Lake Ice and Climate in High Latitude Regions

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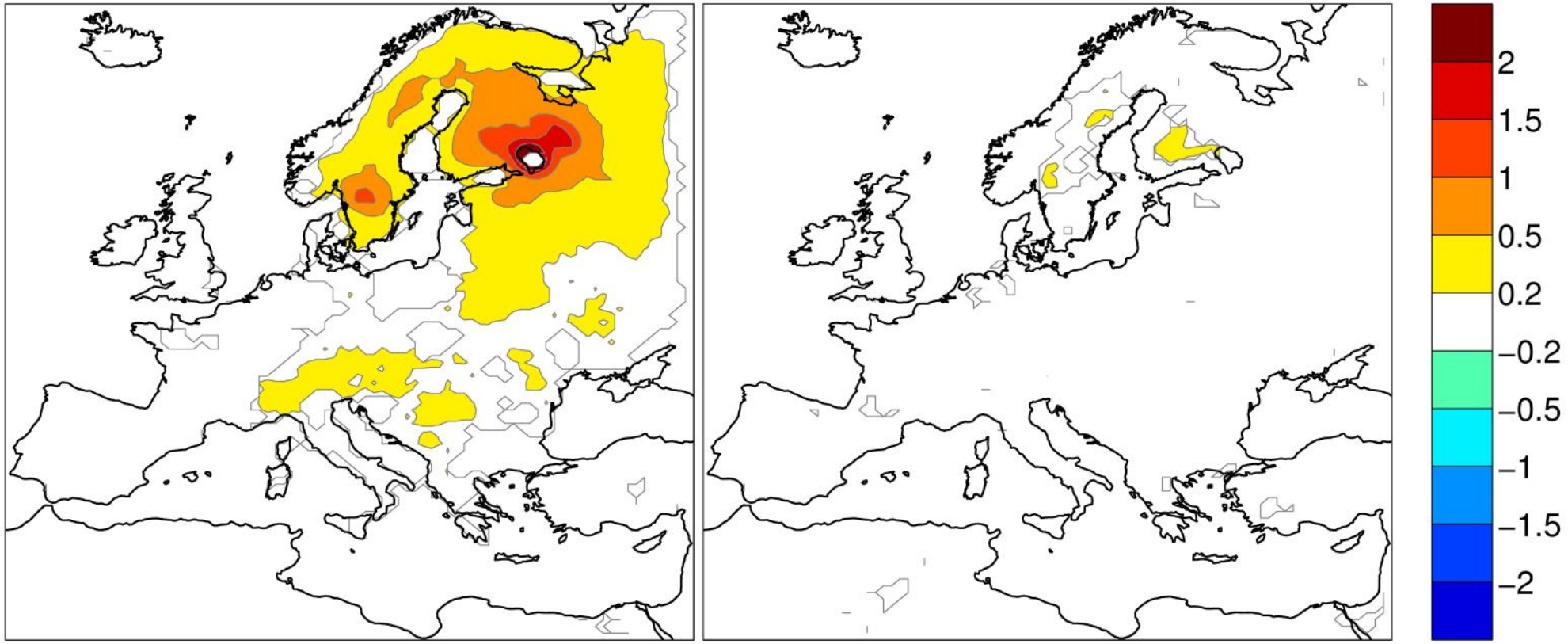
Importance of lake ice

- Ice cover extent/concentration has an important impact of lake-atmosphere interactions (e.g. thermal moderation, lake-effect snowfall)
- 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
- Manual measurements of ice dates (freeze-up/break-up) and ice thickness have drastically decreased at many national networks over the last three decades

Role of lakes in climate

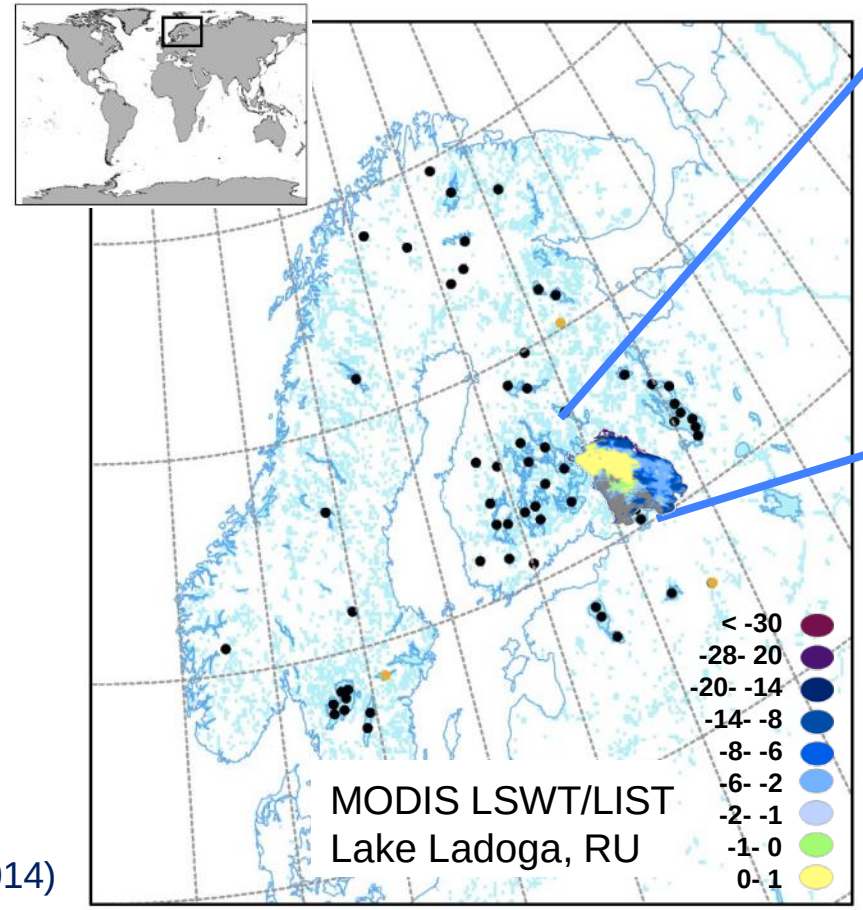


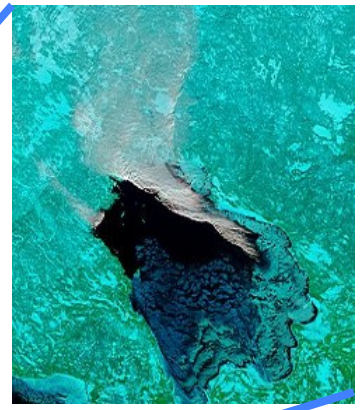
Differences in simulated air temperature (°C) 2 m from RCA model with lakes (coupled with FLake lake model) and without lakes (open land) for **winter (left) and spring (right)** 1961-1990. Courtesy of P. Samuelsson, SMHI.

Role of lake ice in weather

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

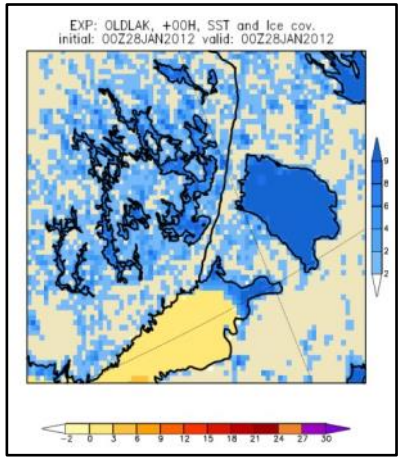
70 pixels over 41 lakes chosen for
extraction of satellite-derived LSWT/LIST



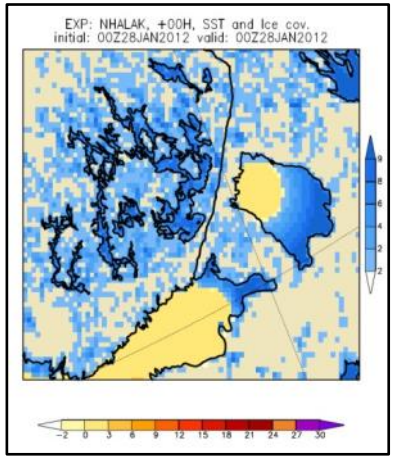


MODIS visible image
28 January 2012
Lake Ladoga (Russia)

Analyzed ice cover
without assimilation



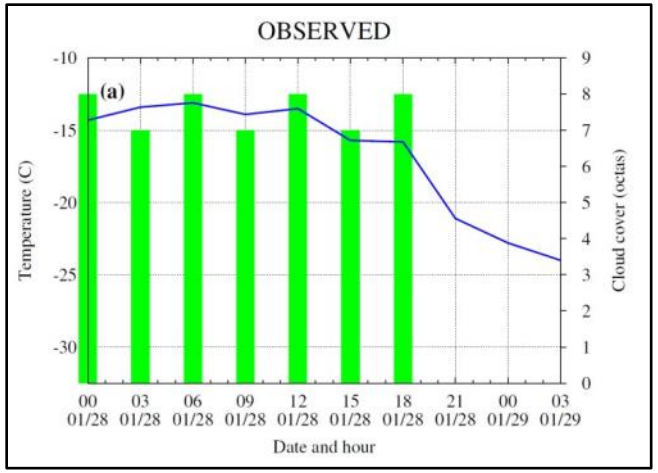
Analyzed ice cover
with assimilation



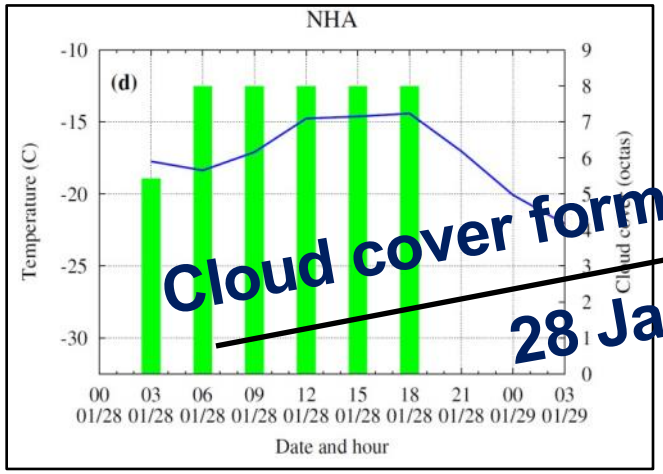
Eerola *et al.* (2014)

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

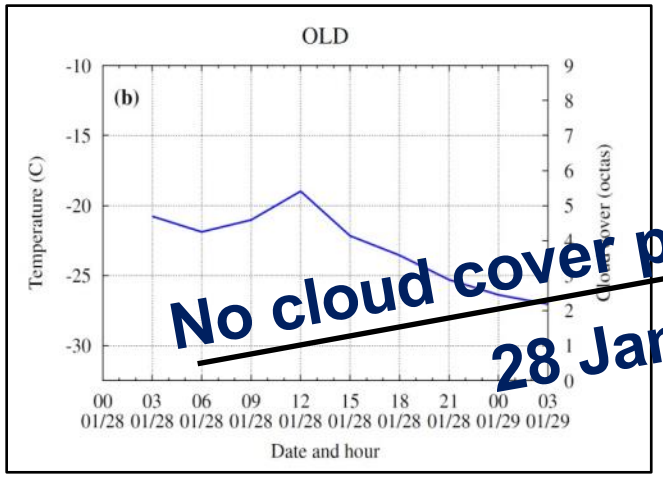
Joensuu station Observations



Predicted with assimilation



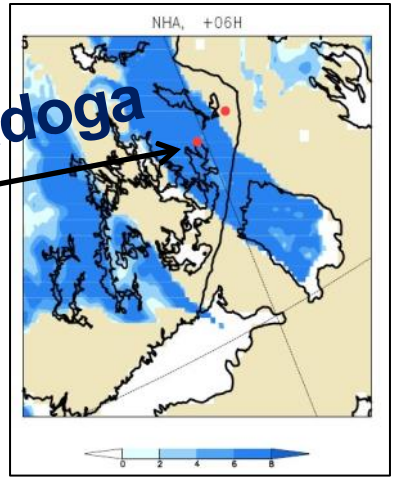
Predicted without assimilation



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

Cloud cover formation over Lake Ladoga

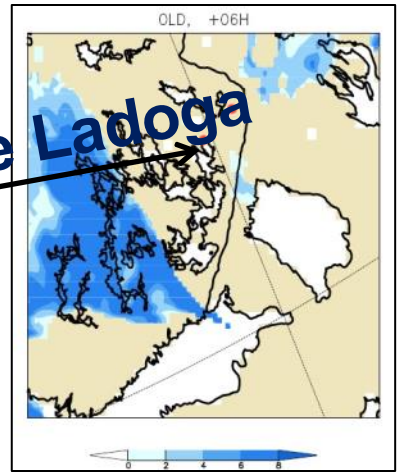
28 Jan 2012 - 06 UTC



Predicted with assimilation

No cloud cover predicted over Lake Ladoga

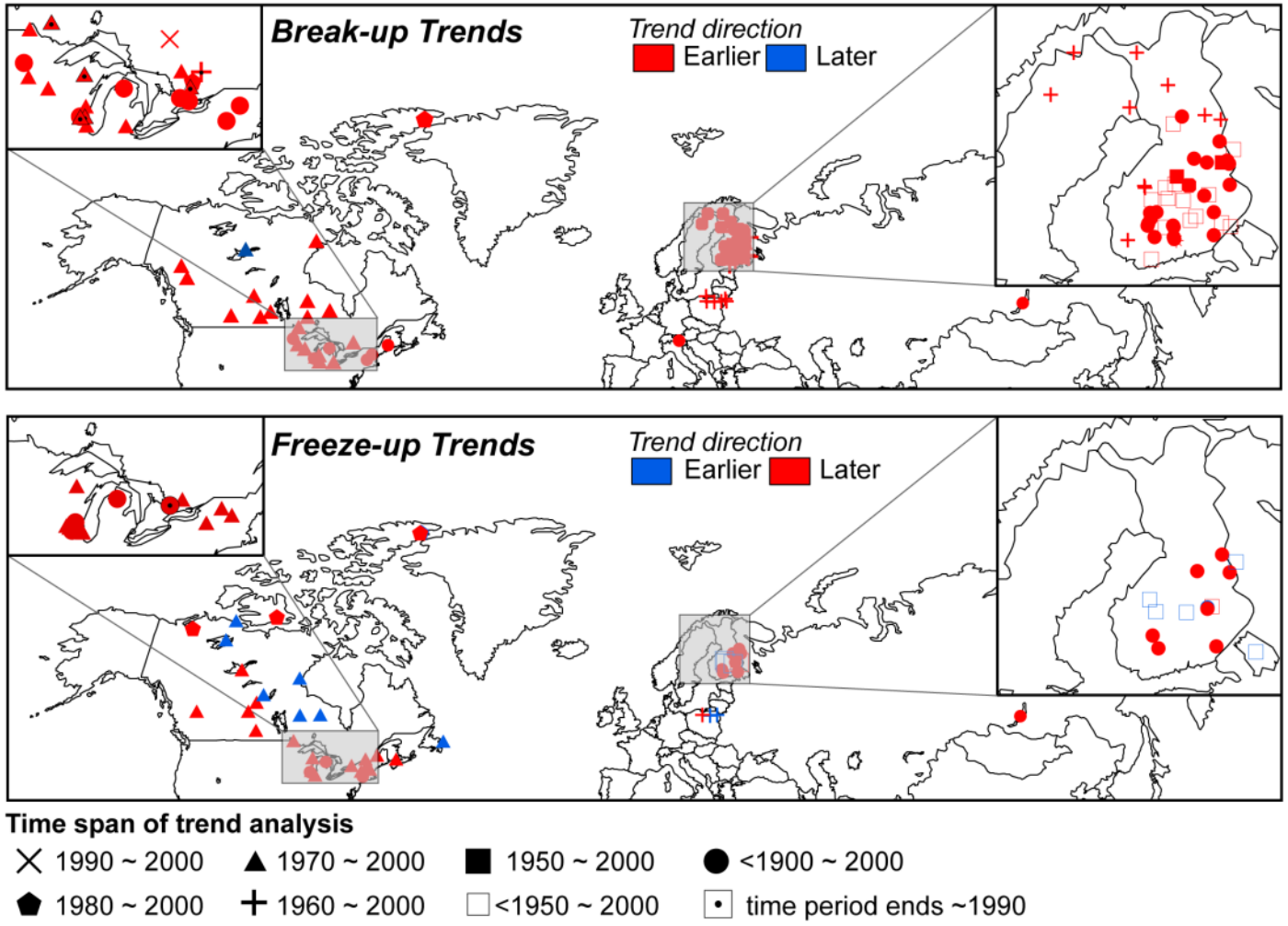
28 Jan 2012 - 06 UTC



Predicted without assimilation

Eerola *et al.* (2014)

Response of lake ice to climate



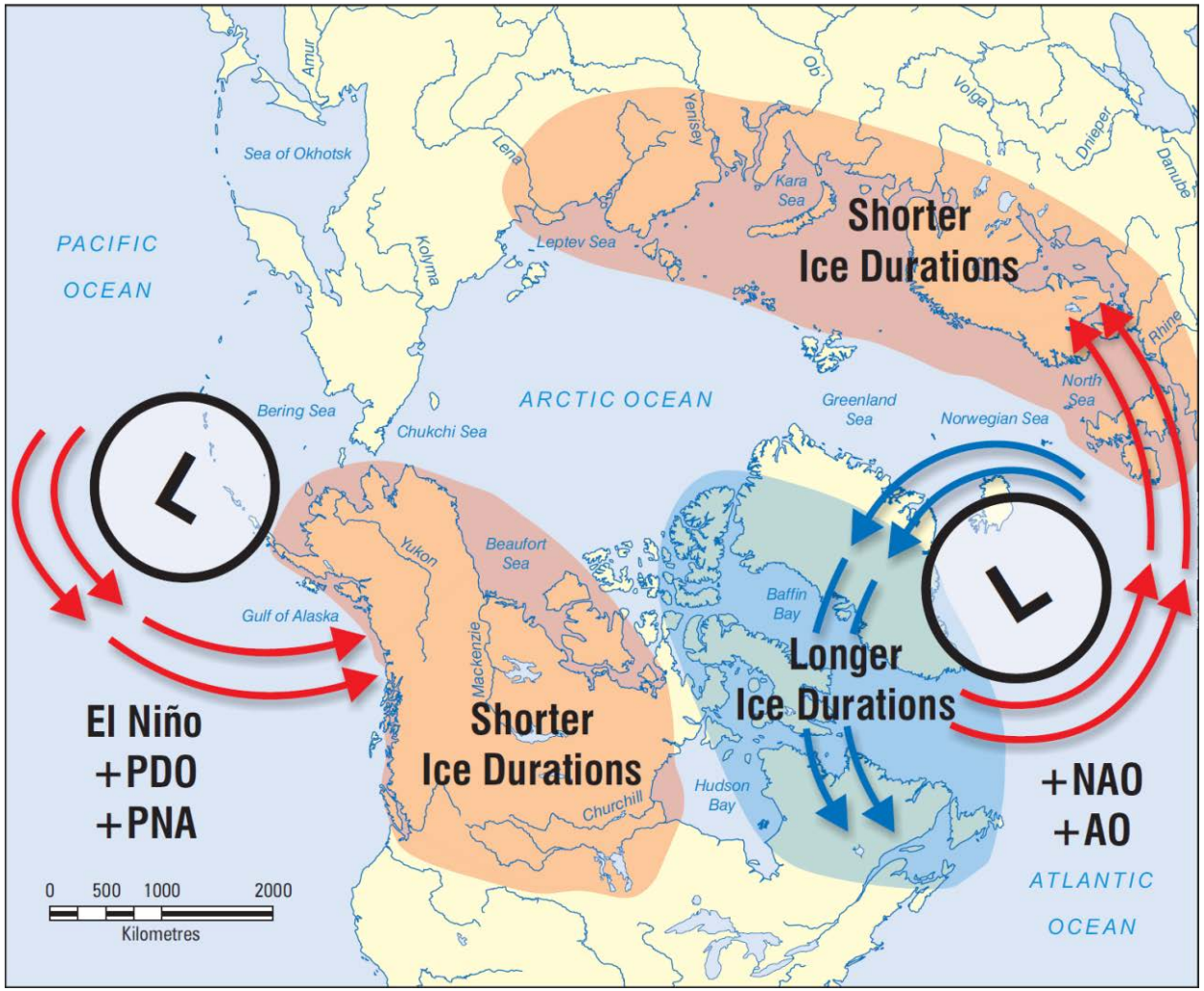
Freeze-up/break-up (ice cover duration)

Robust indicators of climate variability and change

In situ
historical records

Brown and Duguay (2010)

Response of lake ice to climate

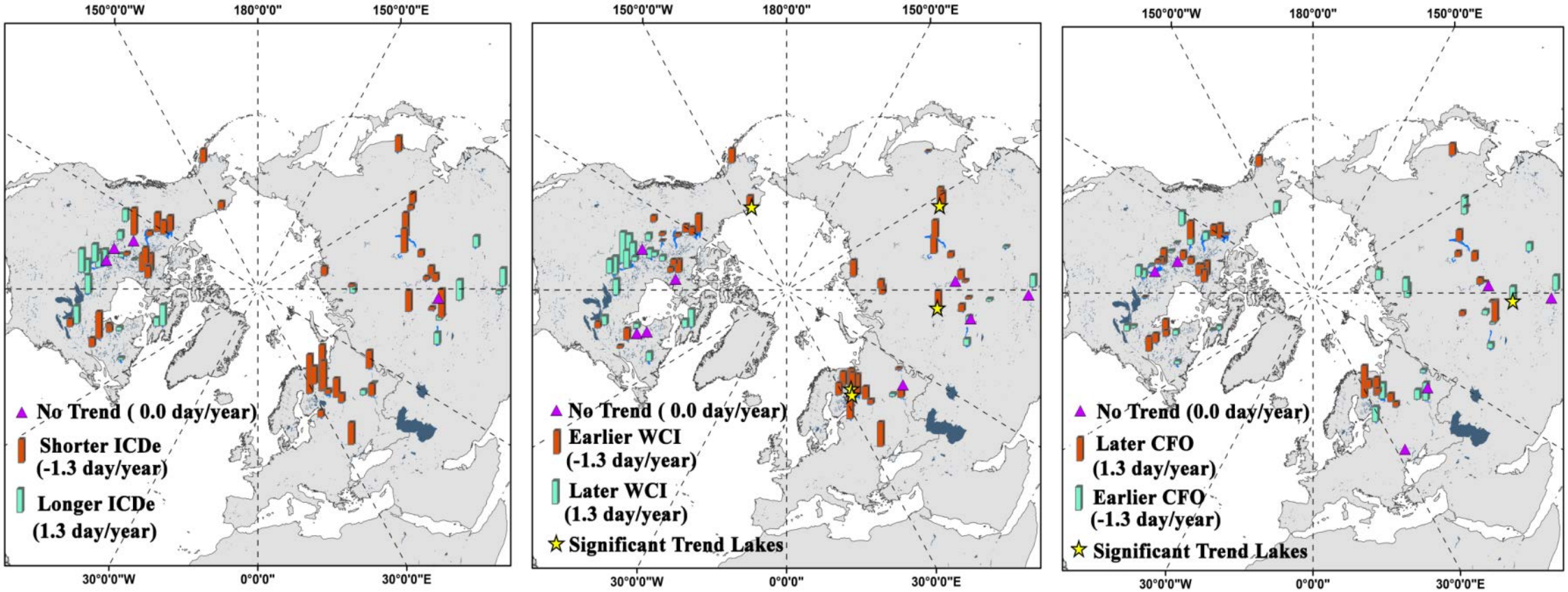


Freeze-up/break-up (ice cover duration)

Robust indicators of climate variability and change

Prowse *et al*. (2011)

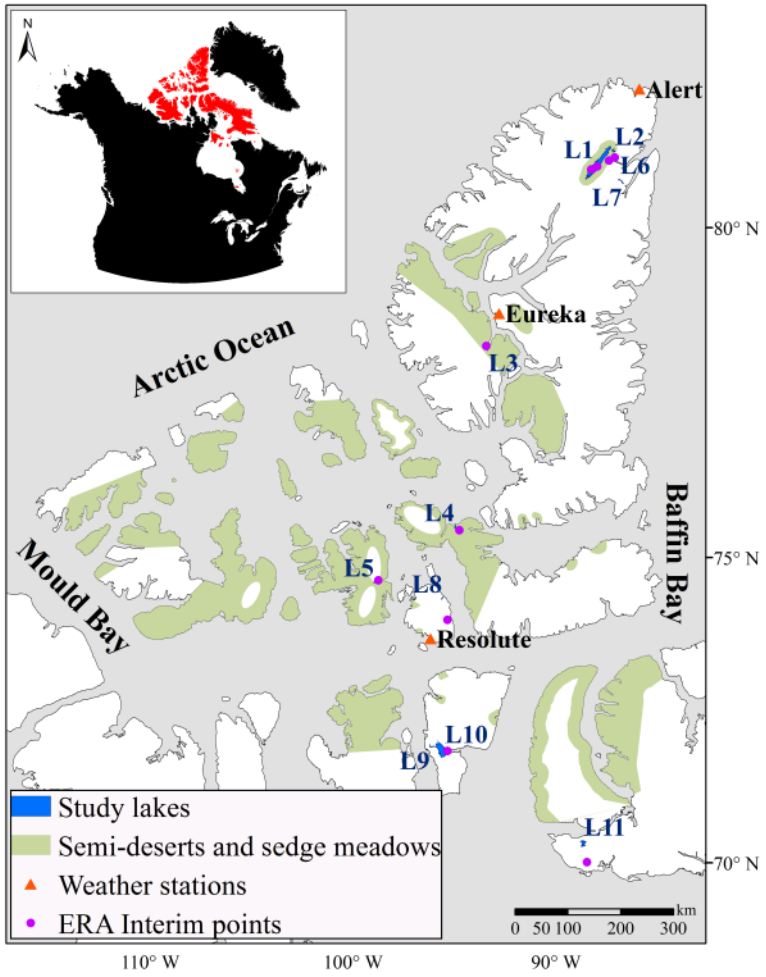
Ice dates from passive microwave (AMSR-E/2; 5 km)

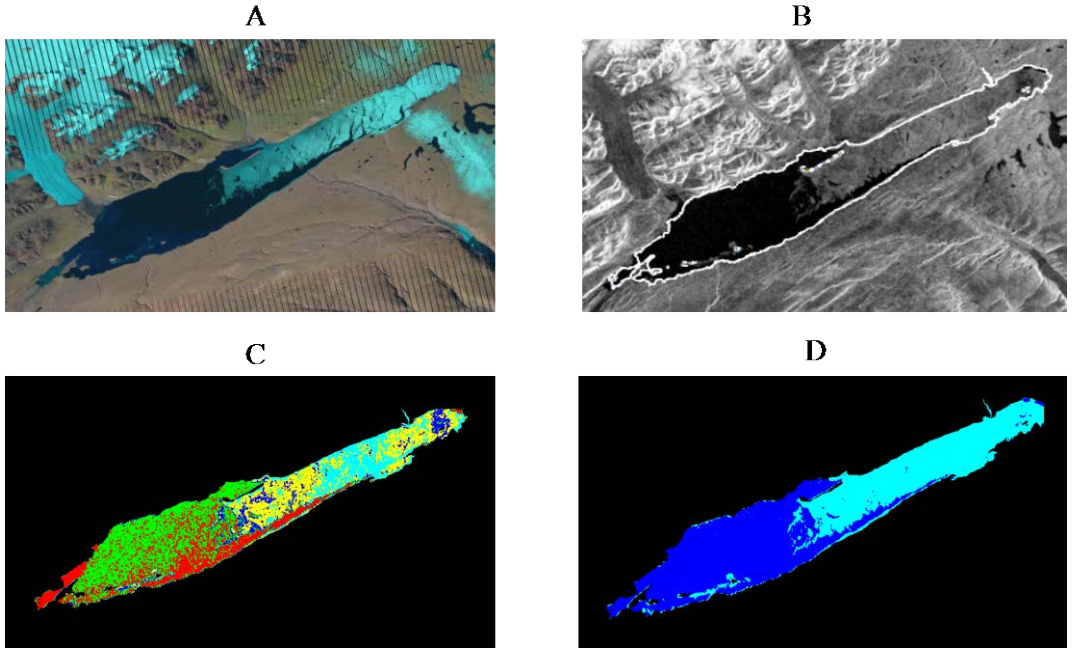


Changing trends of (a) ice cover duration (ICDe), (b) water clear of ice (WCI) dates and (c) complete freeze over (CFO) dates of 71 lakes for the **period 2002-2015**.

Du *et al*. (2017)

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

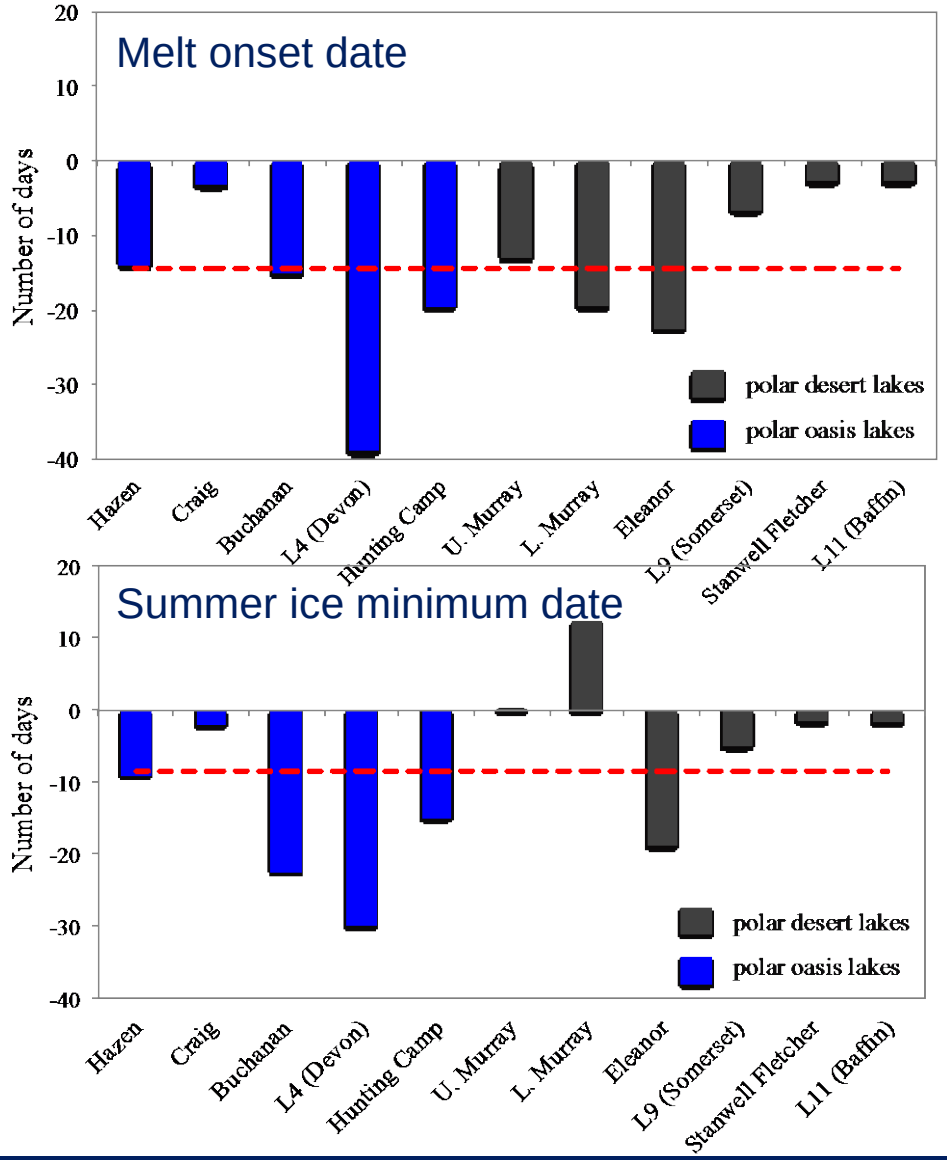


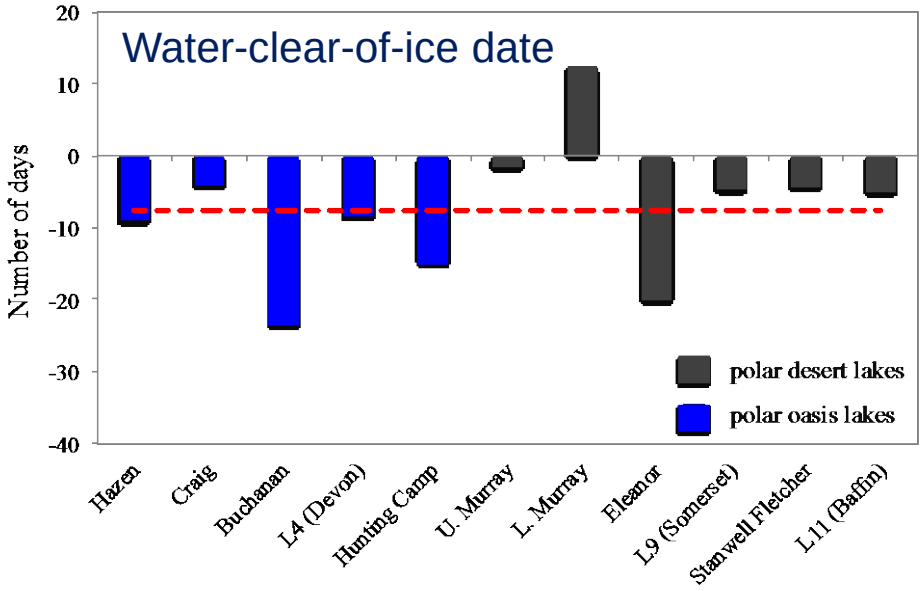


(A) Landsat image of Lake Hazen, 19 July 2010; **(B)** original ASAR image of Lake Hazen acquired on 19 July, 2010; **(C)** K-means classified image (five clusters); **(D)** two-class map of ice (light blue) and open water (dark blue)

Surdu *et al*. (2016)

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

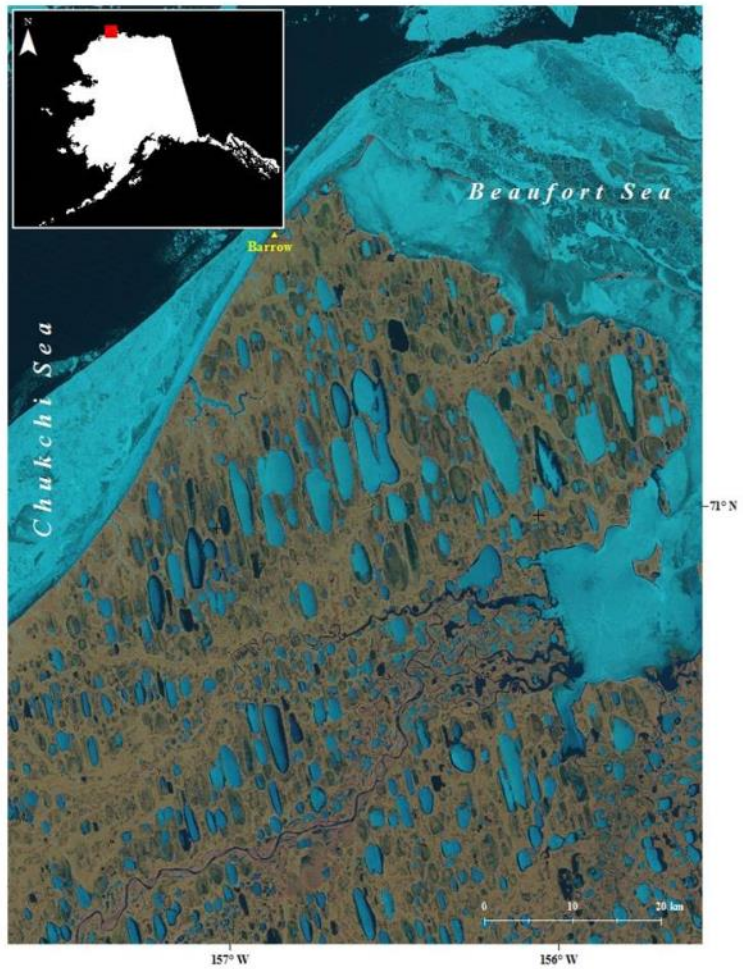




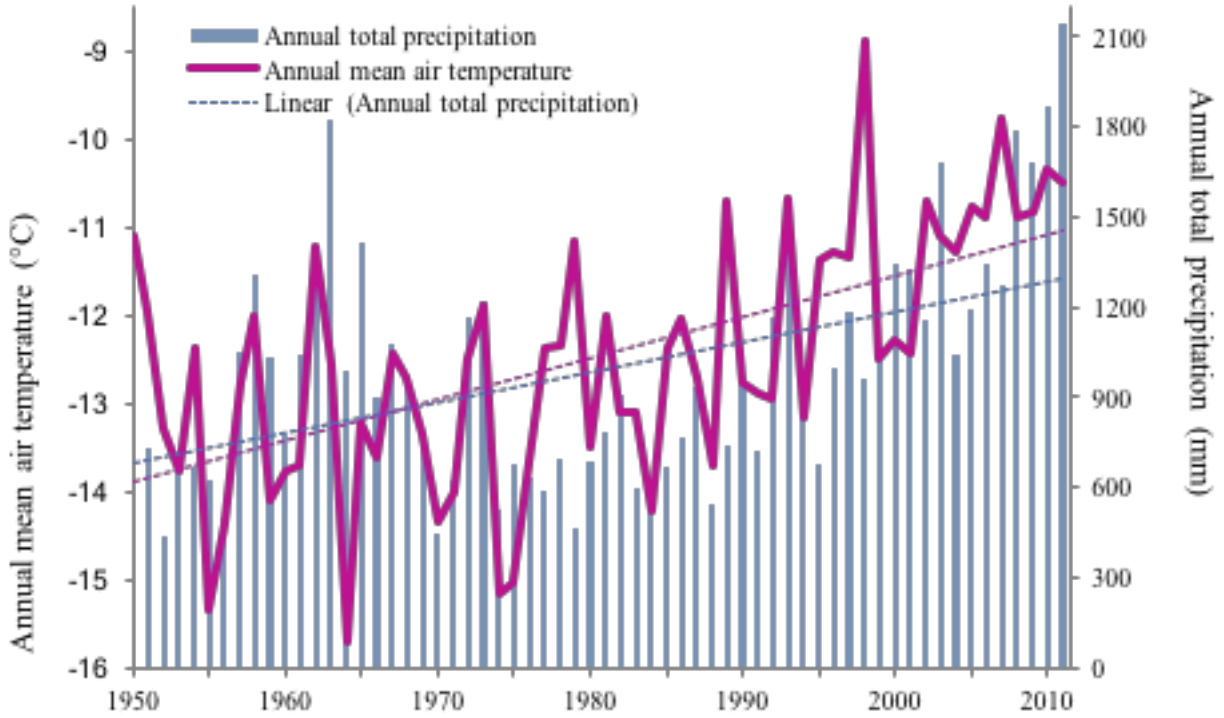
- Changes examined over 1997-2011 period
- ~27,000 SAR acquisitions (RADARSAT-1/2 and ASAR) and over 2,000 Landsat images (30-100 m)
- Earlier summer-ice minimum and water-clear-of-ice dates,
- Some lakes may be transitioning from a perennial/multiyear to a seasonal ice regime, with only a few lakes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

Surdu *et al*. (2016)

Grounded and floating ice fractions from SAR (100 m)



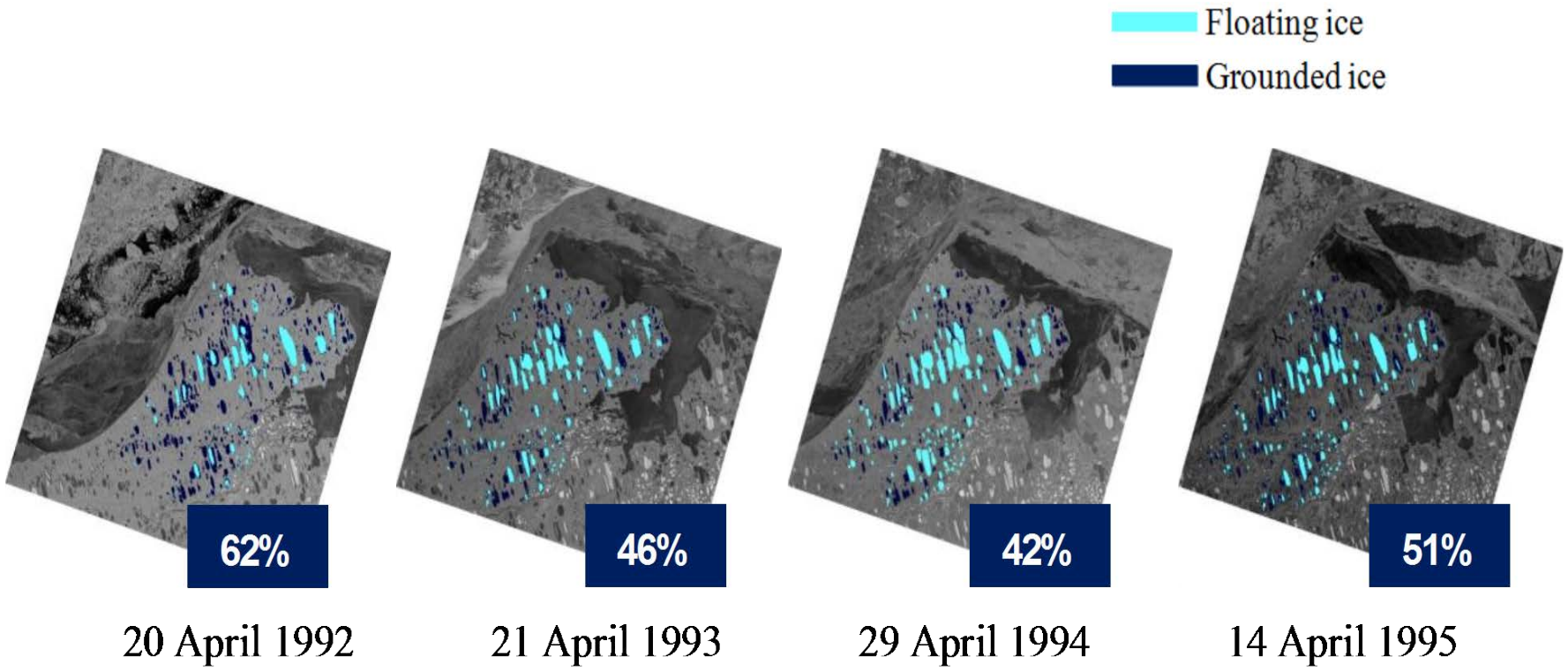
Sub-region of the Alaskan Arctic Coastal Plain, near Barrow (71°17’ N, 156 °46’ W)



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

Surdu *et al*. (2014)

Grounded and floating ice fractions from SAR (100 m)

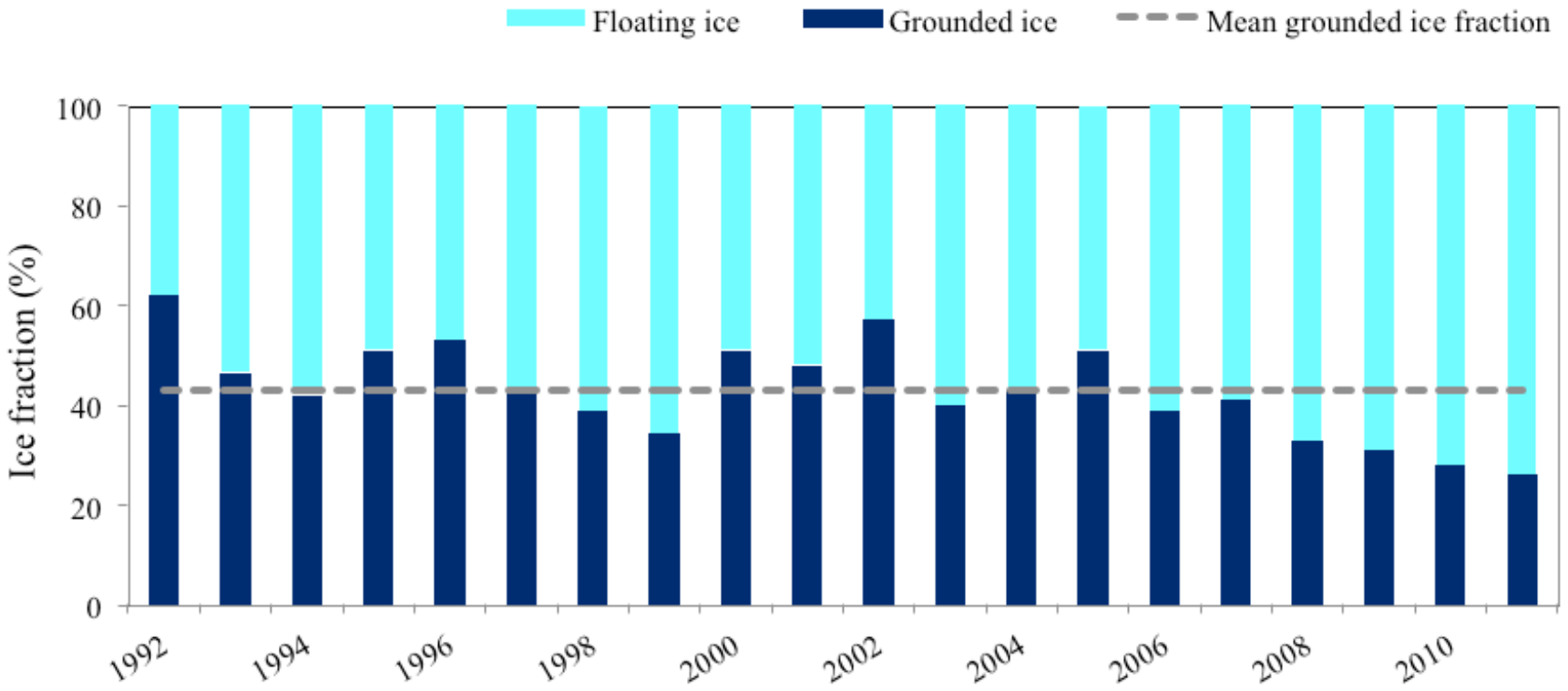


n = 402 lakes

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)

Grounded and floating ice fractions from SAR (100 m)



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)

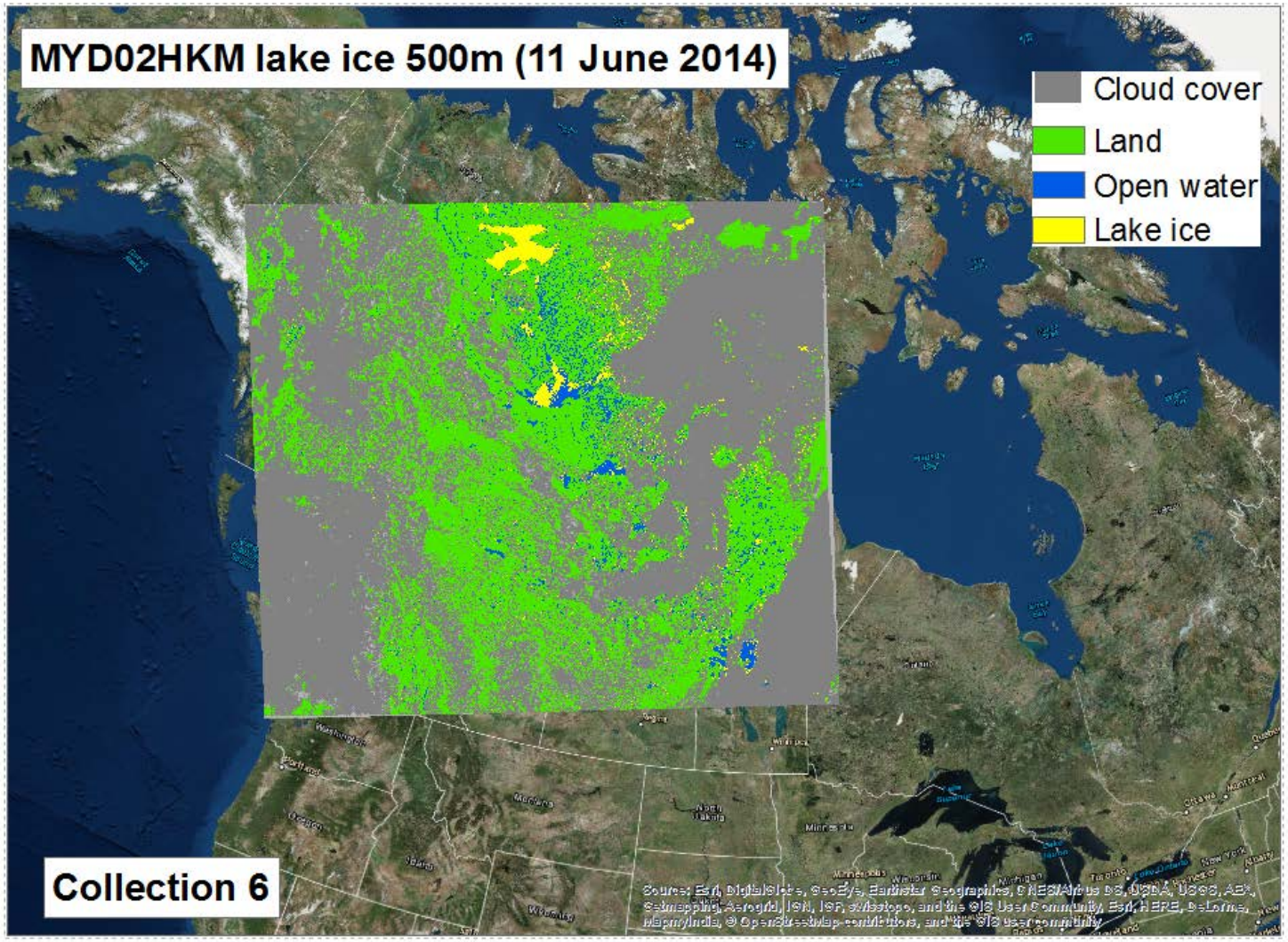
Outlook

- Significant advances are anticipated in the development of new retrieval algorithms for several lake ice parameters from recent and upcoming satellite missions (e.g. RADARSAT RCM, Sentinels, SWOT)
    - Ice extent/concentration
    - Ice dates and ice cover duration
    - Ice thickness
    - Snow depth on lake ice
    - Snow/ice surface temperature
    - Snow/ice albedo (broadband)
- Significant investment is needed to develop “long” historical records (1980s-present) of ice dates and ice thickness for climate studies (e.g. AVHRR, MODIS, passive microwave, SAR and altimeter data from several satellite missions)


Thank you for your attention!

Backup Slides

MODIS retrieval of lake ice cover extent



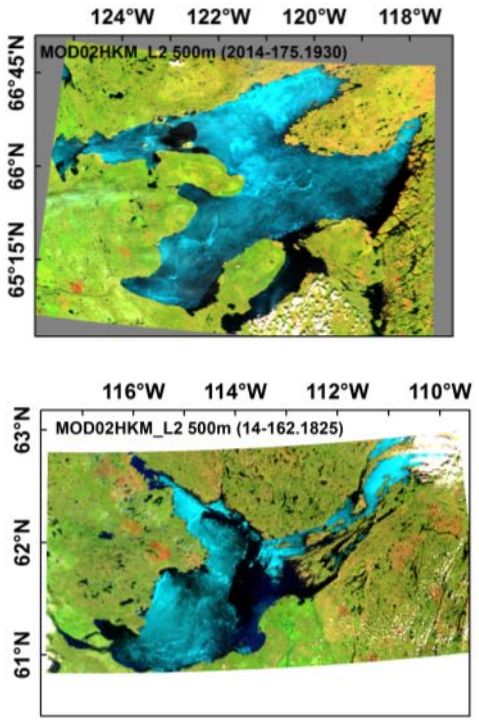
New ice cover extent product from MODIS data

- For operational use by ice and weather forecasting services

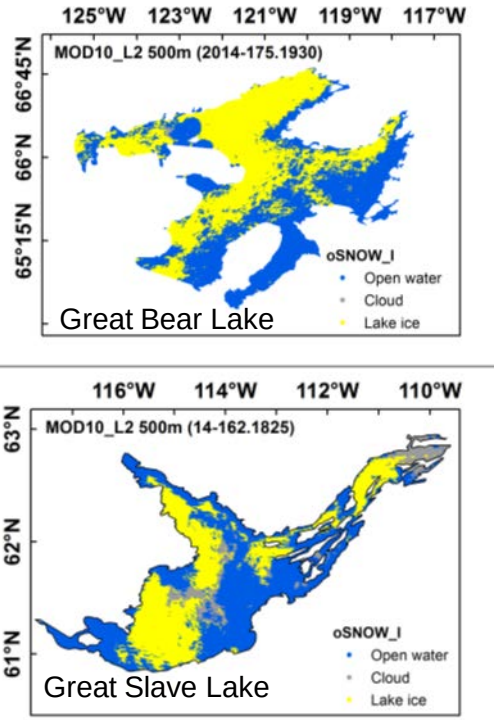
Kang *et al.*, in prep.

MODIS retrieval of lake ice cover extent

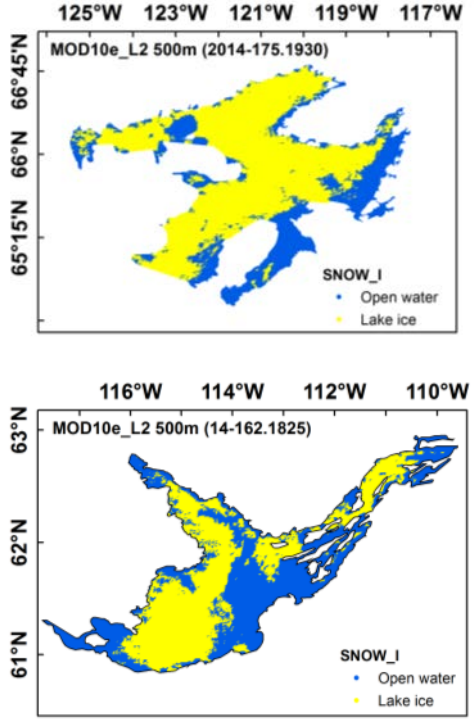
MODIS colour composite



MODIS SNOWMAP product



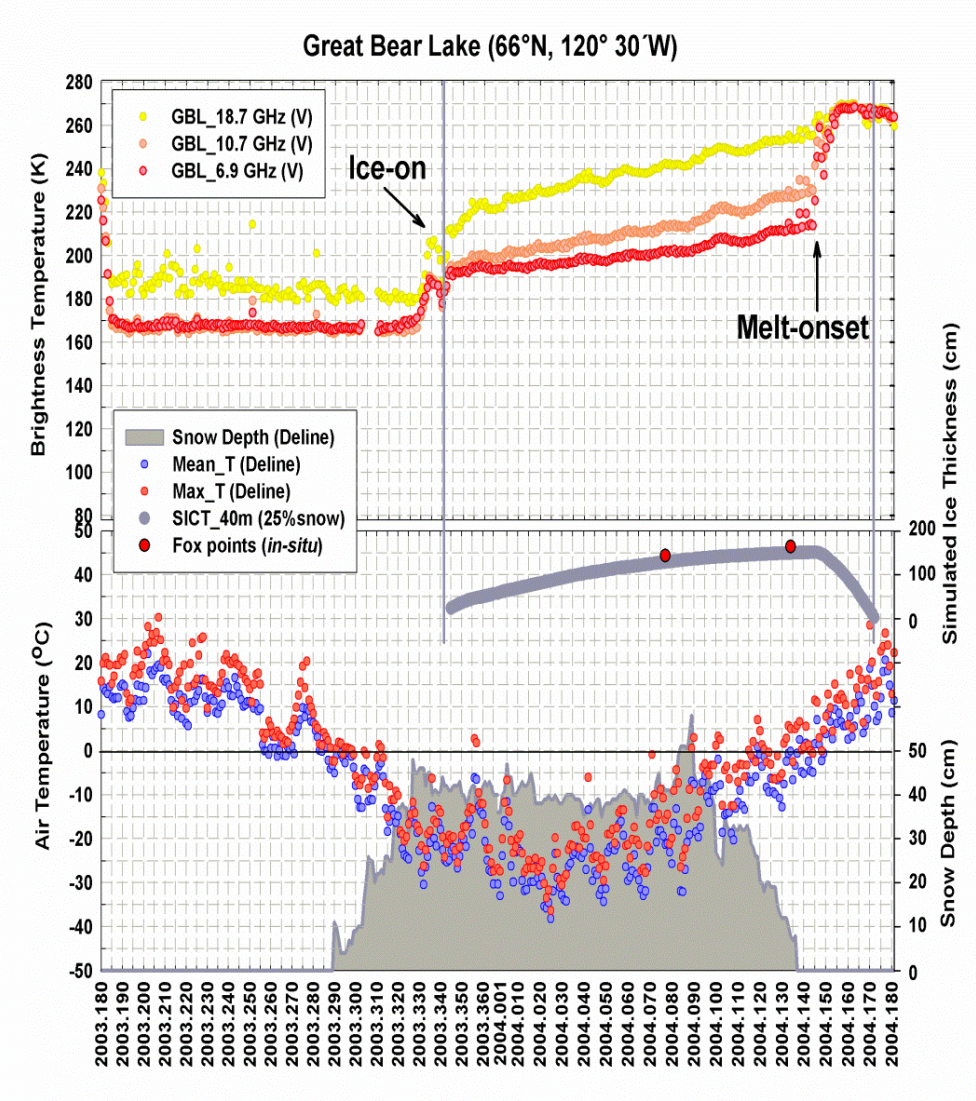
New MODIS lake ice product



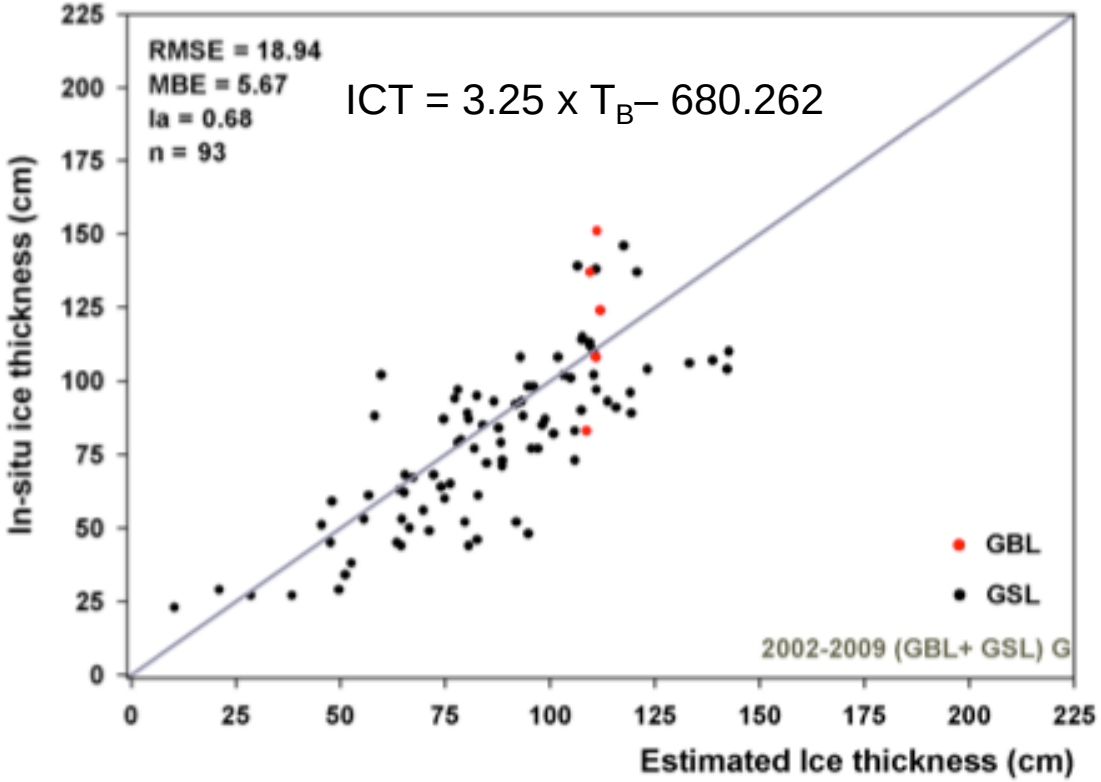
New (revised) MODIS SNOWMAP algorithm improves lake ice mapping

Kang *et al*., in prep.

Passive microwave retrieval of lake ice thickness



Retrieval algorithm
AMSR-E 18.7 GHz V-pol



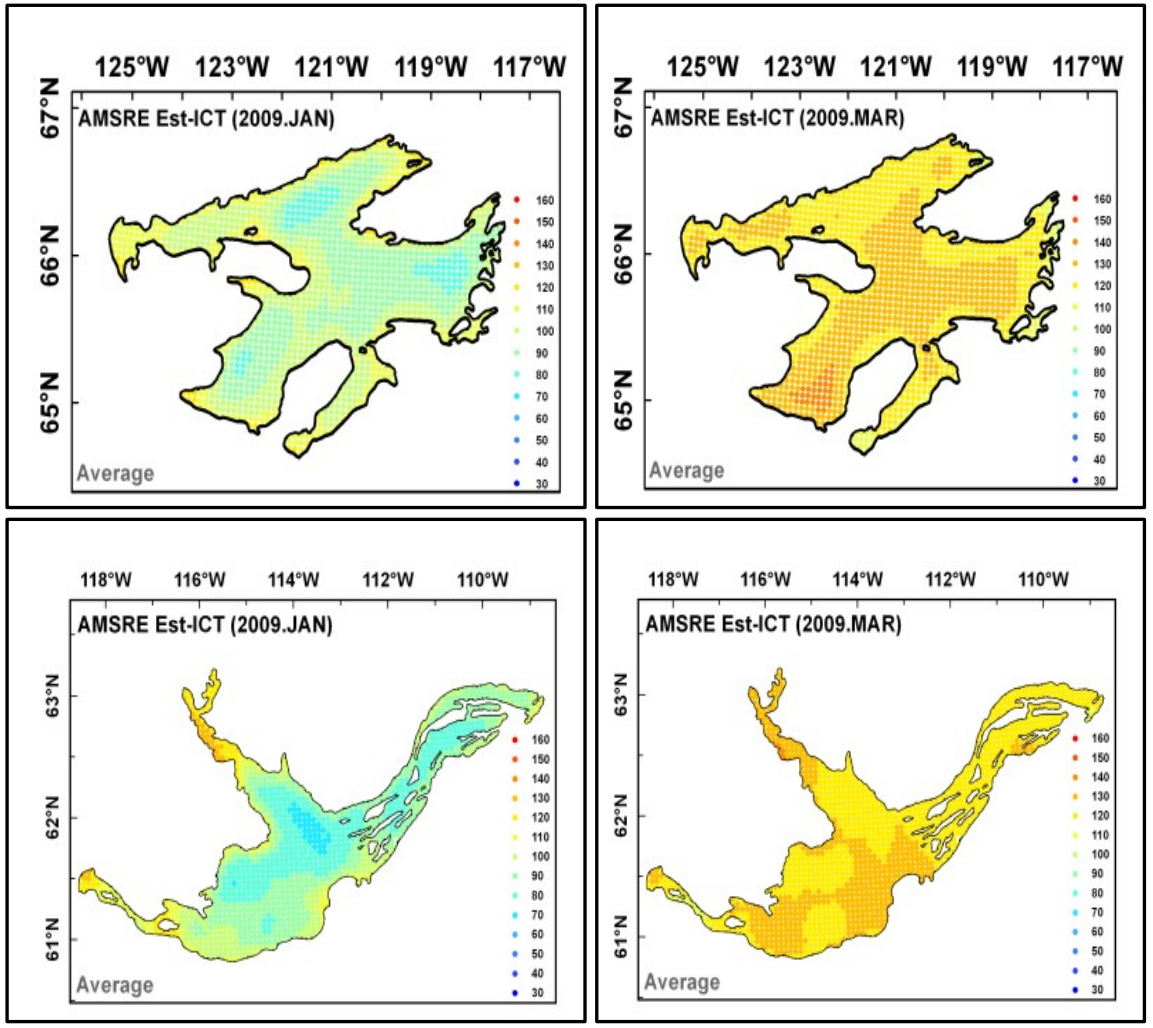
From daily data at 10 km

Kang *et al*. (2014)

Passive microwave retrieval of lake ice thickness

Great Bear Lake (Canada)

Great Slave Lake (Canada)

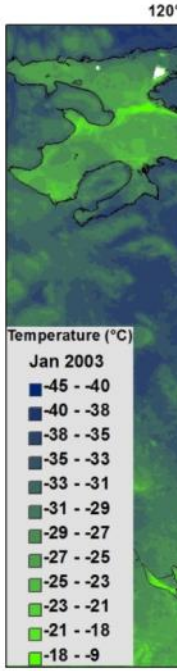


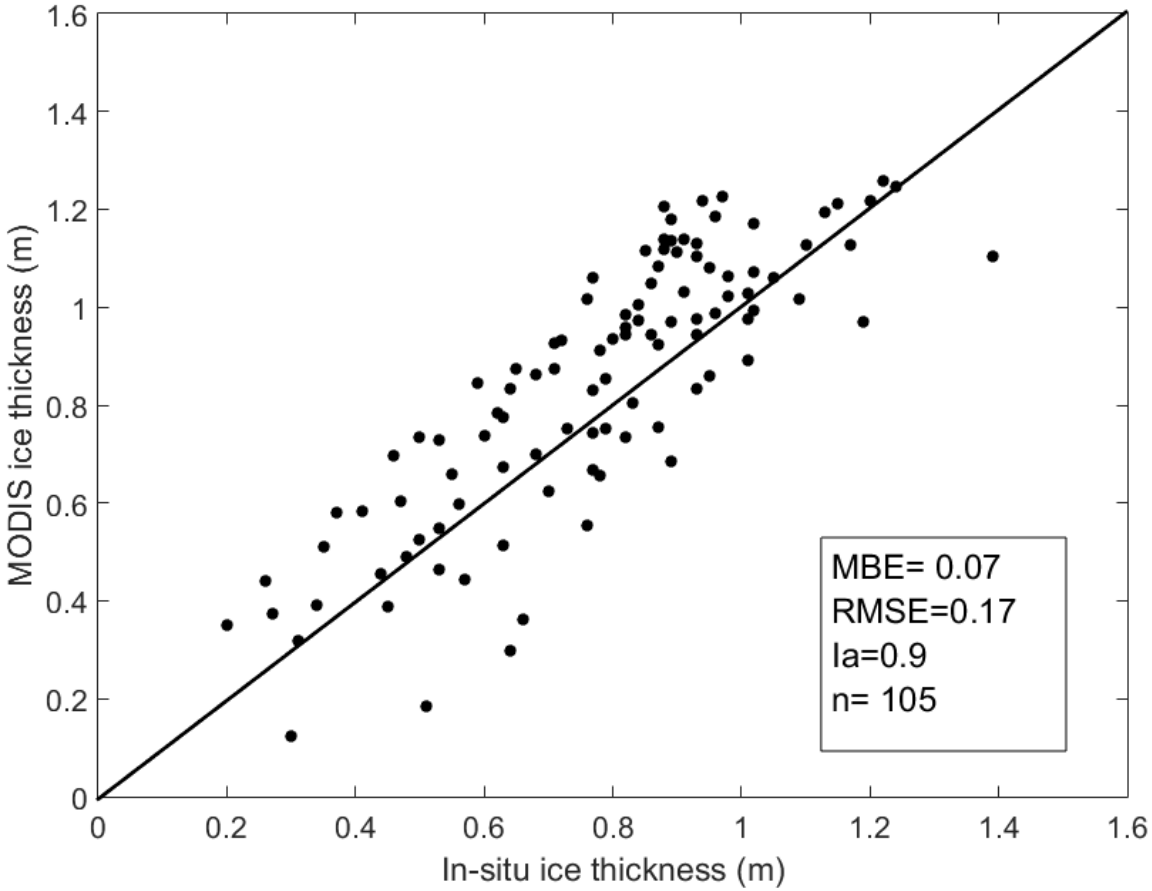
Retrieval algorithm
AMSR-E 18.7 GHz V-pol

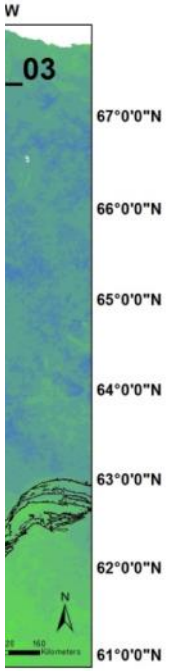
Monthly maps
January (left) and March (right)
2009

Kang *et al*. (2014)

Thermal infrared retrieval of lake ice thickness







MODIS

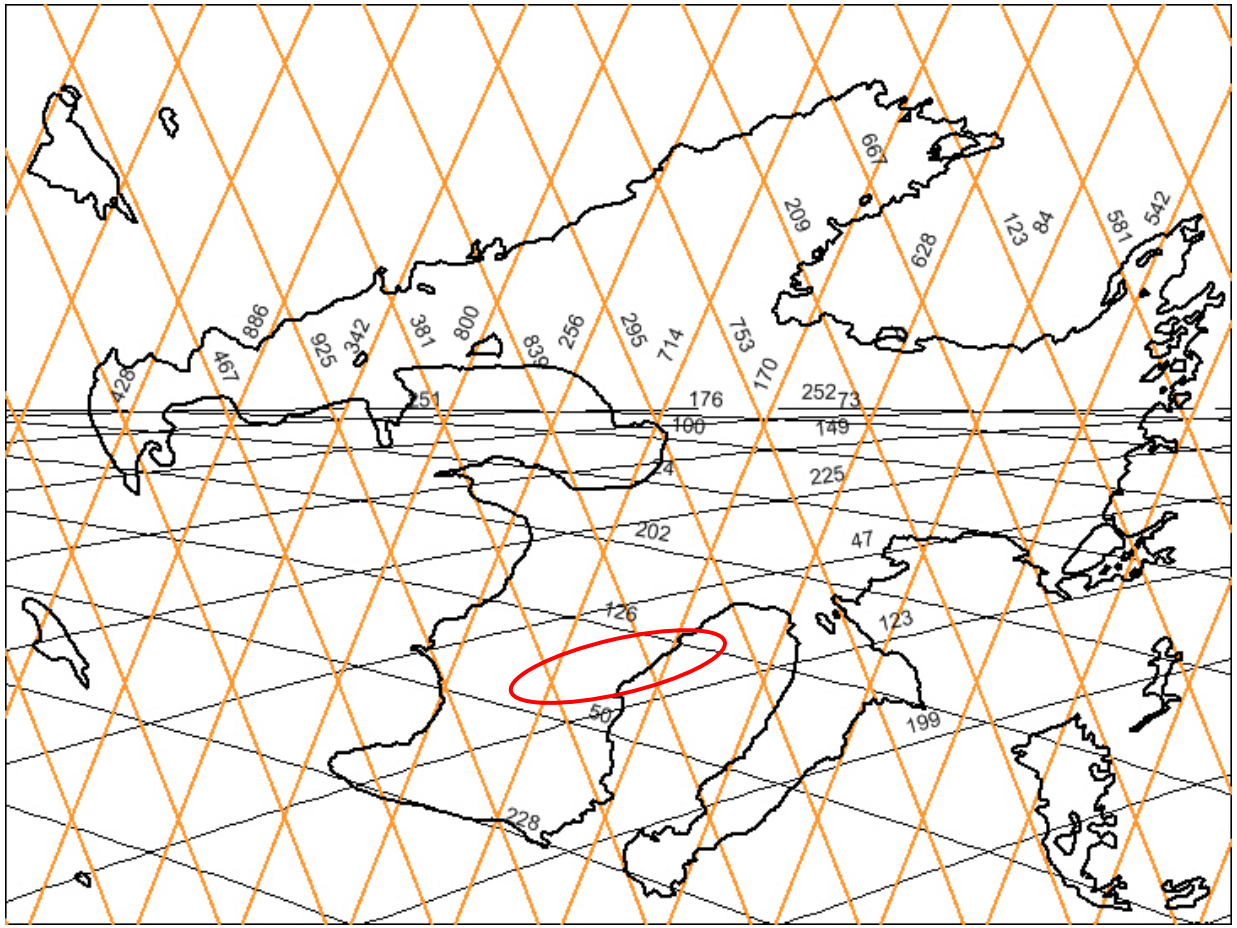
Lake and Great Slave Lake region (January, February, and March, 2003)

Ice thickness (conductive heat flux) signal

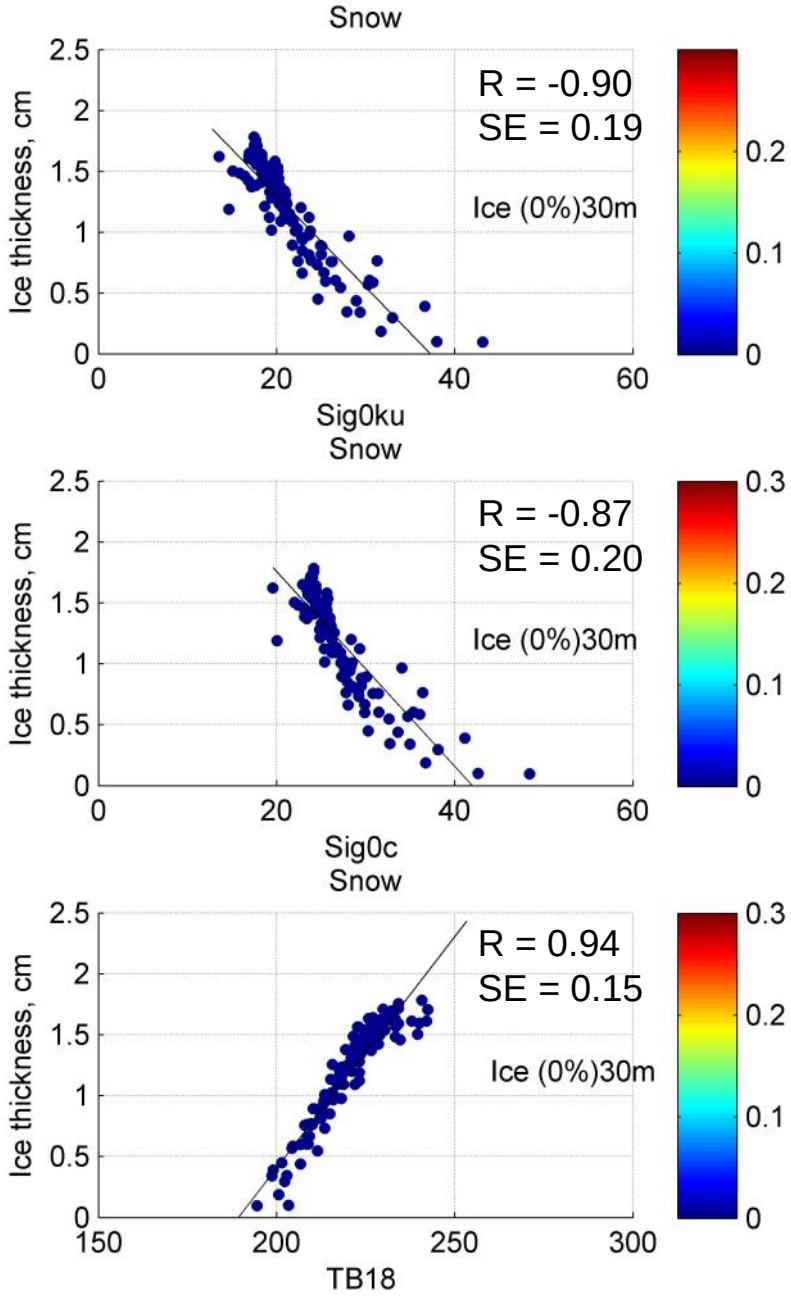
Kheyrollah Pour *et al.*, in press

Jason-2 retrieval of lake ice thickness

Duguay *et al*., in prep.

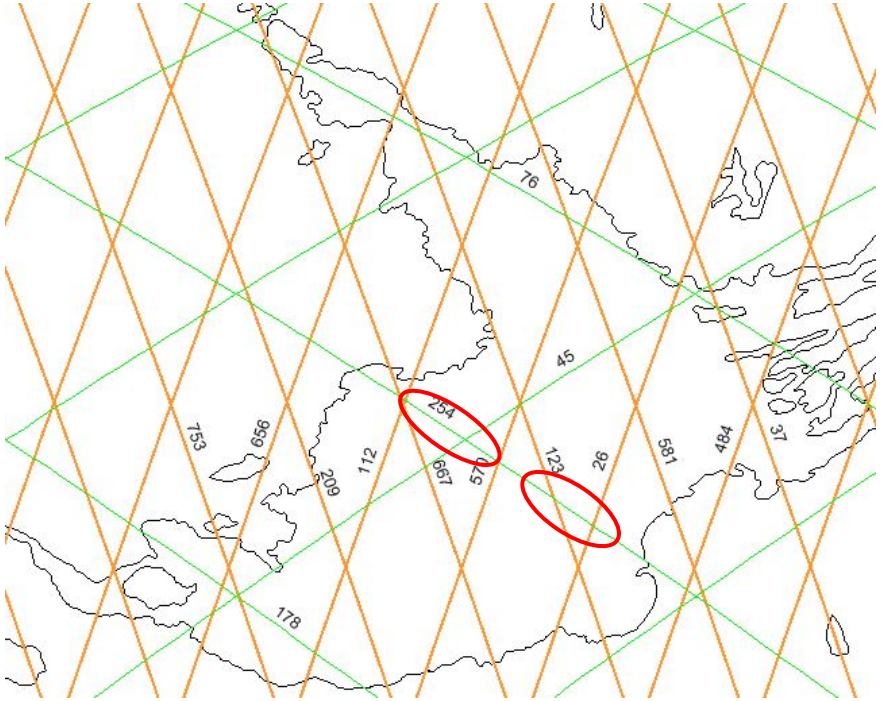


Great Bear Lake



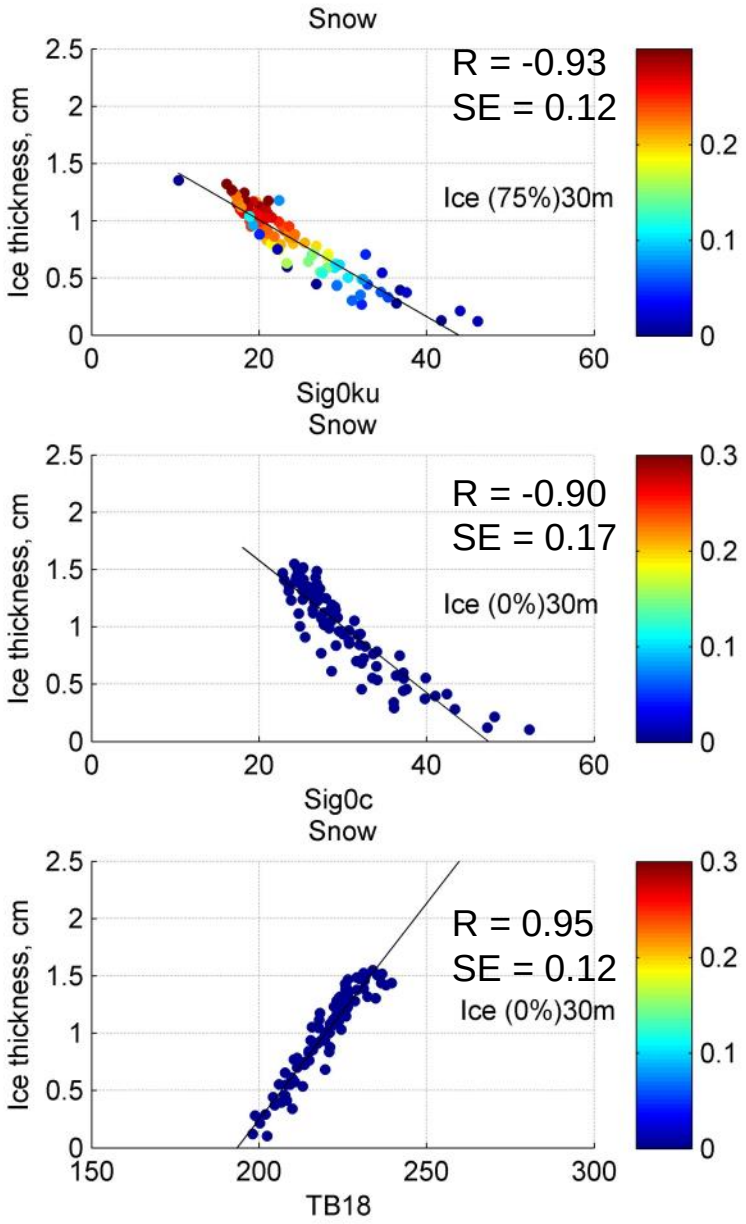
Jason-2 retrieval of lake ice thickness

Duguay *et al*., in prep.

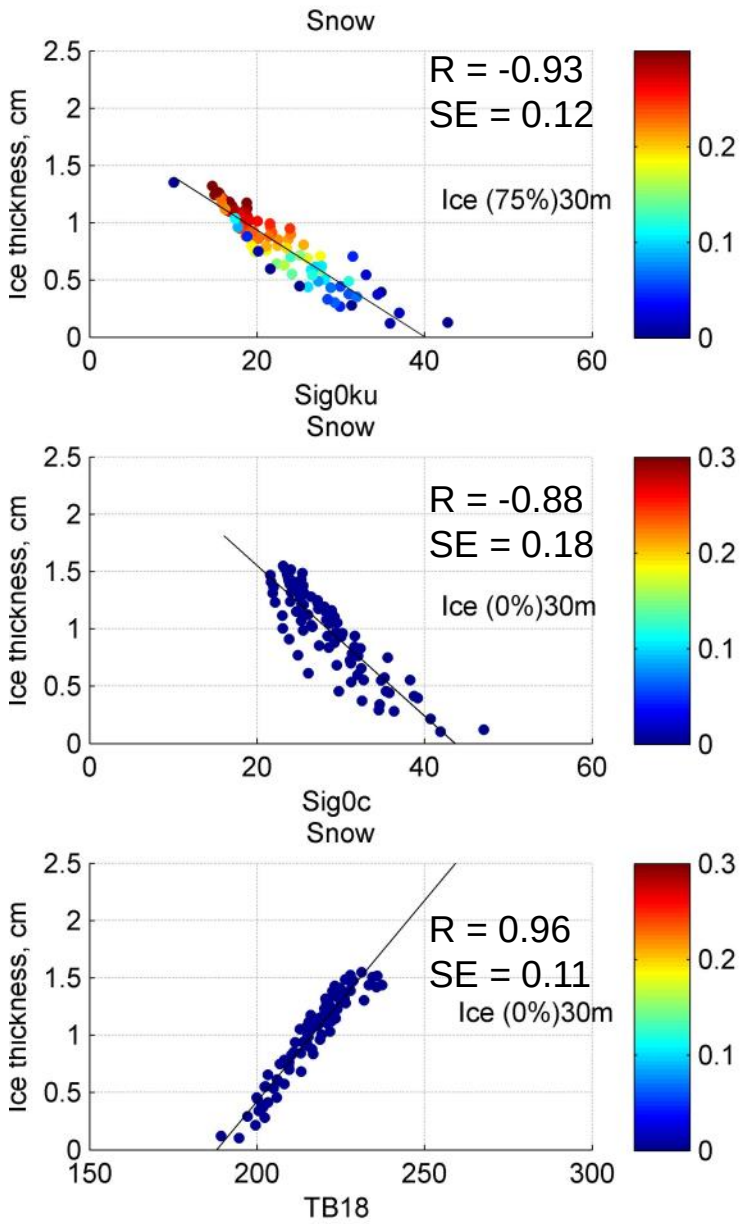


Great Slave Lake

Track 254 North



Track 254 South



Lake ice model - CLIMo

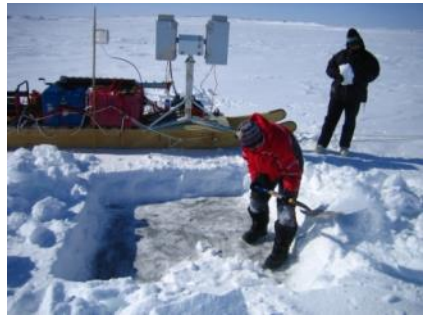
Duguay *et al*., 2003

INPUT

- Air Temperature
- Relative Humidity
- Wind Speed
- Cloud Amount
- Snow Accumulation

CLIMo

0% and 100 % snow scenarios



OUTPUT

- Freeze-up/Break-up dates
- On-ice Snow Depth
- Ice Thickness (Snow/Clear Ice)
- Temperature Profile (ice and water temperature during the ice-free period)
- Energy Balance Components