study by Nelson and Finan (2009) provides a critical perspective of drought-related policies, arguing that they constitute an example of maladaptation as they do not try to solve the causes of vulnerability and instead undermine resilience. Tompkins *et al.* (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 from groundwater pumping (Döll, 2009; Kundzewicz and Döll, 2009; Zagonari, 2010; Burte *et al.*, 2011); fog interception practices (Holder, 2006; Klemm *et al.*, 2012), and 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 (Geerts *et al.*, 2010; Montenegro and Ragab, 2010; Van Oel *et al.*, 2010; Bell *et al.*, 2011; Jara-Rojas *et al.*, 2012), and changes towards less water intensive crops (Montenegro and Ragab, 2010).

Flood management practices also provide a suite of options to deal with actual and future vulnerabilities related to hydrologic extremes, such as the management of ENSO-related events in Peru via participatory (Warner and Oré, 2006) or risk reduction approaches (Khalil *et al.*, 2007), the role of land use management (Bathurst *et al.*, 2010; 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 (Mittermeier *et al.*, 1997; Guevara and Laborde, 2008). 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). Tropical deforestation is the second largest driver of anthropogenic climate change on the planet, adding up to 17%-20% of total greenhouse gas emissions during the 1990s (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 annual 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 45.6% of the biome in Brazil (Soares-Filho *et al.*, 2010). Using LandSHIFT modeling framework for land use change and the IMPACT projections of crop/livestock production, Lapola *et al.* (2011) projected that 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.

Local deforestation rates or rising greenhouse gases globally 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; Salazar *et al.*, 2007; Sampaio *et al.*, 2007; Lenton *et al.*, 2008; Nobre and Borma, 2009). 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, under a high emission scenario (A2), from 2050-2060 to 2100 (Betts *et al.*, 2004; Cox *et al.*, 2004; Salazar *et al.*, 2007; Sampaio *et al.*, 2007; 2008; Malhi *et al.*, 2008; Sitch *et al.*, 2008; Malhi *et al.*, 2009; Nobre and Borma, 2009; Marengo *et al.*, 2011c). The possible 'savannization' or 'die-back' of the Amazon region would potentially have large-scale impacts on climate, biodiversity and people in the region. The possibility of this die-back scenario occurring, however, is still an open issue and the uncertainties are still very high (Rammig *et al.*, 2010; Shiogama *et al.*, 2011).

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 have historically 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 (see 27.6.1 and Chapter 3) or have few protected areas and high rates of habitat loss (Nogueira *et al.*, 2010).

The faster and more severe the rate of climate change, the more severe the biological consequences such as species decline (Brook *et al.*, 2008). Vertebrate fauna in North and South America is projected to suffer species losses until 2100 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 until 2100 will be as high as 90% in specific areas of CA and the Andes Mountains for emission scenarios varying from low B1 to mid-high A2 (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 (by 2055, scenarios HHGSDX50 and HHGGAX50; Siqueira and Peterson, 2003) of the Cerrado indicate that distribution 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 (Brooker *et al.*, 2008; Anthelme *et al.*, 2012). 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 have negative consequences on biodiversity and ecosystem services in this region.

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).

27.3.2.2. Adaptation Practices

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; see also Glossary). 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).

Since PES schemes have developed more commonly in CA and SA than in other parts of the world (Balvanera *et al*., 2012), this topic will be covered as a case study (see 27.6.2 in this Chapter).

Ecological restoration can be an important tool for adaptation. A meta-analysis of 89 studies by Benayas *et al*. (2009) (with timescale of restoration varying from <5 to 300 years), including many in SA, showed that ecological restoration enhances the provision of biodiversity and environmental services by 44% and 25%, respectively, as compared to degraded systems (Benayas *et al*., 2009) 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). Chazdon *et al*. (2009) also highlight the potential of restoration efforts to build ecological corridors (see Harvey *et al*., 2008, for example in Central America).

Community management of natural areas is another efficient tool to adapt to climate change and to reconcile biodiversity conservation with socio-economic development. 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 higher 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. This somehow contrasts with the findings of Miteva *et al*. (2012) that found protected areas more efficient in constraining deforestation than other schemes. Other good examples of adaptive community management in the continent include community forest concessions (e.g., Guatemala; Radachowsky *et al*., 2012), multiple-use management of forests (Guariguata *et al*., 2012 ; see also examples in Brazil – Klimas *et al*., 2012, Soriano *et al*., 2012, and Bolívia – Cronckleton *et al*., 2012); and local communities where research and monitoring protocols are in place to pay the communities for collecting primary scientific data (Luzar *et al*., 2011).

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 left in the world that remain unaffected by human influence (Halpern *et al*., 2008). Anthropogenic drivers associated with climate change decreased ocean productivity, altered food web dynamics, reduced abundance of habitat-forming species, shifting species distributions, and greater incidence of disease (Hoegh-Guldberg and Bruno, 2010). Coastal and marine impacts and vulnerability are often associated with 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). For instance, the Ocean Health Index (Halpern *et al.*, 2012) that measures how healthy the coupling of the human-ocean system is for every coastal country (including parameters related to climate change), indicates that CA countries rank amongst the lowest values. For SA, Suriname stands out with one of the highest scores.

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 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 (see Figure 27-5). (ECLAC, 2011a)

[INSERT FIGURE 27-5 HERE
Figure 27-5: 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)

The majority of literature concerning climate change impacts for coastal and marine ecosytems consideres coral reefs, mangroves and fisheres. 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 with ocean warming and acidification (Baker *et al.*, 2008). If extreme sea surface temperatures are to continue, the projections of scenario SRES A1F indicate that 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). Reef but also mangrove ecosystems are estimated to contribute greatly to goods and services in economic terms. In Belize, for example, this amount is approximately US$395-US$559 million annually, 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, eastern Brazilian reefs might suffer a massive coral cover decline in the next 50 years. Francini-Filho *et al.* (2008) pointed out that coral diseases intensified between 2005 and 2007 based on qualitative observations since the 1980s and regular monitoring since 2001. They have also predicted 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. All 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). Moreover, estimates are that climate change may lead to a maximum global loss of 10–15% of mangrove forest by 2100 (Alongi, 2008). 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). The rate of survival of original mangroves lies between 12.8% and 47.6% in the Tumaco Bay (Colombia), 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 Guiana.

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, between 1978 and 2000, which is one of the highest rates documented in the world (Freire and Pauly, 2010).

Despite the focus in the literature 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., Gutiérrez *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 on the one hand (Francini-Filho and Moura, 2008), and the improvement of livelihoods, as well as the cultural survival of traditional populations on the other (Moura *et al*., 2009; Hastings, 2011).

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 especially vulnerable. The same applies to countries with high shares of land (e.g., Brazil ranking 7th worldwide of the total land area in the LECZ) and/or population (e.g., Guyana and Suriname rank 2nd and 5th by the share of population in the LECZ, having respectively 76% and 55% of their populations in such areas (McGranahan *et al*., 2007). Adaptation will demand effective and enforceable regulations and economic incentives, 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

Increases in the global demand for food, forage, fiber and biofuels promoted a sharp increase in agricultural production in SA and CA mainly associated with the expansion of planted areas (see Chapter 7). This trend is predicted to continue since SA accounts for 40% of the global potential arable land (Nellemann *et al*., 2009). Agro-ecosystems are being and will be affected in isolation and synergistically by climate variability/change and land use changes, which are comparable drivers of environmental change. According to projections based on 30 GCMs (under SRES A1B and B1) by the end of 21th century (2070-2099), 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. 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). Examples for this are, e.g., in 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 the Argentinas Pampas current land use changes disrupt water and biogeochemical cycles and may result in soil salinization, altered C and N storage, surface runoff and stream acidification (Nosetto *et al*., 2008; Berthrong *et al*., 2009; Farley *et al*., 2009). 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).

Observed impacts: The SESA region has shown significant increases in precipitation and wetter soil conditions during the 20th century (Giorgi, 2002) (see Table 27-1). Rainfall increases benefited summer crops and pastures productivity, and contributed to a significant expansion of agricultural areas, mainly in climatically marginal regions of Argentina (Barros, 2010; Hoyos *et al*., 2012). Comparing the periods 1930-60 and 1970-2000, maize and soybean yields increased between 9% and 58% in Argentina, Uruguay and South Brazil (Magrin *et al*., 2007b) mainly due to precipitation increases. However, current agricultural production systems, which evolved partially in response to wetter conditions, could be threatened if climate reverts to a drier situation, putting at risk the the viability of continuous agriculture in marginal regions of the Argentina's Pampas (Podestá *et al*., 2009). During the 1930s-1940s, dry and windy conditions 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).

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, simulated potential wheat yield has been decreasing at increasing rates since 1930 (1930-2000: -28 kg/ha/year; 1970-2000: -53 kg/ha/year) in response to increases in minimum temperature during October-November (1930-2000: +0.4°C/decade; 1970-2000: +0.6°C/decade) (Magrin *et al*., 2009). Lobell *et al*. (2011) showed that the observed changes in the growing season temperature and precipitation between 1980 and 2008 have slowed the positive yield trends due to improved genetics in Brazilian wheat, maize and soy, as well as Paraguayan soy. In contrast, rice in Brazil and soybean in Argentina have benefited from precipitation and temperature trends. In

Argentina, increases in soybean yield may be associated with weather types that reduce thermal stress during flowering and pod set stages and favour stability at harvest time (Bettolli *et al*., 2009).

Projected impacts: In SESA climate change could benefit some crops until mid-21st-century if CO_2 effects are considered (see Table 27-5), although interannual and decadal climate variability coul provoke important damages. In Uruguay, productivity could increase steadily until the 2030s-2050s depending on the SRES scenario.(ECLAC, 2010c). In Argentina average yields of soy, maize and wheat could increase or remain almost stable. Increases in temperature and precipitation may benefit crops towards the southern and western zone of the Pampas (Magrin *et al*., 2007c; ECLAC, 2010c). In South Brazil, irrigated rice yield (Walter *et al*., 2010) and bean productivity (Costa *et al*., 2009) is expected to increase. If technological improvement is considered, the productivity of common bean and maize could increase between 40% and 90% (Costa *et al*., 2009). Sugarcane production could benefit as warming could allow the expansion of planted areas towards the south, where 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). In Paraguay the yields of soybean and wheat could remain almost stable or increase slightly until 2030 (ECLAC, 2010a).

In Chile and western Argentina, yields could be reduced by water limitation. In central Chile (30ºS to 42ºS) temperature increases, reduction in chilling hours and water shortages may reduce productivity of winter crops, fruits, vines and radiata pine. Conversely, rising temperatures, more moderate frosts and more abundant water will *very likely* benefit all species towards the South (Meza and Silva, 2009; ECLAC, 2010a). In northern Patagonia (Argentina) fruit and and vegetable growing could be negatively affected because of a reduction in rainfall and in average flows in the Neuquén River basin. At the same time in the region, in specific in the north of the Mendoza basin, increases in water demand, because of population growth, may compromise the availability of subterranean water for irrigation, pushing up irrigation costs and forcing many producers out of farming towards 2030. Also, water quality could be reduced by the worsening of existing salinization processes (ECLAC, 2010a).

In CA, northeastern Brazil and parts of the Andean region (Table 27-5) climate change could affect crop yields, local economies and food security. Results from 23 GCMs suggest a high probability (>90%) that growing season temperatures in parts of tropical SA, east of the Andes and CA will exceed the extreme seasonal temperatures documented from 1900 to 2006 at the end of this century, affecting regional agricultural productivity and human welfare (Battisti and Naylor, 2009). For NEB, declining crop yields in subsistence crops such as beans, corn and cassava are projected (Lobell *et al*., 2008; Margulis *et al*., 2010). In addition, increases in temperature could reduce the areas currently favorable to cowpea bean (Silva *et al*., 2010). The warming up to 5.8 °C foreseen for 2070 could make the coffee crop unfeasible in Minas Gerais and São Paulo (SE Brazil) if no adaptation action is accomplished. By 2070 the coffee crop may have to be transferred to southern regions where frost risk will be much lower (Camargo, 2010). A Great increases in Arabica coffee production (principally in the Uruguayan border and North of Argentina) are expected in low climatic risks areas with 3ºC increases in mean temperature (Zullo *et al*., 2011). Brazilian potato production could be restricted to a few months in currently warm areas, which today allow potato production all around the year (Lopes *et al*., 2011). Large losses of suitable environments for the “Pequi” tree (*Caryocar brasiliense*; an economically important Cerrado fruit tree) are projected by 2050, mainly affecting the poorest communities in Central Brazil (Nabout *et al*., 2011). 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 (HadCM3 climate and no CO_2 fertilization).

Teixeira *et al*. (2011) identified hot spots for heat stress towards 2071-2100 under the A1B scenario and 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, warming conditions combined with more variable rainfall are expected to reduce maize, bean and rice productivity endangering the food security of many people and increasing poverty (ECLAC, 2010c) (see Table 26-7). According to Lobell *et al*. (2008), rice and wheat yields could decrease up to 10% by 2030. In Panamá, maize production could modestly increase over the century because of accelerated development helping the grain-filling period to be completed before the worst water stresses occur, although the large interannual climate variations 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. According to DaMatta *et al*. (2010), many crops (such as soybean, common bean, maize and sugarcane) can probably respond with an increasing productivity as a result of higher growth rates and better water use efficiency. However, food quality could decrease due to higher sugar contents in grain and fruits, and decreases in the protein content in cereals and legumes.

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. However, the trends presented here represent the current available information (see Table 27-5).

[INSERT TABLE 27-5 HERE
Table 27-5: Impacts on agriculture.]

Climate change may also alter the current scenario of plant diseases and their management, having effects on productivity (Ghini *et al*., 2011). In Argentina, years with severe infection of late cycle diseases in soybean could increase; severe outbreaks of the Mal de Rio Cuarto virus in maize could be more frequent; and wheat head fusariosis will increase slightly in the south of the Pampas region, and decrease in the north by the end of the century (ECLAC, 2010a; Martínez *et al*., 2011). Potato late blight (*Phytophtora infestans*) severity is expected to increase in Perú (Giraldo *et al*., 2010). However, there is uncertainty related to how plants will respond to diseases because of a potential increase in plants' photosynthesis and accelerates in their metabolism under the effect of elevated CO_2 and higher temperature (Sage, 2002), possibly offsetting many of the diseases' effects in the future.

The impacts of climate change on livestock production would vary by species and climate scenarios. By 2060, under a hot and dry scenario, beef and dairy cattle, pigs and chickens could decrease between 0.9 and 3.2%, while sheep could increase by 7% mainly in the Andean mountain countries. Dairy cattle could increase only in Uruguay and Argentina. 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 Seo *et al*. (2010). Future climate could strongly affect milk production and feed intake in dairy cattle in Brazil. Furthermore, substantial modifications in the Brazilian areas at present suitable for livestock, particularly in the main Pernambuco region are expected (Silva *et al*., 2009).

Climate change impact 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. Despite experiencing significant negative yield shocks, some countries tend to gain from higher commodity prices (Hertel *et al*., 2010). Increases in prices during 2007-2009 led to rising poverty in Nicaragua, but decreasing poverty in Peru (see chapter 7).

27.3.4.2. Adaptation Practices

Genetic advances and suitable soil and technological management may induce an increase in some crops' yield despite 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). Adjustments in sowing dates and fertilization rates could reduce negative impacts in maize and wheat crops in Argentina and Chile (Magrin *et al*., 2009; Meza and Silva, 2009; Travasso *et al*., 2009b). Furthermore, in central Chile and southern Pampas in Argentina warmer climates could allow performing two crops per season increasing productivity per unit land (Monzon *et al*., 2007; Meza *et al*., 2008). In Brazil, adaptation strategies for coffee crops include: planting at high densities, vegetated soil, accurate irrigation and breeding programs, and shading management system (arborization) (Camargo, 2010). Shading is also used in Costa Rica and Colombia. In South Brazil, a good option for irrigated rice could be to plant early cultivars (Walter *et al*., 2010).

Several adaptation practices have been oriented towards water management (see section 27.3.1), especially in irrigated crops for a needed better preparedness regarding water scarcity. Adaptive strategies might need to look at the harvest, storage, temporal transfer and efficient use of rainfall water (Quiroga and Gaggioli, 2011). Adaptation to water scarcity can be improved by taking into account a well-known set of agronomic practices like: fallowing, crop sequences, groundwater management, no-till operations, cover-crops and fertilization. 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).

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 which the use of climatic forecasts in agricultural planning presents a measure. Increased access to scientific forecasts, and increased availability of improved forecast information would greatly enhance the ability of the farmers in the Brazilian Amazon to cope with El Niño events (Moran *et al*., 2006). Other climatic indices such as 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 in Argentina (Travasso *et al*., 2009a). Another possibility to cope with extreme events, consists in transferring weather-related risks by using different types of rural insurance (Baethgen, 2010). Index insurance is one mechanism that has been recently introduced to overcome obstacles to traditional agricultural and disaster insurance markets (see chapter 15). For the support of such a parametric agricultrual insurance, a Central American climate data base was recently established (CRRH-SICA, 2010).

Local and indigenous knowledge have the potential to bring solutions even in the face of rapidly changing climatic conditions (Folke *et al*., 2002; Alteri and Koohafkan, 2008), Crop diversification is used in the Peruvian Andes to suppress pest outbreaks and dampen pathogen transmission (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 runoff and have helped retain more topsoil and moisture during periods of droughts (Holt-Gimenez, 2002). A case study with indigenous farmers in highland Bolivia indicates that constraints on access to key resources must be addressed for reducing vulnerability over time (McDowell and Hess, 2012). Otherwise, adaptation measures may include an orientation towards non-farming activites as was the case for NEB. In that case, vulnerability has been increasing since the late 1990s due mainly to the overuse of natural resources to which smallholders responded with off-farm activities to sustain their livelihoods (Sietz, 2011). In El Salvador, if local sustainability efforts continue the future climate vulnerability index could only slightly increase by 2015 (Aguilar *et al*., 2009).

Shifting in agricultural zoning has been an autonomous adaptation observed in SA. In Argentina e.g., increases in precipitation promoted the expansion of the agricultural frontier to the West and North of the traditional agricultural area, resulting in environmental damage that could be aggrevated in the future (Barros, 2007; República Argentina, 2007). Adjustment of production practices, like farmers in the semi-arid zones of mountain regions of Bolivia have begun as they noticed strong changes in the climate since the 1980s, including upward migration of crops, selection of more resistant varieties and water capturing, presents a further adaptation measure (PNCC, 2007).

Organic systems are highly adaptive to climate change due to the application of traditional skills and farmers' knowledge, soil fertility-building techniques and a high degree of diversity (ITC, 2007). A controversial, but important issue in relation to adaptation is the use of genetically modified plants to produce food, with biotech crops being likely to be key to cope with the needed food productivity increase considiering global population trend (see Chapter 7) Brazil and Argentina are the 2nd and 3rd fastest growing biotech crop producers in the world after the US (Marshall, 2012).

Two of the main challenges to maintain food quality and food security in most regions of the world will be 1) the integration of agriculture based in breeding and biotech with organic strategies and 2) the integration between food and bioenergy production. These two issues have to be addressed 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.

27.3.5. Human Settlements, Industry, and Infrastructure

According to the World Bank database (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 (Smolka and Larangeira, 2008; Winchester, 2008; Roberts, 2009; Romero-Lankao, 2012).

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 Ruiz, 2009). More than 20% of the population in the region tends to be concentrated in the largest city of each country (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 (Bradley *et al*., 2006; Hegglin and Huggel, 2008; Melo *et al*., 2010). The excess of water is also a preoccupation in several cities. In São Paulo for example, according to Marengo *et al*. (2009b; 2012b) 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 27-1. Increases in flood events during 1980-2000 have been observed also in the Buenos Aires province and Metropolitan Area (Andrade and Scarpati, 2007; Barros *et al*., 2008; Hegglin and Huggel, 2008; Nabel *et al*., 2008). There are also the combined effects of climate change impacts, human settlements' features and other stresses, such as more intense pollution events (Moreno, 2006; Nobre *et al*., 2011; Nobre, 2011; Romero-Lankao *et al*., 2013b) and more intense hydrological cycles from urban heat-island effects.

______START BOX 27-1 HERE______

Box 27-1. Vulnerability of South American Megacities to Climate Change: The Case of the Metropolitan Region of São Paulo (MRSP)

Research in the Metropolitan Region of São Paulo (MRSP), between 2009 and 2011, reveals a very comprehensive and interdisciplinary project on the impacts of climate variability and change, and vulnerability of Brazilian megacities. Studies derived from this project (Nobre *et al*., 2011; Marengo *et al*., 2012b) identify the impacts of climate extremes on the occurrence of natural disasters and the impacts on human health. These impacts are linked to a projected 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 based on data from 1933-2010 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 (Marengo *et al*., 2012b) 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 27-1 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; 2013b).

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 (Hsiang, 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 in Latin America and the Caribbean 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 risks in daily life, climate change adds a new dimension to these risk settings (Pielke Jr *et al.*, 2003; Roberts, 2009; Romero-Lankao and Qin, 2011). Since urban development remains fragile in many cases, with weak planning responses, climate change is *likely* to compound existing challenges. The probabilities and magnitudes of these events in each urban center will differ signigicantly according to socioeconomic, institutional and physical context.

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 set of challenges and opportunities for mainstreaming flood management, warning systems and other adaptation responses with sustainability goals (Bradley *et al.*, 2006; Hegglin and Huggel, 2008; Hardoy and Pandiella, 2009; Romero-Lankao, 2012; Romero-Lankao *et al.*, 2013a).

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. (Barton, 2009; Luque *et al.*, 2013)

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 land use and economic develop 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, Buenos Aires, Quito, Esmeraldas, Santiago and other large cities (Romero-Lankao, 2007b; Carmin *et al.*, 2009;

Romero-Lankao, 2012; Luque *et al.*, 2013; Romero-Lankao *et al.*, 2013a). 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 policies, plans and programs 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 climate related hazards (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; Winchester and Szalachman, 2009; Hardoy and Romero-Lankao, 2011). 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 (Costa Fereira *et al.*, 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 of climate change considerations into wider city planning is still a challenge, as are more inter-sectoral and participative processes that have been linked to more effective policies (Barton, 2009; De Oliveira, 2009; Romero-Lankao *et al.*, 2013a). 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 and Buenos Aires.

27.3.6. Renewable Energy

27.3.6.1. Observed and Projected Impacts and Vulnerabilities

Table 27-6 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 the most representative source of RE 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 27-6 HERE
Table 27-6: 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).]

Lucena *et al.* (2009) 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 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. 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. 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 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 can 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), some 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. 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).

The production of energy from renewable sources such as hydro- and wind power are greatly dependent on climatic conditions and therefore may be impacted in the future by GCC. The analysis by Lucena *et al*. (2010a), related to liquid biofuels and hydropower, suggests an increasing energy vulnerability of the poorest regions of Brazil to GCC together with a possible negative influence on biofuels production and electricity generation, mainly biodiesel and hydropower respectively.

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 direct land use changes, according to simulation performed by Lapola *et al*. (2010) of the effects for 2020. The same study 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). Thus, 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.

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 adaptation measure will be to increase the productivity of bioenergy crops due to planting in high productivity environments with highly developed technologies, in order to use less land. 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, may not 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). 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. Therefore, increased protection of natural areas in species-rich areas is necessary to preserve biodiversity in the face of these pressures (Brooks *et al*., 2009).

27.3.6.2. Adaptation Practices

RE will, in general, become increasingly more important over time as this is closely related with the emissions of GHG (Fischedick *et al*., 2011). Thus, 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 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 area of CA and SA. However, for small countries it might not be possible to use bioenergy. Instead, they could benefit in the future from other types of RE, such as geothermal, 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).

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). Some of the most important adaptation measures regarding RE are: (1) management of land use change (LUC); (2) modeling 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 carefully managed, biofuel crops can be used as a means to regenerate biodiversity as proposed by Buckeridge *et al*. (2012) who pointed 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 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 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 on the other hand. 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). For example, these teleconnections may link Amazon deforestation derived from soy expansion to the economic growth in China due to changes in the demand of soy. The effects of such teleconnections may possibly mean 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 27-6).

[INSERT FIGURE 27-6 HERE
Figure 27-6: 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).]

27.3.7. Human Health

27.3.7.1. Observed and Projected Impacts and Vulnerability

Climate variability and climate change (CV/CC) are negatively affecting human health in CA and SA, either by increasing morbidity, mortality, and disabilities (very high confidence), and through the emergence of diseases in regions previously non-endemic, or the re-emergence of diseases in areas where they have previously been eradicated or controlled (high confidence) (Winchester and Szalachman, 2009; Rodríguez-Morales, 2011). Heat waves and cold spells are affecting mortality rates in cities (McMichael *et al*., 2006; Bell *et al*., 2008; Hardoy and Pandiella, 2009; Muggeo and Hajat, 2009; Hajat *et al*., 2010). 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 have increased in the last five decades, along with air temperatures, in Colombia (Poveda *et al*., 2011b; Arevalo-Herrera *et al*., 2012), as well as in urban and rural areas of Amazonia, concomitantly with large environmental changes (Gil *et al*., 2007; Tada *et al*., 2007; Cabral *et al*., 2010; Da Silva-Nunes *et al*., 2012). Malaria vector densities have increased in northwestern Argentina along with climate variables (Dantur Juri *et al*., 2010; 2011). 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 (Rodríguez-Morales *et al*., 2006; Osorio *et al*., 2007). 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 (Torres and Castro, 2007; Tapia-Conyer *et al*., 2009; Shepard *et al*., 2011). 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) (Rodríguez-Morales and Herrera-Martinez, 2009; Herrera-Martinez and Rodríguez-Morales, 2010). Weather and climate variability are also associated with DF in southern SA (Honório *et al*., 2009; Costa *et al*., 2010; De Carvalho-Leandro *et al*., 2010; Degallier *et al*., 2010; Lowe *et al*., 2011). A study in Rio de Janeiro found that a 1°C (10-mm) increase in monthly minimum temperature (rainfall) led to a 45% (6%) increase in DF in the following month (Gomes *et al*., 2012). Despite large vaccination campaigns, the risk of major Yellow Fever (YF) outbreaks has increased in tropical America amidst changes in 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). It is possible that the incidence of SCH will increase as a result of increasing temperatures (Mangal *et al*., 2008; Mas-Coma *et al*., 2009; Lopes *et al*., 2010), while vegetation indices (e.g. Normalized Difference Vegetaion Index), which are directly related to climate conditions, are associated with human fascioliasis in the Andes (Fuentes, 2004).

Hantaviruses (HV) have been reported in Honduras, Panama, Costa 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). 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, in which climate and environmental changes play an important role (Abad-Franch *et al*., 2009; Araújo *et al*., 2009; Moncayo and Silveira, 2009), as in Panama and Argentina (Tourre *et al*., 2008; Gottdenker *et al*., 2011). Ciguatera fish poisoning (CFP) is a tropical disease correlated with water temperature, and thus climate change could increase its incidence across the Caribbean (Tester *et al*., 2010). Climate is an important factor of Paracoccidioidomycosis, Latin America'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) (Gomez *et al*., 2006; García *et al*., 2009). 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; 2007; 2008). 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 it 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 to the occurrence of El Niño (Ready, 2008), as is also the case in Argentina, Paraguay, and Uruguay (Bern *et al*., 2008; Dupnik *et al*., 2011; Salomón *et al*., 2011; Fernández *et al*., 2012). VL transmission in western Venezuela is also associated with the bimodal annual rainfall regime (Feliciangeli *et al*., 2006; Rodríguez-Morales *et al*., 2007). On the other hand, the incidence of skin cancer in Chile has increased in recent years, which is statistically correlated to climatic and geographic variables (Salinas *et al*., 2006).

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). Leptospirosis is particularly prevalent in warm and humid tropical regions of CA (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 (Koelle, 2009; Jutla *et al*., 2010; Marcheggiani *et al*., 2010; Hofstra, 2011), and thus high correlations exist between El Niño and cholera in Peru, Ecuador, Colombia, Mexico and Venezuela (Cerda Lorca *et al*., 2008; Martínez-Urtaza *et al*., 2008; Salazar-Lindo *et al*., 2008; Holmner *et al*., 2010; Gavilán and Martínez-Urtaza, 2011; Murugaiah, 2011). 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; Martins and Andrade, 2008; Gurjar *et al*., 2010; Jasinski *et al*., 2011; Rodriguez *et al*., 2011).

Extreme weather and climate events affect mental health by exposure to psychological trauma (Higginbotham *et al*., 2006; Berry *et al*., 2010). Drought-prone areas in NEB 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 are associated with climate seasonality 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 (Perera, 2008; Martiello and Giacchi, 2010; Graham *et al*., 2011; 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 disability-adjusted life years (DALYs- a measure of disease burden, expressed as the number of years lost owing to disability, ill-health or early death) in LA, many of which are climate-sensitive diseases (Hotez *et al*., 2008; Allotey *et al*., 2010). Mega-cities' vulnerability (see 27.3.5) is aggravated by the provision of drinking water and by the rapid spread of diseases. It further is increasing due to migration from rural areas forced by environmental degradation and disasters (Campbell-Lendrum and Corvalán, 2007; Borsdorf and Coy, 2009; Hardoy and Pandiella, 2009), and in turn mega-cities are vulnerable to natural disasters (earthquakes, fires, storms etc.) that might change in frequency and intensity in the context of global climate change. The provision of drinking water and the spread of diseases make mega-cities vulnerable to global environmental change (Borsdorf and Coy, 2009). Diverse vulnerability assessments to the impacts of climate change on human health have been developed in Brazil at national, regional and municipal scales. The approach uses composite indicators, which included downscaled climate scenarios, epidemiological variables, economic and demographic projections and the status of natural ecosystems (Confalonieri *et al*., 2009; 2011; Barbieri and Confalonieri, 2011; FIOCRUZ, 2011). 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

Despite the attempt to implement adaptation strategies 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; Romero and Boelaert, 2010; Karanja *et al*., 2011). 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 (Tirado *et al*., 2010; Team and Manderson, 2011). 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 reducing GHG emissions, such as the 11% reduction of methane by landfills (De Oliveira, 2009; Nath and Behera, 2011).

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, a general tendency aims at studying vulnerability to climate change especially in SA and CA using a holistic or systemic approach (Ison, 2010; Carey *et al*., 2012b), 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 (Young and Lipton, 2006; Corfee-Morlot *et al*., 2011) 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, and requires therefore international involvement as one facilitating factor in natural hazard management and climate change adaptation (Carey *et al*., 2012b). 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 sch as SA and CA, 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 (Tompkins *et al*., 2008; Nelson and Finan, 2009), 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 (Roncoli, 2006; Young and Lipton, 2006; Corfee-Morlot *et al*., 2011), 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 when local, short-term strategies designed to deal with specific threats or challenges do not integrate a more holistic and long-term vision of the system at threat (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). 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).

In natural hazard management contributing to climate change adaptation, specific cases such as the one in Lake 513 in Peru (Carey *et al*., 2012b) clearly allowed to identify facilitating factors for a successful adptation process (technical capacity, disaster events with visible hazards, institutional support, committed individuals, and international involvement) as well as impediments divergent risk perceptions, imposed government policies, institutional instability, knowledge disparities, and invisible hazards).

In certain cases, 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

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.

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. Up to date, in total 18 regional Non-Annex countries, including Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Guyana, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela, have already responded through their initial and most cases second National Communication to the UNFCCC from 1997 until 2012 (see UNFCCC, 2012) allowing to measure the country's emissions and to assess its present and future vulnerability. In addition, 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. As an example, the 'CentroAmerican Integration System' (see SICA, 2013 gathers every three months climate experts for regional institutions as well as sectorial experts (agriculture, energy, etc.) in order to discuss climate trends, increase capacity-building and anticipate major climate threats. 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 (Kok *et al*., 2007).

Table 27-7 presents programs, projects and initiatives with focus on current and past practical adaptation measures maintained in the data collection by the UNFCCC under the Nairobi Work Programme (NWP) (distinguishing Private Sector Initiatives (PSI); Local Coping Strategies (LCP) (UNFCCC, 2012b); EbA approaches; and Adaptation Practices (AP); complemented with international projects from the weAdapt database (weAdapt, 2012).

[INSERT TABLE 27-7 HERE
Table 27-7: Overview on local, regional, national and international adaptation programs, projects and initiatives relevant for the region]

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. Such initiatives also depend on local and organizational leaderships (UN-Habitat, 2011).

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 in CA and SA (see section 27.3.6). Although there is debate about GHG emissions from hydropower reservoirs (especially in tropical environments, Fearnside and Pueyo, 2012) this form of electricity generation is often seen as a major contributor to mitigating GHG emissions worldwide (see IPCC SRREN [5]; Kumar *et al.* (2011). On the other hand, hydropower is also a climate-related (water) sector, thus making it prone to serious efects from climate change (see section 27.3.1.1).

The CA and SA region constitute a unique example to study these relations between climate change mitigation and adaptation in relation to hydropower generation. 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 of hydropower energy generation in the world, displaying a 20% share of total annual generation. The quality of water resources availability in CA and SA 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 (Table 27-6 in section 27.3.6.1). The hydropower proportion of total electricity production is over 40% in the region, and in some cases is near or close to 80%, as in the case of Brazil, Colombia and Costa Rica.

Diverse studies have analyzed the potential impacts of climate change on hydropower generation (see details in Table 27-4 in section 27.3.1.1). Maurer *et al.* (2009) studied future hydrologic conditions for the Lempa River basin across El Salvador, Honduras and Guatemala, which feeds major hydroelectric facilities. Assesmment of projections including uncertainty analysis show a reduction in hydropower capacity of 33% to 53% by 2070-2099. 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, thus reducing electricity generation up to 35% compared to base conditions (Ospina-Noreña *et al.*, 2009a). Further studies (Ospina-Noreña *et al.*, 2011a;

2011b) have estimated vulnerability indices for the hydropower sector in the same basin, and identified reservoir operation 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*., 2010). In Brazil, the country with the largest installed hydroelectric capacity in the region, continuous efforts are made to improve the management of the system under variable climatic conditions (Lima and Lall, 2010). There is still unused generation capacity in sub-basins of the Amazon River (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; Finer and Jenkins, 2012). According to Lucena *et al*. (2009), hydropower systems in southern Brazil (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 hydropower system, and especially those located in the North East region, could face a reduction in power generation, thus reducing the reliability of the whole system (Lucena *et al*., 2009).

An obvious implication of the mentioned impacts is the need to replace the energy lost due to climate change impacts. In this regard, a typical adaptation measure would be to increase alterantive energies (see 27.3.6.2). Lower cost of adaptation measures have been studied for Brazil (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 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 average electricity that needs to be replaced 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 efficiency or demand growth that could mitigate the expected impacts on hydropower systems in the Colombian Sinú-Caribe River basin.

Some other implications are, for instance, changes in the seasonality of inflows to hydropower generation systems such as those projected for Peru (Juen *et al*., 2007), Chile (ECLAC, 2009a), and Argentina (Seoane and López, 2007), that could affect the relationship between different water users within a basin. In Chile for example, hydrologic impacts of climate change could affect water supply to agriculture irrigation triggering economic and social conflicts between this and the hydropower sector that share water resources from the same river basin. It is worth noting that 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 operation (Ferreira and Teegavarapu, 2012) and 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. Payment for Ecosystem Services

Payment for ecosystem services (PES) is commonly described as a set of transparent schemes for securing a well-defined ecosystem service (or a land use capable to secure that service) through conditional payments or compensations to voluntary providers (Engel *et al*., 2008; Tacconi, 2012). Van Noordwijk *et al*. (2012) provides a broader definition to PES by arguing that it encompasses three complementary approaches, (i) the one above, i.e., commodification of pre-defined ecosystem services so that prices can be negotiated between buyers and sellers; plus (ii) compensation for opportunities forgone voluntarily or by command and control decisions; and (iii) coinvestment in environmental stewardships. Therefore, the terms ´conservation agreements´, ´conservation incentives´ and ´community conservation´ are often used as synonyms or as something different or broader than PES (Milne and

Niesten, 2009; Cranford and Mourato, 2011). For simplicity, we refer to PES in its broadest sense (sensu van Noordwijk *et al*., 2012).

Services subjected to such types of agreements 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 mostly privately owned, policies often aim at supporting landowners to maintain the provision of services over time (Kemkes *et al*., 2010). Irrespective of the debate of as to whether payments or compensations should be designed to focus on actions or results (Gibbons *et al*., 2011), experiences in Colombia, Costa Rica and Nicaragua show that PES can finance conservation, ecosystem restoration, and better land use practices (Montagnini and Finney, 2011; see also Table 27-5). 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. Other setbacks to PES schemes might include cases where there is a perception of commoditization of nature and its intangible values (e.g. Bolivia, Cuba, Ecuador and Venezuela), cases where mechanisms are inefficient to reduce poverty, slowness to build trust between buyers and sellers, as well as gender and land tenure issues that might arise (Asquith *et al*., 2008; Peterson *et al*., 2010; Balvanera *et al*., 2012; van Noordwijk *et al*., 2012).

Table 27-8 lists selected examples of PES schemes in Latin America, but a more complete and detailed list is given in Balvanera *et al*. (2012).

[INSERT TABLE 27-8 HERE
Table 27-8: Cases of government-funded PES schemes in CA and SA.]

The PES concept (or ´fishing agreements´) also applies to coastal and marine areas, although only a few cases have been reported. Begossi (2011) argues that this is due to three factors: origin (the mechanism was originally designed for forests), monitoring (marine resources such as fish are more difficult to monitor than terrestrial resources) and definition of resource boundaries in offshore water. One example of a compensation mechanism in the region is the so-called *defeso*, in Brazil. It consists of a period (reproductive season) when fishing is forbidden by the government and fishermen receive a financial compensation. It applies to shrimp, lobster and both marine and freshwater fisheries (Begossi *et al*., 2011).

27.7. Data and Research Gaps

The lack of high quality and continuous climate, oceanic and hydrological records, together with the very few complete regional studies, poses challenges for the region to address climate variability and the identification of trends in climatic extremes, in particular for CA. The non-availability of high resolution climatic and hydrological data also hampers studies on frequency and variability of extremes. This situation affects the studies of related impacts and vulnerability analyses in present climates, and the development of vulnerability assessments and adaptation actions for the future.

Related with observed impacts in most of the sectors, there is a great difference in information availability between countries, While more studies have been performed for the SESA region, much less are available for CA and for some regions of tropical SA. The problem is not only the lack of studies of observed impacts, but also the lack or poor dissemination of results in peer-reviewed publications. There is a need for studies focused on current impacts and vulnerabilities in all the sectors throughout CA and SA, potentially with a certain emphasis on extremes in order to improve risk management assessments.

The complex interactions between climate and non-climate drivers can challenge impacts assessment and projections, as can for instance be the case for water availability and streamflow when looking at current and potential deforestation; or overfishing and pollution regarding the impacts on fisheries, or impacts on hydroenergy production. In this sense, the lack of interdisciplinary integrated studies limits the knowledge of such complex processes that involve not only physical but also socioeconomical factors.

In addition, the accelerated changes in some issues like deforestation and changes in land use, as well as economic conditions, demand continuous and detailed studies to update available information to be made available to the research community.

To address the global challenge of food secturity and food quality, being important issues in CA and SA, investments in the production of scientific agricultural knowledge will be reinforced in relation to: integration of agriculture with organic production; and the integration of food and bioenergy production. With the important interlinakges of renewable energy, adaptation and mitigation, sufficient knowledge on RE project implementation and on crops is requested.

Also, a better understanding is needed of potential adverse effects of bioenergy production and indirect land use changes. Equally, further research is needed on future projections of renewable energy, e.g. wind power. However, it is indispensable that the competition for food and bioenergy production considers ethical aspects; identifying which activity is most important and whether bioenergy production would affect food security.

Sea level rise and costal erosion are also relevant issues, and the lack of comparable measurements of sea level rise in CA and SA makes integrated assessments on sea level rise and impacts on the region difficult, both for the present and future. Of local and global importance will be an enhancement of the understanding of the physical processes on the ocean, in specific the Humboldt Current system flowing along the West Coast of SA, being the most fish productive system worldwide.

While the majority of the coastal section literature focuses on fisheries, there is a recognized need for research on how corals reefs, mangroves and benthic marine invertebrates, that are key to reef systems as well, could be impacted upon by climate change.

There is still a need for more research and information about the impacts of climate variability and change on human health, mainly in CA. One problem is the difficulty to accessing health data that are not always archived and ready to be used in integrated studies. Another need refers to building the necessary critical mass of transdisciplinary scientists to tackle the climate change-human health problems in the region. The prevailing gaps in scientific knowledge hamper the implementation of adaptation strategies, thus demanding a review of of research priorities towards better disease control. With the aim of further studying the health impacts of climate change and identifying resilience, mitigation and adaptation strategies, South-South cooperation and multidisciplinary research are considered to be relevant priorities.

In despite of the uncertainty that stems from global and regional climatic projections, the region needs to act. In this sense it is usseful to promote research activities leading to assist people to cope with current climate variability, as for example, risk assessment and risk management. Other important aspect is the improvement of climate modeling that can be done in the region, thus lowering uncertaintities. Since the AR4, experiences on model development and the generation of high resolution climate scenarios have allowed for the production of the first integrated regional studies on impacts and vulnerability assessments of climate change, for sectors such as agriculture, energy and human health.

Research on adaptation and the scientific understanding of the various processes and determinants of adaptive capacity is also key to the region, with particular potential in increasing adaptation capacity when focusing on traditions and how they are transmitted. Linking indigenous knowledge with scientific knowledge is also needed. Although adaptation processes have mostly been intiated in the past years, still their efficiency is difficult to determine owing to a lack of literature to evaluate them.

There is a need for change in the research agenda in order to address vulnerability and foster adaptation in the region; encompassing an inclusion of the regions' researchers and focusing also on governance structures and action-oriented research that also addresses resource distribution inequities.

Regional and international partnerships, networks, research programs have allowed a linkage of those programs with local strategies for adaptation and mitigation, also providing opportunities to address research gaps and exchange among researchers. Examples are the Ibero-American Network of Climate Change Offices- RIOCC; the European Union funded projects CLARIS LPB in SESA and AMAZALERT in Amazonia. Other important initiaves come from the WHO, GEF, IDB, ECLAC (CEPAL), La Red, BirdLife International. The same holds for local international networks such as ICLEI or C40, of which CA and SA cities form part. The weADAPT initiative is a good example on how practitioners, researchers and policy makers for CA and SA can have access to credible, high quality information and to share experiences and lessons learnt in other regions of the world.

27.8. Conclusions

In CA and SA there is ample evidence of increases in extreme climate events and on their impacts on natural and human systems. Changes in climate variability and in extreme events have been severely affecting CA and SA since the second half of the 21st century. Since the AR4, unusual extreme weather and climate events have occurred in most countries: drought/flood episodes in Amazonia in 2010/2009, 2012, the drought in NE Brazil in 2012, cold waves and floods in the Andes from 2010-2012, among others. Temperature increases have been identified in most of CA and SA, with the exception of the southern coast of South America that has experienced cooling during the last decades. Changes in observed warm days and cold nights have been identified in CA, and some sectors of SA, while more frequent and intense rainfall extremes in SESA have favored an increase in the occurrence of landslides and flash floods. Since the AR4, there is growing evidence that glaciers (both tropical and extratropical) are retreating and the cryosphere in the Andes is changing according to the warming trends, affecting the hydrometeorological regimes in SA.

Land cover change is a key driver of environmental change with significant impacts on 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 rates in the Amazon have decreased substantially in the last eight years, other regions like the Cerrado and the Chaco forests still present high levels of deforestation with rates as high as 1.33%. In Argentina, Bolivia, Brazil and Paraguay, agricultural expansion, mainly soybean, has exacerbated deforestation and has intensified the process of land degradation. The agricultural expansion has affected fragile ecosystems such as the edges of the Amazon forest and the Pampas region; or the tropical Andes, increasing the vulnerability of communities to extreme climate events, particularly floods, landslides and droughts.

Socioeconomic development shows a high level of structural heterogeneity and a very unequal income distribution resulting in the high vulnerability of the region to climate variability and change. There is still a high and persistent level of poverty in most countries in spite of the sustained economic growth observed in the last decade. The economic inequality translates into inequality in access to water, sanitation and adequate housing; particularly for the most vulnerable groups living in poverty. However, high vulnerability can be found in regions with high income.

Coastal and marine ecosystems have been undergoing significant transformations that pose threats to marine excosystems and to the services they offer. Frequent coral bleaching events have been recently reported for the Mesoamerican Coral Reef. 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 have been found in CA and SA, which is reason for concern since 3/4 of the population of the region live within the range of 200 km of the coast.

Conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region, and in parallel is a driver of anthropogenic climate change. 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. However, the region has still large extensions of natural vegetation cover for which the Amazon is the main example. Ecosystem-based Adaptation practices, such as conservation agreements, community management of natural areas, and payment for ecosystem services, begin to appear across the region.

Figure 27-7 presents a summary of some of the main observed trends in global environmental change drivers across different representative regions of CA and SA. The figure presents changes in climate and non climate drivers and has to be compounded with other socioeconomic related trends, such as the rapid urbanization process experienced the region.

[INSERT FIGURE 27-7 HERE
Figure 27-7: Summary of observed changes in climate and other environmental factors in representative regions of CA and SA. The boundaries of the regions in the map are conceptual (not precise geographic nor political) and follow those developed in Figure 3-1 of the IPCC SREX (IPCC, 2012). Information and references to changes provided are presented in different sections of the chapter.]

In terms of attribution to climate change, some of the observed impacts on human and natural systems detected and reported in the literature are shown in Figure 27-8. Some of them can be directly or indirectly attributed to human influences, and can be summarized as:

- Reduction in tropical glaciers and icefields in tropical and extra tropical Andes over the second half of the 20th century that can be attributed to an increase in temperature.
- There have changes identified in river flows in SA. Extreme streamflow in the Amazon River have changed during the last two decades, robust positive trends in streamflow in different sites have been detected in sub-basins of the La Plata River basin and increased dryness for most of the river basins in west coast of South America have been detected during the last 50 years.
- Mangrove degradation in the Northern South American coast and reduction in fisheries stock.
- Increase in agricultural yield in SESA, and shifting in agricultural zoning: significant expansion of agricultural areas, mainly in climatically marginal regions.
- Increase in frequency and extension of dengue fever, yellow fever and malaria.

However, the fact that in some impacts the number of studies is still insufficient leads to extreme low levels of confidence for attribution to human influences.

[INSERT FIGURE 27-8 HERE
Figure 27-8: Observed impacts of climate variations and attribution of causes in CA and SA.]

By the end of the century, the projected mean warming for CA ranges from 1.5°C to 4.0 °C, while rainfall tends to decrease between 5 and 10%. SA shows a warming between 1.0°C to 5.0 °C, with rainfall reduction up to 10% in tropical SA and an increase of about 10-15% in SESA, and in other regions of the continent. Heavy precipitation is projected to increase in SESA, while dry spells would increase in northeastern South America. Increases in warm days and nights are very likely to occur in most of SA. Projections for CA show summertime precipitation reduction, accompanied by projected warming in most of the region. However, there is some degree of uncertainty on climate change projections for regions, particularly for rainfall.

In present climates, there are regions that experience vulnerability in terms of current water availability, and this vulnerability is expected to increase in the future due to climate change impacts. Already vulnerable regions in terms of water supply, like the semi-arid zones in SA and CA and the tropical Andes, are expected to increase even further their vulnerability due to climate change. This would be complicated by the expected glacier retreat, and a reduction in water availability due to expected precipitation reduction and increase evapotranspiration demands as expected in the semi-arid regions of CA and SA. These scenarios would affect water supply for large cities, small communities, hydropower generation and the agriculture sector.

This results in a need for re-assessing current practices to reduce the mismatch between water supply and demand. Thiscould be used to reduce future vulnerability, and to implement constitutional and legal reforms towards more efficient and effective water resources management in the region, as part of adaptation strategies to cope with climate variability and change. Changes in agricultural productivity as a consequence of climate change are expected to have a great spatial variability, and while in SESA projections show that average productivity could be sustained or increased until the mid-century (SRES: A2, B2), in other regions increases in temperature and decreases in rainfall could decrease the productivity in the short-term (before 2025), threatening the food security of the poorest population. The great challenge for CA and SA will be to increase the food and bioenergy production and at the same time sustain the environmental quality in a scenario of climate change.

Renewable energy has a great potential for adaptation and mitigation. Hydropower is currently 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, mainly with sugarcane and soybean, and future climate conditions may lead to an increase in productivity and production. 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 biofuels productivity in the region. 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 employment in some countries. This would also also affect food security.

Climate variability and climate change are negatively affecting human health in CA and SA, either by increasing morbidity, mortality, and disabilities and through the emergence of diseases in regions previously non-endemic, or the re-emergence of diseases in areas where they have previously been eradicated or controlled. Climate-related drivers have been recognized for respiratory and cardiovascular diseases, vector- and water-borne diseases, mainly malaria, dengue and yellow fever. Vulnerabilities vary with geography, age, gender, race, ethnicity, and socio-economic status, and climate change and variability may exacerbate current and future risks to health.

Climate change would bring new environmental conditions resulting from modifications in space and time, and in the frequency and intensity, of weather and climate processes. The best way to be prepared to adapt to future climate change is by assisting people to cope with current climate variability, particurly to weather and climate extremes. 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 CA and SA population. Such conditions weaken the importance of adaptation planning to climate change on the political agenda. In the present, there are few experiences on synergies between development, adaptation and mitigation planning, which can help local communities and governments to allocate available resources in the design of strategies to reduce vulnerability and to develop adapation measures. Facing a new climate system and, in particular, the exacerbation of extreme events, will call for new ways to manage human and natural systems for achieving ustainable development.

Frequently Asked Questions

FAQ 27.1: What is the impact of receding glaciers on natural and human systems in the tropical Andes?

Andean tropical 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. 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, runoff tends to decrease. This reduction in runoff is more evident during dry months when glacier melt is the major contribution to runoff. A reduction in runoff could reduce water related benefits and intensify conflicts among different users of water in high elevation Andean tropical basins which concentrates highly vulnerable populations. Glacier retreat has also been associated with disasters such as glacial lake outburst floods (GLOFS) that are a continuous threat in the region. And finally glacier retreat could have impacts on activities that rely on these high mountainous ecosystems such as alpine tourism, mountaineering and adventure tourism.

FAQ 27.2: Can PES be used as an effective way for helping local communities to adapt to climate change?

PES can be used as an effective way to help local communities to adapt to climate change. It can simultaneously help protect natural areas, while improving livelihoods and human well-being. However, during design and planning, a number of factors at local level need to be taken into consideration in order to avoid potentially negative side effects. Reported setbacks include: poor definition if design should focus on actions or results, perception of commoditization of nature and its intangible values, inneficiency in reducing poverty, difficulties in building trust between parts involved in agreements, and eventual gender or land tenure issues.

FAQ 27.3: Are there emerging and re emerging human diseases as a consequence of climate variability and change in the region?

Climate variability and climate change (CC/CV) are negatively affecting human health in CA and SA, either by increasing morbidity, mortality, and disabilities (very high confidence), or by the emergence of diseases in previously non-endemic regions, or the re-emergence of diseases in areas where they have previously been eradicated or controlled (high confidence). Climate-related drivers have been recognized for respiratory and cardiovascular diseases, vector- and water-borne diseases (malaria, dengue, yellow fever, leishmaniasis, cholera, and other diarrheal diseases), Hantaviruses and Rotaviruses, pregnancy-related outcomes, diabetes, chronic kidney diseases, and psychological trauma. It is very likely that CC/CV together augment current and future risks to health, amidst the region's vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, and pollution.

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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 (Seneviratne *et al.*, 2012) and Chapter 2 IPCC WGI AR5 [2.4, 2.5, 2.6]

Region	Period	Observed trends	References
CA and Northern SA			
Increase of precipitation in the NAMS during the onset season	1943-2002	+0.94 mm/day/58 years	Englehart and Douglas (2006)
Delay in the entire cycle of the summer NAMS reinfall in SW USA	1948-2004	-10 to -20 days/57 years	Grantz *et al*. (2007)
Positive rainfall trends during the summertime NAMS on the core region in the Southwest of USA.	1931-2000	17.6 mm century^{-1}	Anderson *et al*. (2010)
Positive trends in rainfall extremes (P95), mainly due to intense precipitation from tropical cyclones (TCs) in the NAMS	1961-1998	+1.3% decade^{-1}	Cavazos *et al*. (2008)
Increase of precipitation in the NAMS core region	1979-2008	+ 2 mm/day decade^{-1}	Wang *et al*. (2012)
Reduction in cold days and nights in CA and Northern SA	1951-2000	Cold days: -1 day decade^{-1} Cold nights: -2 day decade^{-1}	Donat *et al*. (2013)
Increase warm days and nigts in Northern SA	1951-2000	Warm days: +2 to +4 day decade^{-1} warm nights: +1 yo +3 day decade^{-1}	Donat *et al*. (2013)
Increase in heavy precipitation (R10) in Northern SA	1951-2000	+1 to +2 day decade^{-1}	Donat *et al*. (2013)
Reduction in consecutive dry days (CDD) in Northern SA	1951-2000	-2 day decade^{-1}	Donat *et al*. (2013)
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)
Decrease in cold days and nights in all South American coast,	1951-2000	Cold days: -1 days decade^{-1}; cold nights: -2 days decade^{-1}	Donat *et al*. (2013)
Decrease in warm nights in all South American coast, increase in warm days in the northern coast of South America, decrease of warm days off the coast of Chile	1951-2000	Warm night: -1 days decade^{-1}; warm days: +3 days decade^{-1} ; warm days: -1 days decade^{-1}	Donat *et al*. (2013)
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)
Decrease in cold days and nights in most of the region	1951-2000	warm nights: +3 days decade^{-1}; warm days: +4 days decade^{-1}	Donat *et al*. (2013)
Increase in warm days and nights in most of the region	1951-2000	Cold nights: -3 days decade^{-1}; cold days: -3 days decade^{-1}	Donat *et al*. (2013)
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	+15 to +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 number of days with precipitation bove 10 mm (R10) in most of the region	1951-2000	+2 days/decade^{-1}	Donat *et al*. (2013)
Increase in heavy precipitation (R95) in most of the region	1951-2000	+1% decade $^{-1}$	Donat *et al*. (2013)
Increase in consecutive dry days	1951-2000	-4 days decade $^{-1}$	Donat *et al*. (2013)
Increase in heavy precipitation (R95) in most of the region	1961-1990	+45 to +135 mm/31 years	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	Marengo *et al*. (2011b)

		days/decade during 196-2002	
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; 2009c; 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*. (2011b)
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)
Decrease in number of days with rainfall above 10 mm (R10)	1950-2000	-3 days decade^{-1}	Donat *et al*. (2013)
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 (2009c)
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*. (2009a), Satyamurty *et al*. (2010)
Decrease in rainfall in all the region	1975-2003	-0.32 %/28 years	Espinoza *et al*. (2009a; 2009b)
Delay on the onset of the rainy season in southern Amazonia	1950-2010	-1 month since 1976 to 2010	Butt *et al*. (2011), Marengo *et al*. (2011b)
Increase of precipitation in the SAMS core region	1979-2008	+ 2 mm/day decade^{-1}	Wang *et al*. (2012)
Onset becomes steadily earlier from 1948 to early 1970s, demise dates have remained later, and SAMS duration was longer after 1972.	1948-2008	SAMS from 170 days (1948–1972) to 195 days (1972–1982).	Carvalho *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*. (2009a)
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*. (2009a; 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/m2/23 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 from CMIP3 and various RCPs scenarios for CMIP5, and different time slices from 2010 to 2100. In order to make results comparable, the CMIP3 and CMIP5 at 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), and Chapters 9 and 14 from IPCC WG1AR5 [9.5, 9.6 and 14.2, 14.7]

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*. (2013)
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*. (2011a)
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*. (2009a; 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*. (2011a)
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*. (2009a; 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*. (2011a)
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.	Cabré *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*. (2009a; 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*. (2011a)
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*. (2009a)
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 2070-99	RCA forced with ECHAM5, A1B	Increases of +1 to +3 mm/day, +5 mm and of +5 to +10 days	Sörensson *et al*. (2010)
Reduction in summer precipitation and increase in surface air temperature in the Altiplano region by 2099	9 CMIP3 models, A2	Reduction in precipitation between -10% and -30%, an temperature increase of +3 C	Minvielle and Garreaud (2011)
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*. (2011a)
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*. (2009a)
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)
Early onset and late demise of the rainy season in SAMS by 2040-2050 relative to 1951-80	10 CMIP5 models, RCP8.5 (high emission)	Onset 14 days earlier than present, demise 17 days later than present	Jones and Carvalho (2013)
Increase precipitation in SAMS during the monsoon wet season in 2071-2100 relative to 1951-80	10 CMIP5 models, RCP8.5 (high emission)	Increase of 300 mm during the wet season	Jones and Carvalho (2013)
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*. (2011a)
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*. (2009a)
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. Equilibrium Line Altitude (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 (2004); Mark and Seltzer (2005); Silverio and Jaquet (2005); Raup *et al*. (2007) Jomelli *et al*. (2009); UGHR (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	Analysis of radiosonde data of central Chile shows mid-tropospheric warming with an elevation increase of the 0ºC isotherm of 122 ± 8 m and 200 ± 6 m in winter and summer, respectively, during the 27-year period between 1975 and 2001.	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	Hydrologic Variable	Projected Change	Period	GCM	Scenarios	References
La Plata Basin and SESA	Paraná	Runoff	Runoff: + 4.9% (not robust) Runoff: +10 to +20%	2081-2100 2100	CMIP3 Eta forced with HadCM3	A1B A1B	Nohara *et al*. (2006) Marengo *et al*. (2011a)
	Carcarañá	ET, Recharge	Increase in ET not compensated with increase in precipitation, slight reduction in recharge.	2010-2030	HadCM3	A2	Venencio and García (2011)
	Grande (Parana)	Runoff	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)	Runoff	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	Runoff	Some basins increased, some reduced	Three time slices	BCM2, CSMK3 and MIHR	A1B, B1	Lavado Casimiro *et al*. (2011)
	Ecuador - Tomebamba/Paute	Runoff	Some scenarios increase and some reduction	2070-2100	CMIP3	A1B	Buytaert *et al*. (2011)
	Amazon at Obidos	Runoff	Average change + 5.4% (not robust)	2081-2100	CMIP3	A1B	Nohara *et al*. (2006)
		Runoff	+6%	2000-2100	ECBilt-CLIO-VECODE	A2	Aerts *et al*. (2006)
	Amazon -Orinoco	Runoff	-20%	2050s	HadCM3	A2	Palmer *et al*.(2008)
Tropical Andes	Colombian glaciers	Glacier extent	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)
		Glacier extent	2050: area is reduced by 38 to 60%. Increased seasonality 2080: area is reduced by 49 to 75%. Increased seasonality	2050 (climatology)	Not specified	A1, A2, B1, B"	Juen *et al*. (2007)
	Basins providing water to cities of Bogota, Quito, Lima and La Paz	Water availability	Inner tropics: Only small change because of an offset of an increase in precipitation by an increase in evapotranspiration. Outer tropics: severe reductions due to a decrease in precipitation and increase in evapotranspiration	2010-2039 and 2040-2069	19 CMIP3 models	A1B and A2	Buytaert and De Bièvre (2012)

Central Andes	Maipo	Runoff Unmet demand	Reduction up to 30% Unmet demand up to 50%	Three 30-year periods 2070-2090	HadCM3	A2, B2	Melo *et al*. (2010); ECLAC (2009a) Meza *et al*. (2012)
	Maule, Laja	Runoff	Reduction up to 30%	Three 30-year periods	HadCM3	A2, B2	McPhee *et al*. (2010); ECLAC (2009a)
	Bio Bio						Stehr *et al*. (2010)
	Limari	Runoff	Reduction range -20 to -40%. Change in seasonality	2070-2100	HadCM3	A2, B2	Vicuña *et al*. (2011)
	Limay	Runoff	Reduction range -10 to -20%.	2080s (climatology)	HadCM2	Not specified	Seoane and López (2007)
North East Brazil	Brazilian Federal States of Ceara´ and Piauı´	Runoff	No significant change up to 2025. After 2025: strong reduction with ECHAM4; slight increase with HadCM2.	2000-2100	HadCM2, ECHAM4	Not clear	Krol *et al*. (2006); Krol and Bronstert (2007)
	Paracatu (Sao Francisco)	Runoff	A2: +31 to +131%; B2: no significant change	2000-2100	HadCM3	A2, B2	De Mello *et al*. (2008)
	Jaguaribe	Demand	Increase in demand: +33 to +44%	2040	HadCM3	A2, B2	Gondim *et al*. (2008)
	Parnaiba	Runoff	-80%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Mimoso catchment	Runoff	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)
	Tapacurá River	Runoff	Low emission: decrease by 4.89%, 14.28% and 20.58% High emission: increase by 25.25%, 39.48% and 21.95%	Three 30-year periods	CSMK3 and MPEH5	A2, B1	Montenegro and Ragab (2012)
	Benguê catchment	Runoff	-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)	Runoff	-50%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Magdalena (Colombia)	Runoff	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)	Runoff	-2 to -35%	2010-2039	CCSRNIES, CSIROMK2B, CGCM2, HadCM3 (different runs of these models)	A2	Ospina-Noreña *et al*.(2009a; 2009b)
CA	Lempa	Runoff	Statistically significant reduction 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	Runoff	-70%	2050s	HadCM3	A2	Palmer *et al*. (2008)
	Mesoamerica (6.5-22 N and 76.5-99 W)	Runoff	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: Impacts on agriculture.

Country/ Region	Activity	Time slice	SRES	CO_2	Changes	Source
Uruguay (SESA)	Annual crops Livestock Forestry	2030/2050/2070/2100 2030/2050 2030/2050/2070/2100 2030/2050 2030/2050/2070/2100 2030/2050/2070	A2 B2 A2 B2 A2 B2		+185/-194/-284/-508 +92/+169 +174/-80/-160/-287 +136/+182 +15/+39/+52/+19 +6/+13/+18	ECLAC (2010d)
Paraguay (SESA)	Cassava Wheat Maize Soybean Bean	2020/2050/2080 2020/2050/2080 2020/2050/2080 2020/2050/2080 2020/2050/2080	A2 A2 B2 A2 B2 A2 B2 A2		+16/+22/+22 +4/-9/-13 -1/+1/-5 +3/+3/+8 +3/+1/+6 A2 0/-10/-15 0/-15/-2 -1/+10/+16	ECLAC (2010d)
Argentina (SESA)	Maize Soybean Wheat	2080 2080 2080	A2/B2 A2/B2 A2/B2 A2/B2 A2/B2 A2/B2	N Y N Y N Y	-24/-15 +1/0 -25/-14 +14/+19 -16/-11 +3/+3	ECLAC (2010d)
	Soybean Maize	2020/2050/2080 2020/2050/2080	A2 B2 A2 B2	Y Y Y Y	+24/+42/+48 +14/+30/+33 +8/+11/+16 +5/+5/+9	Travasso et al. (2008) AIACC
Brazil (SESA)	Rice		$2CO_2$/0ºC $2CO_2$/+5ºC	Y Y	+60 +30	Walter *et al*. (2010)
	Bean Maize	2050-2080 2020-2050-2080 2020-2050-2080 2050-2080 2050-2080 2020-2050-2080	A2 A2+CO_2 A2+CO_2+T A2 A2+CO_2 A2+CO_2+T	N Y Y N Y Y	Up to -30% Up to: +30/+30/+45 Up to: +45/+75/+90 Up to -30% Near to -15% Up to: +40/+60/+90	Costa *et al*. (2009) (*1)
	Arabica coffee (*2)		0 to +1ºC +1 to +2ºC +2 to +3ºC +3 to +4ºC		+1.5% +15.9% +28.6% -12.9%	Zullo *et al*. (2011)
Brazil Sao Pablo	Sugarcane	2040 2040	Pessimistic Optimistic		+6% +2%	Marin *et al*. (2009)
Brazil Northeast	Cassava Maize Rice Wheat	2030 2030 2030 2030		N N N N	0 to -10 0 to -10 -1 to -10 -1 to -14	Lobell *et al*. (2008)
	Maize Bean Rice				-20 to -30 -20 to -30 -20 to -30	Margulis *et al*. (2010)
	Cowpea bean (*2)		+1.5ºC +3.0ºC +5.0ºC		-26% -44% -63%	Silva *et al*. (2010)
Central America (CA)	Maize Bean Rice	2030/2050/2070/2100	A2 A2 A2		0/0/-10/-30 -4/-19/-29/-87 +3/-3/-14/-63	ECLAC (2010d)
	Rice Wheat	2020-2040 2020-2040		N N	0 to -10 -1 to -9	Lobell *et al*. (2008)
Panamá	Maize	2020-2050-2080 2020-2050-2080	A2 B1	Y Y	-0.5/+2.4/+4.5 -0.1/-0.8/+1.5	Ruane et al. (2011)
Andean Region	Wheat Barley	2020-2040		N N	-14 to +2 -1 to -8	Lobell *et al*. (2008))

	Potato Maize			N N	0 to -5 0 to -14	
Colombia	All main crops	2050	17GCM-A2		80% of crops impacted in more than 60% of current cultivated areas	Ramirez *et al.* (2012)
Chile 34.6ºS/38.5ºS	Maize Wheat	2050 2050	A1FI A1FI	Y Y	-5% to -10% -10% to -20%	Meza and Silva (2009)

N: Without considering CO2 biological effects; Y: Considering CO2 biological effects
(*1) Huge spatial variability, the values are approximated
(*2) Changes in the percentage of areas with low climate risk

Table 27-6: 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

Table 27-7: Overview on local, regional, national and international adaptation programs, projects and initiatives relevant for the region.

Countries	Name of Project/ Case Study/ Business Case	Specification of Approach/ Strategy/ Adaptation Area	Platform- NWP (PSI;LCS;EbA;AP)/ weAdapt	Details on platform specification*
Argentina	Adaptation strategies for the Jujuy model forest in NW Argentina	Adaptation efforts in a forest model in Argentina	weAdapt	n.a.
Belize	Adapting to climate change in the Mesoamerican Reef	Assessment of vulnerability; Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Marine and coastal (WWF)
Belize	Ecosystems, Development and Climate Adaptation: Improving the base for policies, planning and management	Mainstreaming EbA in Belize	weAdapt	n.a.
Bolivia	Qhuthañas in Bolivia Collecting and storing rainwater in small dams (qhuthañas)	Rainwater harvesting	NWP- LCS	Hazards: Drought, aridity/ Impacts: Loss of crops; Water shortage
Bolivia	Enhancing adaptive capacity in semi-arid mountainous regions, Bolivia	Assessment of vulnerability; Improvement in capacity design and policy measures; Implementation of EBA measures	NWP- EbA	Mountain; Forest and woodland (The Netherlands Climate Assistance Programme (NCAP))
Bolivia	Building Capacity in Vulnerable Mountain Regions	Water Scarcity in Mountain Regions	weAdapt	n.a.
Bolivia	Climate Change Adaptation in Practice; Rescuing the Past: Using Indigenous Knowledge to Adapt to Climate Change in Bolivia	Using Indigenous Knowledge to Adapt to Climate Change in Bolivia	weAdapt	n.a.
Bolivia	Understanding Adaptation and Mitigation Strategies of Andean People - Bolivia	INCA- Bolivia	weAdapt	n.a.
Bolivia	Adaptation strategies for the Chiquitano tropical dry forest in Eastern Bolivia	Adaptation efforts in the tropical dry forest of Bolivia	weAdapt	n.a.
Bolivia	Ecosystem-based strategies and innovations in water governance networks for adaptation to climate change in Latin American Landscapes	EcoAdapt	weAdapt	n.a.
Brazil	New technologies for climate change adaptation	Food security, agriculture, forestry and fisheries	NWP- PSI	Chemicals (BASF)
Brazil	Insuring against climate impacts and rewarding sustainable business practices	Business	NWP- PSI	Financial Services (Allianz)
Brazil	Disaster preparedness, local capacity building, and planning	Science, assessment, monitoring and early warning; Education and training	NWP- PSI	Consulting and Environmental Services (Riverside Technology)

Brazil	New insurance products and climate risk	Business; Transport, infrastructure and human settlements	NWP- PSI	Financial Services (HSBC)
Brazil	Community Reforestation in Rio de Janeiro, Brazil; Preventing soil erosion and landslides	Soil conservation; Natural resource management	NWP- LCS	Hazard: Floods/ Impact: Soil erosion
Brazil	Babassu Palms in Brazil Harvesting the fruits for oil and protein	Diet diversification	NWP- LCS	Hazards: Drought, aridity/ Impacts: Loss of crops
Brazil	Tires walls in Rio de Janeiro, Brazil Building retaining walls from crape tires	Soil conservation	NWP- LCS	Hazard: Floods/ Impact: Soil erosion
Brazil	Rio de Janeiro's Community Reforestation Project	Improvement in capacity; design and policy measures; Implementation of EBA measurres	NWP- EbA	Urban; Forest and woodland (City of Rio)
Brazil	Ecosystem-Based Adaptation in Marine, Terrestrial and Coastal Regions as a Means of Improving Livelihoods and Conserving Biodiversity in the Face of Climate Change	Assessment of vulnerability; Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Marine and coastal; forest and woodland; agriculture; inland water (Federal Environment Ministry of Germany, Conservation International Foundation)
Brazil	Adaptive management of pirarucu (Arapaima gigas)	Adaptive management	weAdapt	n.a.
Brazil	Promotion of drought resistant native fruits	Resistance to droughts	weAdapt	n.a.
Chile	SMCE/NAIADE: Evaluating the effects of the Alumysa Project in the Aysen Region in Chile	Adaptation tools, case study SMCE/NAIADE	weAdapt	n.a.
Chile	Adaptation strategies for the Alto Malleco model forest in Chile	Adaptation efforts in a forest model in Chile	weAdapt	n.a.
Colombia	Adaptation program to support ecosystem services	Water resources	NWP- PSI	Water Management (EEAB-Bogotá Water and Sewage Company)
Colombia	Integrated National Adaptation Plan - Colombia highland ecosystems	Assessment of vulnerability; Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Mountain; Inland Water (GEF; World Bank; Conservation International)
Colombia	Orito Ingi Ande Medicinal Plants Sanctuary	Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Forest and woodland (Government of Colombia; local communities)
Colombia	Implementing Climate Adaptation Strategies in the World's Most Outstanding Natural Places	Delivering Adaptation	weAdapt	n.a.
Colombia	Building Capacity in the Colombian coastal area	Integrated Coastal Management for Adaptation	weAdapt	n.a.

Colombia, El Salvador, Nicaragua	Integrating Climate Change Risks and Opportunities into National Development Processes and United Nations Country Programming (UNDP)	not specified	NWP- AP	Academic, Governmental, Intergovernmental
Costa Rica	Flood preparedness in Costa Rica Implementing a community training programme	Disaster risk management	NWP- LCS	Hazard: Floods/ Impact: Damage to human settlements
Costa Rica	Hurricane-resistant housing in Costa Rica Constructing low-cost reinforced bamboo houses	Improved housing design	NWP- LCS	Hazard: Storms/ Impact: Damage to human settlements
Ecuador	Providing farming training and assistance	Education and training; Food security, agriculture, forestry and fisheries; Water resources	NWP- PSI	Food and Beverages (Nestlé)
Ecuador	Flood-Resistant Housing in Ecuador Constructing elevated bamboo houses	Improved housing design	NWP- LCS	Hazard: Floods/ Impact: Damage to human settlements
Ecuador and Peru	The CEIBA-PILARES project	Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Forest and woodland (Nature and Culture International)
El Salvador	Vulnerability and Capacity Analysis of Communities Amando López and Octavio Ortiz in the Lower Lempa Valley	Vulnerability and Capacity Analysis of Communities in El Salvador	weAdapt	n.a.
El Salvador, Costa Rica, Panama	Climate Change Governance Capacity: Building Regionally and Nationally Tailored Ecosystem-Based Adaptation in Mesoamerica	Assessment of vulnerability; Improvement in capacity design and policy measures; Implementation of EBA measures	NWP- EbA	Marine and coastal; Agriculture; Inland waters (Federal Environment Ministry of Germany, International Union for Conservation of Nature)
El Salvador; Guatemala; Nicaragua	Coffee Under Pressure: Climate Change and Adaptation in Mesoamerica (CUP)	Food security, agriculture, forestry and fisheries	NWP- PSI	Food and Beverages; Agriculture (Green Mountain Coffee Roasters (GMCR); International Center for Tropical Agriculture (CIAT); Catholic Relief Services (CRS))
El-Salvador	Drought-resistant agriculture in El-Salvador	Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Agriculture (Red Cross; World Food Programme)
Guatemala	Finding Points of Engagement to Integrate Climate Change Adaptation into Water Management Planning	Integrating Climate Adaptation into National Policy (NCAP)	weAdapt	n.a.
Guyana	Participatory school and community-based disaster preparedness	Community-based disaster preparedness	weAdapt	n.a.
Honduras	FORCC: Using forests to enhance resilience to climate change	FORCC Honduras	weAdapt	n.a.
Nicaragua	Reduction of risks and vulnerability from floods and droughts in the Estero Real	Adaptation fund: reducing floods and droughts	weAdapt	n.a.

	watershed			
Nicaragua, Guatemala, El Salvador	Using the Maya Nut Tree to increase tropical agroecosystem resilience to climate change in Central America and Mexico	Improvement in capacity, design and policy measures; Implementation of EBA measures	NWP- EbA	Forest and woodland; Agriculture (Maya Nut Institute)
Peru	Adaptation for Smallholders to Climate Change (AdapCC)	Food security, agriculture, forestry and fisheries	NWP- PSI	Food and Beverages (Cafédirect; GIZ)
Peru	Waru Waru in Peru; Utilizing an ancient irrigation and drainage system	Sustainable water management	NWP- LCS	Hazards: Drought, aridity; Floods/ Impact: Loss of crops
Peru	Understanding Adaptation and Mitigation Strategies of Andean People - Peru	INCA- Peru	weAdapt	n.a.
Peru	Response to impacts of glacial retreats	Response to impacts of glacial retreats	weAdapt	n.a.
Suriname	Sustainable Livelihoods in the Coastal Zone of Suriname	Local Adaptation in Coasts	weAdapt	n.a.
Central America	Hurricane guarantees and waivers	Tourism	NWP- PSI	Tourism and Recreation (Apple Vacations; Club Med; Sandals; SuperClubs; TNT Vacations)
Multiple	Provision of solar energy builds resilience of rural population	Renewable energy systems	NWP- PSI	Energy and Utilities (HiNation AB)
Multiple	SkyHydrant Water Purification Technology	Water resources	NWP- PSI	Science and Technology (Siemens)
Multiple	Adapting to Climate Changes for Potato Production in The Andes	Water resources	NWP- PSI	Food and Beverages (PepsiCo South America, Caribbean and Central America Foods)
Multiple	Product solutions for a future of more constrained resources	Water resources	NWP- PSI	Consumer Packaged Goods (Unilever)
Multiple	Boosting crop yield for every drop of water	Capacity building, education and training; Finance and insurance; Food, agriculture, forestry and fisheries; Technology and Information &Communications Technology (ICT); Water resources	NWP- PSI	Agriculture (Syngenta)
Multiple	The Latin American Water Funds Partnership	Capacity building, education and training; Finance and insurance; Science, assessment, monitoring and early warning; Water resources	NWP- PSI	Food and Beverages (Femsa Foundation)
not specified	Partners for Resilience	Capacity building; Communication and awareness raising; Knowledge management	NWP- AP	Non-Governmental
not specified	Assessment of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AICCC)	Education; communication and awareness raising; financial support	NWP- AP	Intergovernmental

not specified	BASIC project	Education; communication and awareness raising; knowledge management	NWP- AP	Academic
not specified	Iberoamerican Network of Climate Change Bureaus (RIOCC)	Knowledge management, education; training	NWP- AP	Intergovernmental
not specified	Inter-American Development Bank Activities (IDB)	Financial support	NWP- AP	Intergovernmental
not specified	Oficina de Riesgo Agropecuario (ORA) - República Argentina Activities	Education	NWP- AP	Governmental
not specified	Practical Action Activities	Pilot adaptation programmes/projects	NWP- AP	Non-Governmental
not specified	ProVentium Consortium Activities	Education, training; knowledge management	NWP- AP	Non-Governmental
not specified	The Netherlands Climate Assistance Programme	Communication and awareness raising; training; education	NWP- AP	Non-Governmental
not specified	Water Center for the Humid Tropics of Latin America and the Caribbean Activities (CATHALAC)	Communication and awareness raising; training; education	NWP- AP	Academic

* Details are provided for NWP platforms and comprehend for PSI, business sector/ company; for LCS, hazard/impact; for EbA, ES/ implementing institution; and for AP, the type of organization (see also NWP interface, UNFCCC, 2012xx).

Source: Authors based on UNFCCC (2012b) and weAdapt (2012)

Table 27-8: 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)

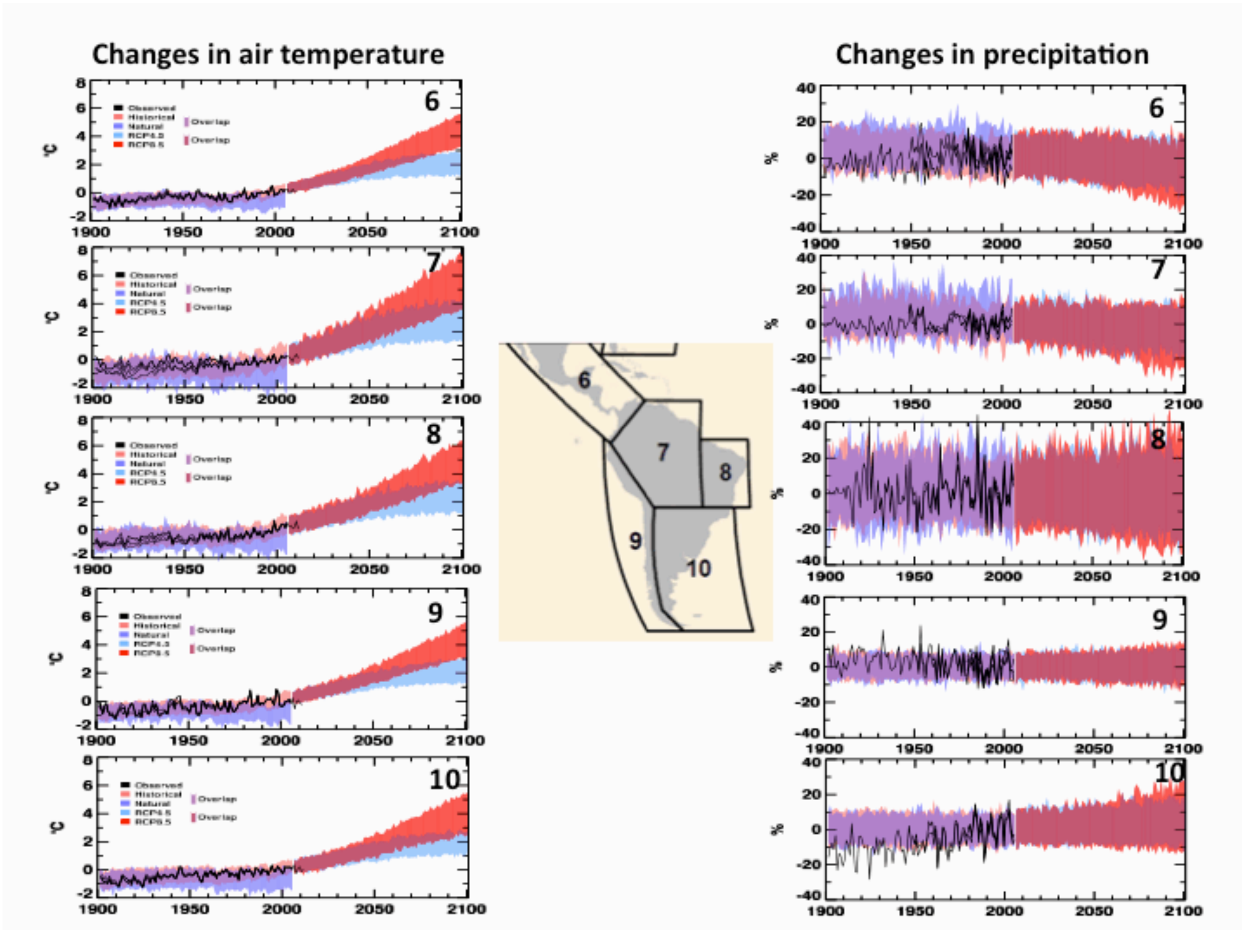

Figure 27-1: Observed and simulated variations in past and projected future annual average temperature over land areas of the Central and South American "SREX regions". Black lines show several estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.

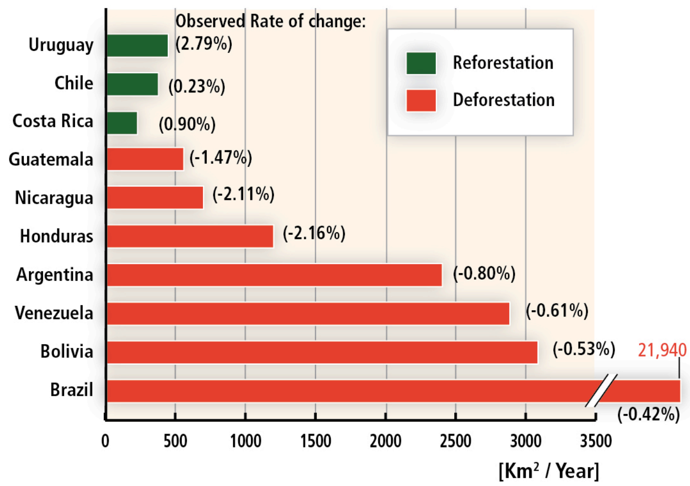

Figure 27-2: Area deforested per year for selected countries in CA and SA (2005-2010). Notice three countries listed with a positive change in forest cover (based on data from FAO, 2010).

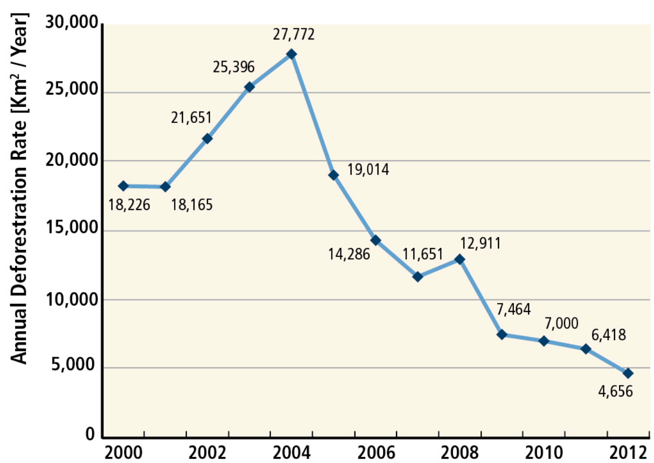

Figure 27-3: Deforestation rates in the Brazilian Amazonia (km²/year) based on measurements by the PRODES INPE project (see also INPE, 2011).

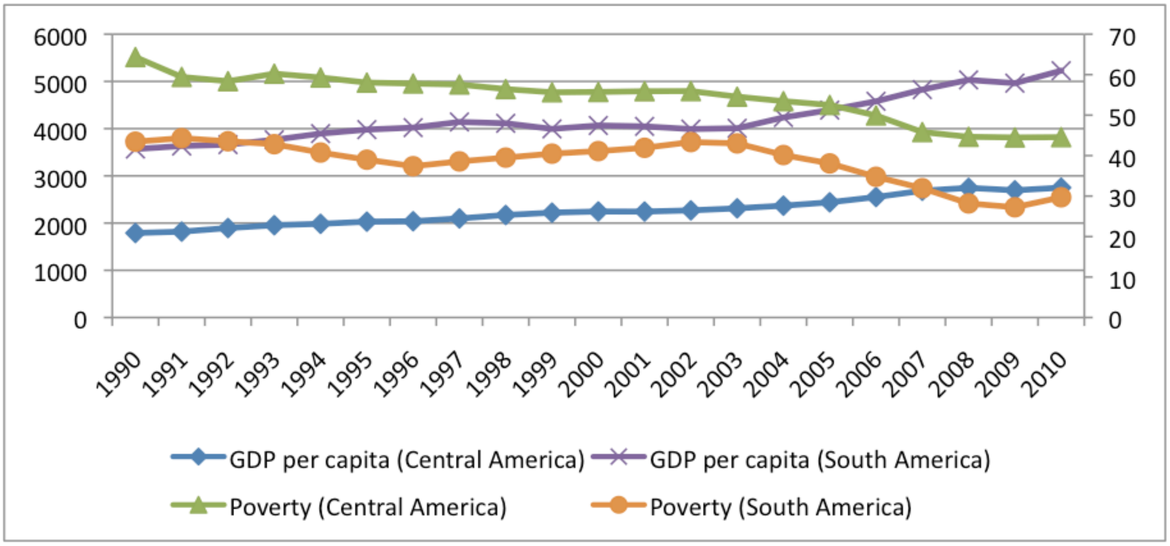

Figure 27-4: Evolution of GDP per capita and poverty from 1990-2011: CA and SA (US-Dollars per inhabitant at 2005 prices and percentages) (ECLAC on the basis of CEPALSTAT (2012) and ECLAC (2011))

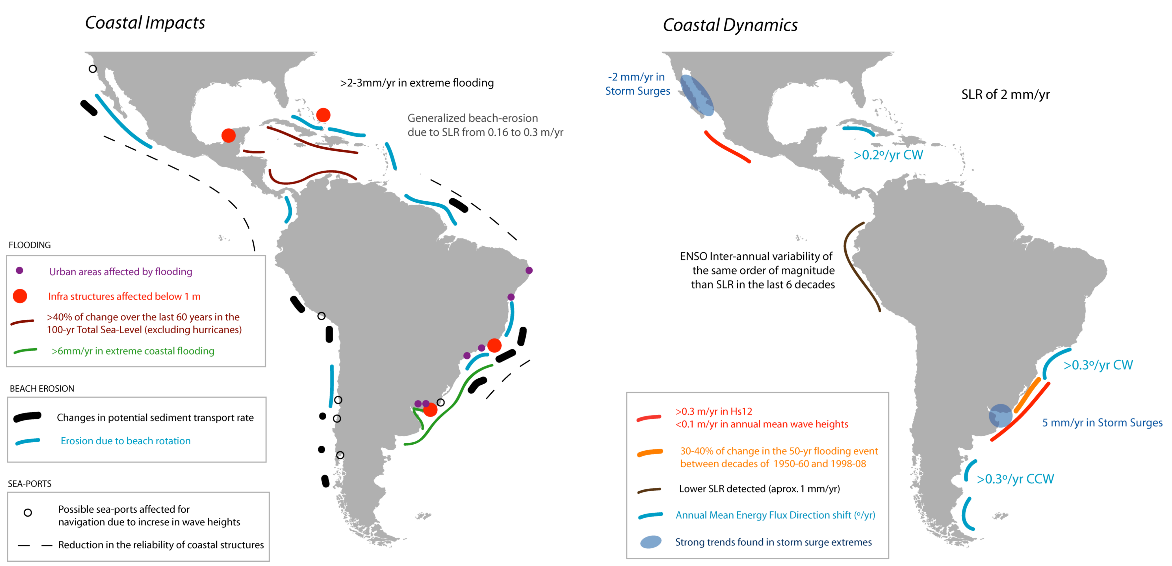

Figure 27-5: Current and predicted coastal impacts and coastal dynamics in response to climate change (elaborated by Iñigo Losada, ECLAC)

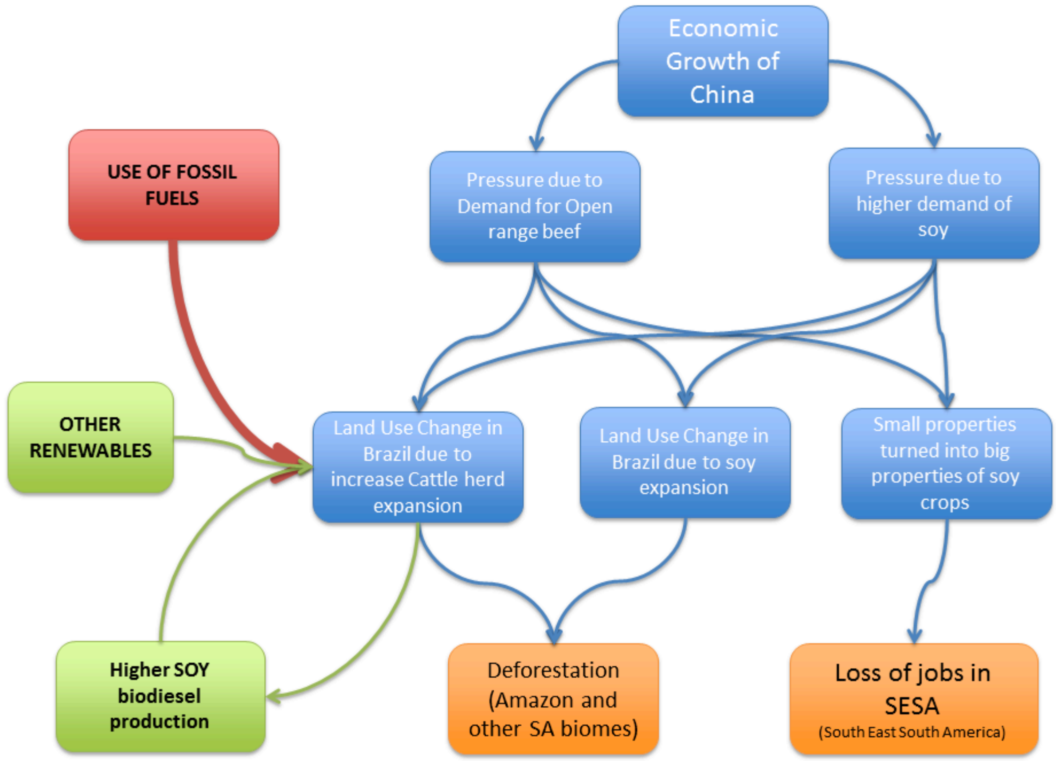

Figure 27-6: Soy teleconnections and major effects in SA. Economic growth giant consumers as China pressurize the soy production system in SA, increasing the production of biodiesel, but demanding more energy in general. (partly based on Nepstad and Stickler (2008), and Tomei and Upham (2009))

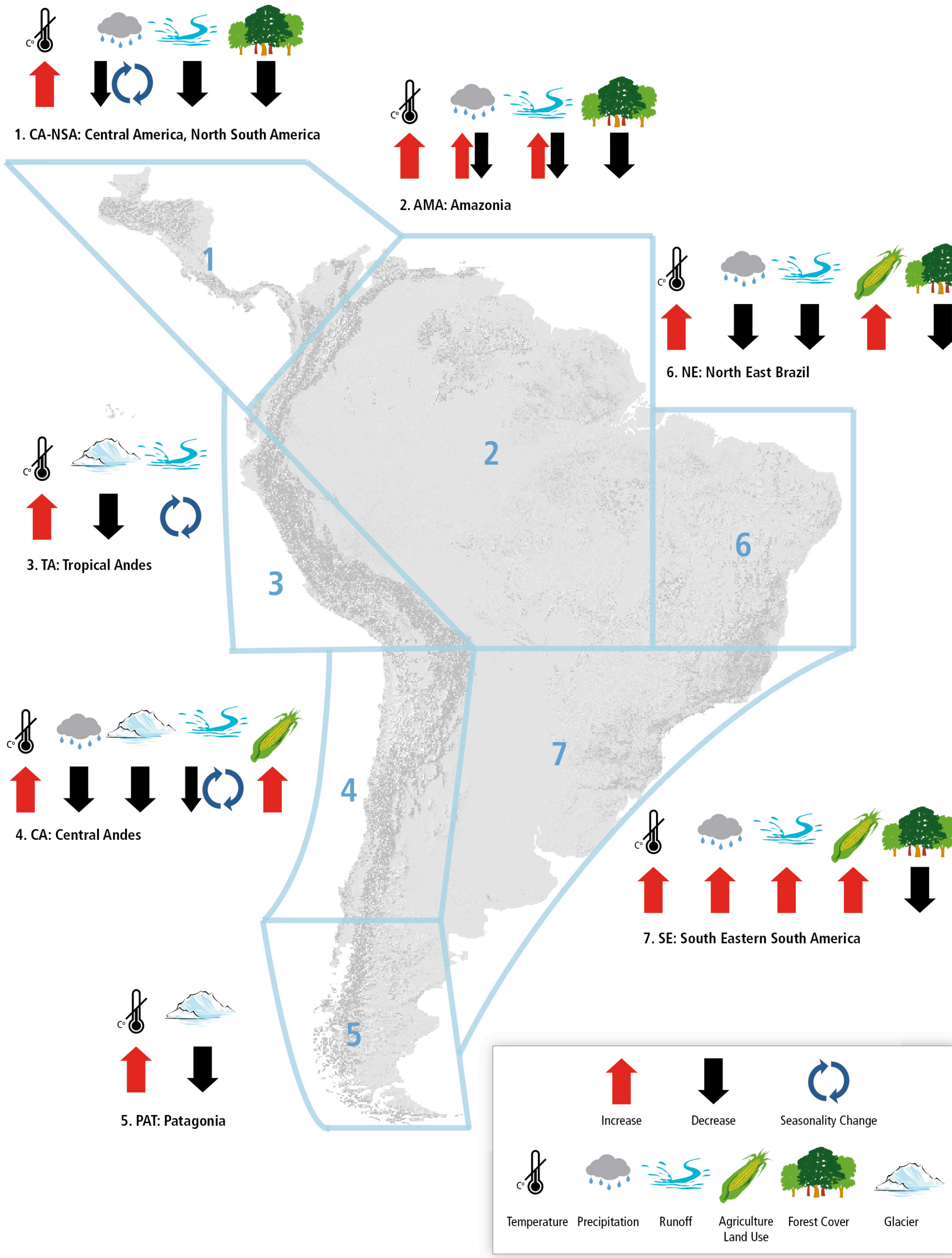

Figure 27-7: Summary of observed changes in climate and other environmental factors in representative regions of CA and SA. The boundaries of the regions in the map are conceptual (not precise geographic nor political) and follow those developed in Figure 3-1 of the IPCC SREX (IPCC, 2012). Information and references to changes provided are presented in different sections of the chapter.

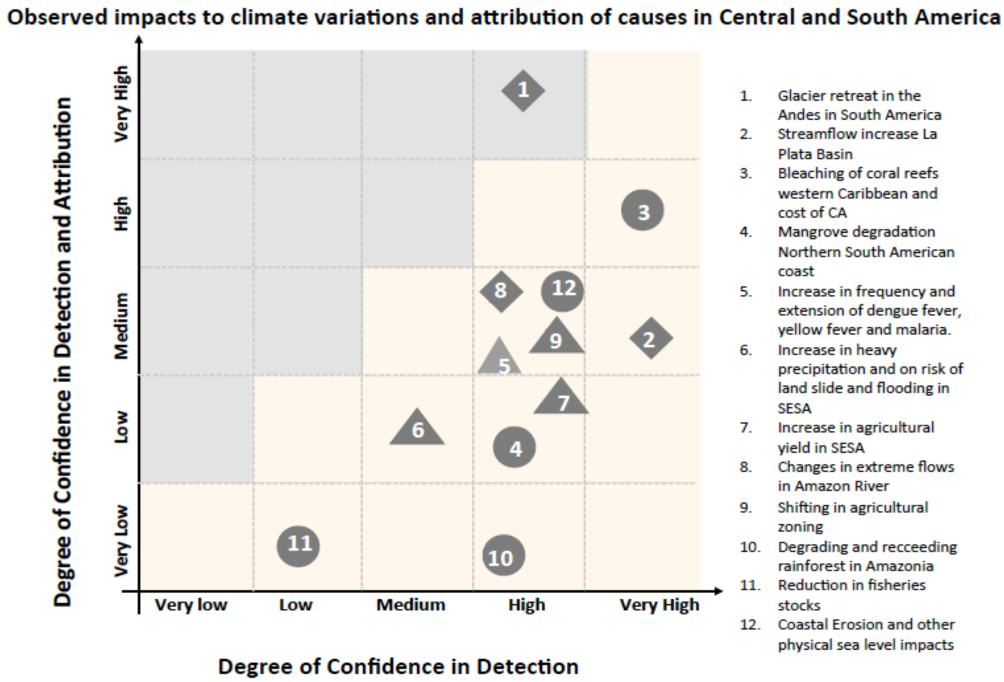

Figure 27-8: Observed impacts of climate variations and attribution of causes in CA and SA.