Q&A on "Widespread Decline of Congo Rainforest Greenness in the Past Decade"
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The authors would like to provide answers to several frequently asked questions about this research. Three figures are also provided on pages 5-6.

What is the major finding of this research?

We found a widespread decline in satellite-measured vegetation greenness in the Congo rainforest in the past 10-13 years, and this large-scale forest browning is generally consistent with the gradual temporal changes in moisture, vegetation and climate parameters observed from several independent satellite sensors (optical, thermal, microwave and gravity).

What is the implication of the finding?

The severe short-term droughts that occurred recently in Amazonia in 2005 and 2010 have drawn broad attention to the vulnerability of tropical forests to climatic disturbances. Previous studies have focused mostly on short-term drought effects on Amazonian forests while little attention has been paid to African rainforest, let alone to the impacts of long-term drought on the forests.

Our finding relates directly to the growing concerns of future climate change on rainforests in the tropical regions where most climate models project increasing drought under global warming. Under the stress of an increased severity of water deficit in a warmer and drier 21st century climate, the gradual loss of photosynthetic capacity and water content over a long period may alter forest species composition and structure and thus affect biodiversity and carbon storage of tropical rainforests. For example, drier conditions may favor deciduous trees at the expense of evergreen trees.

Why were remote sensed data primarily used?

Systematic monitoring of the forests is essential to understanding their response to climate change, and remote sensing remains the only viable way of synoptically and repeatedly monitoring vast remote regions such as the Congo basin where *in situ* observations are very limited. This is probably the most comprehensive observational study thus far exploring the effects of long-term drought on Congolese rainforest using several independent satellite sensors over the Congo Basin

What is satellite measured vegetation greenness?

Vegetation greenness measures vegetation vigor of plant life. It is often quantified as a vegetation index (a single number) calculated from solar radiation reflected back to remote sensors at different spectral bands. It generally correlates well with *in situ* photosynthesis and chlorophyll content. Hence higher greenness values relate to increased presence of chlorophyll in the vegetation being monitored.

Satellite measured vegetation indices such as enhanced vegetation index (EVI) used in this study are radiometric measures of photosynthetically active radiation absorbed by canopy chlorophyll and are therefore good surrogate measures of the physiologically functioning surface greenness level in a region. They allow us to study the seasonality of vegetation growth, measure vegetation health, and detect climatic impacts such as drought and flooding on vegetation. EVI is found to be especially useful in high biomass tropical broadleaf forests like in the Congo Basin.

What is vegetation browning?

Under drought conditions, the water deficit stress on trees will be manifested as less turgid leaves, and if the stress is beyond some threshold, the trees may drop their leaves. This behavior can be detected as a decline in vegetation greenness or EVI. A slow decline of EVI over time implies loss of photosynthetic capacity, which is referred to as vegetation browning.

Why did you study the African rainforest?

The central African rainforest, the second-largest on Earth, has experienced a long-term drying trend whose impacts on vegetation dynamics remain mostly unknown because *in situ* observations are very limited.

Why did you choose the Congolese rainforest instead of the entire African rainforest?

The African rainforests span the equatorial region by nearly seven degrees from north to south, but some forested regions such as in West Africa have extensive cloud and aerosol contaminations on satellite measured vegetation indices. We focus our study only on the intact forested region in the Congo Basin (5° N–6° S, 14° E–31° E) as this region has high-quality satellite measured vegetation greenness data.

Why did you focus your analysis during a three-month period in April–May–June?

This period represents the first of two rain and peak growing seasons and exhibits the highest percentage of forested area with high-quality satellite measured vegetation greenness data.

What are major differences in drought between Amazonian and Congolese rainforests?

The Amazonian forests have experienced two short-term and very intense droughts in 2005 and 2010. In contrast, the Congolese forests have experienced long-term and gradual rainfall reduction.

What are major differences in drought impacts on Amazonian and Congolese rainforests?

There is a gradually decreasing trend in the Congolese rainforest greenness and water content, suggesting a slow adjustment to the long-term drying trend. That’s in contrast to the more rapid response in the Amazon such as large-scale tree mortality brought about by the two more episodic drought events.

Did you see large-scale tree mortality in the Congolese rainforest?

Nope. We analyzed two other vegetation parameters derived from active and passive microwave satellite sensors and also examined high-resolution Landsat images. Our results only show small and gradual changes in vegetation water content and canopy structure, rather than large-scale tree mortality as observed recently in the Amazon. The small and gradual changes in the Congolese forest are consistent with the gradual changes in rainfall and moisture in the Congo Basin.

Why did you attribute the large-scale browning to the long-term drying trend?

The widespread decline in vegetation greenness, particularly in the northern Congolese forest, is generally consistent with decreases in rainfall, terrestrial water storage, water content in aboveground woody and leaf biomass, and the canopy backscatter anomaly caused by changes in structure and moisture in upper forest layers. It is also consistent with increases in photosynthetically active radiation and land surface temperature. These multiple lines of evidence indicate that this large-scale vegetation browning, or loss of photosynthetic capacity, may be, at least partially, attributable to the long-term drying trend.

What are the major uncertainties of this study?

It is important to keep the following points in mind when interpreting our results. First, although we have paid much attention to ensuring high-quality vegetation greenness data used in our analysis, satellite products do contain errors and noise. Uncertainties also exist in rainfall data due to lack of adequate ground observations over tropical rainforests. Furthermore, the effects of long-term drought on vegetation are more complex than severe short-term drought and thus are less obvious and difficult to observe.

Second, we use statistical approaches to quantify the association between vegetation parameters and moisture and climate variables. However, a statistical correlation, no matter how strong, does not imply causality. Also most of satellite data used in the study are only 10-13 years long, which limits our understanding of vegetation-climate interactions and our attribution of the large-scale browning. Therefore, further detection and attribution of drought impacts on tropical forests require long-term ground observations and drought manipulative experiments as done for the Amazon forests; these, however, are not available for the Congolese forest and should be a research priority.

Third, we express the change of most variables as a linear trend per decade. This is just one simple way to quantify the interannual variations in vegetation and climate variables while reducing the year-to-year data noise. The estimated trend only applies to the study region and to the study period, and thus should not be extrapolated into other regions or over longer periods.

In summary, remote sensing data, like all scientific observations, have uncertainties. As stated at the beginning of our paper, the impact of changes in precipitation patterns, such as short-term and long-term droughts, on tropical rainforests is poorly understood and currently under debate. We hope that our paper will promote such debate and more research.

Advances in science require new observations, rigorous and transparent analyses. This study provides evidence that hopefully will contribute to our understanding of how tropical forests respond to drought. However, different plant species show different responses to climate change. It's important to note that our assessment is just one first step and full consideration of the vast and complex range of processes affecting different tropical rainforest species is needed to fully assess future resilience of tropical forests.

What will you do next?

Understanding complex interactions between climate change and tropical rainforests is a critical, exciting and challenging research topic. We are now expanding our analyses to other forests and searching for more data, particularly long-term ground observations, to understand the physical processes and mechanisms driving the complex vegetation-climate interactions.

Other relevant news about droughts and rainforests

Drought strikes the Amazon rainforest again
http://www.nature.com/news/2010/101029/full/news.2010.571.html

Climate change crisis for rainforests
http://www.nature.com/news/2009/090305/full/news.2009.136.html

Drought could have lasting effect on trees, specialist says
http://www.purdue.edu/newsroom/outreach/2012/120719PurcellTrees.html

Severe drought has lasting effects on Amazon
http://www.nature.com/news/severe-drought-has-lasting-effects-on-amazon-1.12129

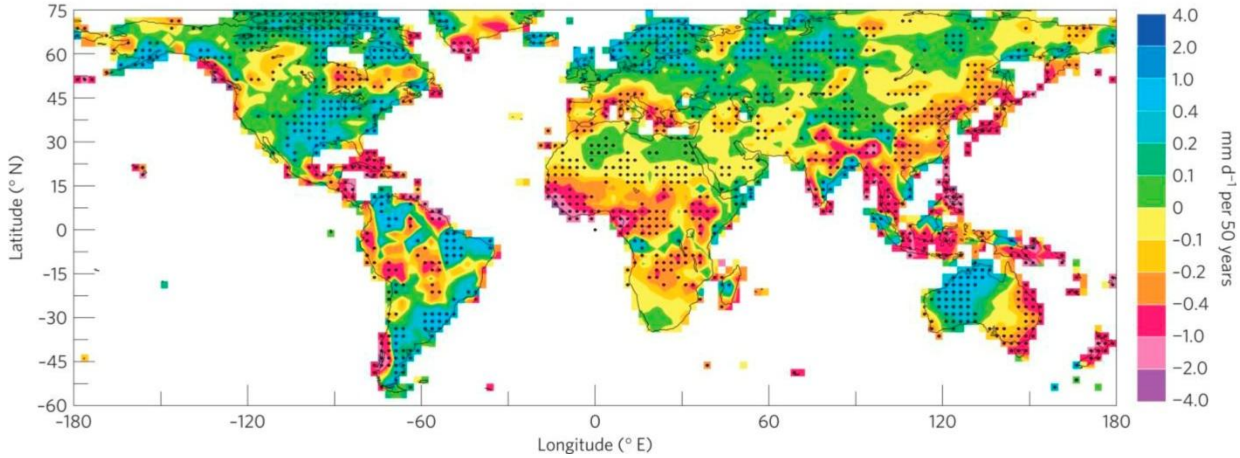

Figure 1: Global long-term trend map for observed annual mean precipitation (mm per day) from 1950 to 2010. The stippling indicates the trend is statistically significant at the 5% level. (Courtesy: Dai, A., Increasing drought under global warming in observations and models, Nature Climate Change, Published online: 5 August 2012 | DOI: 10.1038/NCLIMATE1633).

(High quality image: http://www.atmos.albany.edu/facstaff/zhou/press_release_Congo_forest/press_fig1.jpg)

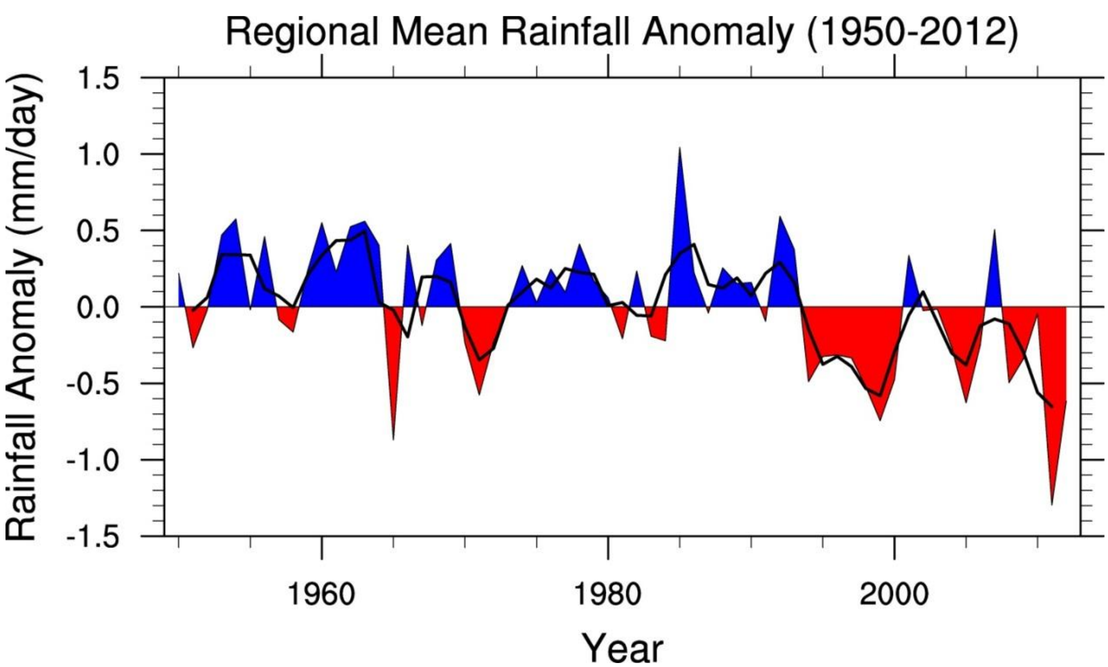

Figure 2: Regional mean rainfall anomalies (mm per day) in April–May–June for the period 1950–2012 averaged over the intact Congo rainforest (6°S–5°N, 14–31° E). The solid line represents three-year average rainfall anomalies. (Courtesy: Liming Zhou).

(High quality image: http://www.atmos.albany.edu/facstaff/zhou/press_release_Congo_forest/press_fig2.jpg)

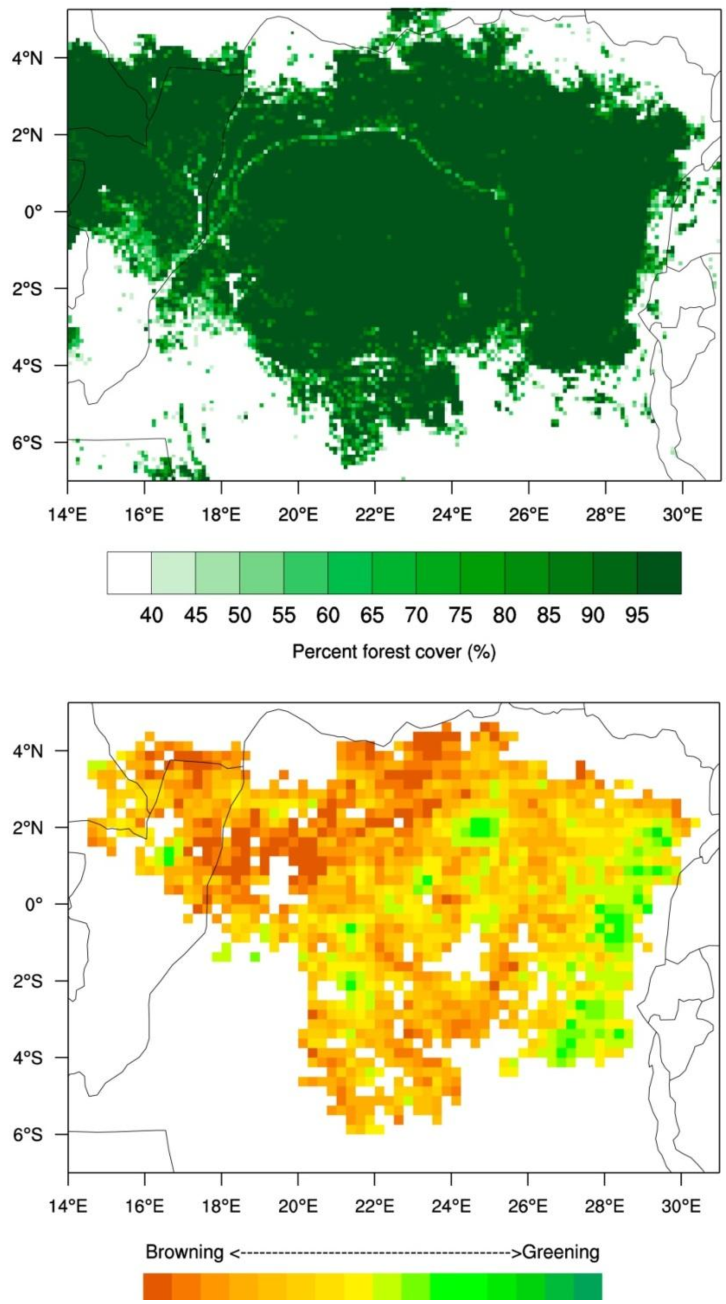

Figure 3: (Top) Climatology of percentage forest cover and (bottom) spatial patterns of changes in April–May–June vegetation greenness for the period 2000–2012. Only the high-quality satellite data during April–May–June over the intact Congo rainforest (6°S–5°N, 14–31° E) are analyzed (Courtesy: Liming Zhou).

(High quality image: http://www.atmos.albany.edu/facstaff/zhou/press_release_Congo_forest/press_fig3.jpg)