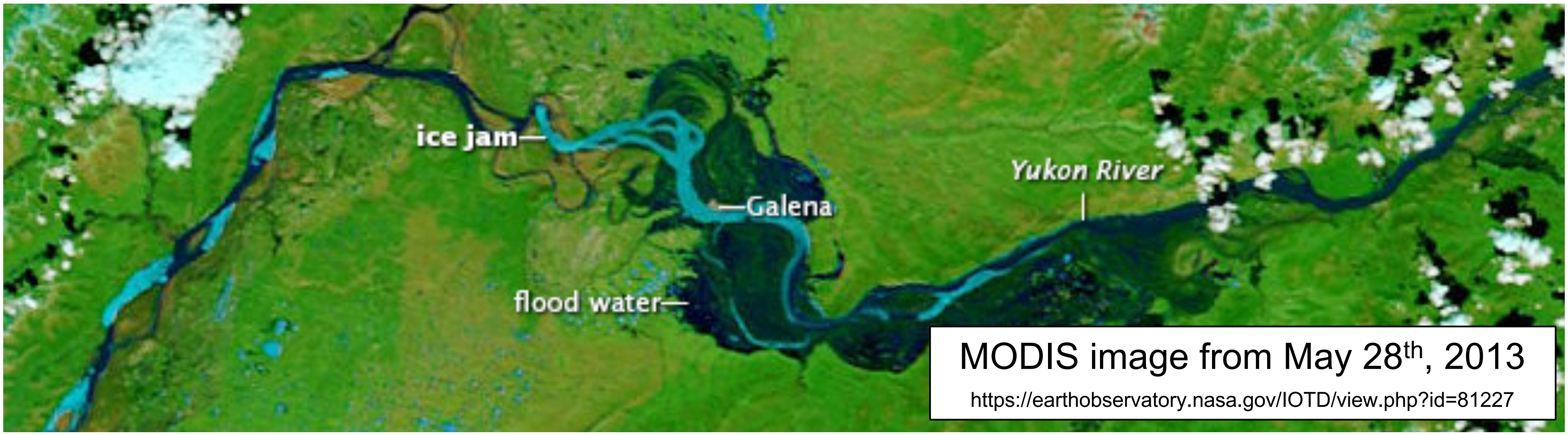
SWOT Ice Flagging: Current Status and Options



MODIS image from May 28th, 2013
https://earthobservatory.nasa.gov/IOTD/view.php?id=81227

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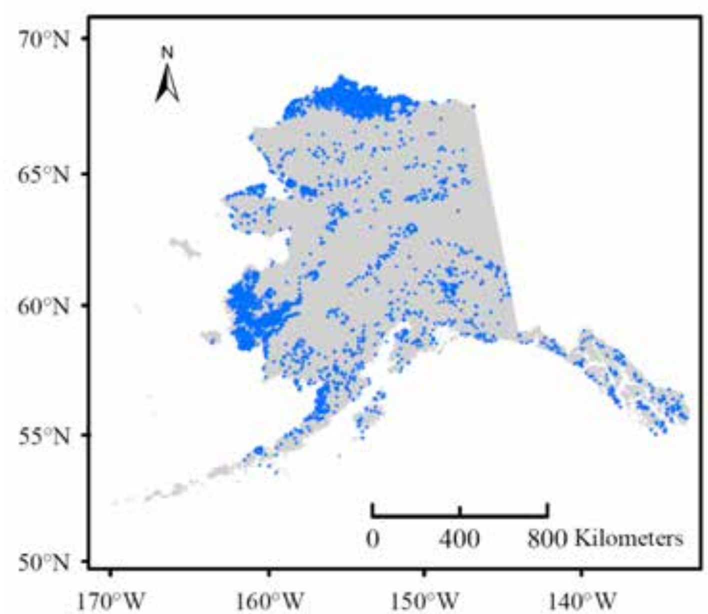
The Challenge of Global Ice Flagging for SWOT

- SWOT phenomenology over ice remains uncertain, so direct ice flagging from SWOT is not a viable option
  - Snow vs. ice
  - Meltwater on ice
  - Ice roughness
  - Snow wetness
- SWOT Science requirement: "**SWOT shall provide flagging of frozen surface water in both the pass-by-pass and global data, with 68% accuracy of the frozen water flag**"
  - Depending on how this requirement is interpreted, it is not challenging to meet.
  - Just meeting this requirement would be suboptimal for science.
- What are our options for ice flagging in the absence of direct SWOT observations?

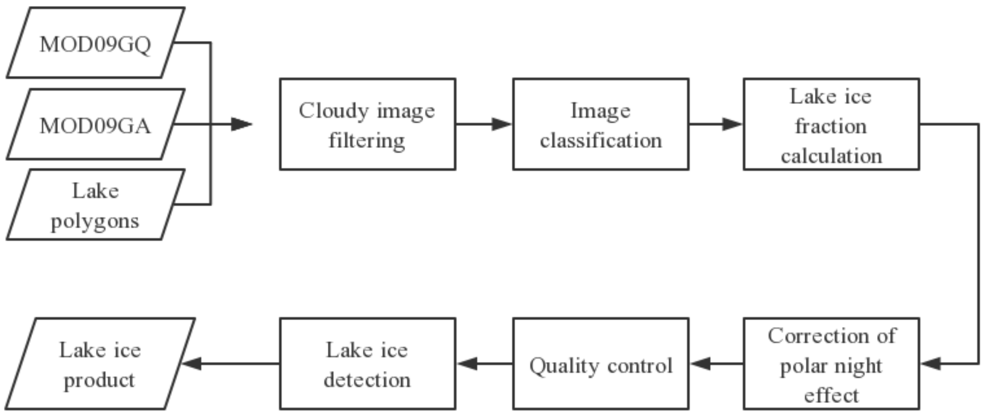
Options for SWOT Ice Flagging

- Directly compute ice extent based on MODIS/VIIRS data.
- Use a climatology of ice fraction on each day for each lake.
- Use a simple model based on temperature to infer ice cover.
- Use climatology or simple model to compute ice flag in initial product, then replace with calculated ice flag during reprocessing.

Measuring Lake Ice Directly from MODIS or VIIRS

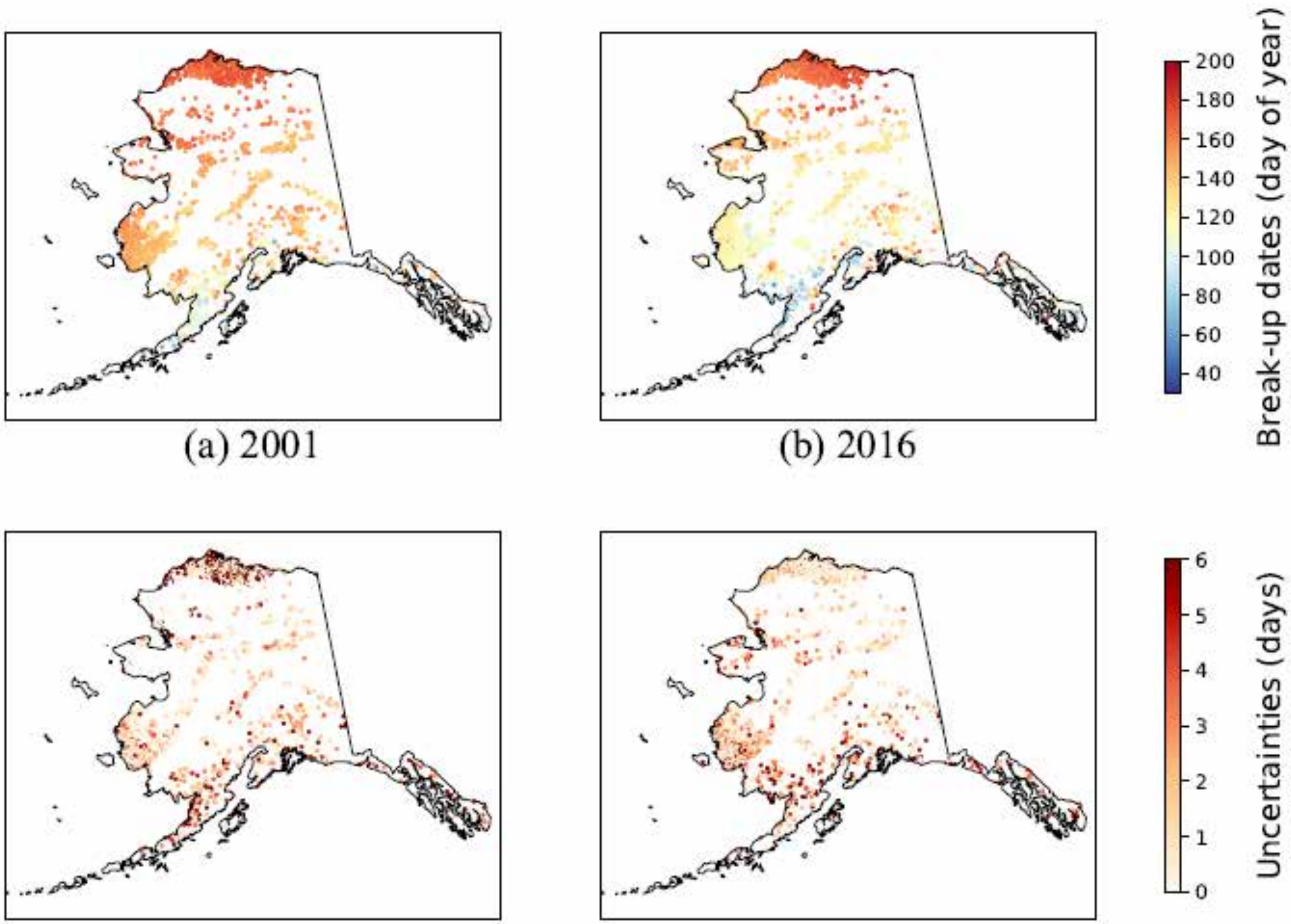


Selected lakes in this study



Flowchart of the algorithm

- Lakes with area larger than 1 km² in Alaska are selected.
- The total number of selected lakes is 4241.
- Study period is from 2000 to 2016.
- For SWOT Processing, MODIS can be replaced by VIIRS



(a) 2001 (b) 2016

(c) 2001 (d) 2016

Using MODIS data, we can calculate both the date of breakup (or freezeup) and the uncertainty in breakup timing.

Most of the uncertainty is due to cloudy conditions.

Validation results based on comparison with Landsat

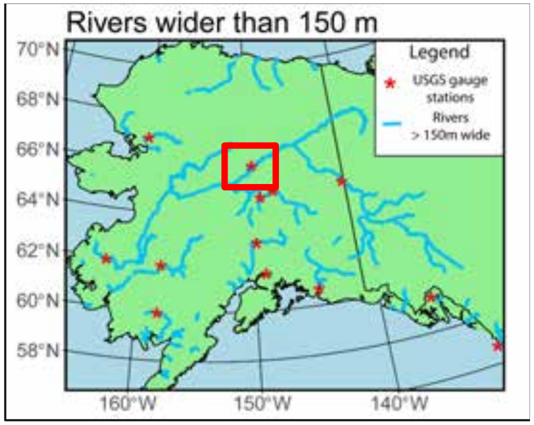
- For each lake, we calculated the fractional ice cover in each clear-sky MODIS image. We then calculated a binary ice flag, using a threshold of 20% ice cover.
- In the absence of in situ measurements, we validated against measurements from all clear-sky Landsat imagery available over Alaska.

Lake area (km^2)	MAE (%)	Percentage of incorrect days (%)
1 ~ 2	3.0	2.3
2 ~ 4	2.8	1.9
4 ~ 5	3.1	1.9
5 ~ 6	3.2	2.3
> 6	2.9	2.2

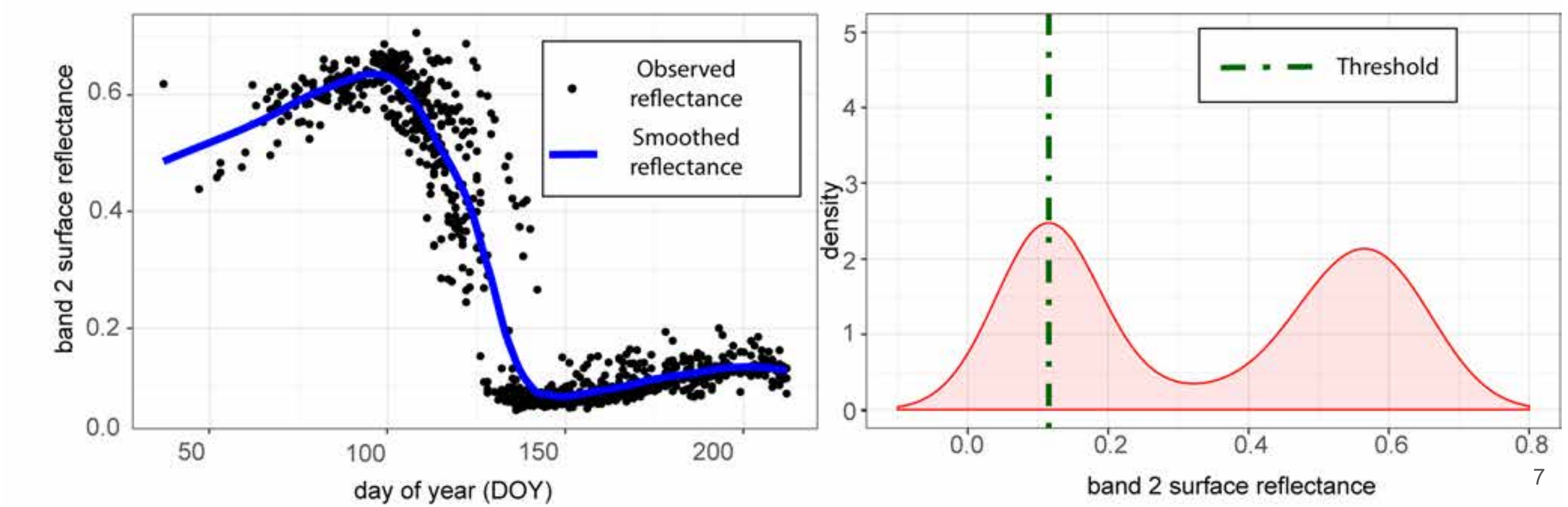
MAE: Mean absolute values of difference between MODIS ice fraction and Landsat ice fraction during the entire study period.
Incorrect day: Each day is classified into an ice day or non-ice day depending on the fraction of ice coverage. If MODIS result is not consistent with Landsat, we consider it as an incorrect day.

Measuring River Ice Directly from MODIS or VIIRS

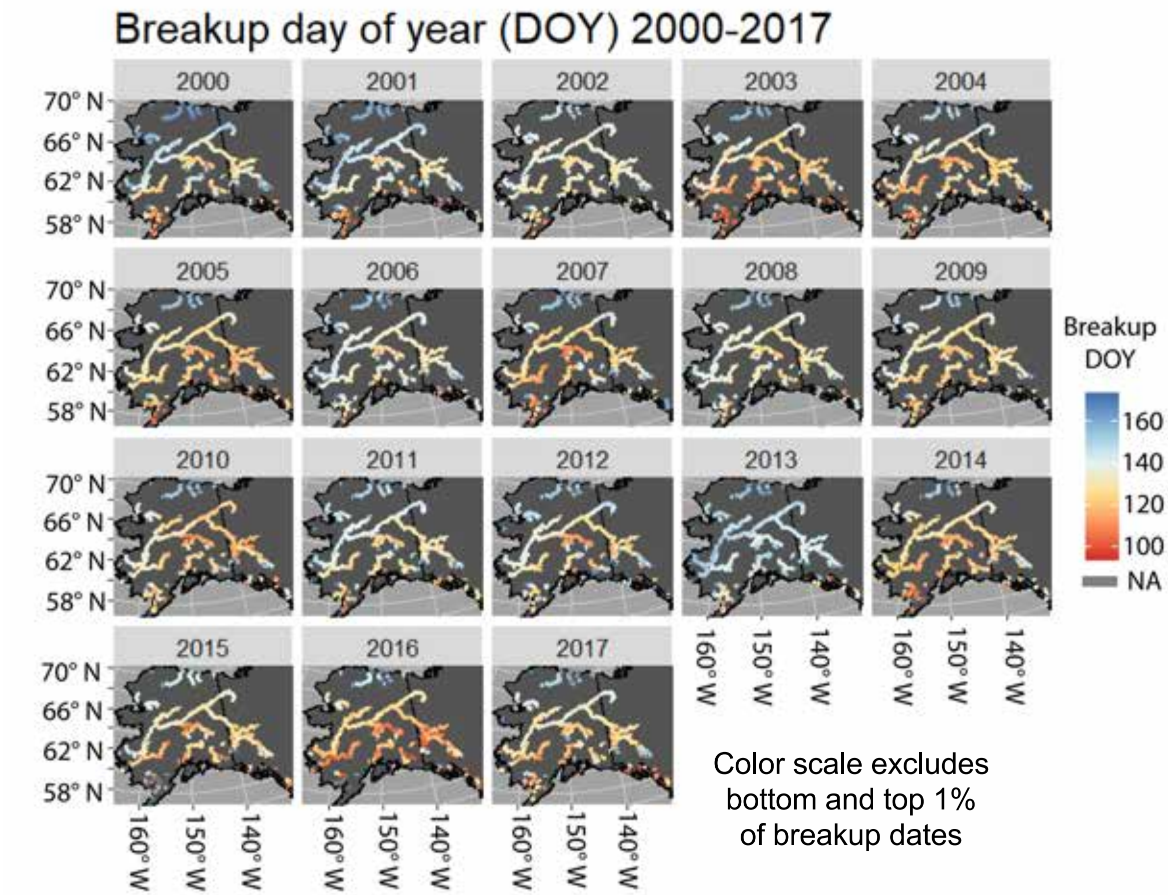
- Measure average reflectance within water pixels for a river reach in each image across all years.
- Smooth resulting time series of reflectance values
- Determine threshold value for ice free conditions
- Identify first date in each year when smoothed reflectance is below this value
- Slightly different method from lakes because rivers are often narrower than 2 MODIS pixels.



Average daily surface reflectance timeseries and density plot (2000-2017)

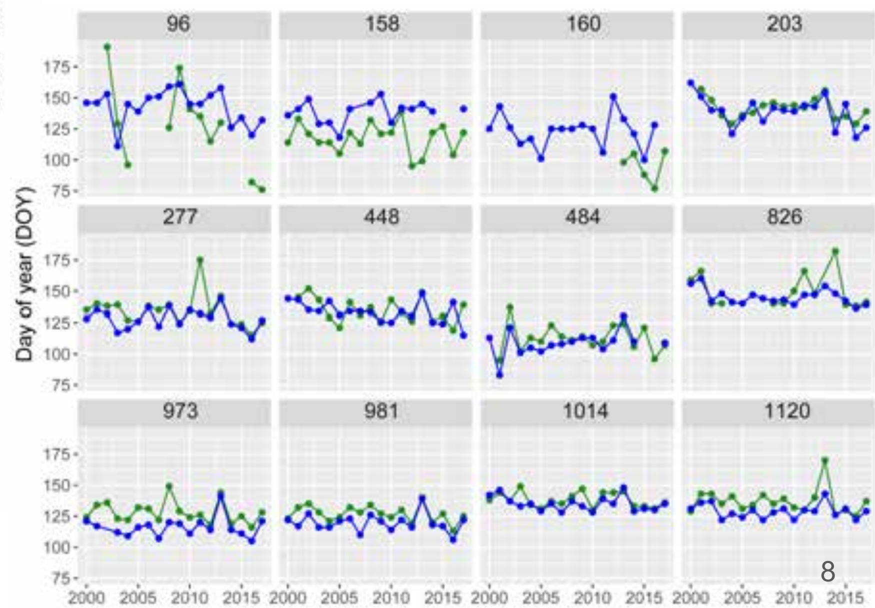


Using reflectance thresholds, we can map dates of ice breakup using time series of MODIS data.



Color scale excludes bottom and top 1% of breakup dates

Comparison against USGS gauges. Note that systematic differences may reflect differences in definition of breakup..



Options for SWOT Ice Flagging

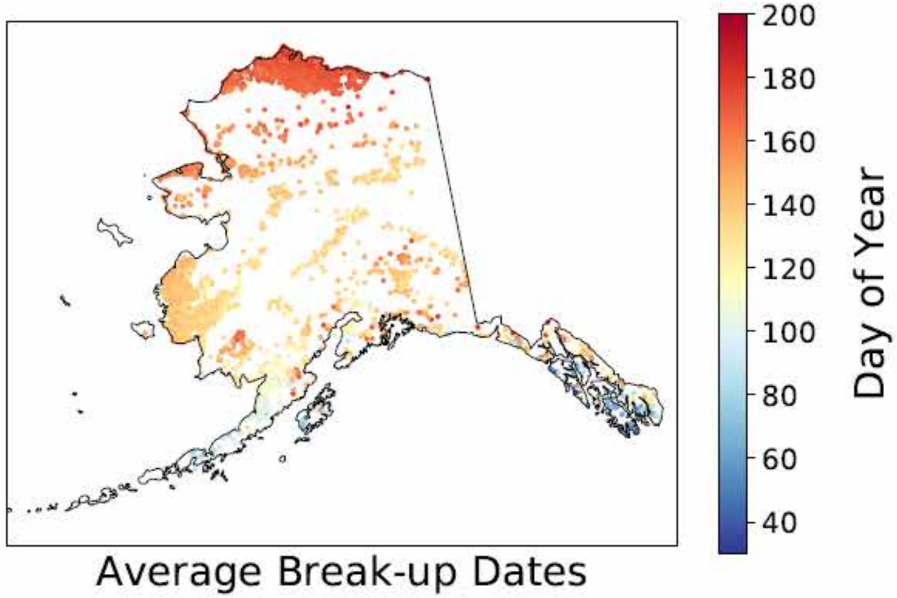
- Directly compute ice extent based on MODIS/VIIRS data.
  Advantages: High accuracy, captures spatial and temporal variability, makes no assumptions about stationarity.
  Disadvantages: Requires routine download and processing of satellite imagery for large parts of the northern hemisphere.

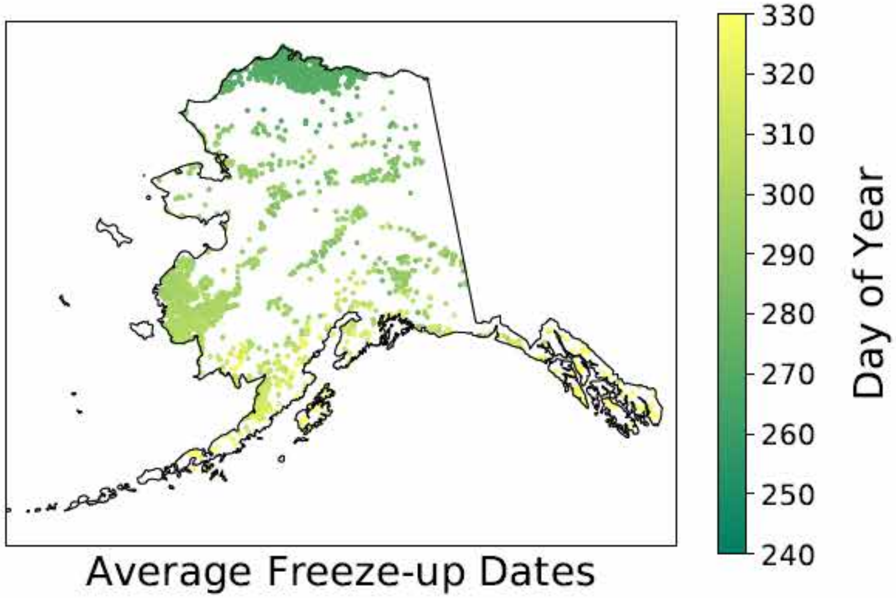
- Use a climatology of ice fraction on each day for each lake.

- Use a simple model based on temperature to infer ice cover.

- Use climatology or simple model to compute ice flag in initial product, then replace with calculated ice flag on reprocessing.

Breakup and Freezeup Climatology: Lakes

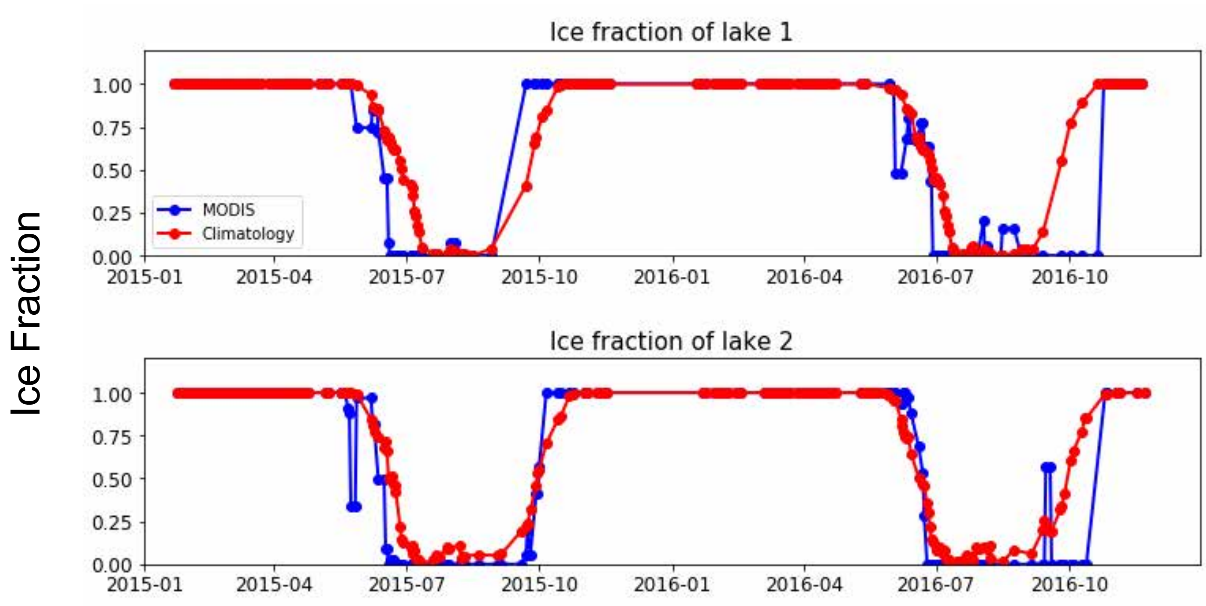




Using MODIS and/or VIIRS, we can use a time series to capture the average date of ice breakup for each lake. How accurately can we use climatology to produce an ice flag?

Comparison of Climatology vs. Direct MODIS Observation of Ice Fraction

- We created a climatology of lake ice fraction for each lake by averaging the MODIS ice fraction from 2000 to 2014
- We compared MODIS-based lake ice fraction with the climatology interpolation for 2015 - 2016 over >4000 lakes. Here we show two sample lakes:

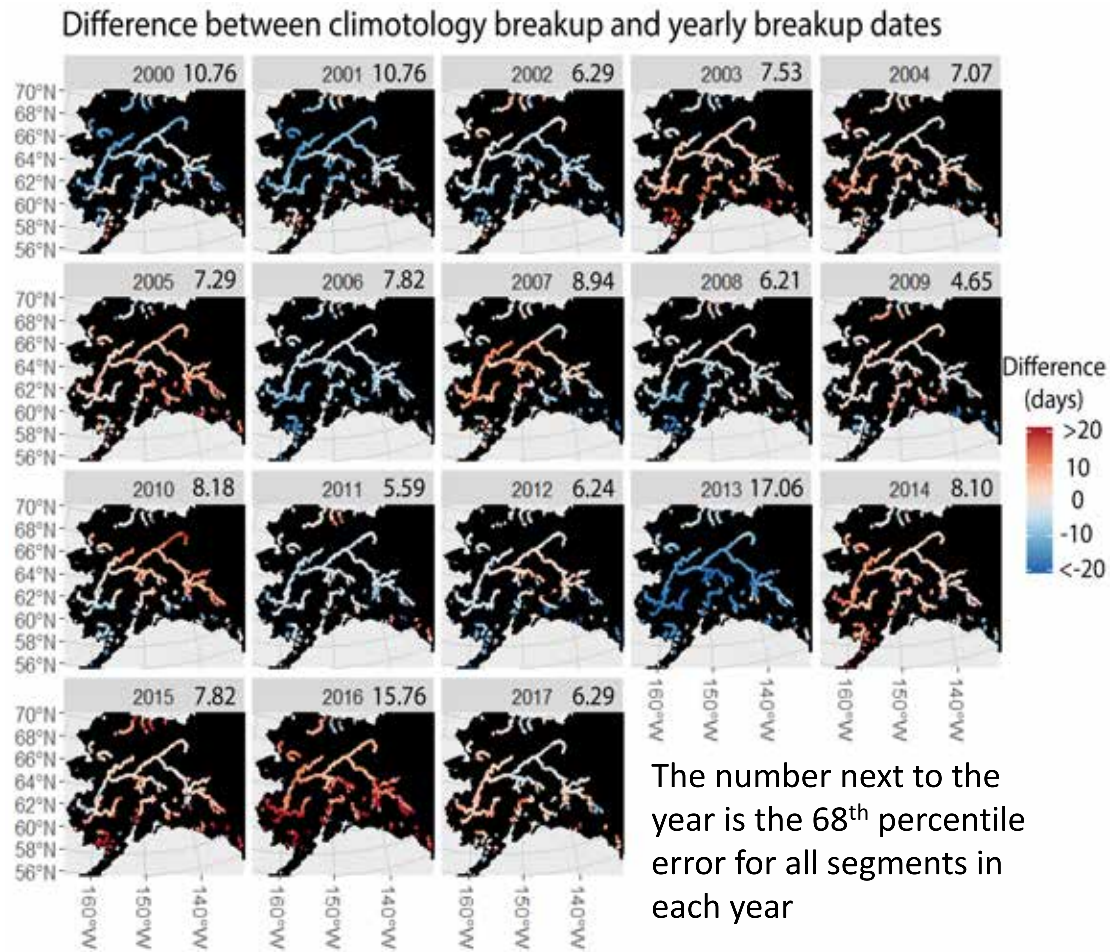


The difference of lake ice fraction between two approaches for all 4000+ lakes in Alaska

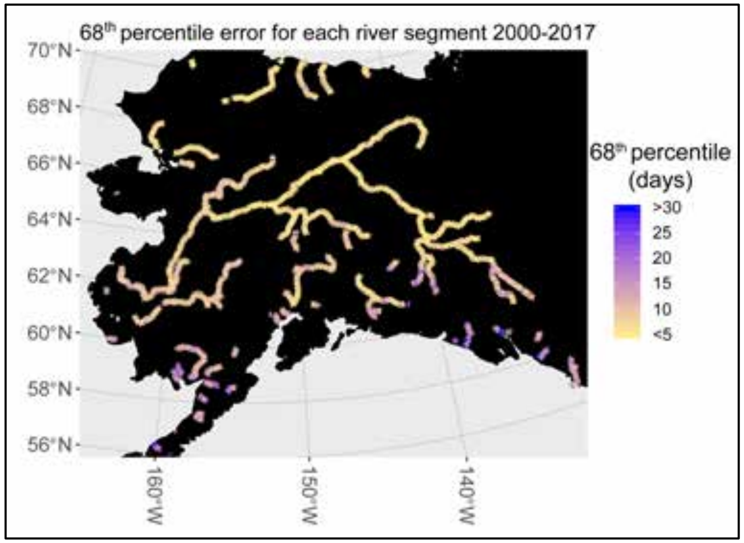
	Mean absolute difference of ice fractions	Percentage of days with incorrect ice flag
Entire period (2015 - 2016)	8.06%	10.51%
Transition periods	34.61%	52.48%

Transition periods: the periods when lake ice is forming and decaying

The average length of transition period is 70.92 days for each year



The number next to the year is the 68th percentile error for all segments in each year



Summary statistics (all segments, all years):

MAE: 7.38 days

RMSE: 10.01 days

68th percentile: 8.59 days

Takeaways:

- Climatology does not account for yearly variation in breakup dates (Figure, *right*)
- Climatology is less reliable in southern Alaska where rivers may or may not totally freeze in a given year (Figure, *top*)

Options for SWOT Ice Flagging

- Directly compute ice extent based on MODIS/VIIRS data.

- Use a climatology of ice fraction on each day for each lake.

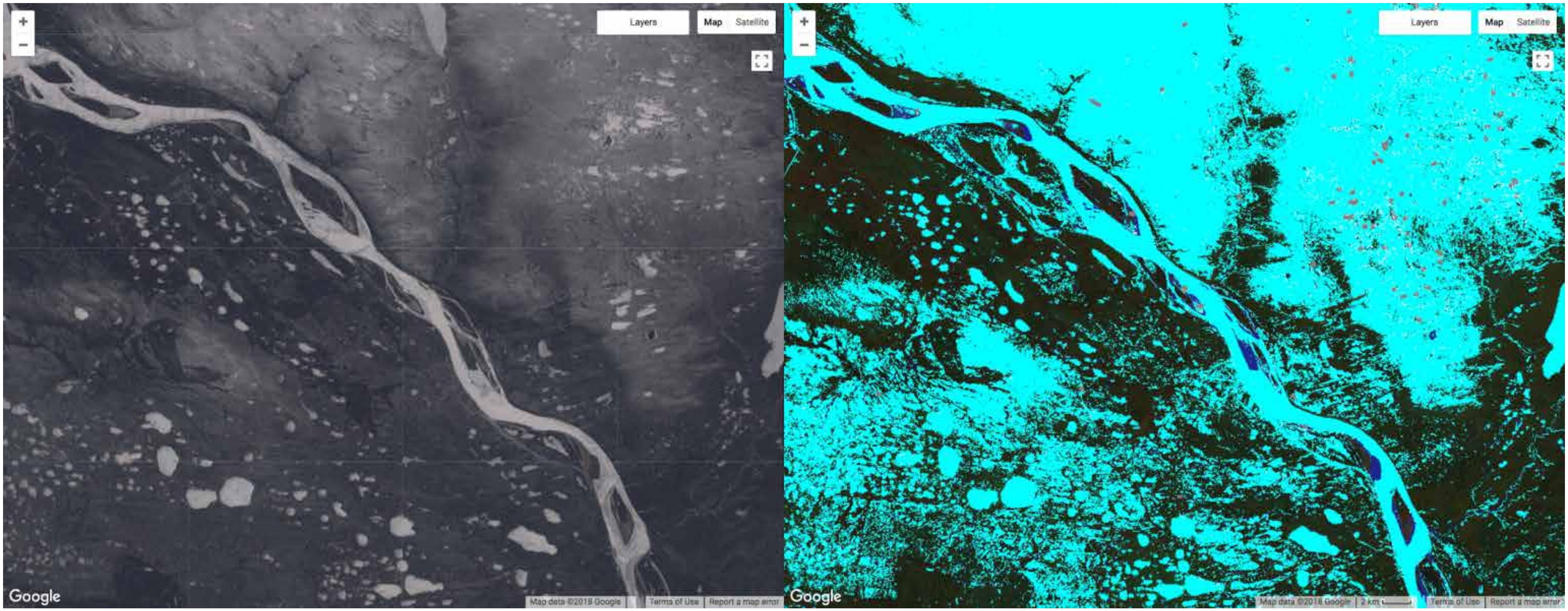
  Advantages: all processing done a priori, code required for flagging is very simple.

  Disadvantages: does not reflect interannual variability or nonstationarity. Particularly high uncertainty during scientifically important breakup period.

- Use a simple model based on temperature to infer ice cover.

- Use climatology or simple model to compute ice flag in initial product, then replace with calculated ice flag during reprocessing.

Fmask dataset shows snow/ice extent in Landsat 5/7/8 scenes

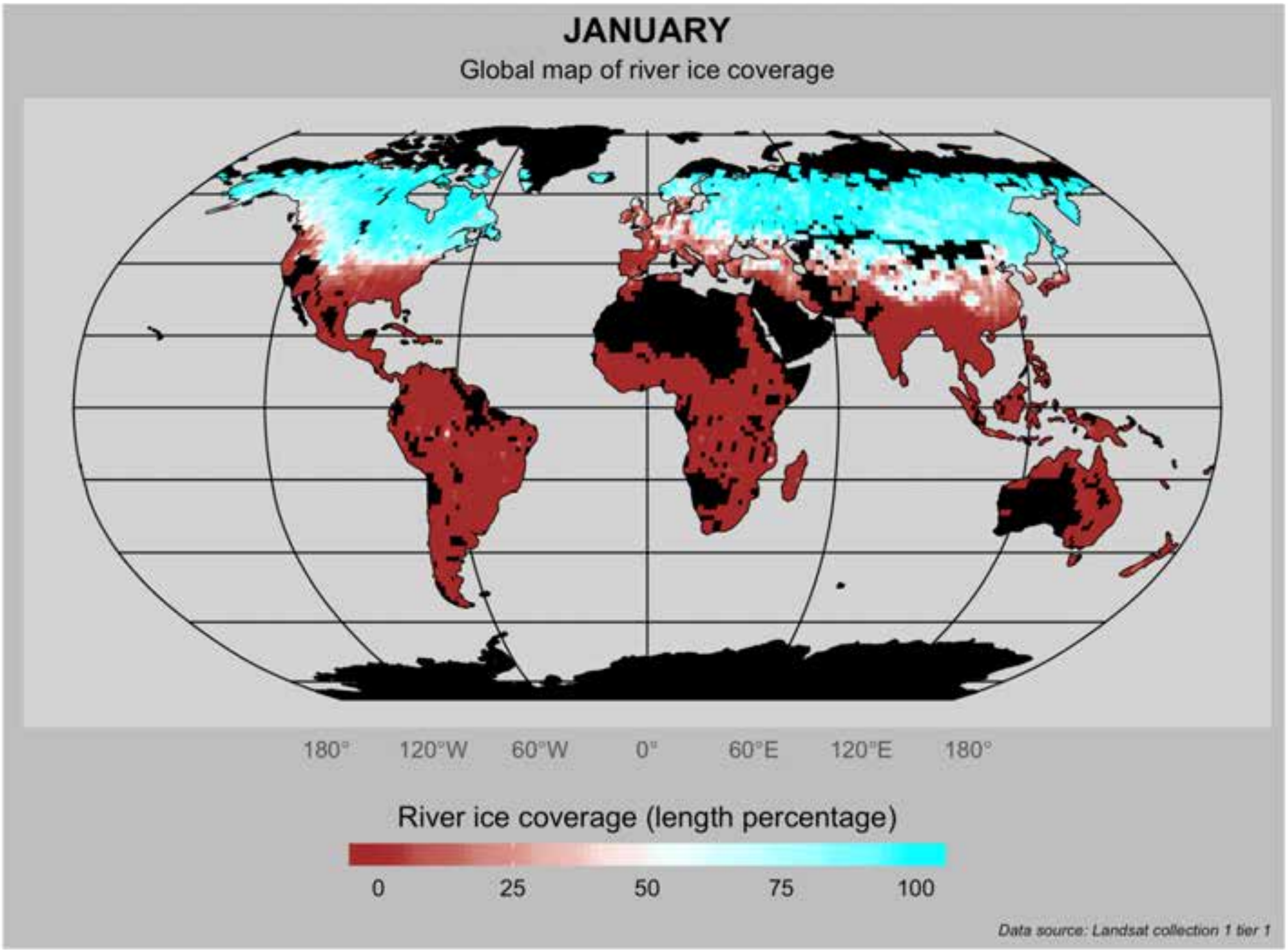


Mackenzie River north of Fort Good Hope

2018-05-09

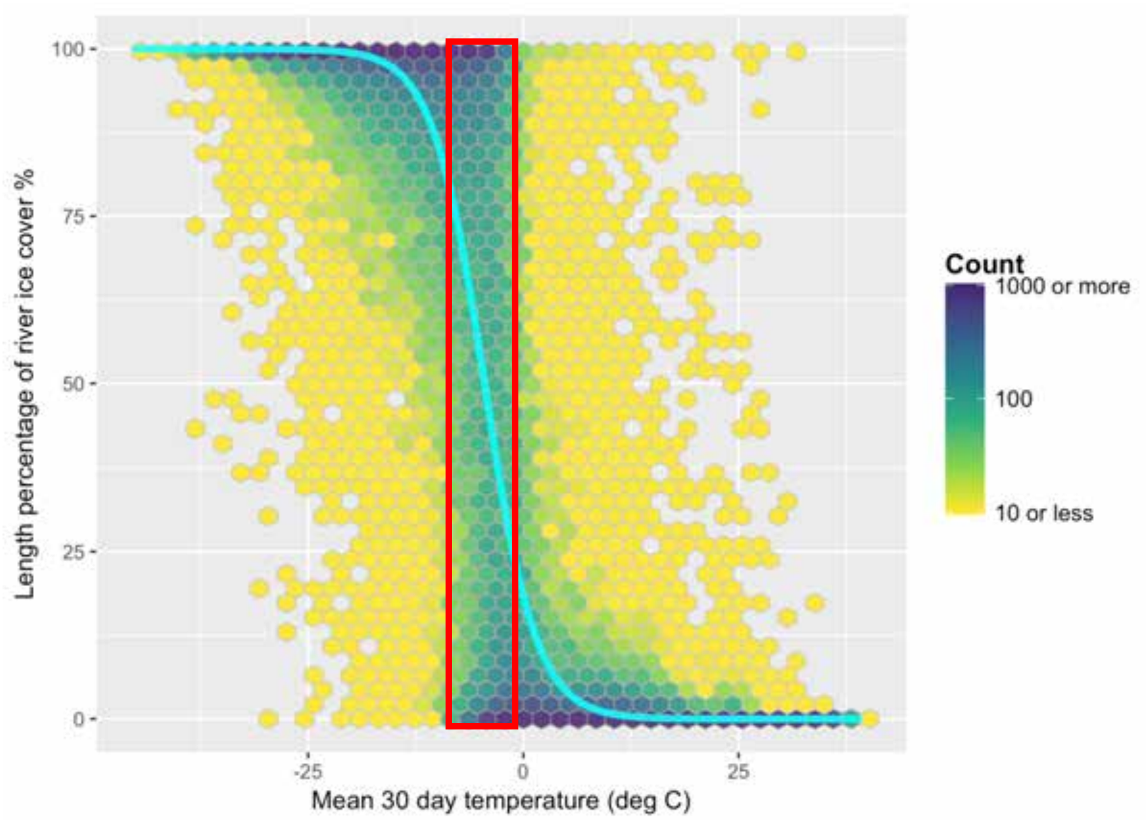
Current map center: (-128.9716, 66.2732)

Monthly mean river ice fraction



Using the full time series of Landsat and GRWL river centerlines, we calculated the distribution of river ice globally.

River ice fraction vs. 30 day mean air temperature



By combining river ice fraction data with global temperature reanalysis, we can develop temperature—ice cover rating curve.

This relationship could be used to infer ice cover based on a global temperature dataset.

Comparison to observations and climatology is ongoing.

Options for SWOT Ice Flagging

- Directly compute ice extent based on MODIS/VIIRS data.
- Use a climatology of ice fraction on each day for each lake.
- Use a simple model based on temperature to infer ice cover.

  Advantages: captures spatial and temporal variations in ice breakup, requires download of simple global temperature dataset.

  Disadvantages: may not be highly accurate during transition periods, still requires data download and processing.
- Use climatology or simple model to compute ice flag in initial product, then replace with calculated ice flag during reprocessing.

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- Directly compute ice extent based on MODIS/VIIRS data.
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No decision has been made yet about how best to proceed. The science team should provide input.