Advances in Remote Sensing of Lake Ice

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Motivation

Satellite retrieval of lake ice parameters
- Ice extent/concentration
- Freeze-up and break-up/ice cover duration
- Snow/ice albedo (broadband)
- Snow/ice surface temperature
- Ice thickness
Motivation

Ice mapping/monitoring at CIS

**Daily ice charts** of Great Lakes produced by North American Ice Service (partnership between the Canadian Ice Service, the International Ice Patrol, and the U.S. National Ice Center)

Concentration (in tenth)

Stage of development
Motivation

Ice mapping/monitoring at CIS

Weekly ice fraction for over 130 lakes from visual interpretation of SAR and optical imagery by ice analysts

Weather forecasting at CMC
Motivation

Ice mapping/monitoring at CIS

CIS would like to:
move from a manual (visual) approach using optical and SAR data

On right Sentinel-1a image overlaid on MODIS image (18 February 2016)
CIS would like to:
move from a manual (visual) approach using optical and SAR data to an automated approach

Top right: Ice polygons from Sentinel-1a SAR image (18 February 2016)

Bottom right: Image segmented into open water and a few ice classes, and then merged into two classes

Wang et al., in prep.
Motivation

Ice mapping/monitoring at CIS

Weekly ice fraction for over 130 lakes from visual interpretation of SAR and optical imagery by ice analysts

CIS would like to:
move from a manual (visual) approach using optical and SAR data to an automated approach

Hoekstra et al., in prep.
Motivation

Climate monitoring

• GCOS Essential Climate Variable (ECV): Lakes
  - Lake ice dates (freeze-up and break-up)
Satellite retrieval of lake ice parameters

Ice extent/concentration

- MODIS snow algorithm (SNOWMAP) has limitations, particularly in discriminating clouds from snow-covered lake ice and the detection of ice cover:
  1) underestimation of ice when snow on ice is absent and during break-up period
  2) false detection of clouds with high sediment loads (e.g. river inflow) and advanced stage of break-up.

Source: NSIDC

MODIS/Terra Snow Cover Daily L3 Global 500 m Product
Ice extent/concentration

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

Kang et al. (in prep.)

New (revised) MODIS SNOWMAP algorithm improves lake ice mapping
Satellite retrieval of lake ice parameters

Ice extent/concentration

A retrieval algorithm, similar to the new MODIS lake ice algorithm, has been developed to map lake ice using VIIRS I-Band data.
Satellite retrieval of lake ice parameters

New ice cover extent product from MODIS data
- For operational use by ice and weather forecasting services

Kang et al., in prep.
Freeze-up and break-up/ice cover duration

Satellite retrieval of lake ice parameters

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

From daily data at 10 km

Kang et al. (2012)
Satellite retrieval of lake ice parameters

Freeze-up and break-up/ice cover duration

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

Ice-off

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

Great Bear Lake

Great Slave Lake

Kang et al. (2012)
Satellite retrieval of lake ice parameters

Snow/ice albedo (broadband)

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

Svacina *et al.* (2014)

Malcolm Ramsay Lake (Churchill, Manitoba)
Snow/ice albedo (broadband) at 3 stations

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

<table>
<thead>
<tr>
<th>Statistic</th>
<th>MOD10A1</th>
<th>MYD10A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size, $n$</td>
<td>30</td>
<td>39</td>
</tr>
<tr>
<td>Observed mean (standard deviation)</td>
<td>0.65 (0.10)</td>
<td>0.66 (0.10)</td>
</tr>
<tr>
<td>MODIS mean (standard deviation)</td>
<td>0.66 (0.08)</td>
<td>0.68 (0.07)</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>MAE</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>MBE</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

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

Svacina et al. (2014)
Satellite retrieval of lake ice parameters

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)
Satellite retrieval of lake ice parameters

Ice thickness

Retrieval algorithm
AMSR-E 18.7 GHz V-pol

\[ ICT = 3.25 \times T_B - 680.262 \]

From daily data at 10 km

Kang et al. (2014)
Satellite retrieval of lake ice parameters

Ice thickness

Retrieval algorithm
AMSR-E 18.7 GHz V-pol

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

Kang et al. (2014)
MODIS
Lake and Great Slave Lake region (January, February, and March, 2003)

Ice thickness (conductive heat flux) signal

Kheyrollah Pour et al. (in review)
Satellite retrieval of lake ice parameters

Ice thickness

Jason-2 Ku-band altimeter data (top) vs AMSR-E derived thickness (bottom) on Great Slave Lake (Back Bay)

A 2010 idea!

* AMSR-E $T_B$ influenced by maximum temperature above 0 °C

Jason-2

In situ

AMSR-E TB influenced by maximum temperature above 0 °C
7 years later!

Ice thickness

Jason-2 Ku-/C-band altimeter and passive microwave radiometer Great Bear Lake

Duguay et al. (in prep.)
Ice thickness

Jason-2 Ku-/C-band altimeter and passive microwave radiometer Baker Lake

Duguay et al. (in prep.)
Questions?