Lake ice cover and surface water temperature II:
Satellite remote sensing

Claude Duguay
University of Waterloo (Canada)

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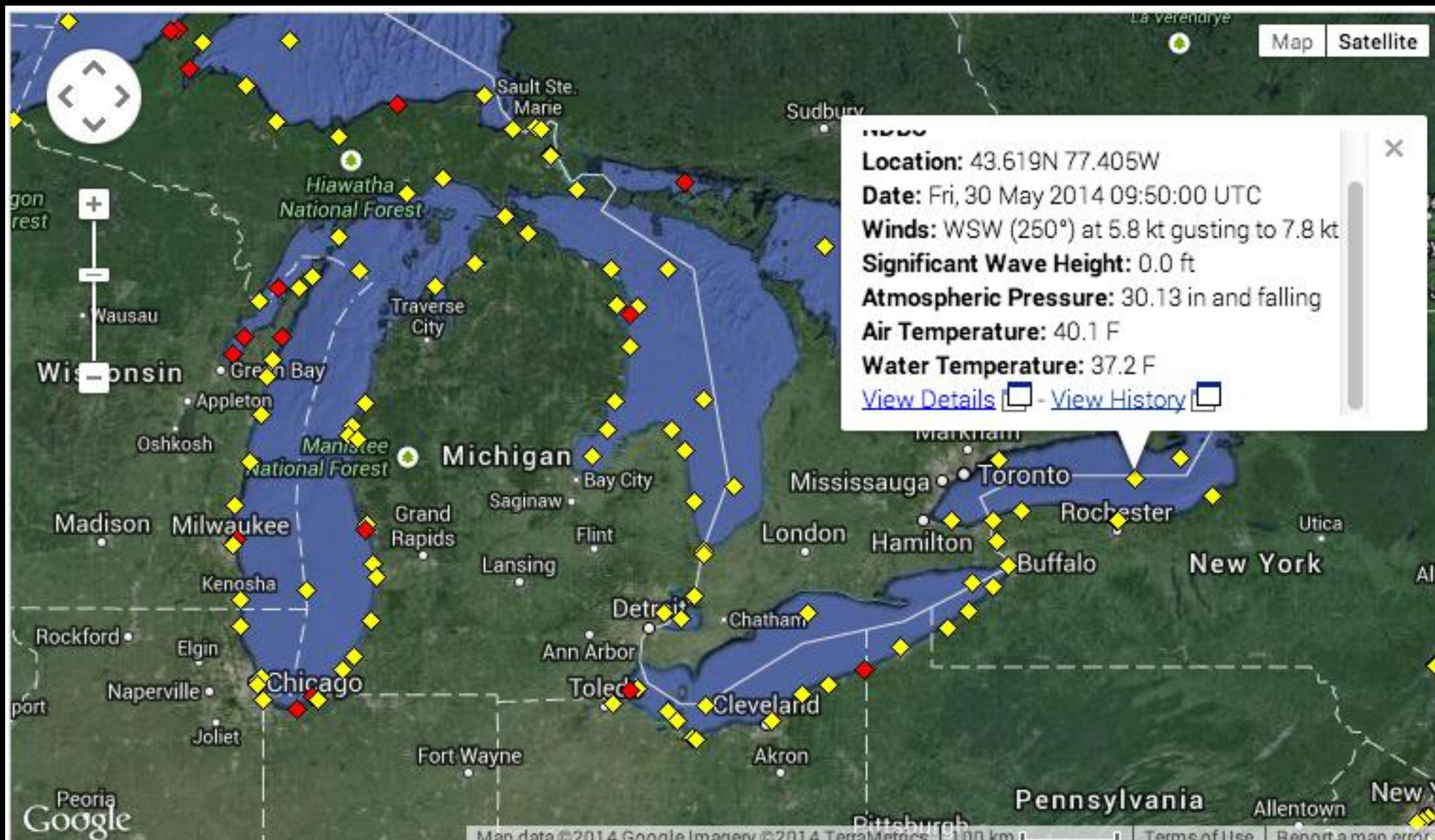
Acknowledgements

Thanks to graduate students (G. Gunn, K.-K. Kang, H. Kheyrollah Pour, C. Surdu and N. Svacina) for provision of some of the figures used in this lecture.

Why remote sensing?

In situ observations tend to be sparse

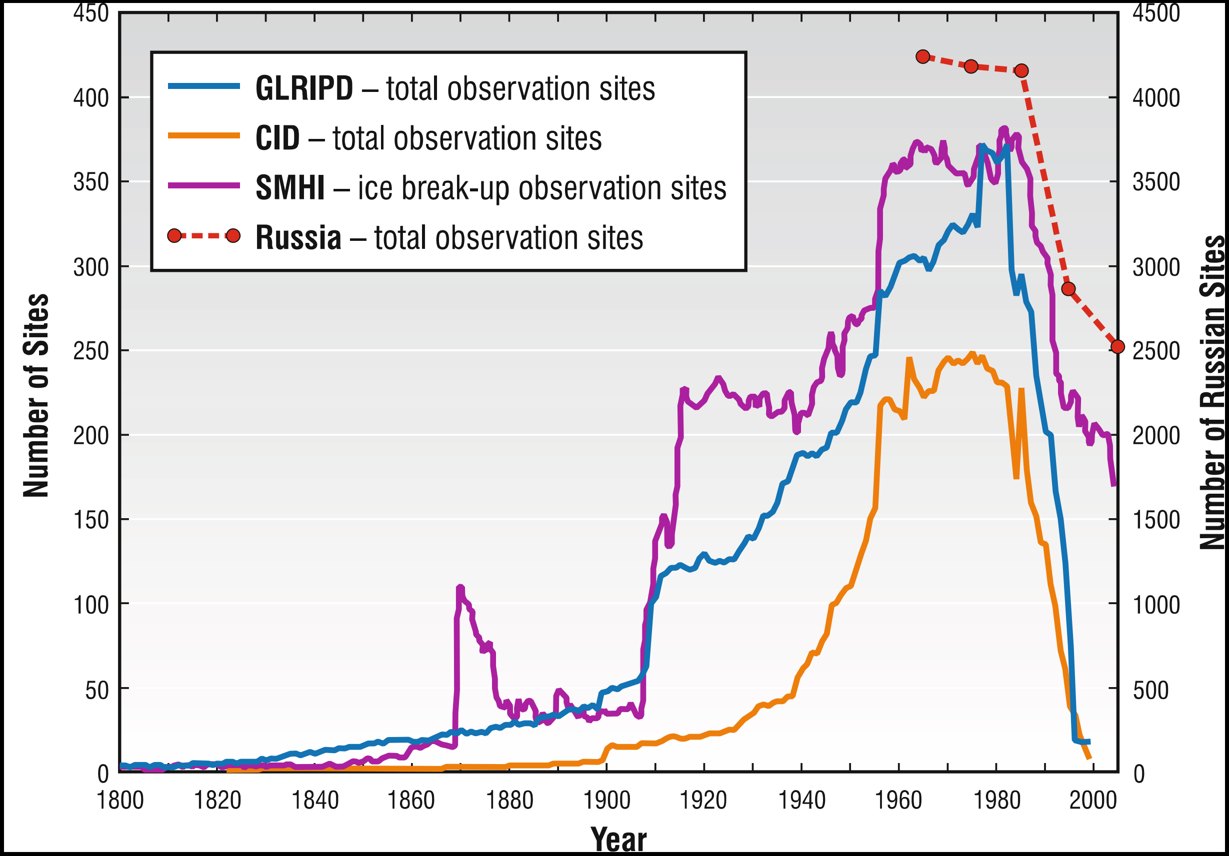


NOAA National Data Buoy Center

Why remote sensing?

Ice monitoring networks have nearly disappeared in the last 30 years

Historical evolution of the number of in situ lake-ice and river-ice observation sites recorded in various databases.



Source: Prowse et al. (2011)

Why remote sensing?

GCOS: Lakes as terrestrial ECV

- Lake water level
- Lake surface area
- Lake surface temperature
- Lake freeze-up and break-up?

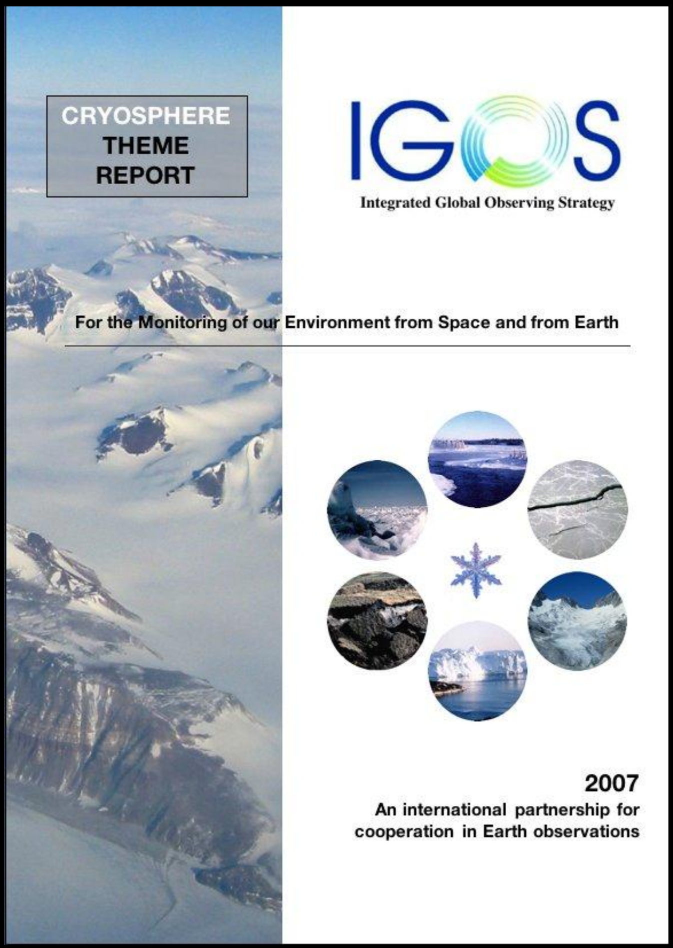
"Changes in ***lake volume, level, and area*** *may be indicators of changes in climate.*

Analysis of temporal and spatial variability of lake levels and lake surface areas is important to global climate research and the planning and management of regional resources.

Lake temperature *affects freeze-up and break-up dates, which are markers used in regional climate monitoring."*

Stitt, S., Dwyer, J.L., Dye, D.G., Josberger, E.G., 2011. Terrestrial essential climate variables at a glance. *U.S. Geological Survey Scientific Investigations Map 2011–3155*, 1 plate.

Why remote sensing?



Remote sensing of lake ice

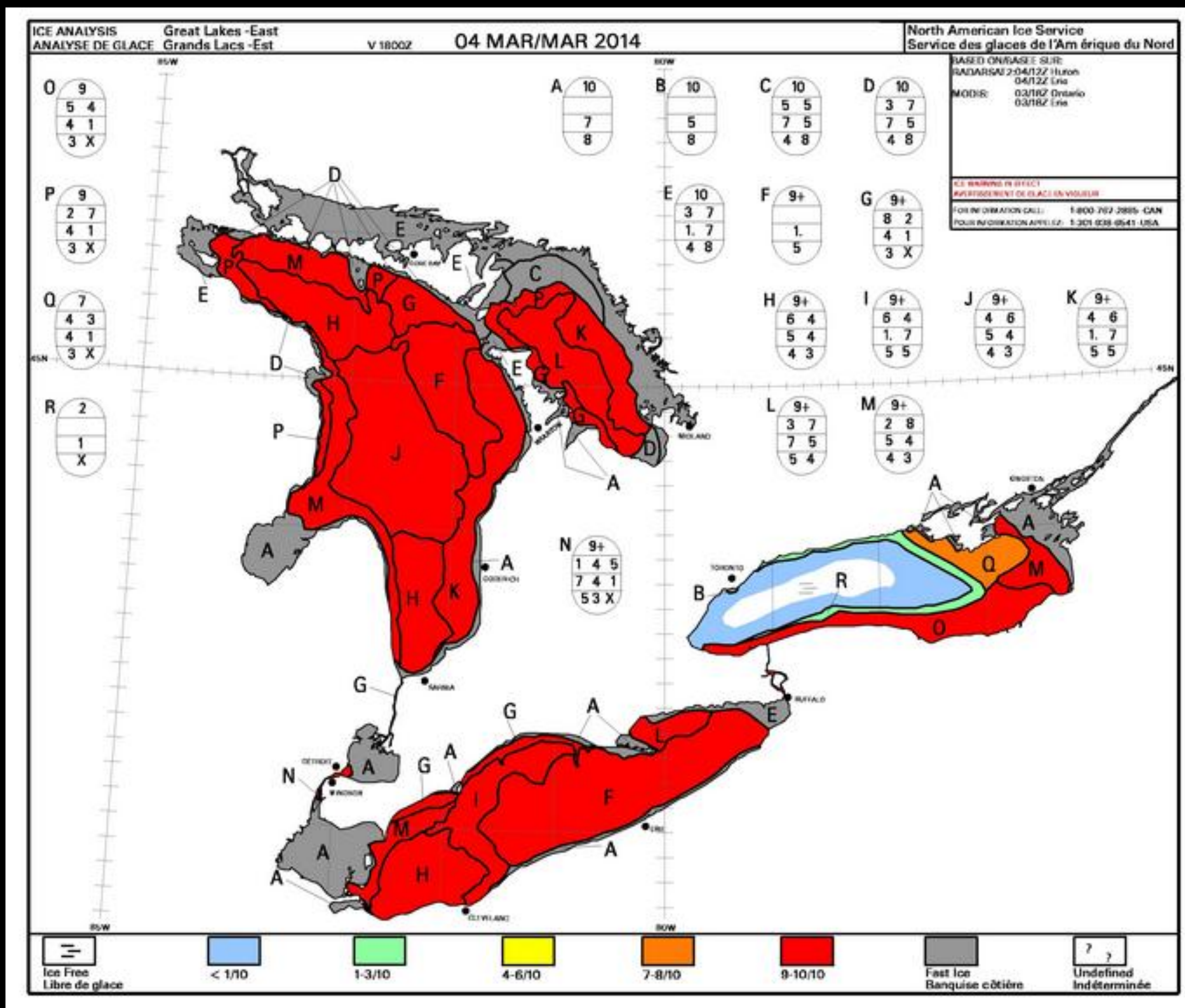
IGOS-P: Cryosphere Theme Report (2007)

Parameters identified for lake ice

- Ice concentration (fraction)
- Ice areal extent (and open water area)
- Freeze-up and break-up/ice cover duration
- Thickness
- Snow depth on ice
- Areal extent of floating and grounded ice (shallow lakes)
- Snow/ice albedo (broadband)
- Snow/ice surface temperature

Remote sensing of lake ice

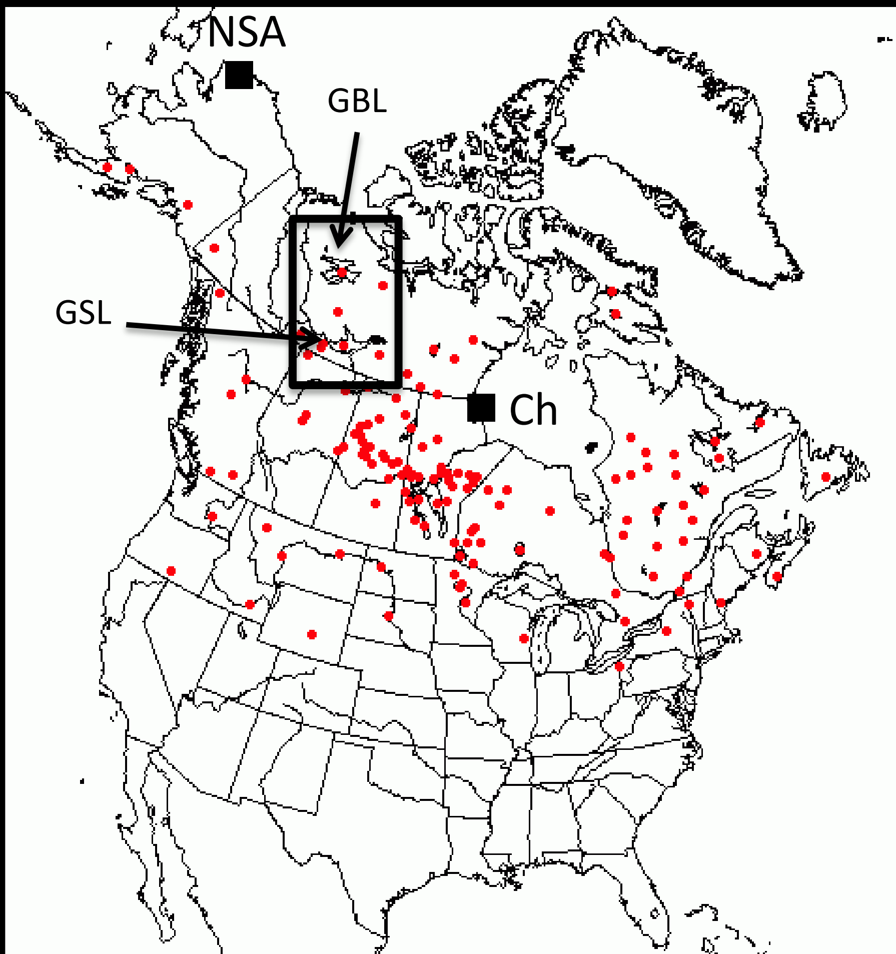
Ice concentration (fraction)



- Operational product of Great Lakes (CIS/NOAA): 1960-on
- Based on visual interpretation of optical and SAR data (also airplanes and ships).
- Provides information on ice fraction and ice types.
- Location of open water areas is known.

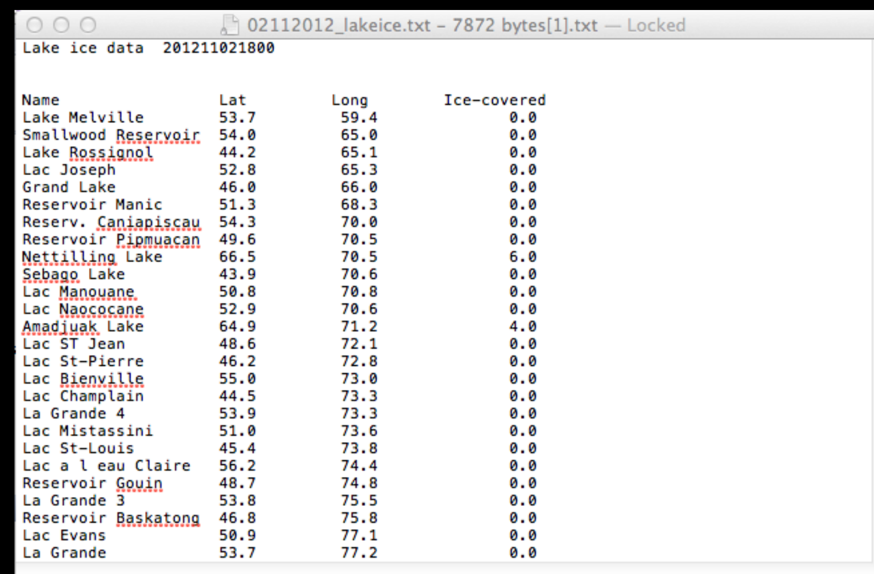
Remote sensing of lake ice

Ice concentration (fraction)



Canadian Ice Service

Weekly ice fraction (concentration) from visual interpretation of Radarsat and AVHRR by ice analyst



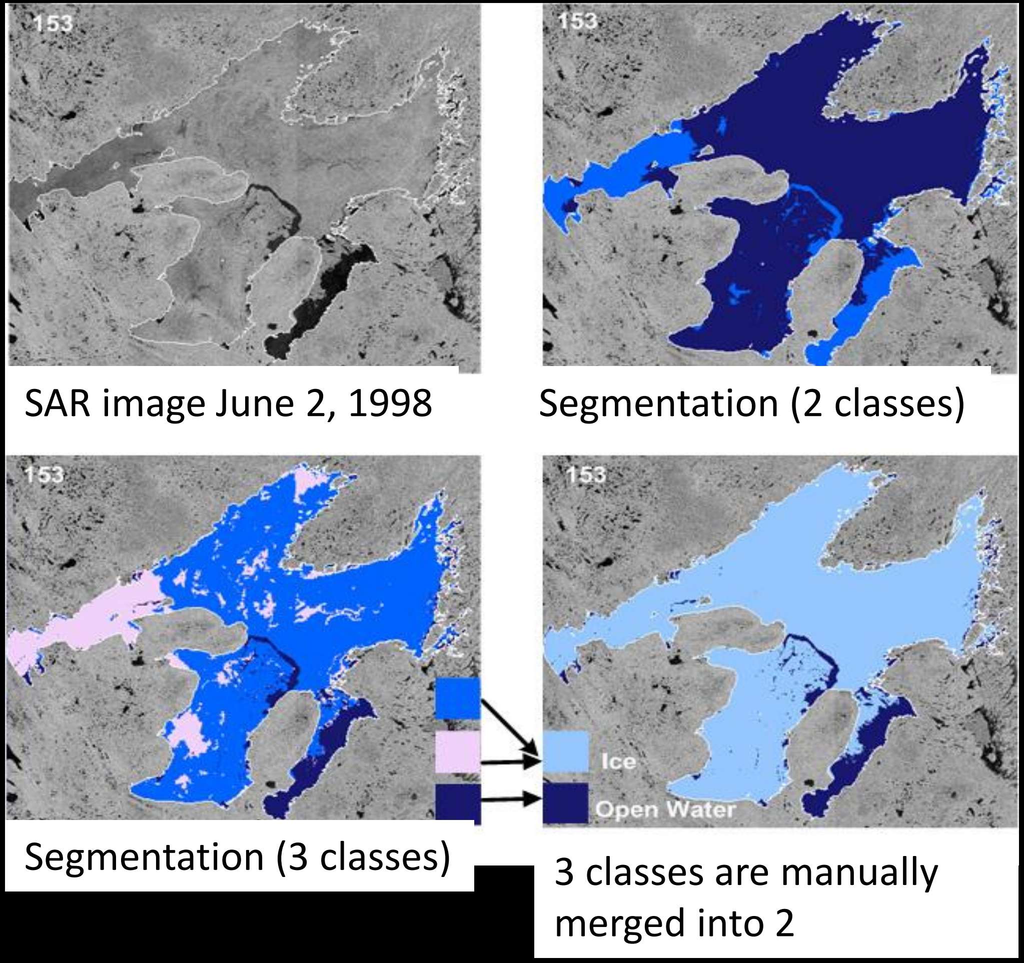
Lake ice data 201211021800

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 for CMC weather forecasting

Remote sensing of lake ice

Ice concentration (and ice extent)



Weekly ice extent and fraction (concentration)

Great Bear Lake (GBL)

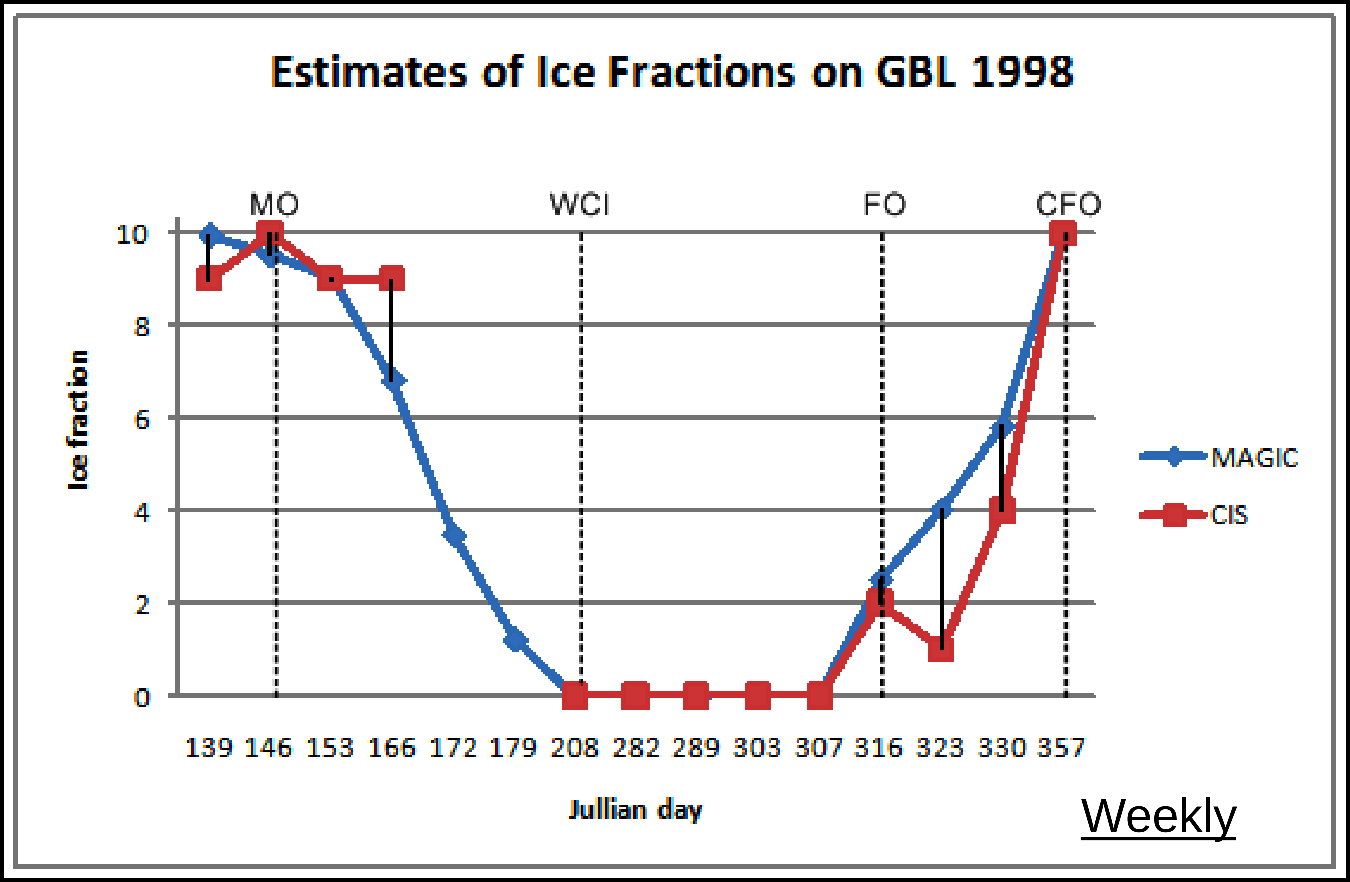
- Radarsat ScanSAR (HH) data (100 m) used at CIS (also tested on ASAR WS HH)
- Automated segmentation at pixel level (manual labeling) – Iterative Region Growing using Semantics (IRGS) in MAGIC software (Clausi *et* al., 2010)

Ochilov *et al*., in prep.

Remote sensing of lake ice

Ice concentration (fraction)

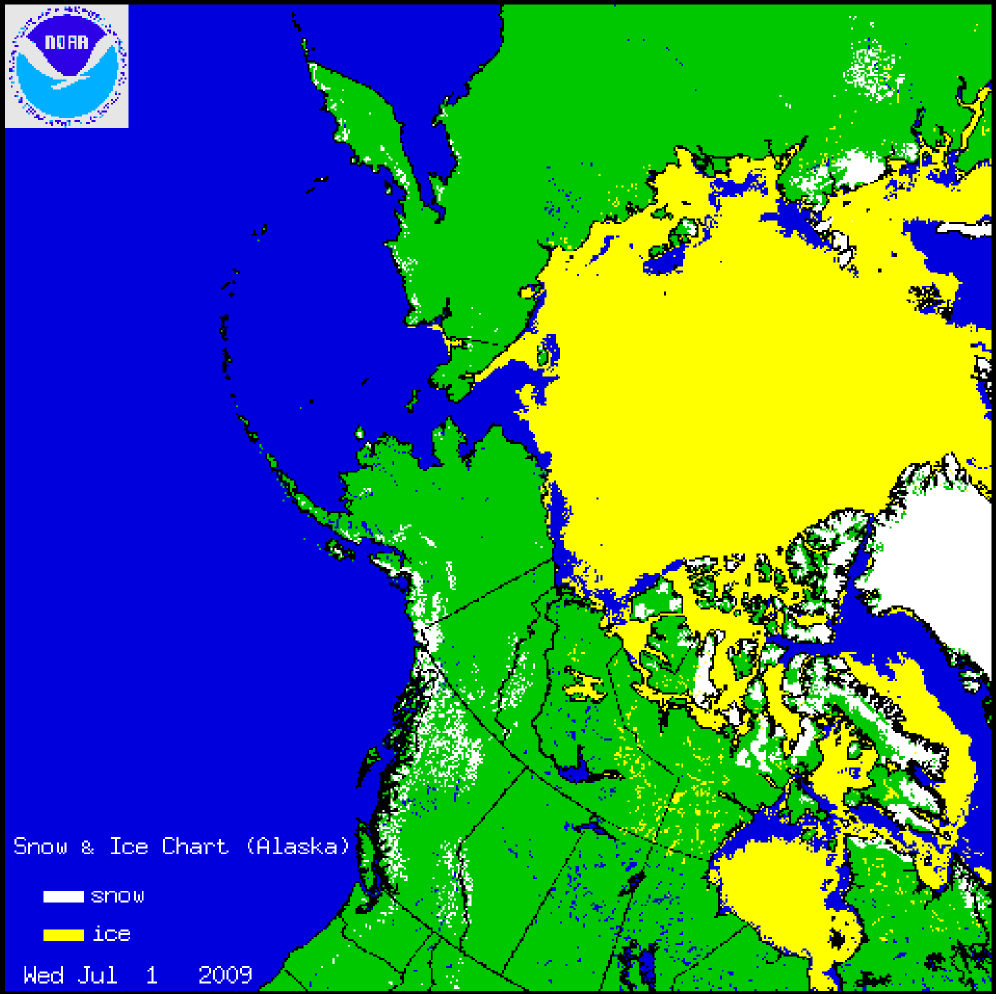
Comparison CIS ice analyst and IRGS in MAGIC



Ochilov *et al.*, in prep.

Remote sensing of lake ice

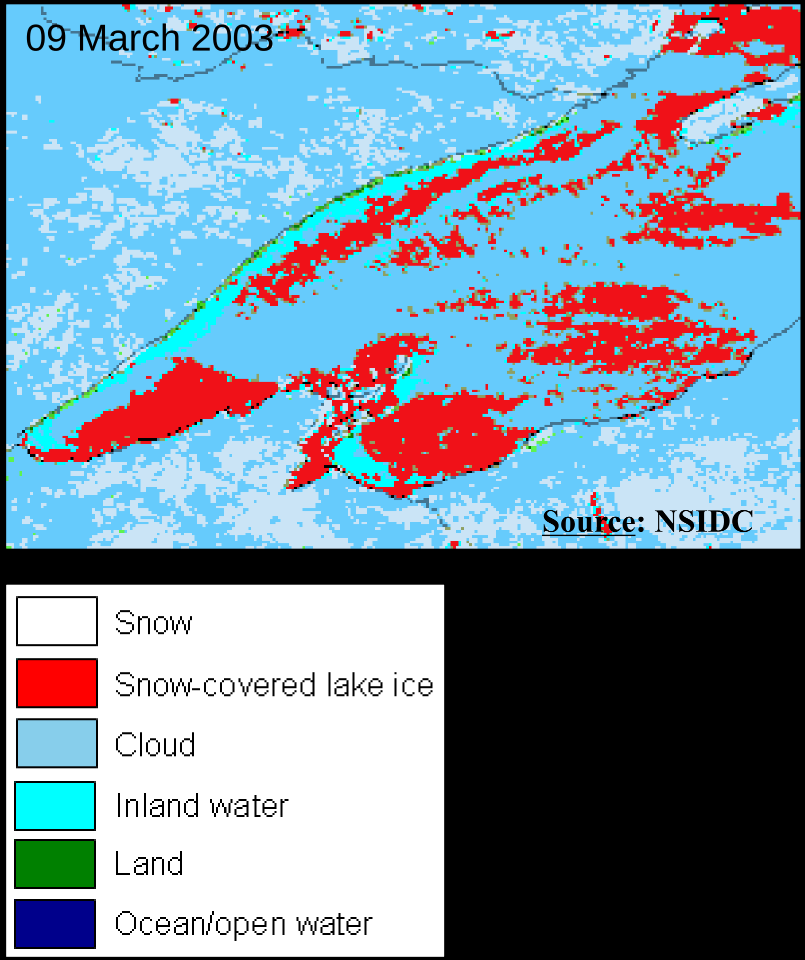
Ice areal extent (and open water area)



- **Global operational product - IMS daily ice cover fraction at 4 km resolution: 2004-on**
- **Based on the use of AVHRR, GOES, and SSM/I data.**
- **Relatively coarse resolution and short time series.**

Remote sensing of lake ice

Ice areal extent (and open water area)



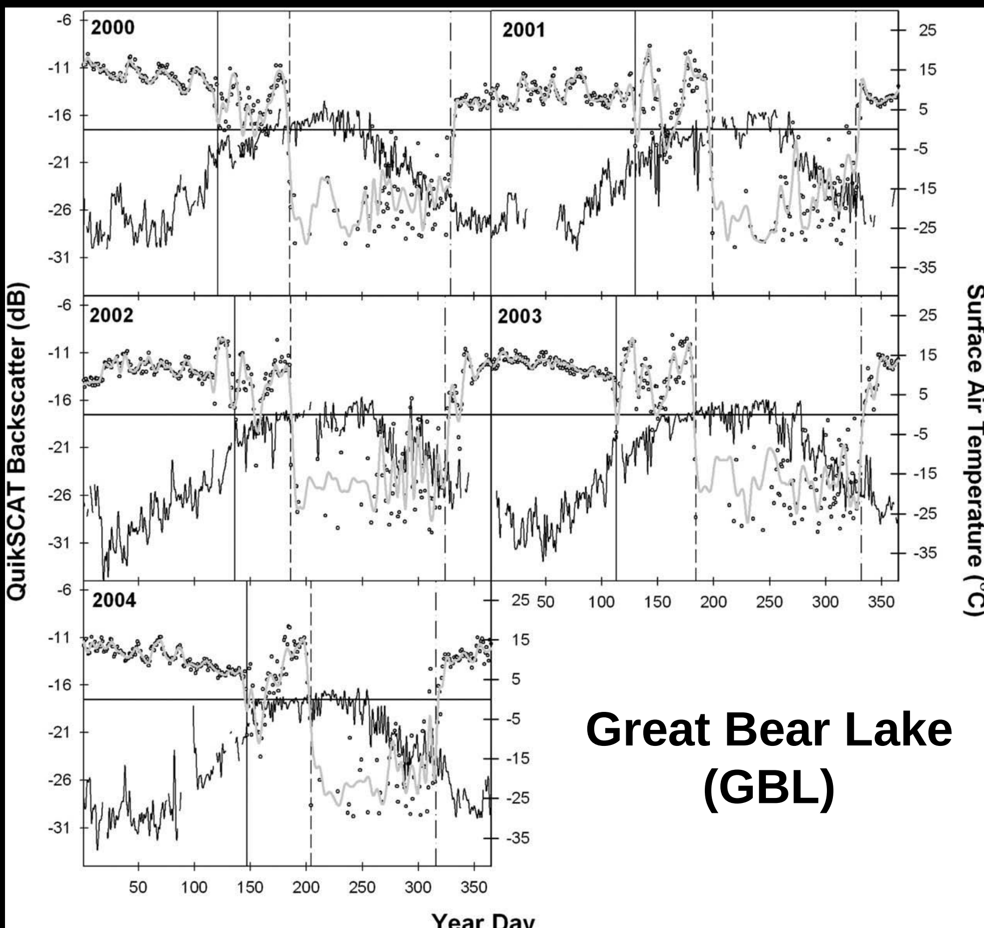
- Global operational product - MODIS daily snow product (NASA): 2000-on
- The MODIS snow algorithm still has limitations, particularly in discriminating clouds from snow-covered lake ice and the detection of ice cover when snow on ice is absent.
- Cloud cover and darkness are a problem in polar regions during fall/early winter.
- The product has not been validated to date.

MODIS/Terra Snow Cover Daily L3 Global 500m Product

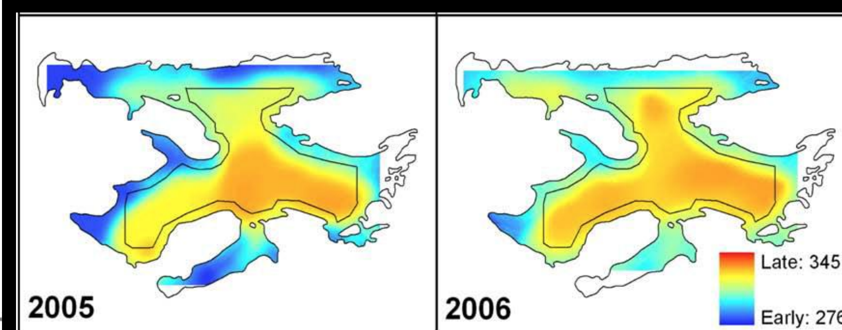
Remote sensing of lake ice

Freeze-up/break-up and ice cover duration

MO WCI FO MO WCI FO



Ice phenology retrieval algorithm – Ku-band QuikSCAT (HH)



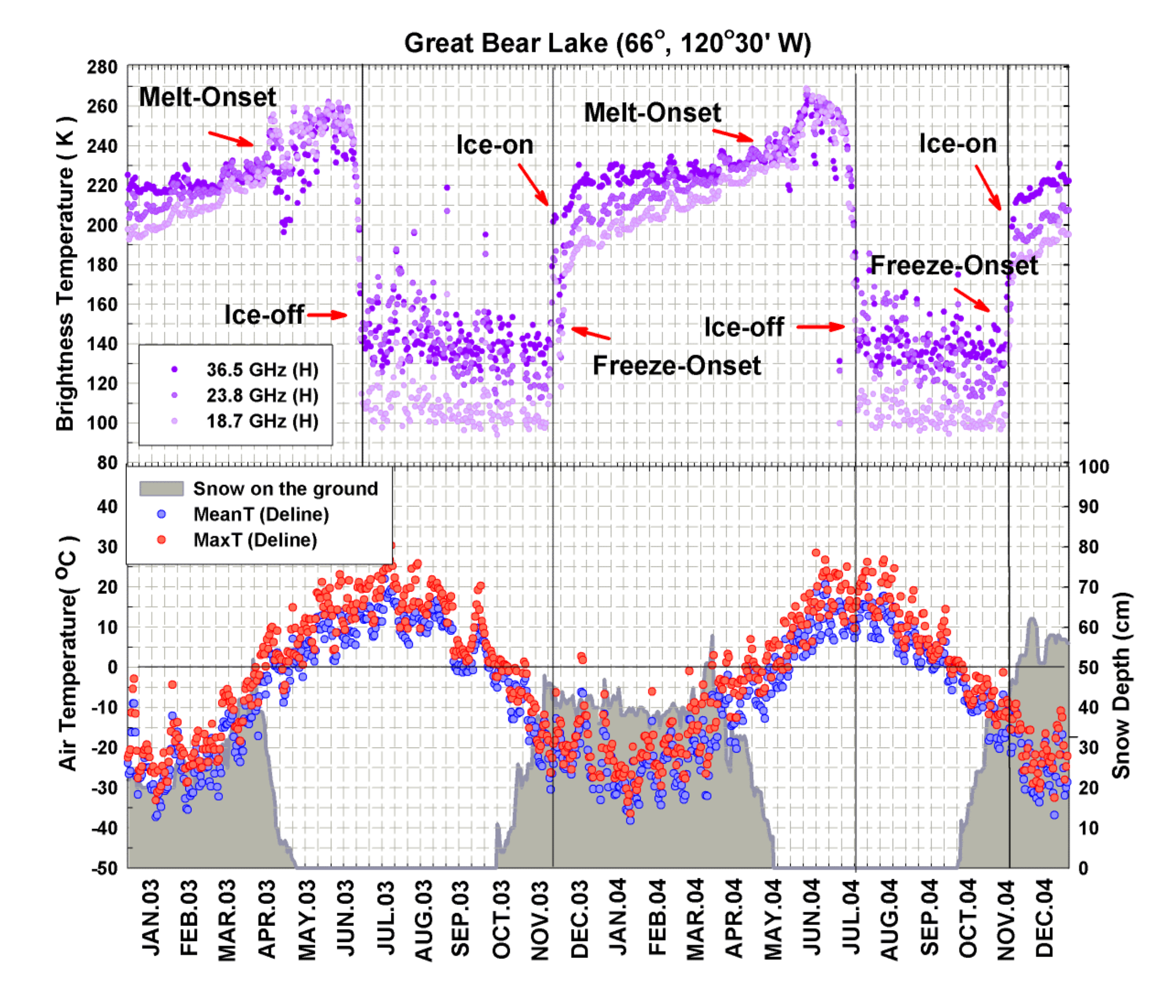
Freeze onset (FO)

From daily data at ~ 4 km

Howell *et al*. (2009)

Remote sensing of lake ice

Freeze-up/break-up and ice cover duration



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

From daily data at 10 km

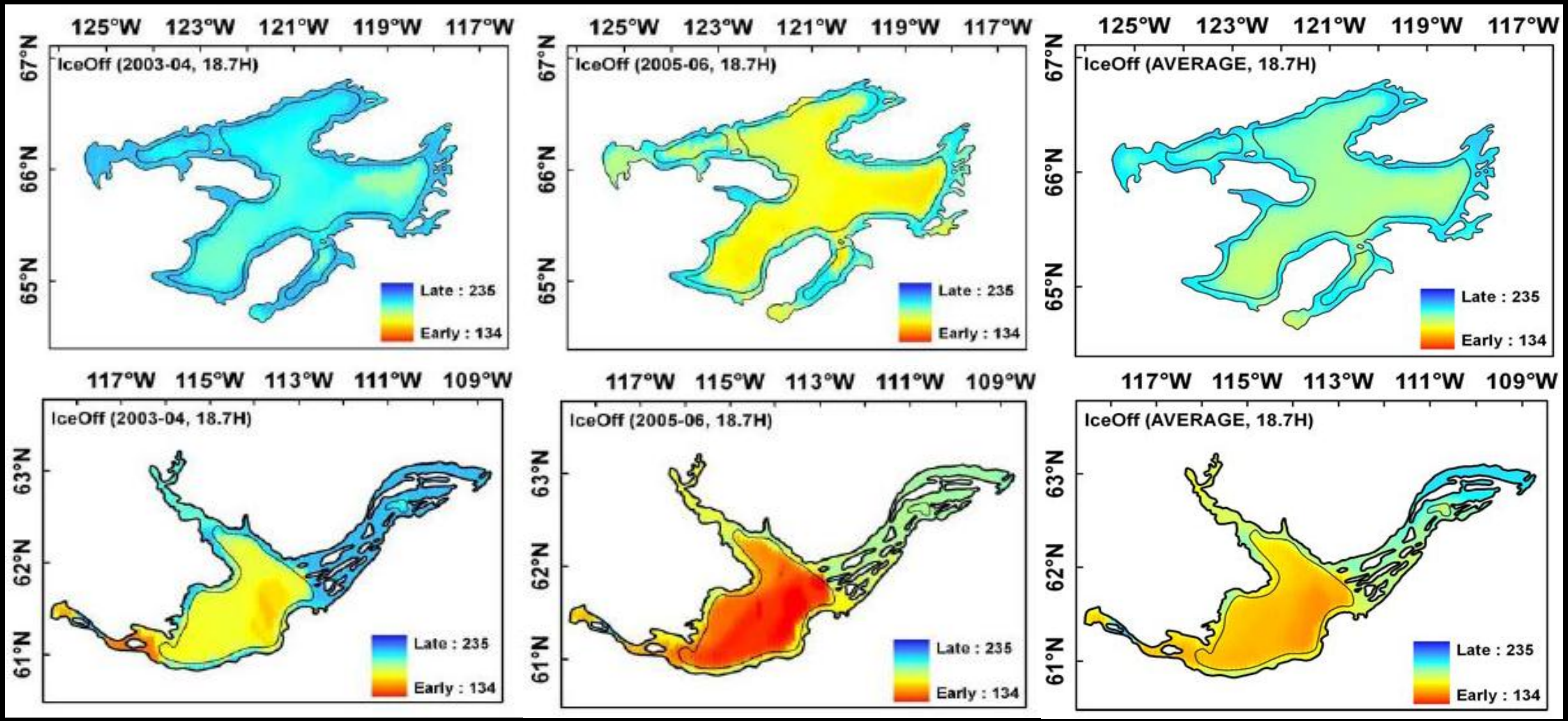
Kang *et al*. (2012)

Remote sensing of lake ice

Freeze-up/break-up and ice cover duration

Ice phenology retrieval algorithm – AMSR-E (18.7 GHz H-pol)

Ice-off

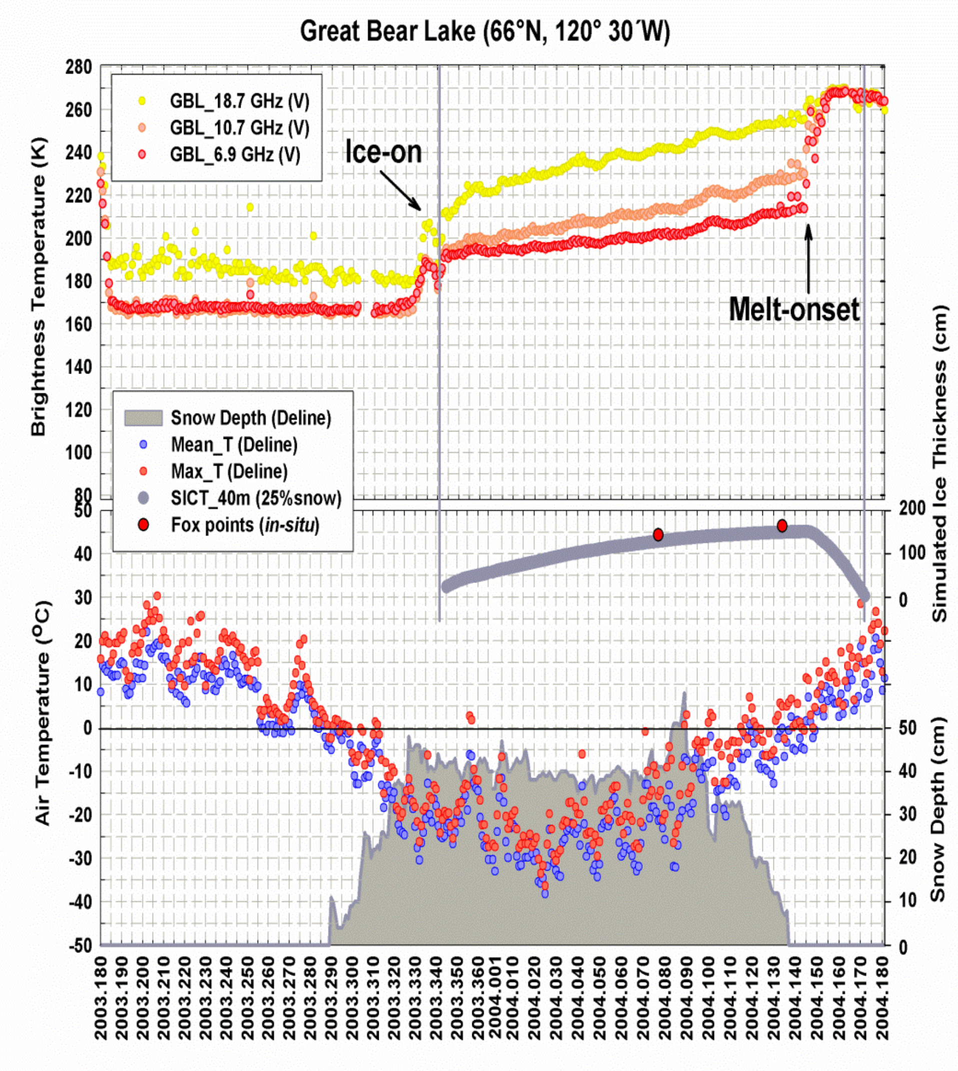


2003-04 (cold) 2005-06 (warm) Average

Kang *et al*. (2012)

Remote sensing of lake ice

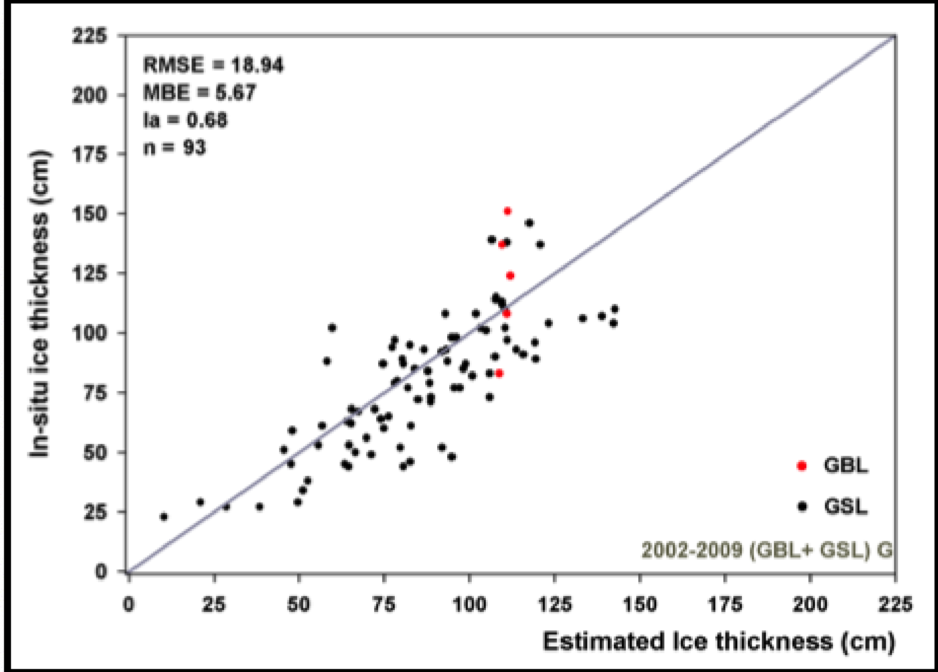
Ice thickness



Retrieval algorithm

AMSR-E 18.7 GHz V-pol

ICT = 3:25 x T_B– 680:262



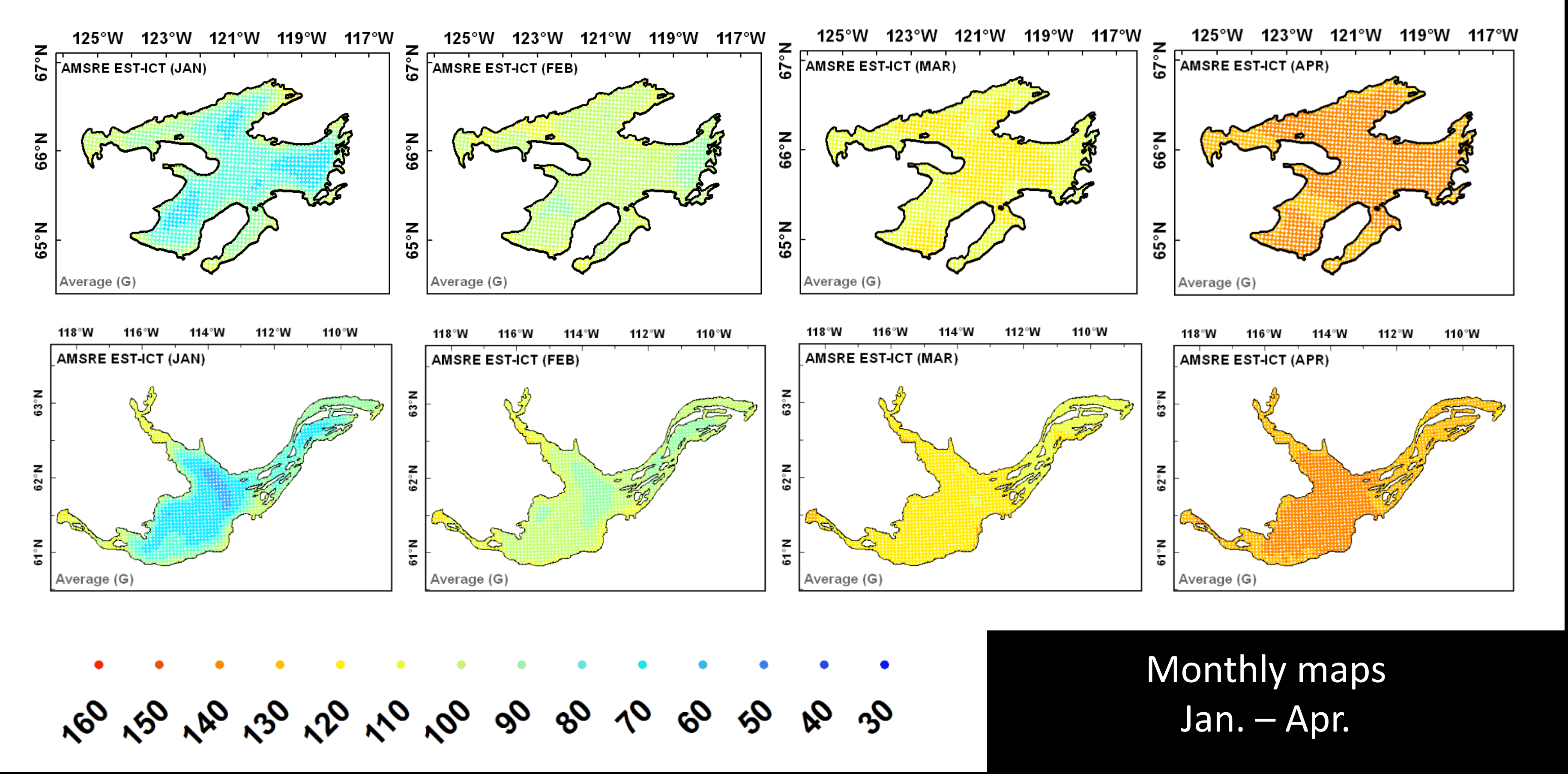
From daily data at 10 km

Kang *et al*. (2014)

Remote sensing of lake ice

Ice thickness

Retrieval algorithm
AMSR-E 18.7 GHz V-pol

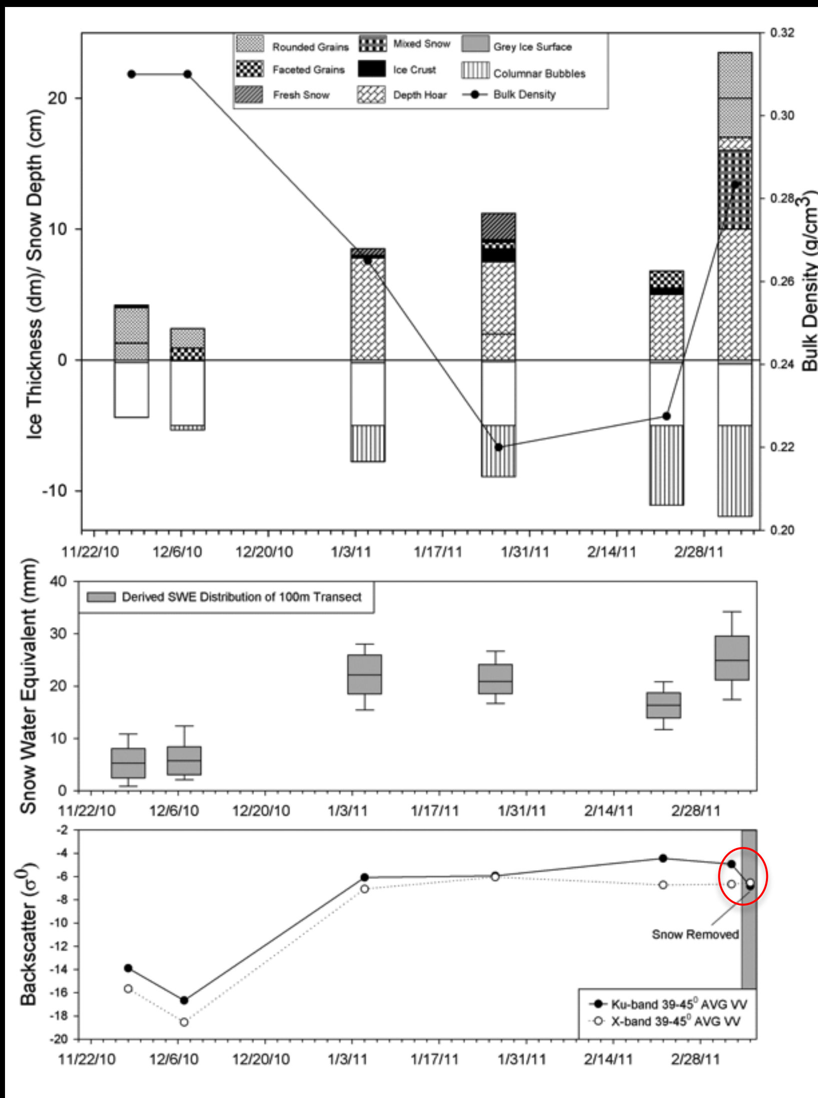


Monthly maps
Jan. – Apr.

Kang *et al*. (2014)

Remote sensing of lake ice

Snow depth on ice



2-3 dB drop at Ku

Snow removal experiment

CASIX 2010-2011

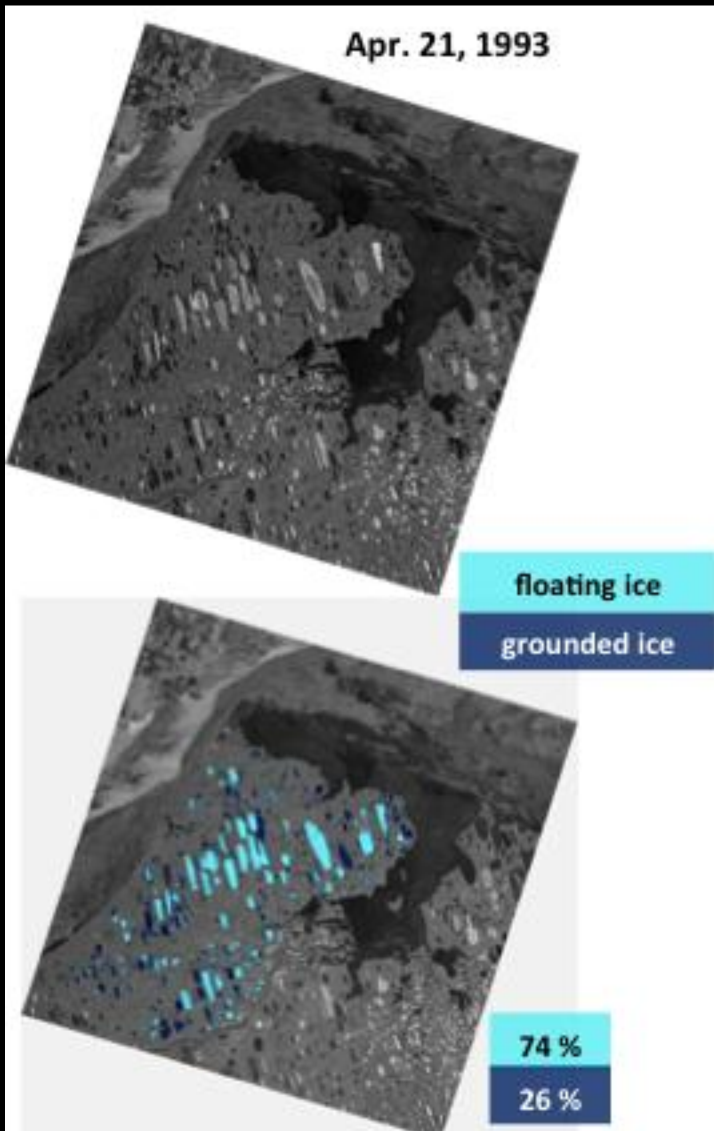
X- and Ku-band backscatter at 39°

Malcolm Ramsay Lake
Churchill, Canada

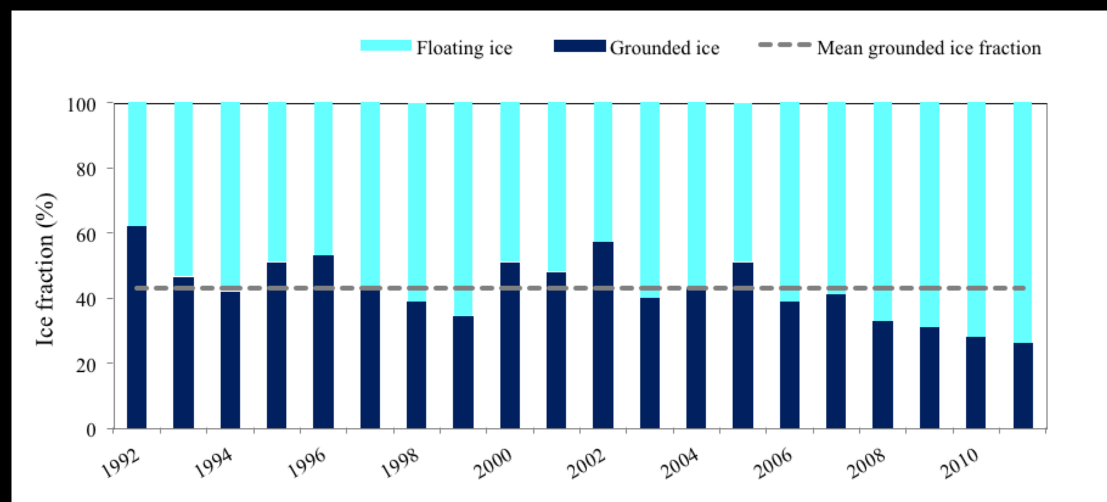
Gunn *et al*. (in prep.)

Remote sensing of lake ice

Areal extent of floating and grounded ice



North Slope of Alaska (ERS-1/2 20-year time series)
ASF 100 m product

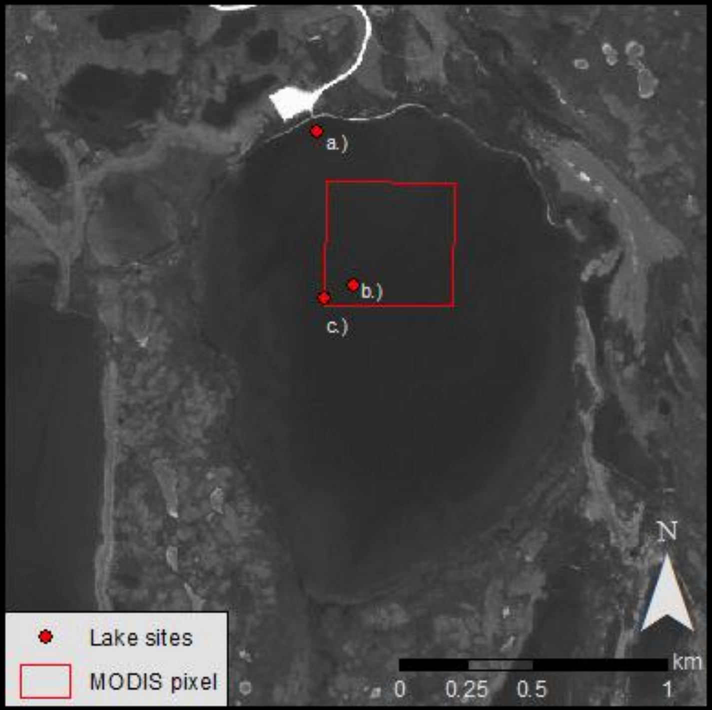


Late winter (April/May) floating and grounded ice fractions from 1992 to 2011

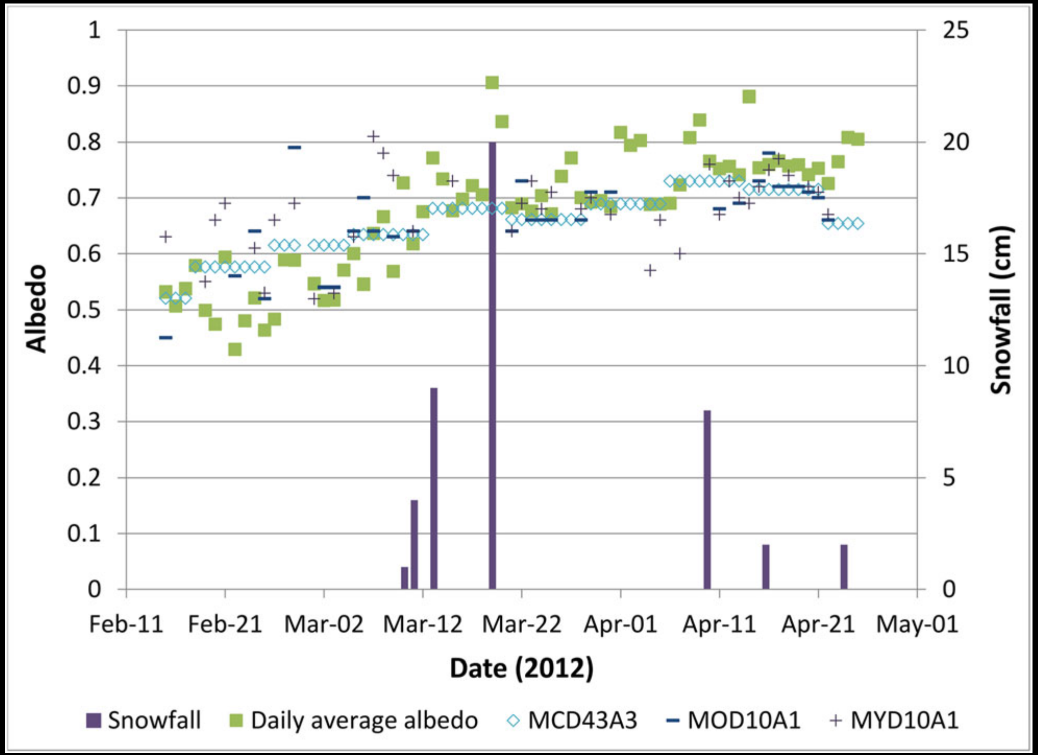
Surdu *et al*. (2014)

Remote sensing of lake ice

Snow/ice albedo (broadband)



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



Svacina *et al*. (2014b)

Remote sensing of lake ice

Snow/ice albedo (broadband)

Variable snow depth and ice types at 3 stations

MODIS daily albedo values evaluated with in situ observed albedo (15 February - 25 April 2012)

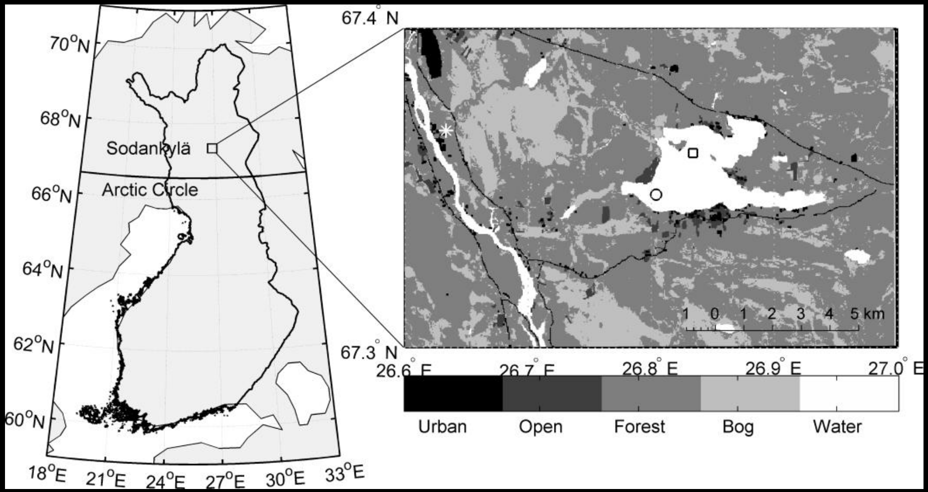
Statistic	MOD10A1	MYD10A1
Sample size, *n*	30	39
Observed mean (standard deviation)	0.65 (0.10)	0.66 (0.10)
MODIS mean (standard deviation)	0.66 (0.08)	0.68 (0.07)
RMSE	0.07	0.08
MAE	0.05	0.06
MBE	0.01	0.02

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

Svacina *et al*. (2014b)

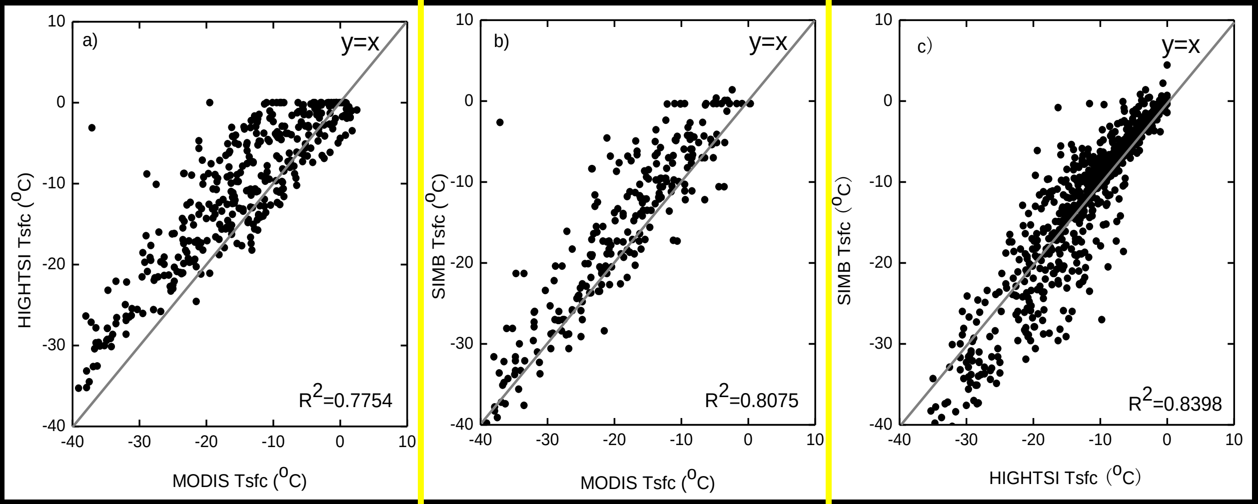
Remote sensing of lake ice

Snow/ice surface temperature



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



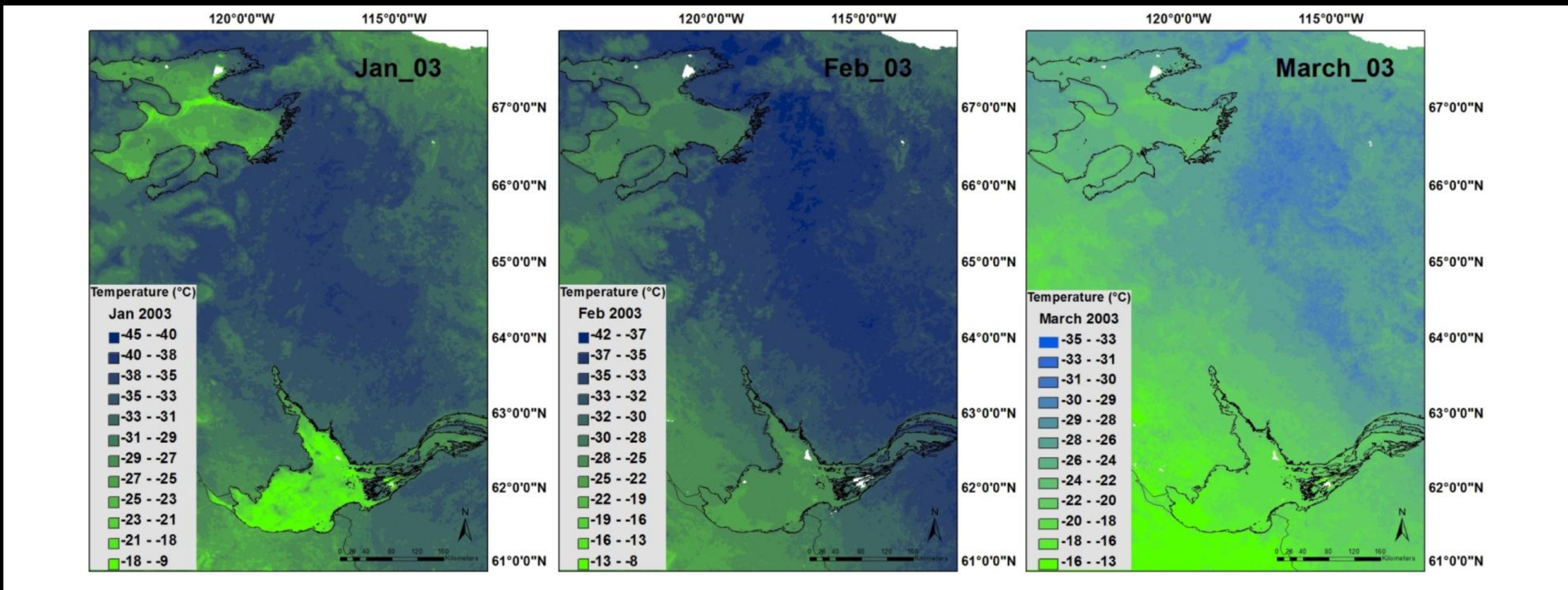
Comparison of surface temperature: (a) MODIS versus HIGHTSI; (b) MODIS versus SIMB, and (c) HIGHTSI versus SIMB for winter 2011/2012.

MODIS has cold bias

Cheng *et al.* (2014)

Remote sensing of lake ice

Snow/ice surface temperature

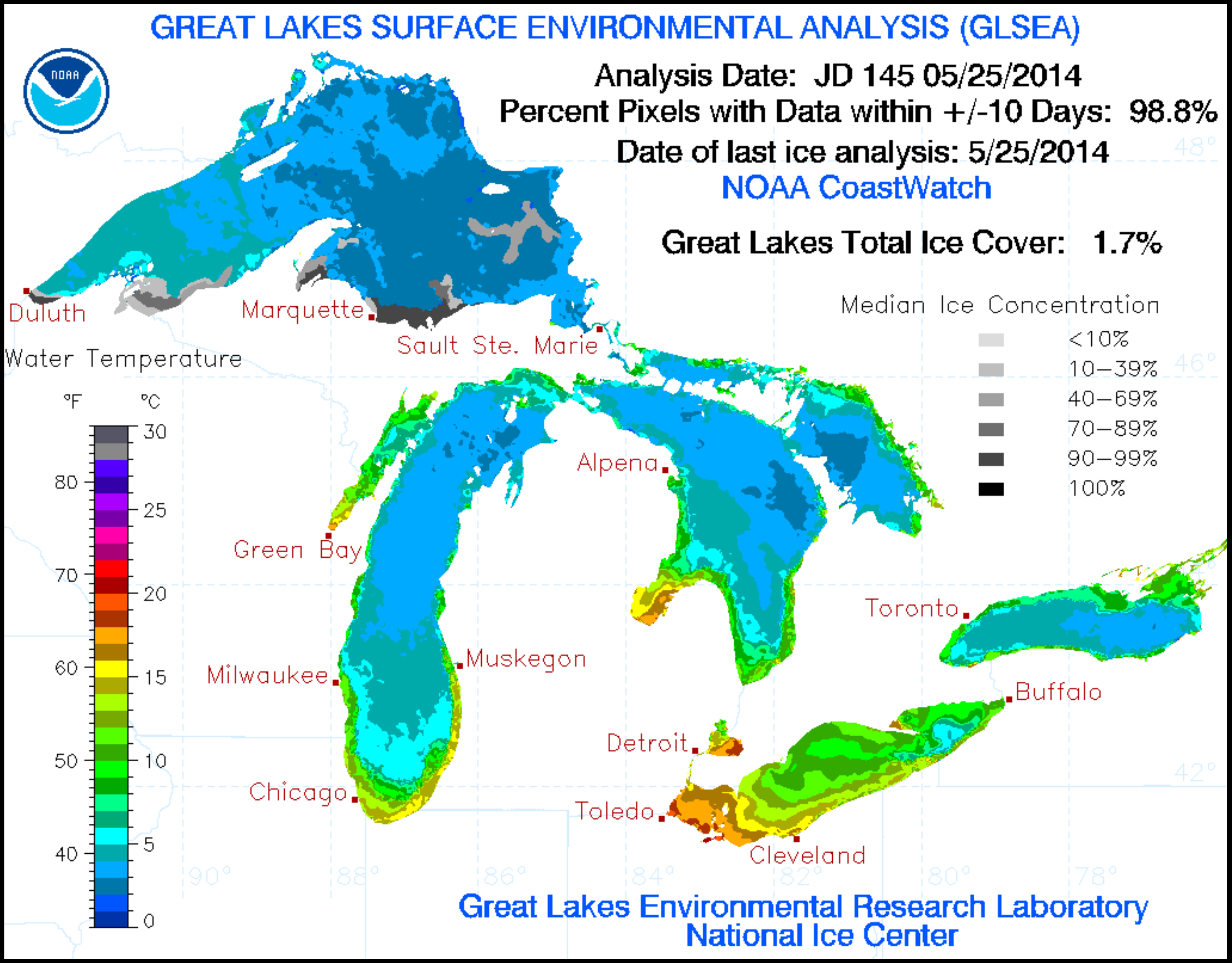


MODIS Land/Lake surface temperature in the Great Bear Lake and Great Slave Lake region (January, February, and March, 2003)

Thin ice thickness, conductive heat flux?

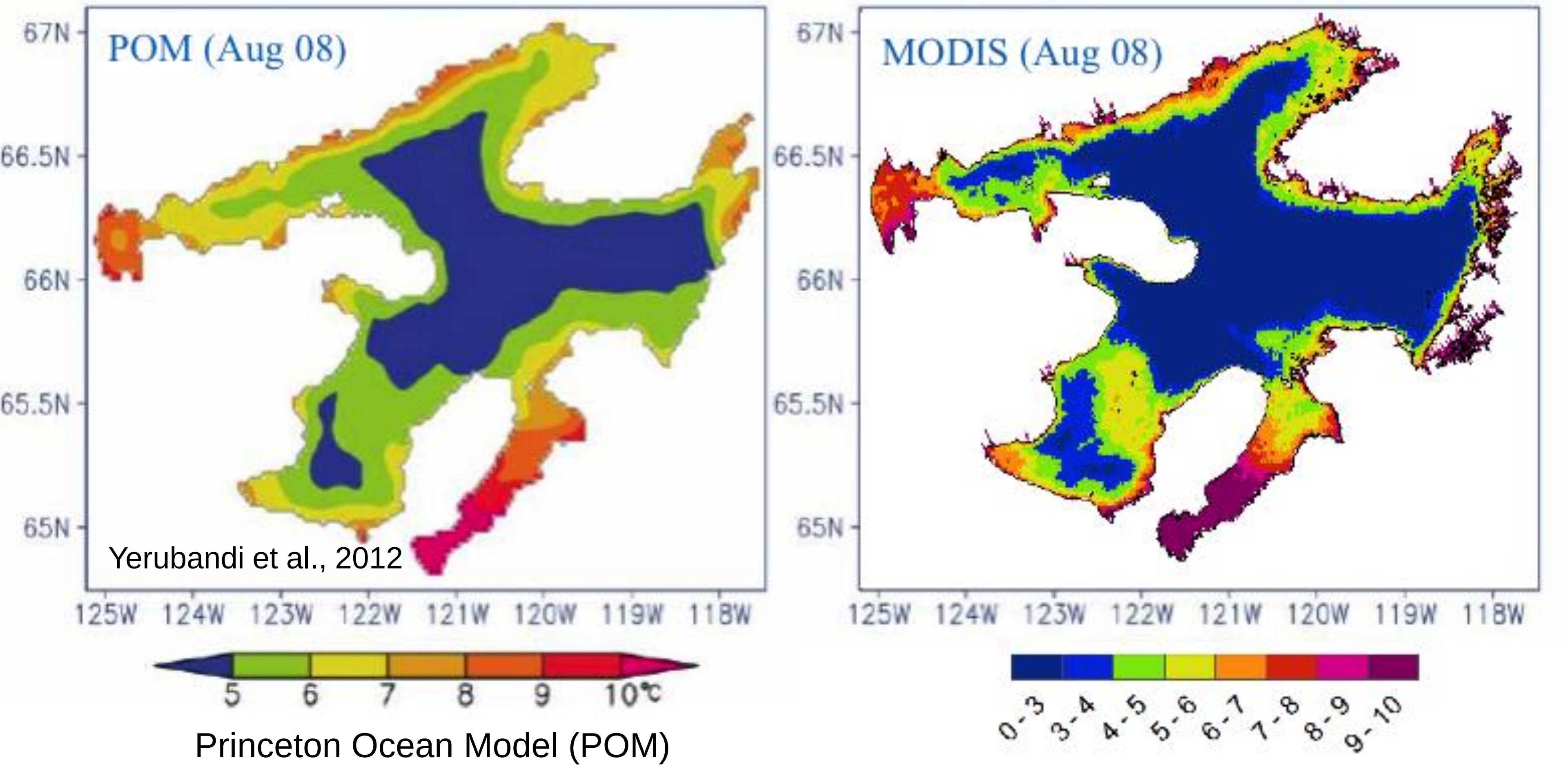
Kheyrollah Pour *et al.* (in prep.)

Remote sensing of lake surface water temperature (LSWT)



Remote sensing of lake surface water temperature (LSWT)

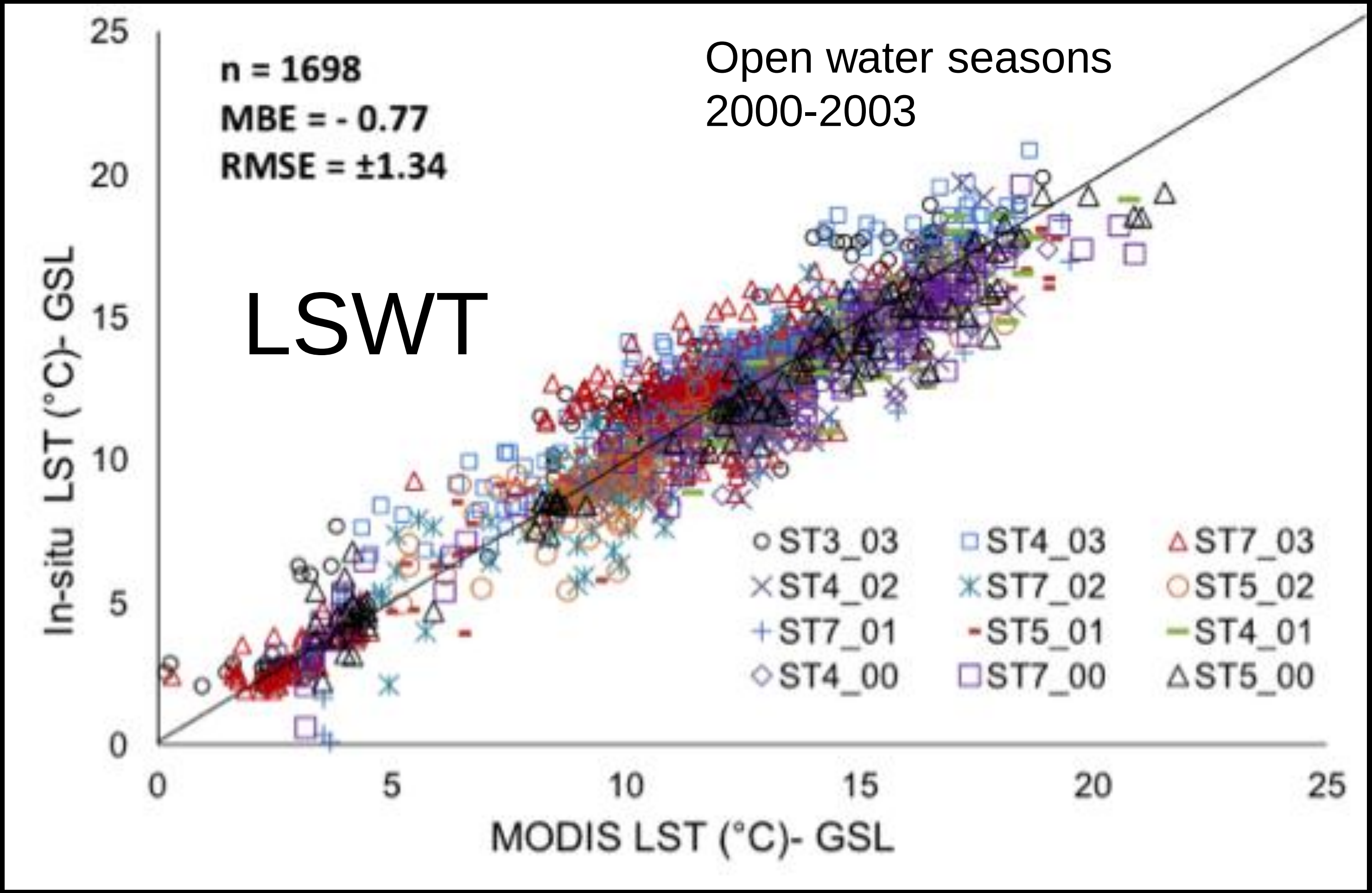
Development and evaluation of satellite products



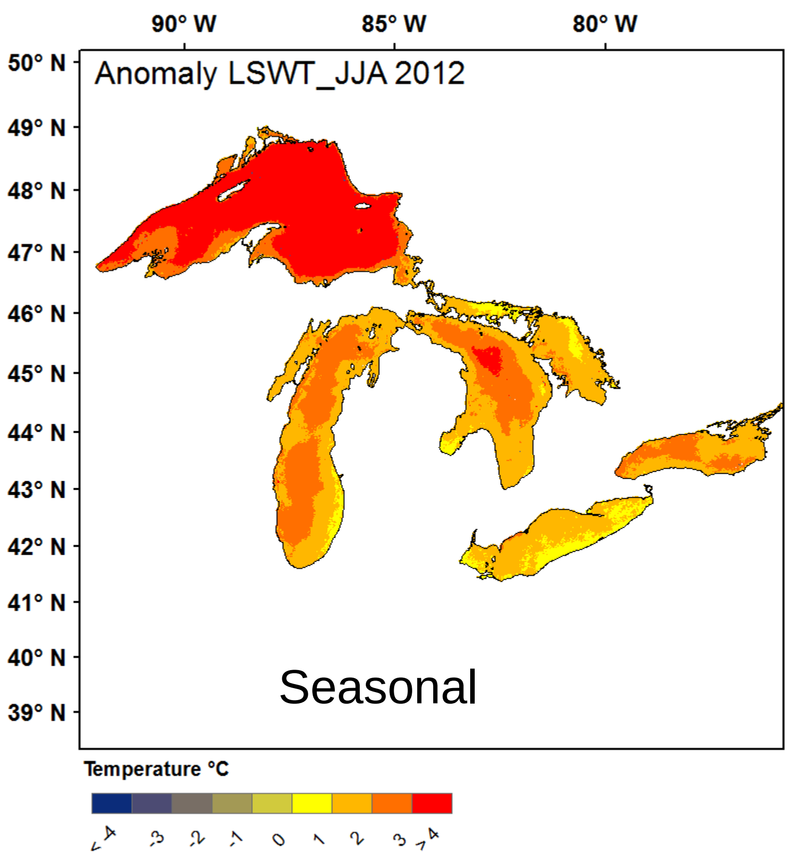
Princeton Ocean Model (POM)

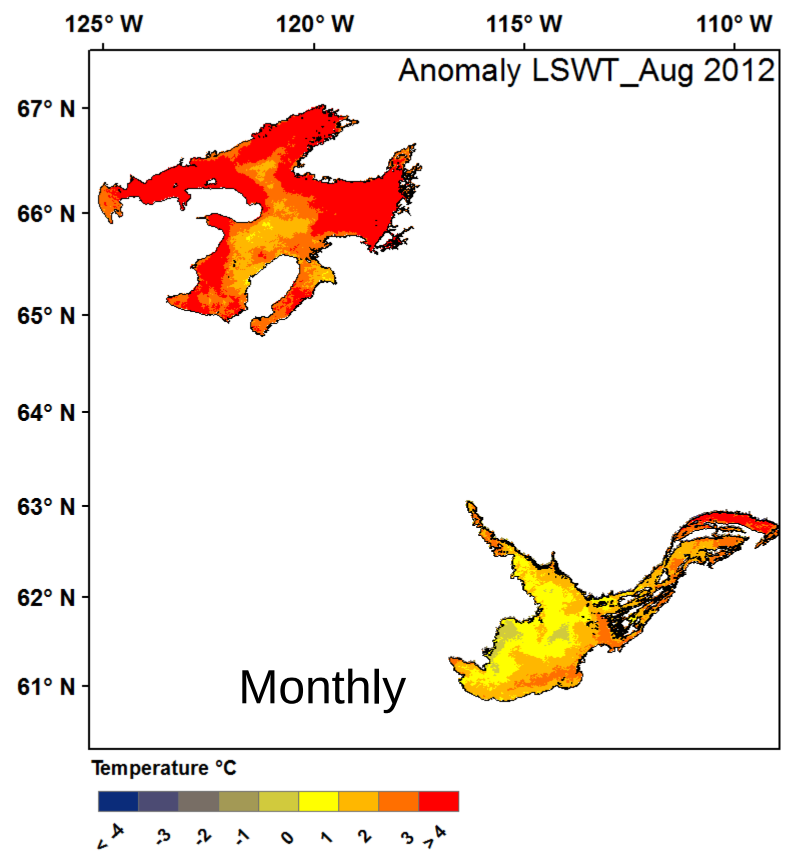
Remote sensing of lake surface water temperature (LSWT)

Development and evaluation of satellite products



Remote sensing of lake surface water temperature (LSWT)





LSWT anomalies from MODIS

Summary and outlook

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

- Automated approaches (algorithms) have been developed from scatterometer and passive microwave data (AMSR-E): provide high temporal (daily) resolution but spatially too coarse for all but the largest lakes of the northern hemisphere.
- Automated approaches (image segmentation algorithms) applied to SAR are promising but labeling currently needs interpreter/analyst.
- Operational IMS product (4 km) is suitable for climate monitoring but spatial resolution limits its use to the largest lakes.
- MODIS 500 m snow product is limited due to cloud cover and polar darkness. It remains to be validated for lakes.
- Multi-frequency/-polarization daily data at 10-100 m (lakes of various sizes) with emphasis on SAR would meet most requirements.

Summary and outlook

Ice thickness and snow depth on ice

- A retrieval algorithm has been developed from passive microwave data (AMSR-E): provides high temporal (daily) but spatial resolution too coarse for all but the largest lakes of the northern hemisphere. It also needs to be evaluated on lakes other than GBL and GSL.
- Multi-frequency SAR data remains to be evaluated to estimate ice thickness (variations in ice types present a challenge).
- No on-ice snow depth algorithm has yet been developed. Radar altimeter data (Jason-2, Cryosat, and follow-up missions) need to be examined.

Areal extent of floating and grounded ice in shallow lakes

- An approach has been developed and successfully applied using C-band SAR data from ERS-1/2 (VV). It has also been shown to work with Radarsat and ASAR WS (HH) data.
- Need to ensure continuity of same SAR configuration for long-term monitoring (1991-beyond) in lake-rich coastal regions of the Arctic.

Summary and outlook

Snow/ice surface temperature and albedo

- “The continued production of unified, consistent time series maps of surface temperature is recommended to add to the time series of surface skin temperature and broadband albedo from NOAA AVHRR that extend back to the early 1980s.
- Methods for estimating the spectral albedo of snow and ice from satellite should continue to be developed. ” (IGOS-P Cryosphere Theme Report, 2007).

Other

- Need to establish Super (lake) Sites for algorithm development/validation and for long-term monitoring.
- Need to intensify the development of lake ice products for data assimilation into numerical weather prediction (NWP) models and for the assessment of lake models used as parameterization schemes in NWP and RCMs.

Tomorrow

Lake ice cover and surface water temperature III:

Numerical modelling