

Lake-Atmosphere Interactions at High Latitudes

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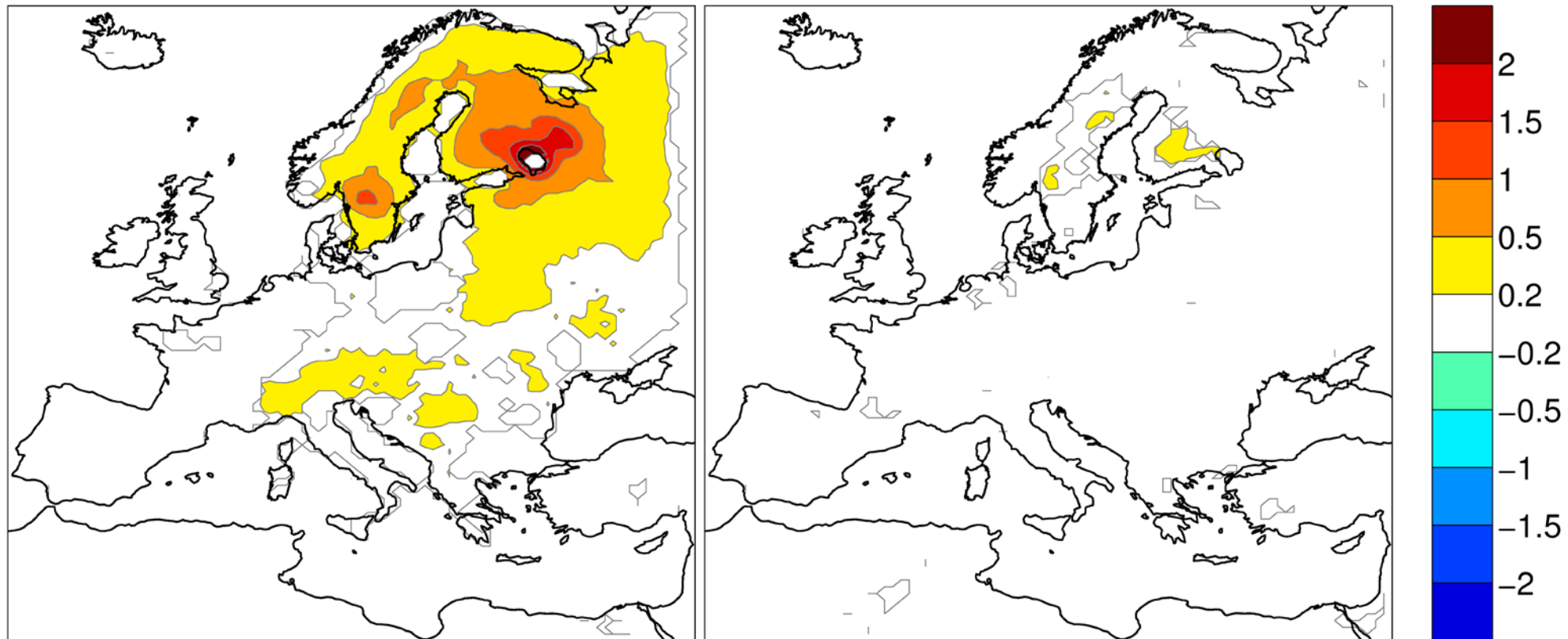
2017 Connaught Summer Institute in Arctic Science
Alliston, Ontario, 17-21 July 2017

Rationale for lake observations

- Ice cover concentration and surface temperature have an important impact on lake-atmosphere interactions (e.g. thermal moderation, lake-effect snowfall) and thus needed for improvement of NWP and climate models
- Ice dates and ice thickness are sensitive indicators (integrators) of weather/climate conditions
- Changes in ice thickness have implications for the sustainability of winter ice roads used to supply remote northern settlements

Role of lakes

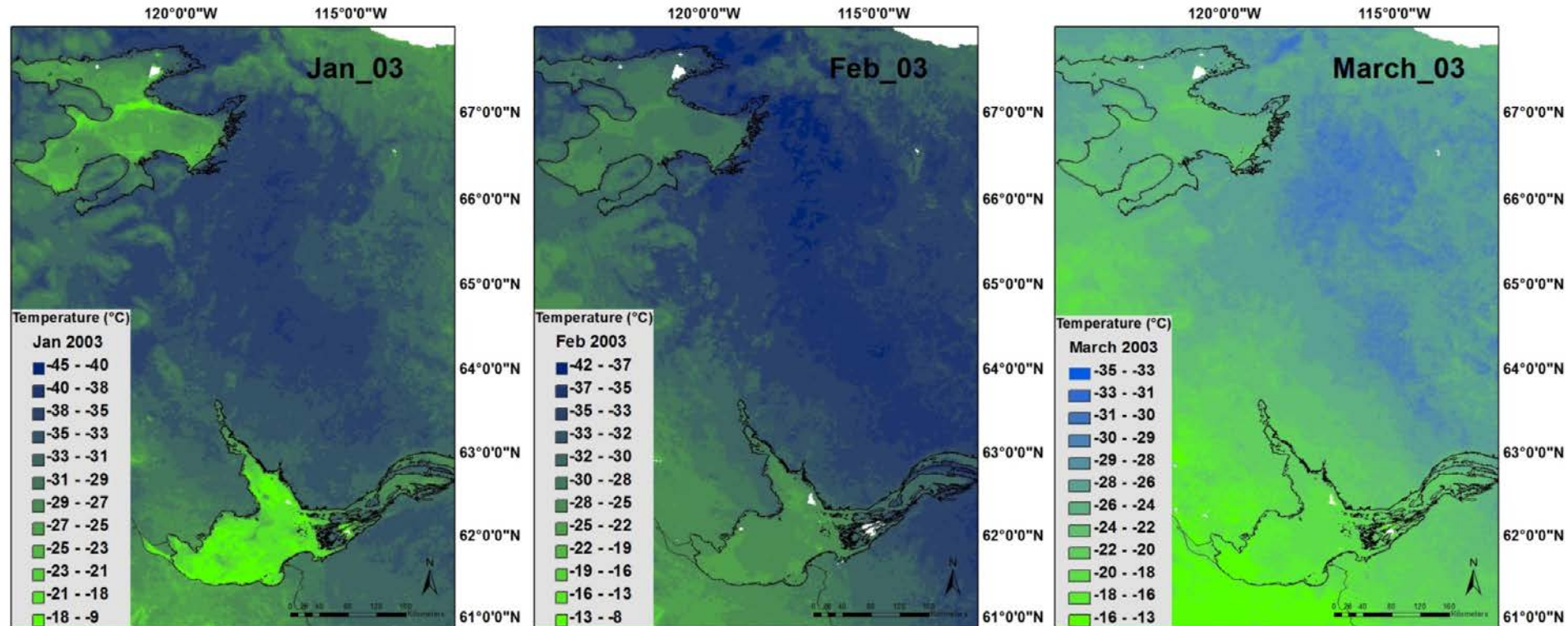
- Thermal moderation (winter & spring) -



Differences in simulated air temperature ($^{\circ}\text{C}$) 2 m from RCA model with lakes (coupled with FLake lake model) and without lakes (open land) for **winter (left) and spring (right) 1961-1990**. Courtesy of P. Samuelsson, SMHI.

Role of lakes

- Thermal moderation (winter) -



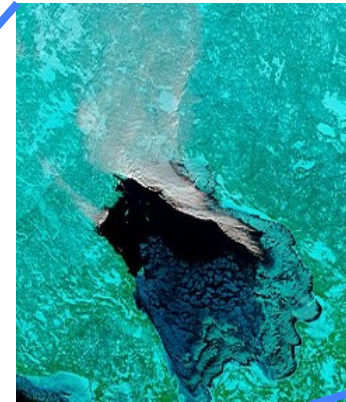
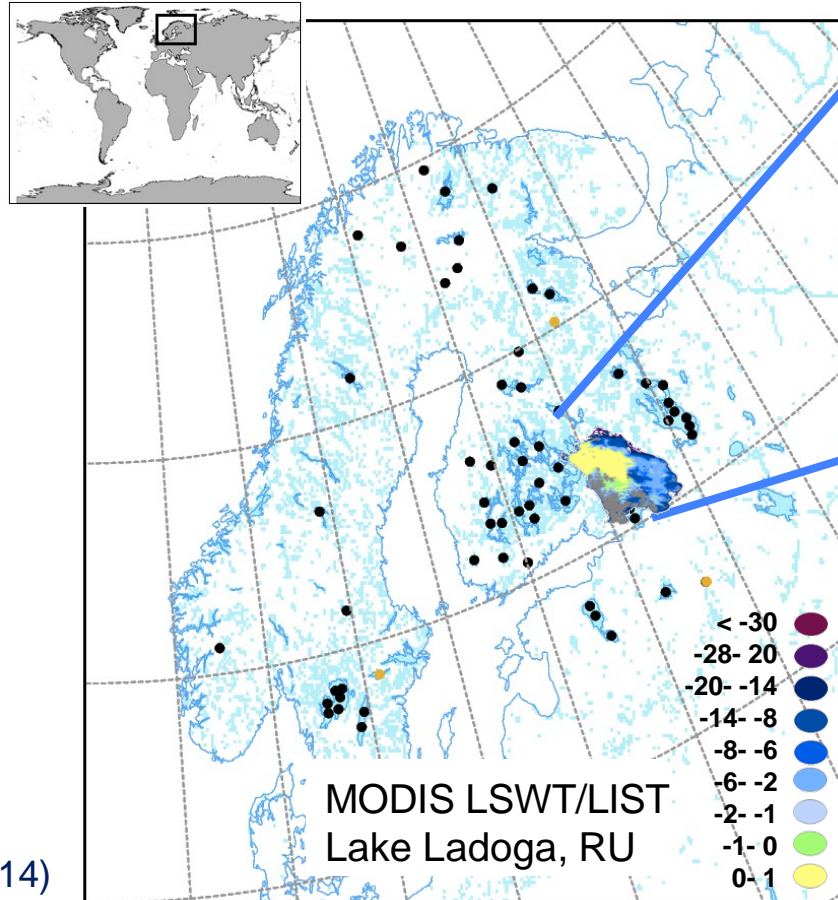
MODIS Land/Lake ice-snow temperature (LIST) in the Great Bear Lake and Great Slave Lake region (January, February, and March, 2003)

Role of lakes

- Thermal moderation (winter cloud cover) -

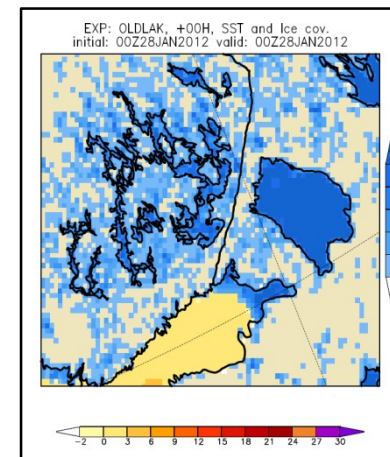
Data assimilation of satellite-derived LSWT/LIST observations into a NWP model (HIRLAM)

70 pixels over 41 lakes chosen for extraction of satellite-derived LSWT/LIST

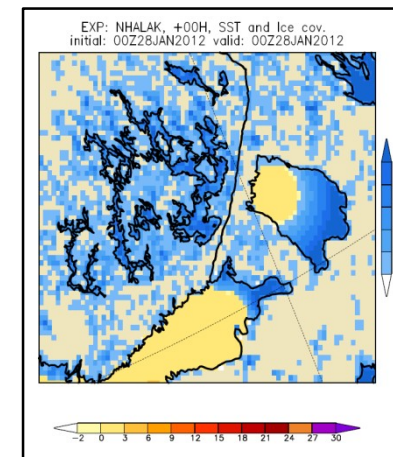


MODIS visible image
28 January 2012
Lake Ladoga (Russia)

Analyzed ice cover
without assimilation

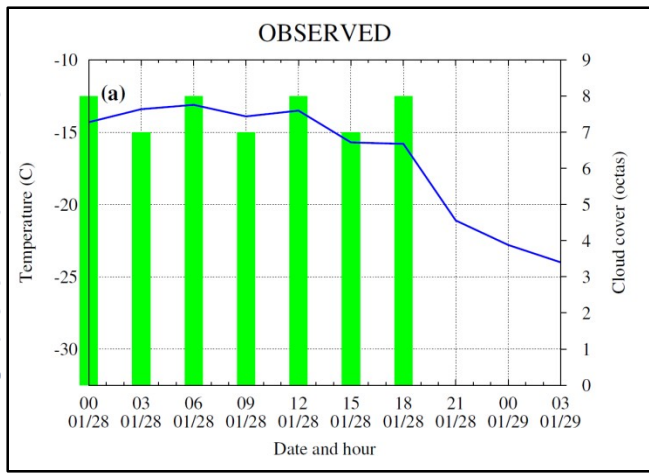


Analyzed ice cover
with assimilation



Eerola *et al.* (2014)

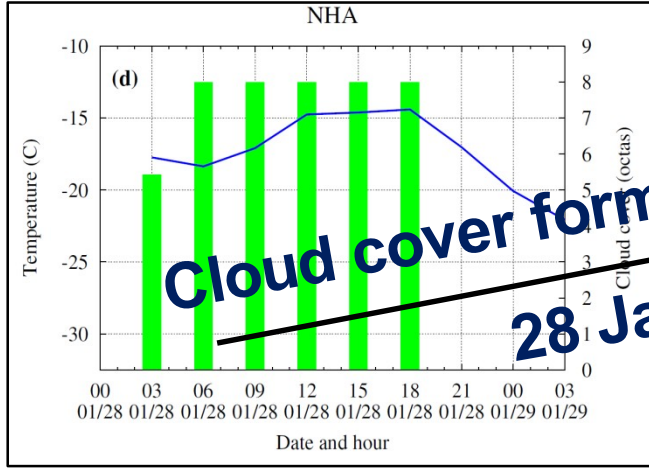
Joensuu station
Observations



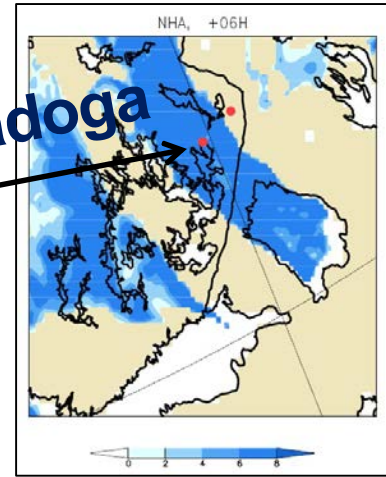
Data assimilation of satellite-derived LSWT/LIST observations into a NWP model (HIRLAM)

Observed and predicted 2-m air temperature and low-level cloud cover at Joensuu station

Predicted with
assimilation

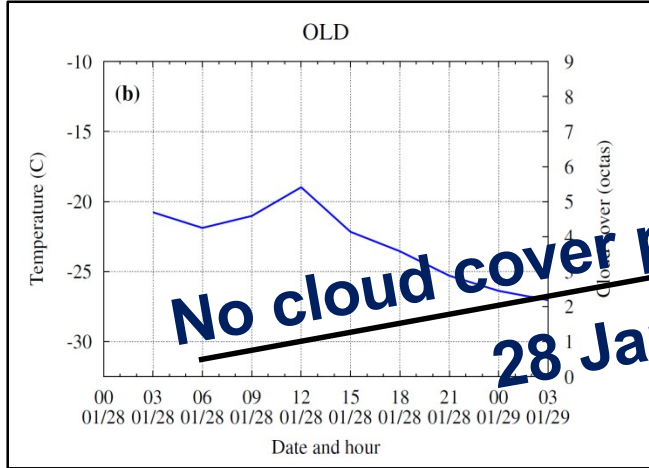


Cloud cover formation over Lake Ladoga
28 Jan 2012 - 06 UTC

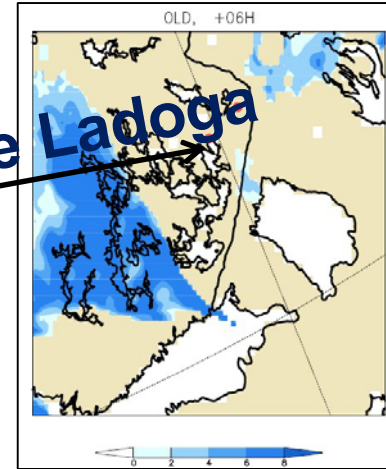


Predicted with
assimilation

Predicted without
assimilation



No cloud cover predicted over Lake Ladoga
28 Jan 2012 - 06 UTC

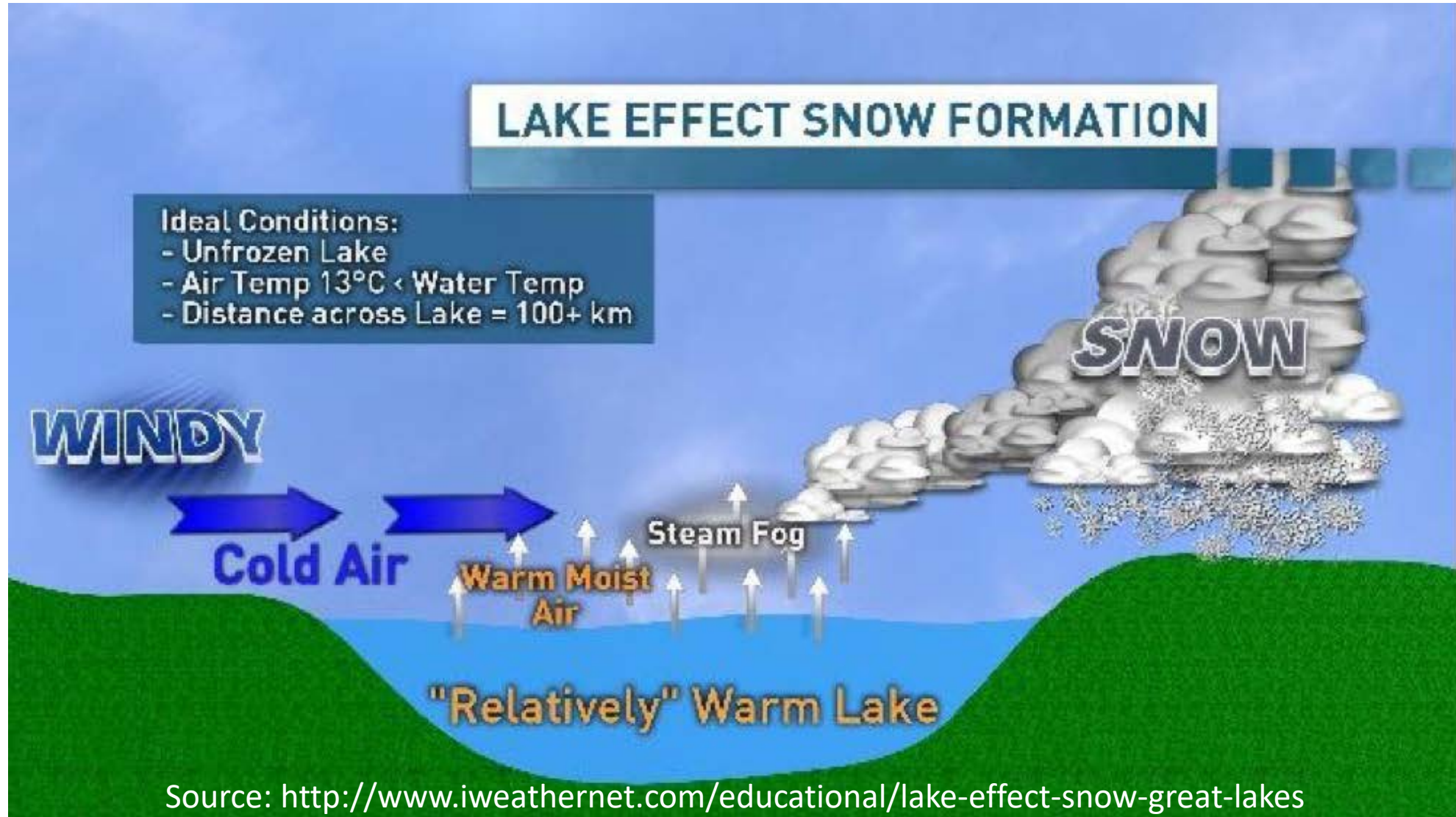


Predicted without
assimilation



Role of lakes

- Lake-effect snow (fall & winter) -



Role of lakes

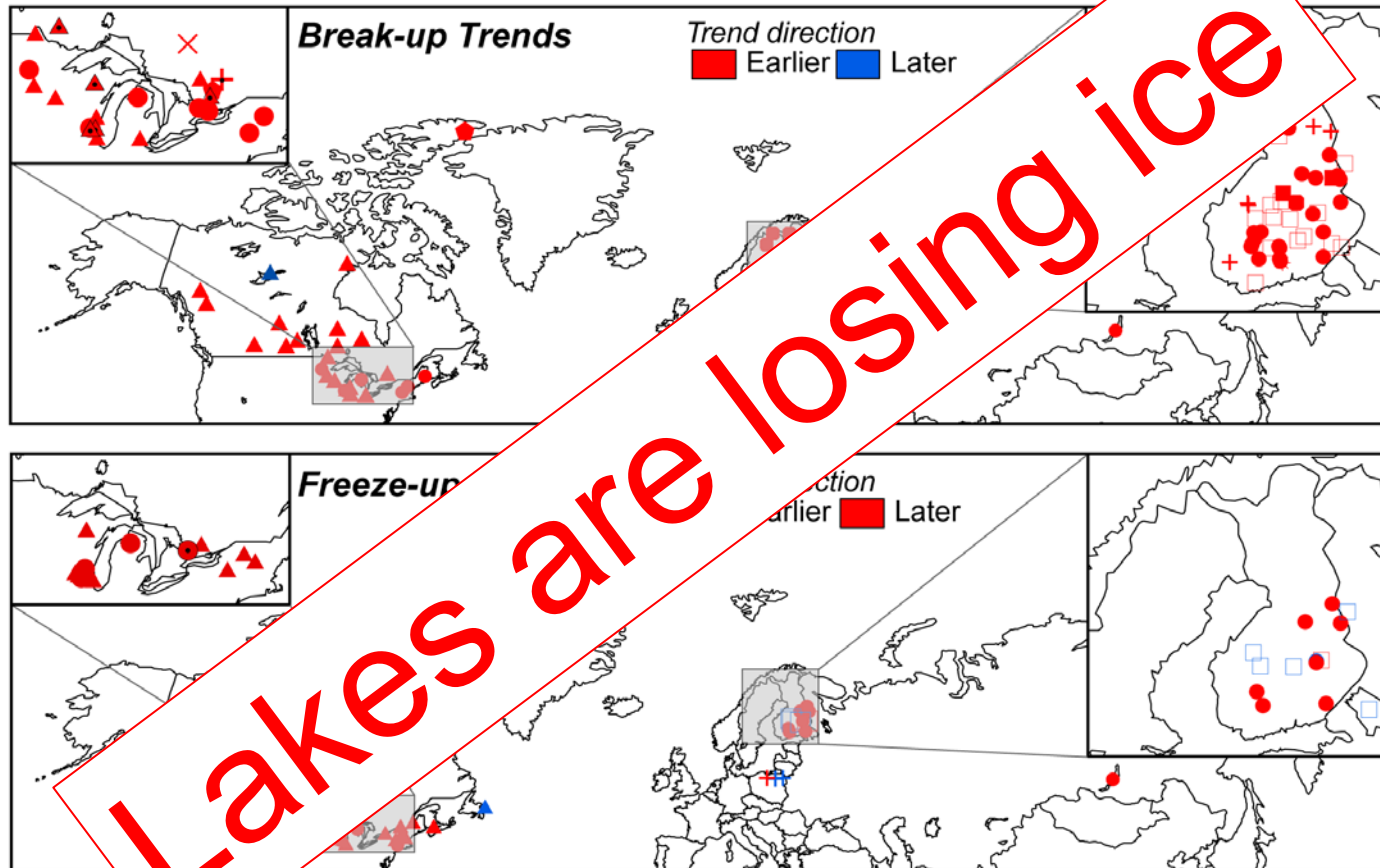
- Lake-effect snow (fall & winter) -



<https://www.youtube.com/watch?v=gee6je0YX1U>

Buffalo – November 2014

Response of lakes - Ice



Time span analysis

× 1990 ~ 2000	▲ 1970 ~ 2000	■ 1950 ~ 2000	● <1900 ~ 2000
◆ 1980 ~ 2000	+ 1960 ~ 2000	□ <1950 ~ 2000	◻ time period ends ~1990

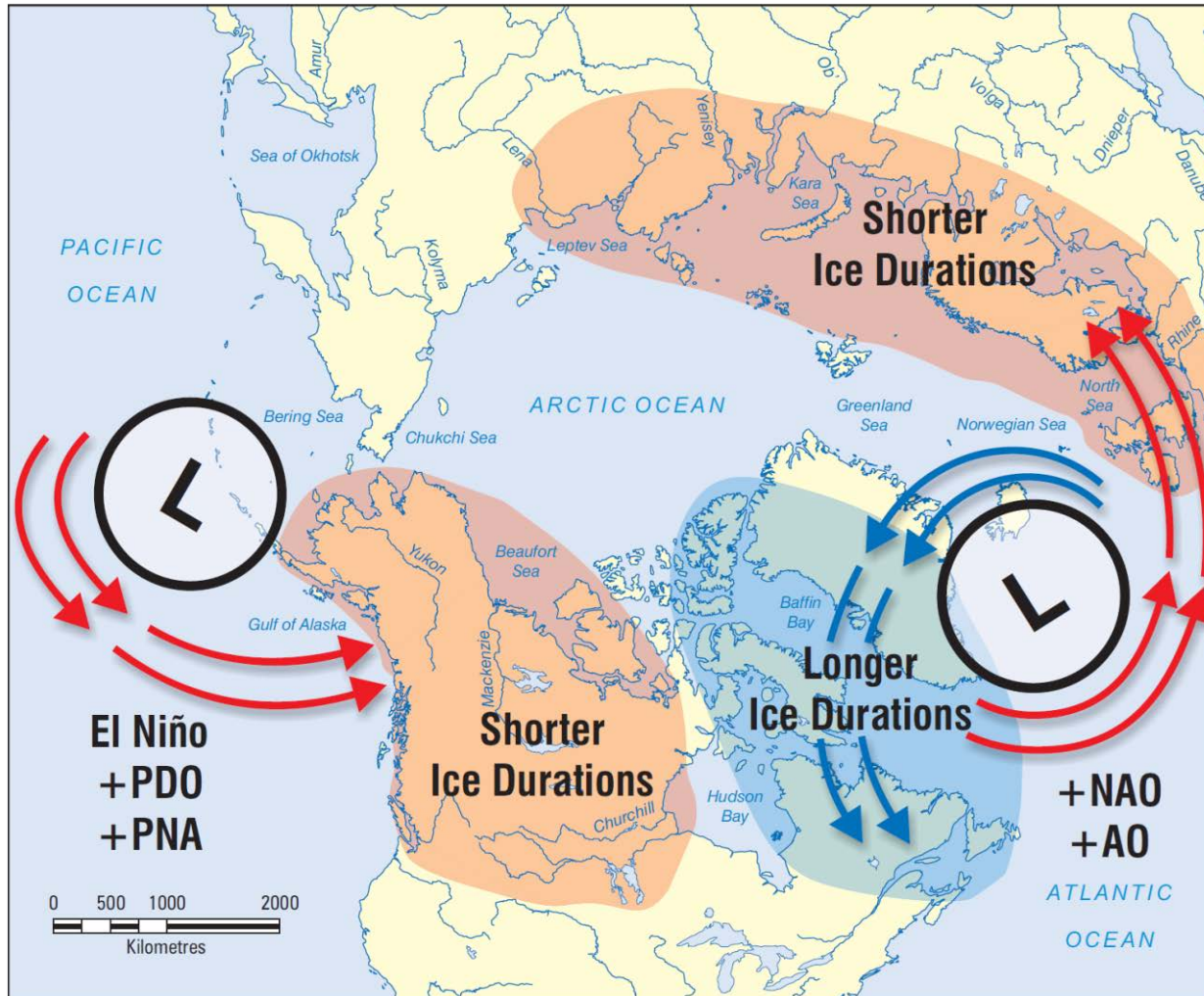
**Freeze-up/break-up
(ice cover duration)**

**Robust indicators
of climate
variability and
change**

In situ
historical records

Brown and Duguay (2010)

Response of lakes - Ice

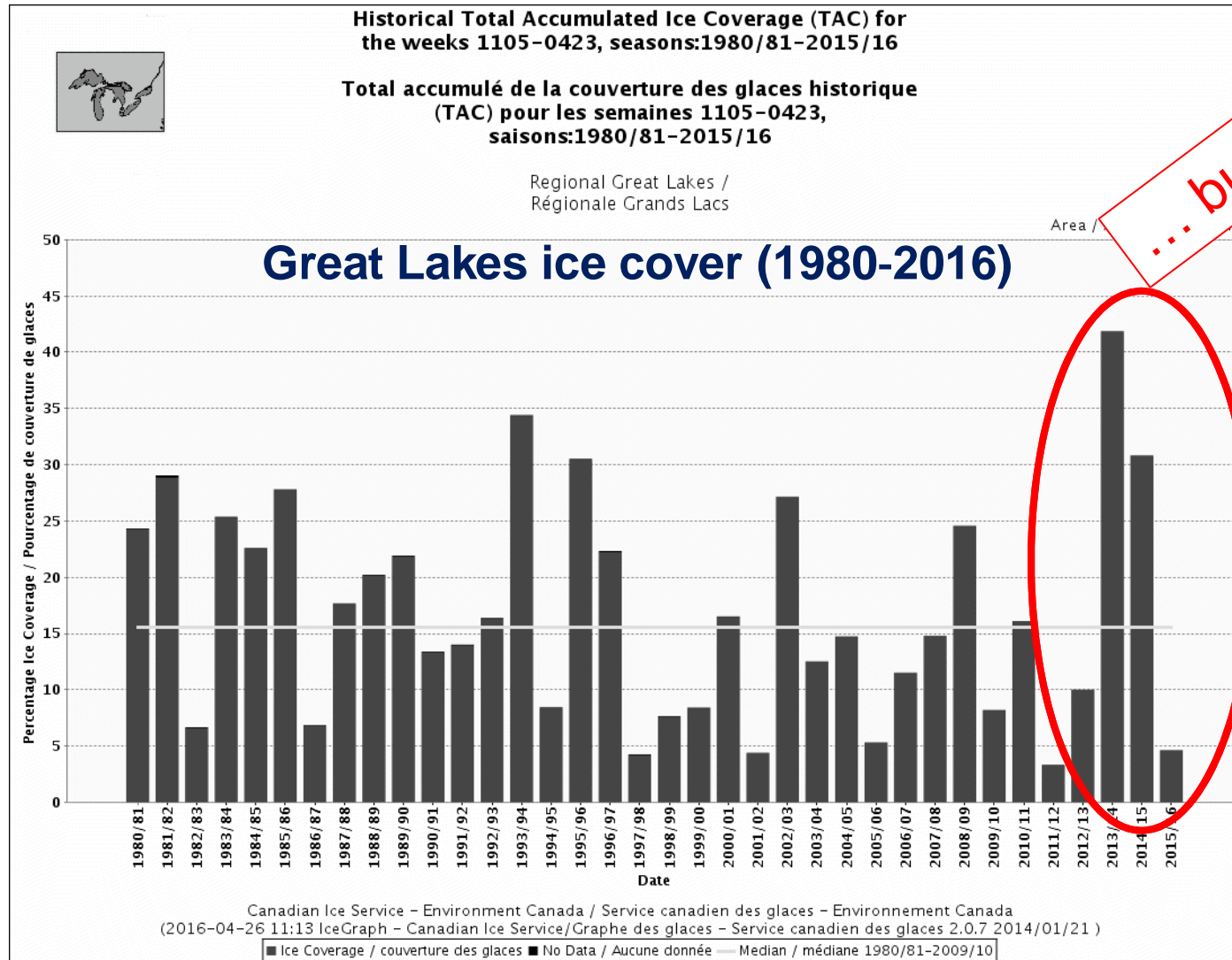


**Freeze-up/break-up
(ice cover duration)**

**Robust indicators
of climate
variability and
change**

Prowse *et al.* (2011)

Response of lakes - Ice

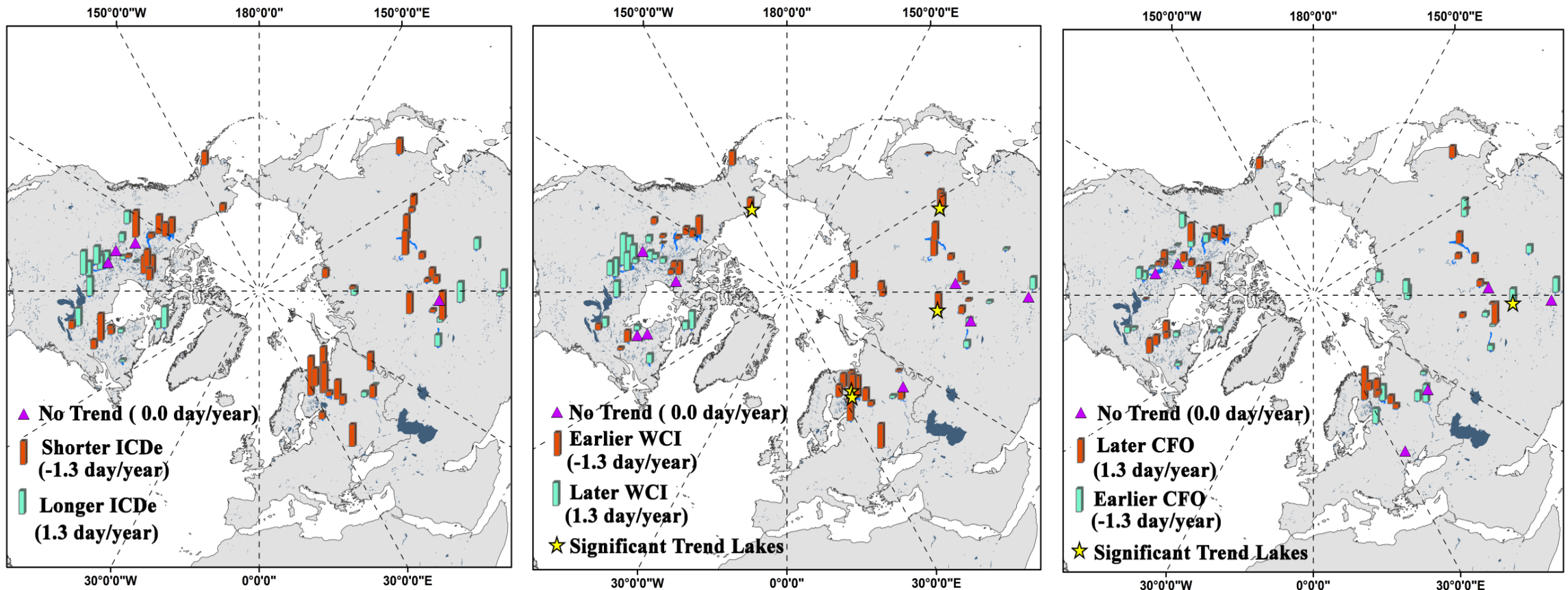


... but also high variability

Adapted from Lenters *et al.* (2016)

Response of lakes - Ice

Ice dates from passive microwave (AMSR-E/2; 5 km)

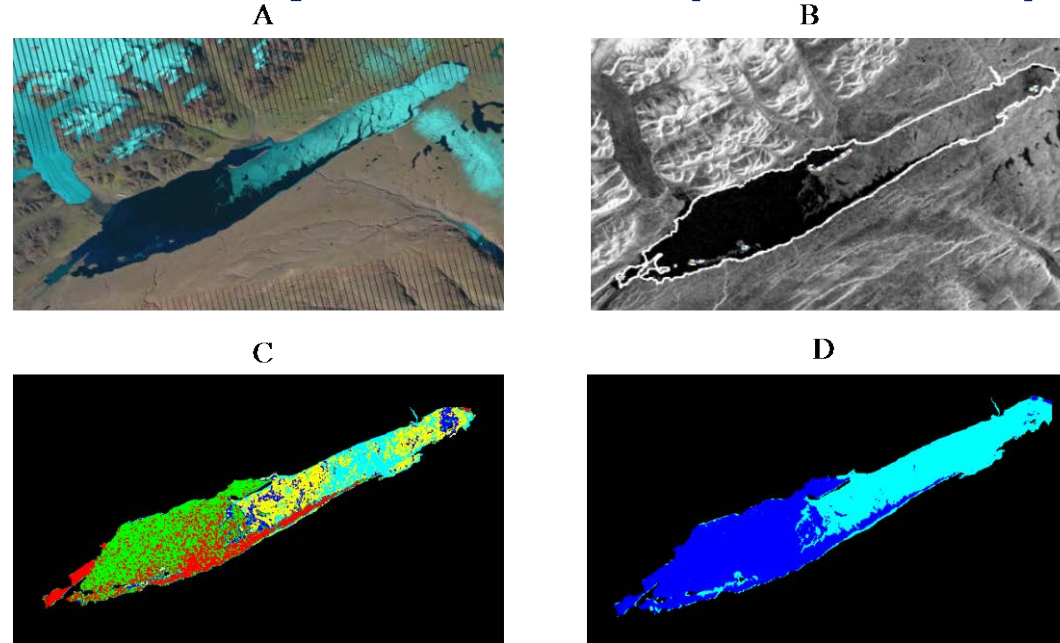
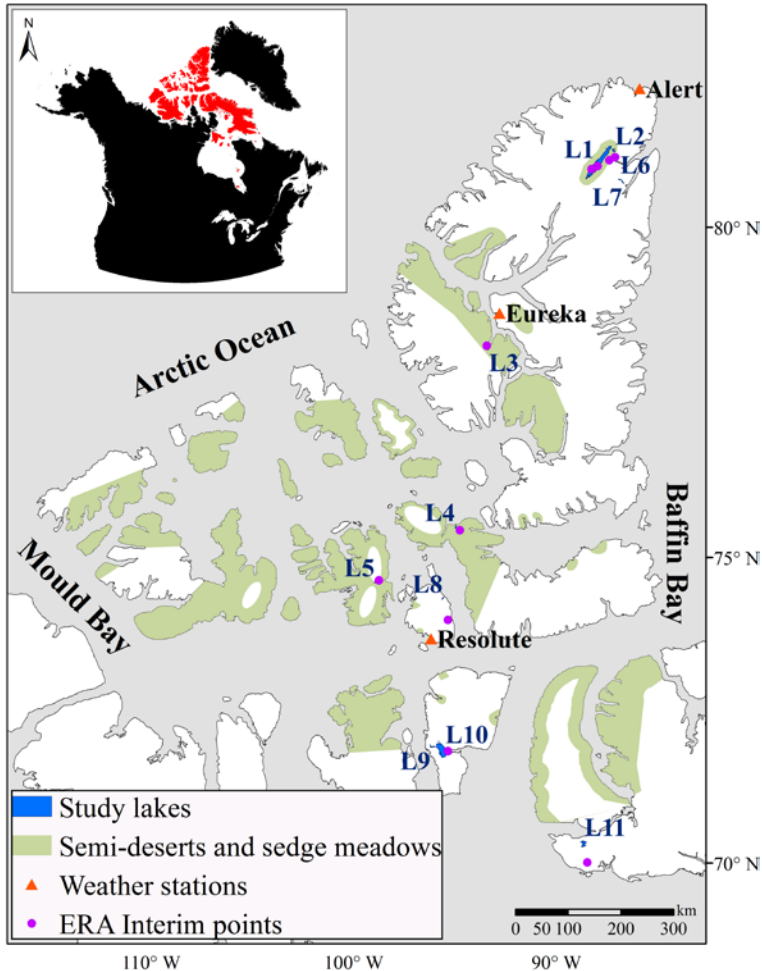


Changing trends of (a) ice cover duration (ICDe), (b) water clear of ice (WCI) dates and (c) complete freeze over (CFO) dates of 71 lakes for the **period 2002-2015**.

Du *et al.* (2017)

Response of lakes - Ice

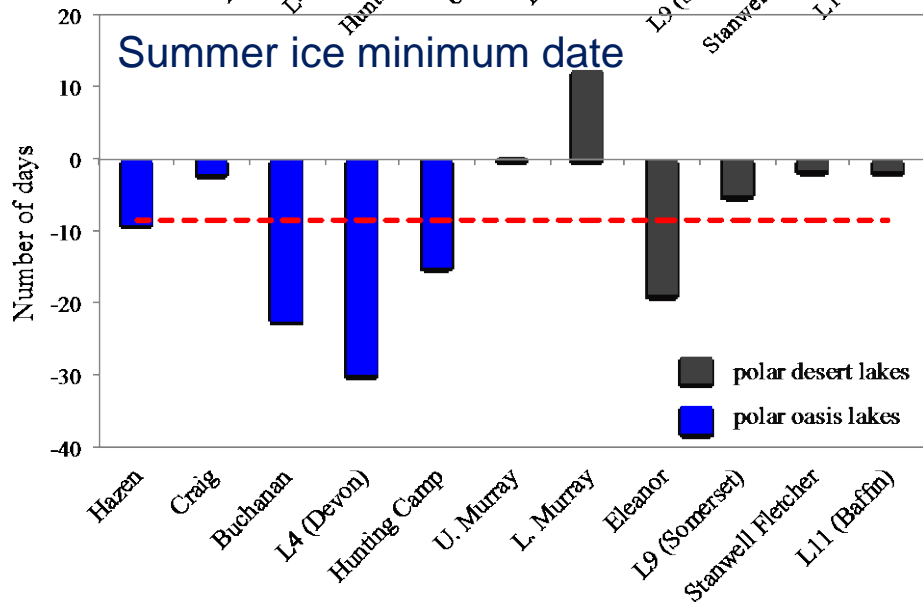
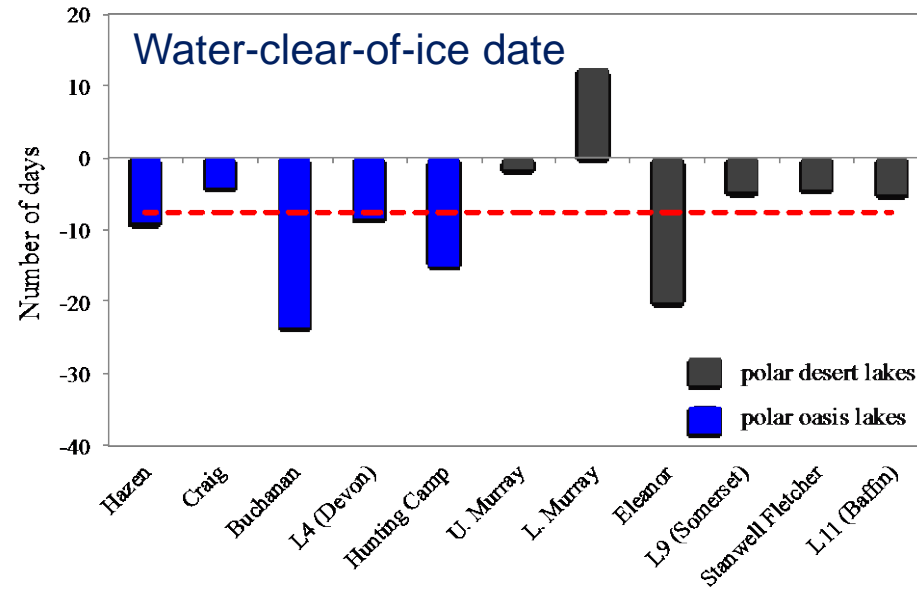
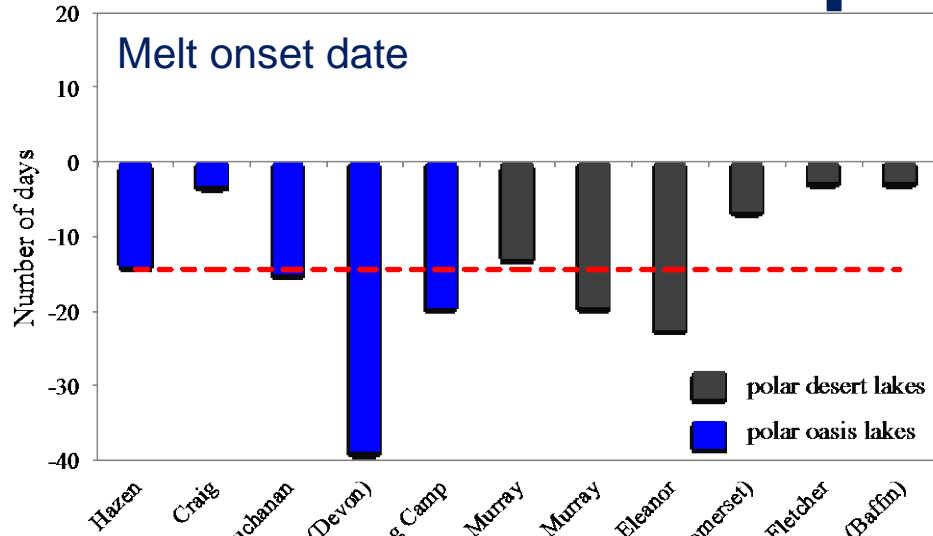
Ice dates from SAR and optical data (30-100 m)



(A) Landsat image of Lake Hazen, 19 July 2010; **(B)** original ASAR image of Lake Hazen acquired on 19 July, 2010; **(C)** K-means classified image (five clusters); **(D)** two-class map of ice (light blue) and open water (dark blue)

Surdu *et al.* (2016)

Response of lakes - Ice

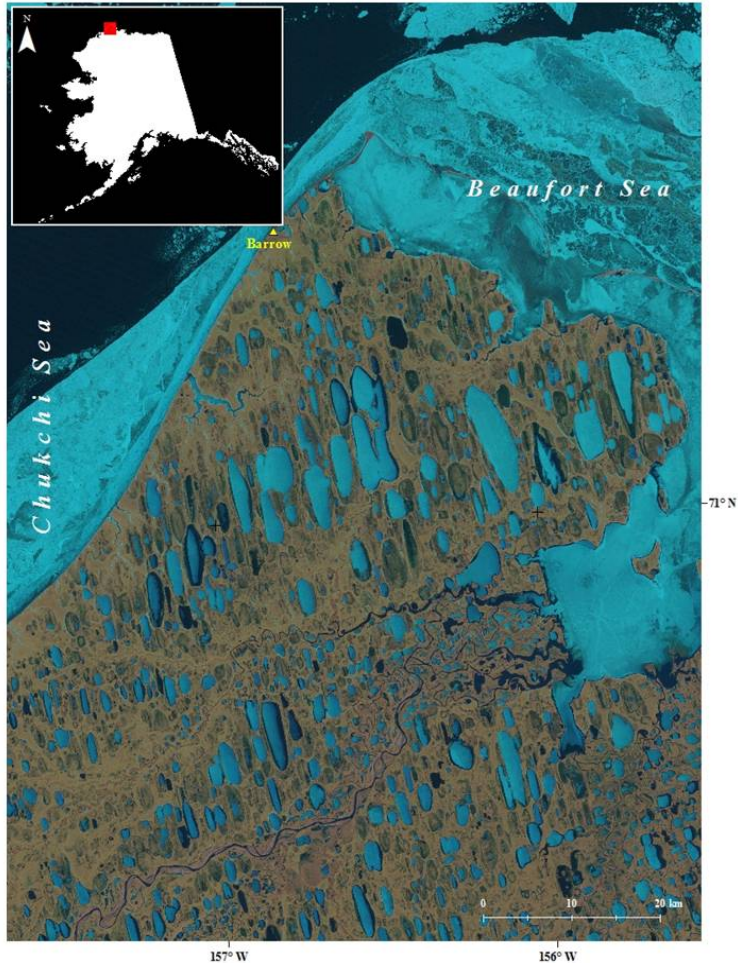


- Changes examined over 1997-2011 period
- ~27,000 SAR acquisitions (RADARSAT-1/2 and ASAR) and over 2,000 Landsat images (30-100 m)
- Earlier summer-ice minimum and water-clear-of-ice dates,
- Some lakes may be transitioning from a perennial/multiyear to a seasonal ice regime, with only a few lakes maintaining a multiyear ice cover on occasional years.

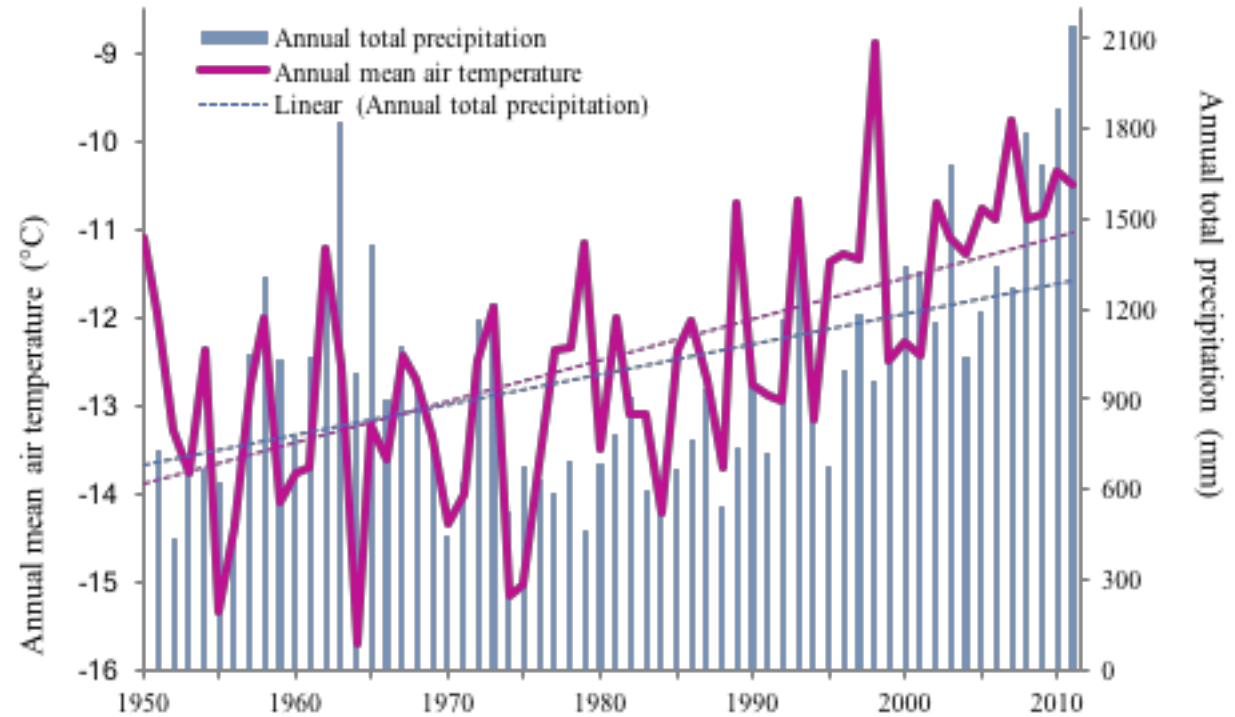
Surdu *et al.* (2016)

Response of lakes - Ice

Grounded and floating ice fractions from SAR (100 m)



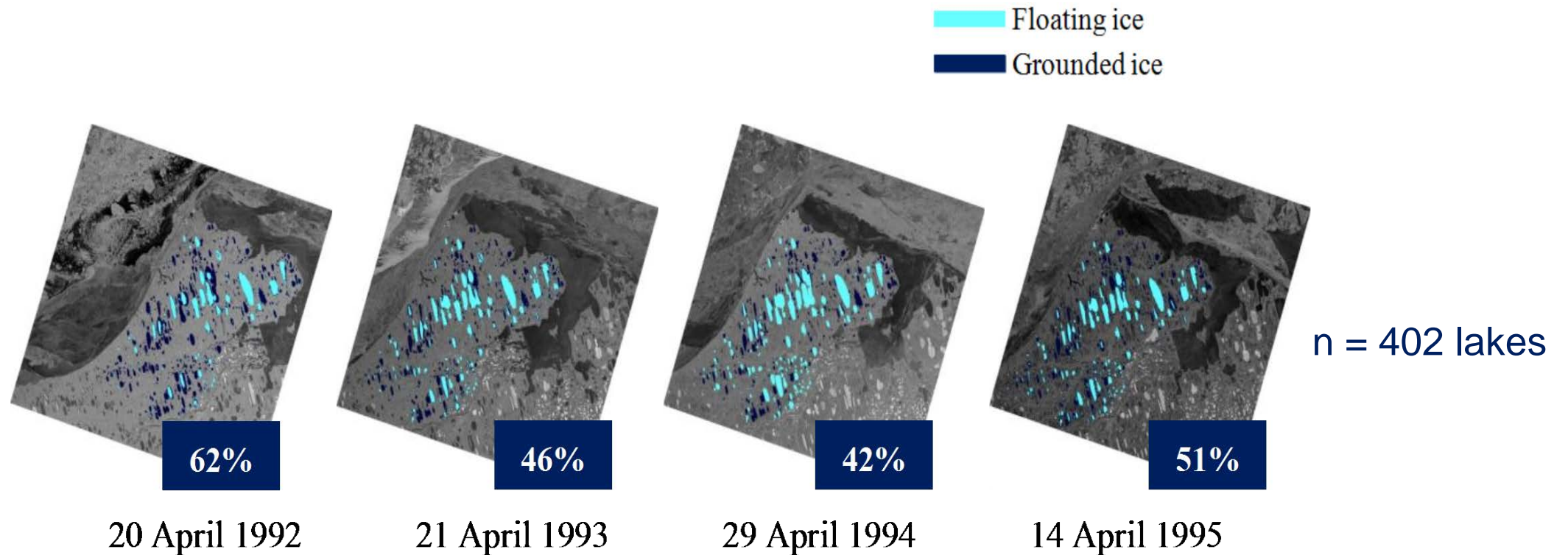
Sub-region of the Alaskan Arctic Coastal Plain, near Barrow (71°17' N, 156 °46' W)



1950-2011 annual mean air temperature and total precipitation (rain and snowfall) recorded at Barrow station

Surdu *et al.* (2014)

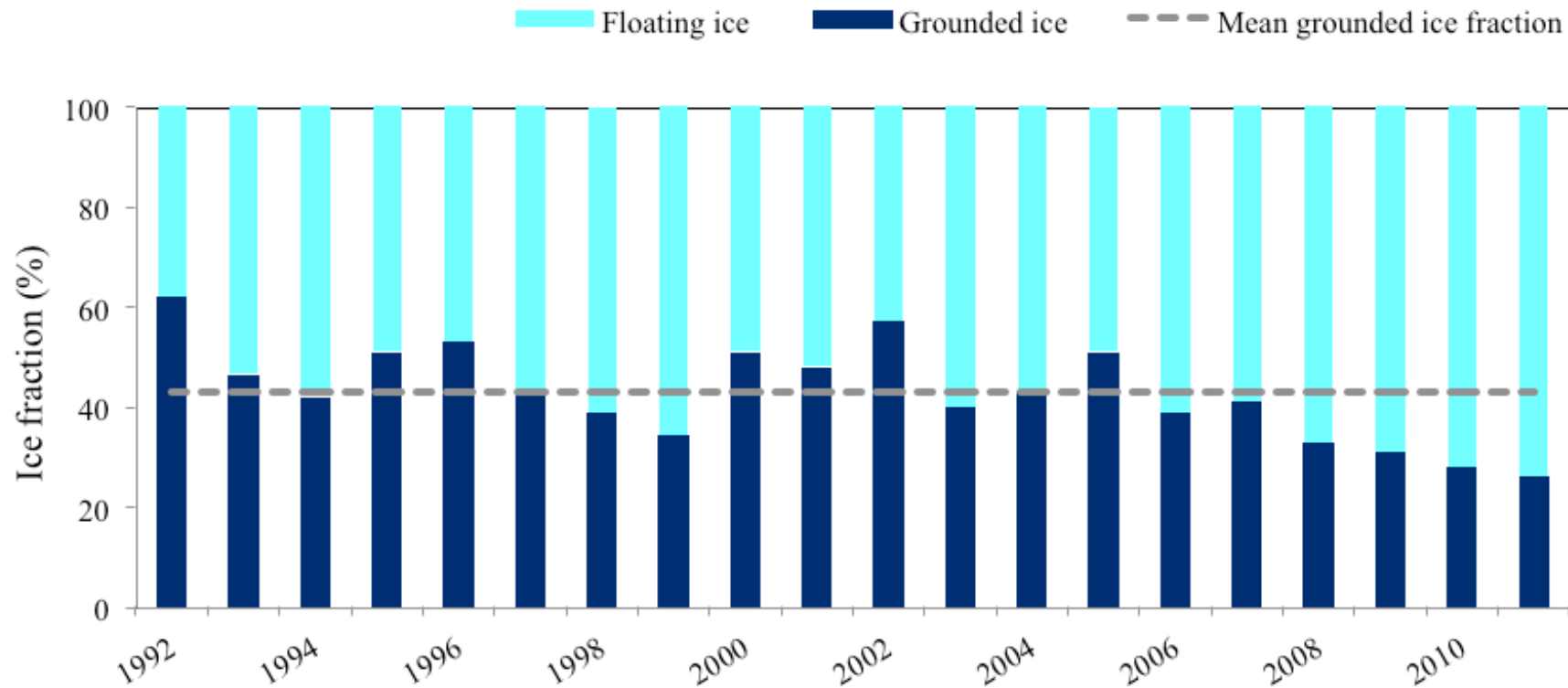
Response of lakes - Ice



Grounded and floating ice from ERS-1 SAR images (1992 to 1995) acquired near the time of maximum ice thickness (April) for shallow lakes near Barrow, Alaska

Surdu *et al.* (2014)

Response of lakes - Ice

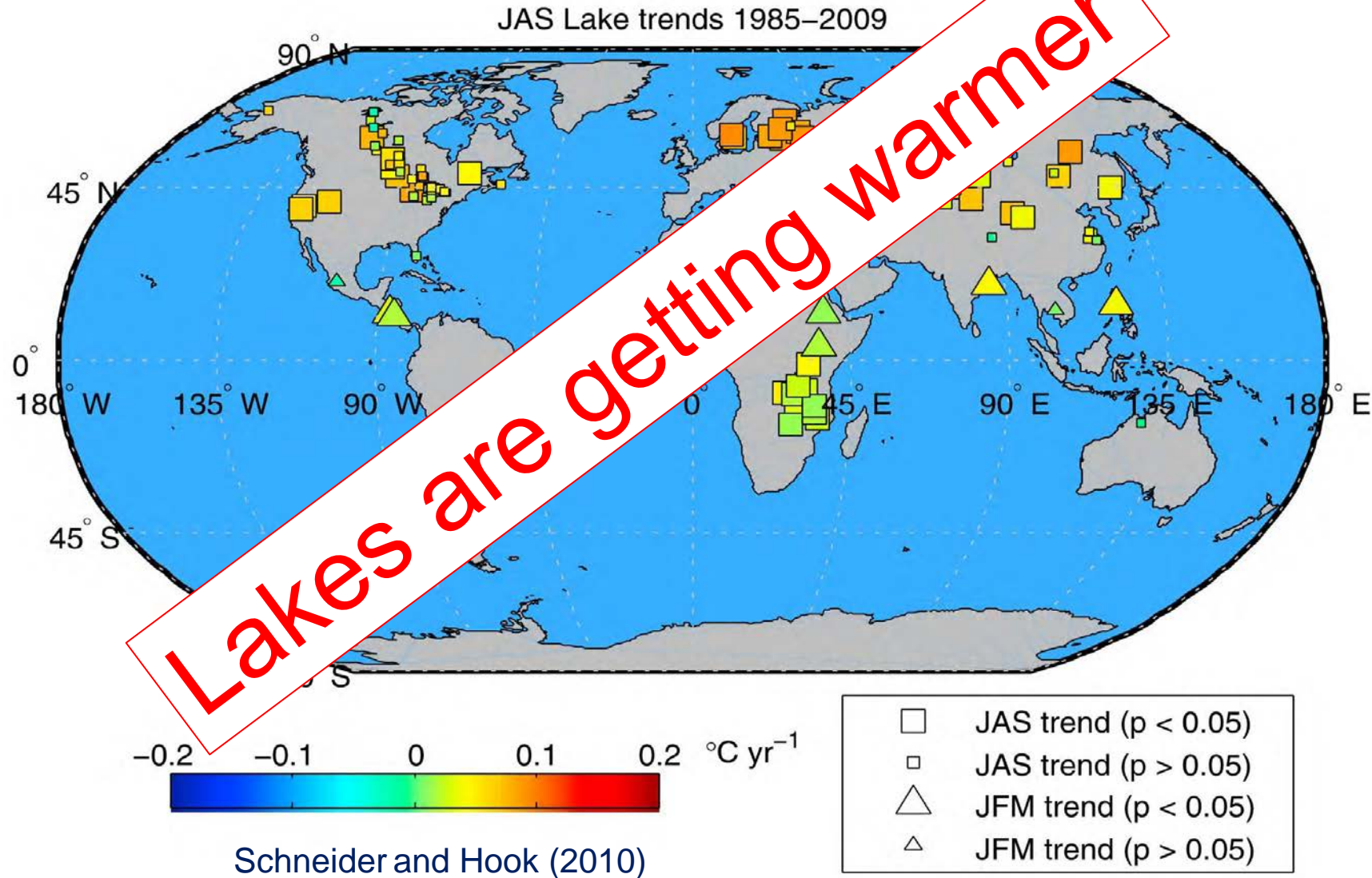


Changes in fraction of grounded lake ice (decrease of 22% or ca. 20 cm ice thickness; $\alpha = 0.01$) from ERS-1/2 SAR images (April; 1992 to 2011) near Barrow, Alaska

Surdu *et al.* (2014)

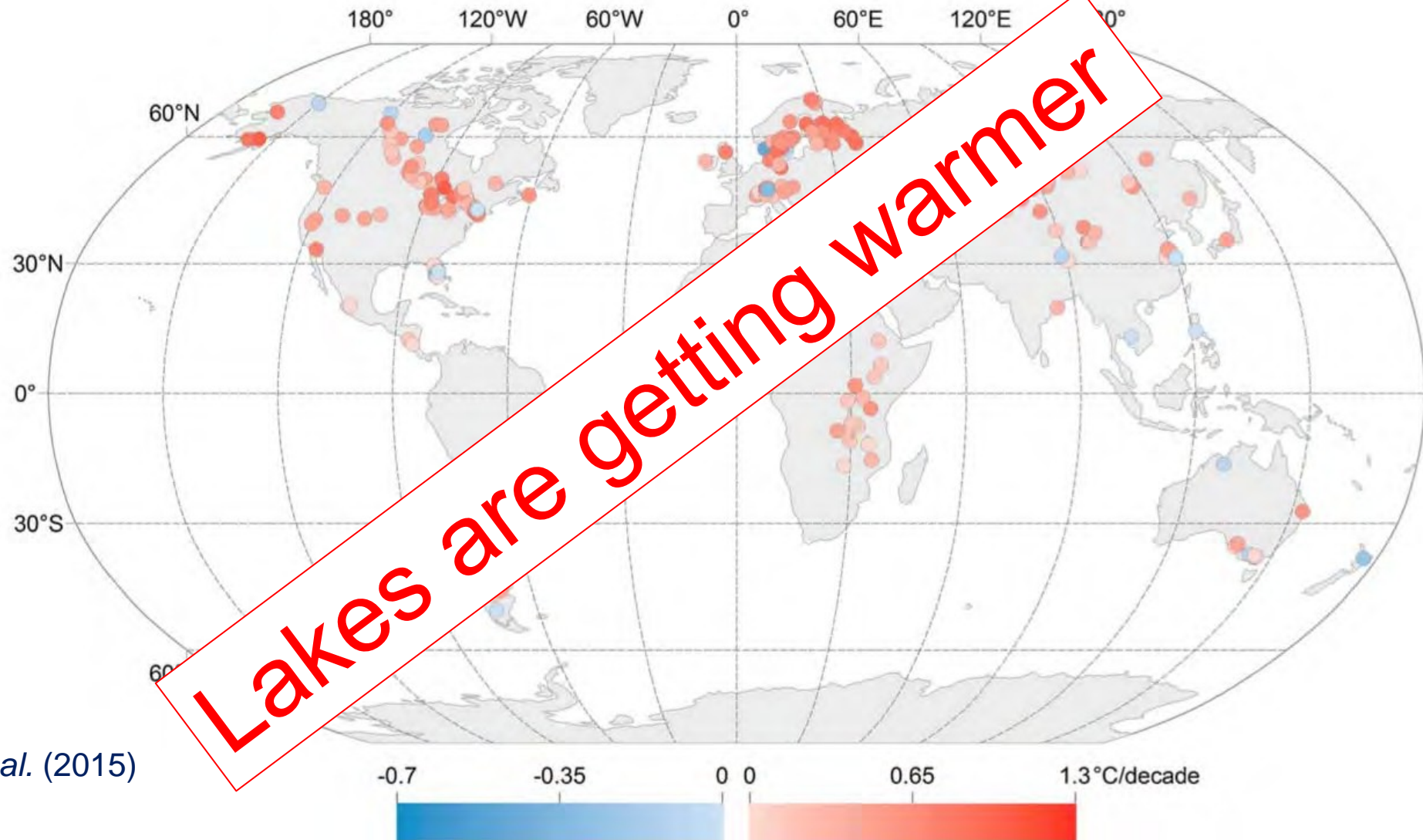
Response of lakes

Lake surface water temperature (LSWT) trends
(1985-2009; satellite-based)



Response of lakes

Lake surface water temperature (LSWT) trends
(1985-2009; satellite and ground-based; summer only)



O'Reilly *et al.* (2015)

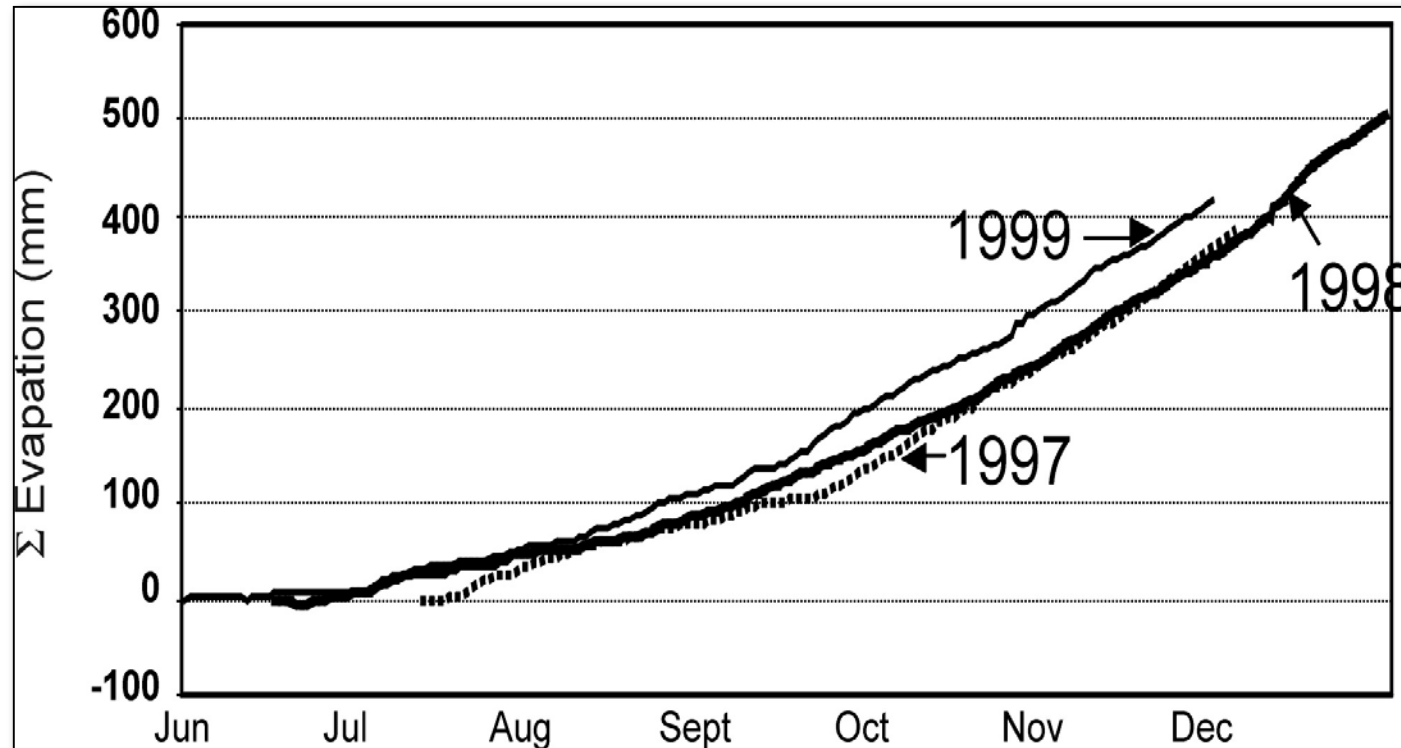
Impacts are becoming evident

Changes in lake ice cover can have an impact on ...

- Evaporation/water balance/lake level
- Temperature
- Stratification
- Lake chemistry
- Vertical mixing
- Lake ecology

Impacts are becoming evident

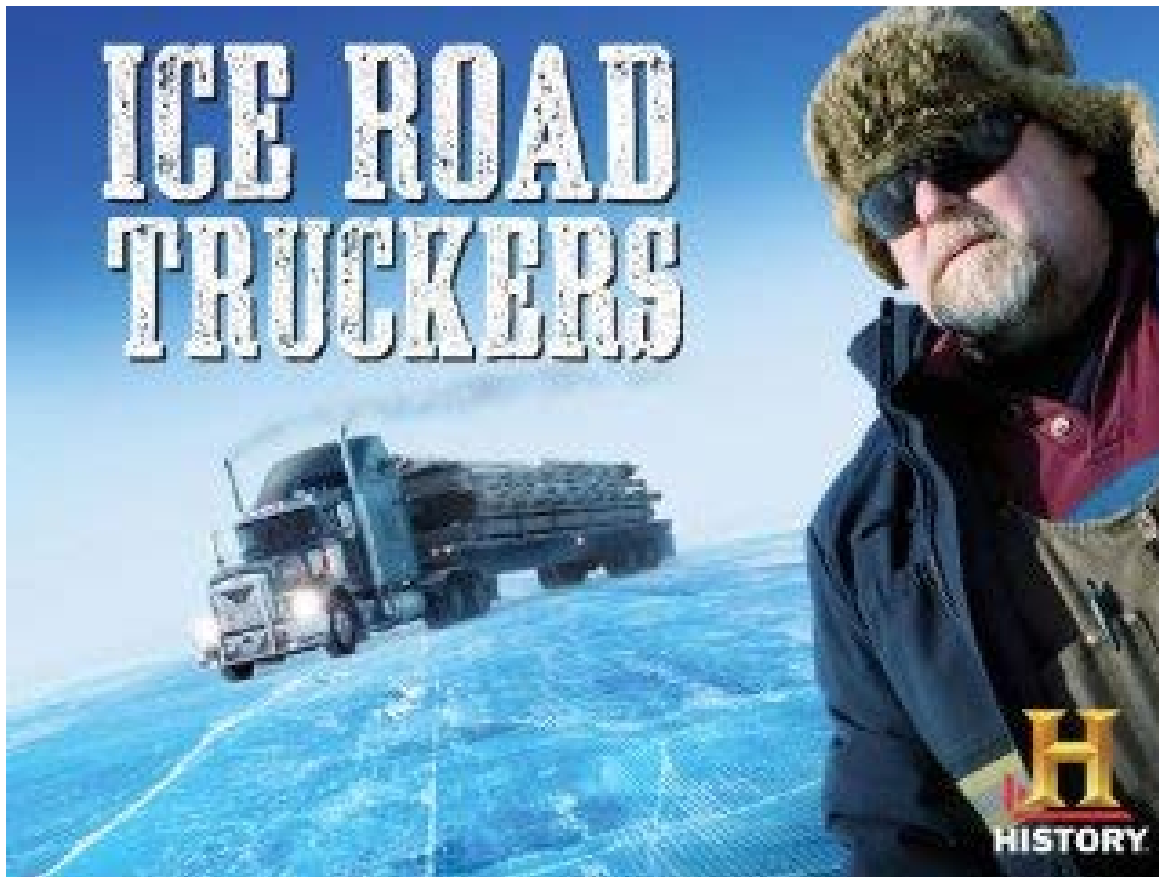
Impact of shorter ice season on cumulative lake evaporation (Great Slave Lake, NWT)



The date of final ice melt in June exerts the largest single control on the seasonal thermal and energy regimes of GSL. An early thaw greatly enhances the magnitude of absorbed solar radiation in the high sun season. This becomes stored heat energy that drives the large sensible and latent heat fluxes during fall and early winter.

Impacts are becoming evident

Transportation on northern (winter) ice roads



Driving on thin ice



Impacts are becoming evident

How do we know?

- **Measurements**
 - Ground-based data
 - Satellite data } Lecture 2/3
- Long-term monitoring programs

- **Models**
 - Physical, hydrological, biological
 - Climate models
 - Lake models } Lecture 3/3

Adapted from
Lenters *et al.* (2016)

Questions?

