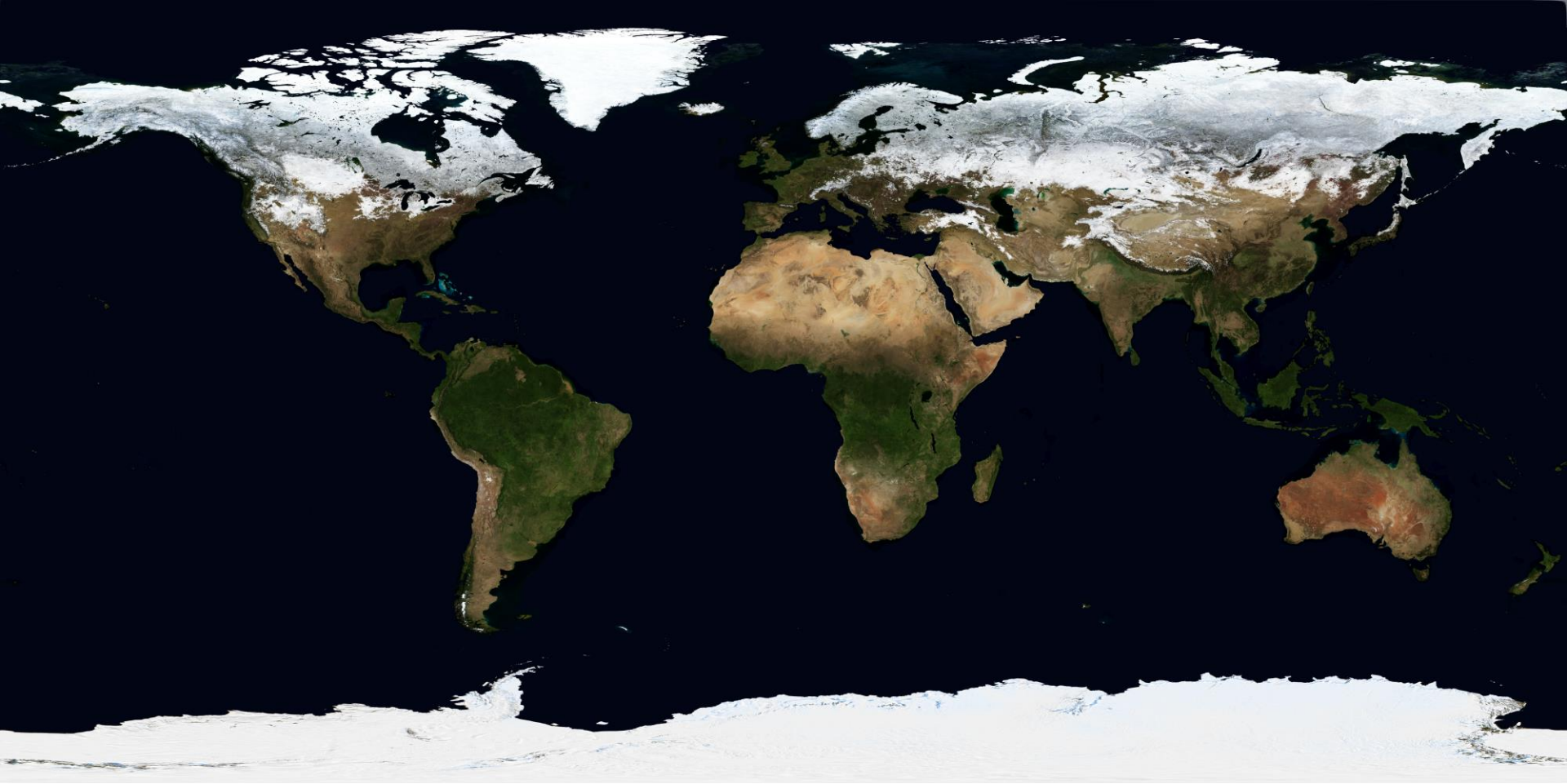
Monitoring Lake Ice Extent on hemispherical scale

Finnish Satellite Workshop and
Remote Sensing Days 2023

Heinilä K., Väkevä S., Metsämäki S., Luojus K. and Schwaizer, G.

Riku Lumiaro, SYKE



https://visibleearth.nasa.gov

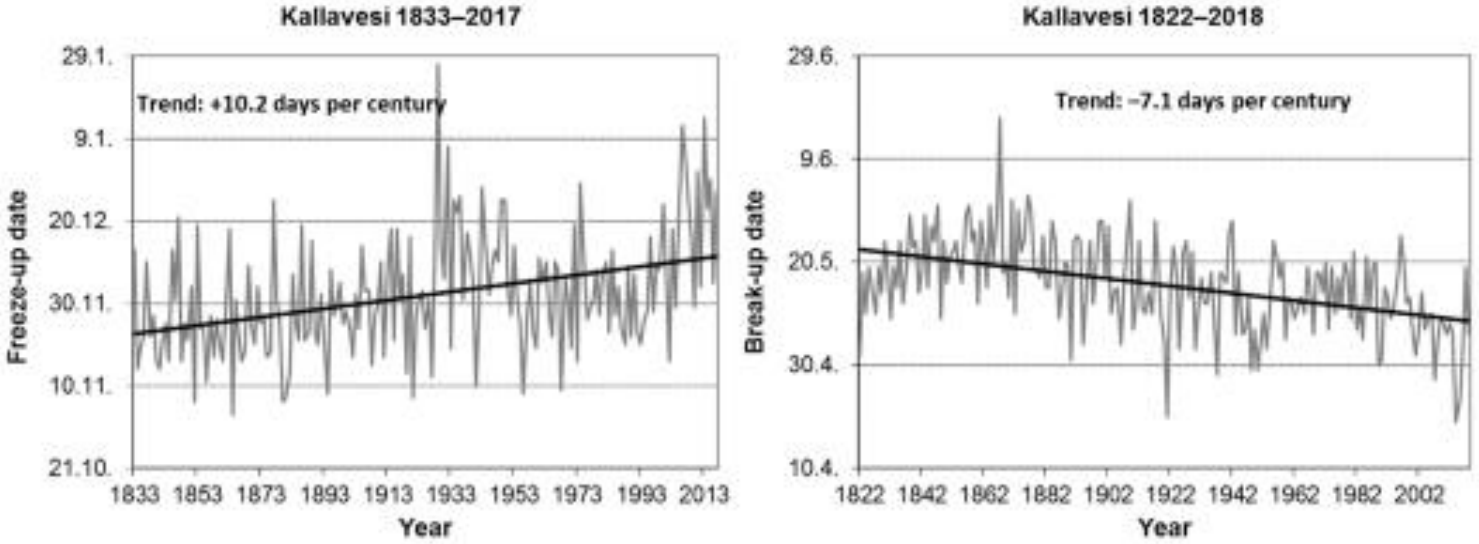
N
La

- S
- C
  c

➢ U
  h

In-situ time series

SYKE



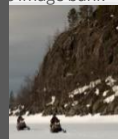
Korhonen, J. (2019). Long-term changes and variability of the winter and spring season hydrological regime in Finland. Report series in geophysics, No 79, https://helda.helsinki.fi/bitstream/handle/10138/298308/longterm.pdf?sequence=1&isAllowed=y

s image bank



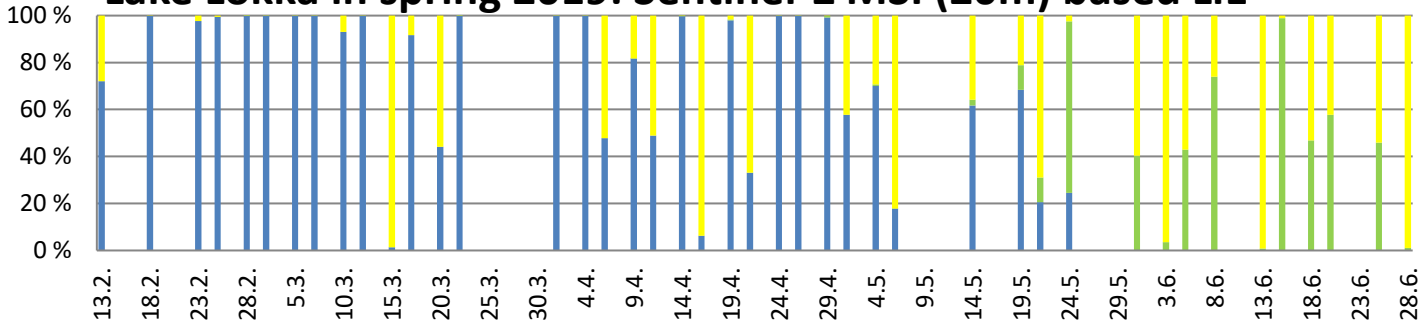




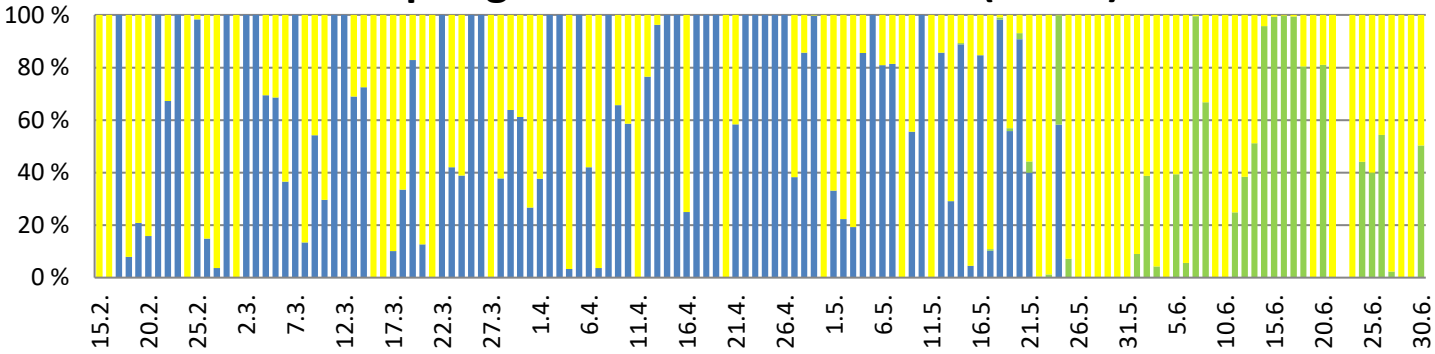


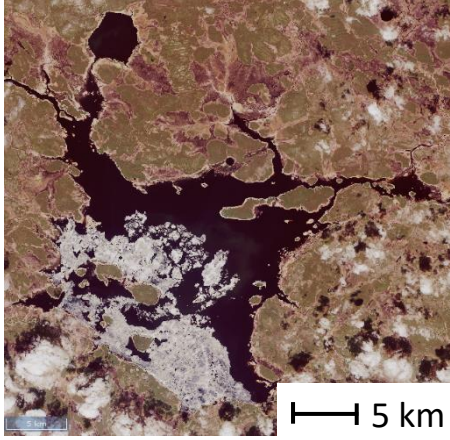
1 2 3 4 5 6 7

Lake Lokka in spring 2019: Sentinel-2 MSI (20m) based LIE



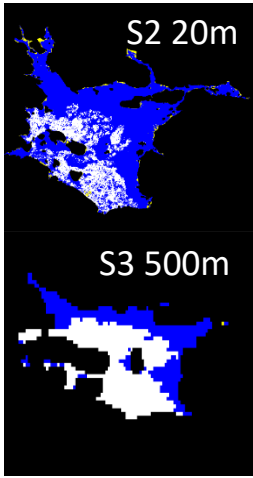
Lake Lokka in spring 2019: Sentinel-3 SLSTR (500m) based LIE





Lake Lokka reservoir on 24 May 2019 S2, MSI RGB image

cloud
water
ice

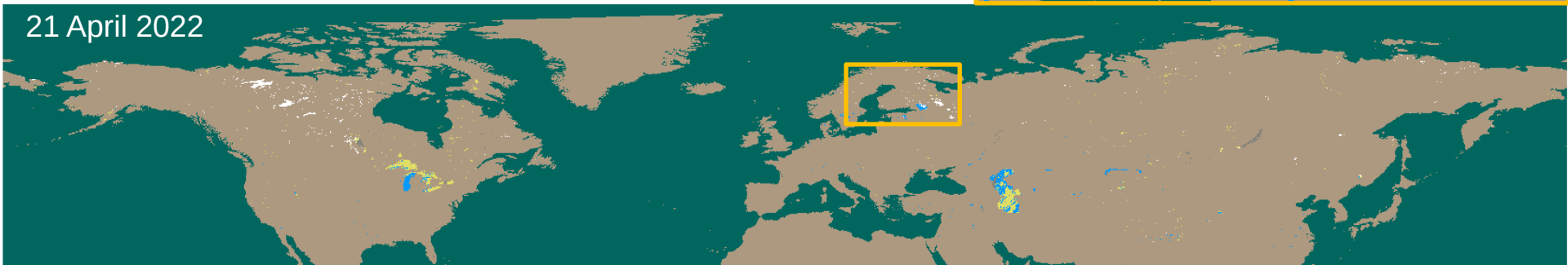


- Satellites with high spatial resolution often have longer revisit times
  - Ice breakup and freeze-up are typically fast phenomena and clouds hamper data frequency even further

Northern Hemisphere Lake Ice Extent (LIE-NH)

- SYKE is the LIE service provider in CGLS
  - Processing together with FMI and ENVEO
- Based on the *ICEmod* method developed at SYKE
- The main advantages of the *ICEmod*:
  - Inclusion of simultaneous cloud detection
  - Simplicity of processing
  - Easy transition between different satellite sensors

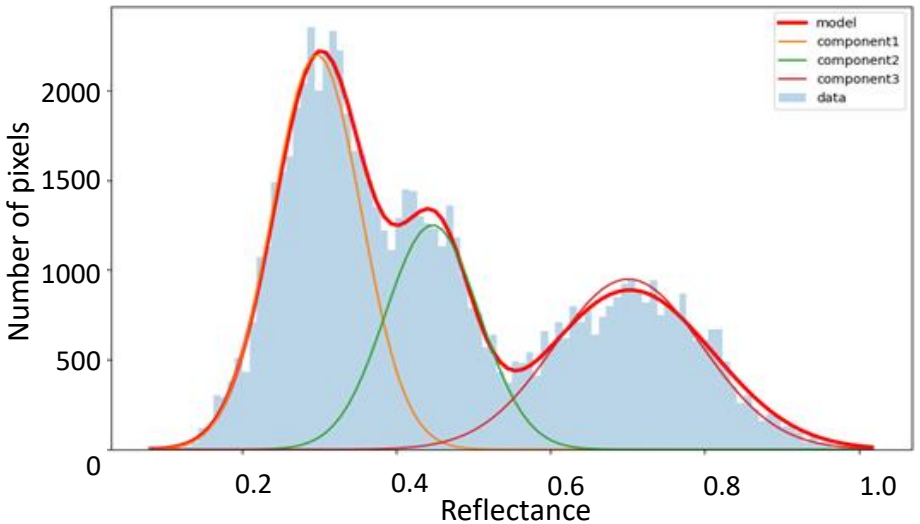
NoData
Ice
Water
Sea area
Cloud
Land



Icemod -method

- Based on Gaussian Mixture Model (GMM) distributions of several reflectance/thermal bands and indices derived from S3-SLSTR data

- Characteristics of the new method:
  - Use of several bands and band relations
    - *Increased separation ability*
    - *Reduced effect of varying illumination*
  - Use of fitted probability distributions
    - *Determine statistical probability for the estimate*
  - Use of thermal bands
    - *Diminish effects of water properties (algae, turbidity)*

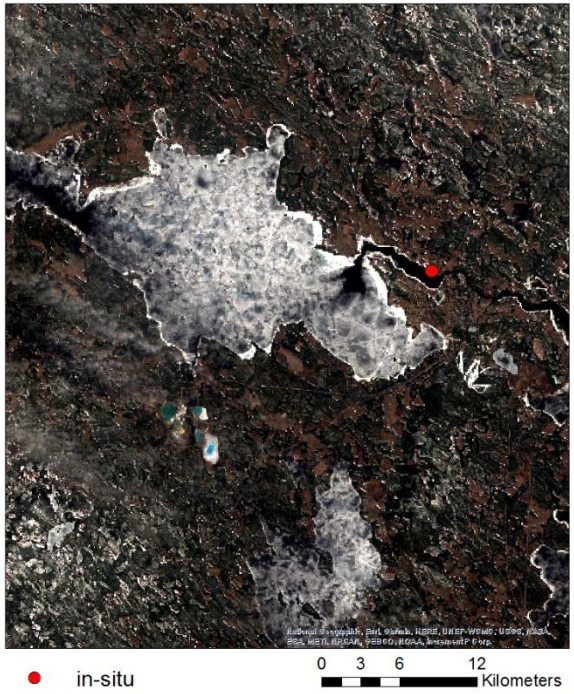


For clarity only three components are used in figure. In LIE-NH the initial number of classes (fitted distributions) is 21 and the number of dimensions is 8: SLSTR channels 1, 2, 5, 6, 8 and 9 and two indices NDSI and NDWI.

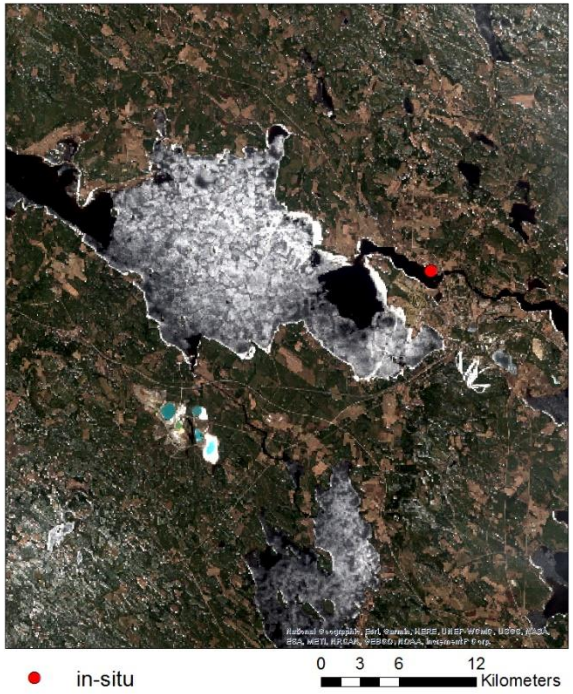
Heinilä, K., Mattila, O.-P., Metsämäki, S., Väkevä, S., Luojus, K., Schwaizer, G. & Koponen, S. (2021).
A novel method for detecting lake ice cover using optical satellite data. International Journal of Applied Earth Observation and Geoinformation. 104. 102566. DOI:10.1016/j.jag.2021.102566.

Validation: Based on high resolution satellite data

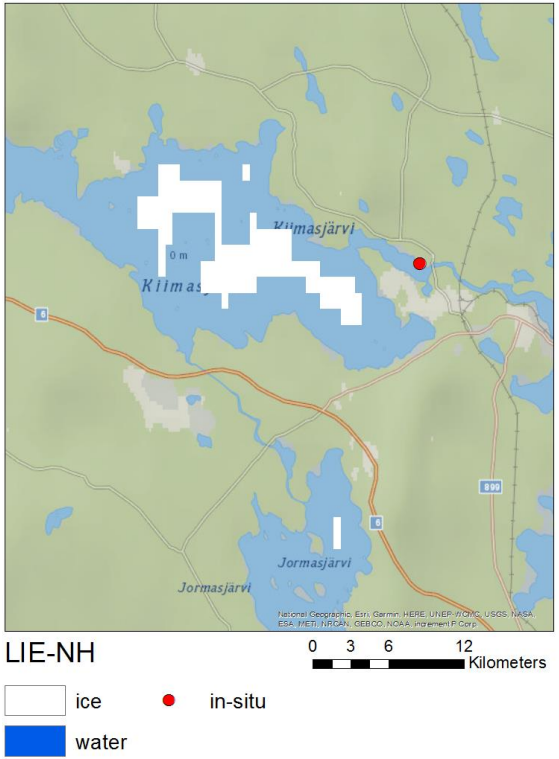
- In-situ observation ” The whole horizon is ice-free” in Nuasjärvi, Finland, on 26 April 2019



S2 MSI image on 25 April 2019



S2 MSI image on 28 April 2019



Current validation: Based on Sentinel-2 MSI data

Over 1700 cloud-free or almost cloud-free S2 MSI images were selected between 16 January 2020 and 31 May 2022

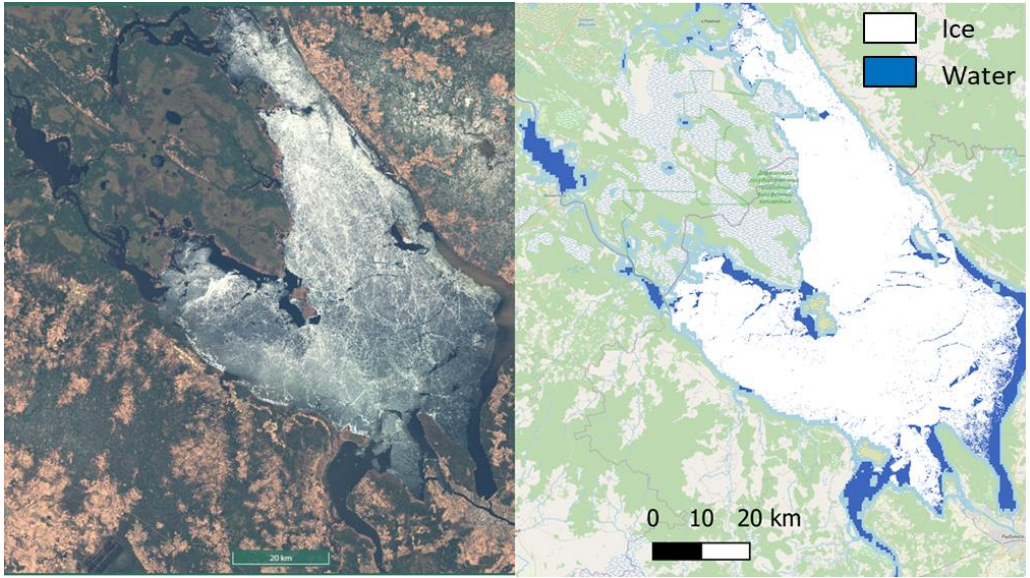
- Cover all seasons from 45 different lakes
  - 15 lakes from each continent (Europe, Asia, and North America)
- The product performance and accuracy throughout the year can be assessed quite reliably
  - However, polar darkness for the northernmost lakes reduces the validation data during the late-autumn and mid-winter

All seasons included

SYKE

Preparation of S2 MSI-based reference data

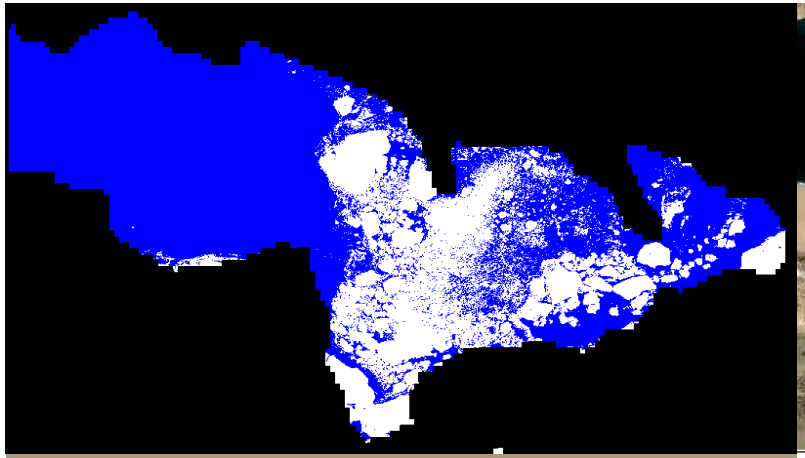
- A simple tree-decision model was created by using extensive and well-prepared training data to classify S2 MSI pixel as either water or ice
  - Training data included over 38 million classified ice or water pixel
- The model was encoded to Sentinel hub
- The processed S2 MSI -based LIE products were afterwards quality checked

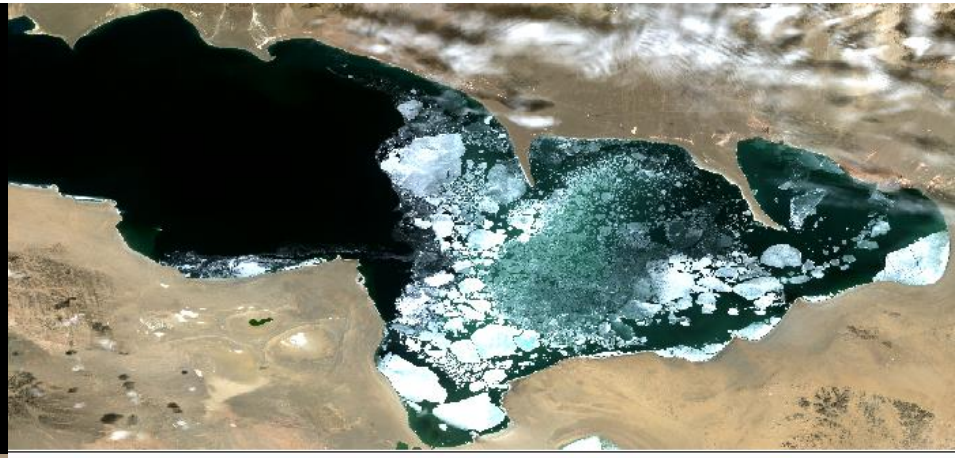


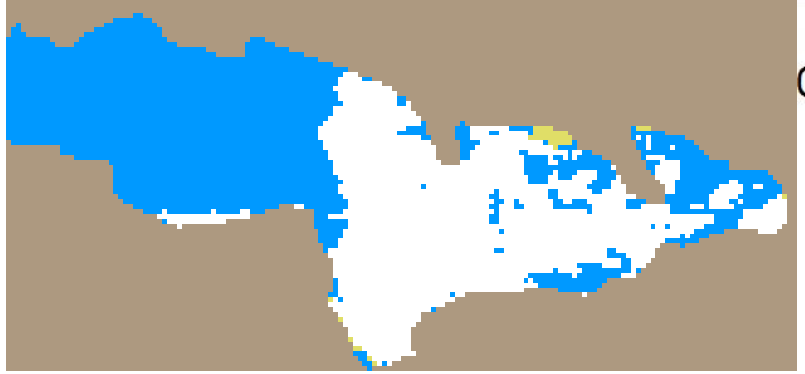
Example of the automatically generated 20m resolution S2 MSI-based LIE reference product from Rybinsk reservoir on 19 April 2021

SYKE

Challenges in preparation of S2-based reference data for validation







Lake Hyargas Nuur in Mongolia on 23 April 2019

How to create high resolution lake ice extent maps – ice or open water?

Resampled high resolution data was classified as open water if <50% of the pixels were ice covered

- This shows up as “false” ice commissions and omissions in the validation results

Validation results

- Recall 98.9%
  - Percentage of correctly classified ice out of all true ice pixels
- False alarm rate 0.6%
  - Falsely classified ice out of all open water pixels
- Precision 99.7%
  - Percentage of correctly classified ice out of all classified ice pixels
- F-Score 99.3%
  - The weighted harmonic mean of the precision and recall

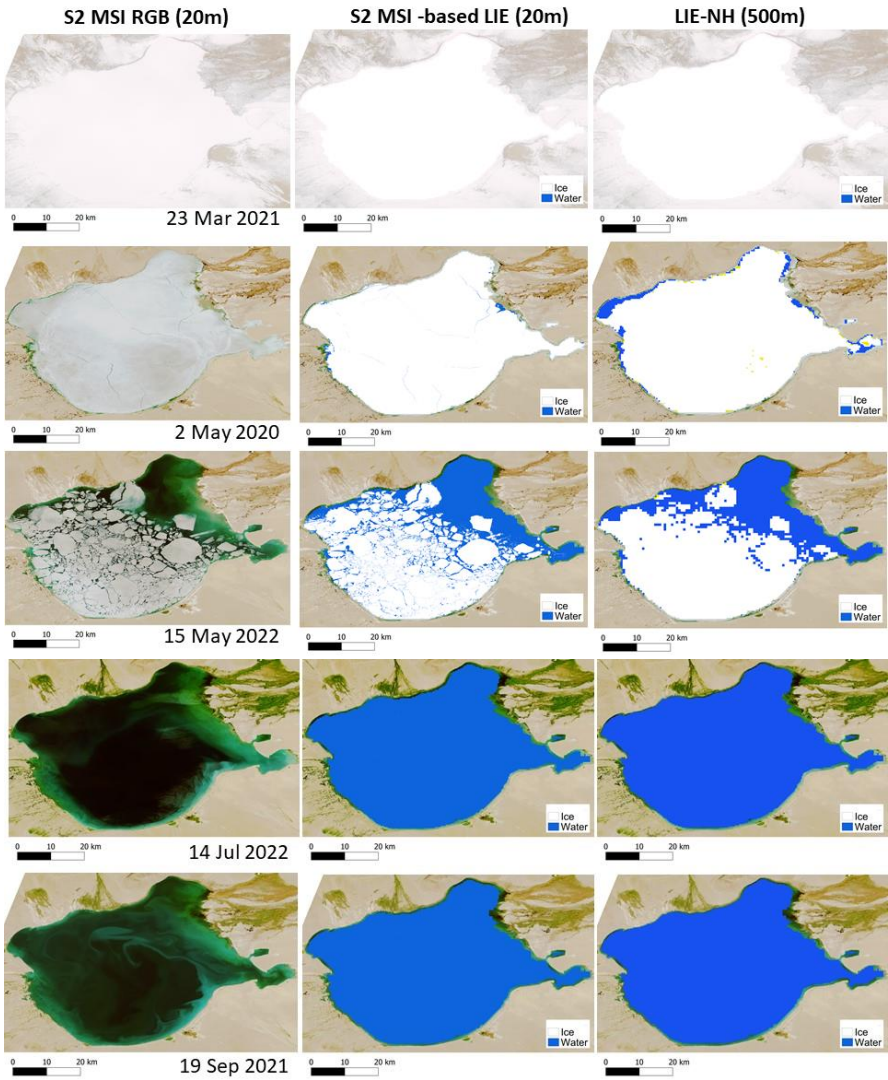
➢ Almost all the inaccuracies were found during the low light conditions in late autumn and mid-winter (Nov, Dec, Jan) and for the complex case lakes i.e. including both open and ice-covered pixels

	LIE-NH 500m		
S2-LIE	No ice	Ice	N cases
No Ice	383144 (TN)	23488 (FP)	3854928
Ice	75697 (FN)	665115 (TP)	6726850
N cases	3907137	6674641	10581778

➢The total number of validated cloud-free LIE-NH 500m resolution lake pixels was over 10 million

Pros and cons

- Recognizes dark ice well
- When the ice is very dark with water on it, ice is not identified
  - However, all true 500m ice pixels incorrectly classified as water included some 20m open water pixels
- The commission error is affected by the applied threshold for ice classification (50% in reference data)
  - ➢ Even rather small pieces of white ice within a 500 m pixel may increase the visible reflectance and the pixel is classified as ice, see Uvs Lake on 15 May 2022



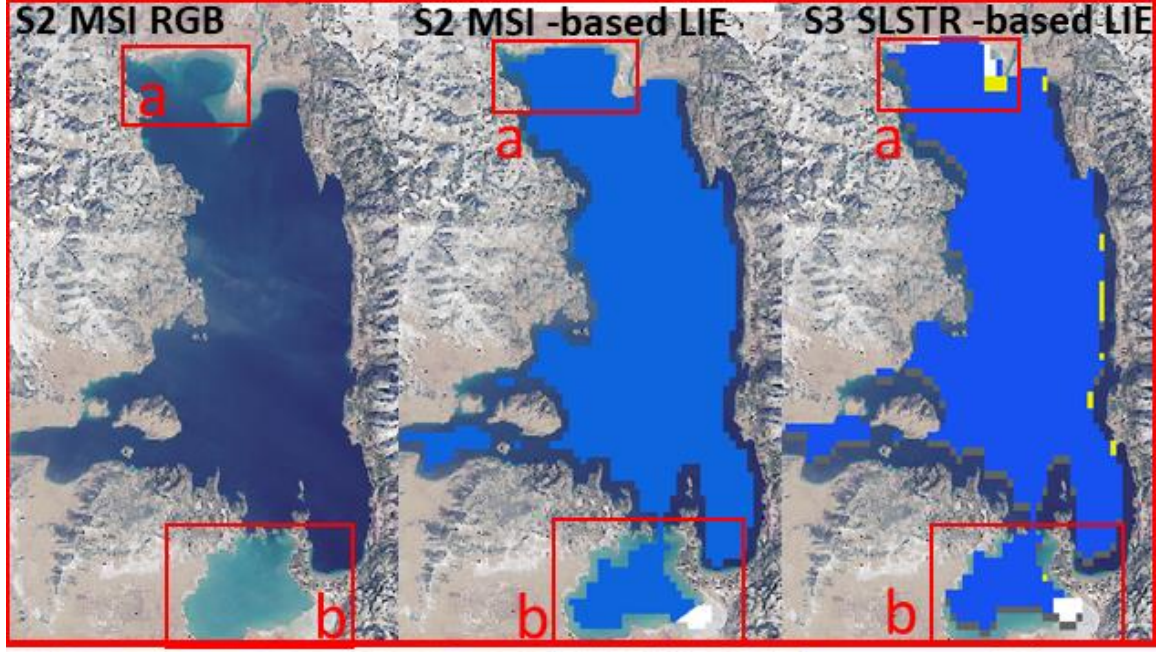
SYKE

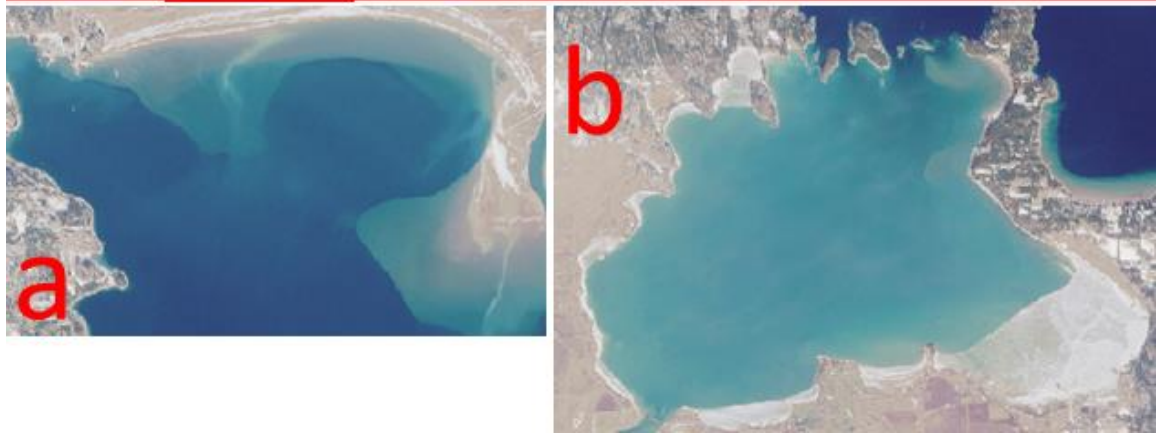
Uvs Lake, Asia

Pros and cons

- Recognizes cold and turbid open water from ice
- Very heavy turbidity can cause a false ice commission in conditions when water is close the freezing point
  - Temperature limitation aids

Flathead Lake, North America, 12 February 2022

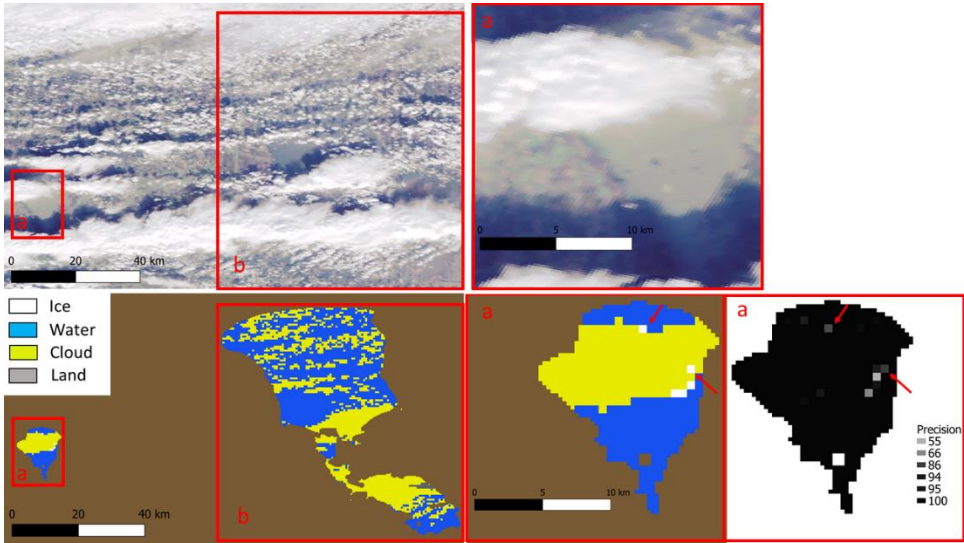




SYKE

Validation of the cloud-cover

- A set of Sentinel-3 images from different locations and at different kind of cloud conditions was collected
  - ➢ Manual validation was chosen since there is no valid product that detects clouds from S3 SLSTR data over northern lakes well enough to be used as a “truth”
- The validation showed that the *ICEmod* method distinguishes different kind of cloud covers very well from ice and water
- Only very few incorrect classifications due to the cloud cover was found
  - Low light conditions and turbid water increases the possibility of errors at the edge of clouds where e.g. the fog can be presented

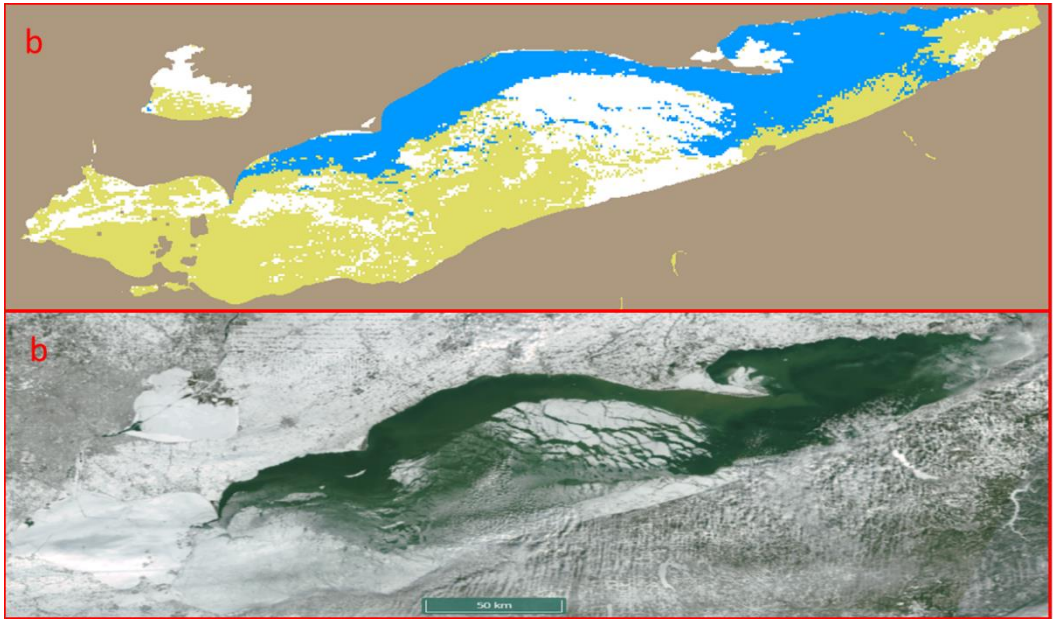


Lakes Peipus and Võrtsjärve, Europe, 22 October 2021

Validation of the cloud-cover

- Especially over ice, *ICEmod* tends to detect thin clouds even if ice is visible for human eye
  - This was intentional to diminish false ice commissions due to the thicker haze over cold water (spectra in these cases are very similar)
- Over open water, *ICEmod* detects water despite the haze/fog, especially when the water is warm due to the utilization of thermal bands in the algorithm

Lake Erie, USA,
on 11 February 2021



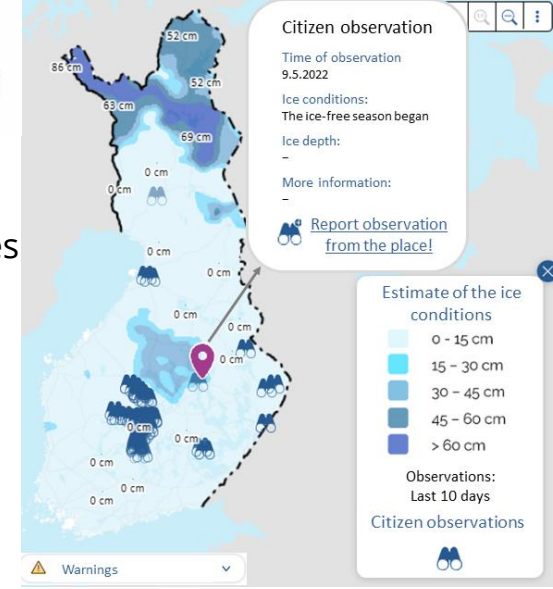
SYKE

Lake Ice Service

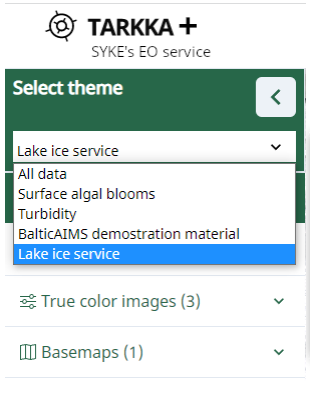
ARCTIC PASSION

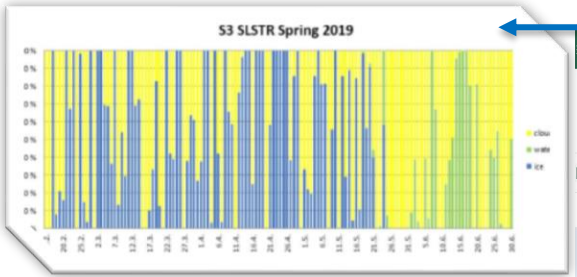
- Collects lake ice information from multiple sources:
  - Earth observation data: Copernicus Lake Ice Extent products, true color images
  - In situ data: Citizen observations, SYKE's lake ice observation network
- Visualization for user friendly and easy access
  - Integrated to public TARKKA+ webmap service

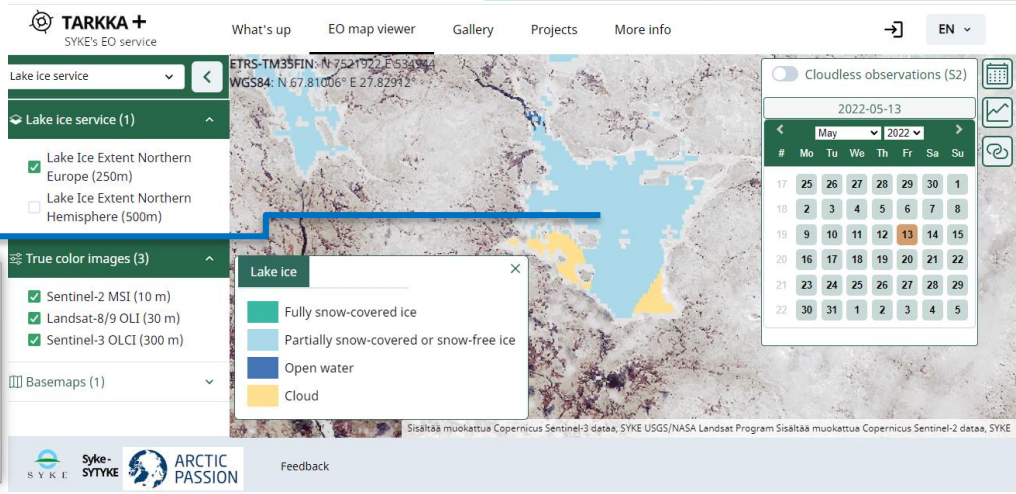
Users may propose other value-added information to be included in the service



https://testbed.ymparisto.fi/eo-tarkka/mapandwaterareas/







Lake Ice Service: Current status and future plans

- Currently available:
  - Earth Observation (EO) data
    - Daily 250m NRT Lake Ice Extent Northern Europe
    - Daily 500m NRT Lake Ice Extent Northern Hemisphere
    - High and medium resolution true color images (Sentinel-3 OLCI, Sentinel-2 MSI, Lansat OLI)
  - Platforms for connecting EO and Citizen Observation (CO) data (SYKE/TARKKA and SYKE/CitobsDB)
  - Language independent gathered data:
    - Numeric values of options in CO can be used to directly compare with EO product classifications
    - Technical configuration information makes it possible to translate the instructions in a structured manner
  - Widgets for displaying observation submission questionnaires on web applications
  - Demonstration questionnaire in TARKKA to submit citizen observed features from satellite EO data

Lake Ice Service: Current status and future plans

- Next steps:
  - Adding more data available:
    - Copernicus high resolution River and Lake Ice Extent (RLIE) for Pan-European region
    - Sentinel-1 SAR data
    - Thermal data
    - Citizen observations
    - Observation from governmental network: Ice thickness, freezing/melting off dates, water temperature
  - More convenient Citizen Observation user interface technology
    - Mobile phone friendly systems which are less dependent of web access, installation to mobile phones etc.
  - Modification of visualizations and adding tools for statistics in TARKKA+ lake ice service

Interested user requirements specifiers? ☺

kirsikka.heinila@syke.fi

Winter by Jacob Grimmer in 1577

Thank you!

SYKE