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Vegetation greenness in 2024

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2024 witnessed record-high global vegetation greenness, far outpacing the previous high set in 2020. A total of 67.7% of vegetated land surfaces experienced greening, notably in Eurasian and tropical grasslands, and global croplands.

Terrestrial vegetation has exhibited a greening trend since the 1980s when examined at the global scale – referred to as global greening[1]. This trend can be partially attributed to rising atmospheric CO_2 concentrations which, to date, have consistently promoted vegetation greening. Land use management and climatic conditions also have strong roles[2], with their impacts varying regionally: irrigation and afforestation, and warmer and wetter climatic conditions, generally promote vegetation growth, as exemplified by afforestation-driven greenness increases in China[3]; and irrigation deficits, flooding and deforestation, and hot–dry or cold–wet conditions, often suppress vegetation growth, as seen by deforestation and drought-related greenness decreases in the Amazon[4]. Thus, vegetation responses to the climatic events of 2024, including the dissipation of an El Niño event, hot–dry conditions in the Amazon and Congo rainforests, along with higher precipitation in Europe, Australia and the Sahel, were all expected to have modified the magnitude of the ongoing global greening signal. Quantifying these effects is vital, given the role of greening in enhancing terrestrial carbon uptake, contributing to Net Zero, and influencing biogeophysical processes.

Here, we evaluate global and regional vegetation greenness in 2024 using Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data[5] during the growing season ($NDVI_{GS}$). We use $NDVI_{GS}$ anomalies in 2024 relative to the long-term average (2000–2024 average) to assess the integrated changes encompassing both the long-term trends arising from all forcings (including rising atmospheric CO_2, climate change, etc.), as well as short-term anomalies induced by climate variability and human land use changes. To further estimate short-term anomalies, we derive $NDVI_{GS}$ anomalies in 2024 relative to the short-term average (2021–2023 average). Comparing the 2024 anomaly relative to the long-term average with that relative to the short-term average helps us understand whether short-term climate fluctuations reinforce or dampen the long-term trend in vegetation greenness.

Global greening continues and strengthens

The observed long-term global greening signal persists. In fact, the 2024 global mean $NDVI_{GS}$ reached its highest recorded level since at least 2000, surpassing the previous record (set in 2020, closely followed by 2021 and 2023) by a considerable margin (Fig. 1a). The 2024 $NDVI_{GS}$ value was sufficiently elevated to raise the magnitude of long-term trends: the global greening trend was $7.7 \times 10^{-4}\ yr^{-1}$ over 2000–2023, increasing to $8.1 \times 10^{-4}\ yr^{-1}$ when assessed over 2000–2024, both statistically significant ($p < 0.01$) (Fig. 1a). This substantial increase in the global mean $NDVI_{GS}$ can be linked to a high areal proportion of vegetated surfaces experiencing greening. Indeed, 67.7% of vegetated areas exhibited positive $NDVI_{GS}$ anomalies (greening) relative to the long-term average (Fig. 1b,c), exceeding the 63% observed in 2023 (ref. 2). Negative $NDVI_{GS}$ anomalies (browning) span the other third of vegetated land surfaces, some of which are substantial (Fig. 1b,c).

Looking globally, the spatial pattern of 2024 anomalies relative to the long-term (2000–2024) average broadly resembles those relative to the short-term (2021–2023) average (Fig. 1c,d). Increased greenness was present in the northern mid-latitudes, including central North America and much of Eurasia. Higher $NDVI_{GS}$ anomalies also appeared in many tropical regions, encompassing the Sahel, eastern Africa, southern and eastern South America, and Australia (Fig. 1c,d). By contrast, vegetation in southern Africa, Ukraine, the Congo rainforest, and parts of the Amazon in 2024 exhibited browning signals relative to the short-term and long-term periods (Fig. 1c,d).

Greening varies by vegetation type

Assessing $NDVI_{GS}$ anomalies across four key vegetation types[6] – forest, other woody vegetation (including shrubland and woody savanna), grassland, and cropland – reveals differences in their contribution to global greening.

Grasslands cover 42.7% of all vegetated land surfaces and contributed most strongly to greening signals in terms of spatial area. A total of 70.6% of these grasslands exhibited positive $NDVI_{GS}$ anomalies relative to 2000–2024, meaning 30.1% of all vegetated land was grassland that greened in 2024 (Fig. 1b, outer circle). These grassland greening

Key points

- Record positive anomalies in 2024 amplified the global greening trend from $7.7 \times 10^{-4}\ yr^{-1}$ over 2000–2023 to $8.1 \times 10^{-4}\ yr^{-1}$ over 2000–2024; although the trend continues to be positive, interannual variability remains important in shaping the magnitude of these trends.
- Greening signals spanned two thirds of vegetated lands, dominated in space by grasslands, shrublands and savanna, but with most pronounced changes in grasslands and croplands. Hotspots include Eurasian and tropical grasslands, central North America, Europe and Australia, linked to increased precipitation and effective human management.
- Although greening signals dominate, approximately one third of vegetated land surfaces exhibited browning, largely driven by hot–dry conditions. The most pronounced browning anomalies were observed in southern Africa, Ukraine, the Congo rainforest, and parts of the Amazon.

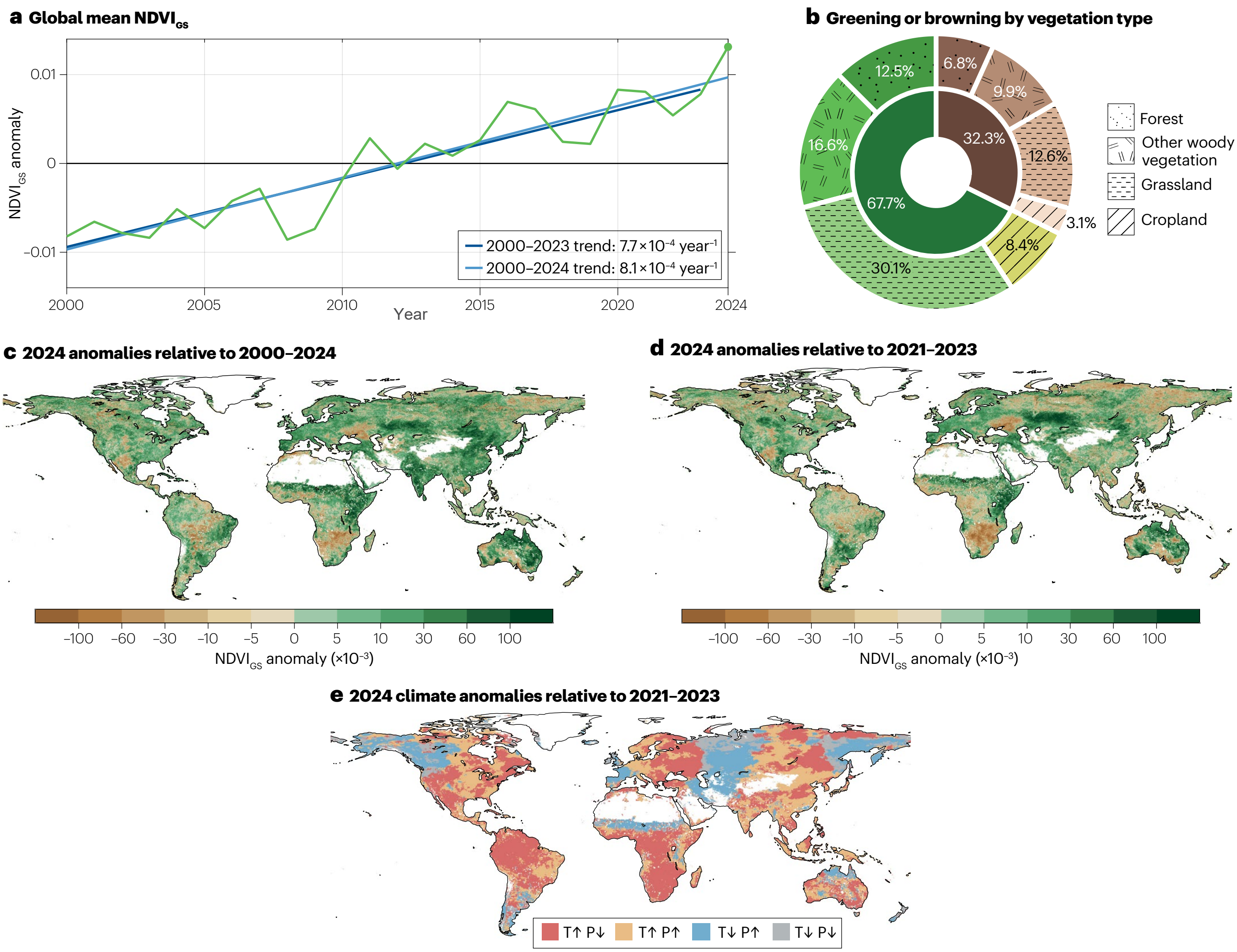

Fig. 1 | Growing season vegetation greenness. a, Global-mean growing season normalized difference vegetation index ($NDVI_{GS}$) anomalies relative to the 2000–2024 mean derived from MOD13C2 (ref. 5) data. The dark blue and light blue lines and text annotations depict the greening trends from 2000 to 2023 and from 2000 to 2024, respectively. **b**, The proportion of vegetated land area experiencing greening and browning in 2024 relative to 2000–2024 (inner circle), and the proportion of forest, other woody vegetation, grassland and cropland exhibiting greening and browning; land cover types are from MCD12C1 (ref. 6) and aggregated into four vegetation types only[3]. **c**, $NDVI_{GS}$ anomalies in 2024 relative to the 2000–2024 average. **d**, $NDVI_{GS}$ anomalies in 2024 relative to the 2021–2023 average. **e**, Growing season temperature[9] (T) and precipitation[10] (P) anomalies in 2024 relative to 2021–2023, presented as either positive (upward arrow) or negative (downward arrow) changes. The global greening continued and strengthened in 2024, dominated by greening in grasslands and croplands, while noting that hot–dry meteorological conditions caused browning signals in the tropics.

anomalies were predominantly located across Eurasia, the Sahel, eastern Africa, southern and eastern South America, and northeastern Australia (Fig. 1c). Comparing the 2024 anomalies relative to the long-term average (Fig. 1c) with those relative to the short-term average (Fig. 1d) reveals any additional impact of short-term climate variability. In the grasslands of Central Asia, the regional average 2024 $NDVI_{GS}$ anomaly was 3.9×10^{-2} relative to the long-term average, lower than the 5.5×10^{-2} relative to the short-term average. This comparison suggests that the short-term greening anomaly linked to higher precipitation in 2024 (Fig. 1e) could entirely offset the long-term browning trend due to drying, thereby resulting in a positive anomaly relative to the long-term average. By contrast, in the grasslands of eastern South Africa, the 2024 anomaly was positive relative to the long-term average (1.2×10^{-2}) but negative when compared to the short-term average (-2.5×10^{-2}); thus, the long-term greening trend has fully offset a short-term reduction in vegetation greenness driven by precipitation deficits coupled with higher temperature in 2024 (Fig. 1e).

Despite occupying only 11.5% of all vegetated land, croplands contributed substantially to the high global $NDVI_{GS}$. Indeed, 72.8% of cropland exhibited positive $NDVI_{GS}$ anomalies in 2024 relative to the long-term average, such that 8.4% of all vegetated land consisted of cropland that greened in 2024 (Fig. 1b, outer circle). Greening was evident in several major agricultural regions, including central North America, Europe, India and northern China (Fig. 1c). Human management has been critical to these greening trends, ensuring a steady rise in global food production[3] and thus supporting food security. In the croplands of India, for example, a short-term greening anomaly driven by precipitation increases in 2024 (1.3×10^{-2}) accounted for a quarter of the greening anomaly relative to the long-term average (5.3×10^{-2}) (Fig. 1c–e). Thus, short-term variability amplifies the long-term greening trend driven by human management.

Forests (covering 19.3% of all vegetated land) and other woody vegetation (covering 26.5% of all vegetated land) also had important contributions to global greening. In 2024, 64.8% and 62.8% of forest and other woody vegetation possessed positive $NDVI_{GS}$ anomalies compared to the long-term average, respectively, meaning that they represented 12.5% and 16.6% of all vegetated land (Fig. 1b, outer circle). Notable forest regions that experienced positive $NDVI_{GS}$ anomalies in 2024 included eastern North America, eastern Europe and western Amazon (Fig. 1c). For eastern Europe, the $NDVI_{GS}$ anomaly in 2024 relative to short-term average (1.9×10^{-2}) could account for 82.6% of the greening anomaly relative to long-term average (2.3×10^{-2}). Accordingly, the short-term increase in vegetation greenness driven by springtime warming in 2024 was much stronger than the long-term greening trend. For other woody vegetation, Australia and central Siberia stood out as regions of prominent change (Fig. 1c). In the southwestern part of Australia, the $NDVI_{GS}$ anomaly in 2024 relative to the short-term average (3.3×10^{-2}) is almost twice as large as the greening anomaly relative to the long-term average (1.8×10^{-2}), suggesting that the short-term greening driven by increased precipitation in 2024 overcompensated for the long-term browning trend (Fig. 1c–e).

Browning signatures are also widespread

Although the majority of global vegetated lands underwent greening in 2024, negative $NDVI_{GS}$ anomalies were widespread (Fig. 1c). Specifically, 32.3% of vegetated lands experienced browning (or loss of greening) in 2024: 12.6% from grassland, 9.9% from other woody vegetation, 6.8% from forest, and 3.1% from cropland (Fig. 1b).

Similar to greening, the magnitude of browning anomalies can vary from year to year owing to climate variability. In the Amazon rainforest, for instance, negative $NDVI_{GS}$ anomalies in 2024 were -3.2×10^{-3} and -4.5×10^{-3} relative to the long-term and short-term average, respectively (Fig. 1c,d). As a result, the negative anomalies in 2024 relative to the long-term average were entirely due to the short-term reduction in vegetation greenness, which was related to compound extreme hot–dry events (Fig. 1e) that decrease vegetation carbon uptake and increase mortality[7]. The Congo rainforests also exhibited stronger browning anomalies in the short term.

For croplands, the most substantial browning anomalies occurred in the Ukraine. Here, short-term anomalies were also strengthened owing to hot–dry conditions (and potentially temporary changes in human management) during 2024, rising from -1.8×10^{-2} relative to the long-term average to -2.5×10^{-2} relative to the short-term average (Fig. 1c,d). In addition, grasslands and other woody vegetation in southern Africa and southern Australia also exhibited substantial browning anomalies due to hotter and drier climatic conditions (Fig. 1d,e). By contrast, browning anomalies in Siberia can be linked to greening suppression associated with low springtime temperatures and summertime water deficiency (Fig. 1d,e).

Summary

Based on satellite measurements available since the year 2000, 2024 recorded the highest value of global mean vegetation greenness, reinforcing the long-term global greening trend. Notable high levels of vegetation greenness were observed in Eurasian and tropical grasslands, as well as in major agricultural regions; these increases occurred primarily as a result of increased precipitation and human management. By contrast, compound hot and dry meteorological conditions hindered vegetation growth in southern Africa, the Congo rainforest and the Amazon rainforest.

Examining changes in vegetation greenness provides critical insights into the dynamics of ecosystem carbon sequestration capacity. Such knowledge establishes clear links and valuable information for societal planning regarding climate mitigation proposals, such as achieving Net Zero. Despite the global mean vegetation greenness reaching a record high in 2024, the spatial distribution of this enhanced greenness exhibited substantial heterogeneity. The increase in global mean vegetation greenness was primarily contributed by grasslands and croplands, while notable browning trends were observed in tropical rainforests and boreal forests. Given the pivotal role of forests in terrestrial carbon sinks[8], the overall strength of the terrestrial carbon sink in 2024 might be weaker than that suggested by the aggregate area-weighted vegetation greenness, underscoring the need for comprehensive and localized quantitative assessments of vegetation functioning.

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Competing interests

The authors declare no competing interests.

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