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ORIGINAL PAPER

Drought in Northeast Brazil—past, present, and future

Jose A. Marengo[1] · **Roger Rodrigues Torres**[2] · **Lincoln Muniz Alves**[3]

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Abstract This study provides an overview of the drought situation in Northeast Brazil for the past, present, and future. Droughts affect more people than any other natural hazard owing to their large scale and long-lasting nature. They are recurrent in the region and while some measures have been taken by the governments to mitigate their impacts, there is still a perception that residents, mainly in rural areas, are not yet adapted to these hazards. The drought affecting the Northeast from 2012 to 2015, however, has had an intensity and impact not seen in several decades and has already destroyed large swaths of cropland, affecting hundreds of cities and towns across the region, and leaving ranchers struggling to feed and water cattle. Future climate projections for the area show large temperature increases and rainfall reductions, which, together with a tendency for longer periods with consecutive dry days, suggest the occurrence of more frequent/intense dry spells and droughts and a tendency toward aridification in the region. All these conditions lead to an increase in evaporation from reservoirs and lakes, affecting irrigation and agriculture as well as key water uses including hydropower and industry, and thus, the welfare of the residents. Integrating drought monitoring and seasonal forecasting provides efficient means of assessing impacts of climate variability and change, identifying vulnerabilities, and allowing for better adaptation measures not only for medium- and long-term climate change but also for extremes of the interannual climate variability, particularly droughts.

1 Introduction

The semiarid region of Northeast Brazil (NEB) is located between 2.5° S and 16.1° S and 34.8° W and 46° W, with an area of about 1,542,000 km^2 or about 18.26 % of the area of Brazil (Magalhaes et al. 1988). The Brazilian semiarid region is the world's most densely populous dry land region (Marengo 2008), with more than 53 million inhabitants and a human population density of ~34 inhabitants per square kilometer (IBGE 2010). NEB is vulnerable to the observed extremes of interannual climate variability, and global and regional climate change scenarios indicate that the region will be affected by rainfall deficit and increased aridity in the next century (Franchito et al. 2014; Marengo and Bernasconi 2015; Vieira et al. 2015). Rainfall variability, land degradation, and desertification are some of the factors that, if combined, could make this region one of the world's most vulnerable to climate change (IPCC 2012, 2014).

Droughts are natural phenomena, which are deviations from the long-term climate, and in NEB, they affect mainly vulnerable residents of the semiarid region, creating situations of water deficiency and risks to water, energy, and food security (Eakin et al. 2014); they are part of the natural climate variability in that region, have occurred in the past, are occurring in the present, and according to climate change projections, are likely to continue and intensify in the future. In addition, ~57 % of the land in semiarid NEB has been used intensely during the last decades, resulting in severe degradation of its natural assets.

✉ Jose A. Marengo
jose.marengo@cemaden.gov.br

[1] Centro Nacional de Monitoramento e Alerta de Desastres Naturais-CEMADEN, Sao Paulo, Brazil

[2] Universidade Federal de Itajuba-UNIFEI, Itajuba, Minas Gerais, Brazil

[3] Centro de Ciencia do Sistema Terrestre/Instituto Nacional de Pesquisas Espaciais-CCST INPE, Sao Paulo, Brazil

Projected climate change due to the increase in the concentration of greenhouse gases and in land use changes in the region may result in a shifting of climate regimes from semiarid to arid conditions (Marengo and Bernasconi 2015 and references quoted therein). While aridity is a permanent feature of a dry climate, desertification is a more or less permanent degradation of land in semiarid and dry subhumid areas. About 94 % of NEB is under moderate to high susceptibility to desertification (Vieira et al. 2015).

Drought events in the past in the NEB states generated massive losses of agricultural production and livestock, loss of human lives to hunger, malnutrition and diseases, and displacements of people, as well as impacts upon regional and national economies. The economies of the northeast rural and urban areas have since changed, and migration due to drought does not take place anymore in such dramatic proportions. The drought that intensified in 2012 and has extended into 2015 is considered to be the most severe in the last decades and has had an impact on many districts in semiarid regions of NEB states, affecting almost 9 million people (Marengo et al. 2013). Public drought policies, such as lines of credit available to small farmers and the distribution of water by tank trucks (*carros pipa*), did somewhat diminish the impacts but in crisis management policies, they may have been insufficient to withstand the exceptional multiyear drought of 2012–2015. Superimposing droughts upon preexisting social-economical-political stresses place intense pressure on freshwater availability and quality in the region and threatens its water, energy, and food security (e.g., Gutiérrez et al. 2014).

The prospect of increases in frequency and length of dry spells and droughts in future climates in NEB has generated concern among natural resource managers, farmers, development specialists, researchers, and policy makers, trying to understand the extent to which these changes will impact water resources, food production, incomes, and livelihoods. Over the long term, the projected rainfall deficits in the region together with increased temperature and more frequent droughts and dry spells may exacerbate environmental degradation. A possible aridification of the NEB region in the future together with a deterioration of the environment due to non-sustainable land use practices may result in an increased risk of desertification in the region. The likely intensification of extreme droughts has shown the importance of proactive measures to increase the population's resilience to the expected impacts of droughts. However, while drought can contribute to desertification, the main reasons for it are overgrazing, increased fire frequency, deforestation and/or overexploitation of groundwater.

Therefore, in this article we present an account of past and present droughts and discuss some of the physical causes involved, including the role of El Niño and the tropical Atlantic Ocean. We also discuss the prospects for drought intensification and the risk of aridification in a changing climate in the semiarid drylands of NEB out to the year 2100.

2 Droughts: historical aspects, interannual variability, and physical causes

Regarding the definition of drought: According to the US National Drought Mitigation Center of the University of Nebraska (drought.unl.edu), in the most general sense, drought originates from a deficiency of precipitation over an extended period of time—usually a season or more—resulting in a water shortage for some activity, group, or environmental sector. Its impacts result from the interplay between the natural event (less precipitation than expected) and the demand people place on water supply; thus, human activities can exacerbate the impacts of drought.

In physical terms, changes in sea surface temperature (SST) in the tropical Pacific manifested as the extremes of El Niño-Southern Oscillation (ENSO) influence precipitation anomalies over those regions via changes in the zonally oriented Walker circulation (Ambrizzi et al. 2004). However, ENSO explains only part of the rainfall variability in this region. Kane (1997) shows that of 46 El Niño events (strong and moderate) during 1849–1992, in which only 21 were associated with droughts in northern Northeast Brazil. From the more recent droughts of 1992, 1998, 2002, 2010, and now 2012–2015, only those of 1998, 2002, and recently in 2015 occurred during ENSO years (Fig. 1). In fact, Northeast Brazil rainfall exhibits marked interannual variability, part of which has been attributed to ENSO, while other drought events are due to an anomalously northward position of the Intertropical Convergence Zone (ITCZ) over the Atlantic sector, due to a warmer tropical North Atlantic Ocean (Moura and Shukla 1981; Kousky et al. 1984; Aceituno 1988; Aceituno et al. 2009; Ropelewski and Halpert 1987, 1989; Kousky and Ropelewski 1989; Hastenrath 1990, 2012; Hastenrath and Greischar 1993; Kane 1997; Uvo et al. 1998; Marengo et al. 2013; Andreoli et al. 2012; Kayano et al. 1988; Nobre and Shukla 1996; Giannini et al. 2004; Coelho et al. 2002, 2012; Amorim et al. 2014, among others). Moreover, NEB is one of the regions around the world that exhibits high seasonal climate predictability, as shown by experience and operational forecasts with dynamic and statistical models (Hastenrath 1990, 2012; Hastenrath and Greischar 1993; Marengo et al. 2003; Giannini et al. 2004; Nobre et al., 2006, among others).

Droughts have been reported in Northeast Brazil since the sixteenth century. The history of droughts in this region, as collected from various sources (Moura and Shukla 1981; Araujo 1982; Magalhães et al. 1988; de Carvalho 2012; Gutiérrez et al. 2014; Wilhite et al. 2014) and updated in this study can be summarized in this list: 1583, 1603, 1624, 1692,

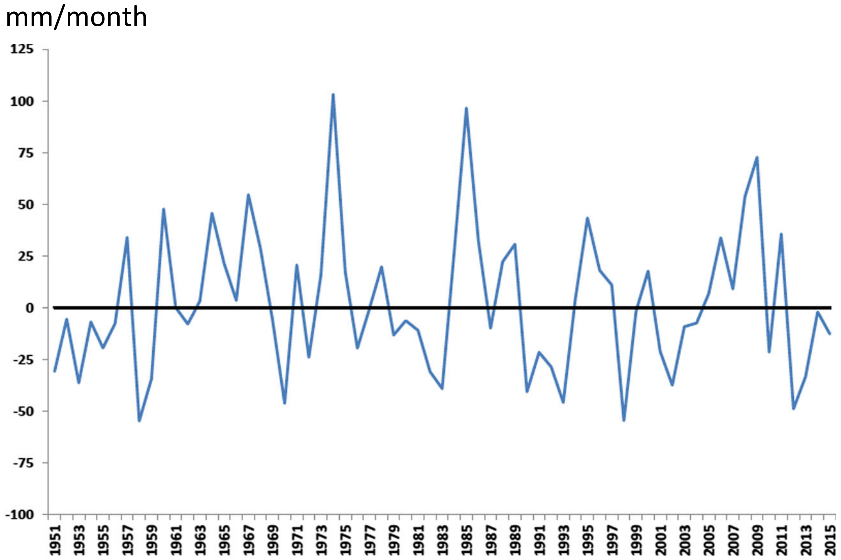


Fig. 1 Rainfall anomaly (mm month^{-1}) during the peak rainy season (February–May) in Northeast Brazil from 1951 to 2014. (Source: Global Precipitation Climatology Centre; Marengo et al. 2013)

1711, 1723–1724, 1744–1746, 1754, 1760, 1772, 1766–1767, 1777–1780, 1784, 1790–1794, 1804, 1809, 1810, 1816–1817, 1824–1825, 1827, 1830–1833, 1845, 1877–1879, 1888–1889, 1891, 1898, 1900, 1902–1903, 1907, 1915, 1919, 1932–1933, 1936, 1941–1944, 1951–53, 1958, 1966, 1970, 1976, 1979–1981, 1982–1983, 1992–1993, 1997–1998, 2001–2002, 2005, 2007, 2010, and 2012–2015.

Based on reported previous droughts in Northeast Brazil, we prepared a compilation of facts on the impacts of these events and actions from the government to cope with this phenomenon:

- In *1777–1780*, almost 85 % of livestock died and half of the population died due to famine.
- In *1877–1879*, almost 200,000 people died in the city of Fortaleza, capital of the state of Ceará, due to famine and as a consequence of diseases brought in by a mass migration of people fleeing the threat of famine after the harvest failure in 1877, which is a migration that depopulated the semiarid region of NEB (*Sertão*). Accurate mortality statistics are not available but estimates of the drought-related death toll ranged from 200,000 to 500,000 (Villa 2000; Davis 2001; Greenfield 2001; Aceituno et al. 2009). Brazil began to focus on mitigating the effects of droughts after this harsh event. In 1886, under a monarchy with a strong central government, the construction of the first reservoir (*açude*, Portuguese for dam) represented the start of institutional planning for the building of infrastructure to address droughts (Gutiérrez et al., 2014).
- In *1915*, more than 278,000 people died in the state of Ceará, and about 75,000 people migrated to other regions.
- In *1958*, an estimated 10 million people fled from Northeast Brazil as a result of a drought (Namias 1972; Hastenrath and Heller 1977).
- In *1979–1981*, there was a >70 % reduction in production of rice, beans, and cotton, and prices went up by about 100 %.
- In *1982–1983*, there was a decrease of 80 % in livestock. Analyzing the drought from 1979 to 1983, the report of the Brazilian Senate in 1997 (Senado Federal-Brasil 2007) estimates that among the losses sustained by agriculture in the region were the following: 1.6 million MT of cotton, 4 million MT of cassava, 3 million MT of corn, and 953,000 MT of beans. Almost 29 million people were affected by this drought.
- In *1986–1987*, a drought affected the region but with less intensity.
- In *1990*, up to the beginning of *1995*, the longest drought on record up to that time occurred—comparable only to the event of 1911–1915 (Senado Federal-Brasil 2007).
- In *1993*, there was a very severe drought, connected at least partially to the unusual ENSO conditions during that year (Rao et al. 1995).
- In *1997–1998*, 57 % of the total agricultural production of the region was lost, and the economic damage was estimated to be 5 % of the GDP of the entire region; the drought in 1998 stretched across ten states in the region, severely affecting crop production in the area and threatening the local food supply.
- In *2012*, the current drought began, reaching its highest intensity in *2012–2013* and continuing to a lesser degree in *2015*. This extended drought gripping the northeast has taken a toll on more than 1100 towns, even triggering fighting and social unrest in rural areas. The government declared a state of emergency in 997 of the 1794 districts in the region due to severe drought. At this time, we have not found studies in which economic losses as a consequence of this drought are discussed, so we have had to rely on estimates published by state and federal government agencies.

Regarding the human impacts of droughts in the region, Moran et al. (2006) demonstrated the vulnerability of poor Northeast Brazil farmers to droughts associated with strong El Niño events. Since the 1950s, the government started taking action against droughts, including the building of cisterns and channels and creation of social programs for affected people, and since the 1970s, no more deaths due to drought were registered, even though the exodus from the semiarid region during droughts continues albeit to a much lesser degree.

During the drought of 1958, the government spent about $US 803 million on actions to cope with the drought, while $US 430 million were spent during the drought of 1970. During the drought of 1976, the government investment reached $US 447 million. Perhaps the most costly drought during the twentieth century was in 1979–1983, when government expenses reached about $US 7.8 billion.

The drought of 2012–2015 is considered the worst in recent decades and has been proven devastating to some agricultural, livestock, and industrial producers (Gutiérrez et al. 2014). According to the Brazilian Ministry of Integration, estimated losses of the order of $US 6 billion are expected due to the impacts of drought on the agricultural sector.

Figure 1 shows that 2010 was already a dry year, and during the period 2010–2015, only 2011 had slightly above average rainfall, but this was followed by the most severe rainfall deficits in 2012. This suggests a multiyear nature of the current drought, of which the first signals started in 2010. According to Marengo et al. (2013), the February–May rainy season in NEB in 2012 was the driest between 1961 and 2012, characterized by the very dry percentile.

Wilhite et al. (2014) and Gutiérrez et al. (2014) indicated that this current drought in NEB has sparked a new round of discussions on improving drought policy and resilience to drought, as well as management at the federal and state levels in the region. Gutiérrez et al. (2014) show that although there is a rich history of drought management throughout NEB and other regions, there are short- and long-term gaps and opportunities, in which decision makers might consider focusing on reducing vulnerability, building resilience, and improving monitoring, forecasting and early warning systems, impact assessments, and mitigation and response planning measures. However, despite this long and detailed institutional history in managing and adapting to droughts in Brazil, the extent of the impacts from the 2012 to 2015 northeast

Table 1 List of models, approximate model horizontal resolutions, future (RCPs 2.6, 4.5, 6.0, 8.5) and historical simulations, and the number of runs in the CMIP5 dataset used in this study

Models	Resolution (lat/lon)	Historical	RCPs			
			2.6	4.5	6.0	8.5
FGOALS-g2	3.1° × 2.8°	4	1	1	–	1
BCC-CSM1-1	2.8° × 2.8°	3	1	1	1	1
CanESM2	2.8° × 2.8°	5	5	5	–	5
MIROC-ESM	2.8° × 2.8°	3	1	1	1	1
FIO-ESM	2.8° × 2.8°	1	1	1	1	1
MIROC-ESM-CHEM	2.8° × 2.8°	1	1	1	1	1
GFDL-CM3	2.0° × 2.5°	5	1	1	1	1
GFDL-ESM2G	2.0° × 2.5°	1	1	1	1	–
Giss-E2-R	2.0° × 2.5°	5	1	5	1	1
GFDL-ESM2M	2.0° × 2.5°	1	1	1	1	1
IPSL-CM5A-LR	1.9° × 3.8°	4	1	3	1	3
NorESM1-M	1.9° × 2.5°	3	1	1	1	1
CSIRO-Mk3-6-0	1.9° × 1.9°	10	10	10	10	10
MPI-ESM-LR	1.9° × 1.9°	3	3	3	–	3
INMCM4	1.5° × 2.0°	1	–	1	–	1
CNRM-CM5	1.4° × 1.4°	1	1	1	–	1
MIROC5	1.4° × 1.4°	1	1	1	1	1
IPSL-CM5A-MR	1.3° × 2.5°	1	1	1	–	1
HadGEM2-CC	1.3° × 1.9°	1	–	1	–	1
HadGEM2-ES	1.3° × 1.9°	4	1	1	1	4
ACCESS1.0	1.3° × 1.9°	1	–	1	–	1
EC-EARTH	1.1° × 1.1°	1	1	1	–	1
MRI-CGCM3	1.1° × 1.1°	5	1	1	1	1
CCSM4	0.9° × 1.3°	6	5	5	5	5

Models are ranked by their spatial resolution (as used in Torres and Marengo 2014)

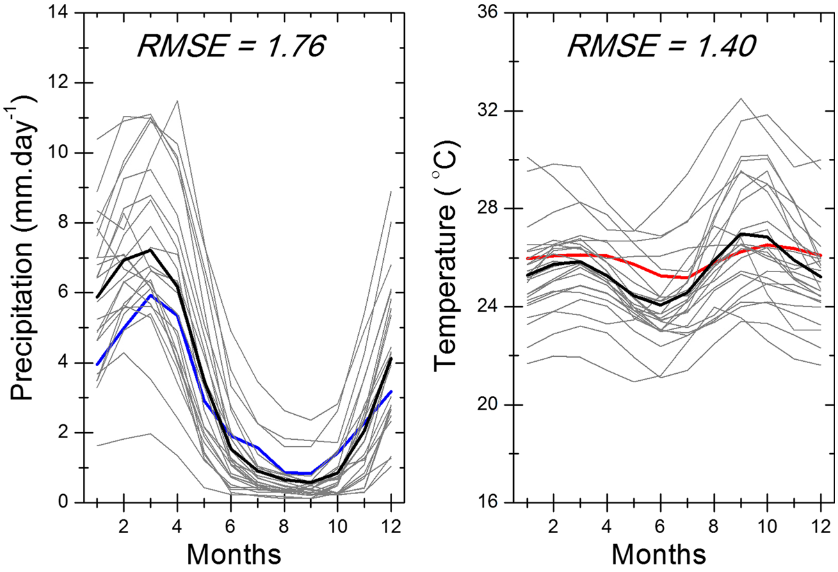


Fig. 2 Seasonal cycle of precipitation (*left panel*) and temperature (*right panel*) from the CMIP5 models listed in Table 1 for the present time 1961–1990. In each one of the panels, the *thick black line* represents the ensemble model mean; the *thick blue line* represents precipitation observations; and the *thick red line* represents temperature observations from Climate Research Unit (CRU). In both lines, the root mean square error (RMSE) is shown, and individual models are shown in *thin lines*

droughts indicates that there is still a need to improve preparation and response measures (Wilhite et al. 2014).

3 CMIP5 models used for climate change projections in Northeast Brazil

For the northeast region, we discuss the climate projections from state-of-the-art general circulation models used in the IPCC Fifth Assessment Report (AR5) archived at the Coupled Model Intercomparison Project Phase 5 (CMIP5) data bank. The CMIP5 climate projections analyzed in this study were provided by the Program for Climate Model Diagnosis and Intercomparison (PCMDI, http://www-pcmdi.llnl.gov), and by the Earth System Grid (ESG, http://www.earthsystemgrid.org) data distribution portal. The variables used are monthly precipitation and surface air temperature data simulated for the present climate (1961–1990) and

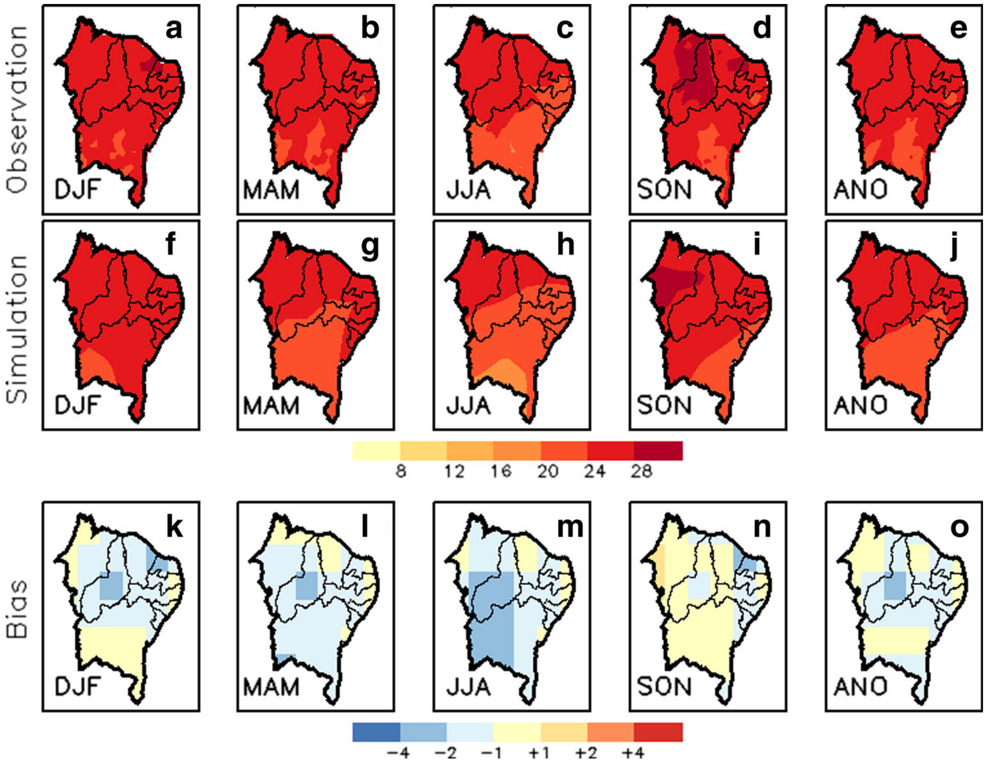
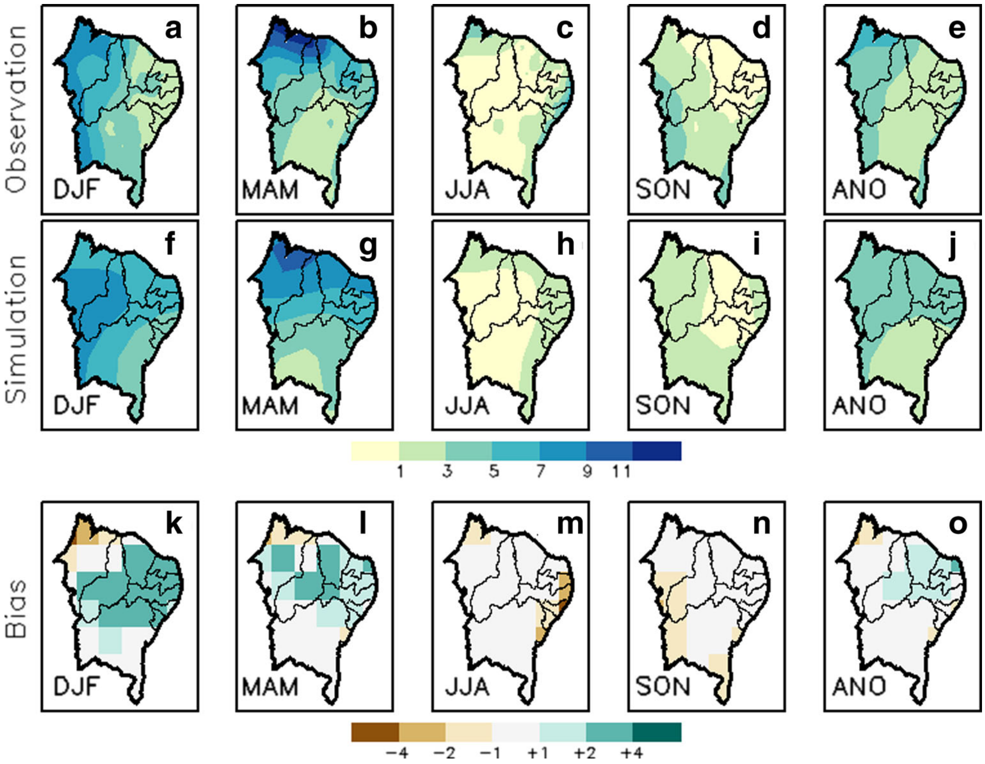


Fig. 3 Simulation of seasonal and annual temperature from observations (*a*–*e*), the mean ensemble model (*f*–*j*) in the *upper* and *middle panel*, and bias (model minus observations, *k*–*o*) in the *lower panel*. Units are in °C

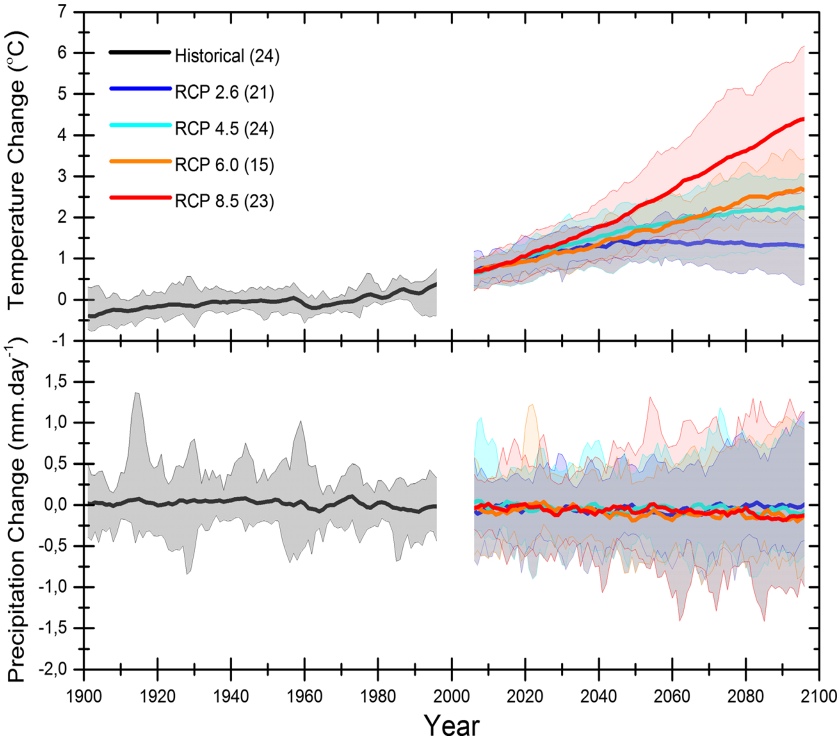
Fig. 4 Same as in Fig. 3 but for precipitation. Units in mm day^{-1}



projected to the end of this century (2071–2100) by 24 general circulation models (GCMs) from CMIP5 (Taylor et al. 2012; Table 1), representing nearly 450 runs.

Hereafter, changes refer to the difference between the mean values of the climate variables simulated for the periods 2071–2100 ("future climate") and 1961–1990 ("present-day" climate). Moreover, all of the model simulations for the twentieth century are compared against the observed surface air temperature and precipitation from the CRU TS 3.0 dataset (Mitchell and Jones 2005) produced

Fig. 5 Time series of rainfall (mm day^{-1}) and temperature anomalies (°C) for Northeast Brazil for the four RCPs and the historical runs from the CMIP5 models listed in Table 1. The number of models used is shown in *brackets*. Anomalies are relative to 1961–1990. *Shaded areas* represent the dispersion among CMIP5 models. All the time series have been smoothed using a 5-year moving average



by the University of East Anglia Climate Research Unit (UEA/CRU).

The CMIP5 future climate simulations are performed using the new generation of forcing scenarios called Representative Concentration Pathways (RCPs; Moss et al. 2010) and denominated as RCP2.6, 4.5, 6.0, and 8.5, corresponding to an approximate radiative forcing by the end of the century of 2.6, 4.5, 6.0, and 8.5 Wm^{-2}, respectively, relative to preindustrial conditions (Moss et al. 2010). With regard to the equivalent CO_2 concentrations, these RCPs correspond roughly to 490, 650, 850, and 1370 ppm, respectively, in 2100. Further details about the RCPs can be found, for example, in Moss et al. (2010) and Van Vuuren et al. (2012). The CMIP5 GCMs' horizontal resolutions vary from ~1° to 3° (Table 1).

In addition to slightly higher horizontal resolutions, CMIP5 also includes GCMs and experiments that are more comprehensive (e.g., including carbon cycle or decadal climate predictability experiments) as compared to those of CMIP3, which allows scientists to explore a broader spectrum of scientific questions. Some of the main improvements in the CMIP5 GCMs are the addition of interactive ocean and land carbon cycles of varying degrees of complexity and the more complete radiative forcings due to, among other things, the inclusion of more comprehensive modeling of the indirect effect of aerosols and the use of time-evolving volcanic and solar forcing in most models (Taylor et al. 2012; Knutti and Seclacek 2013; Sillmann et al. 2013).

In the following, we discuss projections of seasonal changes in austral summer (DJF), fall (MAM), winter (JJA), and spring (SON) temperatures, and rainfall from the IPCC AR5 models is shown in Table 1, under the RCP2.6, 4.5, 6.0, and 8.5 scenarios.

4 Climate change projections from the CMIP5 models for Northeast Brazil

The annual cycles of rainfall and temperature for the present climate are well simulated by all models, with the timing of

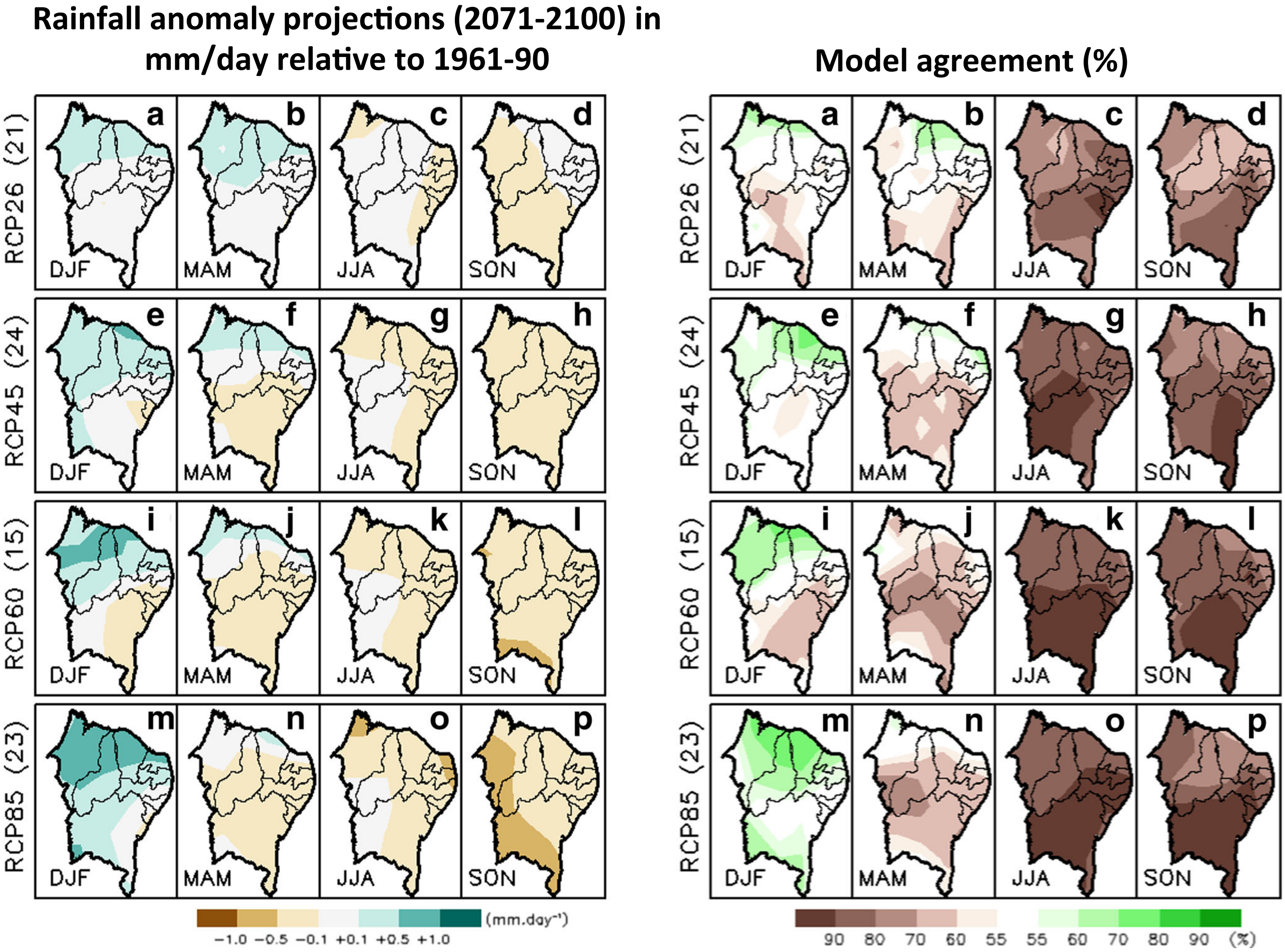


Fig. 6 *Left side*: rainfall anomaly projections (mm day^{-1}) of seasonal rainfall anomalies for 2071–2100 relative to 1961–1990 (*left side*, *a*–*p*). *Right side*: agreement among model projections (mm day^{-1}) for seasonal rainfall anomalies for 2071–2100 relative to 1961–1990 (*left side*, *a*–*p*), expressed in percentage (%). Anomalies are for the four RCPs, and the number of models used is shown in *brackets*. Color scales are at the *bottom*

the February–April peak of the rainy season well depicted by the models (Fig 2—left), albeit with some models underestimating or overestimating the observed rainfall. The mean observed peak of the rainy season from CRU varies from 5 to 6 mm/day, while the ensemble models show 6–7 mm/day. With regard to temperature (Fig 2—right), the models tend to overestimate the amplitude of the annual cycle and to underestimate temperatures during summer to spring (by less than 0.5 °C).

For the simulation of spatial patterns of observed seasonal and annual air temperature (Fig 3) and rainfall (Fig. 4), the ensemble mean shows a cold bias (2–4 °C) over most of the semiarid region from austral summer to winter and with a slight positive bias (~1 °C) in spring. Additionally, rainfall simulations show a wet bias (up to 4 mm/day) over the most of the region in austral summer and fall (Fig. 4).

The projections from the CMIP5 models at the regional level for Northeast Brazil are shown in Fig. 5 for all RCPs. The figure shows that in relation to the baseline period 1961–1990, temperatures for the region are projected to increase by ~1.3 °C (between 0.4 and 1.9 °C) for the RCP2.6 scenario and by 4.4 °C (between 2.7 and 6.2 °C) for the RCP8.5 scenario by the end of this century. Moreover, regarding the historical simulation, it is possible to identify an increase of temperature from 1901 to 2000 of about 0.8 °C.

Regional precipitation changes depend on regional forcings and on how models simulate their local and remote effects. For NEB, there is a spread among rainfall projections of between +1.5 and −1.5 mm/day, making it hard to identify any projected rainfall change. However, the RCP8.5 scenario shows a slight rainfall reduction of about 0.3 mm/day by 2100.

Figures 5 and 7 show that by the late twenty-first century, the CMIP5-derived projections indicate temperature increases ranging from 1 to 2 °C in the RCP2.6 to above 5 °C for the RCP8.5, with some seasonal variations. The warming is more intense in austral winter and spring. For rainfall changes (Fig. 6), the ensemble mean of all models shows rainfall increases that vary from 0.5 mm/day for the RCP2.6 to 1.0 mm/

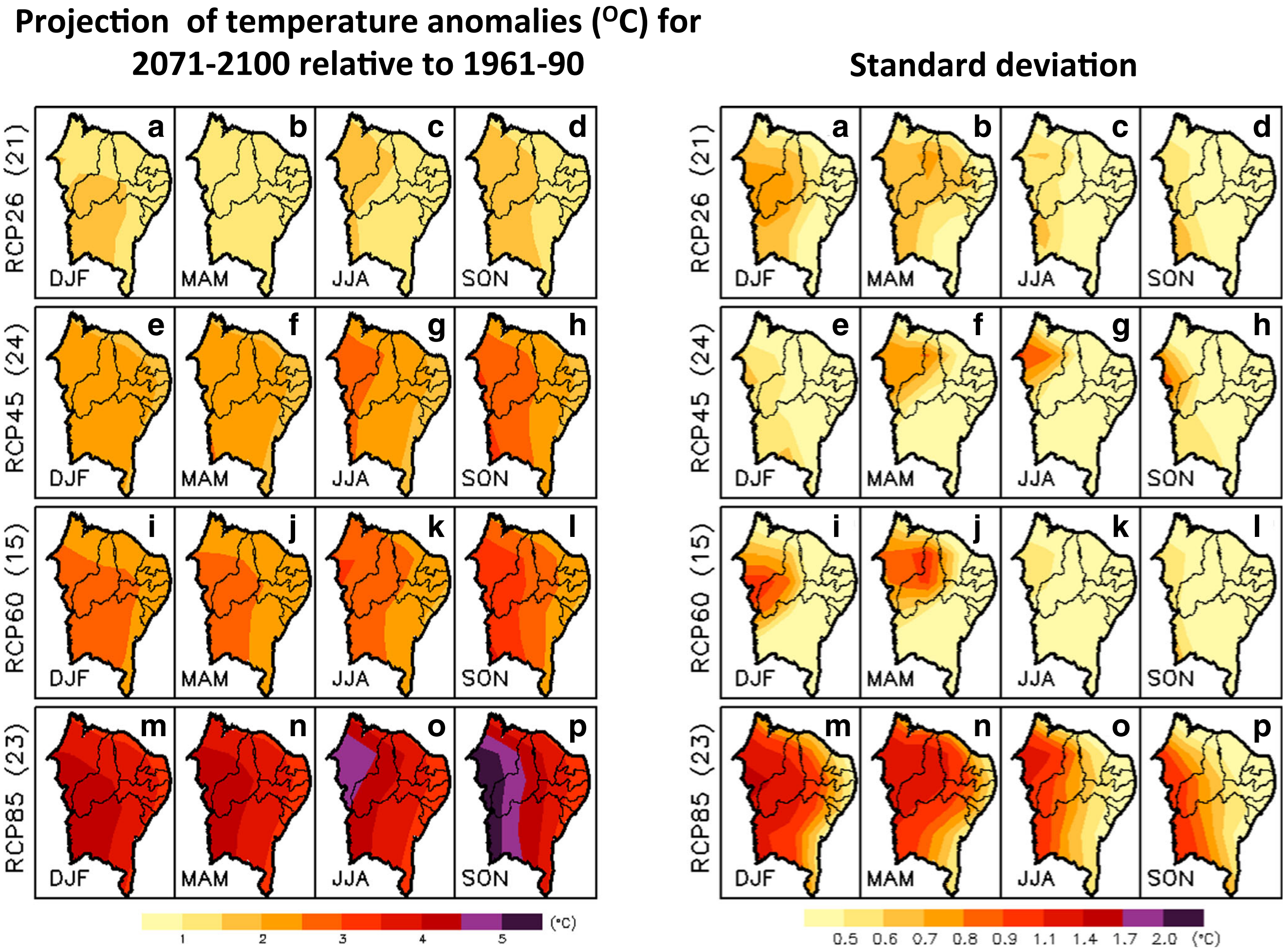


Fig. 7 *Left side*: seasonal air temperature (°C) anomalies for 2071–2100 relative to 1961–1990 (*left side*, *a–p*). *Right side*: agreement among model projections (mm day^{-1}) for seasonal rainfall anomalies for 2071–2100 relative to 1961–1990 (*left side*, *a–p*), expressed by the standard deviation. Anomalies are for the four RCPs, and the number of models used is shown in *brackets*. Color scale is on the *lower side* of the panels

day for the RCP8.5, while for the rest of the year the model ensemble shows rainfall reductions during the rainy season (MAM) of the order of 0.5 mm/day over almost all of the region for the RCP8.5, while for the RCP2.5, rainfall is projected to increase by 0.5 mm/day. The largest reductions are for austral winter and spring, with rainfall reductions of up to 1 mm/day for the RCP8.5.

As an indication of the uncertainty in the change in precipitation, the degree to which the models used in this study agree is indicated in Fig. 6. For the RCP8.5 scenario, 70–80 % of the models agree with the rainfall increases in austral summer, 70–80 % agree with the rainfall reductions in austral fall, and between 80 and 90 % of the models show rainfall reductions during austral winter and spring. Regarding temperature projections, the standard deviation is used in Fig. 7 as a measure of ensemble spread, and consequently, serves as an approximate measure of uncertainty. Temperature projections show larger spread over the western part of Northeast Brazil. Therefore, both Figs. 6 and 7 show that there is some degree of uncertainty in climate change projections for Northeast Brazil, but with good reliability for rainfall decreases and temperature increases during the peak rainfall season (MAM) until austral spring.

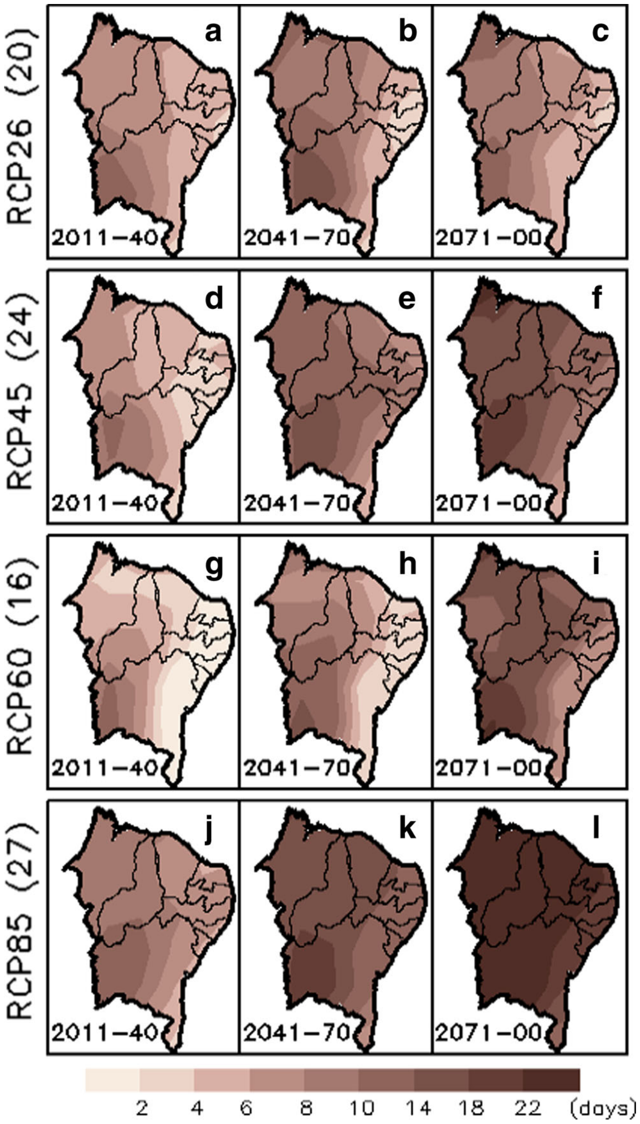


Fig. 8 Projections of consecutive dry days (CDD; days) for 2011–2040, 2041–2070, and 2071–2100 for RCP2.6 (*a–c*), RCP4.5 (d–f), RCP6.9 (*g–i*), and RCP8.5 (*j–l*). The number of models used is shown in *brackets*

Corroborating the results presented in this study, Collins et al. (2013) show that agreement among CMIP5 models and the consistency with other physical features of climate change indicate high confidence for Northeast Brazil such as surface soils are projected to dry; annual evapotranspiration and runoff are projected to decrease; and days and even nights are projected to be warmer in a drier atmosphere. Although rainfall tends to decrease, there is still a tendency for intense rainfall episodes in between dry and warm periods without rain, with the dry spells projected to be longer, bringing the possibility of triggering seasonal droughts. These dry spells can be depicted by the annual consecutive dry days (CDD) index (defined as the annual largest number of consecutive days with rainfall below 0.1 mm/day). Figure 8 shows the projections of CDD for the three time slices and four RCPs. The largest CDD values are observed during 2071–2100 for the RCP8.5, consistent with Collins et al. (2013) and Sillmann et al. (2013). Figure 9 shows the trends in CDD for the NEB region under the RCP8.5 from each individual model and the ensemble mean of the CMIP5 models listed in Table 1. All models show a gradual increase in CDD, and the ensemble mean shows an increase from 100 days in 1901 to 140 days in 2100.

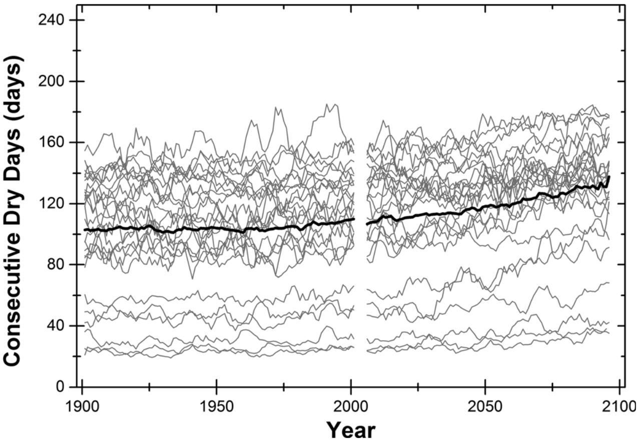


Fig. 9 Time series of CDD (days) for Northeast Brazil for the RCP8.5 from each one of the CMIP5 models and the ensemble listed in Table 1, from 1901 to 2100. *Thick black line* represents the ensemble model mean, and the individual models are shown in *thin lines*. All the time series have been smoothed using a 5-year moving average

5 Conclusions

This paper presents a historic overview of the drought situation in Northeast Brazil and provides some information that could be usable for the development of national drought policies and plans to improve the level of preparedness for drought, so that societal vulnerability to this natural hazard could be reduced. Droughts affect more people than any other natural hazard owing to their large scale and long-lasting nature. The drought currently affecting the northeast, however, has had an intensity and impact not seen in several decades and has already destroyed large swaths of cropland, affecting hundreds of cities and towns across the region, and leaving ranchers struggling to feed and water cattle. Large cities in the semiarid region in NEB are suffering shortages of drinking water for the population and energy supply in urban areas. Droughts are recurrent in the region and while some measures have been taken by the governments to mitigate the impacts, there is still a perception that the residents mainly in rural areas are not yet adapted to these hazards and those recent social gains from antipoverty governmental programs may be offset by climatic change.

Spinoni et al. (2014) show that the arid areas increased throughout the northeast between 1951 and 2010, and highlight this region as under risk of desertification. Future climate projections show temperature increases and rainfall reductions, and the tendency for increases in CDD (a measure of drought) suggests an increase in the tendency for greater frequency/intensity of dry spells and droughts and toward aridification in the region. All these conditions lead to an increase in evaporation in reservoirs and lakes, affecting irrigation and soil moisture and impacting agriculture and population. Thus, in a warmer and drier climate, the scarcity of water would have impacts on the regional sustainable development in Northeast Brazil.

According to IPCC (2013, 2014), increases in the severity and duration of droughts are likely to occur by the second half of the twenty-first century but with low confidence for such projections for the first half of the century. This is confirmed in our own analyses of rainfall, temperature, and dry spell anomalies from the CMIP5 models. However, while drought and aridification on their own do not cause land degradation, both can increase the susceptibility of land to human-induced degradation. Thus, climate change may become the biggest challenge. It will require that a number of technical, socioeconomic, and institutional obstacles be identified and dealt with through adequate policies.

Considering the human dimensions of drought in NEB, such as how it affects family agriculture and the regional economy or its environmental consequences for natural systems, we note that there is a need to develop and institutionalize long-term proactive approaches to drought management and decision-making processes, directed to adaptation of the local population and to cope with the risk of future droughts in the region.

As concluded by Gutiérrez et al. (2014), besides the need for improving data collection and information organization, an articulation of the role of drought preparedness in the context of watershed management areas at the state and federal level is needed. Several states in NEB have made great advances in the expansion of the hydraulic infrastructure that have greatly increased their water security and resilience against drought. With more measures such as these, we would be in a better position to develop vulnerability assessments at the seasonal, medium- and long-term levels. Other options would be adaptation of cropping and livestock systems, ecosystem-based adaptation, sustainable land management, and income diversification measures.

Integrating drought and desertification monitoring and seasonal forecasting provides a better way to assess impacts of climate variability and change, identifying vulnerabilities and allowing for better decision making in terms of adaptation measures not only for medium- and long-term climate change but also for extremes of the interannual climate variability, particularly droughts.

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