Ground-Based and Satellite Observations of Arctic Lake Ice

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Ground-based observations

Why are ground-based lake ice observations needed?

- To document variability and change in ice phenology (freeze-up/break-up/duration) and ice thickness in response to weather/climate

- To understand interactions between EM radiation (optical, thermal, microwave) with ice properties (surface, volume and interfaces) needed to develop satellite retrieval algorithms

- To evaluate and improve numerical lake models

Satellite-based observations

Why are satellite-based lake ice observations needed?

- To rebuild the lost ground-based observational network(s) in countries such as Canada
- To provide a broader geographical coverage than what is possible from ground-based observations (and with increasingly higher temporal frequency)
- To improve high-latitude numerical weather forecasting

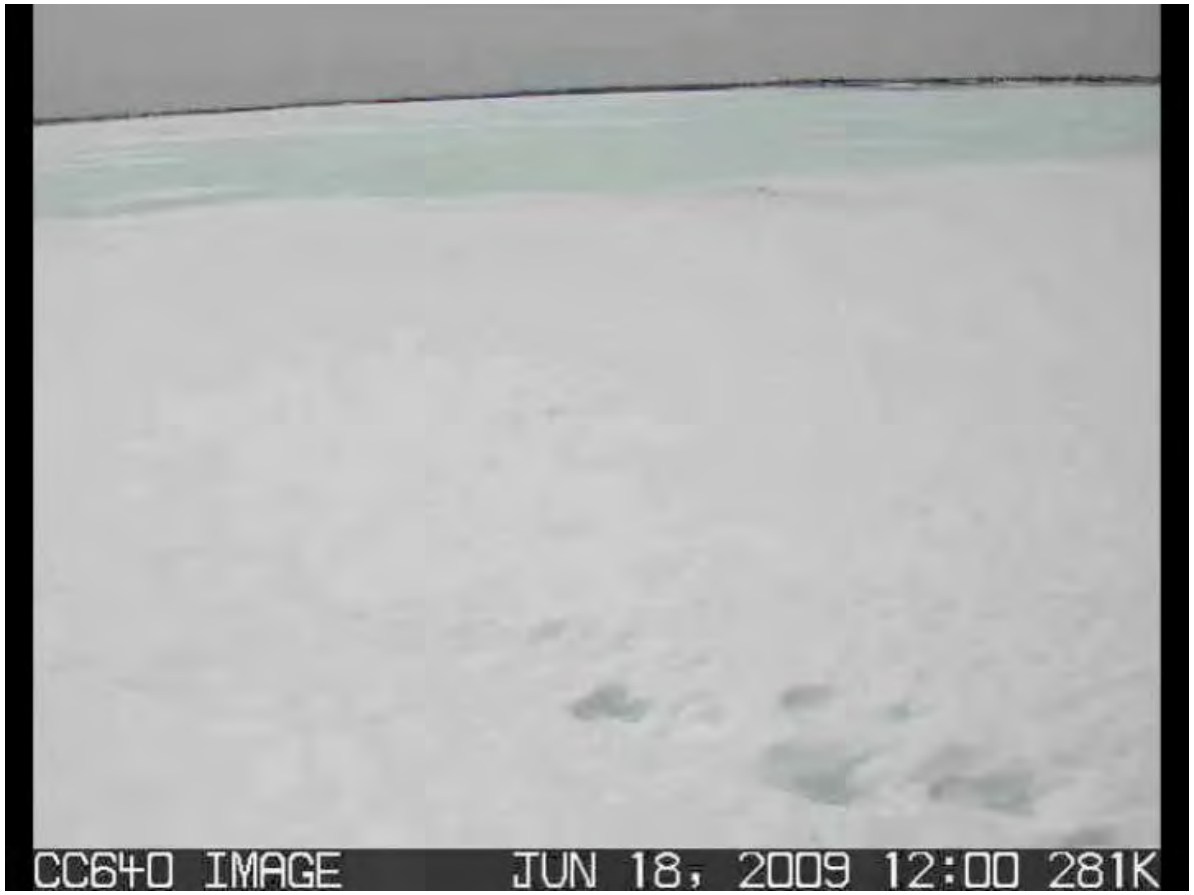
Ground-based and satellite observations

Parameters of interest for Arctic lake ice

- Ice extent and lake-wide fraction from which freeze-up (freeze onset to complete freeze over) and break-up (melt onset to water clear of ice) dates, and ice cover duration can be derived
- Snow/ice albedo (broadband)
- Snow/ice surface temperature
- Areal extent of floating and grounded ice (shallow lakes, ca. < 3 m deep)
- Ice thickness
- Snow depth/SWE on ice

Ground-based observations

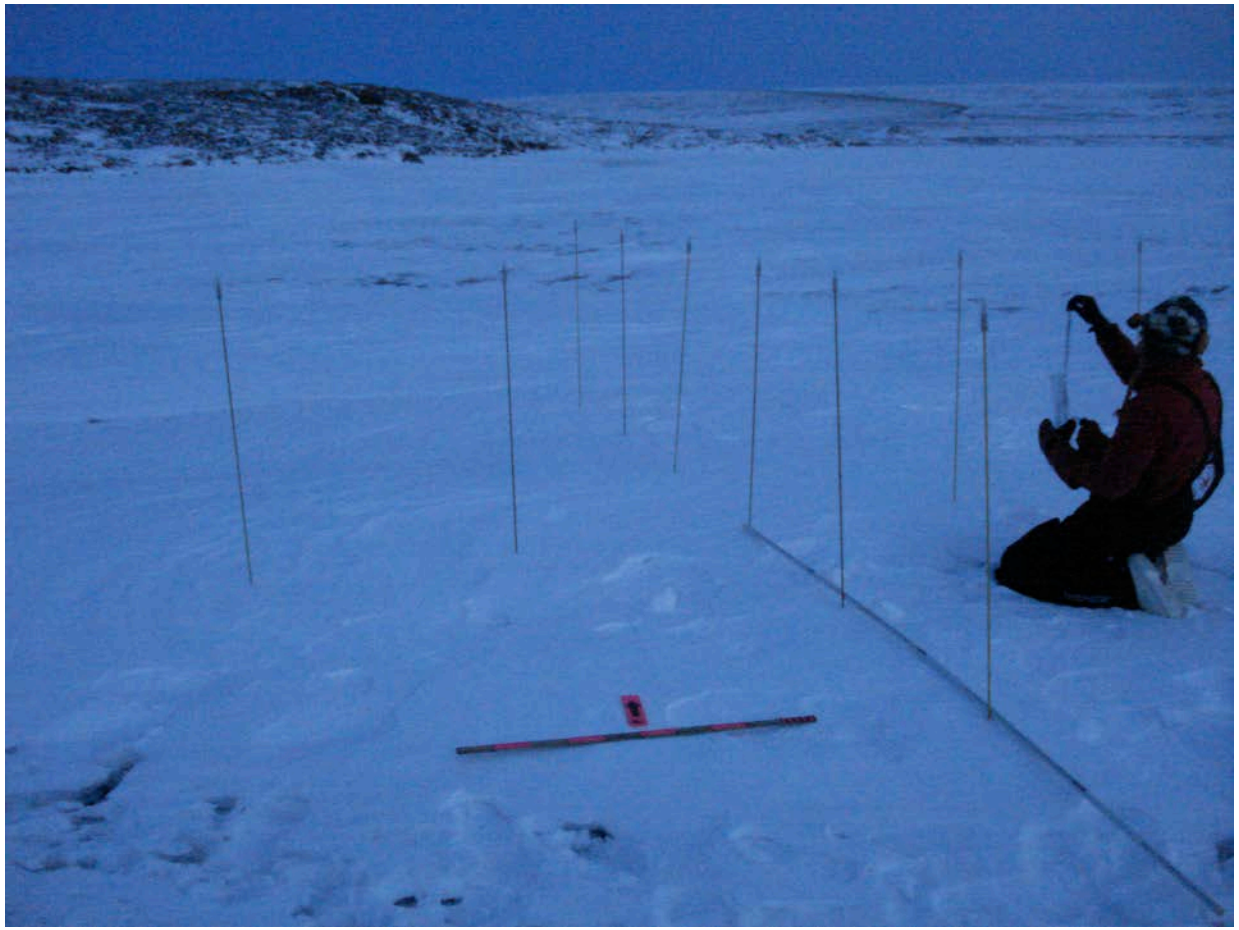
Ice extent and phenology (freeze-up/break-up/ice duration)



Ground-based observations
Snow/ice albedo and temperature

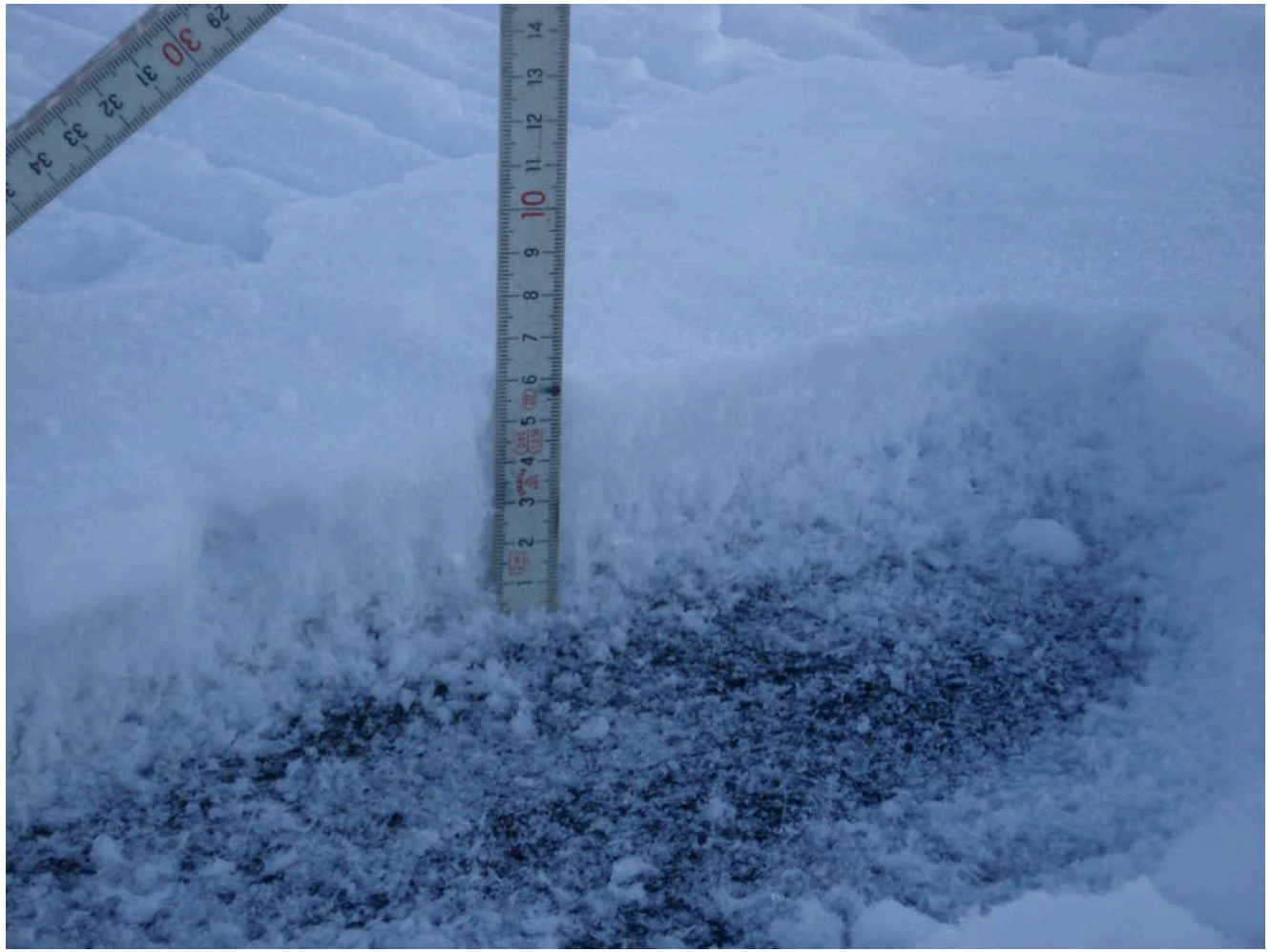
Ground-based observations

Air-snow and snow-ice interface temperatures



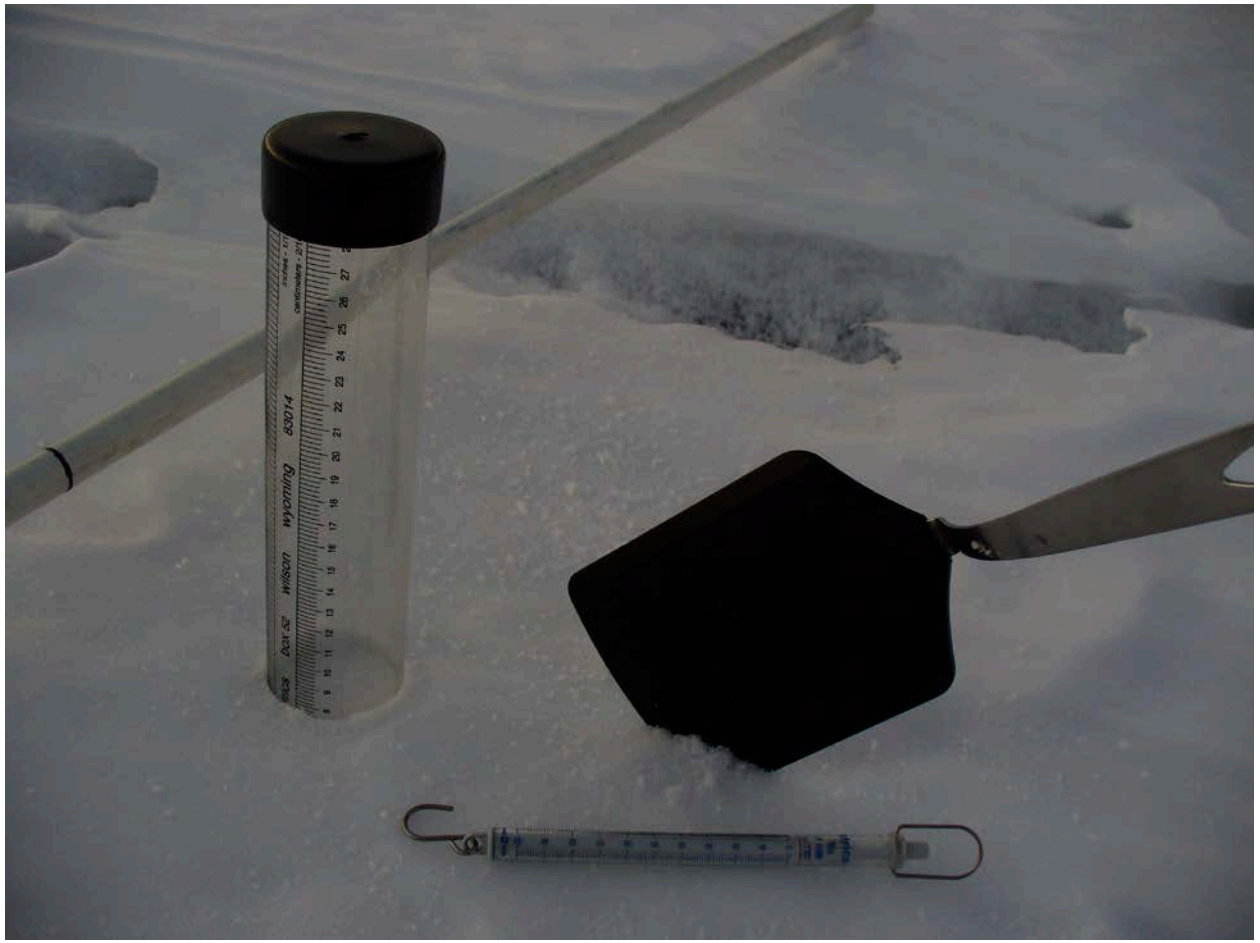
Ground-based observations

Snow depth



Ground-based observations

Snow water equivalent (SWE)

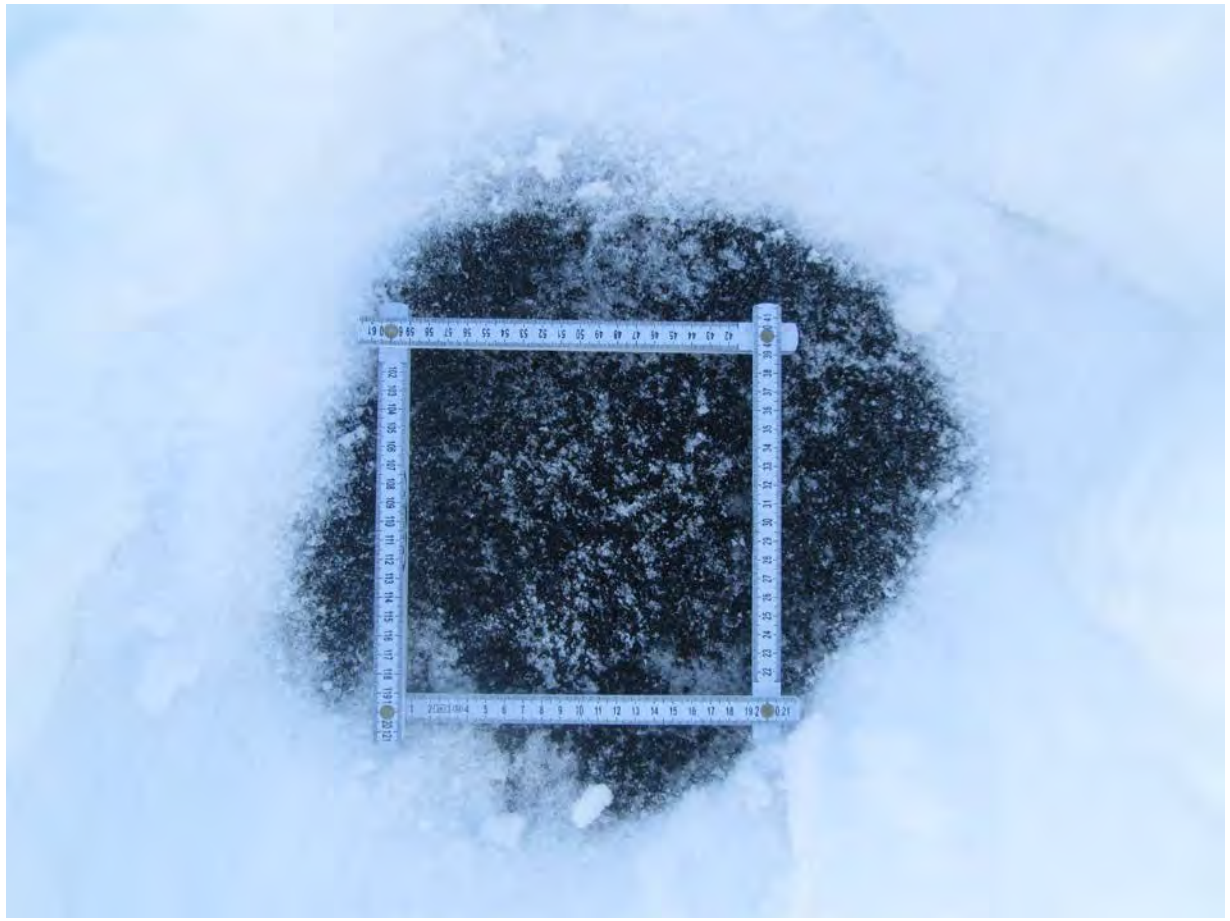


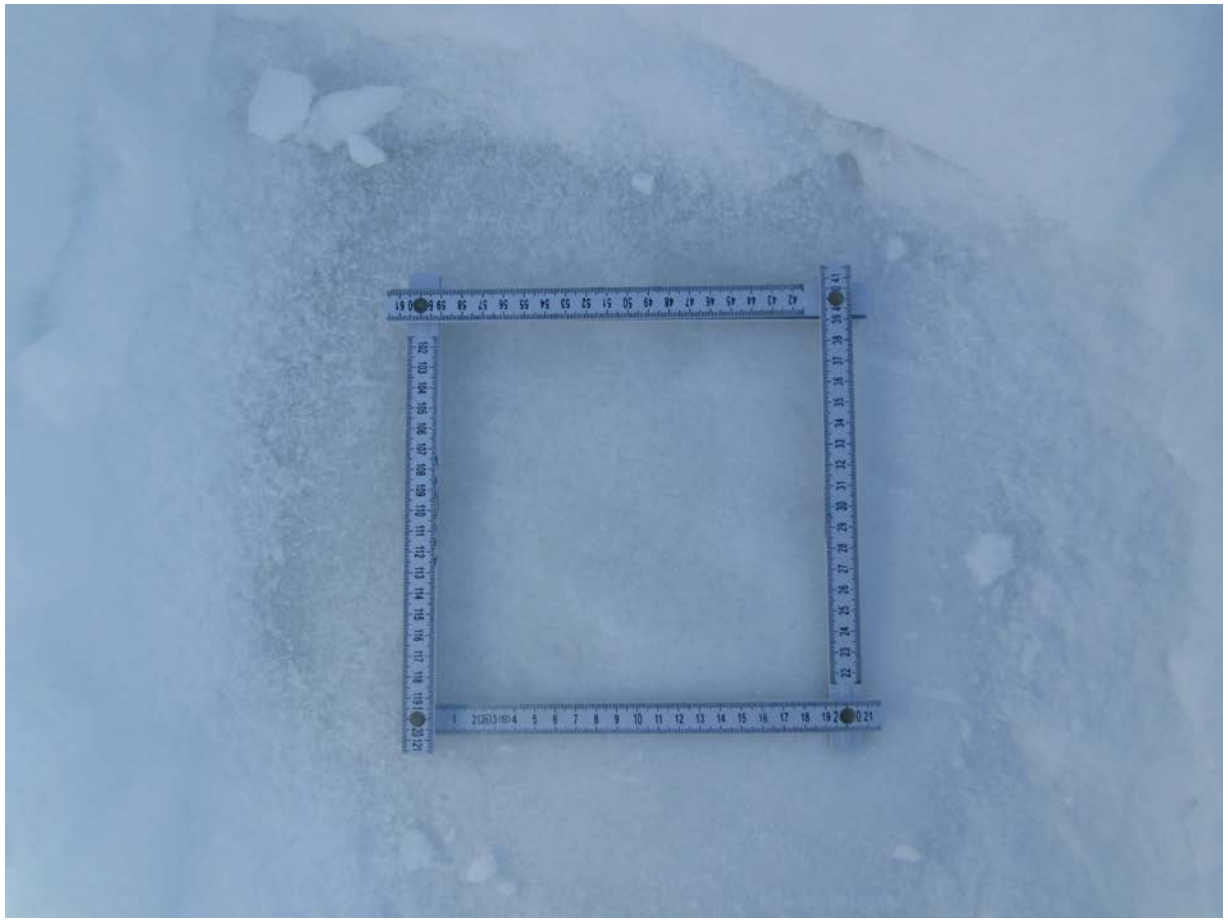
Ground-based observations

Snow pit/stratigraphy

Ground-based observations

Ice surface properties/type





Ground-based observations

Ice thickness

Ground-based observations

Monitoring ice phenology and ice thickness automatically

Malcolm Ramsay Lake, Churchill, MB

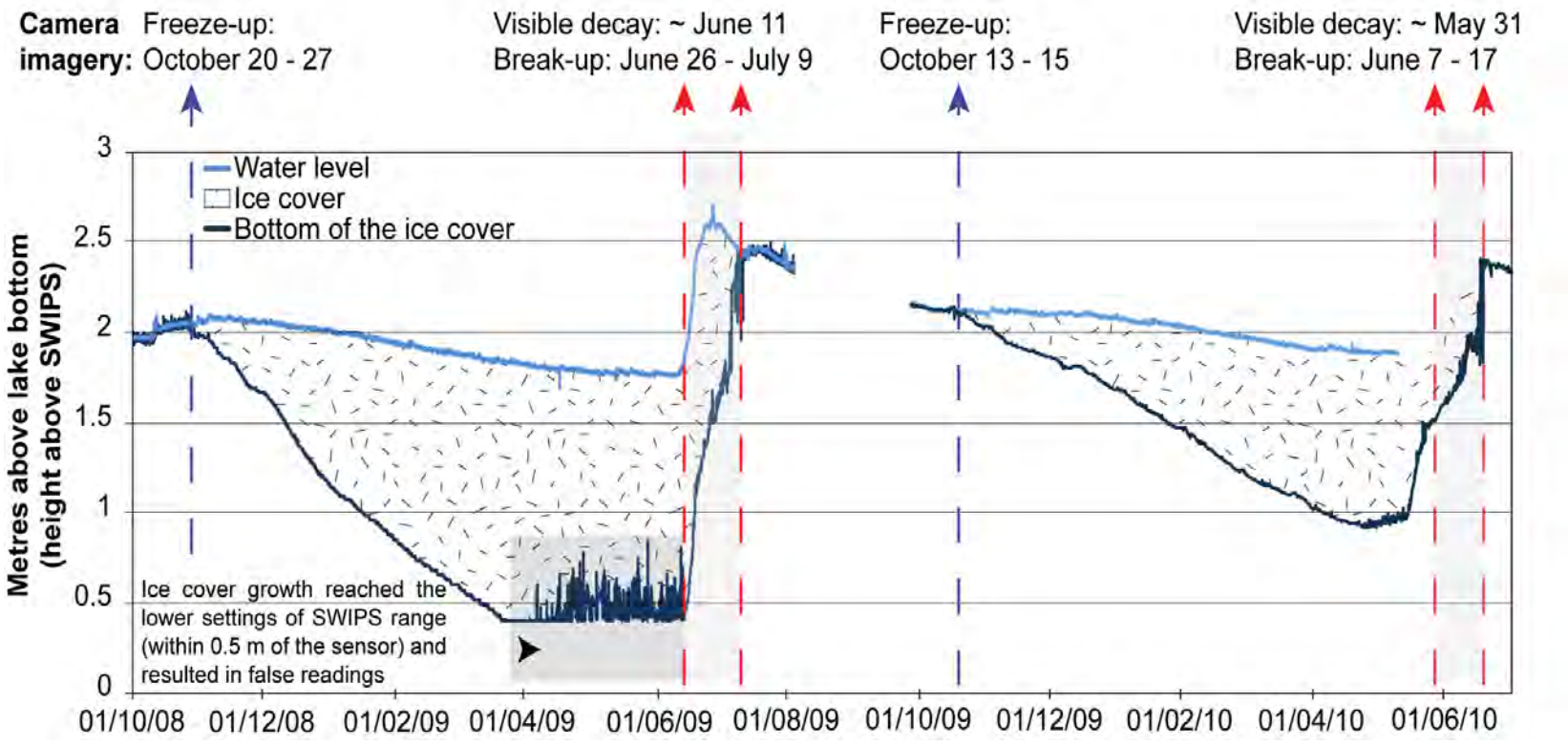
Shallow Water Ice Profiler (SWIP)

Deployed on lake bottom

Ground-based observations

Monitoring ice phenology and ice thickness automatically

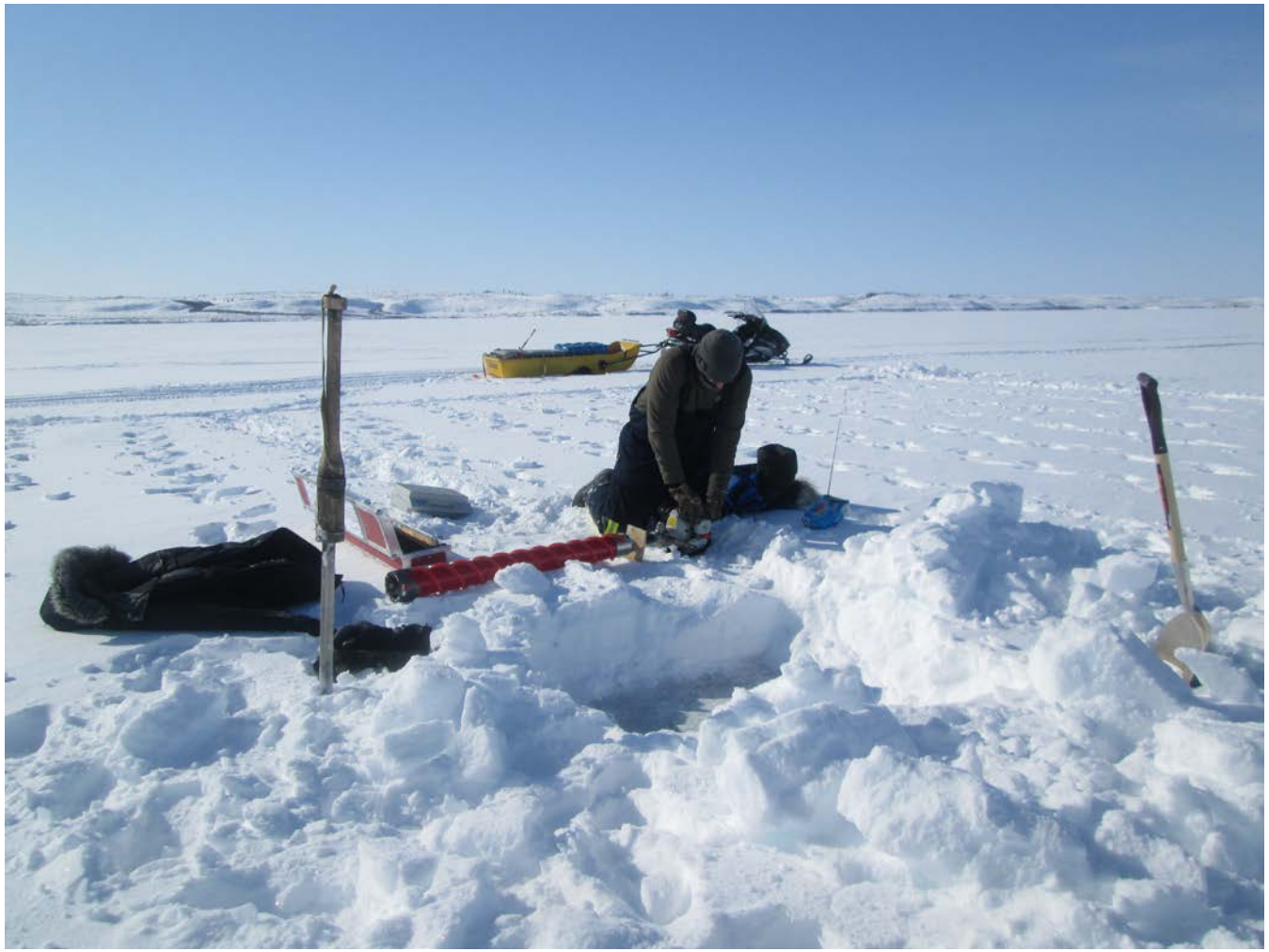
Malcolm Ramsay Lake, Churchill, MB



Brown and Duguay, 2011

Ground-based observations

Ice coring



Ground-based observations

Ice cores (stratigraphy and crystal texture)

(Slide courtesy of M. Jeffries)

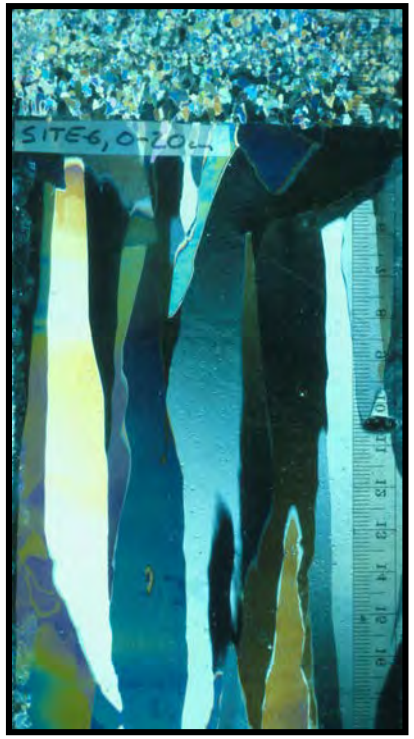
Ground-based observations

Ice cores (stratigraphy and crystal texture)

How to reveal lake ice crystal texture

First (1), split the core lengthwise.

Second (2), cut a thin/thick slice.

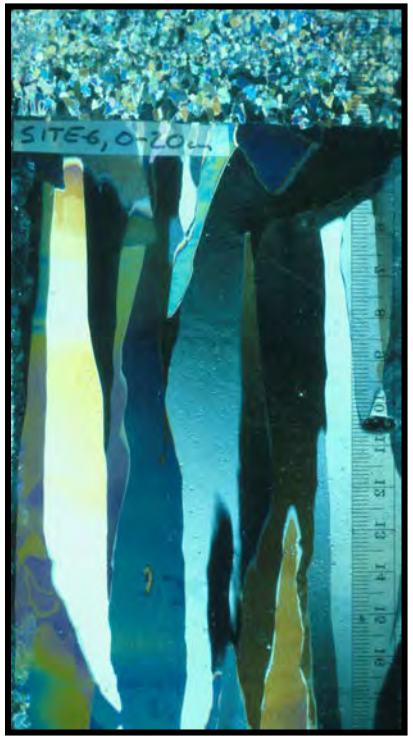


Third (3), illuminate between crossed polarizing filters.

(Slide courtesy of M. Jeffries)

Ground-based observations

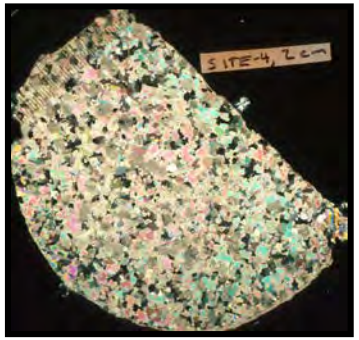
Ice cores (stratigraphy and crystal texture)



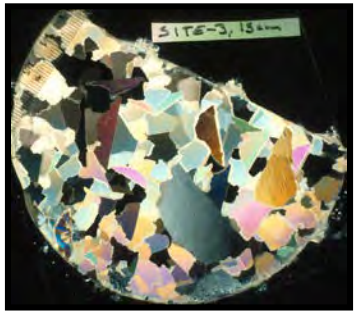
0 m

0.2 m

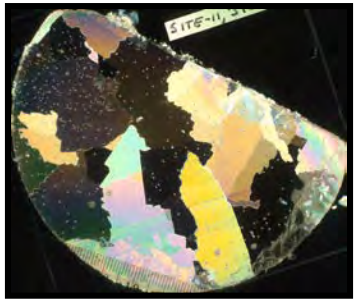
Congelation ice
overlain by snow ice



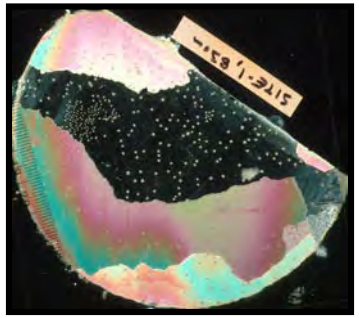
0.02 m



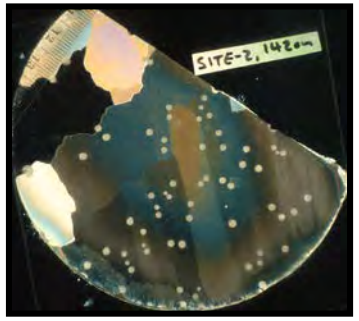
0.15 m



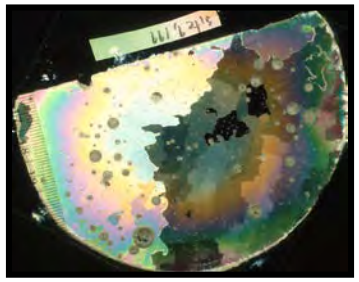
0.39 m



0.83 m



1.42 m



1.99 m

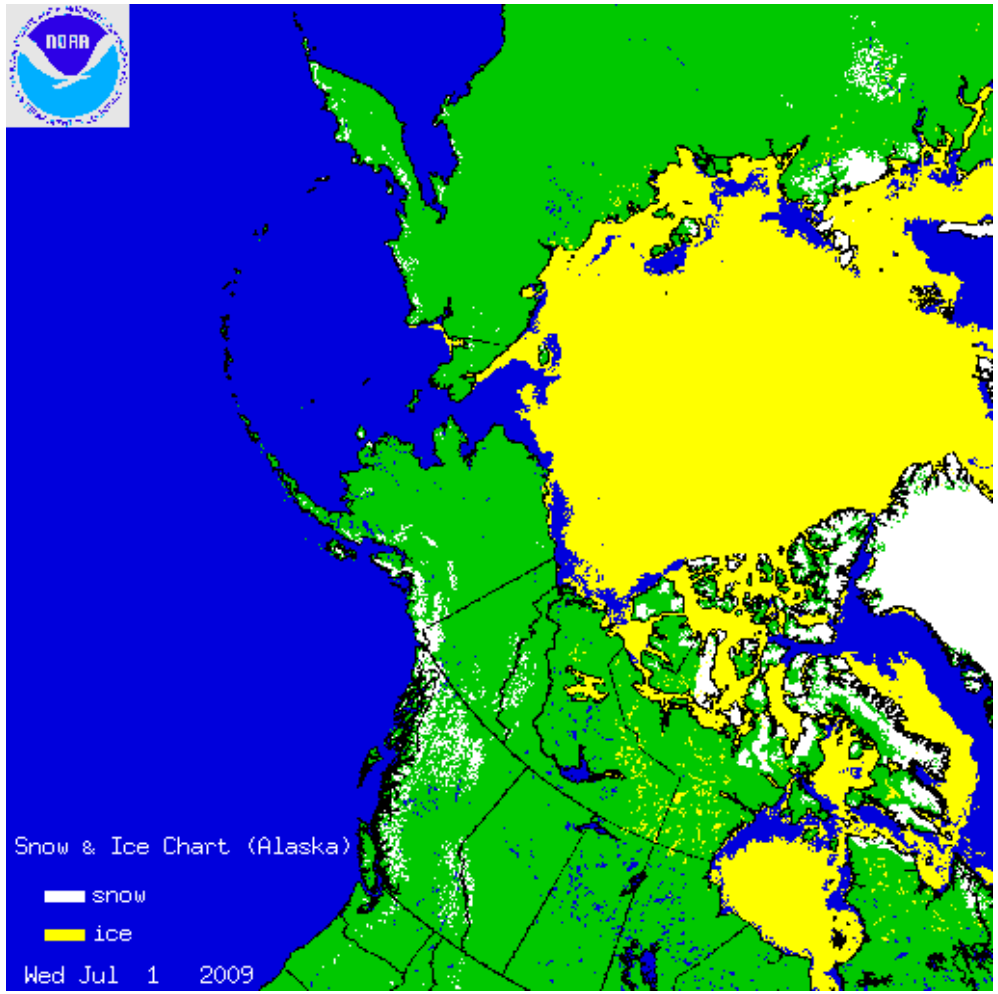
Grain size increases as the total thickness of snow and ice increases and growth rates decrease.

(Slide courtesy of M. Jeffries)

Ground-based observations

Bubbles and roughness at ice-water interface

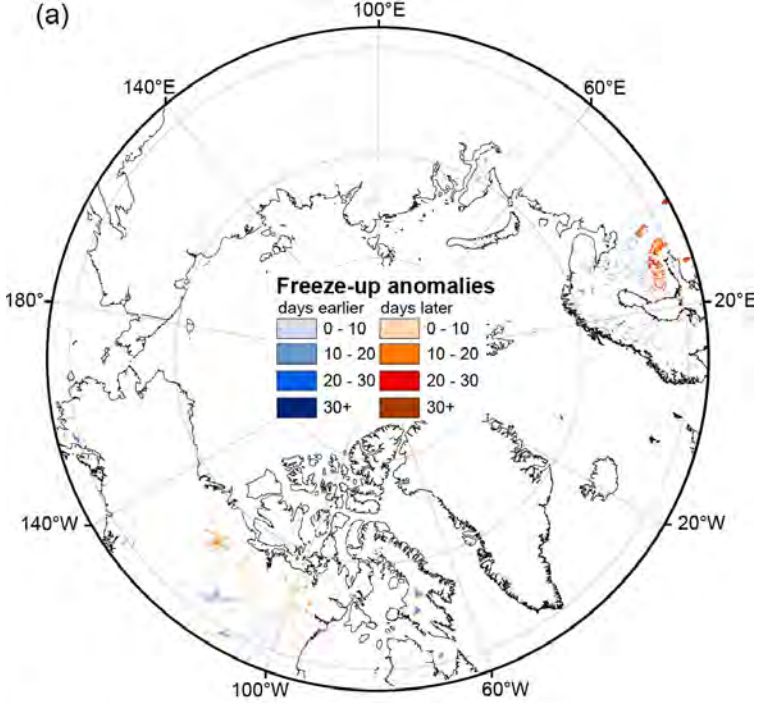
Satellite observations (retrievals)
Ice extent



- Global **operational product** - IMS daily ice cover extent at 4 km resolution: 2004-on
- Binary: either ice-on or ice-off (open water) each pixel
- Largely from visual interpretation
- Based on the use of AVHRR, GOES, MODIS, SSM/I data

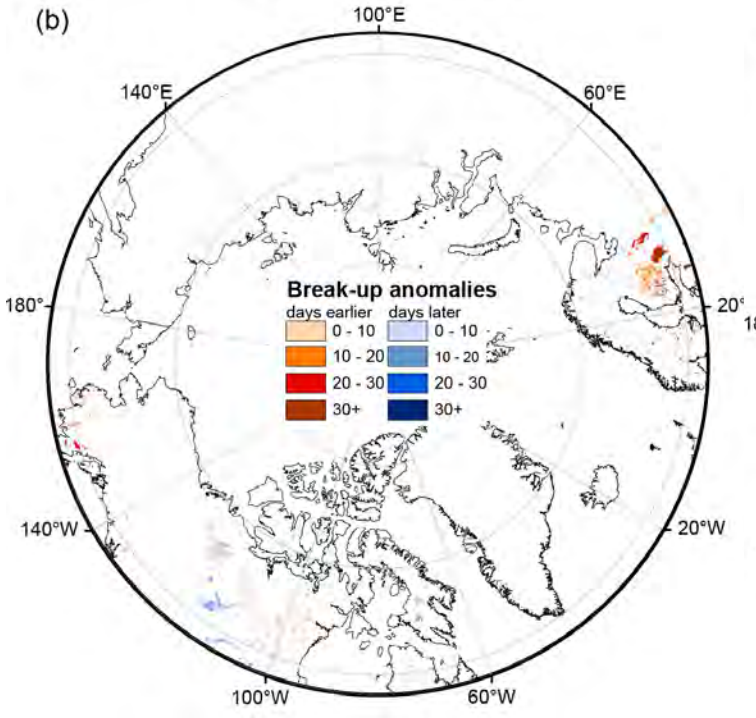
Satellite observations (retrievals)

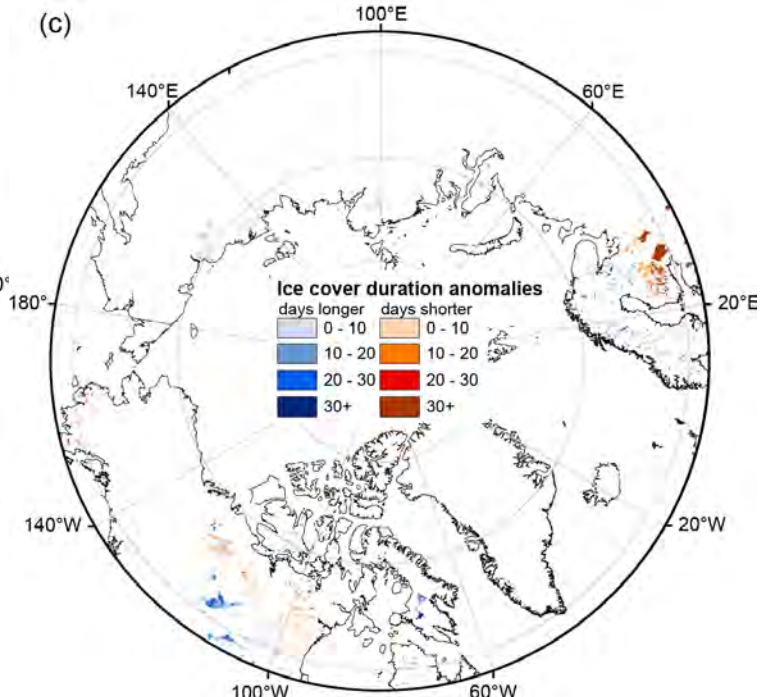
Ice phenology



State of the Climate 2014
"The Arctic"

Duguay *et al*. (*BAMS*, 2015)

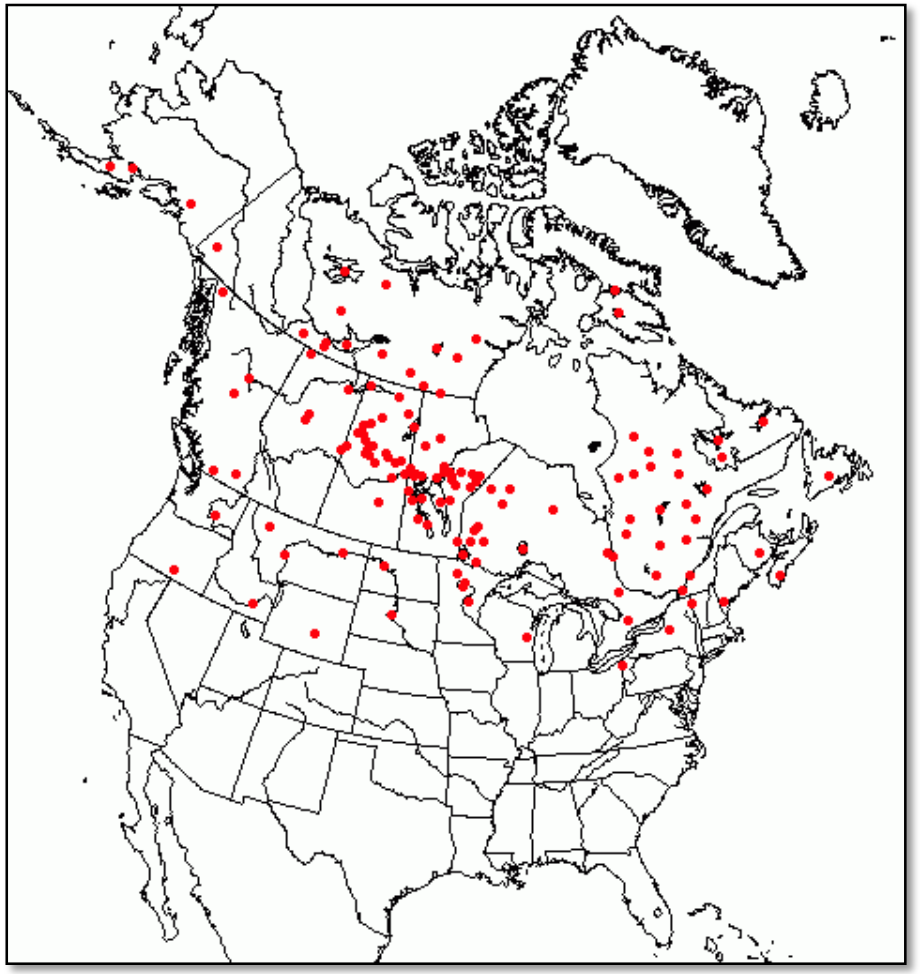




Ice cover anomalies in 2013-2014 ice season relative to 2004-2013 mean from NOAA IMS 4 km daily product, 2004-present

Satellite observations (retrievals)

Ice extent and lake-wide fraction



Weekly lake-wide ice fraction (in tenth) from visual interpretation of SAR and optical imagery by ice analysts at the Canadian Ice Service (CIS) since 1995

02112012_lakeice.txt – 7872 bytes[1].txt — Locked

Lake ice data 201211021800

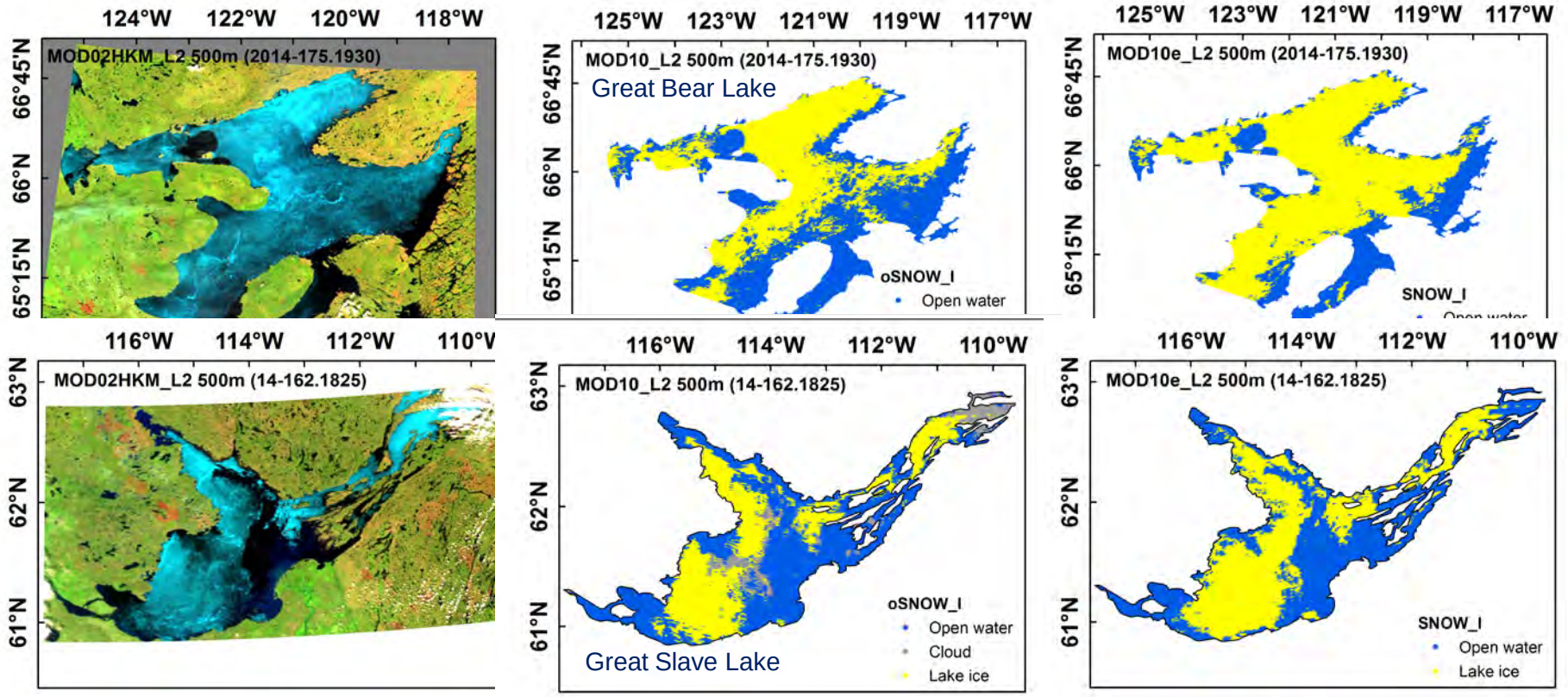
Name	Lat	Long	Ice-covered
Lake Melville	53.7	59.4	0.0
Smallwood Reservoir	54.0	65.0	0.0
Lake Rossignol	44.2	65.1	0.0
Lac Joseph	52.8	65.3	0.0
Grand Lake	46.0	66.0	0.0
Reservoir Manic	51.3	68.3	0.0
Reserv. Caniapiscau	54.3	70.0	0.0
Reservoir Pipmuacan	49.6	70.5	0.0
Nettilling Lake	66.5	70.5	6.0
Sebago Lake	43.9	70.6	0.0
Lac Manouane	50.8	70.8	0.0
Lac Naococane	52.9	70.6	0.0
Amadjuak Lake	64.9	71.2	4.0
Lac ST Jean	48.6	72.1	0.0
Lac St-Pierre	46.2	72.8	0.0
Lac Bienville	55.0	73.0	0.0
Lac Champlain	44.5	73.3	0.0
La Grande 4	53.9	73.3	0.0
Lac Mistassini	51.0	73.6	0.0
Lac St-Louis	45.4	73.8	0.0
Lac a l eau Claire	56.2	74.4	0.0
Reservoir Gouin	48.7	74.8	0.0
La Grande 3	53.8	75.5	0.0
Reservoir Baskatong	46.8	75.8	0.0
Lac Evans	50.9	77.1	0.0
La Grande	53.7	77.2	0.0

Operational product for CMC weather forecasting

Satellite observations (retrievals)
Ice extent and lake-wide fraction (optical)

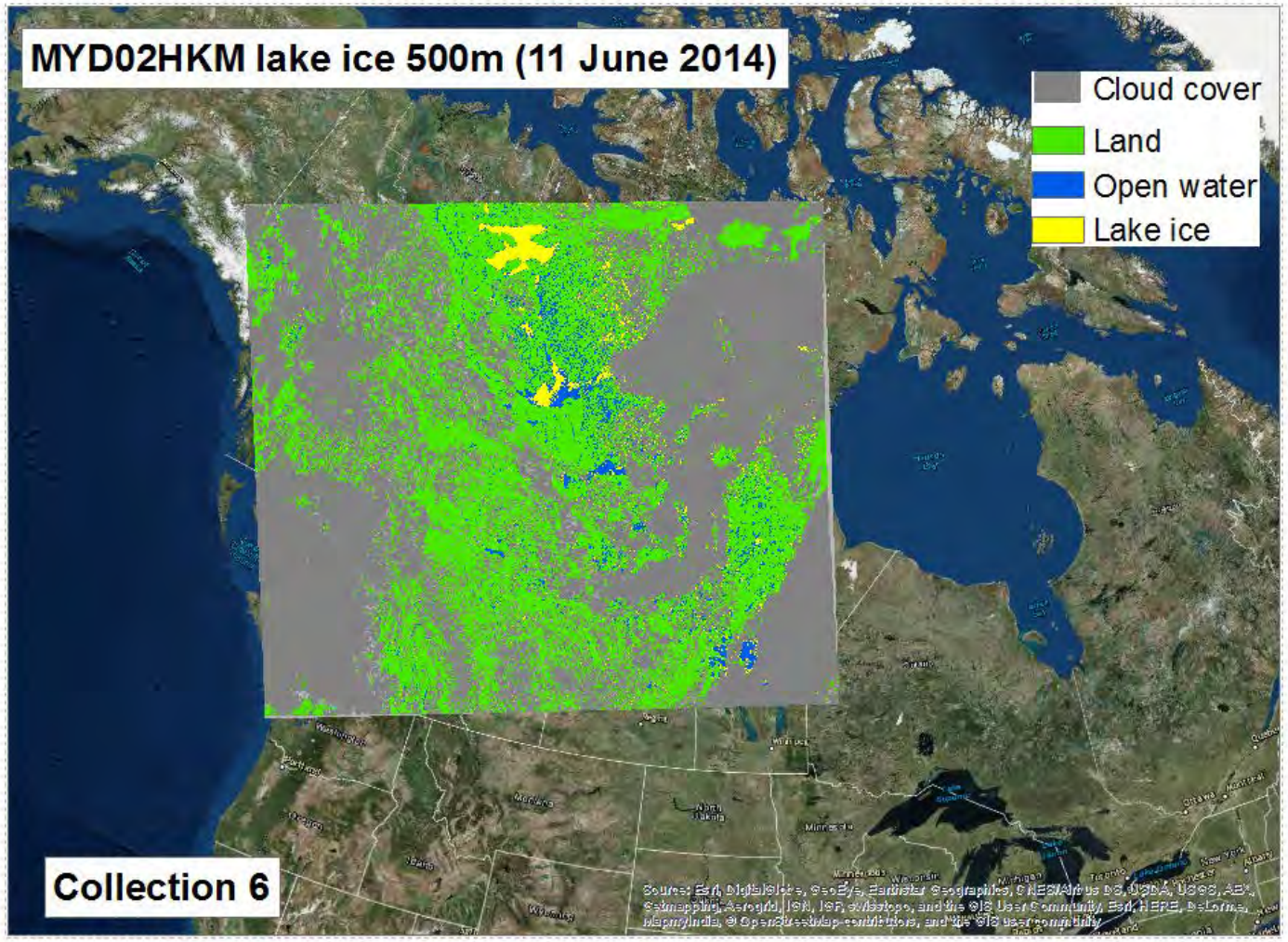
Towards automation of weekly lake-wide ice fraction product for CIS

MODIS colour composite **MODIS SNOWMAP product** **New MODIS lake ice product**



Kang *et al*. (in prep.)

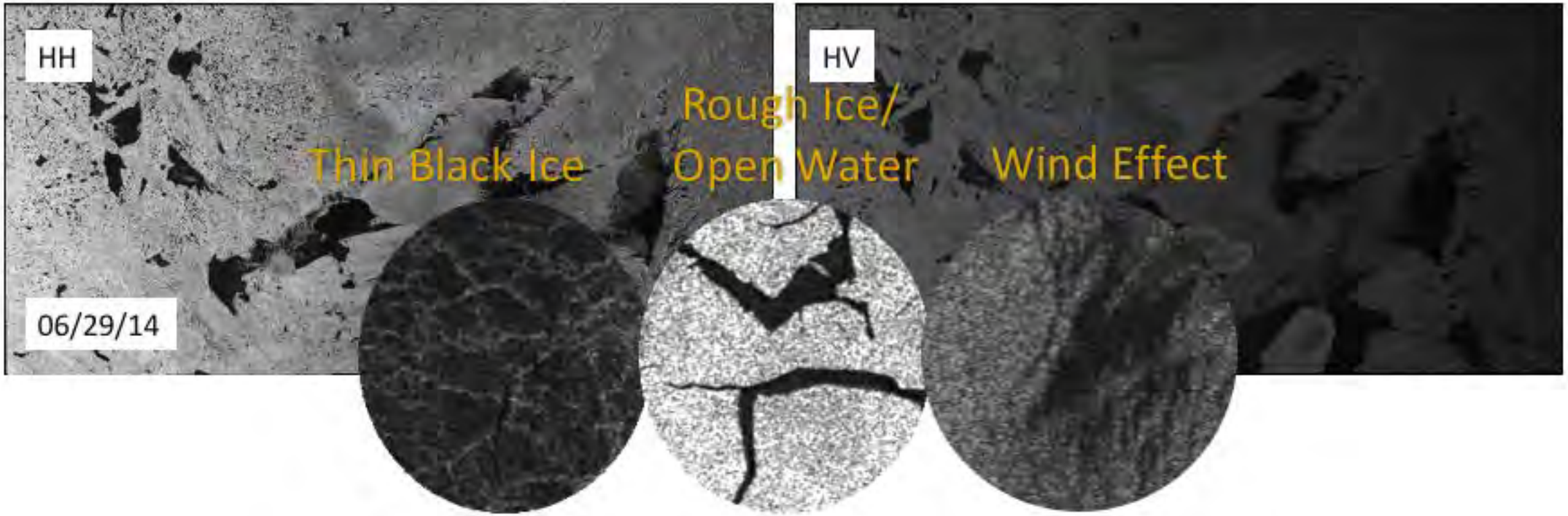
Satellite observations (retrievals)
Ice extent and lake-wide fraction (optical)



Towards automation of weekly lake-wide ice fraction product for CIS

Kang *et al.*, in prep.

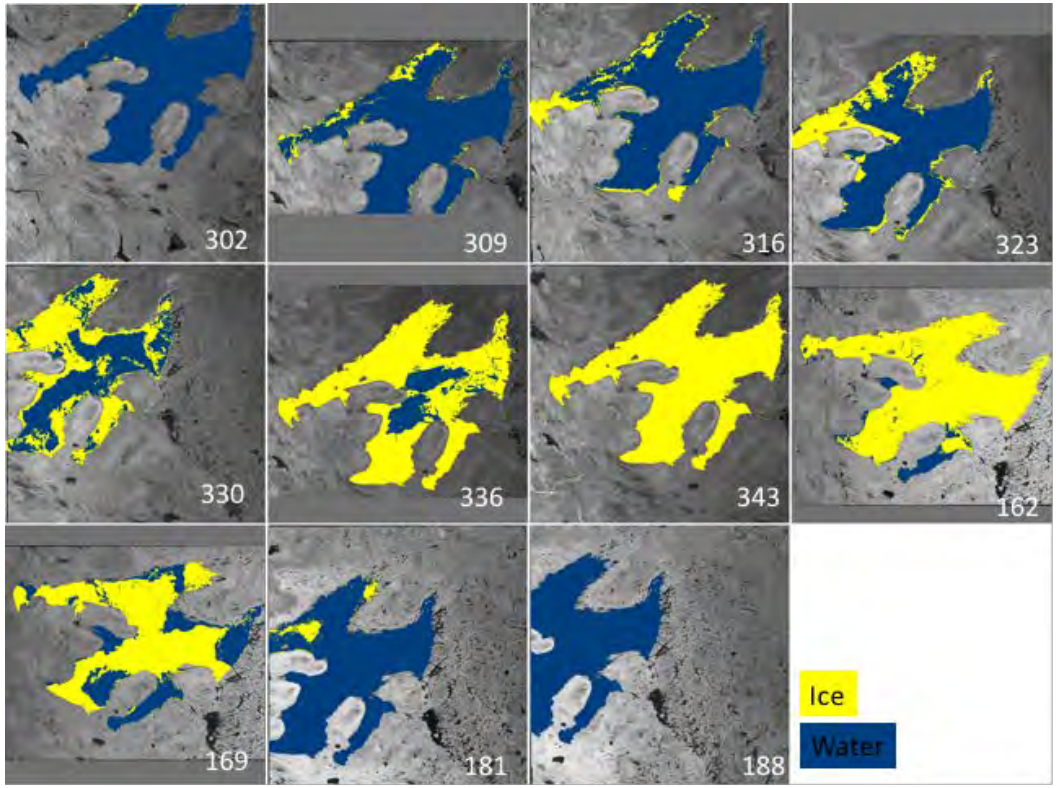
Satellite observations (retrievals)
Ice extent and lake-wide fraction (radar)

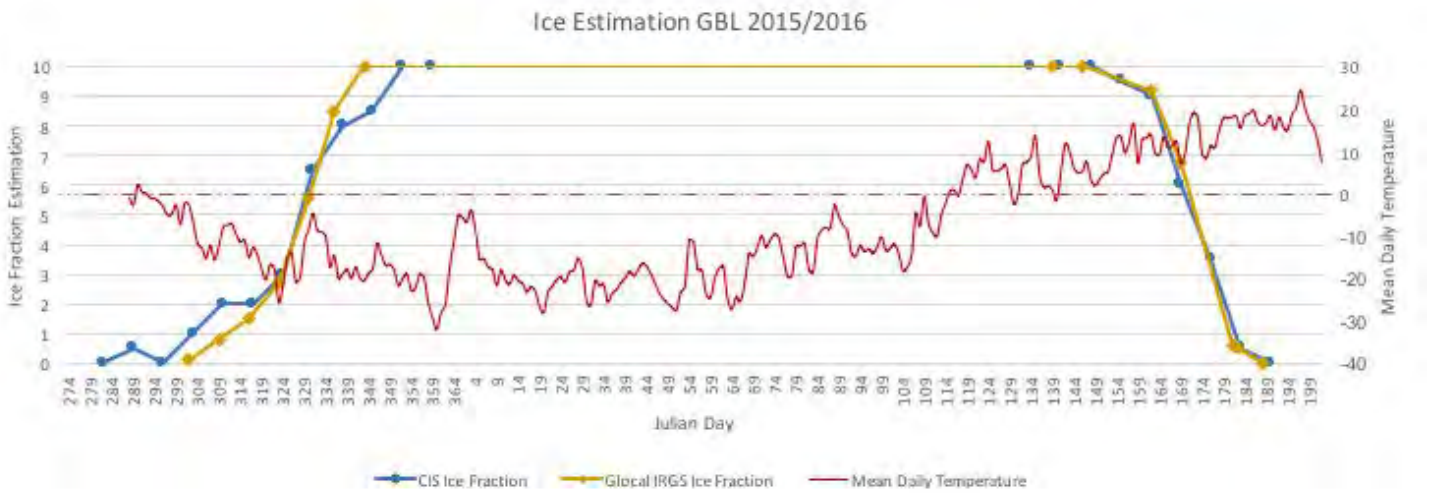


Hoekstra *et al.*, in prep.

Satellite observations (retrievals)
Ice extent and lake-wide fraction (radar)

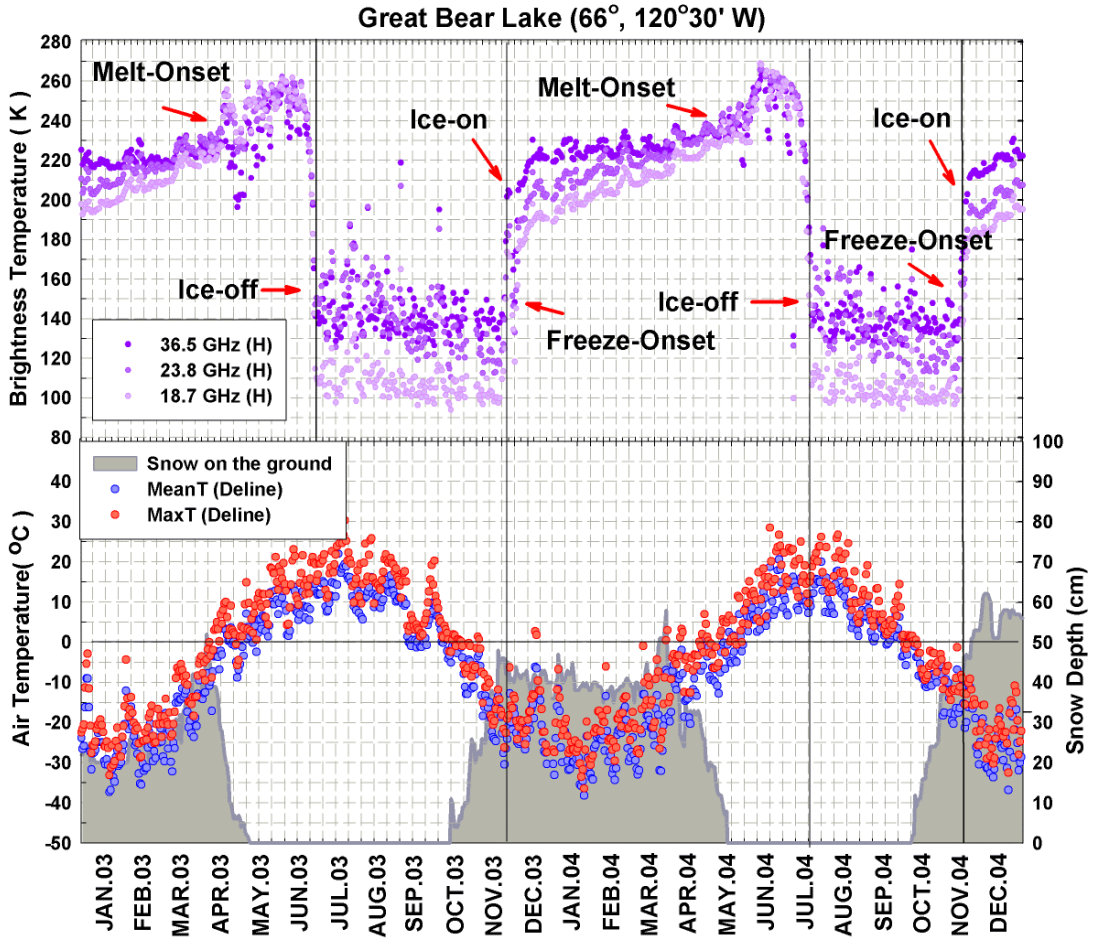
Towards automation of weekly lake-wide ice fraction product for CIS





Hoekstra *et al.*, in prep.

Satellite observations (retrievals)
Ice phenology (passive microwave)



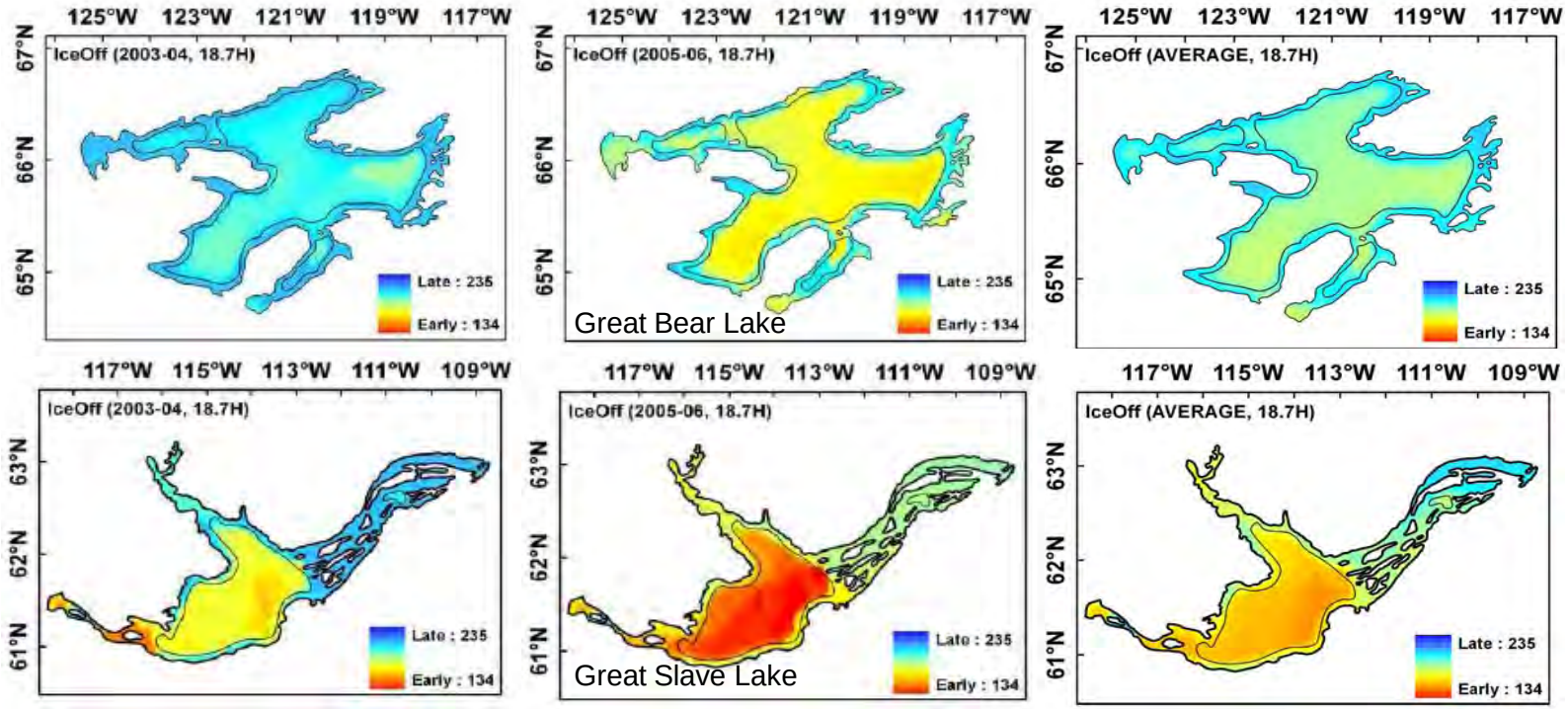
Ice retrieval algorithm –
AMSR-E
18.7 GHz H-pol

From daily data at 10 km

Kang *et al*. (2012)

Satellite observations (retrievals)
Ice phenology (passive microwave)

Ice-off



2003-04 (cold) 2005-06 (warm) Average

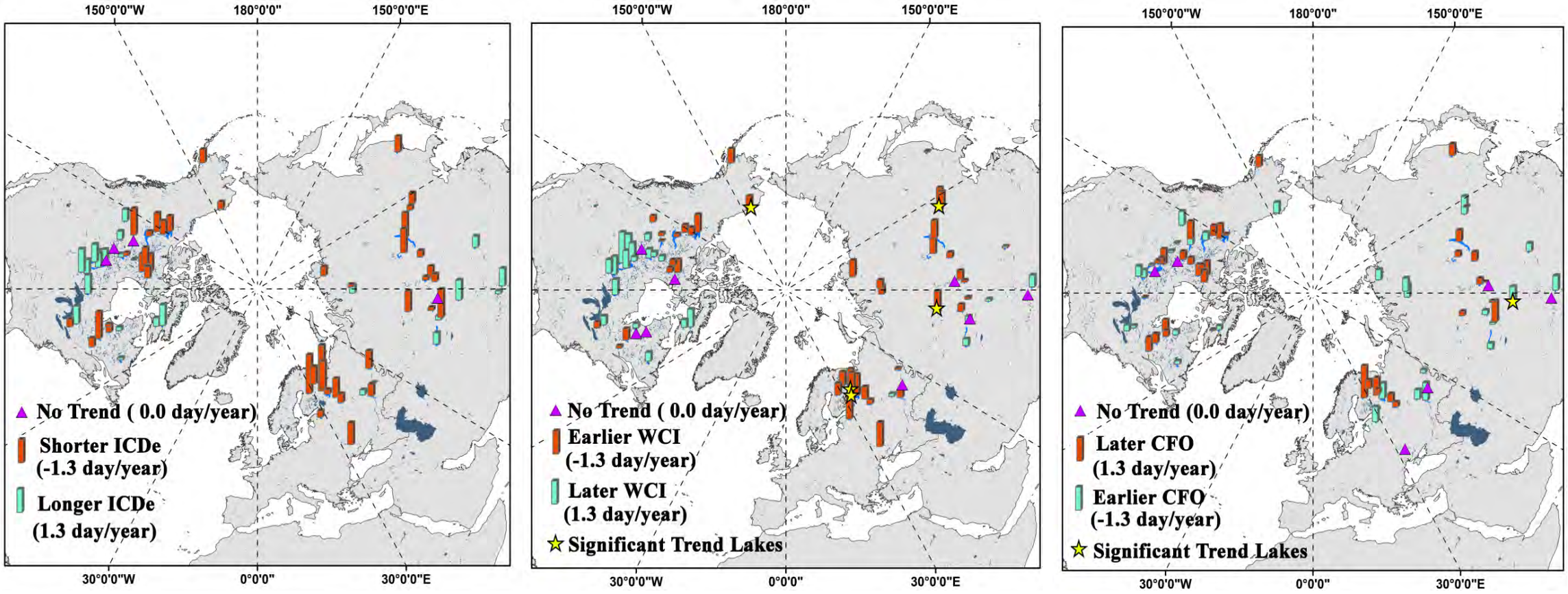
Ice retrieval algorithm – AMSR-E 18.7 GHz H-pol

From daily data at 10 km

Kang *et al*. (2012)

Satellite observations (retrievals)

Ice phenology (passive microwave; AMSR-E/2; 36.5 GHz; 5 km)

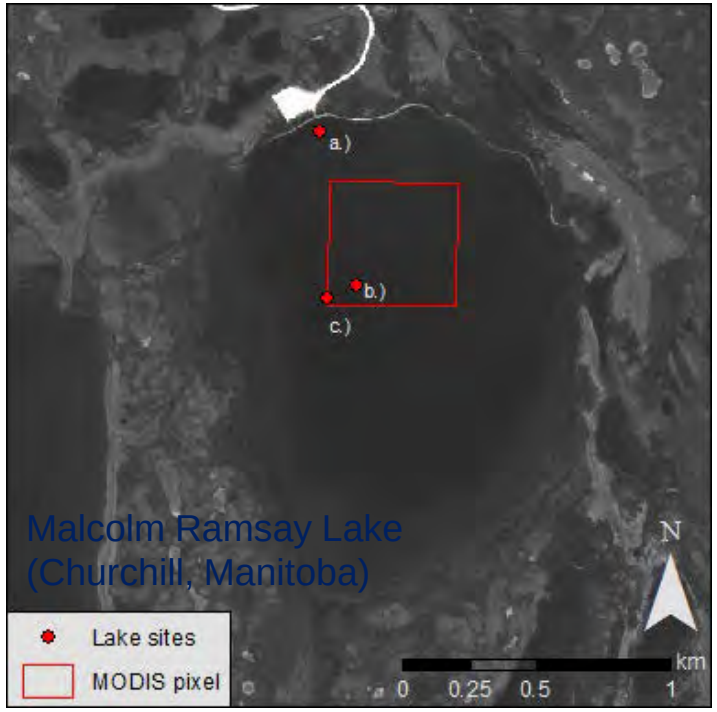


Changing trends of (a) ice cover duration (ICDe), (b) water clear of ice (WCI) dates and (c) complete freeze over (CFO) dates of 71 lakes for the **period 2002-2015**.

Du *et al*. (2017)

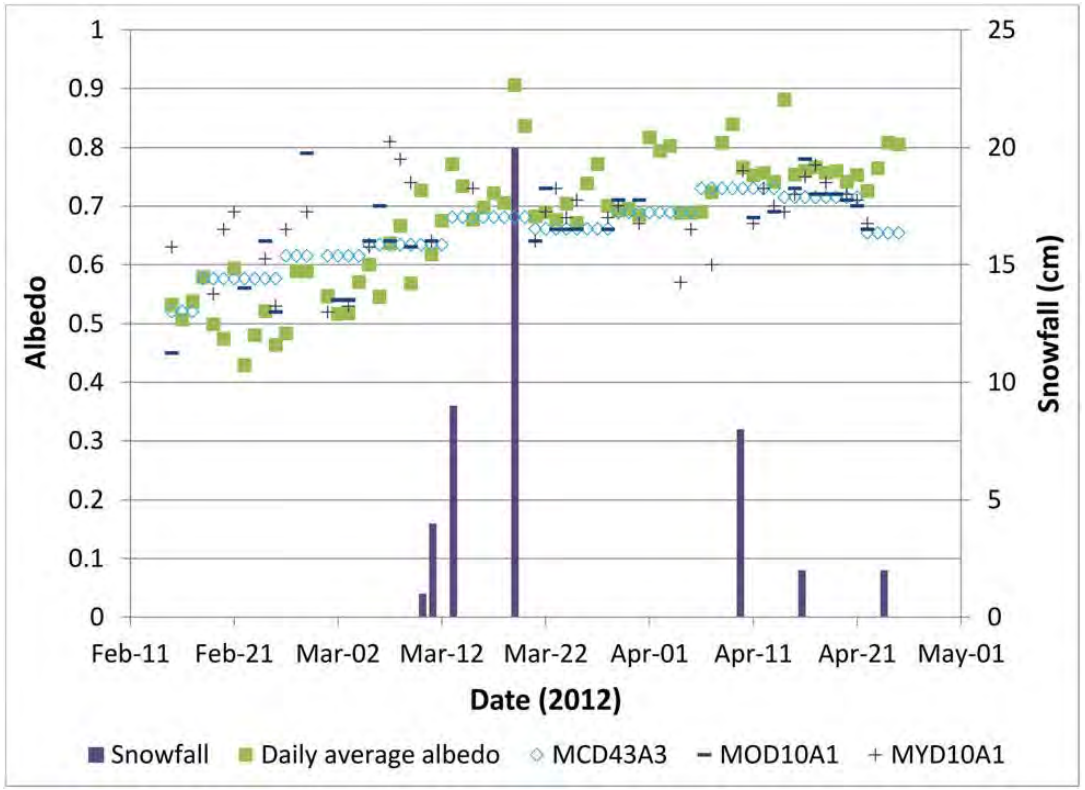
Satellite observations (retrievals)

Snow/ice albedo (optical; MODIS)



Svacina *et al*. (2014)

MODIS albedo products (500 m) compared to *in situ* measurements



Satellite observations (retrievals)

Snow/ice albedo (optical; MODIS)

Variable snow depth and ice types at 3 stations

MODIS daily albedo values evaluated with ground-based albedo measurements (15 February - 25 April 2012)

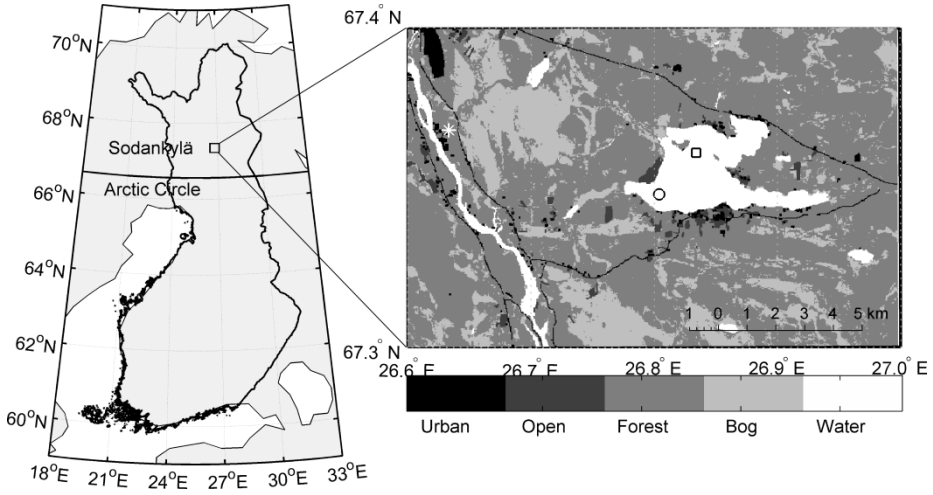
Statistic	MOD10A1	MYD10A1
Sample size, *n*	30	39
Observed mean (standard deviation)	0.65 (0.10)	0.66 (0.10)
MODIS mean (standard deviation)	0.66 (0.08)	0.68 (0.07)
RMSE	0.07	0.08
MAE	0.05	0.06
MBE	0.01	0.02

MODIS, moderate resolution imaging spectrometer; RMSE, root mean square error; MAE, mean absolute error; MBE, mean bias error.

Svacina *et al*. (2014)

Satellite observations (retrievals)

Snow/ice surface temperature (thermal; MODIS)

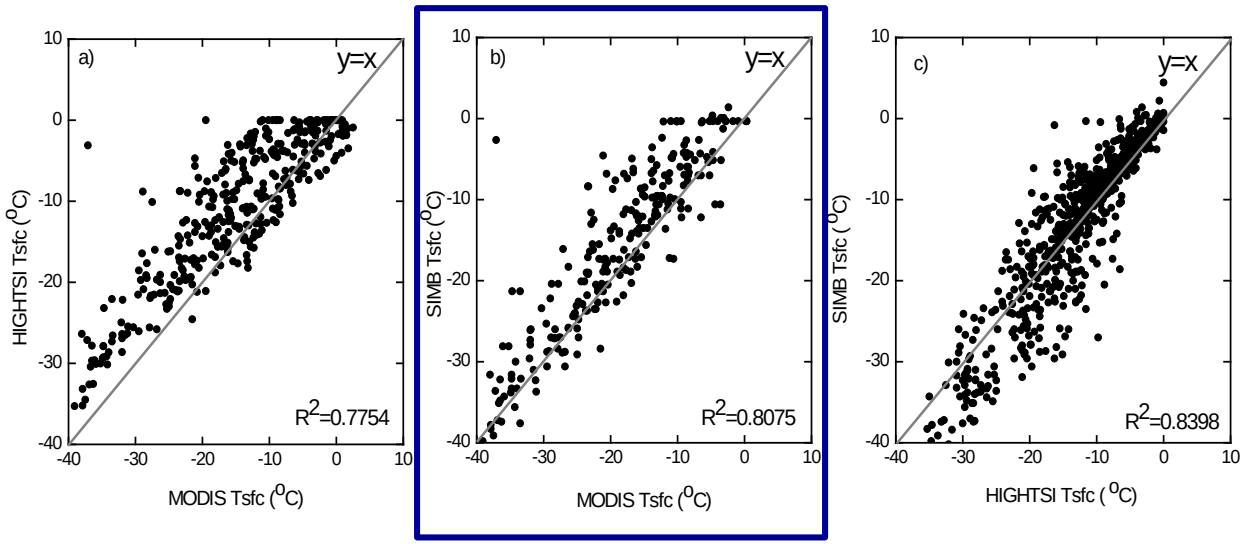


Lake Orajärvi in Sodankylä. The symbols in right panel:
○: regular snow and ice thicknesses measurement site;
□: SIMB site and;
*: Sodankylä weather station

SIMB: In situ buoy measurement
HIGHTSI: lake ice model

Comparison of surface temperature: (a) MODIS versus HIGHTSI; (b) MODIS versus SIMB, and (c) HIGHTSI versus SIMB for winter 2011/2012.

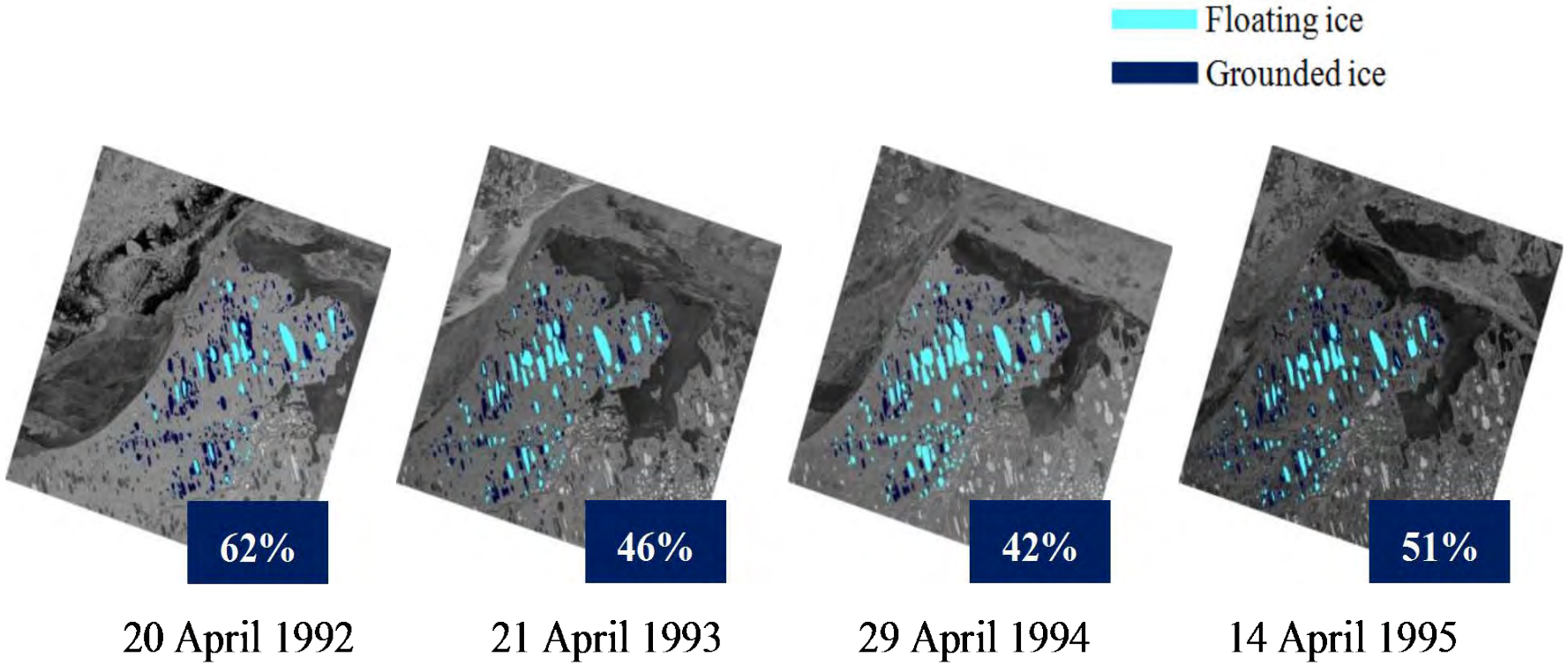
MODIS has cold bias



Cheng *et al.* (2014)

Satellite observations (retrievals)

Floating and grounded ice (radar)



n = 402 lakes

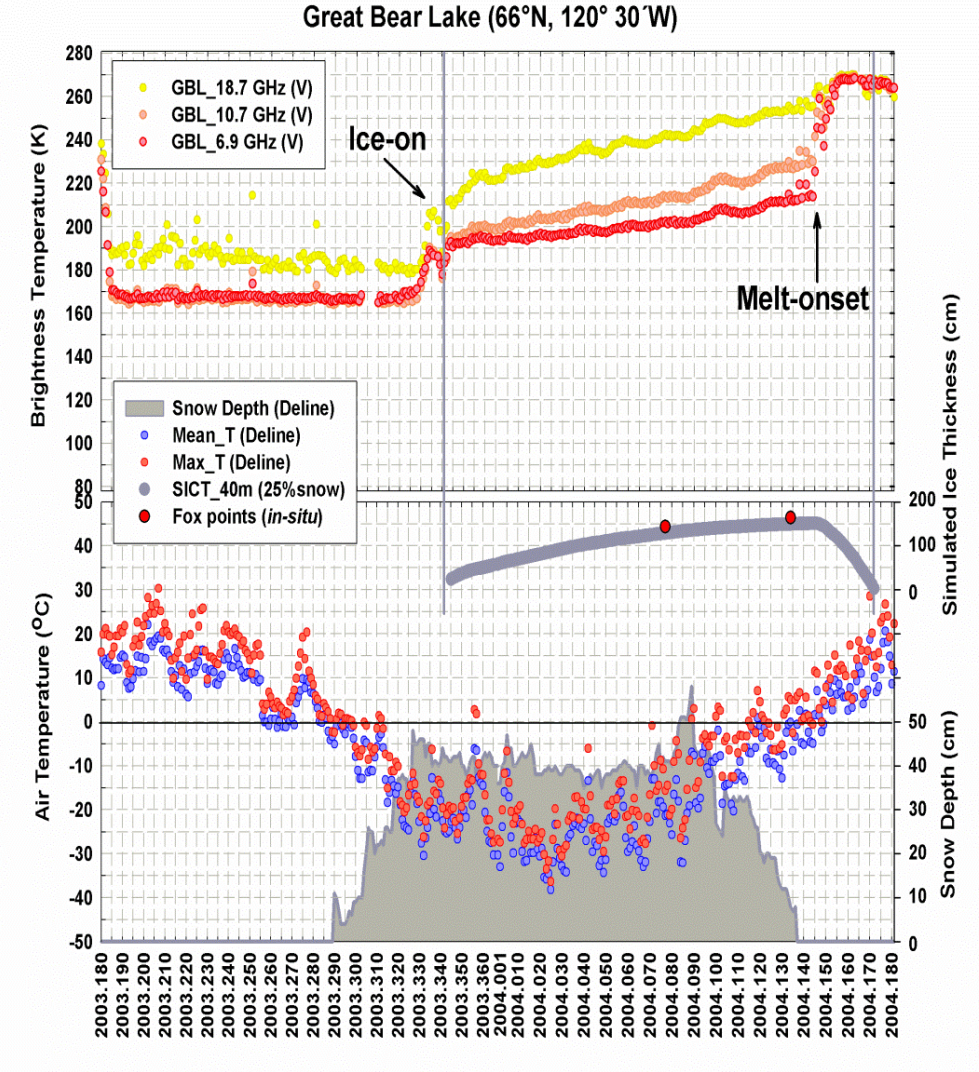
Grounded and floating ice from ERS-1 SAR images (1992 to 1995) acquired near the time of maximum ice thickness (April) for shallow lakes near Barrow, Alaska

Surdu *et al*. (2014)

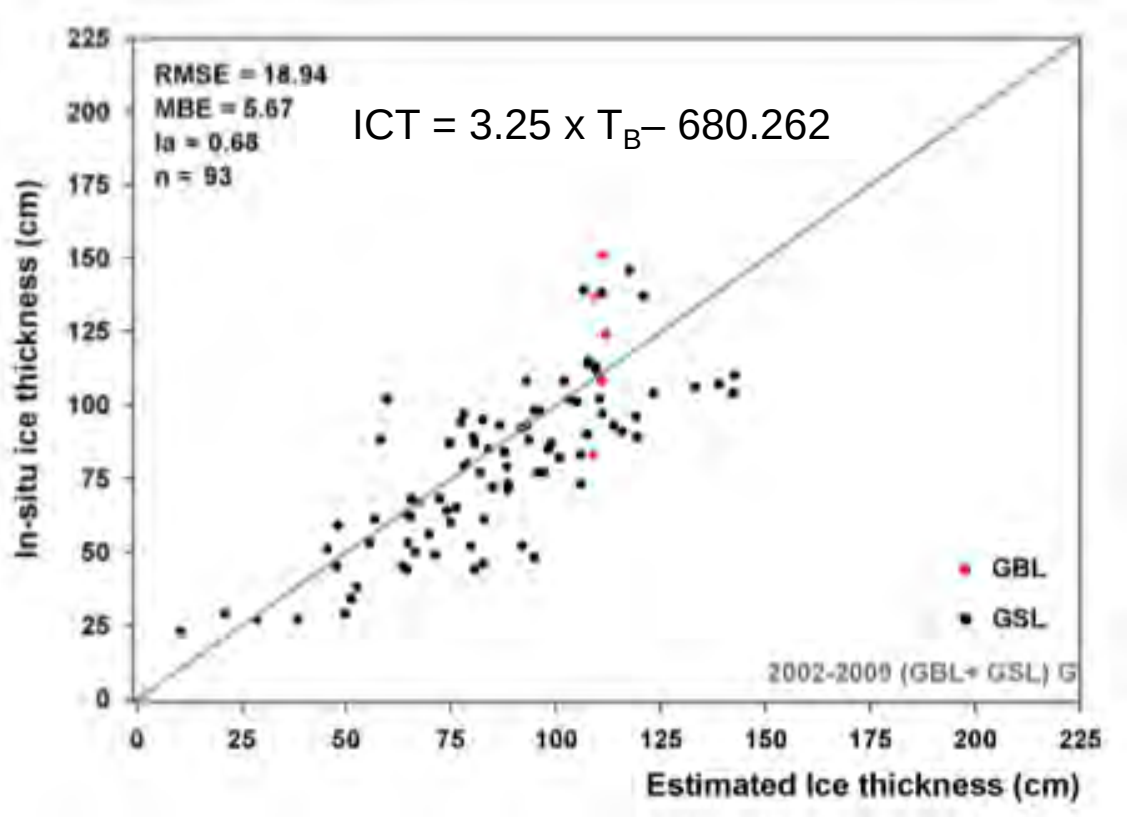

Shallow Lake Ice Trends from Satellite Radar
Data Analysis by
University of Waterloo, Ontario
Animation by
Planetary Visions
Funded by ESA's Support to Science Element (STSE)

Satellite observations (retrievals)

Ice thickness (passive microwave; AMSR-E)



Retrieval algorithm
AMSR-E 18.7 GHz V-pol



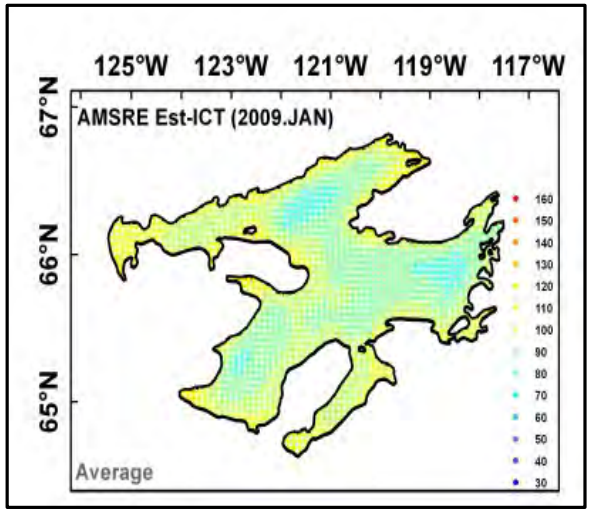
From daily data at 10 km

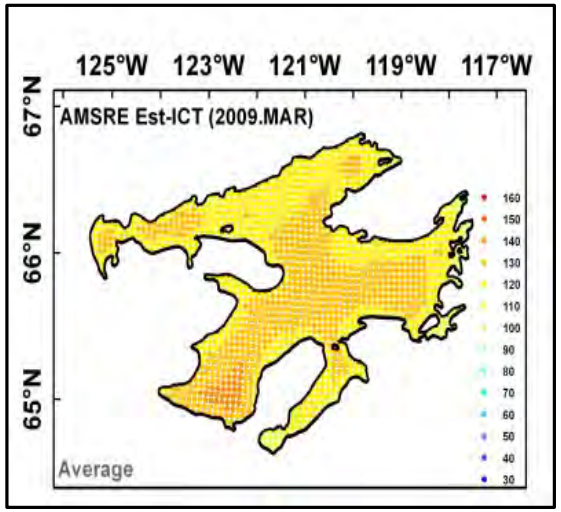
Kang *et al*. (2014)

Satellite observations (retrievals)

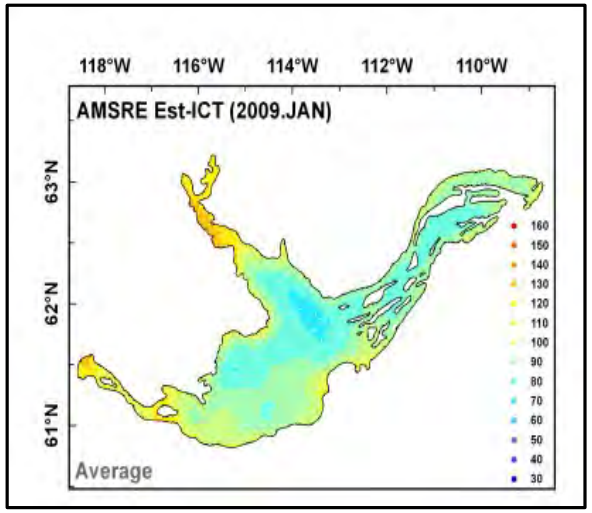
Ice thickness (passive microwave; AMSR-E)

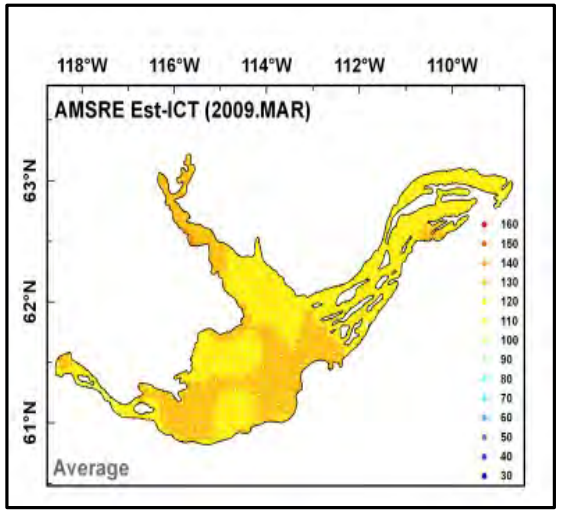
Great Bear Lake (Canada)





Great Slave Lake (Canada)





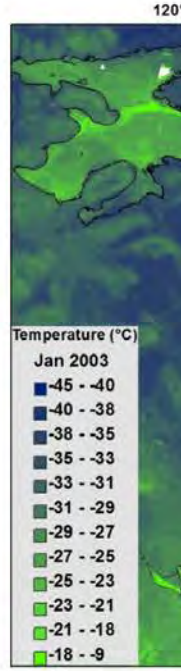
Retrieval algorithm
AMSR-E 18.7 GHz V-pol

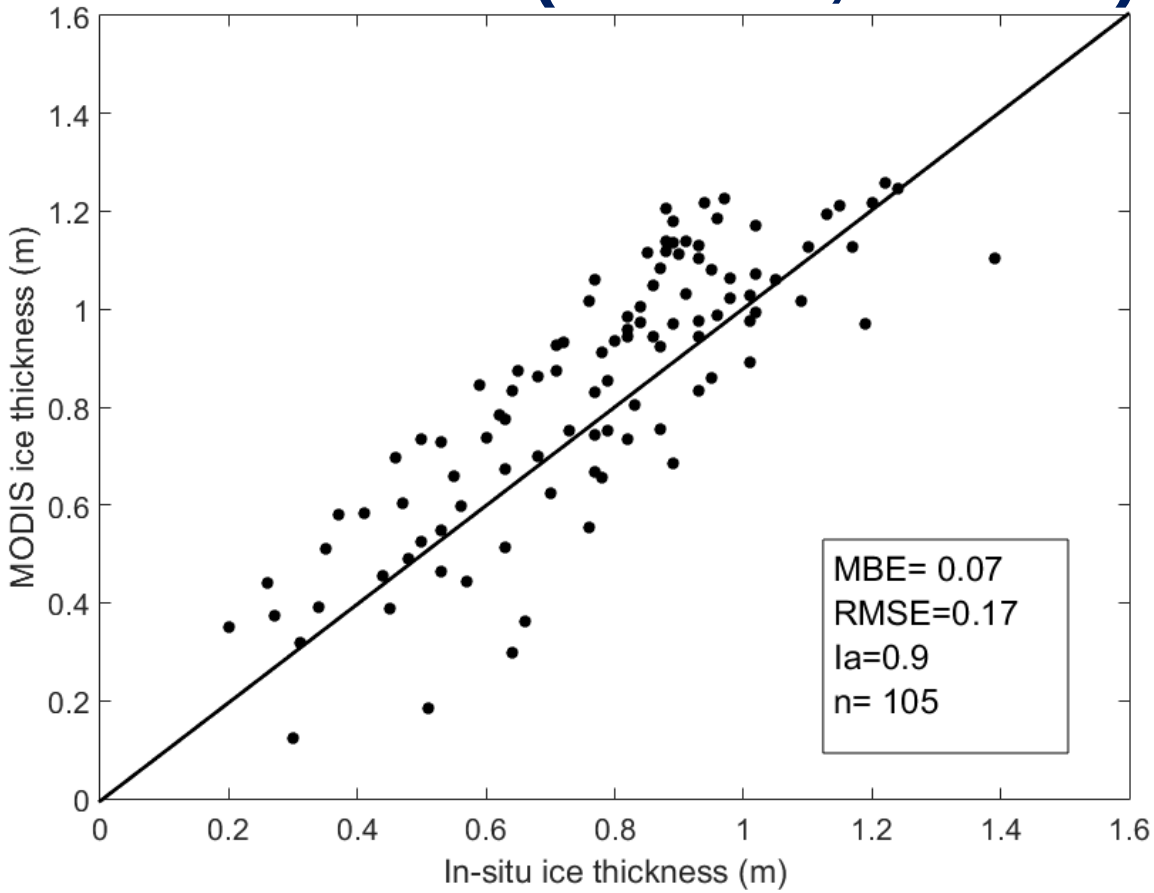
Monthly maps
January (left) and March (right)
2009

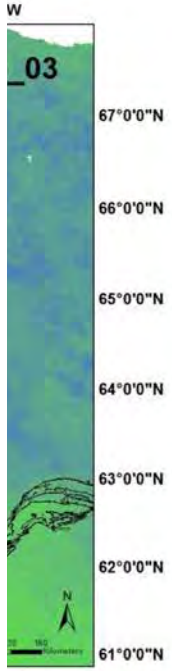
Kang *et al*. (2014)

Satellite observations (retrievals)

Ice thickness (thermal; MODIS)







MODIS

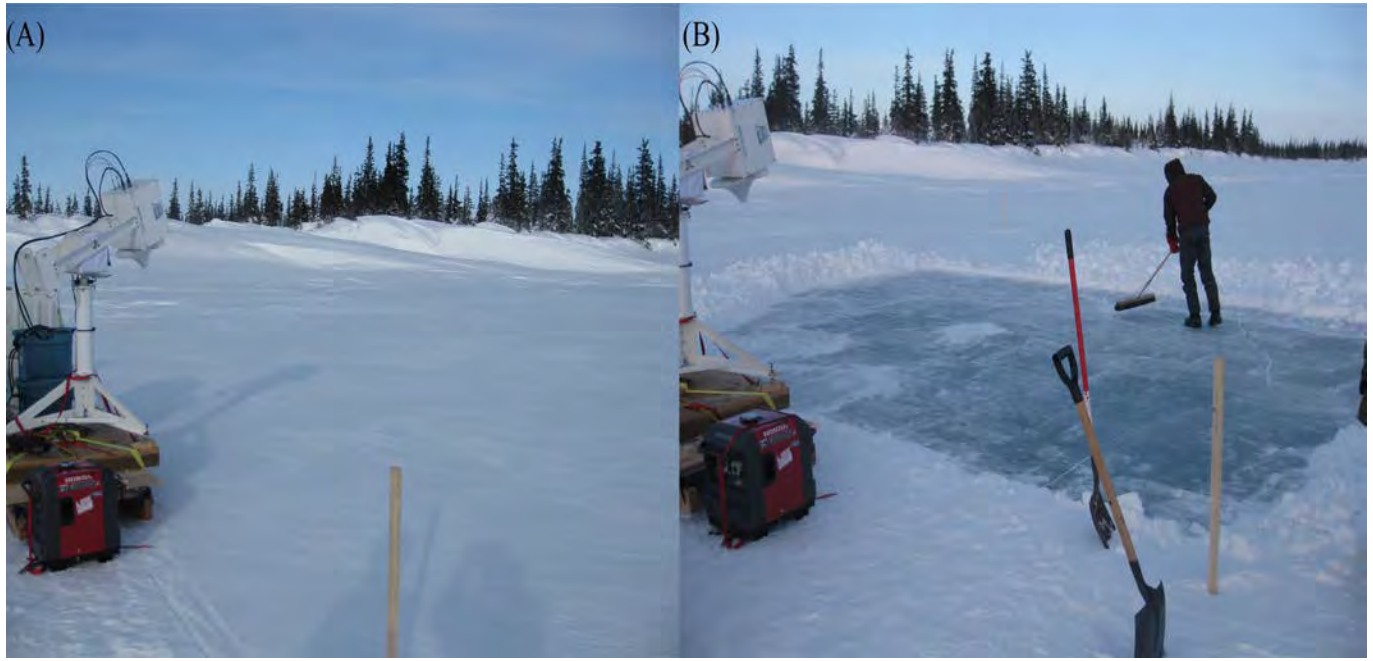
Lake and Great Slave Lake region (January, February, and March, 2003)

Ice thickness (conductive heat flux) signal

Kheyrollah Pour *et al.* (in press)

Ground-based observations
Radar (scatterometry) sensitivity to snow depth/SWE

- Snow depth and SWE sensitivity was observed with UW-Scat most notably in Ku-band (VV and VH) through snow removal experiments (5 March 2011 - Malcolm Ramsay Lake).



Procedure of snow removal from snow-on (A) to snow-off (B) within the scatterometer field of view at Site 1 upon completion of the observation period (5/3/2011).


Questions?