Chapter 22 In Brief

Long-term variability, extremes, and changes in temperature and hydro meteorology

Cheia do rio Negro no centro de Manaus 2021 (Foto: Alberto César Araújo/Amazônia Real)

THE AMAZON WE WANT
Science Panel for the Amazon

Long-term variability, extremes, and changes in temperature and hydro meteorology in the Amazon Region

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Key Messages & Recommendations

1) Land use changes have amplified the risk of fires and the vulnerability of human and natural systems.
2) Over the long-term, climate variability may have strong impacts on the water cycle in the region, biodiversity resilience, and the structure of the forest, with implications for the regional and global climate.
3) Lengthening of the dry season and changes in the frequency and intensity of extreme drought episodes threaten society, ecosystems, and wildlife. Current data show that the dry season has expanded by about one month in the southern Amazon since the 1970s.
4) There is an urgent need to rescue data and foster better integration and comparability of data among Amazonian countries, with free access for the scientific community.
5) High-resolution climatic and hydrological gridded data sets for the Amazon should be generated by means of a cooperation between state and national meteorological services, international climate agencies, and universities, as well as private data sets.
6) Local people and policy makers need to be better educated on climate, hydrology, and atmospheric science, especially the impacts of land use and climate change on livelihoods. Local and cultural knowledge are invaluable sources of climate-proxy information.

Abstract This chapter describes the observed and projected changes in temperature, river discharge, and precipitation patterns and extremes in the Amazon region, as well as their impacts and possible thresholds. The emphasis is on the effect of climactic extremes on biodiversity and ecological processes.

Temperature Warming over the region is a fact, but the magnitude of the warming trend varies among datasets and time periods. The warming trend is clearly apparent from 1980, and is even more significant since 2000[1–8]. Historical records show an increasing trend for all seasons, with a greater warming rate detected for the June-August (JJA) and September-November (SON) seasons. A contrasting West-East pattern is observed, with warming rates over Eastern Amazonia almost double those of Western Amazonia. This can be attributed to effects of land cover change, and subsequent alteration of the energy balance[9].

Strong El Niño events, as in 1997/98 and 2015/16, have a significant influence on air temperatures in the central region of the Amazon basin[3,10]. For example, in September 2015 the monthly average daily mean maximum and minimum temperatures

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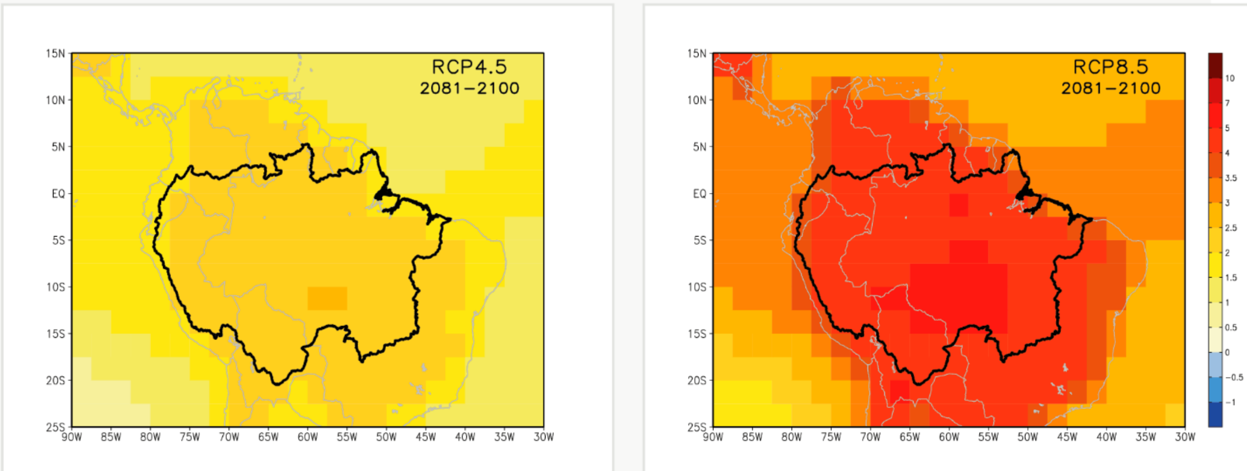

Figure 22.1 Multi-model CMIP5 average percentage change in annual mean near-surface air temperature, relative to the reference period 1986–2005, averaged over the period 2081–2100, under the RCP4.5 and 8.5 forcing scenarios.

were 2.2-2.3˚C higher compared to the same month's averages for the previous five years.

Hydrology Historical trends in Amazonian precipitation vary considerably among studies, depending on the data set, time series period and length, season, and the region evaluated[2,11–13]. Most modern rainfall records start in the 1960s, hampering the quantification of trends in the Amazonian region. Various studies have reported an intensification of the hydrological cycle and a lengthening of the dry season in the southern Amazon, while the northern Amazon experienced increased frequency of extreme rainfall and subsequent flood events[10,14–19]. Significant reductions in rainfall are also observed in the Eastern Amazon.

Substantial warming of the tropical Atlantic since the 1990s plays a central role in the region's hydrology, increasing atmospheric water vapor imported by trade winds into the northern Amazon basin and increasing precipitation, especially during the dry-to-wet and wet seasons[14,19,20]. The simultaneous cooling of the equatorial Pacific during this period strengthens the Walker circulation and deep convection over the Amazon[15,19,21].

In the Amazonian lowlands of Colombia, Ecuador, and northern Peru, precipitation has been increasing since the 1990s[8,12,17,22] where a growth of around 17% has been documented during the wet season[18]. Increasing rainfall in the northwestern Andean-Amazon currently contributes to an intensification of extreme floods during the last three decades[15].

The southern part of the Peruvian Andean-Amazon basins exhibit decreasing rainfall since the mid-1960s[7,20,23–27], and consequently, diminished discharge during the low-water season. In the Bolivian Amazon, rainfall diminution is mainly observed in the southern part of the Bolivian Madeira basin[12,28,29].

Human influences Other factors leading to changes in the hydrological cycle are related to land-use changes, such as large-scale deforestation in catchment areas for agriculture and cattle ranching[9,20,30], and the construction of hydroelectric power plants[31]. Massive and abrupt changes to streamflow regimes are expected from hydroelectric dams, resulting in complex spatiotemporal disturbances to floodplains downstream of dams[32]. The multiple dams being built or planned for the Tapajós, Xingú, Tocantíns-Araguaia, Marañón, and other river basins will have cumulative and cascading effects on the downstream hydrological cycle[33], including massive losses of biodiversity and the environmental services upon which society, and in particular Indigenous peoples and local communities, depend. The combination of high deforestation rates, construction of dams, and an increasingly warmer and longer dry season[33] have the potential to significantly disrupt the hydrological cycle.

Wet season rainfall helps the forest survive dry seasons as water is readily available in soils and roots. Dry seasons in the Amazon have become more intense in recent years leading to greater forest loss and increased fire risk, particularly over the southern Amazon[2,34,35 (and references therein)]. Drivers of this trend include changes in the sea surface temperature gradient of the North and South Atlantic seas, seasonal increments of solar radiation[2,35–40], a poleward shift of the southern hemispheric subtropical jets[39], and an equatorward contraction of the Atlantic ITCZ[41]. The rainy season in the southern Amazon now starts almost a month later than it did in the 1970s[2,39,40]. This is influenced by large scale atmospheric circulation and land-use change[42]. Wright et al. (2017)[43] examine interactions among land surface processes, atmospheric convection, and biomass burning, which may alter the timing of wet season onset[44], possibly through a negative feedback mechanism that enhances drought conditions[45,46]. Recent work by Agudelo et al. (2018)[47] and Arias et al. (2020)[48] show that longer dry seasons in the southern Amazon are also related to enhanced atmospheric moisture content over the Caribbean and northern South America, and changes in moisture transport and moisture recycling in the southern Amazon. Leite-Filho et al. (2019)[42] show a delay

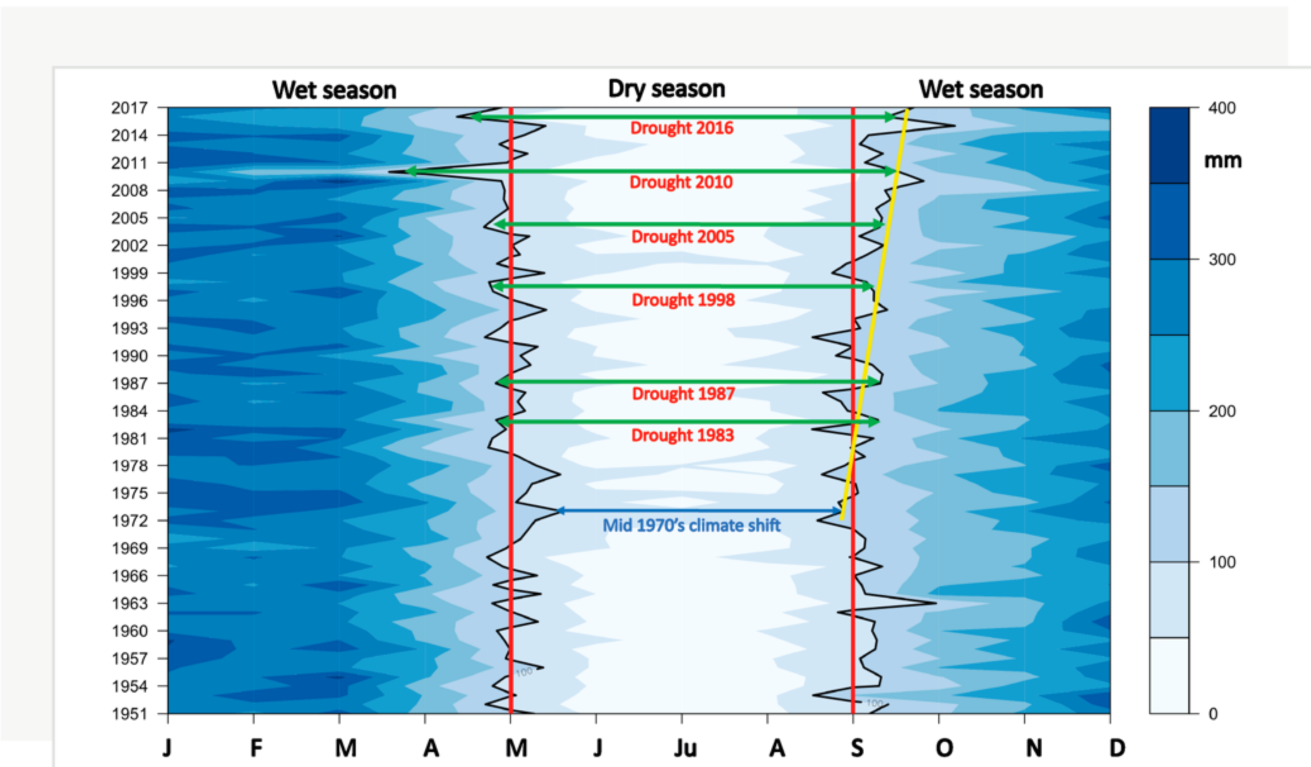

Figure 22.2 Monthly rainfall for the southern Amazon (mm/month). Drought years are indicated with green lines, onset and end of the rainy season with red, tendency for a longer dry season after the mid 1970's with yellow[2].

in the onset of the wet season of about 4 days per decade for each additional 10% of deforestation.

Droughts and floods Strong interannual variability of rainfall over the Amazon basin leads to recurrent droughts and floods of variable intensity. Drought is almost always associated with an increase in surface air temperature, and most of the severe droughts in the Amazon region are El Niño-related, as in 1998, 2010, and 2015-16[49]. In contrast, "mega-floods" were detected in 2009, 2012, 2014[25 (and references therein)] and 2021. Most of these events are related to El Niño, La Niña, or to warm TNA. Observed extreme climatic events augmented fire risk with associated impacts on climate, health, and biodiversity. This suggests an overall increase in climate variability in the region[50 (and references therein)]. Furthermore, in the beginning of the 21st century there has been an unprecedented number of extreme drought events, while the region has undergone large-scale conversion of forests into pasture and cropland, altering the land–atmosphere interface and contributing to changes in the regional and local hydrological cycle[16,51,52]. Deforestation in the Amazon reduces the regulation capacity of river basins and exacerbates both the magnitude of floods and low flows[53].

Atmospheric moisture Precipitation and evapotranspiration (ET) recycling are strongly correlated in the Amazon; regional ET provides about 28% of the precipitation falling in the basin[54]. The forests' roots pump soil moisture from the wet season into the air to maintain rainfall during the dry season[55–57]. This constant or even higher ET during the dry season relative to the wet season is central[35,43], and helps buffer against droughts[58]. Changes of ET, especially during the dry season, have significant impact on rainfall and wet season onset. Surface dryness is a leading contributor to delays in the onset of the wet season in the past several decades[39,59].

On average the Amazon rainforest receives 2000-2500 mm of rain each year, with much of the water coming from the Atlantic Ocean and from the forest itself[60] through ET and cloud formation from the production of organic aerosols[61]. During the wet season, moisture is exported from the Amazon basin and transported via "Aerial Rivers" to other regions[2,62–66]. These aerial rivers contribute to precipitation over the Andes, southern Brazil, and the La Plata River basin. A disruption of moisture transport induces drought. Reducing atmospheric moisture transport and the respective recycling of precipitation due to deforestation and land use change in climate-critical regions may induce a self-amplified

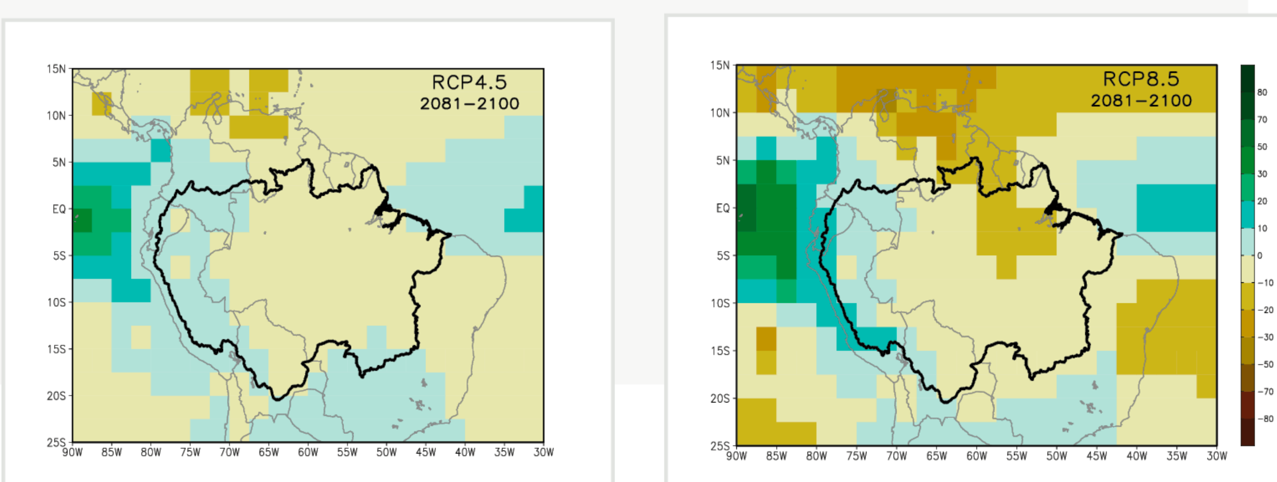

Figure 22.3 Projected (a) percent changes in the annual maximum five-day precipitation accumulation and (b) change in annual CDD, the maximum number of 4 consecutive dry days when precipitation is less than 1 mm, over the 2081–2100 period, in the RCP4.5.

drying process which would further destabilize Amazonian forests in downwind regions, i.e., the southwestern and southern Amazon regions. This also reduces moisture export to Southeastern Brazil, the La Plata basin, and the Andes mountains[52,58]. This could have more significant consequences for rainfed agriculture and natural ecosystems in these areas than previously thought. In addition, Staal et al. (2018)[58] show that around 25–50% of annual rainfall in the tropical Andes originates from Amazonian tree transpiration. Removal of forests increases temperature, reduces evapotranspiration, and has been shown to reduce precipitation downwind of deforested area[58,67–69].

Local and remote causes and influences Projections from climate models from the Coupled Model Intercomparison project (CMIP5) used in the IPCC AR5[70,71] show that temperature is generally better simulated than precipitation, although these models

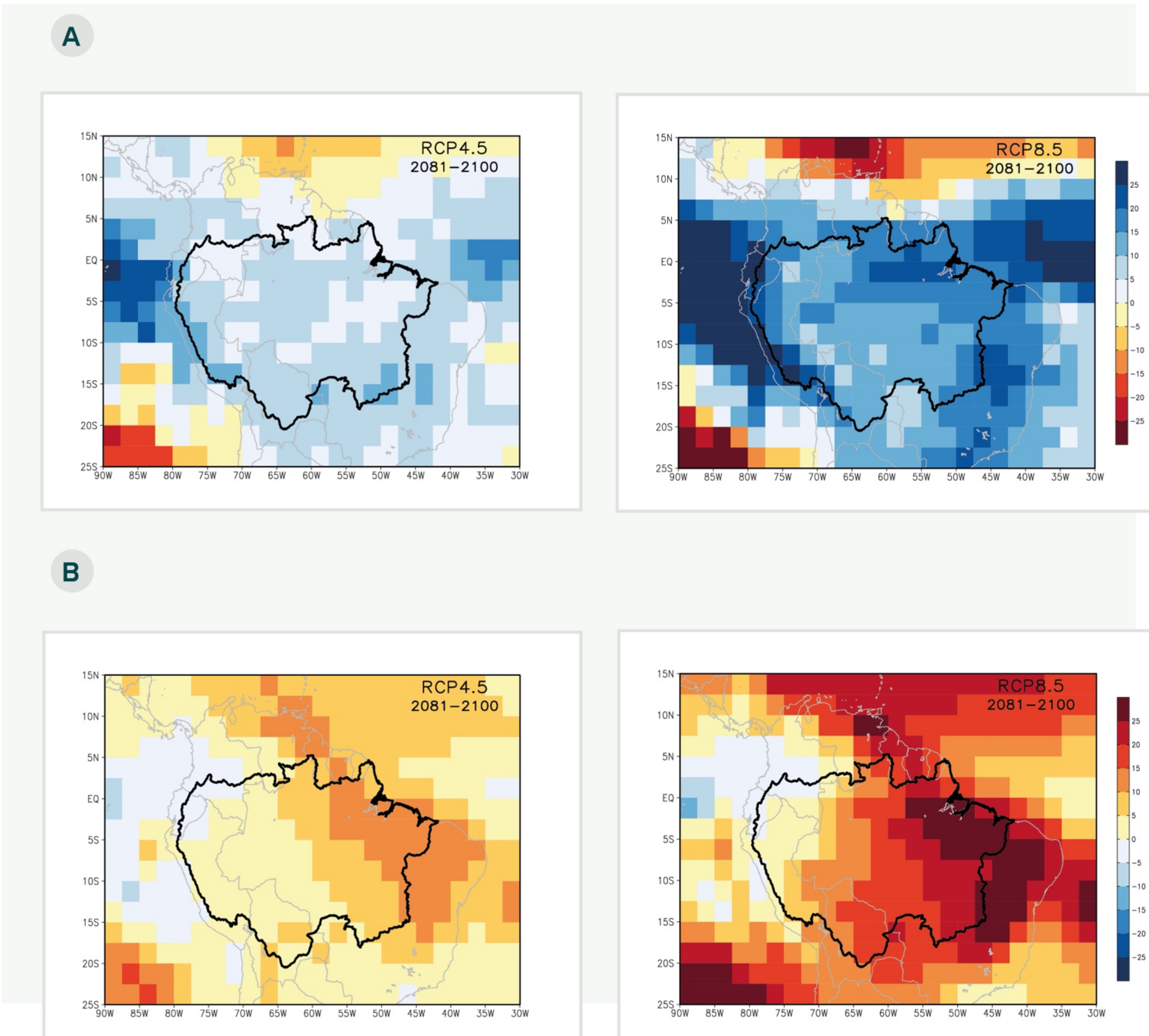

Figure 22.4 (a) Projected percent changes in annual RX5day, the annual maximum five-day precipitation accumulation and (b) projected change in annual CDD, the maximum number of consecutive dry days when precipitation is less than 1 mm, over the 2081–2100 period in the RCP4.5 and 8.5 scenarios (relative to the 1986–2005 reference period) from the CMIP5 models.

have been found to simulate the Amazon's recent climate past reasonably well. The models project annual mean temperature to rise everywhere. Using the RCP4.5 scenario, the rise is about 2°C higher than the present day across the region, whereas in the RCP8.5 scenario increases are more than 6°C by the late 21st century.

Over the basin as a whole, projected changes in rainfall vary spatially and by season. In general, as rainfall increases so does flooding, and as rainfall decreases droughts increase; this variability in precipitation tends to increase with increased warming. There is high confidence that annual mean precipitation will decline, and this trend is more pronounced in the east and south of the Amazon over the 21st century. In line with observations, dry season length is also expected to expand over the southern Amazon[72]. Spracklen and Garcia-Carreras (2015)[73] assessed the impacts of deforestation on rainfall, showing that more than 90% of simulations agree that deforestation leads to a reduction in rainfall. There is also general agreement among models for an increase in precipitation for the end of the 21st century over the northwestern Amazon (Colombia, Ecuador, and northern Peru)[74,75]. On the other hand, in the southern Peruvian and Bolivian Amazonia, a longer and drier dry season is projected[39,72]. Minvielle and Garreaud (2011)[76] project likely reduced rainfall in the Andes-Altiplano (-10% to -30%) and over the highest region of the upper Amazon by the end of the 21st century. Observations also show an unprecedented and accelerating glacial retreat since the late 1970s[77,78]. Many glaciers could disappear, which will increase the risk of water scarcity in upper Andean valleys.

The most serious impacts of climate change are often related to changes in climate extremes. The maximum number of consecutive dry days (CDD) is projected to increase substantially, indicating not only more frequent dry days, but also an increase in intense precipitation as shown by the maximum five-day precipitation accumulation (RX5day) index, a strong contributor to flash-floods.

The Amazon forest's ability to provide environmental services is threatened by anthropogenic forcing at various scales, such as deforestation, fire, global and regional climate change, and extreme events. Such services include maintenance of biodiversity, water cycling, evaporative cooling, and carbon stocks. These services have a much greater value to human society than do the timber, beef, and other products obtained by destroying the forest[67]. Perhaps one of the most valuable services provided by the forest is the atmospheric moisture transport to the Andes, southern Amazon, Pantanal, and La Plata basin. In these downwind regions, reductions in moisture transport from the Amazon may favor rainfall reductions and warmer temperatures, increasing the risk of drought, fire, and food insecurity[69].

Conclusions An intensification of the hydrological cycle in the region has been observed in various studies[14,15,17], and this is consistent with increases in recent extreme hydro-climatic events[25 (and references quoted in)]. At interannual time scales ENSO and TNA have played an important role in temperature and rainfall variability. At large scale, connections with anomalies in the Pacific, Tropical, and Subtropical Atlantic SSTs, as represented by the AMO, PDO, and others, have shown impacts on rainfall anomalies. As shown by model projections, large-scale deforestation and the prospects of global climate change can intensify the risk of a drier and warmer Amazon, risking to expose millions of vulnerable people in small towns in the region to extreme heat stress. While land-use change is the most visible threat to the Amazonian ecosystem, climate change is emerging as the most insidious peril to the region's future.

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