Reduced tree growth across the semiarid United States due to asymmetric responses to intensifying precipitation extremes

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Precipitation variability has increased across most of the United States, especially the Southwest, over the past century.
How does forest growth respond to increasing precipitation variability?
A linear response of growth to precipitation in which reduced growth during dry extremes is compensated by increased growth during wet extremes. No long-term change in mean growth as precipitation variability increases.
Conceptual models

Positive Asymmetric

A nonlinear response of growth to precipitation in which reduced growth during dry extremes is more than offset by increased growth during wet extremes. Long-term increase in mean growth as precipitation variability increases.
A nonlinear response of growth to precipitation in which reduced growth during dry extremes is not offset by increased growth during wet extremes. Long-term decrease in mean growth as precipitation variability increases.
Conceptual models were tested across the U.S. using growth records from 1,314 tree-ring sites and PRISM precipitation estimates.

Dannenberg, Wise & Smith (2019), Science Advances
78 species

Number of sites per species

- Ponderosa pine
- Douglas-fir
- Piñon pine
- Blue oak
- Limber pine

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Subalpine fir
Mountain hemlock
Engelmann Spruce
78 species

Dannenberg, Wise & Smith (2019), Science Advances
Methods

Growth responses from each tree-ring site were classified into one of four conceptual models based on the best fit from ordinary least squares regression.

Dannenberg, Wise & Smith (2019), Science Advances
Responses to extreme events were detected using an extreme value capture method corrected for chance agreement using Cohen’s kappa ($\kappa$).

Dannenberg, Wise & Smith (2019), Science Advances
Widespread negative asymmetries in western U.S.
(increasing precipitation yields diminishing returns for growth)
Dry years are very likely to have very low growth.
But wet years are less likely to have very high growth.
Mostly symmetric throughout U.S.

Except for bur oak

Warm season (Apr-Sep)
what **long-term effect** does increasing precipitation variability have on tree growth?

**Growth Response**
- Widespread negative asymmetries between growth and precipitation

**Change in precipitation variability**
- Large increase in precipitation variability
Simulations with two precipitation scenarios (same mean, different variance)
High-variability scenario:
Double the likelihood of low growth
No change in likelihood of high growth

Dannenberg, Wise & Smith (2019), Science Advances
Summary

1. Growth responds **asymmetrically** to precipitation variability (especially western conifers and bur oak).

2. Increased precipitation variability can drive **decreases** in forest growth.
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Earth’s hydroclimatic variability is increasing, with changes in the frequency of extreme events that may negatively affect forest ecosystems. We examined possible consequences of changing precipitation variability using tree rings in the conterminous United States. While many growth records showed either little evidence of precipitation limitation or linear relationships to precipitation, growth of some species (particularly those in semiarid regions) responded asymmetrically to precipitation such that tree growth reductions during dry years were greater than, and not compensated by, increases during wet years. The U.S. Southwest, in particular, showed a large increase in precipitation variability, coupled with asymmetric responses of growth to precipitation. Simulations suggested roughly a twofold increase in the probability of large negative growth anomalies across the Southwest resulting solely from 20th century increases in variability of cool-season precipitation. Models project continued increases in precipitation variability, portending future growth reductions across semiarid forests of the western United States.

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