Climate-related changes on New England lakes and rivers during the last two centuries

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Purpose

- Test for significant changes over time in historical water-resources data, such as lake ice, river flow, and river ice, in New England
- Quantify the magnitude of changes
- Look at relation between lake and river data and meteorological data (air temperature and precipitation)

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Data

- Lake ice-out data from observers
- Streamflow and river-ice data from rural, unregulated New England rivers
  - At least 50 years of USGS gaging station data up to the present
- Meteorological data
  - NCDC, U.S. Historical Climatology Network
  - Much quality control and corrections

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Methods

- Trends over time
  - Non-parametric Mann-Kendall test
  - Long-term persistence not considered
    - Cohn and Lins, Geophysical Research Letters, 2005
- Magnitude of changes
  - Not impacted by long-term persistence
  - LOESS smooths
    - Locally weighted regression (at each point on curve)
    - Downweights outliers and points farther away
  - Sen slope
    - Median of all pairwise slopes
- Correlations with meteorological data
  - Pearson's *r*

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Lake ice-out dates

- Typical definition
  - The date that ice cover completely leaves a lake

Not quite out

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Lake ice-out dates

- 29 lakes in New England
- Length of record, 64 to 163 years
- 16 lakes with >100 years of data
- Oldest record, Sebago Lake, 1807
  - Oldest known lake ice-out record in the world

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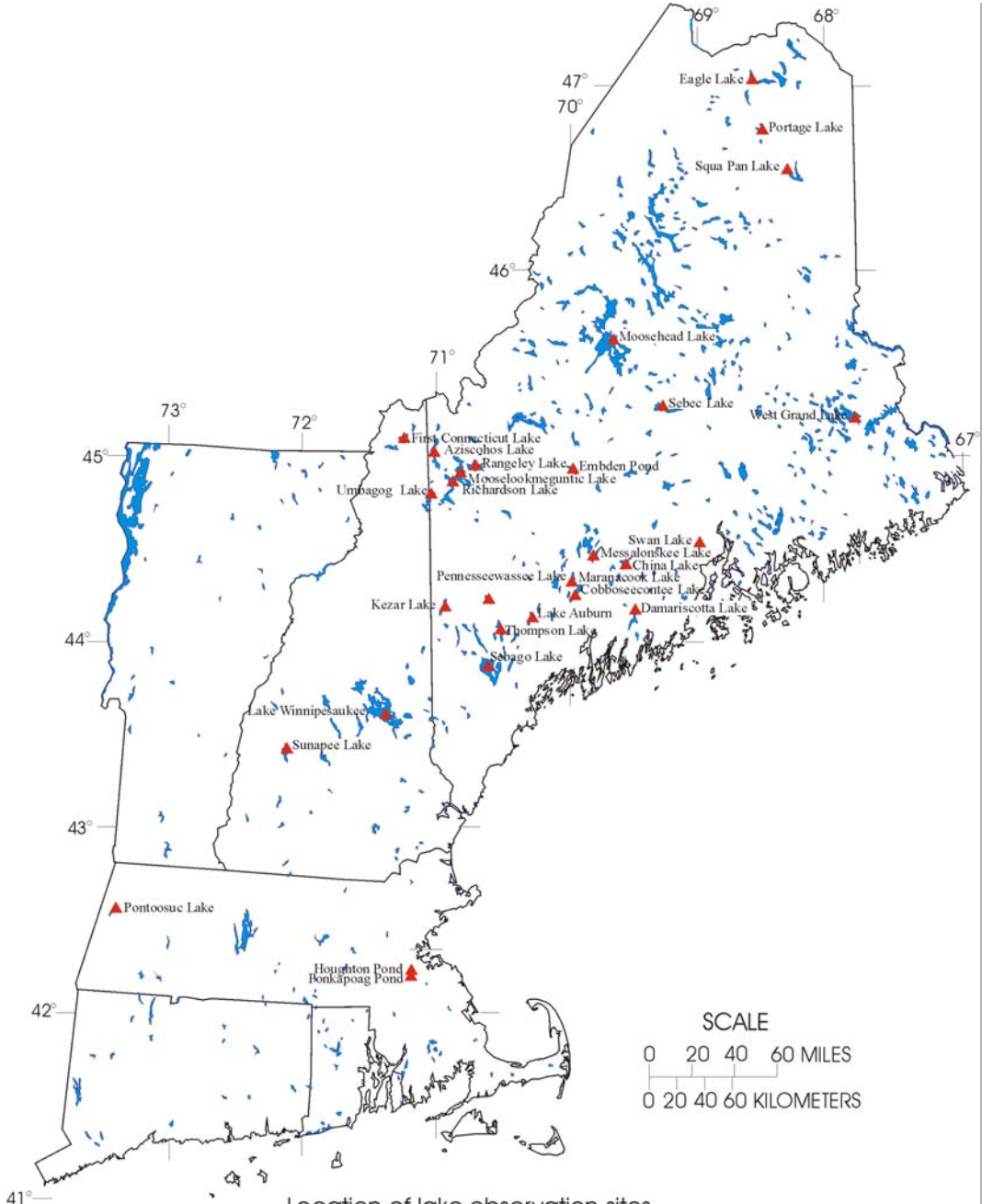

Location of lake observation sites.

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Lake ice-out dates

- Significantly earlier ice-out dates at 19 out of 29 lakes ($p<0.1$)
- Significantly earlier ice-out dates at all 5 lakes with > 150 years of data ($p<0.0001$)
  - Damariscotta, Sebago, Auburn, Cobbosseecontee, Moosehead
- No significantly later ice-out dates ($p<0.1$)

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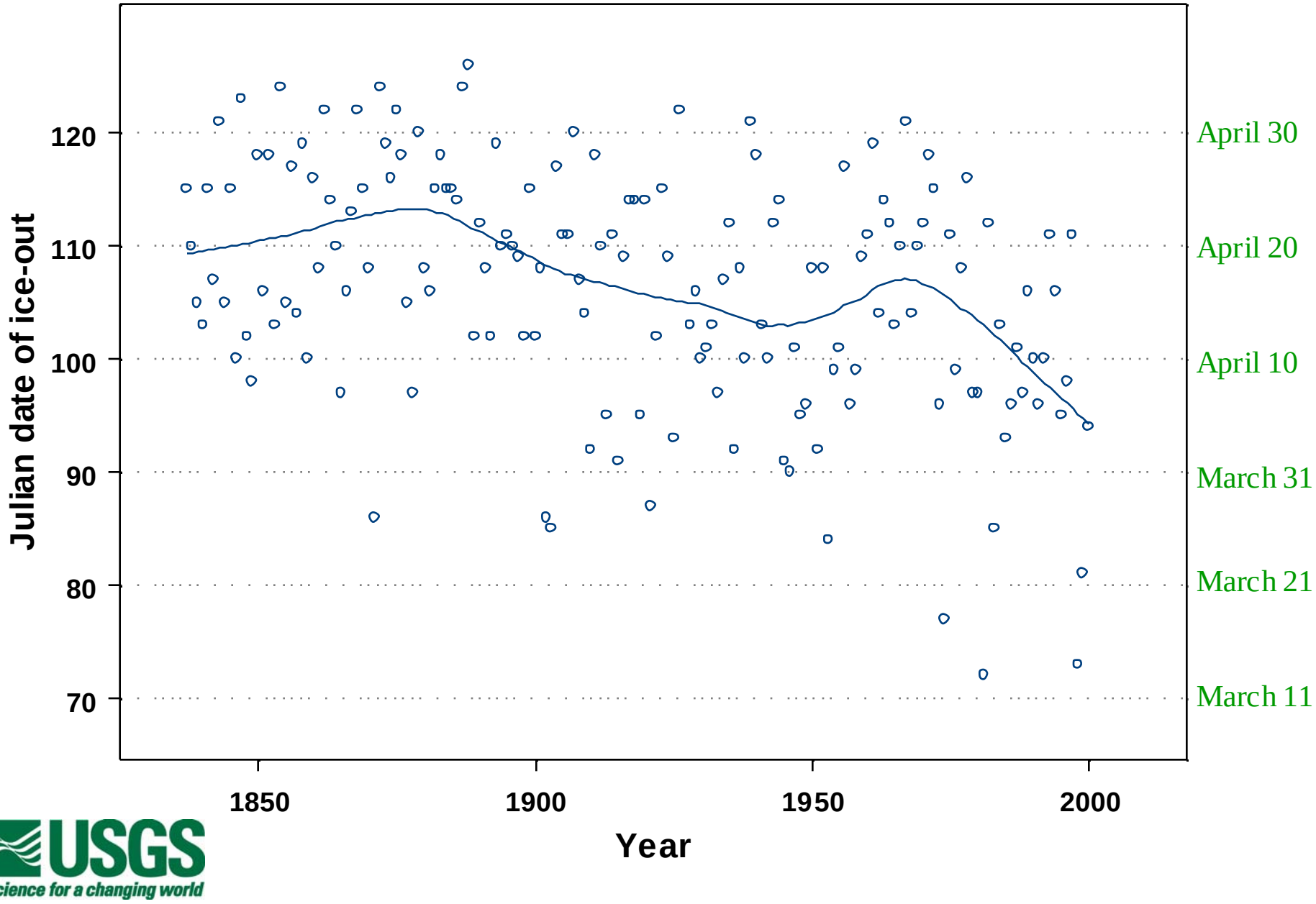
Damariscotta Lake Ice-Out Dates



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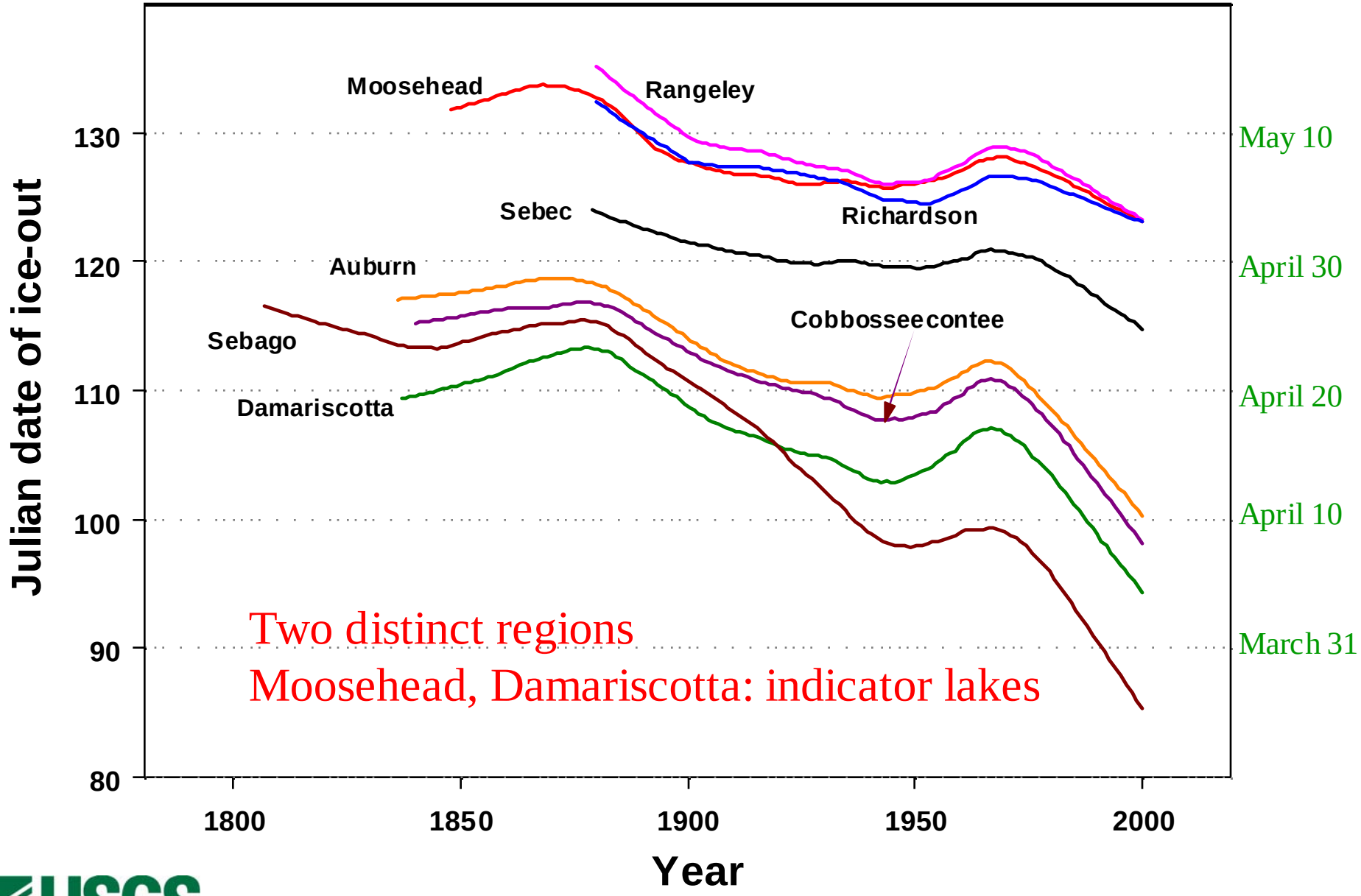
Smoothed ice-out dates for 8 selected lakes in New England



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How many days earlier?

- Since 1850…

- Damariscotta Lake, 16 days
- Moosehead Lake, 9 days

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New England River Flows

- 27 rivers in New England
  - Rural, unregulated
  - Average 68 years of record
- Changes in the timing of seasonal river flows in New England during the 20th Century

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Timing of Seasonal Flows

- Seasonal center of volume date
  - Annual date by which half of the total volume of water for a given period of time flows past a river gaging station
- Trends over time in annual dates

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WSCV Dates driven by high flows

Timing of Seasonal Flows

- Winter-Spring (January 1 - May 31)
  - Flows significantly earlier at all 11 gaging stations in northern and mountainous New England
    - Median seasonal maximum snow depth > 28 inches
- Fall (October 1 - December 31)
  - Few significant changes over time

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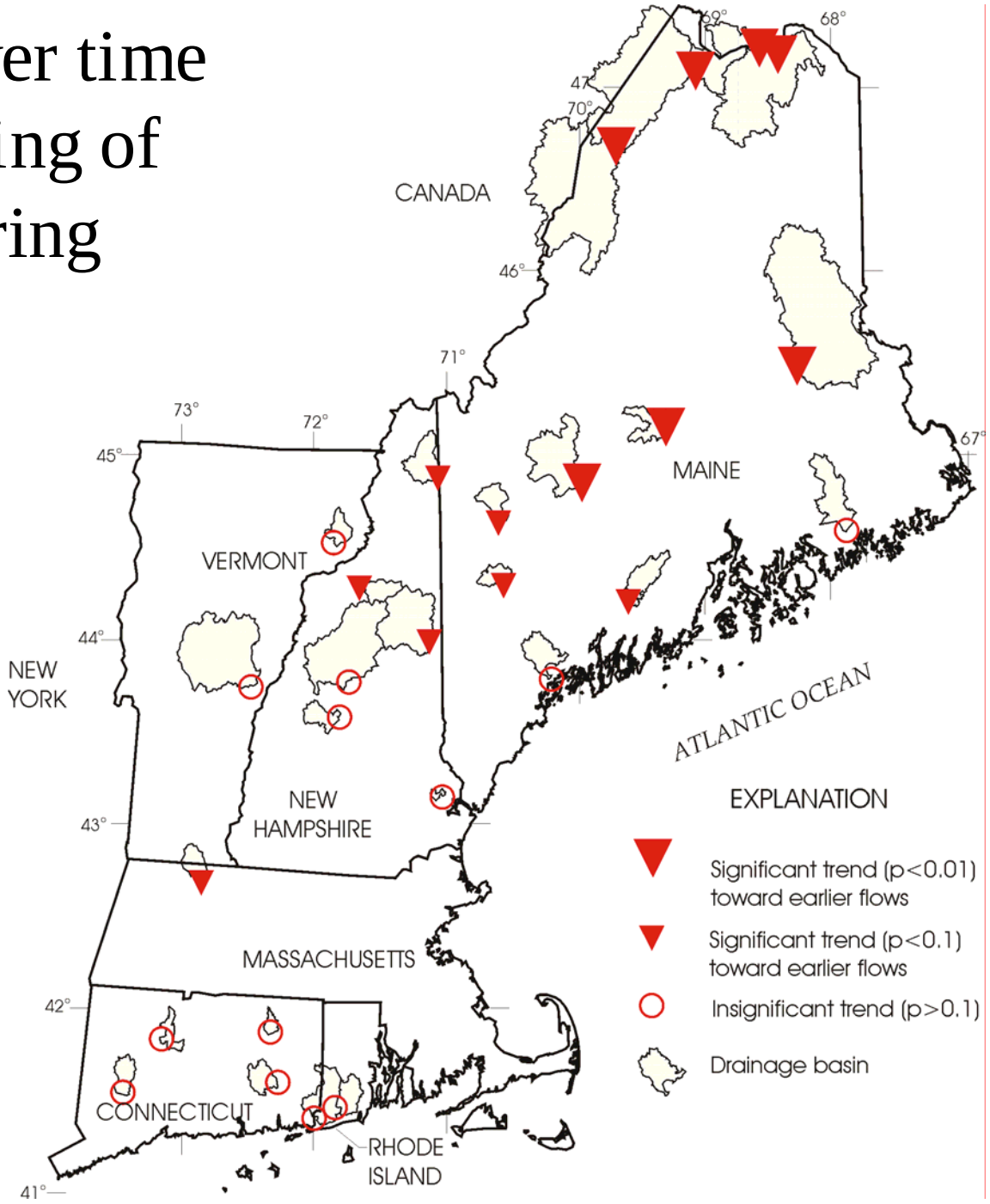
Trends over time in the timing of winter-spring flows



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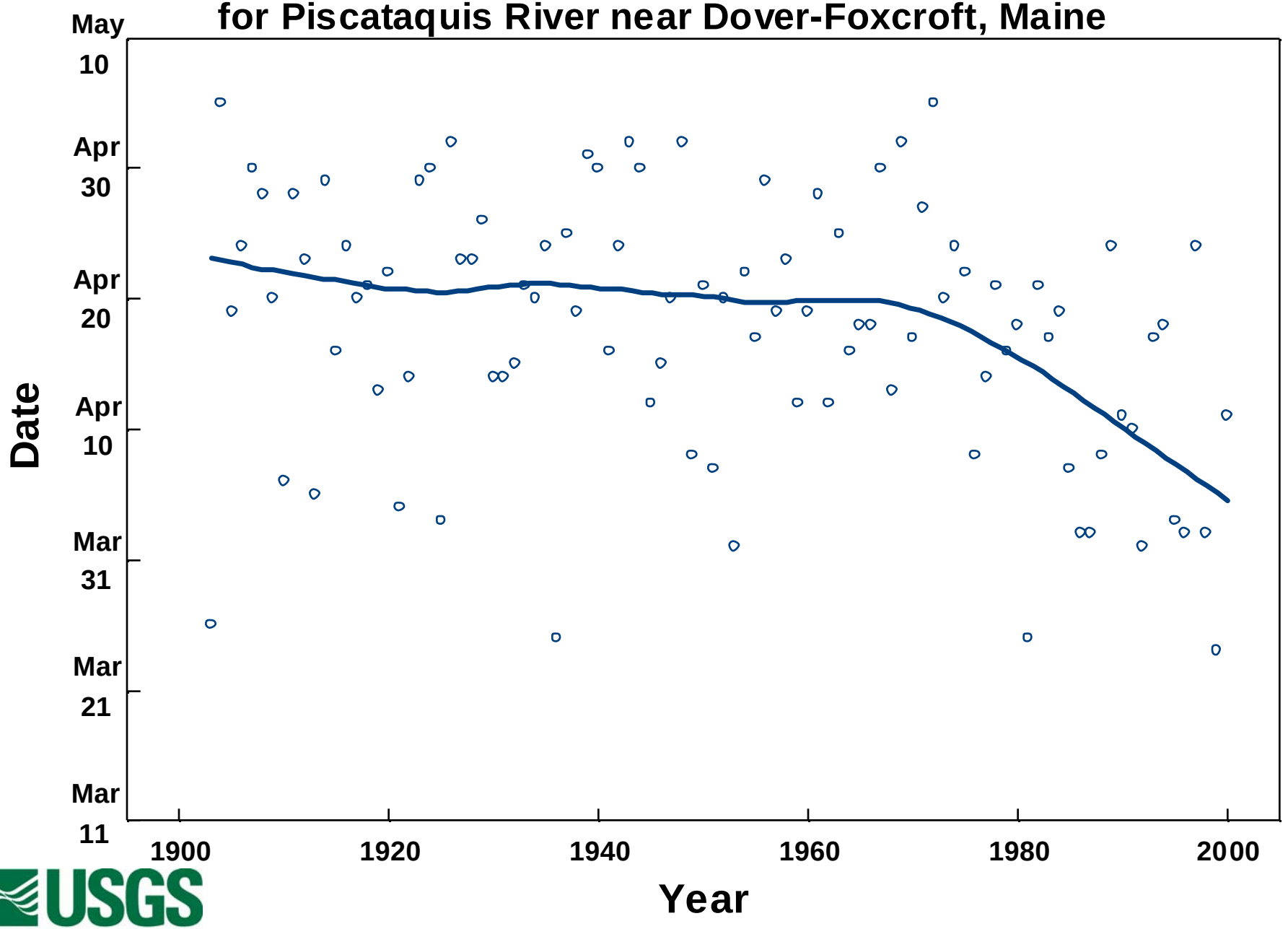
Annual winter/spring center of volume dates and LOESS smooth for Piscataquis River near Dover-Foxcroft, Maine



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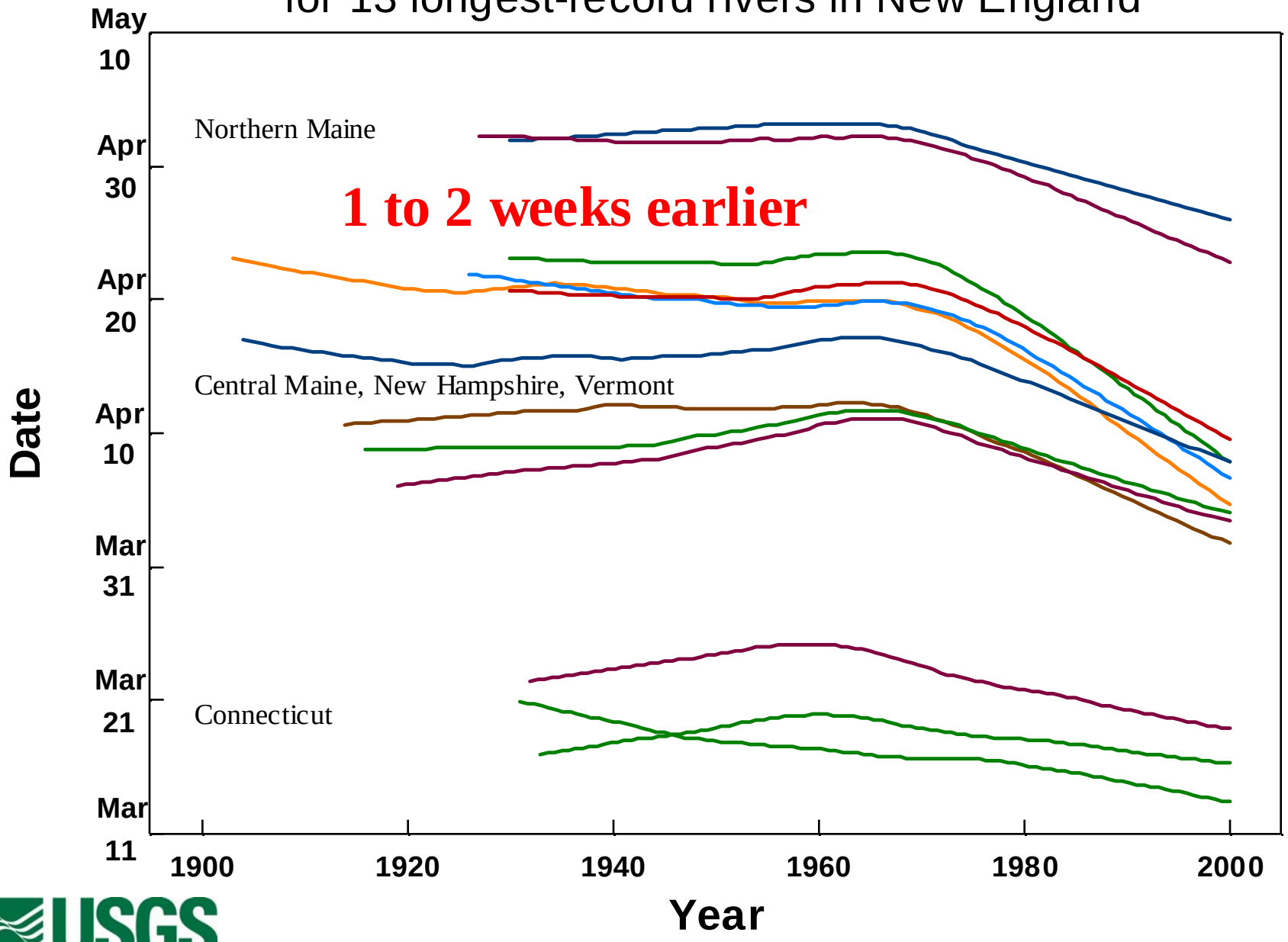
LOESS smooths of winter/spring center of volume dates for 13 longest-record rivers in New England



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Summer low flows in New England

- Hypothesized earlier recession to low flows, longer low-flow period, lower summer-fall low flows
- Little evidence of consistent changes during the 20th century in the timing or magnitude of low flows

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Annual and monthly mean flows

- Evidence of changes other than earlier winter-spring flows?
- Same 27 rural, unregulated streamflow gaging stations
- Trends over time in the magnitude of annual and monthly mean flows

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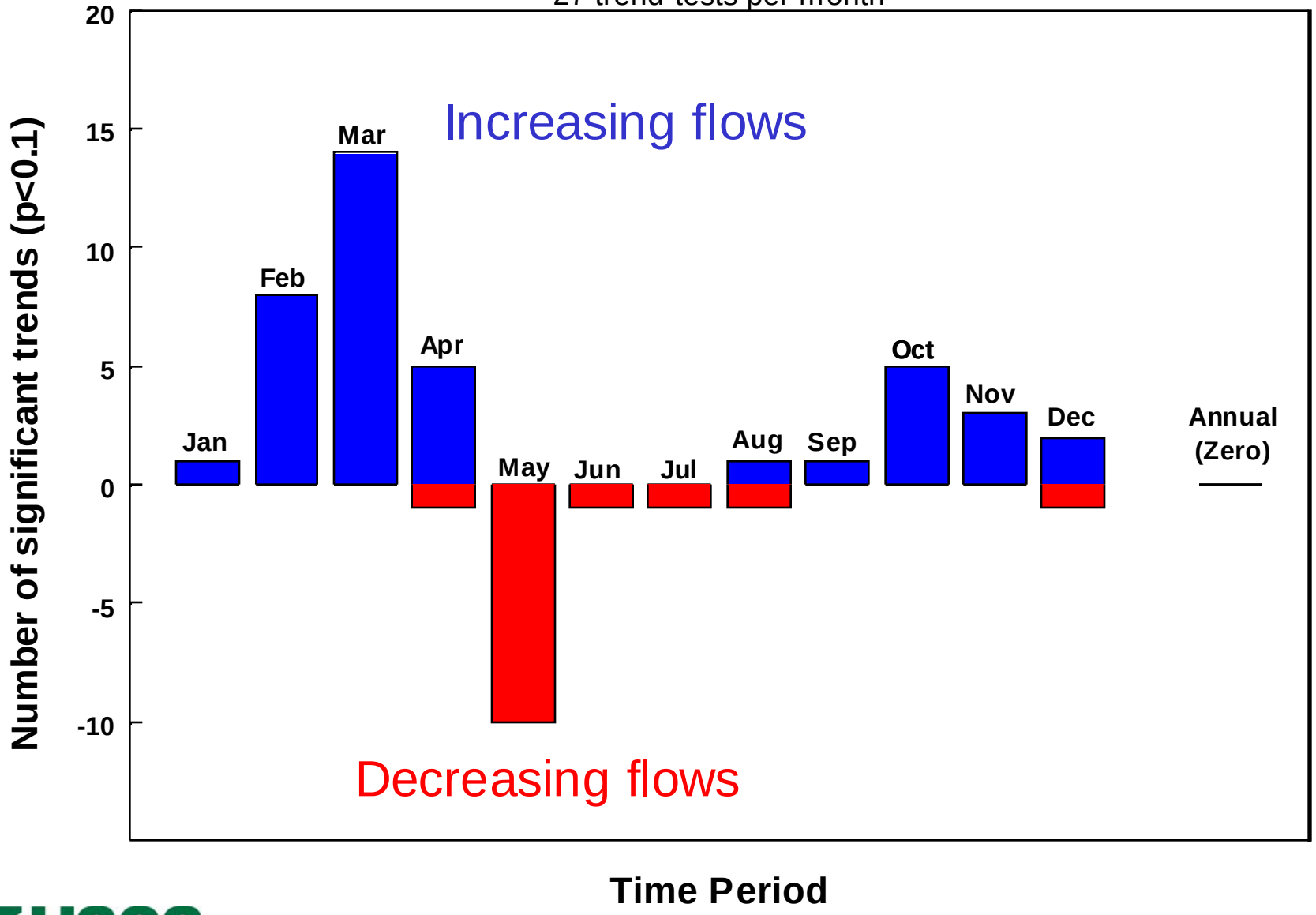
Number of significant trends for mean flows for all sites

27 trend tests per month



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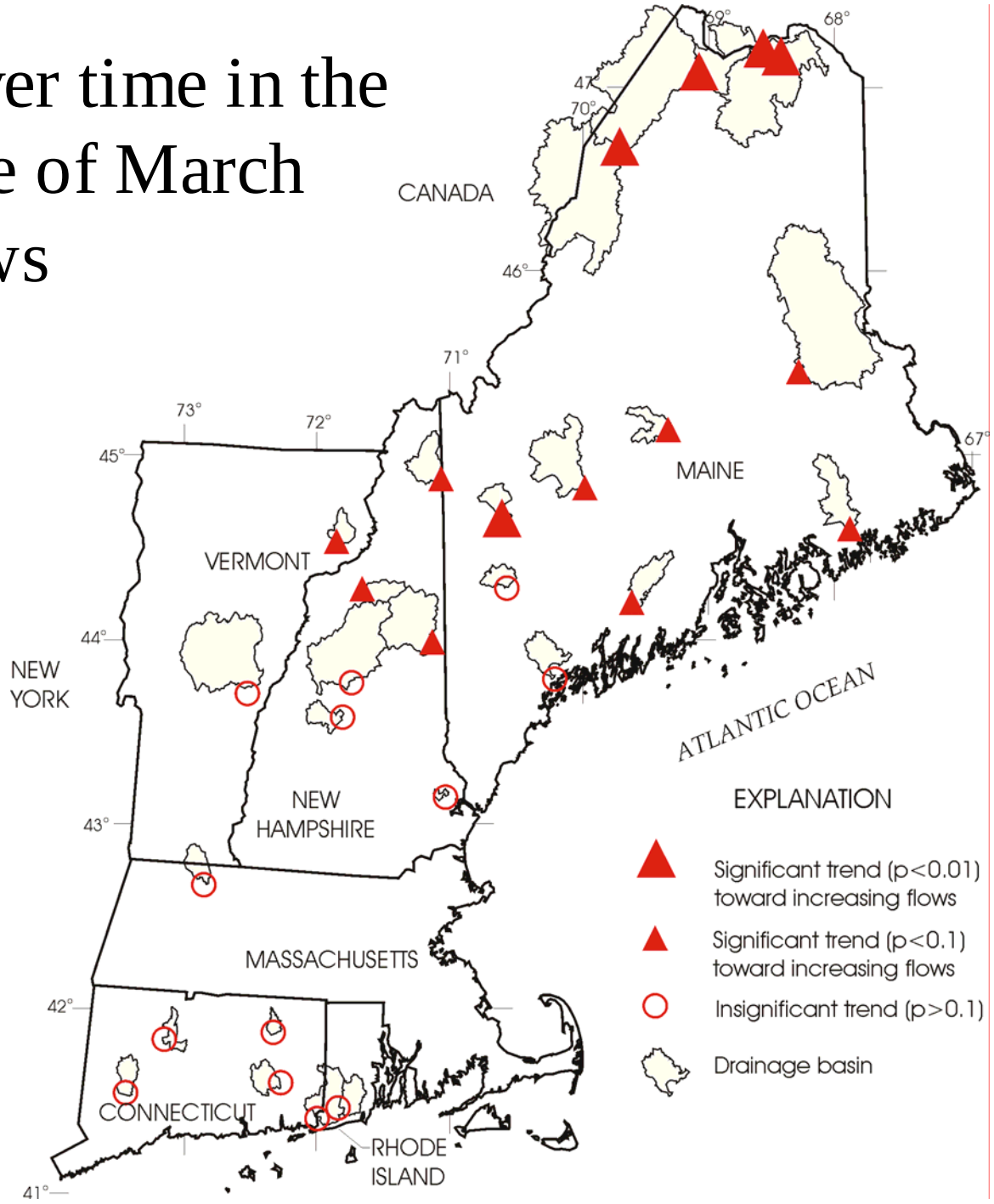
Trends over time in the magnitude of March mean flows



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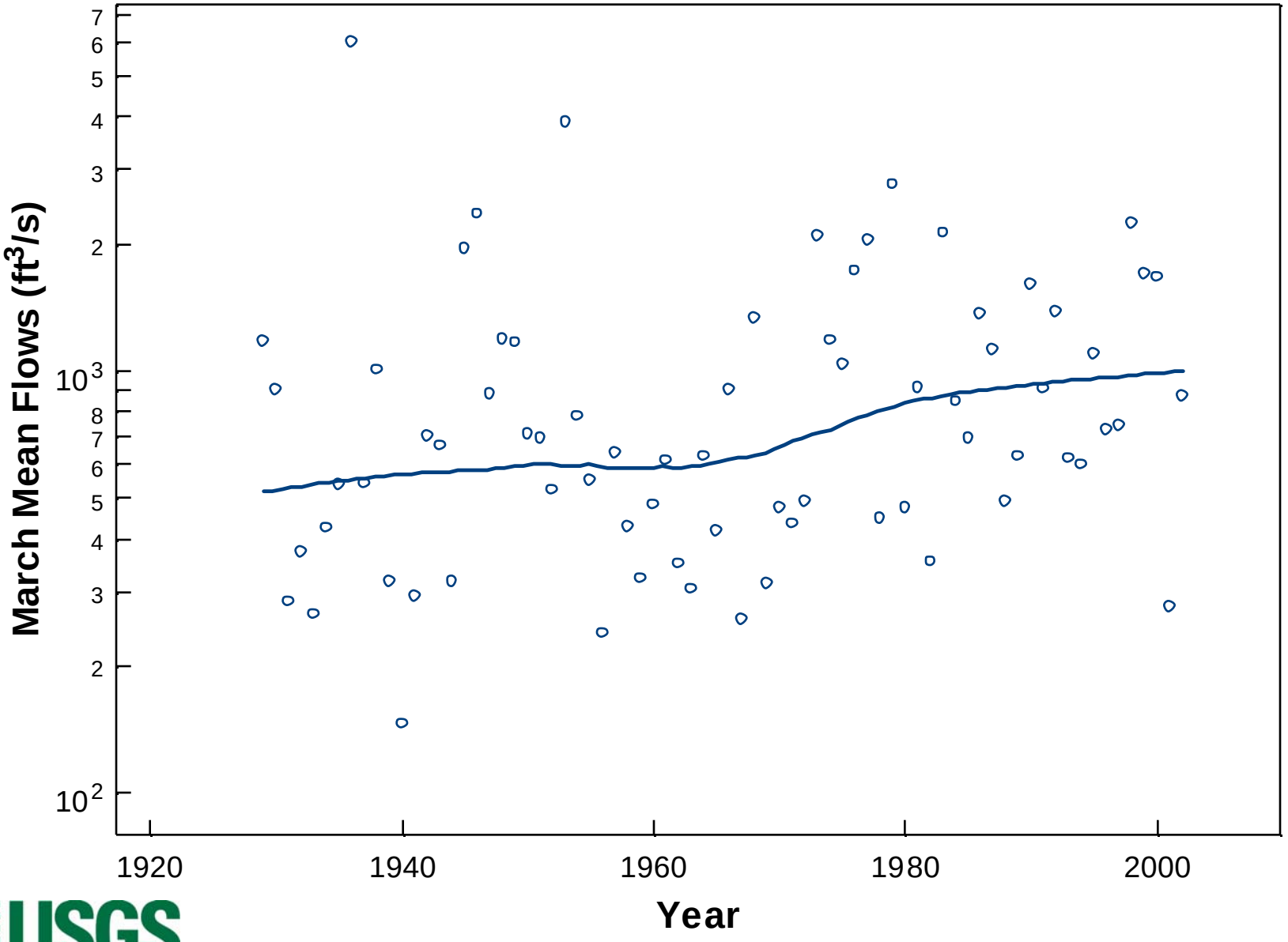
March Mean Flows

Saco River near Conway, New Hampshire



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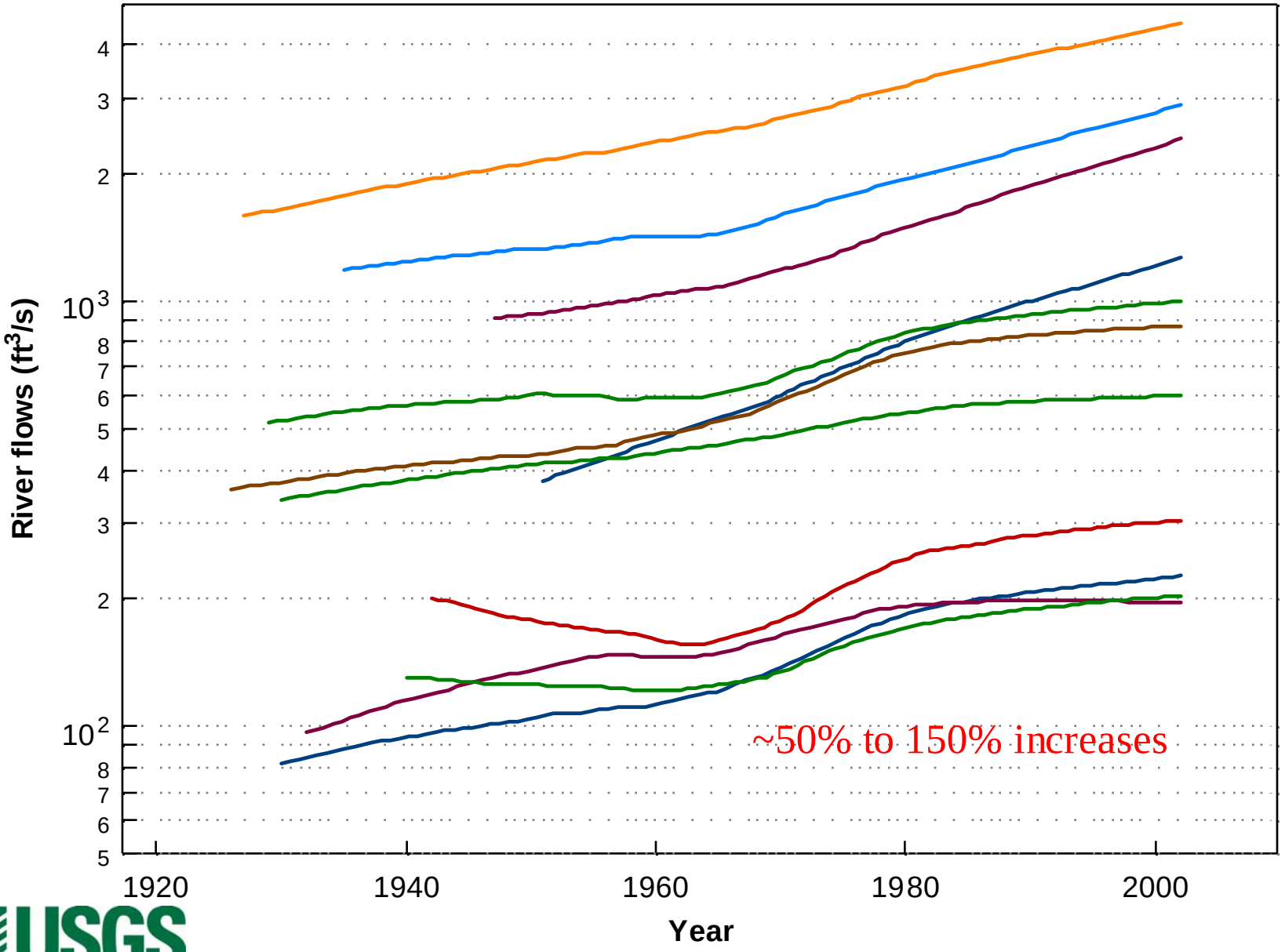
March mean flows for 11 rivers in northern and mountainous New England



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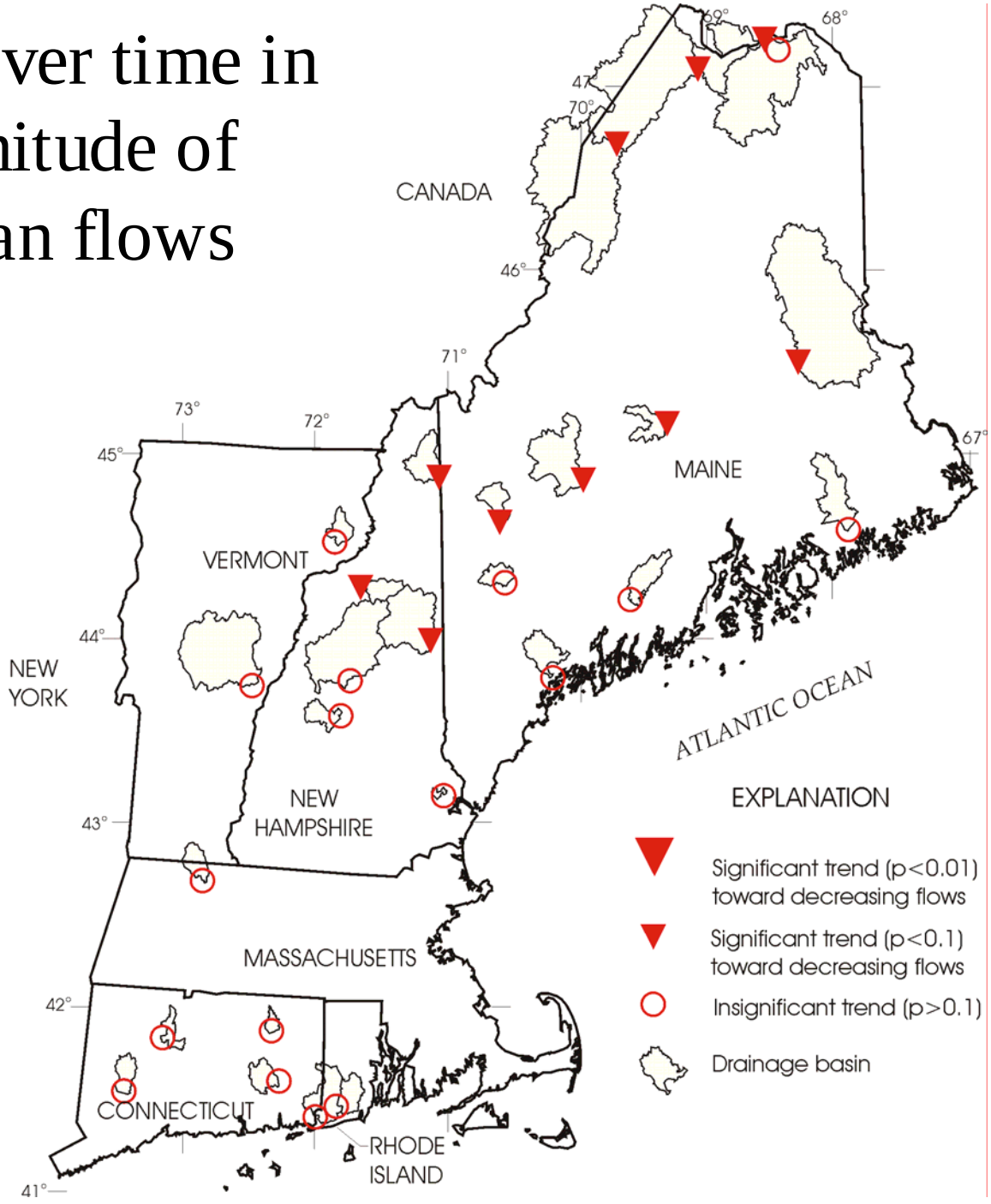
Trends over time in the magnitude of May mean flows



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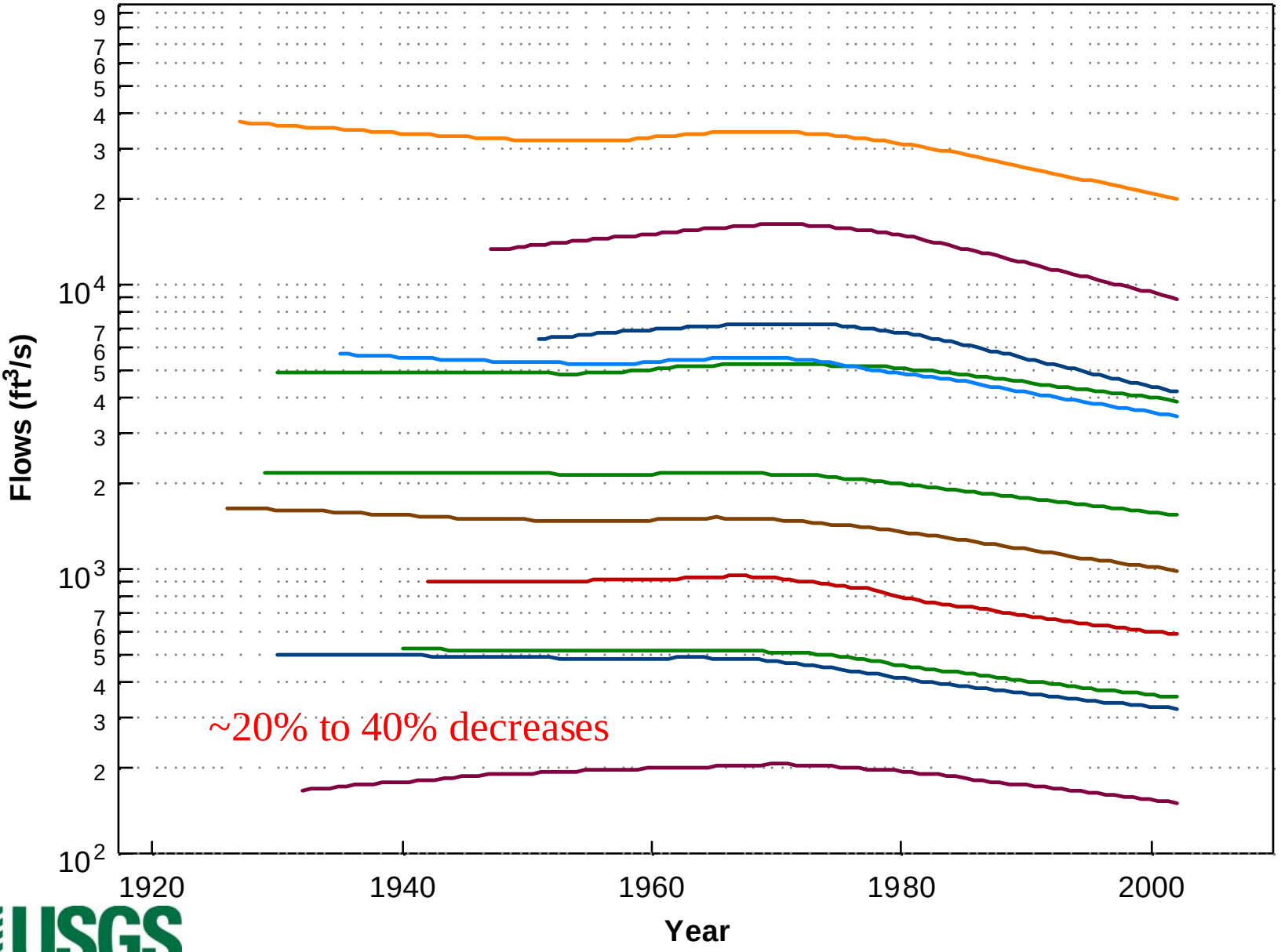
May mean flows for 11 rivers in northern and mountainous New England



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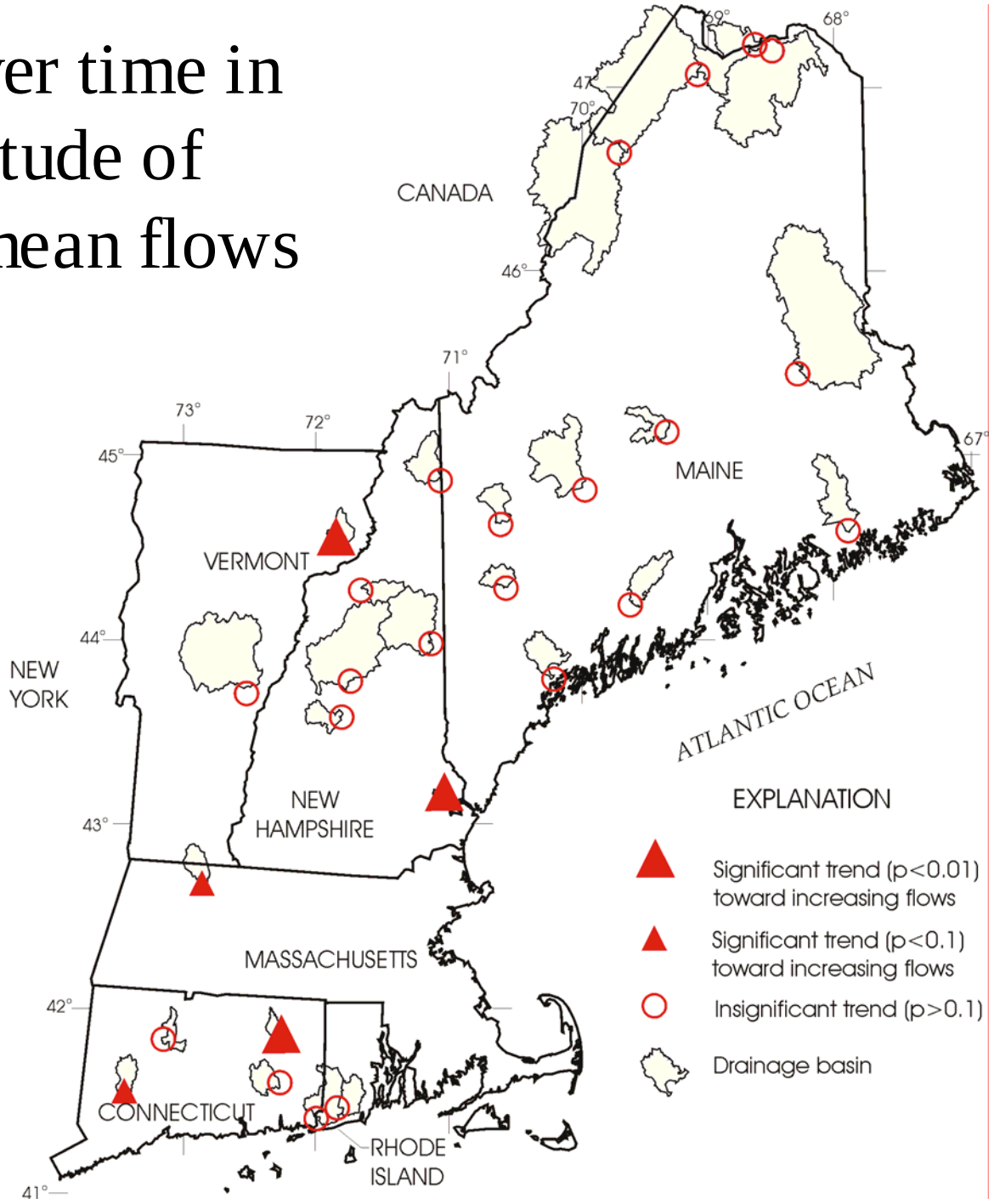
Trends over time in the magnitude of October mean flows



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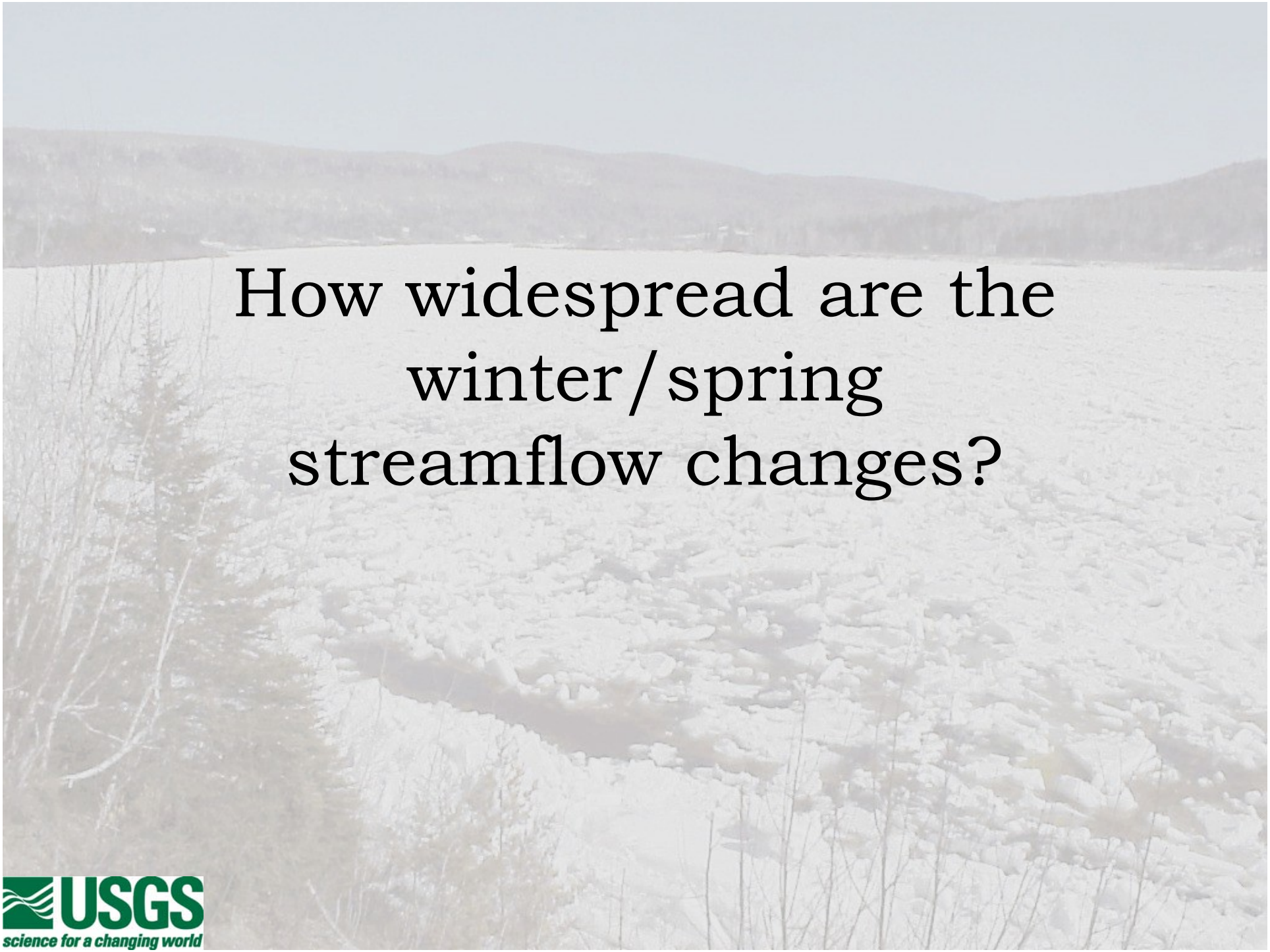

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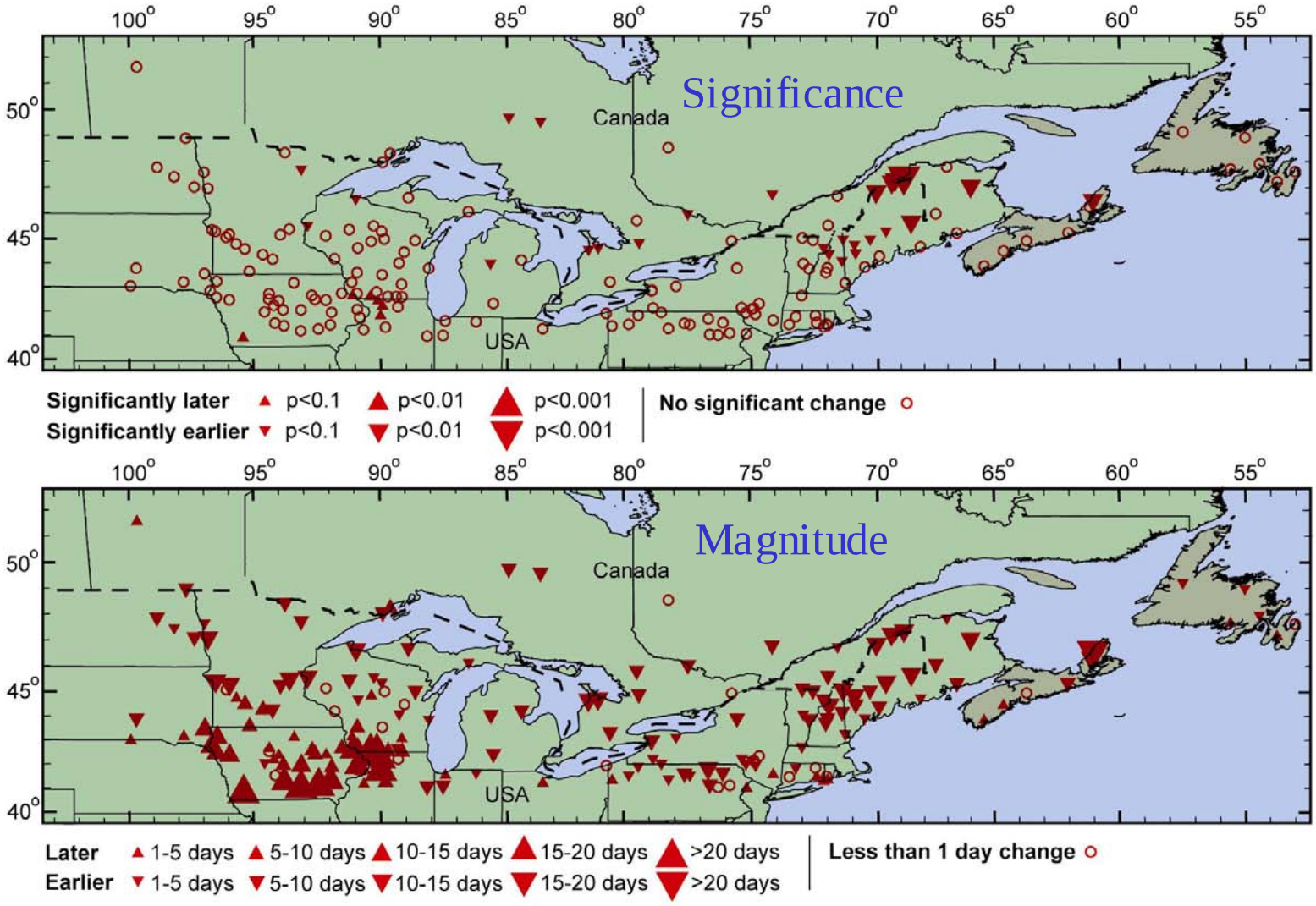
Timing of winter-spring streamflows, 1953-2002



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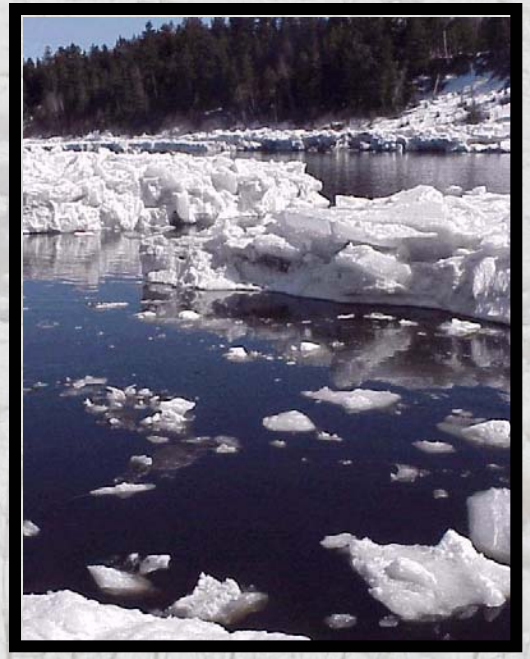
New England River Ice

- Changes in the number and timing of days of ice-affected flow on northern New England rivers



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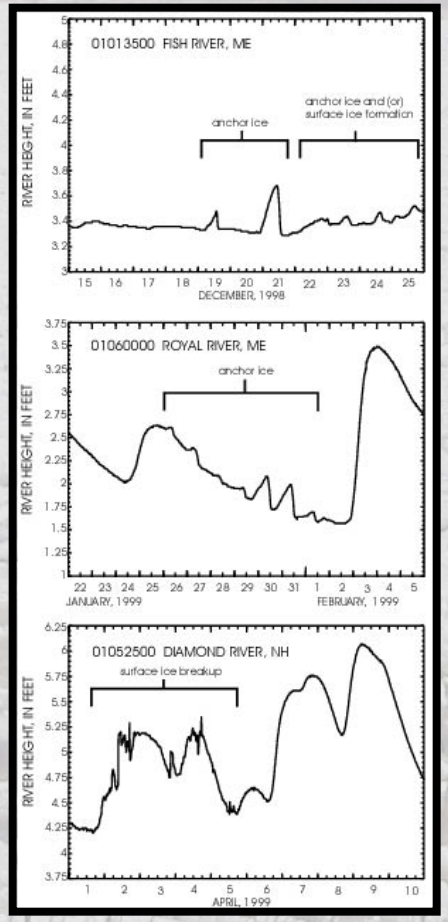
New England River Ice

- Days of ice-affected flow calculated by USGS when computing daily flows in winter
  - River height/flow relations at rivers affected by anchor ice and surface ice
  - Consistent methods since 1930's



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New England River Ice

- 16 rural, unregulated rivers
  - Average of 63 years of recorded flows
  - All in northern New England
- Total annual days of ice-affected flow decreased significantly at 12/16 rivers

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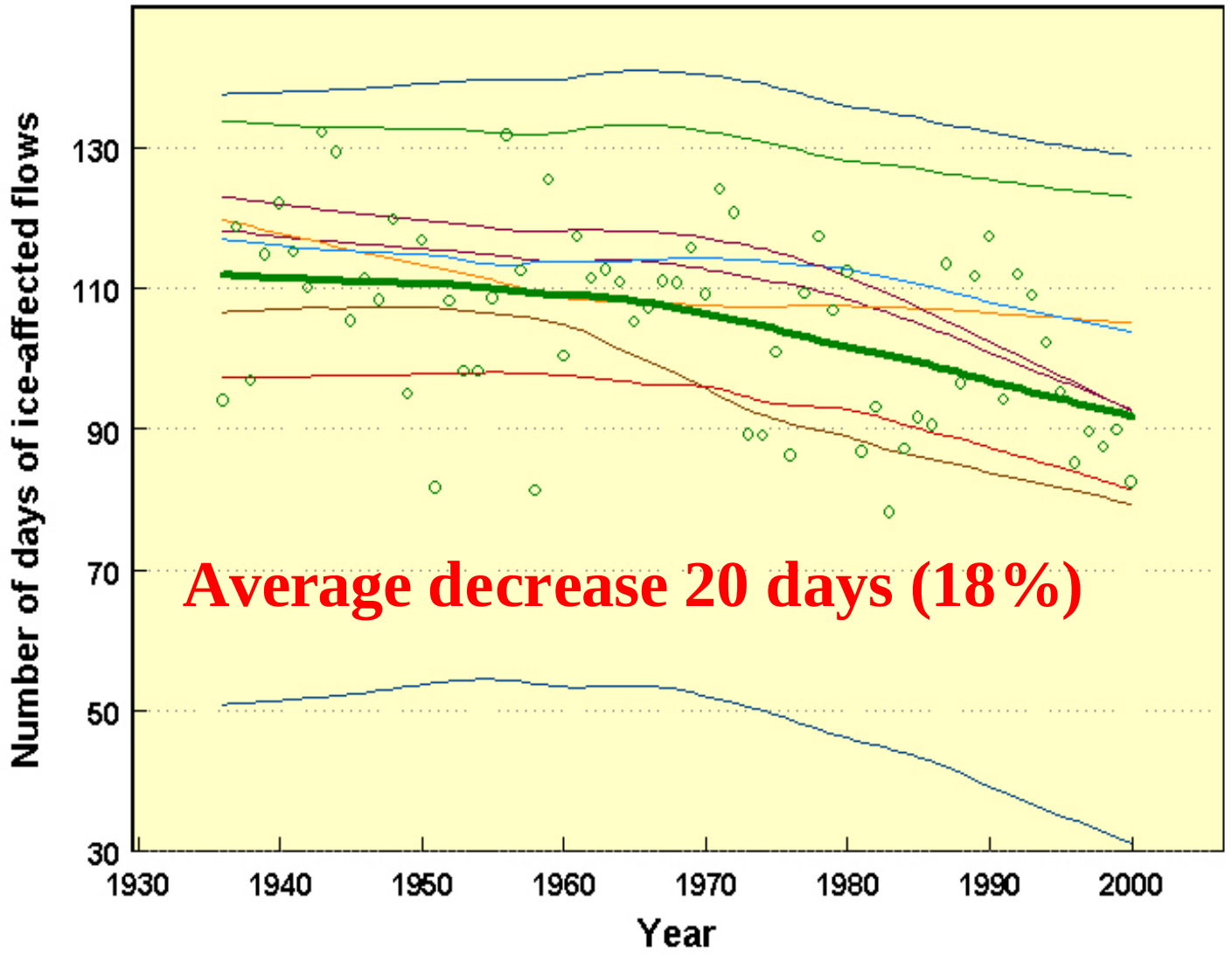
Total days of ice-affected flow, 9 longest-record rivers



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New England River Ice

- Earlier last spring date of ice-affected flow
  - 11 days earlier, 1936-2000
- Few significant changes in the first fall dates of ice-affected flows

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Why are things changing in winter and spring in New England?

- Higher air temperatures and earlier snowmelt likely the primary cause
  - Higher rain to snow ratio
    - Huntington et al., 2004, Journal of Climate
  - Earlier melting of snowpack

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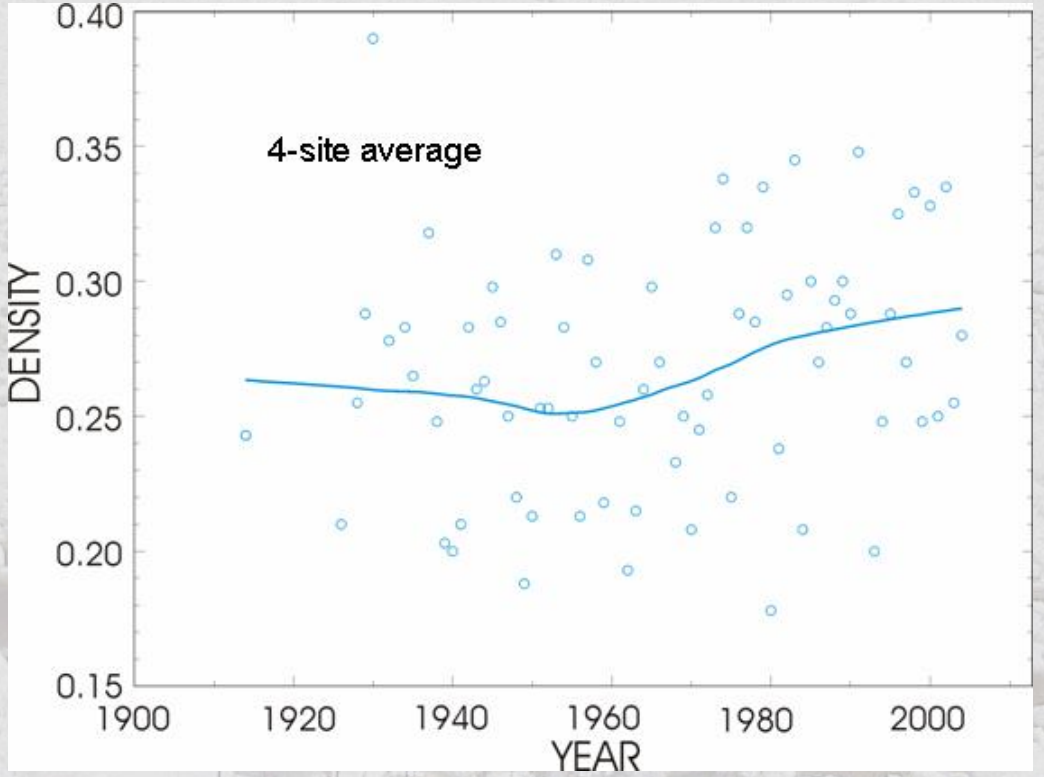
Earlier melting of snowpack

- Significant decrease in late-winter snowpack depth or increase in density at 18 of 23 snow-course sites in Maine during the 20th century



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Meteorological data vs. river and lake data in New England

Highest correlations

- March-April air temps: r = 0.7
  - Lake ice-out dates
  - Timing of spring high river flows
  - Last spring dates of ice-affected river flow
- July-October precipitation: r = 0.6
  - Magnitude of summer-fall low flows

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Why are these changes important?

- Overall, human and ecological impacts of winter-spring lake and river changes not well understood

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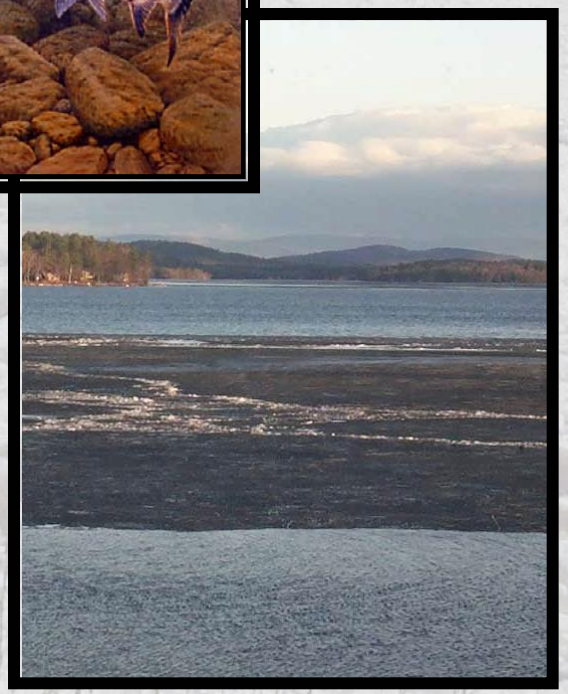
Ecological impacts

- Could endanger survival of Atlantic salmon (McCormick and others, 1998)
- Rate of summer oxygen depletion in lakes (Stewart, 1976)



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Human impacts

- Increase in winter river ice jams (Beltaos, J. Hydrol., 2002)
- Problems with summer water supply?

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