

Impacts of Prolonged ENSO-Induced Droughts on Forest Resilience in the Amazon

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Introduction

The purpose of this research is to examine the impacts of long-lasting El Niño Southern Oscillation (ENSO)-induced droughts on trees in the Amazon rainforest. As global temperatures rise due to climate change, there is increasing concern that ENSO phases are lasting longer and contributing to extended droughts in the region. These prolonged dry periods threaten trees and the surrounding environment by reducing soil moisture and limiting water availability.

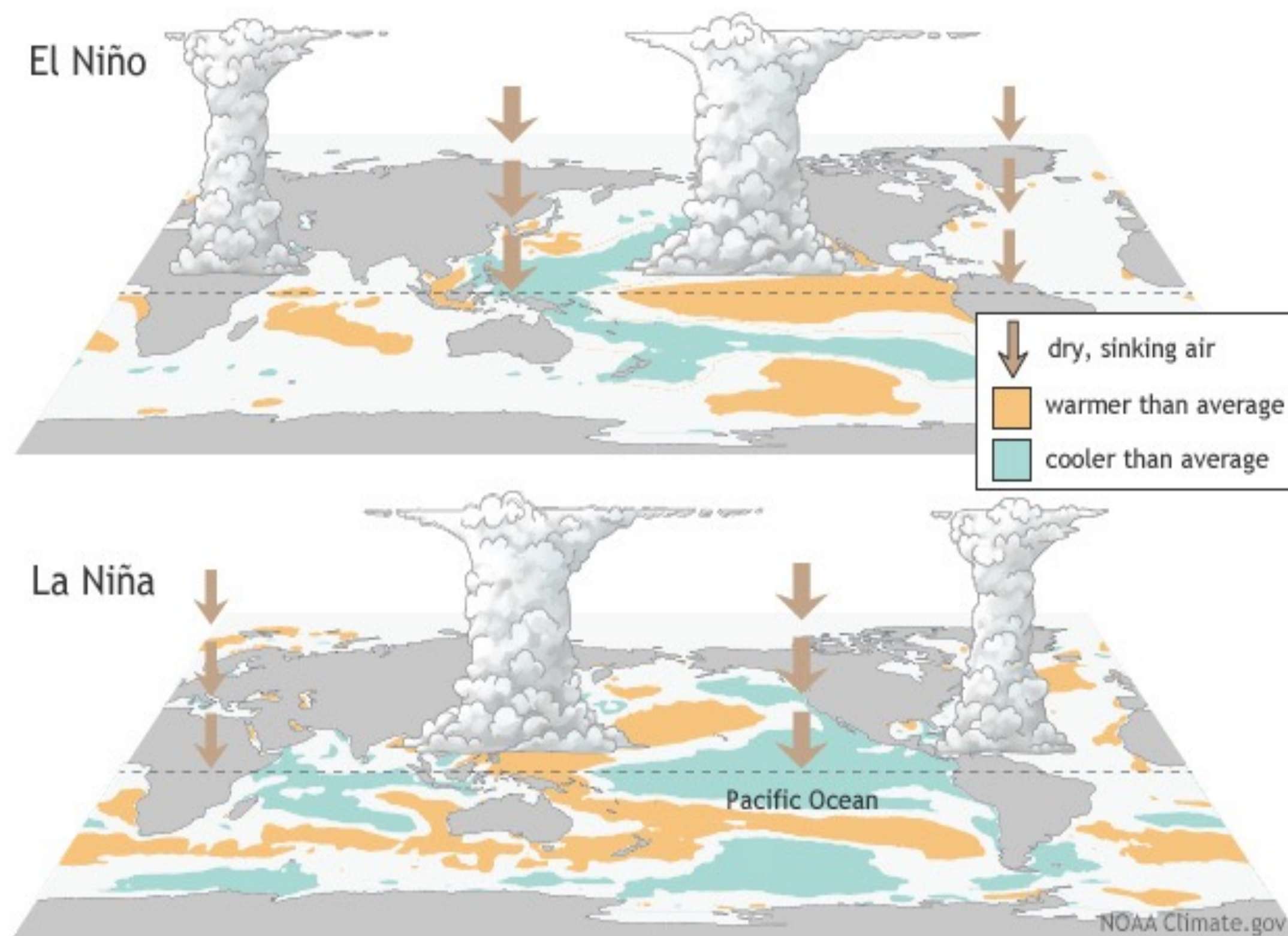


Figure 1. Schematic depiction of atmospheric circulation associated with El Niño and La Niña (NOAA, 2020)

Methodology

- ENSO conditions are identified using the Oceanic Niño index (ONI) (Figure 2). Positive values indicate El Niño, and negative values indicate La Niña, marking likely drought periods in the Amazon.
- Drought severity is assessed using canopy and sub-canopy tree comparisons with similar stem diameters but different heights, including height and root depth from soil coring

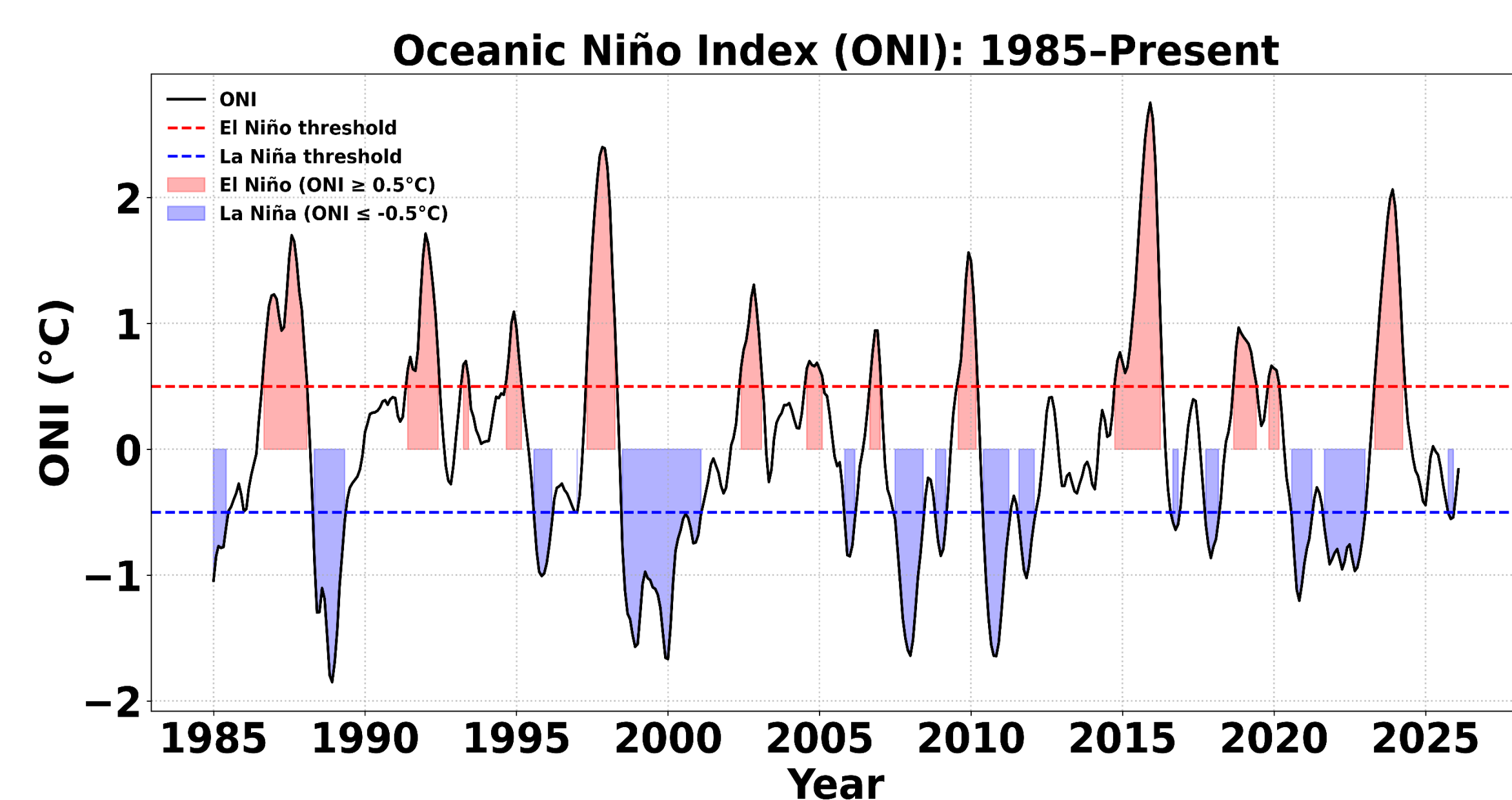


Figure 2. Oceanic Niño Index (ONI) 1985–present. El Niño (red) and La Niña (blue) periods are shaded.

Results

Historical Rainfall and Tree Growth Response

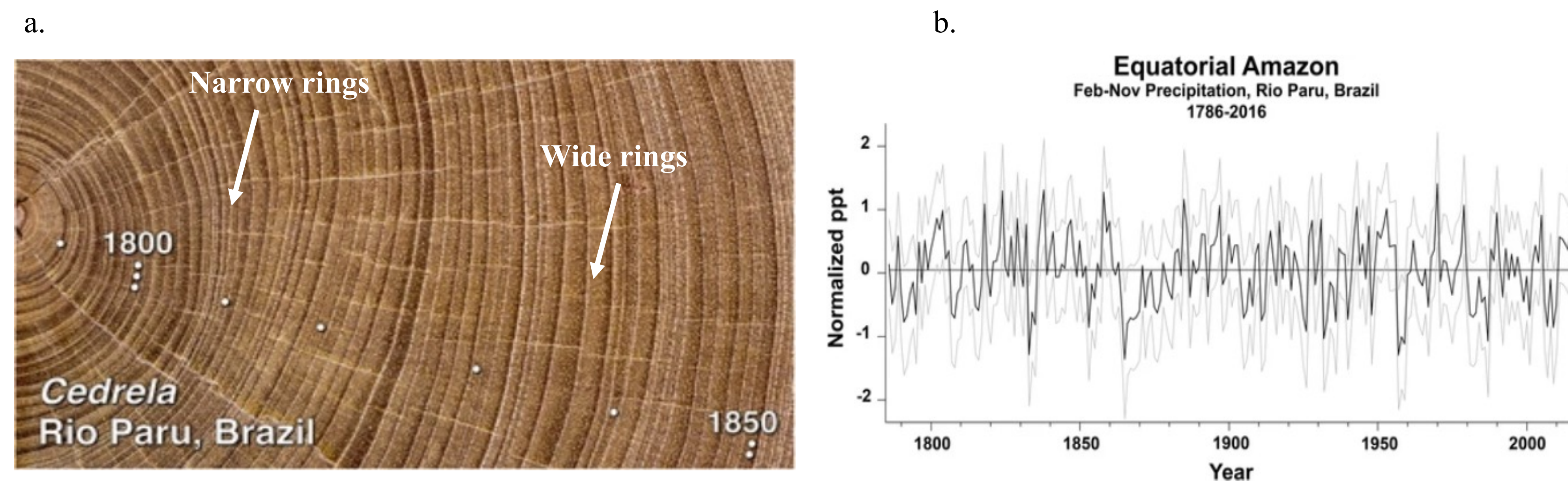


Figure 3. Cross section of a *Cedrela* tree harvested near the Rio Paru depicting distinct annual growth bands. White markers identify decades beginning in 1785 (a) (Granato-Souza et al., 2018). A 230-year record of annual rainfall totals reconstructed using tree ring growth (b). Adapted from Granato-Souza et al., 2018.

- Tree rings serve as a natural archive where the width of each ring reflects the amount of rainfall during that growing season (Figure 3a).
- Narrower rings indicate slow growth during years of water stress, while wider rings indicate faster growth during wet years.
- Declines in the reconstructed precipitation record (Figure 3b) corresponds to a narrow ring in the tree ring cross section (Figure 3a).
- The relationship between the width of growth rings and rainfall deficits demonstrates that while Amazon trees are resilient to drought, extended droughts can lead to a noticeable decrease in tree growth.

Response of Vegetation to Drought

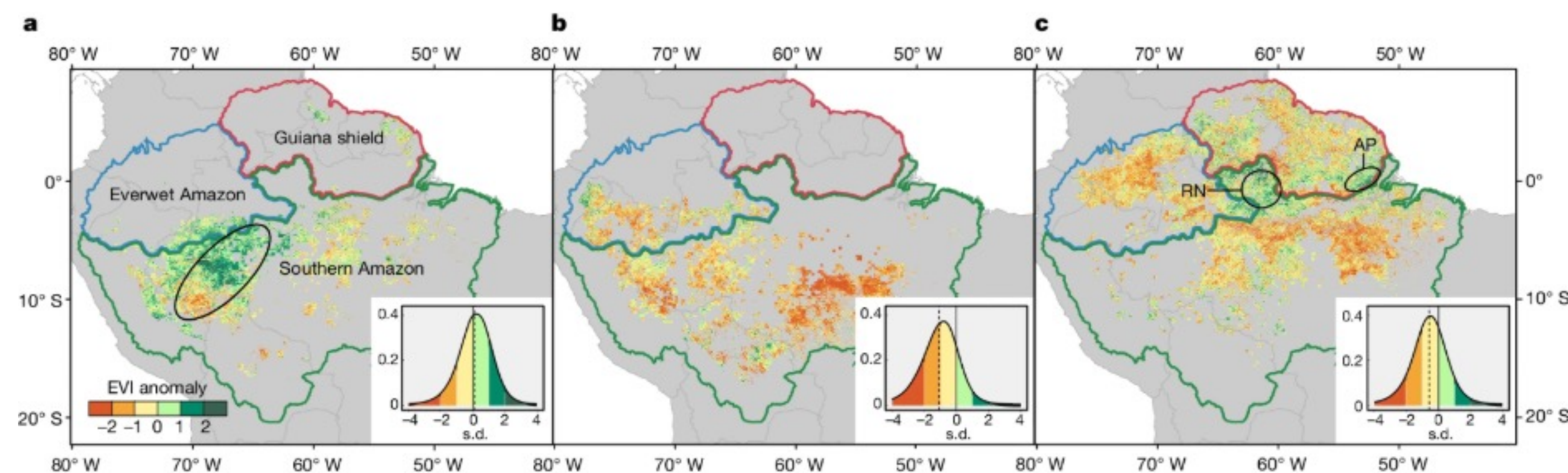


Figure 4. Remote sensing of forest health during the 2005 (a), 2010 (b), and 2015/2016 (c) droughts. These maps depict anomalies in the Enhanced Vegetation Index (EVI), which acts as a proxy for photosynthetic capacity (Chen et al., 2024).

- The shift from green to orange/red is direct indicates canopy thinning, where trees lose leaves or experience health declines due to a lack of water.
- While some areas show resilience, the Southern Amazon is particularly vulnerable owing to its deeper water table making it difficult for trees to access moisture during extended droughts.
- Figure 4 shows how the overall health of the forest shifted significantly toward the negative (orange/red) during the 2012 and 2015 droughts compared to 2005.

Impacts

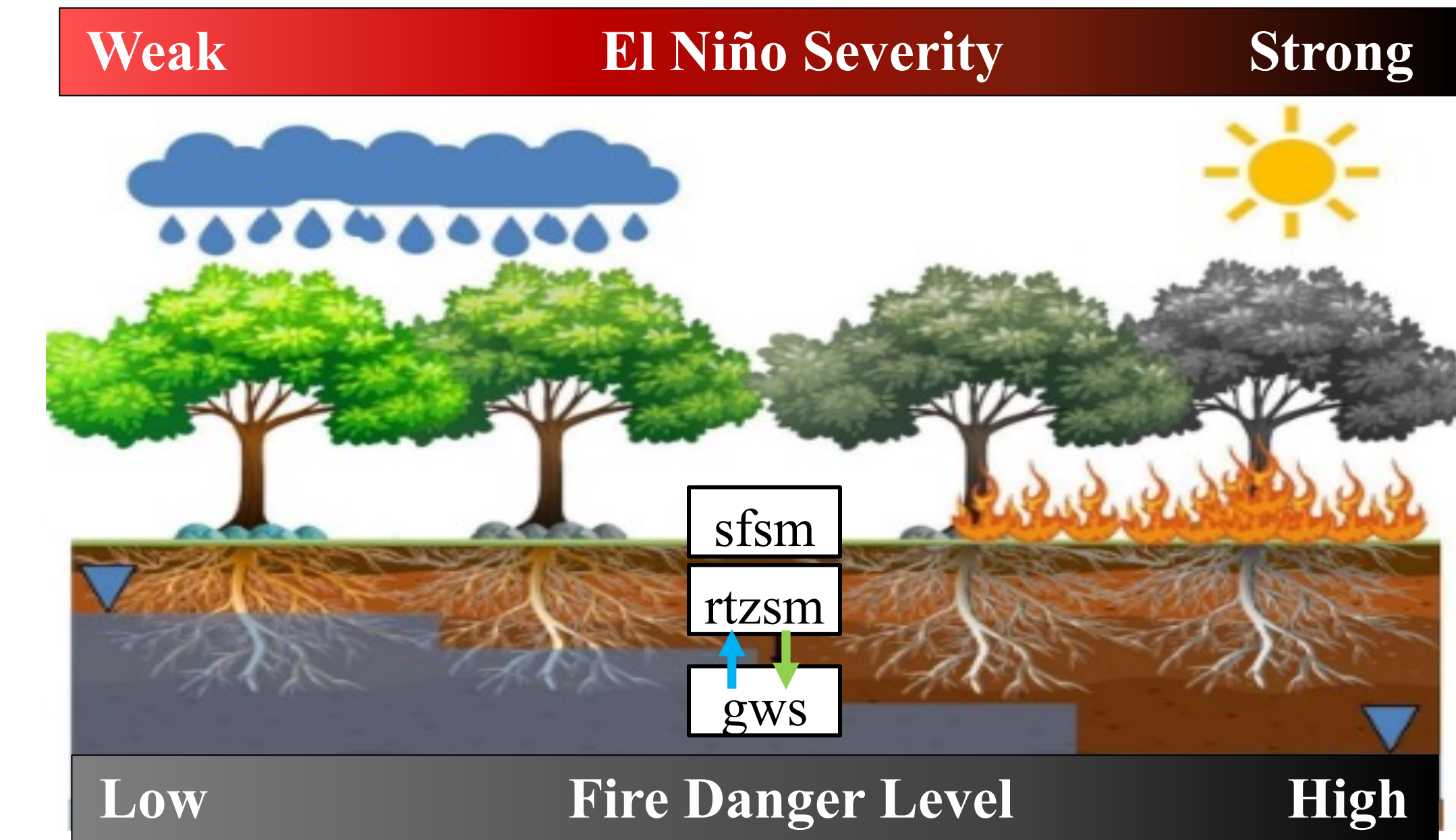


Figure 5. Relationship between ENSO intensity and depletion of soil water storage in surface soil moisture (sfs), root zone soil moisture (rtzsm), and groundwater storage (gws). Adapted from Toledo et al., 2024).

- Intensifying El Niño events drive declines in surface soil moisture, root zone water, and deep groundwater storage (Figure 5).
- Ecosystems shift into a “very high” fire risk state when soil water depletion reaches the 50% threshold.
- Loss of moisture reserves weakens drought buffering, increasing Amazon fire vulnerability.

Conclusions

- Strong El Niño events disrupt rainfall, driving prolonged drought in the Amazon.
- Extreme events deplete groundwater, reflected in reduced tree growth and thinner canopies in satellite imagery.
- A ~50% soil moisture threshold marks a critical tipping point, with declining vegetation health and rising fire risk.
- Soil-profile water depletion tracks El Niño intensity and corresponding regional fire risk.
- Overall, results show that drought can rapidly and significantly alter Amazon forest structure and health.

References

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