Machine learning approaches to retrieve Pan-Arctic melt ponds from visible satellite imagery and inter-comparison of melt pond products

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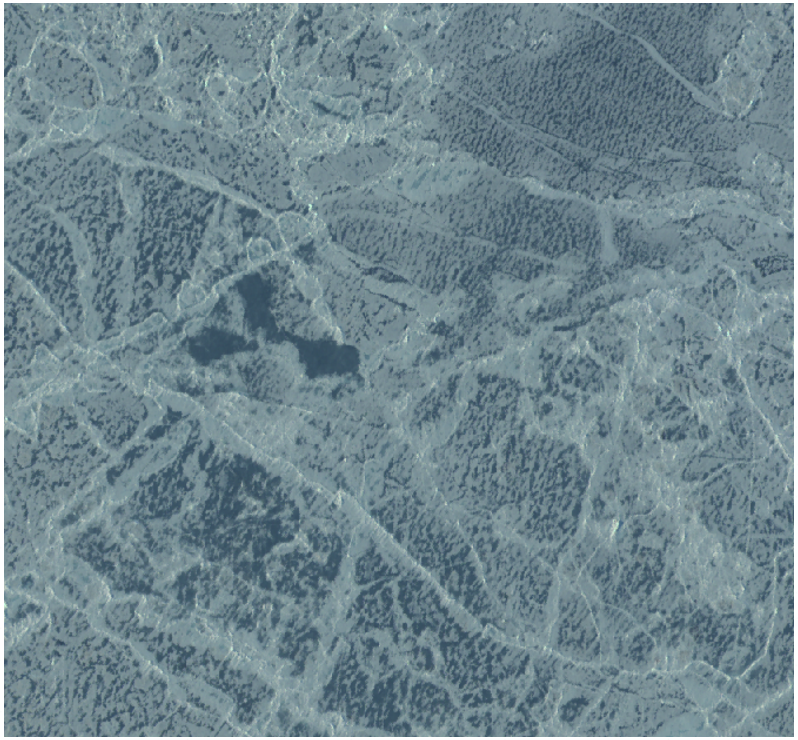
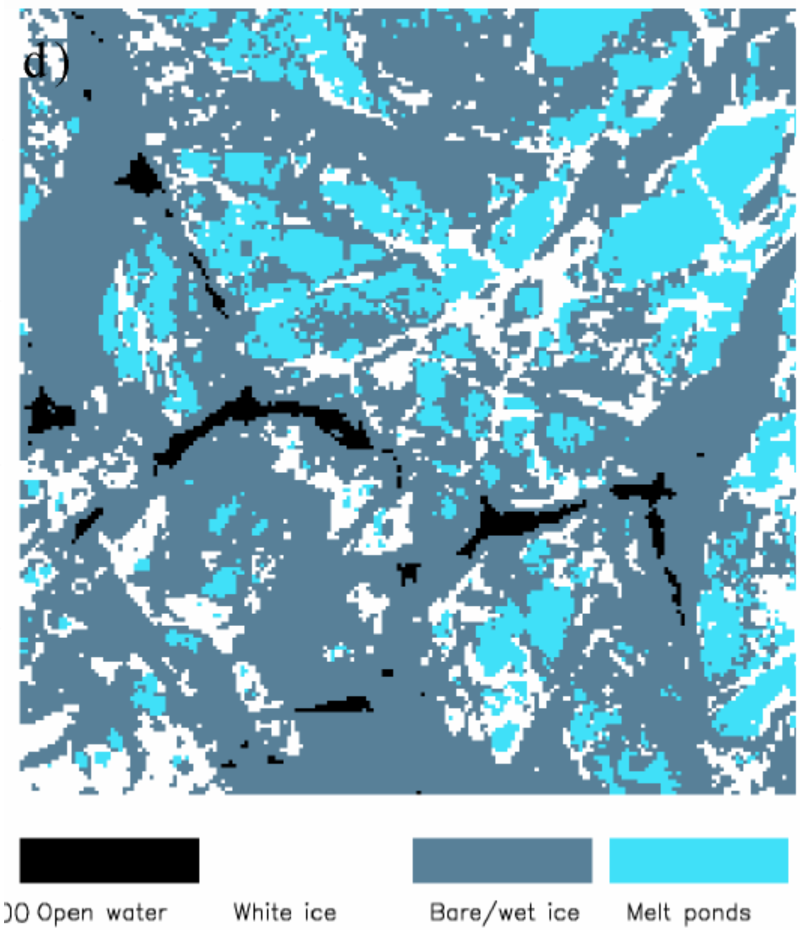
The importance of melt pond



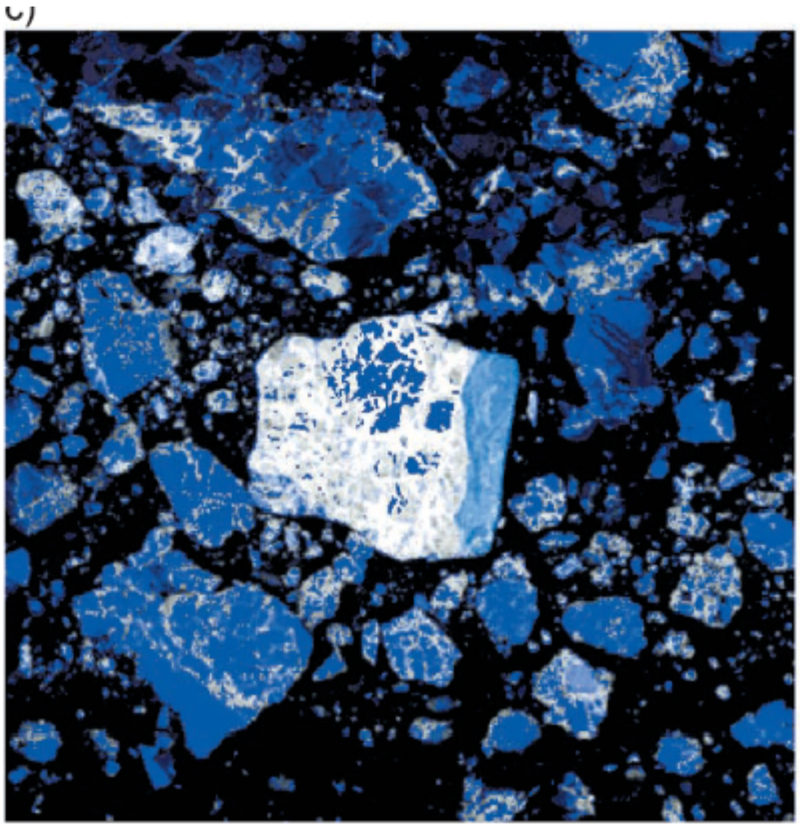
World view-2 imagery in 9 July 2015

- Melt ponds are a dominant feature on the sea ic e surface in the summer season, which occupie s up to about 50-60% of the sea ice surface.
- During this period, 96% of total annual solar hea t coms into ocean throughout sea ice.
- The presence of melt ponds significantly influen ces on sea ice radiation balance.
- In climate model simulations, melt ponds have b een found to play an important in future sea ice evolution.

Previous studies

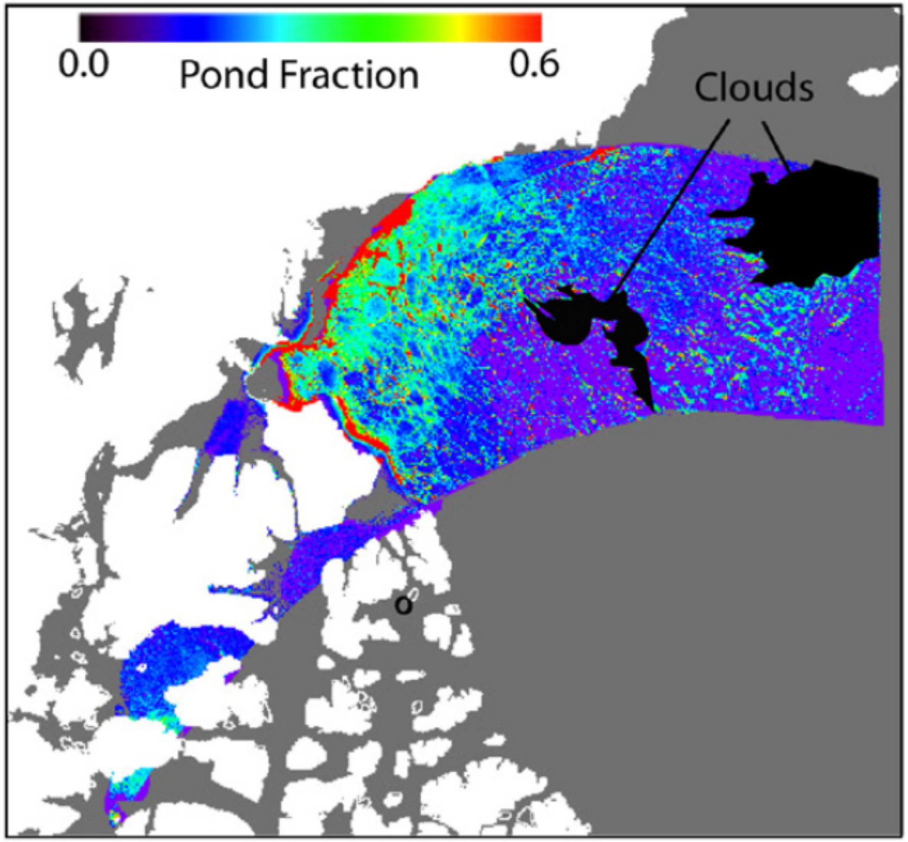


Markus et al., 2002

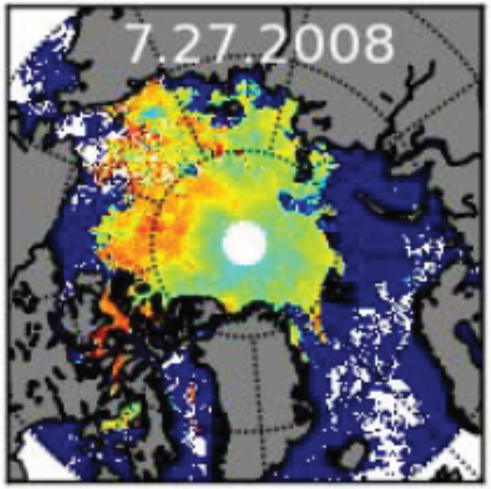


Markus et al., 2003

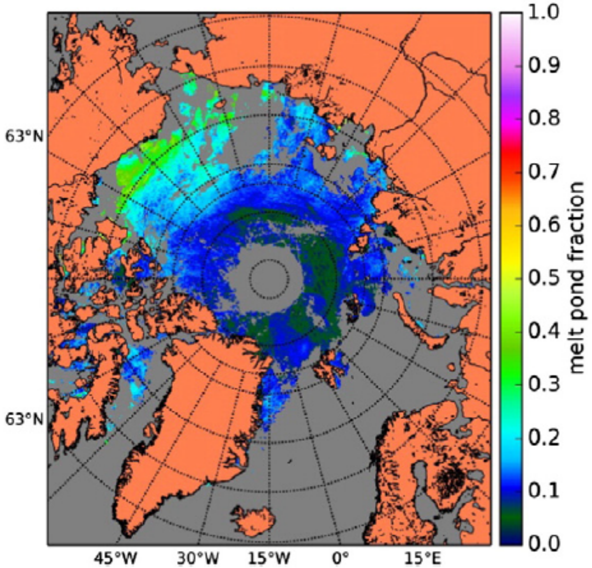
Previous studies



Tschudi et al., (2007)

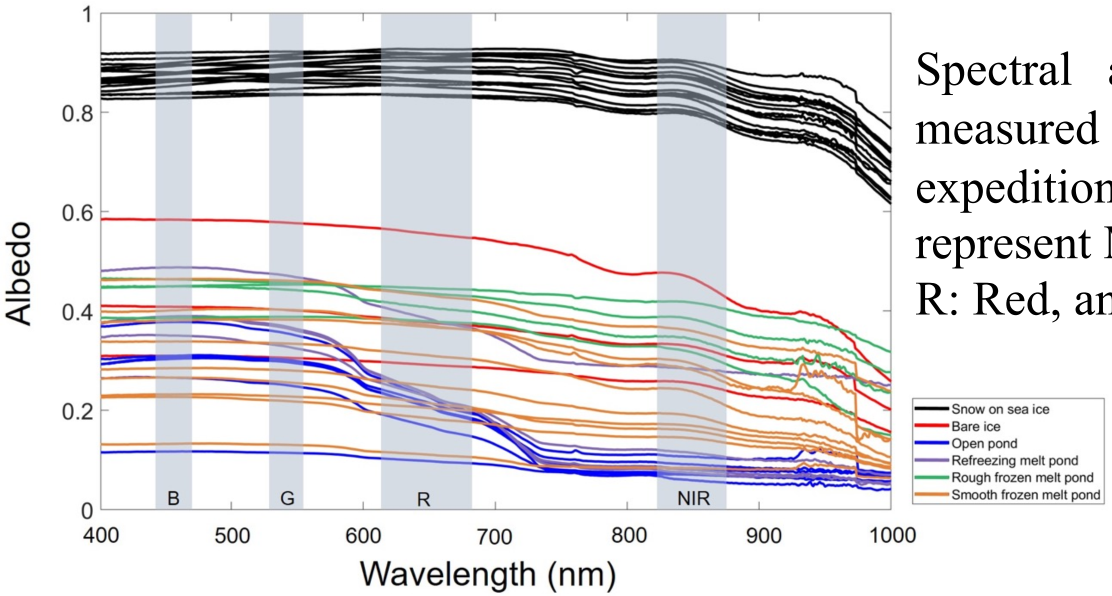


Rosel et al., (2012)

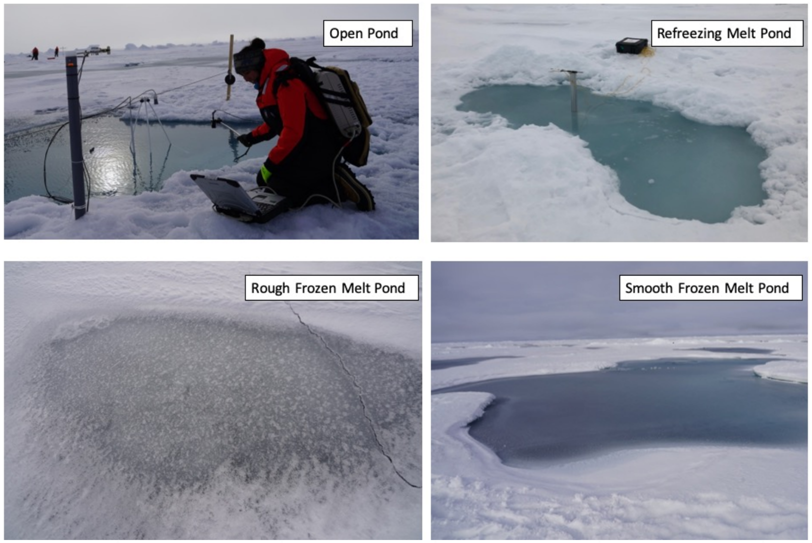


Zege et al., (2015)

Spectral properties of melt pond and sea ice



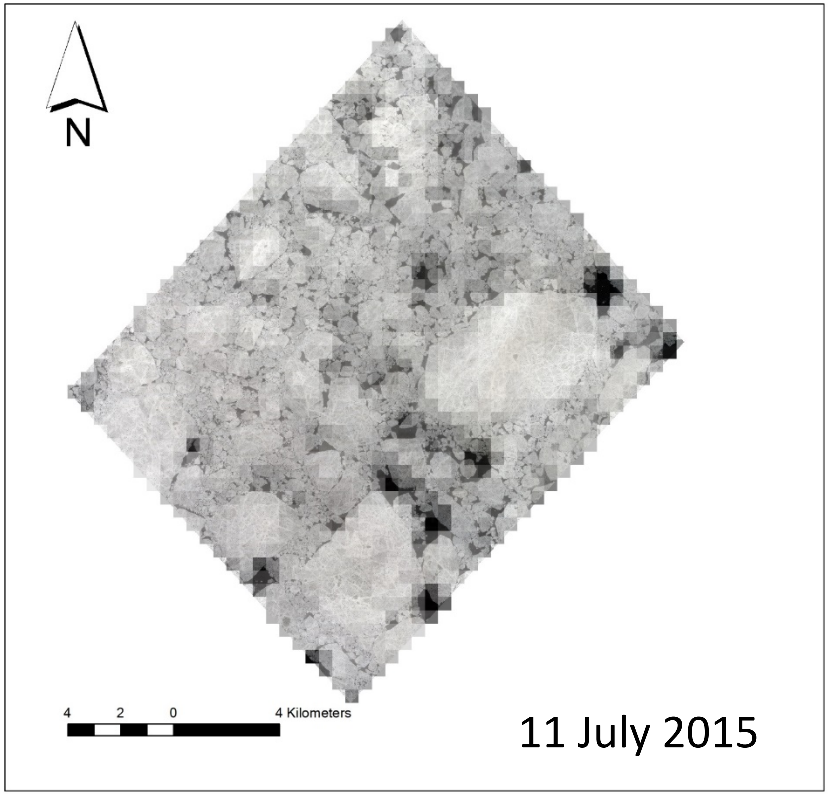
Spectral albedo for different surface types measured during 2018 R/V Araon Arctic expedition. The overlaid gray columns represent MODIS bands 1-4 (B: Blue, G: Green, R: Red, and NIR: Near- infrared).



Lee et al., (2020) in revision

Machine learning approaches
to retrieve Pan-Arctic melt ponds from visible satellite imagery

MODIS & World view



Machine learning

Deep neural network
Multinomial Logistic regression

Melt ponds classification and fraction over the entire MODIS data record (2000 to present)

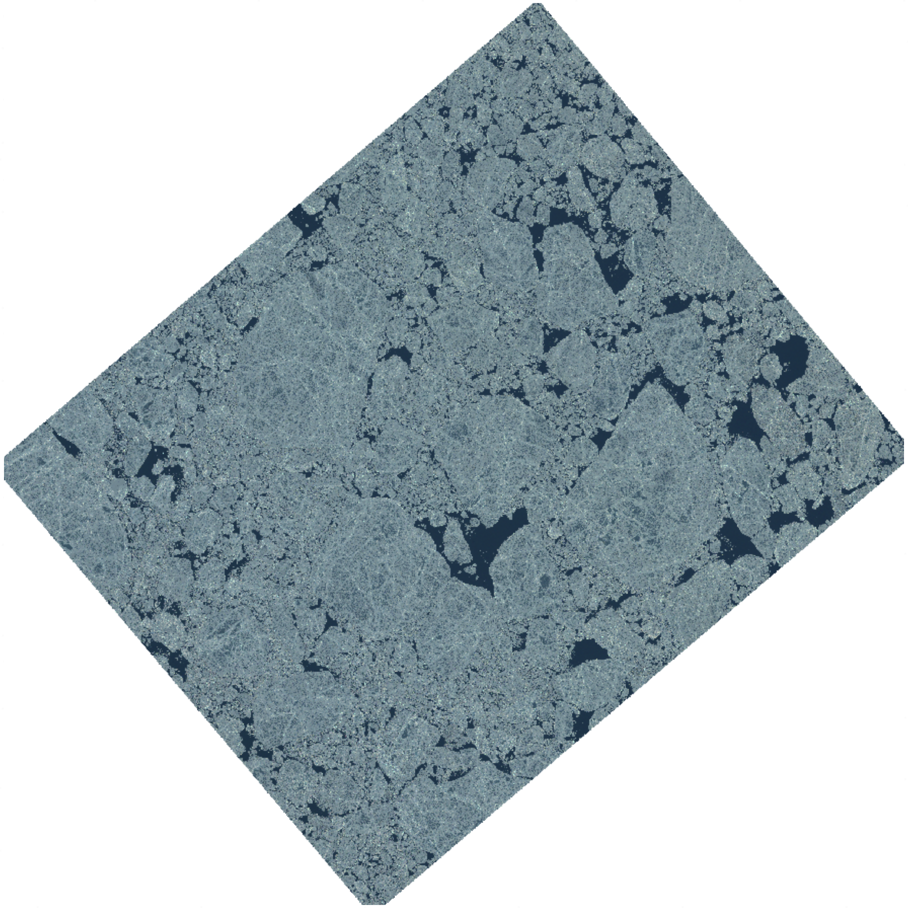
Data

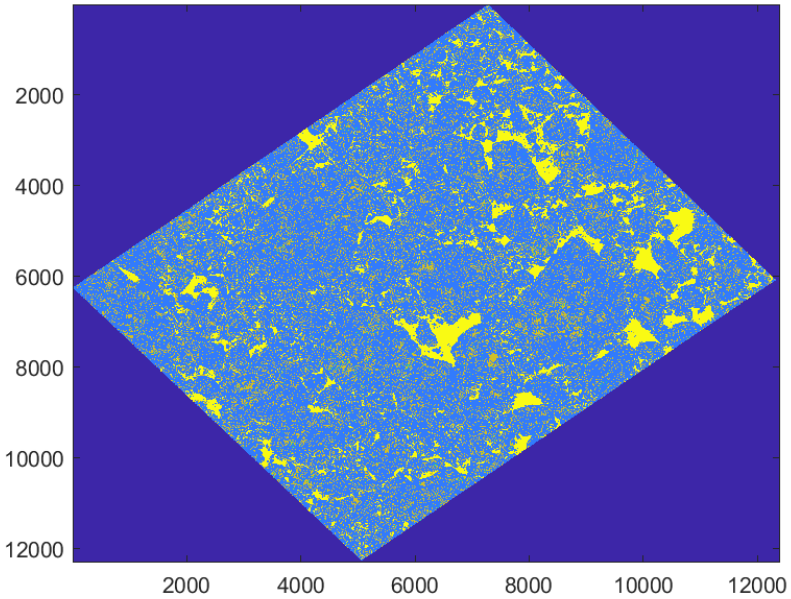
MODIS

MOD03 (solar and sensor zenith angle)
MOD02HKM (band 1-4, 250m & 500m)
MOD021KM (band5, 13, 16, and 19, 500m)
MOD29 (Ice surface temperature, 1000m)
MOD35(Cloud mask)

World view-2 (~2m)

World view sea ice classification





1: Snow / Thick Ice
2: Dark and Thin Ice
3: Melt Ponds and Submerged Ice
4: Ocean

Nicholas et al., 2018

Spectral properties of melt pond and sea ice

MODIS

Band 1 (620-670nm), Red
Band 2 (841-876nm), Near-infrared
Band 3 (459-479nm), Blue
Bnad 4 (545-565nm), Green

Input Feature	
Normalized band 1 and 2	Band1-Band2/Band1+Band2
Normalized band 2 and 3	Band3-Band2/Band3+Band2
Normalized band 2 and 4	Band4-Band2/Band4+Band2
Normalized band 1 and 4	Band4-Band1/Band4+Band1
Normalized band 1 and 3	Band3-Band1/Band3+Band1
Normalized band 3 and 4	Band3-Band4/Band3+Band4

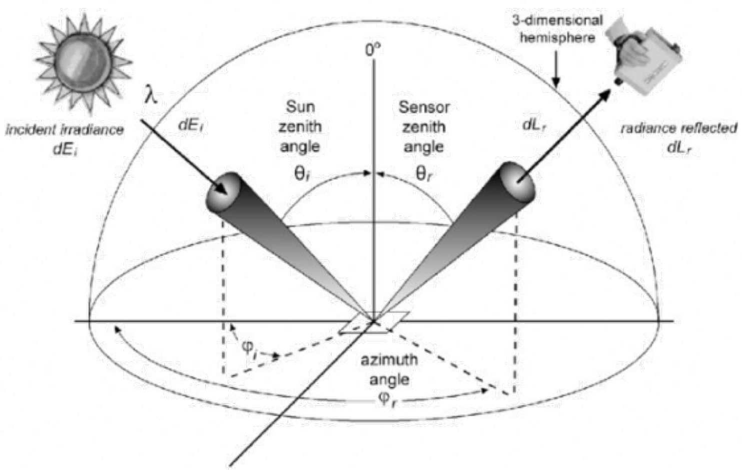
Spectral properties of melt pond and sea ice

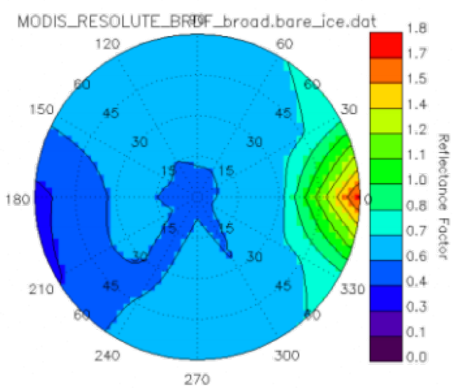
- Bidirectional Reflectance Distribution Function (BRDF)

Surface albedo from satellite is that the surface does not reflect incoming solar radiation isotropically.

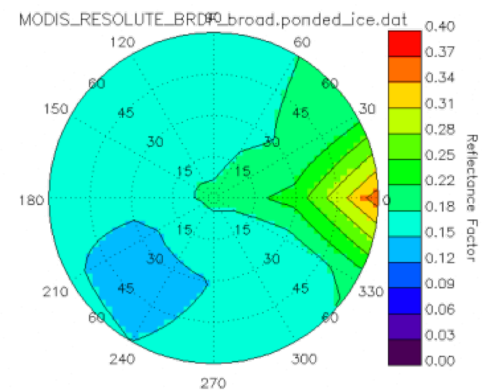
$$R(\theta_0,\theta,\emptyset_0,\emptyset,\lambda) = \frac{dI(\theta,\emptyset,\lambda)}{\mathrm{COS}(\theta_0)\,dF(\theta_0,\emptyset_0,\lambda)}$$

θ_0 solar zenith angle
$\emptyset_0$ Solar azimuth angle
θ Sensor zenith angle
$\emptyset$ Sensor azimuth angle





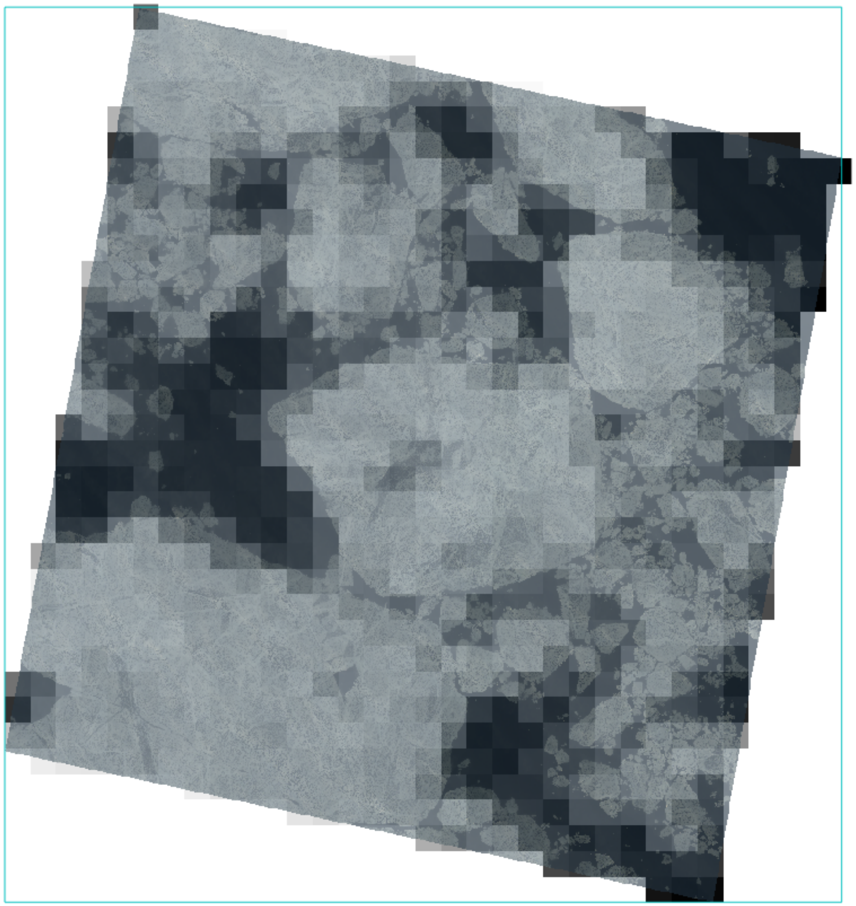
Bare ice BRDF at Resolute, Alaska. Solar zenith angle is 60. (0.4 – 1.0μm)



Ponded ice BRDF at Resolute, Alaska. Solar zenith angle is 60. (0.4 – 1.0μm)

- Atmospheric correction

Determination of melt pond and sea ice class based on world view classification



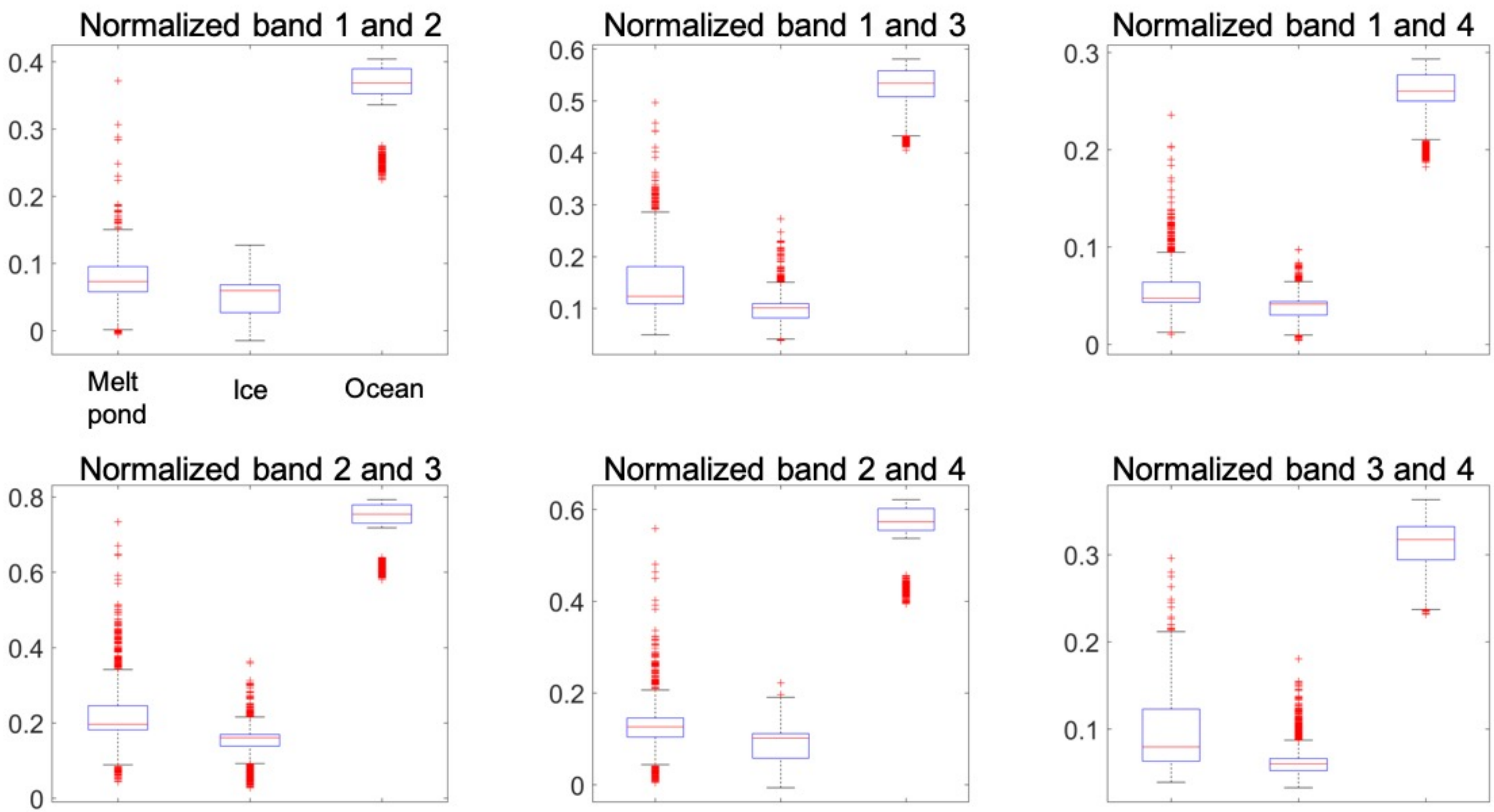
MODIS and World view in 14 July 2015

Over 50 % of ice pixel (class, snow, dar k/thin ice) is going to ice class. Otherwise, other class (melt pond) is going to melt pond class.

MODIS & WV	Time differenc e (min)
13 July 2011	30
21 May 2015 (2)	9
12 June 2015 (2)	3
09 July 2015 (9)	10
11 July 2015	45
14 July 2015 (2)	11
29 June 2016	20

Determination of melt pond and sea ice class based on world view classification

Box plot of input feature



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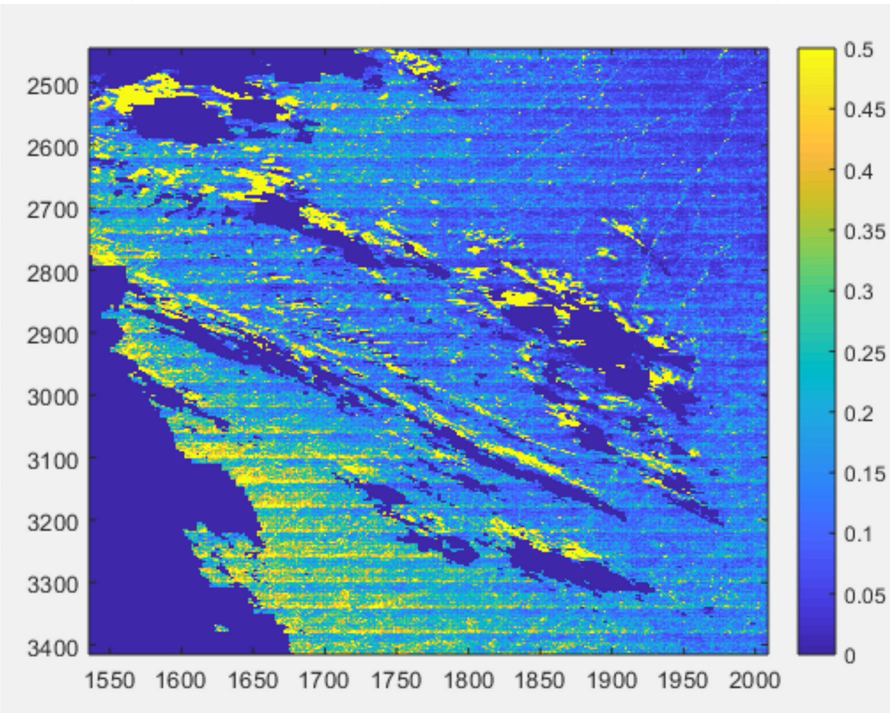
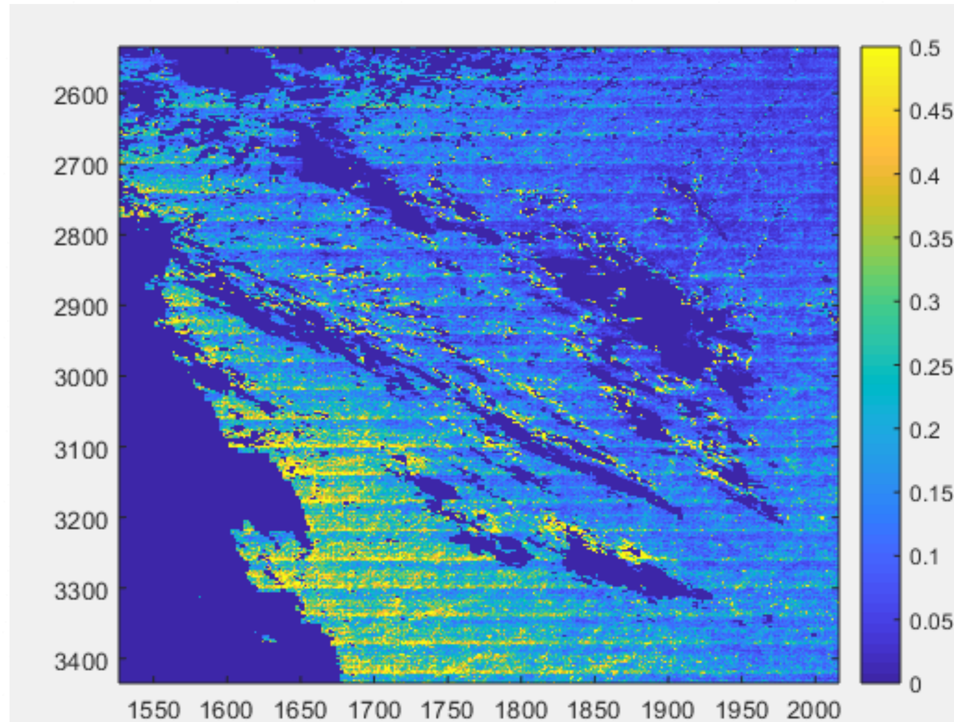
Cloud & cloud shadow masking

before



After



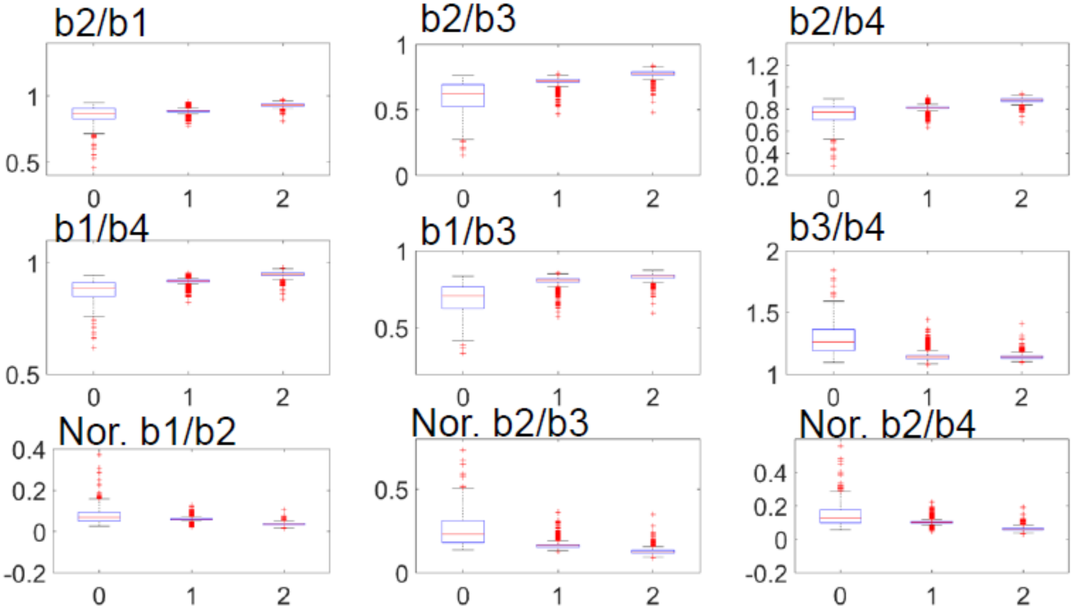
Moving window

shadow_mask = b19 <0.05 & b5 < 0.15 & b16/b13 > 0.3
(Hutchison et al., 2009)

B5 = 1.2 nm
B13 = 0.66
B16 = 0.87
B19 = 0.94

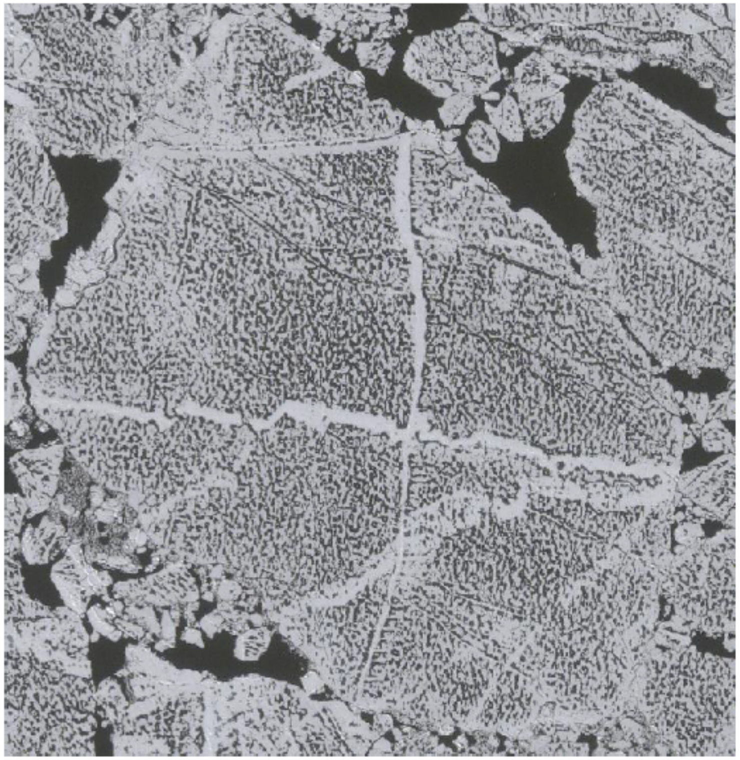
Spectral signature of sea ice in refreezing or early freezing season

Spectral signature of refreezing or early freezing season is very different from melting season!



Boxplot of melt pond and sea ice sample on July and August.

0 = melt pond in July
1 = sea ice in July
2 = mixed refreezing melt pond and sea ice



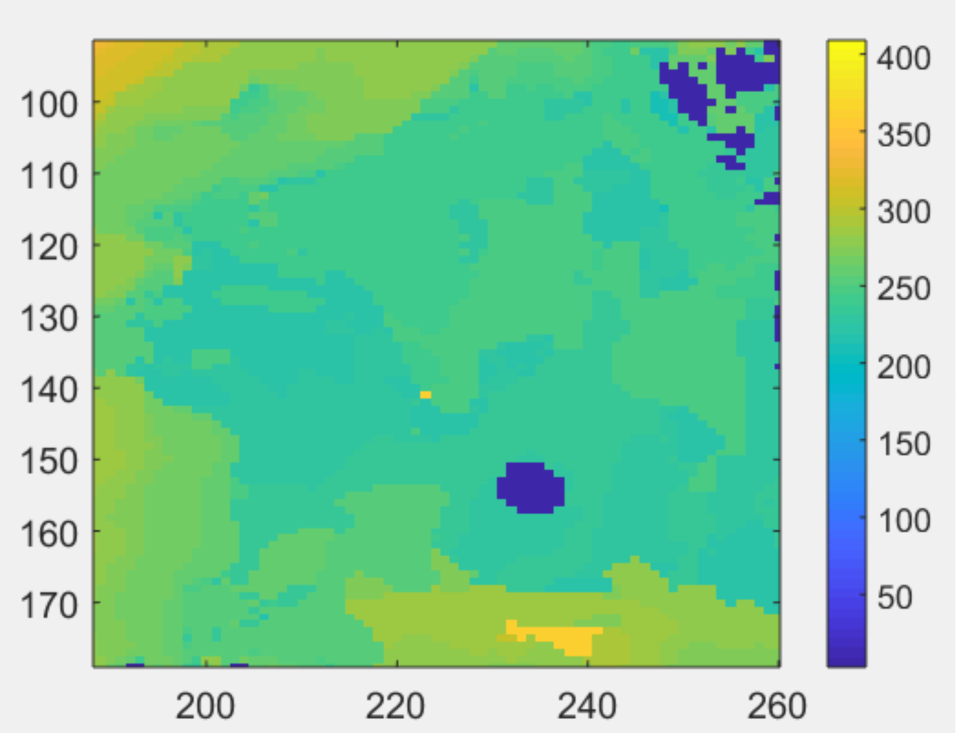
A example of refreezing melt pond and sea ice in August (cropped WV)

Masking refreezing area

Early melt, freeze date & IST

(Markus et al., 2009 and Stroeve et al., 2014)

2015 Early freeze



Average day : 236 (24 Aug. 2015)

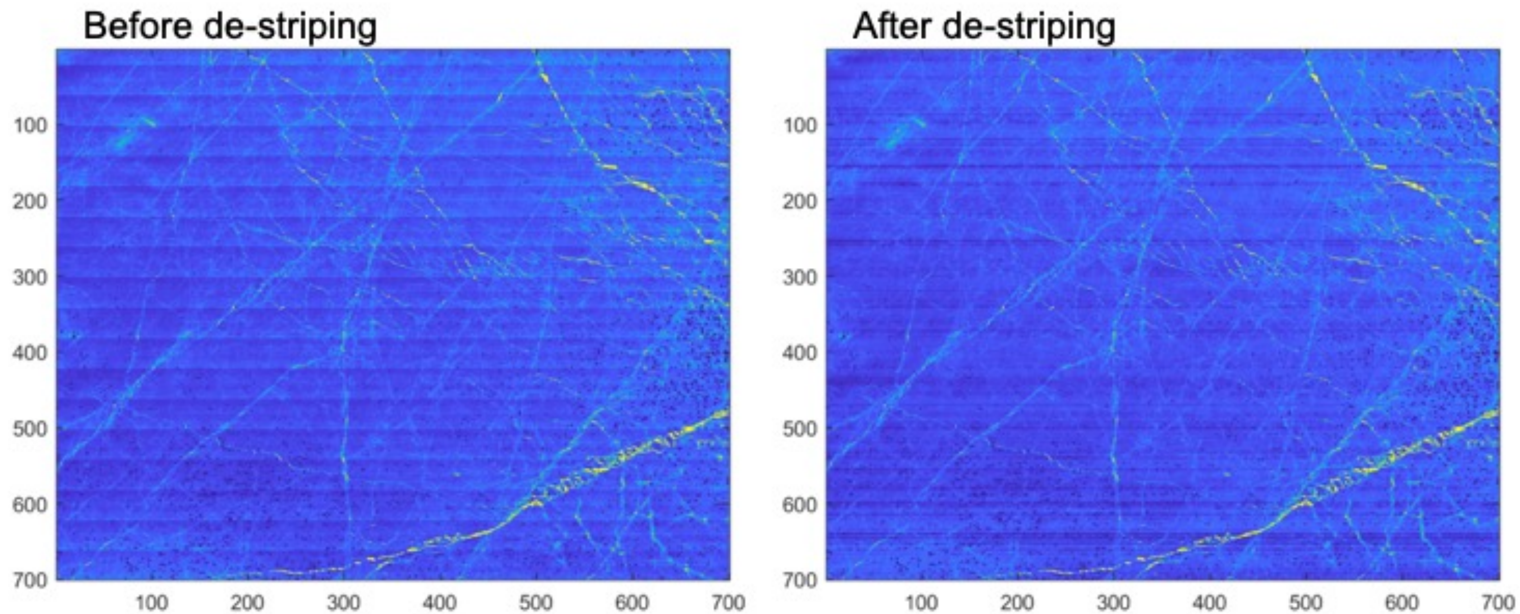
Example

Finding IST on 24 Aug. 2015

Averaging IST (+/- 3 days) on 24 Aug. 2015 : 271!!

Masking melt ponds by using the average d IST temperature (271) in Aug.

De-striping



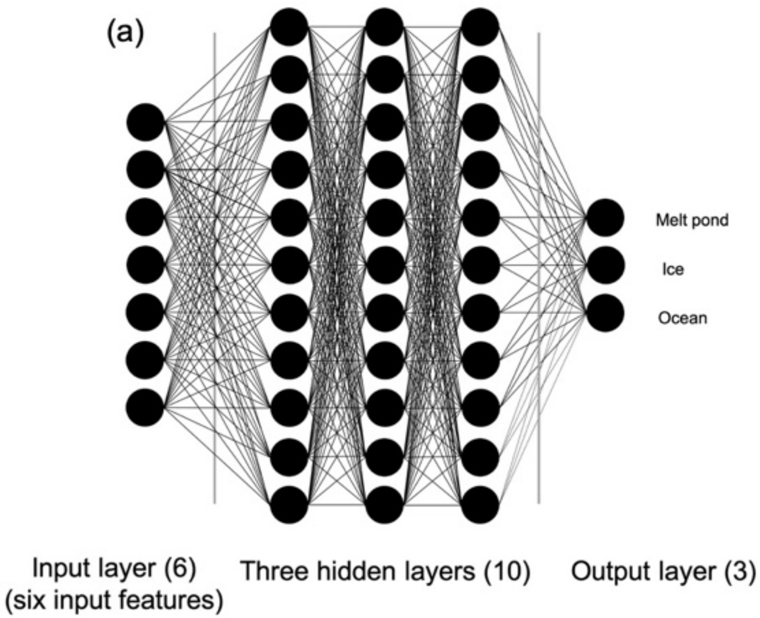
An example of before and after the de-striping of melt pond fraction on 1 May (MOD02HKM 2002121.0100).

- The stripes are horizontal and periodically appear in the images, each image is horizontally averaged and the averaged profile is smoothed using a 10x10 moving average filter.
- The MODIS image is then subtracted from the difference between the averaged profile and smoothed profile.
- This process does not affect the overall reflectances.
- Although this method cannot perfectly remove all the stripes, it is the most time-efficient way to process MODIS imagery on a large pan-Arctic scale.

Lee et al., (2020) in revision

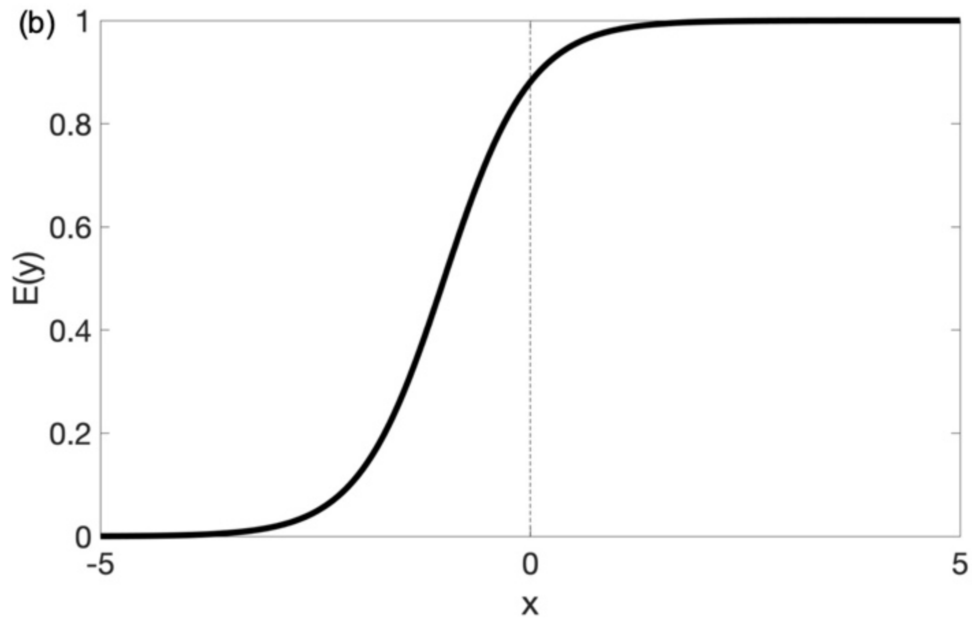
Machine learning approaches

Multi-layer Neural Network (MNN)



Weight initialization : Nguyen-Widrow initialization
Activation function : Tangent sigmoid
Training function for feedforward
: Levenverg-Marquardt method
Epoch : 25

Multinomial Logistic regression (LR)



The LR model is used to predict the probabilities of categorically distributed dependent variables.
As LR does not assume linearity or normality, it often is regarded as an effective analysis.

Lee et al., (2020) in revision

Machine learning approaches

of melt pond = 1323
# of ice = 9053
# of ocean = 3088

Randomly selected ice and ocean (1:1)

Running 26 times

Majority voting (threshold is 13)

- If the number of melt pond class is over 13, a pixel should be melt pond class.
- If the number of melt pond class is below 13, a pixel should be ice class.
- If the number of ocean class is over 13, a pixel should be ocean class.

Cross-validation (leave-one-out)

Accuracy assessment results from MNN for the classification of melt pond. (Unit is percentage)

Year and day	Producer's accuracy for melt pond	Producer's accuracy for ice	User's accuracy for melt pond	User's accuracy for ice	Overall accuracy
13 July 2011	86.3	62.9	37.3	94.7	67.7
21 May 2015 (1)	67.1	93	89.9	75.6	80.6
21 May 2015 (2)	0	90.4	0	99.3	89.9
12 June 2015 (1)	nan	100	nan	100	100
12 June 2015 (2)	0	100	0	99.8	99.8
9 July 2015 (merged)	72	87	32	97.3	85.9
11 July 2015	54.3	98.2	47.5	98.6	96.9
14 July 2015 (1)	91.3	63.5	63.1	91.5	74.8
14 July 2015 (2)	92.3	55.1	50	93.7	67.3
29 June 2016	37.9	99.2	86.6	92.2	91.9

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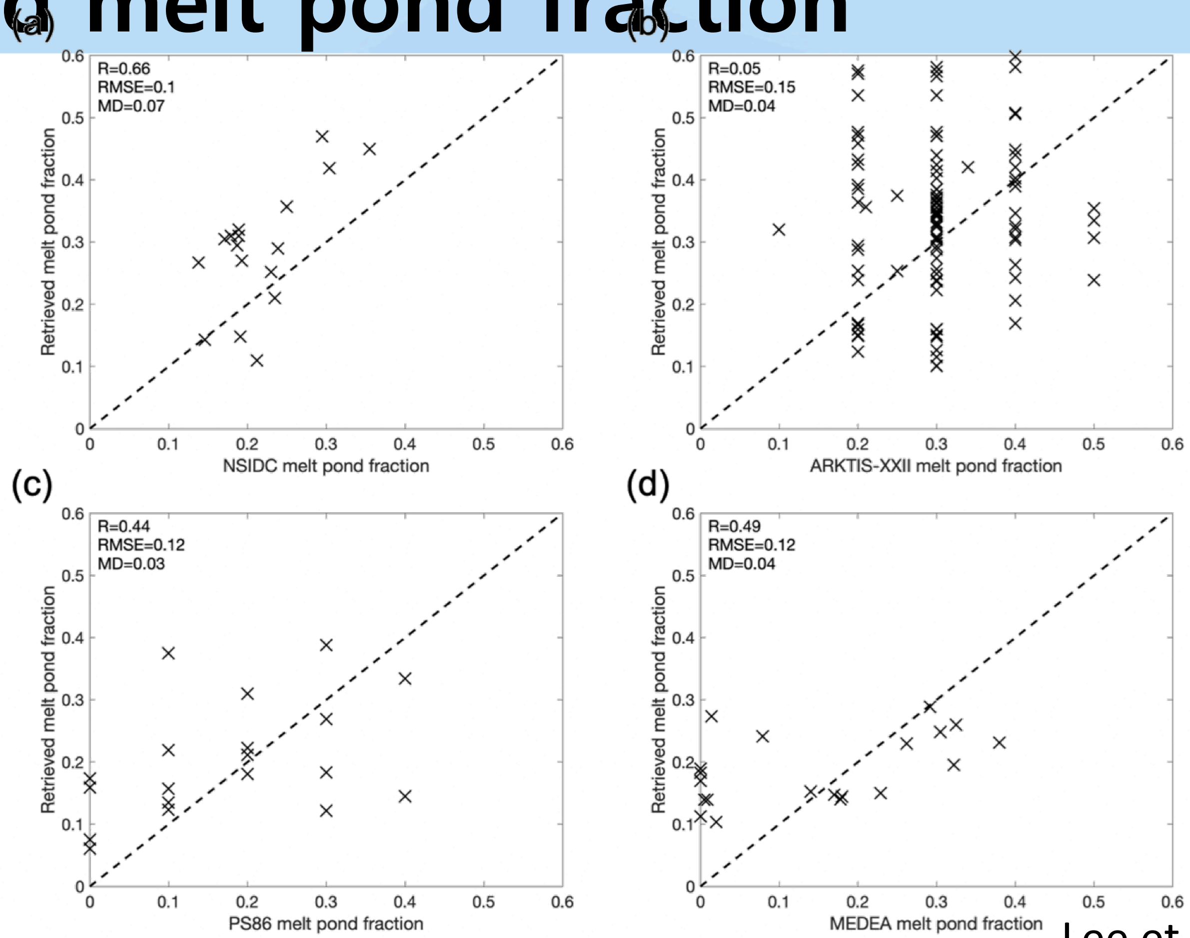
Cross-validation (leave-one-out)

RMSE and correlation coefficient for the evaluation of LR

Year and day	RMSE	Correlation coefficient
13 July 2011	0.1	0.6
21 May 2015 (1)	0.2	0.69
21 May 2015 (2)	0.31	0.36
12 June 2015 (1)	0.1	0.37
12 June 2015 (2)	0.12	0.55
9 July 2015	0.15	0.61
11 July 2015	0.17	0.55
14 July 2015 (1)	0.18	0.8
14 July 2015 (2)	0.18	0.8
29 June 2016	0.27	0.31

Lee et al., (2020) in revision

Validation against satellite and ship-based melt pond fraction

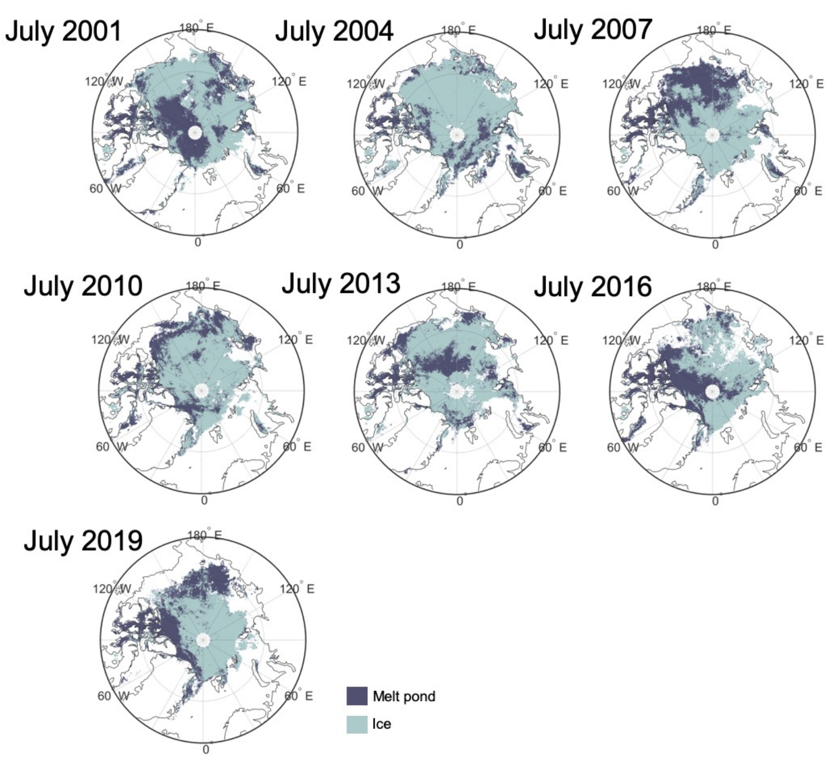


Lee et al., (2020) in revision

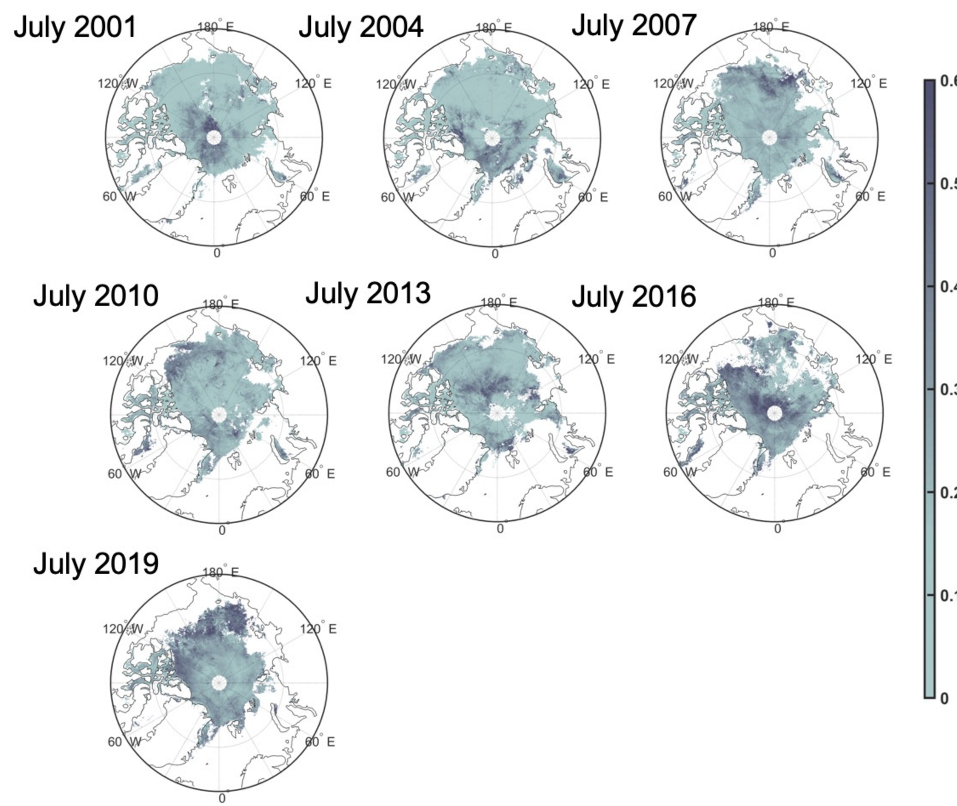
Melt pond fraction validation with satellite and ship-based melt pond fractions showing statistical metrics, including correlation coefficient (R), Root Mean Square Error (RMSE), and Mean Difference (MD). (a) Retrieved melt pond fraction vs. NSIDC melt pond fraction on May, June, and July 2000 and 2001. (b) Retrieved melt pond fraction vs. ARKTIS-XXII melt pond fraction on August 2007. (c) Retrieved melt pond fraction vs. PS86 melt pond fraction on July 2014. (d) Retrieved melt pond fraction vs. MEDEA melt pond fraction on May and June 2011 and July 2007, 2011, and 2013.

Monthly melt pond binary classification and fraction

Melt pond binary classification



Melt pond fraction



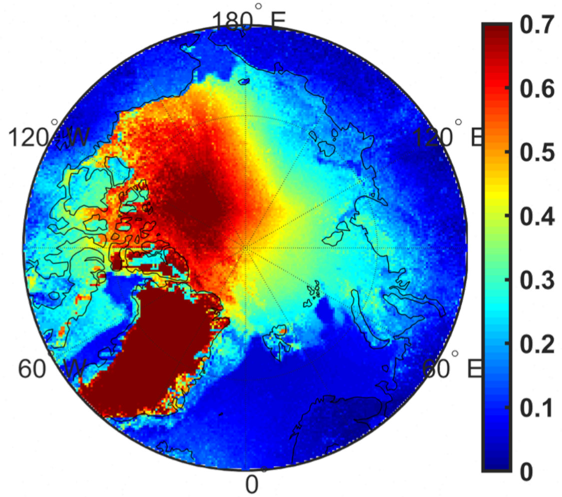
Lee et al., (2020) in revision

Inter-comparison of melt pond products

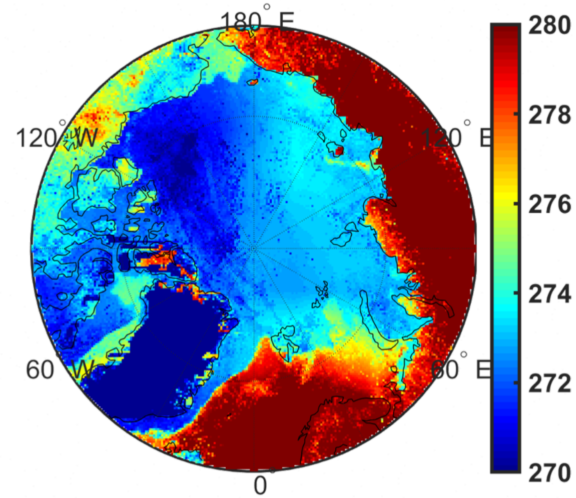
	Rösel et al., (2012) TC	Zege et al., (2014) RSE	Lee et al., (2020) In revision
Sensor	MODIS	MERIS	MODIS
Period	May to first week of Sep. 2000-2011 (8days-based)	June to Sep. 2002-2011 (Daily-based)	*May to Aug. 2000-2019 (Daily-based)
Spatial resolution	12.5km	12.5km	5km
Retrieval method	Artificial Neural Network	Analytically iterative process based on the Newton-Raphson method	Multi-layer Neural Network & Multinomial Logistic Regression
Bands	1,2, and 3	412.5, 442.5, 490, 681.25, 753.75, 865, and 885 nm	Six normalized bands among 1-4
The spatial resolution of initial bands	500m	1000m	250m
Melt pond reference	Melt pond fraction published by Tschudi et al. (2008)		Melt pond classification based on Wright and Polashenski. (2018)

Inter-comparison of melt pond products

Albedo from APPX



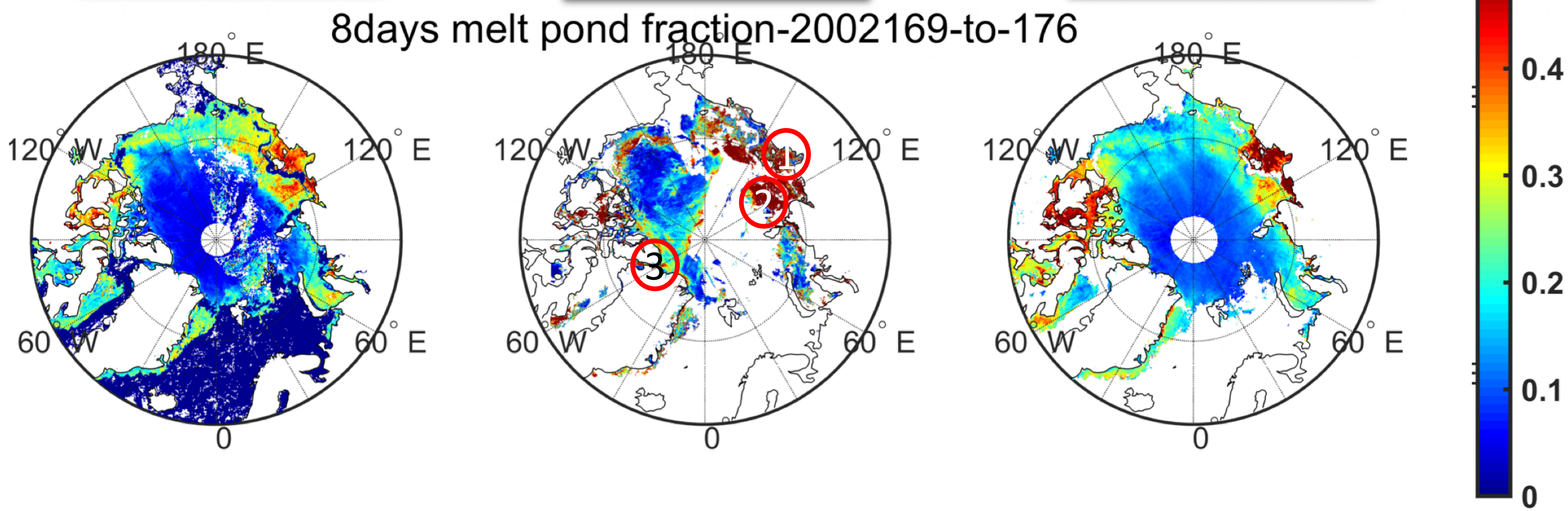
Surface temp. from APPX



Rösel et al. (2012)

Lee et al. (2020)
in revision

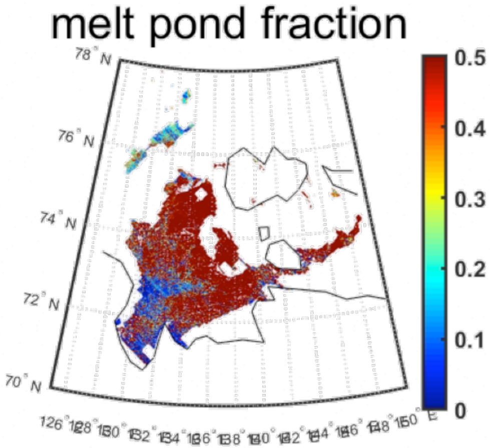
Zege et al. (2014)



Inter-comparison of melt pond products

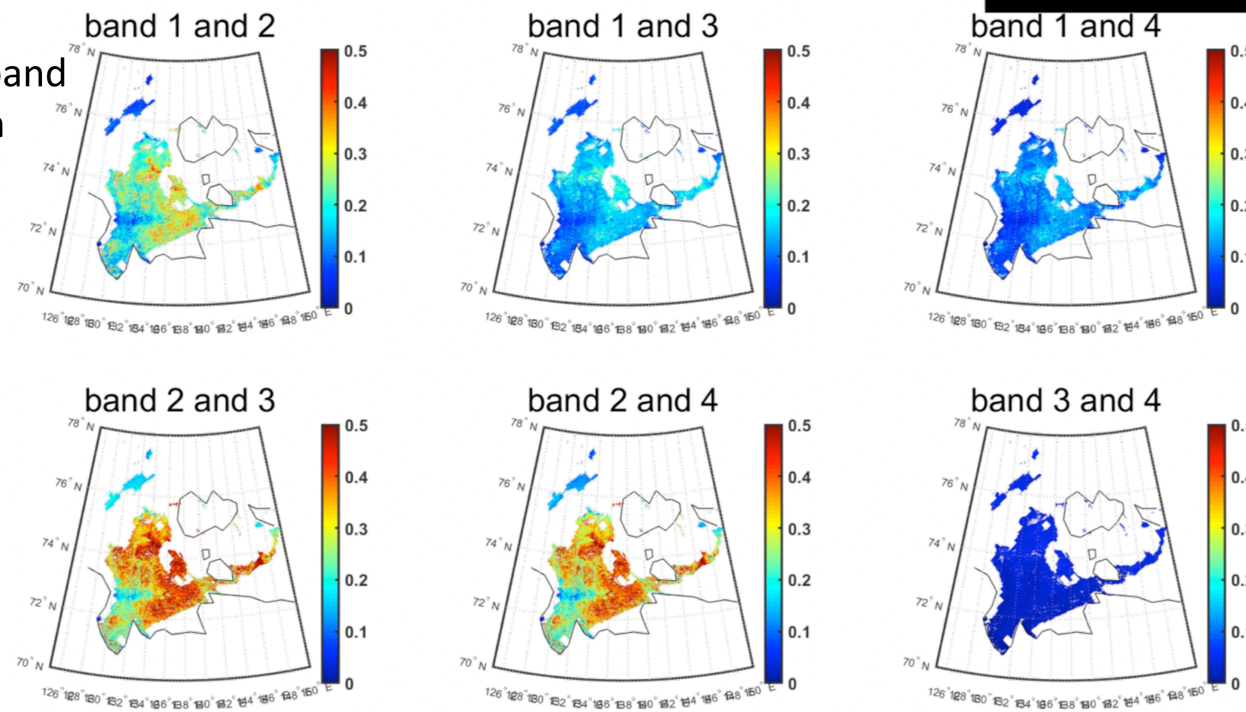
1

18 Jun. (169) 2002
MODIS swath



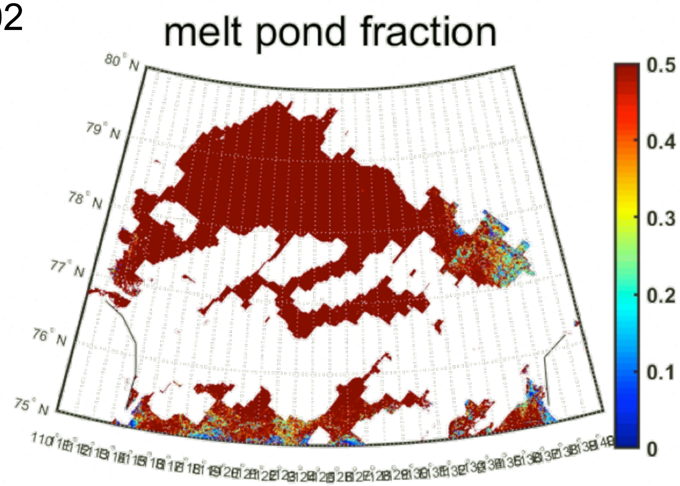
18 Jun. (169) 2002
MODIS RGB

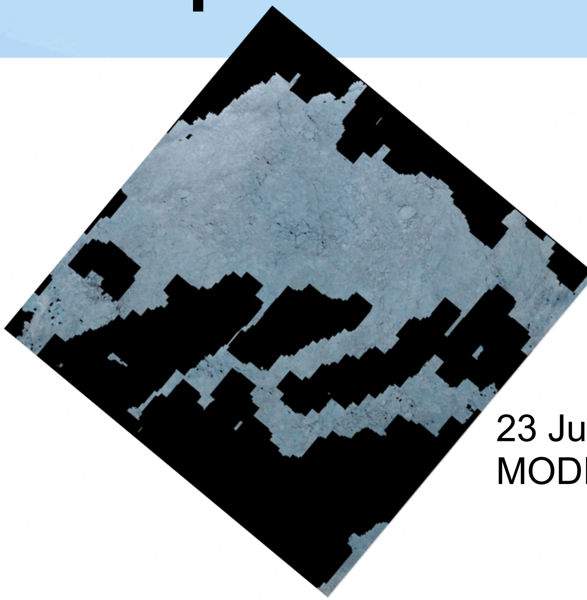
Normalized band differences in page 10



2 Inter-comparison of melt pond products

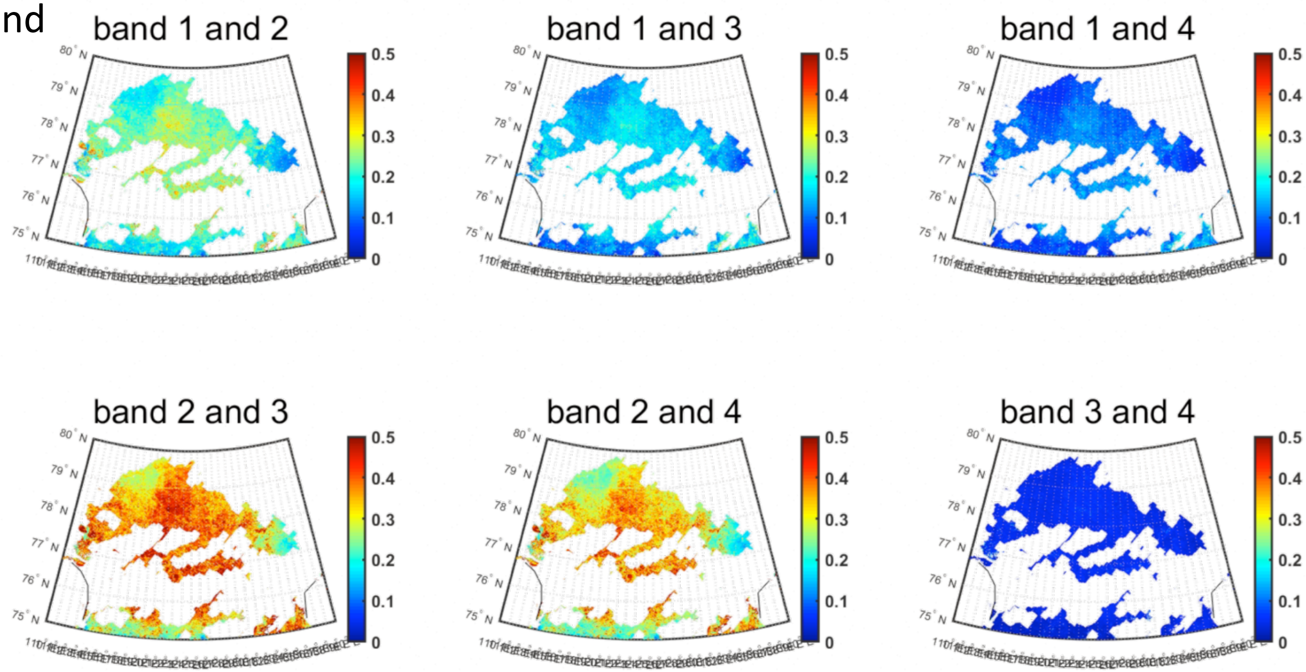
23 Jun. (174) 2002
MODIS swath





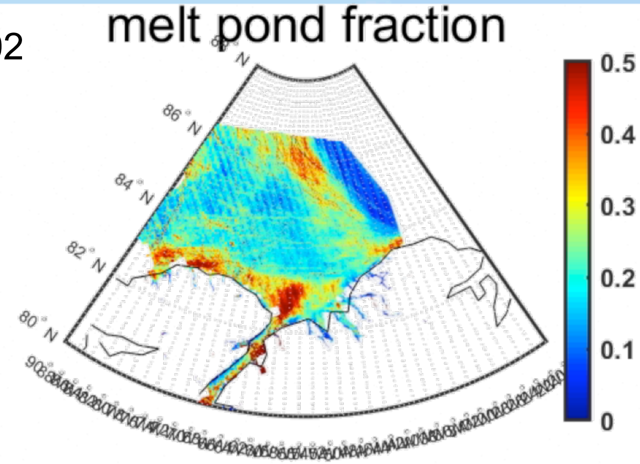
23 Jun. (174) 2002
MODIS RGB

Normalized band differences in page 10



3 Inter-comparison of melt pond products

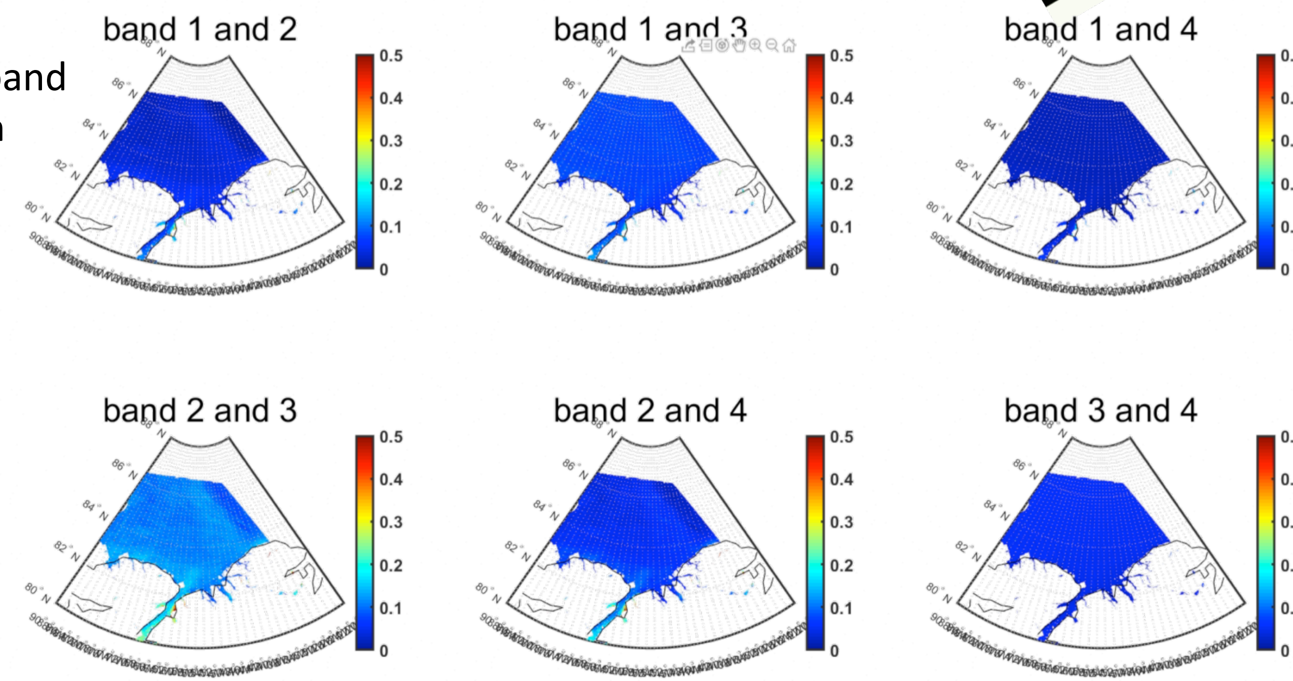
18 Jun. (169) 2002
MODIS swath



Cracks and open water are found

18 Jun. (169) 2002
MODIS RGB

Normalized band differences in page 10



Conclusions

- Each melt pond products show regionally similarly varying.
- Our melt pond fraction is quite sensitive to band 2 (Band 2 is a key band for the retrieval of melt pond in this study).
- Our melt pond fraction is high on broken apart sea ice and marginal sea ice zone.
- Our melt pond fraction likely represents leads and broken apart sea ice as high melt pond fraction.
- The differences in melt pond fraction are likely attributed by melt pond reference used for the retrieval and the spatial resolution of initial main input data.
- Each melt pond products might have pros and cons.
- Each melt pond products might have a different use.

Future plan

- Analyzing the differences after 2002.
- Using high spatial resolution data in common region.
- Analyzing space and time series of melt pond products.
- Analyzing some relationship with sea ice albedo, 2-m temp., and sea ice concentration.

Thank you!!