MULTI-SENSOR MONITORING OF ICE REGIMES OF HIGH ARCTIC LAKES

Cristina M. Surdu¹, Claude R. Duguay¹ and Diego Fernández Prieto²

¹ University of Waterloo, Ontario, Canada  
² European Space Agency, ESRIN, Italy

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Objectives

- To document and analyze the response of High Arctic lakes to recent climate conditions:
  - start and duration of ice break-up
  - timing of summer minimum ice cover
  - presence of perennial ice
  - response of lakes in polar desert vs. those in polar oasis environments
11 lakes in the Canadian Arctic Archipelago (CAA), including Lake Hazen, world’s largest lake north of the Arctic Circle

- Lakes are ice covered for more than 9 months/year
- Some maintain a perennial ice cover
- Polar deserts (pd) – cold, dry climate (7 lakes)
- Polar oases (po) – warmer climate, more vegetation and higher biological diversity (4 lakes)
Data

- **C-band SAR acquisitions (1997-2011):**
  - RADARSAT-1/2 (ScanSAR Wide Swath B) (100 m, with a pixel spacing of 50 m – 2x2 block averaged to 100 m)
  - ASAR (Wide Swath) (150 m spatial resolution, with a pixel spacing of 75 m)

- **Optical imagery (1997-2011):**
  - Landsat 4/7 (30 m spatial resolution)

- **Climate data (1997-2011):**
  - Weather station records (Alert, Eureka, Resolute, NU)
  - ERA-Interim Reanalysis data (~ 0.75°x 0.75° resolution)
<table>
<thead>
<tr>
<th>Year of observations</th>
<th>RADARSAT-1</th>
<th>RADARSAT-2</th>
<th>ASAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>231</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1998</td>
<td>761</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>787</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2000</td>
<td>718</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>1777</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2002</td>
<td>1476</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2003</td>
<td>1431</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2004</td>
<td>1392</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2005</td>
<td>1282</td>
<td>-</td>
<td>126</td>
</tr>
<tr>
<td>2006</td>
<td>1202</td>
<td>-</td>
<td>403</td>
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<tr>
<td>2007</td>
<td>1435</td>
<td>-</td>
<td>316</td>
</tr>
<tr>
<td>2008</td>
<td>1100</td>
<td>2740</td>
<td>339</td>
</tr>
<tr>
<td>2009</td>
<td>65</td>
<td>1561</td>
<td>539</td>
</tr>
<tr>
<td>2010</td>
<td>155</td>
<td>1077</td>
<td>380</td>
</tr>
<tr>
<td>2011</td>
<td>-</td>
<td>-</td>
<td>855</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13812</strong></td>
<td><strong>5378</strong></td>
<td><strong>2958</strong></td>
</tr>
</tbody>
</table>

Number of images used for analysis

- > 2000 Landsat images
Methods

- **Image segmentation**: the unsupervised K-means algorithm

- ~1600 segmented images in order to derive ice/open water fractions

Landsat, 19 July 2010

ASAR, 19 July 2010

K-means classified image (5 clusters)

Two-class map of ice and open water

Histogram statistics (text files) – ice and open water fraction (%)
Melt Onset

- Spatial resolution of RADARSAT-1/2 ScanSAR Wide Swath and ASAR Wide Swath = too coarse to detect melt onset on small lakes (1-5 km² surface area)

Landsat, 10 July 2003

RADARSAT-1, 11 July 2003

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The Ice Season

Landsat, 8 June 2010
Melt onset observed

ASAR, 12 June 2010

ASAR, 9 June 2010
Melt onset not detected

Landsat, 18 June 2010

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The Ice Season – cont.

Landsat, 24 June 2010

Landsat, 26 June 2010

Landsat, 29 June 2010

ASAR, 30 June 2010

Copyright: Team Duguay
The Ice Season – cont.

Landsat, 2 July 2010

ASAR, 7 July 2010

Landsat, 5 July 2010

ASAR, 11 July 2010

Copyright: Team Duguay
The Ice Season – cont.

Landsat, 13 July 2010

ASAR, 14 July 2010

Ice 44%

Ice 93%

ASAR, 17 July 2010

Ice 76%

ASAR, 19 July 2010

Ice 44%

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The Ice Season – cont.

ASAR, 22 July 2010

Ice 33%

RADARSAT-2, 25 July 2010

Ice 18%

Landsat, 27 July 2010

ASAR, 29 July 2010

Ice 4%

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The Ice Season – cont.

RADARSAT-2, 31 July 2010

Ice 0%

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Results – cont.

Melt onset

Number of days

-40 -30 -20 -10 0 10 20

1997-2011 mean # of days change

Mean melt onset (CAA)

polar desert lakes
polar oasis lakes

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Results – cont.

**Summer ice minimum**

Number of days

- 1997-2011 mean # of days change
- Mean summer ice min. (CAA)

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Results – cont.

Break-up end

Number of days

-40 -30 -20 -10 0 10 20

polar desert lakes
polar oasis lakes

1997-2011 mean # of days change
Mean break-up end (CAA)

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Ice conditions for 11 lakes in the Canadian High Arctic were observed between 1997-2011 from combined ASAR, RADARSAT-1/2 and Landsat observations.

- Melt onset started earlier for all 11 lakes.
- Summer ice minimum occurred earlier for all lakes excepting Lower Murray Lake (Ellesmere Island).
- Break-up ended earlier for all lakes excepting Lower Murray Lake that experienced longer ice duration by 12.5 days.
- Perennial ice was occasionally observed for 5 lakes.

<table>
<thead>
<tr>
<th>Arctic environment</th>
<th>Melt onset (# of days early)</th>
<th>Summer ice minimum (3 days early)</th>
<th>Ice-off (# of days early)</th>
<th>Perennial ice (occasionally)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar desert</td>
<td>2.7-22.5</td>
<td>1.5-18.8</td>
<td>1.6-20</td>
<td>3 lakes</td>
</tr>
<tr>
<td>Polar oasis</td>
<td>14-39</td>
<td>9-30</td>
<td>9-23.6</td>
<td>2 lakes</td>
</tr>
</tbody>
</table>
Main Limitations

- **Spatial resolution** of the SAR beam modes (100-150 m) – does not capture melt onset for (small) lakes
  - melt onset observed with Landsat

- **Temporal resolution** of both SAR and optical sensors
  - transition from minimum ice to open water can occur within 1-2 days
  - optical and SAR acquisitions are at times 5 days apart
Acknowledgements

- This work was supported by a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Claude Duguay.

- **RADARSAT-1** images are copyright the Canadian Space Agency (CSA), 1997-2010.

- **RADARSAT-2** Data and Products, © MacDonald, Dettwiler and Associates Ltd., 2008-2011, all rights reserved.

- **ASAR** data is copyright the European Space Agency (ESA), 2005-2011.

- **Landsat** images were provided by the U.S. Geological Survey.