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Vegetation greenness in 2023

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Global greening continued into 2023, reaching near-record values that were dominated by regional enhancement in the mid-western USA, Europe, northern Australia and parts of equatorial Africa. In contrast, climatic events contributed to browning signals in Russia, Canada, Mexico and tropical drylands.

Since the early 1980s, satellite observations reveal a consistent increasing trend in global vegetation greenness[1,2] — as measured through remotely sensed vegetation indices such as the normalized difference vegetation index (NDVI) — with particularly strong signals in China, India, Europe and central North America[2,3]. Global greening is primarily attributed to rising atmospheric CO_2 concentrations (CO_2 fertilization) alongside effects from altered near-surface meteorological conditions (namely rising temperature and modified precipitation patterns) and direct changes in land use and management[2–4]. Within this positive trend is interannual variability, encompassing changes driven via climatic extremes such as wildfires, heatwaves, droughts and flooding. Recurrent droughts in Amazonia, for instance, can substantially reduce vegetation greenness[5]. With numerous extreme events in 2023 — including mega wildfires in Canada, extreme heat in Europe and intense drought over the southern USA — vegetation growth is likely to have been strongly affected, with global greening signals responding accordingly.

Here, we use Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI data[6] to assess vegetation greenness in 2023. We focus on NDVI during local growing seasons ($NDVI_{GS}$) (ref. 4) when vegetation photosynthesis is active, determining annual production and growth.

Greening signals

2023 global mean $NDVI_{GS}$ ranked as the third highest recorded since 2000, falling slightly below levels in 2020 and 2021 (Fig. 1a). 2023 thus reinforces observations of an uninterrupted and ongoing long-term global greening trend[7]. Indeed, $NDVI_{GS}$ trends are broadly consistent, reaching ~7.6×10^{-4} yr^{-1} over 2000–2019, ~8.1×10^{-4} yr^{-1} over 2000–2021, and ~7.7×10^{-4} yr^{-1} over 2000–2023. These slight differences highlight the impact of shorter-term variability, including a minimal overall increase in $NDVI_{GS}$ since 2020, as evidenced by 2023 aligning closely with the average of the preceding three years.

Contributing to this near-record 2023 signal are hotspots of enhanced vegetation greenness. Overall, 63% of vegetated areas exhibited positive $NDVI_{GS}$ (greening) anomalies (Fig. 1b). More than half of those positive anomalies rank within the top five since 2000, and 13% the highest values on record (Fig. 1c). Strong greening is particularly visible in the parts of equatorial Africa, northern Australia, the mid-western USA, Europe, India and China (Fig. 1b–c). However, the primary causes of these signals are highly divergent; greening in the parts of equatorial Africa (especially in the African Sahel) and northern Australia is primarily driven by increased precipitation[2], while greening in China, India, Europe and the USA benefitted from continuous land use management practices, including afforestation, agricultural intensification and land abandonment[3].

Despite enhanced greenness across much of the global land surface, regions of reduced $NDVI_{GS}$ were also apparent in 2023 (Fig. 1b). Negative $NDVI_{GS}$ anomalies (browning) were observed across 37% of the vegetated surface, with around 15% of vegetated lands exhibiting values in the lowest fifth on record. A notable browning signal was in Central Asia (Fig. 1b–c), attributed to an accelerating drying trend and the high vulnerability of fragile arid ecosystems to frequent and severe droughts[8]. Such intensifying water deficit stress also suppressed vegetation in Central America (particularly Mexico), western Argentina and southern Africa where conspicuous browning signals were observed (Fig. 1b).

Influence of climatic events and land use change

While comparing 2023 to the entire MODIS record offers key insight into longer-term greening signals in response to concurrent changes in CO_2 concentration, background climate change, nitrogen deposition and human land use and management, this approach makes it difficult to elucidate the influence of short-term climate extremes and changes in human land use. Hence, comparing 2023 to 2020–2022 offers an opportunity to isolate the influence of extreme climate events and land use change given that other drivers can be considered near stable or minor.

Although there was no major overall difference in 2023 global vegetation greenness compared to 2020–2022 (Fig. 1a), strong regional variations are evident (Fig. 1d). For example, an overarching increase in $NDVI_{GS}$ was notable in the mid-western USA and Europe compared to 2020–2022 (Fig. 1d). While both locations experienced extreme summer heat in 2023, agricultural intensification and forest management offset what would have had negative impacts on the greening signals. However, climatic events did still have a role. In Europe, for instance, warmer spring temperatures and corresponding phenology changes (an earlier green-up) in 2023 enhanced $NDVI_{GS}$ across croplands and forests — the location of the strongest greening signals — which might have partially offset adverse impacts of summer heat

Key points

- 2023 global vegetation greenness was the third highest observed in satellite records, following 2020 and 2021.
- While the greening trend continued into 2023, shorter-term variability modulates the long-term greening pace.
- Multiple extreme climatic events, in tandem with an El Niño event, markedly diminished vegetation greenness in many regions during 2023.

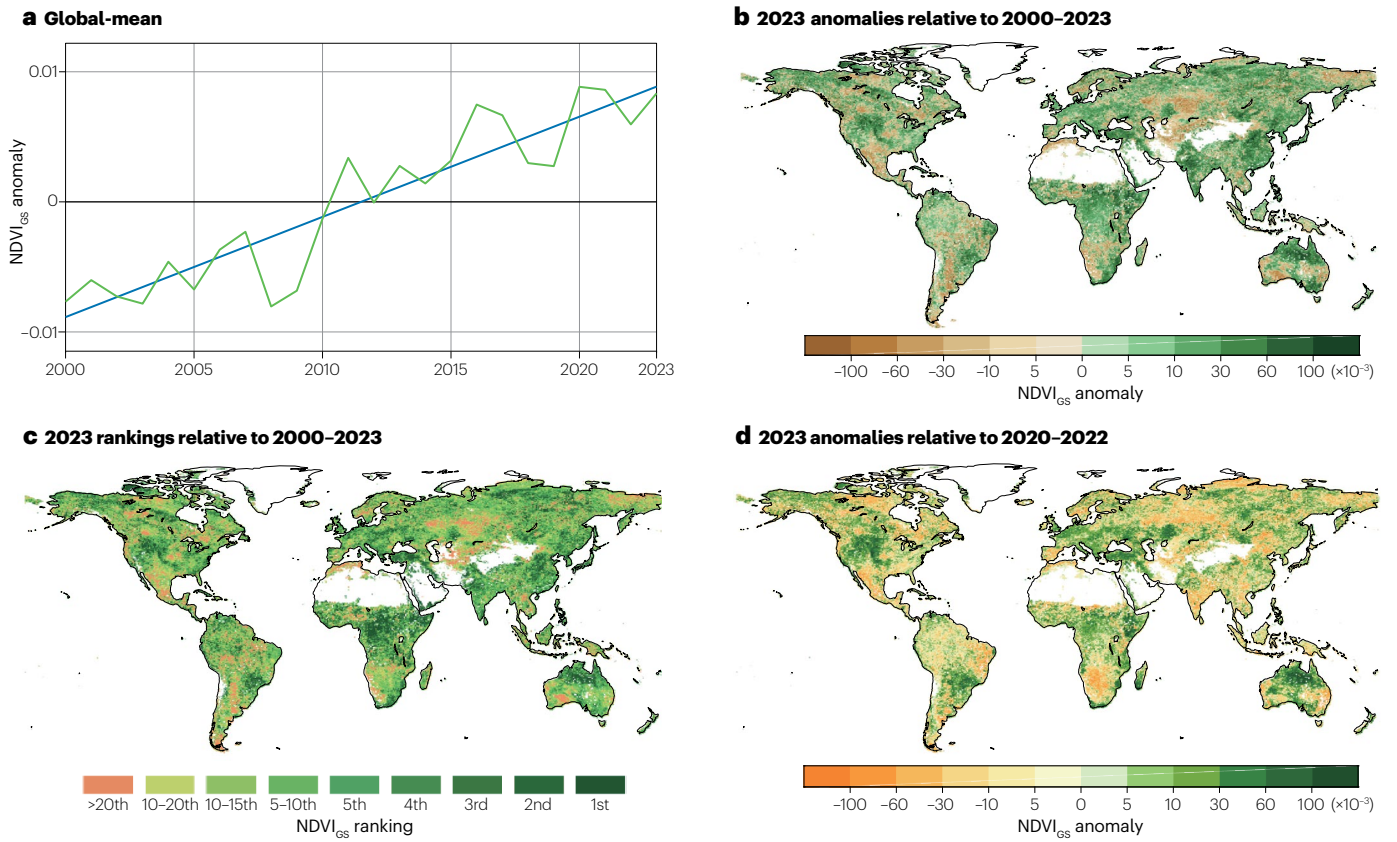

Fig. 1 | Difference of growing season vegetation greenness. a, Global-mean growing season normalized difference vegetation index ($NDVI_{GS}$) anomalies relative to the 2000–2023 mean from the MOD13C2 data product[6]. The growing season of each grid was defined following ref. 4. The blue line depicts the greening trend from 2000 to 2023. **b**, 2023 $NDVI_{GS}$ anomalies relative to the 2000–2023 average. **c**, Ranking of 2023 $NDVI_{GS}$ anomalies relative to 2000–2023; 1st implies 2023 is the greenest year. **d**, 2023 $NDVI_{GS}$ anomalies relative to the 2020–2022 average. The global greening continued in 2023, yet the intensified browning observed in certain regions due to multiple climatic events has the potential to impact the overall greening rate.

extremes[1,2]. Moreover, the above-average precipitation in the western USA in comparison to 2020–2022 contributed to regional greening. Similarly, higher 2023 $NDVI_{GS}$ in some tropical regions, namely northern Australia and parts of equatorial Africa (Fig. 1d), was also linked to enhanced precipitation.

In contrast, widespread climatic events also led to reduced greenness in Russia, Canada and Mexico during 2023 (Fig. 1d). In Russia, an exceptionally cold spring delayed the onset of the growing season, resulting in the anomalously negative $NDVI_{GS}$ (Fig. 1d) and contributing to a browning signal (Fig. 1b). Conversely, reduced greenness in Canada and Mexico was primarily caused by weaker vegetation growth during the hot and dry summer. The long and record-setting wildfire season across Canada also exacerbated vegetation damage, thereby reducing greening.

Across much of the tropics, El Niño-related climatic anomalies are known to suppress vegetation photosynthesis, increase tree mortality and drive higher biomass loss[9], contributing to anomalous browning. Evidence of these characteristics are also evident in 2023 when an El Niño emerged (Fig. 1d). In particular, negative $NDVI_{GS}$ anomalies were observed in several arid or semi-arid regions, including croplands of southern India, and tropical savannas of eastern Brazil and southern Africa. These changes are associated with El Niño-related hot and dry climates.

Summary

2023 provided a broad continuation of the vegetation greening trend observed since 2000, with global average values near the highest recorded in 2020. Compared to 2020–2022, regions of enhanced and suppressed greenness anomalies were closely linked to meteorological events: favourable temperatures and rainfall enhanced greening in the mid-western USA, Europe, northern Australia and parts of equatorial Africa, while extreme heat, drought and wildfires reduced vegetation growth in Russia, Canada, Mexico and many tropical drylands.

Such overall enhanced greenness and related increased vegetation productivity has the potential to strengthen the terrestrial carbon sink, with implications for partially offsetting anthropogenic CO_2 emissions. However, if some extreme climatic events become routine, suppressed vegetation growth might lead to lasting decreases in vegetation cover. Although additional fertilization at higher CO_2 levels and ongoing efforts in vegetation restoration and agricultural intensification are expected to continue to drive global mean greening upwards, these effects could saturate in the future owing to limitations in nutrients and resources[10]. If that happens, the fraction of CO_2 emissions offset by the terrestrial carbon sink could be lowered, with corresponding impacts on the global climate system.

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Competing interests

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