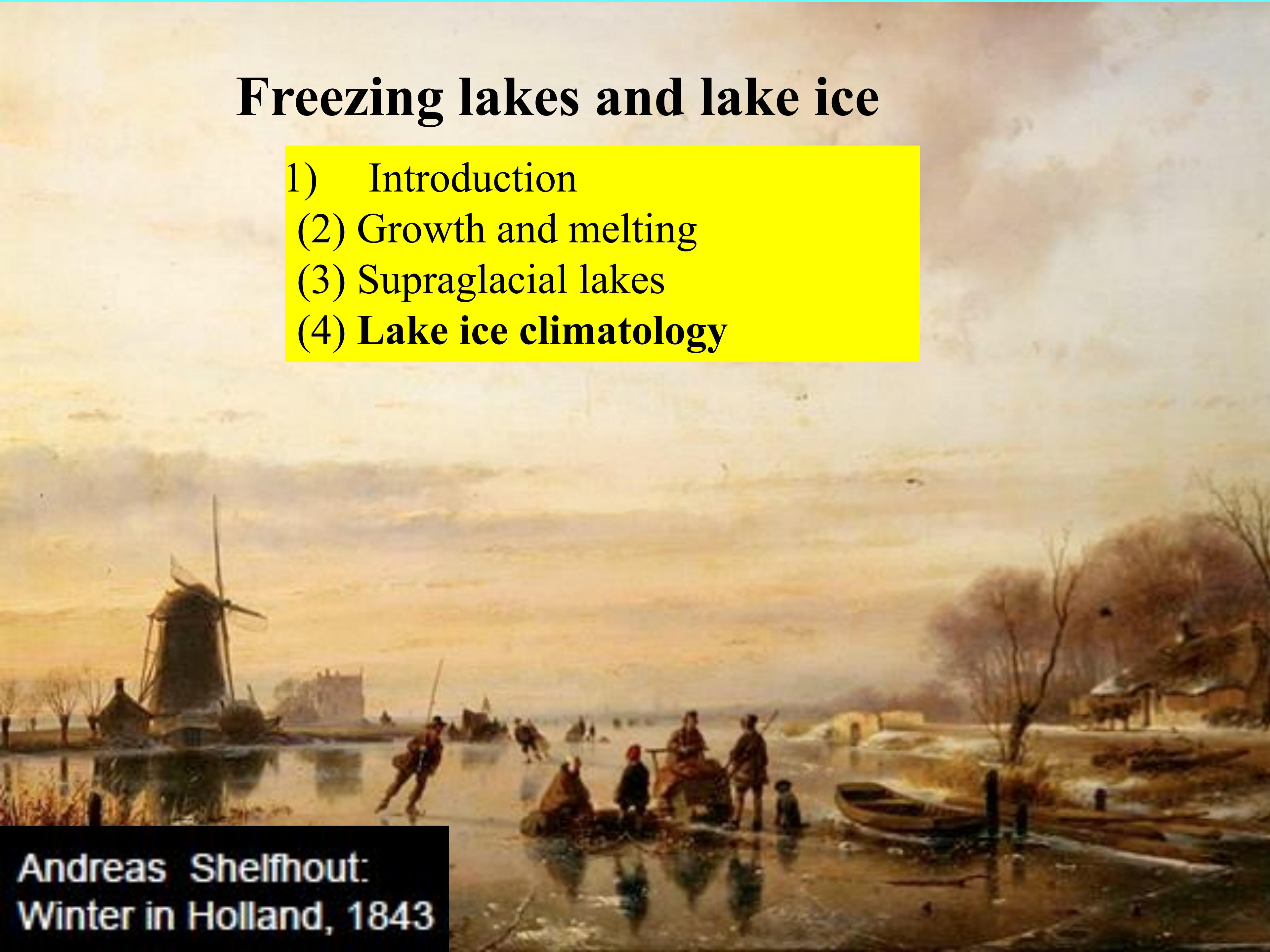
Freezing lakes and lake ice

1) Introduction
(2) Growth and melting
(3) Supraglacial lakes
(4) **Lake ice climatology**

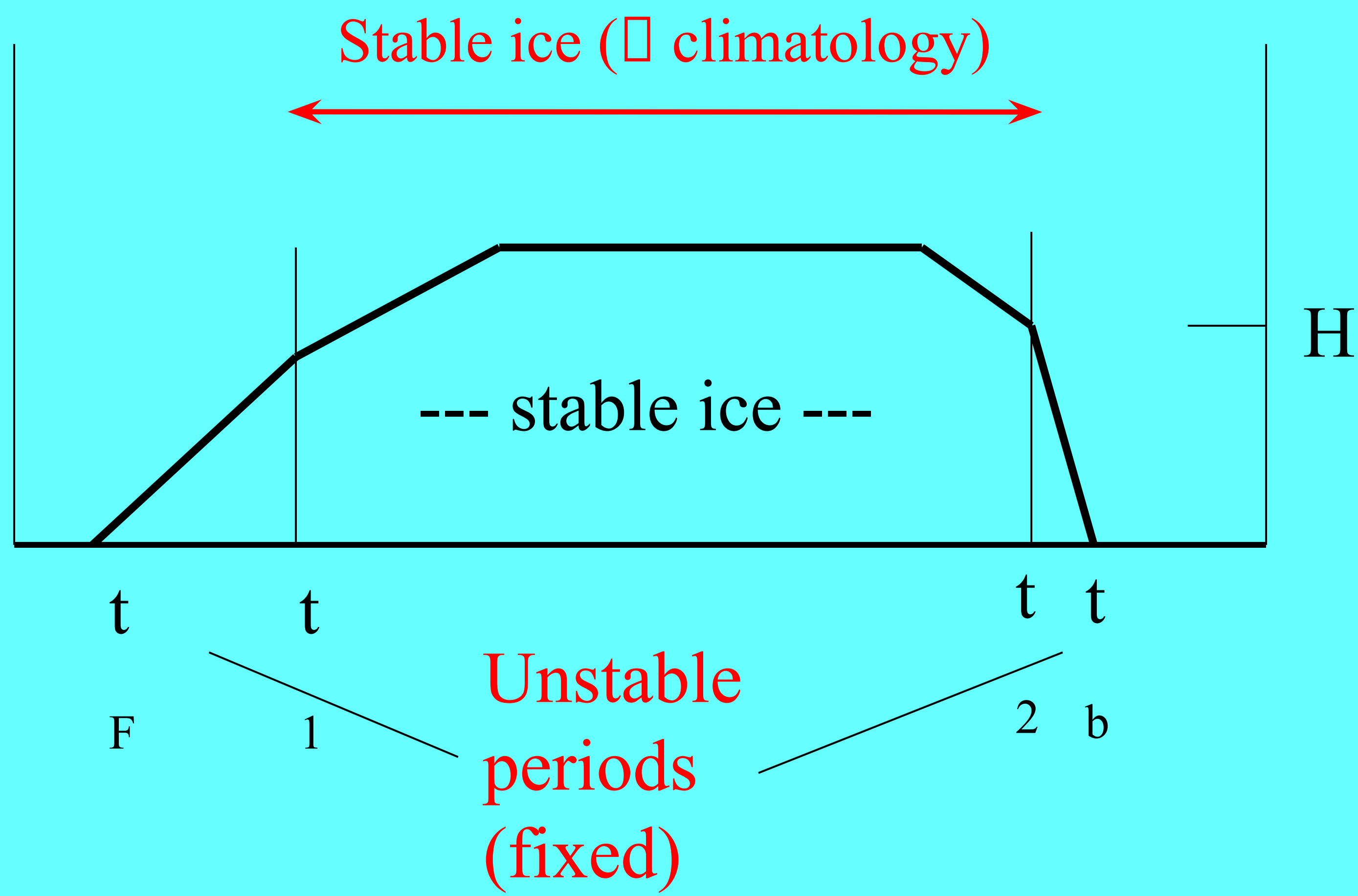


Andreas Shelfhout:
Winter in Holland, 1843

Lake ice season

H = min thickness
for stable ice,
10 cm (small lakes)–
50 cm (large lakes).

Ice thickness



Warming climate □ ?

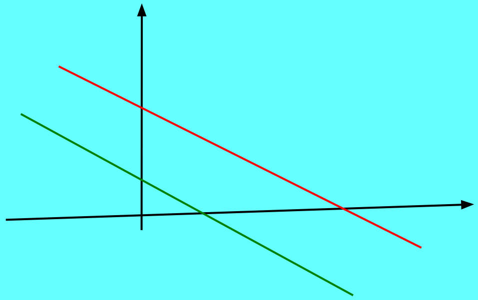
- Will the lake freeze in future ?
- How much are freezing date and break-up date affected ?
- How much is ice thickness affected ? And ice quality?
- Ice cover stability ?
- Ice coverage ?

Ice phenology

- **Freezing date**
- Strongly connected to air temperature (long-wave radiation, turbulent fluxes)
- Connection depends on lake depth
- Freezing after 0^{o}C downcrossing
- Air temperature falling rate major factor

Breakup date

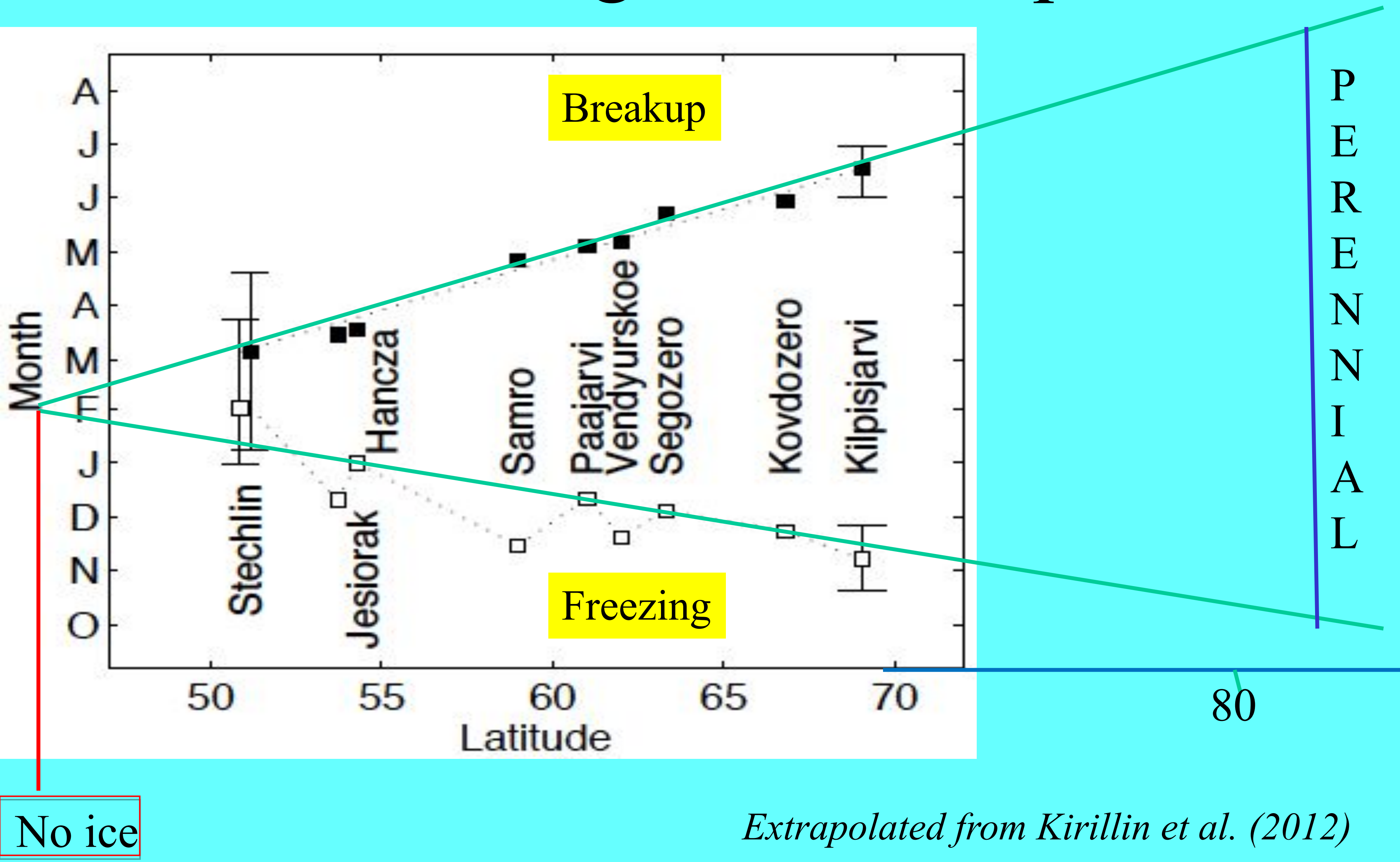
- Solar radiation driving force – no long-term trend
- Ice and snow thickness – weak positive trend
- Turnover day from negative to positive heat balance key factor
- Degree-days correlate with net solar flux



time

Thickness $\sim \sqrt{\text{freezing-degree-days}}$

Freezing and breakup



Extrapolated from Kirillin et al. (2012)

Lake ice time series

Ice phenology

-freezing date

-breakup date

How to define?

Ice cover properties

•Ice thickness – max annual value

•Ice concentration (large lakes)

Variability

-independent winters

-interannual variability externally forced

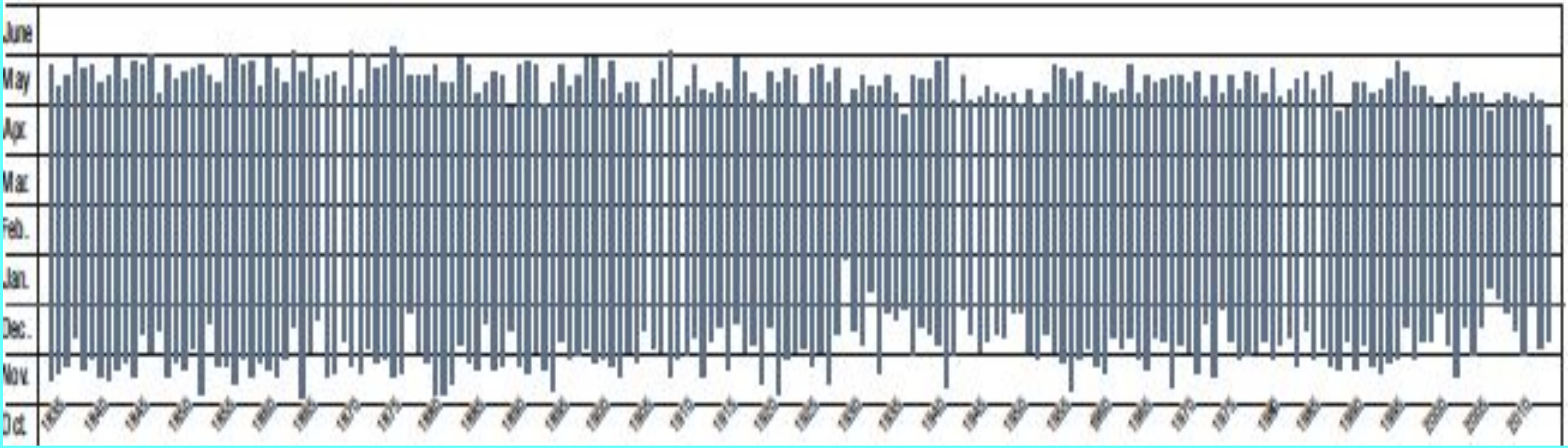
□*Aperiodic time series outcome*

-weak intra-seasonal connections

Lake Kallavesi, Finland 1830 – 2014

Breakup

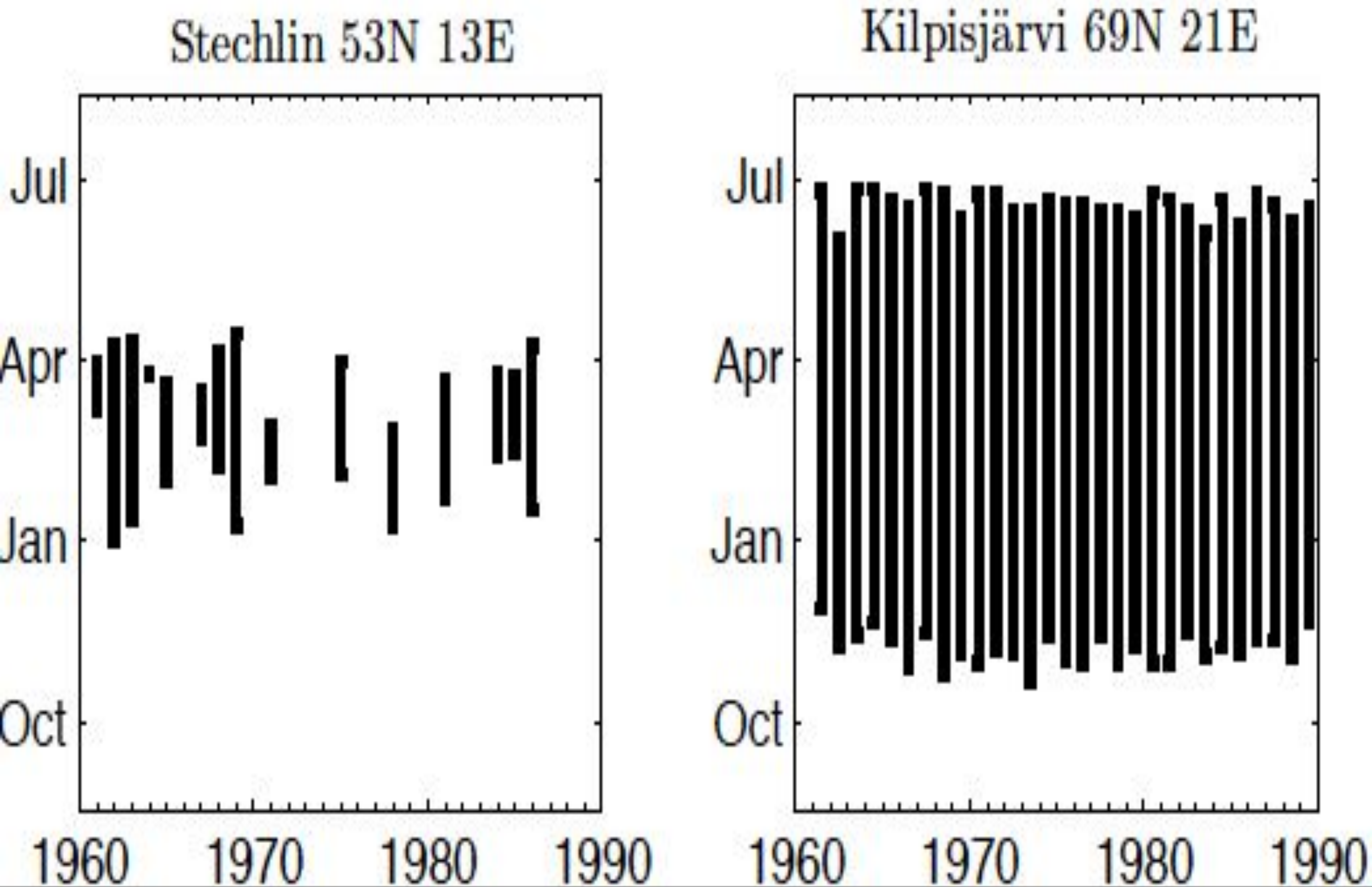
- Trend 10 days/100 years
- Aperiodic
- Variability 45 days



Freezing

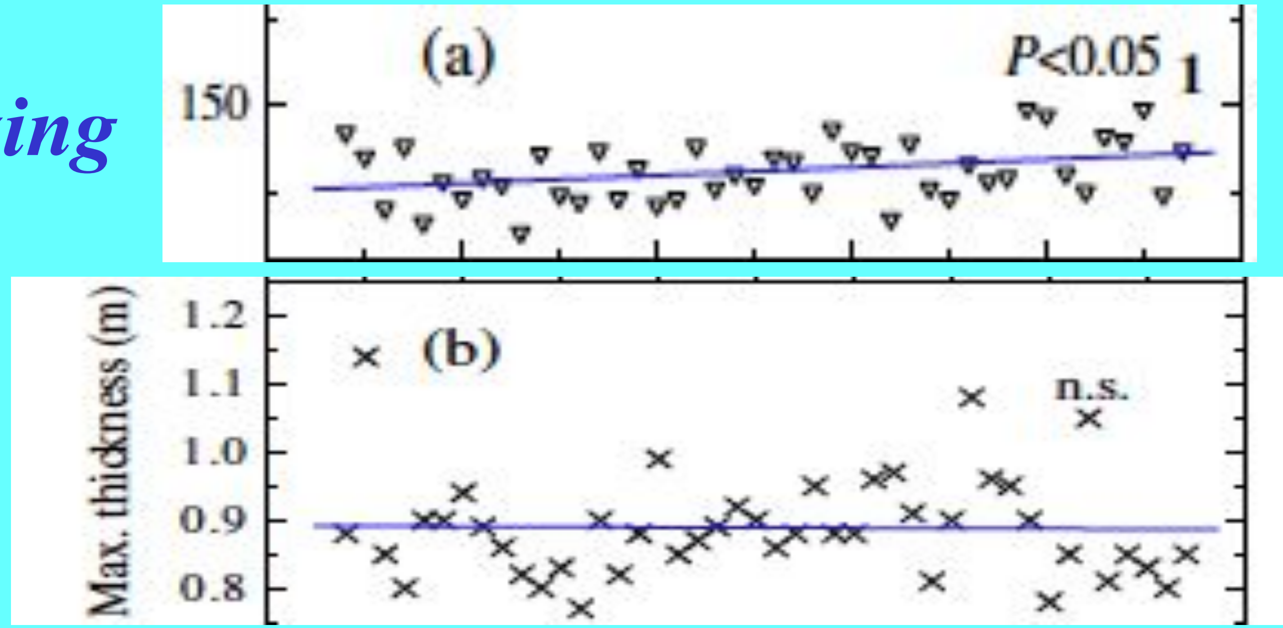
-Trend 10 days/100 years
-Aperiodic
-Variability 80 days
-Extrema far from mean

Colder climate less variability Kirillin et al. (2012)

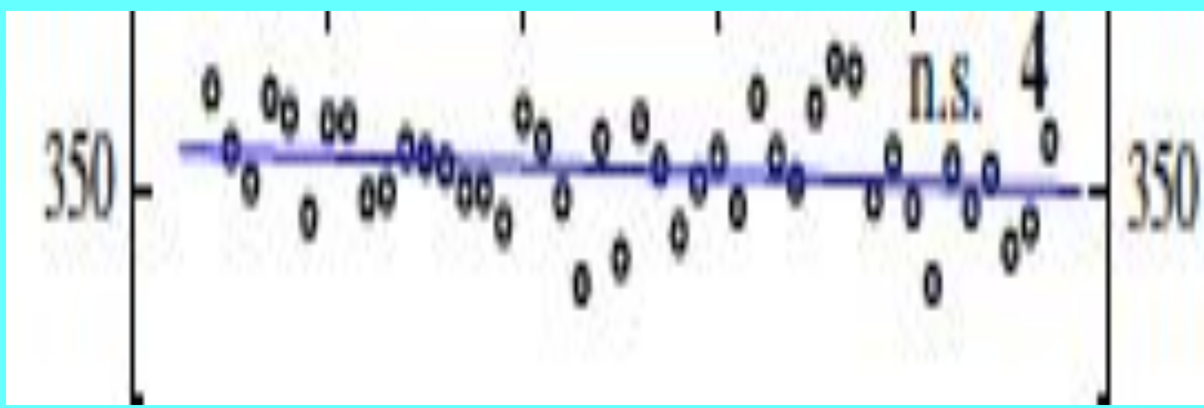


Kilpisjärvi trends 1952 – 2010 (Lei et al., 2012)

Freezing date



Breakup date



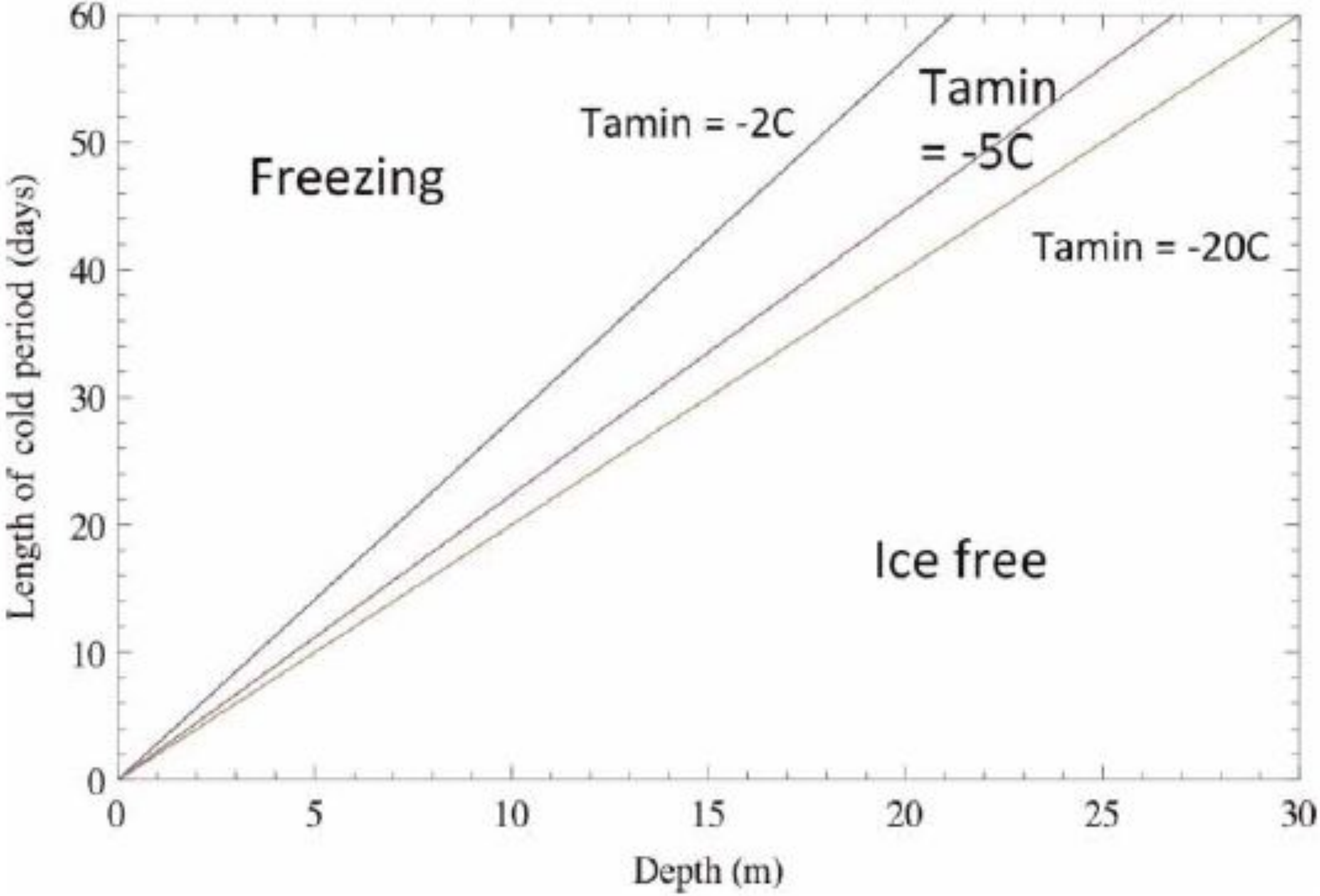


Figure 1 | Freezing conditions for lakes as a function of the lake depth and length of the cold period ($T_a < 0\,^{\circ}C$).

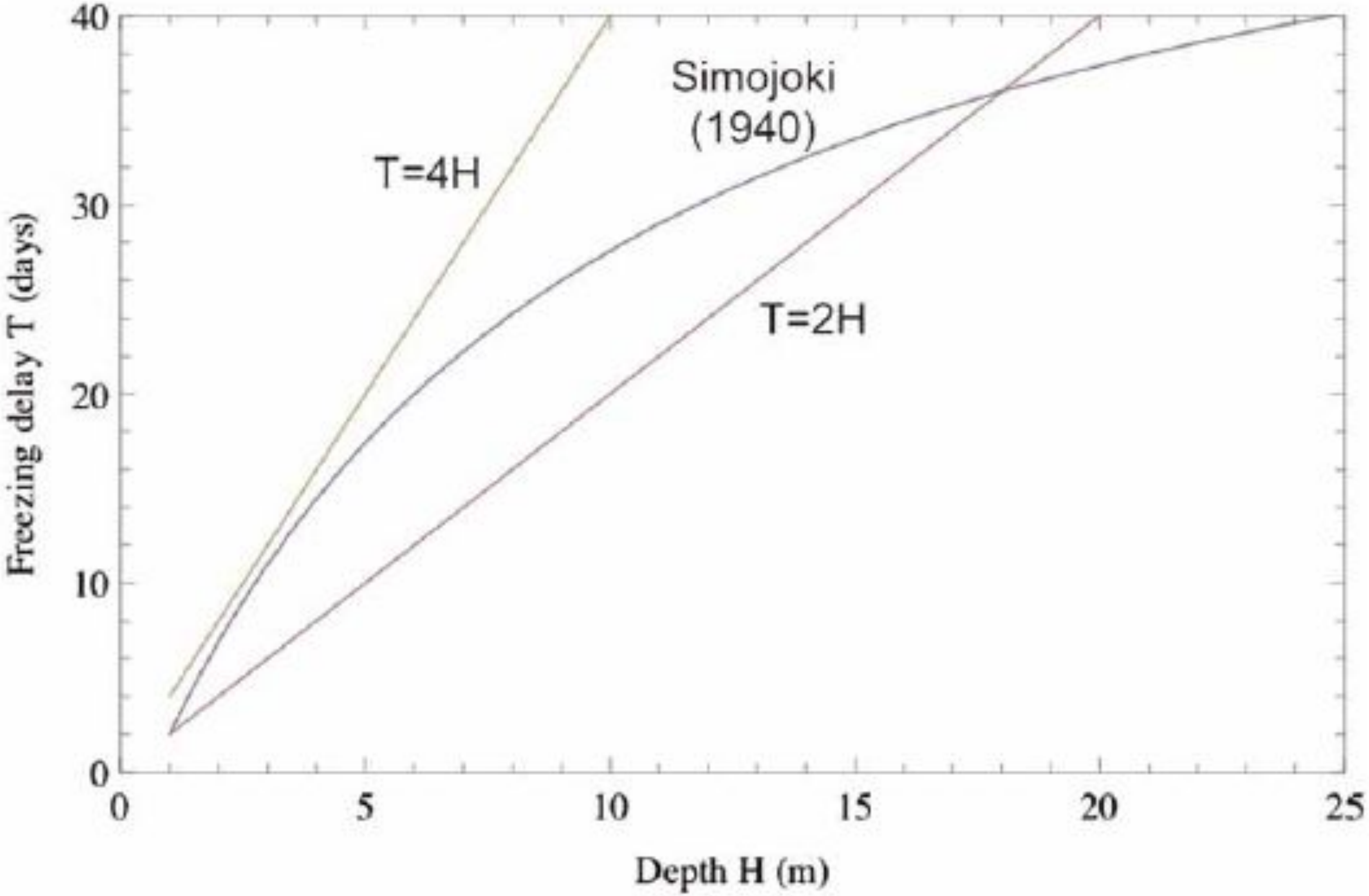
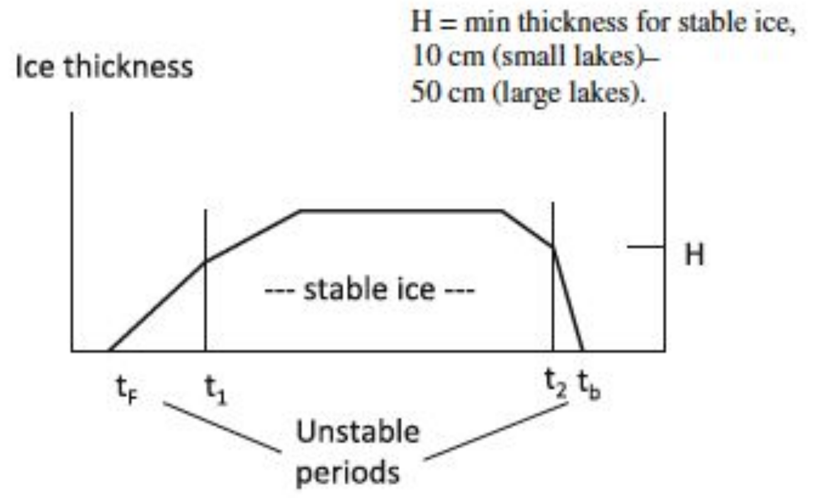


Figure 2 | Delay of the freezing date from the air temperature downcrossing of 0 °C as a function of the mixed layer depth (H) of the lake. The empirical curve of Simojoki (1940) is shown together with lines T[days] = 2 H[m] and 4 H[m].

1^{st} order: climate change impact



- **Freezing date**

  ~ 5 day/°C

$$\Delta t_F = \frac{\Delta T_a}{\dot{T}_a}$$

- **Ice thickness**

  5–10 cm/°C

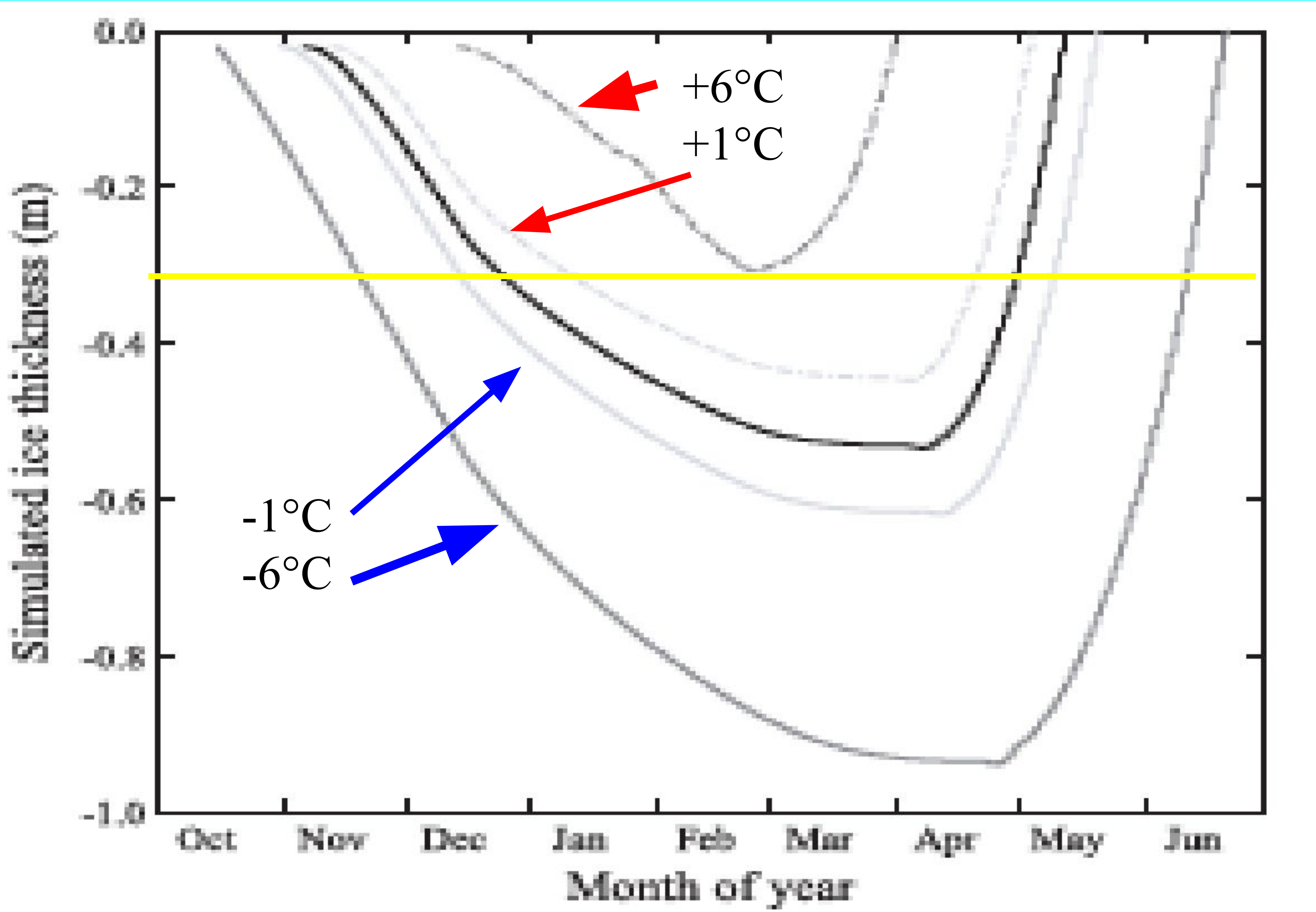
$$\frac{h_2}{h_1} = \frac{a_2}{a_1} \cdot \left(1 + \frac{\Delta T_a}{T_{a,\min}}\right)^{\frac{1}{2}}$$

- **Breakup date**

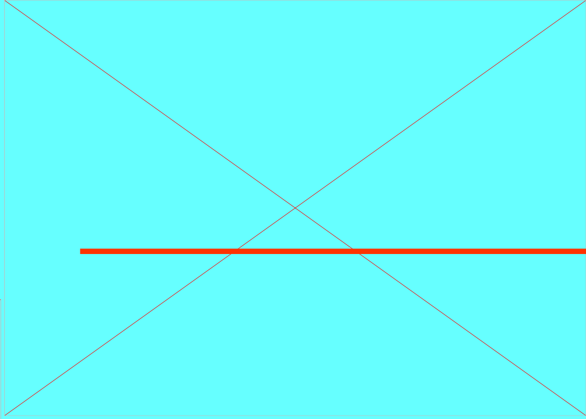
~ *n* days after zero upcrossing of heating

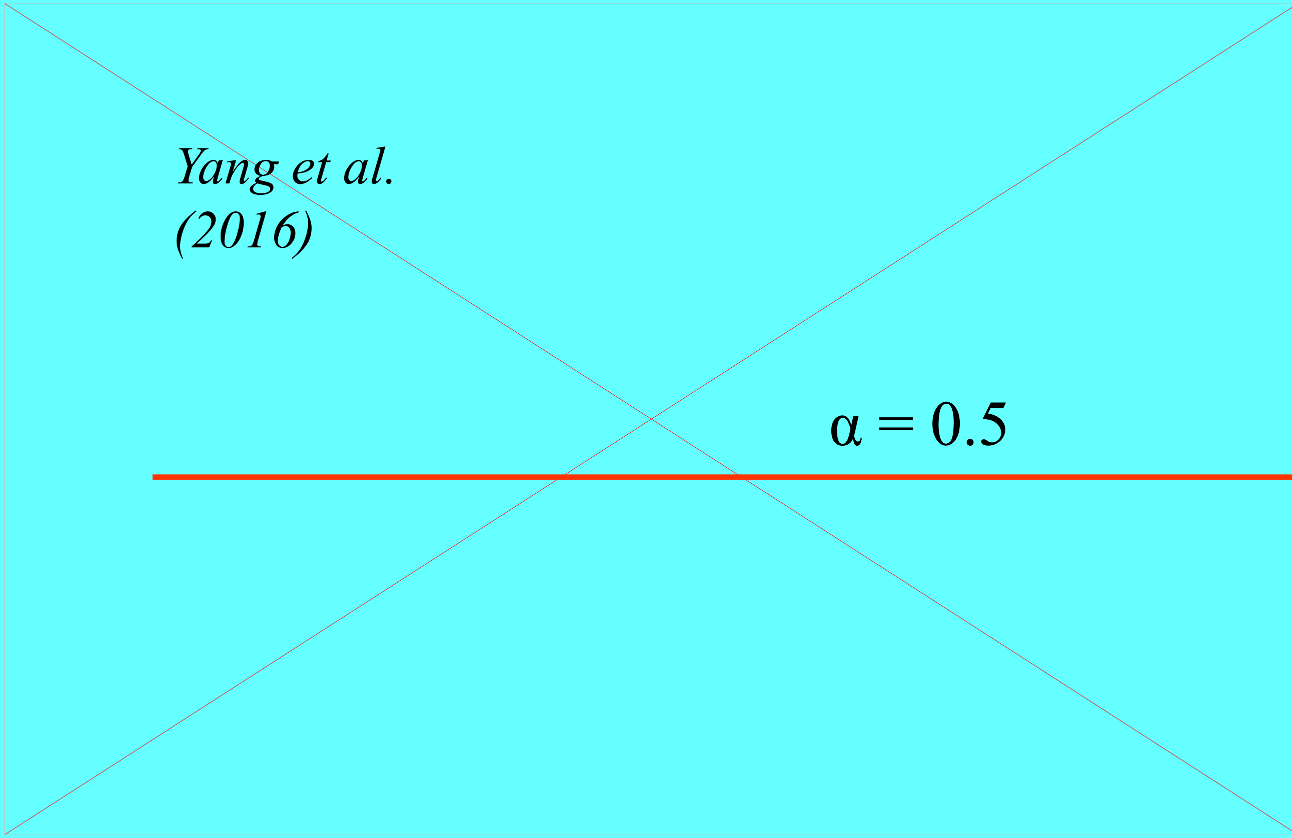
$$t_b - t_m = \left[\frac{3}{\mu c}(\rho L h_0 - k_1 R)\right]^{\frac{1}{3}}$$

Lake Vanajavesi: model for climate change impact



Ice thickness cycle – albedo sensitivity, Prydz Bay





α = 0.7

α = 0.6
α = 0.5

Polar ice does not melt fully but breaks due to internal deterioration. Light transmissivity of ice also has an important role.

Lake Ladoga: Finnish – Soviet – Russian data

1913 – 1937
Ice charts and reports

1943 – 1992
Aircraft observations
-Approx. twice a month
-Plots of ice distribution'

1971 ->
-NOAA and MODIS satellite images
-On average 19 images /winter

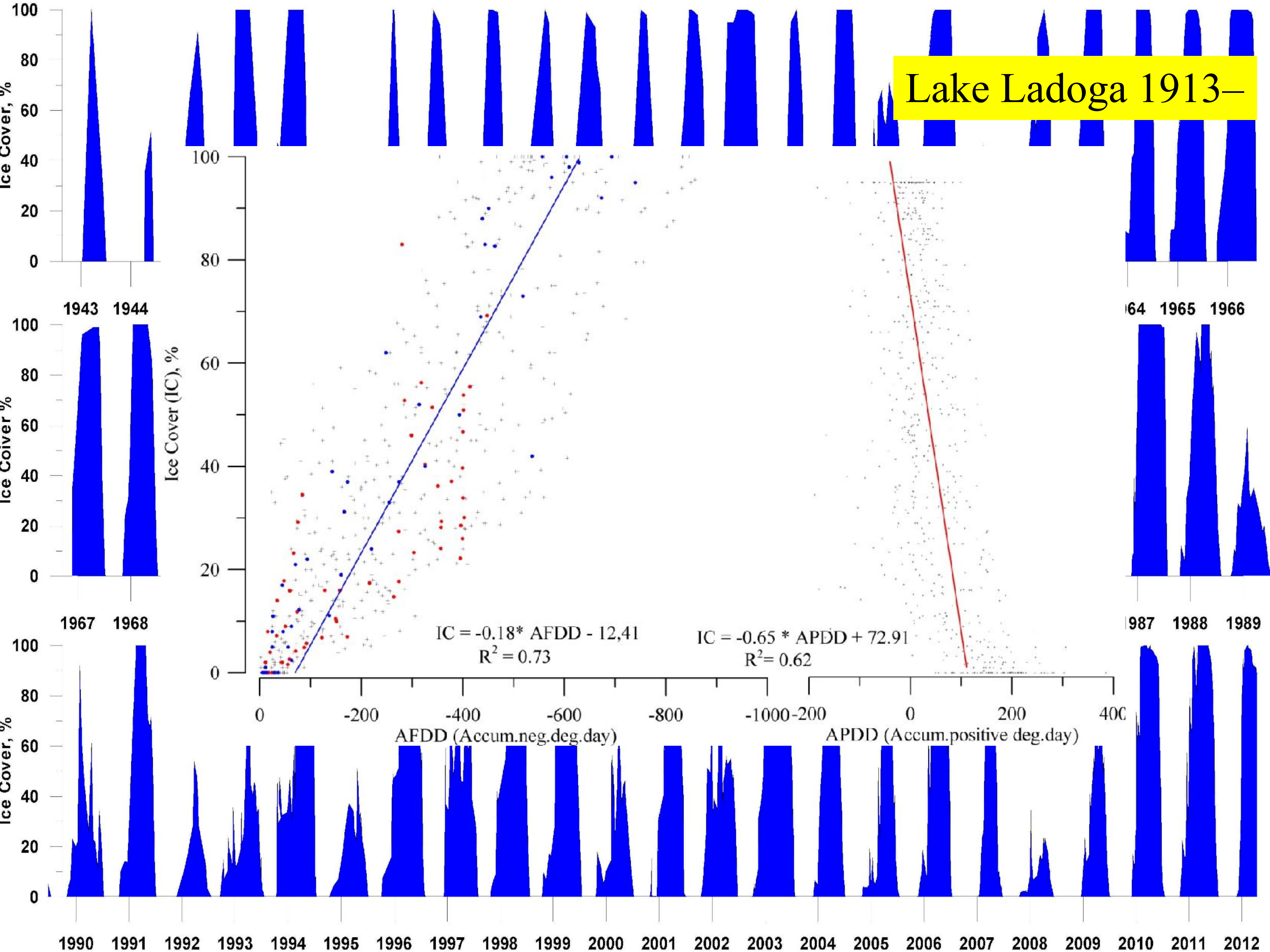
Ice concentration A

- A = relative area of ice in the lake
- Freezing □ depth: t = F(h)
- Hypsographic curve = G(h)

Formally:

$$A(t) = G[F^{-1}(t)/\max(h)$$

Thus fall evolution of ice concentration is related on the hypsographic curve. Also decrease of concentration depends on that as melting starts From shallow parts. Wind and lake size add further modifications.


Lake Ladoga 1913–
Ice Cover, %
Ice Coiver %
Ice Cover (IC), %
1943 1944
1964 1965 1966
1967 1968
1987 1988 1989
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
IC = -0.18* AFDD - 12,41
R^2 = 0.73
IC = -0.65 * APDD + 72.91
R^2 = 0.62
AFDD (Accum.neg.deg.day)
APDD (Accum.positive deg.day)

Summary: warming (?)

- Freezing day delays
- Max annual ice thickness likely decreases
- Ice quality (congelation ice/snow ice) ?
- Period of stable ice cover shortens
- Transient open water periods in smaller lakes than presently
- Ice breakup date likely earlier

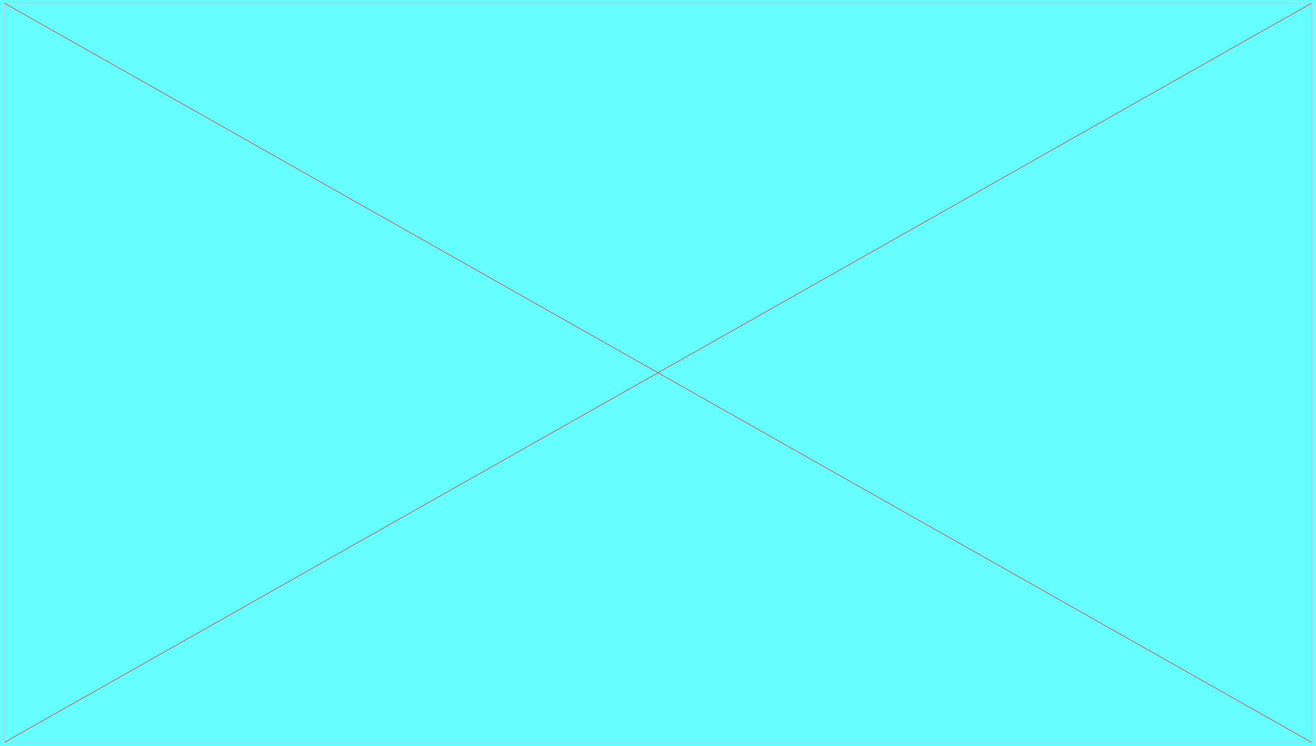
… consequences to water body

- Shorter ice season

AND

- More sunlight
- More transient open water periods
- Improved oxygen level
- How winter ecology will be adapted?

Climate warming □ Lake seasons



Annual cycle:
qualitative changes
-Summer stratification stronger
-Stable ice period shorter

Lake ice and society: climate change impact

- Lake ecology (+/- ?)
- Traffic on-ice
- Recreation: sport, fishing ice-water bathing
- Local weather changes warmer surfaces
- Open areas may persist moisture fluxes, frazil ice
- *Snow is main question!*

Jacob Grimmer: Winter (1500s)

If the climate changes, not only the length of ice season and the thickness of ice change, but the quality of physics, ecology and practical life will be different.