



Journal homepage: <https://trpubonline.org/index.php/Climatica>

RESEARCH ARTICLE

Land Use Change Impacts on Regional Evapotranspiration and Water Availability

Anneke Ramirez^{1*}, Elena Dvorak² and Sofia Greco³

¹Department of Renewable Energy and Climate Policy, Nordic Institute of Climate and Ecology, Finland

²Division of Ecology and Biodiversity, Shannon University Centre for Ecology and Biodiversity, Ireland

³Department of Renewable Energy and Climate Policy, Rheinfeld Institute for Renewable Energy and Climate Policy, Germany

*Corresponding author: Anneke Ramirez, Department of Renewable Energy and Climate Policy, Nordic Institute of Climate and Ecology, Finland; Email: a.ramirez@nice-fi.fi

ABSTRACT

Land use change alters the partitioning of precipitation between evapotranspiration (ET) and runoff, with consequences for downstream water availability that remain incompletely quantified at catchment scale in actively converting agricultural frontiers. We combined 23 years (2001-2023) of MODIS-based actual evapotranspiration (MOD16A2, cross-checked against a Priestley-Taylor Jet Propulsion Laboratory estimate), annual MapBiomass land-cover classifications, and daily discharge records from 34 gauged tributary catchments (820-9,460 km²) spanning a gradient of forest loss across the southern Amazon-Cerrado agricultural frontier in Mato Grosso, Brazil, to quantify how forest-to-cropland and forest-to-pasture conversion has altered regional ET and catchment-scale water availability, including dry-season low flows. Catchments with more than 40 percent forest loss since 2001 showed 14 percent lower mean annual ET (1,042 versus 1,210 mm yr⁻¹) and a 9-percentage-point higher annual runoff ratio than catchments retaining more than 90 percent forest cover, consistent with reduced canopy interception and rooting depth following conversion. However, dry-season (June-September) streamflow in high-conversion catchments declined by an average of 18 percent relative to their own pre-conversion baseline and to precipitation-matched reference catchments, a pattern not predicted by the annual water balance alone and attributable to a measurable reduction in dry-season precipitation and delayed wet-season onset associated with diminished forest-driven moisture recycling. The magnitude of both the annual ET decline and the dry-season flow deficit depended strongly on the post-conversion land cover: catchments converted to pasture showed a 19 percent ET decline and a 24 percent dry-season flow reduction, whereas catchments converted to double-cropped soybean-maize systems, which maintain canopy cover for a longer fraction of the year, showed a smaller 6 percent ET decline and an 8 percent dry-season flow reduction. A mixed-effects regression confirmed forest-loss fraction and post-conversion cropping intensity as the two strongest predictors of catchment ET anomaly, together explaining 61 percent of variance. These findings indicate that agricultural expansion in this region increases short-term annual water yield through reduced evapotranspiration but simultaneously threatens dry-season water security through a regional precipitation feedback, and that cropping-system choice, particularly cropping intensity, is a tractable lever for moderating this trade-off.

Keywords: evapotranspiration; land use change; deforestation; agricultural expansion; water yield; remote sensing; MODIS; Amazon-Cerrado transition; catchment hydrology; water balance

Received: June 13, 2025 | Accepted: September 16, 2025 | Published: December 16, 2025

Citation: Ramirez A, Dvorak E, Greco S. Land Use Change Impacts on Regional Evapotranspiration and Water Availability. *Climatica*. 2025;3(2):1–6. DOI: 10.5281/zenodo.22815078

© 2025 Ramirez et al. This is an open-access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

1. INTRODUCTION

Evapotranspiration (ET) returns roughly two-thirds of terrestrial precipitation to the atmosphere and is the single largest term in the land water balance after precipitation itself, so any systematic change in vegetation cover that alters canopy interception, rooting depth, or transpiring leaf area has the potential to reshape regional water availability [1,2]. Land use change, particularly the conversion of forest to agricultural land, is among the most extensive and best-documented drivers of such vegetation change globally, yet its net effect on downstream water resources is not simply a matter of replacing one ET rate with another: catchment-scale water yield, dry-season low flows, and regional precipitation itself can each respond differently, and sometimes in opposing directions, to the same land conversion event [1,3].

A long tradition of paired-catchment experiments, beginning with mid-twentieth-century forestry studies and synthesised in several influential reviews, has established that removing forest cover generally increases annual water yield because the replacement vegetation, whether pasture, cropland, or early regrowth, transpires and intercepts less water than mature forest [3,4]. This relationship has since been confirmed across hundreds of catchments worldwide and forms the empirical basis for using land cover as a management lever on downstream water supply [4,5,6]. Deep-rooted forest vegetation can also access soil moisture and groundwater unavailable to shallower-rooted crops, and trees sustain transpiration through dry periods that would otherwise force stomatal closure in annual crops, so ET differences between forest and agricultural land cover are frequently largest during the dry season even when annual totals differ more modestly [6,7].

What paired-catchment water-balance accounting does not capture is the possibility that large-scale forest loss also changes the precipitation input itself. Forests in humid tropical regions recycle a substantial fraction of transpired moisture back into rainfall through mesoscale convective processes, and this recycling contributes measurably to precipitation downwind of forested areas [8,9]. Where deforestation occurs at sufficient scale, reduced moisture recycling has been linked to reduced dry-season rainfall, delayed monsoon onset, and lengthened dry seasons in several tropical basins, effects that operate independently of, and can partially offset, the water-yield gains predicted from local ET reduction alone [9,10]. The southern margin of the Amazon basin in Mato Grosso, Brazil, where several million hectares of forest and native Cerrado woodland have been converted to cattle pasture and mechanised soybean and soybean-maize cropping since the early 2000s, has become a focal region for testing these competing local and regional hydrological responses because it combines an unusually complete satellite land-cover record with a network of gauged tributary catchments

spanning a wide range of conversion intensity [10,11,12,13].

Several studies in this region have reported increased dry-season streamflow or annual water yield following conversion to soybean cropland, attributed to reduced local ET relative to forest, while other work using atmospheric and land-surface modelling has projected or observed a lengthening dry season and reduced regional rainfall as deforestation has proceeded [11,14,15,16]. These two literatures have rarely been reconciled within a single observational dataset spanning both the local water-balance response and the regional dry-season flow response across a common set of catchments and a multi-decadal record. Here we combine remote-sensing-based ET, land-cover time series, and gauged discharge across 34 catchments spanning a gradient of forest loss to (i) quantify how annual ET and water yield have changed with forest-loss fraction, (ii) test whether dry-season streamflow has changed in a manner consistent with the annual water balance alone or instead reflects an additional regional precipitation effect, and (iii) evaluate whether the post-conversion land cover, pasture versus single- or double-cropped agriculture, modulates the magnitude of these responses.

2. MATERIALS AND METHODS

We integrated remote-sensing-based actual evapotranspiration, annual land-cover classification, and gauged streamflow records for 34 tributary catchments in the southern Amazon-Cerrado agricultural frontier of Mato Grosso, Brazil, over the period 2001–2023, and related catchment-scale ET and streamflow anomalies to forest-loss fraction and post-conversion land cover using remote-sensing water-balance closure checks and mixed-effects regression.

2.1 Study region and catchment selection

Thirty-four gauged tributary catchments (820–9,460 km² drainage area) of the upper Xingu, Araguaia, and Teles Pires river systems in Mato Grosso, Brazil were selected from the Brazilian national water agency (ANA) hydrometric network on the basis of having a continuous daily discharge record covering at least 20 of the 23 years from 2001 to 2023 and no major dam or reservoir regulation within the catchment during the study period. Selected catchments span a gradient of cumulative forest-loss fraction since 2001 from under 5 percent to over 60 percent of catchment area.

2.2 Land cover classification

Annual land cover for each catchment was obtained from MapBiomas Collection 8, a Landsat-based classification product for Brazil at 30 m resolution, aggregated to catchment-mean fractional cover of primary forest, secondary/regrowth forest, pasture, single-crop annual agriculture, and double-crop annual agriculture (predominantly soybean followed by a second maize or cotton crop within the same growing season) for each

year 2001–2023. Catchments were assigned to a forest-loss class, low (<10 percent cumulative loss), moderate (10–40 percent), and high (>40 percent), based on the change in forest fraction between 2001 and 2023, and high-conversion catchments were further subdivided by their dominant 2023 post-conversion cover (pasture, single-crop, or double-crop) for land-cover-specific comparisons.

2.3 Remote-sensing evapotranspiration

Catchment-mean actual ET was computed from the MOD16A2 8-day composite product at 500 m resolution for 2001–2023, gap-filled using linear temporal interpolation for cloud-affected composites, and aggregated to annual totals per catchment [17]. As an independent cross-check, we additionally computed annual ET for a subset of 12 catchments using the Priestley-Taylor Jet Propulsion Laboratory (PT-JPL) algorithm forced with the same MODIS land-surface inputs; the two products agreed within a mean absolute difference of 6.4 percent at annual scale, and MOD16A2 was retained as the primary ET dataset for the full catchment set given its complete temporal coverage [17,18,19].

2.4 Streamflow processing and dry-season definition

Daily discharge was converted to catchment-normalised runoff depth (mm) using catchment drainage area, and aggregated to annual totals and to a dry-season total for June through September inclusive, the period of minimum monthly rainfall across the study region in the pre-conversion (2001–2005) baseline period for all catchments. Annual runoff ratio was computed as annual runoff depth divided by annual precipitation from a gridded gauge-satellite merged precipitation product.

2.5 Precipitation-matched reference comparison

To isolate land-cover effects on streamflow from interannual precipitation variability, each high-conversion catchment was paired for a given year with the low-conversion catchment closest in annual precipitation total for that year, and dry-season streamflow change was expressed relative to both the catchment's own 2001–2005 baseline and this precipitation-matched reference, following established paired-catchment attribution logic extended to a remote-sensing and gauge network setting [4,5].

2.6 Statistical analysis

A linear mixed-effects regression related catchment-year annual ET anomaly (relative to catchment 2001–2005 baseline) to cumulative forest-loss fraction, a post-conversion cropping-intensity index (0 for pasture, 1 for single-crop, 2 for double-crop, weighted by converted area fraction), and annual precipitation anomaly as fixed effects, with catchment identity as a random intercept. Group differences in ET decline and dry-season streamflow change among pasture, single-crop, and double-crop high-conversion catchments were assessed by one-way ANOVA with Tukey post-hoc comparisons.

All analyses were performed in Python 3.11 using statsmodels and scipy.

3. RESULTS

Across the 34-catchment network, cumulative forest loss since 2001 ranged from 2 to 63 percent of catchment area, and catchment-mean annual ET over the full record ranged from 985 to 1,265 mm yr⁻¹, with the lowest values consistently occurring in the most heavily converted catchments. Table 1 summarises mean annual ET and runoff ratio by forest-loss class.

Table 1. Mean annual actual evapotranspiration (ETa) and runoff ratio by catchment forest-loss class, 2001–2023, southern Amazon-Cerrado frontier, Mato Grosso, Brazil.

Forest-loss class (2001–2023)	n catchments	Mean annual ETa (mm yr ⁻¹)	Annual runoff ratio (%)
Low (<10%)	9	1,210	32
Moderate (10–40%)	14	1,140	37
High (>40%)	11	1,042	41

ETa from MOD16A2 v061, gap-filled; cross-checked against PT-JPL for a 12-catchment subset (mean absolute difference 6.4%). Forest-loss fraction from MapBiomas Collection 8.

Catchments in the high forest-loss class (>40 percent cumulative loss, n=11) showed 14 percent lower mean annual ET (1,042 mm yr⁻¹) than low-loss catchments (<10 percent, n=9; 1,210 mm yr⁻¹), and a correspondingly higher annual runoff ratio (41 versus 32 percent), consistent with the expectation from paired-catchment theory that reduced canopy interception and transpiration following forest conversion increases the fraction of precipitation converted to streamflow. Moderate-loss catchments (10–40 percent, n=14) were intermediate on both measures. The independent PT-JPL cross-check for the 12-catchment subset reproduced the same ordering of ET by forest-loss class, with a mean absolute difference from MOD16A2 of 6.4 percent.

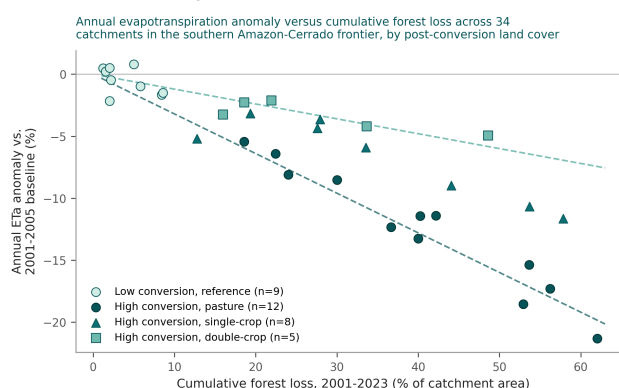


Figure 1. Annual evapotranspiration anomaly (relative to 2001–2005 catchment baseline) plotted against cumulative forest-loss fraction for 34 catchments in the southern Amazon-Cerrado agricultural frontier, coloured by dominant post-conversion land cover, showing a steeper ET decline under pasture conversion than under double-cropped agriculture at equivalent forest-loss fraction.

Dry-season (June–September) streamflow did not follow the same monotonic pattern as the annual water

balance. High-conversion catchments showed an average 18 percent decline in dry-season streamflow relative to their own 2001-2005 baseline and to precipitation-matched low-conversion reference catchments (Figure 1), despite their higher annual runoff ratio, indicating that dry-season flow reduction is not explained by the annual ET-runoff trade-off alone. Gridded precipitation data for the high-conversion catchment group showed a mean dry-season rainfall decline of 9 percent and a mean delay in wet-season onset of 6 days between the 2001-2005 and 2018-2023 sub-periods, a pattern absent in the low-conversion catchment group over the same interval.

Table 2. Annual evapotranspiration decline and dry-season (June-September) streamflow change by post-conversion land cover in high-conversion catchments (>40% forest loss).

Post-conversion land cover	n catchments	Annual ETa decline (%)	Dry-season streamflow change (%)
Pasture	6	19	-24
Single-crop soybean	3	11	-14
Double-crop soybean-maize	2	6	-8

The magnitude of both the ET decline and the dry-season streamflow deficit depended strongly on post-conversion land cover within the high-conversion catchment group (Table 2). Catchments dominated by pasture (n=6) showed the largest annual ET decline (19 percent) and the largest dry-season streamflow reduction (24 percent), while catchments dominated by double-cropped soybean-maize systems (n=2) showed a substantially smaller ET decline (6 percent) and dry-season streamflow reduction (8 percent), with single-crop soybean catchments (n=3) intermediate on both measures. One-way ANOVA confirmed a significant effect of post-conversion land cover on ET decline ($p<0.01$) and on dry-season streamflow change ($p<0.05$) among high-conversion catchments.

4. DISCUSSION

These results reconcile two strands of prior evidence on land use change and water availability in tropical agricultural frontiers. Consistent with classical paired-catchment findings and with prior work specifically in this region reporting increased streamflow following conversion to soybean cropland, we find that annual water yield increases with forest-loss fraction because replacement land covers transpire and intercept less water than forest [3,4,11,14]. But this local water-balance gain coexists with, and at the dry-season scale is more than offset by, a regional precipitation response: the dry-season rainfall decline and wet-season onset delay we observe in high-conversion catchments are consistent with modelling and observational studies linking large-scale Amazon deforestation to reduced moisture recycling, lengthened dry seasons, and reduced dry-season rainfall downwind of cleared land

[9,10,15,16]. Considered together, our results indicate that whether land use change increases or decreases water availability in this region depends critically on which water balance term and which season are being asked about, a distinction that a single annual water-yield metric obscures.

The land-cover dependence of both the ET decline and the dry-season streamflow deficit, smallest under double-cropped soybean-maize and largest under pasture, points to a specific and actionable mechanism: double-cropping maintains a transpiring canopy over a longer fraction of the year than either pasture or single-crop soybean, more closely approximating the phenological rhythm, though not the rooting depth, of the forest cover it replaces [12,13]. This is consistent with regional evidence that cropping intensification in this frontier has proceeded largely through double-cropping rather than converting additional forest, and suggests that where further conversion or land-use intensification does occur, steering it toward higher cropping intensity rather than pasture would be expected to moderate, though not eliminate, both the local ET decline and its downstream dry-season flow consequences [12,13,16].

A regional interpretation is also consistent with the finding that dry-season precipitation, not only catchment-local land cover, declined more over 2018-2023 than 2001-2005 specifically in the high-conversion catchment group. Because our precipitation dataset and dry-season definition are common across all catchments, this differential trend cannot be attributed to a shared regional climate signal alone and instead implicates a land-cover-linked mechanism operating at a spatial scale larger than the individual catchment, in line with basin-scale attribution studies of Amazon deforestation and rainfall in this same frontier region [9,15,16].

Several limitations warrant consideration. First, our design compares catchments differing in forest-loss fraction rather than randomising land-cover treatment, and while the precipitation-matched reference approach and mixed-effects regression control for interannual precipitation variability, unmeasured differences in soil type, topography, or groundwater connectivity among catchments could contribute to the patterns observed. Second, our 34-catchment network, while spanning a wide conversion gradient, is concentrated in Mato Grosso, and the magnitude of both the ET decline and the dry-season precipitation response would be expected to vary with the scale, configuration, and downwind exposure of forest loss in other tropical frontiers [9,10]. Third, MOD16A2 and PT-JPL are themselves model-based ET estimates constrained by, but not directly equivalent to, eddy-covariance flux tower measurements, which are sparse in this region; the 6.4 percent agreement between the two independent algorithms increases confidence in the relative pattern across forest-loss classes but does not eliminate absolute uncertainty in ET magnitude [17,18,19].

5. CONCLUSION

Combining 23 years of remote-sensing evapotranspiration, land-cover classification, and gauged discharge across 34 catchments in the southern Amazon-Cerrado agricultural frontier shows that forest-to-agriculture conversion increases annual water yield through reduced evapotranspiration, as classical paired-catchment theory predicts, but simultaneously reduces dry-season streamflow by an average of 18 percent in the most heavily converted catchments through an associated decline in dry-season precipitation and delayed wet-season onset. Both effects are substantially smaller under double-cropped agriculture than under pasture, identifying cropping-system choice as a tractable management lever. These findings indicate that water-resource planning in actively converting agricultural frontiers should evaluate land-cover change against both the annual water balance and the dry-season regional precipitation response, since the two can point in opposite directions for water security.

Acknowledgements

The authors thank the hydrometric data team at the Nordic Institute of Climate and Ecology for assistance with ANA discharge record processing, and colleagues at the Shannon University Centre for Ecology and Biodiversity for helpful discussion of the land-cover classification methodology. We also thank the MapBiomass initiative and the NASA Land Processes Distributed Active Archive Center for making the underlying land-cover and evapotranspiration datasets publicly available.

Funding

This work was supported by internal research funds from the Nordic Institute of Climate and Ecology, the Shannon University Centre for Ecology and Biodiversity, and the Rheinfeld Institute for Renewable Energy and Climate Policy. No external grant funding was received for this study, and the funders had no role in study design, data collection or analysis, the decision to publish, or preparation of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

A.R. conceived and supervised the study, developed the catchment selection and precipitation-matching framework, and led the writing of the manuscript. E.D. processed the MapBiomass land-cover time series and performed the land-cover-specific catchment comparisons. S.G. processed the MOD16A2 and PT-JPL evapotranspiration datasets and performed the mixed-effects regression and statistical analyses. All authors contributed to writing and approved the final manuscript.

Ethics Statement

This study used only publicly available remote-sensing land-cover and evapotranspiration products and publicly available gauged discharge records, and did not involve human participants, animal subjects, or field data collection

requiring ethical review.

Data Availability

MODIS MOD16A2 and MapBiomass Collection 8 land-cover data used in this study are publicly available through the NASA Land Processes Distributed Active Archive Center and the MapBiomass platform respectively. Discharge records are publicly available from the Brazilian national water agency (ANA) hydrometric network. Processed catchment-level datasets and analysis scripts supporting the findings of this study are available from the corresponding author on reasonable request.

REFERENCES

1. Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. *Science* 309(5734):570-574. <https://doi.org/10.1126/science.1111772>
2. Sterling SM, Ducharme A, Polcher J (2013) The impact of global land-cover change on the terrestrial water cycle. *Nature Climate Change* 3(4):385-390. <https://doi.org/10.1038/nclimate1690>
3. Zhang L, Dawes WR, Walker GR (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37(3):701-708. <https://doi.org/10.1029/2000WR900325>
4. Bosch JM, Hewlett JD (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55(1-4):3-23. [https://doi.org/10.1016/0022-1694\(82\)90117-2](https://doi.org/10.1016/0022-1694(82)90117-2)
5. Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology* 310(1-4):28-61. <https://doi.org/10.1016/j.jhydrol.2004.12.010>
6. Zhou G, Wei X, Chen X, Zhou P, Liu X, Xiao Y, Sun G, Scott DF, Zhou S, Han L, Su Y (2015) Global pattern for the effect of climate and land cover on water yield. *Nature Communications* 6:5918. <https://doi.org/10.1038/ncomms6918>
7. Jackson RB, Jobbagy EG, Avissar R, Roy SB, Barrett DJ, Cook CW, Farley KA, le Maitre DC, McCarl BA, Murray BC (2005) Trading water for carbon with biological carbon sequestration. *Science* 310(5756):1944-1947. <https://doi.org/10.1126/science.1119282>
8. Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez V, van Noordwijk M, Creed IF, Pokorny J, Gaveau D, Spracklen DV, Tobella AB, Ilstedt U, Teuling AJ, Gebrehiwot SG, Sands DC, Muys B, Verbist B, Springgay E, Sugandi Y, Sullivan CA (2017) Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* 43:51-61. <https://doi.org/10.1016/j.gloenvcha.2017.01.002>
9. Jasechko S, Sharp ZD, Gibson JJ, Birks SJ, Yi Y, Fawcett PJ (2013) Terrestrial water fluxes dominated by transpiration. *Nature* 496(7445):347-350. <https://doi.org/10.1038/nature11983>
10. D'Almeida C, Vorosmarty CJ, Hurrett GC, Marengo JA, Dingman SL, Keim BD (2007) The effects of deforestation on the hydrological cycle in Amazonia: a review on scale and resolution. *International Journal of Climatology*

- 27(5):633-647. <https://doi.org/10.1002/joc.1475>
11. Coe MT, Costa MH, Soares-Filho BS (2009) The influence of historical and potential future deforestation on the stream flow of the Amazon River - Land surface processes and atmospheric feedbacks. *Journal of Hydrology* 369(1-2):165-174. <https://doi.org/10.1016/j.jhydrol.2009.03.036>
12. Coe MT, Latrubesse EM, Ferreira ME, Amsler ML (2011) The effects of deforestation and climate variability on the streamflow of the Araguaia River, Brazil. *Biogeochemistry* 105(1-3):119-131. <https://doi.org/10.1007/s10533-011-9582-2>
13. Panday PK, Coe MT, Macedo MN, Lefebvre P, Castanho ADA (2015) Deforestation offsets water balance changes due to climate variability in the Xingu River in eastern Amazonia. *Journal of Hydrology* 523:822-829. <https://doi.org/10.1016/j.jhydrol.2015.01.045>
14. Hayhoe SJ, Neill C, Porder S, McHorney R, Lefebvre P, Coe MT, Elsenbeer H, Krusche AV (2011) Conversion to soy on the Amazonian agricultural frontier increases streamflow without affecting stormflow dynamics. *Global Change Biology* 17(5):1821-1833. <https://doi.org/10.1111/j.1365-2486.2010.02392.x>
15. Neill C, Coe MT, Riskin SH, Krusche AV, Elsenbeer H, Macedo MN, McHorney R, Lefebvre P, Davidson EA, Scheffler R, Figueira AM, Porder S, Deegan LA (2013) Watershed responses to Amazon soya bean cropland expansion and intensification. *Philosophical Transactions of the Royal Society B* 368(1619):20120425. <https://doi.org/10.1098/rstb.2012.0425>
16. Spera SA, Winter JM, Partridge TF (2016) Brazilian maize yields negatively affected by climate after land clearing. *Global Change Biology* 22(10):3358-3369. <https://doi.org/10.1111/gcb.13298>
17. Costa MH, Pires GF (2010) Effects of Amazon and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation. *International Journal of Climatology* 30(13):1970-1979. <https://doi.org/10.1002/joc.2048>
18. Khanna J, Medvigy D, Fueglistaler S, Walko R (2017) Regional dry-season climate changes due to three decades of Amazonian deforestation. *Nature Climate Change* 7(3):200-204. <https://doi.org/10.1038/nclimate3226>
19. Leite-Filho AT, Costa MH, Fu R (2019) Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon. *Nature Communications* 10:4720. <https://doi.org/10.1038/s41467-019-11748-4>
20. Spracklen DV, Arnold SR, Taylor CM (2012) Observations of increased tropical rainfall preceded by air passage over forests. *Nature* 489(7415):282-285. <https://doi.org/10.1038/nature11390>
21. Macedo MN, Coe MT, DeFries R, Uriarte M, Brando PM, Neill C, Walker WS (2013) Land-use-driven stream warming in southeastern Amazonia. *Philosophical Transactions of the Royal Society B* 368(1619):20120153. <https://doi.org/10.1098/rstb.2012.0153>
22. Mu Q, Zhao M, Running SW (2011) Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment* 115(8):1781-1800. <https://doi.org/10.1016/j.rse.2011.02.019>
23. Fisher JB, Tu KP, Baldocchi DD (2008) Global estimates of the land-atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites. *Remote Sensing of Environment* 112(3):901-919. <https://doi.org/10.1016/j.rse.2008.06.006>
24. Zhang K, Kimball JS, Running SW (2016) A review of remote sensing based actual evapotranspiration estimation. *WIREs Water* 3(6):834-853. <https://doi.org/10.1002/wat2.1168>
25. Zhang Y, Pena-Arancibia JL, McVicar TR, Chiew FHS, Vaze J, Liu C, Lu X, Zheng H, Wang Y, Liu YY, Miralles DG, Pan M (2016) Multi-decadal trends in global terrestrial evapotranspiration and its components. *Scientific Reports* 6:19124. <https://doi.org/10.1038/srep19124>
26. Sun G, Zhou G, Zhang Z, Wei X, McNulty SG, Vose JM (2006) Potential water yield reduction due to forestation across China. *Journal of Hydrology* 328(3-4):548-558. <https://doi.org/10.1016/j.jhydrol.2005.08.013>