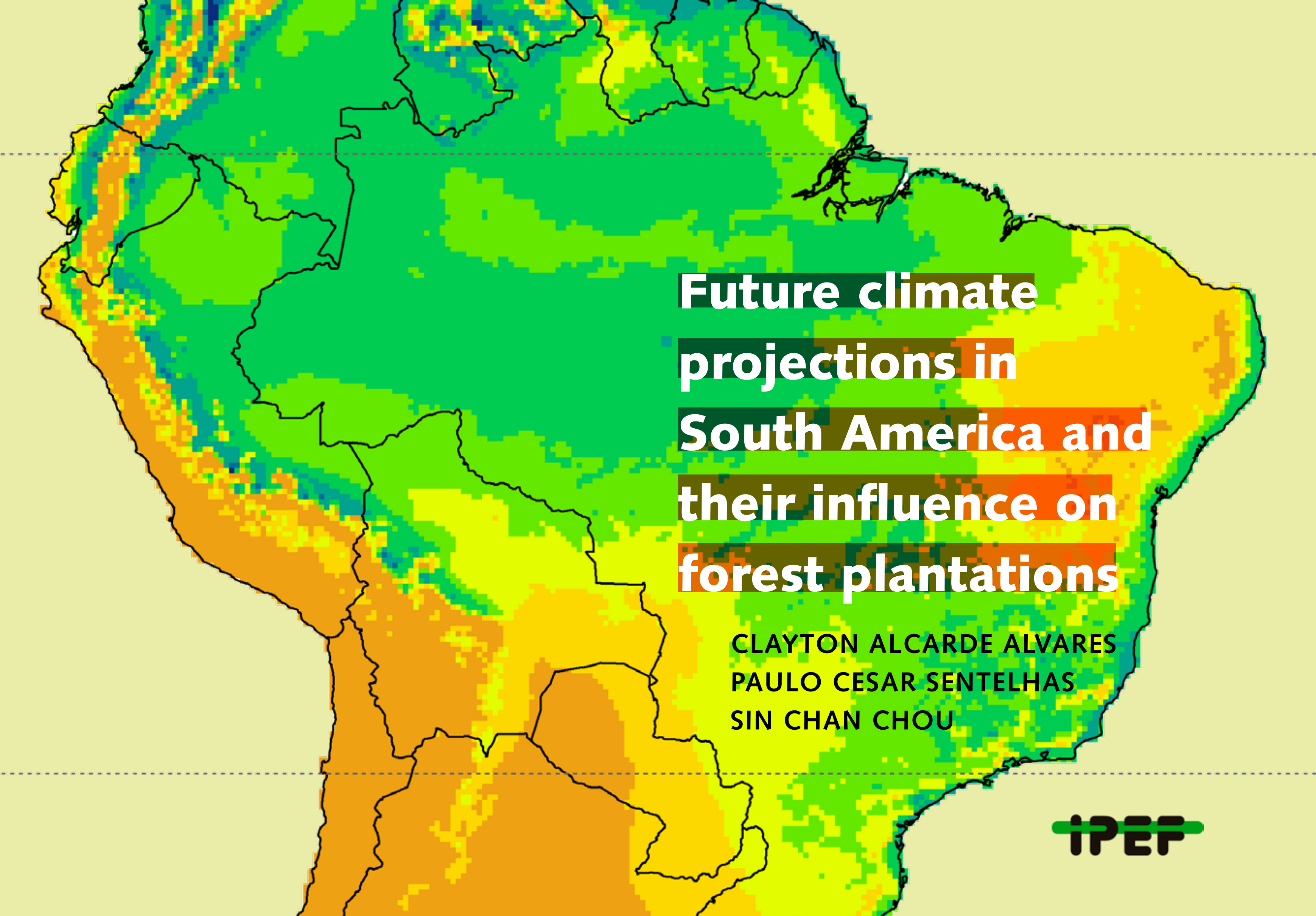

Future climate projections in South America and their influence on forest plantations

CLAYTON ALCARDE ALVARES
PAULO CESAR SENTELHAS
SIN CHAN CHOU

IPEF

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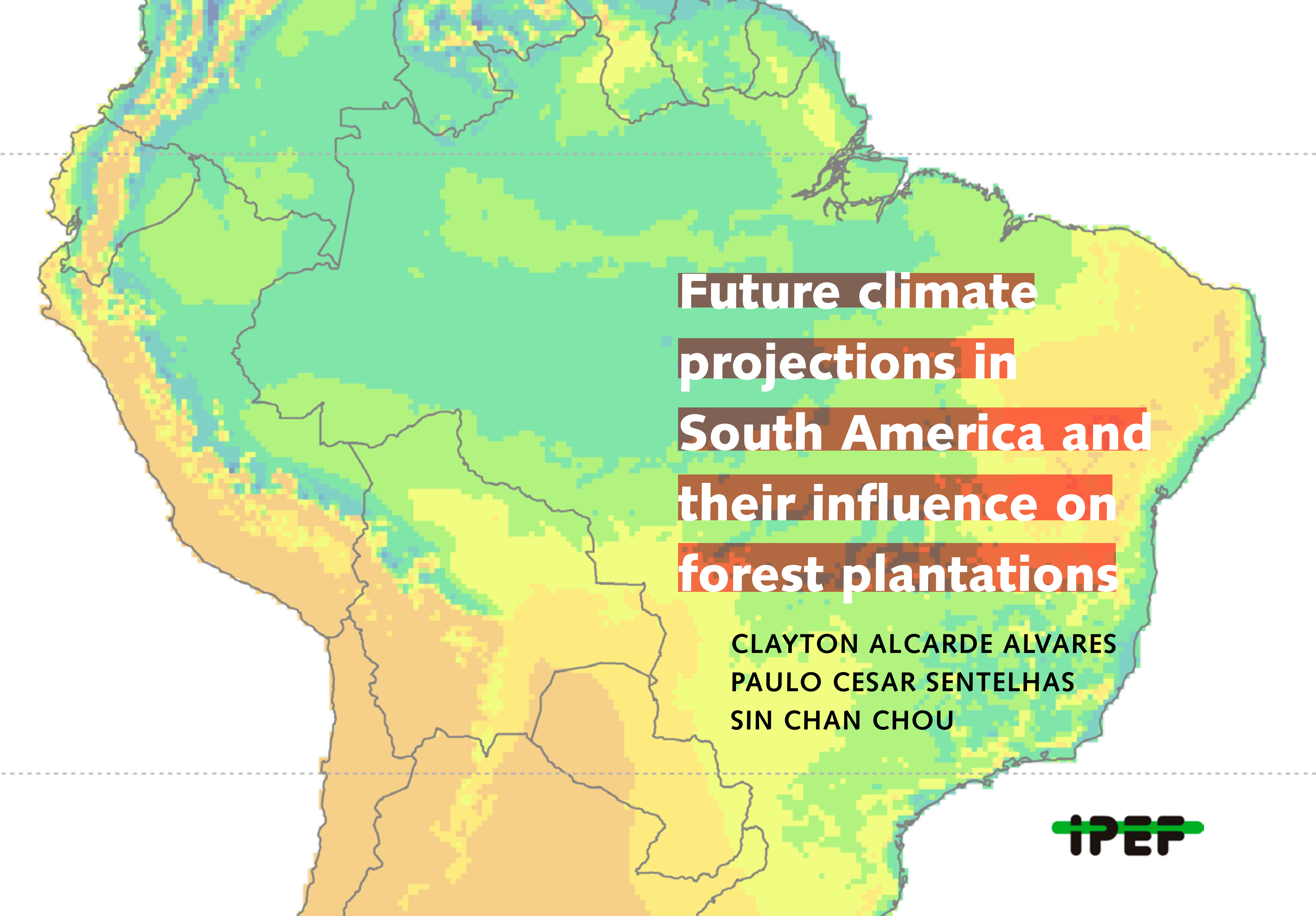

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1 Introduction

Global climate models (GCMs), also known as general circulation models, are a combination of different algorithms able to simulate how energy and matter interact in the Earth system, being able to predict/project present and future climate conditions. These models are based on physics processes to simulate numerically the transfer of energy through the components of the Earth system, which include atmosphere, oceans, cryosphere, land and vegetation, biogeochemical cycles (Mélières and Maréchal, 2015). The GCMs are able to simulate the past climate since the pre-industrial period using the past levels of greenhouse gases (GHG) concentrations. These simulations reach the present climate by increasing the concentrations up to the current GHG levels and then the models project future climate by further increasing gases concentrations according to the considered emission scenario. Therefore, the changes in future climate are assessed by comparing the future outcomes forced by those scenarios with the present or past simulations forced by observed levels of GHG concentrations. In the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - IPCC AR5 (IPCC, 2013), the GHG concentrations were based on four scenarios, the so-called Representative Concentration Pathways (RCP), known as RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The number tags refer to the radiative forcings, 2.6, 4.5, 6.0, and 8.5 Wm^{-2}, respectively, that could be reached at the end of the 21st century and would be caused by the increasing global GHG concentrations. These radiative forcings are used in the GCMs as a proxy by long-term future socio-economic and environmental behavior scenarios.

Based on experiments and modeling tools, climatologists have high confidence that global temperatures will continue to rise for decades to come. They are concerned about the effects that future climate change may have on several human activities and, also, on the Earth system. Therefore, scientists have applied GCMs and socio-economic and environmental scenarios to find out how the climate will change in different countries and regions around the world. Long-term average and distribution of air temperatures and rainfall of a given region are key components of the general state of the climate system at that location at that period of time. Therefore, a well-defined climate classification system, which can be at the same time simple, relevant, and easily replicable, is essential to detect and monitor climate change over time. Köppen climate classification system, for meeting these premises, remains as the most used climate classification procedure to date. Thereby, scientists have been using this classification system with success to identify climate types and tracking climate change at regional and global scales (Wang and Overland, 2004; Rubel and Kottek, 2010, Gallardo et al, 2013; Chen and Chen, 2013; Fernandez et al, 2017; Dubreuil et, al 2019). These studies, encompassing South America, used coarse climate projections maps with spatial resolution around 50 km to 110 km. Moreover, none of them presented detailed results by country level. Besides, these studies did not consider a multimodel ensemble approach to reduce uncertainties in relation to the climate projections.

South America has 14,884,000 ha of forest plantations, approximately 7.8% of world's global total, with Brazil (7,736,000 ha), Chile (3,044,000 ha), Argentina (1,202,000 ha), Peru (1,157,000 ha), Uruguay (1,062,000 ha), Venezuela (557,000 ha), Colombia (71,000 ha) and Ecuador (55,000 ha) being the main producers in the continent (FAO, 2015). In South America, forest plantations for industrial supply were initially established in the subtropical and temperate regions where tax incentives were given to the first growers, like in Brazil and Chile, during the decades of 1960's to 1980's, and more recently in Uruguay and Argentina, between 1980 and 2000 (Gonçalves et al., 2013). Since 2000, forest plantations have expanded to marginal lands, where producers have been mostly encouraged by government subsidies and outgrower schemes promoted by tree industries (Gonçalves et al., 2020). In recent years, due to the scarcity of large farms and the increasing competition of cash crops, forest planters have been forced to expand their lands to the so-called new forest frontiers, where climate, soil and relief conditions are more restrictive for tree's growth. Most of these frontiers are located in wet tropical, dry tropical, and monsoon climates, which present high interannual rainfall variability and high climate risk for wood production (Binkley et al., 2017; Elvis et al 2020a; Binkley et al., 2020). However, concerns about climate change affecting Brazilian forest plantations have been reported for over 20 years (Fearnside, 1999). Every year, forest growers have been losing thousands of hectares of forest plantations due to severe water deficits and persistent heat waves, which have become more frequent than in the past (Gonçalves et al., 2017). In some regions, the adverse weather conditions are imposing a higher risk for forestry activities, compromising the success of forestry business. In addition, these new forest frontiers are expected to be more vulnerable to climate change projected for the coming years, as shown by Elli et al. (2020b, 2020c) for *Eucalyptus* plantations in different Brazilian producing regions.

Considering the importance of climate variability and change for all South American countries, the purpose of this book is to present the Köppen climate classification for the projecting future climate in South American countries, based on the climate projections from the downscaling of two GCMs, and their ensemble, and for two GHG scenarios. In addition, a geographical information system was used to provide detailed information for end users regarding multiple applications for forest and agricultural production in the continent. Finally, a special application is provided of the dynamics of future climate change for six major forest species (Eucalypt, Pine, Teak, Wattle, Rubber, Poplar) in five countries (Argentina, Brazil, Chile, Ecuador, and Uruguay) of South America.

2 Basic climatological definitions and concepts

Considering the importance of climate variability and change for agriculture and forestry, it is particularly necessary to understand the differences of these concepts, since they impact the mentioned activities in distinct ways. Climate variability refers to the oscillations that are observed within the year and between the years, which are called intra-annual and interannual climate variability, respectively. The weather conditions, represented by air temperature, relative humidity, solar radiation, wind speed and rainfall, are very dynamic, and change all the time (hourly, daily, up to weekly). Weather conditions are influenced by several factors, mainly related to the atmospheric circulation systems that in South America are: Fronts, storms, Intertropical Convergence Zone (ITCZ); South Atlantic Convergence Zone (SACZ). On the other hand, climate is considered as a long-term average of weather conditions, comprising 30 consecutive years, period defined by the World Meteorological Organization (WMO, 2020, www.wmo.int) as the one enough to stabilize the mean and reduce the variance.

Examples of phenomena considered of climate scale are: El Niño Southern Oscillation (ENSO); Madden-Julian Oscillation (MDO); Pacific Decadal Oscillation (PDO); the Atlantic Dipole (AD); and Atlantic Multidecadal Oscillation (AMO) and South America Monsoon Circulation (SAMC) (Gun et al., 2004; Garreaud and Aceituno, 2007; Cavalcanti et al., 2009; Reboita et al., 2010). These phenomena are revealed as anomalies of a climatological mean value, and they can cause long term events such as droughts or wetter rainy seasons.

As already mentioned, the weather conditions are daily varying, due to the interactions between various factors such as volcanic eruptions, solar activity variations, clouds and winds, and human-induced factors such as changes in atmospheric composition and land use (Pereira et al., 2002). Therefore, the term "climate variability" is often used to describe the deviations of meteorological conditions of a given month, season, or year in relation to long-term statistics (climate) for the same period. Climate variability can be caused by natural internal processes within the climate system, known as internal variability, or by natural or anthropogenic external factors, also called external variability (WMO, 2020). Therefore, caution must be taken to not make confusion between climate variability and climate change.

Figure 1 shows the inter-annual rainfall variability in Piracicaba, State of São Paulo, Brazil, for the period between 1903 and 2020. From Figure 1, it is possible to identify the climate variability represented by annual rainfall, with values ranging from 812 mm yr^{-1} (observed at 1921) to 2018 mm yr^{-1} (observed at 1983), whereas the mean value (red solid line) is 1283 mm yr^{-1} and the standard deviation (red dashed line) is ± 231 mm yr^{-1}. Also, the example of Figure 1 allows us to identify other two concepts related to climate variability, which are: climate tendency and climatic anomaly. The first concept is a sequence of increasing (positive tendency) or decreasing (negative tendency) values for a period of years, 5, 10 or more years. Such tendencies can be seen in Figure 1 for the periods from 1947 to 1956 (negative tendency) and from 1978 to 1983 (positive tendency). The second concept, represented by the values that were expressively different from the standard deviation (variability), such as those observed, for example, in the years 1911, 1912, 1982, and 1983 of positive anomaly, and the years 1916, 1921, 1978, 1984, and 2014. It is especially

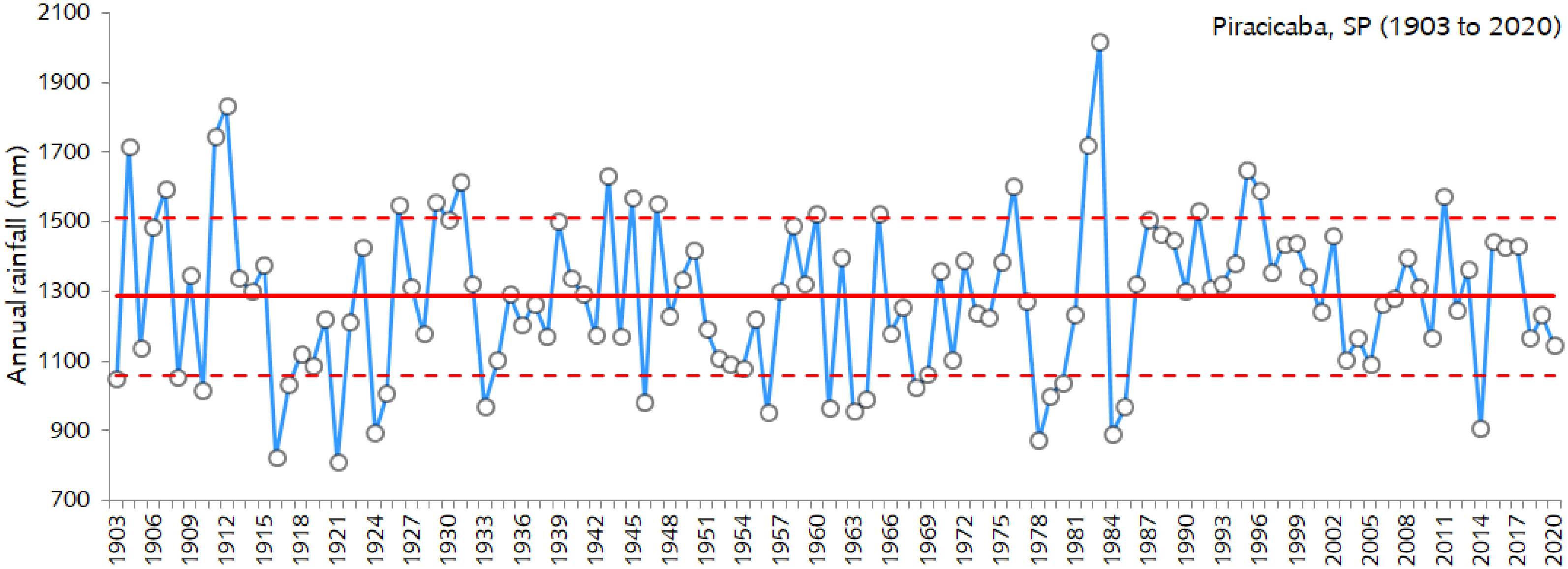

Figure 1. Inter-annual rainfall variability in Piracicaba, State of São Paulo, Brazil, for the period from 1903 to 2020, showing climate variability, tendencies, and anomalies. The central red line represents the average, whereas the dashed red lines represent the standard deviations in relation to the average. Source: Conventional Weather Station of Agricultural College Luiz de Queiroz (ESALQ), University of São Paulo (www.leb.esalq.usp.br/leb/base.html).

important to understand that short-period tendencies and anomalies are an intrinsic part of climate variability and they are partly related to natural causes, as already mentioned.

Another important concept is climate change, which refers to statistically significant change of the mean state of a meteorological variable, change in its variability (tendencies), or change in the frequency and intensity of extreme events (anomalies), change in the duration of the events (decades or longer). Climate change may be caused by natural or external factors, related or not to anthropogenic activities. The main possible causes of climate change are: Extraterrestrial - solar activity; Astronomic – change in the sun-earth distance, obliquity or precession; Terrestrial – Vulcan activity, distribution between oceans and continents, size of polar ice caps, and atmospheric composition. Among these possible factors, the one with expressive changes in the last decades and expected for the next ones is the composition of the global atmosphere, expressed by the greenhouse gases concentration. The increase of GHG is directly or indirectly attributed to human activities. Based on that, the United Nations Framework Convention on Climate Change (UNFCCC) makes a distinction between climate change attributed to human activities that alter the atmospheric composition, and that attributed to natural causes.

Many regions around the world may experience greater climate variability than others, that depends on the weather systems that normally affect those areas. A single extreme event of rare occurrence, such as an intense storm associated with a tropical cyclone, a frost caused by a strong polar mass, or an intense drought in a specific area cannot be attributed to human-induced climate change. However, a series of heat waves, for example, may result in increase of air temperature over decades, in a consistent and continuous tendency, with normal average changing by 1, 2 or 3°C, is a clear signal of climate change or warming. An interesting example was presented by Dias et al. (2017) that applied the rainfall and temperature data from the weather station of Figure 1 and showed that the increase in temperature influenced the regional climate, shifting from subtropical to tropical climate.

3 Methodology

3.1. Climate and GIS databases

In this study, two global climate models, named HadGEM2-ES and the MIROC5, were used to project future climate for South America. HadGEM2-ES is the UK Met Office Hadley Centre Global Environmental Model version 2 - Earth System (Collins et al., 2011). This model describes ocean processes (Johns et al., 2006), sea ice processes (McLaren et al., 2006) and dynamic vegetation (Cox et al., 2001). This model has a resolution in the atmospheric parcel of 1.875° in longitude by 1.25° in latitude and 38 vertical layers. MIROC5 (Model for Interdisciplinary Research On Climate, version 5) was developed in a consortium by the University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (Watanabe et al., 2010). This model has a spatial resolution for the atmospheric parcel of 1.40625° in longitude and 1.40625° in latitude. The atmosphere is coupled to the ocean model (Hasumi and Emori, 2004) with sea ice model (Komuro et al., 2012).

The coarse resolutions of these models provide no detail for local impact studies. Therefore, dynamical downscaling of these global models outputs were carried by the Eta Regional Climate Model (RCM) at 20-km horizontal resolution (Chou et al. 2014a). This model is developed by the Brazilian National Institute for Space Research – INPE (Pesquero et al., 2010; Chou et al., 2012). An updated version of the model (Mesinger et al., 2012; Chou et al., 2014a, b) was used for the Brazilian Third National Communication (MCTI, 2016). The downscaling is carried out by running the Eta model forced by the global models' atmospheric variables at the lateral boundaries. The Eta RCM does not reproduce ocean circulation; therefore, the sea surface temperatures are provided by the global models. The downscaling was produced for the period from 1960 until 2099, under RCP4.5 and RCP8.5 scenarios. The first scenario is considered moderately optimistic, whereas the latter one is the most pessimistic, and adopts very high GHG emission rates. The Eta model run datasets will be from now on referred to as Eta-HadGEM2 or Eta-MIROC5; however, to reduce label length on maps, tables and figures they will be labeled hereafter as HadGEM2 and MIROC5.

South America countries' boundaries used in this study were obtained on the Database of Global Administrative Areas (GADM, 2018, www.gadm.org). Mainland South America has an area of 17,828,705 km^2 and is composed by twelve countries as follows: Brazil with 8,515,799 km^2; Argentina with 2,780,400 km^2; Peru with 1,285,216 km^2; Colombia with 1,141,748 km^2; Bolivia with 1,098,581 km^2; Venezuela with 916,445 km^2; Chile with 756,102 km^2; Paraguay with 406,750 km^2; Ecuador with 276,841 km^2; Guyana with 214,969 km^2; Uruguay with 181,034 km^2; and Suriname with 163,820 km^2; and one territory, French Guiana, a France's overseas region, with 91,000 km^2 (Figure 2).

Spatially differentiated maps of forest plantations from natural and semi natural forests are available for some few countries. However, the identification of the planted species in each forest farm or stand in these maps is still a challenge. In an attempt to solve these gaps, the project Spatial Database of Planted Trees (SDPT) conducted extensive outreach to compile, synthesize, and harmonize national maps of the world's planted forests and tree crops into a global map (Harris et al., 2019). SDPT were used in this study to assess how climate change is expected to affect the current main planted forests in South America.

We considered forest plantation data for the following five countries: Argentina (946,568 ha); Brazil (7,764,671 ha); Chile (878,825 ha); Ecuador (130,014 ha); and Uruguay (1,389,641 ha), and for six major forests species: Eucalypt (7,573,009 ha); Pine (3,256,229 ha); Teak (130,014 ha); Wattle (101,092 ha); Rubber (35,493 ha); and Poplar (13,882 ha) (Table 1, Figure 2).

3.2. The Köppen climate classification system

The Köppen climate types are symbolized by two or three letters, where the first indicates the climate zone and is basically defined by temperature and rainfall patterns, the second considers rainfall distribution and the third is related to seasonal temperature variation. The classification system has a total of 31 climate types grouped into five macroclimate zones (Köppen, 1936), as follows:

- Tropical zone (A) – its main constraint is the coldest month, which requires an average temperature greater than 18°C and absence of a severe water deficit. This zone is divided into Af (Tropical without dry season), Am (Tropical monsoon),

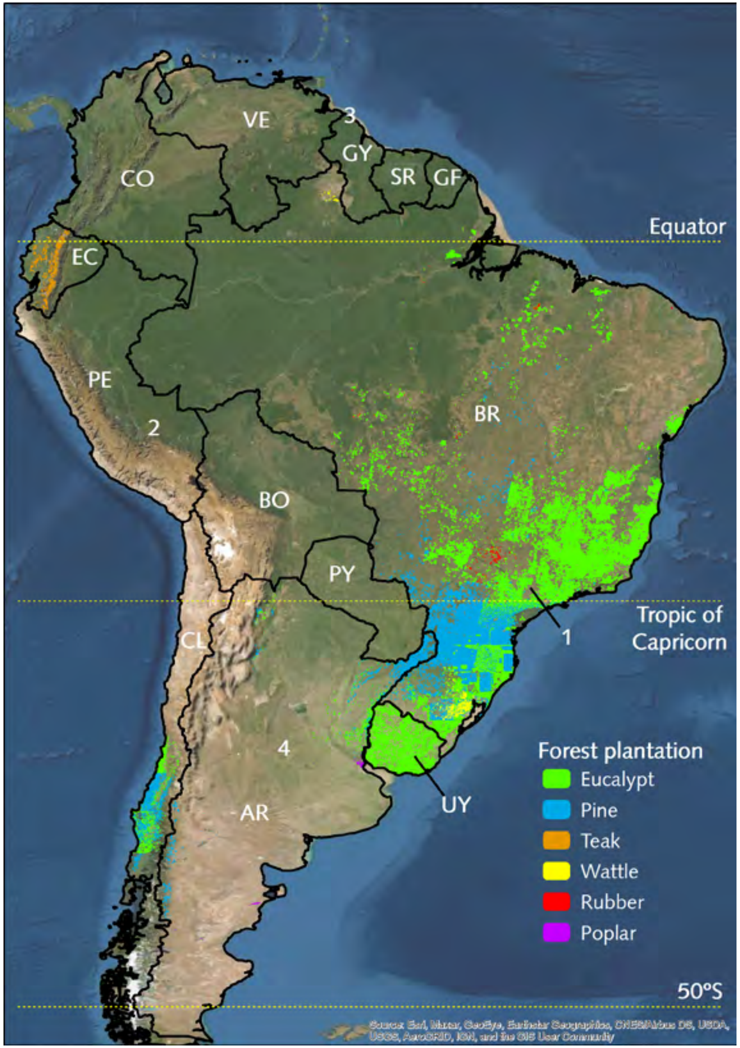

Figure 2. South American countries (AR= Argentina, BO = Bolivia, BR = Brazil, CL = Chile, CO = Colombia, EC = Ecuador, GF = French Guiana, GY = Guyana, PY = Paraguay, PE = Peru, SR = Suriname, UY = Uruguay, and VE = Venezuela) until latitude 50°S. The selected sites to produce Figure 4 are (1) Brazil at 46.8° West longitude and 22.4° South latitude, (2) Peru at 72.0° West longitude and 12.6° South latitude, (3) Guyana at 59.2° West longitude and 7.8° North latitude, and (4) Argentina at 63.8° West longitude and 33.0° South latitude. Forest type plantations adapted from Harris et al. (2019).

Table 1 Area of each forest plantation per country, as considered in this study

Country	Forest type	Main species	Area (ha)
Argentina	Eucalypt	*Eucalyptus camaldulensis*, *E. grandis*, *E. viminalis*, *E. dunnii*, *E. globulus*, *E. saligna*	250,442
	Pine	*Pinus taeda*, *P. elliottii*, *P. caribaea* x *P. elliottii*, *P. radiata*	682,243
	Poplar	*Populus deltoides*, *P. nigra*	13,882
Brazil	Wattle	*Acacia mearnsii*, *A. mangium*	101,092
	Eucalypt	*Eucalyptus grandis*, *E. urophylla*, *E. citriodora*, *E. saligna*, *E. benthamii*, *E. dunnii*	5,490,594
	Pine	*Pinus taeda*, *P. caribaea* var. *hondurensis*, *P. caribaea* var. *caribaea*, *P. elliottii*	2,137,492
	Rubber	*Hevea brasiliensis*	35,493
Chile	Eucalypt	*Eucalyptus globulus*, *E. nitens*	442,333
	Pine	*Pinus radiata*	436,493
Ecuador	Teak	*Tectona grandis*	130,014
Uruguay	Eucalypt	*Eucalyptus grandis*, *E. globulus*, *E. dunnii*, *E. benthamii*	1,389,641

Source: Adapted data from Harris et al. (2019).

As (Tropical with dry summer) and Aw (Tropical with dry winter).

- Dry zone (B) – this is the most distinctive and debated zone of the Köppen's system (Wilcock, 1968). Dry climate should occur at locations where evaporation exceeds rainfall (Trewartha, 1943; Thornthwaite, 1943). As very few data were available for evapotranspiration in the beginning of 20th century, Köppen formulated several aridity indices based on annual rainfall and temperature. In literature these aridity indices are called $R_{THRESHOLD}$ (Kottek et al., 2006; Peel et al. 2007; Rubel and Kottek, 2010). As a first approach, Köppen placed the boundary between desert and steppe where the rainiest month of the year had an average of only 6 days with rain, or, as he said, a rainfall probability of 0.20 (Thornthwaite, 1943). After that, in "Klassification" version (Köppen, 1918), the aridity index was a simple ratio between mean annual rainfall and mean annual temperature. This index obviously did not satisfy Köppen and in the following papers (Köppen, 1919; 1922) he revisited this subject (Wilcock, 1968). According to the rule presented in Köppen (1918), the value of the index was increased by 30% for the winter dry areas and decreased by 30% for the summer dry areas. In this period, Köppen attempted to find a formula for relating the rainfall at the forest boundary with mean annual temperature (Wilcock, 1968). Thereafter, Köppen (1923) and Köppen and Geiger (1928) presented three different formulas to use under the three seasonal rainfall regimes. Therefore, in the "Gundriss" version (Köppen, 1931), Köppen proposed its last version for the aridity index: "Experience shows that where the seasonal differences in temperature and rainfall are significant, the boundary between the steppe and the treeland falls, for predominantly winter rain, where the annual rainfall (R_A, in cm) is approximately equal to $2 \times T_{AAVE}$ (where T_{AAVE} is the mean annual temperature in °C). But if most of the rainfall falls in summer then on this boundary R_A is approximately equal to $2 \times (T_{AAVE} + 14)$. For the boundary between steppe and desert climates, Köppen suggested to take half of these values, i.e. $R_A = T_{AAVE} + 14$. But if the distinction between seasons fails, either in temperature or rainfall amount, an average can be adopted". In other words, the following equation (Köppen, 1931) summarizes the simplified aridity index (Eq. 1). Obviously, these formulas do not have a specific rational basis, but they give a reasonable estimate, for a world scale, of the amount of rain needed to avert aridity (Wilcock, 1968). The possible climatic types in zone B are BSh (Semi-arid of low latitude and altitude), BSk (Semi-arid of mid-latitude and high altitude), BWh (Arid of low latitude and altitude) and BWk (Arid of mid-latitude and high altitude).

$$R_{THRESHOLD} = \begin{cases} (2 \times T_{AAVE}) & \text{if at least 70\% of RA occurs in winter} \\ (2 \times T_{AAVE}) + 28 & \text{if at least 70\% of RA occurs in summer} \\ (2 \times T_{AAVE}) + 14 & \text{Otherwise} \end{cases} \qquad \text{Eq. 1}$$

- Humid subtropical zone (C) – is limited by the temperature of the coldest ($T_{COLD} < 18$°C) and the warmest (T_{HOT} with various procedures, see Table 2) months, the counter variable occurrence of months with temperatures below 10°C (T_{M10}), and according to the seasonal rain (winter or summer). Due to the multi-criteria used for determining the climates and the high climatic variability in the regions of the humid subtropical zone (C), nine climatic types were proposed: Cfa (Humid subtropical of oceanic climate, without dry season and with hot summer), Cfb (Humid subtropical of oceanic climate, without dry season and with temperate summer), Cfc (Humid subtropical of oceanic climate, without dry season and with short and cool summer), Cwa (Humid subtropical with dry winter and hot summer), Cwb (Humid subtropical with dry winter and temperate summer), Cwc (Humid subtropical with dry winter and short and cool summer), Csa (Humid subtropical with dry and hot summer), Csb (Humid subtropical with dry and temperate summer), Csc (Humid subtropical with short dry and cool summer).

- Temperate continental zone (D) – has basically the same definitions as zone C. The boundaries are delimited only by the temperature of the coldest month (T_{COLD}), when $T_{COLD} \leq 3$°C. Thus, in this zone, Köppen (1936) determined that there are 12 climatic types: Dfa (Temperate continental without dry season and with hot summer), Dfb (Temperate continental without dry season and with temperate summer), Dfc (Temperate continental without dry season and with short and cool summer), Dfd (Temperate continental without dry season and with very cold winter), Dwa (Temperate continental with dry winter and hot summer), Dwb (Temperate continental with dry winter and temperate summer), Dwc (Temperate continental with dry winter and short and cool summer), Dwd (Temperate continental with dry winter and very cold summer), Das (Temperate continental with dry and hot summer), Dsb (Temperate continental with dry and temperate summer), Dsc (Temperate continental with dry and short and cool summer), Dsd (Temperate continental with dry summer and with very cold winter).

- Polar climate (E) – characterizes the polar climates Tundra (ET) and Frost (EF), which are defined only based on the mean air temperature of the warmest month, below 10ºC. More details about the E zones see Table 2.

3.3. Map algebra and data visualization

The present study was conducted in several successive steps that included the data acquisition and organization, data compilation in a geodatabase using a geographic information system, geoprocessing techniques, exploratory and statistic descriptive analysis, and data visualization in a sequence of methodological processing and results, as shown in Figure 3.

For this study, twelve monthly climate datasets of the two General Circulation Models (HadGEM2 and MIROC5), and two climate variables, daily rainfall (mm d^{-1}) and 2-m air temperature (ºC), were assessed. The climate analyses were split in four timeslices, one for baseline period (1961-1990), and three future periods (2011-2040, 2041-2070, and 2071-2099). Two levels of radiative forcing due to greenhouse gas emissions were used: RCP4.5 for moderate emissions and RCP8.5 for high emissions of climate change scenarios.

Firstly, daily rainfall was accumulated for every month and then the baseline monthly average was calculated, generating a new database. Each of the four downscaling runs (HadGEM2 RCP4.5, HadGEM2 RCP8.5, MIROC5 RCP4.5, and MIROC5 RCP8.5) were separated in three periods, similar to a climatological normal, as follows: 2011-2040, 2041-2070 and 2071-2099. After preparing the monthly rainfall and air temperature databases for the GCMs and future scenarios, the ensembles of them were processed. A multimodel ensemble

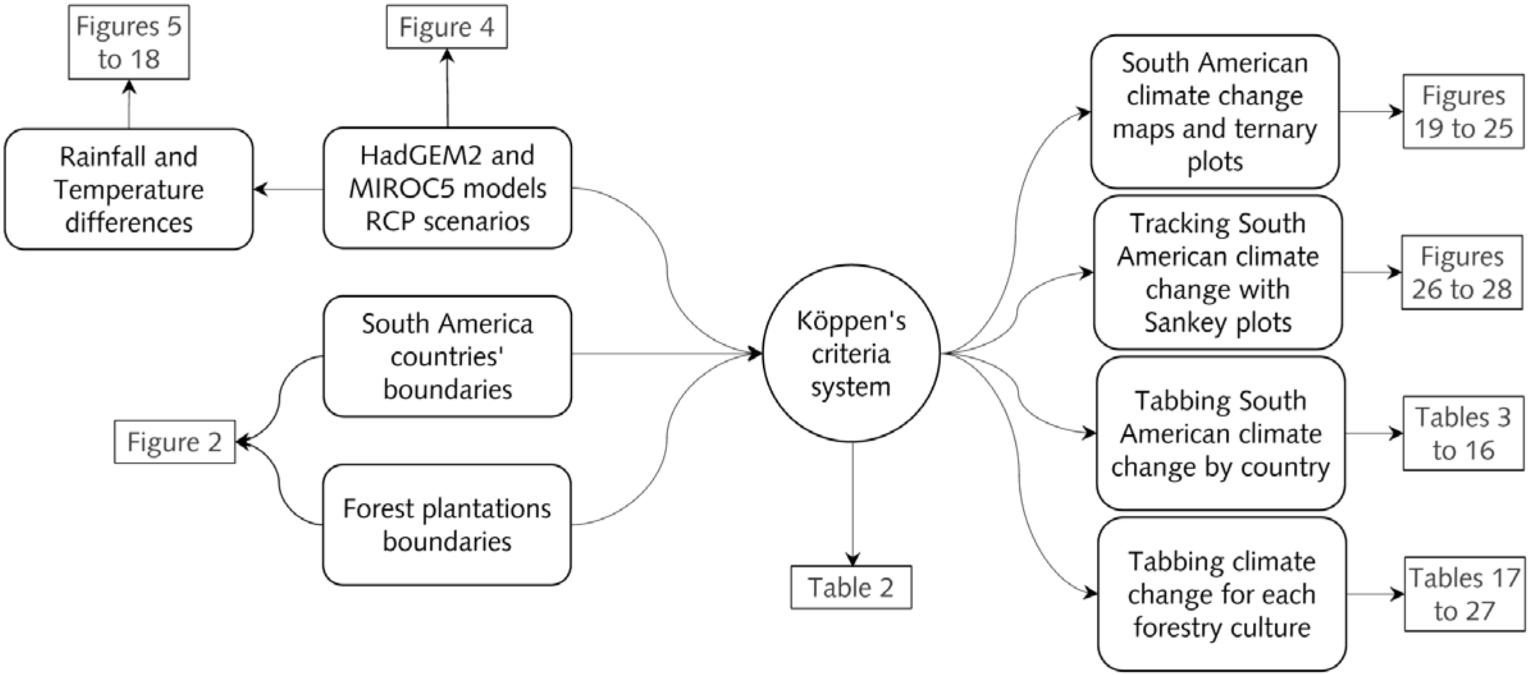

Figure 3. Flowchart of the procedures for detecting and quantifying the climate change in South America and in their key forest plantations by applying Köppen system on HadGEM2 and MIROC5 models for four timeslices, 1961-1990 (baseline), 2011-2040, 2041-2070, 2071-2099, and two greenhouse gases emission scenarios, RCP4.5 and RCP8.5.

was performed by determining the average of rainfall and temperature of the two GCMs for each RCP projection (HadGEM2-MIROC5 RCP4.5, HadGEM2-MIROC5 RCP8.5).

In order to feature the data series of air temperature (°C) and rainfall (mm month^{-1}) output by models and climate change scenarios used in this study, four sites with different climates were selected: (1) Brazil at 46.8° West longitude, 22.4° South latitude, altitude of 650 m above mean sea level (amsl) (region of Itapira, subtropical condition), (2) Peru at 72.0° West longitude, 12.6° South latitude, altitude of 3200 m amsl (region of Cusco, high altitude condition), (3) Guyana at 59.2° West longitude, 7.8° North latitude, altitude of 20 m amsl (region of Barima-Waini, tropical condition), and (4) Argentina at 63.8° West longitude, 33.0° South latitude, altitude of 250 m amsl (region of Río Cuarto, temperate condition) (Figure 2).

Before applying the Köppen criteria system, exploratory and descriptive analysis of the climate projections were carried out by evaluating annual differences of rainfall and air temperature among timeslices of 30 years for each GCM and climate scenarios. The difference between present time (baseline 1961-1990) and projected timeslices (future climatological normal for 2011–2040, 2041–2070, and 2071–2099) for rainfall and air temperature were considered. Simple map algebra techniques such as adding, subtracting, and summarizing were employed to produce the anomaly maps (Tomlin, 1990). Unique map legends for rainfall and air temperature maps were produced for allowing to track differences among timeslices comparisons.

A spatialized Köppen climate classification for South America using a GIS algorithm was implemented. For each model, climate scenario and timeslices full Köppen's climate classification map for South America was produced. For that, a spatial distributed model was generated based on continuous variables such as latitude, longitude, altitude, temperature, and rainfall throughout Brazil. To this end, we adopted the software ArcGIS v.10 (Ormsby et al., 2010) as a work platform in which the entire spatial database was compiled, managed, and processed. The complete Köppen climate classification system was programmed in the "ModelBuilder" (Allen, 2011). "ModelBuilder" is a tool of ArcGIS in which the user can create, edit, and manage models. This tool has a friendly user interface, which allows it to process several functions. Geoprocessing procedures, such as algebra, conditional evaluation, rank, Boolean operators, and other specific codes for spatial modeling were implemented and used (Theobald, 2007).

The key criteria for the climatic classification were divided in ten steps. Firstly, the model generates the latitude variable for each cell, using the code "$$ymap" (Theobald, 2007) and then the studied areas can be set up in northern and southern hemispheres. In the second step, all the rainfall indices were calculated from monthly maps (described later): annual rainfall (R_{ANN}); rainfall of the driest month (R_{DRY}); percentage of rainfall during the summer (to calculate $R_{THRESHOLD}$); rainfall in the driest month during the summer (R_{SDRY}) and winter (R_{WDRY}); rainfall in the wettest month during the summer (R_{SWET}) and winter (R_{WWET}). In sequence, the annual and monthly temperature indices were calculated as the annual mean temperature (T_{ANN}), temperatures of the coldest (T_{COLD}) and hottest (T_{HOT}) months, and finally the counter module of the number of months with temperature below 10ºC (T_{M10}).

Having summer and winter defined and all rainfall and temperature indices calculated, the model started the climate classification by distinguishing A, C, D, and E zones from the B climatic zone, since the temperature and rainfall criteria for classifying B climate can be confused with the others. For this, the rules presented in Eq.1 were used, when the calculation of $R_{ANN} \geq 10 * R_{THRESHOLD}$ starts. As a result, the model generates a Boolean layer, where the pixels identified with 1 are those for A, C, D, and E climates and those with zero are in the B climate. In the next step, the model differentiates areas with value 1 using the simple rules of Table 2, considering for A zone $T_{COLD} \geq 18ºC$, for C zone $-3ºC \leq T_{COLD} < 18ºC$ and $T_{HOT} \geq 10ºC$, for D zone $T_{COLD} < -3ºC$ and $T_{HOT} \geq 10ºC$, and finally for E zone $T_{HOT} < 10ºC$. Thus, the limit $T_{COLD} < -3ºC$ was considered in the model to differentiate the boundaries of C and D zones (Köppen, 1936), rather than using $T_{COLD} < 0ºC$, as considered by Russell (1934), Ackerman (1941), Peel et al. (2007) and $T_{COLD} < -5ºC$, as applied to Europe by Gorczynski (1934).

B climates types were distinguished by applying the conditionals $R_{ANN} \geq 5 * R_{THRESHOLD}$ and $R_{ANN} < 10 * R_{THRESHOLD}$ to define BS (semi-arid) and $R_{ANN} < 5 * R_{THRESHOLD}$ to define BW (arid) climates. With all climatic zones determined, the following steps

Table 2 The complete Köppen's criteria system used for climate classification of South America

Temperature				Rainfall	Climate			Symbol	
T_{COLD}	T_{HOT}	T_{AAVE}	R_M	R_A					
≥ 18 °C			R_{DRY} ≥ 60 mm		(A) Tropical		(f) without dry season	Af	Tropical
			R_{DRY} < 60 mm	≥ 25 (100 - R_{DRY})			(m) monsoon	Am	
				< 25 (100 - R_{SDRY})			(s) with dry summer	As	
				< 25 (100 - R_{WDRY})			(w) with dry winter	Aw	
		≥ 18 °C		≥ 5* $R_{THRESHOLD}$ & < 10* $R_{THRESHOLD}$	(B) Dry	(S) Semi-arid	(h) low latitude and altitude	BSh	Arid
		< 18 °C					(k) mid-latitude and high altitude	BSk	
		≥ 18 °C		< 5* $R_{THRESHOLD}$		(W) Arid	(h) low latitude and altitude	BWh	
		< 18 °C					(k) mid-latitude and high altitude	BWk	
≥ -3 °C <&< 18 °C	≥ 22		R_{DRY} > 40 mm		(C) Humid Subtropical	(f) Without dry season	(a) with hot summer	Cfa	Temperate
	< 22 °C & T_{M10} ≥ 4						(b) with temperate summer	Cfb	
≥ -38 °C &< 18 °C	< 22 °C & 1 ≤ T_{M10} < 4						(c) with short and cool summer	Cfc	
≥ -3 °C <&< 18 °C	≥ 22 °C		R_{DRY} < 40 mm R_{SWET} ≥ 10 * R_{WDRY}			(w) With dry winter	(a) and hot summer	Cwa	
	< 22 °C & T_{M10} ≥ 4						(b) and temperate summer	Cwb	
≥ -38 °C &< 18 °C	< 22 °C & 1 ≤ T_{M10} < 4						(c) and short and cool summer	Cwc	
≥ -3 °C <&< 18 °C	≥ 22 °C		R_{DRY} < 40 mm R_{WWET} ≥ 3 * R_{SDRY} R_{SWET} < 10 * R_{WDRY}			(s) With dry summer	(a) and hot	Csa	
	< 22 °C & T_{M10} ≥ 4						(b) and temperate	Csb	
≥ -38 °C &< 18 °C	< 22 °C & 1 ≤ T_{M10} < 4						(c) and short and cool summer	Csc	
≥ -38 °C &< -3 °C	≥ 22 °C		R_{DRY} > 40 mm		(D) Temperate continental	(f) Without dry season	(a) with hot summer	Dfa	
	< 22 °C & T_{M10} ≥ 4						(b) with temperate summer	Dfb	
	< 22 °C & 1 ≤ T_{M10} < 4						(c) with short and cool summer	Dfc	
< -38 °C &< -3 °C							(d) with very cold winter	Dfd	
≥ -38 °C &< -3 °C	≥ 22 °C		R_{DRY} < 40 mm R_{SWET} ≥ 10 * R_{WDRY}			(w) With dry winter	(a) with hot summer	Dwa	
	< 22 °C & T_{M10} ≥ 4						(b) and temperate summer	Dwb	
	< 22 °C & 1 ≤ T_{M10} < 4						(c) and short and cool summer	Dwc	
< -38 °C &< -3 °C							(d) and very cold winter	Dwd	
≥ -38 °C &< -3 °C	≥ 22 °C		R_{DRY} < 40 mm R_{WWET} ≥ 3 * R_{SDRY} R_{SWET} < 10 * R_{WDRY}			(s) With dry summer	(a) and hot	Dsa	
	< 22 °C & T_{M10} ≥ 4						(b) and temperate	Dsb	
	< 22 °C & 1 ≤ T_{M10} < 4						(c) and short and cool summer	Dsc	
< -38 °C &< -3 °C							(d) and very cold winter	Dsd	
	< 10 & ≥ 0 °C				(E) Polar	(T) Tundra		ET	
	< 0 °C					(F) Frost		EF	

T_{COLD} = average air temperature of the coldest month; T_{HOT} = average air temperature of the hottest month; T_{AAVE} = annual average air temperature; R_M = monthly rainfall; R_A = annual rainfall; R_{DRY} = average rainfall of the driest month; R_{SDRY} = average rainfall of the driest month in summer; R_{WDRY} = average rainfall of the driest month in winter; R_{SWET} = average rainfall of the wettest month in summer; R_{WWET} = average rainfall of the wettest month in winter; T_{M10} = number of months where the temperature is above 10°C; $R_{THRESHOLD} = 2(T_{AAVE})$, if at least 70% of R_A occurs in winter, $R_{THRESHOLD} = 2(T_{AAVE}) + 28$, if at least 70% of R_A occurs in summer, and $R_{THRESHOLD} = 2(T_{AAVE}) + 14$, otherwise; For the southern hemisphere summer is defined as the warmer six-month period (ONDJFM) and winter is defined as the cooler six-month period (AMJJAS). For the northern hemisphere summer is defined as the warmest six-month period (AMJJAS) and winter is defined as the coolest six-month period (ONDJFM). Tropical climate was grouped by the zone A climatic types. Arid climate was grouped by climatic types of zone B. Temperate climate was grouped by climatic types of the zones C, D, and E.

were used to identify types and their subdivisions. In the sixth step of the climate classification model, zones A and B were typified: A climate type was tested for the conditional $R_{DRY} \geq 60$ mm to define Af climate; to generate the Am, As and Aw climate types the conditional $R_{DRY} < 60$ mm was applied as well as other rainfall indices (R_{ANN}, R_{DRY}, R_{SDRY} and R_{WDRY}), as presented in Table 2. In this step, the subdivisions of B zone into BS and BW were also processed by applying the rules $T_{ANN} \geq 18$ºC (for h type) and $T_{ANN} < 18$ºC (for k type). We consider the four tropical climates, however some studies have not computed them, such as Peel et al. (2007) and Sá Junior et al. (2012).

In the following step, the model uses several rainfall indices for defining the f, w and s types for C and D climate zones. In these zones all cells with $R_{DRY} \geq 40$ mm were classified as Cf and Df, whereas the cells classified as Cw and Dw were those that have simultaneously $R_{DRY} < 40$ mm and $R_{SWET} \geq 10 * R_{WDRY}$. For Cs and Ds types the following rules occurred simultaneously: $R_{DRY} < 40$ mm; $R_{WWET} \geq 3 * R_{SDRY}$; and $R_{SWET} < 10 * R_{WDRY}$. For w and s types, the rule $R_{DRY} < 40$ mm was applied just for closing the logic of the system. At the eighth step, the model uses the temperature indices in zones C and D for generating the climatic types a, b, c and d. Therefore, all the cells from the previous steps that satisfied the condition $T_{HOT} \geq 22$ºC were classified as Cfa, Dfa, Cwa, Dwa, Csa or Dsa. The subtype b was considered when $T_{HOT} < 22$ºC and $T_{M10} \geq 4$ºC, whereas climate subtype c was considered when $T_{HOT} < 22$ºC and $1 \leq T_{M10} < 4$ and $T_{COLD} \geq -38$ºC occurred simultaneously. The subtype d was defined whenever the conditions of $T_{HOT} < 22$ºC, $1 \leq T_{M10} < 4$, and $T_{COLD} < -38$ºC occurred. In the ninth step, the model returned once again to the E climate zone, which was generated in the fifth step, to apply the rules $T_{HOT} \geq 0$ºC and $T_{HOT} < 10$ºC to generate ET and EF climates, respectively. In the last step of geoprocessing, the model returned to all outputs and compiled the final map using Boolean logic. Finally, each of the 31 Köppen climatic types receives a symbol in the same sequence as they appear in Table 2.

The proposed model is enclosed and complete, i.e., it is impossible to find a location with more than one type of climate. Then to complete the explanation of the modeling process, for example, a cell that has a mean annual temperature less than 18ºC, temperature of the coldest month greater than or equal to 3ºC, rainfall of the driest month less than 40 mm, rainfall in the wettest month in summer higher than ten times the rainfall in the driest month during the winter, temperature of the hottest month between 10 and 22ºC and at least four months with mean temperature higher than 10ºC, will be classified as a humid subtropical, with dry winter and temperate summer climatic type (Cwb). The final Köppen climate classification maps were color coded according to the climate type, in which was used the same RGB colors pattern presented by Alvares et al. (2013).

The climate types were summarized grouping the 31 types as follows: Tropical (Af, Am, As, Aw); Arid (BSh, BSk, BWh, BWk); Temperate (Cfa, Cfb, Cfc, Cwa, Cwb, Cwc, Csa, Csb, Csc, Dfa, Dfb, Dfc, Dfd, Dwa, Dwb, Dwc, Dwd, Dsa, Dsb, Dsc, Dsd, ET, EF), in order to make feasible to quantify and track the climate changes in South America as a whole and individually for each country of the continent (Table 2).

Ternary charts for each model, climate scenario and timeslice were elaborated. Ternary charts have the function of showing a static normalized climatic distribution of occurrences of Arid, Tropical and Temperate climates. Further on, we show how to read properly the ternary chart (Figure 19). Using data visualization techniques to make results comprehensible and feasible are a key motivator for research and scientific communication. Climate changes between timeslices were shown using Sankey charts. Sankey chart is a very stylish format that enables multi-level traceability among variables and timeslices. This kind of data visualization is elegant and innovative and was not used before in studies with Köppen's climate classification system for present or future scenarios (Wang and Overland, 2004; Rubel and Kottek, 2010, Chen and Chen, 2013; Gallardo et al, 2013; Fernandez et al, 2017; Dubreuil et, al 2019).

Finally, applying basic geoprocessing tools, such as intersect and summarize, the climate changes of each one of 25 Köppen climate types found in South America were tabulated for each country and each forest type in each country, considering all climate scenarios, GCMs and timeslices.

4 Future climate change in South America

Data visualization shows models and climate scenarios have cross-site and within-site variation for both monthly 2-m temperature and rainfall. Looking at the randomly sampled four sites we noted that 2-m temperature has more stability than rainfall models and climate scenarios assessed. There is some major divergence among models and climate scenarios for projecting monthly rainfall at the cost of Guyana and at center-southern Brazil. On the other hand, we figure out a major convergence of rainfall projections to the other two sites (Figure 4). These few examples indicate the importance of considering the use of the ensemble approach in climate modeling to account for the large uncertainty from a single source of simulated data.

In general, for the historical period (also called baseline period) the HadGEM2 model shows South America less rainy and warmer than the MIROC5 (Figures 5 and 12). While Northeastern Brazil, Northern Venezuela and Guyana appear drier for HadGEM2, Argentina and Paraguay showed to be drier for MIROC5. For the baseline period, the MIROC5 model does not present an average annual temperature greater than 25ºC, while the observed official average annual temperature map (1961-1990) from Brazilian National Institute of Meteorology (INMET) shows that this threshold is exceeded in a large part of northern Brazil (Ramos et al., 2009).

The differences in annual rainfall indicate that much of South America will face a mild to strong reduction in rainfall for both models and their ensemble, for the two climate scenarios and all assessed periods (Figure 6 to 11). The differences in 2-m temperature show that all South America will face warmings between 1 and 3ºC, but mainly in central part of Brazil, Paraguay, Bolivia and Peru, the temperature can increase up to 7ºC for HadGEM2 model, under RCP8.5 in the period 2071-2099 (Figure 13 to 18).

In the RCP4.5 scenario and for the 2011-2040 period, the ensemble approach indicated an average rainfall reduction trend of up to 500 mm year^{-1} in most of the southeast, midwest and north of Brazil, an even stronger rainfall reduction (500 to 1000 mm year^{-1}) in the North Atlantic between French Guiana

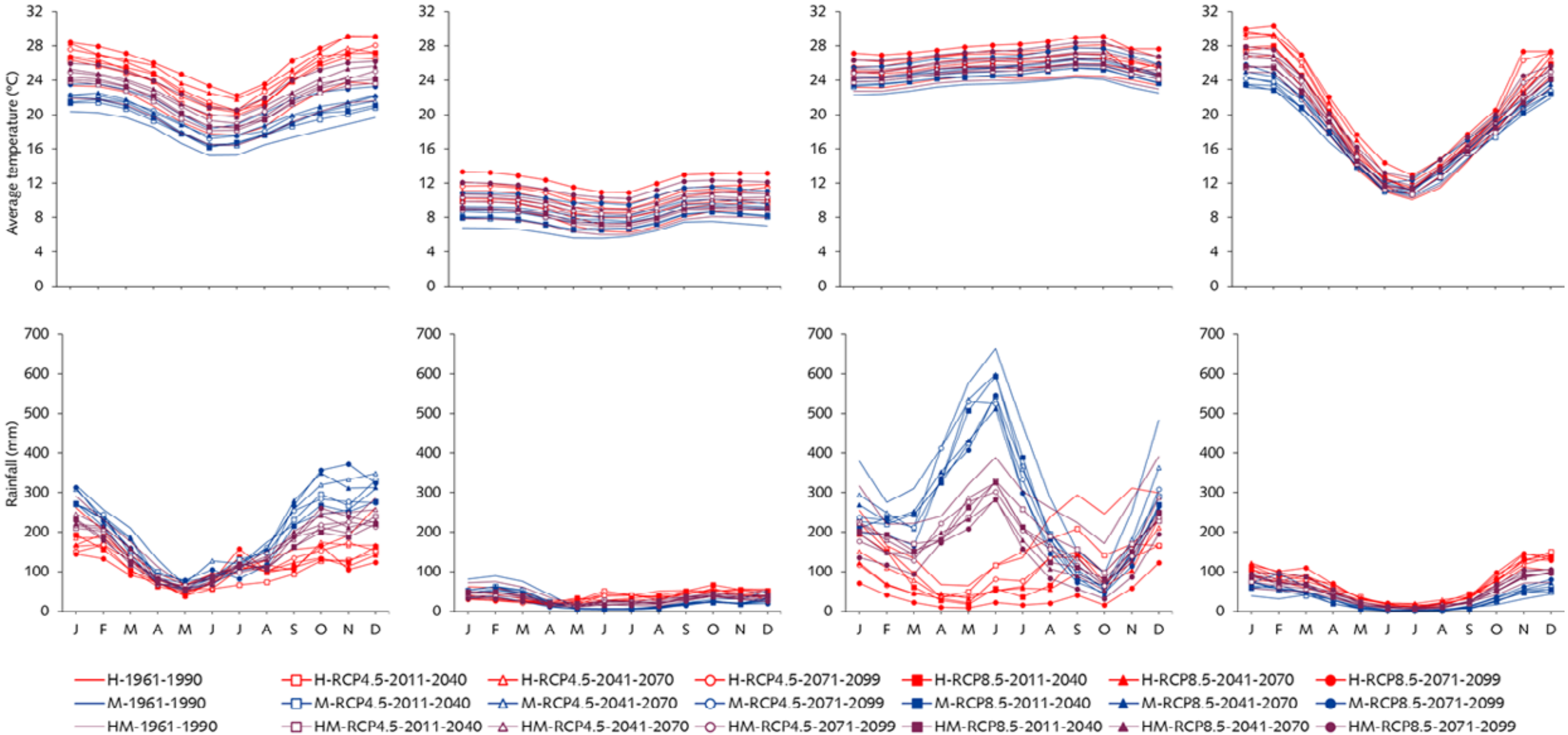

Figure 4. Monthly average air temperature (°C) and rainfall (mm month^{-1}) simulated by the HadGEM2 (H) and MIROC5 (M) models, and their ensembles (HM), for four timeslices, 1961-1990 (baseline), 2011-2040, 2041-2070, 2071-2099, two greenhouse gases emission scenarios, RCP4.5 and RCP8.5, and four locations: Brazil at 46.8°W and 22.4°S (first column), Peru at 72.0°W and 12.6°S (second column), Guyana at 59.2°W and 7.8°S (third column), and Argentina at 63.8°W and 33.0°S (fourth column).

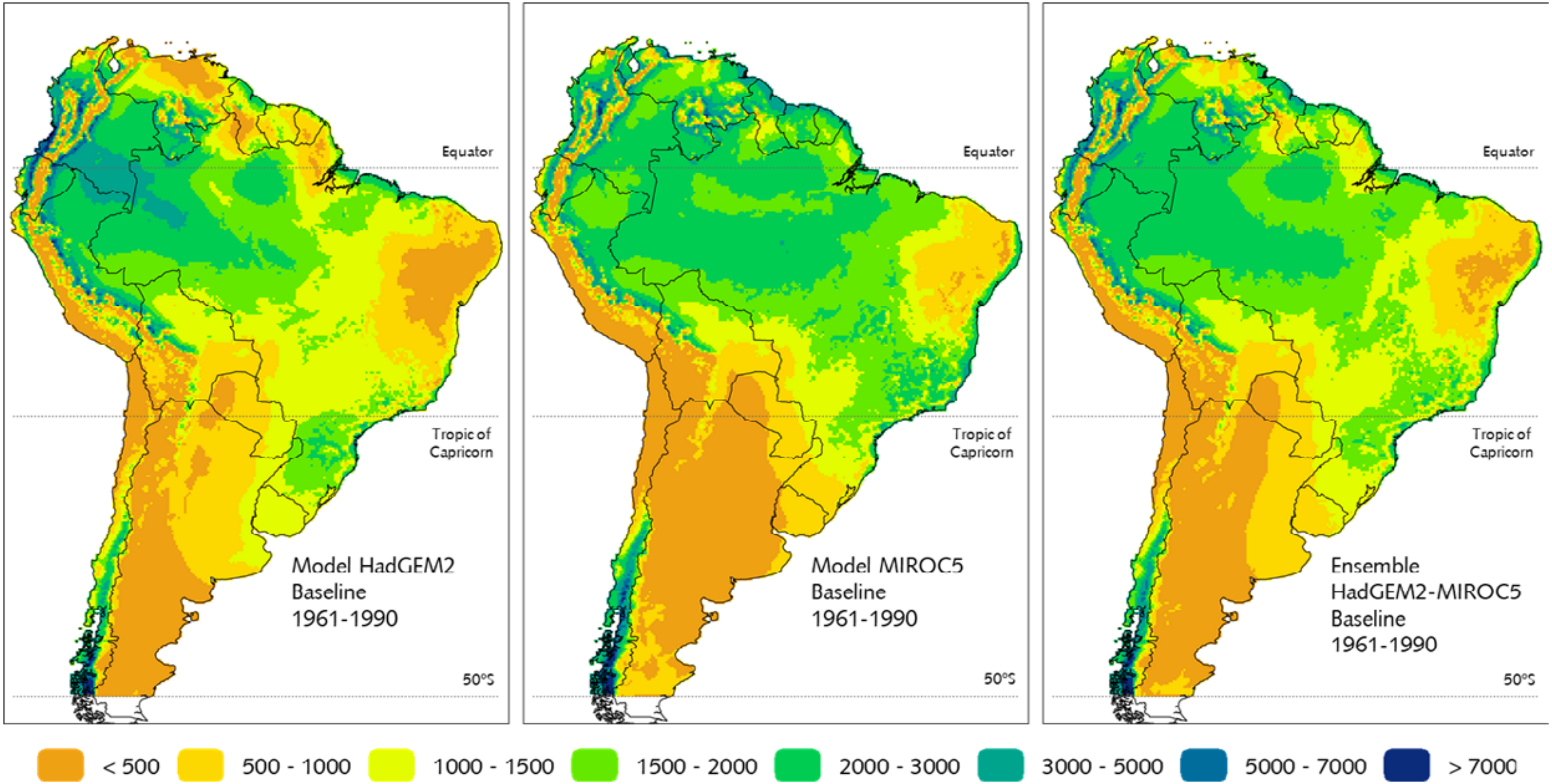

Figure 5. Mean annual rainfall (mm $year^{-1}$) for South America estimated by the HadGEM2 (left) and MIROC5 (middle) models, and their ensembles (right) for the present time (baseline 1961-1990).

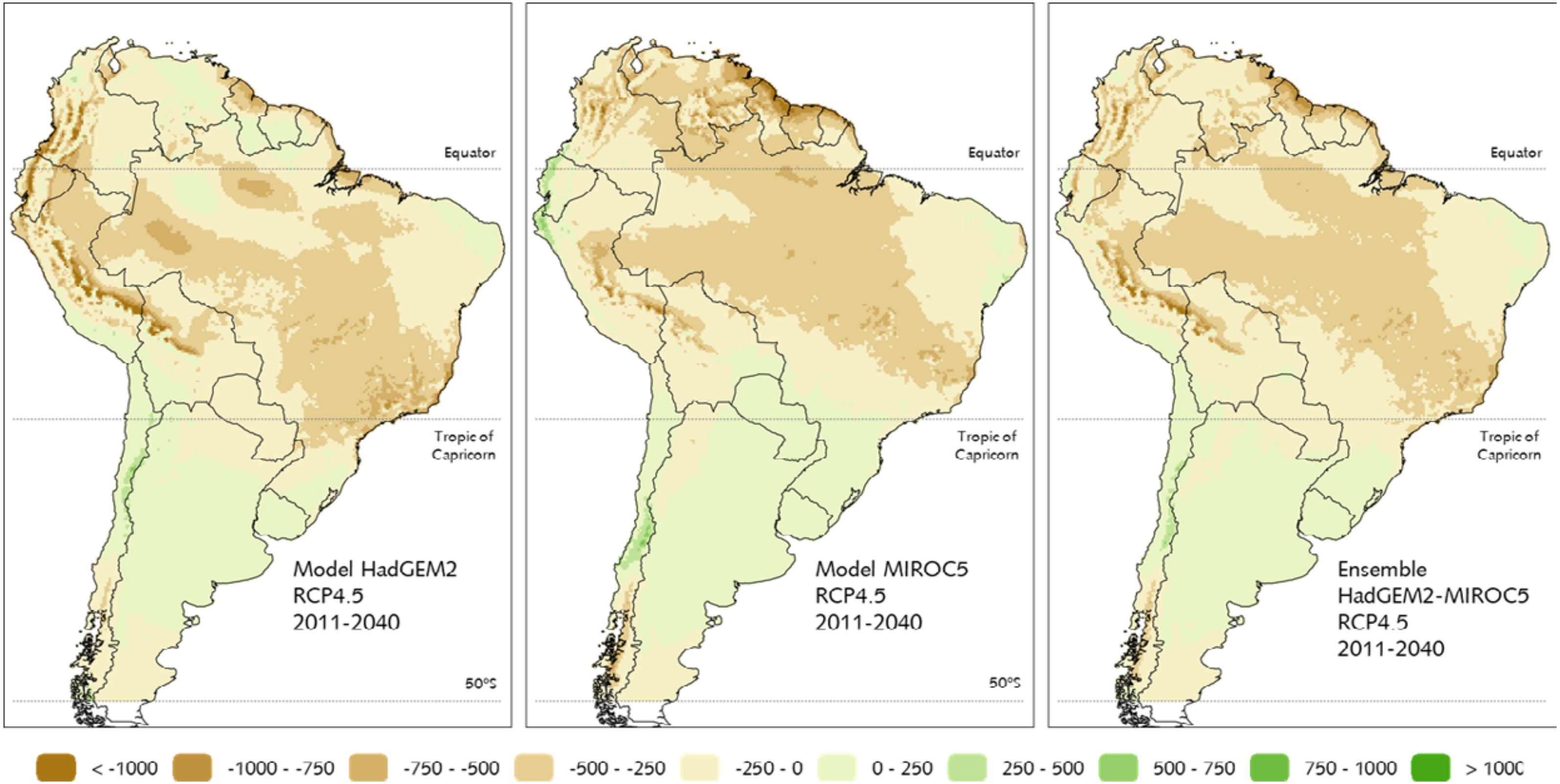

Figure 6. Difference of mean rainfall (mm year^{-1}) between future (2011-2040) and present (1961-1990) periods estimated for RCP4.5 by HadGEM2 (left) and for RCP4.5 by MIROC5 (middle), and their ensembles (right).

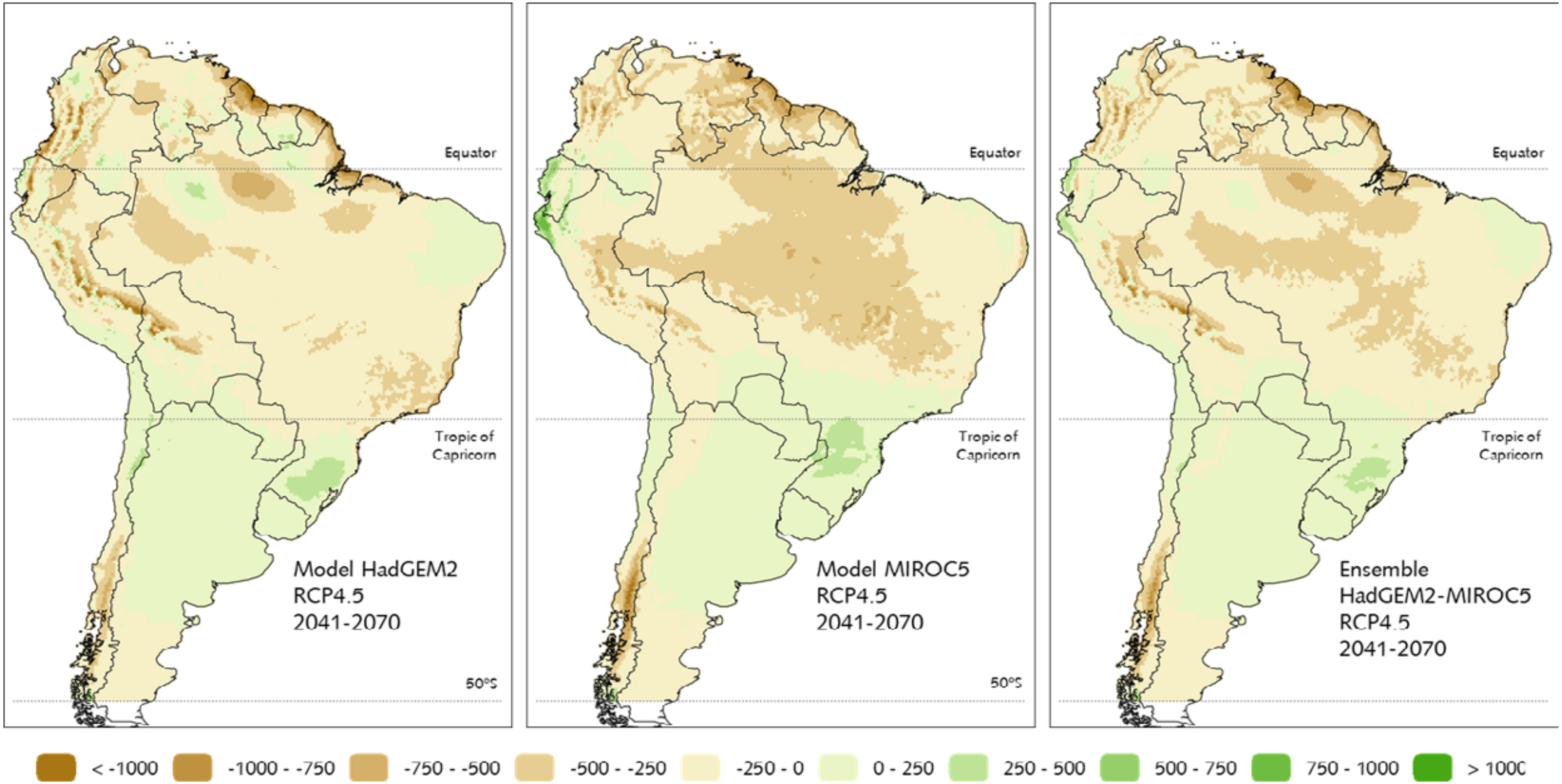

Figure 7. Difference of mean rainfall (mm year-1) between future (2041-2070) and present (1961-1990) periods estimated for RCP4.5 by HadGEM2 (left) and for RCP4.5 by MIROC5 (middle), and their ensembles (right).

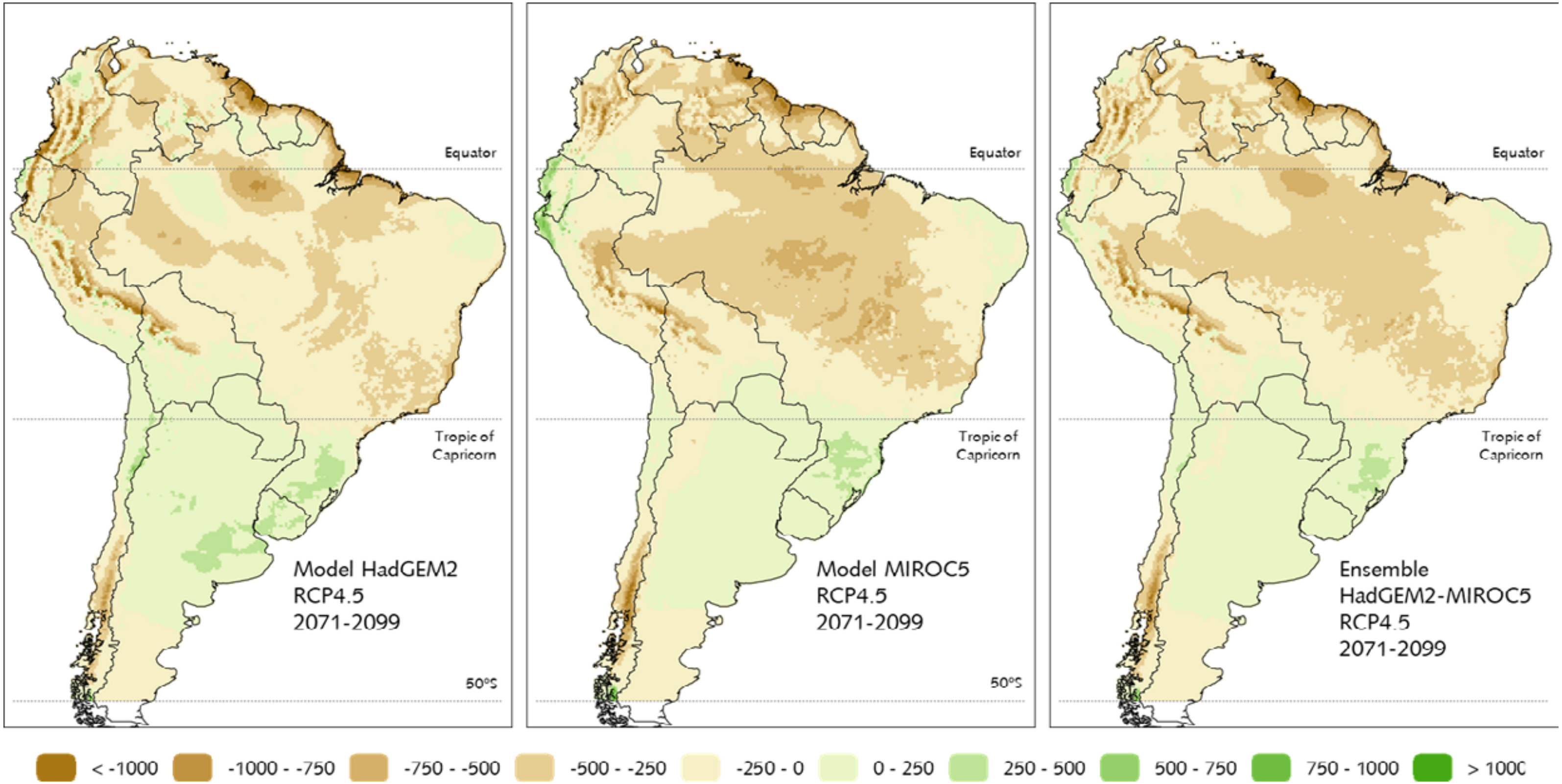

Figure 8. Difference of mean rainfall (mm year^{-1}) between future (2071-2099) and present (1961-1990) periods estimated for RCP4.5 by HadGEM2 (left) and for RCP4.5 by MIROC5 (middle), and their ensembles (right).

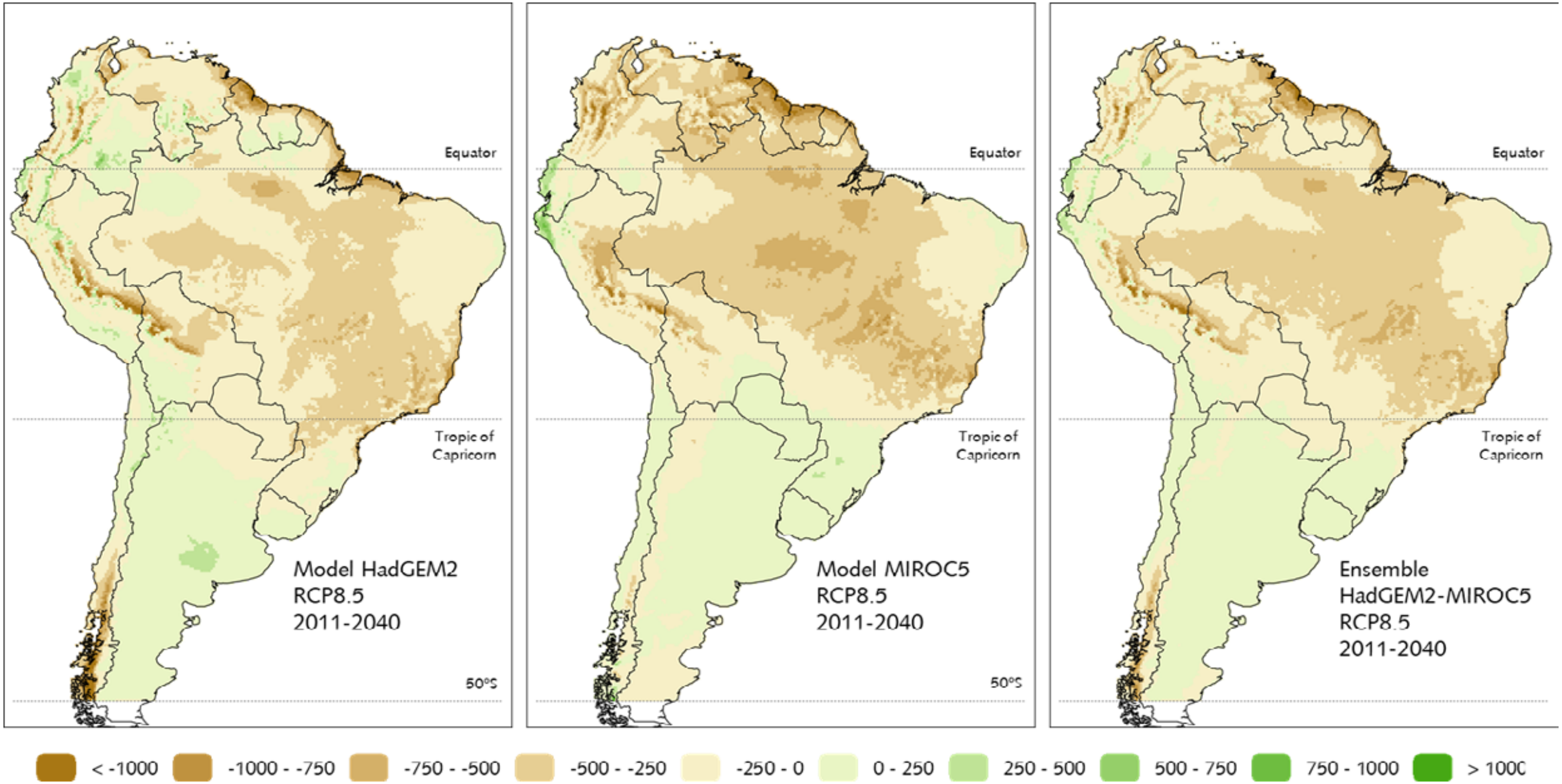

Figure 9. Difference of mean rainfall (mm year^{-1}) between future (2011-2040) and present (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

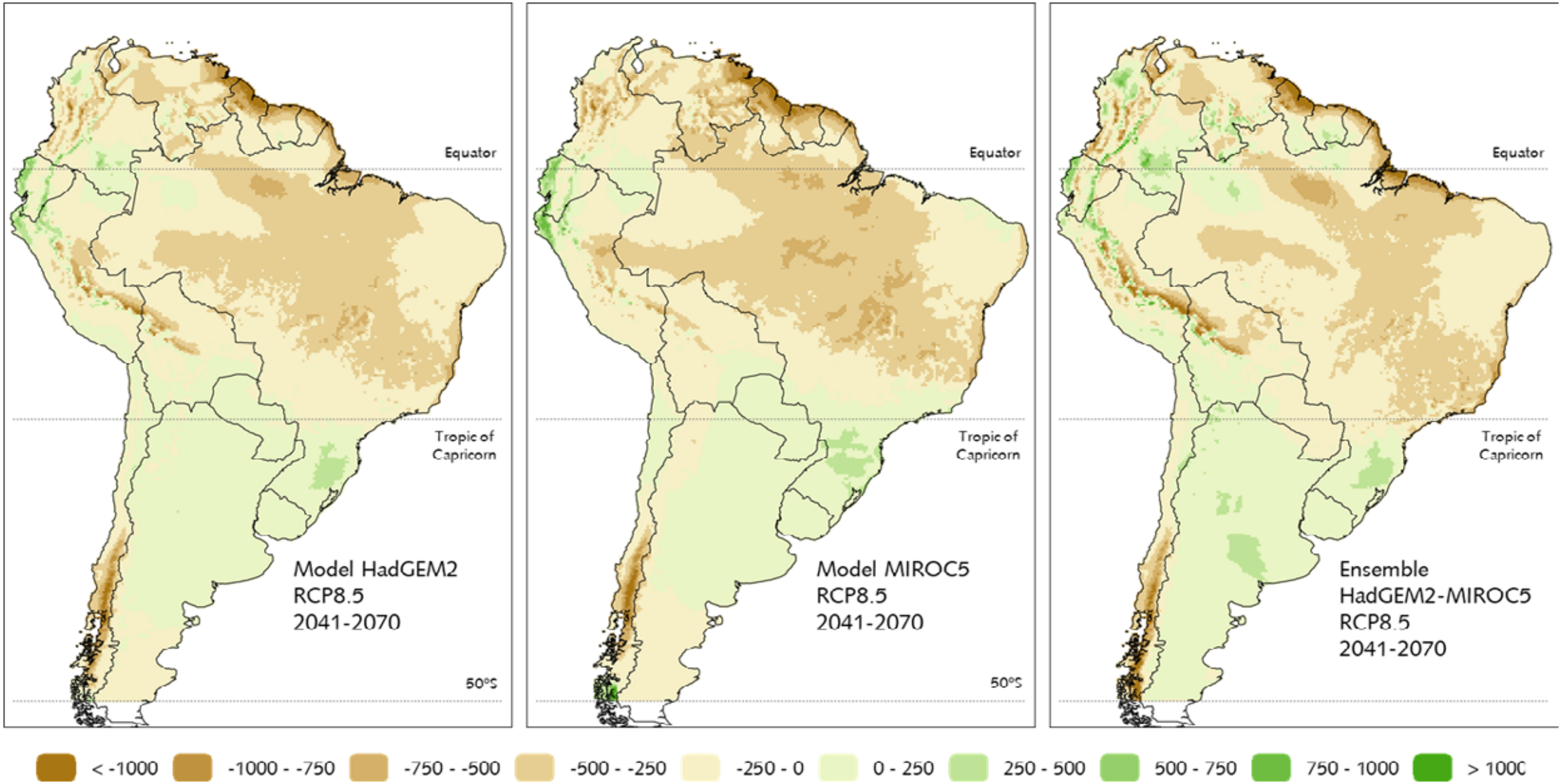

Figure 10. Difference of mean rainfall (mm year^{-1}) between future (2041-2070) and present (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

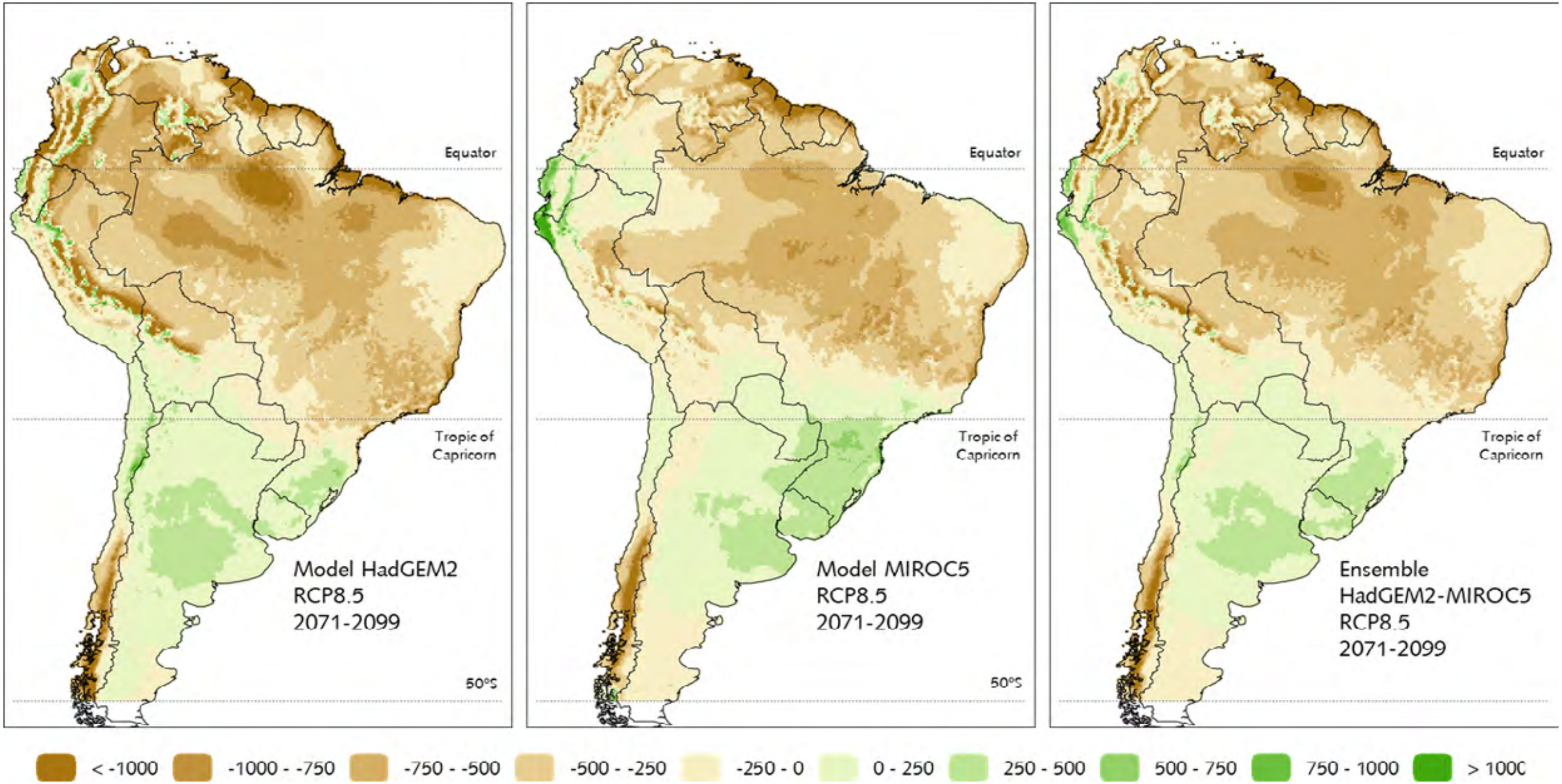

Figure 11. Difference of mean rainfall (mm year[-1]) between future (2071-2099) and present (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

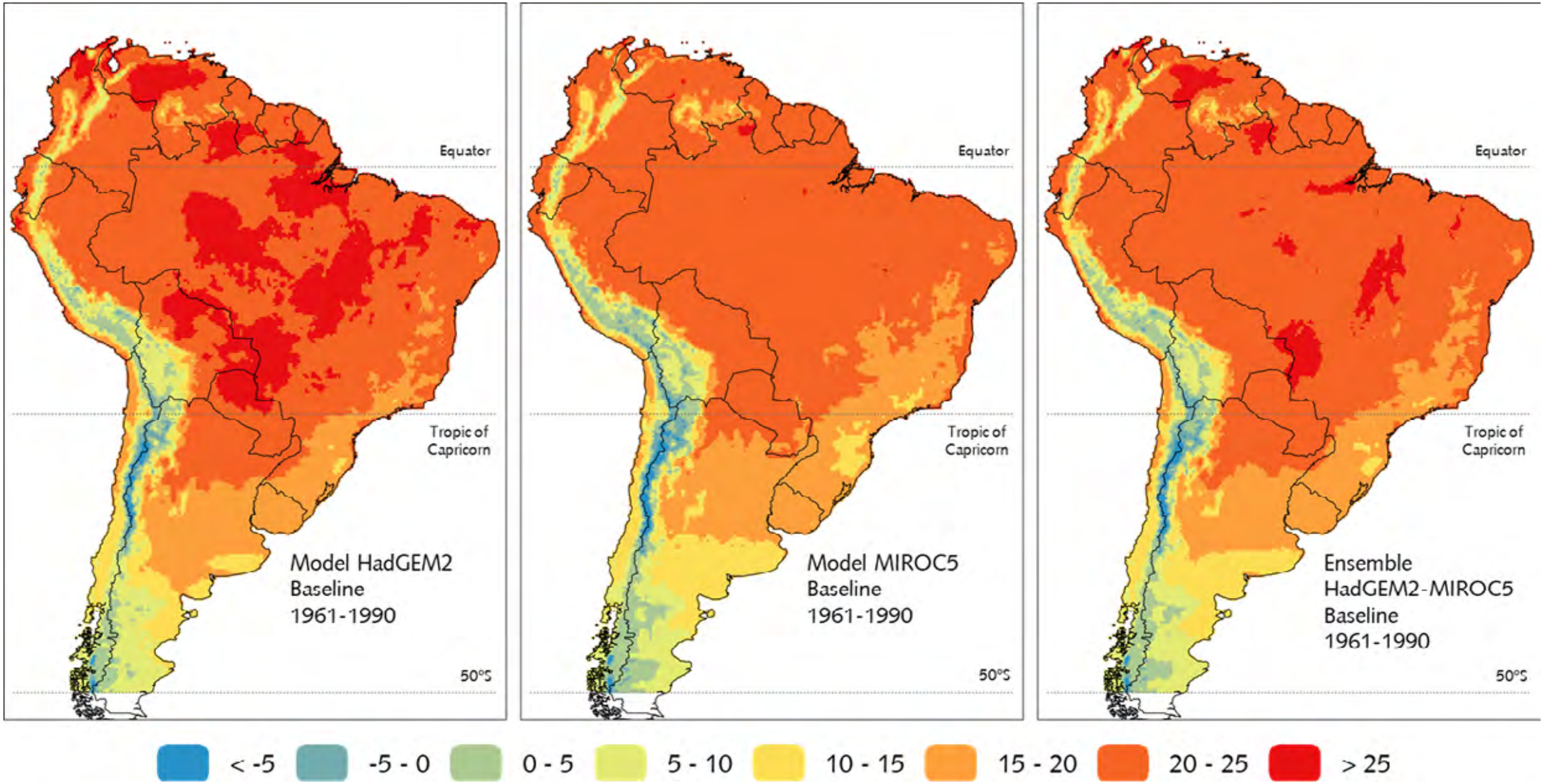

Figure 12. Mean annual 2-m air temperature (°C) for South America estimated by the HadGEM2 (right) and MIROC5 (middle) models, and their ensembles (left) of the present time (baseline 1961-1990).

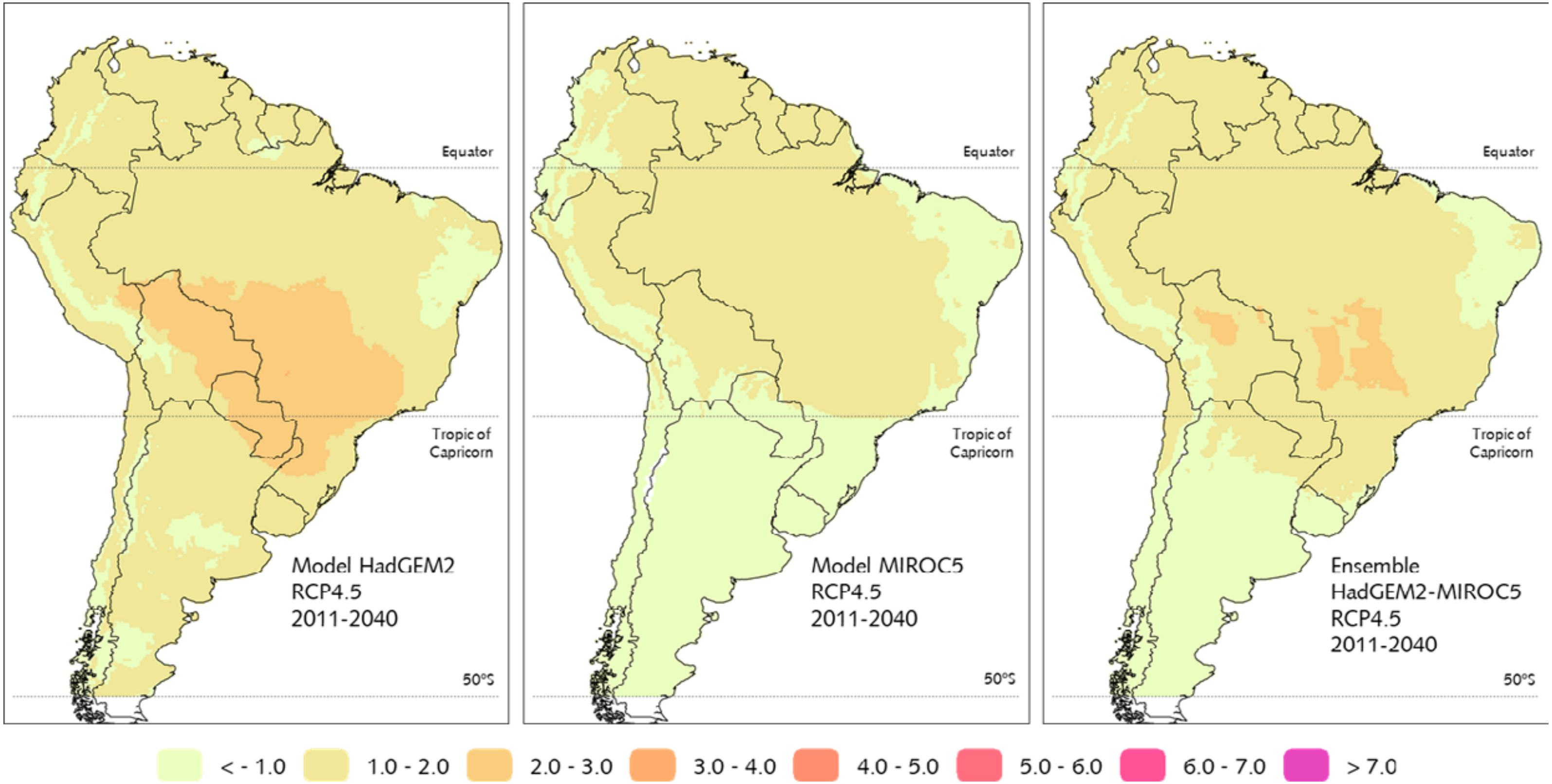

Figure 13. Difference of mean annual 2-m air temperature (ºC) between future (2011-2040) and baseline (1961-1990) periods estimated for RCP 4.5 by HadGEM2 (left) and for RCP 4.5 by MIROC5 (middle), and their ensembles (right).

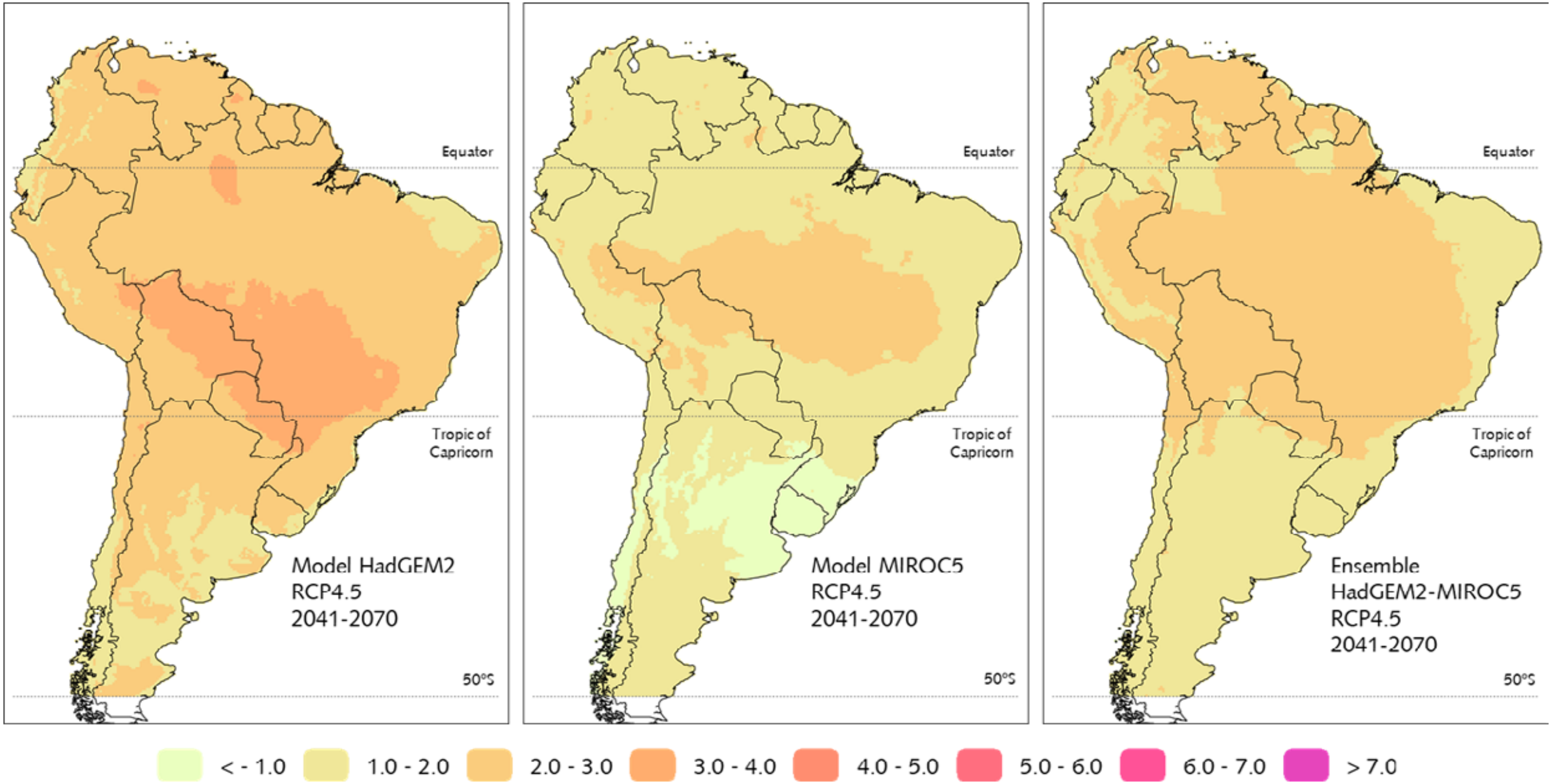

Figure 14. Difference of mean annual 2-m air temperature (ºC) between future (2041-2070) and baseline (1961-1990) periods estimated for RCP4.5 by HadGEM2 (left) and for RCP4.5 by MIROC5 (middle), and their ensembles (right).

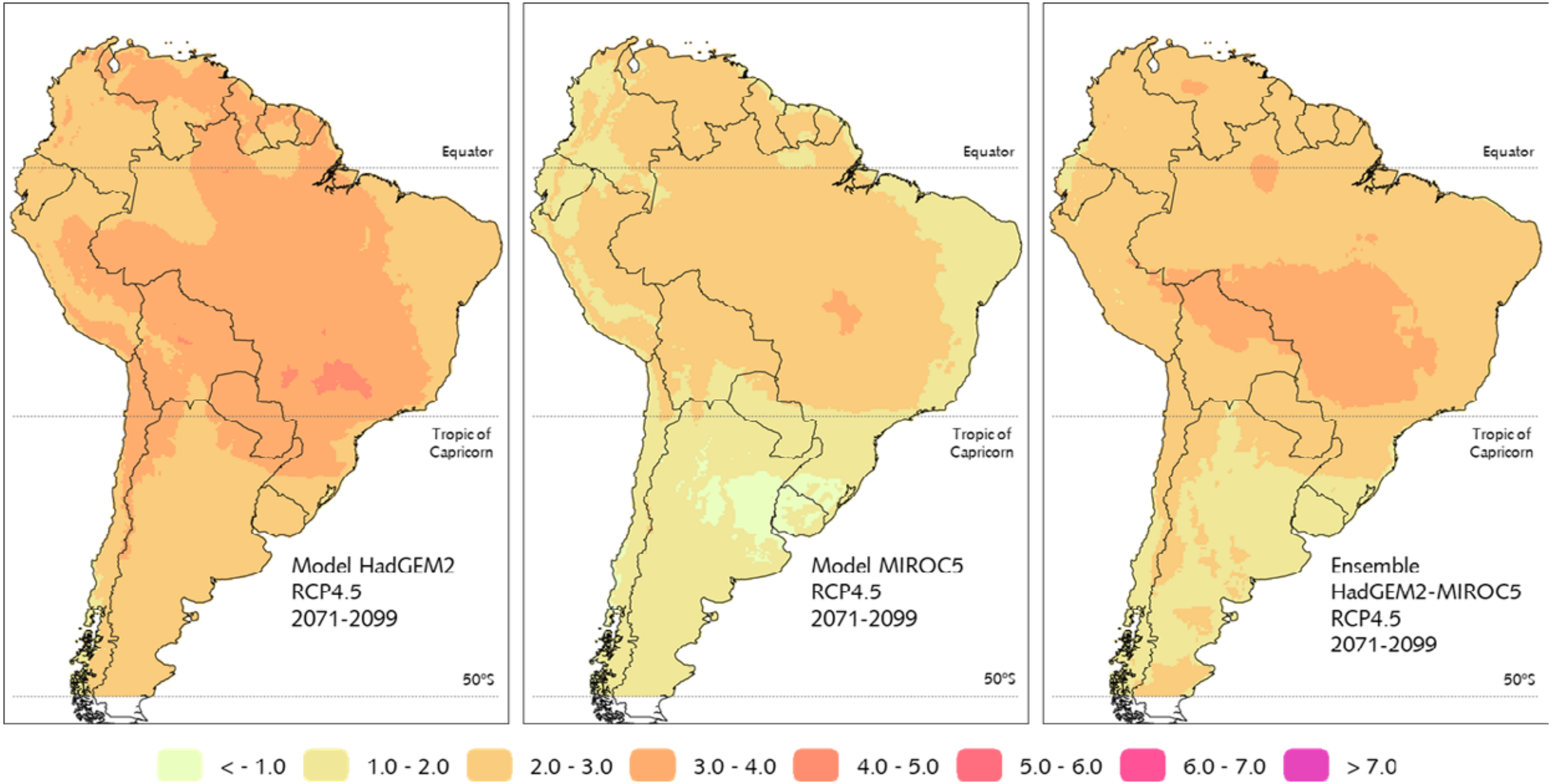

Figure 15. Difference of mean annual 2-m air temperature (ºC) between future (2071-2099) and baseline (1961-1990) periods estimated for RCP4.5 by HadGEM2 (left) and for RCP4.5 by MIROC5 (middle), and their ensembles (right).

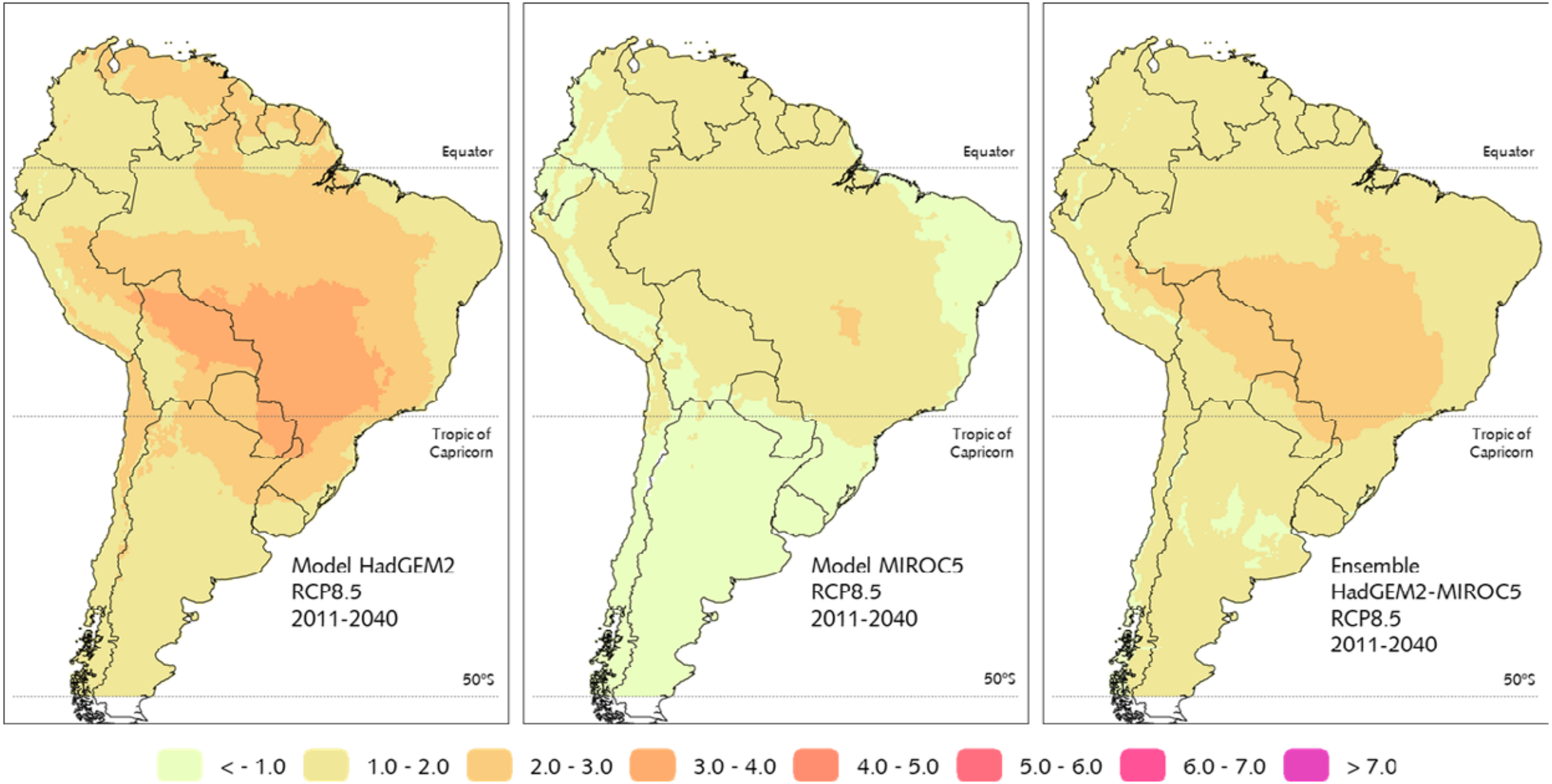

Figure 16. Difference of mean annual 2-m air temperature (ºC) between future (2011-2040) and baseline (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

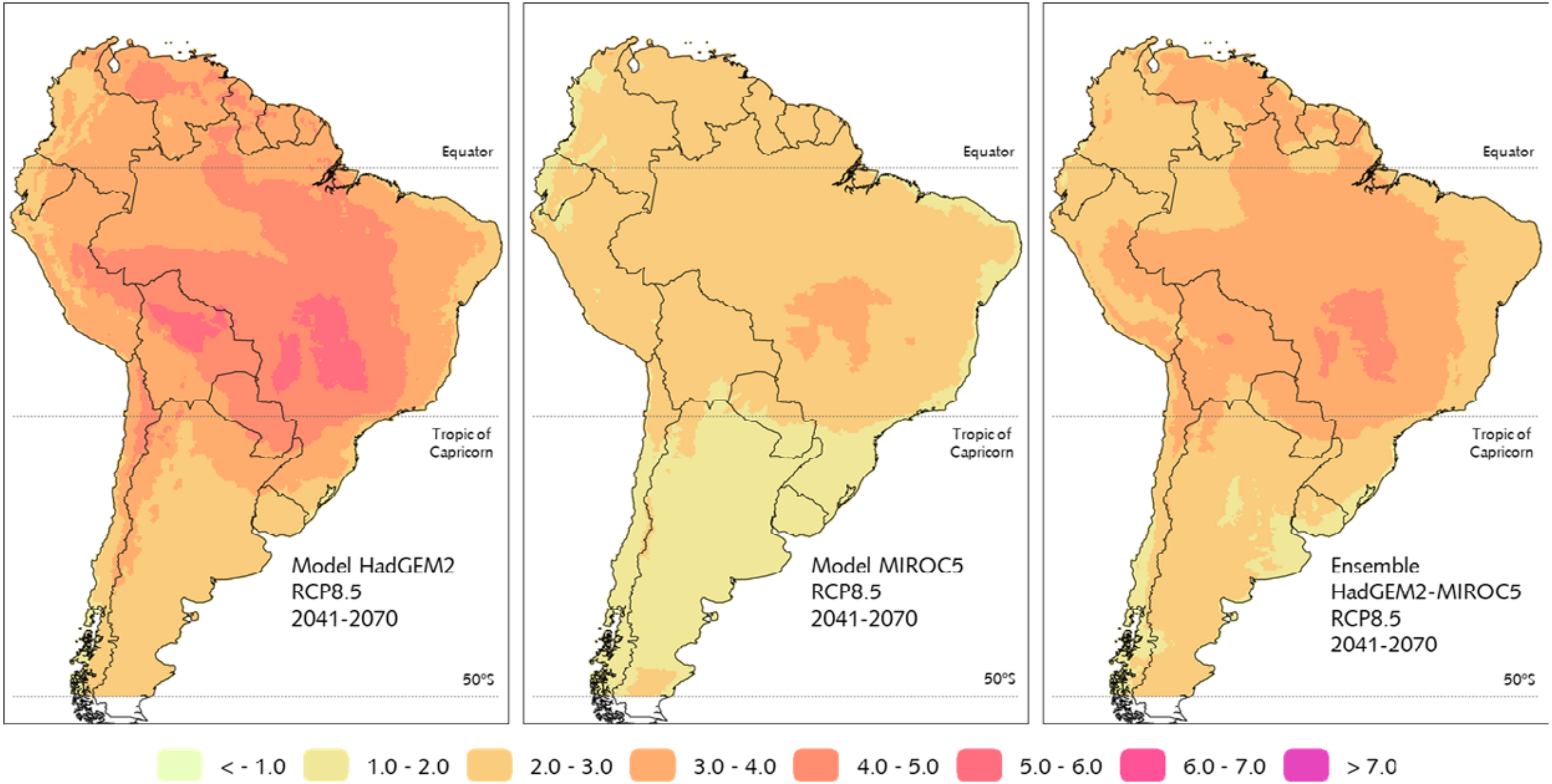

Figure 17. Difference of mean annual 2-m air temperature (°C) between future (2041-2070) and baseline (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

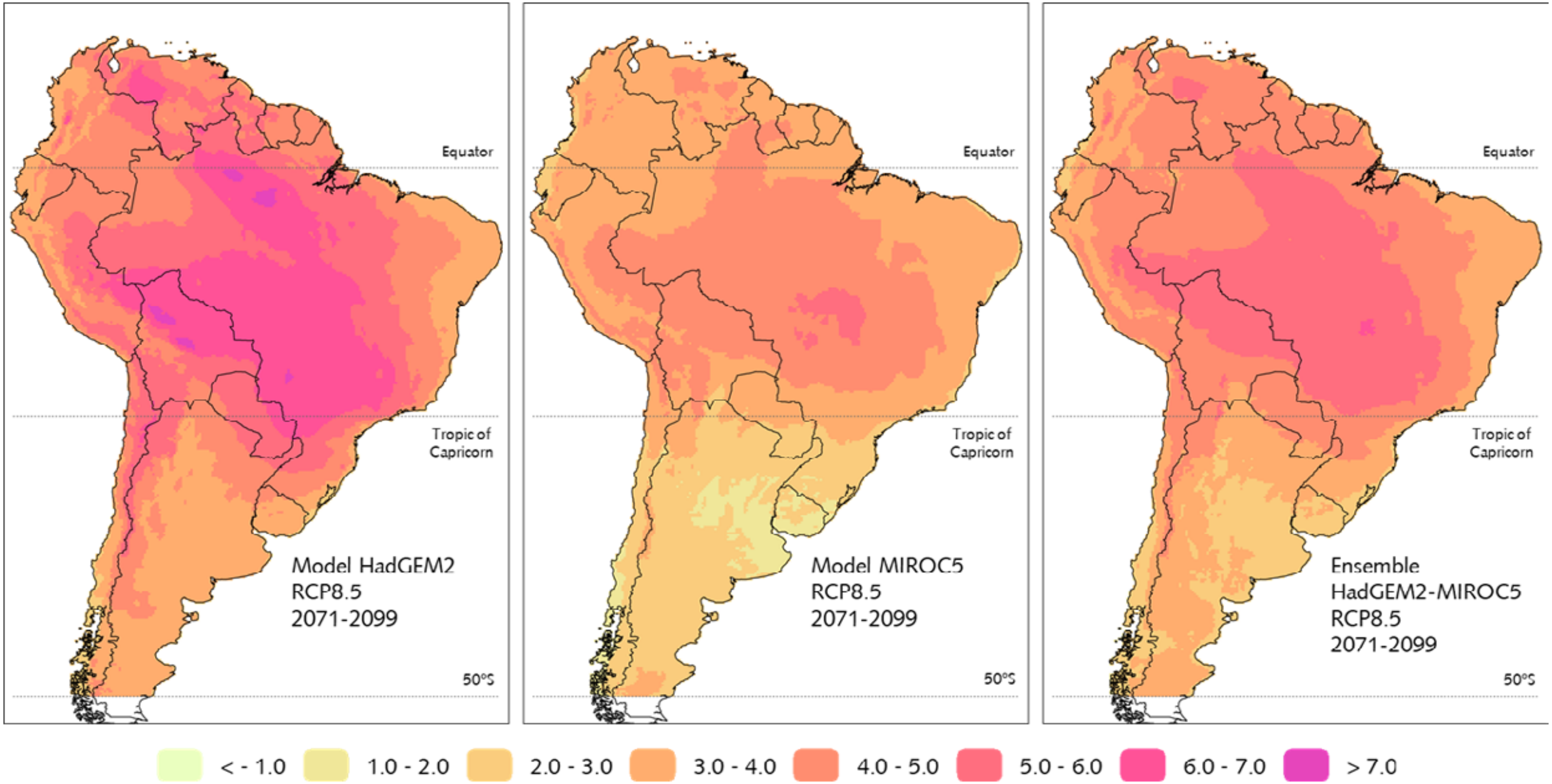

Figure 18. Difference of mean annual 2-m air temperature (°C) between future (2071-2099) and baseline (1961-1990) periods estimated for RCP8.5 by HadGEM2 (left) and for RCP8.5 by MIROC5 (middle), and their ensembles (right).

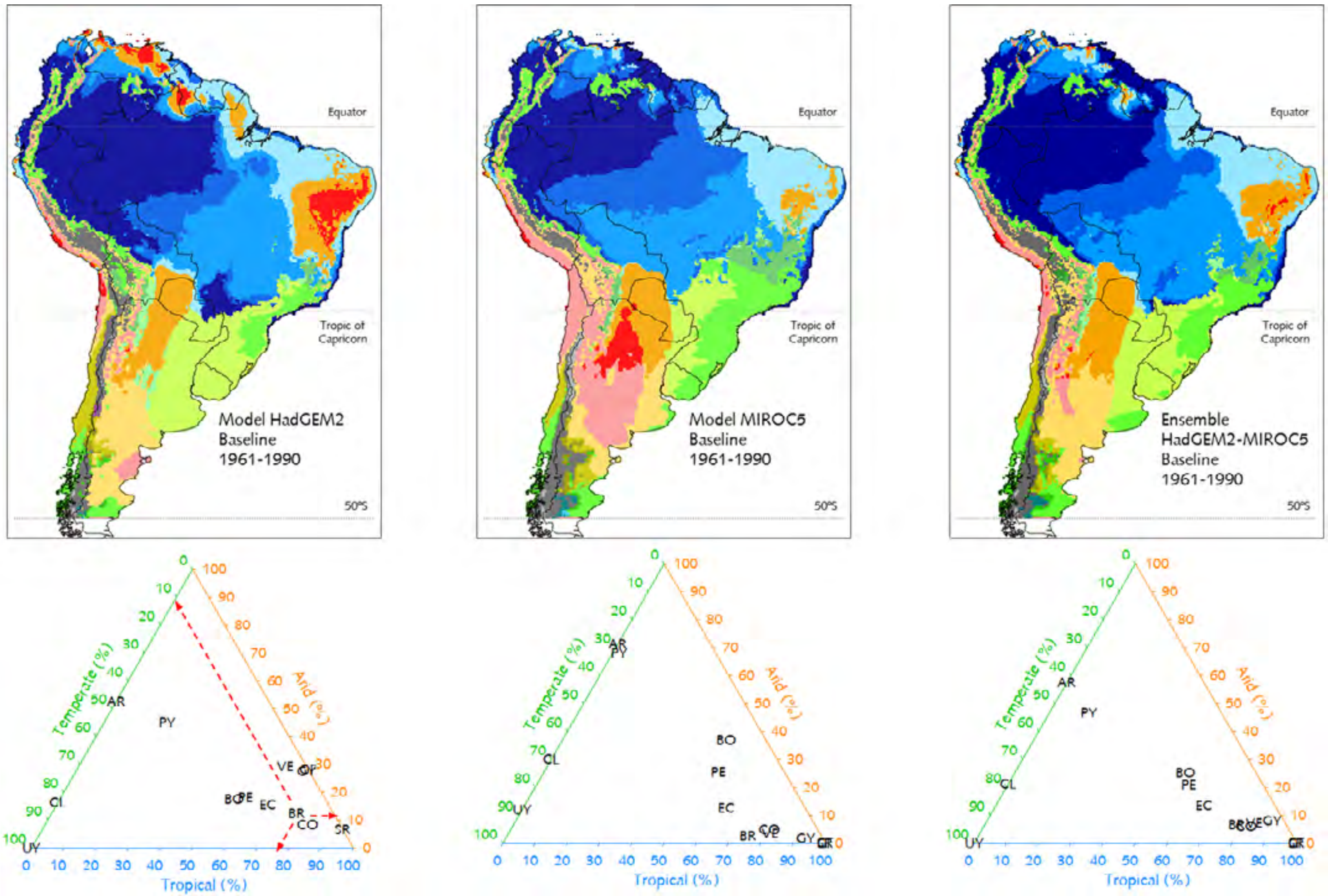

Figure 19. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 1961–1990. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios. Example to read the ternary chart (left): Brazil (BR): Tropical = 76.3%, Arid = 12.4%, Temperate = 11.3%.

and western Venezuela. A reduction of similar magnitude (500 to 1000 mm $year^{-1}$) is also projected for the Andean regions of Bolivia, Peru, Ecuador, Colombia, and for the extreme south of Chile (Figure 6). Conversely, in a small portion of northeastern and southern Brazil, almost all of Uruguay, a large part of Argentina and Chile is expected a rainfall increase of up to 250 mm $year^{-1}$ in relation to the baseline period (1961-1990). In this scenario and period, the ensemble model shows a warming of less than 1°C for a large part of Argentina and Uruguay, southern Chile, and the Andean region of Bolivia, Peru, Ecuador and Colombia, up to 2°C for a large part of Brazil and north of the South American continent, and between 2°C and 3°C for central-western Brazil and Bolivia (13).

In the RCP4.5 scenario and the 2041-2070 period, the ensemble approach pointed to a South America slightly less dry than the previous period. Figure 7 shows an average reduction trend of up to 500 mm $year^{-1}$ for some parts of the midwest and north of Brazil. The strong rainfall reduction in the North Atlantic between French Guiana and western Venezuela will persist for the period 2041-2070, whereas a reduction in rainfall for the Andean regions of Bolivia, Peru, Ecuador, and Colombia will be slightly milder. However, in the far south of Chile a strong rainfall reduction (500 to 750 mm $year^{-1}$) is expected. Most of Argentina, Uruguay, and Paraguay, are expected to increase rainfall in about 250 mm $year^{-1}$ compared to the baseline of 1961-1990. In southern Brazil and part of Ecuador, the trend of increased rainfall reaches amounts of up to 500 mm $year^{-1}$ (Figure 7). In this scenario and period, the ensemble approach indicates that South America will experience a minimum warming of 1°C in annual temperature throughout its area. In most of Brazil, Bolivia, Peru, Ecuador and Venezuela, Guyana, Suriname, and French Guiana, the temperatures will increase between 2 and 3°C (Figure 14).

In scenario RCP4.5 and period 2071-2099, the ensemble of the models indicate that annual rainfall in South America will be very similar to the previous period, with rainfall patterns persisting similar to 2041-2070. In this scenario and period, a greater negative deviation of rainfall in the central part of Brazil, including the Amazon region, will occur, which draws attention to the risks for the Amazon rain forest (Figure 8). In this scenario and period, the ensemble approach shows that a major part of South America will face a warming of at least 2°C in annual average temperature, whereas in the central regions of Brazil and Bolivia the expected warming will be between 3°C and 4°C (Figure 15).

In the RCP8.5 scenario it is noticed that the extreme differences will be stronger and evident. In all future periods most of Brazil, southern Chile, Venezuela, Guyana, Suriname, French Guiana, Bolivia, Peru, and Colombia will experience a rainfall reduction of up to 1000 mm year^{-1}, which is of dramatic concern. On the other hand, southern Brazil, Argentina, and Uruguay will have rainfall increase of about 750 mm year^{-1} (Figures 9, 10, 11). In this scenario, the ensemble of the models shows that South America will suffer warming of 1°C to 3°C in the annual average temperature in the period 2011-2040, of 2°C to 4°C in the period 2041-2070, and of 3°C to 6°C in the period of 2071-2099. The maps that show the differences of mean annual 2-m temperature between the successive periods of time indicate that the central regions of Brazil, Paraguay, Bolivia, Peru, and Venezuela are those that will be mostly affected by global warming (Figures 16, 17, 18).

As previously highlighted, HadGEM2 projects a warmer and drier South America than MIROC5, which will result in drier tropical and less temperate climate types in all scenarios and periods assessed when using this model. Despite these differences, the future climate scenarios will be presented mainly as the ensemble of the two models, and when necessary, we will highlight the specific outcomes of the single model (Figures 19 to 28).

These differences in rainfall and temperature with respect to the baseline period are translated into significant climate change in almost all countries in South America. In scenario RCP4.5 and period 2011-2040, the ensemble model shows increasing trends of arid climate types (BSh, BWh) over the tropical climate types (As, Aw) in Brazil, Venezuela, and Guyana. In Argentina, there is a trade-off between arid (BSh) and temperate (Cfa) climates (Figure 20). In the following period (2041-2070), the results show a continuous expansions of the tropical climate types (Af, Aw) towards southeastern Brazil, and the decline of polar climate types (ET) in the extreme south of Argentina and Chile (Figure 21). In the period 2071-2099, the results draw attention mainly to the increase of the dry tropical climate types (As, Aw) over the humid tropical climate types (Af, Am) in the Amazon regions of Brazil, Bolivia, and Peru, as well as the alarming and strong expansions of arid climate types (BSh, BWh) in Brazil, Bolivia and Venezuela (Figure 22). Finally, a short summary of climate change fluxes between arid, tropical, and temperate climates is show in Figure 28. Arid climate will expand continuously from 19% of the baseline period, to 21% in 2011-2040, to 21% in 2041-2070, and to 22% in 2071-2099, mainly over tropical climates. Temperate climates will decline sharply in 2011-2040 to only 22% of the continent, 21% in 2041-2070, and 20% in 2071-2099. Tropical climates tend to expand from 56% for the baseline period, to 57% in 2011-2040 and 58% in 2041-2070 and 2071-2099.

In the scenario RCP8.5 and period 2011-2040, the ensemble model shows still stronger increasing trends of the arid climate types (BSh, BWh) over the tropical climate types (As, Aw) in Brazil, and over the temperate climate types (Cwa, Cwb) in southern of Brazil (Figure 23). Also, it is observed a continuous advance of tropical climate types (Af, Aw) in southeastern Brazil, and rapid expansion of climate type Af on frontiers Paraguai, Argentina, and Brasil. In the following period, a decline of polar climate types (ET) in the extreme south of Argentina and Chile is projected (Figure 24). The results also show stronger and increasing trends of the arid climate types (BSh, BWh) over the tropical climate types (As, Aw) in Venezuela, Guyana, Bolivia, Paraguai, and Brazil. In the period 2071-2099, the projection generates a major concern since arid climates (BSh, BWh) will expand throughout northeast, part of southeast and north of Brazil (Figure 25). Attention should be given mainly to the increase in dry tropical climate types (As, Aw) over the humid tropical climate types (Af, Am) in the Amazon region of Brazil. Temperate climate types in the southeast of Brazil and in part of the south may disappear at the end the 21st century with the global warming. Current polar climates are expected to decline or disappear in most of the Andean regions of Argentina, Chile, Bolivia, and Peru. Also, the results from the ensemble approach indicates that common temperate altitude climates of southern Brazil may no longer exist until the end of this century. Finally, we made another Sankey plot to show the summary of climate change fluxes between arid, tropical, and temperate climates for the RCP8.5 scenario (Figure 28). Arid climate will rapidly expand from 19% of the continent area at the baseline period, to 21% in 2011-2040, to 23% in 2041 -2070, and to 26% in 2071-2099, and this will occur mainly in

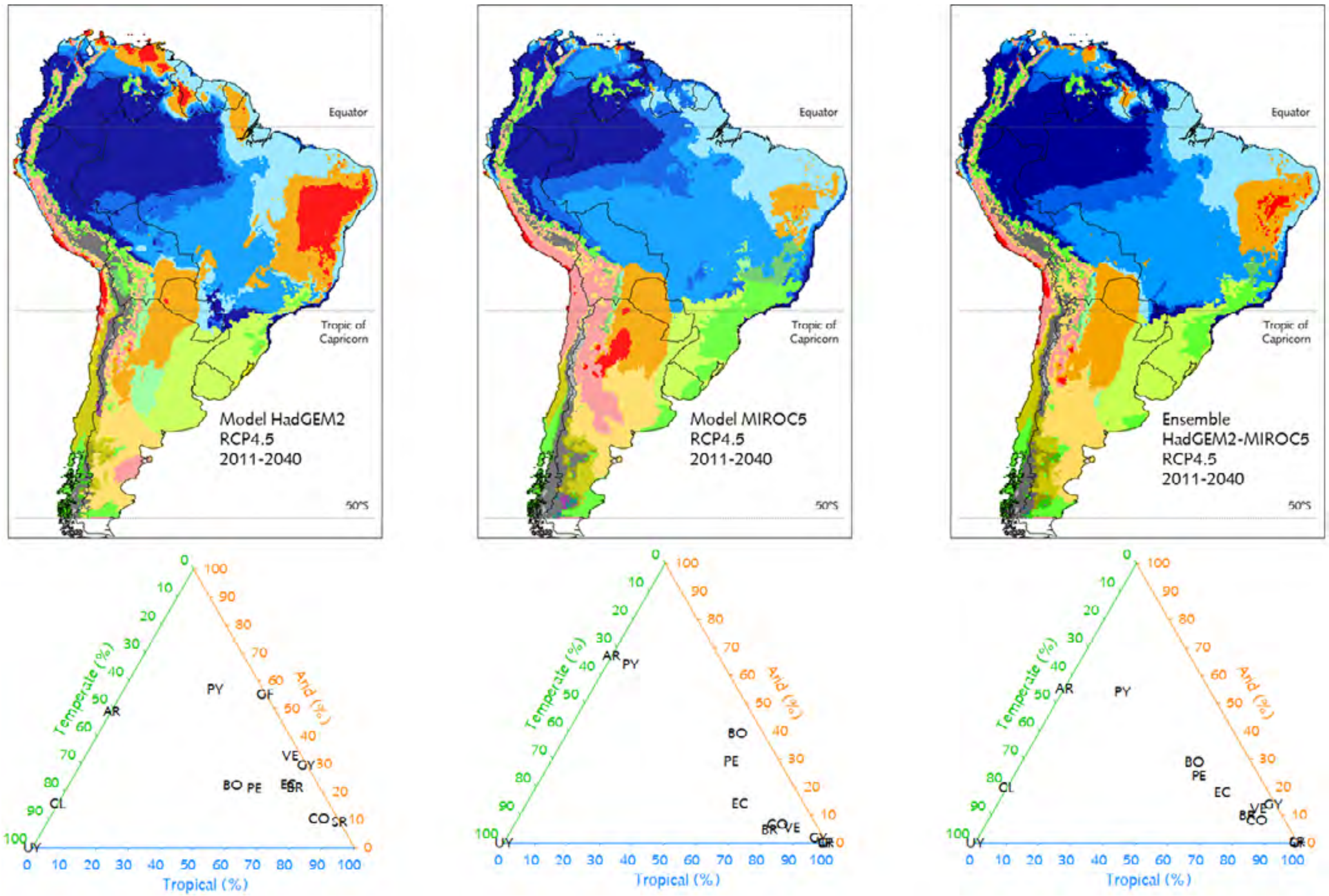

Figure 20. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2011–2040 and climate scenario RCP4.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

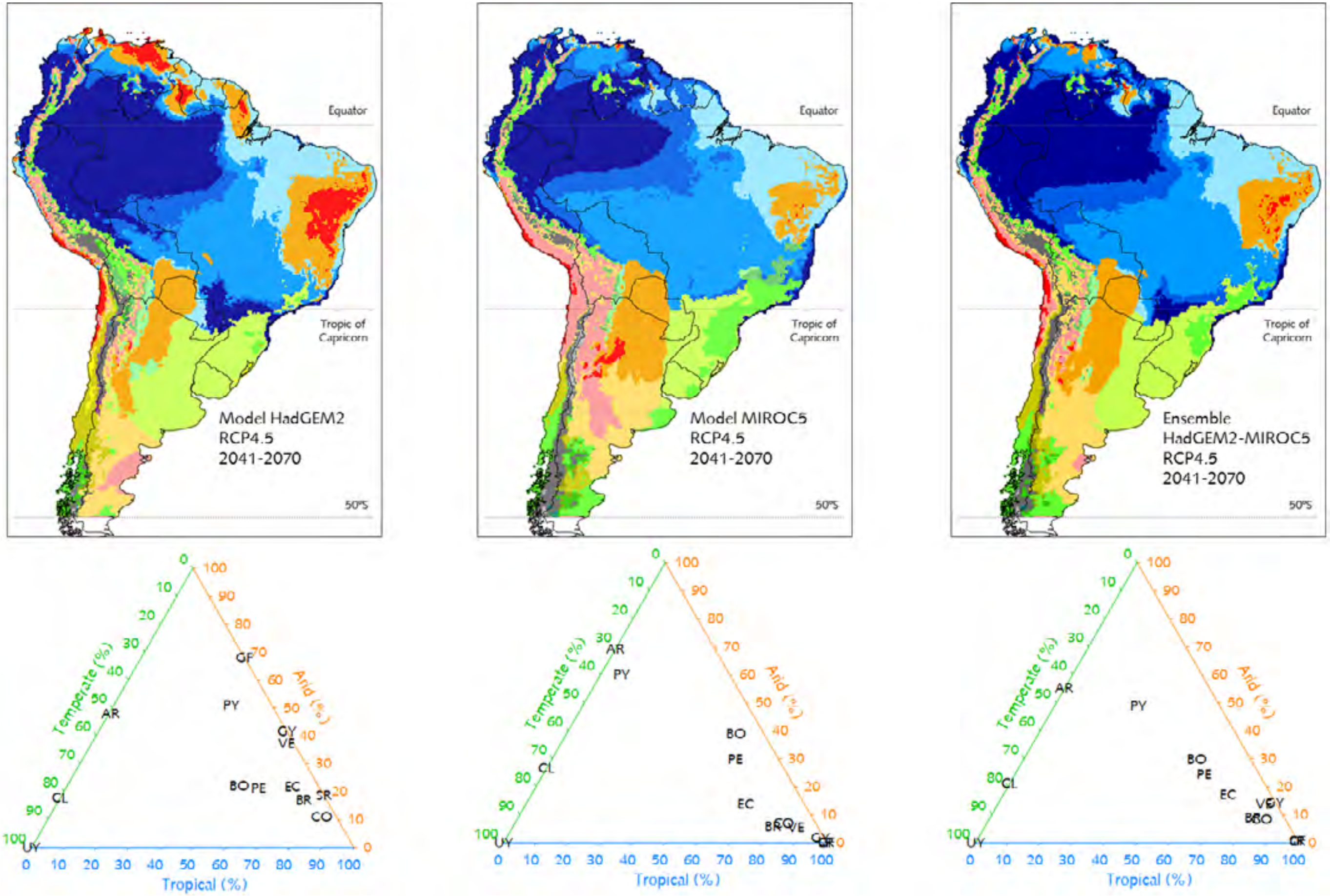

Figure 21. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2041–2070 and climate scenario RCP4.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

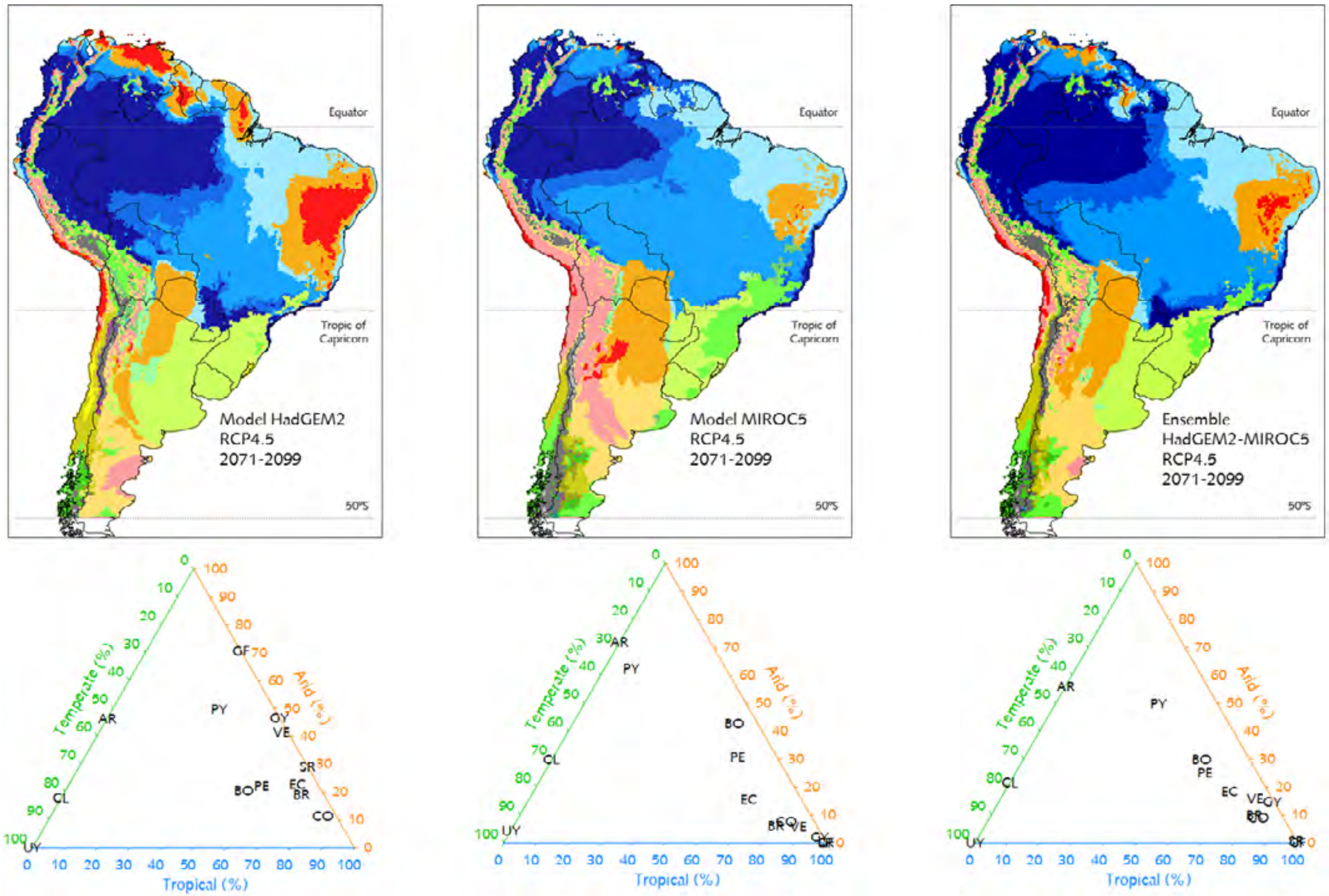

Figure 22. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2071–2099 and climate scenario RCP4.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

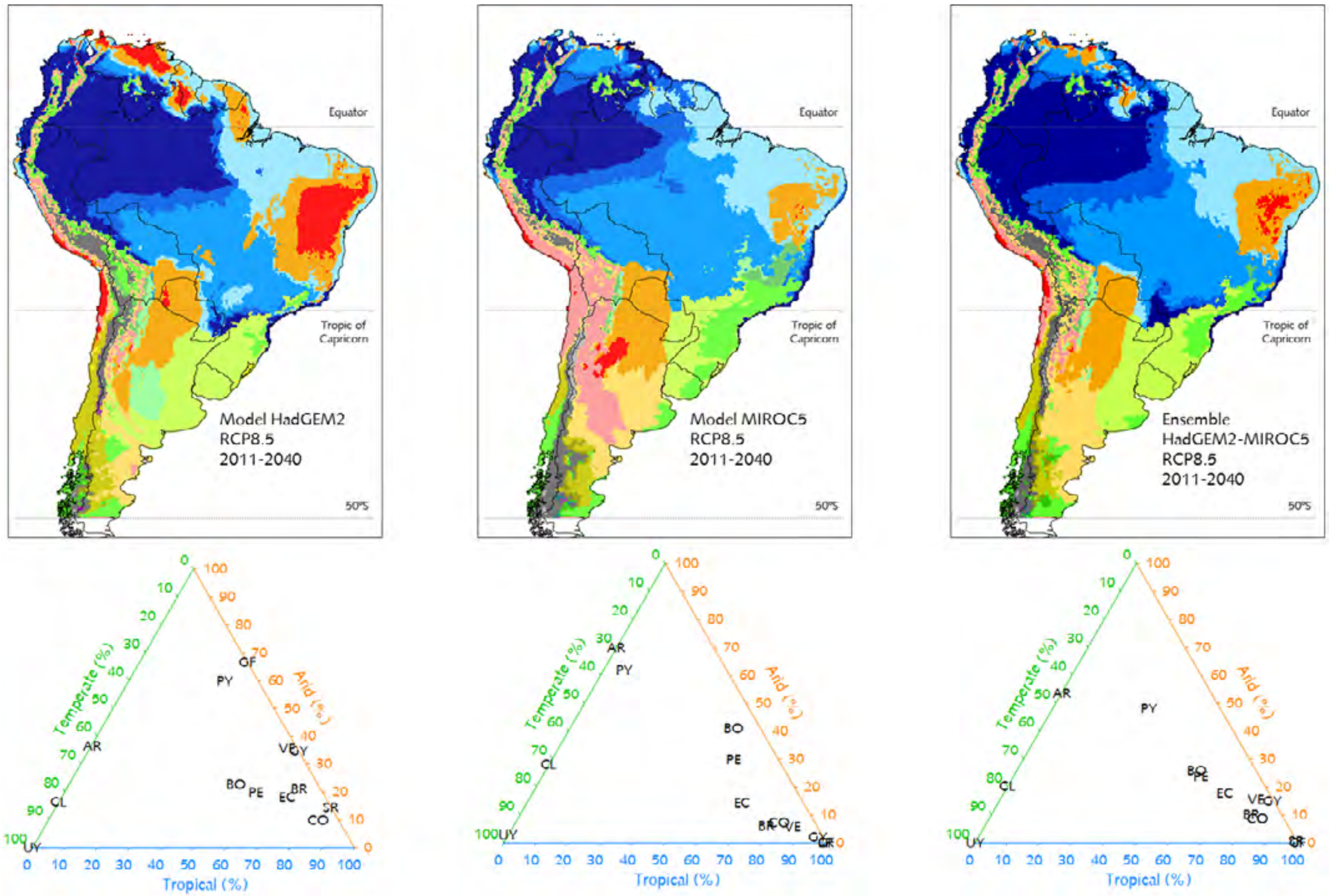

Figure 23. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2011–2040 and climate scenario RCP8.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

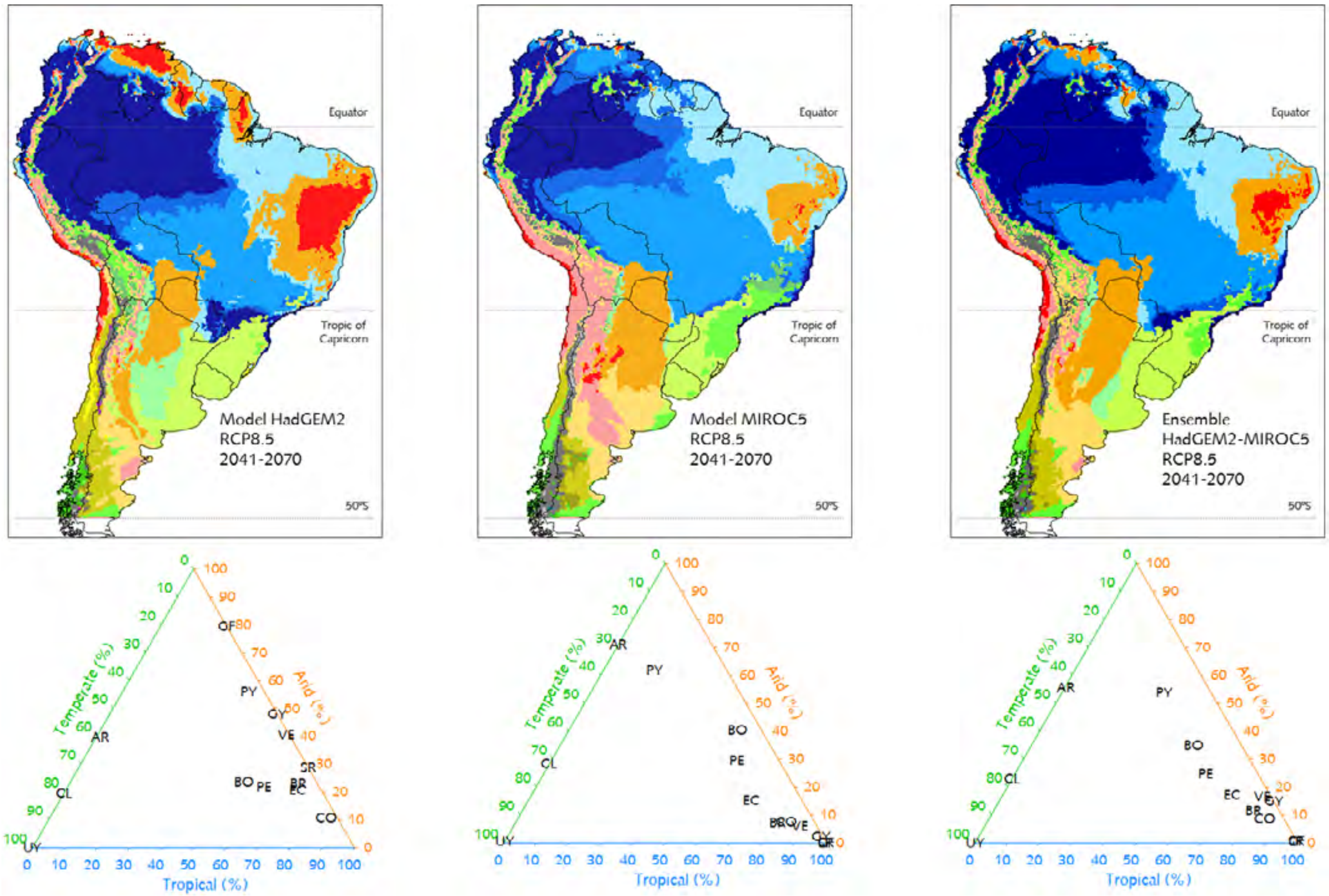

Figure 24. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2041–2070 and climate scenario RCP8.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

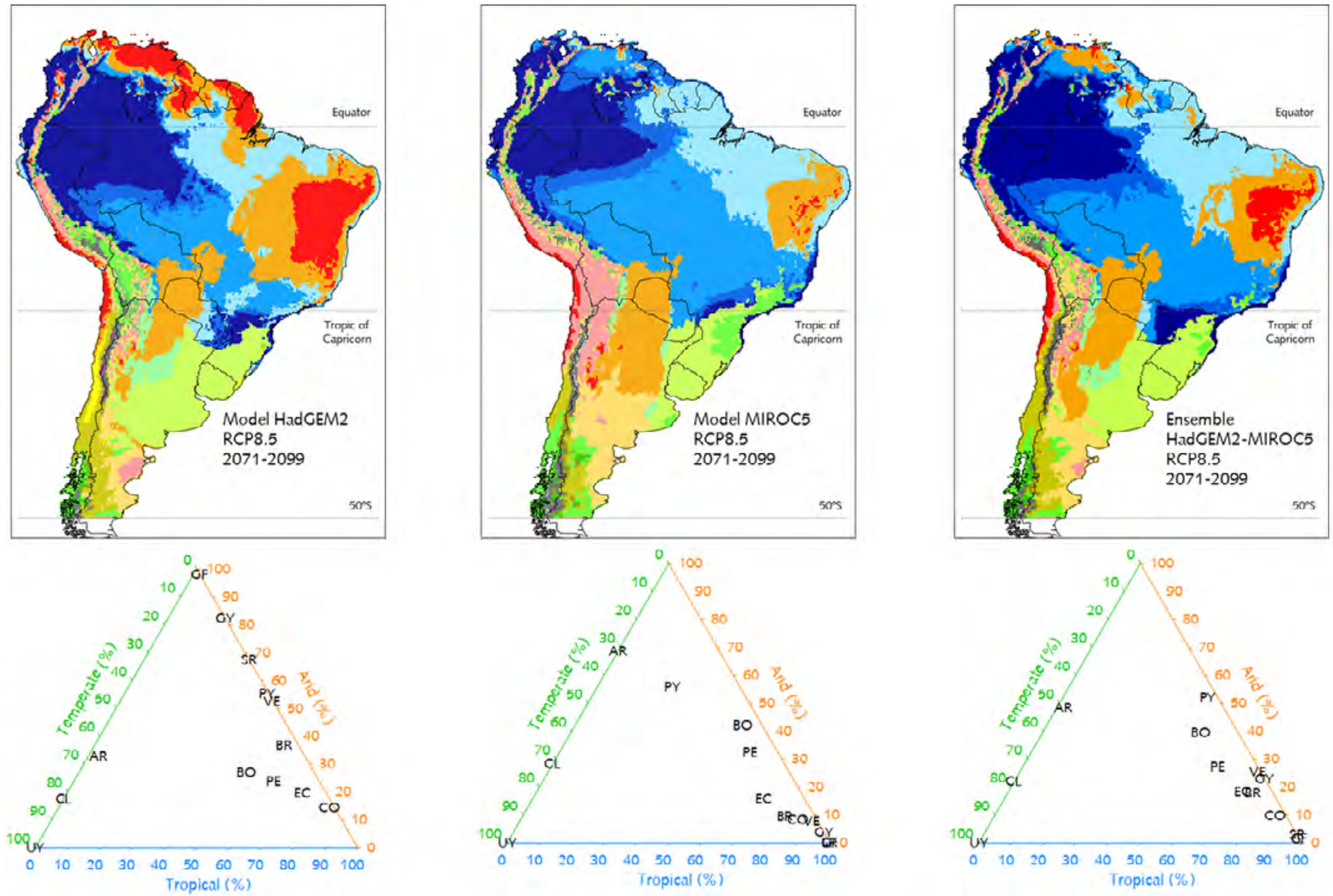

Figure 25. South American maps of Köppen climate classification when considering the models HadGEM2 (left), MIROC5 (middle) and their ensemble (right) for the period 2071–2099 and climate scenario RCP8.5. See Table 2 to read the legend of climate types. Ternary charts show the occurrences of the Arid, Tropical and Temperate climates for these models and climate scenarios.

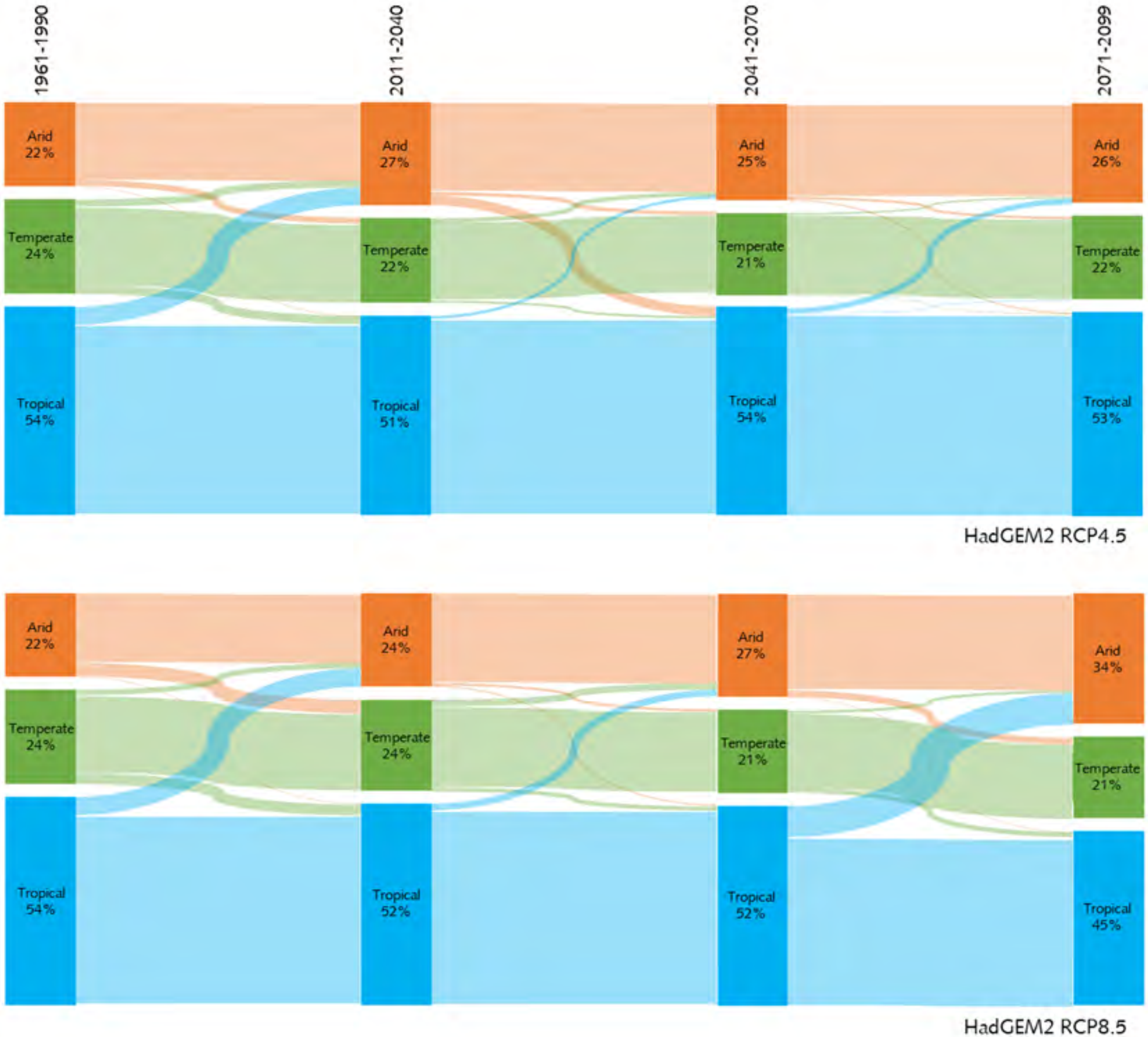

Figure 26. Climate changes between main Arid, Tropical and Temperate climates types of the following periods: baseline (1961-1990); 2011-2040; 2041-2070; and 2071-2099, for the model HadGEM2 and climate scenarios RCP4.5 (top panel) and RCP8.5 (bottom panel).

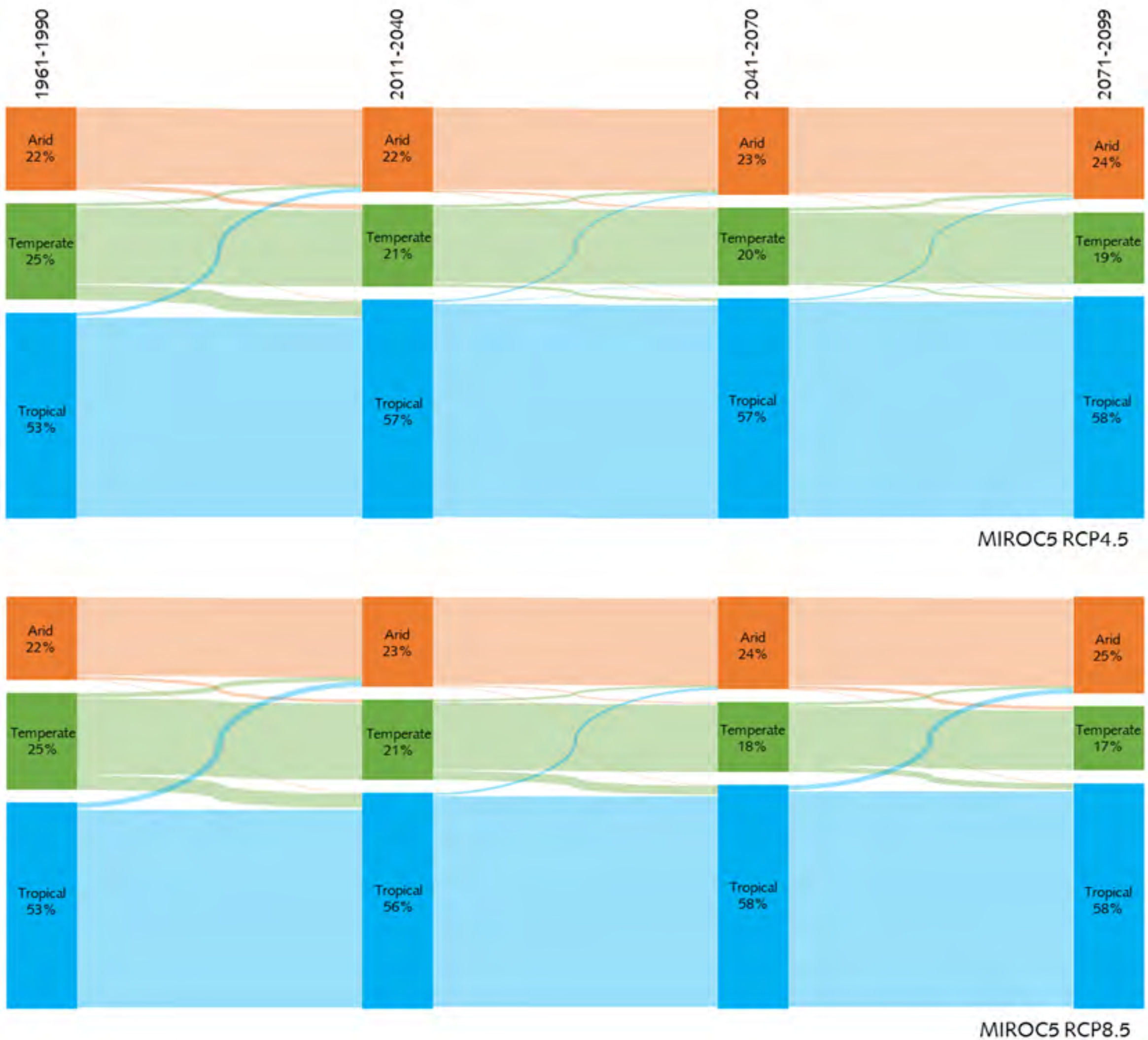

Figure 27. Climate changes between main Arid, Tropical and Temperate climates types of the following periods: baseline (1961-1990); 2011-2040; 2041-2070; and 2071-2099, for the model MIROC5 and climate scenarios RCP4.5 (top panel) and RCP8.5 (bottom panel).

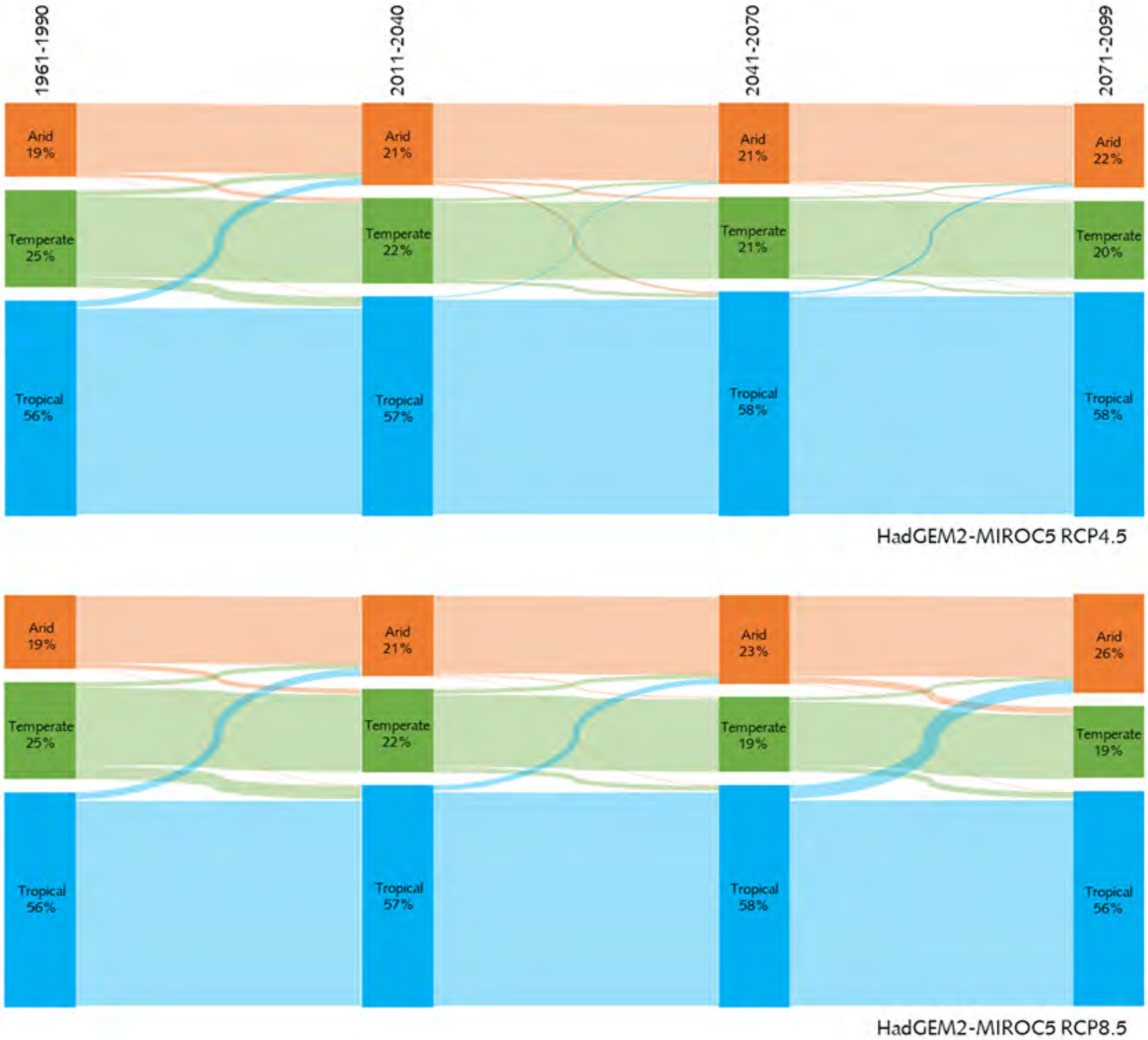

Figure 28. Climate changes between main Arid, Tropical and Temperate climates types of the following periods: baseline (1961-1990); 2011-2040; 2041-2070; and 2071-2099, for the ensemble model HadGEM2-MIROC5 and climate scenarios RCP4.5 (top panel) and RCP8.5 (bottom panel).

tropical climates. Temperate climates will decrease by the same intensity but in the opposite direction, reducing from 25% of the continent area at the present climate, to 22% in 2011-2040, 19% in 2041-2070, and 19% in 2071-2099. Tropical climates tend to occupy with 56% of the continent area from the present period to the end of the century, but with important trade-offs occurring, such as the decline to arid climates, and expansion over the temperate climates (Figure 28).

Climate change will have a major impact in South America (Table 3), since the projections show an important geographic decline in tropical wet climates (Af, Am) and expansion in dry tropical climates (As, Aw). The semi-arid climate (BSh) could have up to 80% of its area increase, and the arid climate (BWh) could expand 700% by 2099 in the RCP8.5 scenario. Another important change will be the shrinkage of the mild Cfb subtropical climate from 8.1% in baseline period to just 3.5% in 2071-2099. As previously presented, polar climates are expected to decline by a third (4.3 to 1.5%) by the end of the 21st century.

Argentina has a long territorial extension and a wide latitudinal range that extends from the Andes Mountains to the seashore, with a complex climate system, constituted by arid, subtropical, temperate, and polar climates. Projections for Argentina for the period 2011-2040 predict no occurrence of tropical climate; however, by the end of the century the Argentinean territory should present almost 2% of tropical climate, mainly Af in the region bordering Paraguay and Brazil (Table 4). Affected by global warming, subtropical climates Cfa, Cwa, and Csb and semi-arid climate BSh may increase dramatically in Argentina during the analyzed periods. On the other hand, as previously presented, polar climates (ET, EF) may decline from the period 2011-2040 in both RCPs scenarios. The rare temperate climate types Dfb and Dfc in South America are predicted to disappear in Argentina by 2041-2070.

The climate projections for Bolivia indicate a major trade-off from wet tropical (Af, Am) to dry tropical climates (Aw) (Table 5). These warmer and drier conditions may induce a considerable expansion of the semi-arid (BSh) conditions in this country, increasing from the present 9.8% to 19% of Bolivian territory by the end of the 21st century. For Bolivia, the main concern is the projection of an intense reduction of the polar climates, from 7% of the territory in the present to 0.7% in 2071-2099.

Table 3 Köppen's climate types and their changes (%) found in South America for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	23.61	22.20	24.53	23.31	22.81	23.81	18.33	17.45	15.51	17.42	15.92	15.79	15.39	14.94	21.52	20.87	22.28	20.46	20.75	20.96	17.96
Am	7.82	5.94	5.80	6.58	4.81	5.09	4.94	14.70	9.99	10.67	8.68	8.33	9.56	8.17	10.79	7.98	8.75	8.86	8.34	7.85	6.59
As	8.57	10.81	10.18	10.20	11.89	10.61	10.82	7.79	9.57	8.68	9.62	10.87	10.96	12.93	8.18	9.60	9.19	9.88	11.18	11.29	13.84
Aw	13.81	12.55	13.41	12.66	12.56	12.27	10.95	13.44	21.65	20.37	23.28	20.88	21.95	22.27	15.15	18.22	17.67	18.86	17.20	17.43	17.31
BSh	9.19	13.10	12.37	12.51	13.08	14.44	18.20	5.51	7.41	8.66	9.22	8.24	10.04	11.40	7.77	10.19	9.97	10.32	9.91	11.84	13.91
BSk	7.33	6.13	5.82	5.22	4.19	4.18	3.57	5.86	6.65	6.60	6.31	6.58	6.09	6.70	7.79	7.34	7.19	7.08	7.21	6.25	5.56
BWh	2.68	4.85	3.88	5.14	5.32	5.91	9.64	1.86	1.20	0.95	1.05	1.03	1.02	1.33	0.46	1.03	1.05	1.37	1.23	2.05	3.27
BWk	2.52	2.48	2.75	2.88	1.74	2.23	2.41	8.36	6.74	6.51	7.36	7.45	6.90	5.60	3.16	2.68	2.81	3.00	2.64	2.87	2.89
Cfa	9.86	8.95	10.64	10.96	9.11	7.95	9.49	4.25	4.73	5.39	4.72	4.68	4.76	5.51	7.49	7.91	8.83	8.28	8.03	7.06	8.04
Cfb	5.38	3.83	3.17	3.30	4.28	3.15	3.20	10.37	7.83	7.54	6.83	7.66	5.88	5.12	8.12	5.68	5.29	5.06	5.70	4.24	3.51
Cfc	0.75	0.62	0.60	0.63	0.54	0.51	0.34	0.78	0.58	0.84	0.75	0.55	0.42	0.48	0.87	0.66	0.61	0.67	0.68	0.46	0.35
Cwa	1.20	1.81	0.95	1.19	2.20	2.95	1.85	0.40	0.36	0.40	0.43	0.56	0.48	0.77	0.61	0.59	0.60	0.65	0.51	1.31	1.19
Cwb	0.90	0.44	0.62	0.67	0.52	0.80	0.66	2.53	1.39	1.03	0.72	1.26	1.08	0.43	1.28	0.53	0.50	0.42	0.45	0.55	0.51
Cwc	0.09	0.04	0.11	0.04	0.06	0.08	0.06	0.04	0.03	0.03	0.02	0.03	0.04	0.02	0.16	0.07	0.05	0.07	0.08	0.06	0.06
Csa	0.01	0.17	0.27	0.42	0.10	0.38	0.67	-	-	-	-	-	-	-	-	-	-	0.00	-	0.01	0.04
Csb	1.49	2.20	2.13	1.88	3.14	3.29	3.17	1.19	1.58	1.03	1.34	1.56	1.66	1.54	1.27	1.86	1.56	1.42	1.68	2.65	2.79
Csc	0.43	0.36	0.24	0.23	0.39	0.39	0.38	0.54	0.63	0.29	0.70	0.52	0.75	0.78	0.45	0.96	0.62	0.80	0.74	0.60	0.53
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	0.00	-	0.00	0.01	-	-	-	0.03	-	-	-	-	-	-	-	0.00	-	0.02	0.00	0.01	-
Dfc	0.05	0.02	0.03	0.02	0.01	0.01	0.02	0.22	0.12	0.06	0.07	0.07	0.03	0.00	0.21	0.04	0.03	0.01	0.04	0.01	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	0.01	0.01	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	0.00	0.01	0.05	0.02	0.04	-	-	-	-	-	-	-	-	-	-	-	0.00	-	-	0.01
Dsc	0.14	0.16	0.20	0.20	0.18	0.18	0.18	-	0.10	0.00	0.02	0.04	0.00	0.03	0.01	0.02	0.01	0.02	0.01	0.04	0.01
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	4.02	3.18	2.21	1.84	2.96	1.67	1.08	4.06	3.24	2.96	2.47	3.24	2.55	1.65	4.30	3.41	2.76	2.52	3.29	2.33	1.56
EF	0.18	0.14	0.06	0.05	0.07	0.04	0.04	0.63	0.68	0.58	0.48	0.67	0.45	0.33	0.43	0.36	0.22	0.21	0.31	0.13	0.07

Table 4 Köppen's climate types and their changes (%) found in Argentina for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	0.20	0.33	0.23	0.33	0.50	0.88	-	-	-	-	-	-	0.01	-	-	0.10	0.10	0.04	0.20	1.10
Am	-	0.04	-	-	0.04	0.24	0.94	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04
As	-	0.06	0.21	0.06	0.07	0.43	1.14	-	-	-	-	-	-	-	-	-	0.11	0.11	0.03	0.17	0.64
Aw	-	-	0.06	0.04	0.01	0.16	0.31	-	-	-	-	-	-	0.01	-	-	-	-	0.01	-	0.17
BSh	13.79	16.72	15.71	16.29	17.86	18.88	14.02	11.10	16.66	21.86	22.65	17.86	25.34	27.45	16.75	20.60	21.07	21.07	19.79	25.75	22.00
BSk	32.43	26.11	24.27	21.73	15.48	15.96	13.53	21.29	28.71	29.15	28.12	28.30	26.48	31.45	33.37	30.09	29.01	29.01	30.07	24.79	21.26
BWh	0.06	0.09	0.13	0.17	0.16	0.13	0.20	9.21	4.80	2.62	2.97	3.70	1.96	1.00	0.37	0.44	0.20	0.20	0.09	0.24	0.24
BWk	6.10	5.83	7.70	7.88	2.77	4.41	5.01	29.70	16.70	15.48	17.90	19.83	17.22	8.72	6.99	4.06	5.44	5.44	3.53	4.70	4.94
Cfa	27.56	25.98	35.57	36.41	29.11	23.29	36.38	2.69	5.38	4.70	3.57	3.78	4.92	8.42	15.10	18.74	22.67	22.67	21.33	16.69	25.00
Cfb	3.27	2.55	1.25	1.48	5.26	2.46	1.99	5.52	6.18	8.94	6.03	5.42	4.74	6.30	9.02	5.38	5.38	5.38	6.59	3.24	3.53
Cfc	1.11	0.64	0.31	0.30	0.16	0.23	0.16	1.14	0.61	2.99	1.89	0.97	0.64	1.07	1.82	1.27	1.15	1.15	1.34	0.36	0.16
Cwa	4.72	9.22	4.38	5.86	11.68	15.91	9.70	0.44	0.50	0.81	1.07	0.58	1.14	2.58	1.31	1.95	2.75	2.75	1.99	6.49	6.05
Cwb	0.73	0.77	0.87	1.42	1.15	1.22	1.38	0.78	0.51	0.41	0.64	0.47	0.37	0.20	0.77	0.53	0.60	0.60	0.55	0.63	0.64
Cwc	0.16	0.07	0.26	0.07	0.21	0.17	0.04	0.04	0.01	0.03	-	0.01	-	-	0.01	0.10	0.13	0.13	0.18	0.07	0.11
Csa	-	0.07	0.04	0.03	0.03	0.09	0.27	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-
Csb	1.79	4.23	3.63	3.03	8.81	10.76	9.78	3.47	6.09	3.20	4.44	6.20	6.56	5.01	3.14	5.58	3.09	3.09	4.77	9.58	8.67
Csc	1.48	1.42	0.64	0.65	1.12	1.18	1.07	2.86	3.36	1.45	3.51	2.80	3.86	2.99	1.81	4.15	2.86	2.86	3.00	2.09	1.51
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	0.01	-	-	0.06	-	-	-	0.17	-	-	-	-	-	-	-	0.01	0.06	0.06	0.01	0.03	-
Dfc	0.20	0.09	0.09	0.07	-	0.07	0.09	1.21	0.65	0.26	0.33	0.38	0.11	0.01	1.14	0.18	0.04	0.04	0.17	0.03	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	0.07	0.06	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	0.01	0.09	0.06	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03
Dsc	0.33	0.38	0.50	0.55	0.50	0.47	0.47	-	0.58	0.01	0.10	0.20	0.01	0.09	0.04	0.07	0.06	0.06	0.01	0.10	0.03
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	5.79	5.17	3.80	3.36	4.98	3.24	2.53	8.38	7.01	6.20	5.22	7.31	5.24	3.64	7.06	5.73	4.71	4.71	5.54	4.50	3.70
EF	0.47	0.37	0.17	0.14	0.18	0.10	0.11	2.01	2.23	1.89	1.55	2.16	1.41	1.05	1.31	1.11	0.58	0.58	0.95	0.34	0.20

Table 5 Köppen's climate types and their changes (%) found in Bolivia for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	20.58	5.52	12.30	14.20	4.42	5.19	3.41	0.24	0.28	0.28	0.24	0.20	0.37	0.32	4.30	2.84	2.84	3.41	4.06	3.13	1.34
Am	17.57	17.41	16.36	17.98	8.12	11.44	3.33	6.78	4.22	4.50	3.69	4.26	5.11	3.37	19.16	8.85	14.37	6.21	9.25	5.36	3.94
As	4.71	4.02	2.19	2.11	3.29	1.58	0.12	0.81	0.24	0.61	0.28	0.49	0.41	0.49	2.84	2.44	1.75	2.92	3.73	0.24	0.24
Aw	11.49	24.11	22.69	21.23	36.08	35.67	45.21	43.02	48.17	47.24	46.10	45.94	46.47	47.69	26.62	39.61	34.66	42.86	38.96	41.56	43.67
BSh	8.32	13.80	12.74	10.92	14.37	13.76	16.92	12.09	11.89	11.69	14.69	13.51	12.82	14.73	9.82	11.36	11.44	10.63	9.05	15.99	19.07
BSk	7.02	6.70	7.18	6.90	6.13	7.06	6.90	14.98	8.48	7.75	5.52	7.35	7.10	3.45	11.93	13.35	13.47	13.47	12.22	13.31	13.35
BWh	-	-	-	0.12	0.04	0.12	0.16	-	-	-	-	-	0.04	-	-	-	-	-	-	-	0.24
BWk	2.03	1.79	2.15	2.31	2.15	2.56	2.96	9.70	18.71	19.36	22.36	19.93	20.21	23.90	3.37	4.18	4.87	5.48	4.50	5.60	6.74
Cfa	1.18	1.22	0.85	0.77	0.12	0.32	0.32	0.04	0.08	0.32	0.16	0.20	0.16	0.24	0.16	0.08	0.20	-	0.16	0.04	0.08
Cfb	9.09	10.55	10.06	12.38	10.84	9.58	11.53	4.10	2.96	2.80	2.60	3.21	2.27	1.58	5.11	5.84	6.09	5.76	6.01	5.40	4.87
Cfc	0.93	0.57	0.73	0.61	0.61	0.45	0.32	-	-	-	-	-	0.04	-	0.61	0.49	0.41	0.49	0.28	0.16	-
Cwa	2.84	2.60	2.68	2.84	2.84	3.13	2.64	1.06	1.38	2.39	1.95	1.58	2.11	2.52	2.35	2.39	3.08	2.76	2.72	3.04	2.31
Cwb	4.95	4.02	5.72	4.75	4.26	6.78	4.99	4.83	3.13	2.88	2.27	2.96	2.84	1.54	4.34	2.72	3.90	3.25	3.61	4.30	3.33
Cwc	0.61	0.32	0.61	0.16	0.24	0.37	0.32	0.20	0.12	0.04	0.04	0.08	-	-	2.19	0.69	0.24	0.37	0.65	0.20	0.12
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	0.04	-	-	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-
Csc	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	8.69	7.39	3.65	2.72	6.49	1.99	0.85	2.15	0.20	0.08	0.08	0.16	-	0.12	6.98	5.11	2.68	2.39	4.75	1.66	0.69
EF	-	-	-	-	-	-	-	-	0.12	0.04	-	0.12	-	0.04	0.20	0.04	-	-	0.04	-	-

Table 6 Köppen's climate types and their changes (%) found in Brazil for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	26.72	25.20	28.25	25.34	24.72	25.61	16.32	14.99	12.11	13.97	11.78	11.45	10.80	10.38	20.94	20.17	22.89	19.49	19.74	19.91	14.55
Am	11.38	7.14	7.87	9.59	6.93	7.16	7.30	23.69	13.89	15.05	11.26	10.58	12.92	10.27	16.96	11.55	12.27	13.62	12.58	11.92	10.04
As	13.02	17.53	16.74	17.56	19.85	18.41	19.43	15.09	17.92	16.79	17.51	20.33	20.23	23.41	14.32	17.52	17.11	17.38	20.08	20.80	24.38
Aw	25.15	21.15	23.19	21.67	20.90	20.02	15.73	20.89	36.24	34.75	40.85	36.14	37.39	37.21	25.97	30.42	29.29	31.31	28.28	28.01	27.17
BSh	8.51	13.53	11.99	11.79	13.04	14.60	23.70	2.39	4.50	5.46	5.76	5.78	6.91	8.87	6.03	8.50	8.15	8.44	8.48	8.99	13.09
BSk	0.07	0.02	-	-	0.01	-	-	0.19	0.07	0.01	0.01	0.07	0.01	-	0.12	0.03	0.01	0.01	0.03	0.01	-
BWh	3.77	7.81	4.83	7.09	7.73	8.24	12.98	0.01	0.04	0.07	0.08	0.07	0.23	0.63	0.31	1.03	0.67	1.32	1.45	2.53	4.64
BWk	0.03	0.02	0.01	-	0.01	-	-	0.01	0.02	0.01	0.01	0.03	0.01	-	0.03	0.02	0.01	0.01	0.01	0.01	-
Cfa	6.54	6.24	6.44	6.58	5.73	5.69	4.28	5.62	4.90	5.98	5.32	5.37	4.93	5.33	6.04	6.19	6.52	5.99	5.73	5.78	5.35
Cfb	3.72	0.95	0.47	0.23	0.91	0.18	0.03	12.21	7.71	6.24	6.53	7.36	4.83	3.50	7.01	3.81	2.84	2.37	3.42	2.01	0.78
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	0.45	0.11	0.07	-	-	-	-	0.57	0.41	0.24	0.14	0.80	0.29	0.21	0.51	0.22	0.13	-	-	-	-
Cwb	0.61	0.01	-	-	-	-	-	4.29	2.20	1.43	0.75	2.01	1.43	0.19	1.75	0.52	0.12	0.07	0.20	0.03	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	0.02	0.29	0.11	0.13	0.15	0.08	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	0.02	0.02	0.02	0.02	0.02	0.04	0.05	-	-	-	0.01	-	-	-	0.01	-	0.01	0.01	0.01	0.01
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 7 Köppen's climate types and their changes (%) found in Chile for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	0.10	0.14	0.14	0.14	0.10	0.10	0.10	-	-	-	-	-	-	-	0.05	0.05	0.10	0.05	0.05	0.05	-
Aw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	0.19	2.38	3.04	4.14	2.24	3.24	5.23	-	-	-	-	-	0.05	-	0.10	0.33	0.38	0.67	0.48	0.48	2.14
BSk	7.42	5.61	6.33	5.71	5.00	5.47	4.71	3.38	3.19	2.81	3.28	3.28	3.19	3.14	7.09	6.57	7.18	6.71	6.61	6.14	5.71
BWh	2.90	5.28	6.57	6.37	7.04	8.28	6.47	0.62	1.28	2.90	3.38	1.38	4.09	7.94	1.24	3.90	6.37	6.99	4.85	8.66	9.61
BWk	5.71	2.38	1.67	1.38	2.00	2.33	0.95	25.93	22.98	20.88	23.17	23.22	20.98	17.17	12.70	8.90	7.23	6.99	8.23	7.61	4.42
Cfa	-	-	-	-	0.14	0.05	0.38	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10
Cfb	18.84	22.79	21.17	22.88	21.46	22.50	25.59	16.37	20.12	25.98	23.69	22.60	27.02	29.45	19.46	22.93	26.78	26.31	24.41	26.45	28.64
Cfc	8.99	8.52	8.56	9.47	8.42	7.99	5.09	10.80	8.75	5.95	7.94	6.99	5.38	5.57	9.13	7.52	6.76	8.04	7.85	7.37	6.04
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	0.43	0.10	0.14	0.48	0.10	0.33	0.33	-	-	-	-	-	-	-	-	0.05	0.05	0.05	0.05	0.05	0.10
Cwc	0.10	0.05	0.19	0.10	0.05	0.14	0.14	-	-	-	-	-	-	-	0.05	-	-	-	-	-	0.05
Csa	-	0.43	4.14	6.90	0.43	6.33	10.23	-	-	-	-	-	-	-	-	-	-	0.05	-	0.14	0.71
Csb	22.55	28.07	28.64	25.88	30.64	27.26	27.88	9.09	10.09	9.13	10.80	9.18	9.90	12.42	13.89	16.98	17.22	16.94	16.32	18.89	24.31
Csc	3.28	2.24	2.38	2.14	3.76	3.52	3.66	0.86	0.86	0.71	1.71	0.67	1.62	4.95	2.71	4.66	4.52	5.85	4.28	4.57	5.09
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	0.10	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	0.05	-
Dfc	0.24	0.19	0.24	0.19	0.19	0.05	0.19	0.10	0.19	0.24	0.19	0.10	0.24	-	0.24	0.19	0.33	0.10	0.14	0.05	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	0.10	0.14	0.67	0.24	0.38	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	0.14
Dsc	1.52	1.81	2.09	2.05	1.71	1.90	1.81	-	0.05	-	0.10	0.05	0.05	0.33	-	0.19	0.14	0.24	0.14	0.38	0.05
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	25.93	18.51	13.80	10.94	15.75	9.71	6.85	27.45	27.02	26.55	21.60	27.07	23.60	16.22	29.88	24.64	20.88	18.84	23.93	17.84	12.13
EF	1.81	1.43	0.62	0.52	0.76	0.43	0.38	5.42	5.47	4.85	4.14	5.47	3.90	2.81	3.47	3.09	2.05	2.00	2.66	1.28	0.76

Table 8 Köppen's climate types and their changes (%) found in Colombia for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	67.38	72.24	73.00	71.84	78.34	80.37	77.90	62.96	67.62	72.52	71.37	69.77	72.52	74.43	67.50	71.49	73.99	73.16	73.04	77.90	78.45
Am	8.24	6.41	6.33	7.37	1.79	1.08	2.07	13.54	8.72	7.96	9.48	9.28	8.60	8.08	9.88	7.77	6.45	6.53	6.45	3.78	3.74
As	0.80	1.83	2.43	2.51	2.55	2.59	2.91	0.96	1.12	0.80	0.76	1.47	0.48	1.08	0.64	0.72	0.60	0.72	1.35	0.92	1.99
Aw	5.26	3.27	2.99	2.99	1.19	2.03	1.19	2.79	4.22	2.03	2.27	1.35	2.39	2.35	3.35	3.42	3.42	3.07	2.59	2.91	2.79
BSh	0.96	1.39	1.71	1.87	1.15	1.79	3.98	0.12	0.36	0.48	0.52	0.32	0.44	0.84	0.40	0.76	1.08	1.23	1.00	1.12	2.15
BSk	2.71	2.87	2.51	2.19	2.83	2.03	1.23	2.91	2.91	2.95	2.59	3.03	2.71	2.35	2.83	2.99	2.67	2.51	2.71	2.55	1.99
BWh	0.64	1.04	1.31	1.87	1.35	2.11	4.02	0.08	0.16	0.20	0.24	0.20	0.44	0.80	0.16	0.32	0.56	0.64	0.36	0.64	1.19
BWk	3.86	5.14	5.22	5.34	4.54	4.74	5.10	1.83	3.07	3.27	4.10	3.58	3.74	4.22	2.67	3.90	4.02	4.58	4.46	4.22	4.50
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	8.52	5.38	4.30	3.90	5.97	3.19	1.59	12.86	11.03	9.32	8.32	10.23	8.44	5.54	11.31	8.12	7.05	7.53	7.69	5.97	3.07
Cfc	0.08	-	-	-	0.16	-	-	0.08	0.12	0.12	0.04	0.12	0.12	-	0.24	0.12	0.04	0.04	0.12	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	0.92	0.20	0.20	0.12	-	0.08	-	0.08	0.04	-	-	0.04	-	-	0.12	0.04	-	-	-	-	-
Cwc	0.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	0.04	-	-	-	-	-	0.04	-	-	0.28	-	-	-	-	-	-	0.12
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	0.52	0.24	-	-	0.08	-	-	1.79	0.64	0.36	0.28	0.60	0.12	0.04	0.92	0.36	0.12	-	0.24	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 9 Köppen's climate types and their changes (%) found in Ecuador for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	59.20	59.55	64.93	66.32	64.24	68.06	67.71	48.26	58.85	65.28	63.19	61.98	66.32	69.44	58.51	63.19	67.19	67.53	65.97	68.92	70.49
Am	3.13	3.30	1.39	1.22	2.43	1.04	1.74	4.69	2.26	1.39	2.43	1.74	0.52	1.04	2.26	1.22	0.69	0.17	0.35	0.35	0.35
As	2.95	3.13	2.26	2.43	2.43	2.60	3.30	9.20	5.03	1.56	2.78	2.78	2.26	0.87	3.65	3.30	1.56	1.74	2.08	1.39	1.56
Aw	0.52	2.26	1.56	1.04	1.04	0.35	0.35	0.87	0.17	-	-	0.17	0.17	0.35	0.17	-	0.35	0.35	0.17	0.52	0.17
BSh	0.35	1.39	1.04	1.39	0.52	1.39	1.74	0.87	0.17	0.17	0.17	0.17	0.17	0.87	0.35	0.35	0.69	0.87	0.17	1.04	1.22
BSk	9.55	10.42	11.11	8.33	10.94	10.24	5.90	7.29	7.99	7.47	7.64	7.99	7.99	6.94	8.68	10.42	8.33	9.38	10.07	8.51	9.20
BWh	0.17	0.35	0.69	1.04	0.35	0.87	1.56	-	-	0.17	0.17	-	0.17	0.35	0.17	0.17	0.17	0.17	0.17	0.17	0.69
BWk	5.38	10.42	8.85	11.81	6.25	8.16	10.42	4.34	5.73	5.90	7.29	6.25	6.77	7.47	4.34	6.94	7.81	7.99	7.29	7.47	7.12
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	14.41	8.85	7.99	6.25	10.07	6.77	6.08	13.89	14.93	13.54	12.67	14.24	12.33	9.38	15.97	11.98	11.11	10.76	11.46	9.72	7.99
Cfc	0.35	-	-	-	0.17	0.35	0.17	0.35	0.52	0.35	0.52	0.52	0.87	0.17	0.69	0.52	0.35	-	0.52	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	0.35	-	-	-	0.35	-	0.69	3.13	-	0.17	0.35	0.17	0.35	0.69	-	-	0.17	0.17	0.17	0.35	0.52
Csc	-	-	-	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	3.65	0.35	0.17	-	1.22	0.17	0.35	7.12	4.34	3.99	2.78	3.99	2.08	2.43	5.21	1.91	1.56	0.87	1.56	1.56	0.69
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 10 Köppen's climate types and their changes (%) found in French Guiana for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.43	1.48	4.93	1.97	1.97	-	-
Am	8.37	0.49	0.99	-	1.97	1.97	-	52.22	16.26	27.09	19.70	16.26	12.32	11.82	24.63	13.30	10.34	5.91	4.43	2.46	-
As	60.10	40.89	27.59	25.12	28.57	15.76	1.97	33.00	82.27	65.02	80.30	81.77	81.77	87.68	61.58	83.25	74.88	88.67	89.66	88.18	96.55
Aw	3.45	3.45	3.45	4.43	2.96	2.96	-	14.78	1.48	7.88	-	1.97	5.91	0.49	9.36	1.97	9.36	3.45	3.94	8.87	1.97
BSh	28.08	55.17	67.49	69.46	66.50	73.89	32.02	-	-	-	-	-	-	-	-	-	0.49	-	-	0.49	1.48
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	0.49	0.99	-	5.42	66.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 11 Köppen's climate types and their changes (%) found in Guyana for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	5.72	4.14	0.59	-	12.03	6.71	-	62.92	14.79	24.65	20.32	24.85	8.88	7.10	56.41	44.38	34.91	26.23	29.98	18.34	1.97
Am	22.68	11.83	6.11	6.90	3.55	7.10	0.59	12.82	53.65	49.31	43.59	41.22	43.39	33.53	9.47	15.38	19.53	24.26	21.30	26.04	9.66
As	32.15	47.14	40.24	36.09	47.34	33.93	10.45	4.34	21.30	20.91	31.95	29.19	39.05	49.11	11.05	15.38	12.82	21.10	20.32	21.50	44.18
Aw	11.05	7.30	11.44	10.45	2.37	4.34	6.71	13.02	6.90	2.37	1.18	1.18	5.92	6.71	11.64	10.45	18.15	13.21	13.21	19.33	21.30
BSh	14.20	15.38	25.25	30.18	19.72	30.97	45.17	0.59	1.58	1.58	1.78	1.78	1.97	2.76	6.71	12.23	12.62	12.82	13.02	13.02	20.51
BSk	0.20	0.20	-	-	-	-	-	0.99	0.20	0.20	0.20	0.20	-	0.20	0.79	0.20	0.20	0.20	0.20	0.20	0.20
BWh	12.43	13.61	15.98	16.17	14.60	16.77	37.08	-	-	-	-	-	-	0.59	0.20	0.99	1.38	1.38	1.38	1.38	2.17
BWk	0.79	0.20	0.39	0.20	0.39	0.20	-	-	-	-	-	-	0.20	-	0.20	0.20	0.20	0.20	0.20	0.20	-
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	0.79	0.20	-	-	-	-	-	5.33	1.58	0.99	0.99	1.58	0.59	-	3.55	0.79	0.20	0.59	0.39	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 12 Köppen's climate types and their changes (%) found in Paraguay for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	10.74	7.02	18.49	20.35	7.44	16.01	5.58	-	-	-	-	-	-	-	1.55	6.30	8.16	13.02	13.95	7.75	17.77
Am	-	5.58	1.76	0.83	4.75	6.61	12.71	-	-	-	-	-	0.31	3.41	0.41	1.14	2.27	0.93	0.41	3.82	3.31
As	7.64	15.91	15.29	11.98	10.64	14.67	23.45	0.41	0.10	-	2.69	0.21	1.86	1.14	6.30	7.85	7.33	12.40	9.40	9.81	10.43
Aw	1.34	-	1.03	0.10	7.23	2.07	2.58	1.76	7.23	6.51	5.79	6.20	13.64	18.90	4.03	3.41	8.26	5.79	6.30	10.43	13.33
BSh	45.04	55.89	51.14	49.59	55.06	55.79	55.37	66.84	63.74	60.12	62.29	61.78	61.67	55.68	46.59	54.03	48.86	49.69	47.93	53.82	52.17
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	0.93	-	-	4.44	-	-	1.14	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	35.23	14.67	12.29	17.15	10.43	4.86	0.31	29.86	28.93	33.37	26.76	31.82	21.69	17.87	41.12	27.27	25.10	18.18	22.00	14.36	3.00
Cfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	2.48	-	0.83	3.00	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13 Köppen's climate types and their changes (%) found in Peru for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	52.15	49.75	53.06	53.94	50.60	52.53	46.59	41.98	38.92	43.56	39.41	40.46	41.56	38.74	51.16	47.92	50.07	47.85	49.54	48.73	43.63
Am	1.37	4.26	2.18	1.58	5.21	4.33	8.62	9.78	12.74	10.52	11.89	11.15	11.37	12.74	1.65	6.30	5.63	7.71	5.42	7.71	10.80
As	3.62	3.48	3.69	3.73	3.55	3.69	3.55	1.94	1.79	0.99	1.48	1.37	1.20	0.60	3.03	2.71	2.53	2.71	2.74	2.32	1.86
Aw	0.25	0.77	0.81	0.99	0.18	0.39	3.27	0.35	2.53	1.94	4.50	3.34	3.52	7.04	0.25	0.53	0.42	0.53	0.46	0.53	4.19
BSh	1.34	2.25	2.29	2.36	1.94	2.04	2.29	1.44	0.99	0.88	0.95	0.77	0.84	0.88	1.51	1.79	1.44	1.65	1.62	1.48	1.58
BSk	6.37	6.72	6.79	6.16	6.86	5.77	5.42	6.79	8.20	7.88	7.95	8.44	7.53	8.13	6.54	7.46	7.39	7.21	6.90	6.83	6.79
BWh	1.94	2.81	2.85	3.31	2.92	3.94	4.61	2.74	3.59	3.98	4.05	3.62	4.33	4.96	2.04	2.85	3.55	3.52	2.81	3.94	5.03
BWk	8.52	9.54	9.39	10.17	8.09	10.06	11.44	14.53	16.43	16.96	17.73	16.82	16.68	18.44	10.77	11.86	11.89	12.53	12.28	12.46	13.62
Cfa																					
Cfb	8.13	7.07	7.71	7.95	7.25	7.67	8.80	6.62	5.77	5.03	4.61	5.98	4.47	3.31	7.92	6.76	6.19	6.30	6.65	5.95	5.81
Cfc	0.32	0.42	0.84	0.70	0.35	0.28	0.39	0.14	0.07			0.11	0.07		0.28	0.11	0.25	0.35	0.11	0.07	0.14
Cwa															0.04						
Cwb	0.84	0.60	1.48	1.51	0.84	2.18	1.44	0.99	1.44	1.90	1.83	1.09	2.60	3.06	0.67	0.49	1.41	1.23	0.56	2.32	2.78
Cwc	0.14	0.14	0.28	0.18	0.04	0.25	0.39	0.25	0.28	0.39	0.25	0.28	0.53	0.32	0.25	0.18	0.42	0.39	0.14	0.56	0.39
Csa																					
Csb		0.04						0.60	0.04												
Csc																					
Dfa																					
Dfb																					
Dfc																					
Dfd																					
Dwa																					
Dwb																					
Dwc																					
Dwd																					
Dsa																					
Dsb																					
Dsc																					
Dsd																					
ET	15.02	12.14	8.62	7.42	12.17	6.86	3.20	11.82	7.21	5.98	5.35	6.54	5.31	1.79	13.76	11.05	8.80	8.02	10.77	7.11	3.38
EF								0.04							0.14						

Table 14 Köppen's climate types and their changes (%) found in Suriname for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	0.58	1.73	-	-	6.36	2.02	-	33.53	-	-	-	-	-	-	60.98	38.15	33.53	28.03	31.21	23.12	0.29
Am	10.40	11.85	10.12	3.47	12.14	17.05	-	64.74	50.00	76.88	46.24	55.20	33.53	11.56	25.14	30.64	33.24	28.61	24.28	26.30	6.94
As	69.36	61.27	58.09	47.11	61.85	43.64	26.88	0.58	36.13	17.34	52.02	41.91	53.18	83.82	4.05	17.92	9.25	26.59	26.59	24.86	61.56
Aw	13.01	15.90	13.29	20.52	5.20	8.67	5.78	1.16	13.87	5.78	1.73	2.89	13.29	4.62	9.83	13.01	23.41	16.18	17.34	25.14	28.32
BSh	6.65	9.25	18.50	28.90	14.45	28.61	47.40	-	-	-	-	-	-	-	-	0.29	0.58	0.58	0.58	0.58	2.89
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	19.94	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 15 Köppen's climate types and their changes (%) found in Uruguay for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	-	-	-	-	-	-	-	-	-	-	3.34	-	-	-	-	-	-	-	-	-	-
BSk	-	-	-	-	-	-	-	12.11	-	-	1.04	2.71	0.42	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	100.00	99.37	100.00	100.00	99.79	100.00	99.16	42.80	73.70	87.27	86.85	68.06	95.41	99.79	95.20	99.79	100.00	100.00	100.00	100.00	100.00
Cfb	-	-	-	-	-	-	-	45.09	26.30	12.73	8.77	29.23	4.18	0.21	4.80	0.21	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	0.63	-	-	0.21	-	0.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 16 Köppen's climate types and their changes (%) found in Venezuela for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	23.60	25.95	24.73	23.80	30.41	32.47	26.64	39.72	40.35	44.61	43.54	43.73	39.23	35.21	36.43	35.26	33.59	32.22	31.44	36.34	33.30
Am	9.99	9.84	8.91	7.98	7.49	6.17	3.67	18.81	15.18	17.58	16.65	16.01	22.48	24.24	13.52	13.76	16.99	14.74	15.28	13.17	10.38
As	10.48	9.35	8.77	7.00	13.61	7.64	7.25	6.37	2.99	2.55	2.84	4.60	3.92	6.76	11.07	5.00	5.48	5.68	7.15	7.79	10.82
Aw	20.37	18.46	18.12	17.97	9.89	12.39	9.65	16.36	28.16	23.02	25.37	22.38	23.31	24.24	22.28	27.77	26.35	26.30	25.61	23.51	19.20
BSh	15.87	18.51	18.61	19.39	16.36	17.92	15.92	0.64	2.06	2.25	2.40	2.15	2.45	4.21	3.53	8.13	9.65	11.61	10.97	12.63	21.20
BSk	1.96	1.76	0.88	0.83	1.08	0.34	0.20	1.47	1.52	1.42	1.32	1.76	1.52	0.98	1.47	1.62	1.42	1.27	1.76	1.03	0.39
BWh	9.35	10.97	16.26	19.34	16.45	20.71	35.70	0.10	0.34	0.39	0.44	0.34	0.44	0.98	0.59	0.83	1.13	1.42	1.27	1.52	2.79
BWk	1.91	1.71	1.62	1.57	1.57	1.32	0.78	1.27	1.42	1.42	1.57	1.52	1.57	1.52	1.57	1.57	1.47	1.47	1.47	1.42	1.03
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	5.39	3.38	2.11	2.11	3.13	1.03	0.20	13.81	7.84	6.76	5.78	7.49	4.90	1.86	8.96	6.02	3.92	5.29	5.04	2.60	0.88
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	1.08	0.05	-	-	-	-	-	1.47	0.15	-	0.10	-	0.20	-	0.59	0.05	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

In Brazil, tropical climate changes are expected to be similar to those projected to Bolivia, that is, a significant reduction in the humid tropical climate (Af, Am) and an increase of dry tropical climates (As, Aw), mainly observed in the Amazon region (Table 6). The current Brazilian semi-arid region may increase from 6.5% to 17.7% of the territory, mainly for BWh arid climate. As described above, subtropical humid (Cfb) and dry (Cwa, Cwb, Csa, Csb) climates are likely to disappear by 2071-2099. The Cfa subtropical climate will remain almost unchanged, but geographically it will move to higher and southern areas of the country.

Projections for Chile indicate a drastic retraction of polar climates in the Andean region to a third of the original area in the baseline period (Table 7). On the other hand, global warming will force the expansion of subtropical climates both in the lower Andean regions and in the southern and central regions of the country. There are also rare temperate climates in Chile (Dfc, Dsc); however, even with a trade-off between subtropical and polar climates, it is expected that these types of climate will disappear by the end of this century.

In Colombia, the projections of the ensemble of the GCMs show an expansion of humid tropical climates (Af, Am) from 77 to 82% of the country (Table 8). Arid climates can expand considerably, especially in high altitude regions. Subtropical Cfa and Cfb climates, which are common in South American countries, will decrease in Colombian territory from 11.5% to 3%. The ET polar climate may disappear as early as 2041-2070.

Climate projections for Ecuador are similar to those for Colombia. Ensemble of the GCMs indicates an expansion of humid tropical climate (Af) from 58.5 to 70.5% of the country in the 2071-2099 period (Table 9). Arid climates can expand considerably already in the 2011-2040 period. The rare Cfc will tend to disappear in 2041-2070 (RCP4.5) or 2011-2040 (RCP8.5), whereas common Cfb may decrease up to 50%. ET polar climate may retract as early as 2011-2040 for both RCP scenarios.

French Guiana territory is presently 100% tropical (Table 10). However, projections indicate that arid climate (BSh) will appear in this country by 2041-2070 for both climate scenarios, as a result of the reduction in annual rainfall and global warming. Wettest climate types Af and Am will disappear by 2041-2070 and 2071-2099 for RCP8.5, respectively. Conversely, tropical with dry summer (As) climate type is expected to reach 96.5% of the area of this territory up to the end of the 21^{st} century.

As described above, projections indicate that northern South America may experience strong rainfall reduction, and this will certainly result in a drastic reduction of humid tropical climates (Af, Am) from 65.9% to 11.6% in Guyana, while tropical dry climates (As, Aw) will expand from 22.7% to 65.5% of the country (Table 11). The only 3.5% of Guyana's subtropical territory is doomed to disappear by 2071-2099 in RCP4.5 or by 2011-2040 in RCP8.5. The GCMs presented here also show that Guyana will face wide expansion of arid climates, increasing from 7.9% in the present period to up to 22.9% of the territory in 2071-2099.

The ensemble of GCMs predicts that Paraguay will face strong climate change, with a huge retraction of the Cfa subtropical climate from 41.1% of the country to 3%, and an expansion of tropical climate types from 12.3% to 44.8% of its territory at the end of the 21^{st} century (Table 12). Arid climate probably will increase in Paraguay, by more than 10% of the country's territory, contributing to the expansion of the Dry Chaco ecoregion.

The dynamics of climate change expected for Peru have the same fate as those observed for Colombia and Ecuador. The ensemble of GCMs indicates an expansion of tropical climates, from the present 56.1% to 60.1% of the country by 2071-2099 (Table 13). Arid climates can expand considerably and will cover 27% of the country by 2071-2099. The ET polar climate may reduce to a quarter in relation to the present time by the end of the century.

The climate projections for Suriname indicate that this country will face severe climate change, with a strong reduction of tropical wet climates (Af, Am), which will shift to dry tropical climates (As and Aw) by 2071-2099 for RCP8.5 (Table 14). Absent in the baseline period, the arid climates will emerge in Suriname by 2011-2040 and gradually increase to close to 3% of the country's territory in 2071-2099.

Uruguay is the only country without a tropical climate in South America and even under climate change with higher temperatures it will remain so until the end of the 21st century for any assessed climate model or scenario (Table 15).

A strong increase in arid climates is expected for Venezuela, from 7.1% in the baseline period to 25.4% of the country by 2071-2099 (Table 16), expanding mainly into the regions with tropical climates (As, Aw) and part of the subtropical climate (Cfb). The subtropical climate will tend to greatly reduce the extent over the next few years (Figures 23, 24, 25).

5 Future climate change in the main planted forests

Future climate changes for the main forest plantations in the South American countries will be presented according to the sequence in Table 1.

Current Eucalypt plantations in Argentina are located 98% in subtropical climates (Cfa, Cwa, Cwb) and only 2% in arid climates (BSh, BSk). By the end of the analyzed period (2071-2099), the same forest base is expected to be cultivated in 15.1% of tropical conditions (Af, As), 84.5% in subtropical climates (Cfa, Cwa), and almost no arid conditions (Table 17). For the current Pine plantations, they are located 84.8% in subtropical climates (Cfa, Cwb, Csc, Csb) and only 1.6% in arid climates (BSk). By the end of the analyzed period (2071-2099), considering the ensemble of GCMs and RCP8.5, the same forest base is expected to be cultivated in 57.2% in tropical conditions (Af), 40.9% in subtropical climates (Cfa, Csb), and only 1.9% in arid conditions (BSk, BSh) (Table 18). Finally, for the current Poplar plantations in Argentina are located 98% in subtropical climates (Cfa, Cwb, Cwa) and only 2% in arid climates (BSh, BSk). By the end of the analyzed period (2071-2099), considering projected climate change for RCP8.5, the same forest base is expected to be 78.4% cultivated in subtropical climates (Cfa, Csb), and 21.6% in arid conditions (BWk, BSk) (Table 19).

In Brazil, the current Wattle plantations are located 90.5% in subtropical climates (Cfa, Cfb), and 9.5% in tropical climates (As, Aw). By the end of the analyzed period (2071-2099), considering the climate change projections for RCP8.5, the same forest base is expected to be cultivated in 2.4% tropical conditions (As), 90.5% in subtropical climates (Cfa), and 7.1% in arid conditions (BSh) (Table 20). For the current Eucalypt plantations, they are located 80.2% in subtropical climates (Cfb, Cfa, Cwb, Cwa), 19.5% in tropical climates (Aw, Am, Af), and only 0.2% in arid climates (BSh). By the end of 21st century for RCP8.5 scenario, the same forest base is expected to be cultivated in 59.4% tropical conditions (Aw, Af), 33.6% in subtropical climates (Cfa, Cfb), and 7% in arid conditions (BSh) (Table 21). When considering the current Pine plantations, Brazil has such forests located 98.7% in subtropical climates (Cfb, Cfa), and only 1.3% in tropical climates (Aw, Am, Af). By the end of the 21st century (2071-2099), considering RCP8.5 scenario, the same forest base is expected to be cultivated in 78.3% in subtropical climates (Cfa, Cfb), and 21.5% tropical conditions (Af, Am) (Table 22). Finally, the current Rubber tree plantations in Brazil are located 93.3% in tropical climates (Aw, Am), and 6.7% in subtropical climates (Cfa, Cfb). By the end of the 21st century (2071-2099), the same forest base is expected to be cultivated in 99.9% tropical conditions (As), and only 0.1% in subtropical conditions (Table 23).

In Chile, the current Eucalypt plantations are located 100% in subtropical climates (Cfb, Csb). By 2071-2099 for RCP8.5 scenario, the same forest base is expected to be cultivated 100% in subtropical climates, and most of them in dry summer (Table 24). For the current Pine plantations in Chile, they are located 100% in subtropical climates (Cfb, Csb) and will remain like that by the end of 21st century (2071-2099), considering the ensemble of GCMs for RCP8.5 scenario, with most part of the Pine forests in subtropical climate with dry summer (Table 25).

In Ecuador the current Teak plantations are located 48.7% in arid climates (BSk, BWk), 17.8% in tropical climates (Aw, Am, Af), and 11.5% in subtropical climates (Cfb, Cfa). Considering the climate change projected to 2071-2099, the same forest base is expected to be cultivated in 67.2% in arid climates (BSk, BWk), 19.7% tropical conditions (Af), and 10.1% in subtropical climates (Cfb, Csb) (Table 26). Considering that our study is using information with different spatial granularities, in the case of Ecuador there is a confusion between the locations of Teak plantations and the polar climates of the Andean region, which were disregarded in the present analysis.

In Uruguay the current Eucalypt plantations are located 100% in subtropical climates (Cfa, Cfb). By the end of the century (2071-2099), under the RCP8.5 scenario, the same forest base is expected to be cultivated 100% in subtropical climate (Cfa) (Table 27).

In general, it is expected that arid climates advance over tropical climates, and the latter ones over subtropical climates, in a moderate to quick intensity, depending on the GHG future emission scenario considered. The effects of climate change are being felt through increasingly extreme weather events, severe summers and frequent heat waves, with higher average air temperature every year, reduction in the total annual rainfall and change in its distribution in various locations, resulting in longer and intense water deficit. All these climate changes have caused most frequent extensive forest fires, environmental imbalances causing the insects natural enemies' reductions, outbreaks of pests and diseases, and large-scale tree mortalities in forest plantations. These are some of the factors that are causing productivity stagnation and, even its decline, as observed in the last decade in several countries where forest species are commercially cultivated. Thus, meteorological monitoring and adaptation strategies will be required to promote increase of forest production. Among the adaptative actions, the establishment of intensive experimentation on factors influencing the tree growth across diverse climate ranges such as broad trials of genetics and silviculture is the key strategy (Munhoz, 2015; Binkley et al., 2017; Stape et al., 2018; Albaugh et al., 2018; Ryan et al., 2020), also the use of ecological modeling tools for better understanding genotype x environment x management interactions (Elli et al., 2019; Caldeira et al., 2020; Queiroz et al., 2020; Lim et al., 2020), the

Table 17 Köppen's climate types and their changes (%) found in present Eucalypt plantations in Argentina for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	0.64	2.40	0.66	2.70	4.88	7.46	-	-	-	-	-	-	-	-	-	-	0.06	-	0.34	12.22
Am	-	0.17	-	-	0.67	3.03	11.13	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47
As	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	0.45	-	0.45	1.78
Aw	-	-	0.45	-	-	1.68	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	0.66
BSh	0.04	0.17	0.02	0.02	0.23	0.03	0.03	16.56	18.66	33.98	56.02	19.14	40.94	30.19	1.58	8.68	3.03	0.90	6.80	8.38	0.27
BSk	0.05	0.05	0.04	0.04	0.04	0.03	0.03	43.61	13.28	9.64	9.31	41.39	3.37	2.06	0.41	0.04	0.04	0.04	0.04	0.04	0.02
BWh	-	-	-	-	-	-	-	0.29	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	0.01	0.01	0.01	0.01	-	0.01	0.01	6.31	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Cfa	85.98	85.56	84.09	85.84	82.47	66.18	67.35	21.26	58.80	46.69	23.76	30.21	44.65	54.61	84.40	77.70	83.13	85.00	79.36	73.07	71.64
Cfb	-	-	-	-	-	-	-	0.59	0.10	-	-	-	-	-	-	-	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	10.50	10.46	10.35	10.79	11.25	21.87	11.63	3.50	3.54	4.44	5.64	3.64	5.83	11.77	5.59	6.43	10.63	10.26	10.37	14.76	10.27
Cwb	3.41	2.94	2.65	2.65	2.65	2.29	0.27	7.87	5.57	5.23	5.23	5.57	5.17	1.34	7.98	7.12	3.14	3.26	3.41	2.93	2.64
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 18 Köppen's climate types and their changes (%) found in present Pine plantations in Argentina for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	5.08	10.49	5.21	10.92	23.65	35.67	-	-	-	-	-	-	-	-	-	-	0.37	-	3.22	56.49
Am	-	0.97	-	-	1.11	7.11	29.29	-	-	-	-	-	-	-	-	-	-	-	-	-	0.26
As	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47
BSh	0.03	0.08	0.71	0.75	0.72	0.77	0.82	3.18	3.21	3.14	4.24	2.83	2.76	3.16	0.09	0.21	0.08	0.16	0.08	0.08	0.79
BSk	1.93	2.77	4.49	5.50	0.34	0.84	1.67	3.36	2.82	3.18	2.94	4.05	3.09	2.97	1.46	1.59	1.58	1.58	1.58	1.55	0.98
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.75	0.75	0.33	0.74	0.74	0.33	0.39	0.09	0.09	0.09	0.09	0.09	0.09	0.10
Cfa	71.92	66.16	62.12	67.41	59.90	41.15	7.49	65.06	69.01	68.99	67.25	68.53	68.95	80.78	71.90	71.90	71.92	71.55	71.92	68.67	17.36
Cfb	-	-	-	-	0.02	-	-	1.89	0.36	0.03	0.06	0.06	-	0.01	-	-	1.12	-	-	-	-
Cfc	3.56	0.78	0.04	0.04	0.03	-	-	-	-	1.77	1.12	-	-	1.01	-	-	2.16	3.19	-	-	-
Cwa	2.24	2.34	2.27	2.27	2.96	3.28	4.05	0.52	-	0.68	0.97	-	1.20	2.16	0.94	1.36	2.52	2.11	2.19	2.58	2.85
Cwb	2.30	1.89	1.83	1.83	1.83	1.51	0.44	2.99	1.54	1.51	1.51	1.54	1.51	1.07	3.35	2.67	1.66	1.98	1.98	1.65	1.48
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	6.35	11.13	15.20	15.46	17.99	19.12	20.51	0.11	0.63	1.93	2.06	2.03	2.48	8.46	2.48	3.54	6.32	4.89	5.99	11.92	19.23
Csc	8.24	8.47	2.83	1.53	3.85	2.56	-	2.48	4.42	2.25	4.60	1.02	7.34	-	6.08	10.82	9.91	12.30	10.26	9.46	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	0.58	0.03	-	-	0.03	-	-	-	-	-	-	-	-	-	0.17	-	0.03	0.03	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	2.83	0.29	0.02	-	0.29	-	-	19.67	17.26	16.17	14.50	19.21	12.33	-	13.43	7.80	2.60	1.74	5.90	0.77	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 19 Köppen's climate types and their changes (%) found in present Poplar plantations in Argentina for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	0.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	-	-	-	-	-	-	0.09	0.71	1.96	0.53	2.05	1.96	0.80	2.15	1.58	0.18	-	-	-	-	-
BSk	8.19	6.94	4.54	4.63	8.54	3.02	5.52	75.98	37.63	72.78	52.40	91.81	46.80	39.50	0.41	21.62	6.58	6.67	23.40	3.65	8.21
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	18.59	18.59	21.80	21.80	12.46	18.59	18.59	15.84	0.09	0.09	0.09	0.09	0.09	0.09	0.04	0.09	18.51	18.68	0.09	18.68	13.39
Cfa	70.02	70.46	70.55	70.73	55.16	69.66	70.91	0.18	54.18	19.13	39.50	0.18	45.11	52.96	84.40	69.93	70.02	70.20	70.02	54.18	70.63
Cfb	-	-	-	-	-	-	-	0.62	-	-	-	-	-	0.18	-	-	-	-	0.18	-	-
Cfc	0.09	-	-	-	-	-	-	0.18	-	0.18	-	-	-	-	-	-	0.09	0.09	-	-	-
Cwa	2.22	1.96	1.87	1.87	17.88	2.76	1.78	1.33	0.09	1.60	0.09	0.09	1.33	0.18	5.59	2.14	2.31	2.31	2.22	18.15	2.32
Cwb	0.36	0.18	0.18	0.18	0.18	0.18	0.18	0.36	0.27	0.27	0.27	0.27	0.27	0.18	7.98	0.27	0.18	0.18	0.27	0.18	0.18
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	0.18	0.18	-	0.18	0.18	0.36	-	-	-	-	-	-	-	-	-	-	-	-	0.18	-
Csb	0.09	0.89	0.53	0.53	5.25	5.25	2.40	2.58	3.65	4.54	3.83	3.83	4.54	4.76	-	4.72	1.51	0.98	2.85	4.18	5.27
Csc	0.09	0.80	0.36	0.27	0.36	0.36	-	1.16	1.16	-	1.33	0.71	0.71	-	-	0.71	0.44	0.53	0.62	0.71	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	0.36	-	-	-	-	-	-	1.07	0.98	0.89	0.44	1.07	0.36	-	-	0.36	0.36	0.36	0.36	0.09	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 20 Köppen's climate types and their changes (%) found in present Wattle plantations in Brazil for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	0.09	9.17	0.33	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	0.03	-	9.20	9.53	9.53	9.53	9.53	9.53	7.15	8.56	8.56	7.15	7.15	9.53	2.44
Aw	-	-	-	-	-	-	-	0.36	-	-	-	-	-	-	2.38	-	-	-	-	-	-
BSh	9.53	9.53	9.53	9.53	8.32	8.32	-	-	-	-	-	-	-	-	-	0.97	0.97	2.38	2.38	-	7.09
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	1.21	1.21	9.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	90.17	80.88	90.44	90.44	90.44	90.44	90.35	3.20	23.64	60.40	48.19	25.57	69.03	89.08	68.97	89.72	90.41	90.41	90.17	90.44	90.47
Cfb	0.30	-	-	-	-	-	-	87.27	66.83	30.07	42.28	64.90	21.44	1.39	21.50	0.75	0.06	0.06	0.30	0.03	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	9.59	0.03	0.03	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 21 Köppen's climate types and their changes (%) found in present Eucalypt plantations in Brazil for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	2.65	1.64	4.71	2.95	2.37	3.86	4.97	6.15	5.23	6.77	6.70	5.53	4.98	7.79	4.46	2.44	5.10	4.58	3.64	5.73	7.23
Am	3.17	0.59	3.28	5.44	2.33	2.86	2.46	3.70	4.93	5.04	5.57	3.75	6.53	9.93	4.29	4.98	6.95	9.64	6.17	8.16	10.22
As	4.16	11.64	12.87	13.88	15.74	19.17	22.36	0.77	1.24	1.58	1.38	2.07	2.38	3.62	1.48	2.45	2.82	2.93	3.44	4.04	4.60
Aw	15.32	15.70	22.76	21.13	21.01	22.87	11.24	2.38	9.25	10.74	12.50	8.56	14.22	20.32	9.29	18.61	23.18	28.08	24.84	32.58	37.33
BSh	3.58	20.21	14.71	15.46	18.24	18.35	25.98	0.02	0.16	0.18	0.16	0.18	0.20	0.56	0.16	1.90	1.04	1.74	3.09	2.11	6.84
BSk	2.08	0.15	-	-	-	-	-	0.04	0.01	-	-	0.01	-	-	0.03	1.02	0.26	0.26	0.85	0.26	-
BWh	0.18	3.34	0.61	2.63	2.30	2.30	8.75	-	0.01	0.01	0.03	0.04	0.04	0.06	0.04	0.06	0.06	0.06	0.10	0.11	0.21
BWk	-	0.26	-	-	0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	20.08	32.73	33.42	34.85	26.26	27.60	22.90	2.13	4.67	7.38	7.41	5.30	9.24	15.49	8.72	19.78	24.46	23.93	16.97	22.29	24.10
Cfb	39.47	11.49	6.28	3.49	11.33	2.77	0.66	72.48	62.53	57.24	61.43	59.98	43.18	37.70	61.69	42.70	34.53	28.41	39.71	24.57	9.36
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	1.96	1.52	1.08	-	-	-	-	0.09	0.56	0.67	0.49	2.01	1.04	1.44	1.08	0.74	0.68	-	-	-	-
Cwb	7.36	0.26	-	-	-	-	-	12.25	11.40	10.40	4.34	12.47	18.21	3.10	8.76	5.21	0.92	0.24	1.07	0.04	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	0.34	0.07	-	0.02	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	0.16	0.22	0.16	0.16	0.22	0.40	-	-	-	-	0.10	-	-	-	0.12	-	0.12	0.12	0.10	0.12
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 22 Köppen's climate types and their changes (%) found in present Pine plantations in Brazil for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	2.34	6.14	11.61	8.24	7.94	19.46	33.47	-	0.06	0.27	0.31	0.27	0.48	3.85	0.27	2.09	3.82	4.55	3.81	4.51	17.51
Am	0.16	0.52	0.58	1.90	2.24	1.67	7.70	0.06	0.06	0.02	0.15	-	1.19	0.73	0.26	0.52	0.48	1.24	1.17	1.72	2.13
As	0.06	0.61	0.30	0.40	0.65	0.81	4.61	0.03	0.05	0.05	0.06	0.11	0.09	0.16	0.04	0.09	0.06	0.08	0.19	0.19	0.12
Aw	0.69	1.96	0.95	1.45	3.38	2.47	2.22	0.42	0.91	0.99	1.20	0.84	1.74	1.34	0.74	1.28	0.91	0.98	0.86	1.54	1.70
BSh	-	0.29	0.11	0.12	0.29	0.30	0.66	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	0.03	0.21
BSk	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	36.56	71.06	79.32	85.76	67.93	73.09	49.26	5.55	11.36	18.47	18.07	12.37	21.42	34.70	18.38	37.01	47.49	51.22	39.25	53.61	65.29
Cfb	60.11	18.24	6.92	1.84	17.27	1.78	0.28	93.61	87.40	80.10	80.17	86.23	74.98	59.20	80.12	58.94	47.24	41.94	54.69	38.40	13.04
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	0.03	0.03	-	-	-	-	-	0.05	0.05	-	0.01	0.06	0.02	0.01	0.07	0.01	0.01	-	-	-	-
Cwb	0.04	-	-	-	-	-	-	0.28	0.11	0.09	0.03	0.11	0.07	-	0.12	0.05	-	-	0.04	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	0.01	0.90	0.11	0.22	0.25	0.33	1.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	0.24	0.10	0.06	0.06	0.10	0.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 23 Köppen's climate types and their changes (%) found in present Rubber tree plantations in Brazil for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	0.13	-	-	-	-	-	-	-	-	-	1.48	-	-	-	-	-	-	-
Am	13.83	4.16	13.69	14.50	4.30	4.30	8.05	6.98	17.99	5.37	4.30	-	1.61	15.03	7.79	1.74	11.68	9.26	8.32	2.28	1.34
As	0.67	4.30	0.67	0.67	8.46	3.76	14.63	0.67	2.15	0.67	0.67	2.15	3.62	3.62	0.67	0.67	0.67	0.67	0.67	3.62	5.50
Aw	84.03	58.93	85.50	84.56	87.11	91.81	65.50	15.97	71.28	85.64	90.87	79.33	93.29	78.93	84.83	96.64	86.85	89.53	90.47	93.69	93.02
BSh	-	32.21	-	-	-	-	11.81	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	1.07	0.27	0.13	0.13	-	0.13	-	67.38	7.11	7.38	3.49	17.45	0.94	0.54	5.77	0.54	0.40	0.40	0.13	0.27	-
Cfb	0.40	0.13	-	-	0.13	-	-	8.99	1.48	0.94	0.67	1.07	0.54	0.40	0.94	0.40	0.40	0.13	0.40	0.13	0.13
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 24 Köppen's climate types and their changes (%) found in present Eucalypt plantations in Chile for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	11.91	2.78	-	-	0.56	-	-	54.84	54.84	55.87	62.37	46.21	66.02	50.93	36.92	30.55	33.59	27.85	36.84	26.64	12.34
Cfc	-	-	-	-	-	-	-	1.98	1.98	1.80	1.44	1.56	1.47	0.50	0.02	0.17	0.02	0.02	0.12	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	1.86	7.96	-	6.61	14.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	87.90	97.21	98.14	92.04	99.44	93.39	85.79	40.84	40.84	40.92	35.62	51.77	31.73	48.05	62.54	68.76	66.21	71.59	62.52	73.19	87.66
Csc	0.19	0.01	-	-	-	-	-	1.31	1.31	0.72	0.01	0.28	0.01	0.35	0.52	0.52	0.17	0.54	0.52	0.16	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	1.02	1.02	0.69	0.56	0.17	0.78	0.17	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 25 Köppen's climate types and their changes (%) found in present Pine plantations in Chile for all climate scenarios and models studied

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	16.30	3.40	0.79	0.46	1.14	0.39	0.18	68.58	68.25	77.67	60.83	81.88	66.34	52.29	57.61	46.69	49.10	43.57	51.76	42.30	14.04
Cfc	-	-	-	-	-	-	-	2.80	2.82	2.73	2.77	2.53	1.31	-	1.34	0.74	-	-	0.57	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	3.51	-	4.75	9.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	83.47	96.60	99.21	96.04	98.86	94.86	90.59	25.98	27.52	19.32	36.16	14.58	32.11	47.46	40.80	52.33	50.66	56.15	47.43	57.48	85.96
Csc	0.24	-	-	-	-	-	-	1.09	0.43	-	-	-	0.01	0.25	0.03	0.25	0.24	0.28	0.25	0.22	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	1.55	0.98	0.28	0.24	1.01	0.24	-	0.22	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 26 Köppen's climate types and their changes (%) found in present Teak plantations in Ecuador for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	17.52	17.43	18.48	18.67	18.27	18.80	18.82	10.73	16.90	18.03	18.03	17.23	18.61	18.84	16.81	18.44	18.92	18.92	18.61	18.98	18.82
Am	0.75	1.03	0.25	0.12	0.63	0.12	0.08	3.25	0.36	0.58	0.45	0.45	0.04	0.37	0.61	0.12	0.01	0.01	0.05	-	0.37
As	0.16	0.36	0.12	0.32	0.33	0.71	0.67	2.17	0.51	0.05	0.18	0.33	0.18	0.05	0.32	0.20	0.13	0.12	0.13	0.12	0.50
Aw	0.04	0.22	0.25	0.03	0.05	-	-	0.09	0.08	-	-	0.08	-	-	0.08	-	0.04	0.04	0.04	0.04	-
BSh	0.04	0.32	0.30	0.62	0.12	0.66	1.01	0.04	-	-	-	-	-	0.28	0.04	0.04	0.25	0.26	-	0.29	0.53
BSk	32.18	36.91	43.90	31.68	46.85	42.89	30.83	24.98	27.46	25.23	27.29	27.93	24.42	27.33	29.06	37.55	33.46	37.04	40.44	35.11	41.85
BWh	-	0.34	0.37	1.62	0.34	1.58	4.15	-	-	0.34	0.34	-	0.34	0.34	-	-	0.34	0.34	0.34	0.34	1.58
BWk	22.10	39.82	32.17	46.26	20.44	31.28	41.45	18.98	23.25	23.48	26.44	24.52	26.44	26.87	19.63	24.18	25.12	25.27	24.92	25.05	23.21
Cfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfb	6.79	3.53	4.16	0.70	9.00	3.48	2.05	8.19	9.61	12.58	12.58	9.28	15.35	13.70	10.85	6.99	13.62	14.32	6.86	14.65	8.46
Cfc	3.19	-	-	-	0.05	0.20	0.30	0.59	3.19	3.65	3.16	3.19	6.38	0.20	0.66	5.29	1.58	-	3.16	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	0.59	-	-	-	1.62	-	0.20	3.11	-	0.09	0.59	0.09	0.59	2.19	-	-	0.09	0.09	0.09	0.59	1.62
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	16.64	0.05	-	-	2.29	0.30	-	27.87	18.65	15.95	10.93	16.90	7.63	9.85	21.96	7.19	6.44	3.58	5.36	4.83	3.07
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 27 Köppen's climate types and their changes (%) found in present Eucalypt plantations in Uruguay for all assessed climate scenarios and global climate models

Köppen Climate type	HadGEM2							MIROC5							HadGEM2-MIROC5						
	Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5			Baseline	RCP4.5			RCP8.5		
	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099	1961-1990	2011-2040	2041-2070	2071-2099	2011-2040	2041-2070	2071-2099
Af	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Am	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BSh	-	-	-	-	-	-	-	-	-	-	3.08	-	-	-	-	-	-	-	-	-	-
BSk	-	-	-	-	-	-	-	12.35	-	-	0.65	2.61	0.18	-	-	-	-	-	-	-	-
BWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BWk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cfa	100.00	99.98	100.00	100.00	100.00	100.00	99.92	34.33	66.89	85.74	85.87	61.25	94.07	99.82	93.80	99.82	100.00	100.00	100.00	100.00	100.00
Cfb	-	-	-	-	-	-	-	53.32	33.11	14.26	10.40	36.14	5.75	0.18	6.20	0.18	-	-	-	-	-
Cfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csa	-	0.02	-	-	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Csc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dfd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dwd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dsd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

development of new clones by breeding programs, and more suitable forest management actions for improving water use efficiency are the main ones to reach a long-term sustainability for forestry business.

The climate data and also the Köppen climate type of all assessed climate scenarios and GCMs are available in gridded-data in the shapefile format at www.ipef.br/publicacoes/climatechange.

6 Acknowledgments

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