

Solicited & Highlight PICO

Flash droughts threaten global managed forests

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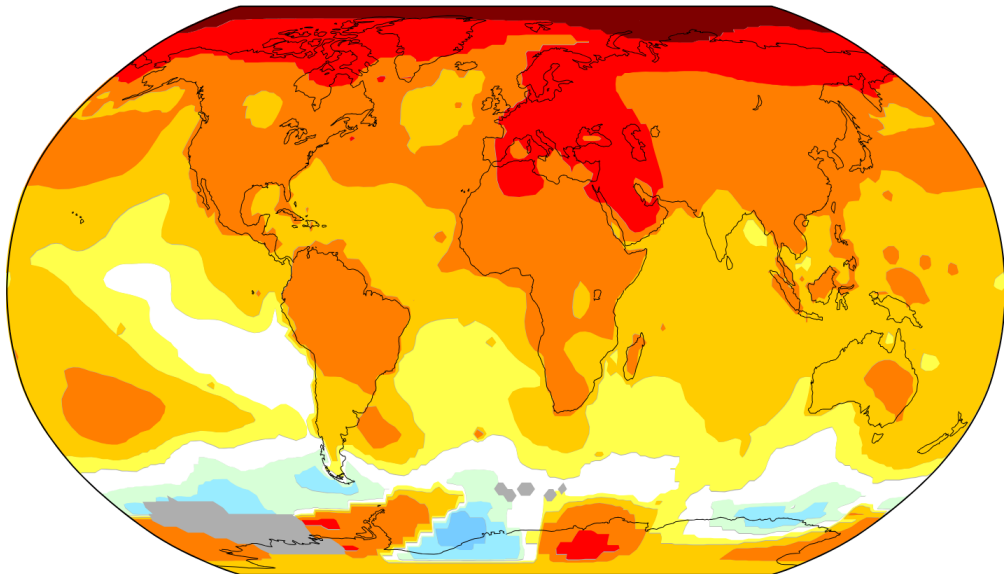
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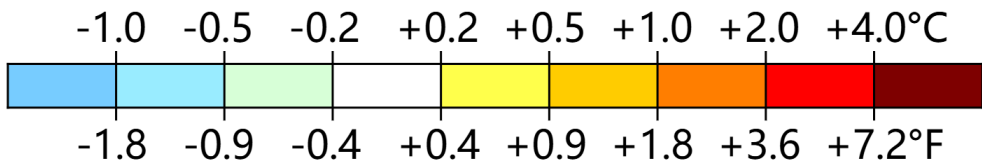
BACKGROUND

Droughts are coming on faster

Temperature change over the past 50 years

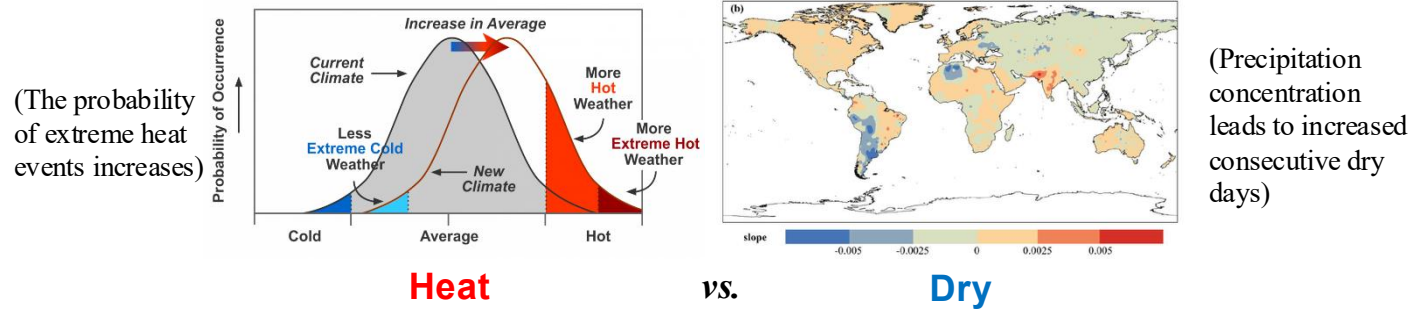


Trend from 1973 to 2023

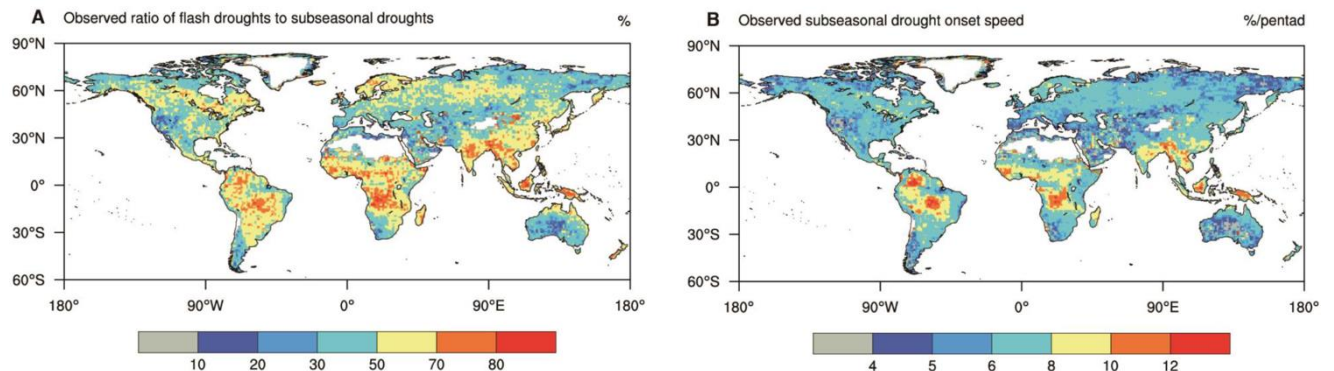


Sources shown on slide: NASA GISS; Walker & Van Loon 2023; Yuan et al. 2023; Sun et al. 2024.

Drought risk is increasingly controlled by both evaporative demand and precipitation deficits.



Soil moisture declines rapidly

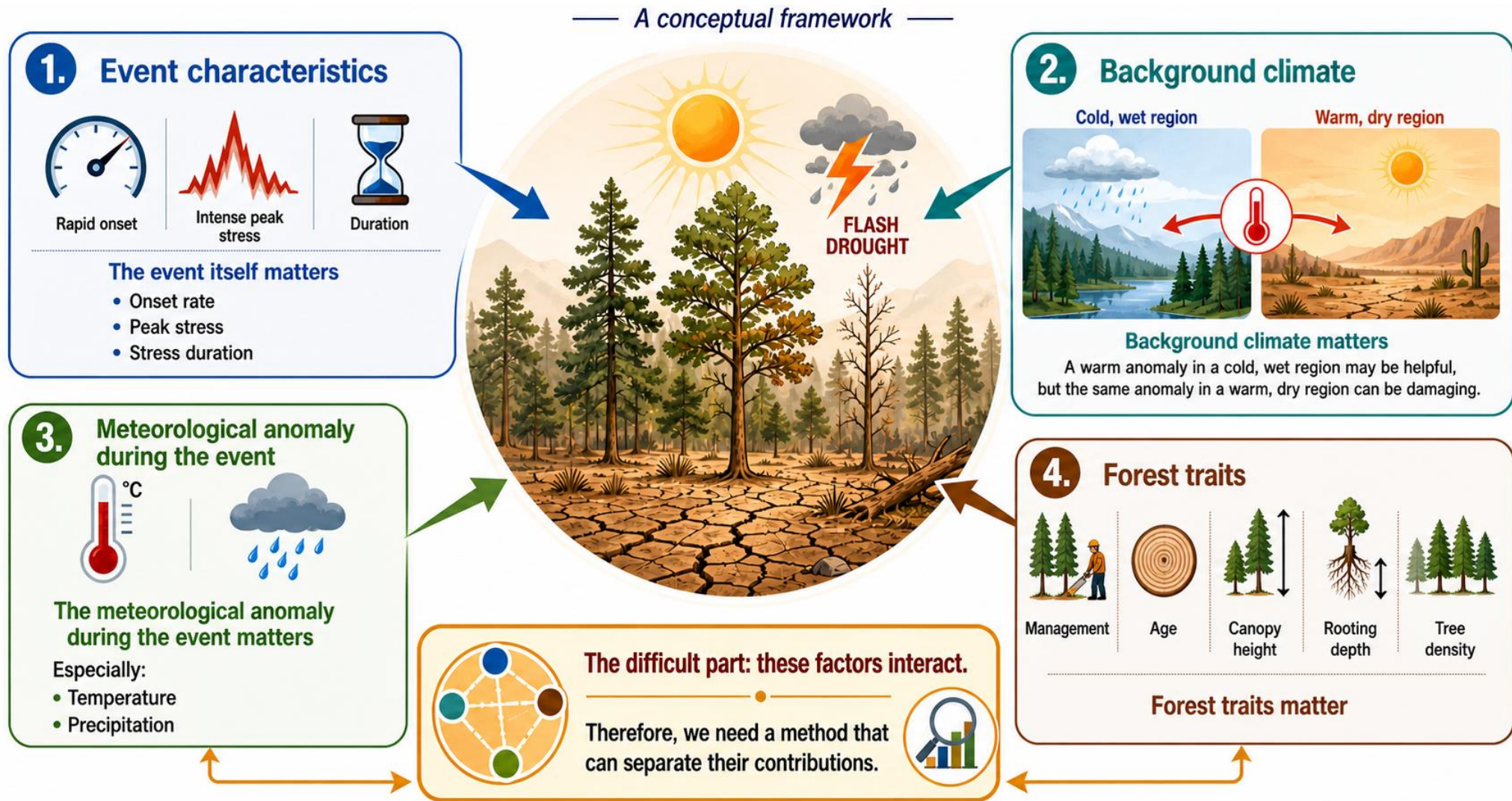


Slow-onset drought

Flash drought

Flash drought is not simply a short drought; it is a drought that intensifies fast enough to push ecosystems into water stress **within weeks**

Four driver groups—and their interactions



The difficult part: these drivers interact, so the analysis must separate individual and interaction effects.

Three questions for a global assessment

- Q1** — How have flash drought characteristics varied across global forests in space and time?

- Q2** — How do forests respond to flash droughts, and what are the dominant regulating factors?

- Q3** — Does forest management amplify or mitigate forest vulnerability to flash droughts?

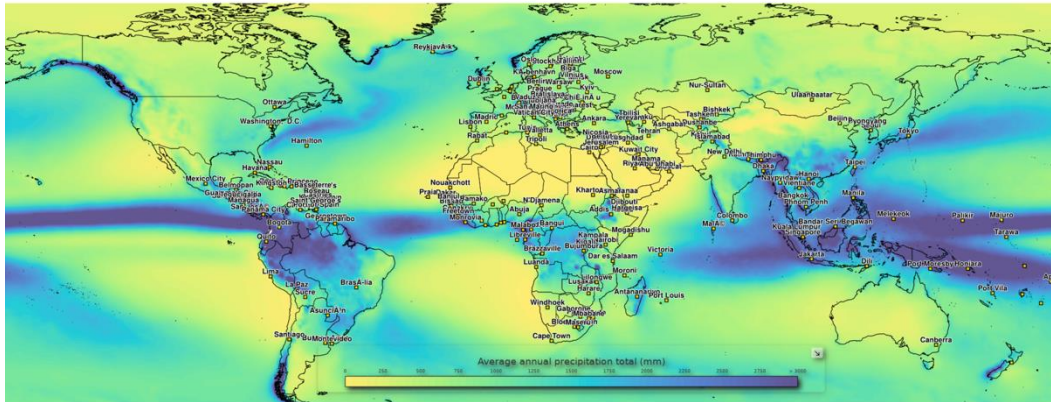
Focus of this talk: climate extremes → forest response → management implications

METHODS

Identifying flash droughts at five-day resolution

Map or search for a city to discover a range of local climate statistics for the period 1979-2020.

ERA5, the 5th generation ECMWF atmospheric reanalysis of the global climate, retrieved by Labelle's Past Climate Explorer

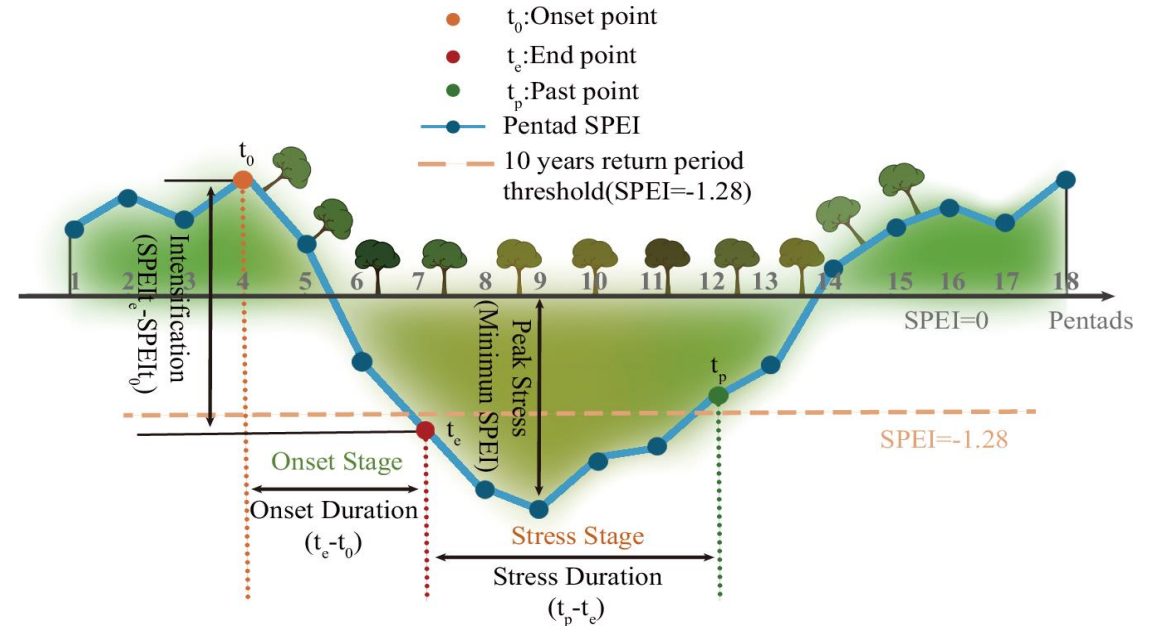


Use and the presentation of material on the map do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

gSPEI-HR dataset

- 0.1° spatial resolution
- Pentad scale: 5-day moving window
- Global forests, 1982–2022

Why pentads? Flash droughts develop too quickly to be captured at a monthly resolution.



Flash-drought criteria

- Rapid decline into water stress
- SPEI ≤ -1.28 within ≤ 5 pentads
- Stress persists for ≥ 3 pentads
- Metrics: onset rate, stress duration, peak stress

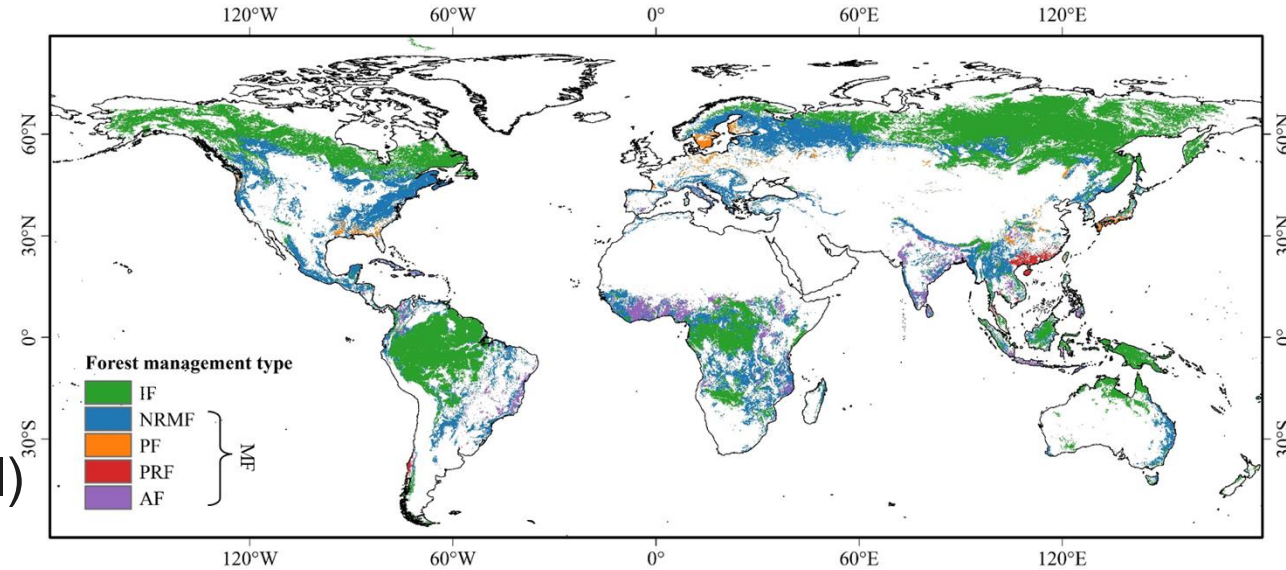
How fast it started, how long the stress lasted, and how severe the peak stress was.

Quantifying forest response and management status

Forest response: standardized Δ NDVI

- Remove seasonal cycle
- Remove long-term growth trend
- Standardize residuals with Z-score
- Δ NDVI < 0: browning during flash drought
- Cross-checks: LAI (structural) and SIF (functional)

Vegetation products: PKU GIMMS NDVI, GLOBMAP LAI, GOSIF. Management map: Lesiv et al. 2022.



Forest management classes

- IF: intact forest
- MF: managed forest
- Retained only dominant-class 0.1° grids
- Excluded pixels with large forest-area change

A negative Δ NDVI means vegetation browning during flash drought relative to normal conditions.

Interpretable machine learning for attribution

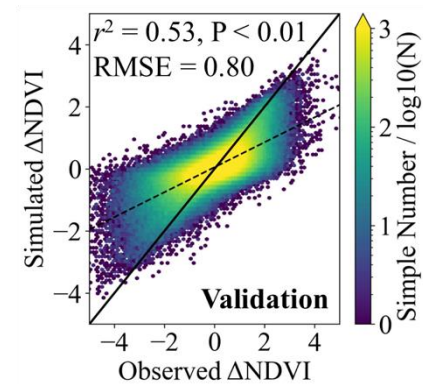
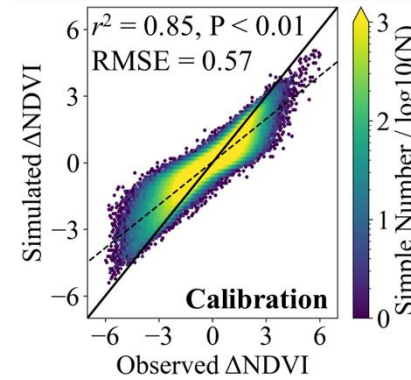
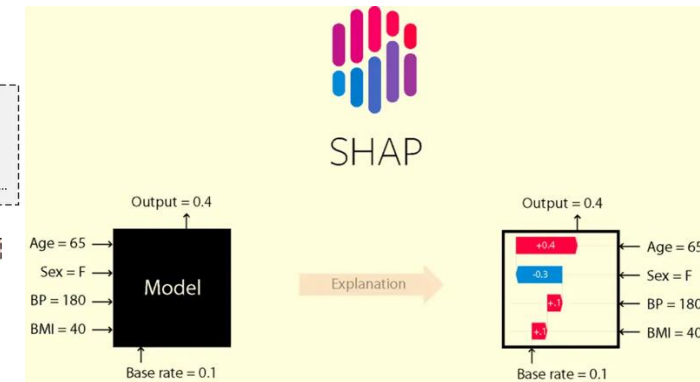
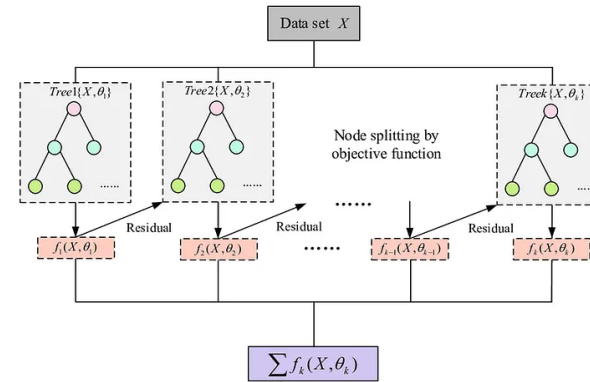
Prediction target

ΔNDVI during flash drought events

Predictors

- Background climate: MAT, MAP
- Event anomalies: temperature, precipitation
- Flash-drought traits: onset, duration, peak stress
- Forest traits: management, age, height, roots, density

Spatial split validation was used to test transferability.

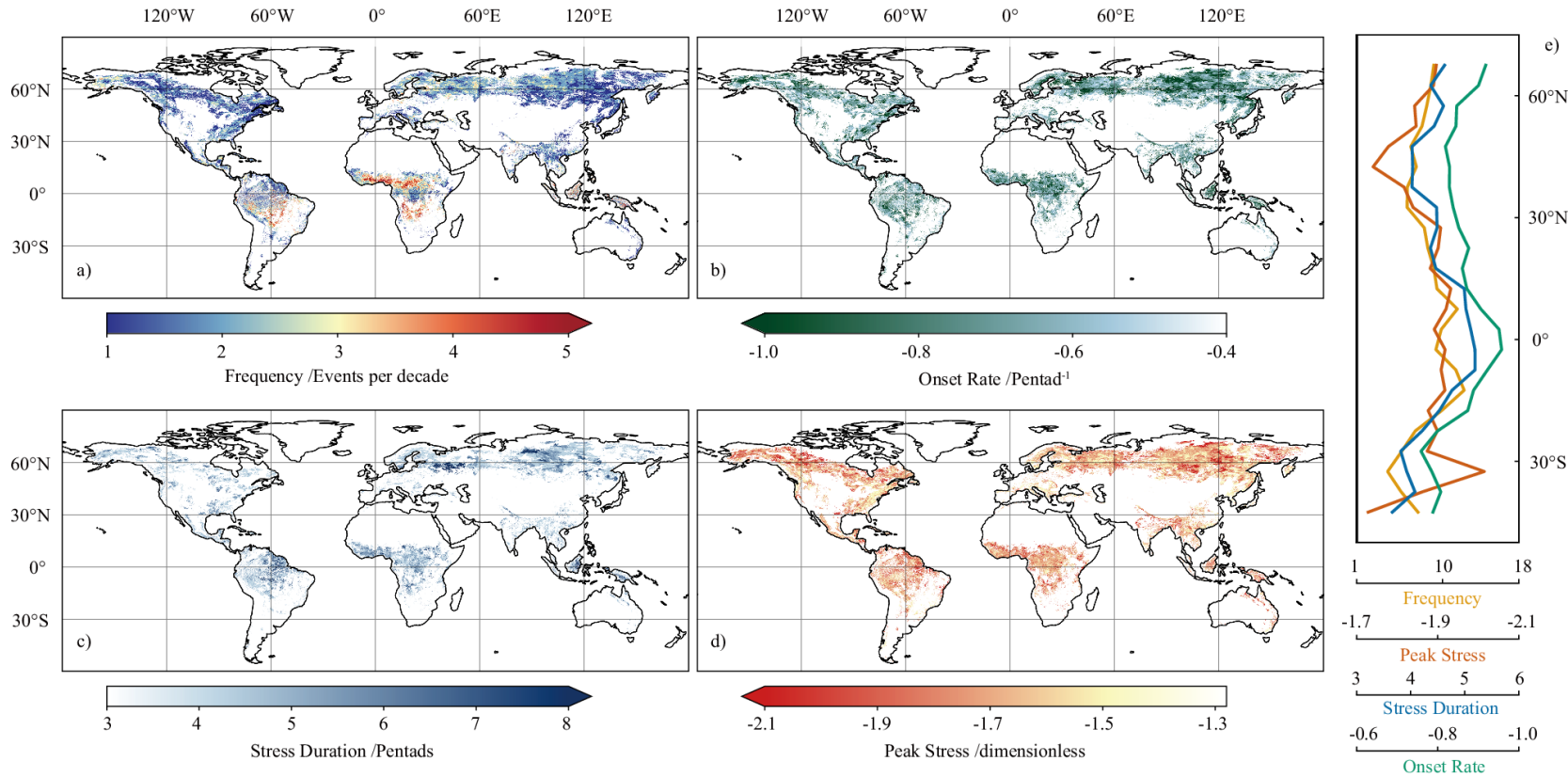


SHAP explains the model

- Total factor importance
- Individual effects
- Interaction effects

RESULTS 1

Spatial pattern of flash drought exposure



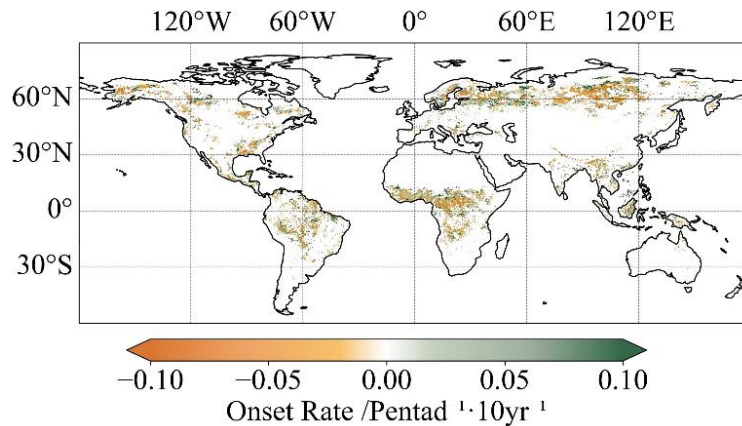
Main pattern

- Flash droughts occur across all major forest regions
- Low-latitude forests have more frequent events
- They also show faster onset, longer stress duration, and stronger peak stress

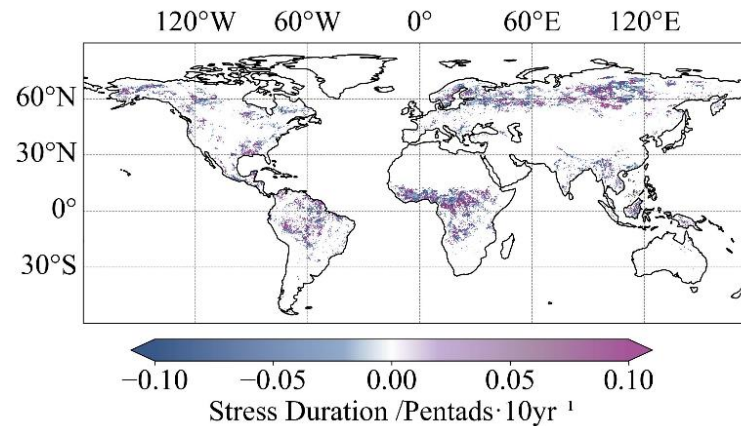
Hotspots include the Sahelian Belt and tropical South America.

Over four decades: faster, stronger, longer

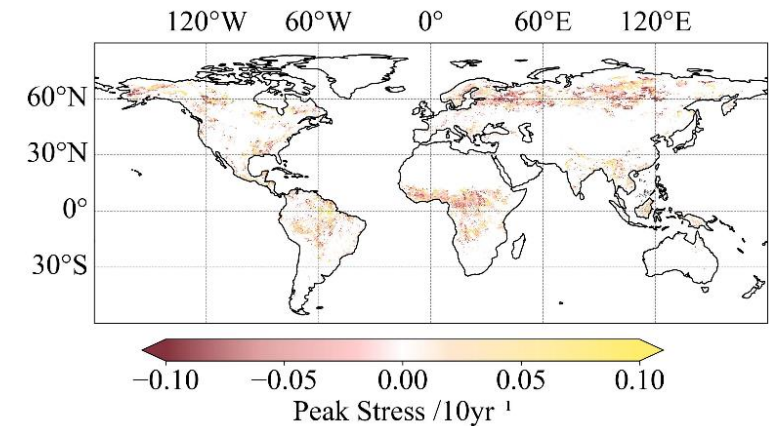
Temporal trends in flash-drought characteristics



Faster onset



Greater peak stress

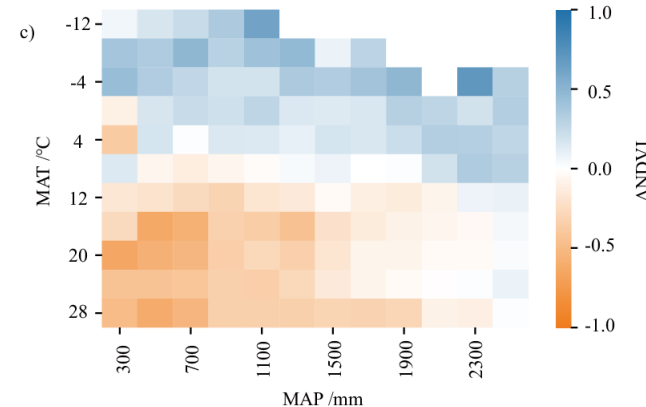
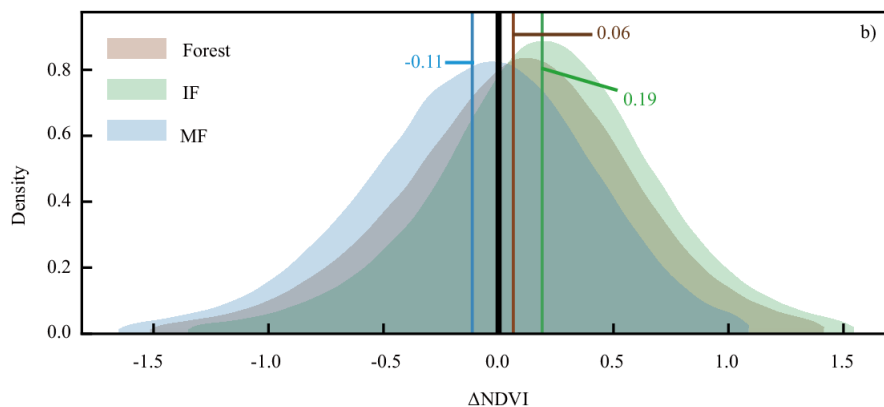
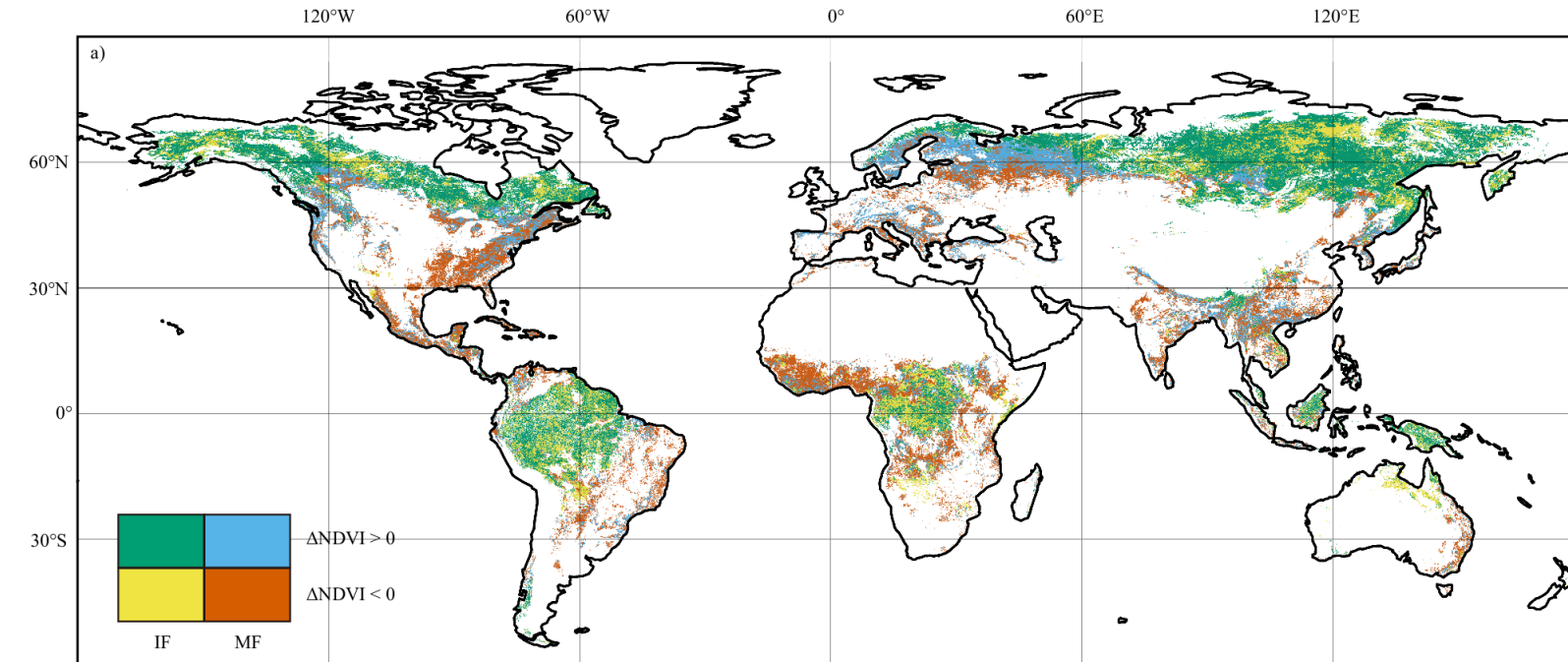


Longer stress duration

- Flash drought stress has intensified with faster onset, stronger peak stress, and longer stress duration.
- Rapid onset reduces the time available for adaptation.
- Longer stress increases the probability of browning.

RESULTS 2

Flash droughts do not brown all forests—but management shifts the response



43%

of global forests showed
browning ($\Delta\text{NDVI} < 0$)

+0.19

Intact forests had a positive
 ΔNDVI mean

-0.11

Managed forests had a negative
 ΔNDVI mean

**Management status is an
important axis of vulnerability.**

Forest management is the single most important factor

XGBoost + SHAP feature importance

- 1 — Forest management **18.37%**
- 2 — Mean annual temperature **12.07%**
- 3 — Temperature anomalies **10.30%**
- 4 — Stress duration **9.98%**

Table 1 | Importance of factors on forest responses based on the XGBoost model

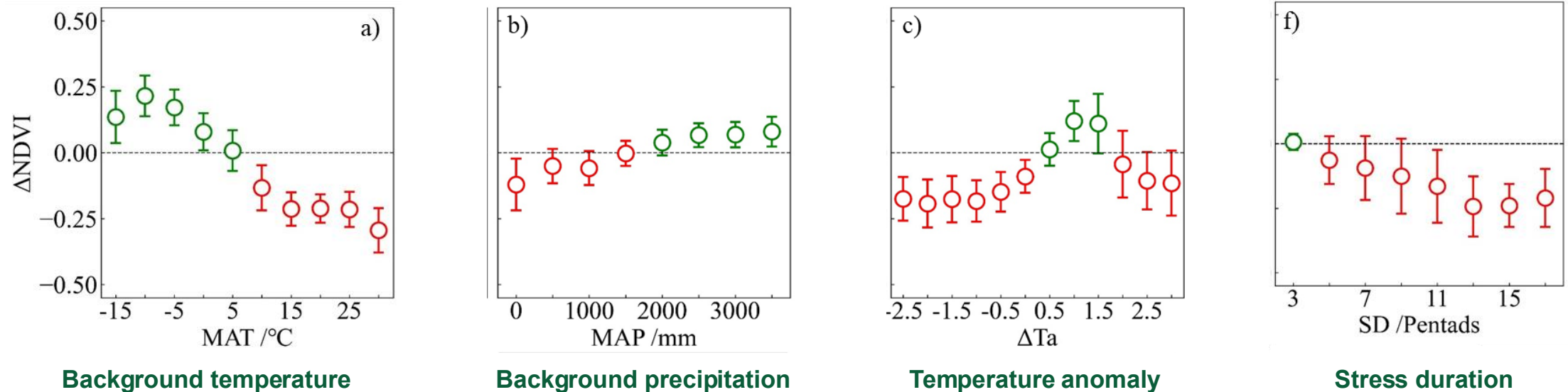
Factor type	Sum. Importance (%)	Factor	Factor importance (%)
Background climate conditions	19.10	Mean annual temperature	12.07
		Mean annual precipitation	7.03
Forest traits	44.91	Forest management	18.37
		Forest age	6.99
		Tree density	6.99
		Canopy height	6.89
		Maximum rooting depth	5.67
		Meteorological anomalies during	17.16
Flash drought characteristics	19.37	Precipitation anomalies	6.86
		Stress duration	9.98
		Peak stress	4.89
		Onset rate	3.96

Forest traits as a group: 45% of total importance

Interpretation: management is not a local disturbance; it shapes global-scale vulnerability to flash drought.

Climate context and stress duration determine when browning occurs

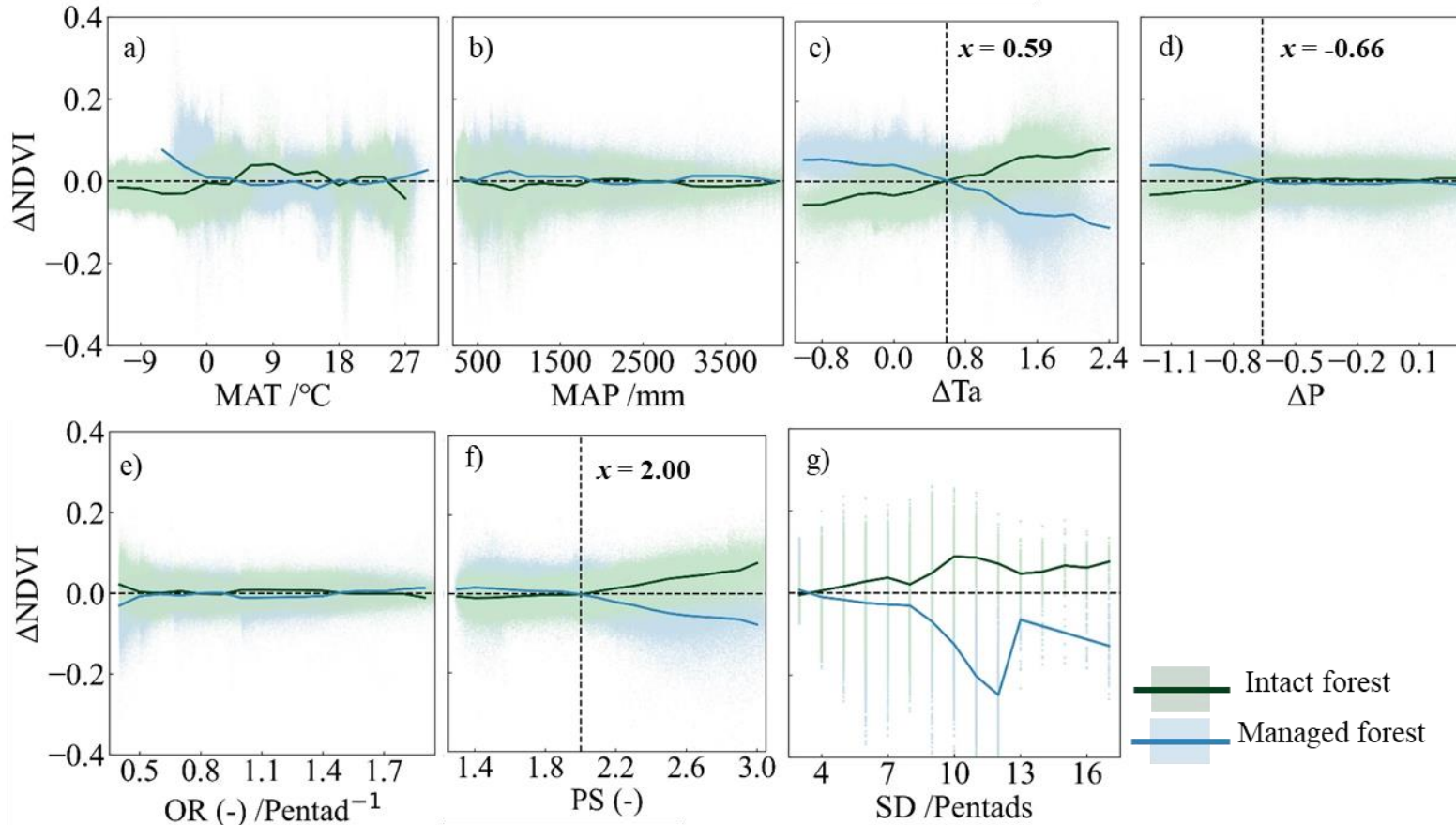
Partial effects from the interpretable model



- NDVI declines were strongest in warm, water-limited climates.
- Moderate warming can temporarily enhance NDVI, but extreme heat and low precipitation reverse this benefit.
- Among flash-drought characteristics, stress duration had the strongest influence. The longer the stress persists, the more likely forests are to brown.

Management mediates heat and duration effects

Interaction effects between forest management and regulating factors

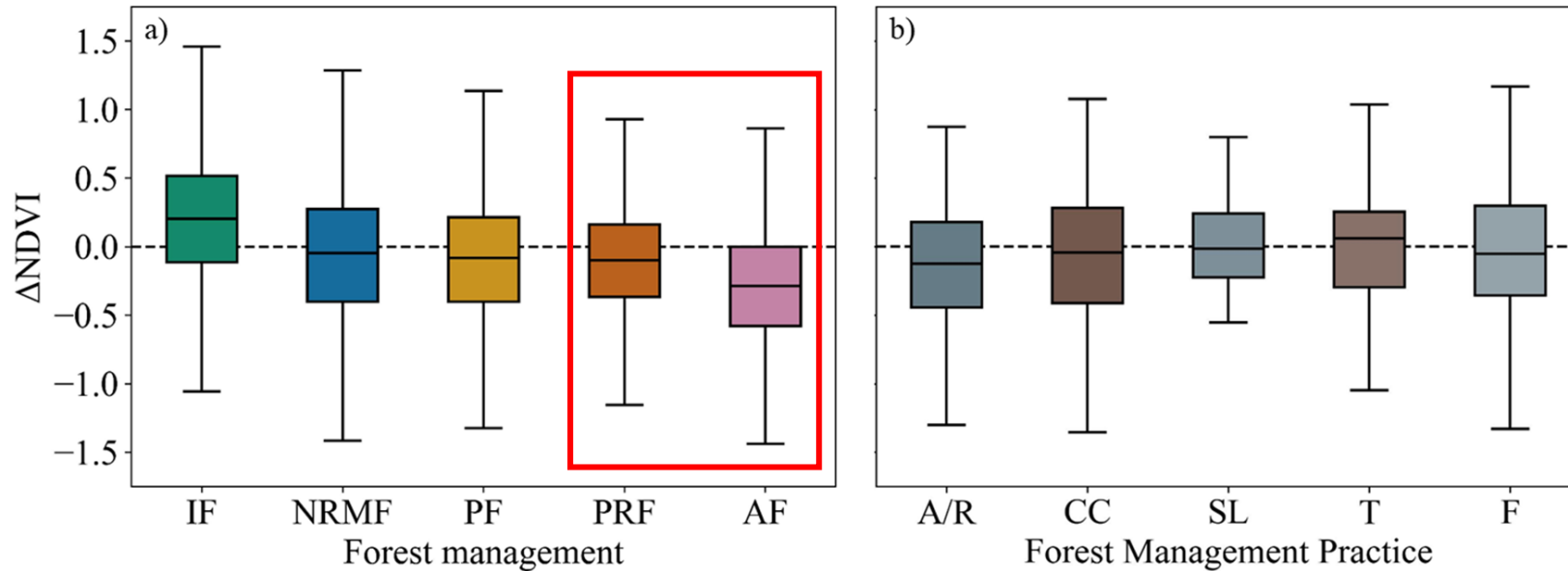


What differs?

- Intact forests buffer NDVI loss under increasing heat.
- Managed forests brown under stronger heat anomalies.
- Stress > ~8 pentads NDVI significantly declined in managed forests.

Mechanism: limited acclimation to rapid, heat-driven drought stress.

Managed forests are not all identical, but the direction is consistent



IF intact · NRMF naturally regenerating managed forest · PF planted forest · PRF rotation plantation · AF agroforestry
 A/R afforestation/reforestation · CC clear-cut · SL selective logging · T thinning · F fertilization

Main interpretation

- All managed-forest types tended to decline.
- Agroforestry and planted systems were especially sensitive.
- Most interventions produced negative effects, except rational thinning

Potential causes: non-native species, high density, homogeneous age, and simplified structure

Management should change goals — not be abandoned

Keep productivity and ecosystem services,
but balance them with resilience to extreme events.

- 1 — Use native and locally adapted species** Reduce vulnerability to rapid heat-driven drought
- 2 — Promote mixed stands and age diversity** Avoid uniform, simplified forests
- 3 — Optimize stand density** Balance productivity with water-use resilience
- 4 — Use sustainable logging and retain residues** Help maintain soil moisture and recovery capacity
- 5 — Build flash-drought early-warning systems** Support timely action before stress becomes severe

Management objectives should combine ecosystem services, resistance, and recovery under climate extremes.



Take-home messages



- 1 — Flash droughts are becoming faster, stronger, and longer across global forests.
- 2 — Managed forests are more vulnerable to flash drought than intact forests.
- 3 — Risk is greatest under heat-driven, prolonged events in low-latitude hotspots.
- 4 — Forest management should explicitly include resistance and resilience to extremes.

Thank you for your attention

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