Automatic sea ice classification using the EM algorithm

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Data Classification

- Overall objective: Automatically categorizes all pixels in an image into thematic classes
- Classification approaches:
  - *Unsupervised* (no training data required)
  - *Supervised*
  - Advanced methods: Semi-supervised, Active learning (exploit unlabeled data)
- Techniques often based on pattern recognition approaches
  - Spectral patterns (spectral intensity values)
  - Spatial patterns (texture, values of "neighbors")
  - Temporal patterns (can be very useful)

Unsupervised Classification

- First determine spectrally separable classes and then define their informational utility (and possibly assign labels)
  - Obtain clusters (automatically determined by the algorithm)
  - Identify/interpret informational values of clusters (manual)
  - Specifically, what does cluster 1 represent, what does cluster 2 represent, etc
  - Redefine input parameters or post-process as needed

Labeling Spectral Classes Obtained from Clustering

Spectral Class	Identity of Spectral Class	Corresponding Desired Information Category
Possible Outcome 1		
1	Water →	Water
2	Coniferous trees →	Coniferous trees
3	Deciduous trees →	Deciduous trees
4	Brushland →	Brushland
Possible Outcome 2		
1	Turbid water →	Water
2	Clear water →	
3	Sunlit conifers →	Coniferous trees
4	Shaded hillside conifers →	
5	Upland deciduous →	Deciduous trees
6	Lowland deciduous →	
7	Brushland →	Brushland
Possible Outcome 3		
1	Turbid water →	Water
2	Clear water →	
3	Coniferous trees →	Coniferous trees
4	Mixed coniferous/deciduous →	
5	Deciduous trees →	Deciduous trees
6	Deciduous/brushland →	Brushland

Ideal result

Likely result

Problematic result:
Spectral classes related to more than one information category

Supervised Classification

- Utilize information from *labeled* data which are associated with each class
  - Labeled data in remote sensing often referred to as "spectral signatures"
  - Labeled data separated into *training* and *test* data
    - Training data employed to "learn" the classifier
    - Test (Validation) data used to evaluate the classification results
  - Derived from spectral values obtained from *field data* or extracted from the image data with *knowledge* of class ground locations of classes
    - Commercial remote sensing analysis software such as Erdas and ENVI provide capability both for ingesting external files and extraction of labeled samples from image data

Supervised Classification

- Define useful information categories (training) and then examine their spectral separability (classification)
- Classification step is automatic, the training effort is anything but automatic! It is both art and science (and often iterative)
  - Objective of training process: assemble a set of statistics (mean, covariance, ranges, etc) to describe the response pattern for each land cover category to be classified
  - Must develop training statistics for all spectral classes making up each informational class of interest

Landsat Program History

- July 23, 1972: Landsat 1 launched
- 1983: Operations of Landsat assigned to NOAA
- Landsats 1, 2, 3: Return Beam Vidicon (RBV) camera (analog system similar to television video) and Multispectral Scanner (MSS)
- Landsat 4, 5: MSS and TM (Thematic Mapper) scanners
- Landsat Program commercialized in 1985 – EOSAT
- 1993: Landsat 6 launched, but satellite failed to obtain orbit. "Deep sea probe in Indian Ocean"
- October 1996, EOSAT purchased by Space Imaging
- April 1999: Landsat 7 with Enhanced Thematic Mapper (ETM)
- Feb 2013: Landsat 8 (LDCM)

Landsat Earth Resources Satellites

- First earth resources satellite to provide near global coverage of the earth's surface on a regular, predictable basis
- Primary Applications: vegetation mapping, geology, agriculture
- Landsats 1-3
  - Launched in 1972, 1975, 1978
  - Altitude 920 km
  - Period: 103 min
  - Repeat Cycle: 18 days
  - Primary Instrument: Multispectral Scanner (MSS)
    - 4 bands on Landsat 1, 2 - green, red, 2 near infrared
    - 5 bands on Landsat 3 – green, red, 2 near infrared, thermal
    - Spatial resolution: 79 m (237 for thermal band)
    - Dynamic range: 7 bit for bands 1-3 (6 bit for band 4)

Landsat 1

Landsat 1, 2, 3 Spectral Bands

Band (Sensor)	Wavelength (um)	Spectral Response	Spatial Resolution (m)
1 (RBV)	0.475 – 0.575	Blue – Green	79
2 (RBV)	0.58 – 0.68	Red	79
3 (RBV)	0.69 – 0.83	Near IR	79
4 (MSS)	0.5 – 0.6	Green	79
5 (MSS)	0.6 – 0.7	Red	79
6 (MSS)	0.7 – 0.8	Near IR	79
7 (MSS)	0.8 – 1.1	Near IR	79

Landsat 4, 5, 7

- Landsats 4, 5, 7
- Launched in 1982, 1984, 1999 (Landsat 6 lost on launch – notice the time gap!)
- Altitude 705 km
- Period: 98.9 min
- Repeat Cycle: 16 days
- Primary Instrument: Thematic Mapper
  - 7 bands – blue, green, red, near infrared, 2 mid-infrared, thermal
  - Spatial resolution: 30 m (thermal 120 m)
  - Swath width: 185 km
  - Dynamic range: 8 bit
- Landsat 7 called *Enhanced Thematic Mapper* (ETM+) with panchromatic band (15m resolution, .52-.90 micron band)

Landsat 4 & 5 TM Bands

Band (Sensor)	Wavelength (um)	Spectral Response	Spatial Resolution (m)
1	0.45 – 0.52	Blue	30
2	0.52 – 0.60	Green	30
3	0.63 – 0.69	Red	30
4	0.76 – 0.90	Near IR	30
5	1.55 – 1.75	Mid IR	30
6	10.40 – 12.50	Thermal IR	120
7	2.08 – 2.35	Mid IR	30

Landsat 7 ETM+ Bands

Band (Sensor)	Wavelength (um)	Spectral Response	Spatial Resolution (m)
1	0.45 – 0.52	Blue	30
2	0.52 – 0.60	Green	30
3	0.63 – 0.69	Red	30
4	0.76 – 0.90	Near IR	30
5	1.55 – 1.75	Mid IR	30
6	10.40 – 12.50	Thermal IR	60
7	2.08 – 2.35	Mid IR	30
8	0.52 – 0.90	Panchromatic	15

Landsat 8 (formerly LDCM) Background

- Landsat 8 (formerly the Landsat Data Continuity Mission, LDCM) planned as the follow-on mission to Landsat 7
- NASA and the Dept. of Interior (DOI) / U.S. Geological Survey (USGS) were interagency partners in the LDCM
  - By virtue of an October, 2000 revision to a 1994 Presidential Decision Directive
- NASA and the DOI/USGS plan to implement the LDCM by procuring data from a privately owned and privately operated remote sensing system.
- Contract to Boeing cancelled by NASA in mid 2003.
- New RFI announced on August 5, 2004.
- Temporary plans to launch on NPOESS – infeasible
- Contract awarded to Ball Aerospace in 2007 for 2013 launch

Landsat 8 Overview

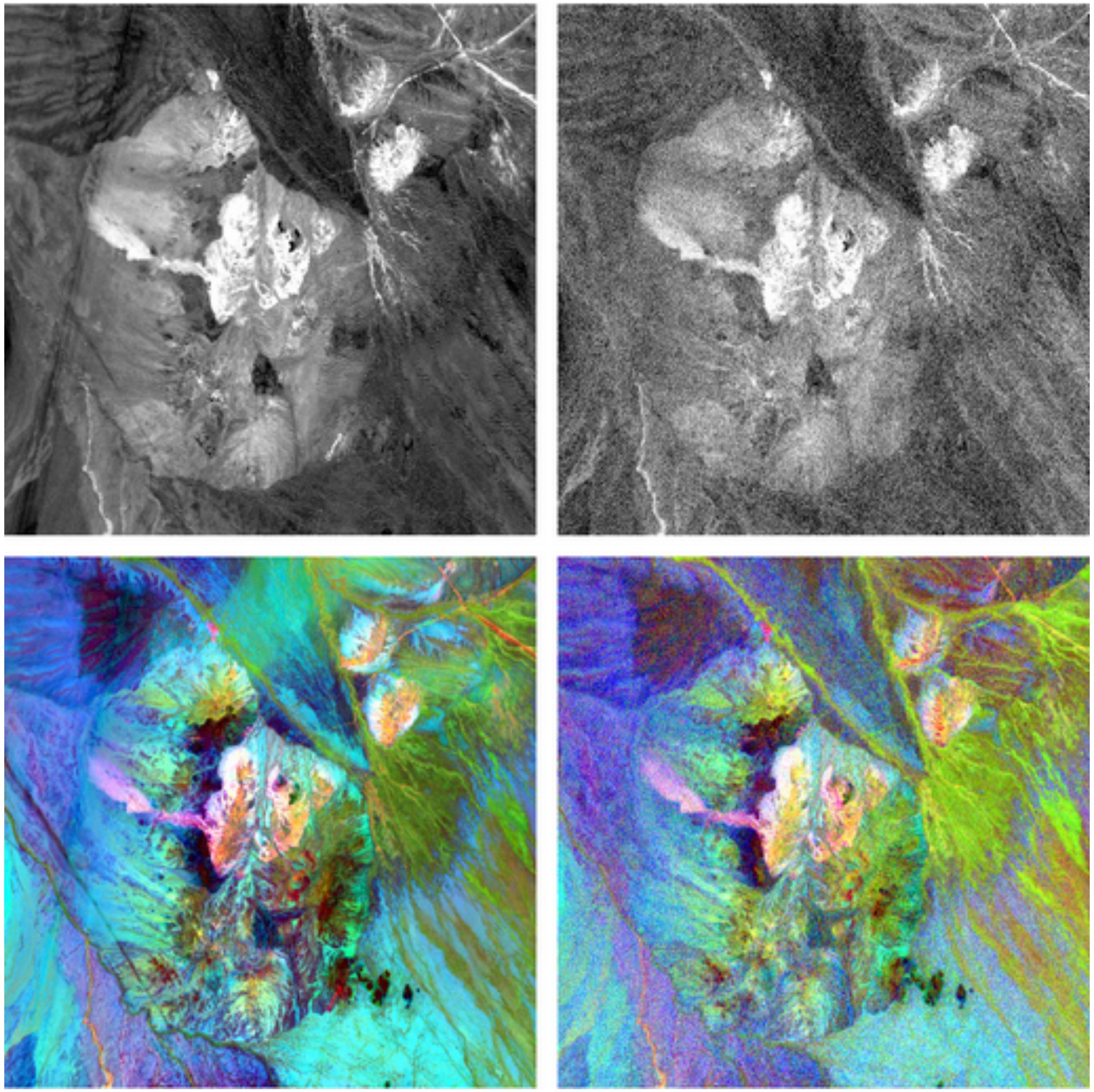
- Landsat 8 was launched on February 11, 2013, from Vandenberg Air Force Base, California
- The Landsat 8 satellite payload consists of two science instruments – the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). These two sensors provide seasonal coverage of the global landmass
- Landsat 8 was developed as a collaboration between NASA and USGS. NASA led the design, construction, launch, and on-orbit calibration phases, during which time the satellite was called the Landsat Data Continuity Mission (LDCM)
- USGS took over routine operations on May 30, 2013, and the satellite became Landsat 8

Landsat 8 OLI Spectral Bands

Band (Sensor)	Wavelength (um)	Spectral Response	Spatial Resolution (m)
1	0.433 – 0.453	Coastal Aerosol	30
2	0.450 – 0.515	Blue	30
3	0.525 – 0.600	Green	30
4	0.630 – 0.680	Red	30
5	0.845 – 0.885	Near IR	30
6	1.560 – 1.660	SWIR	30
7	2.100 – 2.300	SWIR	30
8	0.500 – 0.680	Panchromatic	15
9	1.360 – 1.390	Cirrus	30
10	10.3 – 11.3	Thermal IR	100 (resampled to 30)
11	11.5 – 12.5	Thermal IR	100 (resampled to 30)

Landsat 7 vs Landsat 8

Landsat 8 Landsat 7



The data quality is a marked improvement at 16-bits in comparison to previous Landsat instruments at 8-bits. The noise levels are drastically reduced and features are much better defined in Landsat 8 data.

Objectives

- Supervised classification has proven *effective tools for automatic generation* of land cover maps of extended areas
- Remote sensing data acquired *periodically* make it possible to develop monitoring systems aimed at mapping the land cover classes
- From an operational point of view, it requires a *suitable training set* and hence of ground truth
  - The collection of a reliable ground truth is usually an *expensive task*
  - It is *not possible* to rely on training data as frequently as required to ensure an efficient monitoring
  - This is a serious drawback for the operational monitoring system

Landsat Archives in Polar Regions

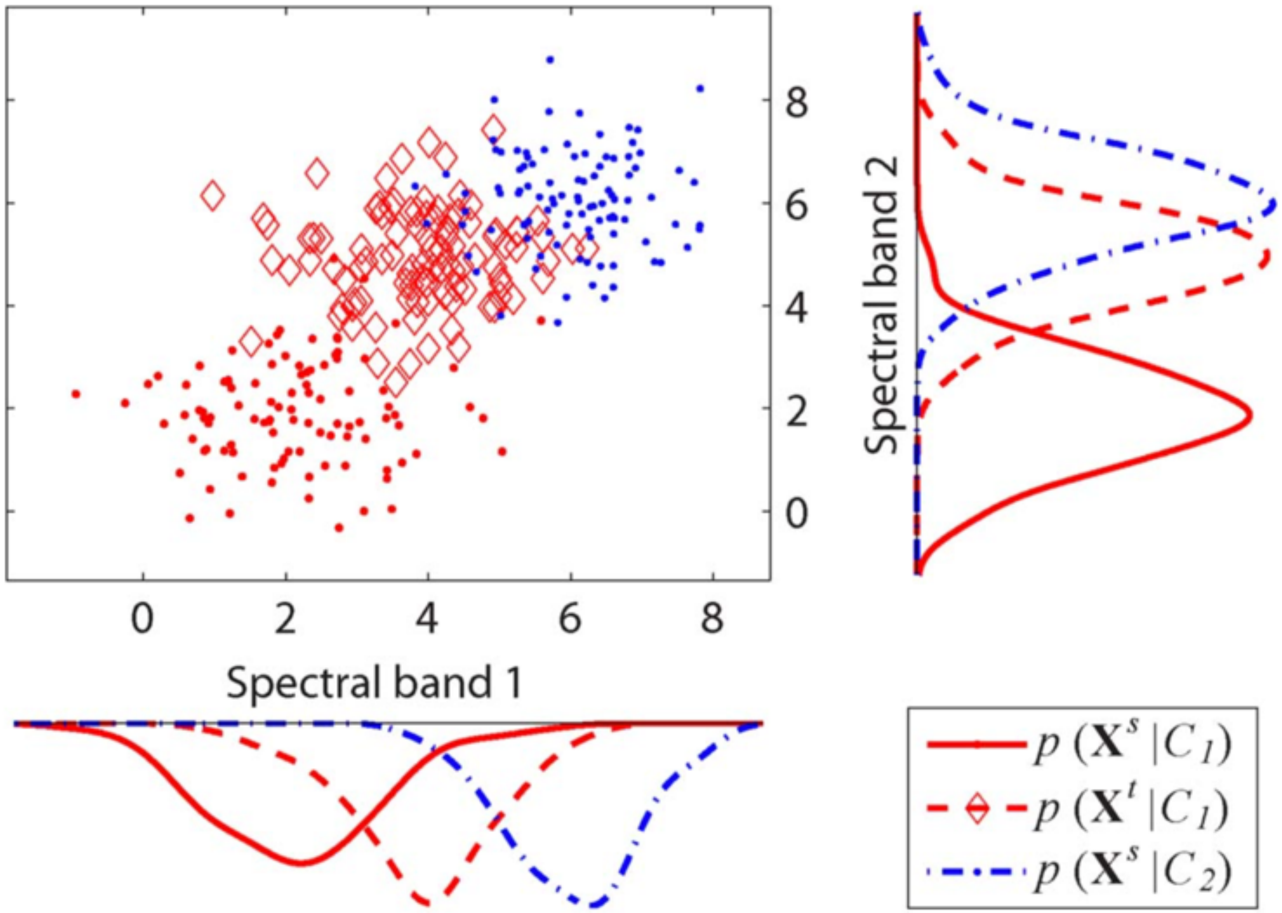
- Landsat 8 images over high latitude areas (> 60 deg)
  - 180km swath per scene
  - 74M pixels per band
  - 2GB per scene
  - Approx. 45,000 images per year
  - Approx. 13,000 cloud free images (less than 10% cloud cover) per year

Multitemporal Image Classification

- Analysis of land cover signatures from images acquired over the same (or similar) location at different times
- *Spectral drift (or shift)** limits effective utilization of multitemporal images

  **Nonstationarity of spectral signatures in multitemporal data*
- *Why?* Differences in the atmospheric and light conditions, sensor nonlinearities, different levels of moisture, etc

Toy Example of Spectral Shift



H. L. Yang, "Spectral and Spatial Proximity-Based Manifold Alignment for Multitemporal Hyperspectral Image Classification," IEEE Trans. Geosci. Remote Sensing, vol. 54, no. 1, pp. 51–64, Oct. 2015.

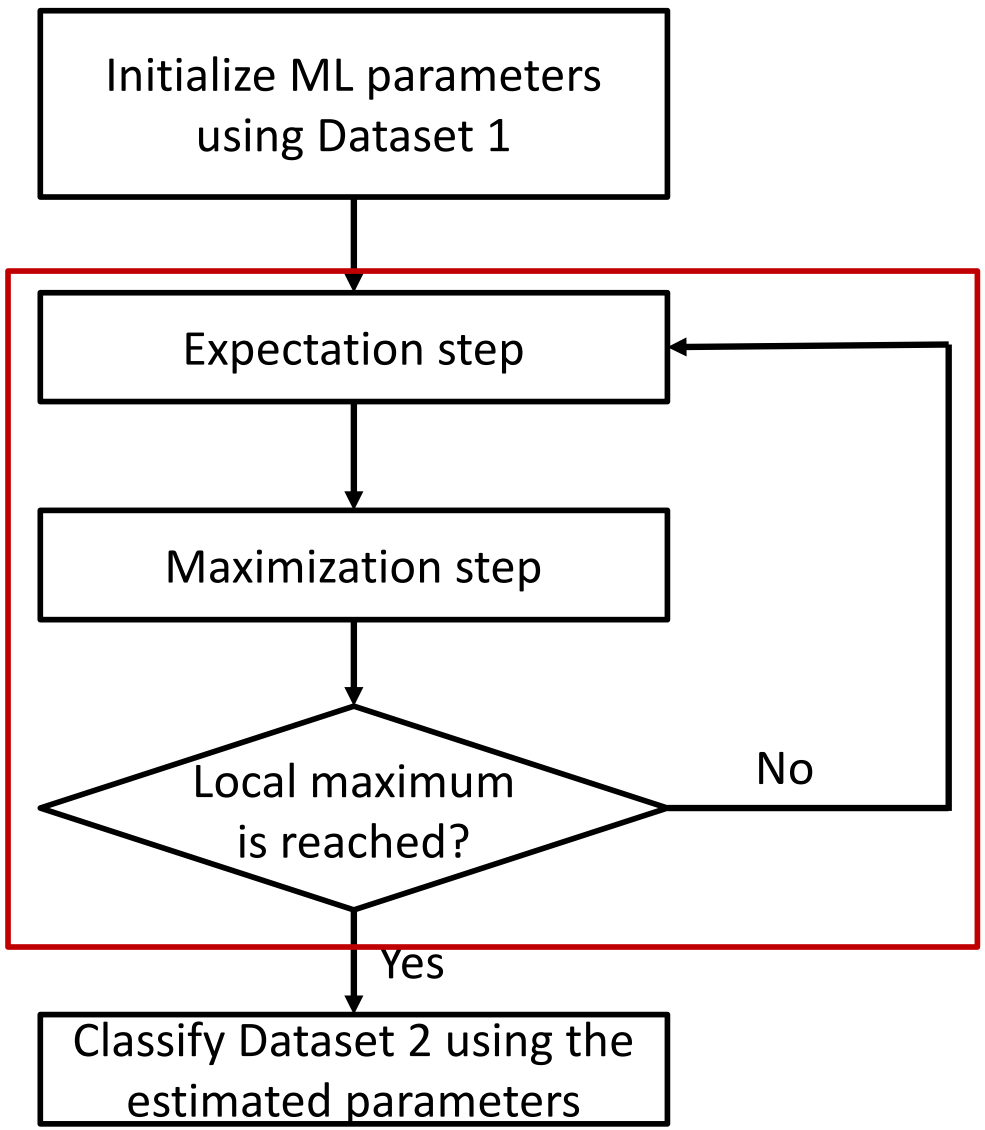
EM Algorithm

- The expectation maximization (EM) algorithm
  - An iterative method for finding *maximum likelihood (ML)* or *maximum a posteriori (MAP)* estimates of parameters
  - Two iterative steps

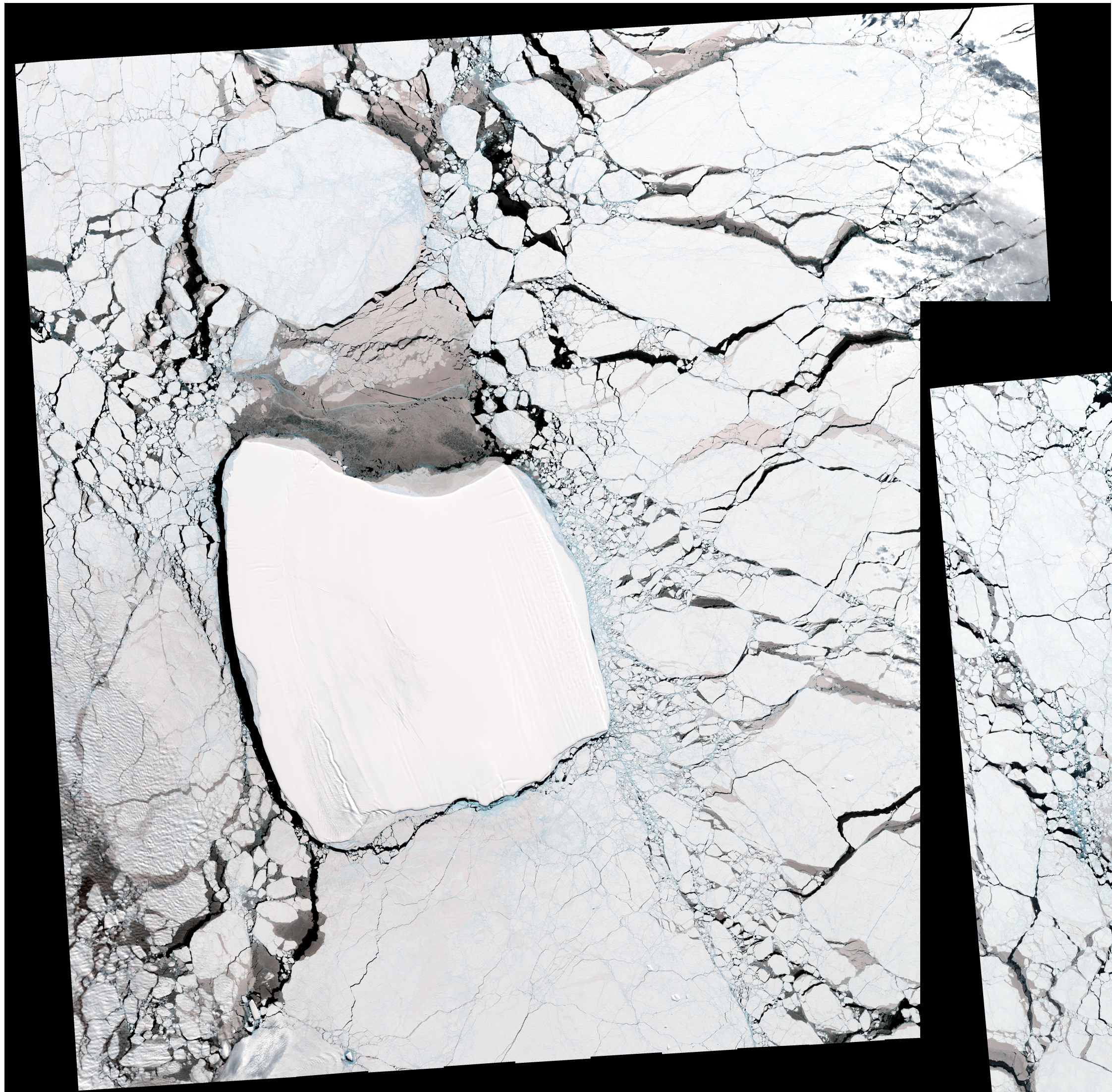
    1) E (expectation) step: Creates a function for the expectation of the log-likelihood

    2) M (maximization) step: Computes parameters maximizing the expected log-likelihood

Workflow of EM Algorithm

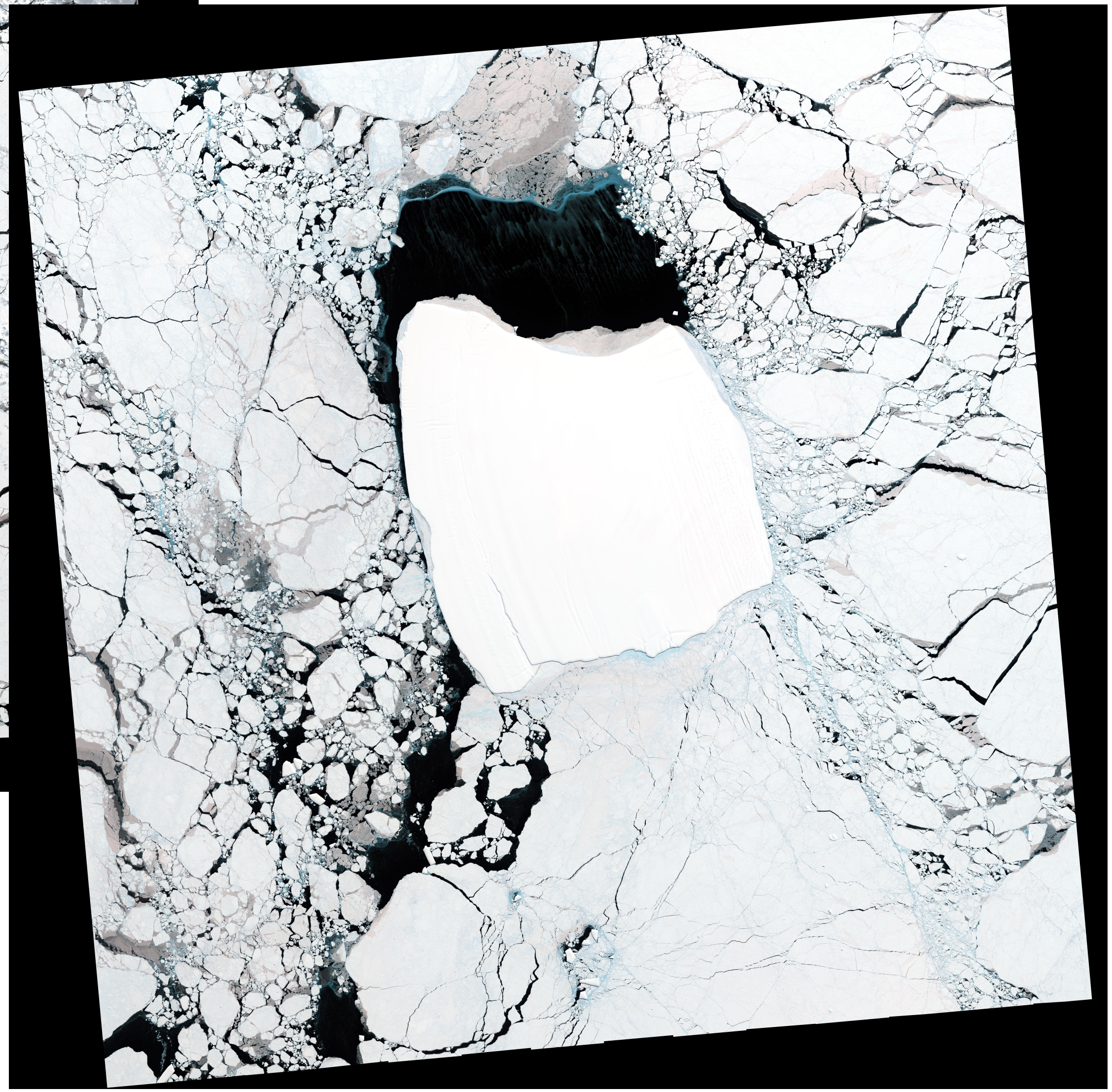


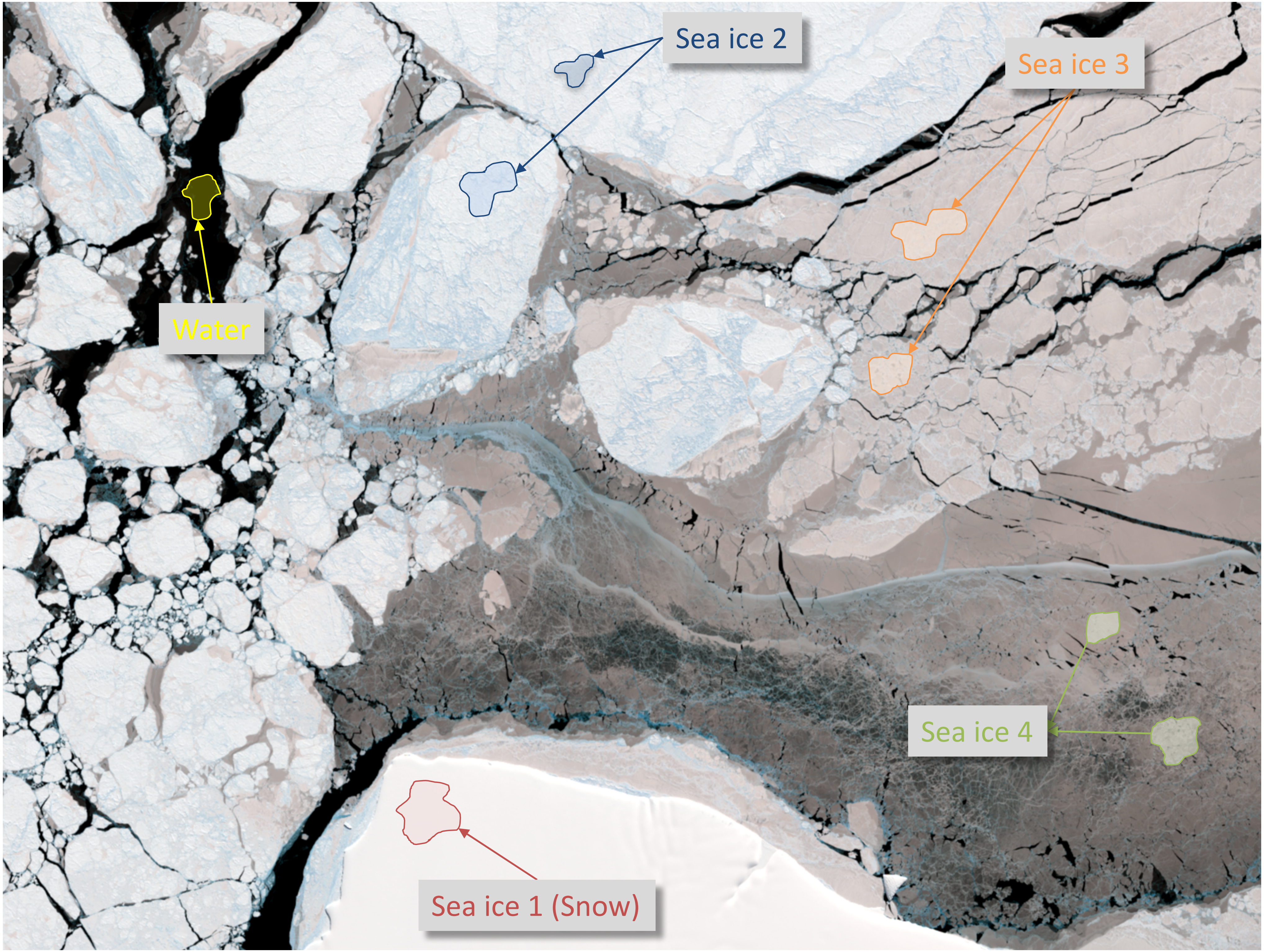
Landsat 8 OLI



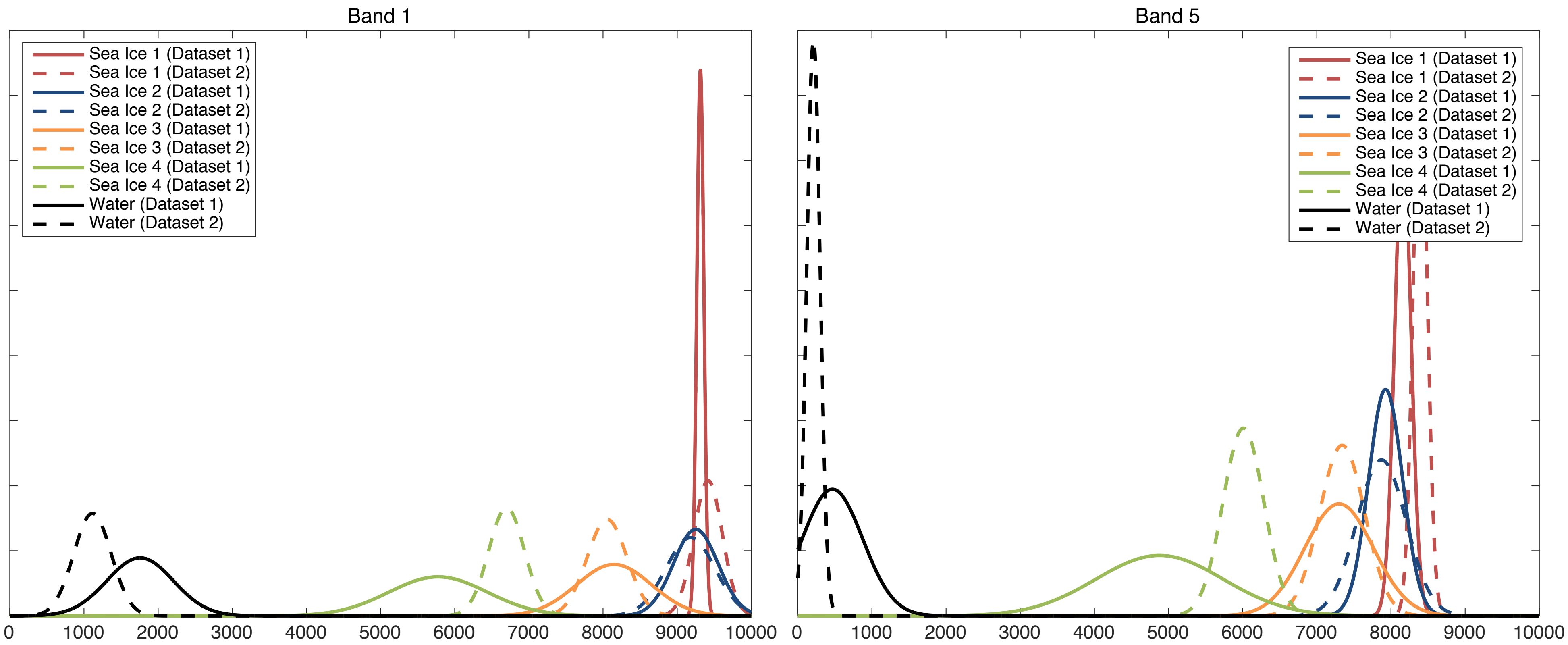
Nov 13, 2015 (Dataset 1)

Nov 20, 2015 (Dataset 2)

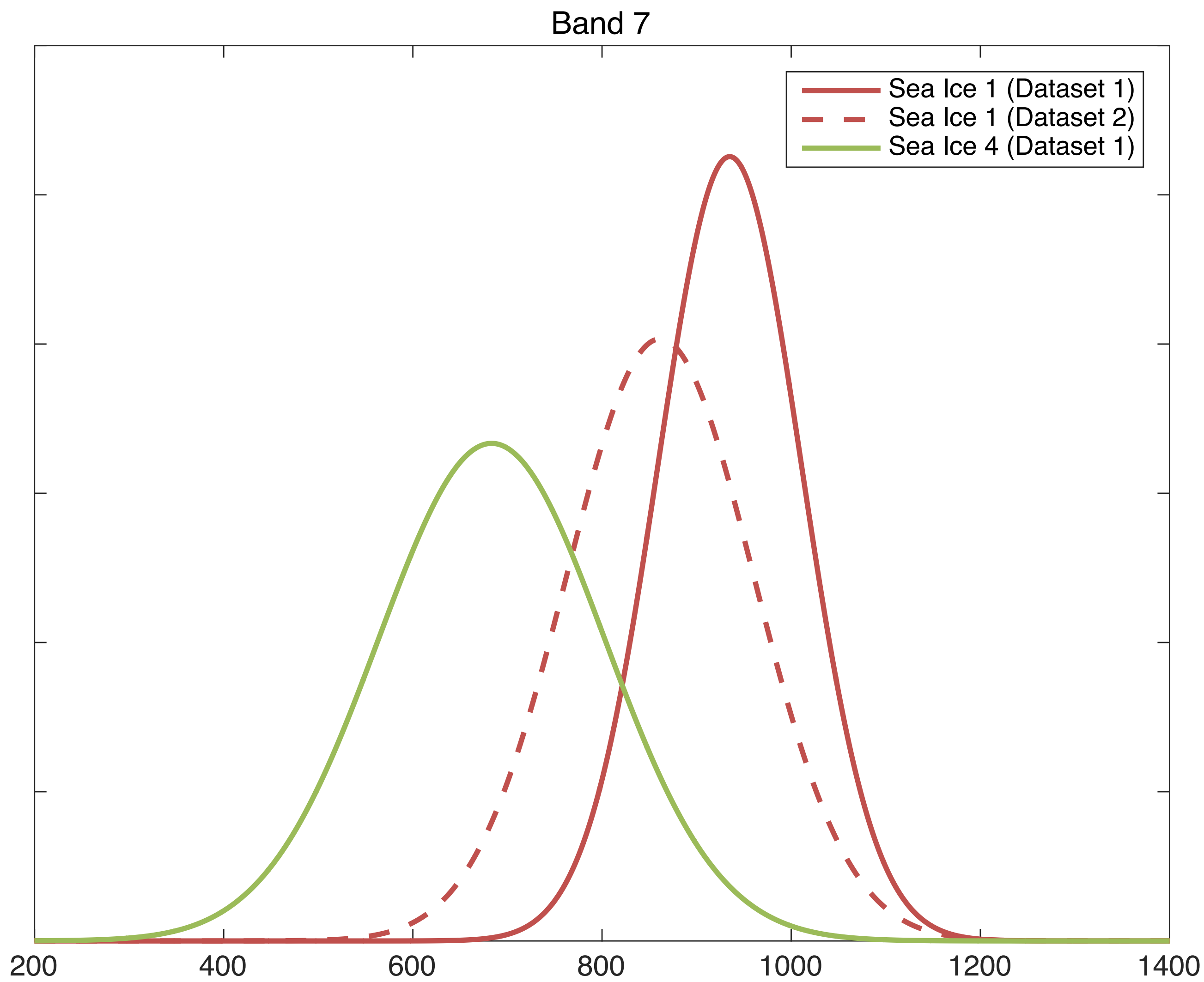



Sea ice 2
Sea ice 3
Water
Sea ice 4
Sea ice 1 (Snow)

Spectral Drift in Multi-temporal Data



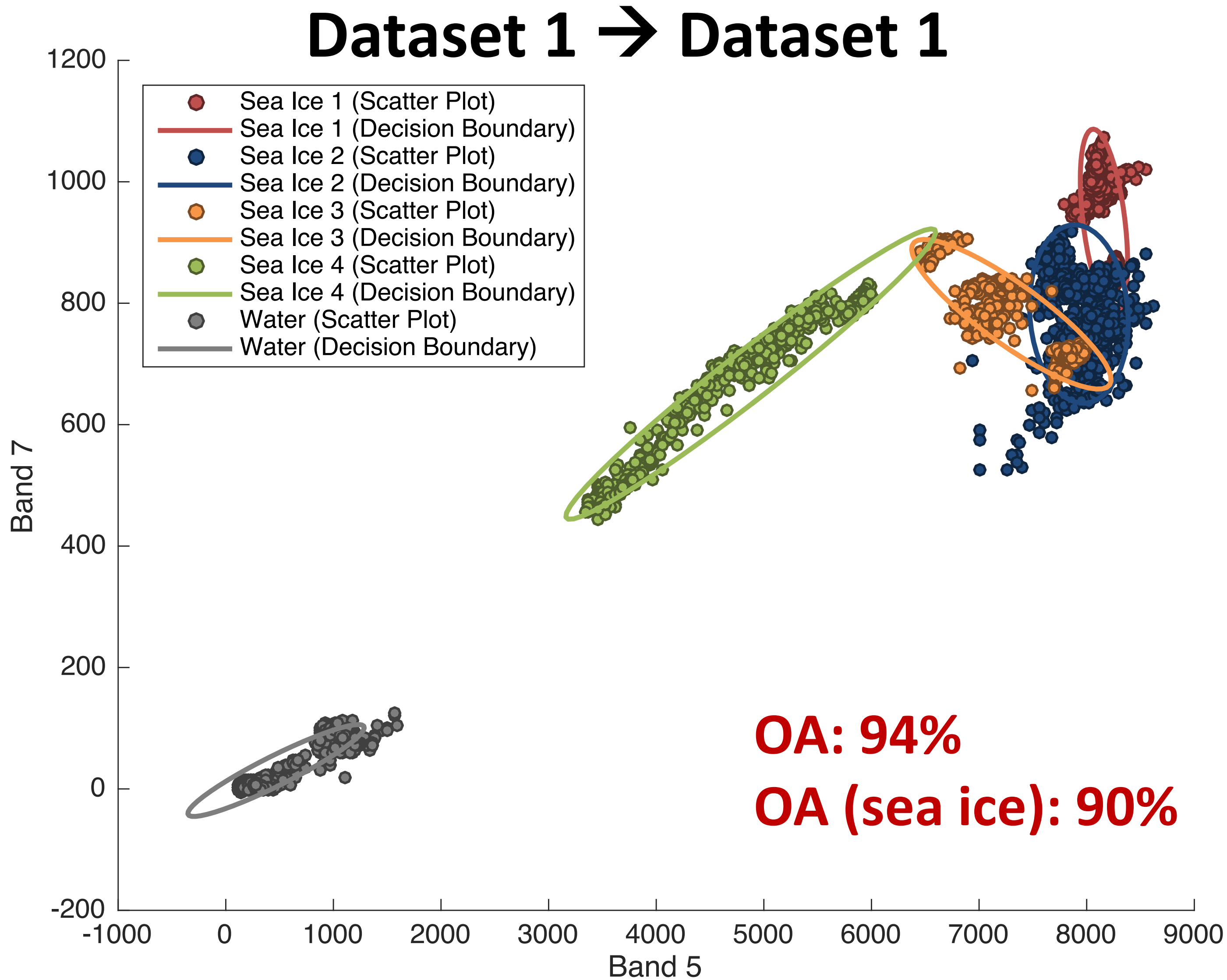
Spectral Drift in Multi-temporal Data



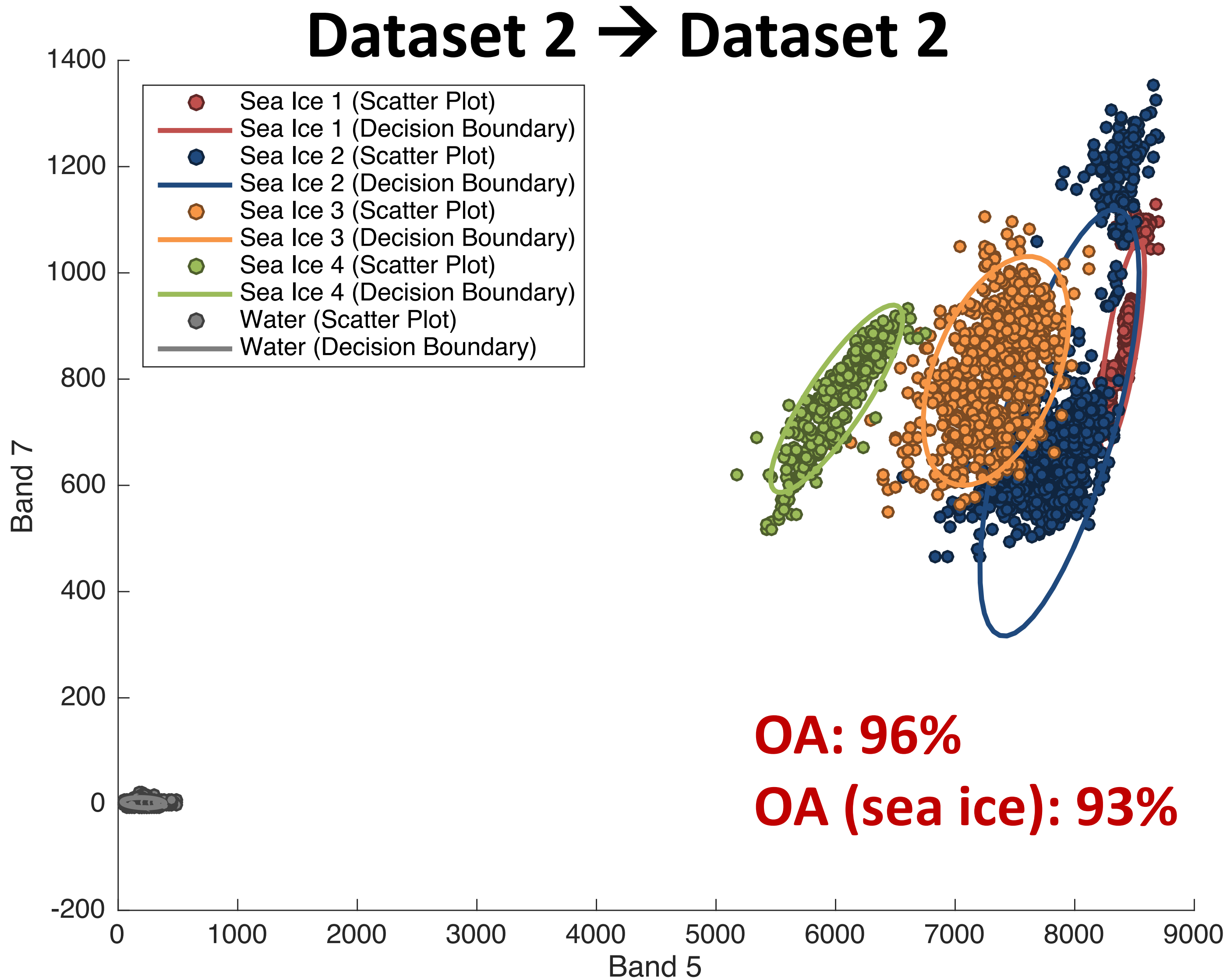
Classification Results

		Classification accuracy (%)		
Training set		Dataset 1	Dataset 2	
Test set		Dataset 1	Dataset 2	
Class	Sea ice 1	97.40	98.60	
	Sea ice 2	76.60	84.40	
	Sea ice 3	96.80	98.20	
	Sea ice 4	100.00	99.80	
	Water	100.00	100.00	
Overall accuracy		94.16	96.20	

Distributions of Classes

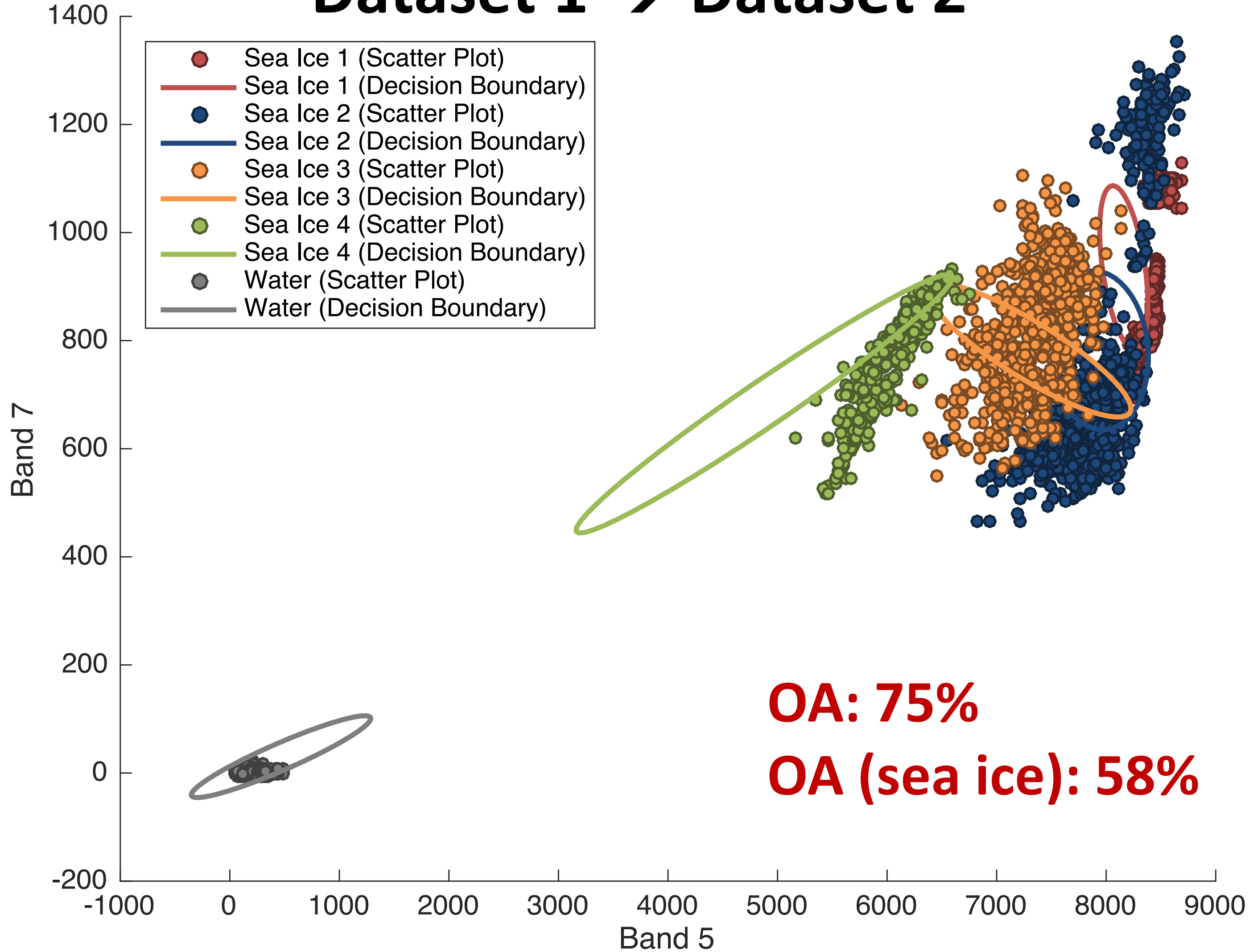


Distributions of Classes



Distributions of Classes

Dataset 1 → Dataset 2

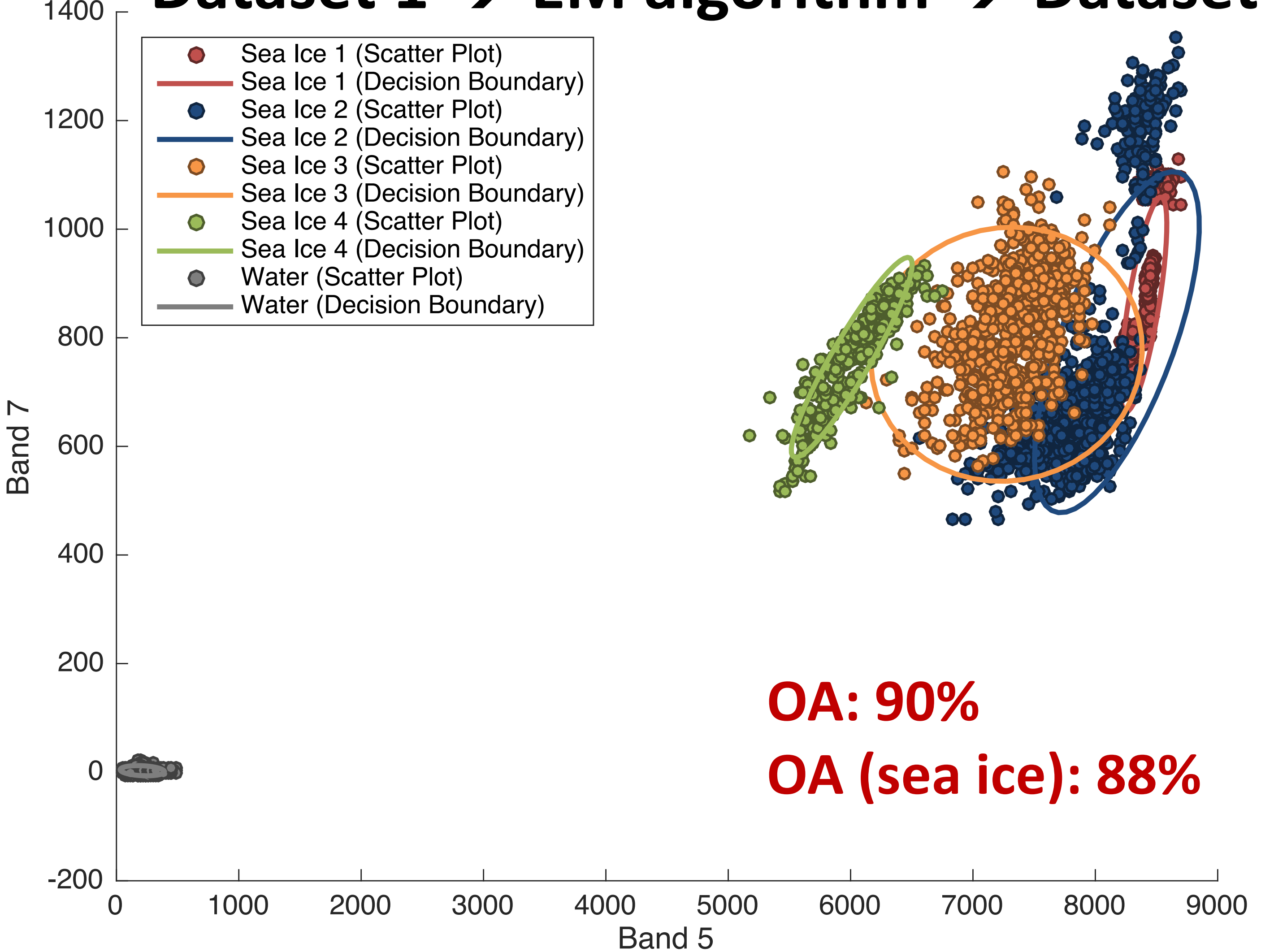


Classification Results

		Classification accuracy (%)			
Training set		Dataset 1	Dataset 2	Dataset 1	Dataset 1 (EM)
Test set		Dataset 1	Dataset 2	Dataset 2	Dataset 2
Class	Sea ice 1	97.40	98.60	32.80	89.20
	Sea ice 2	76.60	84.40	55.00	82.20
	Sea ice 3	96.80	98.20	89.00	100.00
	Sea ice 4	100.00	99.80	99.60	81.00
	Water	100.00	100.00	100.00	100.00
Overall accuracy		94.16	96.20	75.28	90.44
Accuracy of sea ice class		90.27	93.73	58.93	88.10

Distributions of Classes

Dataset 1 → EM algorithm → Dataset 2



OA: 90%

OA (sea ice): 88%

Conclusions

- EM algorithm successfully incorporated with multi-temporal remote sensing images to improve classification accuracy
  → appropriate for automatic sea ice classification
- More datasets (e.g. different regions/dates, etc) should be evaluated
- Field campaigns to create label data are required
- Recent advances such as semi-supervised and active learning are worthwhile to utilize

Thank you!