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ORIGINAL ARTICLE

Climate change impacts in Latin America and the Caribbean and their implications for development

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Abstract This paper synthesizes what is known about the physical and biophysical impacts of climate change and their consequences for societies and development under different levels of global warming in Latin America and the Caribbean (LAC). Projections show increasing mean temperatures by up to 4.5 °C compared to pre-industrial by the end of this century across LAC. Associated physical impacts include altered precipitation regimes, a strong increase in heat extremes, higher risks of droughts and increasing aridity. Moreover, the mean intensity of tropical cyclones, as well as the frequency of the most intense storms, is projected to increase while sea levels are expected to rise by ∼0.2–1.1 mm depending on warming level and region. Tropical glacier volume is found to decrease substantially, with almost complete deglaciation under high warming levels. The much larger glaciers in the southern Andes are less sensitive to warming and shrink on slower timescales. Runoff is projected to be reduced in Central America, the southern Amazon basin and southernmost South America, while river discharge may increase in the western Amazon basin and in the Andes in the wet season. However, in many regions, there is uncertainty in the direction of these changes as a result of uncertain precipitation projections and differences in hydrological models. Climate change will also reduce agricultural yields, livestock and fisheries, although there may be opportunities such as increasing rice yield in several LAC countries or higher fish catch potential in the southernmost South American waters. Species range shifts threaten terrestrial biodiversity, and there is a substantial risk of Amazon rainforest degradation with continuing warming. Coral reefs are at increasing risk of annual bleaching events from 2040 to 2050 onwards irrespective of the climate scenario. These physical and biophysical climate change impacts challenge human livelihoods through, e.g., decreasing income from fisheries, agriculture or tourism. Furthermore, there is evidence that human health, coastal infrastructures and energy systems are also negatively affected. This paper concludes that LAC will be severely affected by climate change, even under lower levels of warming, due to the potential for impacts to occur simultaneously and compound one another.

Keywords Development · Global change · Poverty · Projections · Scenarios · Sustainability

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Introduction

Despite increasing numbers of climate change impact studies in Latin America and the Caribbean (LAC, defined here as the region encompassing the South American continent, Central America, the Caribbean islands and Mexico) summarized in the fifth assessment report of the IPCC (chapters by Magrin et al. 2014; Romero-Lankao et al. 2014; Nurse et al. 2014), knowledge on how climate change affects different subregions and sectors is fragmented. The objective of this paper is to analyze physical and biophysical impacts of climate change in LAC, and their consequences for societies and development, in an integrated way, thereby updating and extending the analysis presented in Schellnhuber et al. (2014). This paper adds to the recent work by the IPCC: Firstly, we consider the latest science published after the IPCC cutoff deadlines. Secondly, we consider climate impacts through a development lense and therefore devote more depth to sectors, subregions and systems which seem most relevant from that risk perspective. Thirdly, we synthesize climate impacts as a function of different levels of global warming at the end of the twenty-first century compared to pre-industrial levels (1.5, 2, 3 and 4 °C, cf. Table ESM.1 and Schellnhuber et al. 2014: Appendix 4) to show what these global warming levels mean for LAC. We focus on warming levels in general and on a 2 and 4 °C world (basically following the warming pathways of the scenarios RCP2.6 and RCP8.5, respectively) in particular since these are important elements of global climate change negotiations, but in such global discourses, regional implications of a global warming level often remain fuzzy.

We combine original data analyses, model projections and meta-analyses of published studies with a comprehensive literature review (the methodological approach is presented in Schellnhuber et al. 2014, especially in Appendices A.1–3). The impacts of climate change in LAC under different warming levels are synthesized in Fig. 5 and Table ESM.1. The temperature, precipitation, evapotranspiration and aridity projections are based on five CMIP5 GCMs (as selected by Warszawski et al. (2014), see Schellnhuber et al. 2014: Appendix A.1). We focus exclusively on climate impacts and do not consider possibilities of adaptation options decreasing these impacts unless otherwise stated.

Social, economic and demographic profile of the Latin America and Caribbean region and vulnerabilities to climate change

The countries in the LAC region differ greatly in their economic and demographic profile (see Table ESM.2). The region comprises a population of 588 million (in 2013) which is expected to rise to 660 million by 2025 (World Bank 2014a). The region is highly urbanized, and in 2010, the urban population accounted for 78.8 % of the total and is expected to increase further (ECLAC 2014). The current GDP of the region is estimated at US$ 5.467 trillion (in 2012) (World Bank 2014b) with a GNI per capita of US$ 9536 in 2013 (World Bank 2014c). In 2012, approximately 25.03 % of the population was living in poverty and 12.02 % in extreme poverty or deprivation (World Bank 2014d). In 2010, the rural poverty rate was twice as high as that of urban areas; when considering extreme poverty, it was four times as high (IFAD 2013). Close to 60 % of the population in extreme poverty lives in rural areas (RIMISP 2011). Moreover, ethnicity, gender and age correlate with poverty. In seven countries for which data are available, the poverty rate is 1.2–3.4 times higher for indigenous and afrodescendent groups than for the rest of the population and poverty rates are 1.7 times higher among minors under 15 than in adults and 1.15 times greater among women than men (ECLAC and UNFPA 2009).

Climate change is expected to accentuate preexisting vulnerabilities in LAC. Several million people live in the path of hurricanes and in low-elevation coastal zones rendering them vulnerable to sea-level rise, storm surges and coastal flooding (McGranahan et al. 2007; Trab Nielsen 2010). LAC's 64,000-km coastline is one of the most densely populated in the world (Sale et al. 2008), and several countries have a large share of their urban population living in areas elevated less than five meters above sea level (CIESIN 2011; cf. Table ESM.3). Moreover, people living in slums built on steep slopes and with poor drainage systems (Douglas et al. 2008), and certain population groups [such as short-term or chronically poor people (Ahmed et al. 2009; Hardoy and Pandiella 2009; Hertel et al. 2010) and women-headed households or children (Kumar and Quisumbing 2011)] are particularly exposed to climate change risks. The rural poor in general, and indigenous groups in particular, are especially vulnerable to climate change because of their reliance on small-scale, rain-fed agriculture, natural resources, traditional knowledge systems and culture (Kronik and Verner 2010; Hoffman and Grigera 2013) and their poor access to infrastructure and technology (Feldt 2011). Many of these population groups also have limited political influence, fewer capabilities and opportunities for participating in decision and policy making and are less able to leverage government support to adapt to climate change (Hardoy and Pandiella 2009; Moser et al. 2010). Climate change may affect also the credibility of elders and traditional leaders, as their authority to predict the natural seasonality is challenged (Kronik and Verner 2010). Finally, a high proportion of the urban population in LAC lives in a few very large cities. National economies, employment patterns and government capacities are also strongly dependent on these large cities making them extremely vulnerable to climate-related disasters (Hardoy and Pandiella 2009). In the following, we revise the state of the art of the climate component of the vulnerabilities stated here.

Regional patterns of climate change

Projected temperature changes

The multi-model mean austral warming for 2071–2099 is about ~1.5 °C in a 2 °C world and ~4.5 °C in a 4 °C world compared to 1951–1980 (Fig. ESM.1) and shows a rather uniform pattern, with more warming toward the interior of the continent (Fig. 1 top left panel, Fig. ESM.2). The normalized warming [i.e., the warming expressed in terms of the local year-to-year natural variability (cf. Schellnhuber et al. 2014: Appendix A.1)—top right panel of Fig. 1, Fig. ESM.2] indicates how the projected warming compares to the natural fluctuations a particular region has experienced during the period 1951–1980 (Hansen et al. 2012; Coumou and Robinson 2013; Mora et al. 2013a). The tropics will see the strongest increase in normalized monthly summer temperatures, since historic year-to-year fluctuations are relatively small, indicating a new climatic regime for the tropical parts of LAC (top right panel of Fig. 1, Fig. ESM.2). Subtropical regions in the south (northern Argentina) and the north (Mexico) are expected to see a much less pronounced shift.

Heat extremes

We find a strong increase in the frequency of austral summer months (DJF) warmer than 3-sigma and 5-sigma by the end of the century (2071–2099) (Fig. 1 bottom panels and Fig. ESM.3–4, see Schellnhuber et al. 2014: Appendix A.1

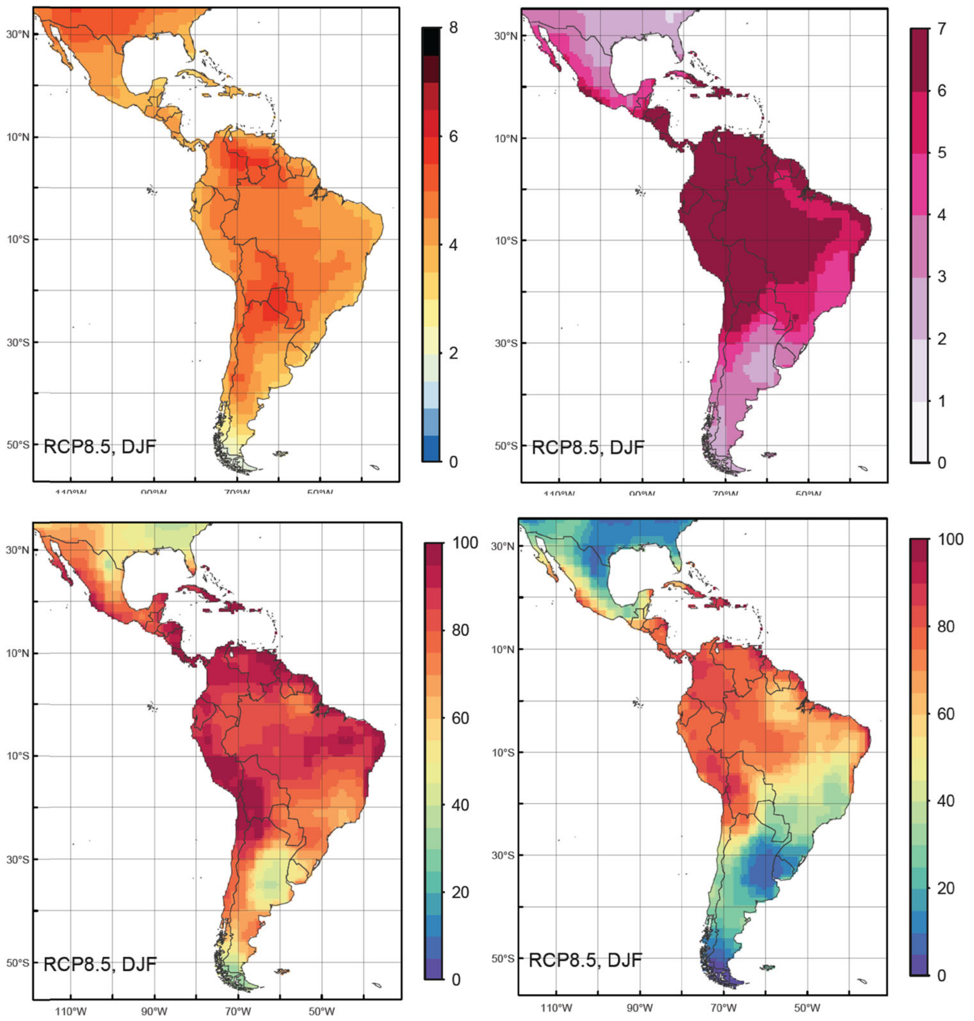


Fig. 1 Temperature changes in LAC for RCP8.5 (4 °C world) for the austral summer months (DJF). Multi-model mean temperature anomalies in degree Celsius (*top row left*) are averaged over the time period 2071–2099 relative to 1951–1980 and normalized by the local standard deviation (*top row right*). Multi-model mean of the percentage of austral summer months (DJF) in the time period 2071–2099 with temperatures greater than 3-sigma (*bottom row left*) and 5-sigma (*bottom row right*)

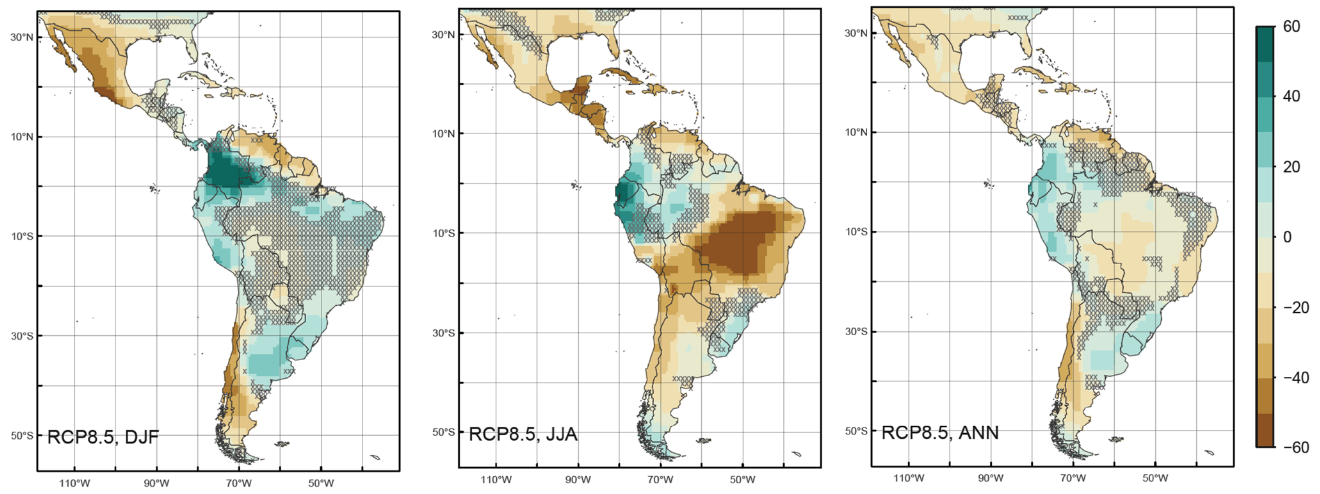


Fig. 2 Multi-model mean of the percentage change in austral summer (DJF, *left*), winter (JJA, *middle*) and annual (*right*) precipitation for RCP8.5 (4 °C world) for Latin America and the Caribbean by 2071–2099 relative to 1951–1980. Hatched areas indicate uncertain results, with two or more out of five models disagreeing on the direction of change. Note that projections are given as percentage changes compared to the 1951–1980 climatology, and thus, especially over dry regions, large relative changes do not necessarily reflect large absolute changes

for more detailed explanations of 3- and 5-sigma events). The tropics, along the coasts, will see the largest increase in such threshold-exceeding extremes which is confirmed by analyses using the full CMIP5 dataset (Coumou and Robinson 2013; Sillmann et al. 2013a, b). The 5-sigma events, which are absent under present-day climate conditions, will emerge in these countries even in a 2 °C world and are projected to occur in roughly 20 % of summer months. At the same time, 3-sigma events, which are extremely rare today, will be exceeded in roughly half of the summer months during 2071–2099. In a 4 °C world, almost all summer months in the tropics will be warmer than 3-sigma and, in fact, most will be warmer than 5-sigma as well (70 %). Compared to the tropics, the subtropical regions in the north (Mexico) and south (Uruguay, Argentina and southern Chile) are projected to see a more moderate increase in the frequency of threshold-exceeding extremes. In a 2 °C world, 5-sigma events will remain absent and 3-sigma events will still be rare (less than 10 % of summer months). In a 4 °C world, at least half of all summer months are expected to be warmer than 3-sigma by 2071–2099 and 5-sigma events will occur typically in about 20 % of summer months over subtropical regions. This does not mean that absolute warming is less in the subtropical regions or that risks by heat extremes are lower there, but solely that there is greater natural variability in these regions.

Precipitation projections

In a 2 °C world, projected changes in annual and seasonal precipitation for 2071–2099 relative to 1951–1980 are relatively small (±10 %) and models exhibit substantial disagreement on the direction of change over most land regions (Fig. ESM.5). However, regions between 10°S and 30°S may experience dry season (JJA) precipitation reductions exceeding 20 % and exceeding 50 % in Mato Grosso, central brazil (Fig. ESM.5). In a 4 °C world, the models converge in their projections over most regions, but intermodel uncertainty remains over some areas (Fig. 2). Well-defined patterns of change in annual precipitation can be extracted for subregions. Tropical countries on the Pacific coast (Peru, Ecuador and Colombia) are projected to see an increase in annual mean precipitation of about 30 %, with changes in seasonal precipitation exceeding 50 %. Also the Río de la Plata basin is projected to experience a wetting trend. Substantial drying exceeding 10–20 % annual precipitation reductions is projected for Patagonia, the Caribbean and Mesoamerica as well as central Brazil. Notably, there are substantial seasonal differences with JJA precipitation reductions exceeding 40–50 % for Mesoamerica and the Caribbean. The annual mean precipitation in central Brazil is projected to drop by 20 % in a 4 °C world by the end of the century due to a strong and robust decrease in dry season (JJA) precipitation (−50 %). These projected changes in annual and seasonal temperatures generally agree well with those provided by the full set of CMIP5 climate models (Collins et al. 2013) with the notable difference of the central Brazil drying that is less pronounced in the multi-model average of the full CMIP5 set.

Extreme precipitation and droughts

Observations since the 1950s indicate a robust increase in overall precipitation and in intensity of extreme precipitation events for South America (Skansi et al. 2013). In a 4 °C world, Kharin et al. (2013) find extreme precipitation events (annual maximum daily precipitation with 20-year return values) to intensify by about 25 % over LAC with a large uncertainty range over an ensemble of CMIP5 models. The return time of a 20-year extreme precipitation event in 1985–2005 would reduce to about 6 years (Kharin et al. 2013). These increases are not homogeneous over the full continent. While little-to-not statistically significant, an increase in frequency is projected for the Caribbean, Mesoamerica, southern Argentina and Chile, and hotspots with extreme precipitation increases of more than 30 % are projected in the Serra do Espinhaco in Brazil, the Pampas region in Argentina and the Pacific coastline of Ecuador, Peru and Colombia (Kharin et al. 2013). The latter may be related to an increase in frequency of future extreme El Niño events (Power et al. 2013; Cai et al. 2014). These regions are also found to show the strongest rise in compound maximum 5-day precipitation (which is relevant for flooding events) in a 4 °C world (Sillmann et al. 2013b). Increases in extreme precipitation in southern Brazil and northern Argentina are in line with results from regional climate models (Marengo et al. 2009) and might be dominated by intensification of the South American monsoon system (Jones and Carvalho 2013).

Dai (2012) finds a statistically significant increase in drought conditions for Central America and the Caribbean for the 1950–2010 period, although the significance of this trend depends on the reference period and the formulation of the underlying drought index (Trenberth et al. 2014). Fu et al. (2013) report a significant increase in the length of the dry season over southern Amazonia since 1979. An increase and intensification in meteorological droughts is projected for large parts of South and Central America in a 4 °C world (Sillmann et al. 2013b), although large model uncertainties remain in particular for Central America (Orlowsky and Seneviratne 2013). Accounting for the effects of runoff and evaporation as well as local soil and vegetation, Dai (2012) found that the Amazon basin, Brazil except the southern coast, southern Chile, Central America and northern Mexico are facing severe to extreme drought conditions relative to the present climate by the end of the twenty-first century under the RCP4.5. These results are confirmed by a multi-model analysis in a 4 °C scenario that additionally reveals a strong increase in drought risk in the Caribbean, although uncertainties remain substantial (Prudhomme et al. 2013). Apart from a reduction in precipitation, warming can also cause more arid conditions as enhanced surface temperatures trigger more evapotranspiration—thereby drying the soil (see ESM Text.1 and Fig. ESM.6–7).

Tropical cyclones

Tropical cyclones have important impacts in LAC such as an average 0.83 % drop in economic output after tropical cyclone strikes with large variations between countries (Strobl 2012). Tropical cyclone frequency has increased in the North Atlantic sharply over the past 20–30 years, but uncertainty is large over longer time periods (Bindoff et al. 2013). Kossin et al. (2013) showed a strong and statistically significant increase in lifetime maximum intensity of tropical cyclones over the North Atlantic of 8 m s^{-1} per decade, over 1979–2010, particularly for mid- to high-intensity storms. Such observed changes were shown to be linked to both anthropogenic climate change and internal climate variability (Camargo et al. 2012; Villarini and Vecchi 2013; Wang and Wu 2013). Differential warming of the tropical Atlantic, with historically observed warming higher than average for the tropics, tends to enhance tropical cyclone intensification in the region (Knutson et al. 2013). No significant trends have been observed over the eastern North Pacific (Kossin et al. 2013), but in general tropical cyclones have been observed to migrate polewards (Kossin et al. 2014).

Projections of tropical cyclone frequency and intensity are difficult, because the interplay of several factors is unclear (Bindoff et al. 2013). El Niño events tend to enhance wind shear over the Gulf of Mexico and the Caribbean Sea and thus suppress Atlantic tropical cyclones (Arndt et al. 2010; Aiyyer and Thorncroft 2011; Kim et al. 2011). On the other hand, El Niño events have been shown to increase tropical cyclone activity in the eastern North Pacific (Kim et al. 2011; Martinez-Sanchez and Cavazos 2014). Observational evidence, however, suggests atmospheric patterns tend to steer tropical cyclones away from the Mexican coast during El Niño years (and toward the coast in La Niña years), so that the net effect on the Pacific coastlines of the Americas remains unclear. In addition to such dynamic changes, thermodynamic processes alone can also work to suppress tropical cyclone formation and intensification (Mallard et al. 2013).

In the long term, simulations from a range of models show that tropical cyclone frequency will not be affected much by continued global warming but mean intensity, as well as the frequency of the most intense tropical cyclones, is projected to increase (Knutson et al. 2010; Tory et al. 2013; Stocker et al. 2013). Using CMIP5 models (50 % uncertainty range across 17 GCMs), Villarini and Vecchi (2013) projected that the Power Dissipation Index would increase by 100–150 % in a 2 °C world over the North Atlantic. A considerably larger increase and a much wider range of about 125–275 % were projected for a 4 °C world.

Bender et al. (2010) used a variety of models to initialize a very high-resolution operational hurricane prediction model, noting an increase of 80 % in the frequency of the strongest category 4 and 5 Atlantic tropical cyclones for about 3.4 °C warming (a 3 °C world). Knutson et al. (2013) also found an 80 % increase in the strongest category tropical cyclones for the same warming level and class of models and around a 40 % increase for roughly 1.5–2.5 °C warming (early and late twenty-first century, RCP4.5). The eastern North Pacific is less well represented in the scientific literature and studies projected either no significant trends for this region under future climate change (Murakami et al. 2011, 2012) or an increase in frequency of tropical cyclones (particularly large near the coast of southeast Mexico) (Emanuel 2013). With projected increased intensity and frequency of the most intense storms, and increased atmospheric moisture content, an increase of 10 % in the rainfall intensity averaged over a 200-km radius from the tropical cyclone center for the Atlantic, and an increase of 20–30 % for the tropical cyclone's inner core by the end of the twenty-first century for roughly 2.5–3.5 °C global warming is estimated (Knutson et al. 2010, 2013).

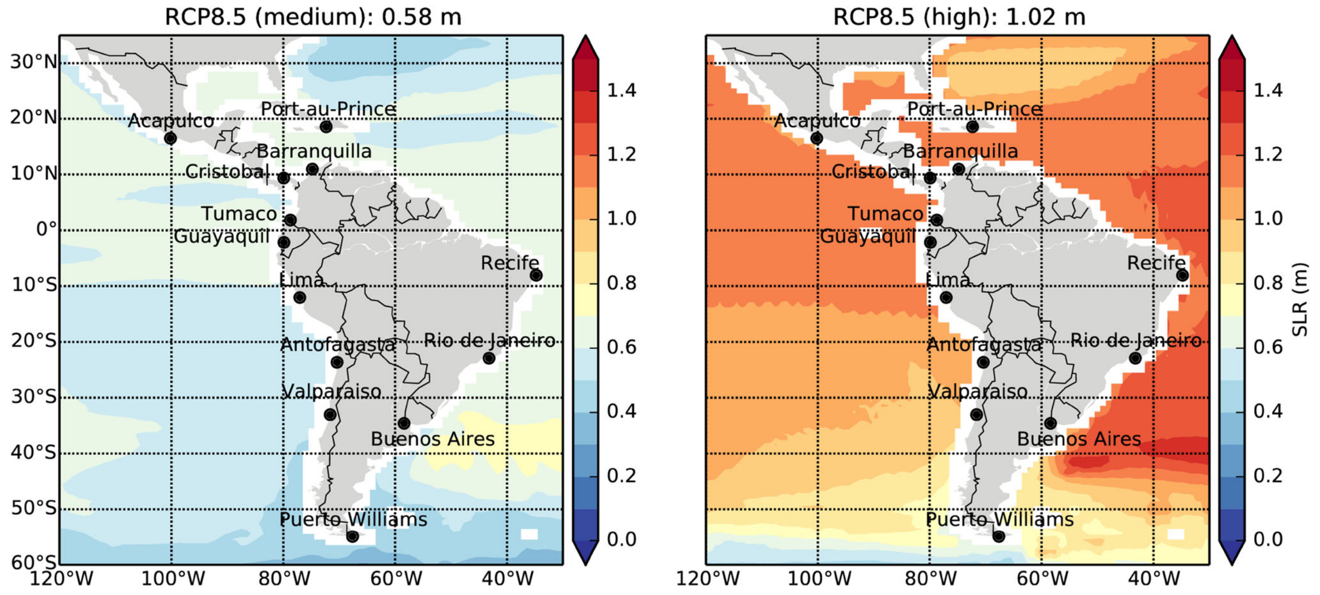
Regional sea-level rise

In LAC, global mean sea-level rise dominates the regional sea-level signal (Fig. 3, Fig ESM.8). Still, regional variation exists with generally higher projected sea-level rise at the Atlantic than at the Pacific coast and an increasing ice-sheet contribution toward lower latitudes. Due to a robust southeasterly trade wind intensification over the Southern Pacific and associated cold water upwelling (Timmermann et al. 2010; Merrifield and Maltrud 2011), sea-level rise below the global mean is projected for the Southern Pacific coast (median estimate for Valparaiso: 0.55 m for a 4 °C world cf. Table ESM.4). In contrast, Recife on the Atlantic coast of Brazil is projected to experience above-average sea-level rise (median estimate 0.63 m). The sea-level rise at the continental Caribbean coast exceeds the projection for the Caribbean islands (Barranquilla, median estimate 0.65 for a 4 °C world). The difference may be linked to a weakening of the Caribbean Current that is connected to the Atlantic meridional overturning circulation (Pardaens et al. 2011).

Regional impacts

Glacial retreat and snowpack changes

Andean glaciers are shrinking because of increased melt rates, decreased accumulation, changes in the ice dynamics and/or a combination of all these factors (Lopez et al. 2010; Ivins et al. 2011; Jacob et al. 2012; Marzeion et al. 2012; Giesen and Oerlemans 2013; Schaefer et al. 2013; Table ESM.1). Across several studies and different methods, a clear change in glacier evolution can be seen after the late 1970s, accelerating in the mid-1990s and again in the early 2000s (Rabatel et al. 2013). This acceleration


RCP8.5 (medium): 0.58 m

RCP8.5 (high): 1.02 m

Fig. 3 Patterns of regional sea-level rise. Median (*left column*) and high (*right column*) estimates of projected regional sea-level rise for the RCP8.5 scenario (4 °C world) for the period 2081–2100 relative to the reference period 1986–2005. Associated global mean rise is indicated in the panel titles. Representative cities are denoted by *black dots* and *numbers* provided in Table ESM.4

started slightly delayed in the 1990s for glaciers located at mid- or high latitudes.

In the subtropical Andes of Chile and western Argentina, there is no significant trend in snowfall over 1951–2004 (Masiokas et al. 2006, 2012). However, the data display a marked inter-annual variability ranging from 6 to 257 % around the 1966–2004 mean, with a clear influence from the warm phases of ENSO. Studies on snowpack in the southern Andes are rare, but changes in snowpack extent magnify changes in the seasonality of the water availability by reducing dry season flows and increasing wet season flows (Vicuña et al. 2013).

Tropical glaciers are projected to lose at least 66 % of their volume in a 3 °C world and to disappear almost completely in a 4 °C warmer world (Marzeion et al. 2012; Giesen and Oerlemans 2013; Radić et al. 2013). The much larger glaciers in the southern Andes are less sensitive to global warming and are projected to shrink by at least 21 % in a 2 °C world up to 72 % in a 4 °C world (see Table ESM.1). The models used in these studies rely on a scaling methodology which may overestimate the recession of the small remnant tropical glaciers. The accelerated melting will lead to increasing runoff, but when the glacier reservoirs disappear runoff will also decrease, particularly in the dry season. Following the trend in the tropical Andes (Poveda and Pineda 2010), this peak is expected within the next 50 years (Chevallier et al. 2011) if it has not already occurred (Baraer et al. 2012). Reliable projections for snowpack and snow cover changes in the Andes are lacking.

Water resources, water security and floods

LAC has abundant water resources, but their distribution is temporally and regionally unequal (Magrin et al. 2007). Due to the unreliable rainfall, groundwater resources and water from glacier and snowmelt play a crucial role in supplying local water (Vuille et al. 2008; Chevallier et al. 2011; Hirata and Conicelli 2012). Moreover, LAC suffers from widespread floods and landslides (Maynard-Ford et al. 2008). Heavy precipitation events in the context of ENSO or tropical cyclones can lead to disastrous floods, especially in regions with steep terrain (Mata et al. 2001; Poveda et al. 2001; Mimura et al. 2007; IPCC 2012). Coastal areas in the Caribbean and Central America suffer from flooding as a result of storm surges and tropical cyclones (Dilley et al. 2005; Woodruff et al. 2013). In the Andes, glacial lake outbursts present a permanent hazard for Andean cities (Chevallier et al. 2011; Carey et al. 2012).

In Central America, there is a high agreement on decreasing mean annual runoff and discharge, although the magnitude of the change varies (Milly et al. 2005; Maurer et al. 2009; Imbach et al. 2012; Arnell and Gosling 2013; Hidalgo et al. 2013; Nakaegawa et al. 2013; Schewe et al. 2013). The trend seems to be more pronounced for the northern than for the southern part of Central America (Imbach et al. 2012; Hidalgo et al. 2013). The Caribbean lacks long-term measured streamflow data, and runoff projections are therefore of low confidence (FAO 2003; Hidalgo et al. 2013). However, freshwater availability may decrease due to a combination of lower precipitation, high abstraction rates and sea-level rise leading to an intrusion of sea water into coastal aquifers (Mimura et al. 2007; Cashman et al. 2010). Although floods often seem to be associated with land-use change, more severe flooding events may also occur with climate change, e.g., related to tropical cyclones (Cashman et al. 2010; IPCC 2012). Higher discharge seasonality is projected for the tropical Andes. Lower dry season discharge has already been observed during the past two decades (Baraer et al. 2012). Streamflows during the dry season are projected to decrease strongly because of ongoing glacier retreat and snowmelt decrease (Juen et al. 2007; Baraer et al. 2012; Kinouchi et al. 2013). However, streamflow during the wet season may increase due to an increase in direct runoff from non-glaciered areas (Juen et al. 2007; Kinouchi et al. 2013). The region has a high flood and landslide risk which is projected to increase (Carey 2005; Hirabayashi et al. 2013). For the Central Andes, a trend toward an earlier snowmelt season and timing of the center of mass of flows was observed and projected locally (Cortés et al. 2011; Vicuña et al. 2013; Demaria et al. 2013). Lower dry season discharges may cause significant water supply problems in downstream and urban areas (Vuille et al. 2008; Viviroli et al. 2011; Masiokas et al. 2013), with poorer areas most affected (Buytaert and De Bièvre 2012), and might endanger electrical power generation (Seoane and López 2007). Runoff projections for the Amazon are uncertain due to the high variability of rainfall projections using different GCMs and uncertainties introduced by hydrological impact models (Buytaert et al. 2009; Exbrayat et al. 2014). Guimberteau et al. (2013) found that, especially in the south, low flows become more pronounced by the middle of this century with 2 °C global warming. Nakaegawa et al. (2013) found total annual runoff decreases in the southern half of the Amazon River in a 3 °C world. However, for the western part of the basin, a likely increase in streamflow, runoff, flood zone and inundation time was projected (Guimberteau et al. 2013; Langerwisch et al. 2013; Mora et al. 2013b). The direction of discharge and groundwater recharge trends in northeast Brazil vary due to diverging rainfall projections (Krol and Bronstert 2007; Montenegro and Ragab 2010; Döll and Schmied 2012; Portmann et al. 2013; Schewe et al. 2013). The Río de la Plata region experienced a 10–30 % increase in river runoff during the twentieth century (García and Vargas 1998; Jaime and Menéndez 2002; Menéndez and Berbery 2005;

Milly et al. 2005). There are no consistent river runoff projections for the basin because the directions of rainfall projections vary (Milly et al. 2005; Nóbrega et al. 2011; Bravo et al. 2013; Nakaegawa et al. 2013). Camilloni et al. (2013) projected an increase in frequency and duration of river flooding in a >3 °C world in the Uruguay and Paraná basins. Hirabayashi et al. (2013) showed a decrease in the twentieth century 100-year return period for floods for the Parana in a 4 °C world, but there was little consistency across the 11 GCMs used. A decrease in mean runoff is projected for southernmost South America (Milly et al. 2005; Schewe et al. 2013).

Agricultural yields

Climate change impacts on crop yields vary depending on crop type and location, but most projections show negative climate change impacts (summarized in Table ESM.1). Yield declines are projected for wheat, soybeans and maize in several countries (Fernandes et al. 2012). Coffee farming might have to migrate to higher altitudes or other cultivation regions to maintain present yields (Camargo 2010; Laderach et al. 2011; Zullo et al. 2011). Yield projections for rice and sugarcane mostly increase (Fernandes et al. 2012; Marin et al. 2012). In several studies, including CO_2 fertilization increases yields or only leads to small negative yield changes for C_3 plants but not for C_4 plants (Costa et al. 2009; ECLAC 2010; Lapola et al. 2011; Rosenzweig et al. 2013).

A meta-analysis of the impacts of climate change on crop yields for LAC (see Schellnhuber et al. 2014: Appendix A.3) reveals no significant influence of temperature increase on crop yields across all available studies but a significant positive relationship between crop yield change and temperature when CO_2 fertilization is considered (see Fig. 4, Table ESM.5). However, the beneficial effects of CO_2 fertilization are uncertain (e.g., Ainsworth et al. 2008). If the effects of CO_2 fertilization are not considered, the relationship remains significant but becomes negative, with increasing temperature leading to considerable yield declines (see Fig. 4, Table ESM.5).

The impact of ozone on crop yields has been neglected in many climate impact projections although it could offset the benefits of CO_2 fertilization in C_3 plants (and even lead to a yield reduction in C_4 plants) (Jaggard et al. 2010). By 2030, increasing surface ozone could decrease yields in Latin America by up to 7.8 % for wheat, 2.9 % for maize and 7.5 % for soybeans depending on the emissions levels of ozone precursors (Avnery et al. 2011). Moreover, the effects of plant diseases are uncertain but potentially negative (Ghini et al. 2011; Luck et al. 2011; Porter et al. 2014). For example, Coffee leaf rust (*Hemileia vastratix)* and soybean rust (*Phakopsora pachyrhizi*) are expected to move further south and affect South American countries (Alves et al. 2011). Estay et al. (2009) projected an increase in insect population densities of grain pests in Chile of 10–14 % in a 3 °C world and 12–22 % in a 4 °C world.

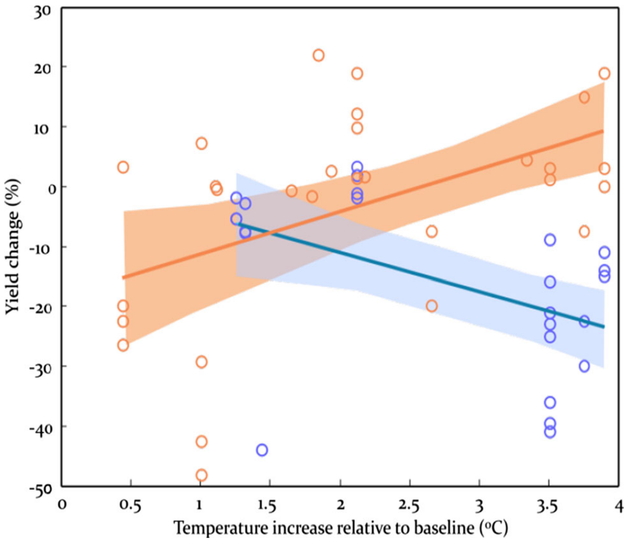


Fig. 4 Meta-analysis of crop yield reductions. Best-fit line for LAC studies not considering the effects of adaptation measures or those of CO_2 fertilization (*blue line*) and for studies considering the effects of CO_2 fertilization (but no adaptation, *orange*) and their 95 % confidence intervals of regressions consistent with the data based on 500 bootstrap samples (*patches*) (color figure online)

Livestock

The livestock sector in LAC is of high economic importance, especially in Brazil and Argentina (ECLAC et al. 2012), but climate impact studies are scarce. Climate change can impact the quantity and quality of livestock feed, and heat stress directly affects livestock productivity. Heat stress is known to reduce cattle food intake and milk production and also to affect reproduction, growth and mortality rates (Porter et al. 2014). In a 1–2 °C warmer world, livestock species choice (i.e., the adoption of new livestock) is projected to mostly decline or marginally increase across Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela for beef cattle, dairy cattle, chicken and pigs (Seo et al. 2010). Meanwhile, the adoption of sheep is projected to increase by up to 20 % because sheep are better adapted to warmer and drier conditions (Seo et al. 2010). In Paraguay, beef cattle production is projected to decrease by 16–27 % in scenarios leading to 2 and 3 °C warming (ECLAC 2010).

Biodiversity

South America is a biodiversity hotspot (MEA 2005; Myers et al. 2000). Habitat destruction and fragmentation by land-use change as well as the commercial exploitation of species groups are currently larger threats to biodiversity than climate change (e.g., Hof et al. 2011), but climate change is projected to become increasingly important for species loss (MEA 2005; Vuuren et al. 2006). Future species loss is difficult to quantify because most biodiversity models do not take biotic interactions (e.g., food-web interactions, species competition) and resource limitations into account.

The G200 ecoregions (Olson and Dinerstein 2002) located in LAC may experience severe climate change in the future (Beaumont et al. 2010; Li et al. 2013). Further, 38.4 and 11.5 % of the surface of the biodiversity hotspot of Tumbes-Choco-Magdalena and the Mesoamerican biodiversity hotspot, respectively, will be experiencing no-analog climates in a warmer than 2 °C world (García-López and Allué 2013). Heyder et al. (2011) project a range of small to severe ecosystem changes for the whole South American continent in a 2 °C and warmer world. In a 4 °C world, results of one dynamic vegetation model show severe ecosystem changes for more than 33 % of the area in 21 out of 26 distinct biogeographic regions in South America (Gerten et al. 2013). Warszawski et al. (2013) projected such severe ecosystem changes in a 3 °C world in South America (notably in Amazon, Guyana moist forests and Brazilian Cerrado) when applying an ensemble of seven dynamic vegetation models. Bellard et al. (2014) projected that out of 723 Caribbean islands, 63 and 356 will be entirely submerged under one and six meters of sea-level rise, respectively. A one-meter sea-level rise is within the range of sea-level rise projected in a 4 °C world (see section "Regional sea-level rise").

Little is known about the consequences of future climate change on specific taxa in the region. There are some studies on insects (Deutsch et al. 2008), amphibians (Lawler et al. 2009; Sinervo et al. 2010; Hof et al. 2011; Loyola et al. 2013; Mesquita et al. 2013; Lemes et al. 2014), sea turtles (Fish et al. 2005), birds (Anciães and Peterson 2006; Jetz et al. 2007, Marini et al. 2009; Souza et al. 2011), marsupials (Loyola et al. 2012), mammals (Schloss et al. 2012; Torres et al. 2012) and plant species (Feeley et al. 2012; Simon et al. 2013). Overall, most studies project range contractions or inability to keep pace with climate. Across different species, Thomas et al. (2004) project increasing extinction rates with increasing warming levels.

Amazon rainforest degradation and tipping point

Old-growth rainforests in the Amazon store approximately 100 billion tons of carbon in their biomass (Malhi et al. 2006; Saatchi et al. 2011) and recycle precipitation through evapotranspiration, thus contributing to local rainfall (Zemp et al. 2014). A loss of these forests due to climate change and deforestation would release an enormous amount of carbon into the atmosphere and reduce their evapotranspiration potential leading to strong climate feedbacks (Betts et al. 2004; Cox et al. 2004; Costa and Pires 2010) and a potential tipping point (Lenton et al. 2008). A critical tipping point has been identified at around 40 % deforestation, when altered water and energy feedbacks between remaining tropical forest and climate may lead to a decrease in precipitation (Sampaio et al. 2007). Recent evidence from a large-scale and long-term experiment suggests that the feedbacks between climatic extreme events such as droughts and forest fires increase the likelihood of an Amazon dieback (Brando et al. 2014). However, the most recent modeling studies suggest that the Amazon dieback is an unlikely, but possible, future for the Amazon region (Good et al. 2013).

The 2005 and 2010 Amazon droughts lead to increased tree mortality and reduced tree growth due to water stress (Lewis et al. 2011) possibly reversing the role of the intact forest as a carbon sink (Phillips et al. 2009; Lewis et al. 2011). Two multi-year rainfall exclusion experiments in Caxiuanã and Tapajós National Forest demonstrated that once deep soil water is depleted, wood production is reduced by up to 62 %, aboveground net primary productivity declines by 41 %, and mortality rates for trees almost double (Nepstad et al. 2007; Brando et al. 2008; Costa and Pires 2010). Thus, an increase in extreme droughts or a prolonged dry season (Fu et al. 2013) may have the potential to cause large-scale forest dieback.

Deforestation and forest degradation are also factors which crucially influence future changes in vegetation carbon. Gumpenberger et al. (2010) found relative changes in carbon stocks of −35 to +40 % in a protection scenario without deforestation and −55 to −5 % with 50 % deforestation in a 4 °C world. Poulter et al. (2010) found a 24.5 % agreement of projections for a decrease in biomass in simulations with 9 GCMs in a 4 °C world.

Studies projecting future fires in the Amazon are scarce. Fires are projected to increase along major roads in the southern and southwestern part of Amazonia with a 1.8 °C global warming by 2040–2050 (Silvestrini et al. 2011; Soares-Filho et al. 2012). High rates of deforestation would contribute to an increasing fire occurrence of 19 % by 2050, whereas climate change alone would account for a 12 % increase (Silvestrini et al. 2011).

Despite a large number of studies (see Table ESM.1 for a summary), the identification of the processes and the quantification of thresholds at which a tipping point is triggered (e.g., a potential transition from forest to savannah) are still incomplete. Recent analyses have downgraded the probability from 21 to 0.24 % for a 4 °C regional warming when coupled carbon-cycle climate models are adjusted to better represent the inter-annual variability of tropical temperatures and related CO_2 emissions (Cox et al. 2013). This holds true, however, only when the CO_2 fertilization effect is realized as implemented in current vegetation models (Rammig et al. 2010). Moreover, large-scale forest degradation as a result of increasing drought may already impair ecosystem services and functions without a forest dieback necessarily occurring and will impact forest dwelling/depending communities.

Fisheries

Anthropogenic changes in temperature, salinity, oxygen content and pH levels have been observed for oceans over the past 60 years (Pörtner et al. 2014). In LAC, small-scale fishers and people dependent on large-scale fishing and associated industries may be particularly affected by climate change if they are unable to diversify their livelihoods. Peru and Colombia are among the countries whose fisheries are most vulnerable to climate change (Allison et al. 2009; Magrin et al. 2014).

In response to changing oceanic conditions, fish stocks have been observed in, and are further expected to shift to, higher latitudes (Perry et al. 2005). A global study that considers the habitat preference of 1066 commercially caught species and projects changes to primary productivity, computes the expected changes in fish species distribution and regional patterns of maximum catch potential by 2055 in a scenario leading to warming of approximately 2 °C in 2050 (and 4 °C by 2100) (Cheung et al. 2010). Their results for LAC indicate a mixed picture: Catch potential is expected to increase up to 100 % further offshore of the southern part of Latin America and to decrease by 15–50 % along the Caribbean coasts, by 5–50 % in Caribbean waters and parts of the Atlantic coast of Central America, by more than 50 % off the Amazonas estuary and the Rio de la Plata and by up to 30 % along the coasts of Peru and Chile (with increases toward the south). These projections are, however, uncertain because expected declines in ocean pH (ocean acidification), direct human pressures and local processes, which escape the coarse resolution of global models, are not taken into account (Cheung et al. 2010). Incorporating the effects of decreasing ocean pH and reduced oxygen availability yields catch potentials that are 20–30 % lower relative to simulations not considering these factors in the northeast Atlantic (Cheung et al. 2011). Considering the effects of species interaction on redistribution and abundance, Fernandes et al. (2013) report latitudinal shifts in the North Atlantic to be 20 % lower than reported by the bioclimatic envelope model developed by Cheung et al. (2010). For the Humboldt Current System, Blanchard et al. (2012) projected a 35 % decline in phytoplankton and zooplankton density and similar magnitudes of change in the overall biomass of fish under 2 °C global warming by 2050.

Coral reefs

Coral reefs provide ecosystem services which are locally important for subsistence fisheries, income from tourism and protection from coastal storm surges (Hoegh-Guldberg et al. 2007). Coral bleaching events on a large scale have been linked to unusually high sea-surface temperatures but also pollution, overfishing and the related shift in species composition are important factors (De'ath et al. 2012). Hurricanes have been found to cool waters, alleviating heat stress and thereby reducing the risk of bleaching (Eakin et al. 2010). This effect could temporarily outweigh the negative effects of direct damage (e.g., through breakage) (Carrigan and Puotinen 2014 but see Gardner et al. 2005).

Due to decreasing availability of calcium carbonate and increasing sea-surface temperatures, Meissner et al. (2012) projected that most coral reef locations in the Caribbean Sea and western Atlantic will be subject to a 60–80 % probability of annual bleaching events with 2 °C warming by 2050, with areas at the coast of Guyana, Suriname and French Guiana being exposed to a 100 % probability. In contrast, under 1.5 °C warming by 2050, most locations in the Caribbean Sea have a comparably low risk of 20–40 % probability of annual bleaching events, with the waters of Guyana, Suriname, French Guiana and the north Pacific being at slightly higher risk (up to 60 % probability). By the year 2100, almost all coral reef locations are expected to be subject to severe bleaching events occurring on an annual basis in a 4 °C world. Exceptions are major upwelling regions, which experience a risk of 50 %. With warming leading to a 2 or 4 °C world, the median year in which bleaching events start to occur annually is 2046 or 2040, respectively (Van Hooidonk et al. 2013). Generally, the reefs in the northern waters of the Caribbean Sea appear to be less sensitive than those in the south. However, reefs at the higher latitude fringes of the tropical coral range (both north and south) are likely to be more heavily affected by ocean acidification (Caldeira 2013). Different scenarios leading to 2, 3 and 4 °C worlds showed little difference in coral cover (Buddemeier et al. 2011): By 2020, live coral reef cover is projected to have halved from its initial state; by the year 2050, live coral cover is less than 5 %; in 2100, it is less than 3 %. Assuming coral adaptation by gaining an additional 1 °C of heat tolerance, the loss of live coral cover below 5 % is prolonged by around 30 years. A 90 % loss of coral reef cover would lead to direct economic losses of \$8.712 billion (2008 value) (Vergara et al. 2009). While there are limitations to the projections of coral reef future, a bleak picture emerges from the studies available, which is in accordance with global studies showing that the global mean temperature at which 90 % of coral reefs are at risk of extinction is 1.5 °C above pre-industrial levels (Frieler et al. 2012).

Human health

Among the main human health risks in LAC are vector-borne diseases such as malaria, dengue fever, leishmaniasis and fascioliasis, and food- and water-borne diseases such as cholera and childhood diarrheal disease. Climate change is expected to play a contributing role in determining the incidence of dengue fever (Confalonieri et al. 2007), although it is difficult to separate the impact of climatic factors from that of urbanization and population mobility (Barclay 2008). Studies from Mexico (Hurtado-Diaz et al. 2007) and Puerto Rico (Johansson et al. 2009) show a correlation between increases in rainfall and temperature and increased incidence of the disease. In Brazil in the period 2001–2009, a 1 °C increase in monthly minimum temperature was associated with a 45 % increase in dengue fever cases the following month and a 10 mm increase in precipitation with a 6 % increase (Gomes et al. 2012). Projections by Colon-Gonzalez et al. (2013) point to an upsurge in dengue incidence in Mexico of 18 % by 2030, 31 % by 2050 and 40 % by 2080 with a warming scenario leading to a 4 °C world by 2100.

Evidence shows an increasing spread of malaria to higher elevations in northwest Colombia during the last three decades due to rising temperatures (Siraj et al. 2014), and it is possible the disease will spread into other high-altitude areas such as the cities of Quito and Mexico City (Moreno 2006). The connection between malaria and climate change is unclear, however, due to the complexity of the factors involved (e.g., land use, domestic water storage patterns, vector control programmes). It is likely that the effect of climate change on malaria patterns will not be uniform, with increased incidence in some areas but declines in places where decreases in precipitation are projected, including parts of the Amazon and Central America (Haines et al. 2006). Caminade et al. (2014) projected a lengthening of the malaria transmission season in the highlands of Central America and southern Brazil by the 2080 s, but a shortening in the tropical regions of South America.

Climatic variables have been shown to be decisive in determining the extent of cholera outbreaks (Koelle 2009). A recent study in Haiti shows that increased rainfall is followed by increased cholera risk 4–7 days later (Eisenberg et al. 2013). The relative risk of diarrheal disease in South America is expected to increase by 5–13 and 14–36 % for the period 2010–2039 and 2070–2099 with 1.3 and 3.1 °C warming, respectively (Kolstad and Johansson 2011).

Coastal infrastructure

Hallegatte et al. (2013) found that, by 2050, coastal flooding could generate approximately $940 million of mean annual losses in the 22 largest coastal cities in LAC with a sea-level rise of 20 cm and about $1.2 billion with a sea-level rise of 40 cm. The damage to coastal infrastructure associated with tropical cyclones making landfall is also projected to change (Hallegatte 2007; Mendelsohn et al. 2011). In a scenario leading to a 4 °C world and featuring a 0.89- to 1.4-m sea-level rise, tropical cyclones in the Caribbean alone could generate an extra $22 billion and $46 billion in storm and infrastructure damages and tourism losses by 2050 and 2100, respectively, compared to a scenario leading to a 2 °C world (Bueno et al. 2008). Cumulative losses induced by increasing tropical cyclone intensity of 2 and 5 % compared to average values from 1995 to 2006 could increase to about $110 and $114 billion, respectively, during the period 2020–2025 in the Caribbean, Central America and Mexico (Curry et al. 2009). The potential increase in tropical cyclone intensity may increase ships' port downtime and therefore increase shipping costs (Esteban et al. 2012; Chhetri et al. 2013). Impacts on seaports will also have indirect consequences on local economies as import disruptions generate price increases for imported goods and export disruptions decrease revenues and incomes (Becker et al. 2012). Beach tourism is particularly exposed to several climate change stressors, including sea-level rise, modified tropical storm pattern and heightened storm surges (Simpson et al. 2011). In Jamaica, for example, coastal tourist resorts are two-to-three times more exposed to climate change-related stressors than inland touristic resorts (Hyman 2013).

Energy systems

LAC countries have a diverse energy mix (see Table ESM.6), but with projected changes in water availability (cf. "Glacial retreat and snowpack changes" and "Water resources, water security, and floods" sections), thermal electricity plant cooling systems may become less efficient (Mika 2013; Sieber 2013) and also hydroelectric power generation will be affected (Hamududu and Killingtveit 2012). In Peru, it is estimated that a 50 % reduction in glacier runoff would result in a decrease in annual power output of approximately 10 %, from 1540 to 1250 GWh (Vergara et al. 2007). Hamududu and Killingtveit (2012) found that production will increase by 0.30 TWh (or 0.03 %) in the Caribbean compared to 2005 production levels, and by 0.63 TWh (or 0.05 %) in South America, under 2 °C global warming by the middle of the twenty-first century. An increase in frequency of low flows in scenarios leading to a 2 °C and 3 °C world implies a proportional decrease in hydropower capacity for the two main large reservoirs used for hydroelectricity generation in El Salvador, reducing the economic return from the existing facility and threatening the return on investments in future hydroelectric infrastructures (Maurer et al. 2009). For Brazil, de Lucena et al. (2009) project that average annual river flows will decrease by 10.8 % with 2.9 °C global warming, and by 8.6 % with 3.5 °C global warming, by 2071–2100. For the Rio Grande River basin, the difference between the lowest (−20 %) and the highest (+18 %) estimates of average river flow with a global warming of 2.1 °C depending on the GCM chosen highlights the limitations of current models to project the potential hydropower production (Nóbrega et al. 2011). Popescu et al. (2014) showed an increase in the maximum hydropower energy potential for the La Plata basin of between 1 and 26 % with a global warming of 1.8 °C by 2031–2050.

The results of these studies need to be interpreted with care. Global studies such as from Hamududu and Killingtveit (2012) do not take into account seasonality and impacts of climate change on the timing of river flows, potential spatial variability and changes occurring over short distances, potential impacts of floods and droughts or impacts on river runoff from decreasing snow cover and snowfall. Such differences may explain, at least partly, the differences between the significant decrease in hydropower capacity at the micro-level as projected by Maurer et al. (2009) and the increase in hydropower generation at the macro-level projected by Hamududu and Killingtveit (2012). Similarly, De Lucena et al. (2009) also only accounted for the average behavior of flows and did not integrate potential change in seasonality or the effects of extreme dry or wet events on hydropower generation.

Implications for regional development

This paper shows that the Latin America and Caribbean region will be severely affected by climate change, even under lower levels of warming (Fig. 5, Table ESM.1). The biophysical impacts described here interact with the

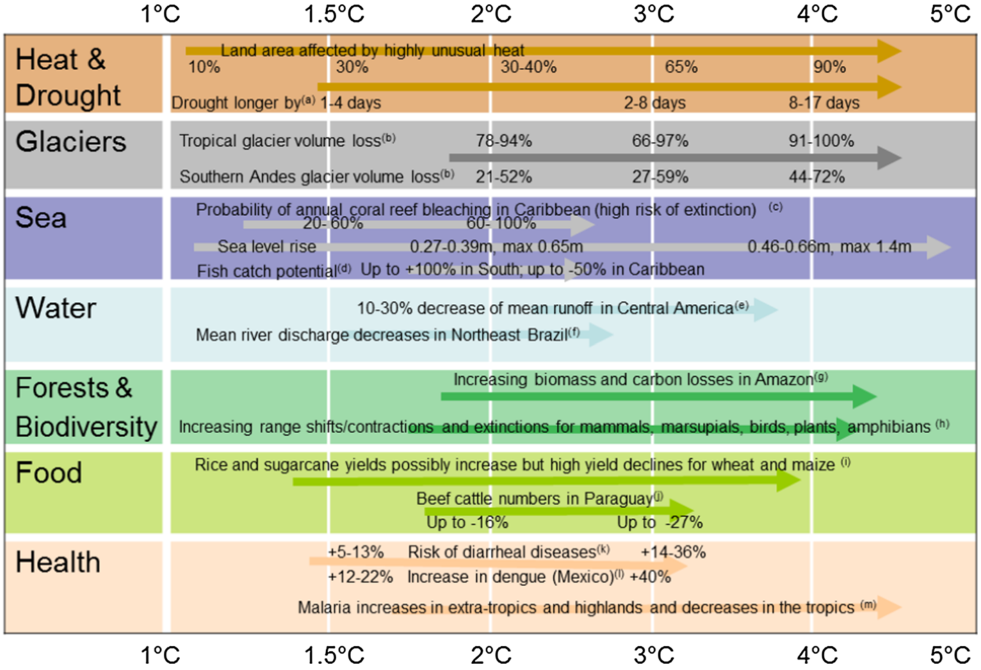


Fig. 5 Projected impacts of climate change in key sectors in the Latin America and Caribbean region. Warming levels are relative to pre-industrial temperatures. The impacts shown here are a subset of those summarized in this paper and in Table ESM.1. The *arrows* indicate solely the range of warming levels assessed in the underlying studies, but do not imply any graduation of risk unless noted explicitly. In addition, observed impacts or impacts occurring at lower or higher levels of warming that are not covered by the key studies highlighted here are not presented (e.g., coral bleaching already occurs earlier than 1.5 °C warming, but the studies presented here only start at 1.5 °C). Adaptation measures are not assessed here although they can be crucial to alleviate impacts of climate change. The layout of the figure is adapted from Parry (2010). The lower-case superscript letters indicate the relevant references for each impact. If there is no letter, the results are based on additional analyses for this report. (*a*) Sillmann et al. (2013b); (*b*) Marzeion et al. (2012); Giesen and Oerlemans (2013); Radic et al. (2013); (*c*) Meissner et al. (2012); (*d*) Cheung et al. (2010); (*e*) Hidalgo et al. (2013); (*f*) Döll and Schmied (2012); (*g*) several studies without considering CO_2 fertilization, see Table ESM.1; (*h*) several studies, see Table ESM.1; (*i*) several studies, see Table ESM.1; (*j*) ECLAC (2010); (*k*) Kolstad and Johansson (2011); (*l*) Colon-Gonzalez et al. (2013); (*m*) Béguin et al. (2011); Caminade et al. (2014); Van Lieshout et al. (2004)

existing vulnerabilities in the region ("Social, economic and demographic profile of the Latin America and Caribbean region and vulnerabilities to climate change" section) and may affect development and human well-being in LAC in a variety of ways: Changes to the hydrological cycle endanger the stability of freshwater supplies and ecosystem services on which many people in LAC depend. Extreme events will strongly affect the rural and urban poor who often reside in informal settlements in high-risk areas (e.g., flood plains and steep slopes). Intense rainfall events can quickly overwhelm natural drainage channels in the landscape as well as urban drainage systems that are unlikely to have been designed for the possible increased intensity of future rainfall events. At lower levels of warming, glacial melt in the Andes will reduce freshwater and hydropower during the dry season for communities and large Andean cities which are often important economic centers, while increasing the risks of flooding in the short term and impacting agriculture and environmental services downstream. More intense tropical cyclones would interact adversely with rising sea levels, exacerbating coastal flooding and storm surge risks, putting entire economies and livelihoods of island states at risk. The Caribbean is particularly vulnerable as more than 50 % of its population lives along the coast and around 70 % live in coastal cities. Degrading coral reefs will endanger tourism revenues and undermine biodiversity, fisheries and the protection of coastal zones. Climate change could also place at risk small-scale subsistence agriculture and large-scale agricultural production for export.

Finally, our assessment of climate change impacts in different sectors shows that impacts are likely to occur simultaneously and possibly interact, thus increasing the risks for development when, e.g., crop yield is reduced, transport disrupted and houses of workers and production infrastructure damaged. Although, climate change challenges those already vulnerable and disfavored the most, large businesses could also suffer which in turn has implications for a large labor force, threatening population groups currently considered less vulnerable. Studies of interacting and cascading impacts and how these affect different population groups and infrastructure types are needed to gain a clearer picture of the relationship between climate change and development, as well as to better plan and implement mitigation and adaptation activities. A key challenge is to properly link biophysical impacts, often projected until the end of this century, to development issues which are highly dynamic and hard to project at similar timescales as the climate impact projections.

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References

Ahmed SA, Diffenbaugh NS, Hertel TW (2009) Climate volatility deepens poverty vulnerability in developing countries. Environ Res Lett 4:034004

Ainsworth EA, Leakey ADB, Ort DR, Long SP (2008) FACE-ing the facts: inconsistencies and interdependence among field, chamber and modeling studies of elevated CO_2 impacts on crop yield and food supply. New Phytol 179:5–9

Aiyyer A, Thorncroft C (2011) Interannual-to-multidecadal variability of vertical shear and tropical cyclone activity. J Clim 24:2949–2962. doi:10.1175/2010JCLI3698.1

Allison EH, Perry AL, Badjeck M-C, Neil Adger W, Brown K, Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish 10:173–196. doi:10.1111/j.1467-2979.2008.00310.x

Alves MC, de Carvalho LG, Pozza EA, Sanches L, Maia JCS (2011) Ecological zoning of soybean rust, coffee rust and banana black sigatoka based on Brazilian climate changes. Proced Environ Sci 6:35–49. doi:10.1016/j.proenv.2011.05.005

Anciães M, Peterson A (2006) Climate change effects on neotropical manakin diversity based on ecological niche modeling. Condor 108:778–791

Arndt DS, Baringer MO, Johnson MR (eds) (2010) State of the climate in 2009. Bull Amer Meteor Soc 91:S1–S224

Arnell NW, Gosling SN (2013) The impacts of climate change on river flow regimes at the global scale. J Hydrol 486:351–364. doi:10.1016/j.jhydrol.2013.02.010

Avnery S, Mauzerall DL, Liu J, Horowitz LW (2011) Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O3 pollution. Atmos Environ 45:2297–2309. doi:10.1016/j.atmosenv.2011.01.002

Baraer M, Mark B, McKenzie J, Condom T, Bury J, Huh K-I, Portocarrero C, Gomez J, Rathay S (2012) Glacier recession and water resources in Peru's Cordillera Blanca. J Glaciol 58:134–150. doi:10.3189/2012JoG11J186

Barclay E (2008) Is climate change affecting dengue in the Americas? Lancet 371:973–974

Beaumont LJ, Pitman A, Perkins S, Zimmermann NE, Yoccoz NG (2010) Impacts of climate change on the world's most exceptional ecoregions. doi:10.1073/pnas.1007217108/-/DCSupplemental. www.pnas.org/cgi/doi/10.1073/pnas.1007217108

Becker A, Inoue S, Fischer M, Schwegler B (2012) Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators. Clim Change 110:5–29. doi:10.1007/s10584-011-0043-7

Bellard C, Leclerc C, Courchamp F (2014) Impact of sea level rise on the 10 insular biodiversity hotspots. Glob Ecol Biogeogr 23:203–212. doi:10.1111/geb.12093

Bender MA, Knutson TR, Tuleya RE, Sirutis JJ, Vecchi GA, Garner ST, Held IM (2010) Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. Science 327:454–458. doi:10.1126/science.1180568

Betts RA, Cox PM, Collins M, Harris PP, Huntingford C, Jones CD (2004) The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming. Theor Appl Climatol 78:157–175. doi:10.1007/s00704-004-0050-y

Béguin A, Hales S, Rocklöv J, Åström C, Louis VR, Sauerborn R (2011) The opposing effects of climate change and socioeconomic development on the global distribution of malaria. Glob Environ Chang 21:1209–1214. doi:10.1016/j.gloenvcha.2011.06.001

Bindoff NL, Stott PA, AchutaRao KM, Allen MR, Gillett N, Gutzler D, Hansingo K, Hegerl G, Hu Y, Jain S, Mokhov I, Overland J, Perlwitz J, Sebbari R, Zhang X (2013) Detection and attribution of climate change: from global to regional. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Chapter 10. IPCC AR5 WG1, Cambridge University Press, Cambridge, pp 867–952

Blanchard JL, Jennings S, Holmes R, Harle J, Merino G, Allen JI, Holt J, Dulvy NK, Barange M (2012) Potential consequences of climate change for primary production and fish production in large marine ecosystems. Philos Trans R Soc Lond B Biol Sci 367:2979–2989. doi:10.1098/rstb.2012.0231

Brando PM, Nepstad DC, Davidson EA, Trumbore SE, Ray D, Camargo P (2008) Drought effects on litterfall, wood production and belowground carbon cycling in an Amazon forest: results of a throughfall reduction experiment. Philos Trans R Soc Lond B Biol Sci 363:1839–1848. doi:10.1098/rstb.2007.0031

Brando PM, Balch JK, Nepstad DC, Morton DC, Putz FE, Coe MT, Silvério D, Macedo MN, Davidson EA, Nóbrega CC, Alencar A, Soares-Filho BS (2014) Abrupt increases in Amazonian tree mortality due to drought-fire interactions. Proc Natl Acad Sci USA 111:6347–6352. doi:10.1073/pnas.1305499111

Bravo JM, Collischonn W, Paz AR, Allasia D, Domecq F (2013) Impact of projected climate change on hydrologic regime of the Upper Paraguay River basin. Clim Change. doi:10.1007/s10584-013-0816-2

Buddemeier RW, Lane DR, Martinich JA (2011) Modeling regional coral reef responses to global warming and changes in ocean chemistry: Caribbean case study. Clim Change 109:375–397. doi:10.1007/s10584-011-0022-z

Bueno R, Herzfeld C, Stanton EA, Ackerman F (2008) The Caribbean and climate change: the costs of inaction. Tufts University, Somerville

Buytaert W, De Bièvre B (2012) Water for cities: the impact of climate change and demographic growth in the tropical Andes. Water Resour Res. doi:10.1029/2011WR011755

Buytaert W, Célleri R, Timbe L (2009) Predicting climate change impacts on water resources in the tropical Andes: effects of GCM uncertainty. Geophys Res Lett 36:1–5. doi:10.1029/2008GL037048

Cai W, Borlace S, Lengaigne M, van Rensch P, Collins M, Vecchi G, Timmermann A, Santoso A, McPhaden MJ, Wu L, England MH, Wang G, Guilyardi E, Jin F-F (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. Nat Clim Change 5:1–6. doi:10.1038/nclimate2100

Caldeira K (2013) Coral Bleaching: coral "refugia" amid heating seas. Nat Clim Change 3:444–445. doi:10.1038/nclimate1888

Camargo MBP (2010) The impact of climatic variability and climate change on arabic coffee crop in Brazil. Bragantia 69:239–247. doi:10.1590/S0006-87052010000100030

Camargo SJ, Ting M, Kushnir Y (2012) Influence of local and remote SST on North Atlantic tropical cyclone potential intensity. Clim Dyn 40:1515–1529. doi:10.1007/s00382-012-1536-4

Camilloni IA, Saurral RI, Montroull NB (2013) Hydrological projections of fluvial floods in the Uruguay and Paraná basins under different climate change scenarios. Int J River Basin Manag 11:389–399. doi:10.1080/15715124.2013.819006

Caminade C, Kovats S, Rocklov J, Tompkins AM, Morse AP, Colon-Gonzalez FJ, Stenlund H, Martens P, Lloyd SJ (2014) Impact of climate change on global malaria distribution. PNAS 111:3286–3291

Carey M (2005) Living and dying with glaciers: people's historical vulnerability to avalanches and outburst floods in Peru. Glob Planet Change 47:122–134. doi:10.1016/j.gloplacha.2004.10.007

Carey M, Huggel C, Bury J, Portocarrero C, Haeberli W (2012) An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Clim Change 112:733–767

Carrigan AD, Puotinen M (2014) Tropical cyclone cooling combats region-wide coral bleaching. Glob Chang Biol. doi:10.1111/gcb.12541

Cashman A, Nurse L, John C (2010) Climate change in the Caribbean: the water management implications. J Environ Dev 19:42–67. doi:10.1177/1070496509347088

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Zeller D, Pauly D (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Glob Chang Biol 16:24–35. doi:10.1111/j.1365-2486.2009.01995.x

Cheung WWL, Dunne J, Sarmiento JL, Pauly D (2011) Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. ICES J Mar Sci 68:1008–1018. doi:10.1093/icesjms/fsr012

Chevallier P, Pouyaud B, Suarez W, Condom T (2011) Climate change threats to environment in the tropical Andes: glaciers and water resources. Reg Environ Change 11:179–187. doi:10.1007/s10113-010-0177-6

Chhetri P, Corcoran J, Gekara V, Corbitt B, Wickramasinghe N, Jayatilleke G, Basic F, Scott H, Manzoni A, Maddox C (2013) Functional resilience of port environs in a changing climate—assets and operations. Work Package 2 of Enhancing the resilience of seaports to a changing climate report series. National Climate Change Adaptation Research Facility, Gold Coast

CIESIN (2011) Population, landscape, and climate estimates (PLACE), v3 (1990, 2000, 2010). In: Center for international earth science information network. NASA Socioeconomic Data and Applications Center (SEDAC). doi:10.7927/H4F769GP. Accessed 12 Jun 2013

Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, Shongwe M, Tebaldi C, Weaver AJ, Wehner M (2013) Long-term climate change: projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Chapter 12. IPCC AR5 WGI, Cambridge University Press, Cambridge, UK, pp 1–100

Colon-Gonzales FJ, Fezzi C, Lake IR, Hunter PR (2013) The effects of weather and climate change on dengue. PLoS Negl Trop Dis 7:e2503

Confalonieri U, Menne B, Akhtar R, Ebi KL, Hauengue M, Kovats RS, Revich B, Woodward A (2007) Human health. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 391–431

Cortés G, Vargas X, McPhee J (2011) Climatic sensitivity of streamflow timing in the extratropical western Andes Cordillera. J Hydrol 405:93–109. doi:10.1016/j.jhydrol.2011.05.013

Costa MH, Pires GF (2010) Effects of Amazon and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation. Int J Climatol 30:1970–1979. doi:10.1002/joc.2048

Costa LC, Justino F, Oliveira LJC, Sediyama GC, Ferreira WPM, Lemos CF (2009) Potential forcing of CO_2, technology and climate changes in maize (Zea mays) and bean (*Phaseolus vulgaris*) yield in southeast Brazil. Environ Res Lett 4:014013. doi:10.1088/1748-9326/4/1/014013

Coumou D, Robinson A (2013) Historic and future increase in the global land area affected by monthly heat extremes. Environ Res Lett 8:6

Cox PM, Betts RA, Collins M, Harris PP, Huntingford C, Jones CD (2004) Amazonian forest dieback under climate-carbon cycle projections for the 21st century. Theor Appl Climatol 78:137–156. doi:10.1007/s00704-004-0049-4

Cox PM, Pearson D, Booth BB, Friedlingstein P, Huntingford C, Jones CD, Luke CM (2013) Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability. Nature 494:341–344. doi:10.1038/nature11882

Curry J, Jelinek M, Foskey B, Suzuki A, Webster P (2009) Potential Economic Impacts of Hurricanes in Mexico, Central America, and the Caribbean ca. 2020–2025. LCR Sustainable Development Working Paper, Washington, DC

Dai A (2012) Increasing drought under global warming in observations and models. Nat Clim Change 3:52–58. doi:10.1038/nclimate1633

Davidson EA, de Araújo AC, Artaxo P, Balch JK, Brown IF, Bustamante MC, Coe MT, DeFries RS, Keller M, Longo M, Munger JW, Schroeder W, Soares-Filho BS, Souza CM, Wofsy SC (2012) The Amazon basin in transition. Nature 481:321–328. doi:10.1038/nature10717

De Lucena AFP, Szklo AS, Schaeffer R, de Souza RR, Borba BSMC, da Costa IVL, Júnior AOP, da Cunha SHF (2009) The vulnerability of renewable energy to climate change in Brazil. Energy Policy 37:879–889. doi:10.1016/j.enpol.2008.10.029

De'ath G, Fabricius KE, Sweatman H, M Puotinen (2012) The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proc Natl Acad Sci USA. doi:10.1073/pnas.1208909109

Demaria EMC, Maurer EP, Thrasher B, Vicuña S, Meza FJ (2013) Climate change impacts on an alpine watershed in Chile: do new model projections change the story? J Hydrol 502:128–138. doi:10.1016/j.jhydrol.2013.08.027

Deutsch CA, Tewksbury JJ, Huey RB, Sheldon KS, Ghalambor CK, Haak DC, Martin PR (2008) Impacts of climate warming on terrestrial ectotherms across latitude thermal safety margin. Proc Natl Acad Sci USA 105:6668–6672

Dilley M, Chen RS, Deichmann U, Lerner-Lam AL, Arnold M, Agwe J, Buys P, Kjekstad O, Lyon B, Yetman G (2005) Natural disaster hotspots: a global risk analysis. Disaster Risk Management Series, Washington DC

Döll P, Schmied HM (2012) How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. Environ Res Lett 7:1–11. doi:10.1088/1748-9326/7/1/014037

Douglas I, Alam K, Maghenda M, Mcdonnell Y, Mclean L, Campbell J (2008) Unjust waters: climate change, flooding and the urban poor in Africa. Environ Urban 20:187–205. doi:10.1177/0956247808089156

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, Alvarez-Filip L, Baca B, Bartels E, Bastidas C, Bouchon C, Brandt M, Bruckner AW, Bunkley-Williams L, Cameron A, Causey BD, Chiappone M, Christensen TRL, Crabbe MJC, Day O, de la Guardia E, Díaz-Pulido G, DiResta D, Gil-Agudelo DL, Gilliam DS, Ginsburg RN, Gore S, Guzmán HM, Hendee JC, Hernández-Delgado EA, Husain E, Jeffrey CFG, Jones RJ, Jordán-Dahlgren E, Kaufman LS, Kline DI, Kramer PA, Lang JC, Lirman D, Mallela J, Manfrino C, Maréchal J-P, Marks K, Mihaly J, Miller WJ, Mueller EM, Muller EM, Orozco Toro CA, Oxenford HA, Ponce-Taylor D, Quinn N, Ritchie KB, Rodríguez S, Ramírez AR, Romano S, Samhouri JF, Sánchez JA, Schmahl GP, Shank BV, Skirving WJ, Steiner SCC, Villamizar E, Walsh SM, Walter C, Weil E, Williams EH, Roberson KW, Yusuf Y (2010) Caribbean corals in crisis: record thermal stress, bleaching, and mortality in 2005. PLoS ONE 5:e13969. doi:10.1371/journal.pone.0013969

ECLAC (2010) Economics of Climate Change in Latin America and the Caribbean. Summary 2010. United Nations Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile

ECLAC (2014) Economic and Social Panorama of the Community of Latin American and Caribbean States, 2013. United Nations Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile

ECLAC, UNFPA (2009) 2009 Social Panorama of Latin America. United Nations Economic Commission for Latin America and the Caribbean (ECLAC) and th United Nations Population Fund (UNFPA), New York, NY

ECLAC, FAO, IICA (2012) The outlook for agriculture and rural development in the Americas: a perspective on latin America and the Caribbean. Economic Commission for Latin America and the Caribbean (ECLAC), Food and Agriculture Organization of the UN (FAO), Inter-American Institute for Cooperation on Agriculture (IICA), Santiago, Chile

Eisenberg MC, Kujbida G, Tuite AR, Fisman DN, Tien JH (2013) Examining rainfall and cholera dynamics in Haiti using statistical and dynamic modeling approaches. Epidemics 5:197–207

Emanuel KA (2013) Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proc Natl Acad Sci USA 110:12219–12224. doi:10.1073/pnas.1301293110

Estay SA, Lima M, Labra FA (2009) Predicting insect pest status under climate change scenarios: combining experimental data and population dynamics modelling. J Appl Entomol 133:491–499. doi:10.1111/j.1439-0418.2008.01380.x

Esteban M, Thao ND, Takagi H (2012) Increase in port downtime and damage in Vietnam due to a potential increase in tropical cyclone intensity. In: Leal Filho W (ed) Climate change and the sustainable use of water resources. Springer, Berlin, pp 101–125

Exbrayat J-F, Buytaert W, Timbe E, Windhorst D, Breuer L (2014) Addressing sources of uncertainty in runoff projections for a data scarce catchment in the Ecuadorian Andes. Clim Change 125:221–235. doi:10.1007/s10584-014-1160-x

FAO (2003) Review of world water resources by country. Water Reports No. 23, Food and Agriculture Organization, Rome

Feeley KJ, Malhi Y, Zelazowski P, Silman MR (2012) The relative importance of deforestation, precipitation change, and temperature sensitivity in determining the future distributions and diversity of Amazonian plant species. Glob Change Biol 18:2636–2647. doi:10.1111/j.1365-2486.2012.02719.x

Feldt H (2011) Fortalecimiento de Organizaciones Indígenas en América Latina: Pueblos Indígenas y Cambio Climático. Relación entre cambio climático y pueblos indígenas y sus posiciones en el contexto de las negociaciones en la Convención Marco sobre el Cambio Climático. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Frankfurt

Fernandes ECM, Soliman A, Confalonieri R, Donatelli M, Tubiello F (2012) Climate change and agriculture in Latin America, 2020–2050. World Bank, Washington DC

Fernandes JA, Cheung WWL, Jennings S, Butenschön M, de Mora L, Frölicher TL, Barange M, Grant A (2013) Modelling the effects of climate change on the distribution and production of marine fishes: accounting for trophic interactions in a dynamic bioclimate envelope model. Glob Chang Biol 19:2596–2607. doi:10.1111/gcb.12231

Ficke AD, Myrick CA, Hansen LJ (2007) Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fish 17:581–613. doi:10.1007/s11160-007-9059-5

Fish MR, Cote IM, Gill JA, Jones AP, Renshoff S, Watkinson AR (2005) Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat. Conserv Biol 19:482–491. doi:10.1111/j.1523-1739.2005.00146.x

Frieler K, Meinshausen M, Golly A, Mengel M, Lebek K, Donner SD, Hoegh-Guldberg O (2012) Limiting global warming to 2 °C is unlikely to save most coral reefs. Nat Clim Chang 2:1–6. doi:10.1038/nclimate1674

Fu R, Yin L, Li W, Arias PA, Dickinson RE, Huang L, Chakraborty S (2013) Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection. doi:10.1073/pnas.1302584110/-/DCSupplemental. www.pnas.org/cgi/doi/10.1073/pnas.1302584110

García NO, Vargas WM (1998) The temporal climatic variability in the Río de la Plata basin displayed by the river discharges. Clim Change 38:359–379

García-López JM, Allué C (2013) Modelling future no-analogue climate distributions: a world-wide phytoclimatic niche-based survey. Glob Planet Change 101:1–11. doi:10.1016/j.gloplacha.2012.12.001

Gardner T, Cote I, Gill J, Grant A, Watkinson A (2005) Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. Ecology 86:174–184

Gerten D, Lucht W, Ostberg S, Heinke J, Kowarsch M, Kreft H, Kundzewicz ZW, Rastgooy J, Warren R, Schellnhuber HJ (2013) Asynchronous exposure to global warming: freshwater resources and terrestrial ecosystems. Environ Res Lett 8:034032. doi:10.1088/1748-9326/8/3/034032

Ghini R, Bettiol W, Hamada E (2011) Diseases in tropical and plantation crops as affected by climate changes: current knowledge and perspectives. Plant Pathol 60:122–132. doi:10.1111/j.1365-3059.2010.02403.x

Giesen RH, Oerlemans J (2013) Climate-model induced differences in the 21st century global and regional glacier contributions to sea-level rise. Clim Dyn. doi:10.1007/s00382-013-1743-7

Gomes AF, Nobre AA, Cruz OG (2012) Temporal analysis of the relationship between dengue and meteorological variable in the city of Rio de Janeiro, Brazil, 2001–2009. Cad Saúde Pública 28:2189–2197

Good P, Jones C, Lowe J, Betts R, Gedney N (2013) Comparing tropical forest projections from two generations of hadley centre earth system models, HadGEM2-ES and HadCM3LC. J Clim 26:495–511. doi:10.1175/JCLI-D-11-00366.1

Guimberteau M, Ronchail J, Espinoza JC, Lengaigne M, Sultan B, Polcher J, Drapeau G, Guyot J-L, Ducharne A, Ciais P (2013) Future changes in precipitation and impacts on extreme streamflow over Amazonian sub-basins. Environ Res Lett 8:1–13. doi:10.1088/1748-9326/8/1/014035

Gumpenberger M, Vohland K, Heyder U, Poulter B, Macey K, Rammig A, Popp A, Cramer W (2010) Predicting pan-tropical climate change induced forest stock gains and losses—implications for REDD. Environ Res Lett 5:014013. doi:10.1088/1748-9326/5/1/014013

Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C (2006) Climate change and human health: impacts, vulnerability and public health. Public Health 120:585–596. doi:10.1016/j.puhe.2006.01.002

Hallegatte S (2007) The use of synthetic hurricane tracks in risk analysis and climate change damage assessment. J Appl Meteorol Climatol 46:1956–1966. doi:10.1175/2007JAMC1532.1

Hallegatte S, Green C, Nicholls RJ, Corfee-Morlot J (2013) Future flood losses in major coastal cities. Nat Clim Chang 3:802–806. doi:10.1038/nclimate1979

Hamududu B, Killingtveit A (2012) Assessing climate change impacts on global hydropower. Energies 5:305–322. doi:10.3390/en5020305

Hansen J, Sato M, Ruedy R (2012) Perception of climate change. Proc Nat Acad Sci 109:E2415–E2423

Hardoy J, Pandiella G (2009) Urban poverty and vulnerability to climate change in Latin America. Environ Urban 21:203

Hertel T, Burke M, Lobell D (2010) The poverty implications of climate-induced crop yield changes by 2030. Glob Environ Chang 20:577–585. doi:10.1016/j.gloenvcha.2010.07.001

Heyder U, Schaphoff S, Gerten D, Lucht W (2011) Risk of severe climate change impact on the terrestrial biosphere. Environ Res Lett 6:034036. doi:10.1088/1748-9326/6/3/034036

Hidalgo HG, Amador JA, Alfaro EJ, Quesada B (2013) Hydrological climate change projections for Central America. J Hydrol 495:94–112. doi:10.1016/j.jhydrol.2013.05.004

Hirabayashi Y, Mahendran R, Koirala S, Konoshima L, Yamazaki D, Watanabe S, Kim H, Kanae S (2013) Global flood risk under climate change. Nat Clim Chang 3:816–821. doi:10.1038/nclimate1911

Hirata R, Conicelli BP (2012) Groundwater resources in Brazil: a review of possible impacts caused by climate change. An Acad Bras Cienc 84:297–312

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742. doi:10.1126/science.1152509

Hof C, Levinsky I, Araújo MB, Rahbek C (2011) Rethinking species' ability to cope with rapid climate change. Glob Chang Biol 17:2987–2990. doi:10.1111/j.1365-2486.2011.02418.x

Hoffman M, Grigera AI (2013) Climate change, migration, and conflict in the Amazon and the Andes. Rising tensions and policy options in South America. Center for American Progress, Washington, DC

Hurtado-Diaz M, Riojas-Rodriguez H, Rothenburg SJ, Gomez-Dantes H, Cifuentes E (2007) Impact of climate variability on the incidence of dengue in Mexico. Trop Med Int Heal 12:1327–1337

Hyman T-A (2013) Assessing the vulnerability of beach tourism and non-beach tourism to climate change: a case study from Jamaica. J Sustain Tour. doi:10.1080/09669582.2013.855220

IFAD (2013) IFAD in Latin America and the Caribbean. In: International Fund for Agricultural Development, Rome. http://www.ifad.org/operations/projects/regions/PL/index.htm. Accessed 25 Mar 2014

Imbach P, Molina L, Locatelli B, Roupsard O, Mahé G, Neilson R, Corrales L, Scholze M, Ciais P (2012) Modeling potential equilibrium states of vegetation and terrestrial water cycle of Mesoamerica under climate change scenarios. J Hydrometeorol 13:665–680. doi:10.1175/JHM-D-11-023.1

IPCC (2012) Special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX). In: Field CB, Barros V, Stocker TF, Dahe Q (eds) A special report of working groups I and II of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, p 582

IPCC (2013) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge (in press)

Ivins ER, Watkins MM, Yuan D-N, Dietrich R, Casassa G, Rülke A (2011) On-land ice loss and glacial isostatic adjustment at the Drake passage: 2003–2009. J Geophys Res 116:B02403. doi:10.1029/2010JB007607

Jacob T, Wahr J, Pfeffer WT, Swenson S (2012) Recent contributions of glaciers and ice caps to sea level rise. Nature 482:514–518. doi:10.1038/nature10847

Jaggard KW, Qi A, Ober ES (2010) Possible changes to arable crop yields by 2050. Philos Trans R Soc Lond B Biol Sci 365:2835–2851. doi:10.1098/rstb.2010.0153

Jaime P, Menéndez AN (2002) Análisis del Régimen Hidrológico de los Rìos Paraná y Uruguay. Instituto Nacional del Agua, Ezeiza

Jetz W, Wilcove DS, Dobson AP (2007) Projected impacts of climate and land-use change on the global diversity of birds. PLoS Biol 5:e157. doi:10.1371/journal.pbio.0050157

Johansson MA, Dominici F, Glass GE (2009) Local and global effects of climate on dengue transmission in Puerto Rico. PLoS Negl Trop Dis 3:e382

Jones C, Carvalho LMV (2013) Climate change in the South American monsoon system: present climate and CMIP5 projections. J Clim 26:6660–6678. doi:10.1175/JCLI-D-12-00412.1

Juen I, Kaser G, Georges C (2007) Modelling observed and future runoff from a glacierized tropical catchment (Cordillera Blanca, Perú). Glob Planet Change 59:37–48. doi:10.1016/j.gloplacha.2006.11.038

Kharin VV, Zwiers FW, Zhang X, Wehner M (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble. Clim Change 119:345–357. doi:10.1007/s10584-013-0705-8

Kim H-M, Webster PJ, Curry JA (2011) Modulation of North Pacific tropical cyclone activity by three phases of ENSO. J Clim 24:1839–1849. doi:10.1175/2010JCLI3939.1

Kinouchi T, Liu T, Mendoza J, Asaoka Y (2013) Modeling glacier melt and runoff in a high-altitude headwater catchment in the Cordillera Real, Andes. Hydrol Earth Syst Sci Discuss 10:13093–13144. doi:10.5194/hessd-10-13093-2013

Knabb RD, Rhome JR, Brown DP (2005) Tropical cyclone report: Hurricane Katrina. NOAA—National Hurricane Center, Miami

Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical cyclones and climate change. Nat Geosci 3:157–163. doi:10.1038/ngeo779

Knutson TR, Sirutis JJ, Vecchi GA, Garner S, Zhao M, Kim H-S, Bender M, Tuleya RE, Held IM, Villarini G (2013) dynamical downscaling projections of twenty-first-century Atlantic Hurricane activity: CMIP3 and CMIP5 model-based scenarios. J Clim 26:6591–6617. doi:10.1175/JCLI-D-12-00539.1

Koelle K (2009) The impact of climate on the disease dynamics of cholera. Clin Microb Infect 15:29–31

Kolstad EW, Johansson KA (2011) Uncertainties associated with quantifying climate change impacts on human health: a case study for diarrhea. Environ Health Perspect 119:299–305. doi:10.1289/ehp.1002060

Kossin JP, Olander TL, Knapp KR (2013) Trend analysis with a new global record of tropical cyclone intensity. J Clim 26:9960–9976. doi:10.1175/JCLI-D-13-00262.1

Kossin JP, Emanuel KA, Vecchi GA (2014) The poleward migration of the location of tropical cyclone maximum intensity. Nature 509:349–352. doi:10.1038/nature13278

Krol MS, Bronstert A (2007) Regional integrated modelling of climate change impacts on natural resources and resource usage in semi-arid Northeast Brazil. Environ Model Softw 22:259–268. doi:10.1016/j.envsoft.2005.07.022

Kronik J, Verner D (2010) Indigenous peoples and climate change in Latin America and the Caribbean. doi:10.1596/978-0-8213-8237-0

Kumar N, Quisumbing AR (2011) Gendered Impacts of the 2007 – 08 food price crisis evidence using panel data from rural Ethiopia. International Food Policy Research Institute (IFPRI), Washington, DC

Laderach P, Lundy M, Jarvis A, Ramirez J, Portilla EP, Schepp K, Eitzinger A (2011) Predicted impact of climate change on coffee supply chains. In: Leal Filho W (ed) The economic, social and political elements of climate change. Springer, Berlin, pp 703–723

Langerwisch F, Rost S, Gerten D, Poulter B, Rammig A, Cramer W (2013) Potential effects of climate change on inundation patterns in the Amazon Basin. Hydrol Earth Syst Sci 17:2247–2262. doi:10.5194/hess-17-2247-2013

Lapola DM, Schaldach R, Alcamo J, Bondeau A, Msangi S, Priess JA, Silvestrini R, Soares-Filho BS (2011) Impacts of climate change and the end of deforestation on land use in the Brazilian Legal Amazon. Earth Interact 15:1–29. doi:10.1175/2010EI333.1

Lawler JJ, Shafer SL, White D, Kareiva P, Maurer EP, Blaustein AR, Bartlein PJ (2009) Projected climate-induced faunal change in the Western Hemisphere. Ecology 90:588–597

Lemes P, Melo AS, Loyola RD (2014) Climate change threatens protected areas of the Atlantic Forest. Biodivers Conserv 23:357–368. doi:10.1007/s10531-013-0605-2

Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S, Schellnhuber HJ (2008) Tipping elements in the Earth's climate system. Proc Natl Acad Sci 105:1786–1793

Lewis SL, Brando PM, Phillips OL, van der Heijden GMF, Nepstad D (2011) The 2010 Amazon drought. Science 331:554. doi:10.1126/science.1200807

Li J, Lin X, Chen A, Peterson T, Ma K, Bertzky M, Ciais P, Kapos V, Peng C, Poulter B (2013) Global priority conservation areas in the face of 21st century climate change. PLoS ONE 8:e54839. doi:10.1371/journal.pone.0054839

Lopez P, Chevallier P, Favier V, Pouyaud B, Ordenes F, Oerlemans J (2010) A regional view of fluctuations in glacier length in southern South America. Glob Planet Change 71:85–108. doi:10.1016/j.gloplacha.2009.12.009

Loyola RD, Lemes P, Faleiro FV, Trindade-Filho J, Machado RB (2012) Severe loss of suitable climatic conditions for marsupial species in Brazil: challenges and opportunities for conservation. PLoS ONE 7:e46257. doi:10.1371/journal.pone.0046257

Loyola RD, Lemes P, Nabout JC, Trindade-Filho J, Sagnori MD, Dobrovolski R, Diniz-Filho JAF (2013) A straightforward conceptual approach for evaluating spatial conservation priorities under climate change. Biodivers Conserv 22:483–495. doi:10.1007/s10531-012-0424-x

Luck J, Spackman M, Freeman A, Trebicki P, Griffiths W, Finlay K, Chakraborty S (2011) Climate change and diseases of food crops. Plant Pathol 60:113–121. doi:10.1111/j.1365-3059.2010.02414.x

Magrin G, Gay García C, Cruz Choque D, Giménez JC, Moreno AR, Nagy GJ, Nobre C, Villamizar A (2007) Chapter 10—Latin America. In: Parry ML, Canziano OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. IPCC AR4 WGII, Cambridge University Press, Cambridge, UK, pp 581–685

Magrin G, Marengo J, Boulanger J-P, Buckeridge MS, Castellanos E, Poveda G, Scarano F, Vicuña S (2014) Central and South America. In: Girardin LO, Ometto JP (eds) Climate change 2014: impacts, adaptation, and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Regional aspects. Chapter 27.

Final draft. IPCC AR5 WGII, Cambridge University Press, Cambridge UK, pp 1–102

Malhi Y, Wood D, Baker TR, Wright J, Phillips OL, Cochrane T, Meir P, Chave J, Almeida S, Arroyo L, Higuchi N, Killeen TJ, Laurance SG, Laurance WF, Lewis SL, Monteagudo A, Neill DA, Vargas PN, Pitman NCA, Quesada CA, Salomao R, Silva JNM, Lezama AT, Terborgh J, Martinez RV, Vinceti B (2006) The regional variation of aboveground live biomass in old-growth Amazonian forests. Glob Chang Biol 12:1107–1138. doi:10.1111/j.1365-2486.2006.01120.x

Mallard MS, Lackmann GM, Aiyyer A, Hill K (2013) Atlantic Hurricanes and climate change. Part I: experimental design and isolation of thermodynamic effects. J Clim 26:4876–4893. doi:10.1175/JCLI-D-12-00182.1

Marengo JA, Jones R, Alves LM, Valverde MC (2009) Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. Int J Climatol. doi:10.1002/joc

Marin FR, Jones JW, Singels A, Royce F, Assad ED, Pellegrino GQ, Justino F (2012) Climate change impacts on sugarcane attainable yield in southern Brazil. Clim Change 117:227–239. doi:10.1007/s10584-012-0561-y

Marini MA, Barbet-Massin M, Lopes LE, Jiguet F (2009) Predicted climate-driven bird distribution changes and forecasted conservation conflicts in a neotropical savanna. Conserv Biol J Soc Conserv Biol 23:1558–1567. doi:10.1111/j.1523-1739.2009.01258.x

Martinez-Sanchez J, Cavazos T (2014) Eastern Tropical Pacific hurricane variability and landfalls on Mexican coasts. Clim Res 58:221–234. doi:10.3354/cr01192

Marzeion B, Jarosch AH, Hofer M (2012) Past and future sea-level change from the surface mass balance of glaciers. Cryosph 6:1295–1322. doi:10.5194/tc-6-1295-2012

Masiokas MH, Villalba R, Luckman BH, Le Quesne C, Aravena JC (2006) Snowpack variations in the central Andes of Argentina and Chile, 1951–2005: large-scale atmospheric influences and implications for water resources in the region. J Clim 19:6334–6352

Masiokas MH, Villalba R, Christie DA, Betman E, Luckman BH, Le Quesne C, Prieto MR, Mauget S (2012) Snowpack variations since AD 1150 in the Andes of Chile and Argentina (30°–37°S) inferred from rainfall, tree-ring and documentary records. J Geophys Res 117:D05112. doi:10.1029/2011JD016748

Masiokas MH, Villalba R, Luckman BH, Montaña E, Betman E, Christie C, Le Quesne C, Mauget S (2013) Recent and historic Andean snowpack and streamflow variations and vulnerability to water shortages in Central-Western Argentina. Climate vulnerability: understanding and addressing threats to essential resources. Elsevier Inc., Academic press, Oxford, pp 213–227

Mata LJ, Campos M, Basso E, Compagnucci R, Fearnside P, Magrin G, Marengo J, Moreno AR, Suárez A, Solman S, Villamizar A, Villers L (2001) Latin America. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Working group II: impacts, adaptation and vulnerability, intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 694–734

Maurer EP, Adam JC, Wood AW (2009) Climate model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America. Hydrol Earth Syst Sci 13:183–194

Maynard-Ford BMC, Phillips EC, Chirico PG, Survey USG (2008) Mapping Vulnerability to disasters in Latin America and the Caribbean, 1900–2007. U.S. Geological Survey, Reston

McGranahan G, Balk D, Anderson B (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environ Urban 19:17–37. doi:10.1177/0956247807076960

MEA (2005) Millenium ecosystem assessment. Ecosystems and human well-being: synthesis. Island Press, Washington, DC

Meissner KJ, Lippmann T, Sen Gupta A (2012) Large-scale stress factors affecting coral reefs: open ocean sea surface temperature and surface seawater aragonite saturation over the next 400 years. Coral Reefs 31:309–319

Mendelsohn R, Emanuel K, Chonabayashi S, Bakkensem L (2011) The impact of climate change on global tropical storm damages. Nat Clim Chang 2:205–209

Menéndez Á, Berbery EH (2005) Hydrological trends. In: Barros V, Clarke R, Silva Días P (eds) Climate change in the La Plata Basin: raising awareness and new tools for water management. Project SGP II 057, Inter American Institute for Global Change Research (IAI), Montevideo, Uruguay, pp 74–86

Merrifield MA, Maltrud ME (2011) Regional sea level trends due to a Pacific trade wind intensification. Geophys Res Lett 38:L21605. doi:10.1029/2011GL049576

Mesquita PCMD, Pinheiro-Mesquita SF, Pietczak C (2013) Are common species endangered by climate change? Habitat suitability projections for the royal ground snake, Liophis reginae (Serpentes, Dipsadidae). North West J Zool 9:51–56

Mika J (2013) Changes in weather and climate extremes: phenomenology and empirical approaches. Clim Change 121:15–26. doi:10.1007/s10584-013-0914-1

Milly PCD, Dunne KA, Vecchia AV (2005) Global pattern of trends in streamflow and water availability in a changing climate. Nature 438:347–350. doi:10.1038/nature04312

Mimura N, Nurs L, McLean R, Agard J, Briguglio L, Lefale P, Payet R, Sem G (2007) Small islands. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. IPCC AR4 WGII, Cambridge University Press, Cambridge, pp 687–71

Montenegro A, Ragab R (2010) Hydrological response of a Brazilian semi-arid catchment to different land use and climate change scenarios: a modelling study. Hydrol Process 24:2705–2723. doi:10.1002/hyp.7825

Mora C, Frazier AG, Longman RJ, Dacks RS, Walton MM, Tong EJ, Sanchez JJ, Kaiser LR, Stender YO, Anderson JM, Ambrosino CM, Fernandez-Silva I, Giuseffi LM, Giambelluca TW (2013a) The projected timing of climate departure from recent variability. Nature 502:183–187. doi:10.1038/nature12540

Mora DE, Campozano L, Cisneros F, Wyseure G, Willems P (2013b) Climate changes of hydrometeorological and hydrological extremes in the Paute basin, Ecuadorean Andes. Hydrol Earth Syst Sci Discuss 10:6445–6471. doi:10.5194/hessd-10-6445-2013

Moreno AR (2006) Climate change and human health in Latin America: drivers, effects, and policies. Reg Environ Chang 6:157–164

Moser C, Norton A, Stein A, Georgieva S (2010). Pro-poor adaptation to climate change in Urban centers: case studies of vulnerability and resilience in Kenya and Nicaragua. World Bank, Washington DC. Retrieved from http://siteresources.worldbank.org/EXTSOCIALDEVELOPMENT/Resources/244362-1232059926563/5747581-1239131985528/ESW_propoorurbanadaptationReport4947GLBweb2.pdf

Murakami H, Mizuta R, Shindo E (2011) Future changes in tropical cyclone activity projected by multi-physics and multi-SST ensemble experiments using the 60-km-mesh MRI-AGCM. Clim Dyn 39:2569–2584. doi:10.1007/s00382-011-1223-x

Murakami H, Wang Y, Yoshimura H, Mizuta R, Sugi M, Shindo E, Adachi Y, Yukimoto S, Hosaka M, Kusunoki S, Ose T, Kitoh A (2012) Future changes in tropical cyclone activity projected by the new high-resolution MRI-AGCM. J Clim 25:3237–3260. doi:10.1175/JCLI-D-11-00415.1

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GA, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858. doi:10.1038/35002501

Nakaegawa T, Kitoh A, Hosaka M (2013) Discharge of major global rivers in the late 21st century climate projected with the high horizontal resolution MRI-AGCMs. Hydrol Process 27:3301–3318. doi:10.1002/hyp.9831

Nepstad DC, Tohver IM, Ray D, Moutinho P, Cardinot G (2007) Mortality of large trees and lianas following experimental drought in an Amazon forest. Ecology 88:2259–2269

Nóbrega MT, Collischonn W, Tucci CEM, Paz AR (2011) Uncertainty in climate change impacts on water resources in the Rio Grande Basin, Brazil. Hydrol Earth Syst Sci 15:585–595. doi:10.5194/hess-15-585-2011

Nurse LA, McLean RF, Agard J, Briguglio LP, Duvat-Magnan V, Pelesikoti N, Tompkins E, Webb A (2014) Small islands. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds). Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1613–1654

Olson DM, Dinerstein E (2002) The global 200: priority ecoregions for global conservation. Ann Missouri Bot Gard 89:199–224. doi:10.2307/3298564

Orlowsky B, Seneviratne SI (2013) Elusive drought: uncertainty in observed trends and short- and long-term CMIP5 projections. Hydrol Earth Syst Sci 17:1765–1781. doi:10.5194/hess-17-1765-2013

Pardaens AK, Gregory JM, Lowe JA (2011) A model study of factors influencing projected changes in regional sea level over the twenty-first century. Clim Dyn 36:2015–2033. doi:10.1007/s00382-009-0738-x

Parry M (2010) Copenhagen number crunch. Nat Rep Clim Chang 4:18–19. doi:10.1038/climate.2010.01

Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. Science 308:1912–1915. doi:10.1126/science.1111322

Phillips OL, Aragão LEOC, Lewis SL, Fisher JB, Lloyd J, López-González G, Malhi Y, Monteagudo A, Peacock J, Quesada CA, van der Heijden G, Almeida S, Amaral I, Arroyo L, Aymard G, Baker TR, Bánki O, Blanc L, Bonal D, Brando P, Chave J, de Oliveira ACA, Cardozo ND, Czimczik CI, Feldpausch TR, Freitas MA, Gloor E, Higuchi N, Jiménez E, Lloyd G, Meir P, Mendoza C, Morel A, Neill DA, Nepstad D, Patiño S, Peñuela MC, Prieto A, Ramírez F, Schwarz M, Silva J, Silveira M, Thomas AS, Ter Steege H, Stropp J, Vásquez R, Zelazowski P, Alvarez Dávila E, Andelman S, Andrade A, Chao K-J, Erwin T, Di Fiore A, Honorio CE, Keeling H, Killeen TJ, Laurance WF, Peña Cruz A, Pitman NCA, Núñez Vargas P, Ramírez-Angulo H, Rudas A, Salamão R, Silva N, Terborgh J, Torres-Lezama A (2009) Drought sensitivity of the Amazon rainforest. Science 323:1344–1347. doi:10.1126/science.1164033

Popescu I, Brandimarte L, Peviani M (2014) Effects of climate change over energy production in La Plata Basin. Int J River Basin Manag. doi:10.1080/15715124.2014.917317

Porter JR, Liyong X, Challinor A, Cochrane K, Howden M, Iqbal MM, Lobell D, Travasso MI (2014) Chapter 7: food security and food production systems. IPCC 2014: climate change 2014: impacts, adaptation, and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Final draft. IPCC AR5 WGII, Cambridge University Press, Cambridge, pp 1–82

Portmann FT, Döll P, Eisner S, Flörke M (2013) Impact of climate change on renewable groundwater resources: assessing the benefits of avoided greenhouse gas emissions using selected CMIP5 climate projections. Environ Res Lett 8:1–14. doi:10.1088/1748-9326/8/2/024023

Pörtner H-O, Karl D, Boyd PW, Cheung W, Lluch-Cota SE, Nojiri Y, Schmidt D, Zavialov P (2014) Ocean systems. In: Drinkwater K, Polonsky A (eds) Climate change 2014: impacts, adaptation and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Chapter 6. Final draft. IPCC AR5 WGII, Cambridge University Press, Cambridge, pp 1–100

Poulter B, Aragão L, Heyder U, Gumpenberger M, Heinke J, Langerwisch F, Rammig A, Thonicke K, Cramer W (2010) Net biome production of the Amazon Basin in the 21st century. Glob Chang Biol 16:2062–2075. doi:10.1111/j.1365-2486.2009.02064.x

Poveda G, Pineda K (2010) Advances in geosciences reassessment of Colombia's tropical glaciers retreat rates: are they bound to disappear during the 2010–2020 decade? Adv Geosci 22:107–116

Poveda G, Jaramillo A, Gil MM, Quiceno N, Mantilla RI (2001) Seasonality in ENSO-related precipitation, river discharges, soil moisture, and vegetation index in Colombia. Water Resour Res 37:2169–2178

Power S, Delage F, Chung C, Kociuba G, Keay K (2013) Robust twenty-first-century projections of El Niño and related precipitation variability. Nature 502:541–545. doi:10.1038/nature12580

Prudhomme C, Giuntoli I, Robinson EL, Clark DB, Arnell NW, Dankers R, Fekete BM, Franssen W, Gerten D, Gosling SN, Hagemann S, Hannah DM, Kim H, Masaki Y, Satoh Y, Stacke T, Wada Y, Wisser D (2013) Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. Proc Natl Acad Sci. doi:10.1073/pnas.1222473110

Rabatel A, Francou B, Soruco A, Gomez J, Cáceres B, Ceballos JL, Basantes R, Vuille M, Sicart J-E, Huggel C, Scheel M, Lejeune Y, Arnaud Y, Collet M, Condom T, Consoli G, Favier V, Jomelli V, Galarraga R, Ginot P, Maisincho L, Mendoza J, Ménégoz M, Ramirez E, Ribstein P, Suarez W, Villacis M, Wagnon P (2013) Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. Cryosph 7:81–102. doi:10.5194/tc-7-81-2013

Radić V, Bliss A, Beedlow AC, Hock R, Miles E, Cogley JG (2013) Regional and global projections of twenty-first century glacier mass changes in response to climate scenarios from global climate models. Clim Dyn 142:37–58. doi:10.1007/s00382-013-1719-7

Rammig A, Jupp T, Thonicke K, Tietjen B, Heinke J, Ostberg S, Lucht W, Cramer W, Cox P (2010) Estimating the risk of Amazonian forest dieback. New Phytol 187:694–706. doi:10.1111/j.1469-8137.2010.03318.x

RIMISP (2011) Poverty and inequality: Latin American report. Latin American Center for Rural Development (RIMISP), Santiago

Romero-Lankao P, Smith JB, Davidson DJ, Diffenbaugh NS, Kinney PL, Kirshen P, Kovacs P, Villers Ruiz L (2014) North America. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1439–1498

Rosenzweig C, Jones JW, Hatfield JL, Ruane AC, Boote KJ, Thorburn P, Antle JM, Nelson GC, Porter C, Janssen S, Asseng S, Basso B, Ewert F, Wallach D, Baigorria G, Winter JM (2013) The agricultural model intercomparison and improvement project (AgMIP): protocols and pilot studies. Agric For Meteorol 170:166–182

Saatchi SS, Harris NL, Brown S, Lefsky M, Mitchard ETA, Salas W, Zutta BR, Buermann W, Lewis SL, Hagen S, Petrova S, White L, Silman M, Morel A (2011) Benchmark map of forest carbon stocks in tropical regions across three continents. Proc Natl Acad Sci USA 108:9899–9904. doi:10.1073/pnas.1019576108

Sale PF, Butler MJ IV, Hooten AJ, Kritzer JP, Lindeman KC, Sadovy de Mitcheson YJ, Steneck RS, van Lavieren H (2008) Stemming decline of the coastal ocean: rethinking environmental management. UNU-UNWEH, Hamilton

Sampaio G, Nobre C, Costa MH, Satyamurty P, Soares-Filho BS, Cardoso M (2007) Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys Res Lett 34:L17709. doi:10.1029/2007GL030612

Schaefer M, Machguth H, Falvey M, Casassa G (2013) Modeling past and future surface mass balance of the Northern Patagonia Icefield. J Geophys Res Earth Surf 118:571–588. doi:10.1002/jgrf.20038

Schellnhuber HJ, Reyer C, Hare B, Waha K, Otto IM, Serdeczny O, Schaeffer M, Schleußner C-F, Reckien D, Marcus R, Kit O, Eden A, Adams S, Aich V, Albrecht T, Baarsch F, Boit A, Canales Trujillo N, Cartsburg M, Coumou D, Fader M, Hoff H, Jobbins G, Jones L, Krummenauer L, Langerwisch F, Le Masson V, Ludi E, Mengel M, Möhring J, Mosello B, Norton A, Perette M, Pereznieto P, Rammig A, Reinhardt J, Robinson A, Rocha M, Sakschewski B, Schaphoff S, Schewe J, Stagl J, Thonicke K (2014) Turn down the heat: confronting the new climate normal. The World Bank, Washington, DC

Schewe J, Heinke J, Gerten D, Haddeland I, Arnell NW, Clark DB, Dankers R, Eisner S, Fekete B, Colón-González FJ, Gosling SN, Kim H, Liu X, Masaki Y, Portmann FT, Satoh Y, Stacke T, Tang Q, Wada Y, Wisser D, Albrecht T, Frieler K, Piontek F, Warszawski L, Kabat P (2013) Multi-model assessment of water scarcity under climate change. Proc Natl Acad Sci USA 104:1–6. doi:10.1073/pnas.0709640104

Schloss CA, Nunez TA, Lawler JJ (2012) Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. Proc Natl Acad Sci 109:8606–8611. doi:10.1073/pnas.1116791109

Seo SN, McCarl BA, Mendelsohn R (2010) From beef cattle to sheep under global warming? An analysis of adaptation by livestock species choice in South America. Ecol Econ 69:2486–2494. doi:10.1016/j.ecolecon.2010.07.025

Seoane R, López P (2007) Assessing the effects of climate change on the hydrological regime of the Limay River basin. GeoJournal 70:251–256. doi:10.1007/s10708-008-9138-8

Sieber J (2013) Impacts of, and adaptation options to, extreme weather events and climate change concerning thermal power plants. Clim Change 121:55–66. doi:10.1007/s10584-013-0915-0

Sillmann J, Kharin VV, Zhang X, Zwiers FW, Bronaugh D (2013a) Climate extremes indices in the CMIP5 multimodel ensemble: part 1. Model evaluation in the present climate. J Geophys Res Atmos 118:1716–1733. doi:10.1002/jgrd.50203

Sillmann J, Kharin VV, Zhang X, Zwiers FW, Bronaugh D (2013b) Climate extremes indices in the CMIP5 multimodel ensemble: part 2. Future climate projections. J Geophys Res Atmos 118:2473–2493. doi:10.1002/jgrd.50188

Silvestrini RA, Soares-Filho BS, Nepstad D, Coe M, Rodrigues H, Assunção R (2011) Simulating fire regimes in the Amazon in response to climate change and deforestation. Ecol Appl Publ Ecol Soc Am 21:1573–1590

Simon LM, Oliveira G, Barreto BS, Nabout JC, Rangel TFLVB, Diniz-Filho JAF (2013) Effects of global climate changes on geographical distribution patterns of economically important plant species in Cerrado. Viçosa-MG 37:267–274

Simpson M, Scott D, Trotz U (2011) Climate change's impact on the Caribbean's ability to sustain tourism, natural assets, and livelihoods. Inter-American Development Bank, Washington, DC

Sinervo B, Méndez-de-la-Cruz F, Miles DB, Heulin B, Bastiaans E, Villagrán-Santa Cruz M, Lara-Resendiz R, Martínez-Méndez N, Calderón-Espinosa ML, Meza-Lázaro RN, Gadsden H, Avila LJ, Morando M, De la Riva IJ, Victoriano Sepulveda P, Rocha CFD, Ibargüengoytía N, Aguilar Puntriano C, Massot M, Lepetz V, Oksanen TA, Chapple DG, Bauer AM, Branch WR, Clobert J, Sites JW (2010) Erosion of lizard diversity by climate change and altered thermal niches. Science 328:894–899. doi:10.1126/science.1184695

Siraj AS, Santos-Vega M, Bouma MJ, Yadeta D, Carrascal DR, Pascual M (2014) Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. Science 343:1154–1158

Skansi MDLM, Brunet M, Sigró J, Aguilar E, Arevalo Groening JA, Bentancur OJ, Castellón Geier YR, Correa Amaya RL, Jácome H, Malheiros Ramos A, Oria Rojas C, Pasten AM, Sallons Mitro S, Villaroel Jiménez C, Martínez R, Alexander LV, Jones PD (2013) Warming and wetting signals emerging from analysis of changes in climate extreme indices over South America. Glob Planet Change 100:295–307. doi:10.1016/j.gloplacha.2012.11.004

Soares-Filho B, Silvestrini R, Nepstad D, Brando P, Rodrigues H, Alencar A, Coe M, Locks C, Lima L, Hissa L, Stickler C (2012) Forest fragmentation, climate change and understory fire regimes on the Amazonian landscapes of the Xingu headwaters. Landsc Ecol 27:585–598. doi:10.1007/s10980-012-9723-6

Souza TV, Lorini ML, Alves MAS, Cordeiro P, Vale MM (2011) Redistribution of threatened and endemic atlantic forest birds under climate change. Nat Conserv 9:214–218. doi:10.4322/natcon.2011.028

Stocker TF, Qin D, Plattner G-K, Alexander LV, Allen SK, Bindoff NL, Bréon F-M, Church JA, Cubasch U, Emori S, Forster P, Friedlingstein P, Gillett N, Gregory JM, Hartmann DL, Jansen E, Kirtman B, Knutti R, Kumar KK, Lemke P, Marotzke J, Masson-Delmotte V, Meehl GA, Mokhov II, Piao S, Ramaswamy V, Randall D, Rhein M, Rojas M, Sabine C, Shindell D, Talley LD, Vaughan DG, Xie S-P (2013) Technical summary. Climate change 2013: physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge, UK

Strobl E (2012) The economic growth impact of natural disasters in developing countries: evidence from hurricane strikes in the Central American and Caribbean regions. J Dev Econ 97:130–141. doi:10.1016/j.jdeveco.2010.12.002

Teixeira MG, Costa CNM, Barreto F F, Barreto ML (2009) Dengue: twenty-five years since remeergence in Brazil. Cad Saúde Pública 35:S7–S18

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, De Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, Van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145–148. doi:10.1038/nature02121

Timmermann A, McGregor S, Jin F-F (2010) Wind effects on past and future regional sea level trends in the Southern Indo-Pacific. J Clim 23:4429–4437. doi:10.1175/2010JCLI3519.1

Torres R, Pablo Jayat J, Pacheco S (2012) Modelling potential impacts of climate change on the bioclimatic envelope and conservation of the Maned Wolf (*Chrysocyon brachyurus*). Mamm Biol - Zeitschrift für Säugetierkd 78:41–49. doi:10.1016/j.mambio.2012.04.008

Tory KJ, Chand SS, McBride JL, Ye H, Dare RA (2013) Projected changes in late-twenty-first-century tropical cyclone frequency in 13 coupled climate models from phase 5 of the coupled model intercomparison project. J Clim 26:9946–9959. doi:10.1175/JCLI-D-13-00010.1

Trab Nielsen S (2010) Coastal livelihoods and climate change. In: Verner D (ed) Reducing poverty, protectinglivelihoods, and building assets in a changing climate social implications of climate change for Latin America and the Caribbean. The World Bank, Washington, DC, pp 123–166

Trenberth K, Dai A, Van Der Schrier G, Jones PD, Barichivich J, Briffa KR, Sheffield J (2014) Global warming and changes in drought. Nat Clim Chang 4:3–8. doi:10.1038/NCLIMATE2067

Van Hooidonk R, Maynard JA, Planes S (2013) Temporary refugia for coral reefs in a warming world. Nat Clim Chang 3:508–511. doi:10.1038/nclimate1829

Van Lieshout M, Kovats RS, Livermore MTJ, Martens P (2004) Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. Glob Environ Chang 14:87–99. doi:10.1016/j.gloenvcha.2003.10.009

Vergara W, Deeb A, Valencia A, Bradley R, Francou B, Zarzar A, Grünwaldt A, Haeussling SM (2007) Economic impacts of rapid glacier retreat in the Andes. EOS Trans Am Geophys Union 88:261–264

Vergara W, Toba N, Mira-Salama D, Deeb A (2009) Latin America and Caribbean region sustainable development working paper 32. Assessing the potential consequences of climate destabilization in Latin America. World Bank, Washington DC

Vicuña S, Gironás J, Meza FJ, Cruzat ML, Jelinek M, Bustos E, Poblete D, Bambach N (2013) Exploring possible connections between hydrological extreme events and climate change in central south Chile. Hydrol Sci J 58:1598–1619. doi:10.1080/02626667.2013.840380

Villarini G, Vecchi GA (2013) Projected increases in North Atlantic tropical cyclone intensity from CMIP5 models. J Clim 26:3231–3240. doi:10.1175/JCLI-D-12-00441.1

Viviroli D, Archer DR, Buytaert W, Fowler HJ, Greenwood GB, Hamlet AF, Huang Y, Koboltschnig G, Litaor MI, López-Moreno JI, Lorentz S, Schädler B, Schreier H, Schwaiger K, Vuille M, Woods R (2011) Climate change and mountain water resources: overview and recommendations for research, management and policy. Hydrol Earth Syst Sci 15:471–504. doi:10.5194/hess-15-471-2011

Vuille M, Francou B, Wagnon P, Juen I, Kaser G, Mark BG, Bradley RS (2008) Climate change and tropical Andean glaciers: past, present and future. Earth Sci Rev 89:79–96. doi:10.1016/j.earscirev.2008.04.002

Vuuren DP, Sala OE, Pereira HM (2006) The future of vascular plant diversity under four global scenarios. Ecol Soc 11:25

Wang R, Wu L (2013) Climate changes of Atlantic tropical cyclone formation derived from twentieth-century reanalysis. J Clim 26:8995–9005. doi:10.1175/JCLI-D-13-00056.1

Warszawski L, Friend A, Ostberg S, Frieler K, Lucht W, Schaphoff S, Beerling D, Cadule P, Ciais P, Clark DB, Kahana R, Ito A, Keribin R, Kleidon A, Lomas M, Nishina K, Pavlick R, Rademacher TT, Buechner M, Piontek F, Schewe J, Serdeczny O, Schellnhuber HJ (2013) A multi-model analysis of risk of ecosystem shifts under climate change. Environ Res Lett 8:044018. doi:10.1088/1748-9326/8/4/044018

Warszawski L, Frieler K, Huber V, Piontek F, Serdeczny O, Schewe J (2014) The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): project framework. Proc Natl Acad Sci USA 111:3228–3232. doi:10.1073/pnas.1312330110

Woodruff JD, Irish JL, Camargo SJ (2013) Coastal flooding by tropical cyclones and sea-level rise. Nature 504:44–52. doi:10.1038/nature12855

World Bank (2014a) Population dynamics. World Development Indicators. http://wdi.worldbank.org/table/2. Accessed 05 Jan 2014

World Bank (2014b) Structure of output. World Development Indicators. http://wdi.worldbank.org/table/4.2. Accessed 05 Jan 2014

World Bank (2014c) Size of the economy. World Development Indicators. http://wdi.worldbank.org/table/1.1. Accessed 05 Jan 2014

World Bank (2014d) Social gains in the balance—a fiscal policy challenge for Latin America and the Caribbean. LAC Poverty and Labor Brief (February), World Bank, Washington, DC. doi:10.1596/978-1-4648-0291-1. License: Creative Commons Attribution CC BY 3.0 IGO

Zemp DC, Schleussner C-F, Barbosa HMJ, van der Ent RJ, Donges JF, Heinke J, Sampaio G, Rammig A (2014) On the importance of cascading moisture recycling in South America. Atmos Chem Phys 14:13337–13359

Zullo J, Pinto HS, Assad ED, Ávila AMH (2011) Potential for growing Arabica coffee in the extreme south of Brazil in a warmer world. Clim Change 109:535–548. doi:10.1007/s10584-011-0058-0