

Future climate change projections for the Latin American region (from Mexico southwards)

Annex B. Technical Report Form

1. General Information:

Project Title	Future climate change projections for the Latin American region (from Mexico southwards)
CIAT's Leader	
Institution (Partner's Name)	National Institute for Space Research (INPE)
Name of Partner's Project Leader	Jose A. Marengo, Ph.D.
Duration (Start-End)	October 2012, ending in May 2013, extended until December 2013
Reporting Period	October 2012-December 2013
Budget	US \$ 65,625.12
Narrative Summary	<p>In this report we show the observed trends in climate and extremes in the central; America and tropical South America, using a variety of studies, as well as an assessments of climate change projections (mainly air temperature and rainfall) at seasonal levels, for the same regions, using the recent regional climate change scenarios derived from the downscaling of the HadGEM2 ES (IPCC AR5 model) using the ETA regional model from INPE, with a resolution of 20 km latitude-longitude up to 2100, for a RCP4.5 (intermediate emission of green house gases). While observations from 1951-2010 show strong increase in war nights and days in central, tropical and Southeastern South America, rainfall extremes tend to increase in southeastern South America as well as the western coast of South America, while central America shows an slight increase in consecutive dry days. Climate projections from the Eta-HadGEM2 ES model shows that during the austral summer rainfall is projected to decrease in southern Amazonia, and increases in the northern coast of Peru-Ecuador, while in boreal summer rainfall tends to decrease until 2100 in all Central America and southern Mexico. Projections of rainfall from the IPCC AR4 models shows increase in consecutive dry days and soils moisture in Eastern Amazonia and Northeast Brazil, while increases in soil moisture are</p>

	detected over Southeastern South America, as well as rainfall extreme increases in western Amazonia-Northwest Coast of Peru and Ecuador, and southeastern South America. Regarding temperature changes, the Eta-HadGEM2 ES shows increases of up to 2 C in Central America, and up to 4 C in southern Amazonia by 2100. Changes in temperature extremes from IPCC AR4 and AR5 model are consistent with this projected warming, with increase in warm days and nights, decrease in cold days and nights, and a longer dry season, especially in tropical South America and Central America.
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2. Research project highlights

This report shows the results of an study on trends in climate during the last 60 years or so, as well as future climate change projections for the Latin American region (from Mexico southwards) up to 2100, using the latest climate change projections from the global models from the IPCC AR5 (Intergovernmental Panel on Climate Change) archived at the CMIP5, and the IPCC AR4 models using in the IPCC Special report on extremes (IPP SREX 2012). We also show the results of the most recent experiences of downscaling at INPE using the Eta regional model nested in the HadGEM2-ES, an IPCC AR5 model from the UK/. High-resolution projections have been used on impacts and vulnerability studies in Brazil and South America, regarding impacts of climate change in biodiversity in Amazonia, agriculture, human health and migration, energy, tropical Andes and on the economy of climate change (Marengo et al 2012, Chou et al 2012).

For the observational part of this study, we used the results of observed trends in extremes from 1951-2010 from Donat et al (2013) and various other studies. For the modeling part we use the projections of extremes using the IPCC AR4 models for the IPCC SREX for the SRES Scenario, as well as the 22 global climate models of the IPCC AR5 WG2 models for two RCPs (Representative Concentration Pathways) emission scenarios developed for the to assess changes in wet and dry seasons, precipitation. The analyses are focused on the medium (2040's) and long term (2070's). At then end, we use the of rain fall and temperatures projected changes using the results of the downscaling of the HadGEM2 ES model from UK using the Eta regional model from INPE, run at a resolution of 20 km.

The focus of this report, according to the needs of CIAT-CCAFS covers:

- a) An outline of current trends in climate and extreme events (mainly temperature and precipitation) from the beginning of the twentieth century onwards based on observations and previously published studies.
- b) An evaluation of 22 CMIP5 coupled climate models' climatology for the region, and assessment of their projections up to the end of the XX Century. Focus will be on temperature and precipitation that are robust indicators of conditions that are related to agricultural production impacts and food security considerations, possibly with regard to crop tolerances and thresholds. These might include changes in wet and dry seasons, precipitation, maximum and minimum temperatures, frequency of dry spells, and threshold temperature exceedance, for

example (some of these diagnostics may already be in the literature). The evaluation should include some interpretation of the state of knowledge about mechanisms of change (particularly for rainfall and temperature), including attention to competing mechanisms that tend to have opposite effects, and some treatment of the uncertainty of the projected impacts at relevant time scales. Indications of areas of considerable disagreement between models at the regional level would be very helpful (e.g. projected changes in the amplitude of future El Niño events).

- c) A brief indication of how the science of climate modeling may develop in the next five years that could increase knowledge of changes in climate and climate variability in LAC in the decades leading up to the middle of the century. Of particular interest would be aspects that are salient for agriculture, such as spatial scale and higher-order statistics of rainfall that impact crops, as well as possible advances in process-based understanding, climate model diagnostics, and empirical methods that may be useful for both detecting ongoing change and quantifying uncertainty.

For objective (a), since we do not have access to meteorological data from each of the region's country, we plan to do a comprehensive analyses of trends of extremes available in published literature, particularly the latest Summary for Policy Makers of the IPCC AR5 WG1 (IPCC 2013), the IPCC Special Report on Managing the Risks of Extreme Event and Disasters to advance Climate Change Adaptation (SREX) published in 2012 (IPCC SREX 2012), as well as the extensive literature reviewed on it on extremes. The analyses will be made for the 5 regions considered on the IPCC SREX: Central America-Mexico, West Coast of South America, Amazon, Northeast Brazil and Southeastern South America. Based on this review, we prepare summary maps to identify the observed trends and changes on extremes and the levels of confidence of those changes in the regions during the last 50 to 60 years.

On the Objective (b), we show assessment of 22 CMIP5 models for the region and sub regions, for the medium and long-term horizons. The focus is on changes in precipitation, temperature, changes in dry and wet seasons, and surface wind circulation, in order to identify mechanisms responsible for changes in rainfall. In addition, we developed downscaling of the HadGEM2 ES (UK model that is part of CMIP5) for the region (south of 30 N, that includes most of Mexico) using the Eta Regional model used by INPE, to analyze projected changes in climate for the medium and long term horizons, and for the same variables listed above, but with a higher space resolution (20 km). For Objective (c), we can work on this, considering INPE's experience on model development.

3. Specific milestones achieved

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes. Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from climate-related disasters. Furthermore, the assessment indicates that in many regions of the world, socio-economic factors will be among the main drivers of future increases in related losses. Many countries in Latin America face severe challenges in coping with climate-related disasters (IPCC SREX 2012).

Vulnerability and exposure are dynamic and depend on economic, social, demographic, cultural, institutional, and governance factors. Individuals and communities are also differentially exposed based on factors such as wealth, education, gender, age, class/caste, and health. Lack of resilience and capacity to anticipate, cope with and adapt to extremes are important factors of vulnerability. For example, a tropical cyclone and hurricanes can have very different impacts depending on where and when it makes landfall. Similarly, heat waves, intense rainfall can have very different impacts on different population groups depending on their vulnerability and exposure, as well as their income and education levels. Extreme impacts on human, ecological, or physical systems can therefore result from individual extreme weather or climate events, from non-extreme events where exposure and vulnerability are high, or from a compounding of events or their impacts (flash floods, landslides).

High vulnerability and exposure are generally the outcome of skewed development processes, for example, environmental mismanagement, demographic change, rapid and unplanned urbanization, failed governance, and a scarcity of livelihood options. This can result in settlements in hazard prone areas, the creation of unsafe dwellings, slums and scattered districts, poverty and lack of awareness of risks. For example, those with awareness, transferable livelihoods, money and access to transport can move away from disaster and live more comfortably out of danger. Those without these assets may be forced to locate their homes in hazard prone areas where they are more vulnerable and exposed to climate extremes. They will also have to deal with the impacts of disaster on the ground, including no water, food, sanitation or shelter.

3.1 Observed tendencies

According to IPCC WG2 AR4-Chapter 13-Latin America (Magrin et al 2007), during the last decades of the 20th century, unusual extreme weather events have been severely affecting the Latin America region contributing greatly to the strengthening of the vulnerability of human systems to natural disasters. In addition, increases in precipitation were observed in Southeastern South America, northwest Peru and Ecuador; while decreases were registered in southern Chile, southwest Argentina, southern Peru and western Central America since 1960. Mean warming was near to 0.1°C/decade. The glacier-retreat trend has intensified, reaching critical conditions in the Andean countries.

As reported on *Chapter 3.4 of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation SREX* (IPCC SREX, 2012), a changing climate leads to changes in the frequency, intensity, spatial extent or duration of weather and climate extremes, and can result in unprecedented extremes. Levels of confidence in historical changes depend on the availability of high quality and homogeneous data, and relevant model projections. This has been a major problem in Central and South America, where a lack of long-term homogeneous and continuous climate and hydrological records, and of complete studies on trends have not allowed for an identification of trends in extremes, particularly in Central America. Recent observational show increases in warm days and decreases in cold days, as well as increases on warm nights and decreases in cold nights have been identified in Central America, Northern South America, Northeast Brazil, Southeastern South America and the west coast of South America. In Central America, there is *low confidence* that any observed

long-term increase in tropical cyclone activity is robust, after accounting for past changes in observing capabilities. In other regions, such as the Amazon region, *insufficient evidence*, inconsistencies among studies and detected trends result in *low confidence* of observed rainfall trends.

In Central and South America, decadal variability and changes in extremes have been affecting large sectors of the population, especially those more vulnerable and exposed to climate hazards. Since around 1950, in Central America and the North American Monsoon System (NAMS), rainfall has been starting increasingly later and has become more irregular in space and time, while rainfall has been increasing and the intensity of rainfall has been increasing during the onset season (see references in Table 27-1). Arias *et al.* (2012) relate those changes to decadal rainfall variations in NAMS. The West coast of South America experienced a prominent but localized coastal cooling of about 1 °C during the past 30-50 years extending from central Peru down to central Chile. This occurs in connection with an increased upwelling of coastal waters favored by the more intense trade winds (Falvey and Garreaud, 2009; Gutiérrez *et al.*, 2011a; Gutiérrez *et al.*, 2011b; Kosaka and Xie, 2013; Narayan *et al.*, 2010; Schulz *et al.*, 2012). In the extremely arid northern coast of Chile, rainfall, temperature and cloudiness show strong interannual and decadal variability, and since the mid-70s, the minimum daily temperature, cloudiness and precipitation have decreased. In central Chile, a negative precipitation trend was observed over the period 1935-1976, and an increase after 1976, while further south, the negative trend in rainfall that prevailed since the 1950s has intensified by the end of the 20th century (Quintana and Aceituno, 2012).

To the east of the Andes, Northeast Brazil exhibits large interannual rainfall variability, with a slight decrease since the 1970s (Marengo *et al.* 2013). Droughts in this region (e.g. 1983, 1987, 1998) have been associated with El Niño and/or a warmer Tropical North Atlantic Ocean. However, not all El Niño years result on drought in NEB, as the drought 2012-2013 occurred during La Niña (Marengo *et al.*, 2013). In the La Plata Basin in Southeastern South America, various studies have documented interannual and decadal scale circulation changes that have led to decreases in the frequency of cold nights in austral summer, as well as to increases in warm nights and minimum temperatures during the last 40 years. Simultaneously, a reduction in the number of dry months in the warm season is found since the mid-1970s, while heavy rain frequency is increasing in this region.

In the central Andes, in the Mantaro Valley (Peru), precipitation shows a strong negative trend, while warming is also detected (SENAMHI, 2007). In the southern Andes of Peru air temperatures have increased during 1964-2006, but no clear signal on precipitation changes has been detected (Marengo *et al.*, 2009). In the northern Andes (Colombia, Ecuador), changes in temperature and rainfall in 1961-90 have been identified by Villacís (2008). In the Patagonia region, Masiokas *et al.* (2008) have identified an increase of temperature together with precipitation reductions during 1912-2002. Vuille *et al.* (2008) found that climate in the tropical Andes has changed significantly over the past 50–60 years. Temperature in the Andes has increased by approximately 0.1 °C/ decade, with only two of the last 20 years being below the 1961–90 average. Precipitation has slightly increased in the second half of the 20th century in the inner tropics and decreased in the outer tropics. The general pattern of moistening in the inner tropics and drying in the subtropical Andes is dynamically consistent with observed changes in the large-scale circulation, suggesting a strengthening of the tropical atmospheric circulation.

Moreover, a positive significant trend in mean temperature of 0.09 °C per decade during 1965-2007 has been detected over the Peruvian Andes by Lavado *et al.* (2012).

For the Amazon basin, Marengo (2004) and Satyamurty *et al.* (2010) concluded that no systematic unidirectional long-term trends towards drier or wetter conditions in both the northern and southern Amazon have been identified since the 1920s. Rainfall fluctuations are more characterized by inter-annual scales linked to ENSO or decadal variability. Analyzing a narrower time period, Espinoza *et al.* (2009a; 2009b) found that mean rainfall in the Amazon basin for 1964–2003 has decreased, with stronger amplitude after 1982, especially in the Peruvian western Amazonia (Lavado *et al.*, 2012), consistent with reductions in convection and cloudiness in the same region (Arias *et al.*, 2012). Recent studies by Donat *et al.* (2013) suggest that heavy rains are increasing in frequency in Amazonia. Regarding seasonal extremes in the Amazon region, two major droughts and three floods have affected the region from 2005 to 2012, although these events have been related to natural climate variability rather than to deforestation (Espinoza *et al.*, 2011, 2012, 2013; Lewis *et al.*, 2011; Marengo *et al.*, 2008, 2012, 2013; Satyamurty *et al.*, 2013). On the impacts of land use changes on changes in the climate and hydrology of Amazonia, Zhang *et al.* (2009) suggest that biomass-burning aerosols can work against the seasonal monsoon circulation transition, thus re-inforce the dry season rainfall pattern for Southern Amazonia, while Wang *et al.* (2011) suggests the importance of deforestation and vegetation dynamics on decadal variability of rainfall in the region. Costa and Pires (2010) have suggested a possible decrease in precipitation due to soybean expansion in Amazonia, mainly as a consequence of its very high albedo. In the SAMS region, positive trends in rainfall extremes have been identified in the last 30 years with a pattern of increasing frequency and intensity of heavy rainfall events, and earlier onsets and late demise of the rainy season.

Figure 1 shows the observed trends in temperature extremes as derived by Donat *et al.* (2013) for 1951-2010. Besides the fact that there are regions without data coverage, the figures suggest an increase in the frequency of warm nights and in in less degree of warm days in Central and South America, being the changes more intense in Northern and Southeastern South America. On the other hand it is noticed a reduction in the frequency of cold days and in less degree in cold nights. This is consistent with the observed warming on those regions.

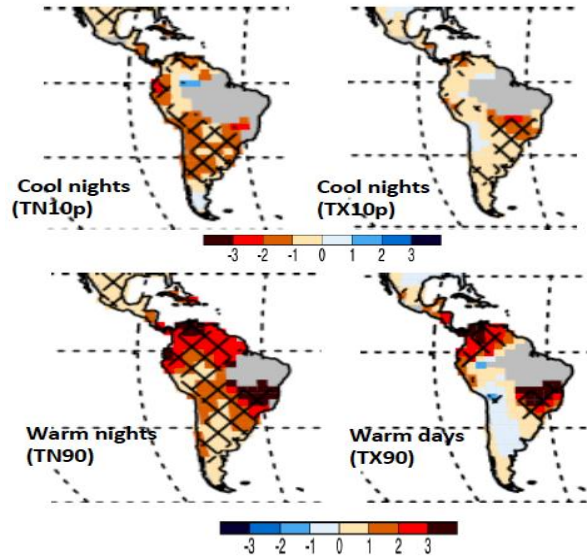


Figure 1. Trends (in annual days per decade) for annual series of percentile temperature indices for 1951– 2010: cool nights (TN10p), warm nights (TN90p), cool days (TX10p), and warm days (TX90p). Trends were calculated only for grid boxes with sufficient data (at least 66% of years having data during the period, and the last year of the series is no earlier than 2003). Hatching indicates regions where trends are significant at the 5% level. Note that for the global average time series only grid boxes with at least 90% of temporal coverage are used, i.e., 99 years during 1901– 2010. Color scale (days) is shown on the lower site of the upper (cool days and nights) and lower (warm days and nights) panels (Donat et al 2013).

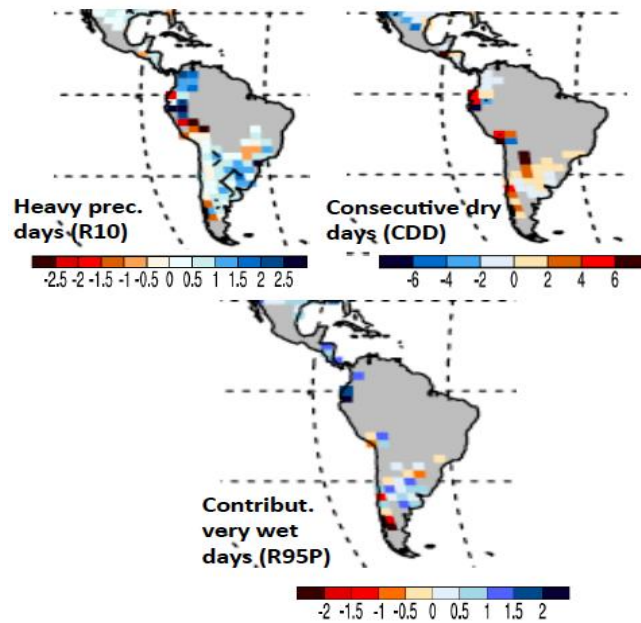


Figure 2. Decadal trends and global average time series for annual indices: Number of heavy precipitation days (R10) in days, contribution from very wet days (R95pTOT) in %, consecutive dry days (CDD) in days. Trend and time series calculations as described in Figure 1 (Donat et al 2013).

On rainfall extremes, Figure 2, the rainfall data coverage is less comprehensive than in the case of temperature. Donat et al (2013) show an increase in the frequency of rainfall extremes in Southeastern South America, as well as in the northern coast of Peru, Ecuador and Colombia and in Central America

from Honduras to Panama. With regard to dry spells (CDD), there is an increase in the frequency of dry spells in Southeastern South America and in the northern coast of Peru and Ecuador, suggesting that on those regions there has been observed a concentration of rainfall extremes in few days, with longer dry spells in between. This situation favours the possibility of floods and landslides triggered by intense rainfall extremes, as already observed in South and Central America, with longer warm and dry spells, that affect human health and agriculture, since those episodes are characterized by dry air and high maximum temperatures and low soil moisture, that are responsible for drought, increase risk of fires and biomass burning and impacts to the population in terms of allergies and respiratory diseases due to smoke.

3.2 Climate change projections: from IPCC AR4 to IPCC AR5

According to the IPCC AR4 (Magrin et al 2007), mean warming for Latin America at the end of 21st century could reach 1°C to 4°C (SRES B2) or 2°C to 6°C (SRES A2) (*medium confidence*) (2012-Ch13). Rainfall anomalies (positive or negative) will be larger for the tropical part of Latin America, as in the Amazon and Northeast Brazil region. The frequency and intensity of weather and climate extremes is *likely* to increase (*medium confidence*). For extremes the IPCC SREX (IPCC SREX 2012), projections for the end of the 21st century for differing emissions scenarios (SRES A2 and A1B) show that for all Central and South America, models project substantial warming in temperature extremes. It is *likely* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century on the global scale. With *medium confidence*, it is *very likely* that the length, frequency and/or intensity of heat waves will experience a large increase over most of SA, with weaker tendency towards increasing in Southeastern South America. With *low confidence*, the models also project an increase of the proportion of total rainfall from heavy falls for South America and the West coast of South America; while for Amazonia and the rest of South and Central there are not consistent signals of change. In some regions, there is *low confidence* in projections of changes in fluvial floods. Confidence is low due to limited evidence and because the causes of regional changes are complex. There is *medium confidence* that droughts will intensify along the 21st century in some seasons and areas due to reduced precipitation and/or increased evapotranspiration in Amazonia and NEB. There is still *low confidence* in changes on El Nino frequency and intensity and on changes in the intense and frequency of tropical storms and hurricanes in Central America.

Figures 3 and 4 show the projected changes in temperature and rainfall extremes for Central and South America, based on the IPCC AR4 models, for the SRES A1B Scenario, for 2081-2100 relative a 1980-1999. Figure 3 shows a pattern that is consistent with a general warming in the region: and increase in the fraction of warm days and nights and decrease in the fraction of cold days and nights. These changes are more intense in Northwestern and Southeastern South America. Increases in extreme rainfall are particularly strong in western Amazonia and the west coast of Peru and Ecuador and in Southeastern South America, while in Central America this is a slight tendency for reduction on the number of days with precipitation above 10 mm.

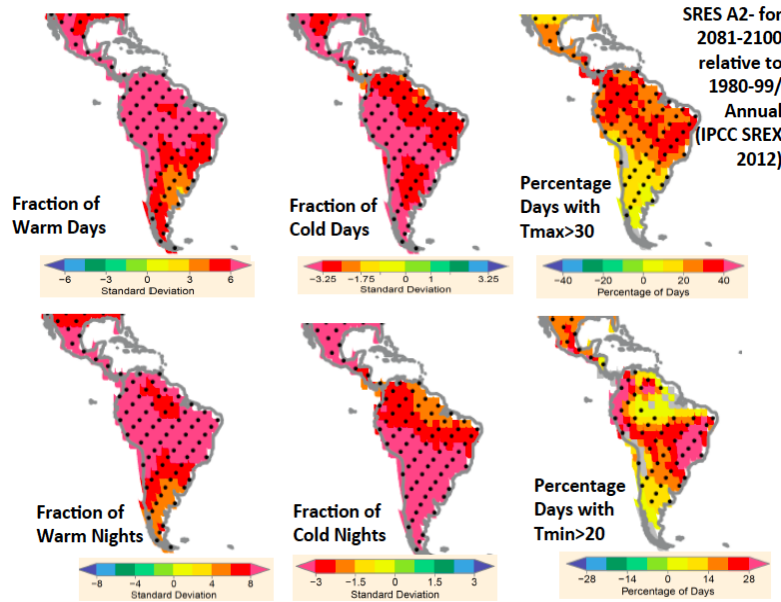


Figure 3. Projected annual changes in some indices for daily T_{min} for 2081-2100 with respect to 1980-1999, based on 14 GCMs contributing to the CMIP3: fraction of warm days (days in which T_{max} exceeds the 90th percentile of that day of the year, calculated from the 1961-1990 reference period); fraction of cold days (days in which T_{max} is lower than the 10th percentile of that day of the year, calculated from the 1961-1990 reference period); percentage of days with $T_{max} > 30^{\circ}\text{C}$; fraction of warm nights (days at which T_{min} exceeds the 90th percentile of that day of the year, calculated from the 1961-1990 reference period); fraction of cold nights (days at which T_{min} is lower than the 10th percentile of that day of the year, calculated from the 1961-1990 reference period); percentage of days with $T_{min} > 20^{\circ}\text{C}$. The changes are computed for the annual time scale, as the fractions/percentages in the 2081-2100 period (based on simulations under emission scenario SRES A2) minus the fractions/percentages of the 1980-1999 period (from corresponding simulations for the 20th century). Warm night and cold night changes are expressed in units of standard deviations, derived from detrended per year annual or seasonal estimates, respectively, from the three 20-year periods 1980-1999, 2046-2065, and 2081-2100 pooled together. $T_{min} > 20^{\circ}\text{C}$ changes are given directly as differences of percentage points. Color shading is only applied for areas where at least 66% (i.e., 10 out of 14) of the GCMs agree in the sign of the change; stippling is applied for regions where at least 90% (i.e., 13 out of 14) of the GCMs agree in the sign of the change.

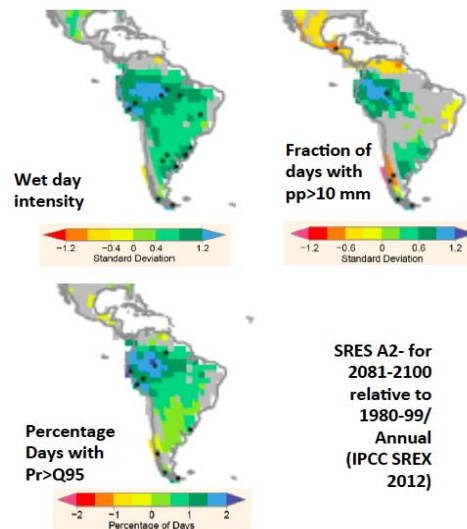


Figure 4. Projected annual and seasonal changes in three indices for daily precipitation for 2081-2100 with respect to 1980-1999, based on 17 GCMs contributing to the CMIP3: wet-day intensity, percentage of days with precipitation above the 95% quantile of daily wet day precipitation for that day of the year, calculated from the 1961-1990 reference period; right column: fraction of days with precipitation higher than 10 mm. The changes are computed for the annual time scale as the

fractions/percentages in the 2081-2100 period (based on simulations under emission scenario SRES A2) minus the fractions/percentages of the 1980-1999 period (from corresponding simulations for the 20th century). Changes in wet-day intensity and in the fraction of days with $Pr > 10$ mm are expressed in units of standard deviations, derived from detrended per year annual or seasonal estimates, respectively, from the 2081-2100 pooled together. Changes in percentages of days with precipitation above the 95% quantile are given directly as differences in percentage points. Color shading is only applied for areas where at least 66% (i.e., 12 out of 17) of the GCMs agree on the sign of the change; stippling is applied for regions where at least 90% (i.e., 16 out of 17) of the GCMs agree on the sign of the change (IPCC SREX 2012).

The intensity of dry spells and soil moisture availability for the mid (2041-65) and long (2081-2100) term shows for the SRES A2 scenario increase in the frequency and duration of dry spells in eastern Amazonia, Northeast Brazil, central and southern Chile and in central America in Mexico, while reductions are projected for the Northern Peru and Ecuador region, consistent with positive rainfall anomalies on those regions (Figure 5). This is perhaps better detected on the soil moisture anomaly maps, where negative anomalies are found over most of Tropical South America, particularly northern South America, Bolivia, Chile and Mexico, consistent with a possible reduction on the intensity and extension of the NAMS.

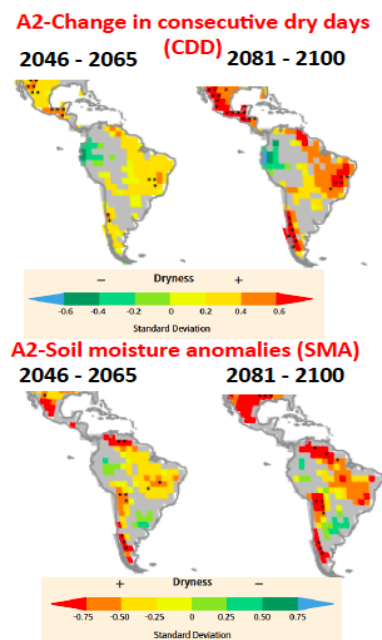


Figure 5. Projected annual changes in dryness assessed from two indices. Upper panels: Change in annual maximum number of consecutive dry days (CDD: days with precipitation < 1 mm); lower panel: Changes in soil moisture (soil moisture anomalies, SMA). Increased dryness is indicated with yellow to red colors; decreased dryness with green to blue. Projected changes are expressed in units of standard deviation of the interannual variability in the three 20-year periods 1980–1999, 2046–2065, and 2081–2100. The figures show changes for two time horizons, 2046–2065 and 2081–2100, as compared to late 20th-century values (1980–1999), based on GCM simulations under emissions scenario SRES A2 relative to corresponding simulations for the late 20th century. Results are based on 17 (CDD) and 15 (SMA) GCMs contributing to the CMIP3. Colored shading is applied for areas where at least 66% (12 out of 17 for CDD, 10 out of 15 for SMA) of the models agree on the sign of the change; stippling is added for regions where at least 90% (16 out of 17 for CDD, 14 out of 15 for SMA) of all models agree on the sign of the change. Grey shading indicates where there is insufficient model agreement (<66%). (IPCC SREX 2012)

Projections based on an ensemble of 22 models from CMIP5 (Figure 6) suggest air temperatures increases in the region, that can reach up to 1-2 C by 2100 on the RCP 2.6 (low emissions), and up to 5-6 C over tropical South America over the Amazon region and Central America, and with relatively lower

warming over Southeastern South America (2-4 C). On rainfall changes, significant increases are projected in southeastern South America and over the Northwest Coast of Peru and Ecuador. Rainfall reductions are projected over the central America-northern South America, eastern Amazonia and central and southern Chile, as well as over eastern North east Brazil. At seasonal scales, rainfall reductions during winter and spring in southern Amazonia may indicate a late onset of the rainy season on those regions and a longer dry season. The changes are more intense for the late 21-st century and for the RCP8.5.

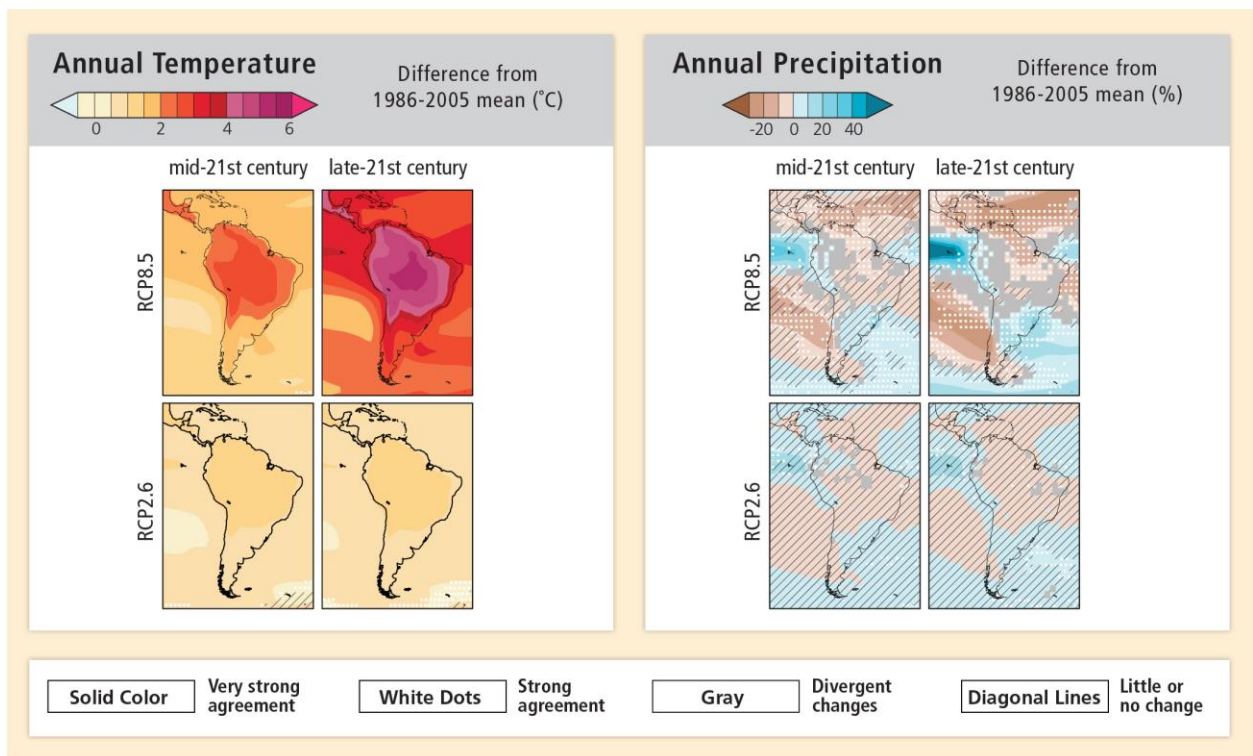


Figure 6. Projections of changes in mean annual air temperature (left) and rainfall (right) for mid- and late 21st century, for the RCP2.6 and 8.5 relative to 1986-2005, from the mean of 23 CMOP5 models. (Source: IPCC WG2 TSU, 2014)

3.3 Regional climate change projections derived from the Eta-HadGEM2 ES models

The models used to generate the high-resolution climate change scenarios are:

RCM: Eta Regional Model

Resolution: 20km latitude-longitude /38 layers.

Grid-point model: Arakawa E grid and Lorenz grid

Eta vertical coordinate: Mesinger, 1984; added refinements in Mesinger et al (2012)

Time integration: 2 level, split-explicit

Adjustmet: forward-backward

Horizontal Advection: first forward and then centered

Vertical Advection: Piecewise linear scheme

Prognostic variables: T, q, u, v, p_s, TKE, cloud water/ice, hydrometeors

Convection scheme: Betts-Miller-Janjic

Cloud scheme: Zhao scheme

Turbulence: Janjic 1994 (MY 2.5), Monin-Obhukov surface layer

Radiation: GFDL package

Land surface scheme: NOAH scheme, 4 soil layers,

LBC: HadGEM2-ES, updated 6h/6h

Initial soil moisture: monthly climatology

Initial albedo: seasonal climatology

CO2 RCP4.5

SST from HadGEM2-ES simulations

Global Model: HadGEM2-ES

The HadGEM2-ES is a coupled Earth System Model developed by the UK Met Office Hadley Centre. It was designed to run the major scenarios for IPCC AR5 and comprises Earth system components such as terrestrial and ocean carbon cycle and tropospheric chemistry.

- Atmospheric GCM - N96 and L38 horizontal and vertical resolution
- Ocean GCM with a 1-degree horizontal resolution (increasing to 1/3 degree at the equator) and 40 vertical levels.
- Earth system components:
 1. Terrestrial and ocean carbon cycle and tropospheric chemistry.
 2. Terrestrial vegetation and carbon is represented by the dynamic global vegetation model, TRIFFID.
 3. Ocean biology and carbonate chemistry are represented by diat-HadOCC
 4. Tropospheric chemistry is represented by the UKCA model

Mr. André Lyra and Mr. Dragan Latinovic did the coupling between the Eta and the HadGEM2 ES at INPE. The model produced almost 50 variables, whereas here we focus our analyses on rainfall and air temperature, at the annual and seasonal level: summer and winter.

3.3.1 Rainfall projections

Figure 7 shows rainfall projections from the Eta-HadGEM2 ES for the RCP4.5 scenario at annual, summer and winter seasons until 2100. At annual time scales, rainfall reductions are projected for Central America, southern and eastern Amazonia and the coast of Northern South America, while rainfall increases are projected for the equatorial Pacific region as well as over the northern coast of Peru and Ecuador. The changes are more intense by 2071-2100. In DJF, during austral summer, rainfall reductions are projected in southern and eastern Amazonia, Pantanal and on the northern coast of South America, particularly in 2041-70, and increases in the northwest coast Peru and Ecuador and on the northern coast of Northeast Brazil. In JJA, the boreal summer, large reductions of rainfall are projected for all of Central America and central-South of Mexico and on the Caribbean coast of South America.

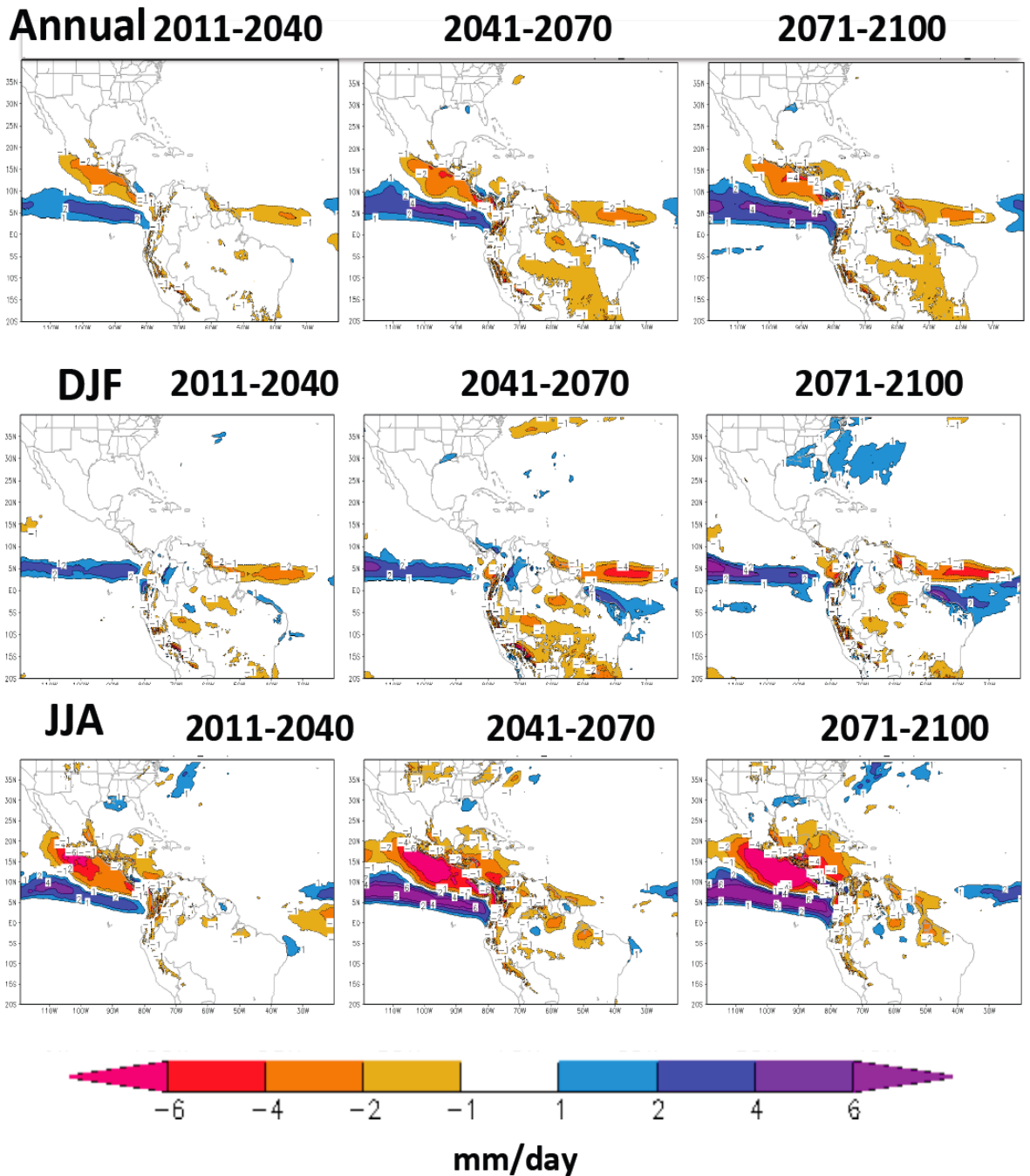


Figure 7. Changes in annual and seasonal rainfall anomaly (DJF and JJA) as projected by the Eta-HadGEM2 for Central and South America. Temperature anomalies are shown for the time slices 2010-40, 2041-70 and 2071-2100, relative to 1961-90. Color scale is shown on the lower side of the panel. Scale is mm/day.

Projections of air temperature (Figure 8), annual temperature changes in 2010-40 show increase of 2 C in southern Amazonia a small warming of 1C in all Central and South America. By 2041-70 the warming in southern Amazonia reached 3-4 C and 2 C in the rest of the region, and by 2071-2100 warming in tropical South America reaches about 3-4 C and between 2-3 C in Central America. The combination of higher temperatures and rainfall reductions in southern Amazonia and the South American monsoon

region may imply in increase water deficit on that regions. We have to remember that this region extremely important because of the soybean cultivation for agroindustry purposes, and the prospects of a longer dry season may have strong impacts on the regional economy, and in the long term on the GDP of the region and of Brazil. For Central America, the rainfall reduction may be related to a reduction on the number of hurricanes in the future, but the uncertainties of such scenario are high. What it can be said is that with lower confidence is a tendency for a weakening of the North American monsoon system in the future.

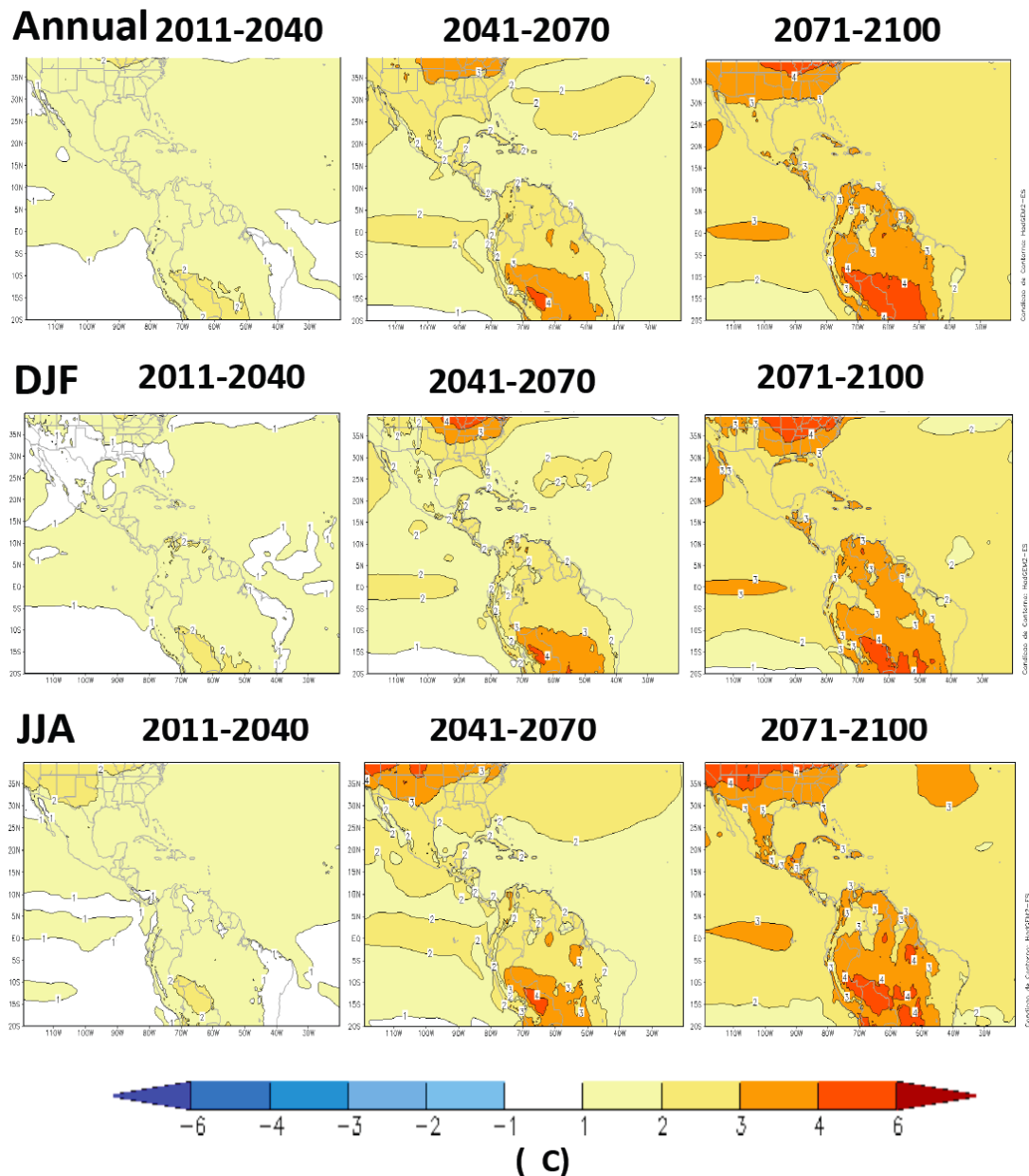


Figure 8. Changes in annual and seasonal air temperature (DJF and JJA) as projected by the Eta-HadGEM2 for Central and South America. Temperature anomalies are shown for the time slices 2010-40, 2041-70 and 2071-2100, relative to 1961-90. Color scale is shown on the lower side of the panel. Scale is $^{\circ}\text{C}$.

For some regions in Central and South America, the annual cycle of rainfall and temperature are shown in Figures 10 e 11, for the present (1961-90) and the three time slices in the future: 2010-40, 2041-70 and 2071-2100 are shown for rainfall (Figure 9) and mean temperature (Figure 10). In Mexico and Central America, the projections show a reduction in rainfall at the peak of the rainy season, from May to October, with a possible extension of the dry season. These reductions are higher by the end of the century. For the Amazon region, Northeast Brazil and Northern South America the models project rainfall reductions all year long, both during the summer and also on the winter season, and larger reductions are detected by the end of the century.

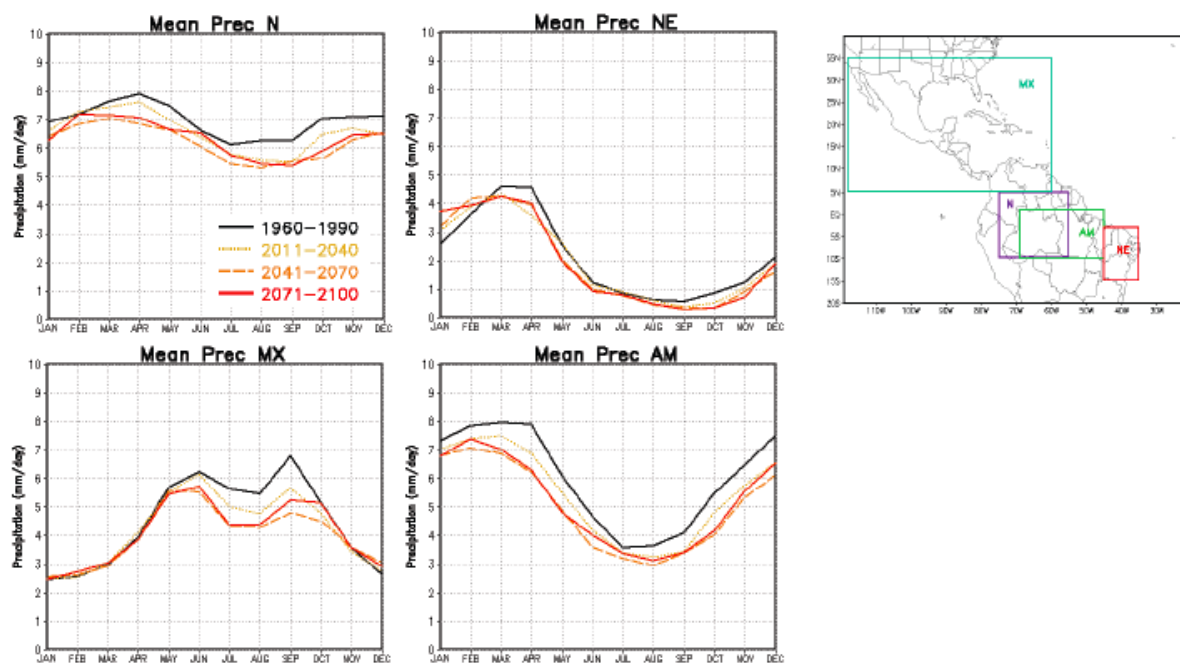


Figure 9. Changes in rainfall as projected by the Eta-HadGEM2 for 4 regions (shown on the right side, for 2010-40, 2041-70 and 2071-2100, relative to 1961-90. Color scale is shown on the upper left side panel identify the time slices.

Regarding air temperature, for all four regions, air temperature increase all year long, reaching warming up to 1-2 C by 2010-40 and up to 2-4 C by 2100 in South America. The combination of higher air temperatures and longer dry seasons suggest strong impacts on the North and South American monsoon systems; and also water availability problems in regions such as Amazonia and Northeast Brazil, suggesting large impacts on natural and human systems in those regions, and increase in the risk of desertification in the semiarid lands of Northeast Brazil, particularly on the second half of the XXI Century.

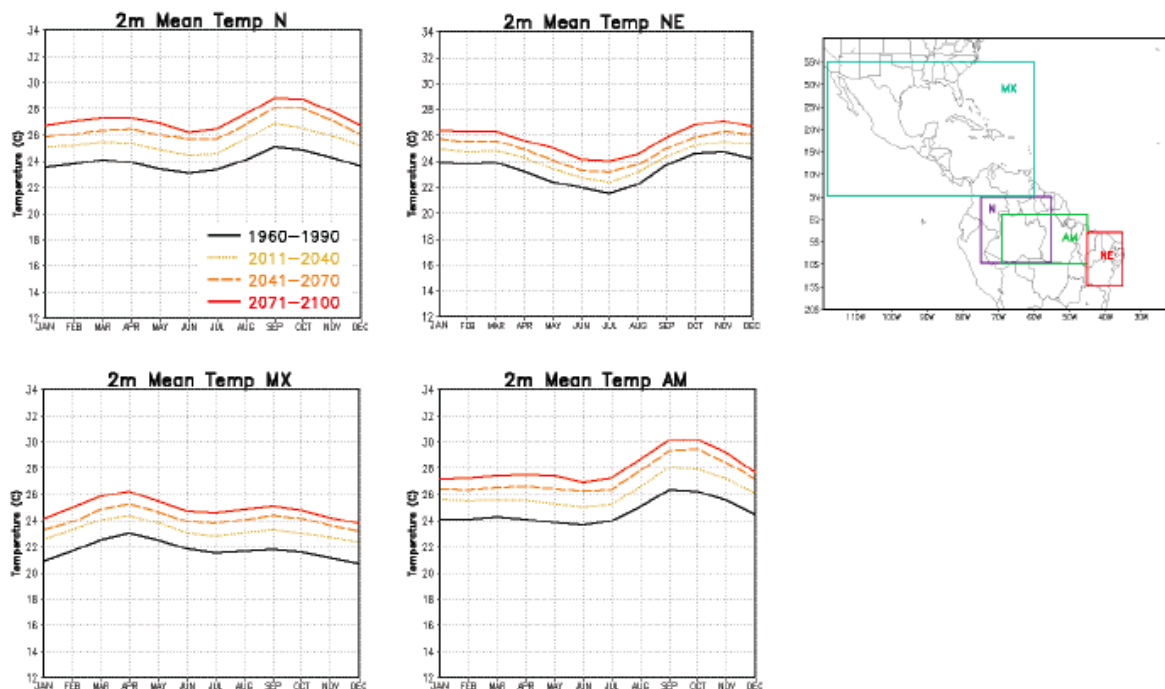


Figure 10. Changes in air temperature as projected by the Eta-HadGEM2 for 4 regions (shown on the right side, for 2010-40, 2041-70 and 2071-2100, relative to 1961-90. Color scale is shown on the upper left side panel to identify the time slices.

4. Update on issues arising during the reporting period (e.g. personnel changes, financial resources, research sites, risks)

No problems were detected on the technical side. One person (Dragan Latinovic, Ph.D. student) was hired for the work on the downscaling, and he produced the scenarios for the future from the downscaling of the Eta-HadGEM2 ES during 9 months. We could not get access to climatic data from the central and South American countries so we based the observational part on publications and studies, mainly from IPCC AR4 and AR5 and IPCC SREX. Resources were used mainly for the hiring and also for equipment and some travel. No risks are involved on this project.

5. Activities planned and results expected during the reporting period

We have prepared the report on three parts: Observed trends, climate change projections derived from IPCC AR4 and AR5, and the downscaling of the Eta-HadGEM2 ES, for time horizons until 2100, and for the RCP4.5 (intermediate emissions). The analysis is for the tropical South America and Central America-Mexico. All these activities are detailed on Section 3 and their results are discussed on this report.

6. Major challenges encountered during the reporting period

Some of the major challenges on this project were the problem with accessing climatic data from the countries, and also some limitations (technical limitations) in terms of disk space to store the regional

climate change simulations. We detected also problems with data coverage in regions such as Amazonia and Northeast Brazil, mainly daily data needed for analysis of climate extremes. Sometimes, the problem is not the lack of data but the quality of the data available, and also the data that exists that are not available to the public. There were also some computational problems related to the coupling of the Eta regional model and the HadGEM2 ES global model that did take more time than expected.

7. What needs to be done, who should do it and by when?

We have solved the problems of the lack of observational data using publications from IPCC and other published literature on trends of climate and extremes in Central and South America. We have noticed that are smaller number of studies on Central America as compared to South America. In addition, few studies on climate change projections for Central America are available, and some of them started to appear after 2010. Some of those simulations were derived from the PRECIS regional model, consequence of training activities organized in Central American and the Caribbean region by the UK Met Office Hadley Centre.

This is the first time that we use the Eta model extended to cover Central America, and we are encouraged for the good results, since the projected tendencies from the Eta-HadGEM2 ES are consistent with those from the PRECIS and from the IPCC AR4 and AR5 models. We need better interaction with the meteorological services of countries in Central and South America, and also INPE can assume a major role in training people for the generation and use of regional climate change scenarios for impacts studies.

8. Lessons learnt and implications for the project

We have had in the past training activities with the Eta regional model in South America, but not for Central American countries. In the past, the Brazilian Government, CEPAL/ECLAC (Economic Commission for Latin American and the Caribbean) and the Red Internacional de Oficinas sobre Cambio Climático (RIOCC) from the Spanish Government and the UK government have funded these training activities for South America by the PRECIS initiative. In the future, these activities should continue and cover Central American countries, perhaps as an initiative of INPE and CIAT. These training activities are important since the production of future climate change simulations is needed for impact studies, particularly on the sectors of water security, food security and energy security, since there are key sectors in the regional economies that contribute largely to the national GDP in Central and South America.

9. Other comments

We are very thankful to CIAT-CCAF for this opportunity to work together with INPE for the generation of regional climate change scenarios for impacts and vulnerability assessments. We would like to show these results for the CIAT people and also for key decision makers in the region, perhaps on a meeting organized by CIAT. We also will make available all the scenarios generated by the Eta-HadGEM2 ES to

CIAT. For that we have to see with CIAT on how that will be done. Certainly, INPE can offer the possibility of hosting a site where the data can be accessed and downloaded by FTP using Internet.

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