Climate Change in the Tropics

Thorsten Peters

Contents

Abstract

In this chapter, different aspects of climate variability at different time and spatial scales and their possible influences on ecosystems and biodiversity are discussed. A comprehensive full survey on climate change is presented in the fifth IPCC (Intergovernmental Panel on Climate Change) assessment report 2013/2014.

Keywords

Tropics • Climate Change • Climate Change Scenarios • Land Use Change • Ecuador

Climate Changes and Predictions

Instrumental climate records are barely older than 150 years and give evidence of a rise in the global surface temperature. When calculated by a linear trend, global mean surface temperatures increased by 0.74 °C ± 0.18 °C over the last 100 years (1906–2005). During this time span, the rate of temperature increase almost doubled after 1956 (from 0.07 °C ± 0.02 °C to 0.13 °C ± 0.03 °C vs. per decade) (Fig. 1, IPCC 2013). Warming has taken place in both land and ocean regions

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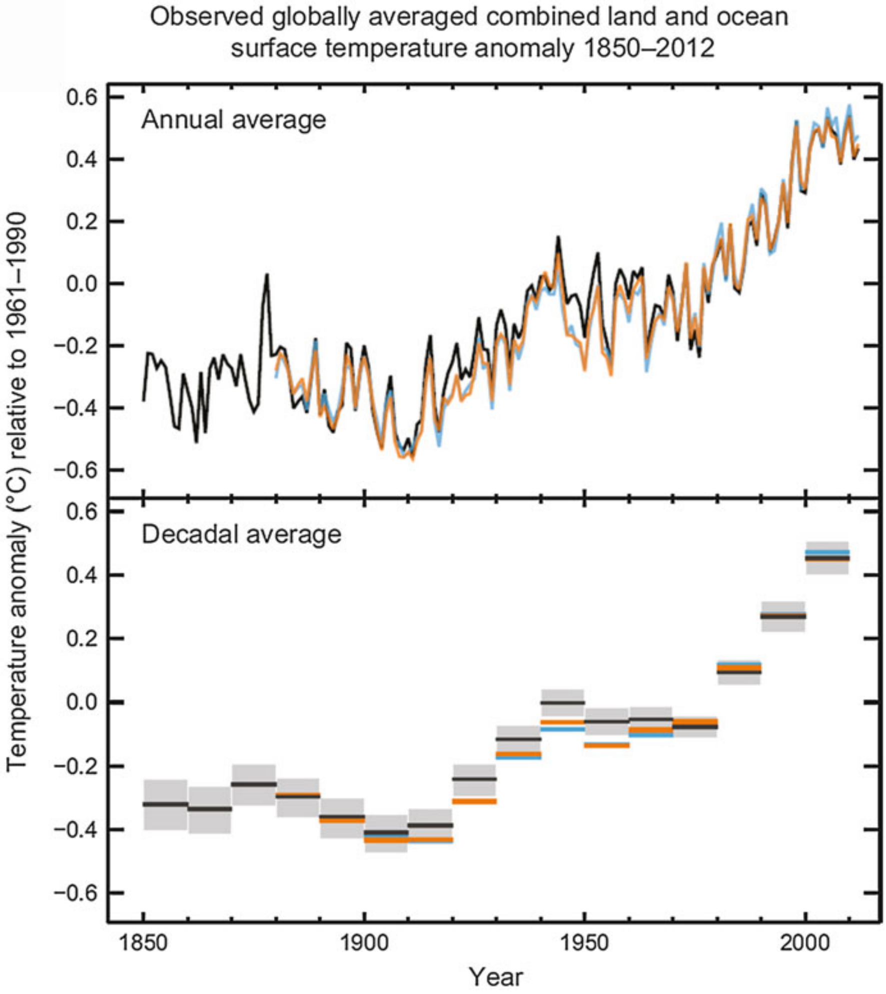


Fig. 1 Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012 (Source: IPCC 2013)

whereupon surface land air temperatures increased at about twice as fast as surface ocean air temperatures since 1979 (from 0.13 °C per decade to 0.27 °C per decade). Consequently, land regions have warmed at a faster rate than the oceans with distinct differences on a global scale. As shown by Fig. 2, clear differences in warming can be observed in the Atlantic, the Pacific, and the Indian Ocean. While the Pacific decadal climate variability is more symmetric about the equator with regional influences of El Niño events, the Indian Ocean is characterized by a steadier warming. These different properties lead to important discrepancies in regional ocean surface warming rates which affect the global circulation patterns as well (IPCC 2013). However, atmospheric circulation variability and change are

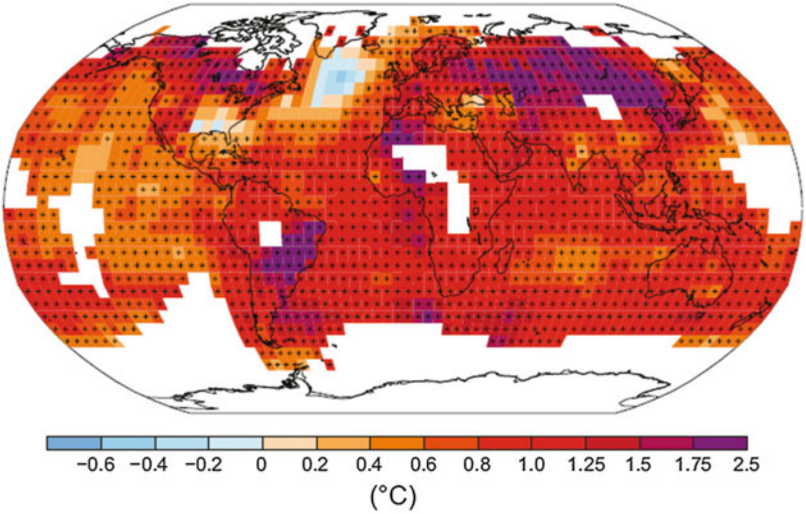


Fig. 2 Observed change in surface temperature 1901–2012 (Source: IPCC 2013)

largely described by relatively few major patterns: "The dominant mode of global scale variability on interannual time scales is ENSO, although there have been times when it is less apparent. The 1976–1977 climates shift (Fig. 1), related to the phase change in the Pacific Decadal Oscillation and more frequent El Niños, has affected many areas and most tropical monsoons. For instance, over North America, ENSO and Pacific-North American teleconnection-related changes appear to have led to contrasting changes across the continent, as the west has warmed more than the east, while the latter has become cloudier and wetter. There are substantial multidecadal variations in the Pacific sector over the twentieth century with extended periods of weakened (1900–1924; 1947–1976) as well as strengthened circulation (1925–1946; 1976–2005). Multi-decadal variability is also evident in the Atlantic as the Atlantic Multidecadal Oscillation in both the atmosphere and the ocean" (IPCC 2013). Referring to the tropical land regions, different warming trends can be observed within all tropical regions (Fig. 2). Especially the eastern parts of Amazonia as well as the northwestern parts of the African continent are affected by strong warming whereas the warming trends are more moderate for the remaining part of the tropics.

In terms of precipitation, rainfall amounts increased over land areas north of 30 ° latitude between 1900 and 2005. In contrast, negative trends distinguish the tropics since the 1970s. From 1900 to 1950 precipitation increased clearly between 10° and 30° northern latitude but decreased after 1970. Between 10 °N and 10 °S negative trends are dominant, in particular after 1977. These negative trends are even stronger than the positive trends outside the tropics and bestride the global mean. On a global scale, rainfall amounts increased significantly in northern Europe, northern and central Asia, and in the eastern parts of North and South America while precipitation decreased significantly in the Sahel Zone, southern Africa, the

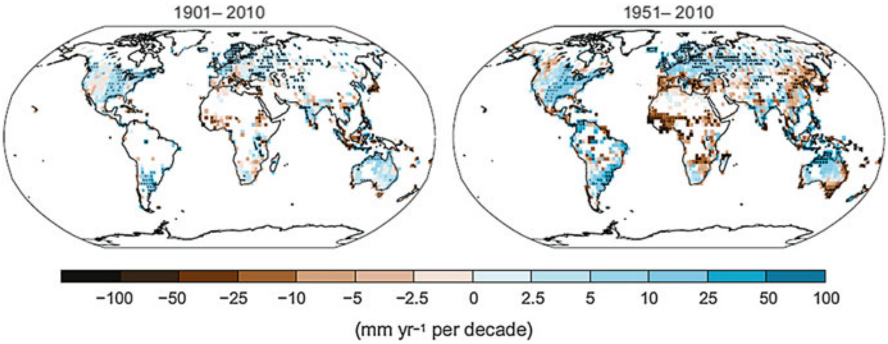


Fig. 3 Observed change in annual precipitation over land (Source: IPCC 2013)

Mediterranean, and parts of southern Asia (Fig. 3). Compared to temperature change, precipitation change patterns are more regionally and seasonally different and where precipitation changes are significant also measured changes in streamflow occur. Simultaneously, to the negative precipitation trends in the tropics droughts have become more common in the tropics and subtropics since the 1970s. The areas where droughts appeared seem to be affected strongly by changes in sea surface temperatures (SSTs) especially in the tropics, by conjoined changes in the regional circulation and precipitation patterns. As measured by the Palmer Drought Severity Index, decreased land precipitation as well as increased temperatures, which raise evapotranspiration rates and drying are important factors for the augmented occurrence of droughts. The most sophisticated coupled atmosphere–ocean general circulation models in current use were developed by the Intergovernmental Panel on Climate change. Up to date the panel issued 5 climate reports in 1990, 1995, 2001, 2007, and 2013/2014. Since the third assessment report, climate change projections have been improved continuously and a "set of coordinated, standard experiments was performed by 14 AOGCM modeling groups from 10 countries using 23 models. The resulting multimodel database of outputs, analyzed by hundreds of researchers worldwide, forms the basis for much of this assessment of model results" (IPCC 2013). The usage of single as well as multimodel ensembles permits more robust surveys of the range of model results and more quantitative model evaluation against observations. "A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. A large number of comprehensive climate models and ESMs have participated in CMIP5, whose results form the core of the climate system projections" (IPCC 2013). According to the RCP scenarios, the global temperature changes over land will exceed the changes over the oceans clearly up to the year 2100 (Fig. 4). Irrespective of the chosen climate scenario (RCP 2.6, 4.5, 6.0, or 8.5), the arctic region will warm most, followed by the North American continent, large parts of Russia, central South America, and the dry areas of Africa. At once there

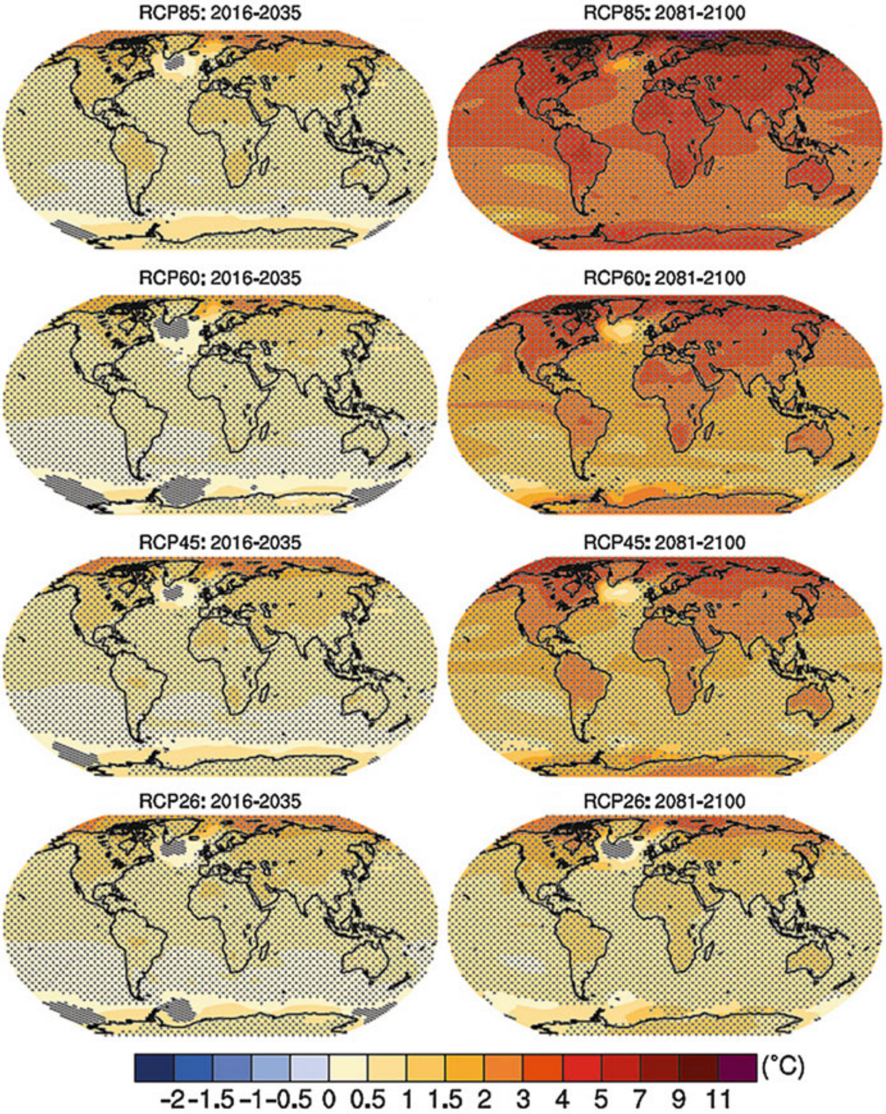


Fig. 4 Annual mean temperature change (Source: IPCC 2013)

will be fewer cold weather extremes and more hot temperature events. Furthermore, a decrease in cloud amounts is predicted for most of the tropics and mid-latitudes, mainly due to reductions in low clouds (IPCC 2013). The expected positive temperature changes of land and sea areas will also lead to a small decrease in relative humidity close to the surface over most land areas except for some parts of tropical Africa. However, on a global scale, the amounts of relative humidity are projected to stay almost stable while the specific humidity is predicted to rise in a

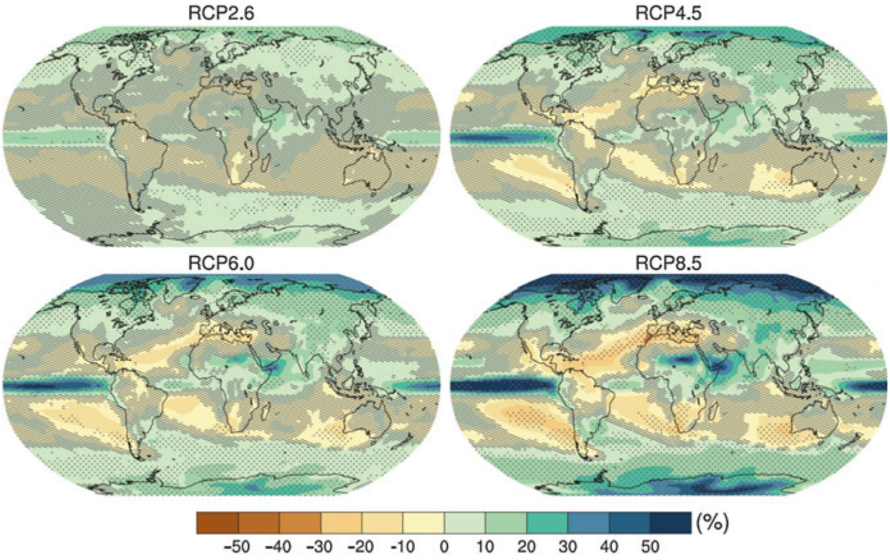


Fig. 5 Annual mean precipitation change (Source: IPCC 2013)

warming environment. This holds also true for global precipitation amounts which are predicted to increase with increasing global mean surface temperatures as well. As demonstrated by Fig. 5, precipitation changes will differ clearly on a regional scale. Even within the Tropics no uniform patterns are predictable and some regions will experience decreasing precipitation amounts and other regions will experience increasing rainfall amounts, while yet others will receive no significant changes at all. Almost certainly the difference of annual mean precipitation between dry and wet regions and consequently the contrast between dry and wet season are predicted to increase on a global scale. Within the wet tropical regions, extreme precipitation events are projected to be more intense and more frequent. At the same time, annual surface evaporation is predicted to change over land in a similar pattern as precipitation (IPCC 2013).

Climate and Land Use Changes Affecting the Andes of Southern Ecuador

Since the announcement of the Millennium Ecosystem Assessment (2005), it is beyond dispute that climate as well as land use change are threatening biodiversity. Based on the fourth IPCC assessment report, prospective climate grid cell maps by Urrutia and Vuille (2009) demonstrate that several parts of the tropical Andes and Amazonia might sustain dramatic temperature and precipitation changes. Depending on the two different IPCC scenarios A2 and B2, a marked increase of air temperature by +3°K relative to the average of 1980–1999 but only a slight

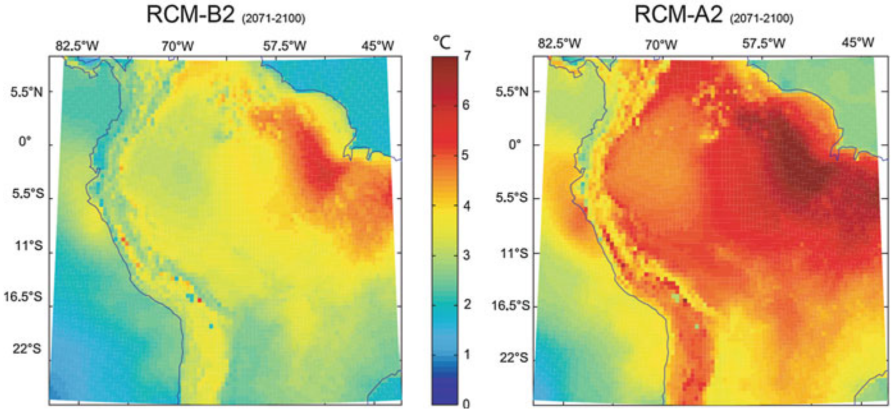


Fig. 6 Prospective climate change scenarios for the tropics of Southern America based on the different IPCC scenarios B2 and A2 (Urrutia and Vuille 2009). In the framework of the B2 scenario technological frontiers are pushed less than they are in A2, and innovations are regionally more heterogeneous

increase of rainfall (+8 %) and cloud fraction (+4 %) is predicted for Southern Ecuador (Figs. 6 and 7) (Meehl et al. 2007). Although it is widely supposed that climate change will lead to the extinction of many species in the future (Colwell et al. 2008; Williams et al. 2007), human land use is currently the most important threat to biodiversity in the Tropics (Pimm and Raven 2000; Köster et al. 2009; de Koning et al. 1998; Southgate and Whitaker 1994; Bebbington 1993). For at least 7,000 years Andean environments have undergone modifications by human activities (Bruhns 1994; Jokisch and Lair 2002; Sarmiento and Frolich 2002), but the intensity of land use has accelerated considerably during the past century (Ellenberg 1979; Luteyn 1992; Peters et al. 2010, 2013). This especially holds true for Ecuador, which exhibits the highest deforestation rate in South America (FAO 2005; Mosandl et al. 2008). Figure 8 demonstrates the important role of road construction for land reclamation in Ecuador. In 1938, only a few roads existed within the coastal plain and the Andes of Ecuador, while the eastern regions of the country were still unaffected. At least 75 % of the western part of the country was forested at that time, and as of 1969 primary forest covered still ca. 63 % (Dodson and Gentry 1991). Only a few new roads were constructed in western and central Ecuador during the interim, while the eastern part of the country remained almost unexploited. During the period up to the year 2000, numerous factors initiated a rapid expansion of road construction which also encroached the eastern lowlands. Ecuador's population increased from less than four to more than ten million people and land reform programs effectively promoted inner colonization of government-owned forested lands. Large sums were invested in road construction to provide communication between and transport to new cities and transfer sites (Dodson and Gentry 1991). Petroleum became the most important export commodity, and the cultivation of cash crops contributed to the derogation of natural environments.

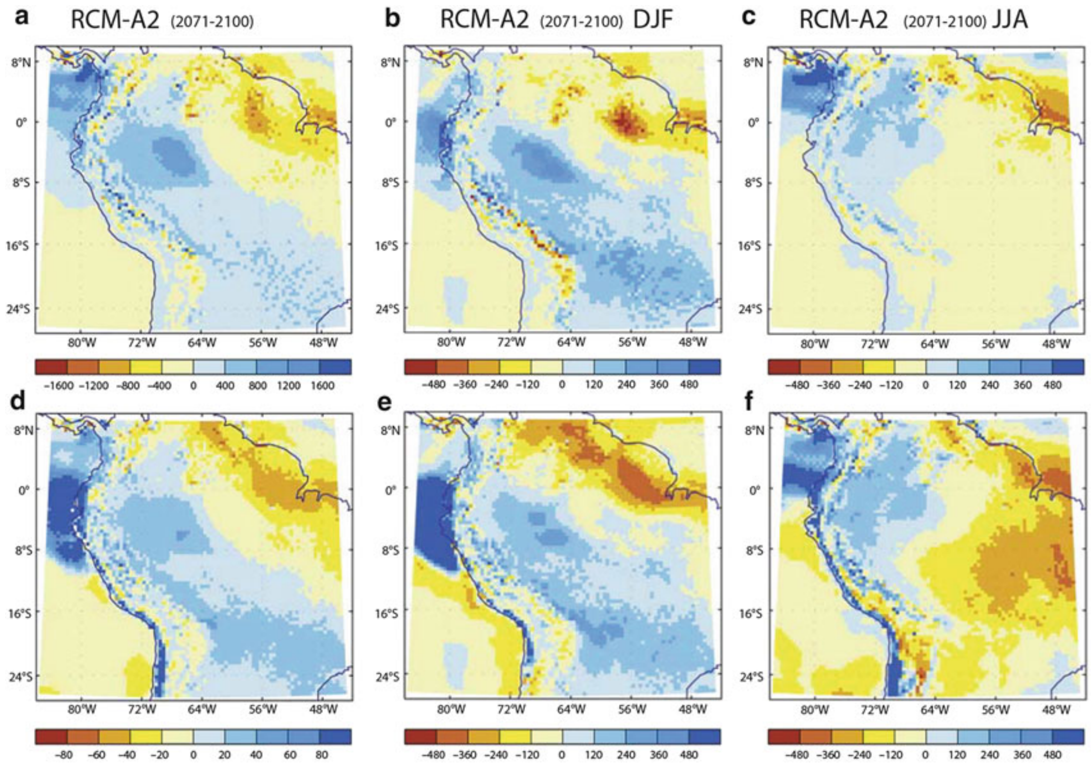


Fig. 7 Differences between the annual mean (**a**), DJF (**b**), and JJA (**c**) precipitation sums (given in mm) according to the IPCC scenario A2 (please note the different scales of **a**, **b**, and **c**). Relative differences (in %) are given in (**d**), (**e**) and (**f**) (After Urrutia and Vuille 2009)

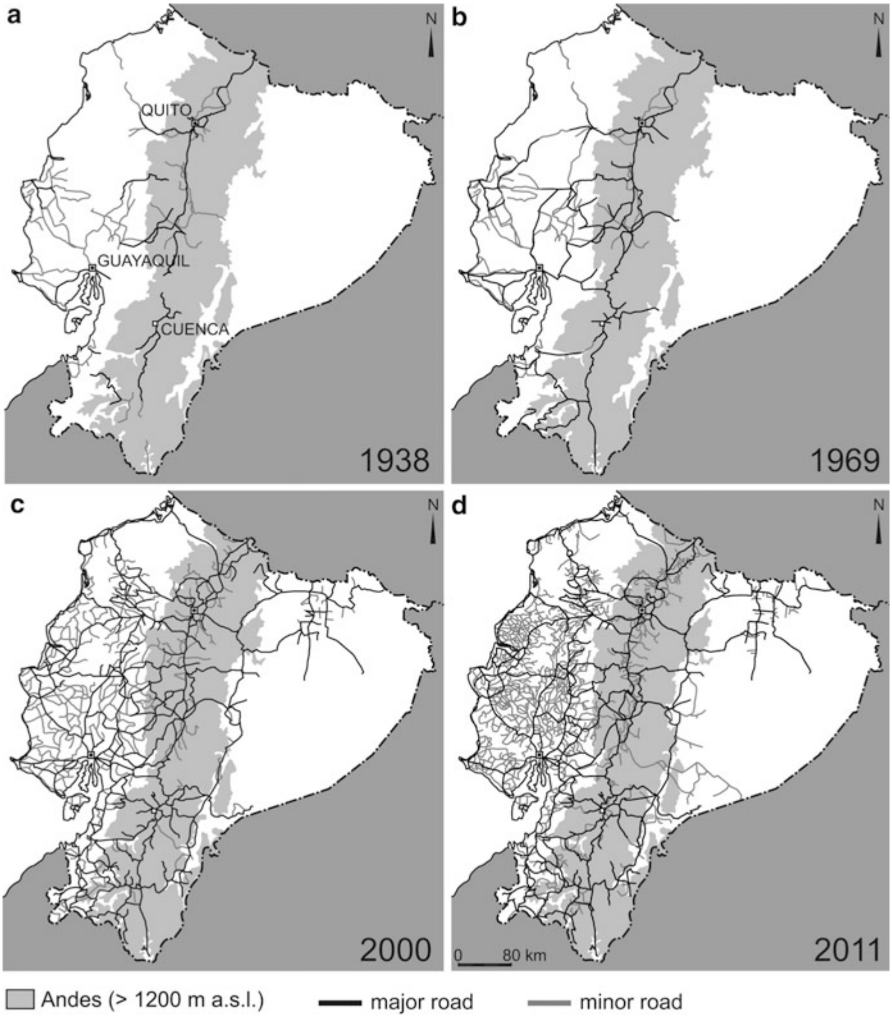


Fig. 8 Road networks of Ecuador in 1938, 1969, 2000 and 2011 (Data sources: (**a**) the American Geographical Society of New York, (**b**) the Head Office of Geodesy and Cartography, German Democratic Republic, Berlin, (**c**) the Instituto Geográfico Militar, Quito, Ecuador and (**d**) own inquiries) (Peters et al. 2013)

Today an extensive network of primary and secondary roads has opened up most of western and central Ecuador, while parts of the Oriente have been converted into protected areas and safeguarded to certain extents (Fig. 8). The area of Ecuador comprises dry and humid mountain biomes as well as lowland tropical dry- and rainforests within a distance of only a few hundreds of kilometers and the tropical Andes contain about one sixth of all known plant species in a space of less than one percent of the world's terrestrial area (Mittermeier et al. 1997).

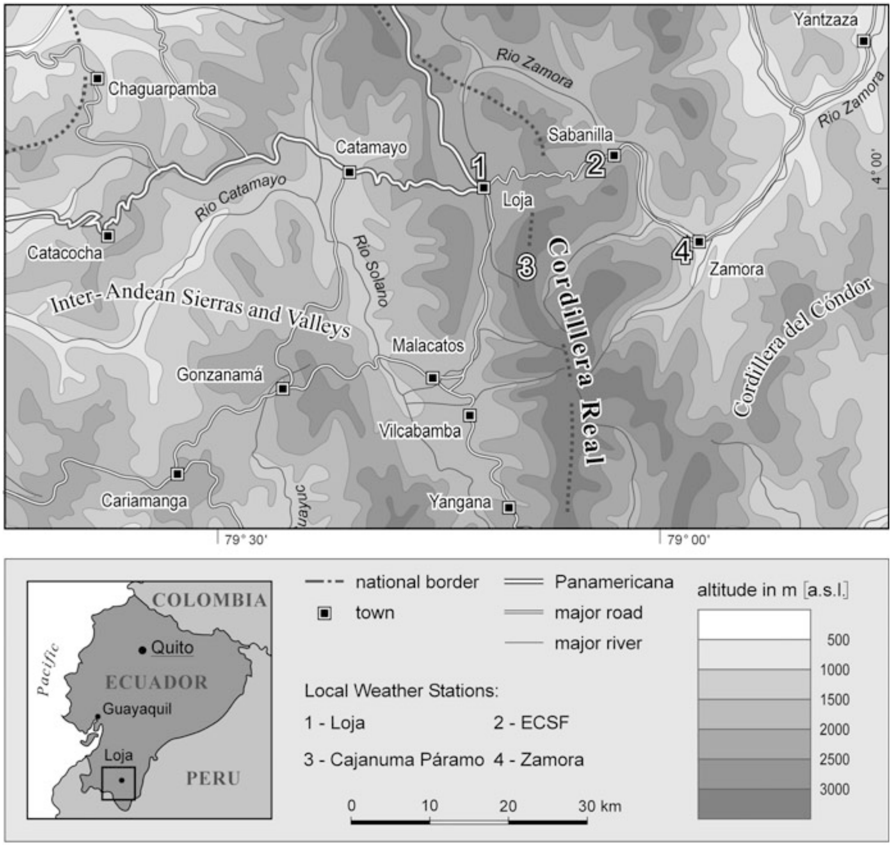


Fig. 9 Location of the text mentioned climate stations in Southern Ecuador

Williams et al. (2007) argued that the climate conditions that favored this biodiversity hotspot during the twentieth century may disappear entirely during the twenty-first century. Unfortunately, longer time series of meteorological measurements from southeastern Ecuador are almost not available. Only the INAMHI (Instituto Nacional de Meterología e Hidrología) station Loja (2,160 m a.s.l.), located in the inter-Andean basin west of the main Cordillera, continuously provides data since 1964. The main station in the Oriente, Zamora (970 m a.s.l.) was shut down in 1993 (Peters et al. 2013). At the eastern escarpment of the Andes, the ECSF meteorological station (1950 m a.s.l.) and the Cajanuma Páramo station (3,400 m a.s.l.) deliver data since 1998 (Fig. 9). The poor data situation is a general problem because the regional climate of Ecuador is highly variable in space and time. Its seasonality changes along a west–east distance of only 40 km from semi-arid conditions west of the main cordillera (at Catamayo) to a perhumid climate east of the main cordillera (at Cerro de Consuelo) (Fig. 10) (Richter 2003). However, despite of the poor data basis some general trends can be observed. Both, the

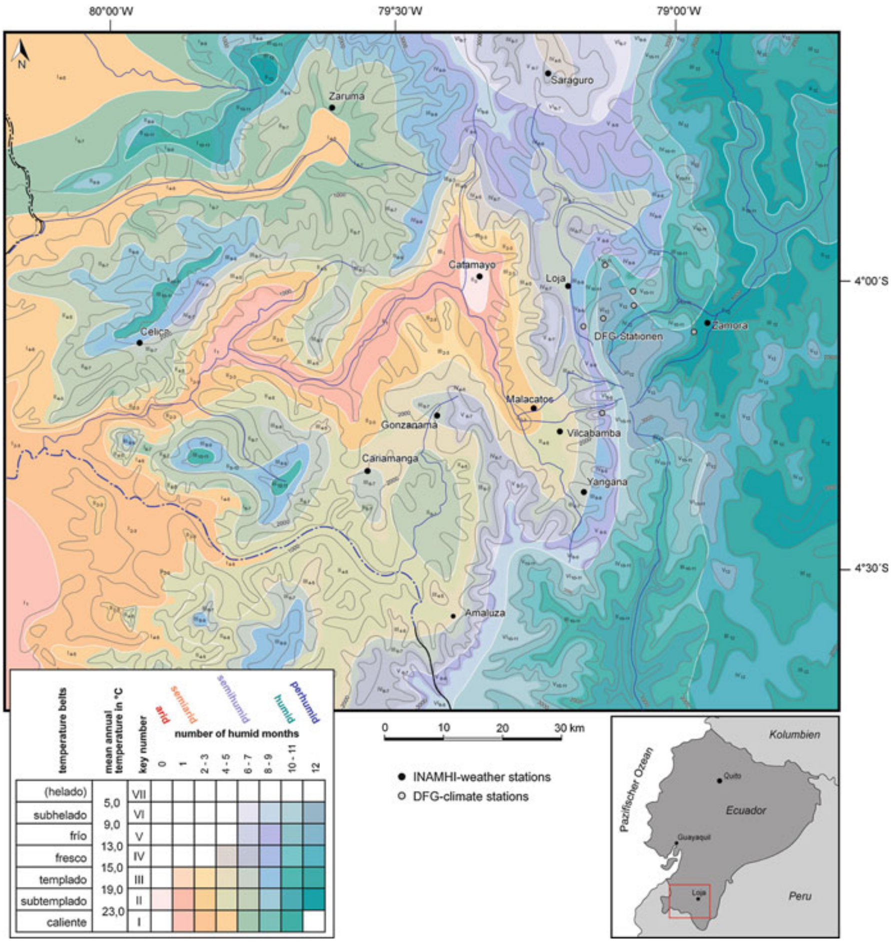


Fig. 10 Hygro-thermal climate differentiation of southern Ecuador (Richter et al. 2009)

western inter-Andean basin of Loja and the eastern Andean escarpment at Zamora reveal a significant warming trend. The air temperature at the station Loja (1964–2008) indicates a warming of ~0.6 °C over the last 45 years (0.13 °C per decade). The station Zamora located in the eastern Andean foothills is characterized by an even stronger warming trend until 1990 (Bendix et al. 2010; Peters et al. 2013). Interestingly, own local climate measurements show partially different trends during March 1998 and March 2012. On the one hand, measurements at the meteorological station ECSF (Estación Científica San Francisco) within the Rio San Francisco Valley indicate a significant net cooling ($\tau = -0.314$, $P = 0.0000$, $n = 136$, Seasonal Mann-Kendall test used for monthly temperature series; Fig. 11a) since 1998. This cooling can be ascribed to a significant increase in daily temperatures ranges ($\tau = 0.321$, $P = 0.0000$, $n = 136$) resulting from a

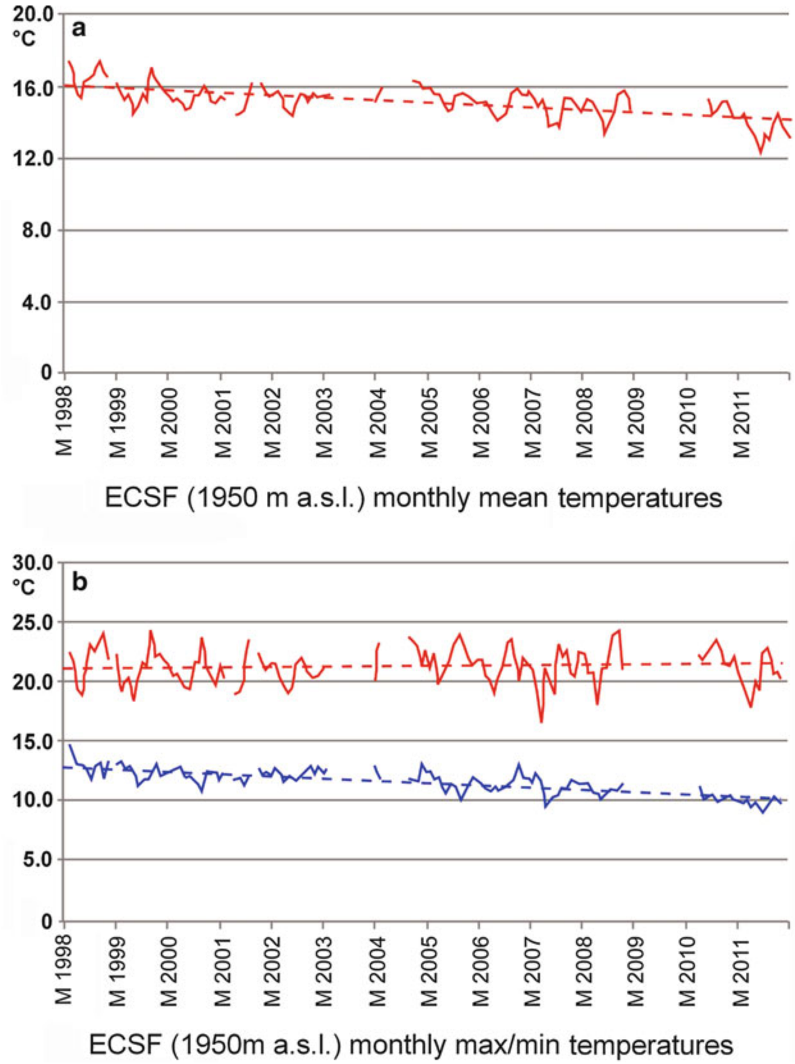
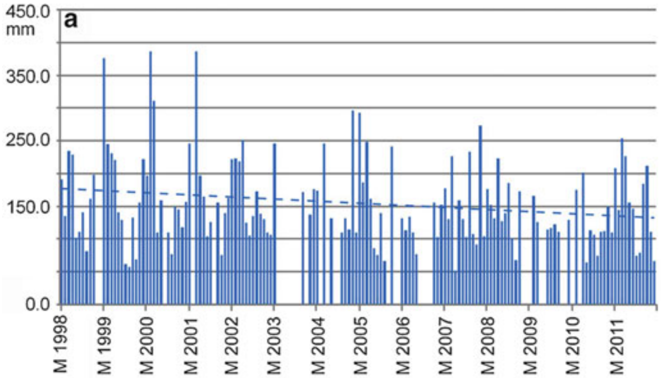
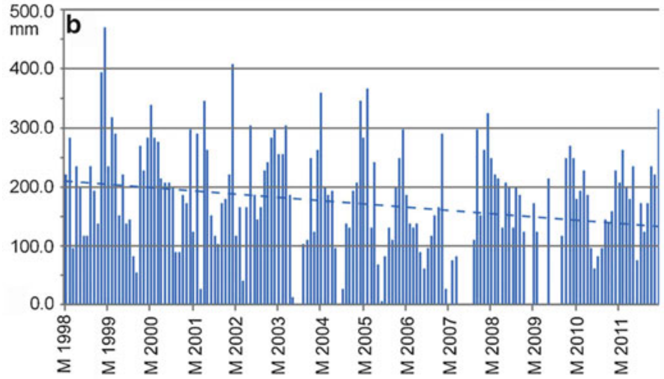


Fig. 11 Air temperatures recorded at the ECSF meteorological station since 1998

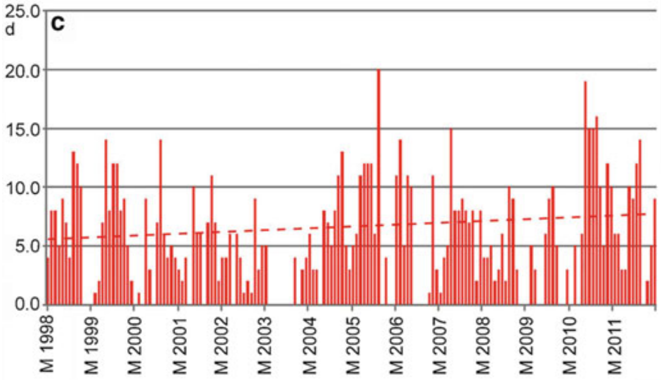
stronger decrease in daily minimum temperatures ($\tau = -0.135, P = 0.011, n = 136$) and a lower increase in daily maximum temperatures ($\tau = 0.101$, $P = 0.0544$, $n =$ 136; Fig. 11b). On the other hand, the data from the higher located meteorological station of Cajanuma Páramo ($\tau = 0.054, P = 0.30697, n = 160$) confirm the positive temperature trends at Zamora and Loja (data not shown). However, it should be kept in mind that the limited length of the data series since 1998 does not yet permit a distinct trend analysis. The ecological importance of such thermal trends is obvious. By assuming a stationary average annual lapse rate of −0.61 °C



ECSF (1950 m a.s.l.) monthly precipitation sums



Cajanuma Páramo (3400 m a.s.l.) monthly precipitation sums



ECSF (1950 m a.s.l.) number of monthly dry days

Fig. 12 (continued)

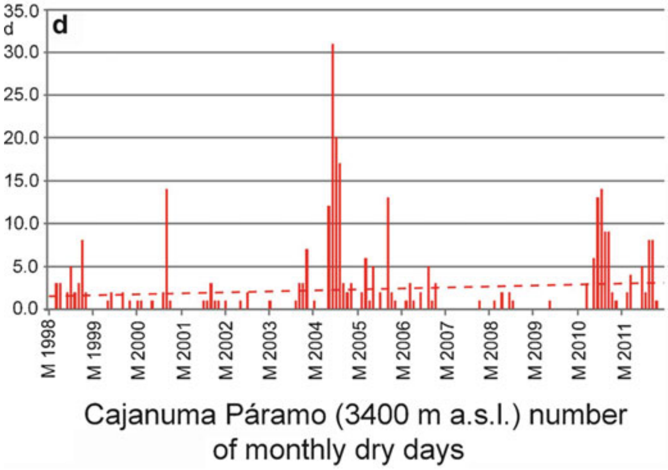


Fig. 12 Precipitation and number of dry days at ECSF and Cajanuma Páramo weather stations

100 m^{-1} (Bendix et al. 2008) until 2100, the increase of temperature must result in an altitudinal shift of ecothermal belts in the working area. As a consequence of a temperature increase by 3 °C in the course of the twenty-first century, the current thermal conditions of the ECSF met station would shift from 1,860 m a.s.l to 2,300 m a.s.l. (Bendix et al. 2010). With regard to the upslope migration of thermophilous species, Colwell et al. (2008) stated that suitable habitat corridors to higher areas are a precondition for uplift. In the Ecuadorian Andes, the numerous valleys from the Precordillerean and Amazon forelands could represent such corridors (Bendix et al. 2010).

Changes in rainfall situation render more complex. Loja shows a very weak but significant trend towards an increase in rainfall from 1964 to 2008. Until 1993, the contrary holds true for the eastern Andean foothills at Zamora, even the slight rainfall decrease is not significant. It seems that the rainfall trend changes along the West-East gradient: Areas west of the main Cordillera are affected by a slight increase of rainfall and vice versa (Bendix et al. 2010; Peters et al. 2013). Similar to Zamora, the ECSF station ($\tau = -0.125$, $P = 0.0309$, $n = 135$, Seasonal Mann-Kendall test used for monthly precipitation series) and the Cajanuma Páramo station ($\tau = -0.138$, $P = 0.0082$, $n = 149$) reveal a significantly accelerated decrease in precipitation (Fig. 12a, b). These negative trends can be mainly traced back to an increase of the number of dry days at the ECSF ($\tau = 0.0898$, $P = 0.1284$, $n = 135$) and Cajanuma Páramo station ($\tau = 0.0589$, $P = 0.3536$, $n = 149$; Fig. 12c, d). Unfortunately, many Andean taxa are restricted to narrow ranges of temperature and humidity, resulting in high rates of endemism and species turnover across altitude and space (Kessler 2002; Brehm et al. 2003; Peters et al. 2014). It is therefore anticipated that climate change will require compensatory species' range shifts of unprecedented pace (Colwell et al. 2008), which is obstructed by widespread anthropogenic habitat fragmentation (Bush 2002). Most studies on climate change impacts on biodiversity assume linear relationships between changes of climate elements to species richness. However, nonlinear processes like damages caused by climate-induced stress such as droughts or extreme rainfalls should also be kept in mind. Concerns on species losses must be raised on possible range-shift gaps and on extinction of cool-adapted taxa of the elevated páramo formations, which on the background of a considerable regional warming may be endangered (Colwell et al. 2008). Thus, knowledge on species composition and distribution is essential for discussing the future of tropical biodiversity and ecosystem functioning. There is growing evidence that high biodiversity and functionally "redundant" species are not a luxury but rather a necessity for providing ecosystem functioning and resilience towards environmental fluctuations (Isbell et al. 2011; Zhang et al. 2012; Werner et al. 2013).

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