Development of an automated extraction method of lake ice phenology dates from AVHRR data

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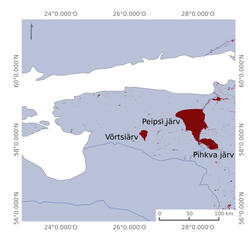
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Introduction

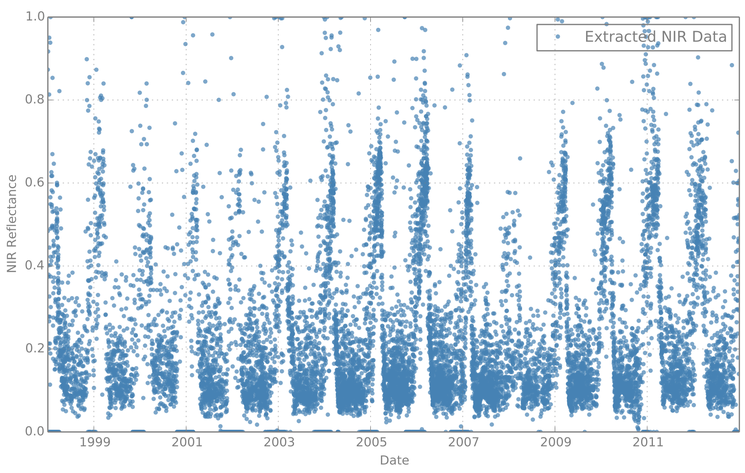
Lake ice phenology is a proxy for climate variability and change. Long-term data series are required to understand these changes and the resulting impacts for lakes ecosystem. In 2006, lake ice has even been announced as **one of the Essential Climate Variables** [1]. A **significant trend of later freeze up and earlier break up** in the Northern Hemisphere had been described in several studies (e.g. [2]). But long-term data series of lake ice monitoring are scarce in cold regions of the world as well as in Switzerland. Satellite data provides an unique source to fill these existing data gaps. This study's goal is a development of an automated extraction method to derive start and end dates for freezing and thawing of lake ice. Near infrared (NIR) was used, utilizing the fact that reflectance increases with formation of ice.

Data

For the development of the algorithm satellite data and in-situ data were chosen for **lakes of the Baltic region** due to the lake size required and the fact, that currently only small lakes freeze up in Switzerland.
Daily 1 km satellite data is obtained from the full resolution archive of the Remote Sensing Research Group, University of Bern. Data of the **Advanced Very High Resolution Radiometer (AVHRR)**, carried on satellites of the National Oceanic and Atmospheric Administration (NOAA) and the European Meteorological Operational satellite system (MetOp), offer **unique potential for climate studies** from the early 1980s until today [3]. Evaluation of the algorithm will be carried out with the in-situ data.

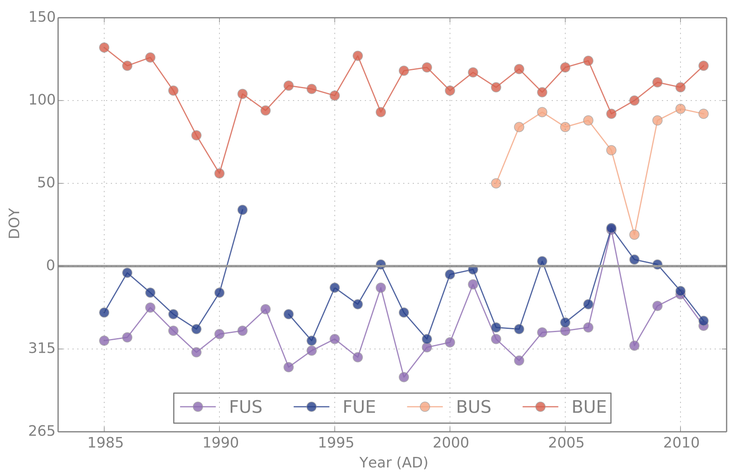


Satellite Data



- Data of AVHRR/2 and AVHRR/3 sensors, except NOAA-15, is used to derive freeze up and break up dates.
- A crucial step of the preprocessing is the application of a cloud mask, developed by Musial et al. [4].
- The Figure shows top-of-atmosphere reflectance in the NIR averaged over all the pixels of the lake, represented by blue dots.
- Additionally to **data gaps**, the signal processing is further complicated by **high signal variability**.

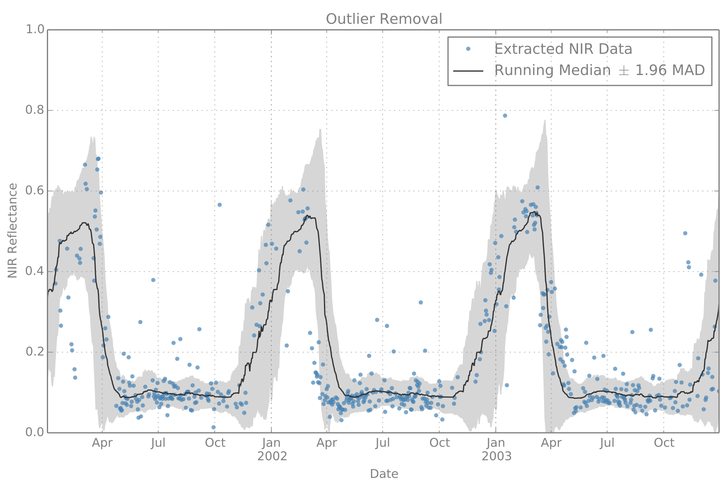
In-situ Data

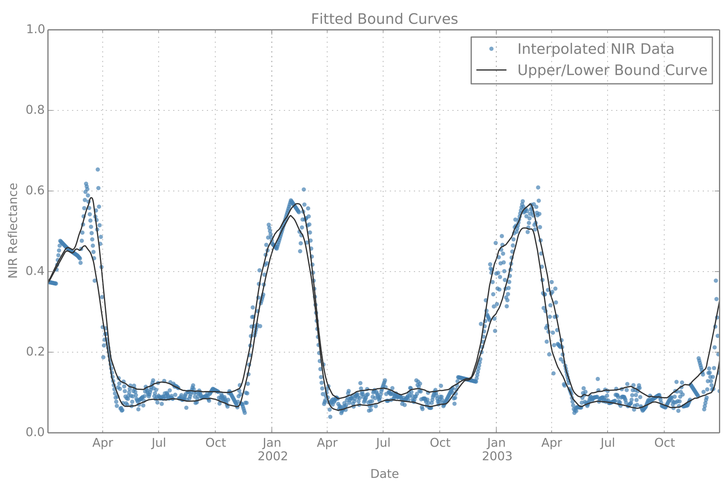


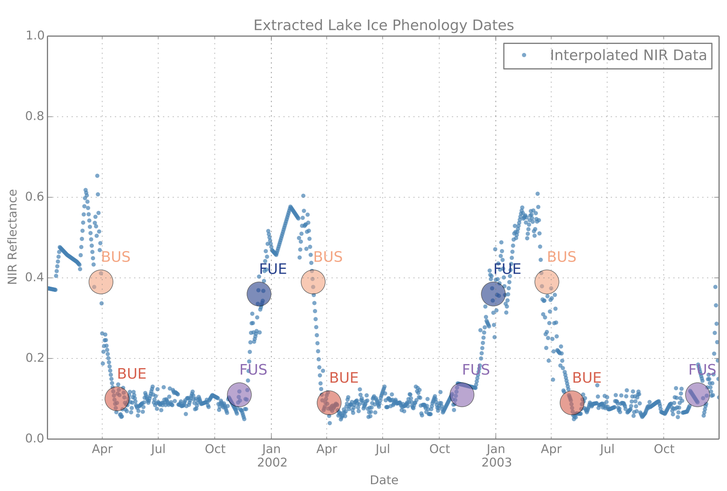
- Data of **Peipsi järv**: A large shallow lake, size of 2611 km^2, mean depth of 8.3 m, located at the eastern border of Estonia
- Analysis and comparison of the in-situ data to local air temperature measurements was done by Nõges and Noges [5]
- Despite a significant warming trend of lake temperature, the **ice phenology trend is weak**, see Figure above
- Lake ice phenology was distinguished by start/end of break up (BUS/BUE) and start/end of freeze up (FUS/FUE).

Method - Work in Progress

Following an **automated extraction technique** developed by Latifovic and Pouliot [6], who retrieved lake ice phenology events in Canada, **reflectance profiles** for each lake were used. These profiles reduced the data volume and improved the handling.



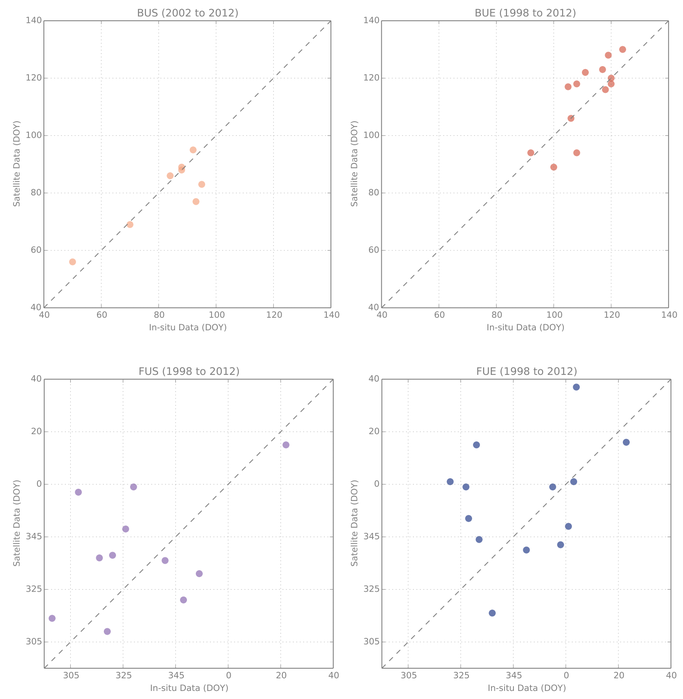




1. Extraction of lake specific reflectance profiles to retrieve start of break up (BUS), end of break up (BUE), start of freeze up (FUS), and end of freeze up (FUE)
2. Re-sampling to daily time resolution
3. Outlier removal through a morphological filtering method
4. Linear interpolation over the removed outliers
5. Fitting of lower and upper bound curves
6. A single iteration with rolling functions over the bound curves for visually assessed threshold values was performed to derive approximate times of the lake ice phenology dates. For BUS and FUS the last ones of these dates were chosen, for BUE and FUE the first.

First Results and Discussion

The Figures below show the results of a comparison between the extracted satellite lake ice phenology dates and the in-situ data for the start and end of freeze up and thawing.
BUS and BUE show a strong agreement, whereby FUS and FUE have larger discrepancies. The result for BUS is good with a mean absolute error (MAE) of 5.1 d. BUE has as well a strong agreement with a MAE of 6.3 d. The MAE for FUS is 18.3 d and for FUE 20.8 d.



The **weak agreement of FUS and FUE** is associated with high variability of the satellite data during winter time. The slope of the bound curves seem not smooth enough, which is partly caused by the interpolation.
Problematic are single year exceptions, occurring with an MAE of more than 30 d. Additionally, some years did even not meet the threshold conditions.

Open issues

- 26 % of missing values for the resampled data and overall high variability
- The dependency on the cloud mask is very high, because only clear-sky data can be used. Sometimes, the cloud mask falsely detects lake ice as clouds.
- Improvement of the signal processing, especially the interpolation of data without outliers and erroneous values. Filling of large data gaps in the slopes of the profiles.
- Optimization of the dates extraction, because some years are below the averaged thresholds conditions and decrease of the mean absolute error of FUS and FUE
- Method to check the results for unlikely estimates

Conclusion and Outlook

- The **first results achieve a good outcome** and approve the method design.
  They show a strong agreement for the start and end of the break up, while the results for the start and end of the freeze up imply an improvement of the method to derive these dates.
- In case of BUE water could be easily distinguished from dark ice. A disadvantage is of course the **lack of data on cloudy days**, which greatly affects the signal processing.
- **Signal processing is further complicated** by strong noise, high variability, and large data gaps.
- Despite the warming trend of lake temperature of Peipsi järv, the **weak trend of ice phenology** implies that "the processes of ice phenology are more complex than those governing lake surface temperature" [5].
- Extension of the time series from 1984 to 2013 and deriving of trend estimations
- Adjustment of the method to smaller lakes and application to Swiss lakes in future

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Acknowledgements

P. Nõges and T. Nõges from the Centre for Limnology, Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Estonia, provided kindly an full record of lake ice phenology dates dating from 1985 to 2011.

For extensive technical support thanks go to Christoph Neuhaus, ICT Expert of the Remote Sensing Research Group, University of Bern, Switzerland.

Furthermore, I want to mention the open source projects used: LaTeX, IPython, Numpy, Matplotlib and Pandas.

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