

Heart of drought



“Long-term drought will likely change the structure and composition of the forest.”

Liming Zhou
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by Agnieszka Gautier

In 1890, traveling on a steamer for a Belgian trading company, a young Joseph Conrad pierced the heart of darkness. As the mighty brown current of the Congo River uncoiled, he drifted into the depths of a colossal jungle that dripped

with steam and glistened under the sun. Dense vegetation unfurled. “[It stood] higher than the wall of a temple,” he would later write in his novella, *Heart of Darkness*, in which nature is as much revered as it is suspect. The tale, set in the Congo Rainforest and centered on an isolated ivory trading post, is steeped with the horrors



A mountain gorilla nestles within dense vegetation in the Mgahinga Gorilla National Park in Uganda. The park covers the northern slopes of three volcanoes in the Virunga Mountains, which are home to a large variety of wildlife, including about half the world's critically endangered mountain gorillas. (Courtesy W. White)

Conrad witnessed, securing his disillusionment with imperialism.

More than a century later, the region still struggles against the avarice of exploiters ready to strip the rainforest of minerals, ivory, and oil. “The region’s political instability continues to be a reason we’ve had to depend on satellite observations,” said Philippe Ciais, a scientist at the Laboratoire des Sciences du Climat et de l’Environnement in France. Unlike the Amazon rainforest, the Congo rainforest lacks in situ observations and resources for field study. Any first-hand accounts are precious.

Conrad described the Congolese foliage as “so dark-green as to be almost black.” But the mighty jungle, according to a recent study, shows that deep green beaten back not by man, but by drought.

Beyond the spotlight

Halfway around the world, the Amazon rainforest experienced severe drought in 2005 and 2010 with record low rainfall, drying tributaries, cracking soil, and collapsing trees. It got press. “We pay so much attention to the Amazon rainforest and so little to the African rainforest,” said Liming Zhou, a researcher at University at Albany. Though effectively less dramatic, an earlier study, examining precipitation rates from 1960 to 1998, alerted Zhou to a decades-long drought in the Congo Basin. Zhou then analyzed gauge and satellite data from 1950 to 2012 and found persistent drying beginning in 1985. Rainfall also reached its lowest levels in the last decade. No trees came crashing down, but Zhou wanted to know if the thirty-year drought had an effect. “This is the first study to link long-term drought to tropical rainforests,” Zhou said.

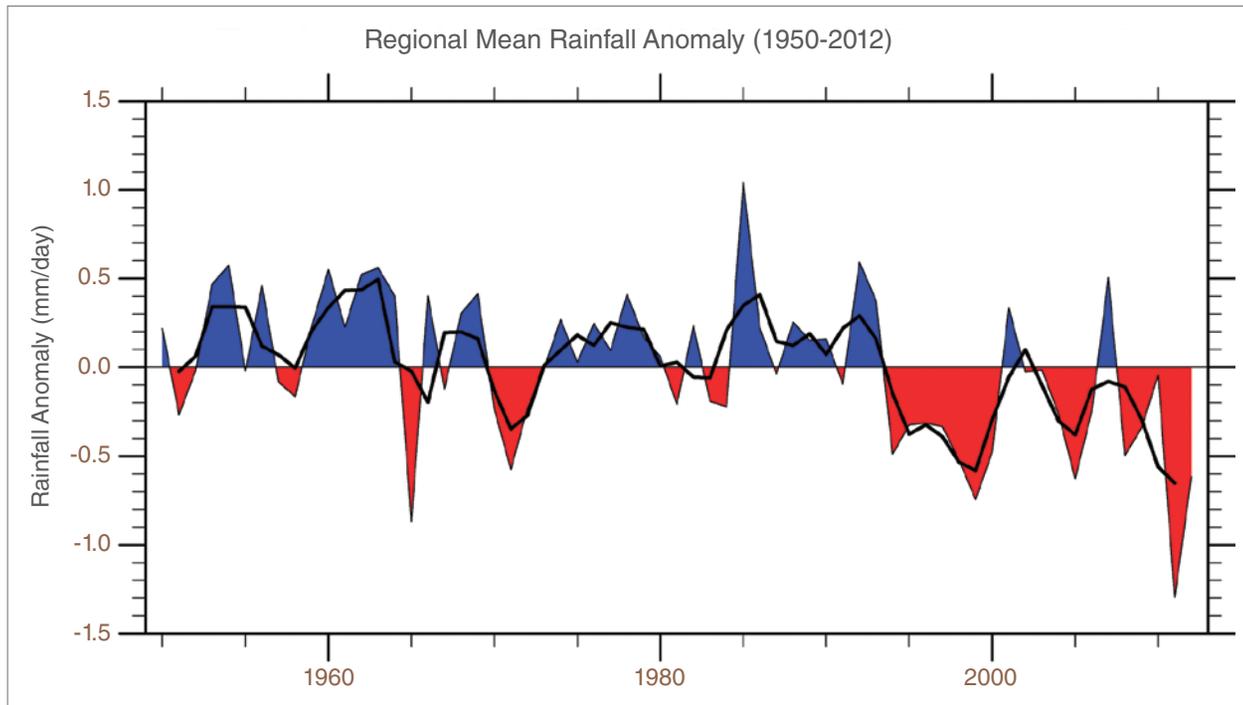


Rays of sunlight break up a downpour in the Congo. (Courtesy A. Thiel)

The Congo rainforest shelters all species of gorilla, the bonobo—a more-peaceful, pygmy cousin of the chimpanzee—the forest elephant, and the shy okapi. It is home to more than 10,000 species of tropical plants, with 30 percent unique to this region. Large herbivores, feeding on smaller trees, shape a canopy of thicker and taller trees than in the Amazon rainforest. Between 250,000 to 600,000 indigenous people live here. The Congo basin stands as the second largest rainforest after the Amazon; it spans six countries, and contains a quarter of the world’s remaining tropical forest. So a drop in plant photosynthetic capacity, even a minor one, would have implications on local biodiversity and the global carbon cycle.

“Before our study, some suggested the African rainforest may be insensitive to drought,” Zhou said. With higher altitudes and more semi-evergreen trees, the Congo rainforest is cooler than the Amazon rainforest. It is also drier. “Researchers thought maybe it already adapted to a drier climate,” Zhou added.

Short, intense droughts lasting less than six months are easy to detect. Rivers dry up. Vegetation shrivels and dies, resulting in erosion and dust bowls. Odds for fire increase. Longer-term droughts, technically more than six months—but stretching into decades—exhibit subtler effects that last longer and are potentially harder to



This graph shows mean rainfall anomalies (millimeters per day) in April, May, and June for the period 1950 to 2012, averaged over the intact Congo rainforest (6°S to 5°N, 14° to 31° E). The solid line represents three-year average rainfall anomalies. The data are from the Global Precipitation Climatology Centre. (Courtesy L. Zhou)

reverse. Land may sink from parched aquifers. Coastal regions may suck saltwater inland. In the case of the Congo, the full effects are yet to be determined, but the rainforest is beginning to take notice.

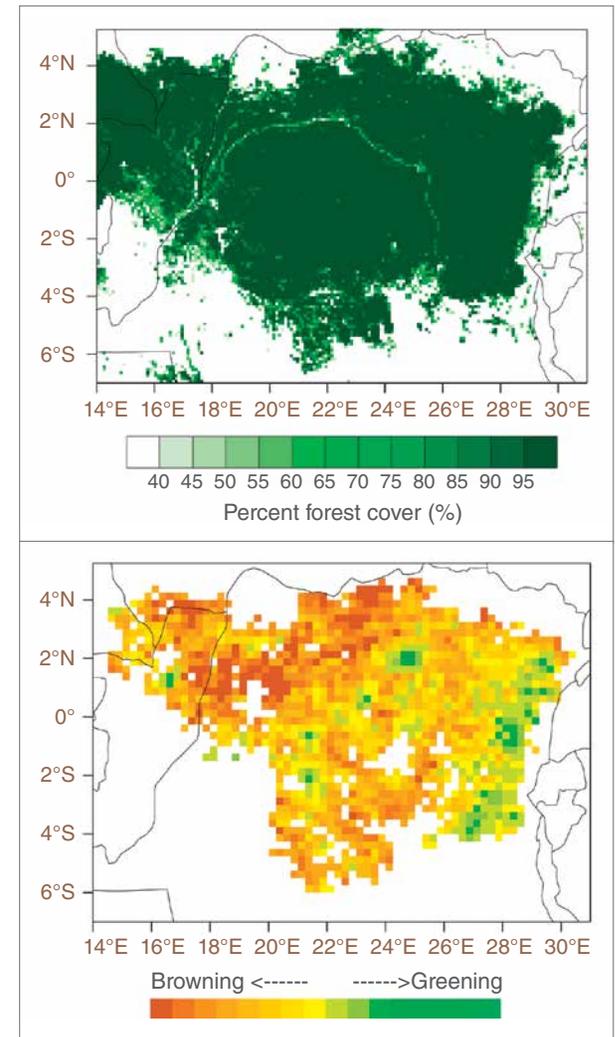
Using data from several satellites, primarily covering 2000 to 2013, Zhou and his colleagues analyzed a region in the Congo Basin with a low deforestation rate. Specifically, the team analyzed vegetation greenness data, a way to measure the health of plants and trees. Simply put, was the forest responding to the drought, and if so, how?

“No one has done a focused analysis like this,” said Ciaia, who helped analyze the data. “Seeing

the data was surprising.” Vegetation greenness experienced widespread decline. Patches of brown splattered throughout satellite images. The sensor at the center of it all is called the Moderate Resolution Imaging Spectroradiometer (MODIS). It flies on the NASA Terra satellite, able to capture and measure both plant growth and atmosphere and cloud properties on a global scale.

The science of green

By observing different wavelength absorptions versus reflections, scientists are able to quantify plant photosynthetic capacity. The more visible light is absorbed, the busier the plant. Chlorophyll, a green pigment within plants, is an agent in photosynthesis. Visible light feeds



The top image shows overall forest cover for the Congo Basin, the majority of which lies in the northern area of the Democratic Republic of the Congo (DRC). Gray lines define borders with the DRC in center, the Congo to the left, and Uganda, Rwanda, and Burundi to the right. The bottom image shows spatial patterns of change in April–May–June vegetation greenness for the period 2000 to 2012. Data are from the Enhanced Vegetation Index (EVI), derived from the Moderate-Resolution Imaging Spectroradiometer (MODIS). (Courtesy L. Zhou)

photosynthesis, transforming light energy into a sugar that further releases energy through its consumption. Virtually all energy used by a living organism stems from this transformation of sunlight to sugar.

Browning occurs when plants are stressed by a lack of water. The plump water cells within leaves wither, and the plant becomes less productive. If the stress is beyond some threshold, trees may even drop their leaves. But what is that threshold?

The Normalized Difference Vegetation Index (NDVI) is an algorithm that uses the different wavelengths of light reflected by vegetation to map the greenness of the world. Zhou's study also used the MODIS-based Enhanced Vegetation Index (EVI) with its finer detail, making it more sensitive to differences within dense vegetation. The team focused on a three-month period from April to June, peak rain and growing seasons, because it shows the highest percentage of high-quality EVI pixels and the least cloud obstruction. From 2000 to 2012, EVI declined over 92 percent of the studied area, with about 40 percent showing a significant negative trend.

To make sure the results were sound, Zhou used multiple satellites. "It's good to get field observations to see what is happening but in this case we can't," Zhou said. "So we used lots of satellites. Each kind of remote sensing technology is different, so you can look at the same area with different information."

The Tropical Rainfall Measuring Mission (TRMM), a sensor that monitors tropical precipitation, verified a decline in rainfall for the thirteen-year period. But even with less water coming down, could the rainforest adapt in how



The shy, endangered okapi rests under the canopy of the Ituri Rainforest, located in the northeastern Democratic Republic of Congo, formerly Zaire. With its stripes, the okapi resembles the zebra, but it is most closely related to the giraffe. A 2013 study determined that 10,000 okapis remain in the wild, down from 40,000 a decade ago. (Courtesy R. Stowe)

it stores and accesses water? Could deep roots even reach ground water? To check, the scientists turned to another mission, the Gravity Recovery and Climate Experiment (GRACE), twin satellites that detect gravity anomalies by sensing subtle changes in Earth's mass. Using GRACE data, Zhou calculated total water storage changes in

the area's wetlands, rivers, ground water, and soil moisture to determine where the storage changed. GRACE confirmed a decline in groundwater levels, further stressing plant productivity.

From the ground up, Zhou shifted to the atmosphere. Cloud cover and aerosol particles influence

About the remote sensing data

Satellites	Terra	Terra and Aqua	Tropical Rainfall Measuring Mission (TRMM)
Sensors	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS	Precipitation Radar Microwave Imager
Data sets	Gridded Atmospheric Product (MOD08_M3)	Vegetation Indices (MOD13C2) Land Surface Temperature and Emissivity (MYD11C3) Land Cover Type (MCD12C1)	TRMM Multi-Satellite Precipitation Analysis
Resolution	1 degree	5.6 kilometer	0.25 x 0.25 degree resolution
Parameters	Aerosol optical thickness (AOT) Cloud optical thickness (COT)	Normalized Difference Vegetation Index Enhanced Vegetation Index Temperature Emissivity Land cover types	Precipitation
DAACs	NASA MODIS Level 1 and Atmosphere Archive and Distribution System Distributed Active Archive Center (MODAPS DAAC)	NASA Land Processes DAAC (LP DAAC)	NASA Goddard Earth Sciences DAAC (GES DAAC)

the rate of photosynthetic productivity. To assess these changes, Zhou used MODIS aerosol optical thickness (AOT) and cloud optical thickness (COT) values. AOT measures the degree of solar light interference. Higher aerosols result in lower visibility and less sunlight reaching vegetation. COT determines the thickness or transparency of cloud cover. Could a change in either confirm drought? From 2000 to 2012, AOT barely changed, but COT showed significant decrease. With thinner clouds, more unobstructed sunlight touches the surface. More sunlight is good for photosynthesis, but the process also transpires water out. A boost in transpiration may empty all moisture out of the soil, causing another level of stress on vegetation.

Another pair of eyes

The persistent browning of the Congolese forests may reflect a slow adjustment to the long-term drying trend. It is nature's way of coping. In the

short-term, proper rainfall offers recovery. "But long-term drought will likely change the structure and composition of the forest," Zhou said. For example, species in the Ghanaian forest shifted from wetter vegetation to favor deciduous trees and a drier canopy after a twenty-year drought.

But detection of such impacts requires long-term ground observations, similar to the Amazon. "People can't expect North American researchers to study the Amazon rainforest or European researchers to study the African rainforest," Ciaia said. "In the end, it has to be local entities that take charge of field observations." The political situation continues to undermine much-needed science. For instance, Africa's oldest national park, the Virunga National Park, battles with political instability and foreign corporations. In the last twenty years, the park has lost more than 150 rangers protecting one of the largest mountain gorilla populations. For the Congo Basin to

be better understood, scientists need to be able to make proper field observations, but that can only happen when the political situation offers the African people security.

"Though we don't have ground observations, the satellite data shows almost everything is impacted," Zhou said. With climate models shaping a future with more frequent droughts, the impact of browning on the carbon cycle and biodiversity conservation needs further study. "It should become a research priority," Zhou added. Because as this study suggests, it is not a matter of whether the rainforests will respond, but more a question of how.

To access this article online, please visit <https://earthdata.nasa.gov/sensing-our-planet/heart-of-drought>.



About the remote sensing data, continued

Satellites	Gravity Recovery and Climate Experiment (GRACE)	Terra and Aqua	Aqua
Sensors	SuperSTAR Accelerometer Star Camera Assembly K-Band Ranging System	Clouds and the Earth's Radiant Energy System (CERES)	Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)
Data sets	GRACE Monthly Land Water Mass Grids (CSR)	SYN1deg_Ed3a	Daily Global Land Surface Parameters Derived from AMSR-E
Resolution	1 degree	1 degree	25 kilometer
Parameters	Terrestrial water storage anomalies	Radiative flux	Canopy microwave transmittance
DAACs	NASA Physical Oceanography DAAC (PO.DAAC)	NASA Atmospheric Science Data Center DAAC (ASDC DAAC)	NASA National Snow and Ice Data Center DAAC (NSIDC DAAC)

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About the scientists



Philippe Ciais is the head of the Atmospheric Composition Department at the Laboratoire des Sciences du Climat et de l'Environnement in France. His research focuses on the global carbon cycle. The Commissariat à l'Énergie Atomique supported his research. Read more at <http://goo.gl/bnGNs7>. (Photograph courtesy P. Ciais)



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- NASA MODIS Level 1 and Atmosphere Archive and Distribution System (MODAPS DAAC). 2002-2012, monthly. MODIS/Gridded Atmospheric Product MOD08_M3. Greenbelt, MD, USA, doi:10.5067/MODIS/MOD08_M3.006.
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For more information

- NASA Land Processes Distributed Active Archive Center (LP DAAC)
<http://lpdaac.usgs.gov>
- NASA MODIS Level 1 and Atmosphere Archive and Distribution System DAAC (MODAPS DAAC)
<http://laadsweb.nascom.nasa.gov>