Passive Microwave Retrieval of Lake Ice Cover and Thickness: Advances and Opportunities

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Virtual Event

Lake Ice Cover and Lake Ice Thickness: GCOS Requirements

ECV Lake Ice Cover	
Measurement uncertainty	10%
Stability	1% per decade
Spatial resolution	300 m
Temporal resolution	Daily

ECV Lake Ice Thickness	
Measurement uncertainty	1-2 cm
Stability	N/A
Spatial resolution	100 m
Temporal resolution	Monthly

GCOS-200, 2016. The Global Observing System for Climate: Implementation Needs.

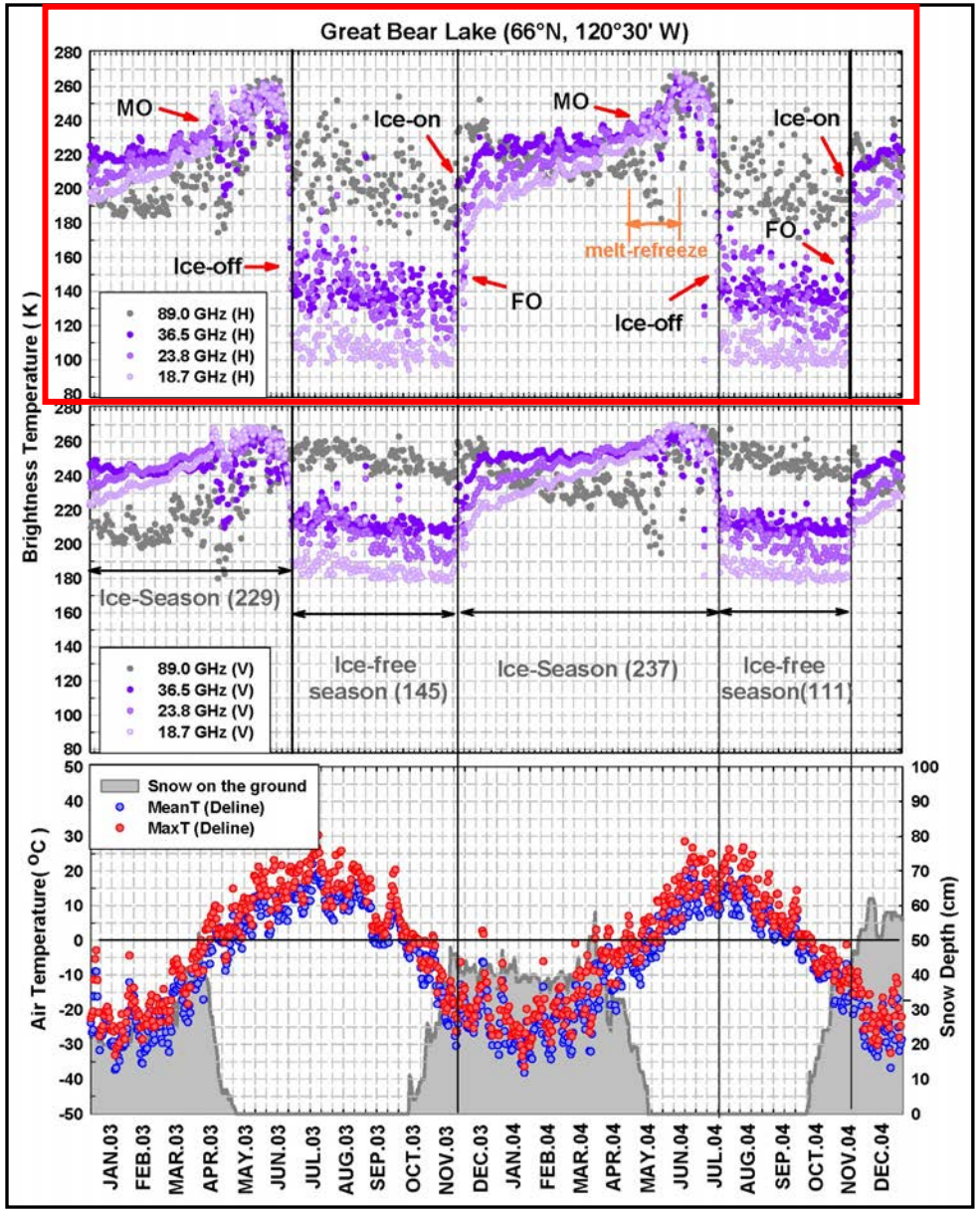
Lake Ice Cover and Lake Ice Thickness: Climate Community Requirements

Parameter	Application	Horizontal Resolution	Observing Cycle	Precision	Accuracy	Stability
Lake Ice Cover	Trend monitoring	200 m	Weekly	10%	10%	1%/decade
	Seasonal / decadal forecasting	10 / 25 km	Daily	10%	10%	1%/decade
	Reanalyses	10 / 25 km	Daily	10%	10%	1%/decade
Lake Ice Thickness	Trend monitoring	< 200 m	Weekly	5 cm	5 cm	
	Seasonal / decadal forecasting	10 / 25 km	Weekly	10 cm	10 cm	
	Reanalyses	10 / 25 km	Daily	10 cm	10 cm	

Table adapted from: CMUG CCI+, 2020. *Deliverable 1.1: Climate Community Requirements*, v2.2, 9 November 2020.

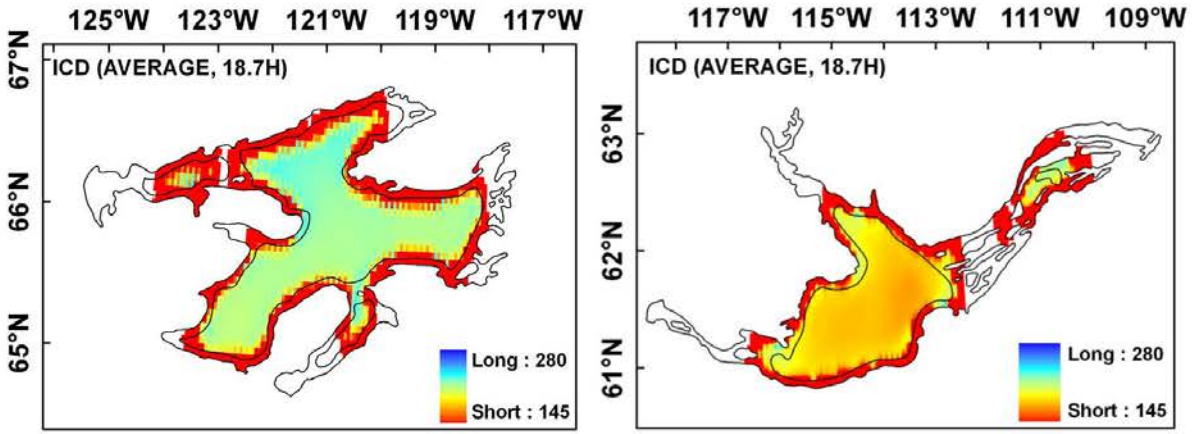
Passive Microwave Retrieval of Lake Ice Cover (LIC)

- Focus has been on the development of retrieval algorithms for the determination of dates associated with ice phenology rather than LIC (extent or concentration)
- ***Frequencies***: ~19 and ~37 GHz
- ***Polarization***: H
- ***Algorithms***: threshold-based tracking evolution of brightness temperature (TB) over time and moving *t* test method
- ***Variables***: freeze onset/ice-on/complete freeze over; melt onset/ice-off/water clear of ice; ice cover duration



Lake Ice Cover (LIC)

- AMSR-E 18.7 GHz H-pol
- 10-km grid
- Threshold-based algorithm tracking evolution of TB over time



Ice cover duration (ICD) (average 2002-2009) for Great Bear Lake (left) and Great Slave Lake (right). Confidence regions drawn with an outer buffer zone of 10 km to exclude land contamination (red areas).

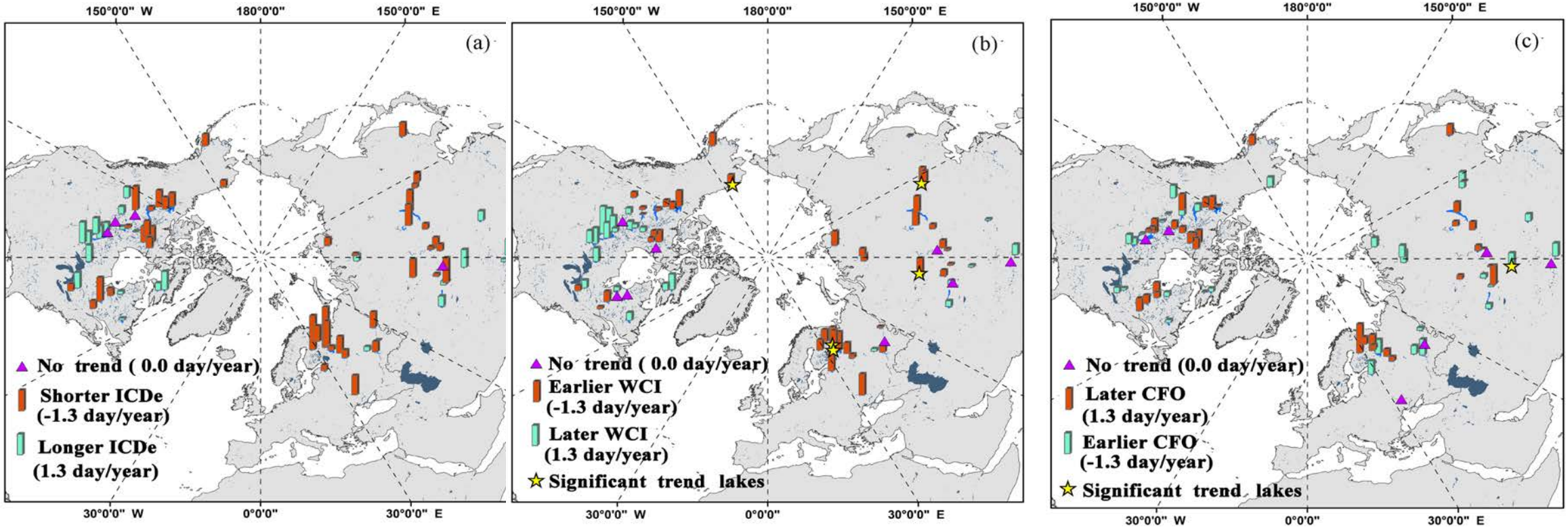
Source: Kang, K-K., C. R. Duguay, and S. E. L. Howell, 2012. Estimating ice phenology on large northern lakes from AMSR-E: Algorithm development and application to Great Bear Lake and Great Slave Lake, Canada. *The Cryosphere*, 6: 235-254.

Lake Ice Cover (LIC)

Maps showing trends for 71 lakes

Ice cover duration (left)
Water clear of ice (centre)
Complete freeze over (right)

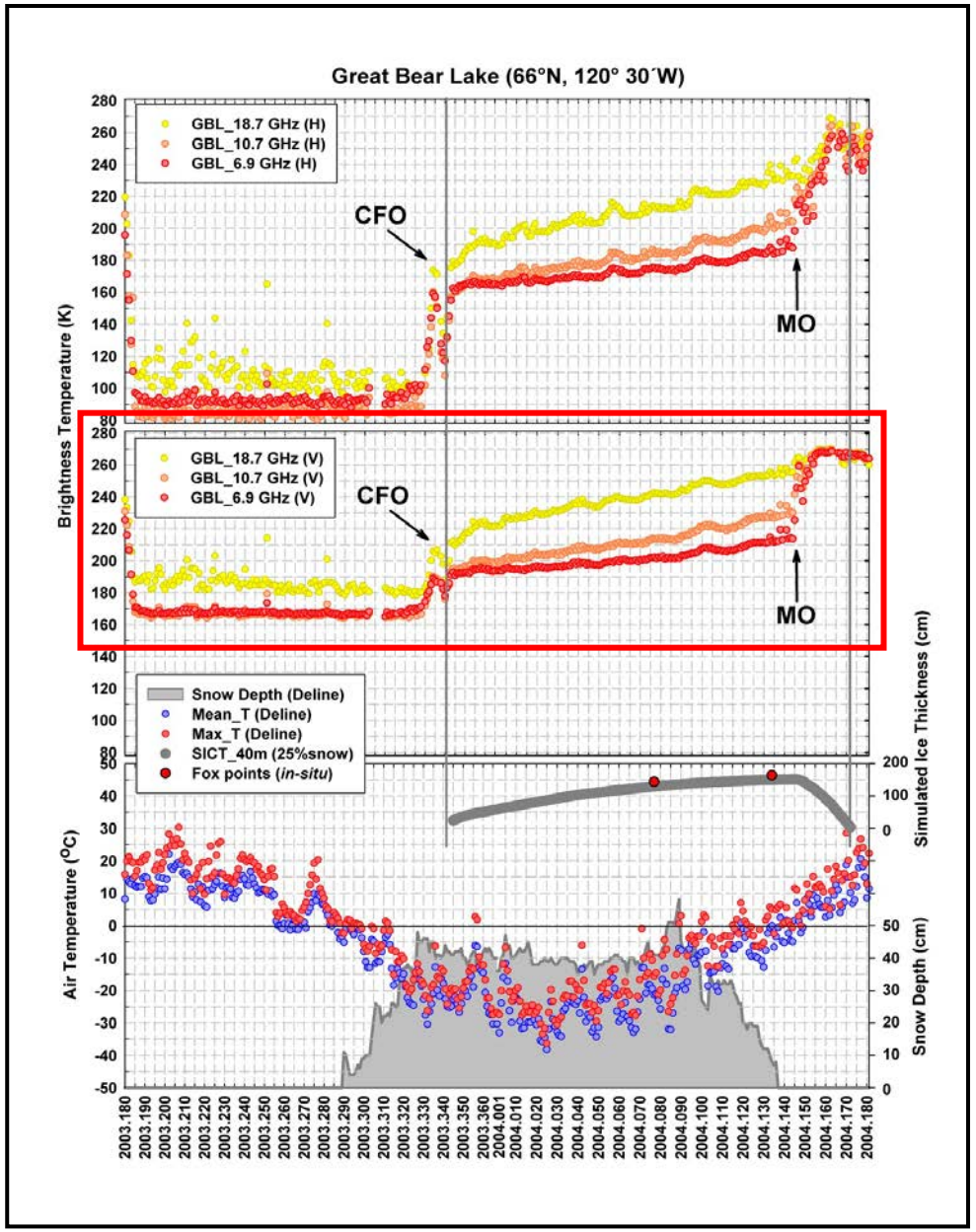
- AMSR-E/2 36.5 GHz H-pol
- 5-km grid
- Moving *t* test method



Source: Du, J., J. S. Kimball, C.R. Duguay, Y. Kim, and J. Watts, 2017. Satellite microwave assessment of Northern Hemisphere lake ice phenology from 2002 to 2015. *The Cryosphere*, 11: 47–63.

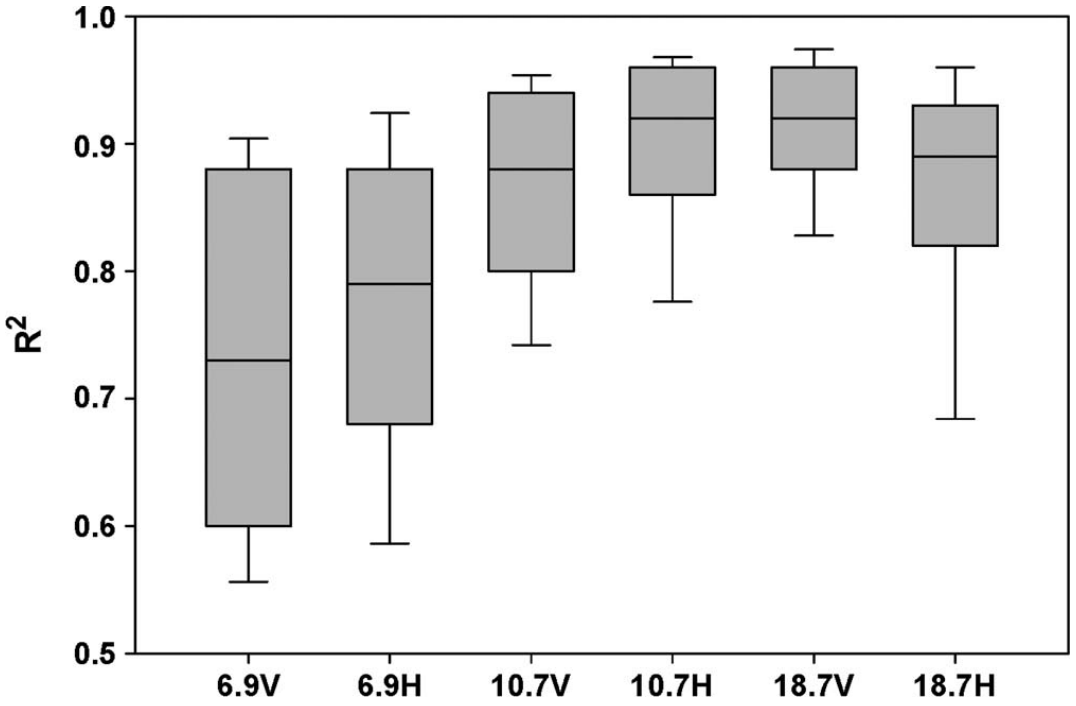
Retrieval of Lake Ice Thickness (LIT)

- ***Frequency***: ~19 GHz
- ***Polarization***: V
- ***Algorithms***: empirical equations established from relation between TB and simulated LIT from 1-D thermodynamic ice model
- ***Variable***: lake ice thickness



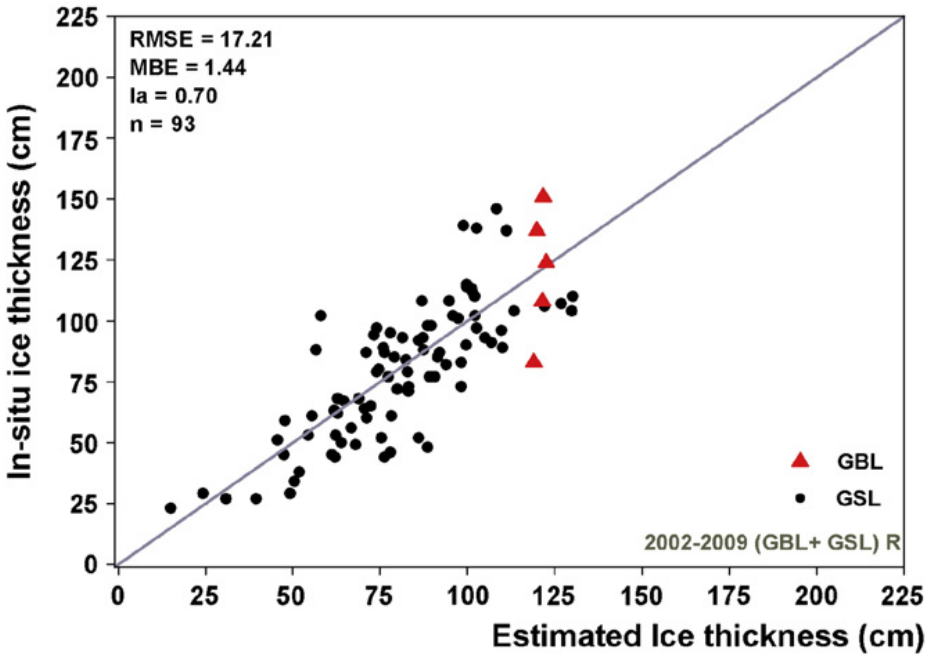
Lake Ice Thickness (LIT)

- AMSR-E 6.9, 10.7 and 18.7 GHz H/V-pol
- Best relation between LIT and TB at 18.7 GHz V-pol



Relation between ice thickness derived from lake ice model and TB (five winter seasons, 2002–2007)

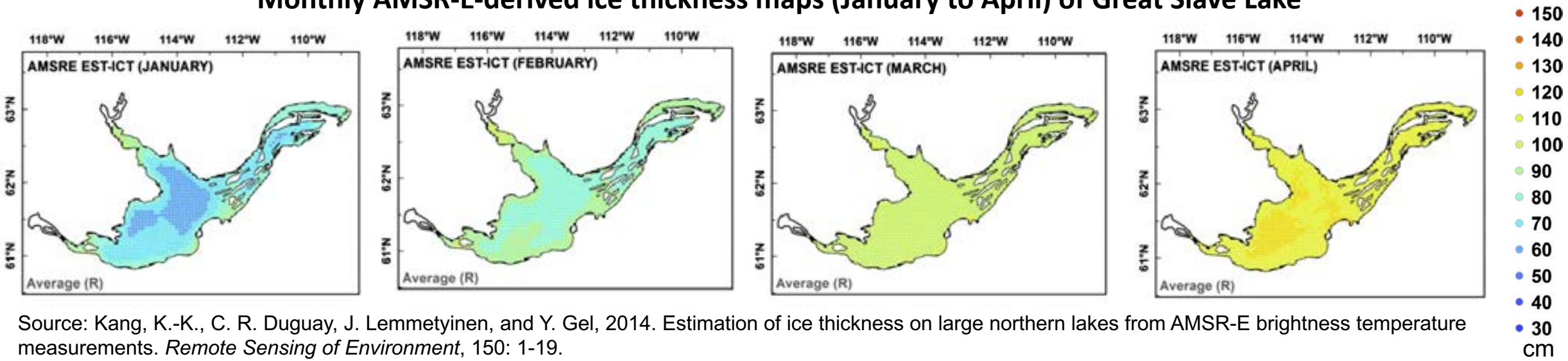
Source: Kang, K.-K., C.R. Duguay, S.E. Howell, C.P. Derksen, and R.E.J. Kelly, 2010. Sensitivity of AMSR-E brightness temperatures to the seasonal evolution of lake ice thickness. *IEEE Geoscience and Remote Sensing Letters*, 7(4): 751-755.



Lake Ice Thickness (LIT)

- AMSR-E 18.7 GHz V-pol
- 10-km grid
- Empirical equations

Monthly AMSR-E-derived ice thickness maps (January to April) of Great Slave Lake



Source: Kang, K.-K., C. R. Duguay, J. Lemmetyinen, and Y. Gel, 2014. Estimation of ice thickness on large northern lakes from AMSR-E brightness temperature measurements. *Remote Sensing of Environment*, 150: 1-19.

What is the impact of varied ice and overlying snow properties on retrievals, particularly LIT?

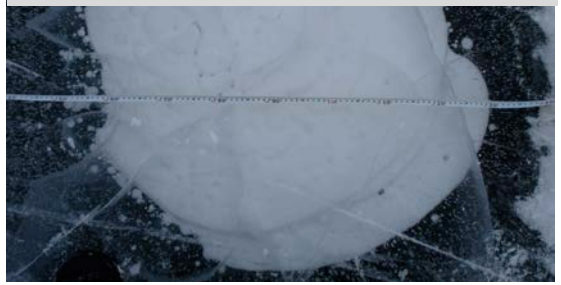
Ice with low and no snow

Pressure ridge
(2 m high, several km long)

Roughness at ice-water interface

Clear ice / grey ice with small bubbles

Clear ice with large bubble



Snow on ice

Slushing / snow ice

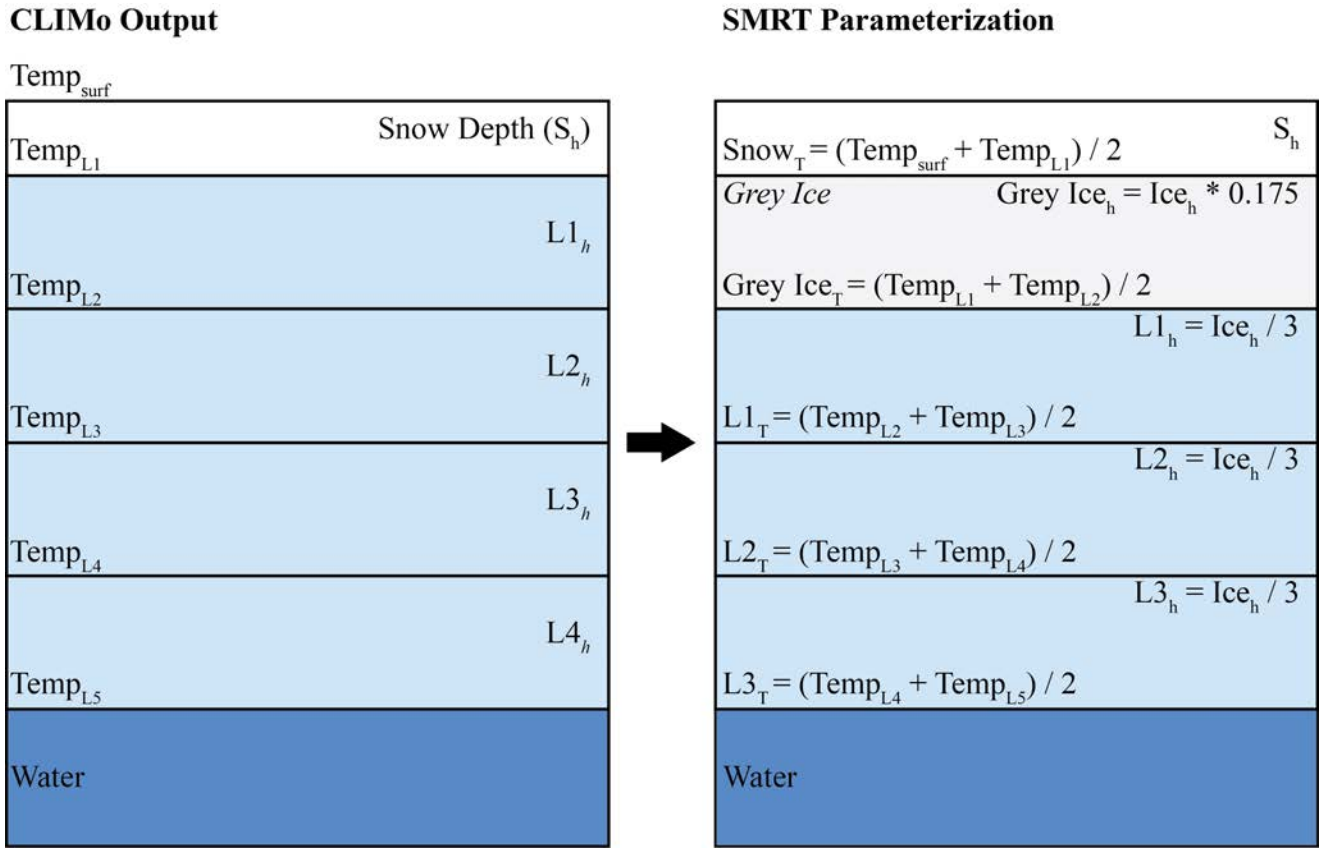
Two ongoing studies on the use of data from altimetry missions (active and passive microwave)

- LIAM Project (Lake Ice from Altimetry Missions)
  - Examination of the sensitivity of backscatter and TB measurements to LIT of varied ice and overlying snow properties, which are sources of uncertainty in retrievals
  - Comparison between forward simulations and satellite observations
  - 12 months (June 2020-June 2021)

- CCI+ Lakes (LIT option)
  - Retrieval of LIT from waveforms and synergy backscatter/TB measurements
  - 16 months (December 2020-April 2022)

Sensitivity of TB to LIT of varied ice and overlying snow properties: Forward simulations CLIMo ---> SMRT

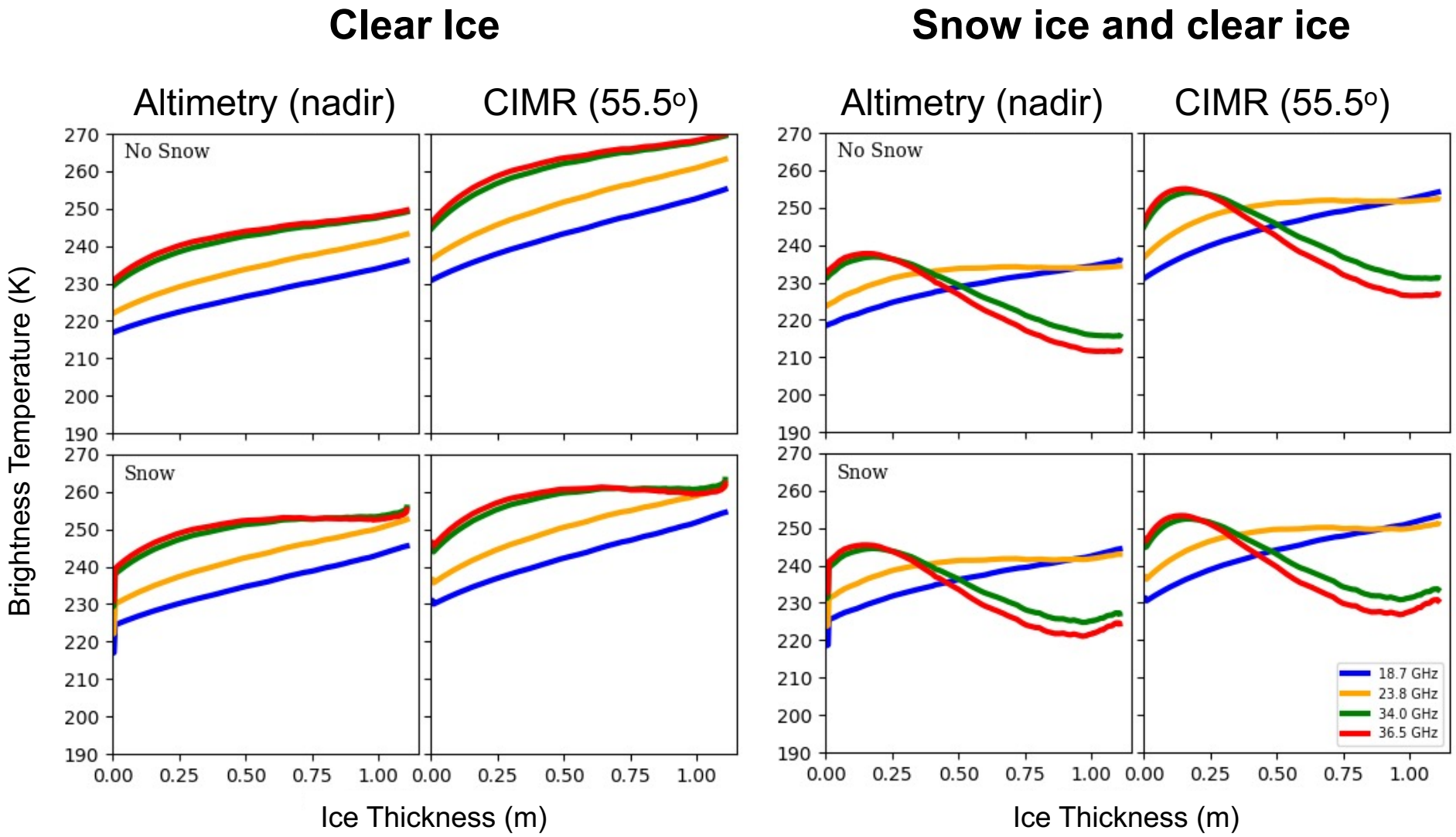
- Emphasis on 18-37 GHz range for various scenarios of ice (snow ice, bubbles, roughness at ice-water interface) and overlying snow (depth, density, wetness) properties using the combination of a one-dimensional thermodynamic lake ice model (CLIMo) and the Snow Microwave Radiative Transfer (SMRT) model



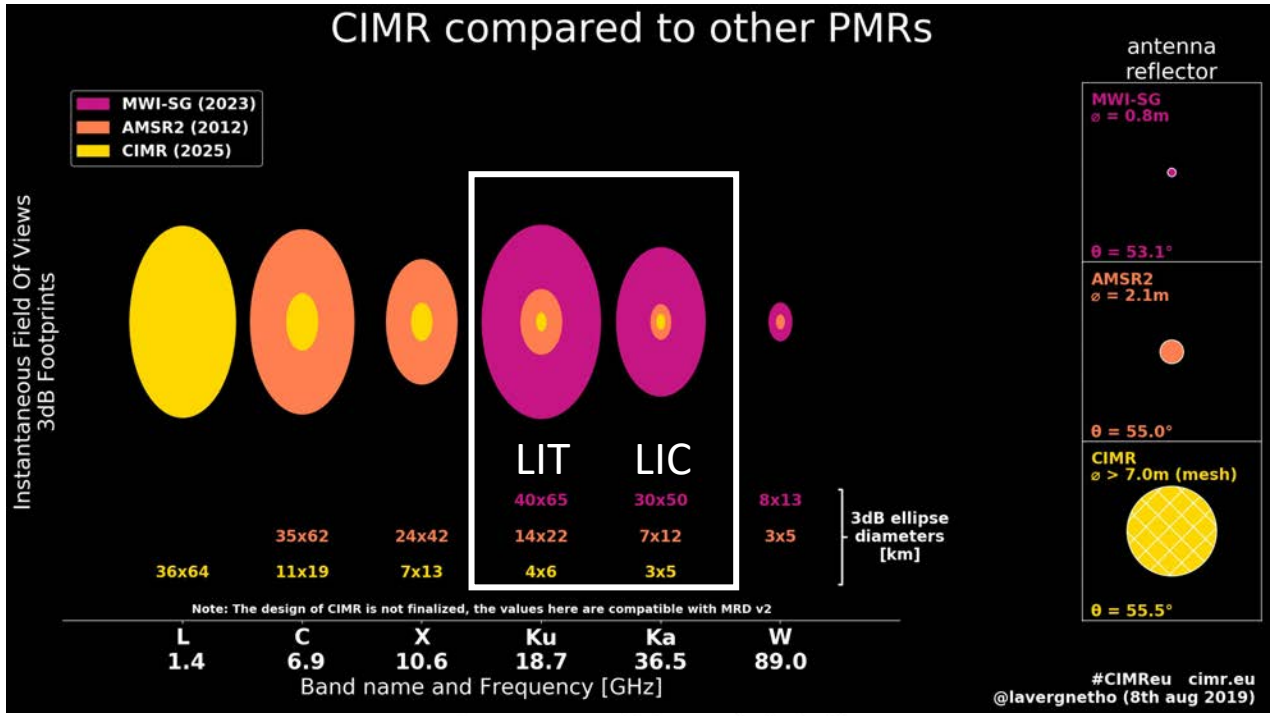
CLIMo: Duguay, C.R., G.M. Flato, M.O. Jeffries, P. Ménard, K. Morris, and W.R. Rouse, 2003. Ice cover variability on shallow lakes at high latitudes: Model simulations and observations. *Hydrological Processes*, 17(17): 3465-3483.

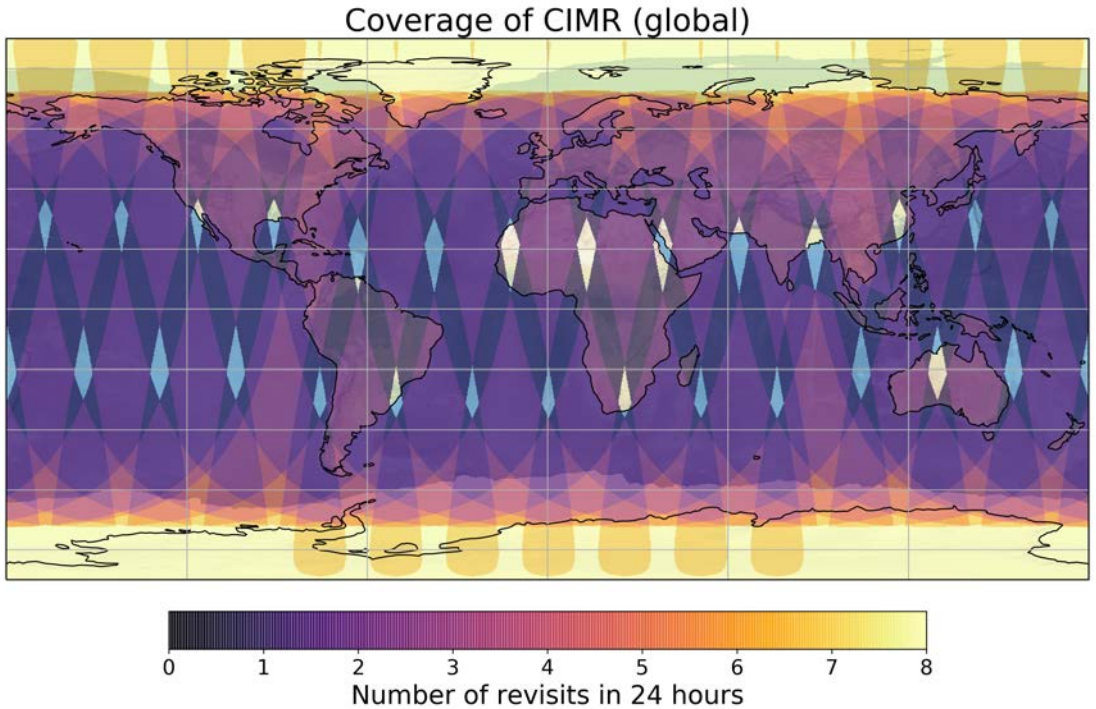
SMRT: Picard, G., Sandells, M., Löwe, H., 2018. SMRT: An active-passive microwave radiative transfer model for snow with multiple microstructure and scattering formulations (v1.0). *Geoscientific Model Development,* 11: 2763–2788.

Forward simulations of TB at nadir and 55.5 deg. (V-pol)



- Simulations at a location on Great Slave Lake
- Snow ice thickness set at 10% of the total ice column
- **18.7 GHZ V-pol best choice for retrieval of LIT**





CIMR's Contribution to Lake Ice Cover and Lake Ice Thickness

- **CIMR** will permit generation of global LIC/LIT products at ≤ 5 km
- CIMR alone or in synergy with other satellite missions (e.g. Sentinel-3, CRISTAL) will help meet several of the requirements from GCOS and the climate community (CCI+ CMUG)
- Activities on LIC/LIT retrieval algorithms and prototype products, including uncertainty characterization, are needed in preparation for CIMR

Thank you for your attention!

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