Light limitation and tree-ring growth in the Schweingruber tree-ring collection

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• **Hypothesis**
  – Arctic tree-ring density is limited by light availability

• **Test 1**
  – Response to volcanism
  – Implications of changes in diffuse radiation

• **Test 2**
  – Response to global dimming
  – Synthetic test for how to best identify a response
  – Analysis using individual tree species
  – Robustness of results to chronology de-trending methodology

• **Conclusions**
Climate influences on Arctic tree-ring density

✓ Temperature:
  – Temperature limitation on photosynthesis widespread in Arctic.
  – Arctic tree-ring density generally positively correlated with temperature.

✗ Water:
  – Water limitation on tree-ring growth has been identified in only a few Arctic locations (i.e. Jacoby and D’Arrigo 1995)
  – Arctic tree-density generally negatively correlated with precipitation

✓ Sunlight:
  – Light is energetic driver of photosynthesis.
  – Temperature and sunlight correlated, making separation difficult
Growth of Arctic vegetation is primarily limited by temperature and light.
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Radiation reaching the Arctic’s surface declined between 1950-1970.

Evolution of column transparency

To explore dependence on light and temperature, four sectors are defined:

- dim/cold
- dim/hot
- bright/cold
- bright/hot
Dim sectors show a greater response to volcanism than bright ones.

- 15 largest explosive volcanic eruption since 1300 identified from ice core records (Gao et al. 2008).
- 13-year tree-ring density segments centered on the time of each eruption are selected and averaged together within each sector.
- The magnitude of response in dim sectors is significantly larger than in bright sectors (P<0.01).
Maps of density decrease following eruptions are similar to those of light-limitation.
The tree-ring density response to volcanism increases with greater light-limitation.

Tree-ring density response to volcanism larger in dim light environments

$R=0.48 \ (P<0.01)$
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• **Conclusions**
Radiation reaching the Arctic’s surface declined between 1955-1975.

Briffa et al.’s (1998) difference method:
- Normalize each chronology relative to 1901-1940 mean and variance.
- Average chronologies regionally.
- Renormalize chronologies relative to 1881-1940 mean and variance.
- Average temperature anomalies regionally.
- Rescale variance of density and temperature according to effective degrees of freedom.
- Subtract normalized temperature from normalized density to yield difference time series
- Divergence is calculated as 1975-1985 average minus 1935-1945 average of this difference series.

The present regression-based method:
- Normalize each chronology relative to pre-1950 mean and variance.
- Remove temperature contribution by regression over full record (typically 1850-1975).
- Divergence is calculated as linear trend from 1955-1975 in the residual density record.
A test to evaluate which method would best identify a response to dimming.

Simulate tree ring density as:

\[ \text{MXD}(x,t) = T(x,t) + b(x)\cdot L(t) + c(x)\cdot n(x,t) \]


Recover divergence using the present method.
A test to evaluate which method would best identify a response to dimming.

Present method has more statistical power than method of Briffa et al’s (1998) for differentiating between hypotheses for spatial pattern of tree-ring response to dimming.

Specifically, when seeking to reject \( H_0 \) at \( P=0.05 \), the statistical power of the test using Briffa et al’s (1998) method gives a 48% chance of identifying pattern of response to dimming, in the case that \( H_1 \) is true, whereas the present test gives an 80% chance.
Response to dimming is greatest in the light-limited regions of the Arctic.

- Remove effects of local temperature variability at each tree-ring chronology by regression.
- Conceptually, we think of this residual as divergence.
- Average over four sectors during 1955-1975.
- Divergence has negative slope in both dim regions (P<0.01).
- The bright/cold slope is not distinguishable from zero.
Similarly, response to dimming and light-limitation appear similar.
Response to dimming increases with greater light limitation

Divergence has a cross-correlation with light limitation of $R=0.66$ ($P<0.001$) and is consistent with zero at the lowest light-limitation levels.
Response to dimming follows light-limitation within individual species: part I

- Larix gmelinii
- Larix sibirica
- Picea abies
- Picea glauca
- Picea mariana
- Picea obovata
- Pinus sylvestris
Response to dimming follows light-limitation within individual species: part II

![Graphs of different species showing response to dimming and light limitation.](image-url)
Results are essentially unchanged after applying signal-free detrending

\[ R = 0.97 \]

\[ R = 0.94 \]

[Signal Free de-trending following Melvin 2008]
1. Two lines of evidence point to an important role for light availability in controlling Arctic tree-ring density:

   a. Declines in density following volcanic eruptions are greater in regions of higher light-limitation.

   b. Divergence between temperature and density is also largest in regions of great light-limitation.
3. Identification of the relationship between tree-ring density and light-limitation is much more likely using the present regression-based approach.

4. Global Dimming occurs during the period identified by Briffa et al. (1998) to experience tree ring divergence. No significant divergence can be detected in regions where light limitation is weakest.