Briefing paper

Importance of Central Africa's forests for regional climate and rainfall

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Scenarios for role of Central African forests in regional climate regulation

What do experts think? All agree that there are uncertainties but a major reduction in the Central African forest will influence regional temperatures and rainfall, leading to a warmer, more variable and more drought prone climate. What do they judge "likely"? Some are more optimistic than others noting that any decline in rainfall due to deforestation may be somewhat counterbalanced by an intensification of the water-cycle due to warming (this is often predicted[1] but not yet observed); most are more pessimistic, recognising the likely disruption of feedbacks that maintain rainfall within the continental interior. Many consider a marked shift in the climate is probable. Even if the initial impact of forest loss on rainfall may appear gradual, there is likely to be tipping point beyond which there is rapid change and any options for recovery would require many decades to implement.

Need to take large forest blocks into account in terms of policy considerations

Africa's forests sustain and stabilise the region's climate providing major benefits. Changes to these forests will impact rainfall, temperatures and water security throughout the continent. If the forests are degraded such benefits will decline. In some credible scenarios these impacts are severe. Whatever weight one might give the likelihood of these scenarios, unless they can be ruled out, they require acknowledgement. The costs of neglect are potentially severe. Reducing risks requires maintaining forest and forest functions through large-scale forest conservation and suitable land-uses, such as agroforestry, that coexist with forest and sustain tree cover.

While forest loss increases threats, forest gain and protection reduces them. Protecting, maintaining and restoring forest offers an effective means to combat global climate change[2,3] and to protect against regional water scarcity, unreliable rainfall and heat extremes[4].

Context

Here, drawing on recent advances, I examine the significance, and practical implications, of Central African forest for Africa's climate and water.

Climate change poses dangers. Two thirds of the world's population already suffer seasonal water scarcity[5,6]. Between 1960 and 2016 per capita global freshwater reserves halved[7] and many ground water reserves will soon be depleted[8]. Furthermore, over the last century droughts and floods killed at least eleven and seven million people respectively while half a billion people were left requiring emergency aid[9]. Extreme heat events have impacted millions more[10]. Such factors fuel conflict and migration, and have stalled achievement of the United Nations Sustainable Development Goals[11]. Further, climate change and population growth will exacerbate these problems[12]. Many among the most vulnerable live in Africa where, even without land-use change, the magnitude and rate of predicted climate change is a recognised threat[4,13,14].

Explaining the relationship between forests and climate

Vegetation influences climate in many ways[12,13]. Tropical forests are typically taller and darker (lower light and heat reflection), possess a greater area of leaves for a given area, and offer greater resistance to wind (greater roughness) than most alternative land-covers. Tropical forests provide year round cooling and stabilise temperatures[15]. They also provide water vapour and the condensation nuclei that promote cloud formation. The many mechanisms by which trees influence water availability—e.g., infiltration, soil storage, stem storage, root access, hydraulic lift, dew and cloud capture, aerosols—each have their own dependencies and scales of action. **Many of these aspects are poorly characterized and remain simplified or absent in modern climate models.**

Much of the rain over land derives from evaporation from land though values vary with location, season and wind patterns[16] (Figure 1 a, b). **Both the likelihood and volume of rain are sensitive to atmospheric moisture, e.g., a 10% drop in relative humidity may reduce precipitation by over 50%[17] thus even small changes in humidity can have a marked influence on rainfall[18,19].** Air that passes over forests captures more water and produces more rain than air that passes over sparse vegetation or open water[20] (Figure 1c). Less well understood is how forest cover influences air movement and circulation.

Researchers often predict the climate impacts of changes in land-cover using models. Such simulations can provide plausible results, for example, indicating that large-scale tropical deforestation can reduce local rainfall by 40%[22]. Unfortunately, models fail to simulate key features of the water-cycle (especially

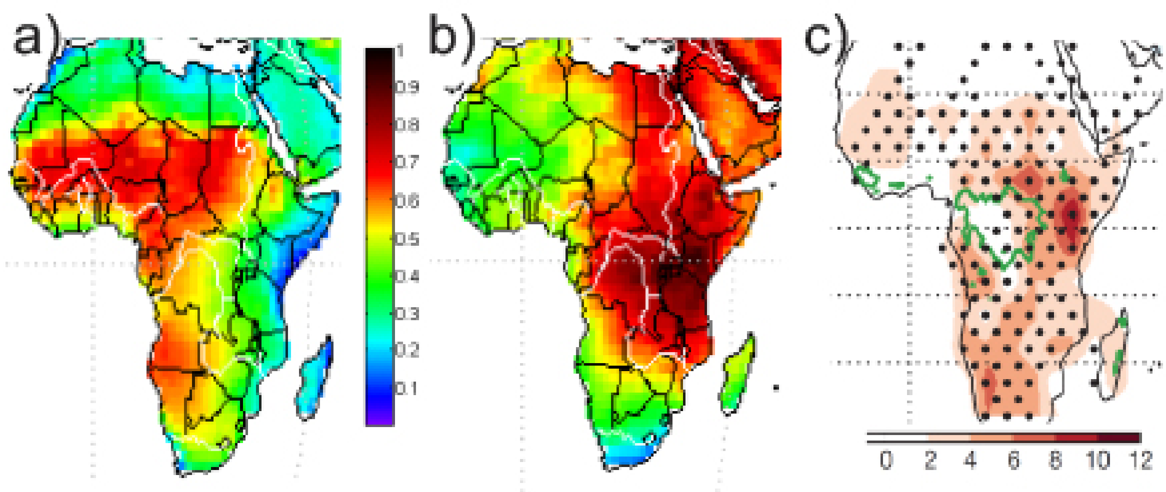

Figure 1. Estimated proportion of recycled rain by where it arrives (a); by where it originates (b); and the regional role of forest (c). (a) Annual average continental precipitation recycling ratio (% of precipitation that is derived from land sources): dark red indicates that over 50% of moisture derives from land—figure developed by and sourced from[21]. (b) Annual average continental evaporation recycling ratio (% of evaporation that falls on land downwind). (c) Relationships between daily rain and cumulative exposure of the local winds to a forest canopy over the previous ten days (measured by "cumulative leaf area index") for 2001–2007. Number of calendar months (red shade scale) with significant (P<0.01) positive relationships between rain and canopy density. Stippling denotes regions where rain is a factor of at least two greater where the wind arrives from dense forest versus open areas. Green contour delimits forest areas with>$3m^2m^{-2}$ mean leaf area. Sourced and simplified from[20].

in the tropics)[1,23-25]. Because models lack reliability, researchers must also draw on theory and observations to judge plausible outcomes.

Many researchers believe that abrupt shifts in climate may result from changes in forest cover. There is less agreement about the nature and likelihood of these shifts. These uncertainties relate to the nature and strength of the processes and feedbacks that determine rainfall. Various studies (mostly focused on Amazonia), have identified feedbacks between forests and rainfall suggesting that forest degradation can switch the region from wet to dry[26,27]. Such feedbacks also appear necessary to explain monsoons and the abrupt climate changes in the past, in Africa[28] and elsewhere[29]. One theory indicating a powerful feedback is the "Biotic Pump"[30,31]. This theory shows how natural forests maintain high evaporation, which support the ascending air motion over the forest and generates low pressures which draws in moist winds from the ocean, sustaining wet climates deep within continents[30,32]. Despite controversy, these ideas are gaining credibility[33]. **Conventional models also agree that regional climates can switch from wet to dry and that any loss of forest increases this risk**[34].

The relationship between Central African forests and regional climate regulation

Sub-Saharan forest (> 10% tree cover) was cleared at around 34,000 $km^2 y^{-1}$ from 2000 to 2010[35]. Nearly two million km^2 of closed forests remains supporting ~112 petagrams of carbon[36] in tree biomass and much more in soils[37] and peatlands[38] (n.b. one petagram = 1015 grams). Estimates suggest 83% of West African and 93% of East African closed forests have been cleared since 1900, while Central Africa (which has ~90% of the remaining closed forest) has been more stable until recently[39], though ~10% was lost from 2000 to 2014[40].

Africa's climate is warming, drying and becoming less predictable and the Sahara Desert expanded by ~10% over the twentieth century[41]. Available observations indicate year round warming, especially in the north, with extreme heat now common in the Sahel[41]. Rainfall has declined around the Niger Basin, the Congo Basin, the Gulf of Guinea[41], and throughout West Africa where extreme rainfall events have become more frequent[42]. Modellers generally ascribe these rainfall trends to global changes and shifts in ocean currents and atmospheric circulation[43,44] but they also appear consistent with the consequences of forest loss. Models reveal large uncertainties in predicted rainfall trends for Africa[41,45] but most suggest reduced forest transpiration and slowing of the regional trade winds[1].

Much of the rainfall within Africa is recycled[21]. Dependencies vary with location and seasons: for example, January rainfall in west Africa is mostly dependent on recycled moisture[21,46]. Atmospheric tracing methods show that Central Africa serves as a distribution hub for the continent's atmospheric moisture[21,47,48]. One tracing study estimated 40% of South Sudan's rain came from Central Africa[49] (Figure 2), another estimated 47%* for the Ethiopian Highlands[50] (Figure 3), while comparable values occur across the Sahel[47].

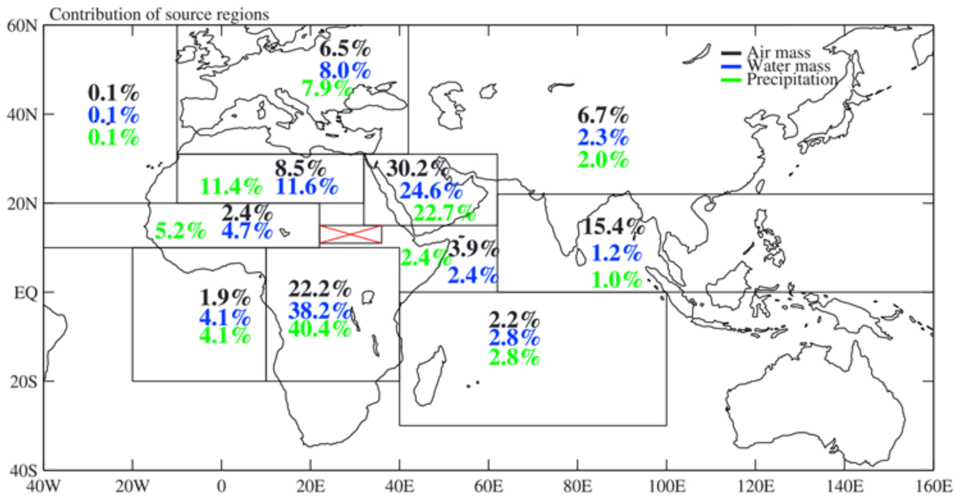

Figure 2. Estimated contributions of different sources to region centred on South Sudan rain (red cross) by air mass (black numbers), water mass (blue numbers), and actual precipitation (green numbers), sourced from[49].

* Note that percentages don't add up precisely to 100%

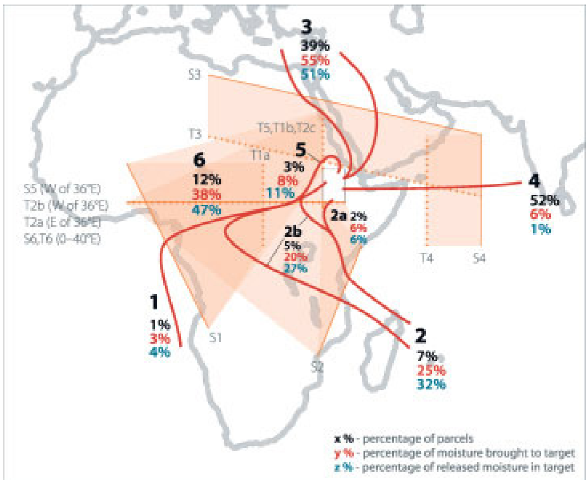

Figure 3. Estimated contributions of different moisture sources to region centred on the Ethiopian Highlands. Main branches (red) of the transport into 8–14°N, 36–40 °E (in Ethiopia) in July–August 1998–2008. Orange sectors mark the lines (S – start, T – transit) used to cluster the trajectories, marked with the branch number. The percentages represent each branch's relative contribution to the inflow of air (black) and moisture (red) to, and the release of moisture within (blue), the boxed region, sourced from[50].

The Congo Basin's hydrology is less studied than other equatorial areas[51,52]. Water storage in the basin is lower and more transient than in the Amazon contributing just 14% (versus 40%) of dry-season stores[53] and the atmosphere over equatorial Africa is drier than over Amazonia[54]. The impact of forest loss on rainfall will not be the same as observed in Amazonia. Rainfall becomes less seasonal from the coast to the interior in the Congo, likely a reflection of sustained recycling (as also found over the Amazon)[55].

Any decline in water is a concern. Some believe human activities have contributed to the continent's aridity—the Sahel was considerably wetter just 5000 years ago[56] and land clearance and burning may have contributed to subsequent changes[57,58]. The rainfall in the Congo Basin is just sufficient to maintain the region's forests during the dry season[53]. A large-scale decline in forest photosynthetic capacity associated with recent drying has been reported over the Congo Basin indicating that the region's transpiration is sensitive to reducing rainfall[59].

The influence of deforestation on regional climate and rainfall

Tropical deforestation impacts regional climates in various ways[33,60,61]. **Extensive reductions in tree cover are generally associated with increased local temperature and temperature variation, and reduced evapotranspiration leading to less cloud, lower humidity and modified patterns of rainfall.** Weakening monsoons have also been correlated to deforestation. Typically tropical forest cover losses of about 50% cause local temperature increases of around 1 °C[62].

Though results vary, model simulations suggest deforestation in Central Africa will cause localised warming, and some decline in rainfall and varied impacts across the continent[63,64]. For example, one simulation predicted that replacing forests with grasslands would increase temperature across the Congo Basin by 2 to 3 degree while local rain would decline markedly with more varied impacts across the continent[65].

Large scale deforestation is likely to disrupt atmospheric moisture transport. The overall volume and reliability of rainfall will decline while droughts and floods become more frequent. Locations furthest downwind from moisture sources are most vulnerable. Switching from wet to dry is possible leading to desiccation and further forest decline[33]. Regions, such as the Eastern Congo Basin that currently enjoy relatively wet climates, risk becoming arid. Prior to such a dramatic shift, rainfall would likely first become more variable and seasonal. Monsoons would be liable to fail. Fires would become frequent enhancing further forest loss. Interior moisture transport would weaken, more rain may fall near the coast and less in the interior. Such a decline, once underway, would be hard to prevent and would threaten all the values associated with these forests.

Any large-scale forest loss involves risk to the local climate. The nature of the conversion matters too—some agroforests, regrowth forest and plantations may possess some properties similar to those of old growth natural forests. The least risk requires the least change: i.e., maintaining as much forest in a natural state as possible. **Indeed, a sensible approach is not to find the tipping point by breaching it, but rather to ensure a good margin of safety** (suggested for the Amazon as ensuring the deforested area remains less than 20% of the natural extent)[34]. According to the Biotic Pump theory relatively continuous tree cover- is especially important near to major sources of atmospheric moisture (e.g., coasts, wetlands, and other forests).

References cited

1 Kooperman, G. J. et al. (2018) "Forest response to rising CO_2 drives zonally asymmetric rainfall change over tropical land". *Nature Climate Change* 8: 434-440.

2 Schimel, D. et al. (2015) "Effect of increasing CO_2 on the terrestrial carbon cycle". *Proceedings of the National Academy of Sciences* 112: 436-441.

3 Lewis, S. L. et al. (2019) "Restoring natural forests is the best way to remove atmospheric carbon". *Nature* 468: 25 – 28.

4 IPCC. (2018) *Global Warming of 1.5° C: An IPCC Special Report on the Impacts of Global Warming of 1.5° C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the*

Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Intergovernmental Panel on Climate Change.
5 Mekonnen, M. M. & Hoekstra, A. Y. (2016) "Four billion people facing severe water scarcity" *Science Advances* 2: e1500323 (2016).
6 Kummu, M. et al. (2016) "The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability". *Scientific reports* 6: 38495.
7 Ripple, W. J. et al. (2017) "World Scientists' Warning to Humanity: A Second Notice". *BioScience* 67: 1026-1028.
8 Wada, Y. et al. (2010) "Global depletion of groundwater resources". *Geophysical Research Letters* 37.
9 Sheil, D. (2014) "How plants water our planet: Advances and imperatives". *Trends in Plant Science* 19: 209-211.
10 King, A. D. et al. (2016) "Emergence of heat extremes attributable to anthropogenic influences". *Geophysical Research Letters* 43: 3438-3443.
11 Gleick, P. H. (2016) "Water strategies for the next administration". *Science* 354: 555-556.
12 Arnell, N. W. et al. (2016) "The impacts of climate change across the globe: A multi-sectoral assessment". *Climatic Change* 134: 457-474.
13 Maxwell, S. et al. (2016) "Biodiversity: The ravages of guns, nets and bulldozers". *Nature* 536, 143.
14 IPCC. (2014) *Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects.* Cambridge University Press.
15 Li, Y. et al. (2015) "Local cooling and warming effects of forests based on satellite observations". *Nature Communications* 6: 6603.
16 van der Ent, R. J. et al. (2010) "Origin and fate of atmospheric moisture over continents". *Water Resources Research* 46.
17 Fan, J. et al. (2007) "Effects of aerosols and relative humidity on cumulus clouds". *Journal of Geophysical Research: Atmospheres* 112.
18 Erfanian, A. et al. (2017) "Unprecedented drought over tropical South America in 2016: significantly under-predicted by tropical SST" *Scientific Reports* 7.
19 Hirsch, R. M. & Archfield, S. A. (2015) "Flood trends: Not higher but more often". *Nature Climate Change* 5: 198.
20 Spracklen, D. V. et al. (2012) "Observations of increased tropical rainfall preceded by air passage over forests". *Nature* 489: 282-286.
21 van der Ent, R. J. (2014) *A new view on the hydrological cycle over continents.* Doctorate, Technische Universiteit Delft,.
22 Spracklen, D. V. et al. (2018) "The Effects of Tropical Vegetation on Rainfall". *Annual Review of Environment and Resources* 43: 193-218.
23 Shepherd, T. G. (2014) "Atmospheric circulation as a source of uncertainty in climate change projections". *Nature Geoscience* 7: 703.
24 Stevens, B. & Bony, S. (2013) "Climate change. What are climate models missing?" *Science* 340: 1053-1054.
25 Marotzke, J. et al. (2017) "Climate research must sharpen its view". *Nature Climate Change* 7: 89-91.
26 Boers, N. et al. (2017)"A deforestation-induced tipping point for the South American monsoon system" *Scientific Reports* 7: 41489.
27 Zemp, D. C. et al. (2017) "Deforestation effects on Amazon forest resilience". *Geophysical Research Letters* 44: 6182-6190.
28 Malhi, Y. et al. (2013) "African rainforests: past, present and future". *Philosophical Transactions of the Royal Society B*: Biological Sciences 368: 20120312.
29 Miller, G. H. et al. (2016) "Disentangling the impacts of climate and human colonization on the flora and fauna of the Australian arid zone over the past 100 ka using stable isotopes in avian eggshell". *Quaternary Science Reviews* 151: 27-57.
30 Makarieva, A. M. & Gorshkov, V. G. (2007) "Biotic pump of atmospheric moisture as driver of the hydrological cycle on land". *Hydrology and Earth System Sciences* 11: 1013-1033.
31 Sheil, D. & Murdiyarso, D. (2009) "How Forests Attract Rain: An Examination of a New Hypothesis". *Bioscience* 59: 341-347.
32 Makarieva, A. et al. (2013) "Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics". *Atmospheric Chemistry and Physics* 13: 1039-1056.
33 Sheil, D. (2018) "Forests, atmospheric water and an uncertain future: the new biology of the global water cycle". *Forest Ecosystems* 5, 1-22.
34 Lovejoy, T. E. & Nobre, C. (2018) "Amazon Tipping Point". *Science Advances* 4.
35 MacDicken, K. et al. (2016) *Global Forest Resources Assessment 2015: How are the World's forests changing?* FAO
36 Lewis, S. L. et al. (2009) "Increasing carbon storage in intact African tropical forests". *Nature* 457, 1003-1006.
37 Köchy, M. et al. (2015) "Global distribution of soil organic carbon – Part 1: Masses and frequency distributions of SOC stocks for the tropics, permafrost regions, wetlands, and the world". *Soil* 1: 351-365.
38 Dargie, G. C. et al. (2017) "Age, extent and carbon storage of the central Congo Basin peatland complex". *Nature* 542: 86.
39 Aleman, J. C. et al. (2018) "Forest extent and deforestation in tropical Africa since 1900". *Nature Ecology & Evolution* 2: 26.
40 Tyukavina, A. et al. (2018) "Congo Basin forest loss dominated by increasing smallholder clearing". *Science Advances* 4.
41 Thomas, N. & Nigam, S. (2018) "Twentieth-Century Climate Change over Africa: Seasonal Hydroclimate Trends and Sahara Desert Expansion". *Journal of Climate* 31: 3349-3370.
42 Mouhamed, L. et al. (2013) "Evolution of some observed climate extremes in the West African Sahel". *Weather and Climate Extremes* 1: 19-25.
43 Hua, W. et al. (2016) "Possible causes of the Central Equatorial African long-term drought". *Environmental Research Letters* 11: 124002.
44 Hua, W. et al. (2018) "Understanding the Central Equatorial African long-term drought using AMIP-type simulations". *Climate Dynamics* 50: 1115-1128.
45 Cook, K. H. & Vizy, E. K. (2019) "Contemporary Climate Change of the African Monsoon Systems" *Current Climate Change Reports.*
46 Keys, P. W. et al. (2014) "Variability of moisture recycling using a precipitationshed framework". *Hydrology and Earth System Sciences* 18: 3937-3950.
47 Keys, P. W. et al. (2012) "Analyzing precipitationsheds to understand the vulnerability of rainfall dependent regions". *Biogeosciences* 9: 733-746.
48 Gebrehiwot, S. G. et al. (2019) "The Nile Basin waters and the West African rainforest: Rethinking the boundaries". *Wiley Interdisciplinary Reviews*: Water 6, e1317.
49 Salih, A. A. et al. (2015) "Lagrangian tracing of Sahelian Sudan moisture sources". *Journal of Geophysical Research*: Atmospheres 120, 6793-6808.
50 Viste, E. & Sorteberg, A. (2013) "Moisture transport into the Ethiopian highlands". *International Journal of Climatology* 33, 249-263.
51 Njitchoua, R. et al. (1999) "Variations of the stable isotopic compositions of rainfall events from the Cameroon rain forest, central Africa". *Journal of Hydrology* 223: 17-26.
52 Balagizi, C. M. et al. (2018) "Influence of moisture source dynamics and weather patterns on stable isotopes ratios of precipitation in Central-Eastern Africa". *Science of the Total Environment* 628: 1058-1078.
53 Guan, K. et al. (2015) "Photosynthetic seasonality of global tropical forests constrained by hydroclimate". *Nature Geoscience* 8, 284-289.
54 McCollum, J. R. et al. (2000) "Discrepancy between Gauges and Satellite Estimates of Rainfall in Equatorial Africa". J*ournal of Applied Meteorology* 39: 666-679.
55 Makarieva, A. M. et al. (2013) "Revisiting forest impact on atmospheric water vapor transport and precipitation". T*heoretical and Applied Climatology* 111: 79-96.
56 Tierney, J. E. et al. (2017) "Rainfall regimes of the Green Sahara Science". *Advances* 3, e1601503.
57 Bayon, G. et al. (2012) "Intensifying Weathering and Land Use in Iron Age Central Africa". *Science* 335: 1219-1222.
58 Garcin, Y. et al. (2018) "Early anthropogenic impact on Western Central African rainforests 2,600 y ago". P*roceedings of the National Academy of Sciences* 115: 3261-3266.
59 Zhou, L. et al. (2014) "Widespread decline of Congo rainforest greenness in the past decade". *Nature* 509: 86-90.
60 Lawrence, D. & Vandecar, K. (2015) "Effects of tropical deforestation on climate and agriculture". *Nature Climate Change* 5: 27-36.
61 Bonan, G. B. (2016) "Forests, Climate, and Public Policy: A 500-Year Interdisciplinary Odyssey". *Annual Review of Ecology, Evolution, and Systematics* 47: 97-121.
62 Prevedello, J. A. et al. (2019) "Impacts of forestation and deforestation on local temperature across the globe". *PLOS One* 14: e0213368.
63 Nogherotto, R. et al. (2013) "Impact of Congo Basin deforestation on the African monsoon". *Atmospheric Science Letters* 14: 45-51.
64 Akkermans, T. et al. (2014) "The Regional Climate Impact of a Realistic Future Deforestation Scenario in the Congo Basin". J*ournal of Climate* 27: 2714-2734.
65 Bell, J. P. et al. (2015) "A process-based investigation into the impact of the Congo basin deforestation on surface climate". J*ournal of Geophysical Research: Atmospheres* 120: 5721-5739.

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