

# Trends in Snowfall versus Rainfall for the Western United States

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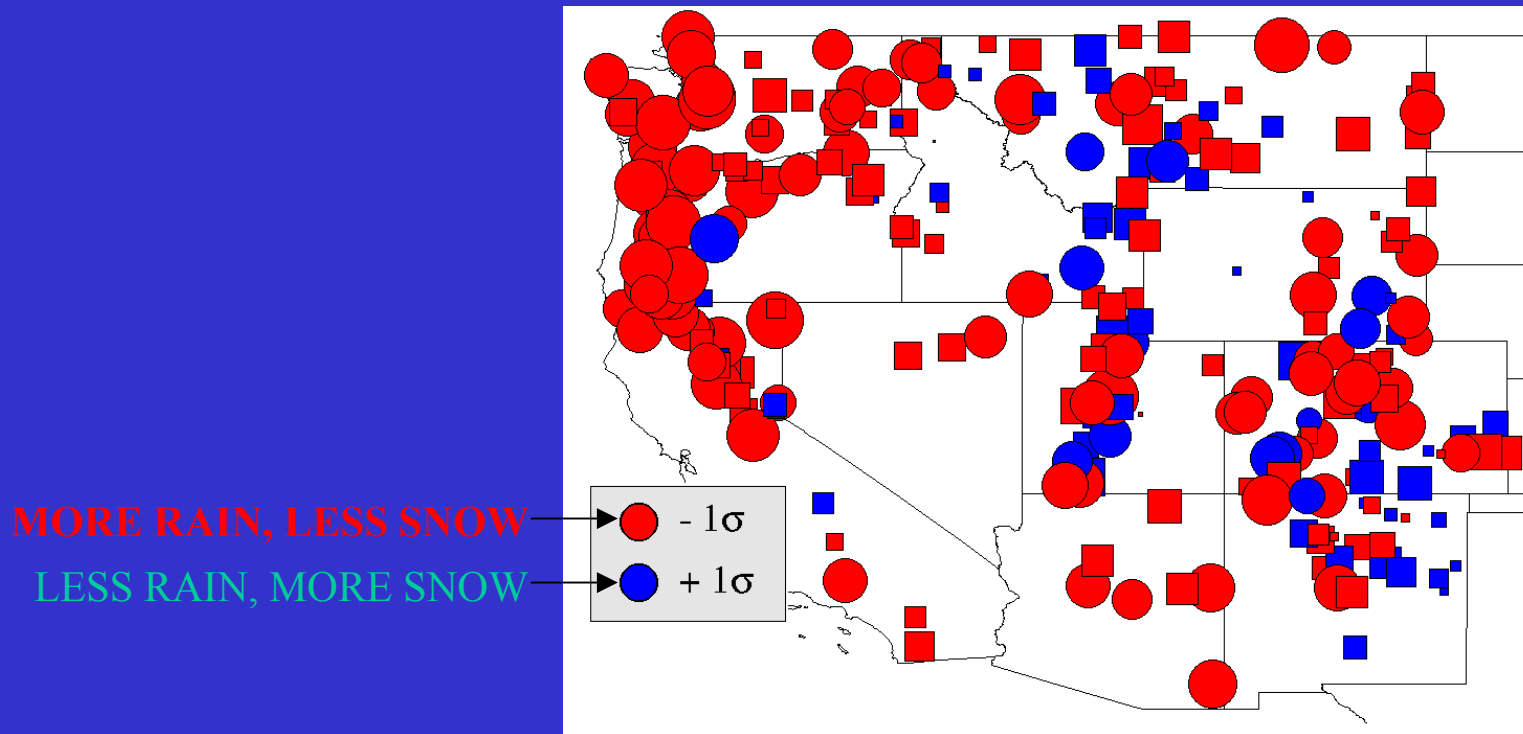
1. Methodology Overview
2. Trends in November-March Snowfall Fraction
3. Temperature Dependence of Trends
4. Underlying Monthly Trends
5. Role of Climate Variability

# 1. Methodology Overview

- Obtained Summary of the Day data from NCDC (snow depth, P, TMAX, TMIN)
- Culled stations for serial completeness to ensure robust trend detection
- Estimated liquid snowfall equivalent (SFE) as the daily precipitation (P) on days when snowfall was recorded (snow depth > 0) (as in Huntington et al., J. Clim. 2004)
- Calculated winter (Nov-Mar) means of wet-day TMIN, winter totals of SFE and P, and winter values of the ratio SFE/P
- Applied Kendall's-tau tests and least-squares linear fits to determine trend significance and magnitudes

## 2. Trends in Nov-Mar Snowfall Fraction

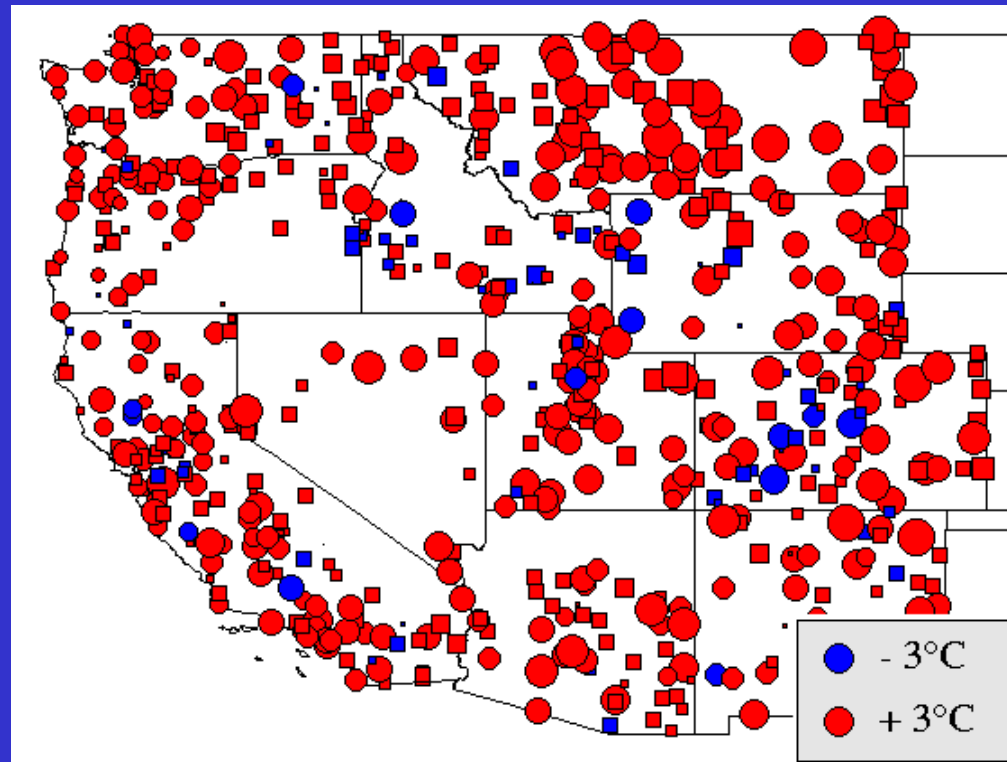
### Shift from Snowfall to Rainfall



Trends in ratio of winter (Nov-Mar) snowfall water equivalent (SFE) to total winter precipitation (rain *plus* snow) for the period WY1949-2004. Circles represent significant ( $p < 0.05$ ) trends, squares represent less significant trends.

### 3. Temperature Dependence

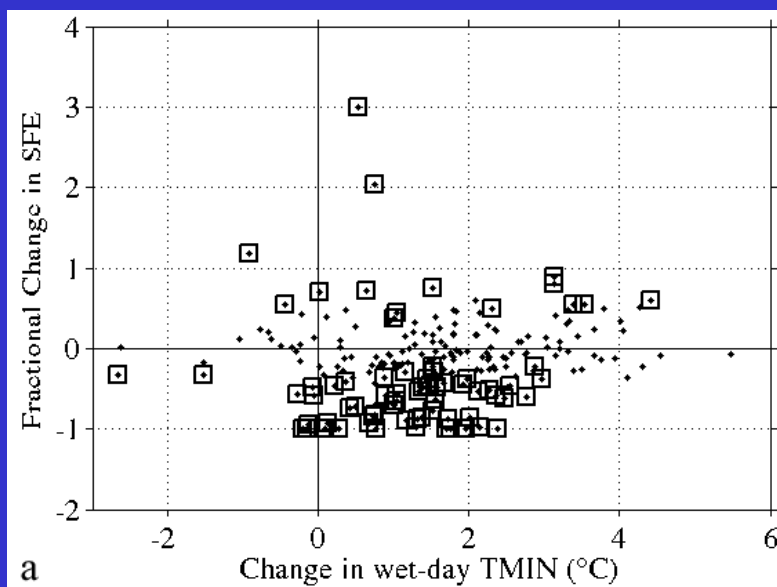
Primary Cause of Shift from Snow to Rain: **Warming**



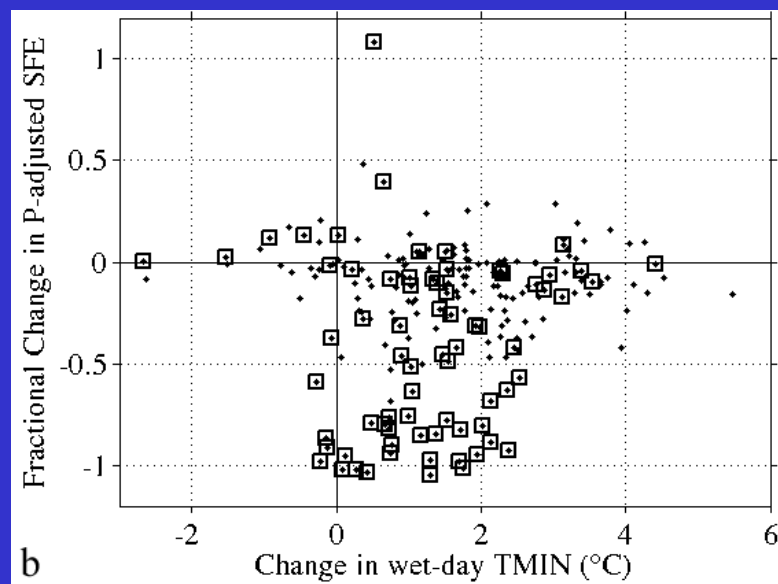
Trends in winter-mean daily-minimum wet-day air temperatures. Circles are significant trends, as in previous slide.

### 3. Temperature Dependence

#### Changes in Winter Snowfall versus Change in Winter Temperature

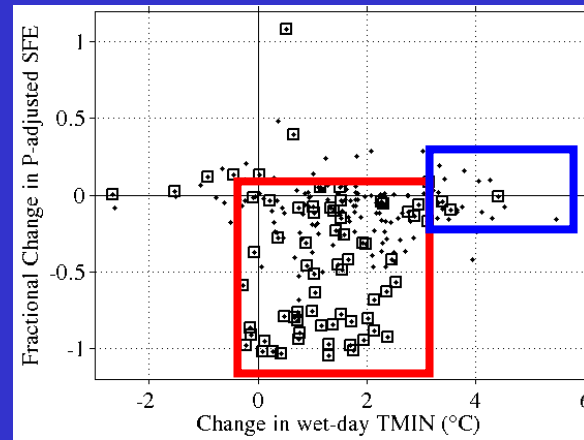


Fractional changes in SFE vs. changes in TMIN<sub>w</sub> over the period 1949-2004, with significant trends in SFE ( $p < 0.05$ ) highlighted as squares.

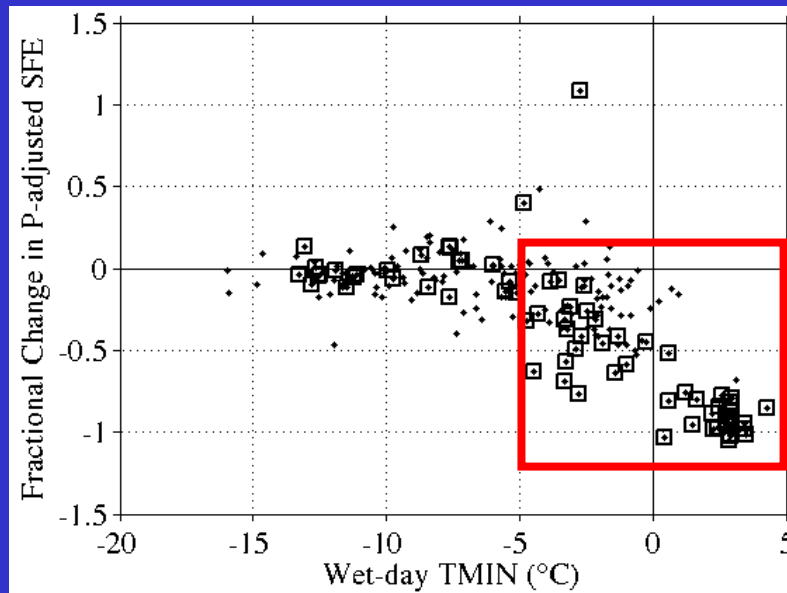


Same, but adjusted to remove portion of SFE trends due to precipitation trends.

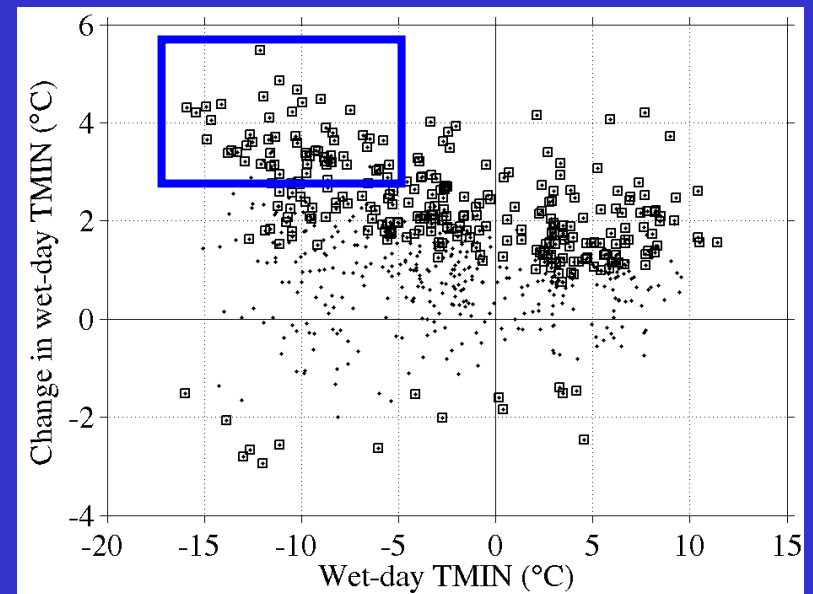
### 3. Temperature Dependence



What explains this pattern of changes?



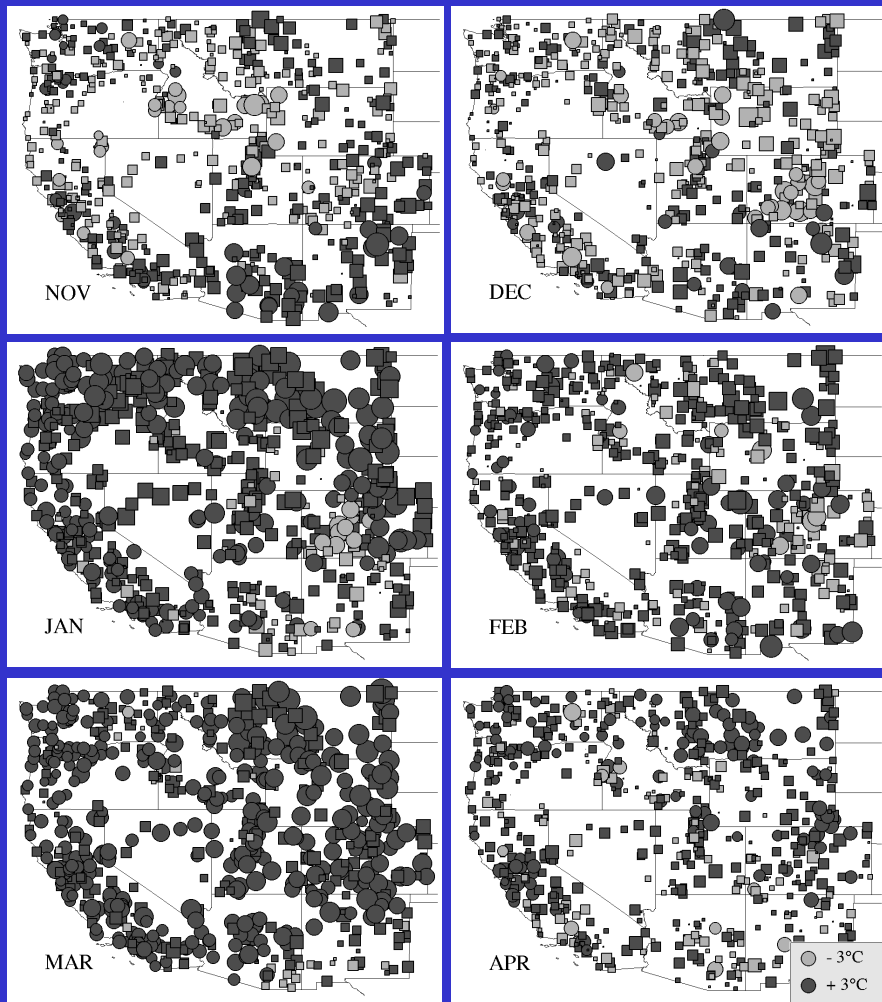
SFE reductions occurred only where it was warm enough for warming to have an impact.



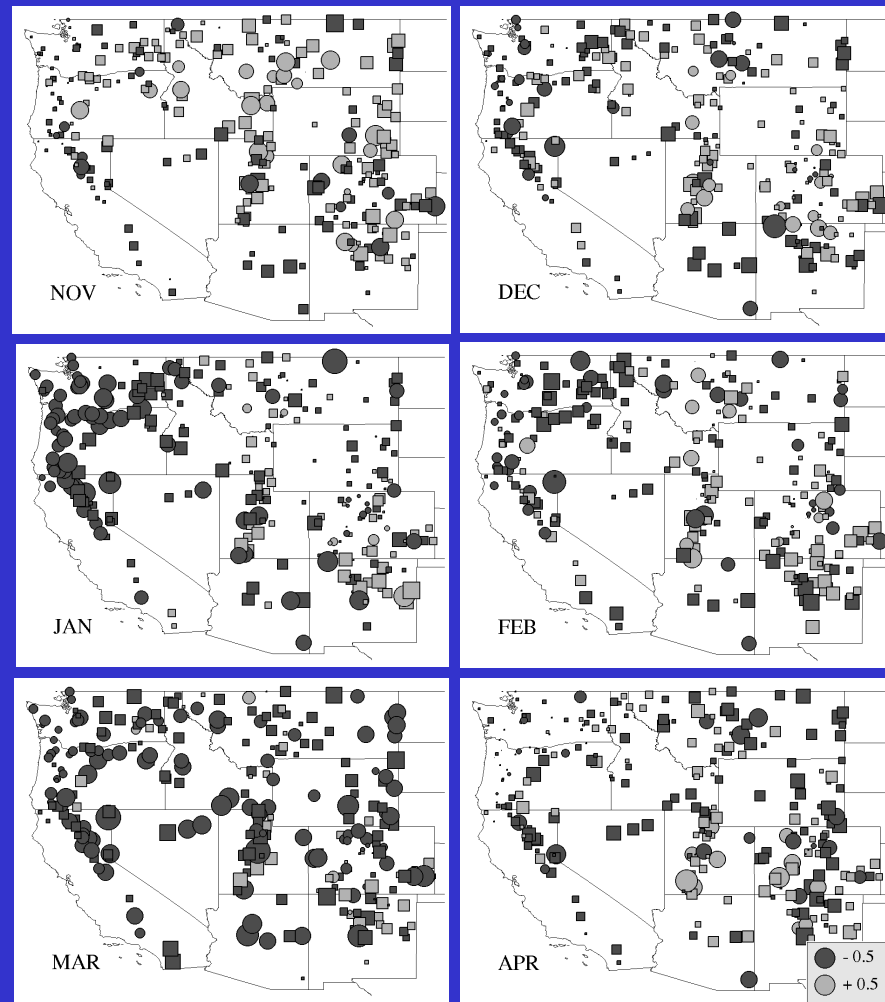
Largest warming (>3°C) occurred mainly at very cold stations.

## 4. Monthly Patterns

Wet-day TMIN trends

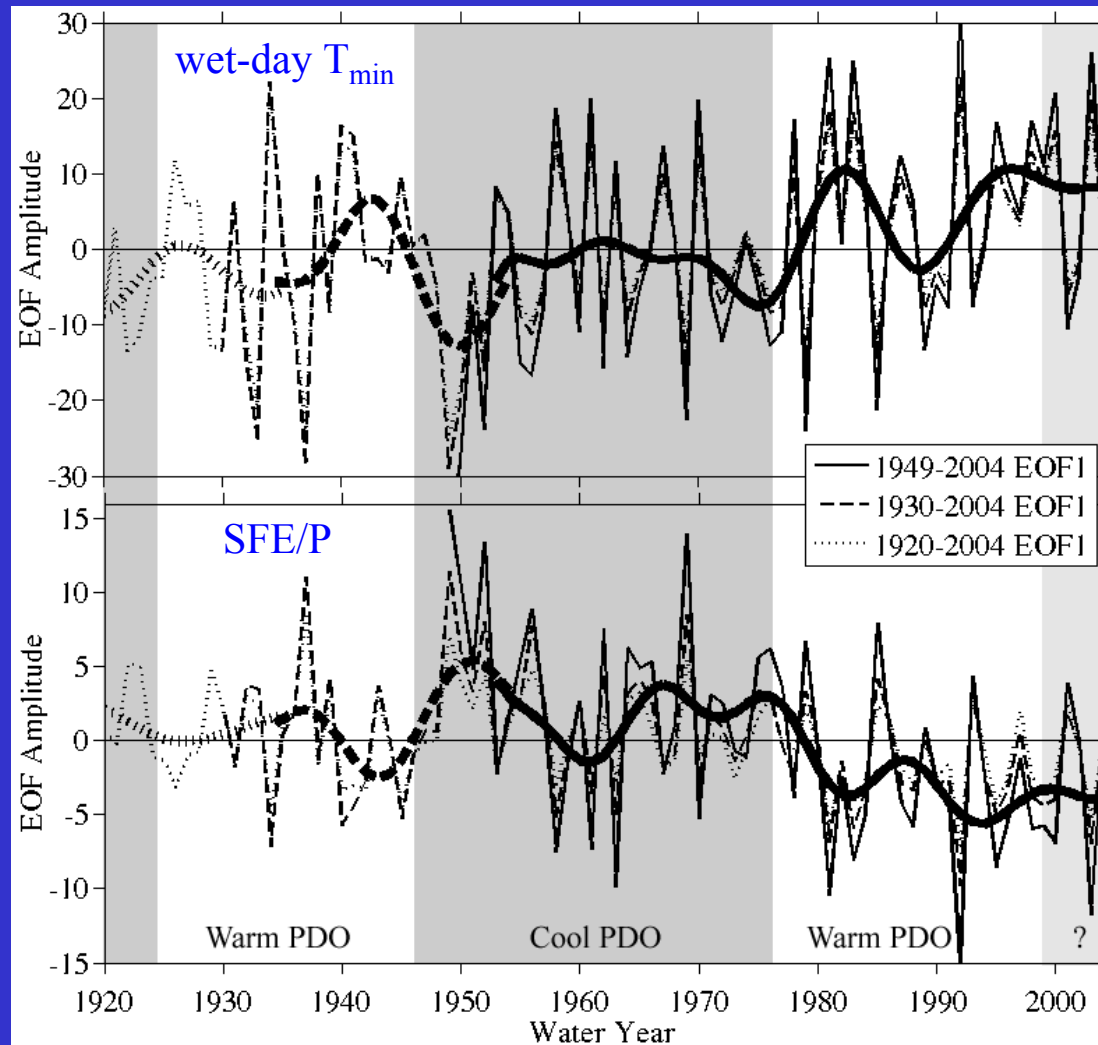


SFE/P trends



Trend amounts for monthly averaged wet-day TMIN and SFE/P. January and March have shown the largest SFE/P reductions in response to warming trends.

## 5. Climate Variability



EOF amplitudes representing trends in winter wet-day minimum temperature (**top**) and fraction of winter precipitation falling as snow (**bottom**), with PDO phases indicated.

## Summary

- West-wide shift from snow to rain over study period
- Caused primarily by temperature increase
- Snowfall reductions most prominent where warming was  $<3^{\circ}\text{C}$  and mean temperatures were warm enough for warming to have an effect
- Trends in January and March explained most of the winter-averaged changes
- PDO might play a role, but longer-term climate change also a factor



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