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Arctic Melt Ponds: Automated Detection Algorithm Using Enhanced Machine Learning

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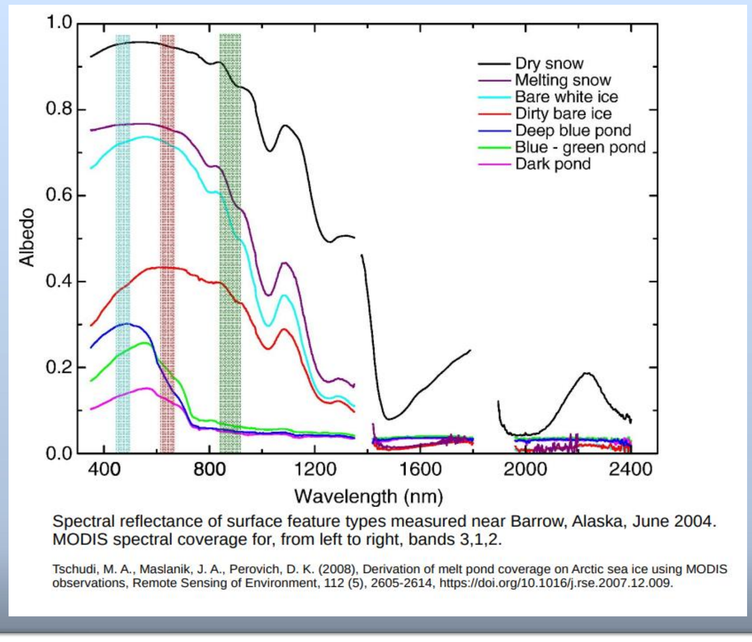
Introduction:

- Melt ponds form on sea ice in spring and summer.
- The fraction and distribution of melt ponds on arctic ice has significant influence on Arctic climate and ecosystem by reducing the albedo.
- Hence there is an urgency for improved accuracy of melt pond distribution estimates.

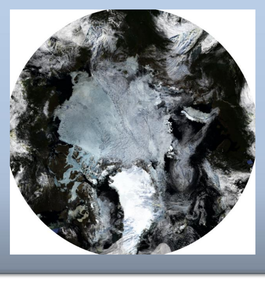
✓ **Foster the long and unique MODIS time series**

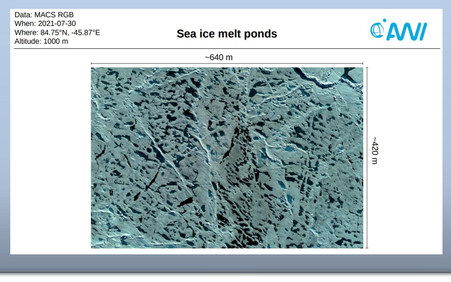


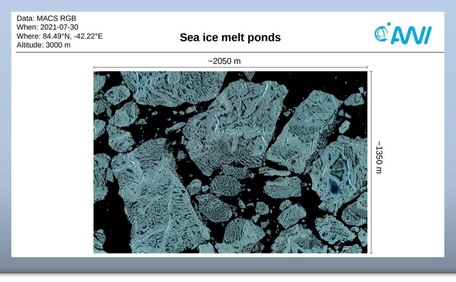
Spectral reflectance of surface feature types measured near Barrow, Alaska, June 2004. MODIS spectral coverage for, from left to right, bands 3,1,2.

Tschudi, M. A., Maslanik, J. A., Perovich, D. K. (2008), Derivation of melt pond coverage on Arctic sea ice using MODIS observations, Remote Sensing of Environment, 112 (5), 2605-2614, https://doi.org/10.1016/j.rse.2007.12.009.

Our Goal: Creating a reliable and realistic melt pond time series for the last decades, using novel technologies, sensors, and insights!

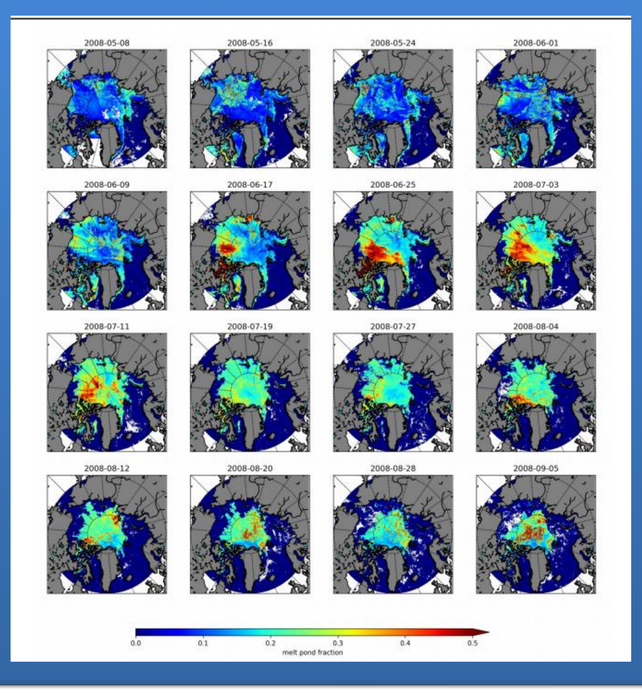




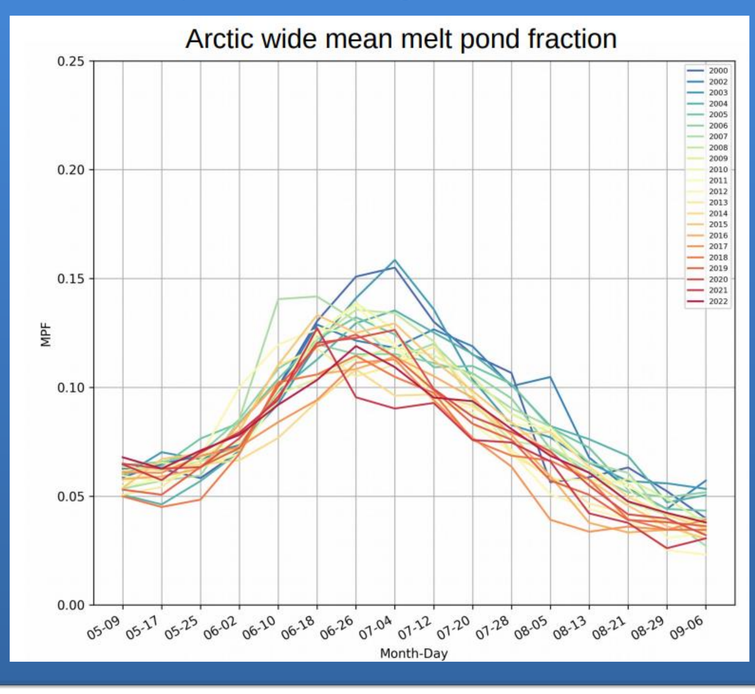


What do we have?

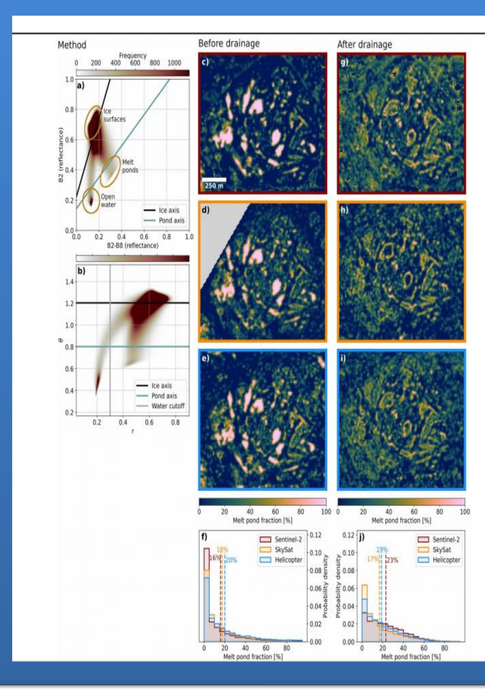
MODIS melt pond set (Rösel, 2012):
Spectral unmixing with CNN; 2000-2011



AWI-MODIS melt pond set (Neckel, unpublished):
classical spectral unmixing; 2000-2024



Sentinel 2 melt pond set (Niehaus, 2022 & 2023):
Principal Component Analysis (PCA); 2017-2021

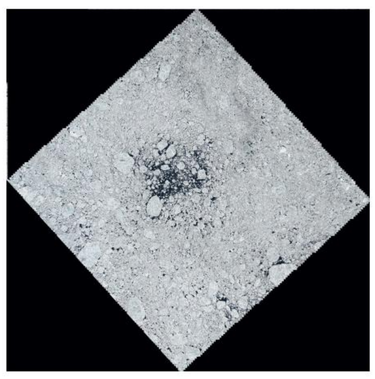


Surface classification of Sentinel-2 data using principal component analysis (a and b).
Classification results of Sentinel-2 (c) on June 30, 2020 over the MOSAiC ice floe (pre-drainage). Downscaled calssification results of SkySat data on July 1, 2020 (d) and of Helicopter-borne classification results on June 30, 2020 (e). After drainage classification results from Sentinel-2 (g), SkySat (h), and from Helicopter data (l) all data acquired on July 22, 2020. Histograms of the MPF distributions (f and j).

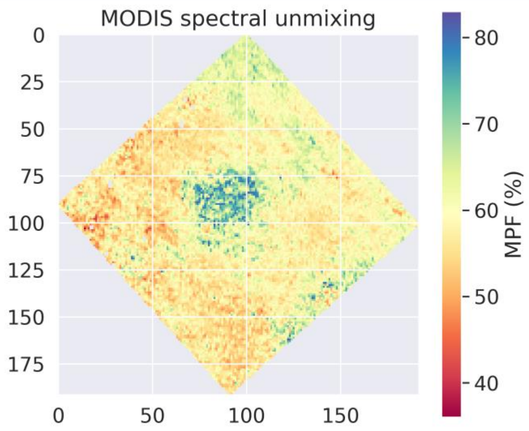
Niehaus, H., Spreen, G., Birnbaum, G., Istomina, L., Jäkel, E., Linhardt, F., Neckel, N., Fuchs, N., Nicolaus, M., Sperzel, T., Tao, R., Webster, M., Wright, N. (2023), Sea Ice Melt Pond Fraction Derived From Sentinel-2 Data Along the MOSAiC Drift and Arctic-wide, 50, e2022GL102102. https://doi.org/10.1029/2022GL102102

Niehaus, Hannah; Spreen, Gunnar (2022): Melt pond fraction on Arctic sea-ice from Sentinel-2 satellite optical imagery (2017-2021) [dataset]. *PANGAEA*, https://doi.org/10.1594/PANGAEA.950885

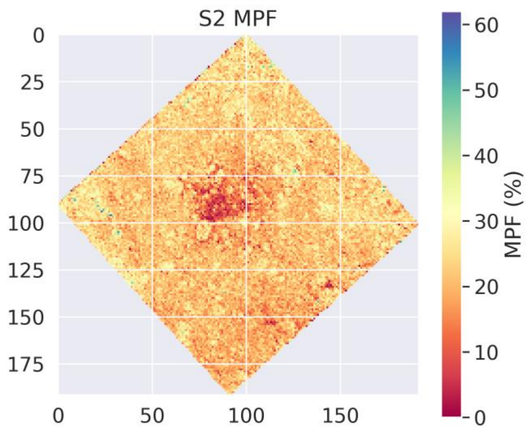
Identified problems:



Sentinel 2, band 1 – selected scene

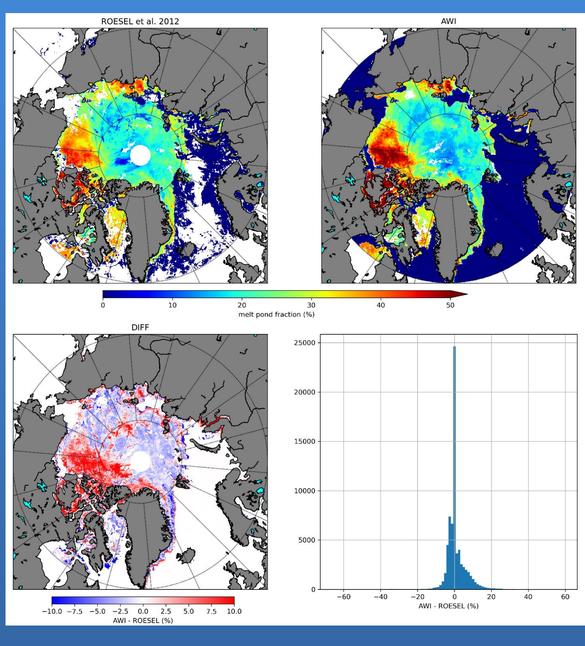


Melt pond fraction using spectral unmixing (Rösel, 2012)



Melt pond fraction using S2 data and PCA algorithm (Niehaus 2023)

This experiment shows a clear misclassification of the open water area using the MODIS spectral unmixing algorithm. This is caused most likely by the coarse resolution, where the broken up ice floes and the open water occur blurry in the MODIS channels. The high resolution Sentinel 2 sensor is able to handle this effect better



Comparison of MODIS melt pond fractions from Rösel et al., 2012 (upper left) with a newly processed melt pond data set from AWI (Neckel, unpublished), with a classical unmixing algorithm and blending with the daily NSIDC G02135 sea ice index (Doi: 10.7265/N5K072F8) to avoid the NAN values, caused i.e. by negative surface reflectance values in the MOD09 product in band 2 over open water areas (upper right).
Here we see a clear distinction of the melt pond fraction with a different spatial distribution of the areas with high, respective low melt pond coverage (lower left).
Until now, we do not have any explanation for this particular effect, but this is a very high motivation to dig further into the products in the near future.

Potential solutions - our visions:

- Our results until now suggest that spectral unmixing over-estimates the melt pond fraction on Arctic sea ice, since open water might always be present in cracks, leads, and broken up ice coverage. Obviously the spectral unmixing method has problems seperating melt pond class and open water class. One idea would be:
- Combine high resolution Sentinel 2 data and low resolution MODIS data with implementation of superresolution techniques
- Develop sophisticated ML methods for S2 data
- Focus on self-supervized learning (SSL) methods, few-shot learning and explainable AI (xAI) to overcome the sparce availability of sufficiant training data
- Implemantation of the Lightning UQ-Box (https://lightning-uq-box.readthedocs.io/) for uncertainty estimation
- Reconstruction of the probability distribution of the S2 and the MODIS method to fully understand the regression problem.
- For maximum utility a model should be chosen for which it is easy to compute confidence intervals and which aids in understanding of the data. For example linear regression models on a polynomial or other basis.
- Exploit time and location (e.g latitude, surrounding) as prior information.
- Explore the potential of further sensors like EnMAP or Sentinel 3

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