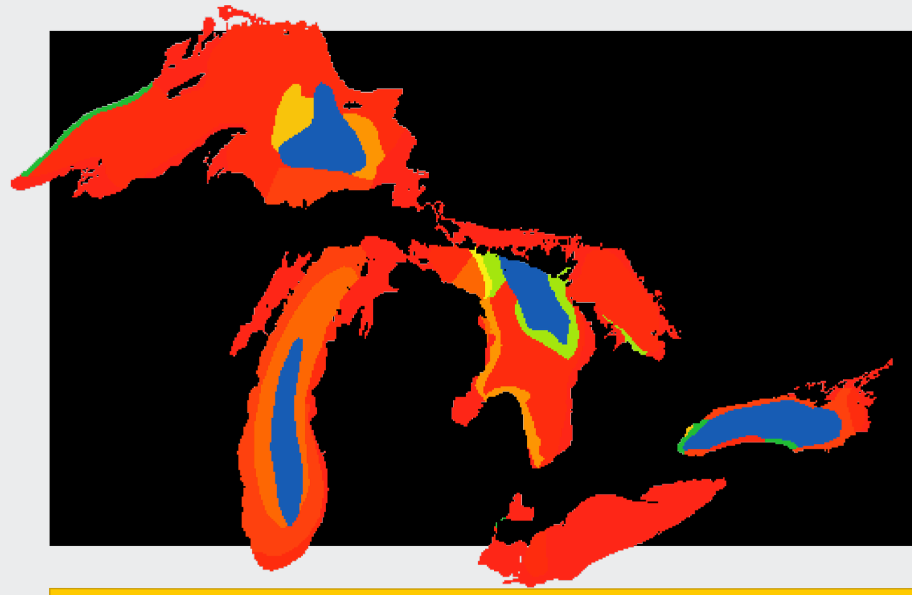

# Consistent, Long-term Ice Cover Observations and Satellite Altimetry Ice Thickness Retrieval Studies for the Laurentian Great Lakes

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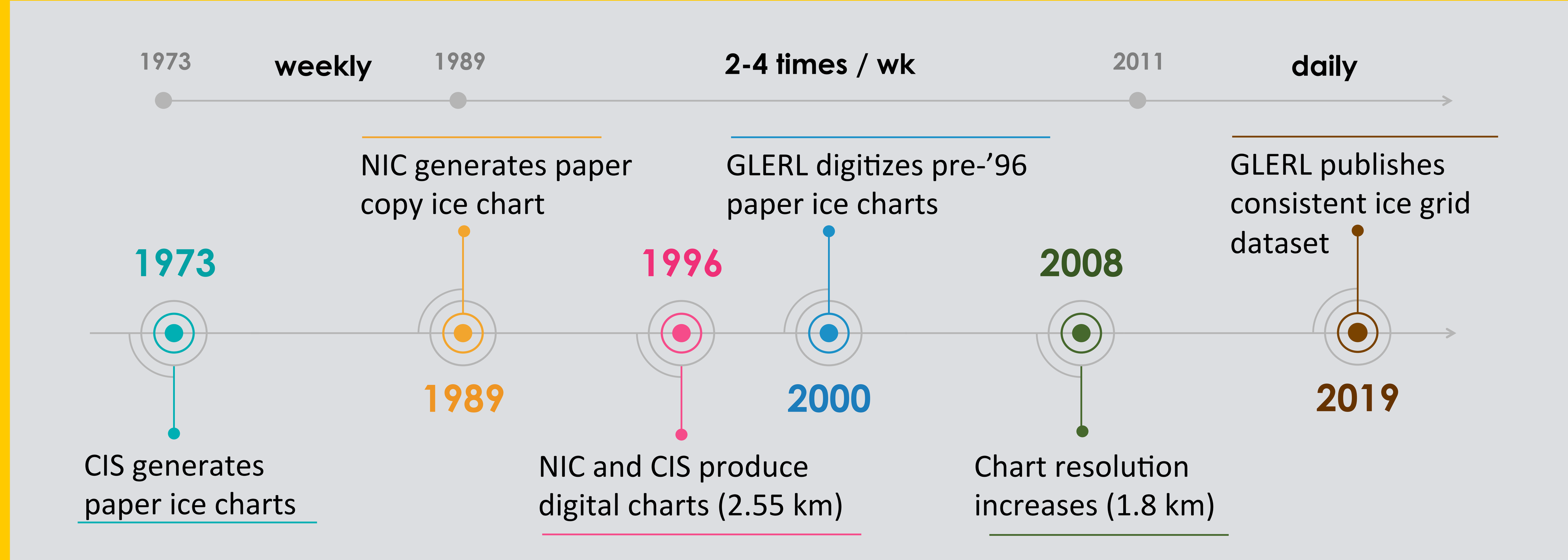
## Consistent Long-term Great Lakes Ice Cover Data[1]

Ice cover in the Great Lakes plays a key role in economy (commercial shipping/fishing), ecology (spring blooms), and regional weather (lake-effect precipitation). Spatial ice data in this region dates back to 1973 but was previously inconsistent in space and time.




Timeline of ice data produced by the National Ice Center (NIC) and Canadian Ice Services (CIS)

### Methods

Problems: (original dataset from NIC/CIS)

- ⓧ Unintuitive WMO ice "codes" instead of ice fraction
- ⓧ Poor temporal resolution before 2011
- ⓧ Inconsistent spatial resolution

Solutions:

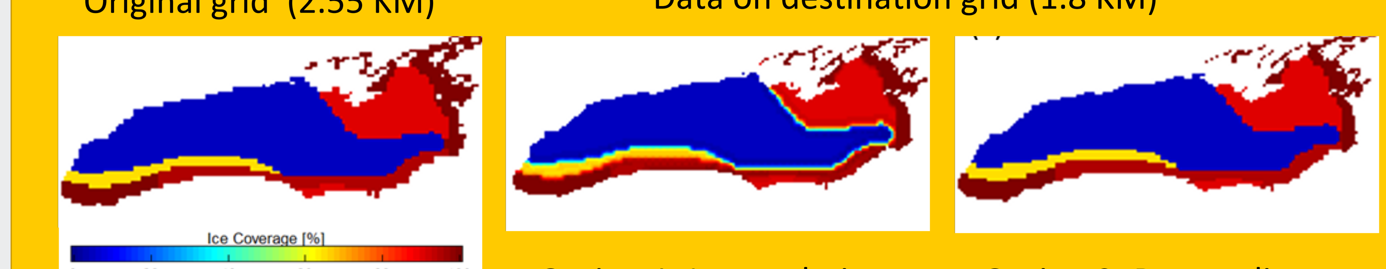
- ☑ Convert ice codes to fractional values (not shown)
- ☑ Linear interpolation in time
- ☑ Resample data to consistent spatial grid

Temporal interpolation:

1. Linearly interpolate between observed data
2. Categorize pixels into standard values [0,5,10,20,..., 80,90, 95, 100]

Spatial method comparison:

Original grid (2.55 KM) — Data on destination grid (1.8 KM)

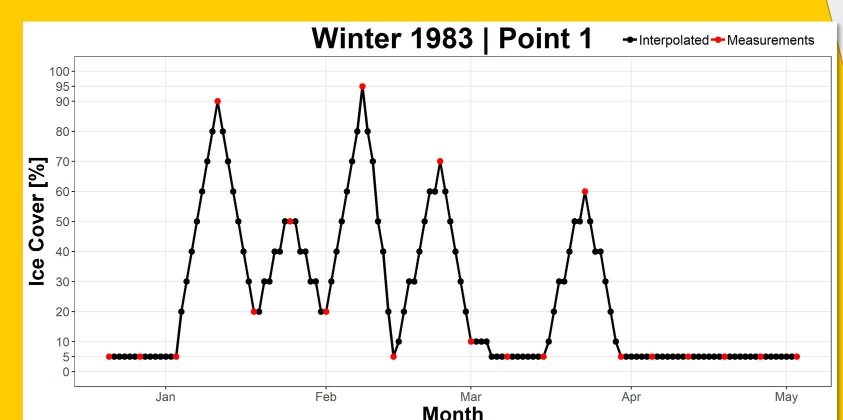


Option 1: Interpolation — Option 2: Resampling

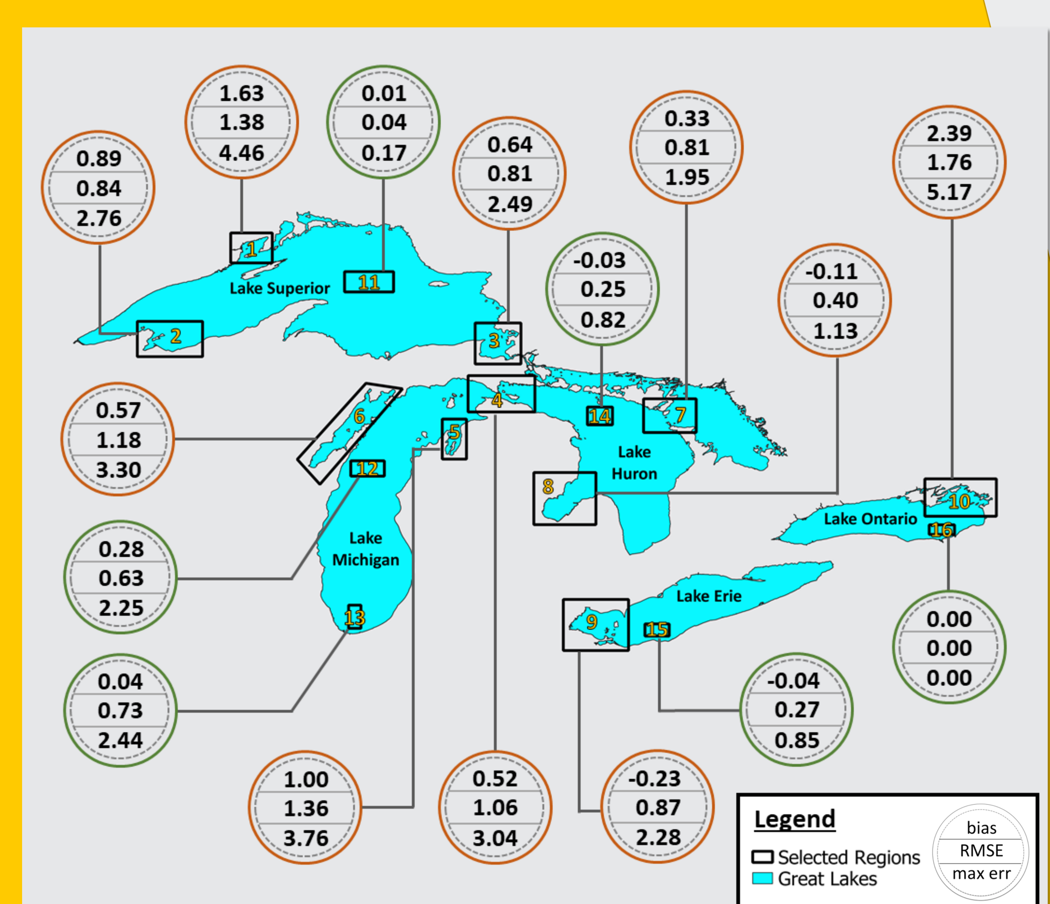
Interpolating the data (option 1) resulted in non-physical features such as artificial transition zones (yellow line) between landfast ice and open water. Therefore, a nearest neighbor resampling method (option 2) using R software was employed instead. Several other methods (not shown) were also evaluated.[1]

To quantify the performance of the various spatial methods, statistical analyses were conducted on a variety of sub regions including coastal, bay and off-shore areas.

### Validation




Temporal interpolation check at a single grid point. Interpolated values (black) are linearly interpolated between observed values (red) and then rounded to standard level.

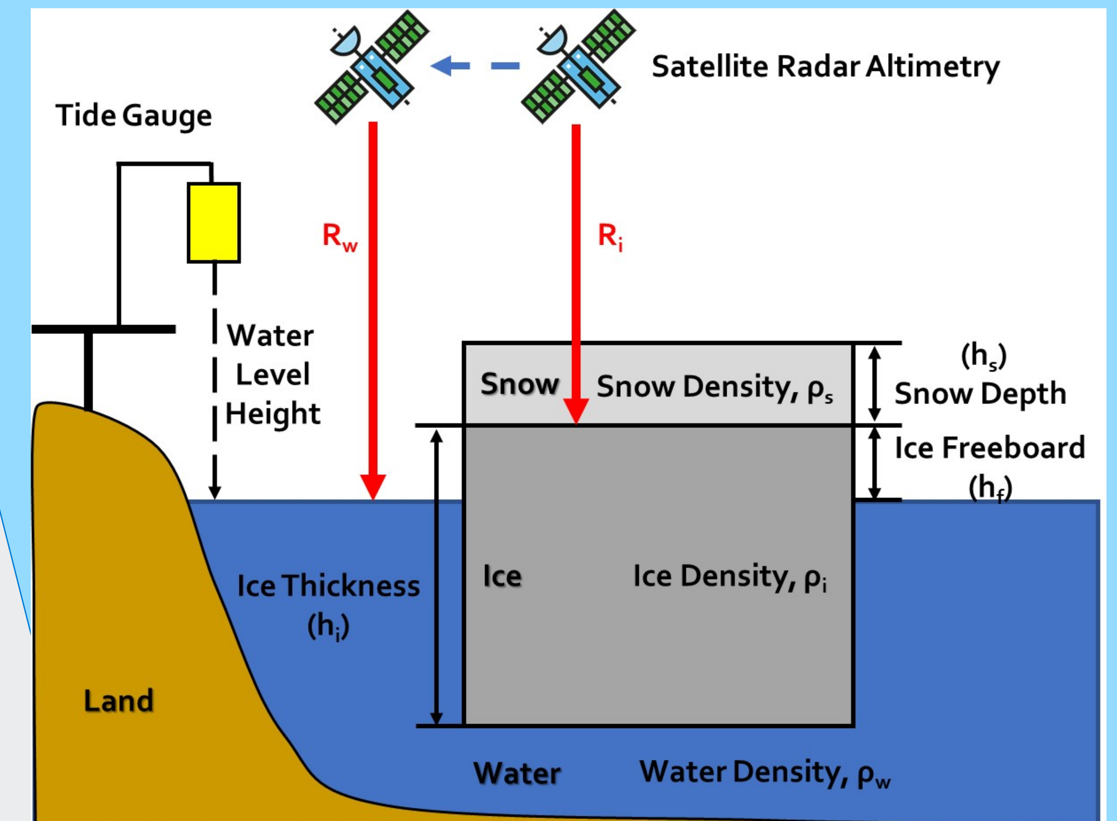



Sub-region validation for resampling method. The statistics describe the error between the original and resampled data in each subregion (units: % ice cover).

## Satellite Altimetry Lake Ice Thickness Retrieval

Ice thickness data is derived using ice freeboard approach using **Cryosat-2**[5] satellite radar altimetry

Case study: **Lake Superior, Jan – Apr 2014**

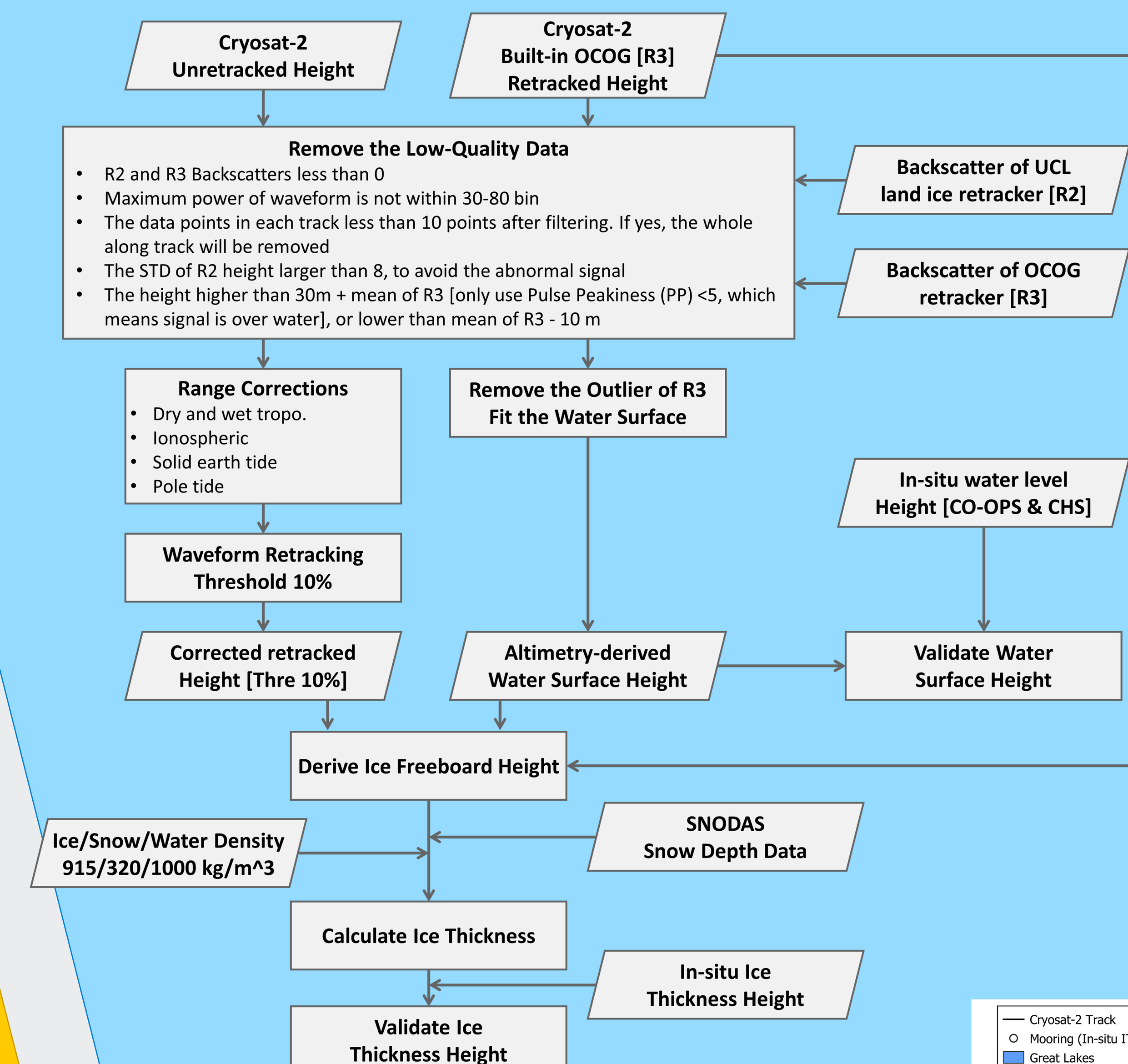


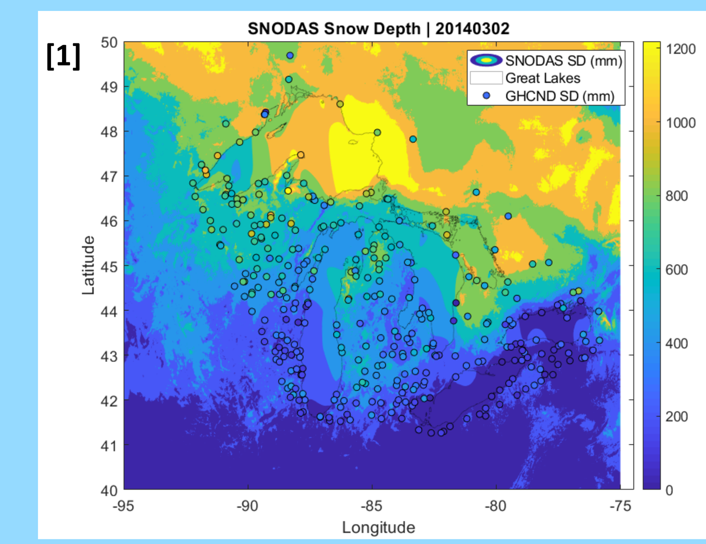

**Ice freeboard method** has been widely used to retrieve sea ice thickness changes in the polar region, however, not yet been commonly used in the Great Lakes. Here we demonstrate the retrieval using CryoSat-2 Low Resolution Mode (LRM) radar altimetry data, assuming that the lake ice is largely in **hydrostatic equilibrium**, and to calculate the lake ice thickness.[6]

$$h_f = R_w - R_i \quad (1)$$

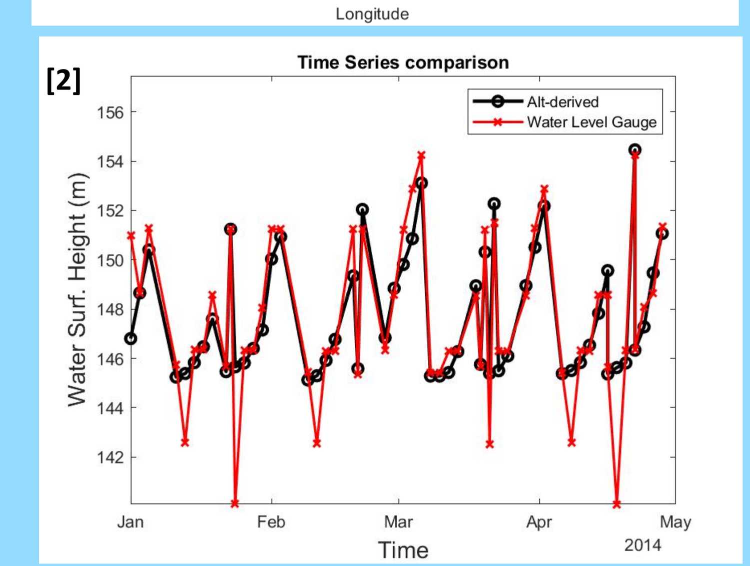
$$h_i = \frac{h_f \rho_w + h_s \rho_s}{\rho_w - \rho_i} \quad (2)$$

$R_w$/$R_i$: Altimetry range measurements over water and snow/ice surface
$h_f$: Ice freeboard height
$h_i$: Ice thickness
$h_s$: Snow depth
$\rho_i$/$\rho_w$/$\rho_s$: Ice/water/snow density

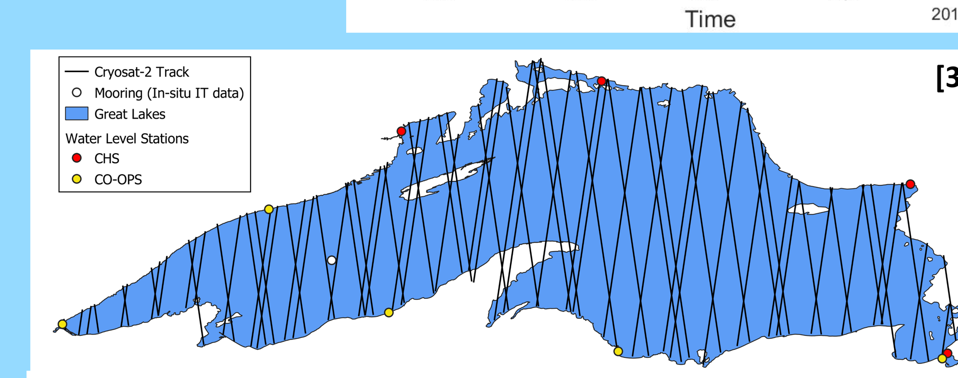


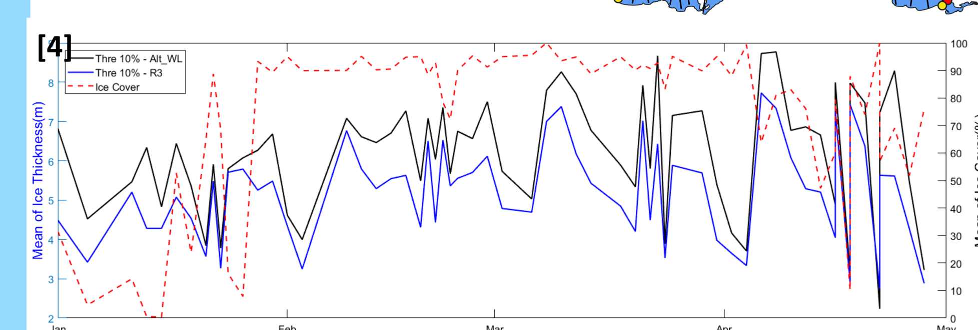

[1] Snow Data Assimilation System **(SNODAS)**[7] **Snow Depth Model Output** [1 km spatial resolution] compare with in-situ GHCN-D[8] snow depth data



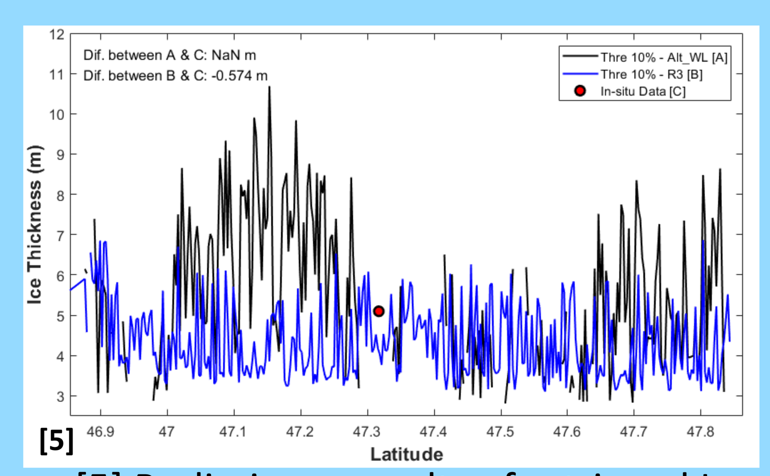

[2] Comparison between CryoSat-2 altimetry-derived water surface height and *in situ* (US CO-OPS[9] & Canada CHS[10]) water level gauge height timer series (referenced to WGS84 ellipsoid)




[3] Black lines are used Cryosa-2 ground tracks. Yellow dots are CO-OPS stations, red dots are CHS stations, and white dots are in-situ ice thickness station (mooring)[11]




[4] Preliminary results of the mean ice thickness and ice cover time series in Lake Superior during winter 2014




[5] Preliminary results of retrieved Ice thickness on 2014/02/19

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