ECL7202 – DENDROECOLOGY

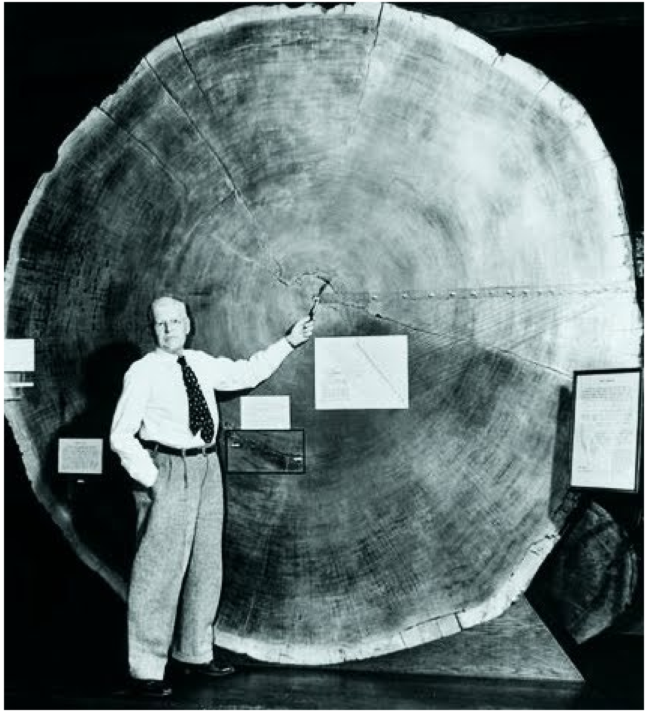
1.2 - Dendrochronology and paleoecology

Dendrochronology and paleoecology

1. Etymology
2. Fundamental principles
3. Multiple traits (proxy) are measurable in tree-rings
4. Strengths and weaknesses of dendrochronology
5. Introduction to paleoecology with tree-rings
    - Tree-rings and fire reconstructions
    - Tree-rings and reconstitutions of forest dynamics
    - Tree-rings and climate reconstitutions

Etymology of dendrochronology

Dendron (tree) + Khronos (time) + Logos (study of)



Andrew Ellicott Douglass

The fundamental principles

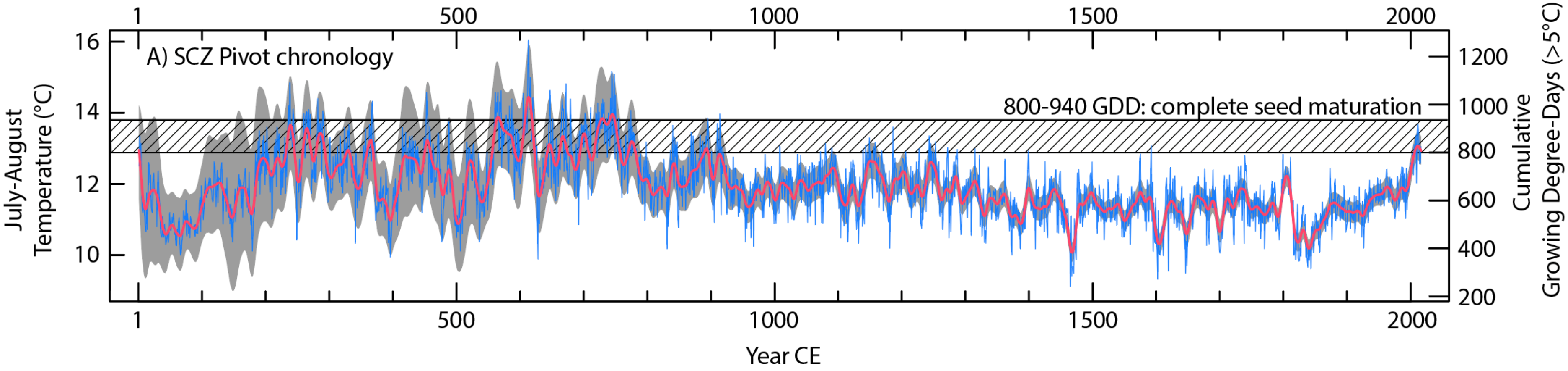
The Uniformitarian Principle
The Principle of Limiting Factors
The Principle of Aggregate Tree Growth
The Principle of Ecological Amplitude
The Principle of Site Selection
The Principle of Crossdating
The Principle of Replication

The Uniformitarian Principle

states that physical and biological processes that link current environmental processes with current patterns of tree growth must have been in operation in the past (after Fritts 1976).

“The present is the key to the past" (James Hutton, 1785).

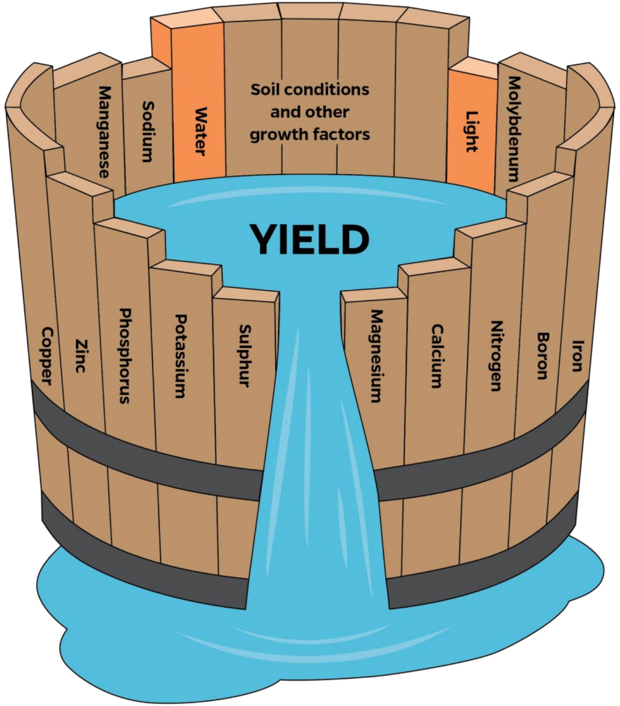
“The past is the key to the future."

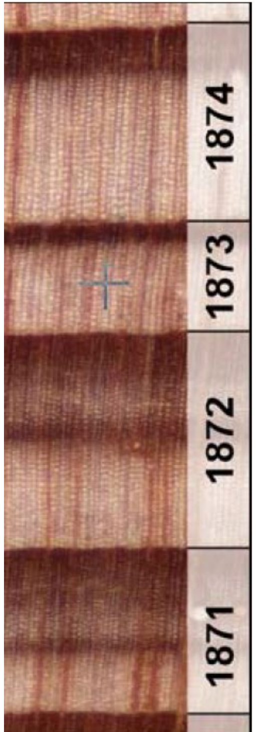


The Principle of Limiting Factors

states that rates of plant processes can occur only as fast as allowed by the factor that is most limiting. For example, if rainfall is the most limiting factor, then the amount of wood produced by a tree in any single year will reflect mostly the amount of rainfall that fell within that year.

Liebig's law of the minimum





The Principle of Aggregate Tree Growth

states that any individual tree-growth series can be "decomposed" into an aggregate of environmental factors, both human and natural, that affected the patterns of tree growth over time.

$$R_t = A_t + C_t + \delta D1_t + \delta D2_t + E_t$$

Ring variation is a function of:

Age or size
Climate
Endogenous disturbances (a blow down)
Exogenous disturbances (an insect outbreak)
Leftover (error)

t = any one year
δ = binary factor

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The concept of signal-to-noise ratio

$$SNR = \frac{C_t}{A_t + \delta D1_t + \delta D2_t + E_t}$$

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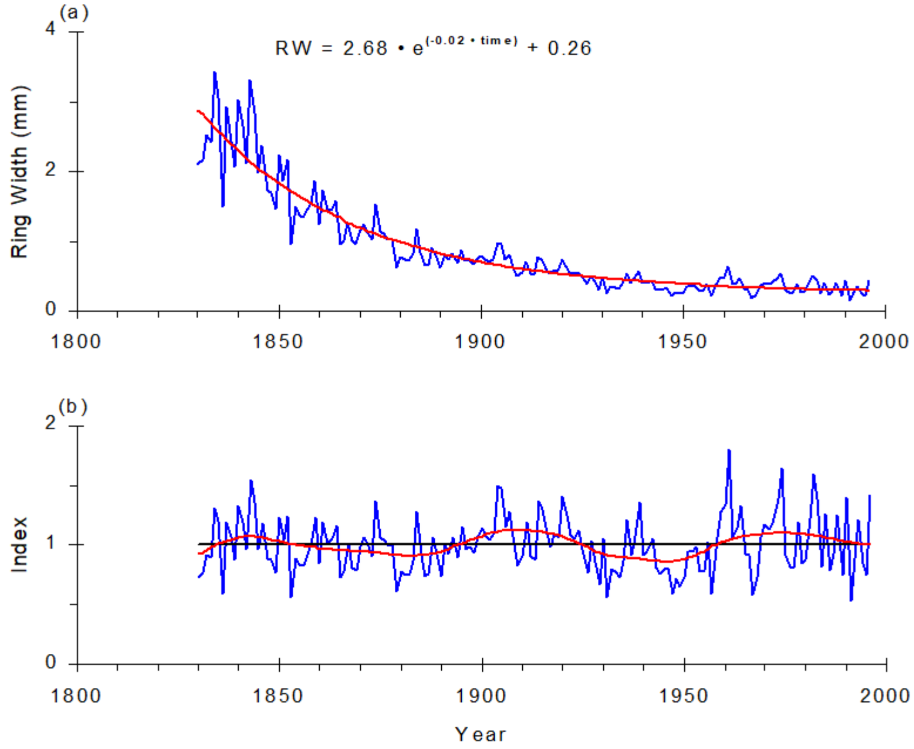
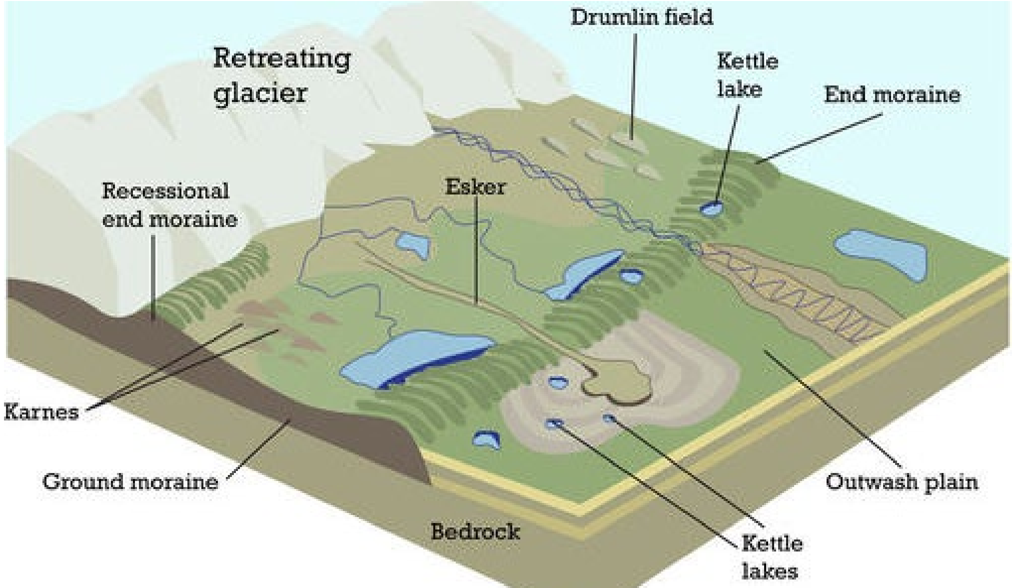


The Principle of Ecological Amplitude

states that species may grow, reproduce, and propagate across wide, narrow, or restricted ranges of habitats. For example, ponderosa pine (Pinus ponderosa) is the most widely distributed of all pine species in North America, growing in a diverse range of habitats (wet, dry, low elevation, and high elevation). Therefore, ponderosa pine has a wide ecological amplitude. Conversely, giant sequoia trees (Sequoiadendron giganteum) grow in restricted areas on the western slopes of the Sierra Nevada of California. Giant sequoia, therefore, has a narrow ecological amplitude. **This principle is important because tree species useful to dendrochronology are often found near the margins of their natural range**, such as black spruce trees (Picea mariana) near the upper latitudinal treeline.

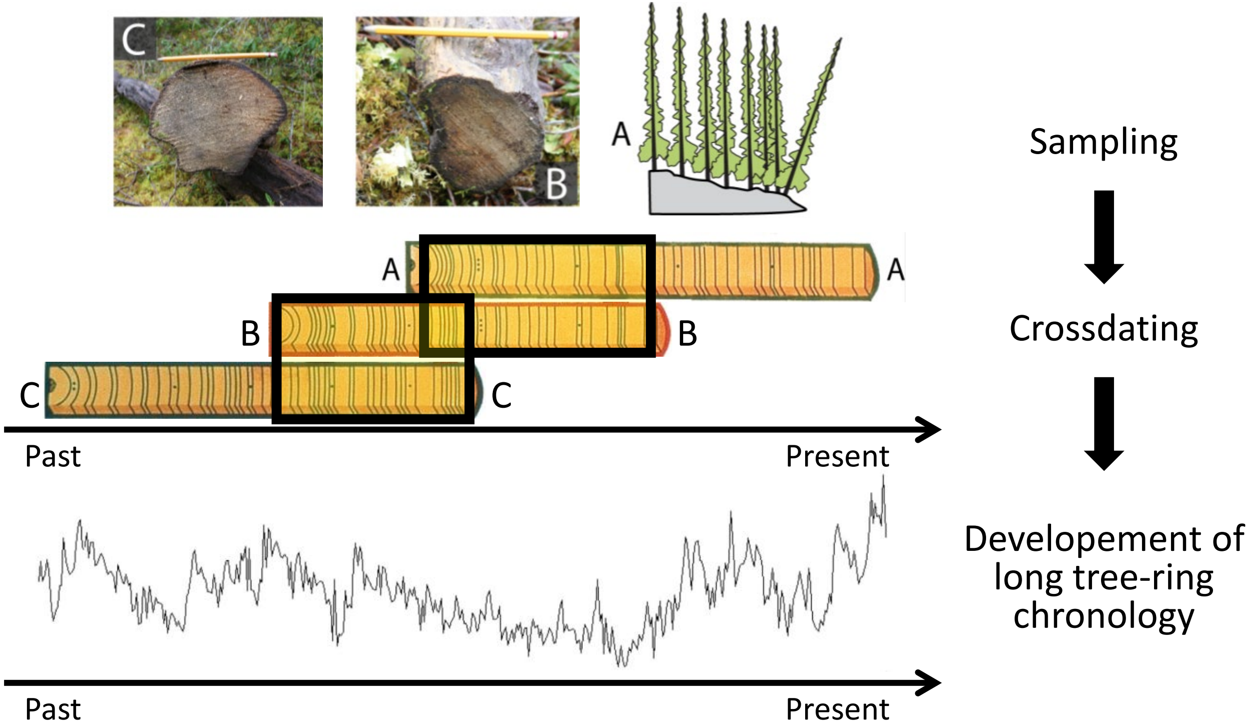
The Principle of Site Selection

states that sites useful to dendrochronology can be identified and selected based on criteria that will produce tree-ring series sensitive to the environmental variable being examined. For example, trees that are especially responsive to drought conditions can usually be found where rainfall is limiting, such as rocky outcrops, or on ridgecrests of mountains. Therefore, a dendrochronologist interested in past drought conditions would purposely sample trees growing in locations known to be water-limited. **The dendrochronologist must select sites that will maximize the environmental signal being investigated.**



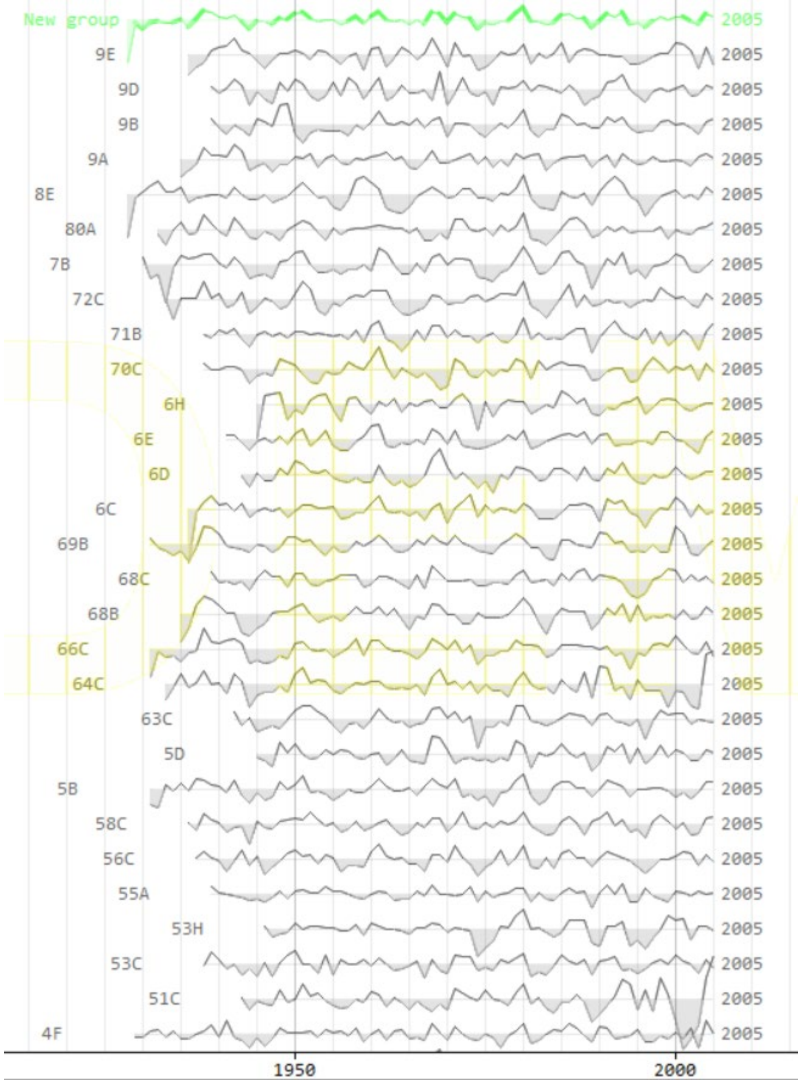
The Principle of Crossdating

states that matching patterns in ring widths or other ring characteristics (such as ring density patterns) among several tree-ring series allow the identification of the exact year in which each tree ring was formed. For example, one can date the construction of a building by matching the tree-ring patterns of wood taken from the buildings with tree-ring patterns from living trees.



The Principle of Replication

states that the environmental signal being investigated can be maximized, and the amount of "noise" minimized, by sampling more than one stem radius per tree, and more than one tree per site. Obtaining more than one increment core per tree reduces the amount of "intra-tree variability", in other words, the amount of non-desirable environmental signal peculiar to only tree. Obtaining numerous trees from one site, and perhaps several sites in a region, ensures that the amount of "noise" (environmental factors not being studied) is minimized.



Strengths of dendrochronology

1. the capability to **date** tree rings to the calendar year with a very high degree of confidence;
2. the existence of large geographic-scale patterns of **common year-to-year tree-ring variability**;
3. the development of very extensive, shared **networks of tree-ring chronologies** meeting common standards;
4. the surprising effectiveness of very **simple linear models** of tree-ring/climate relationships;
5. the growing understanding of the **mechanisms** leading to variability in tree-ring features.

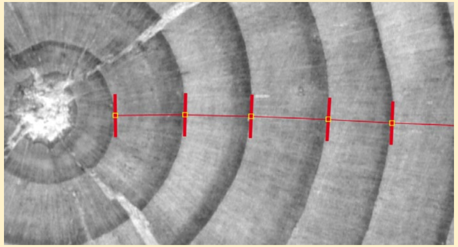
Weakness of dendrochronology

1. tree-ring chronologies **only capture a fraction of climate** variability;
2. their response may be limited to **specific seasonal windows**;
3. they may **not record the climate variables of interest** to climatologists;
4. their use to reconstruct past climate is based on the assumption that the same factors, acting in the same way, controlled the formation of tree rings in the **past as in the twentieth century**;
5. the techniques used to remove non-climatic variability, such as that caused by tree age/size trend and interactions with neighbors, limit the faithful representation of climate variations on **centennial and longer time scales** in many cases.

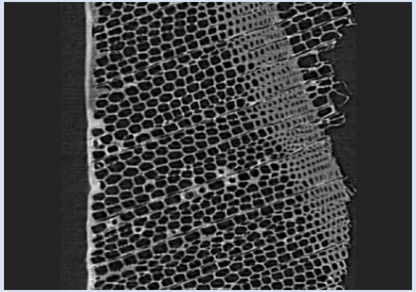
Hughes, M. K. (2002). Dendrochronology in climatology – the state of the art. *Dendrochronologia*, *20*(1), 95–116. doi: https://doi.org/10.1078/1125-7865-00011

Another strength of tree-ring science:
Multiple traits are measurable in tree-rings

Ring width

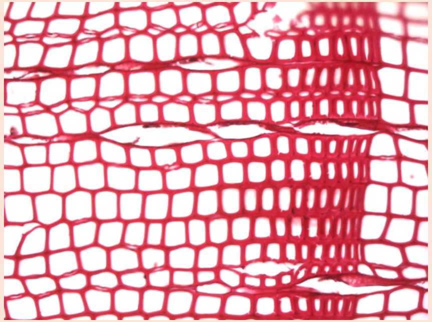


Ring density

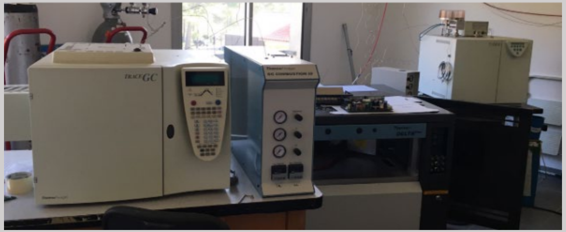


Tree-ring traits

Anatomy



Stable isotopes
$\delta^{13}C$ and $\delta^{18}O$



Sap flow and girth growth in real time

Another strength of tree-ring science:
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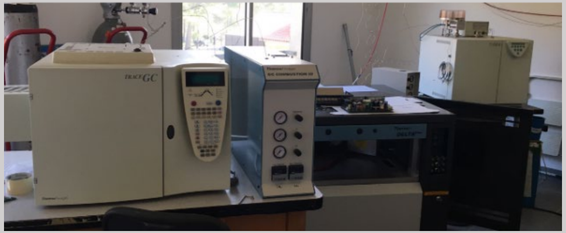
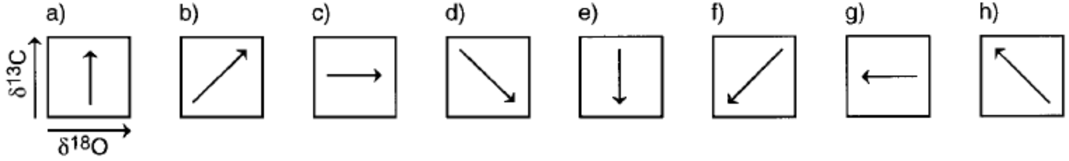
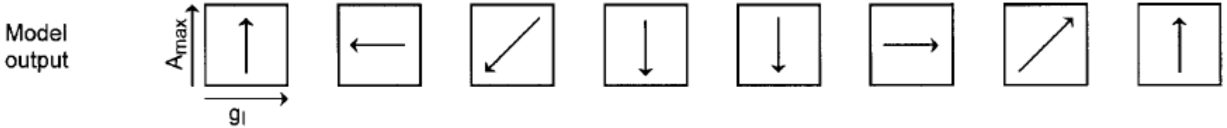


Scheidegger, Y., Saurer, M., Bahn, M., & Siegwolf, R. (2000). Linking stable oxygen and carbon isotopes with stomatal conductance and photosynthetic capacity: a conceptual model. *Oecologia*, *125*(3), 350–357.

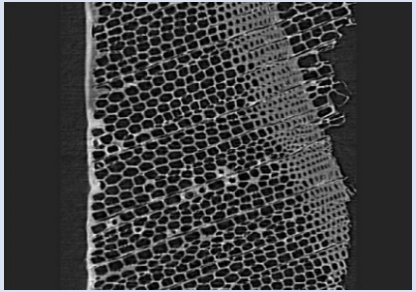


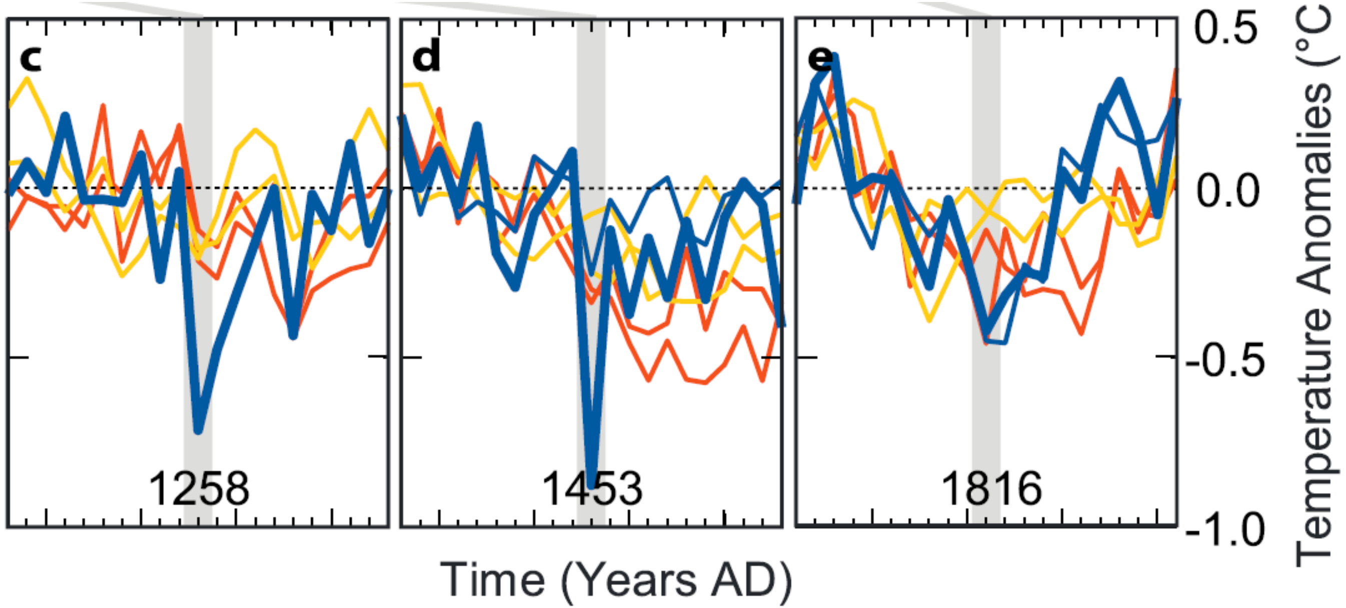
	a)		b)		c)		d)		e)		f)		g)		h)	
$\delta^{18}O$	≈		↑		↑		↑		≈		↓		↓		↓	
rH	≈		↓		↓		↓		≈		↑		↑		↑	
$\delta^{13}C$	↑		↑		≈		↓		↓		↓		≈		↑	
c_i	↓		↓		≈		↑		↑		↑		≈		↓	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
A_{max}	↑	≈	↑	≈	↑	↓	≈	↓	≈	↓	≈	↓	↑	↓	↑	≈
g_l	≈	↓	≈	↓	↑	↓	↑	≈	↑	≈	↑	≈	↑	↓	≈	↓
Selection based on rH change	x			x		x		x		x	x		x		x	



Another strength of tree-ring science:
Multiple traits are measurable in tree-rings

Ring Density





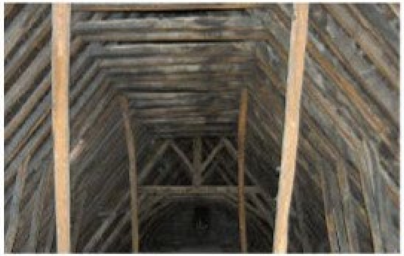
Schneider, L., Smerdon, J. E., Büntgen, U., Wilson, R. J. S., Myglan, V. S., Kirdyanov, A. V, & Esper, J. (2015). Revising midlatitude summer temperatures back to A.D. 600 based on a wood density network. *Geophysical Research Letters*, *42*(11), GL063956. doi: 10.1002/2015gl063956

Introduction to paleoecology with tree-rings

Sources of ancient wood samples




Archeology

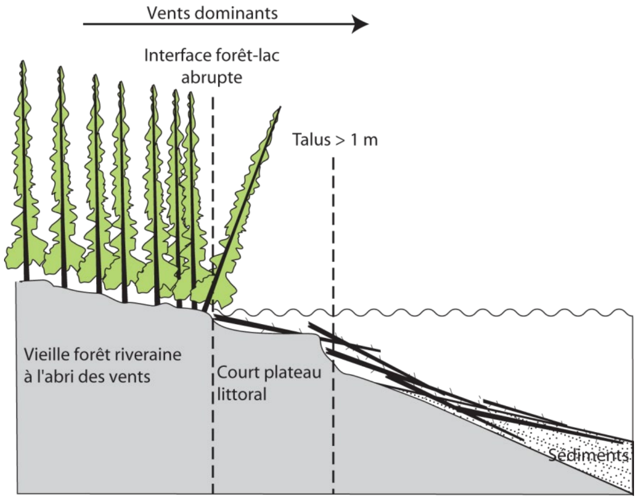



Subfossil wood

Buildings and construction timber


Very old trees

Subfossil trees in taiga lakes



Arseneault, D., Dy, B., Gennaretti, F., Autin, J., & Bégin, Y. (2013). Developing millennial tree ring chronologies in the fire-prone North American boreal forest. *Journal of Quaternary Science*, *28*(3), 283–292. doi: 10.1002/jqs.2612

Sampling

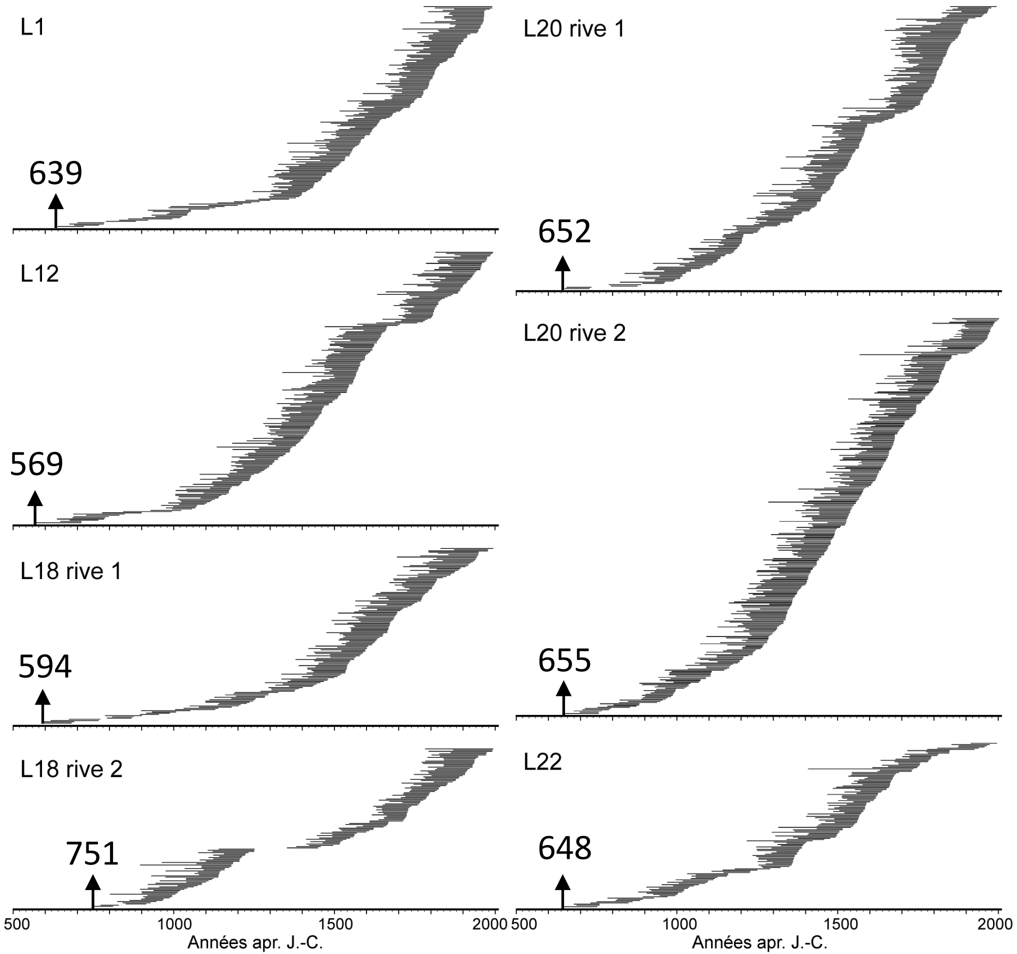
Dating

One subfossil tree at the site L20

Life span: 652-757 AD

More than 1250 years in the lake

Crossdating results

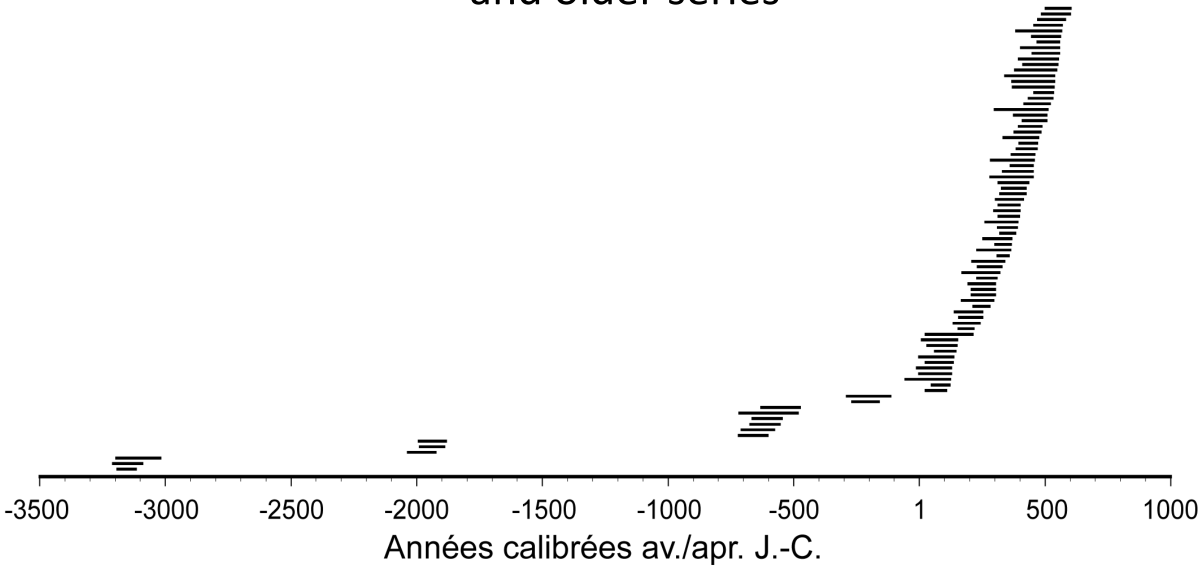


Gennaretti, F., Arseneault, D., & Bégin, Y. (2014). Millennial stocks and fluxes of large woody debris in lakes of the North American taiga. *Journal of Ecology*, *102*(2), 367–380. doi: ?

Crossdating results

83 samples composing some floating series that were radiocarbon dated

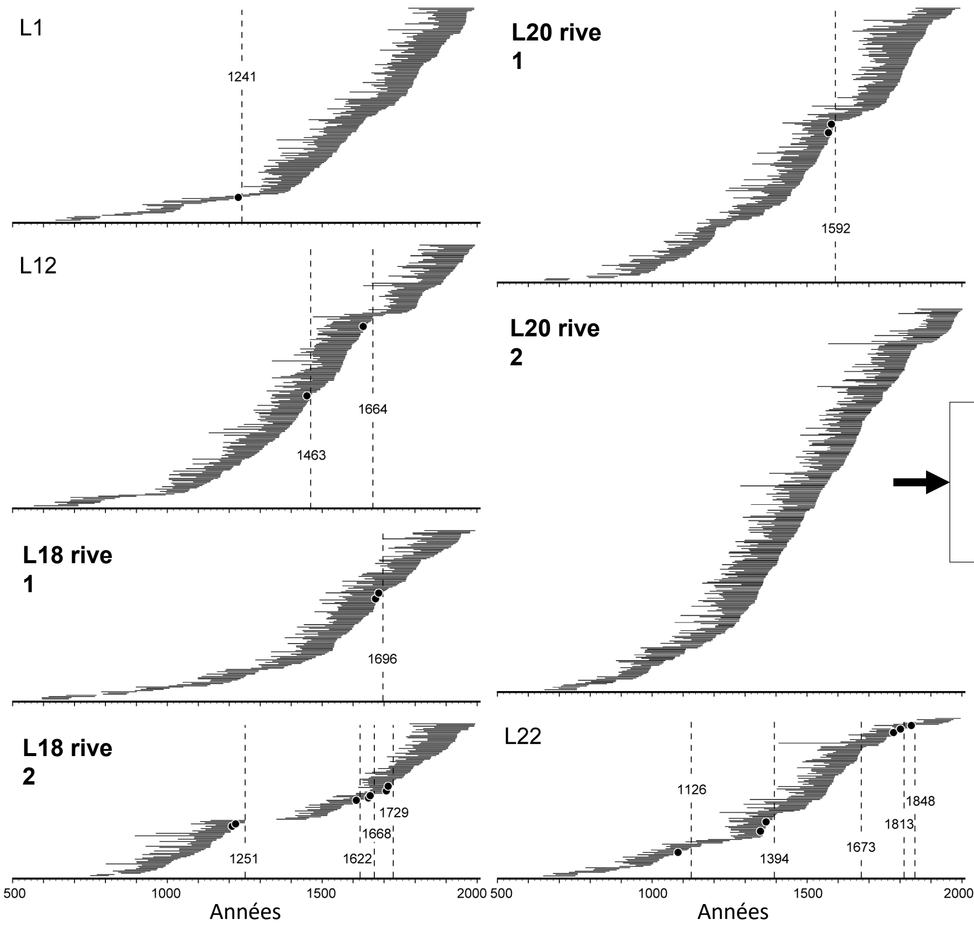
Radiocarbon dating is required if there is no overlap between our master series and older series



Dendroecology and fire reconstructions

Gennaretti, F., Arseneault, D., & Bégin, Y. (2014). Millennial stocks and fluxes of large woody debris in lakes of the North American taiga. *Journal of Ecology*, *102*(2), 367–380. doi: ?

Dating of past fires

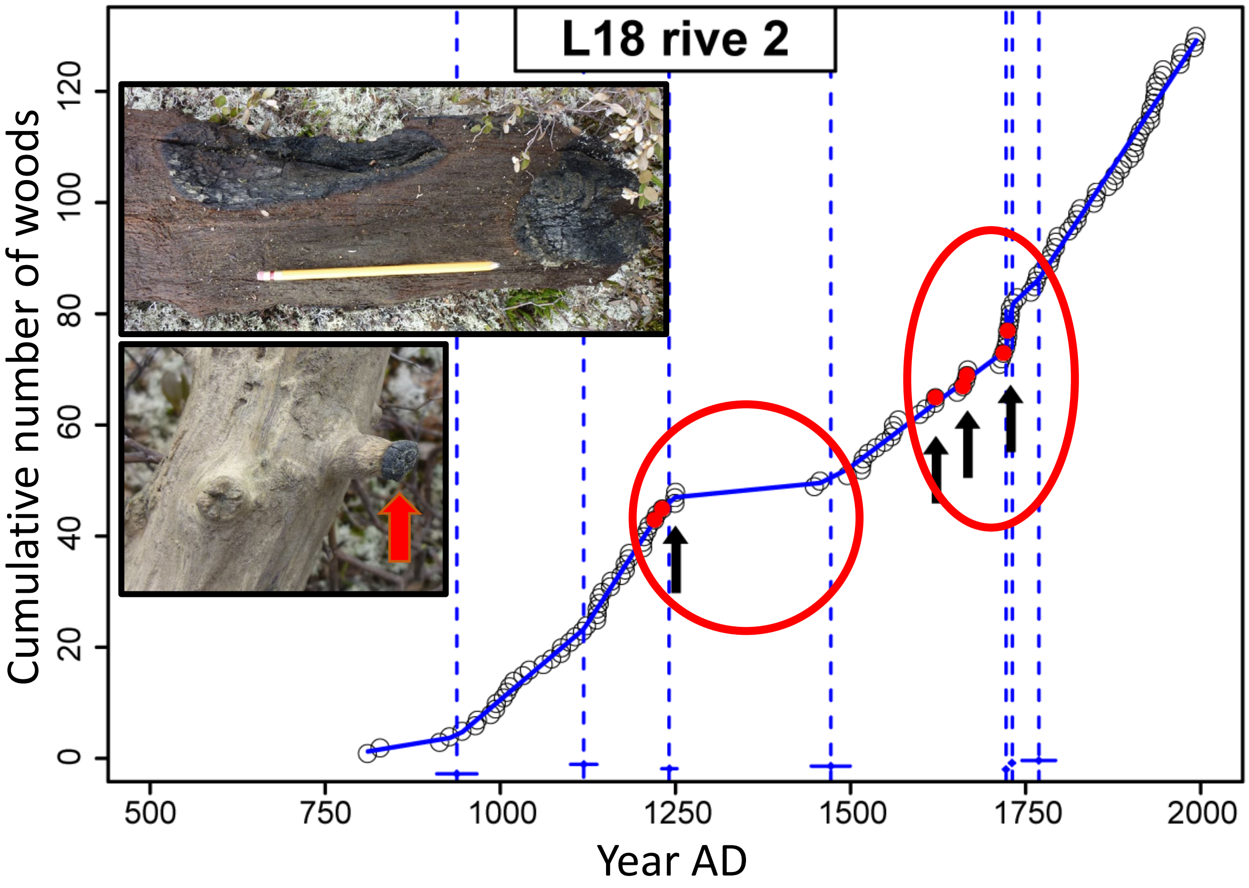


14 fire events

Site experiencing no fire:

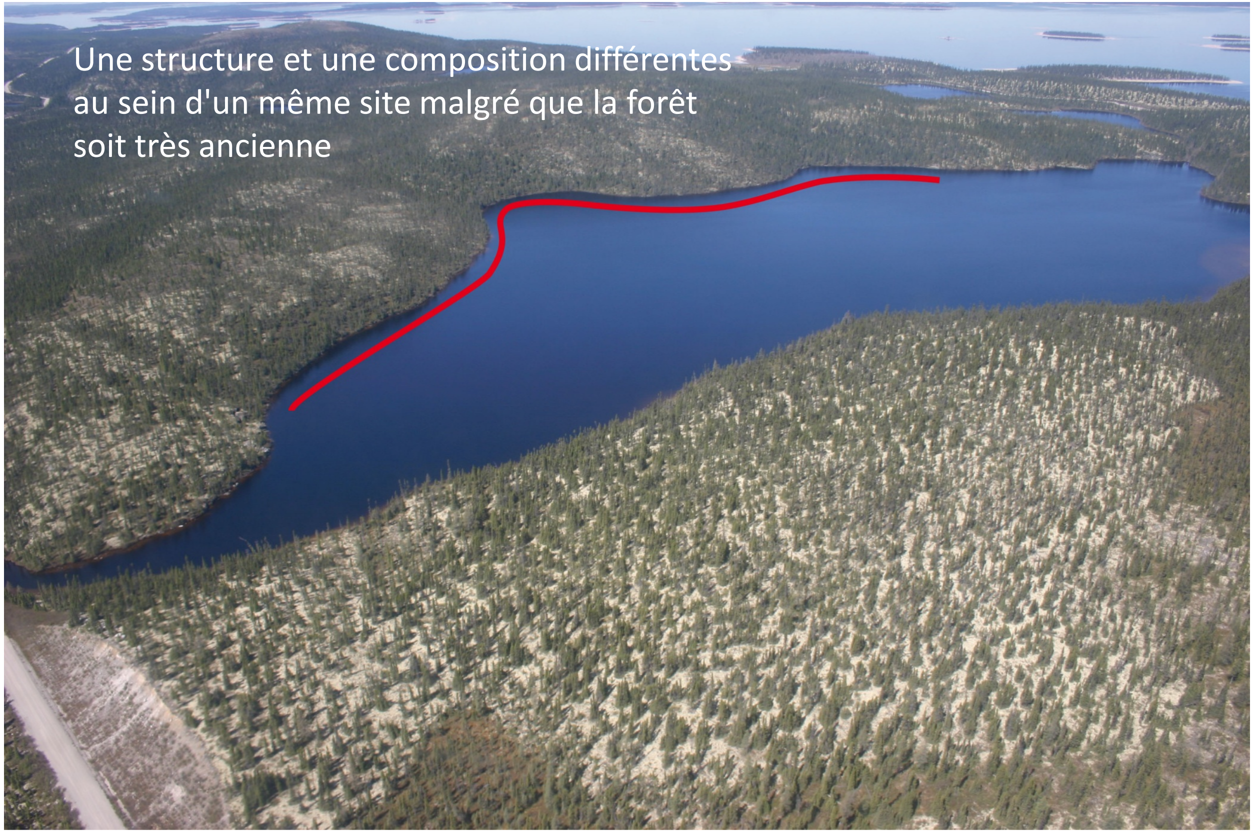
13,4 wood per 100 years per 100 m of shore

Fire influence on wood recruitment into the lake



Dendroecology and reconstitution of forest dynamics

Comparaison de l'état actuel des pessières à lichens sur la rive des lacs échantillonnés avec les données provenant des arbres subfossiles



Gennaretti, F., Arseneault, D., & Bégin, Y. (2014). Millennial disturbance-driven forest stand dynamics in the Eastern Canadian taiga reconstructed from subfossil logs. *Journal of Ecology*, *102*(6), 1612–1622. doi: 10.1111/1365-2745.12315

Clusters of homogeneus forest at the L20 site

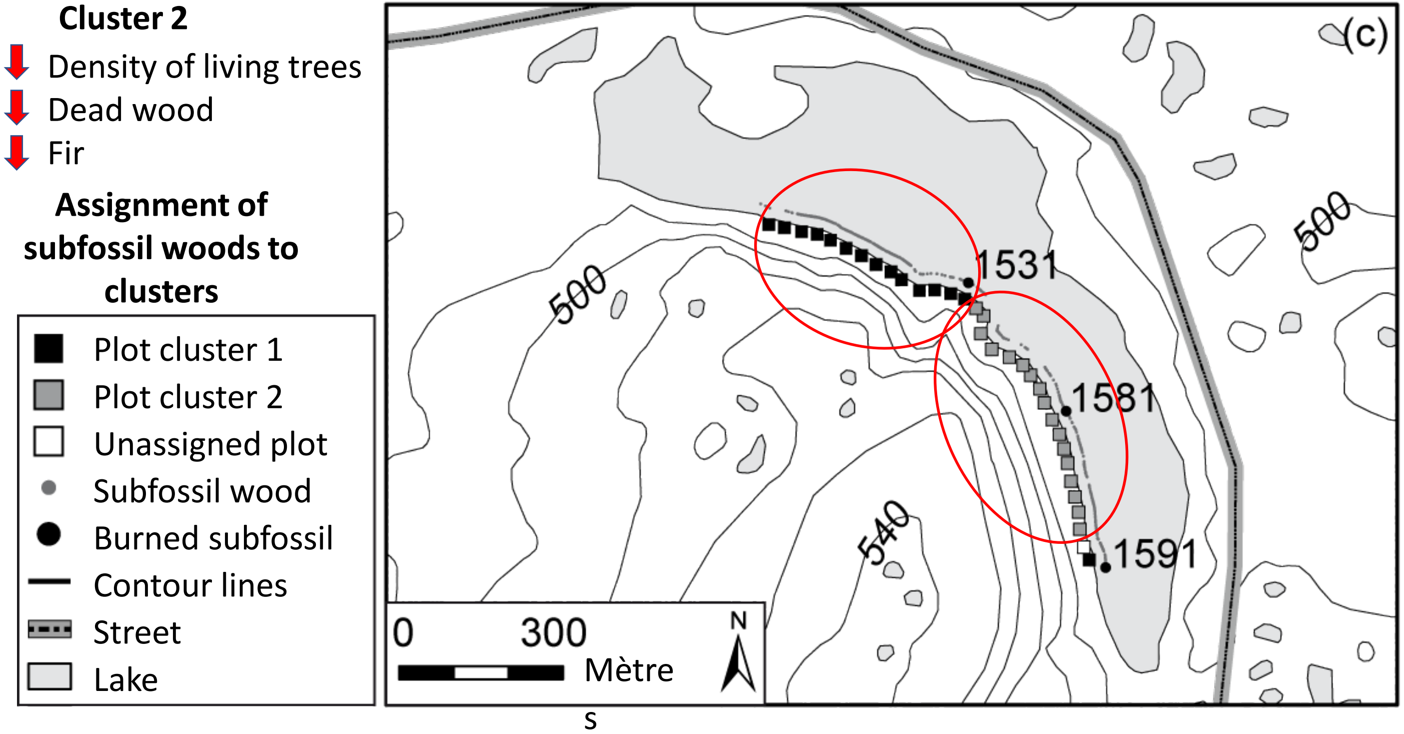
Cluster 1

- ↑ Density of living trees
- ↑ Dead wood
- ↑ Fir

Cluster 2

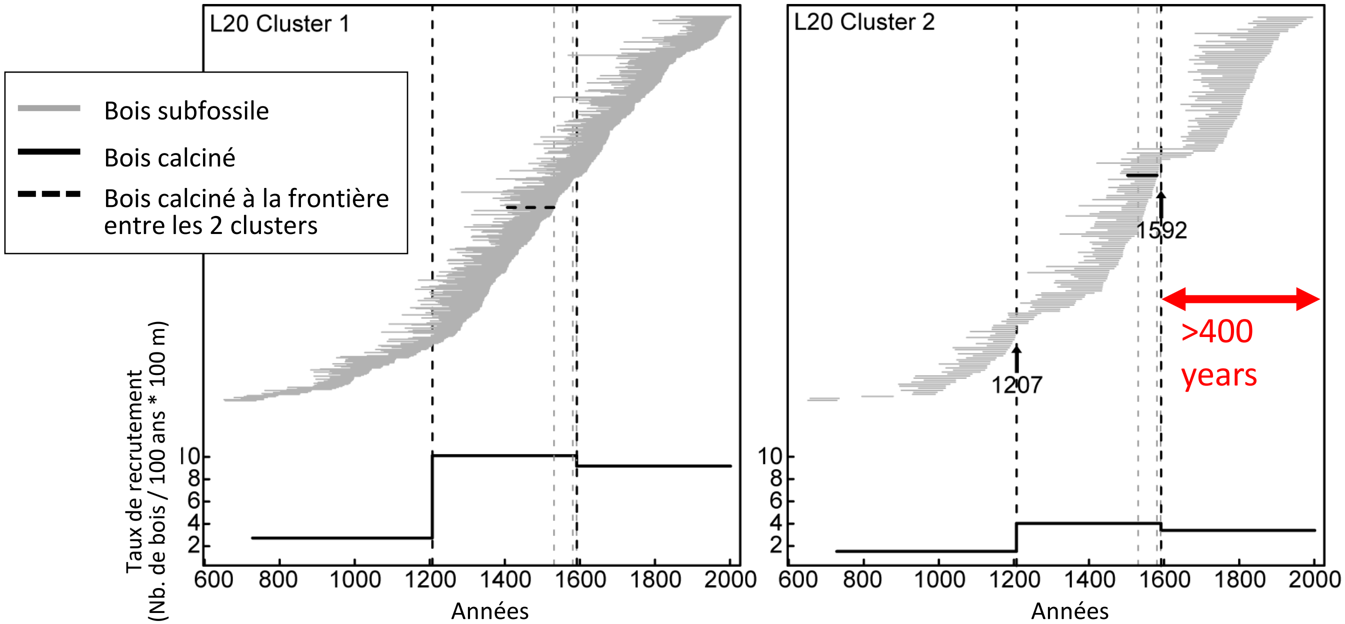
- ↓ Density of living trees
- ↓ Dead wood
- ↓ Fir

Assignment of subfossil woods to clusters



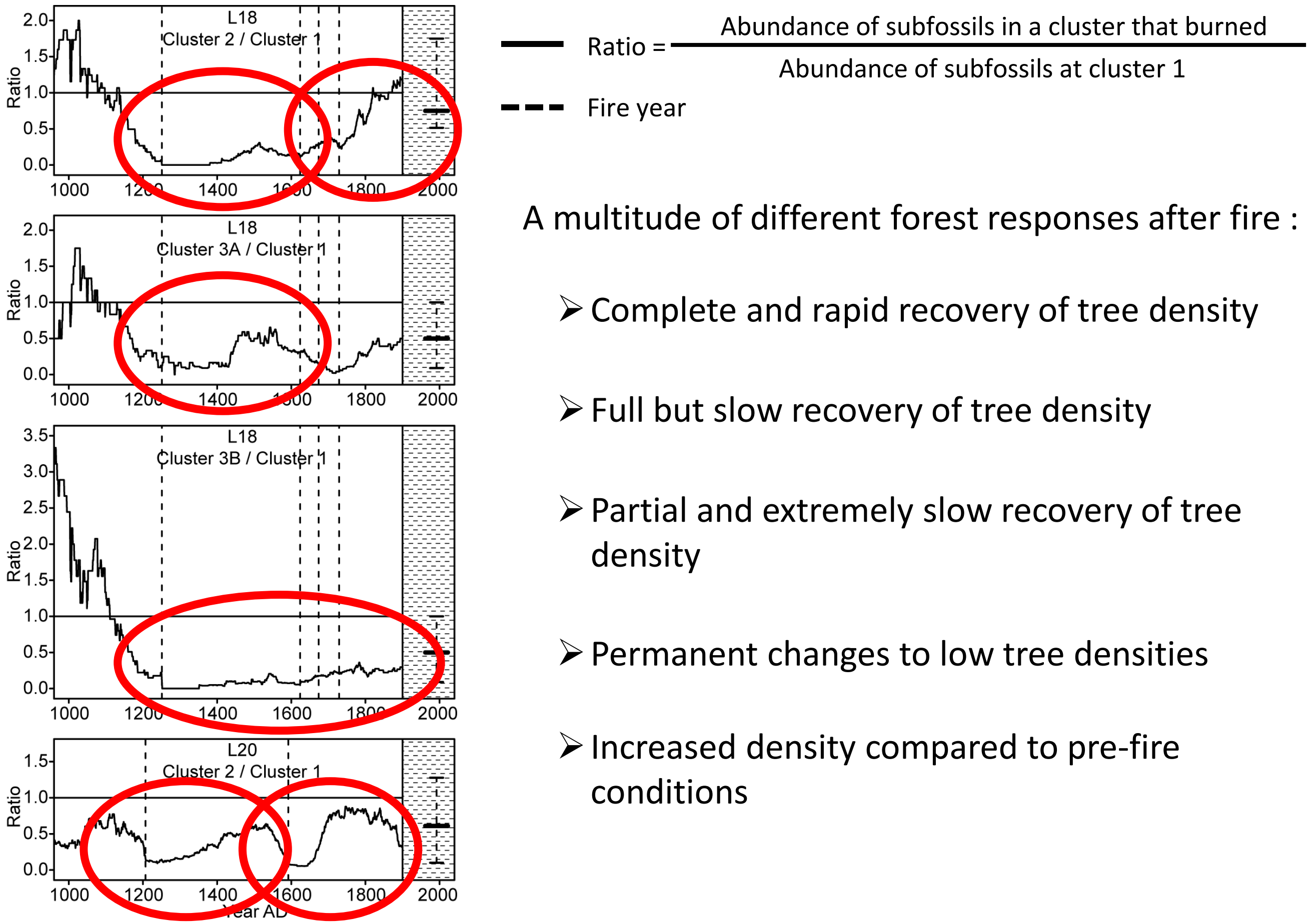
Fire history explains the traits of today's forest

	Cluster 1	**Cluster 2**
Today =	↑ Density of living trees ↑ Dead wood ↑ Fir	↓ Density of living trees ↓ Dead wood ↓ Fir



In the past =	↓ Fire ↑ Tree density	↑ Fire ↓ Tree density

Each fire triggered a specific successional trajectory

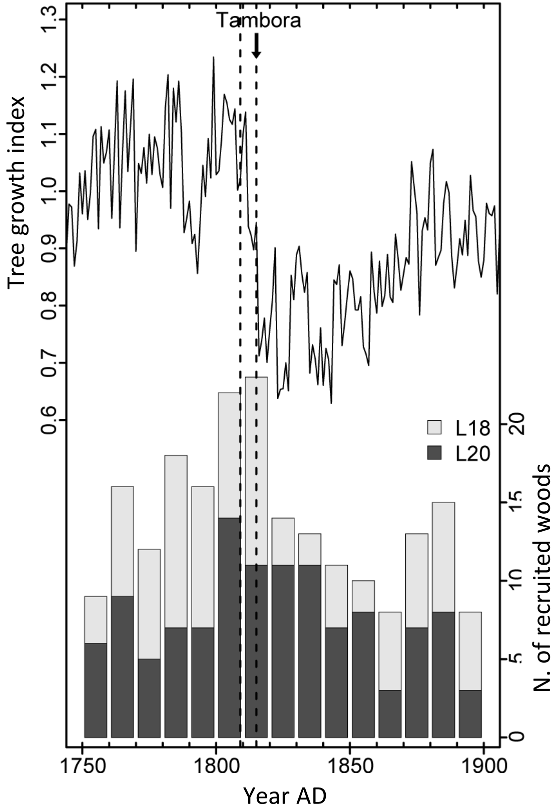


A multitude of different forest responses after fire :

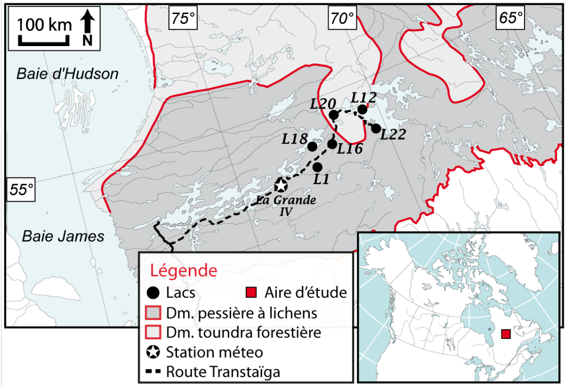
- Complete and rapid recovery of tree density
- Full but slow recovery of tree density
- Partial and extremely slow recovery of tree density
- Permanent changes to low tree densities
- Increased density compared to pre-fire conditions

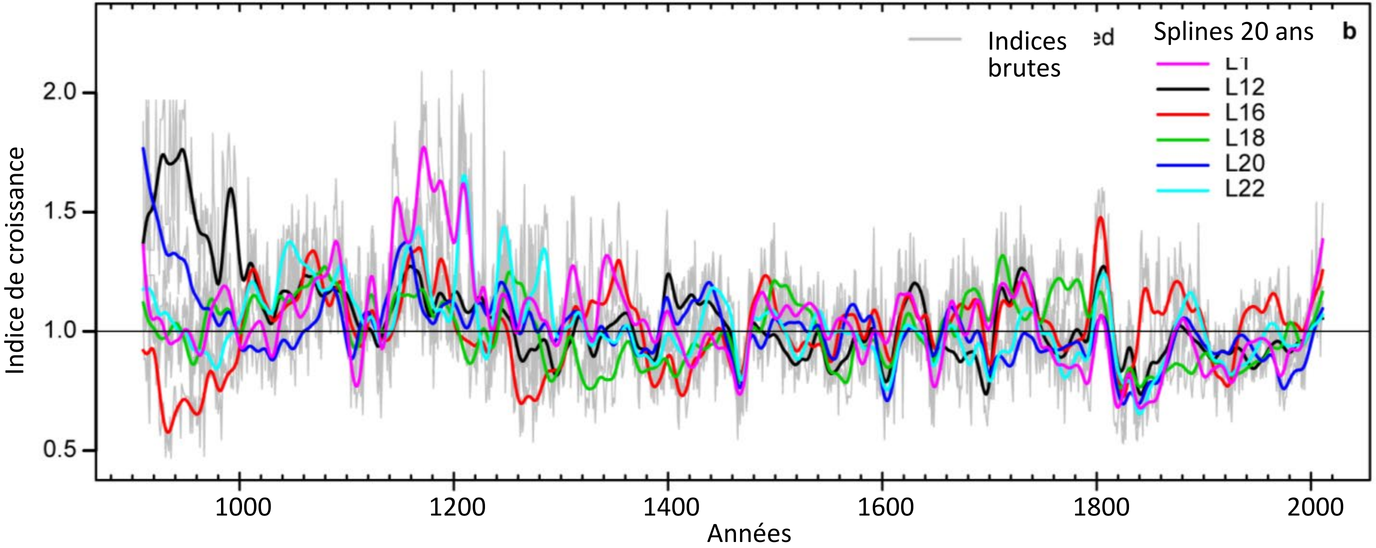
Impact of climate on forest dynamics

A cold period following volcanic eruptions (1809 and 1815) coincided with a sharp reduction in growth and a peak in tree mortality



Dendroclimatic reconstructions

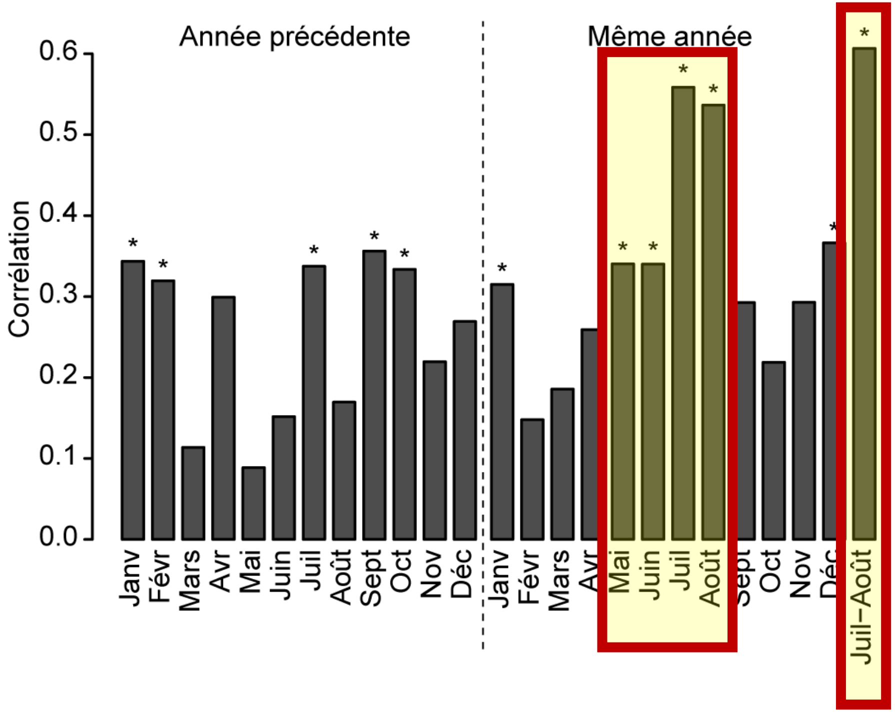


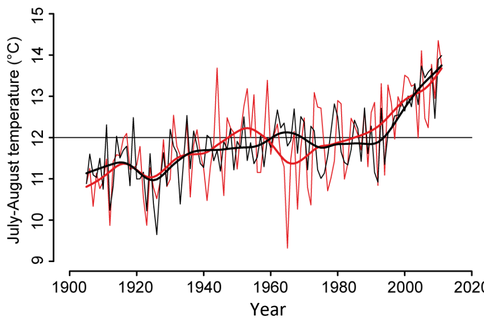


Gennaretti, F., Arseneault, D., Nicault, A., Perreault, L., & Bégin, Y. (2014). Volcano-induced regime shifts in millennial tree-ring chronologies from northeastern North America. *Proceedings of the National Academy of Sciences*, *111*(28), 10077–10082. doi: 10.1073/pnas.1324220111

Sensitivity to summer temperatures

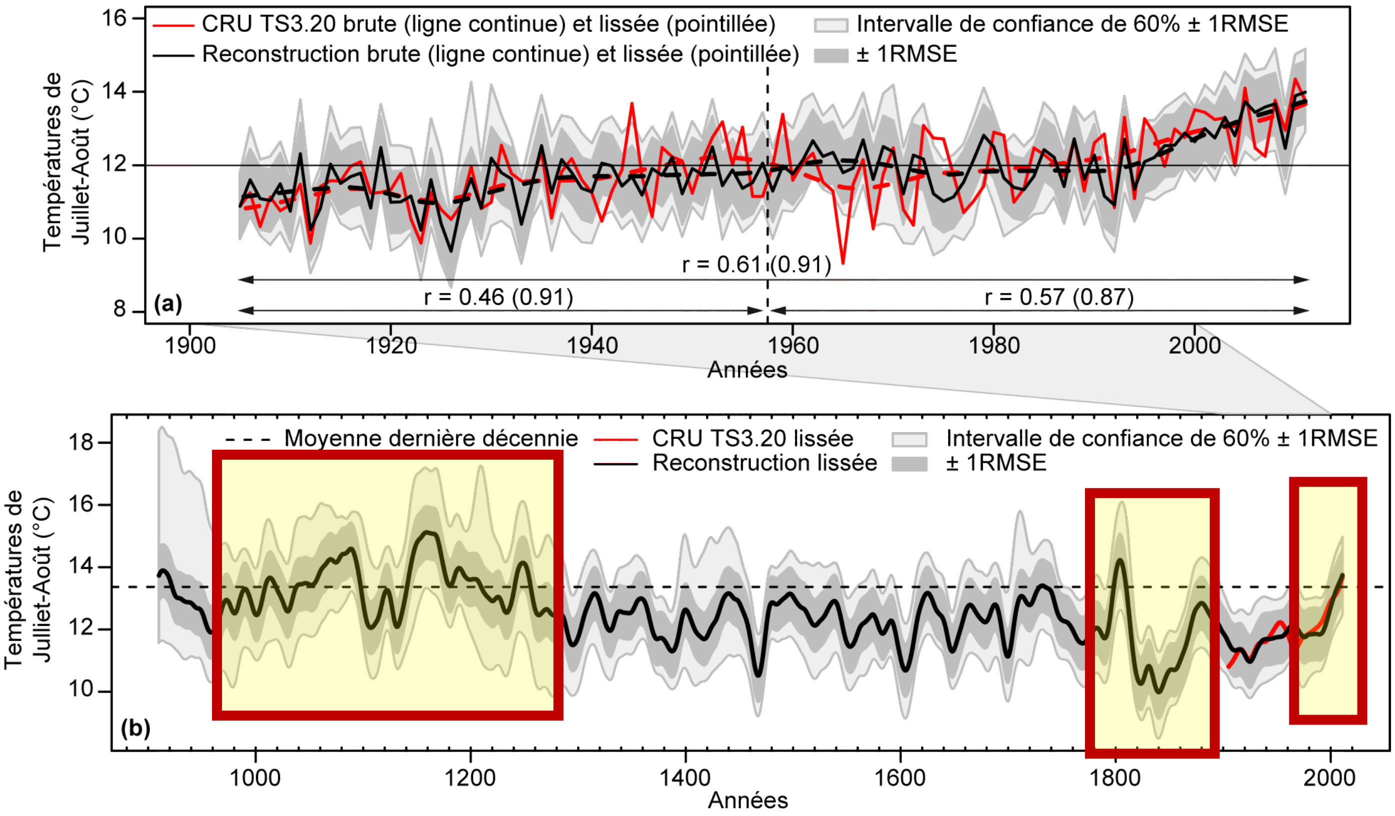
Correlation between chronologies and monthly temperatures of the last century
(climate data: CRU TS3.20)



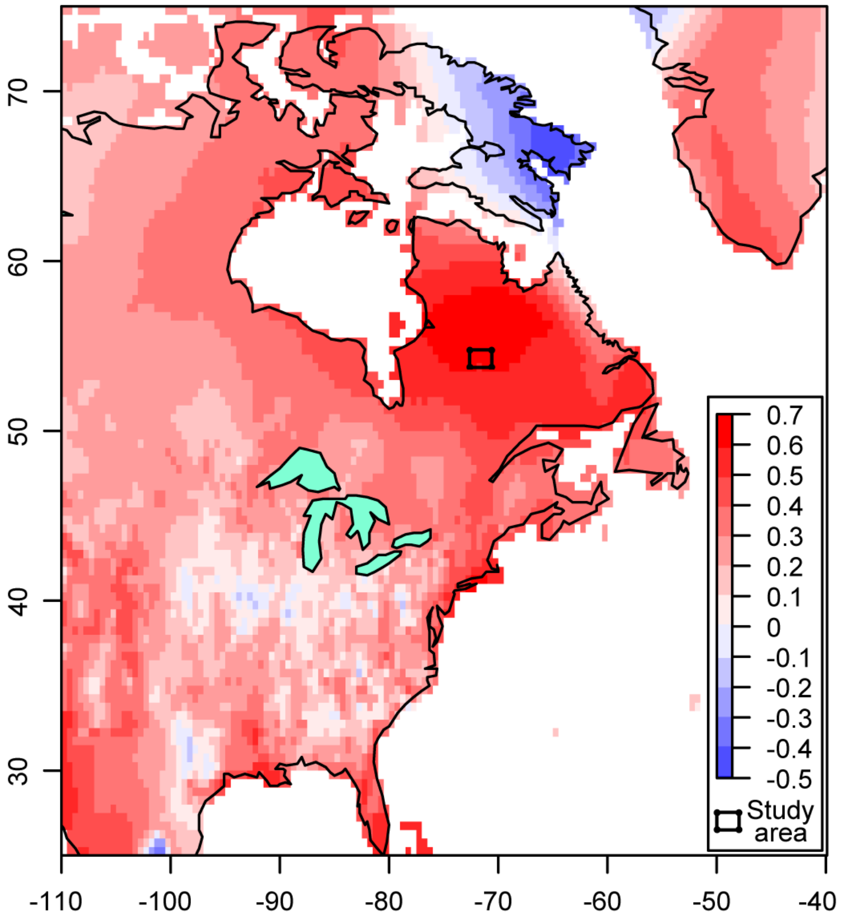


* $p < 0.001$

Summer Temperature Reconstruction for Eastern Canada (STREC)



The spatial domain of the reconstruction



Spatial variation in correlations between reconstructed and observed temperatures (1905-2011)

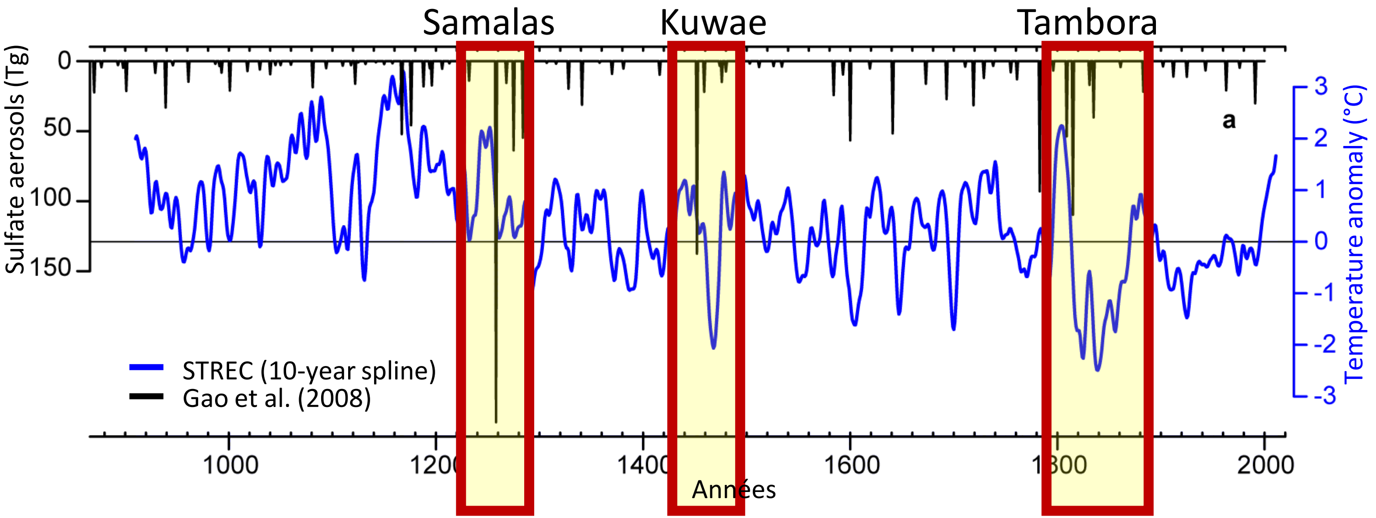
The contribution of volcanism on climate variability

Are climate simulations and dendrochronological records able to reproducing the real impact of volcanism on climate?

Does volcanism have short- or long-term effects?

Influence of volcanic forcing over decades

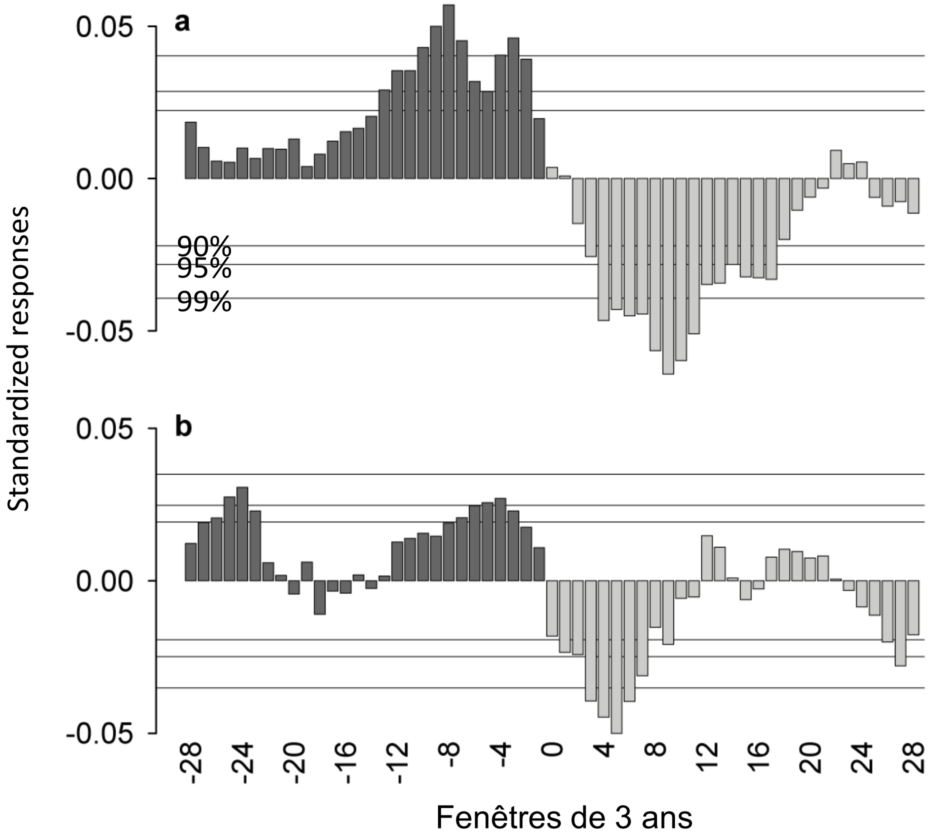
Volcanic injections of sulphate aerosols in the stratosphere (Gao et al. 2008)



Year →	1257	1452	1809 et 1815
ΔT →	-1.3 °C	-1.7 °C	-3.0 °C
Significance (p) →	< 0,001	< 0,001	< 0,001

Influence of volcanic forcing at decadal scale

Superimposed epoch analysis



STREC response to the ten strongest eruptions of the last 1000 years

STREC response to 10 very strong eruptions (intensity just a little lower than the previous ones)

Longer-term impact of volcanic forcing

Bayesian model (HMM) for detecting regime shifts in STREC