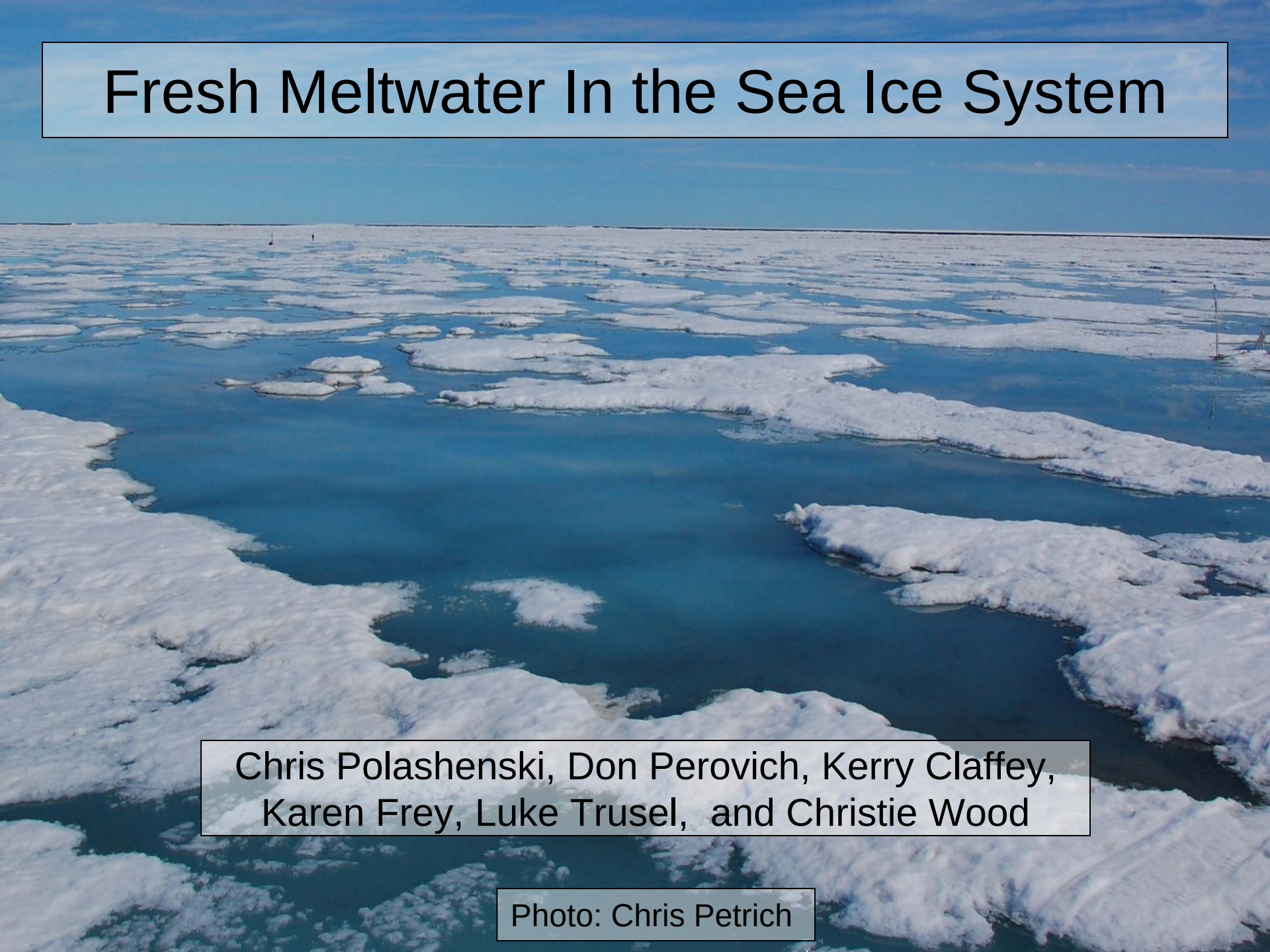
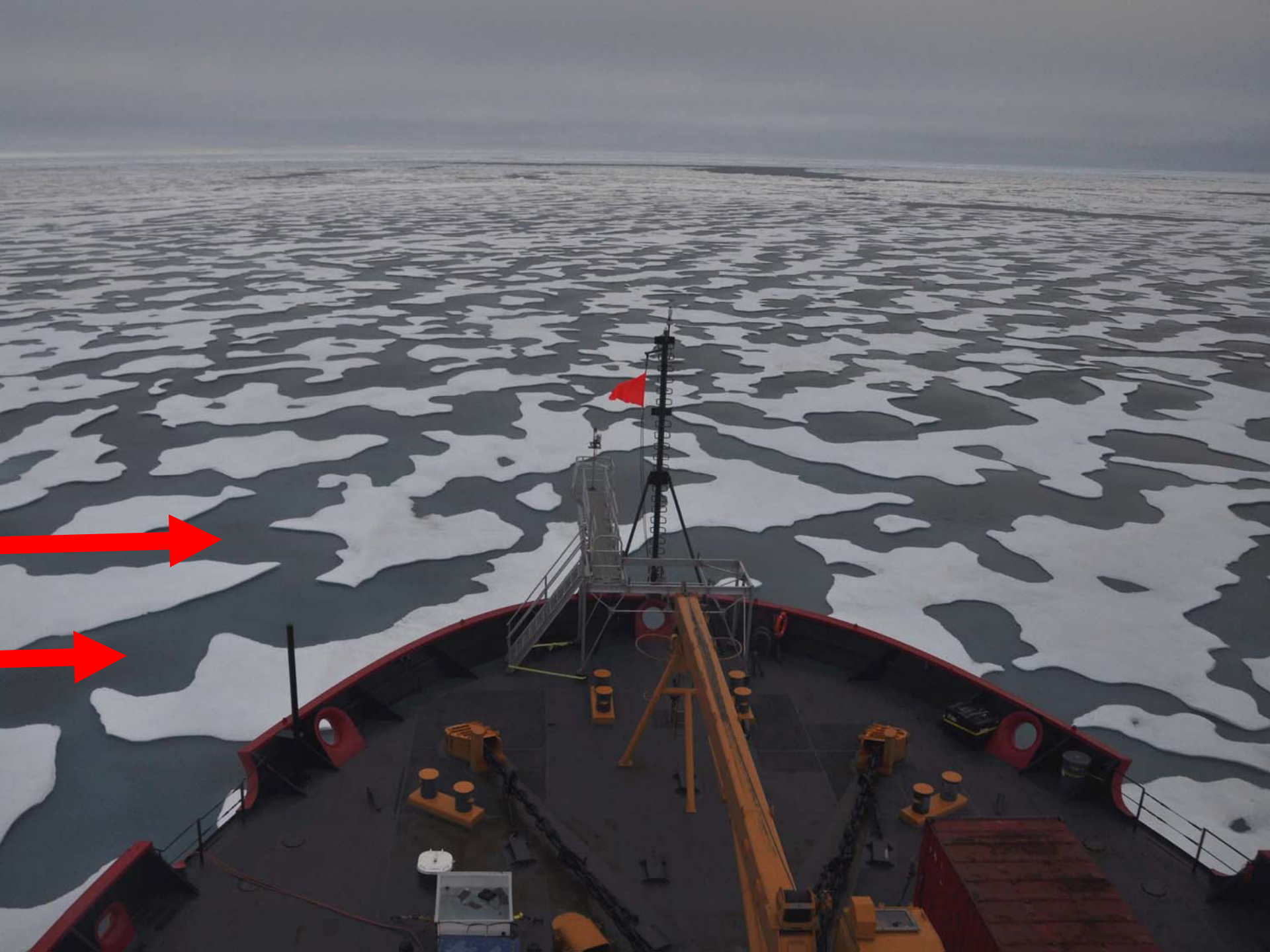
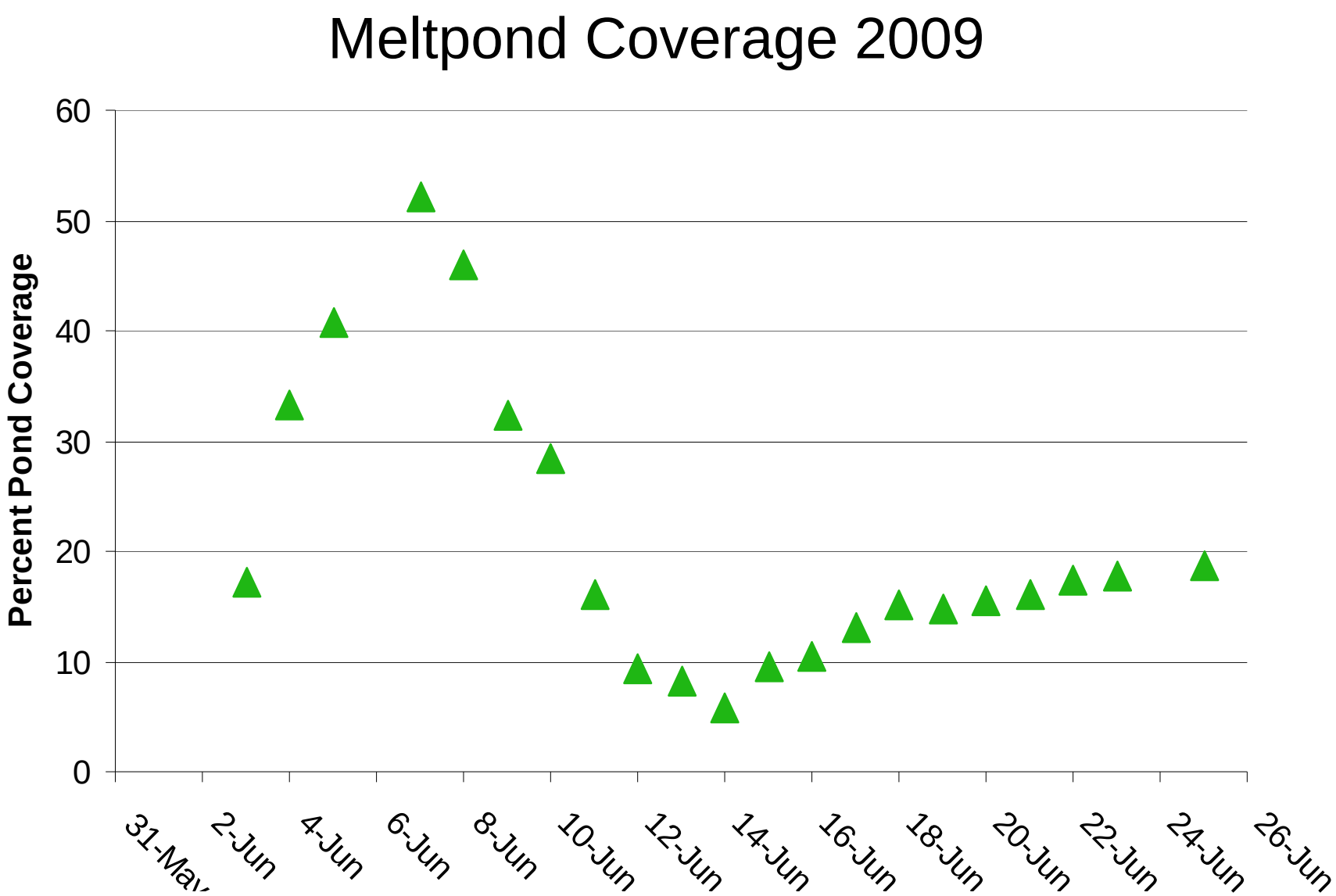
Fresh Meltwater In the Sea Ice System



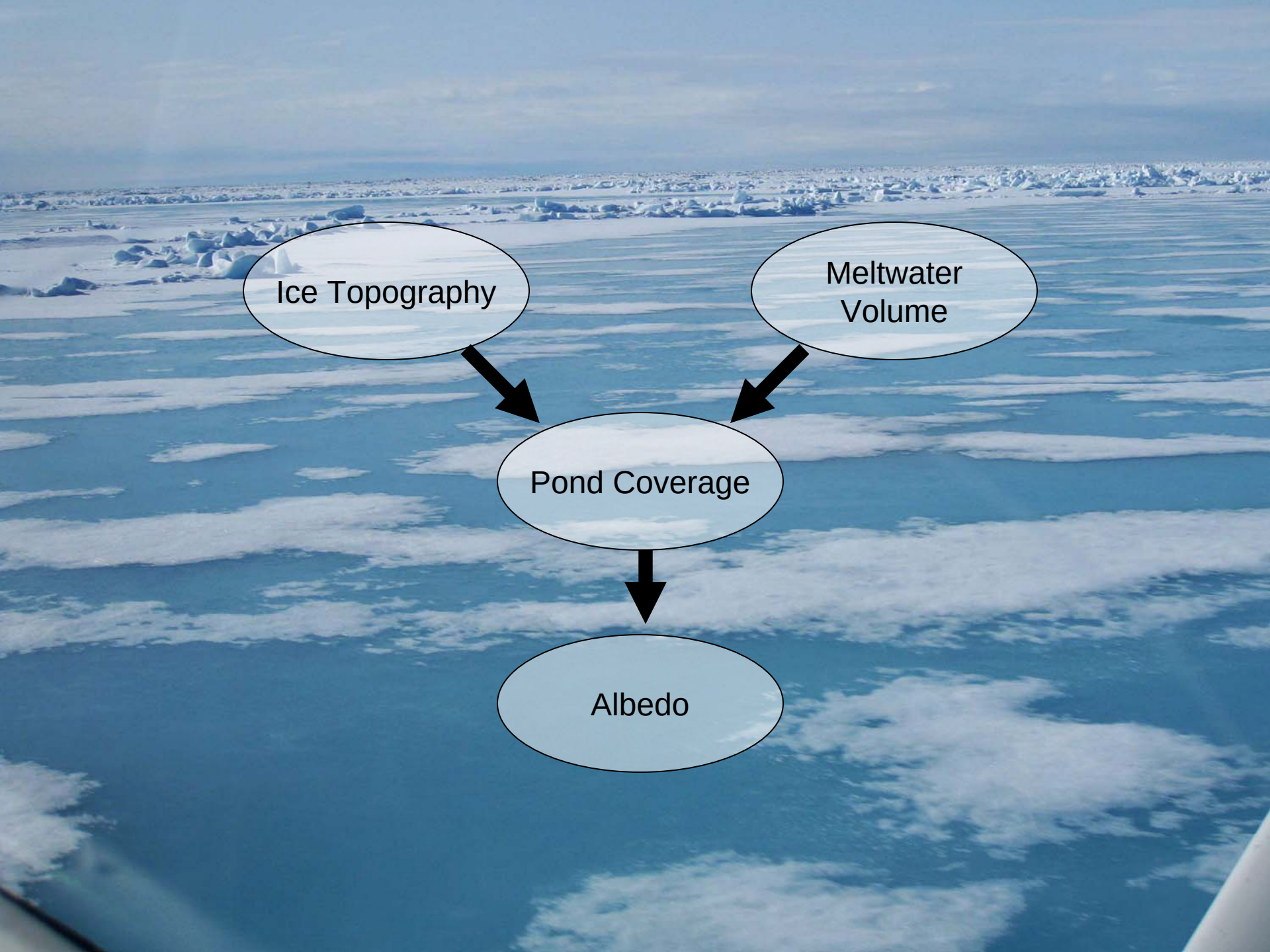
Chris Polashenski, Don Perovich, Kerry Claffey,
Karen Frey, Luke Trusel, and Christie Wood

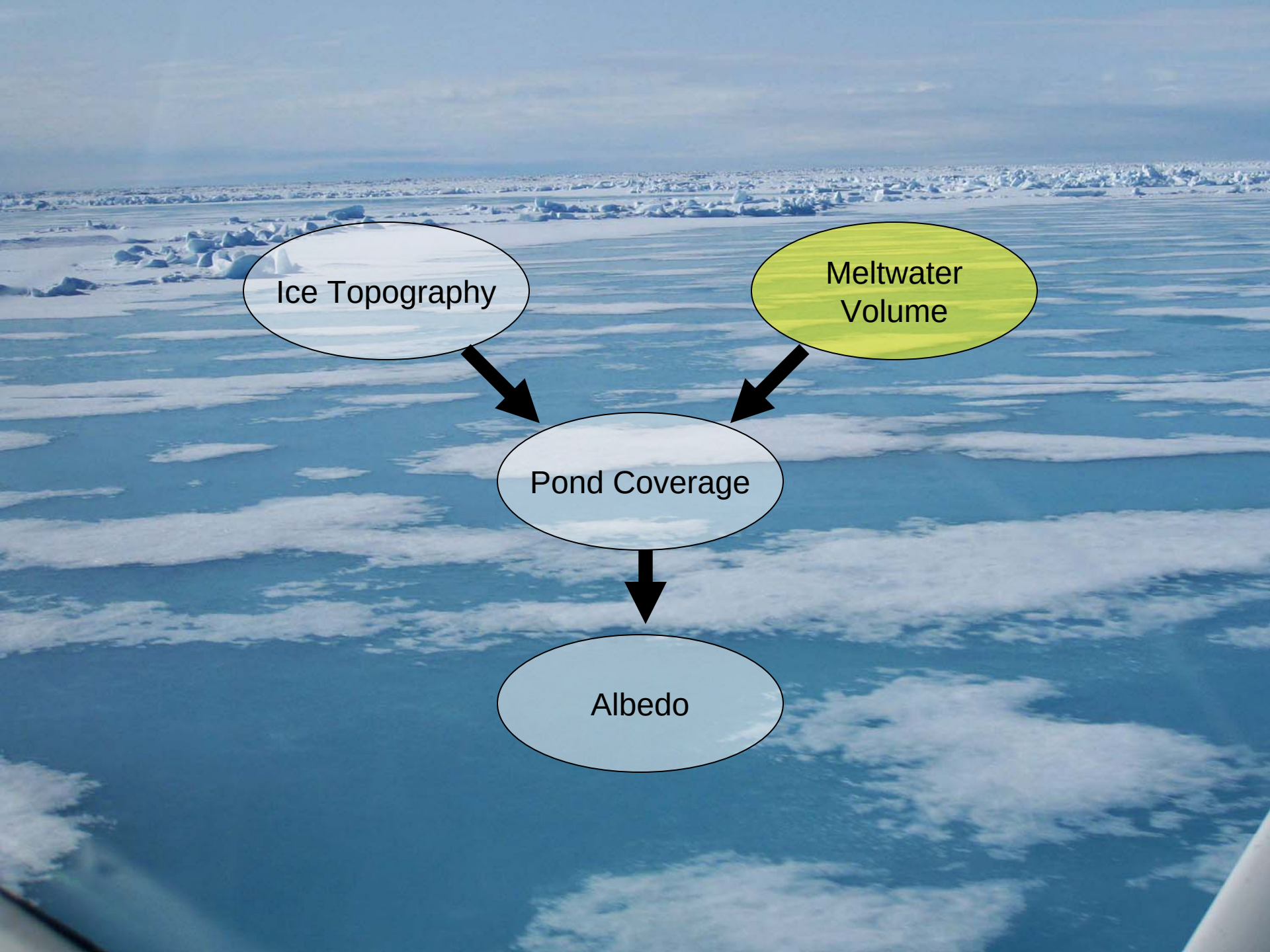
Photo: Chris Petrich

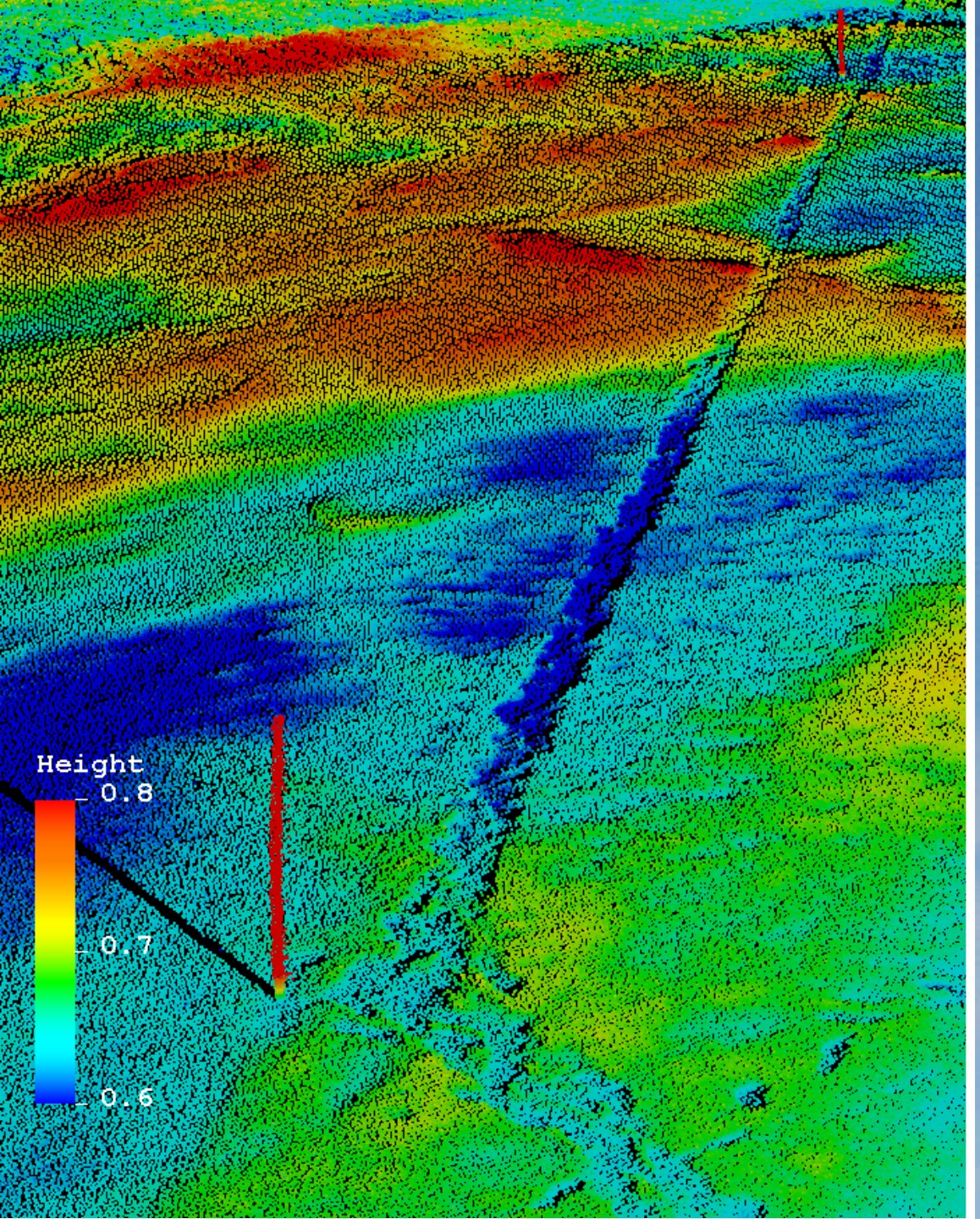




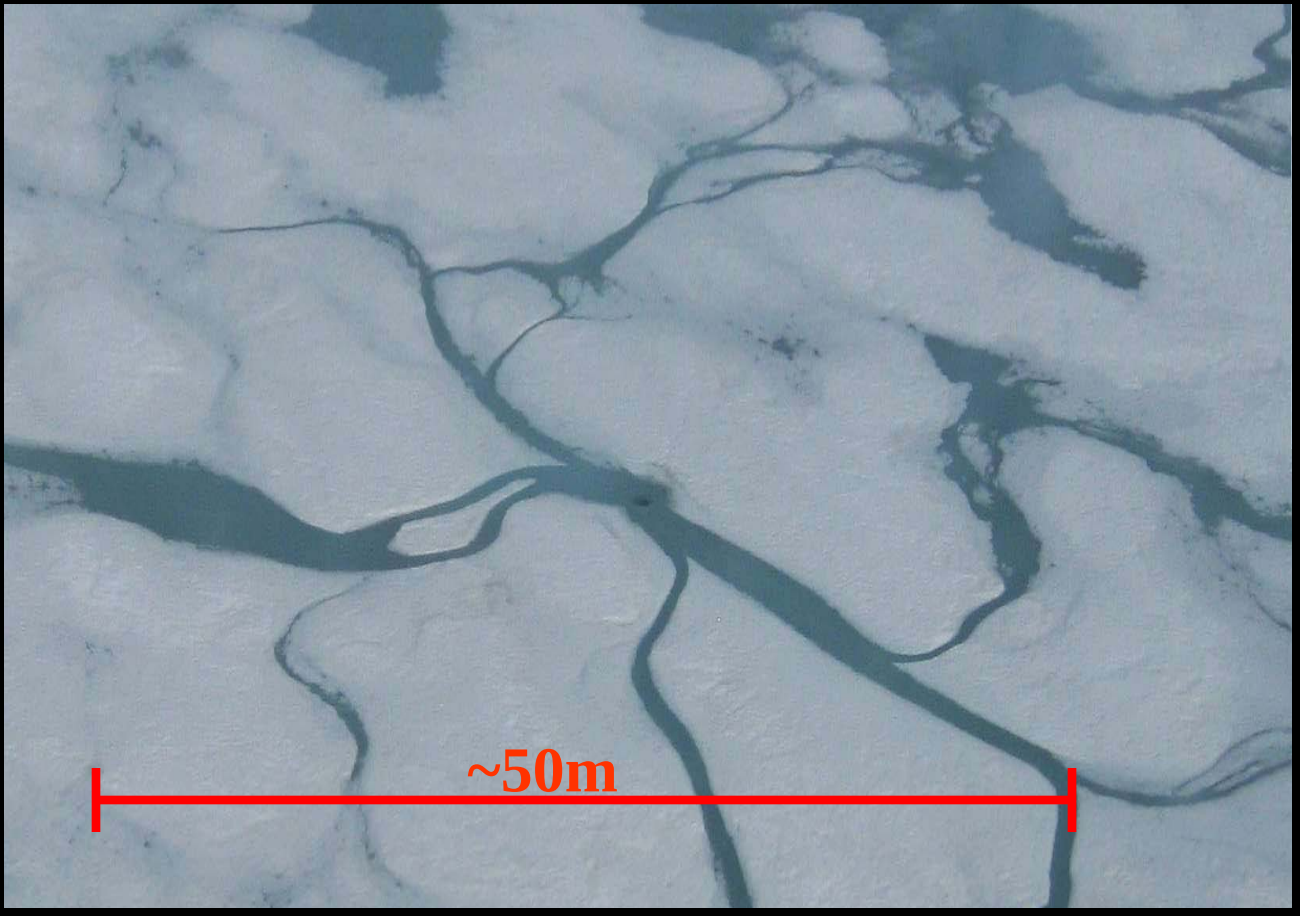
Meltpond coverage varies rapidly.

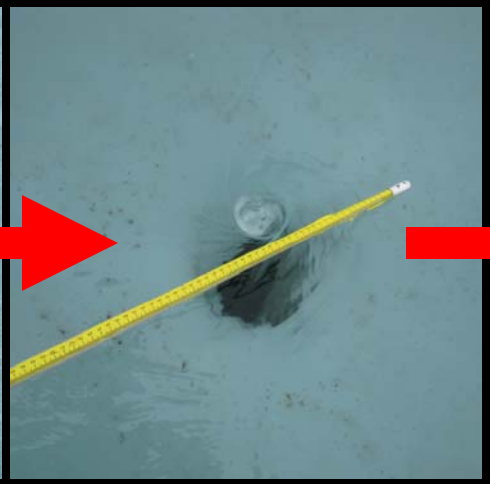

Ice Topography
Meltwater Volume
Pond Coverage
Albedo


Ice Topography
Meltwater Volume
Pond Coverage
Albedo


Height
0.8
0.7
0.6


RIEGL
LMS-Z420





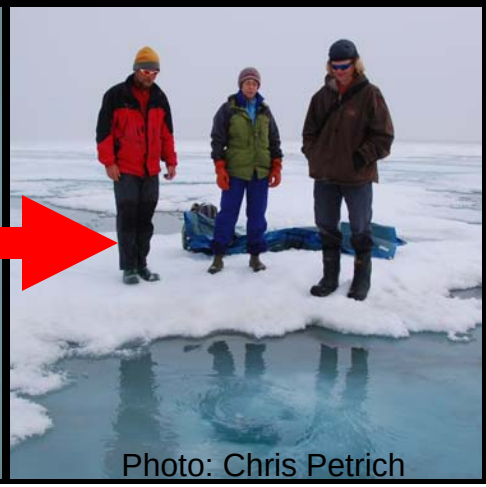
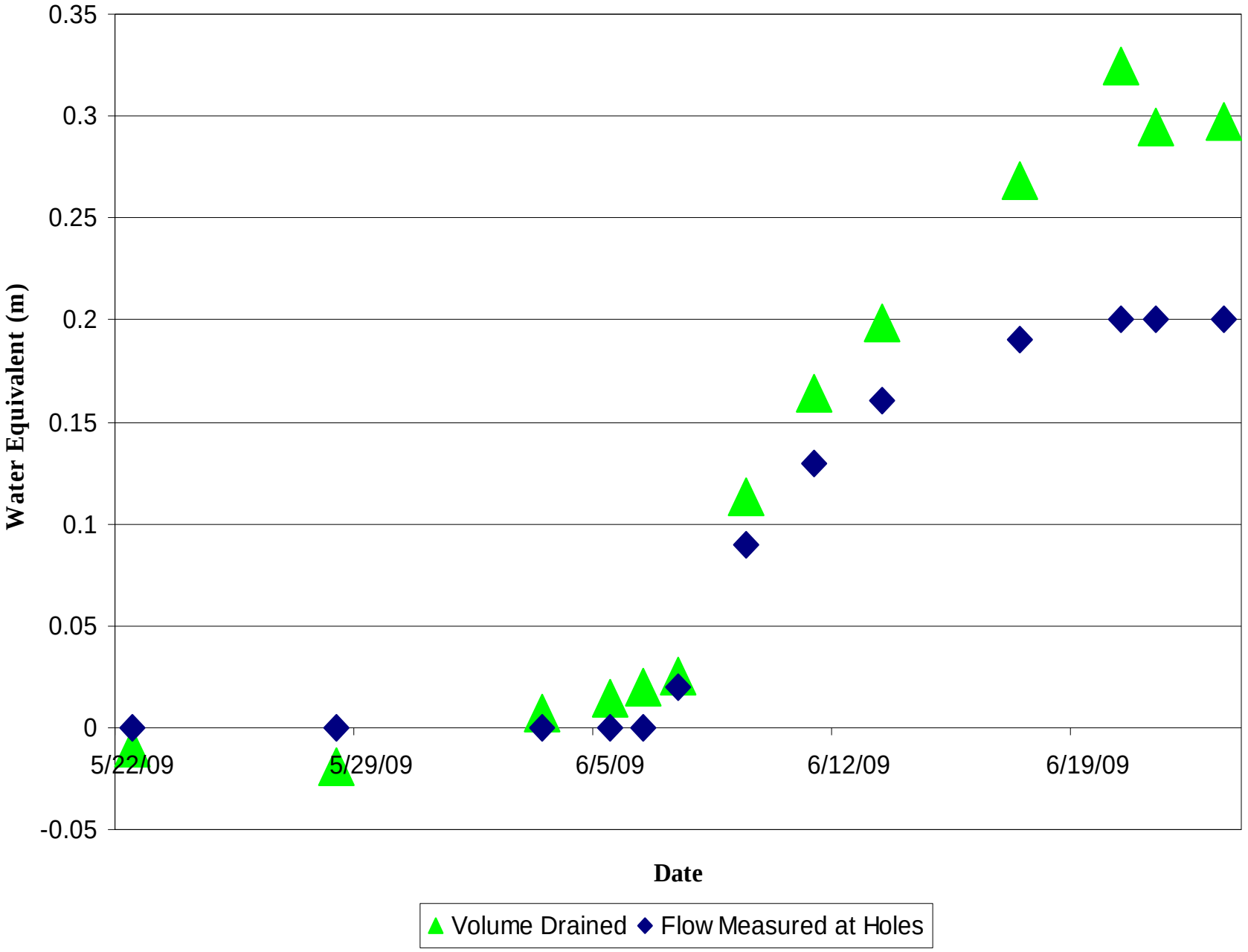
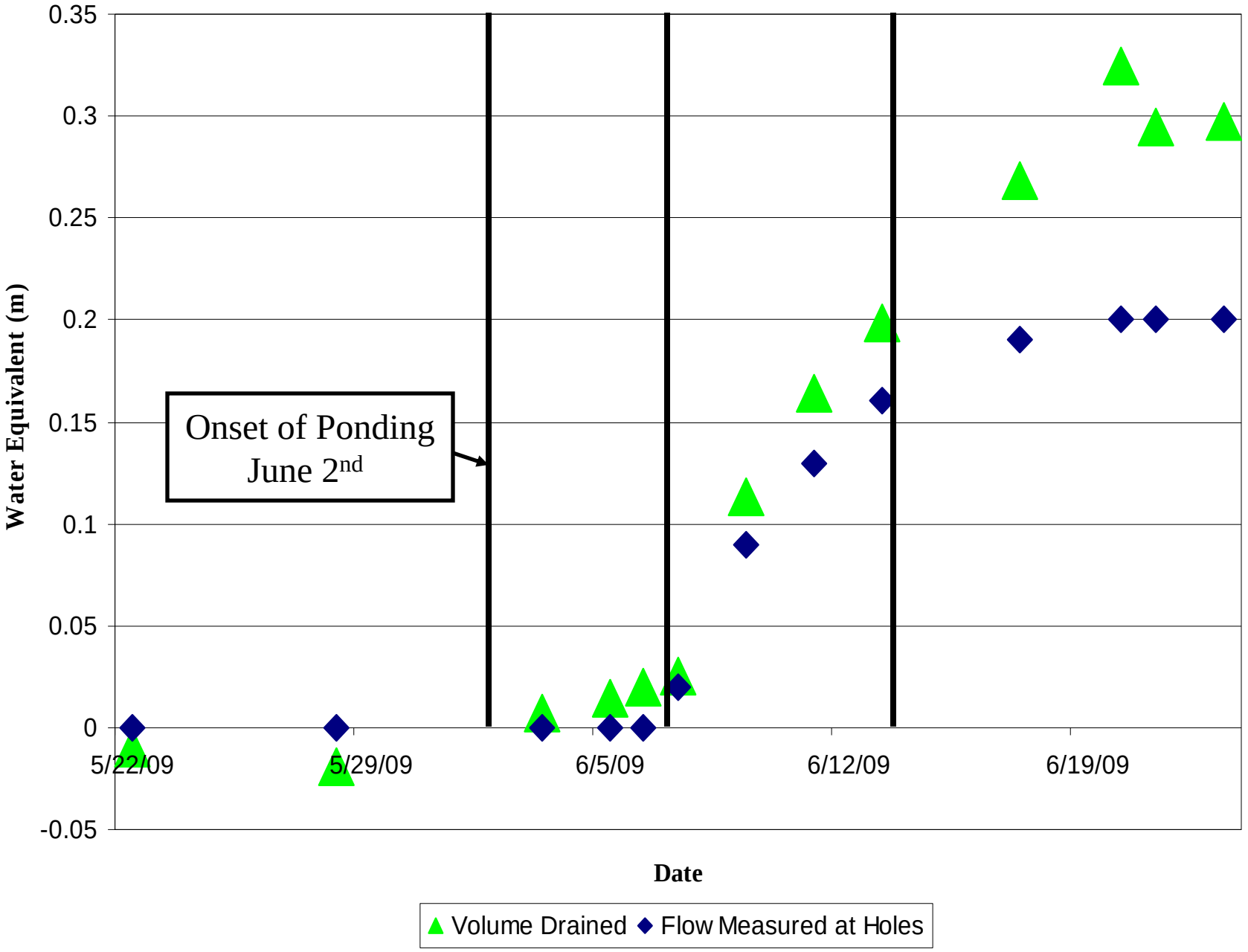


Photo: Chris Petrich

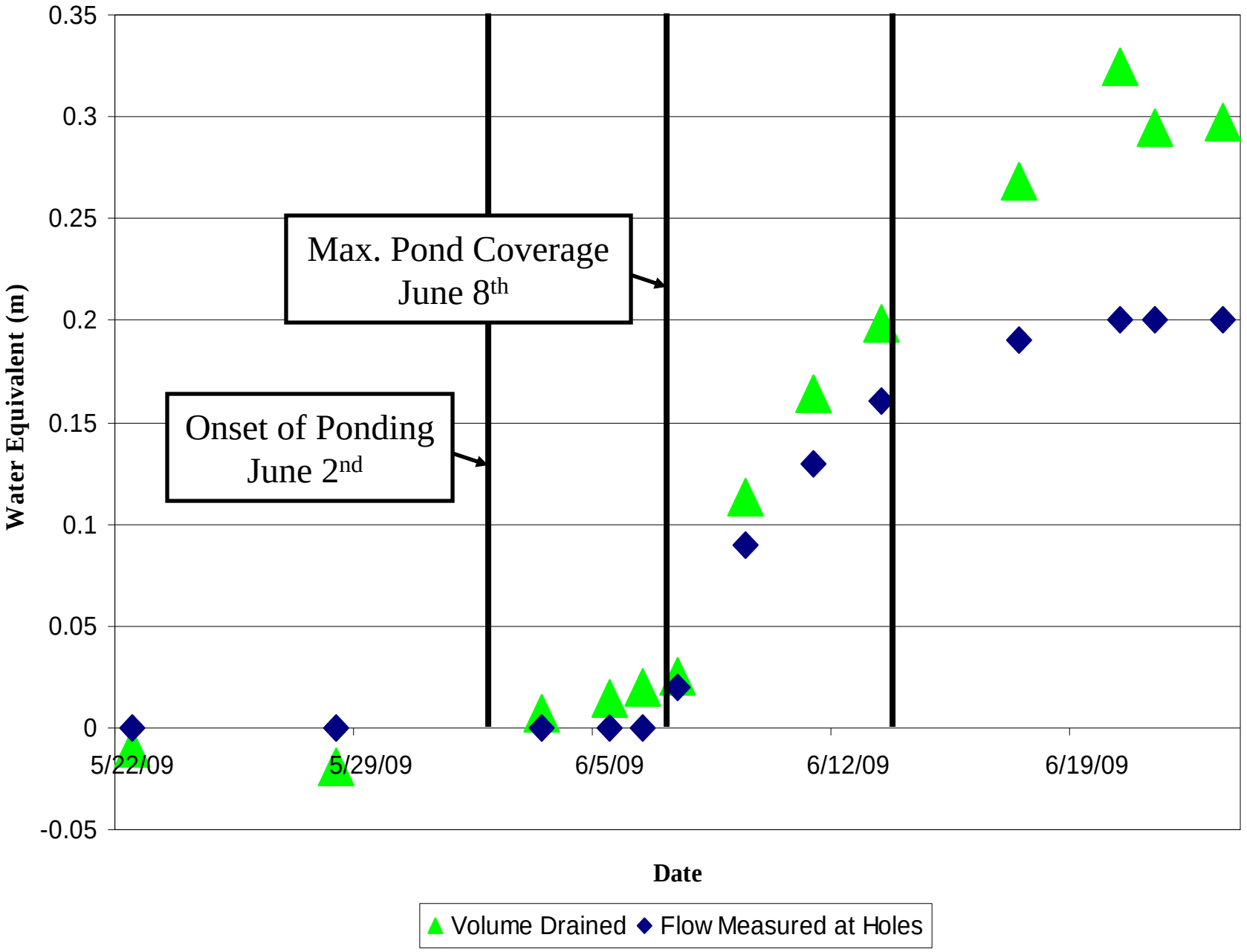
Cumulative Water Movement



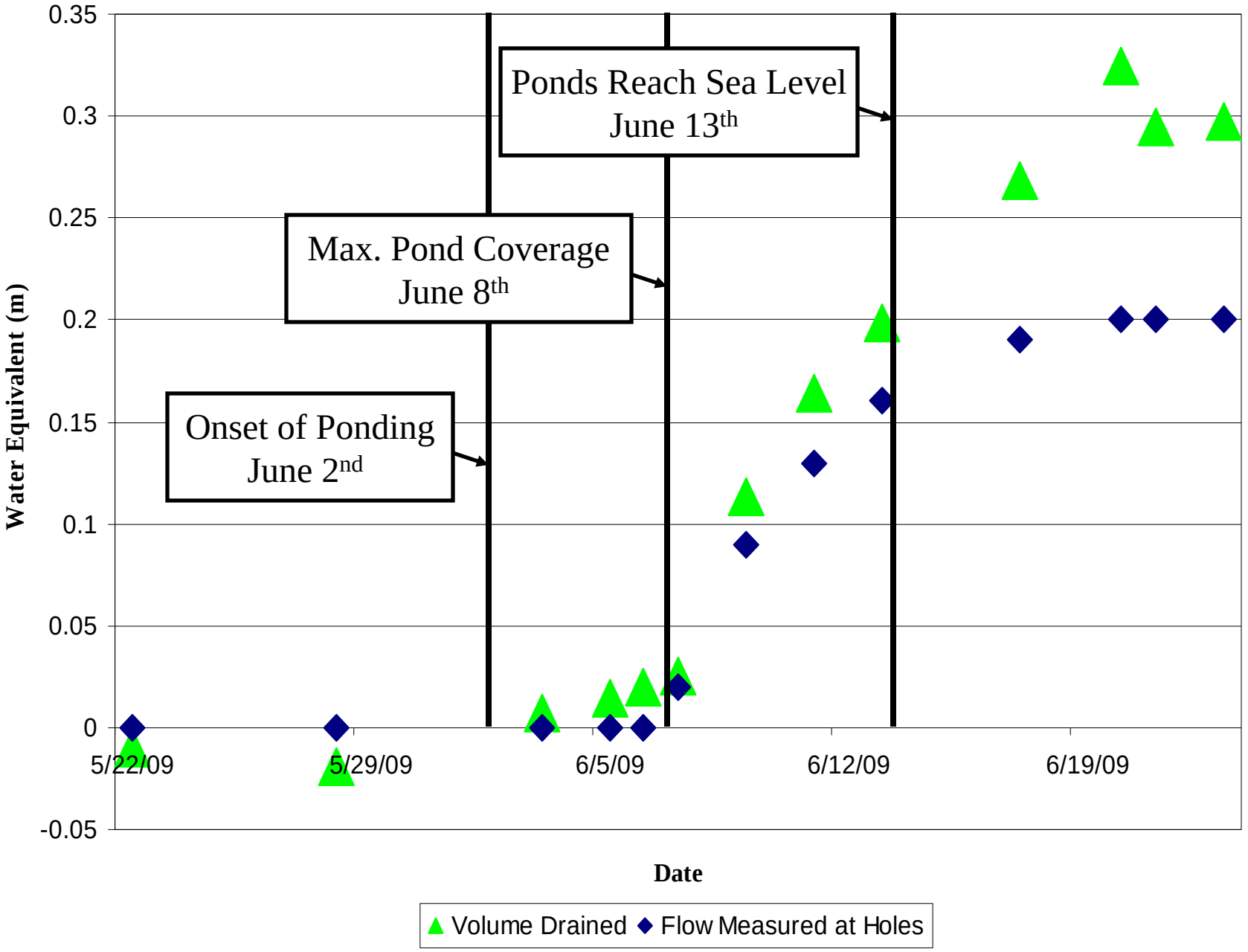
Cumulative Water Movement



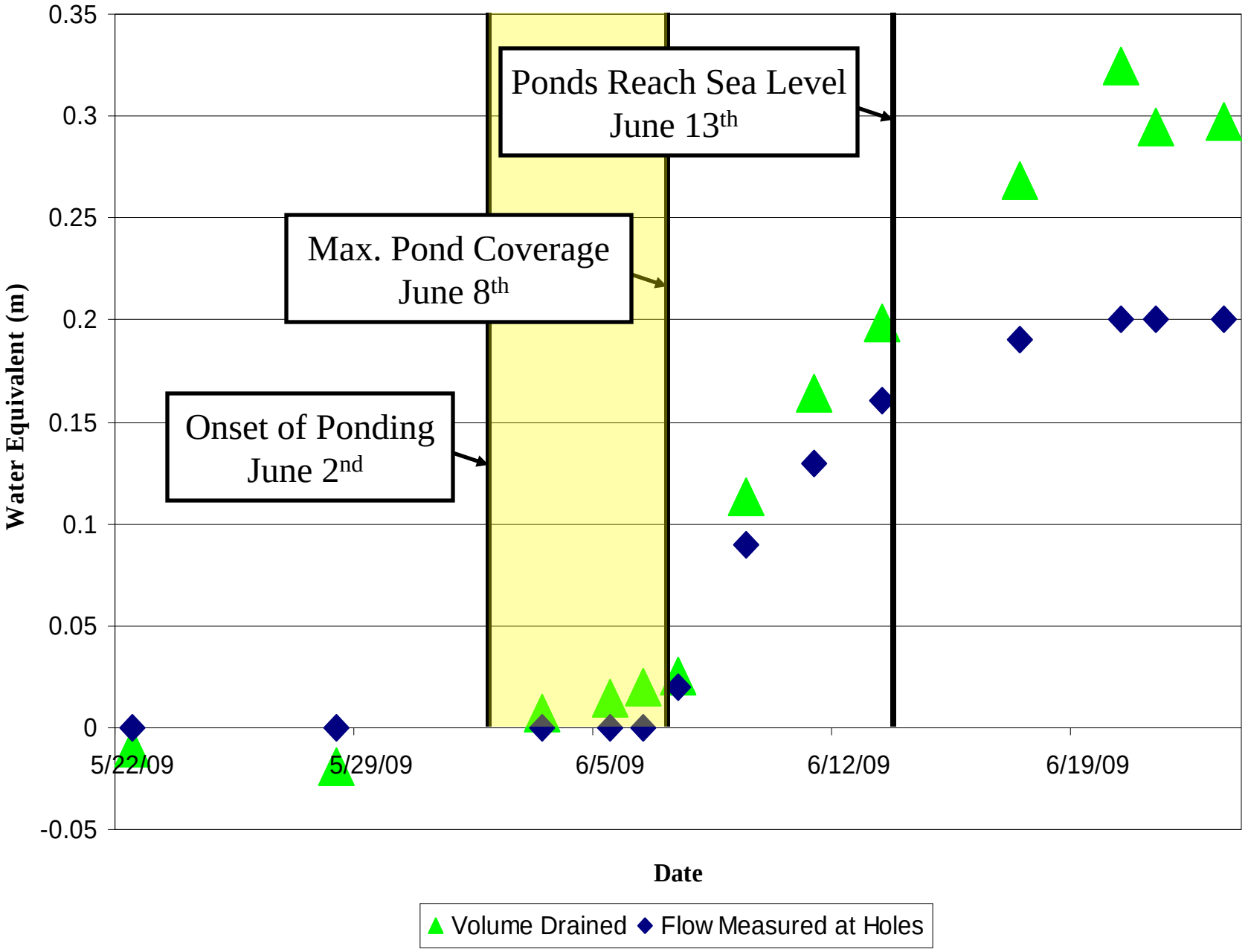
Cumulative Water Movement



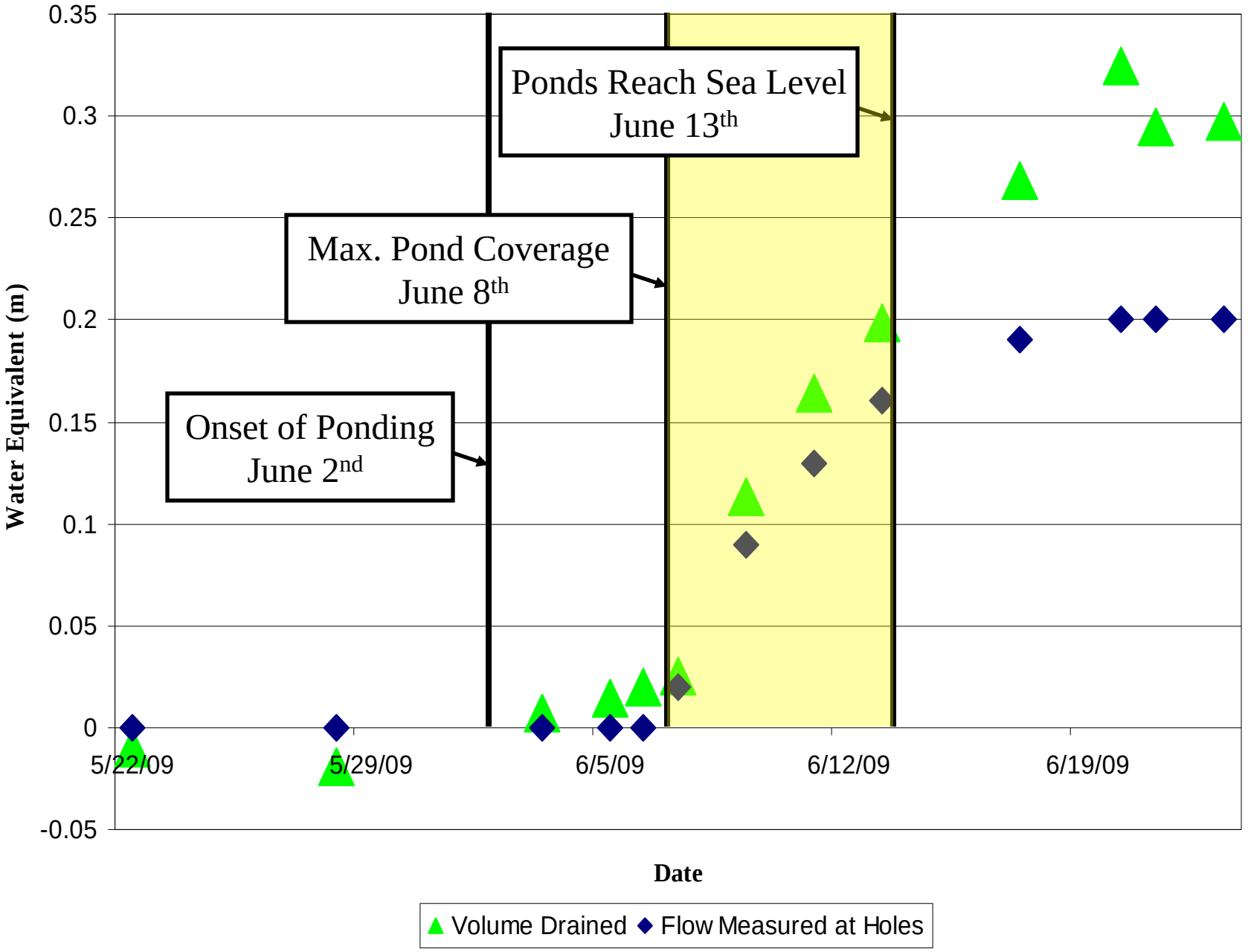
Cumulative Water Movement



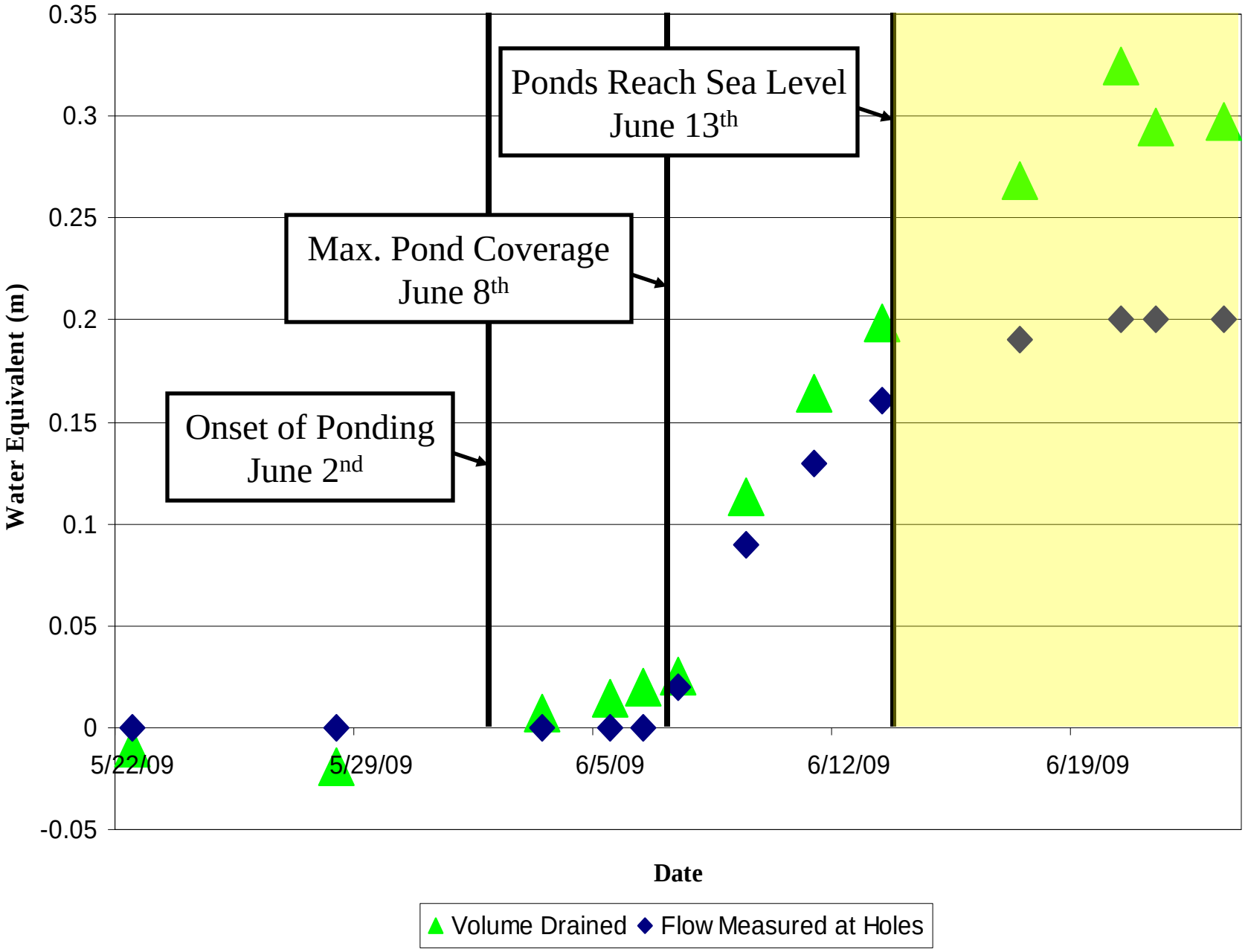
Cumulative Water Movement



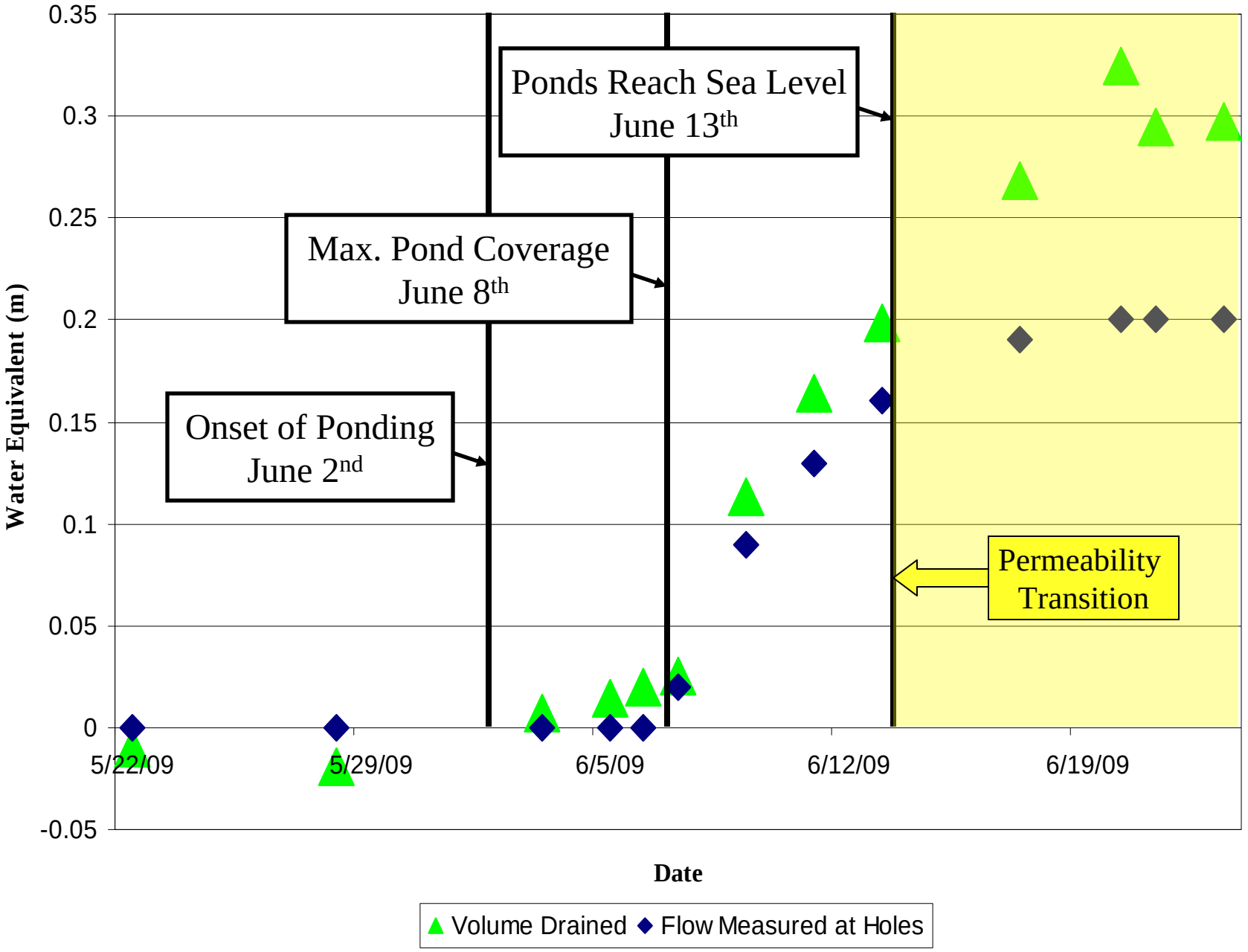
Cumulative Water Movement



Cumulative Water Movement

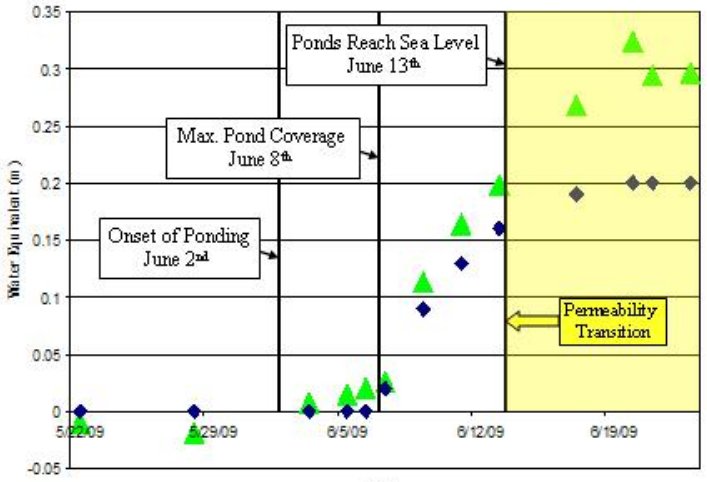


Cumulative Water Movement

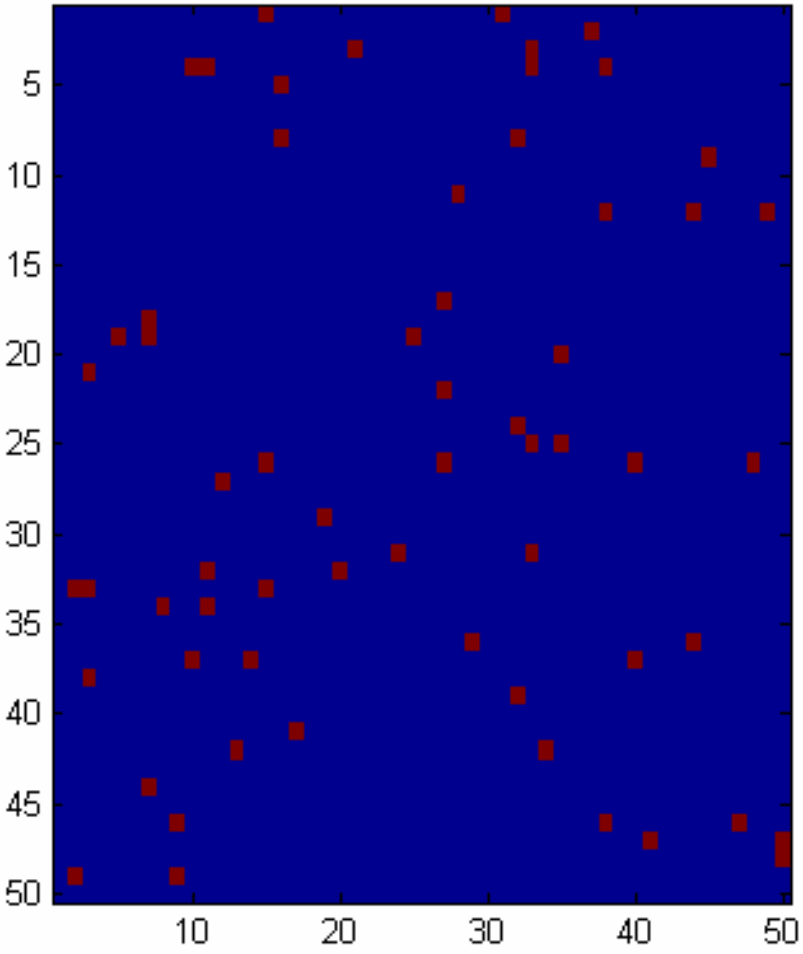


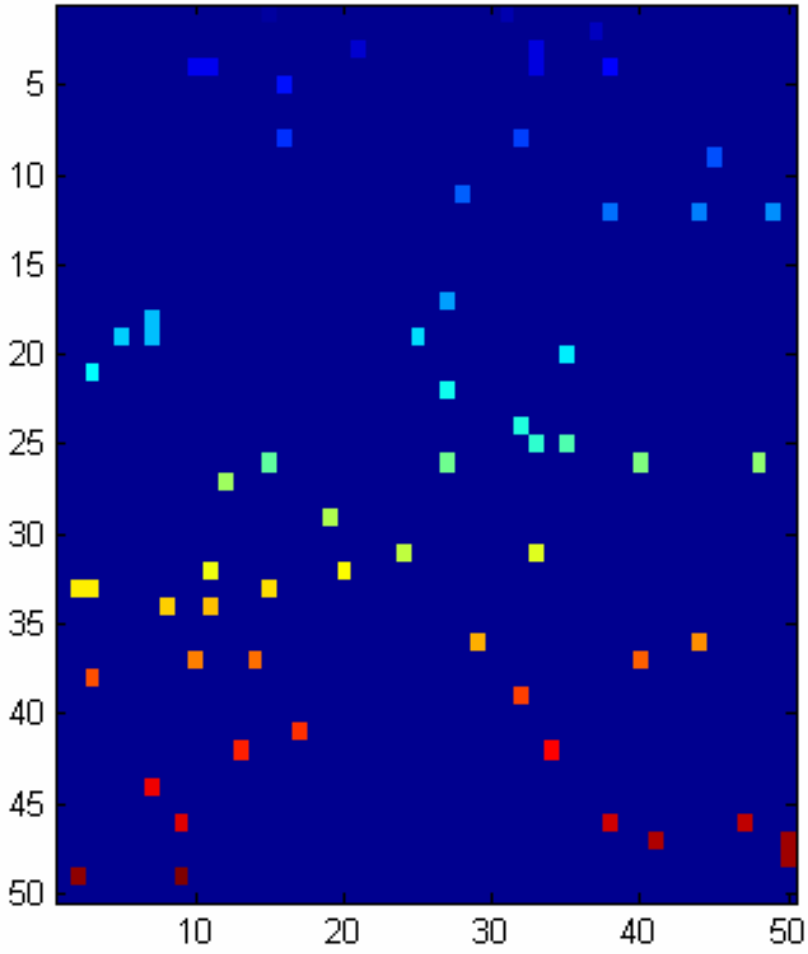
- Why do brine channels spontaneously open and enlarge?

- What causes the permeability transition?



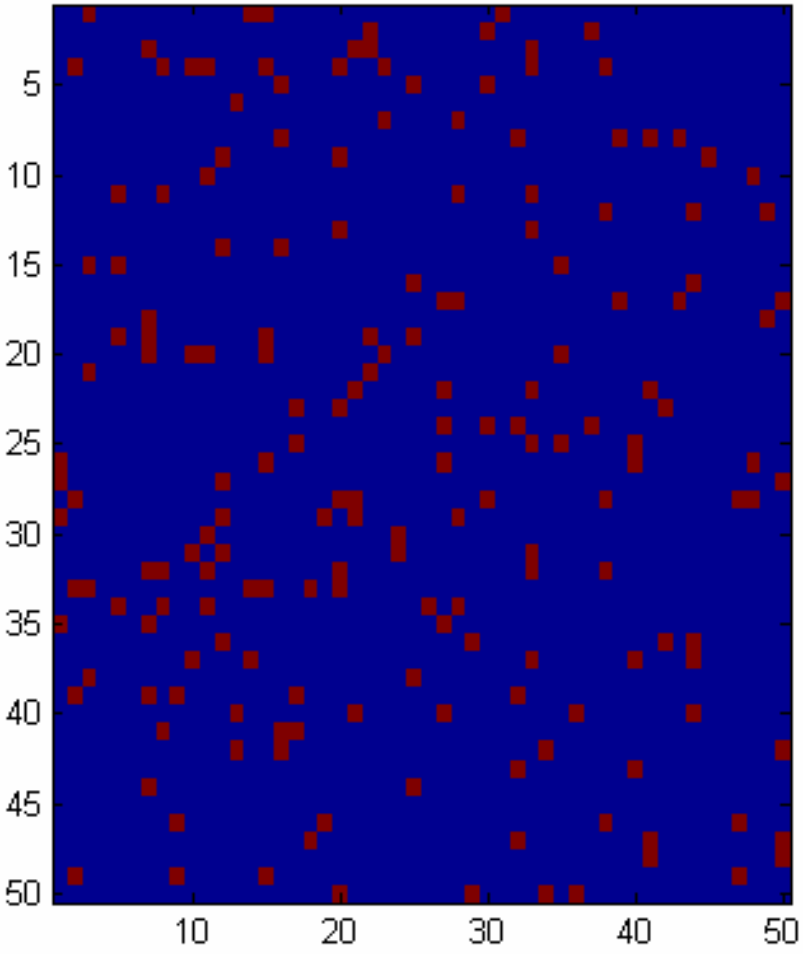
A Conceptual Model: 2D Lattice

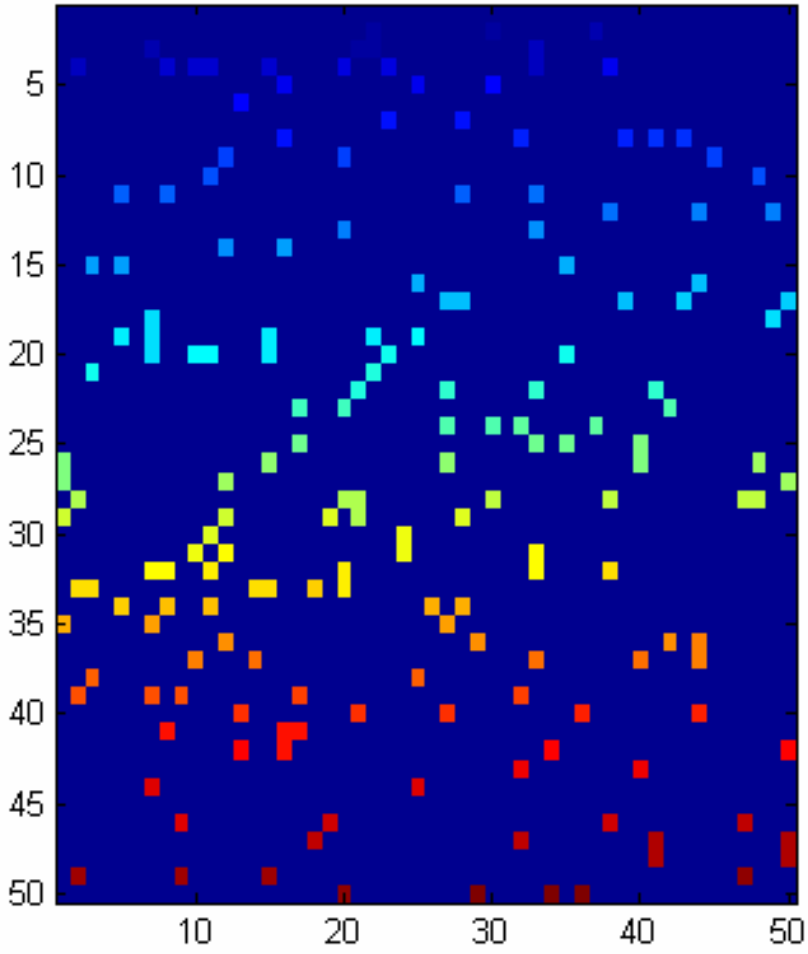




2.5% Liquid

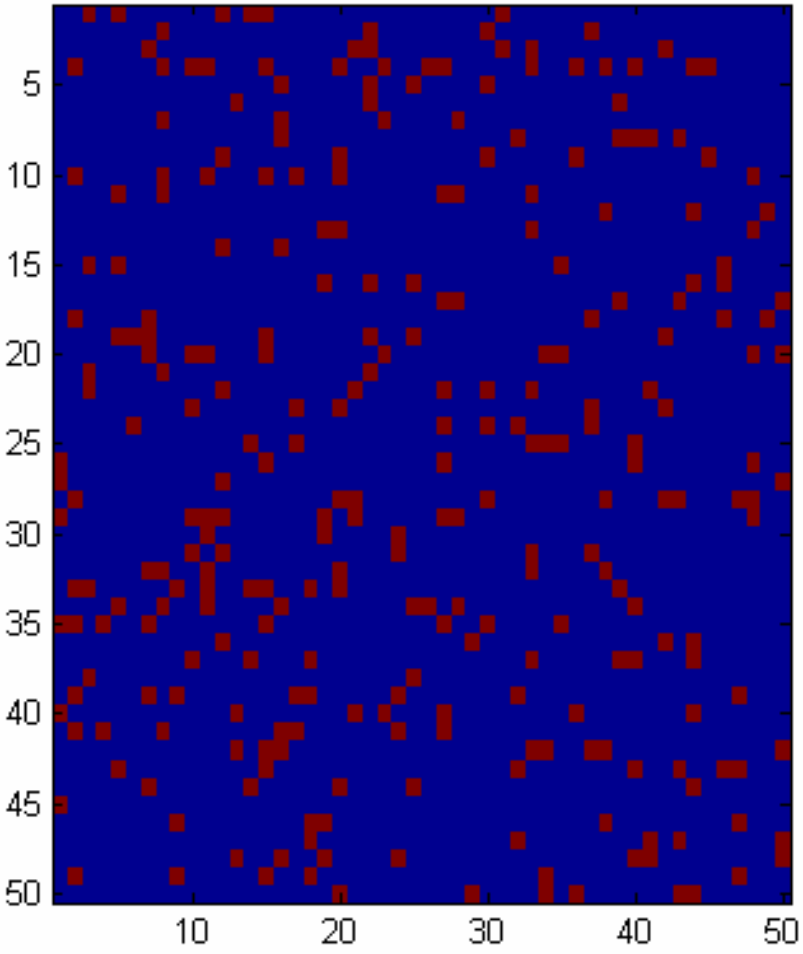
A Conceptual Model: 2D Lattice

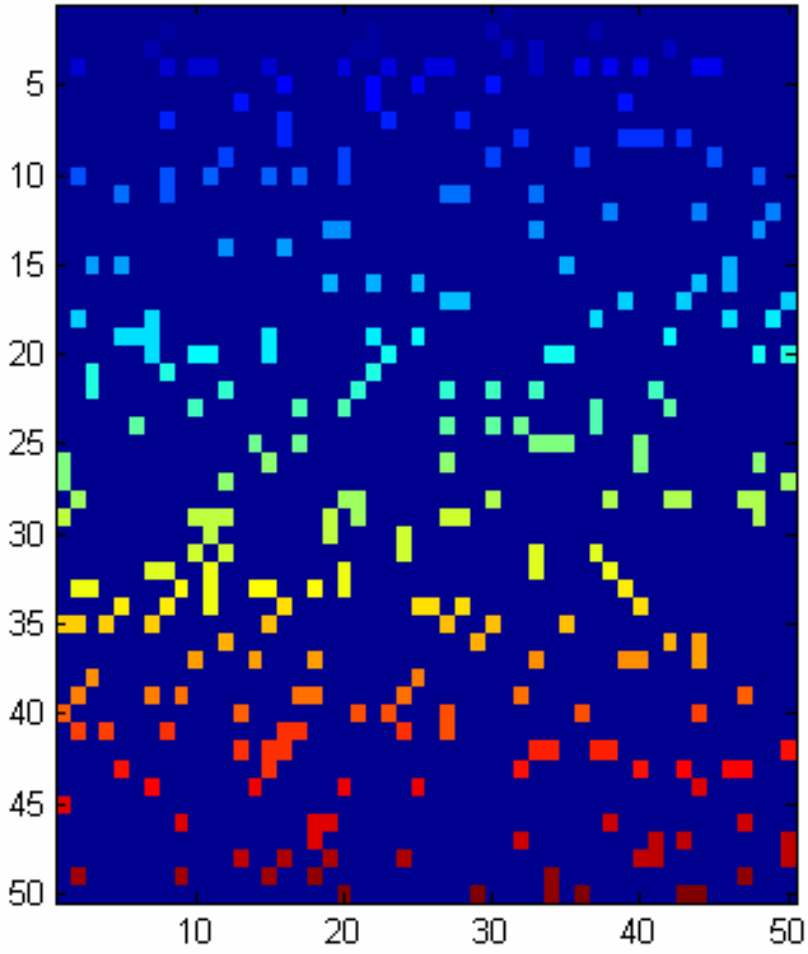




5% Liquid

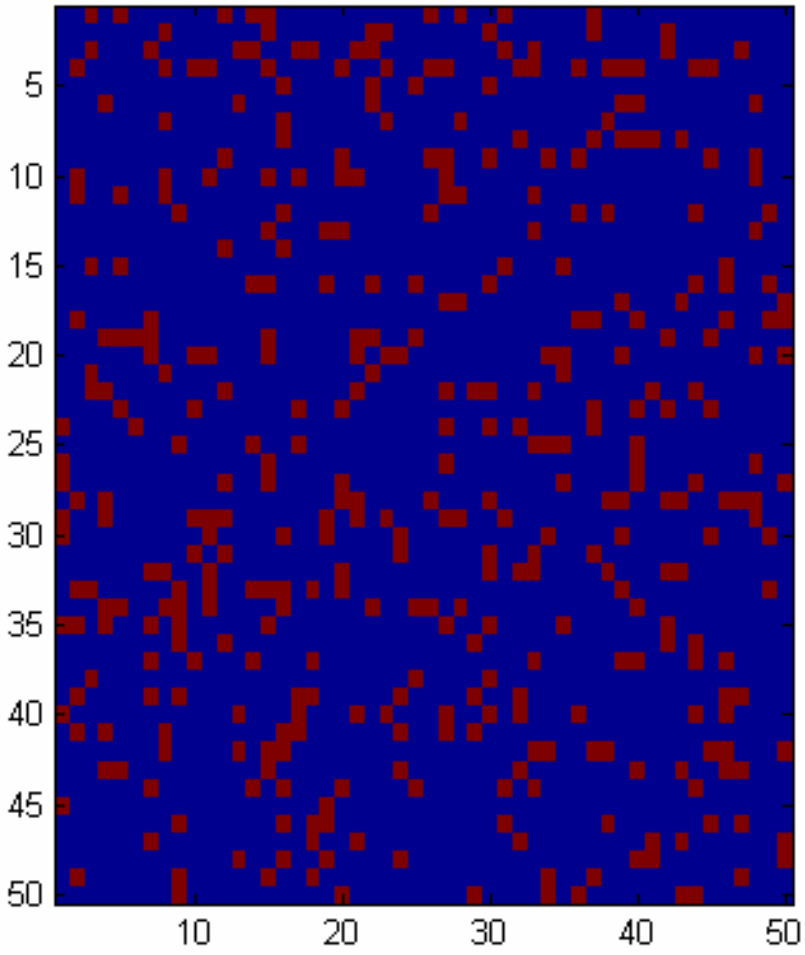
A Conceptual Model: 2D Lattice

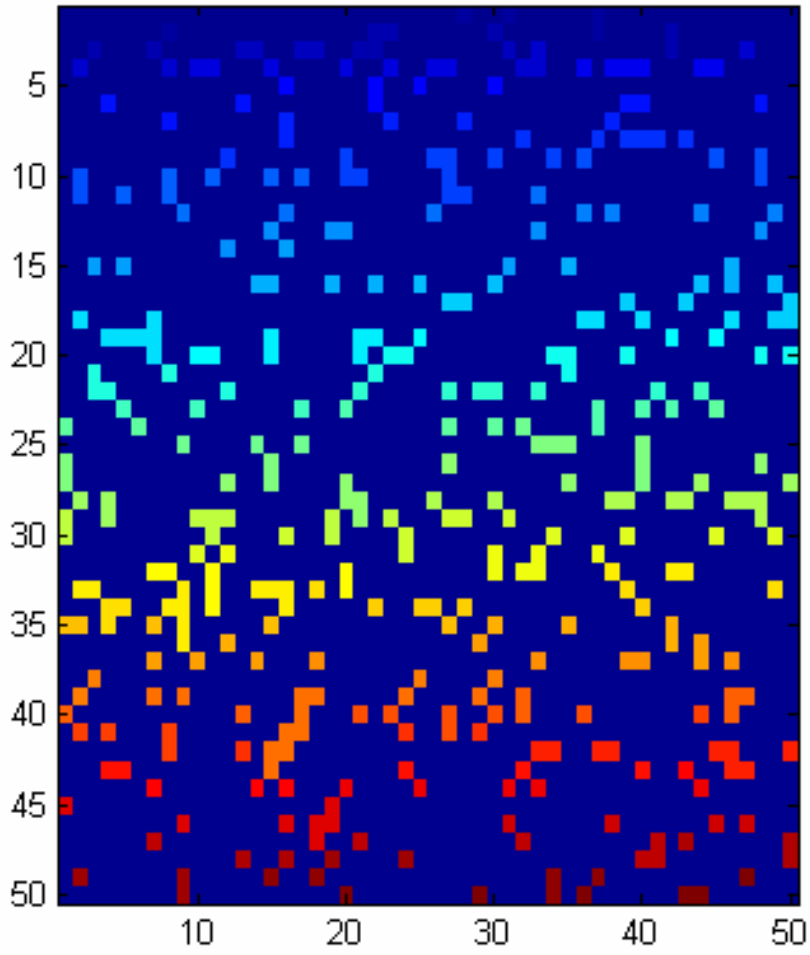




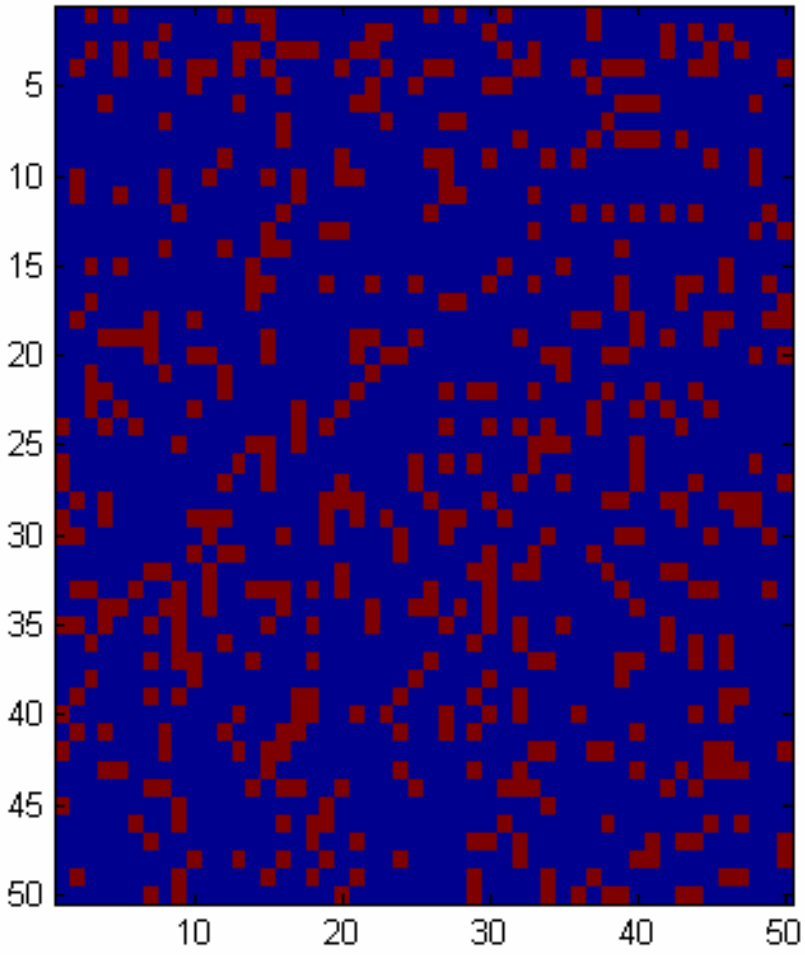
7.5% Liquid

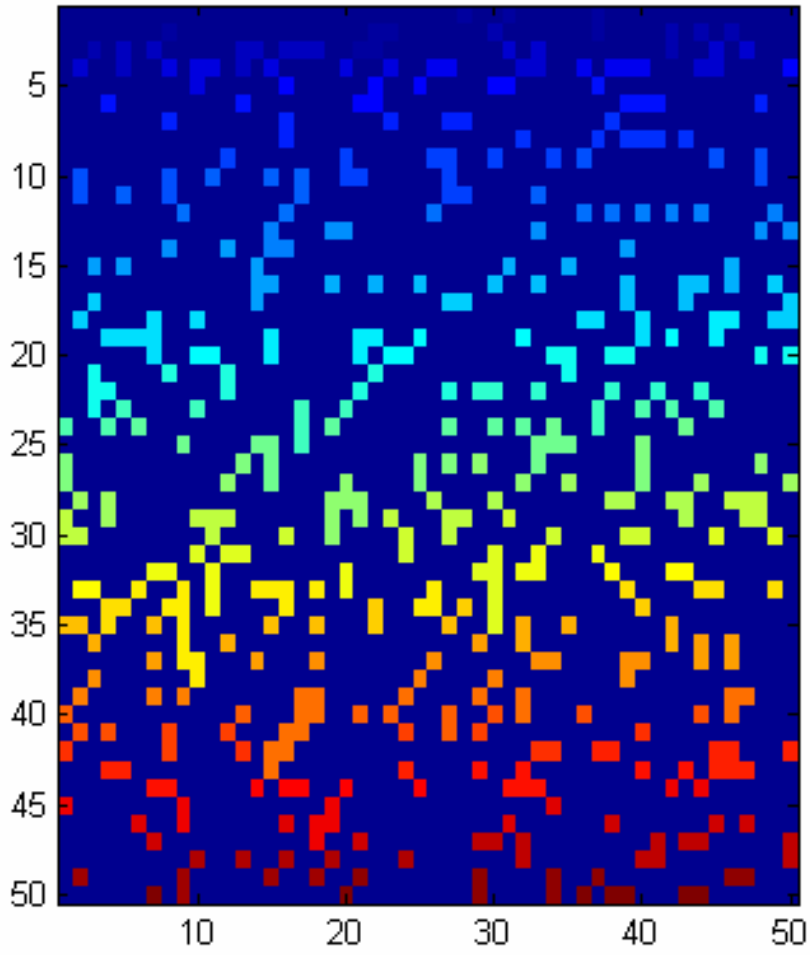
A Conceptual Model: 2D Lattice



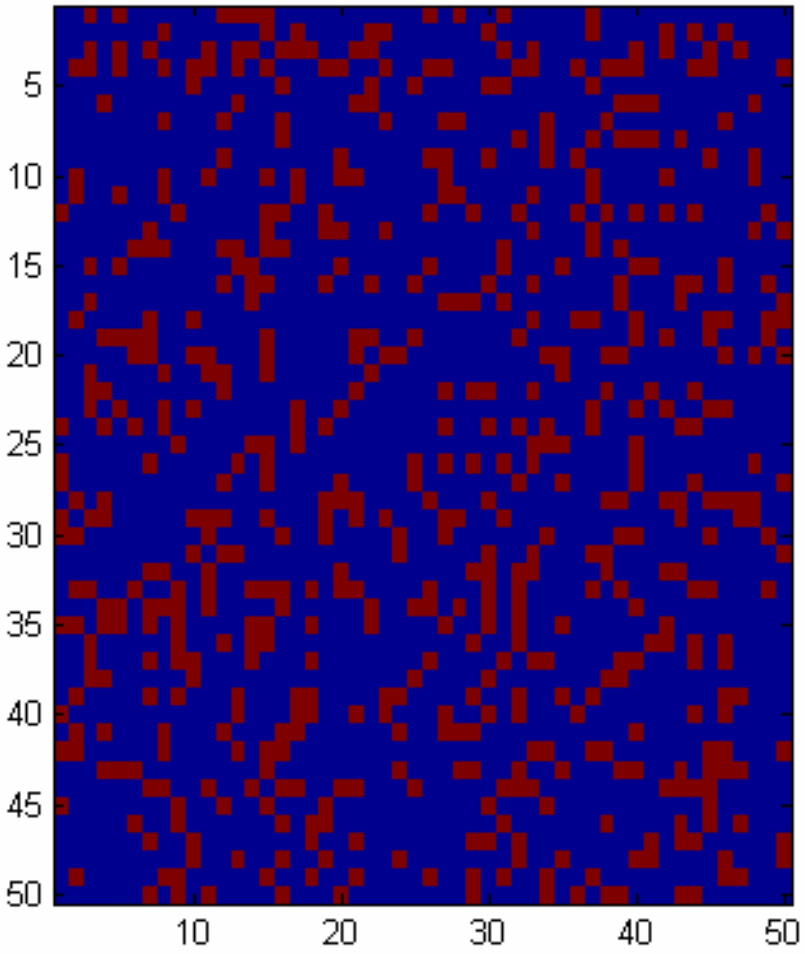


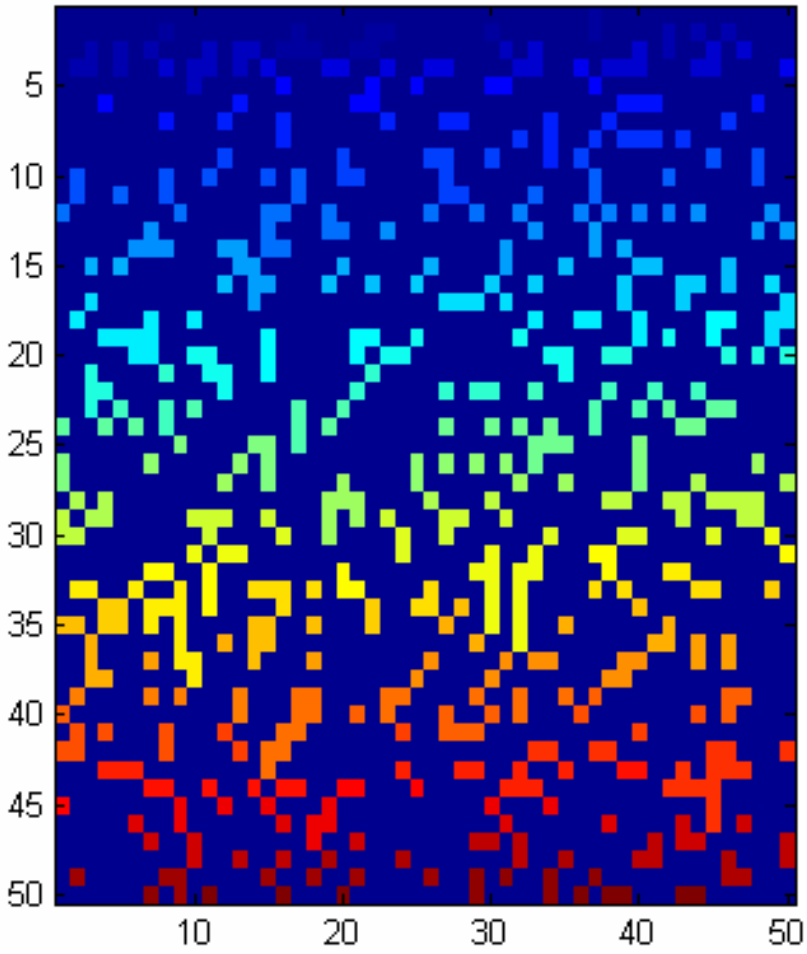
A Conceptual Model: 2D Lattice



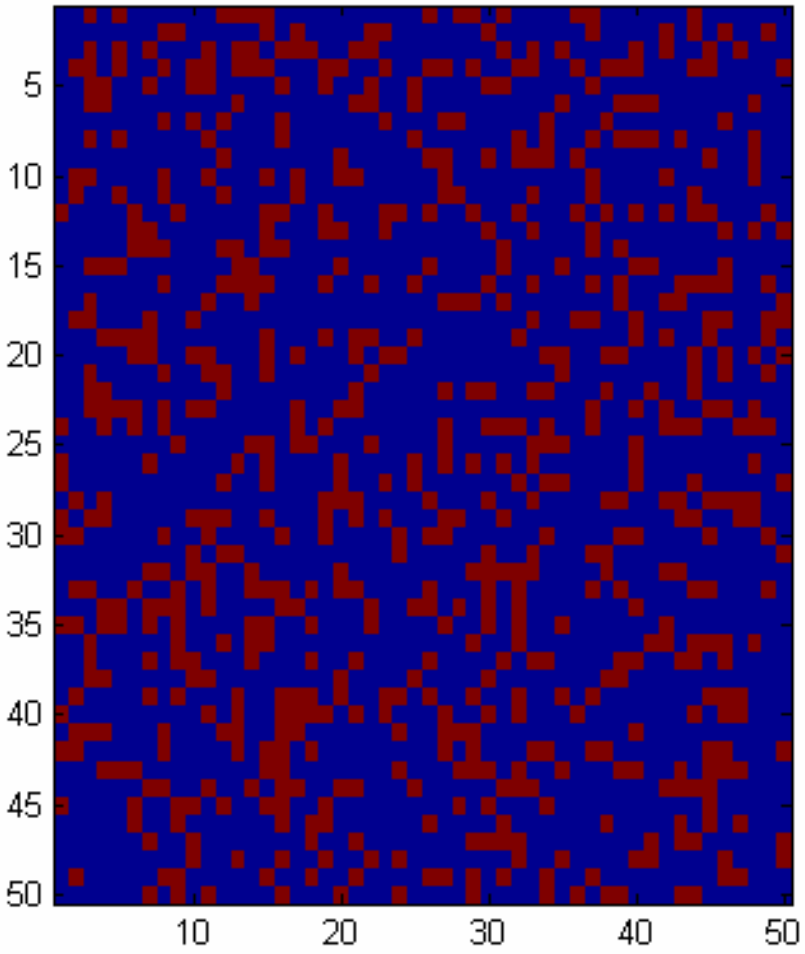


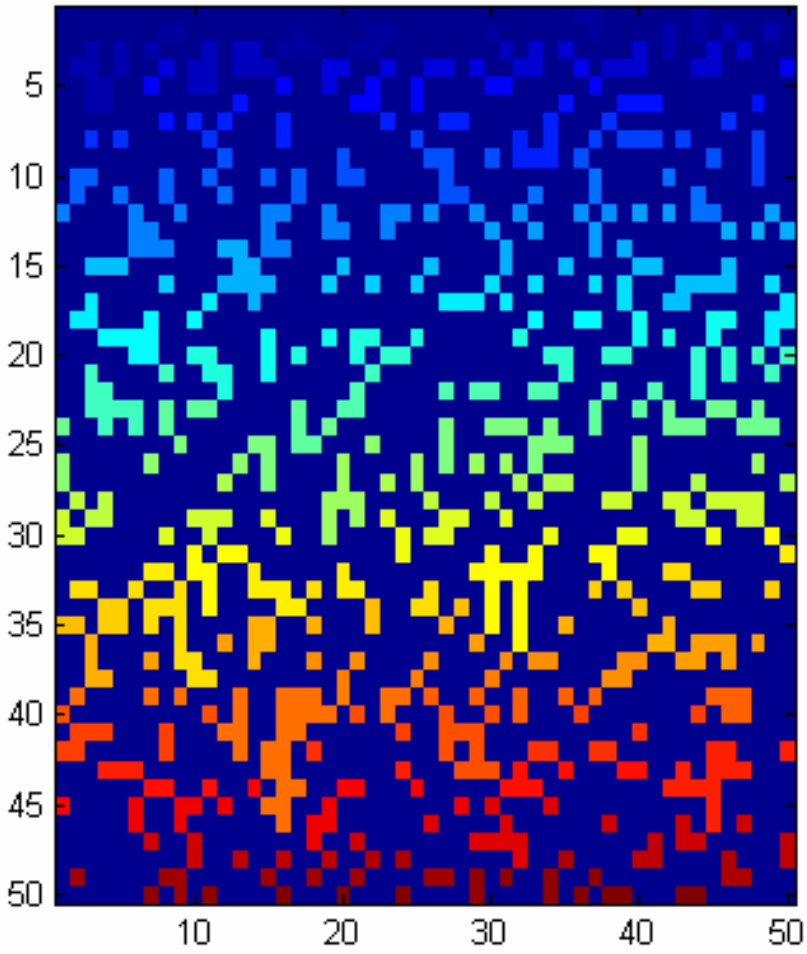
A Conceptual Model: 2D Lattice



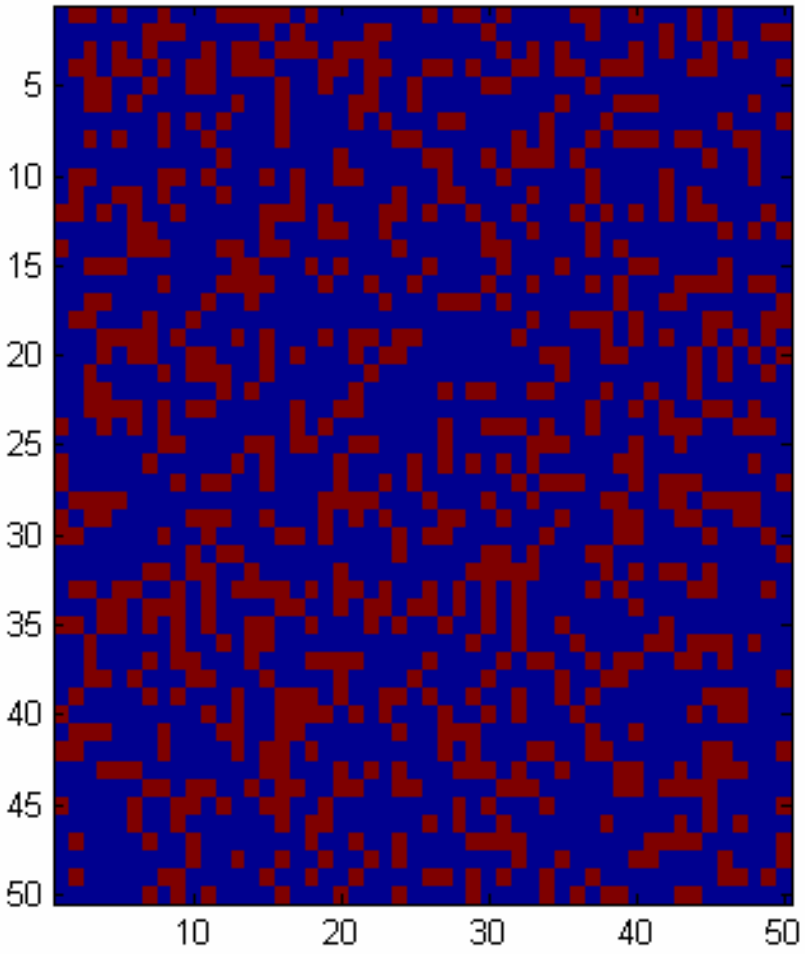


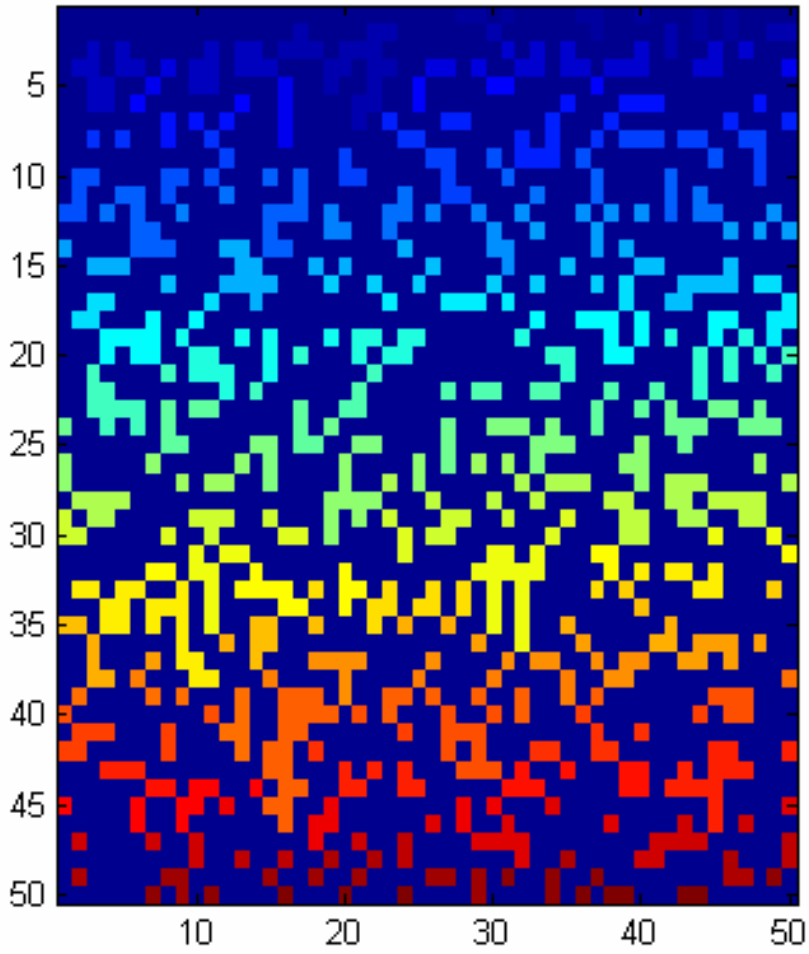
A Conceptual Model: 2D Lattice



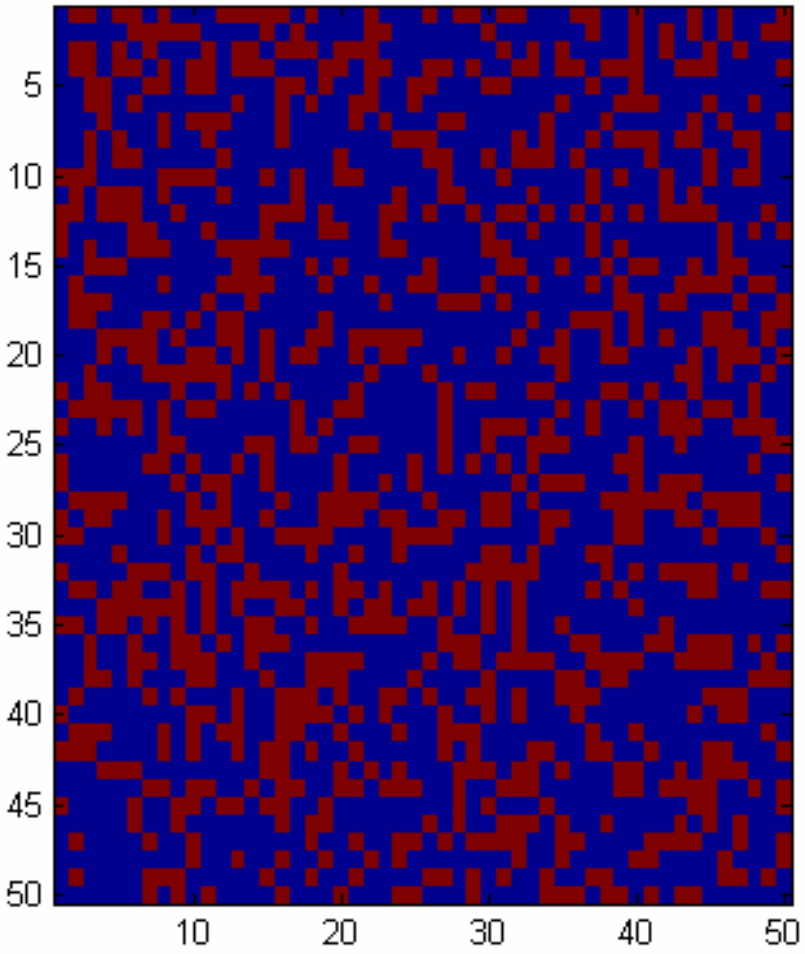


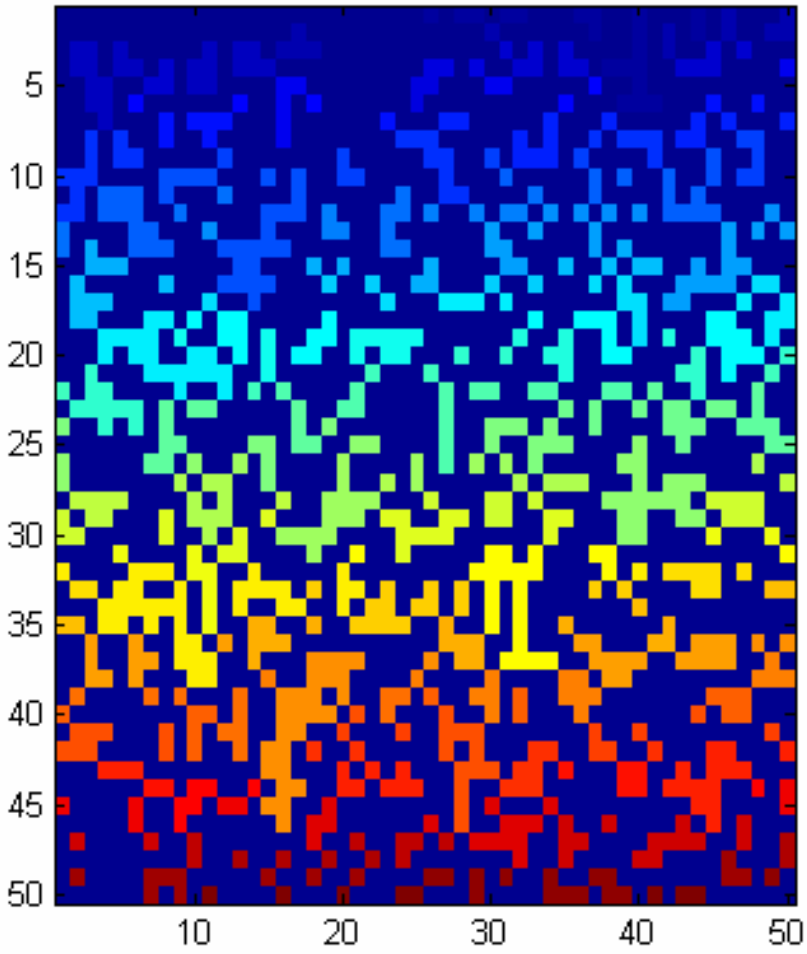
A Conceptual Model: 2D Lattice



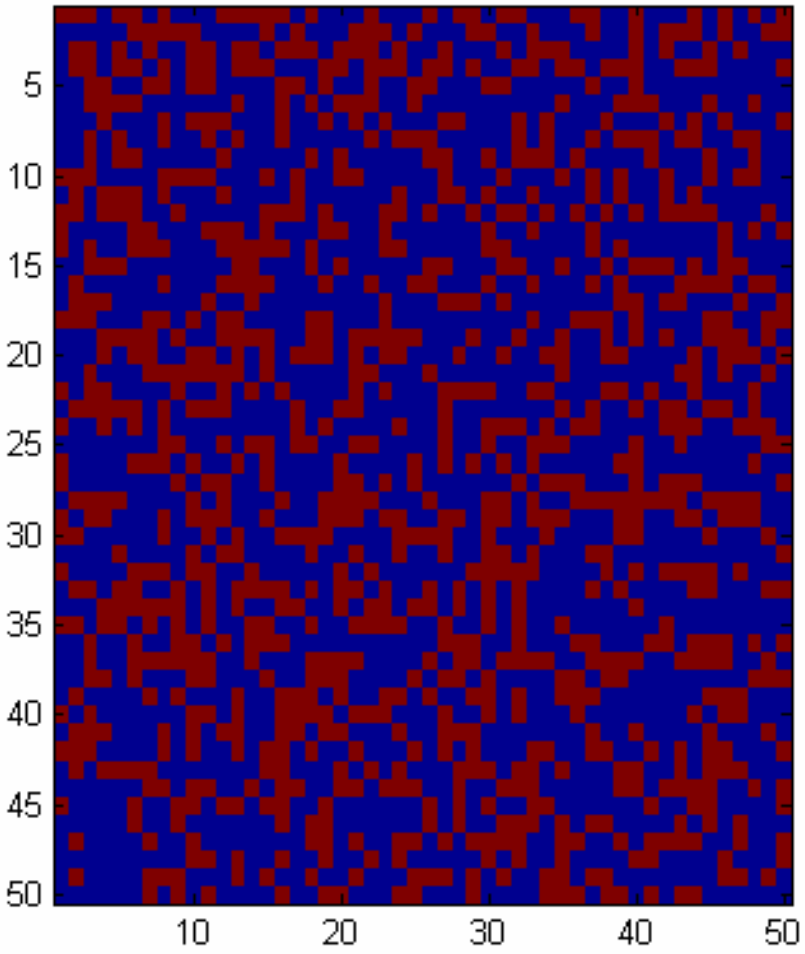


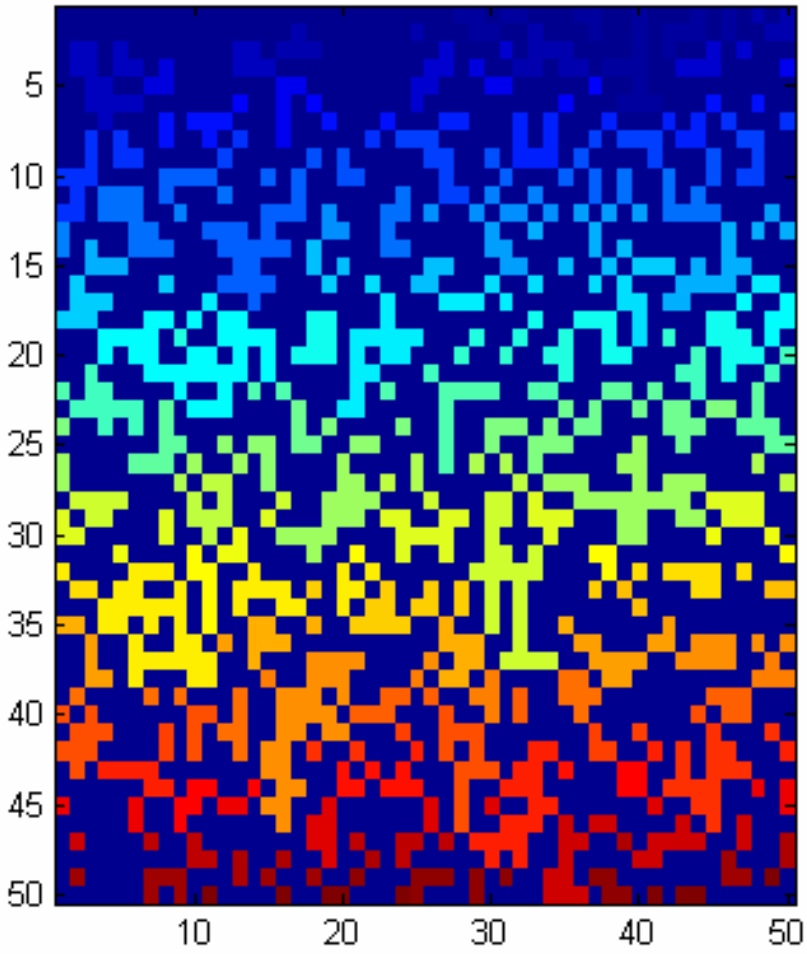
A Conceptual Model: 2D Lattice



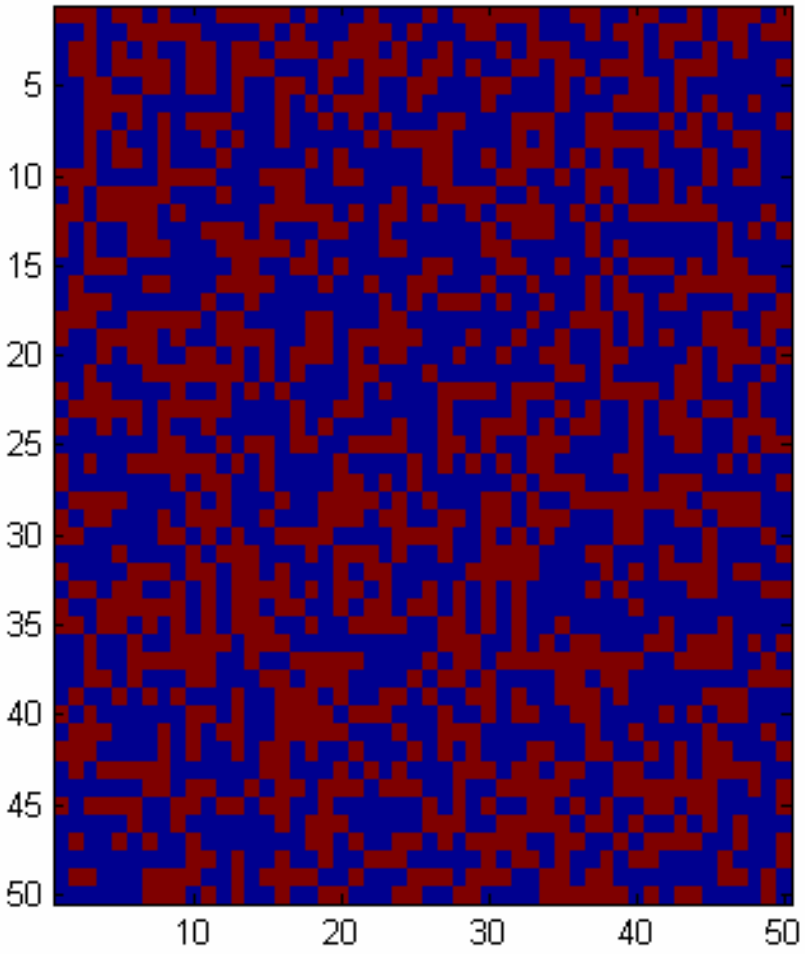


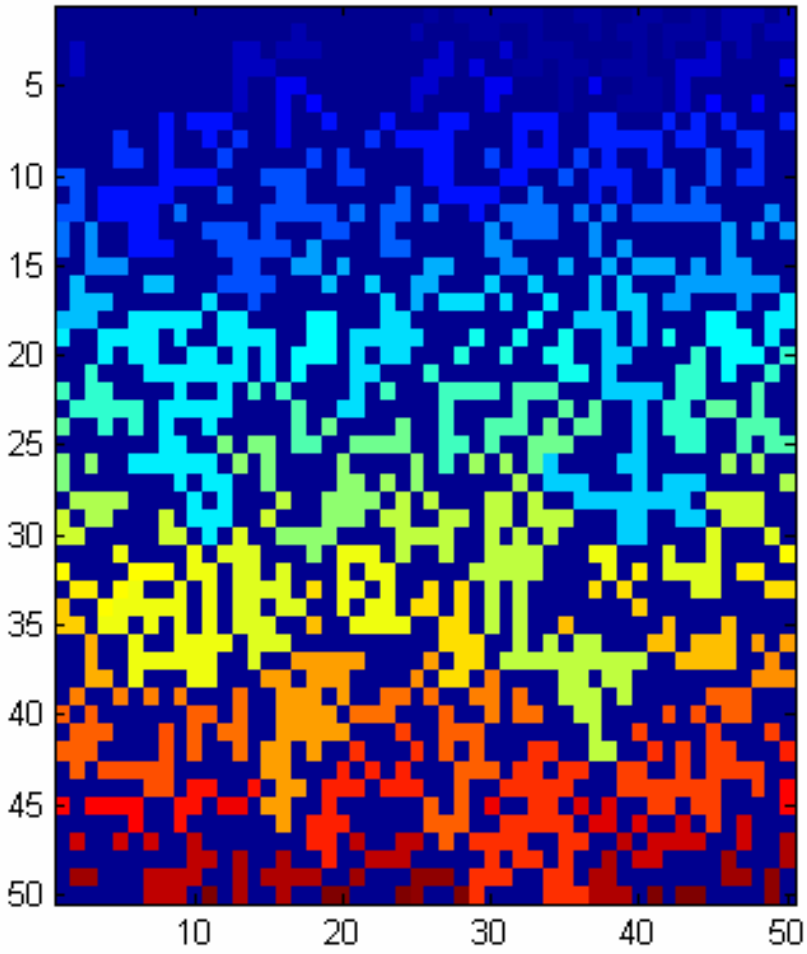
A Conceptual Model: 2D Lattice



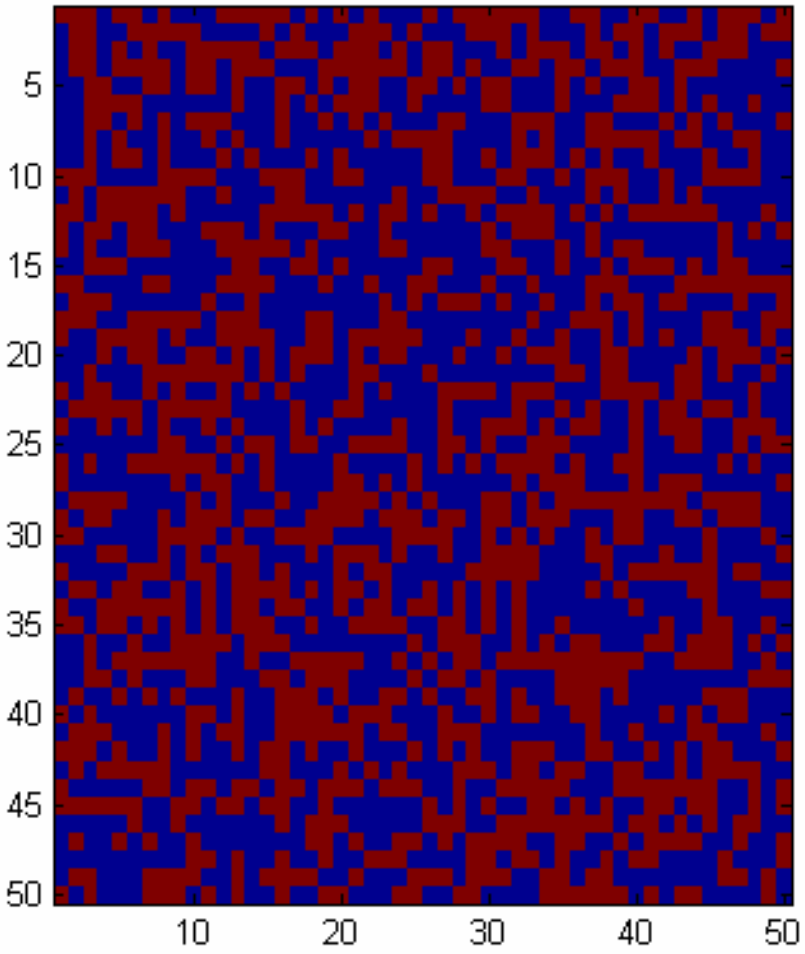


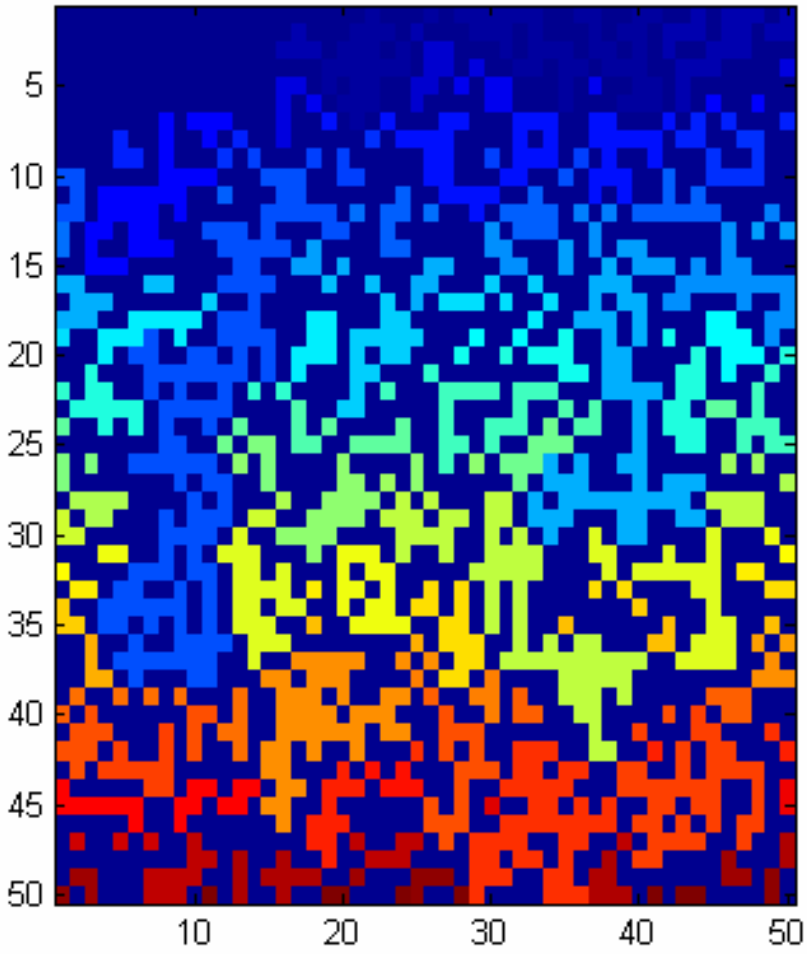
A Conceptual Model: 2D Lattice



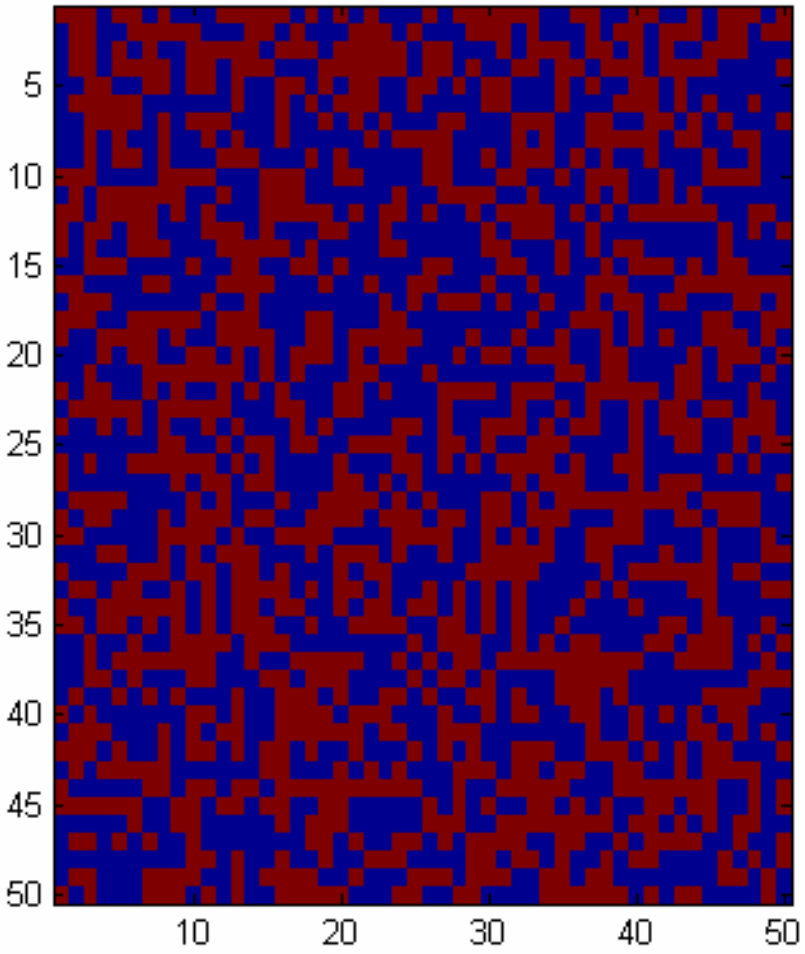


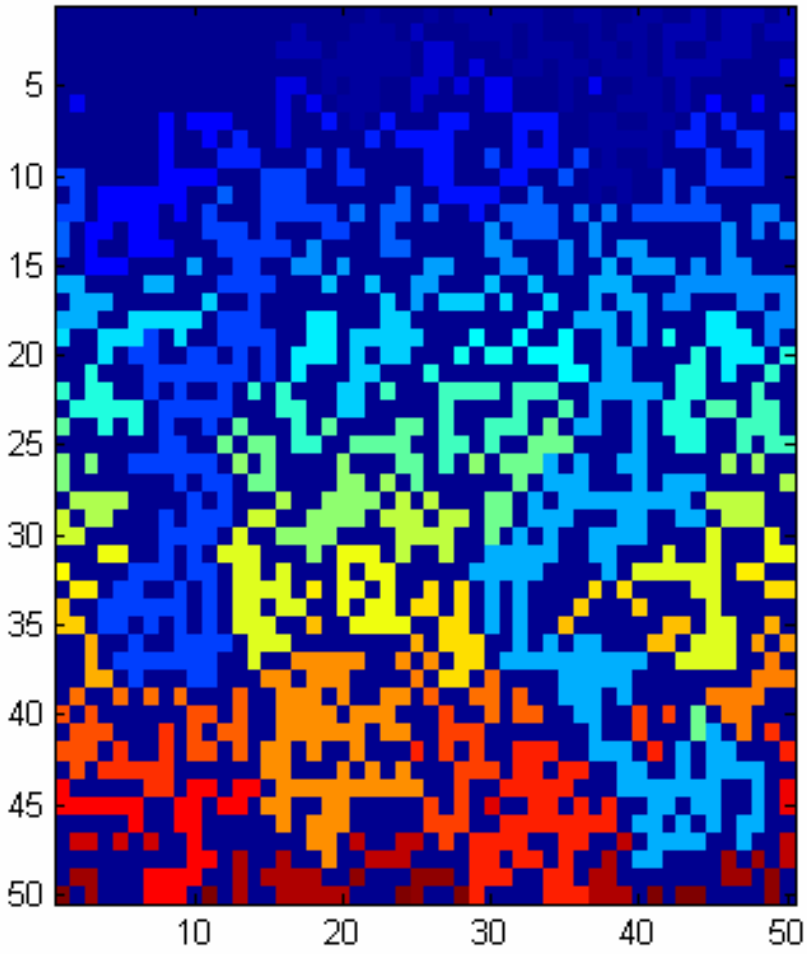
A Conceptual Model: 2D Lattice



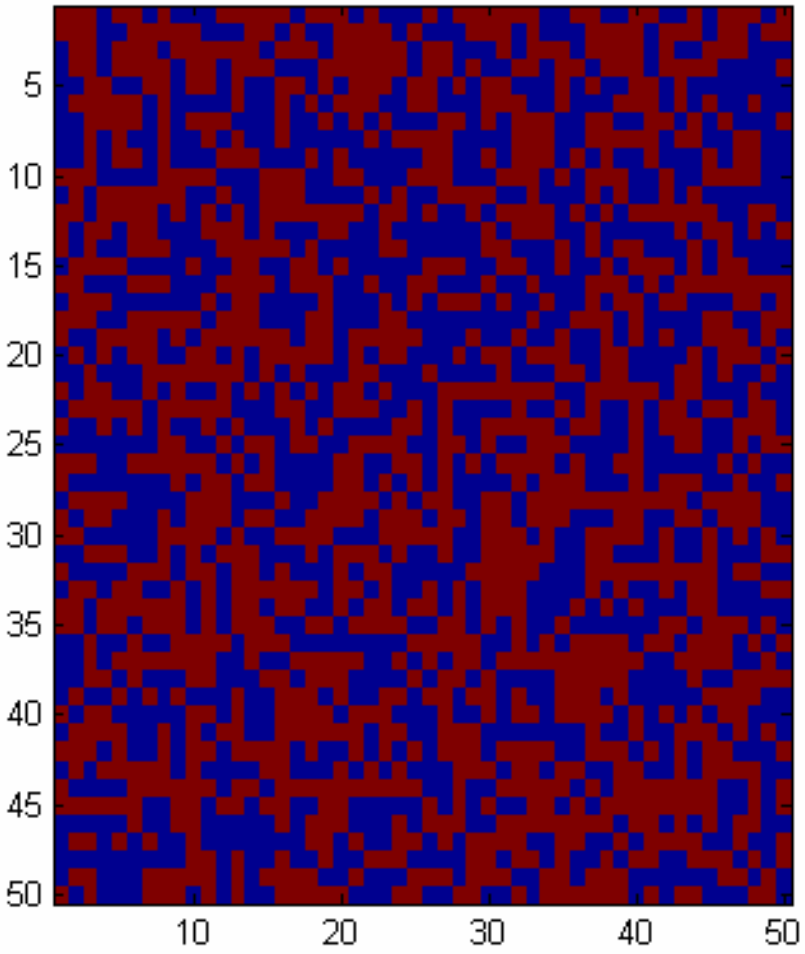


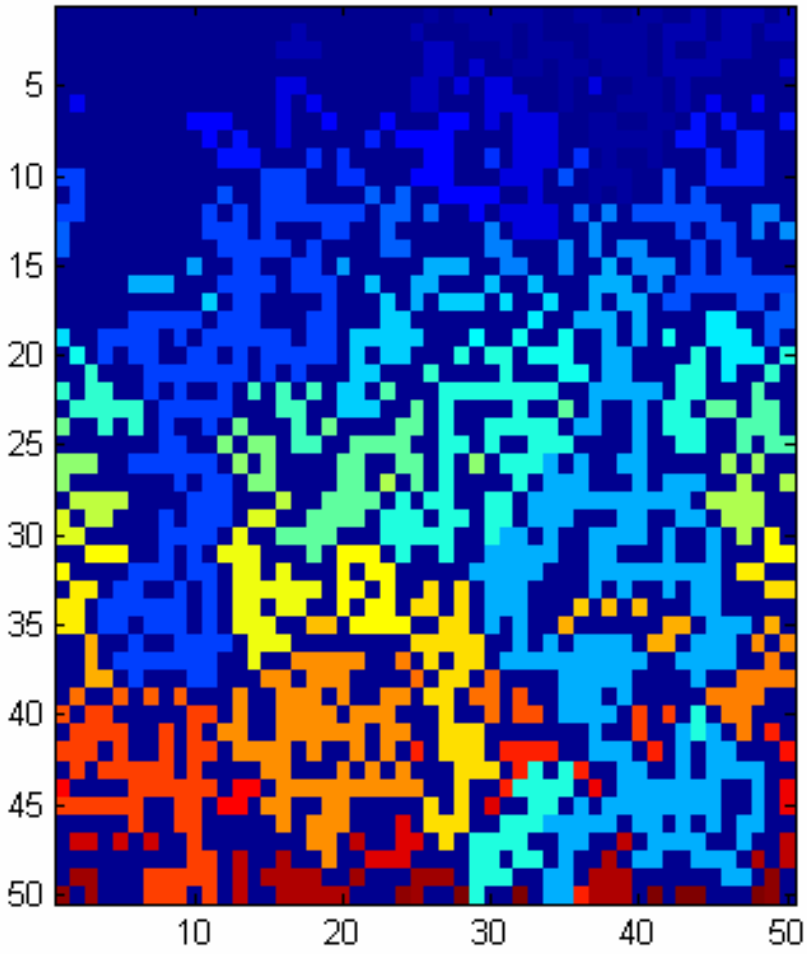
A Conceptual Model: 2D Lattice



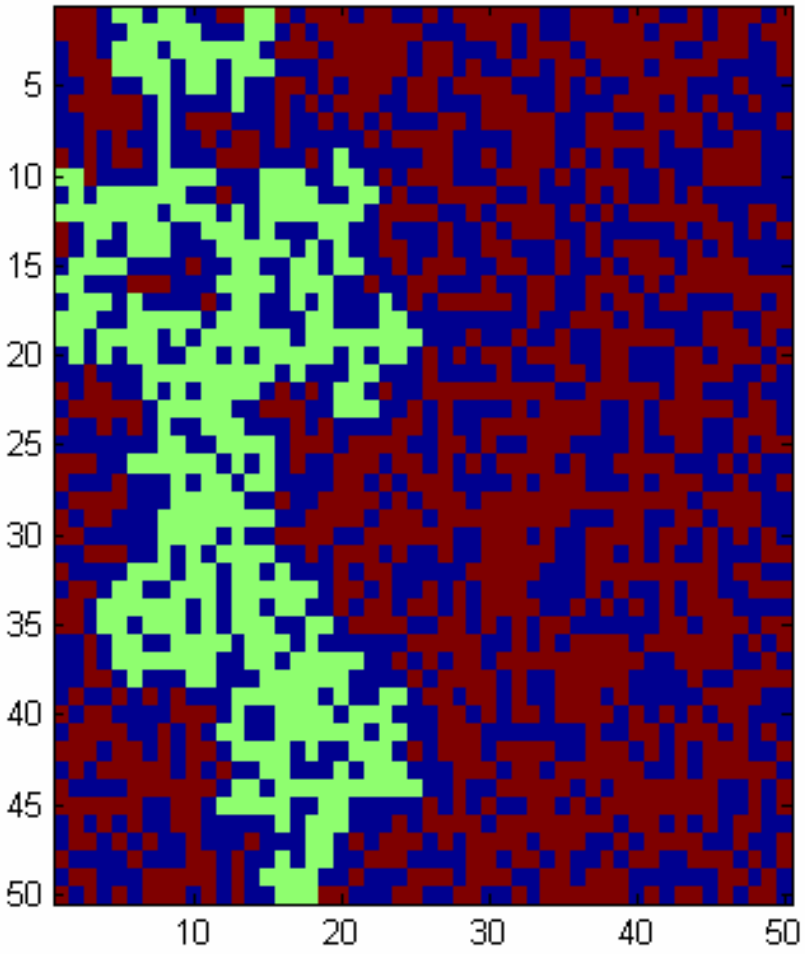


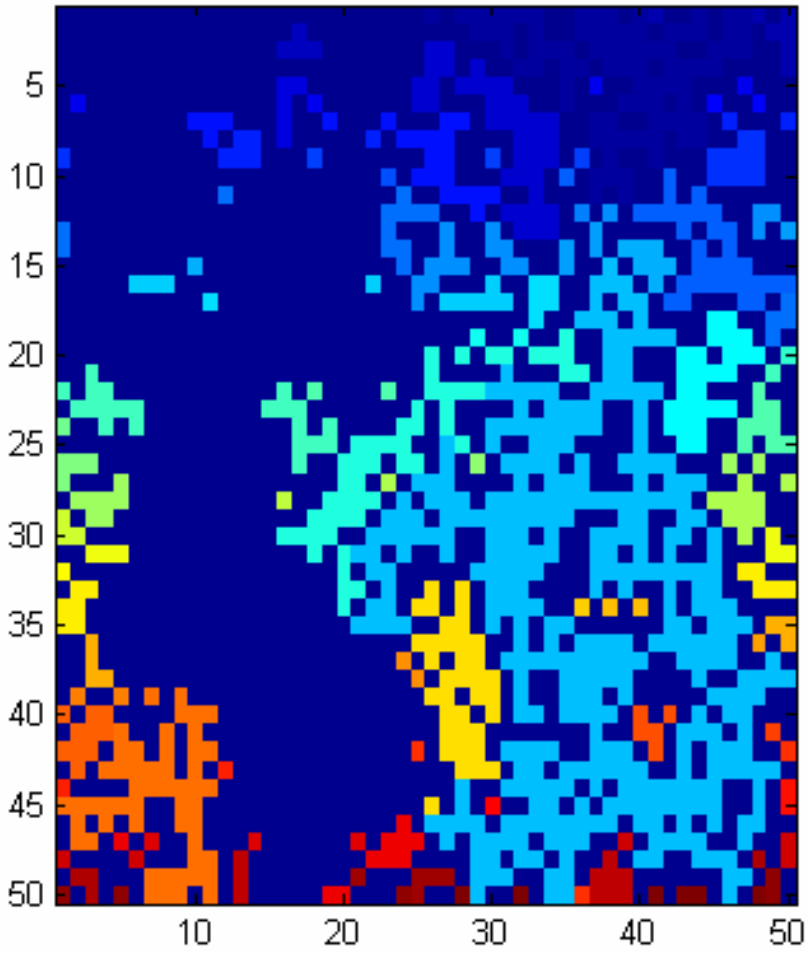
A Conceptual Model: 2D Lattice





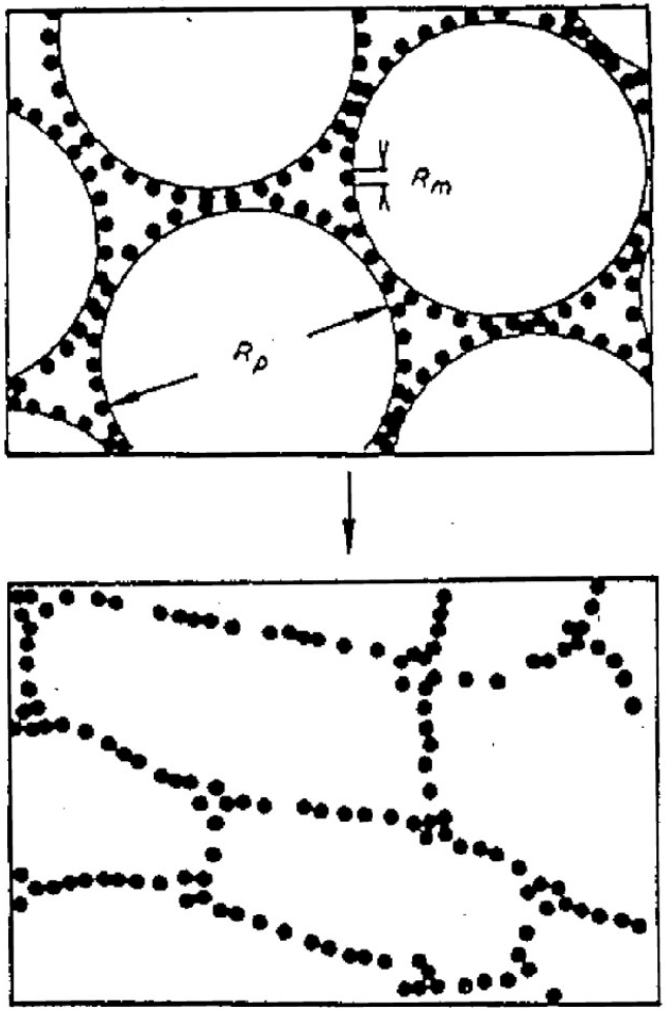
A Conceptual Model: 2D Lattice



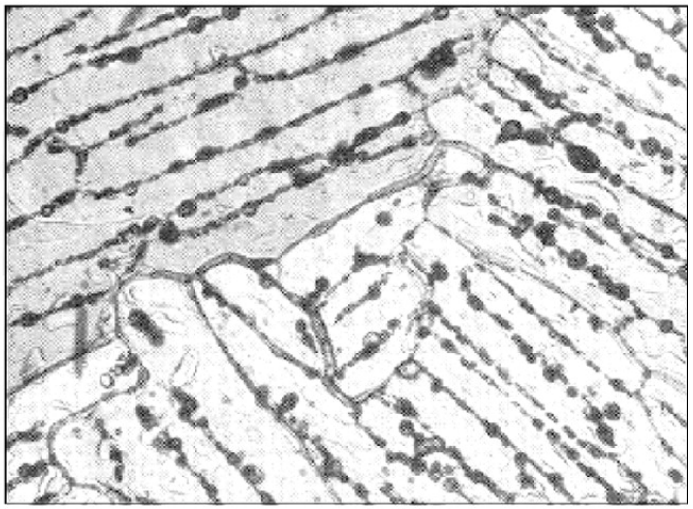


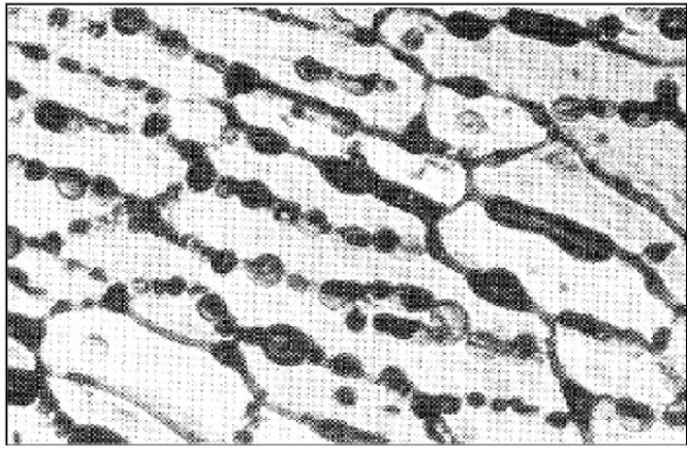
52% Liquid

Compressed Powder



Sea Ice



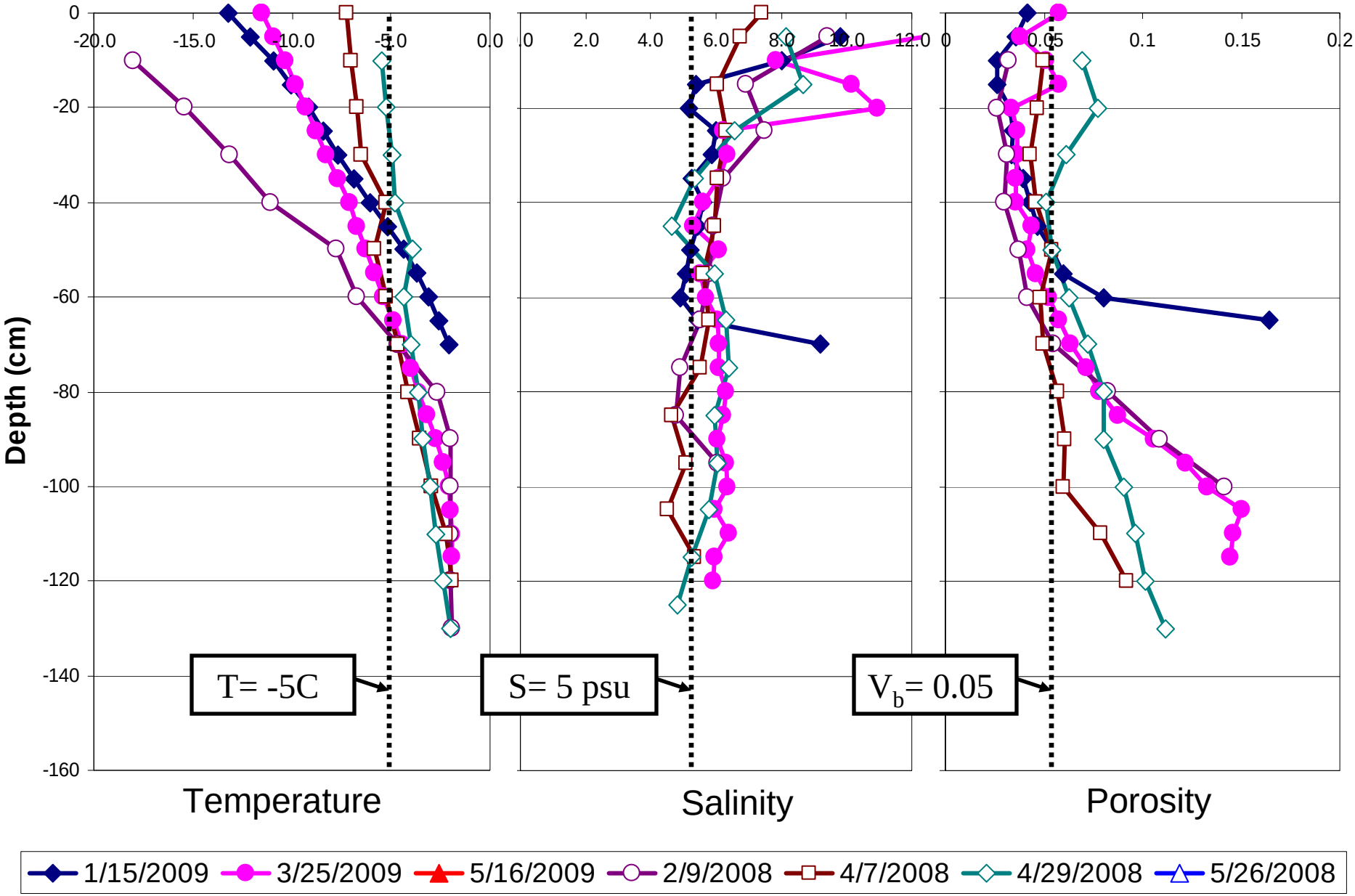


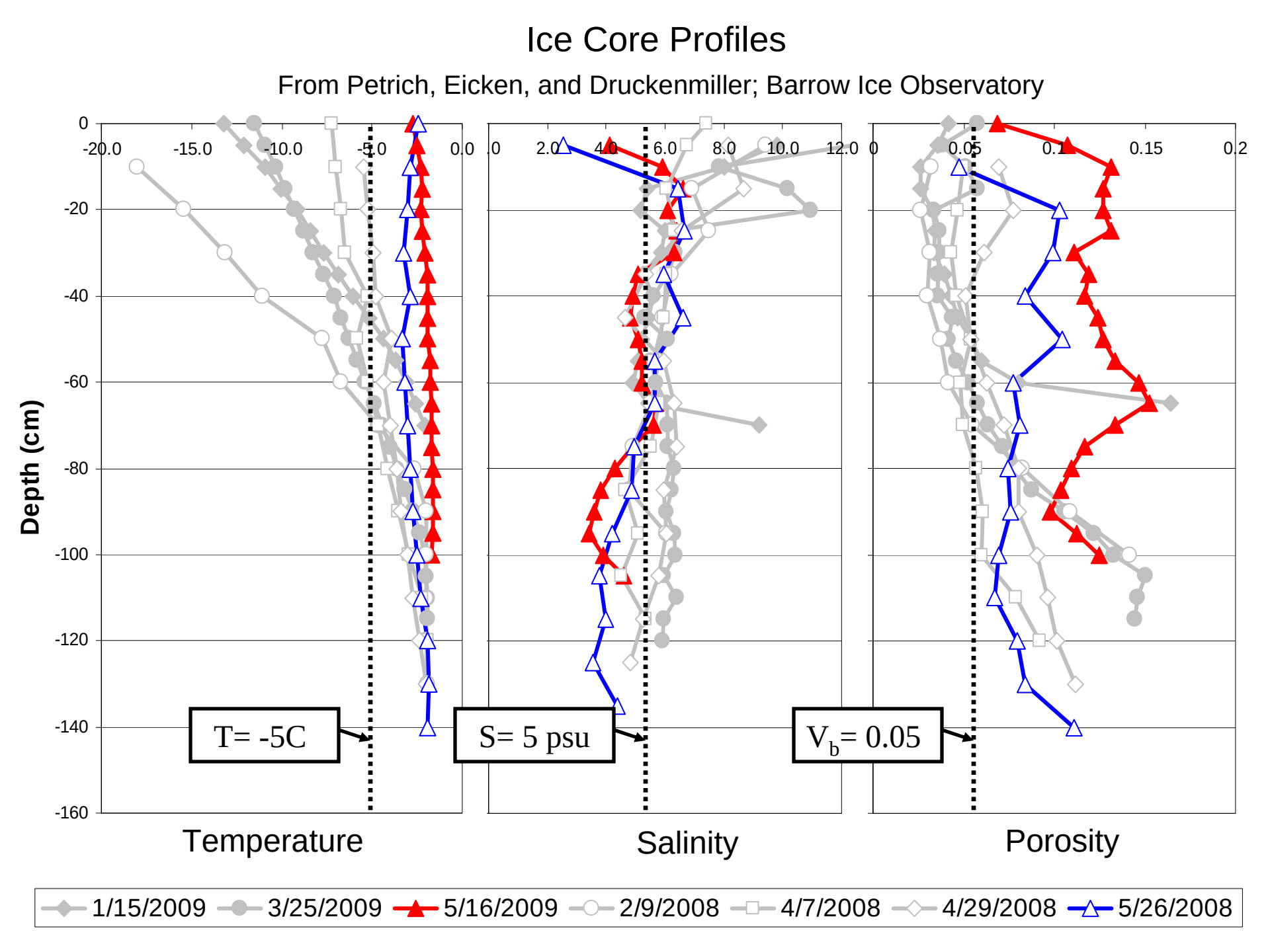
Golden, Ackley, and Lytle. “The Percolation Phase Transition in Ice.” Science. Vol 232, 1998.

Photo: Kathryn Hansen/NASA

Ice Core Profiles

From Petrich, Eicken, and Druckenmiller; Barrow Ice Observatory




Ice Core Profiles
From Petrich, Eicken, and Druckenmiller; Barrow Ice Observatory
Depth (cm)
0
-20
-40
-60
-80
-100
-120
-140
-160
-20.0
-15.0
-10.0
-5.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
0
0.05
0.1
0.15
0.2
T= -5C
S= 5 psu
V_b= 0.05
Temperature
Salinity
Porosity
1/15/2009
3/25/2009
5/16/2009
2/9/2008
4/7/2008
4/29/2008
5/26/2008

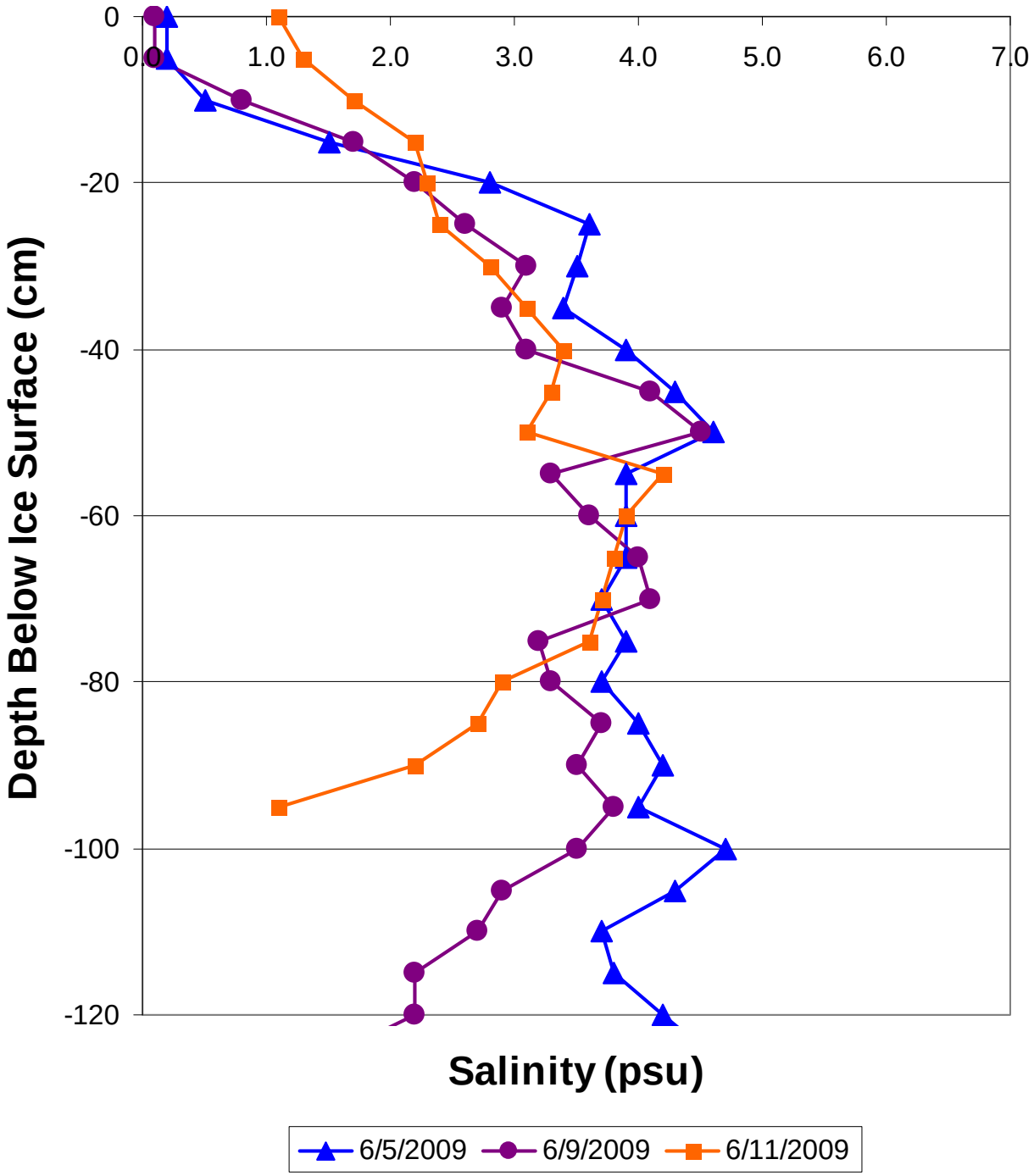

0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
-20
-40
-60
-80
-100
-120
Depth Below Ice Surface (cm)
Salinity (psu)
6/5/2009
6/9/2009
6/11/2009


Photo: Chris Petrich

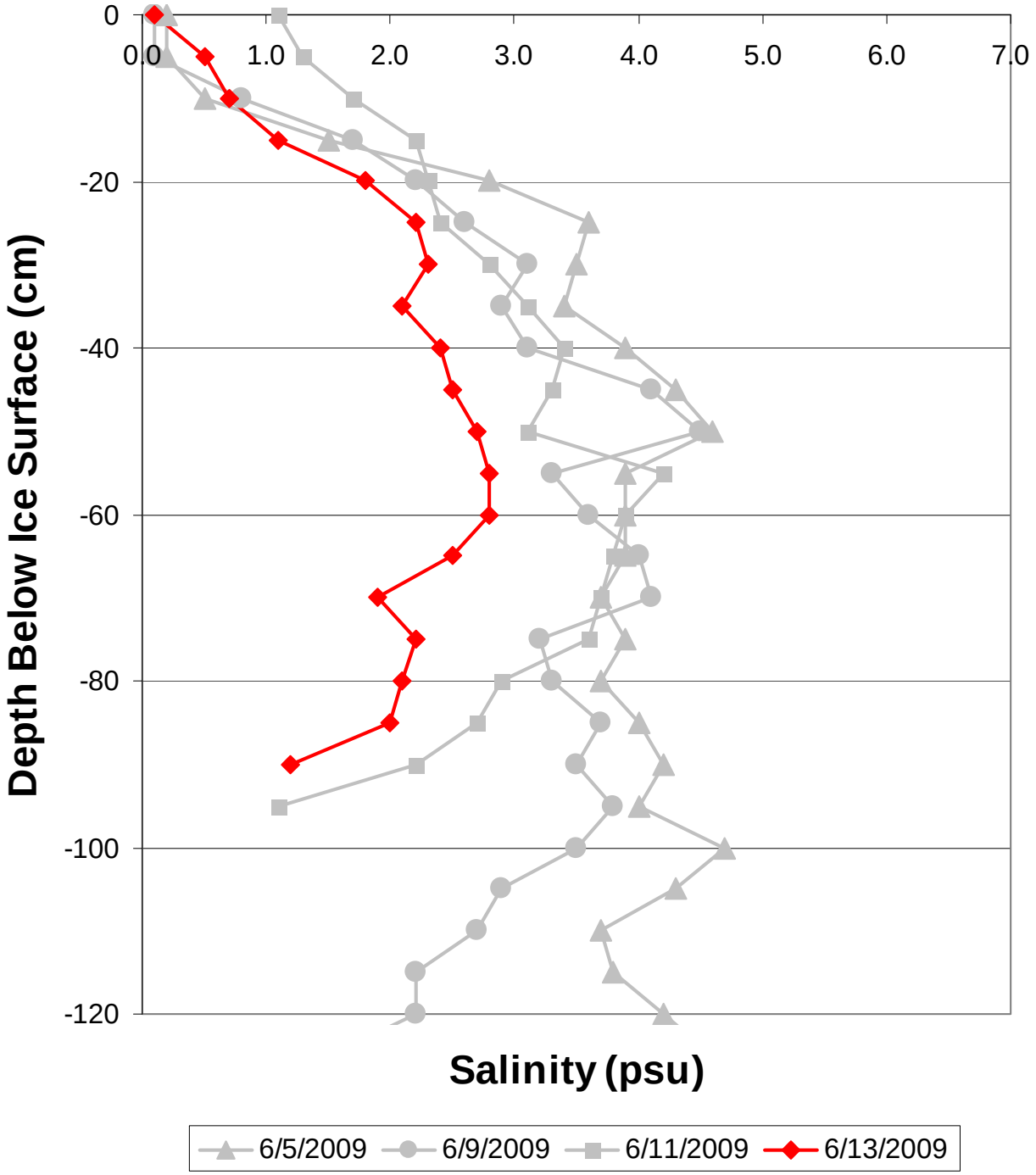

0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
-20
-40
-60
-80
-100
-120
Depth Below Ice Surface (cm)
Salinity (psu)
6/5/2009
6/9/2009
6/11/2009
6/13/2009


Photo: Chris Petrich

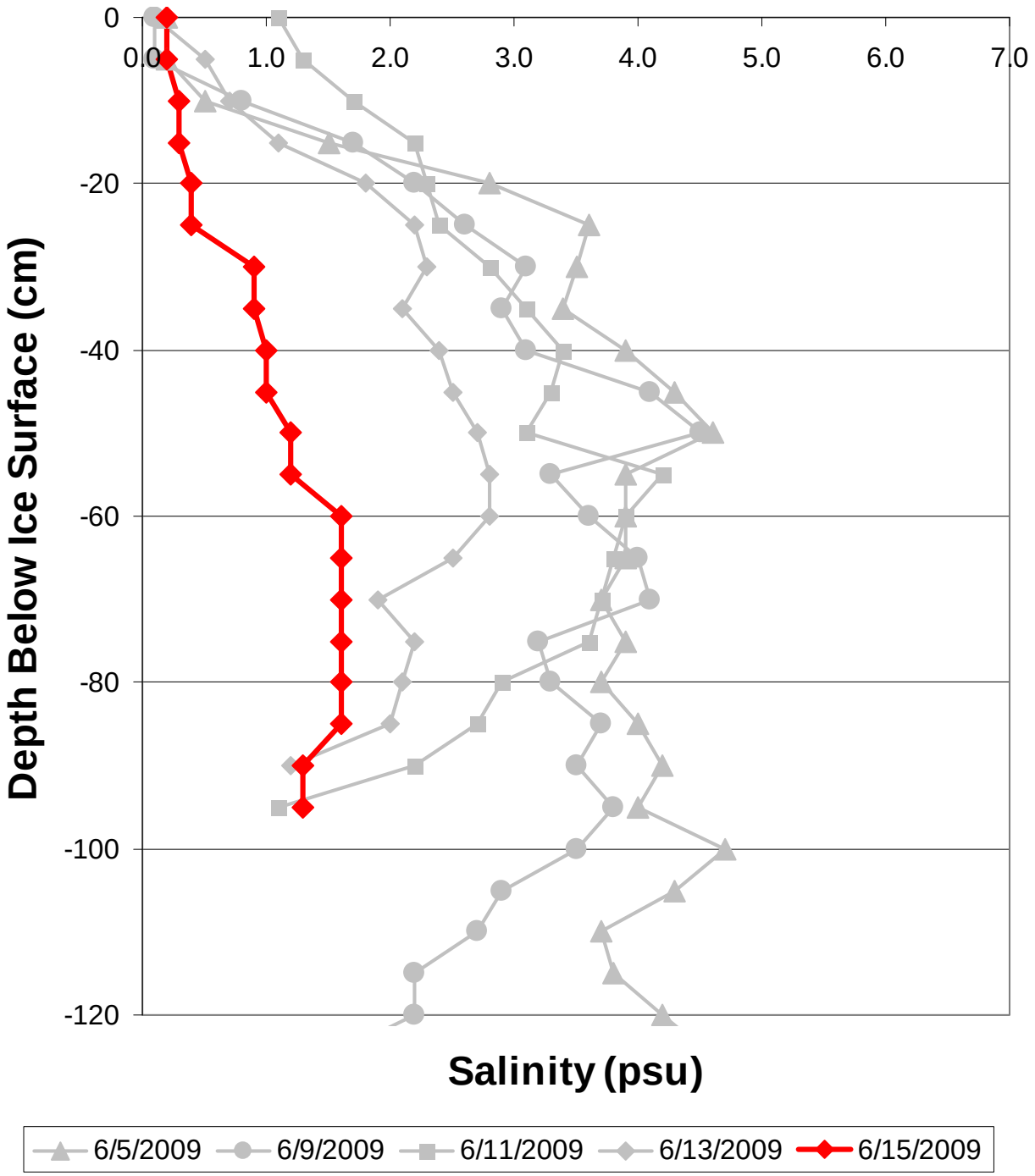
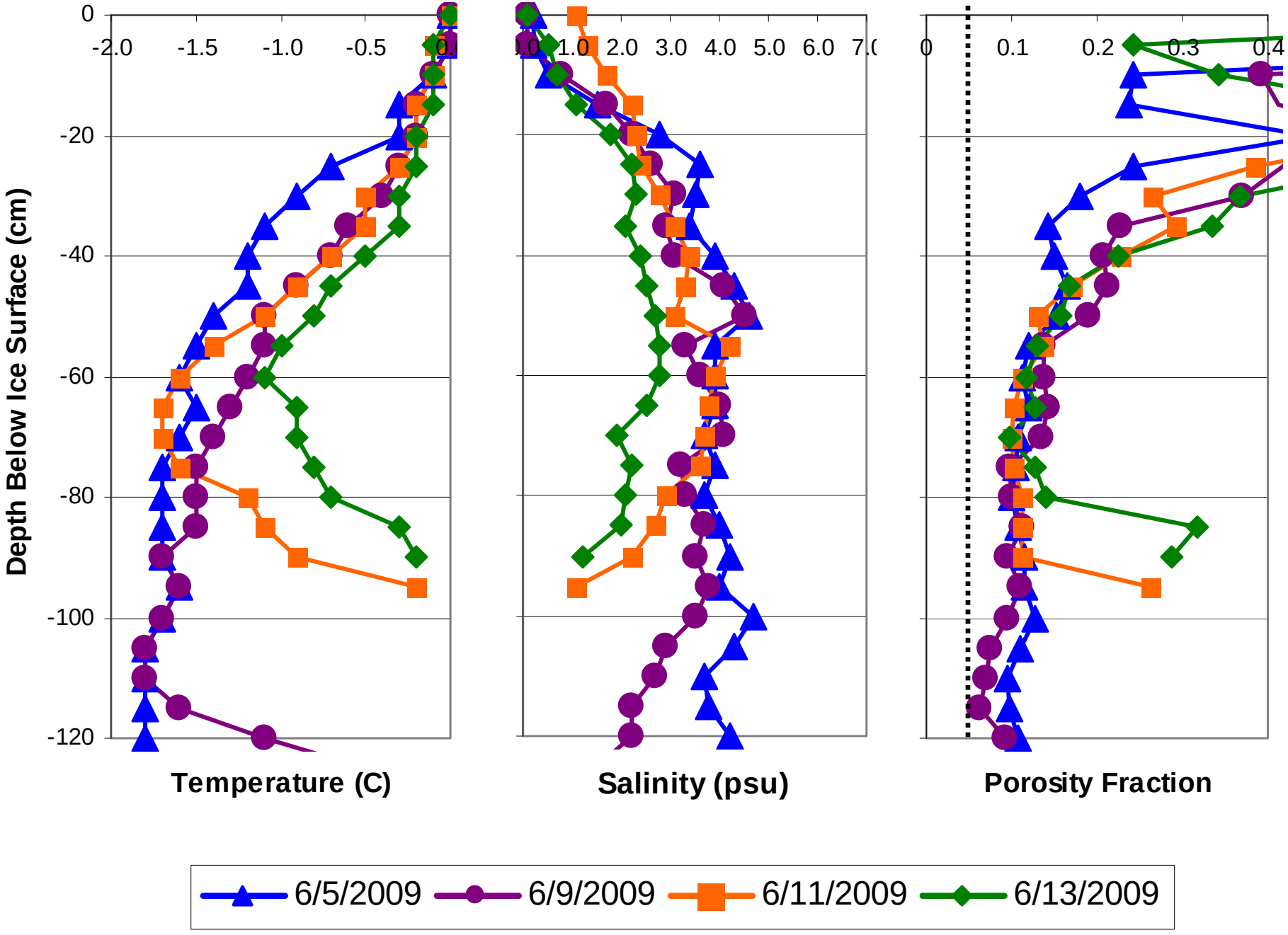
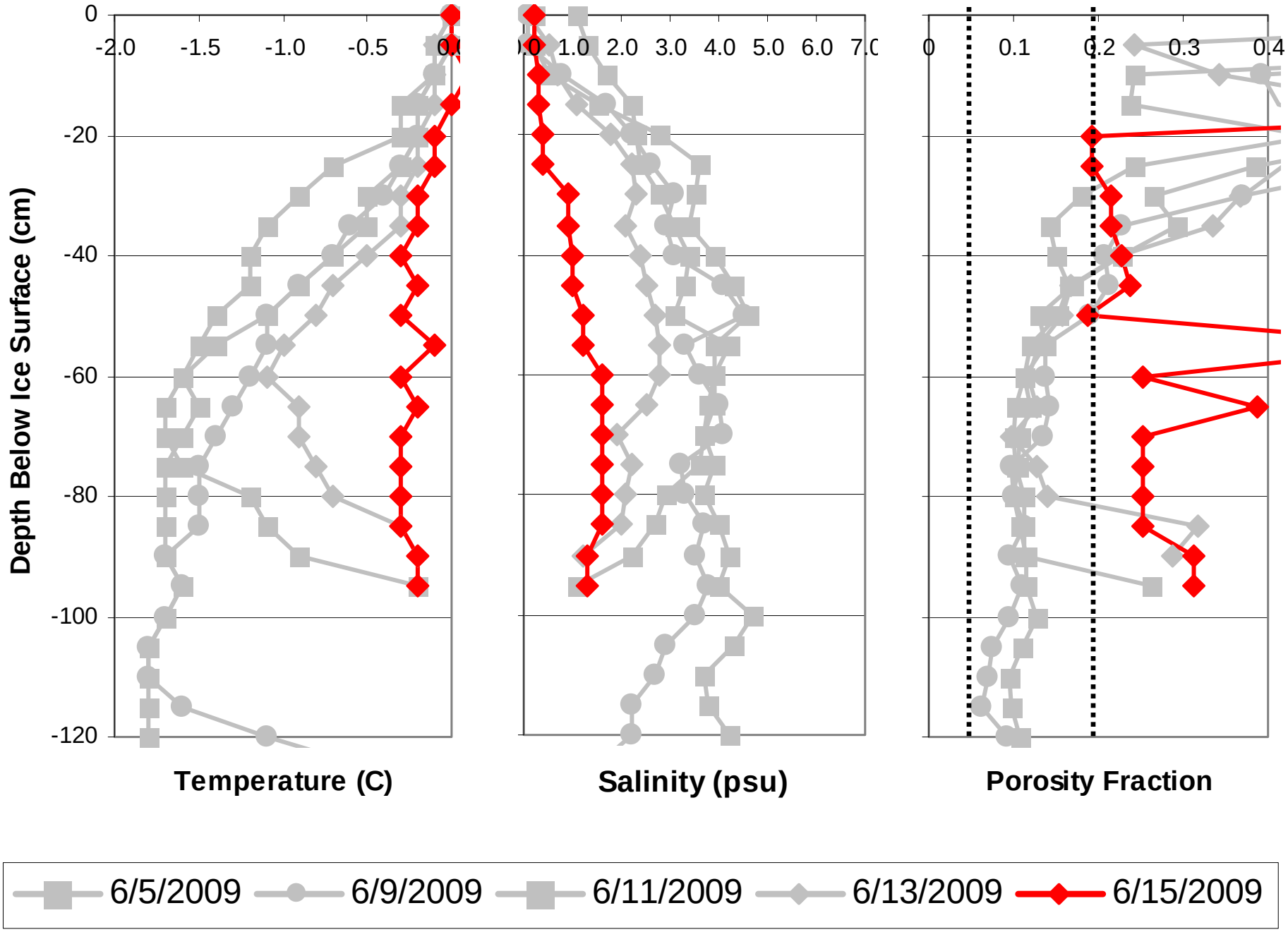
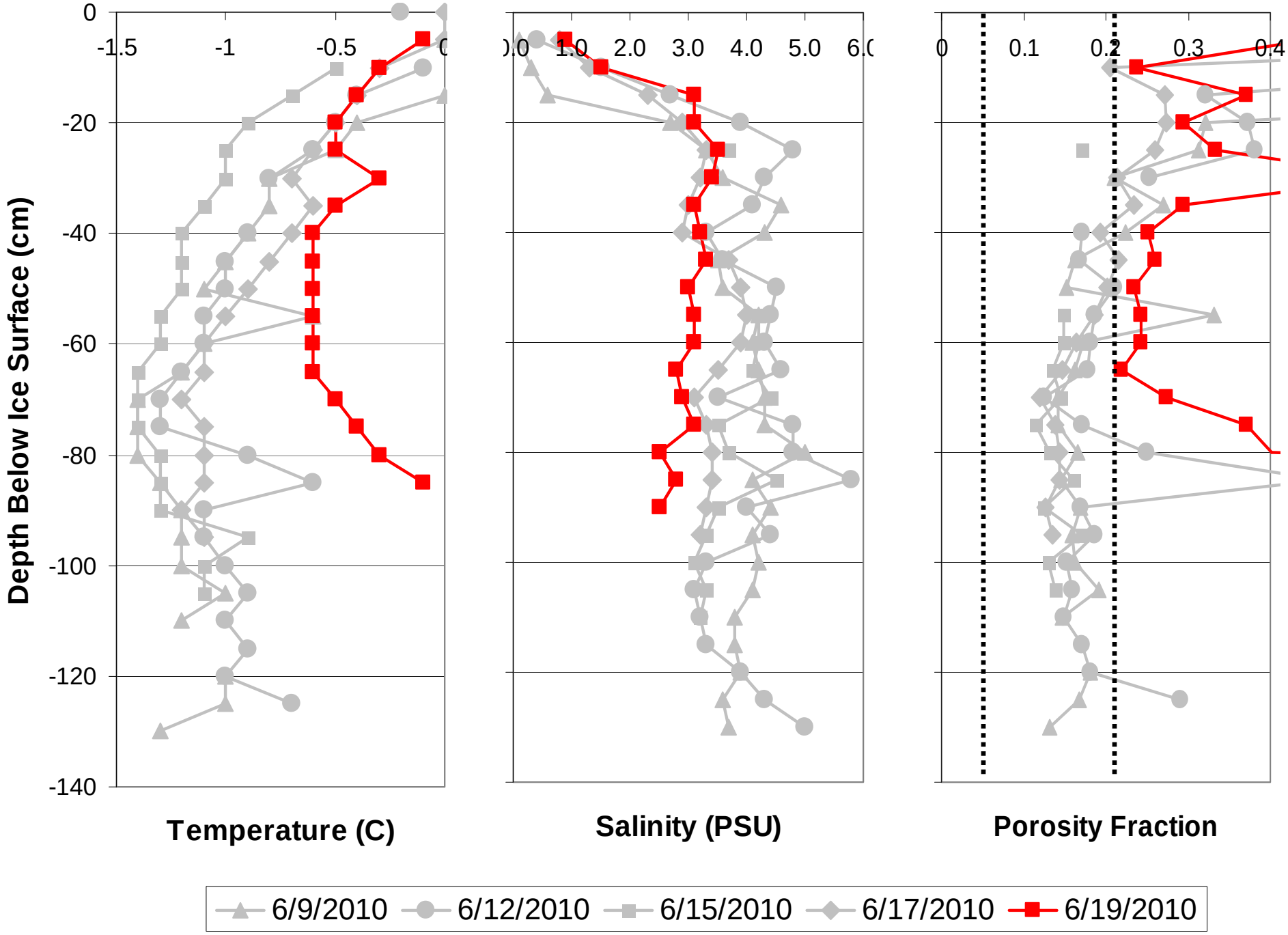
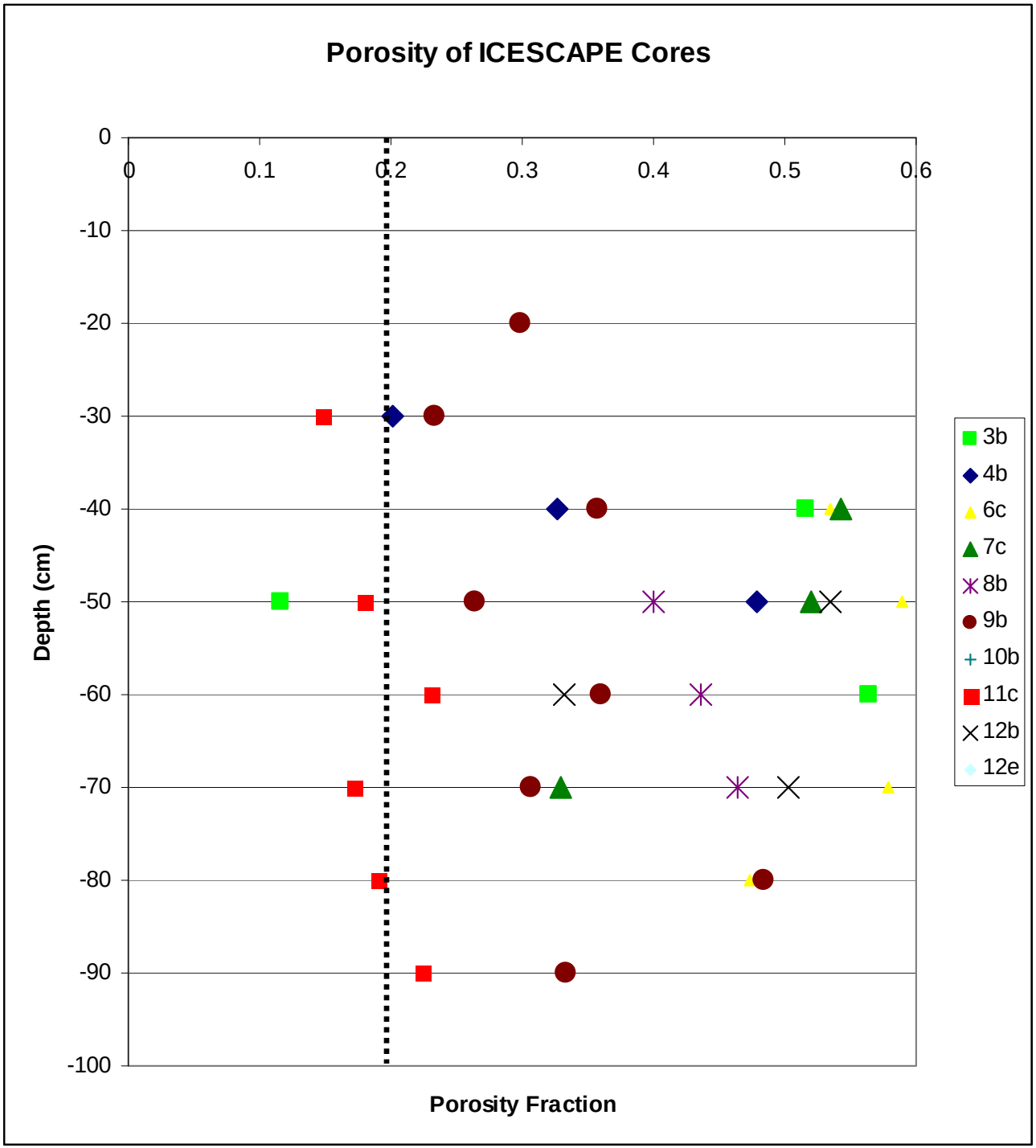

0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
-20
-40
-60
-80
-100
-120
Depth Below Ice Surface (cm)
Salinity (psu)
6/5/2009
6/9/2009
6/11/2009
6/13/2009
6/15/2009


Photo: Chris Petrich


Depth Below Ice Surface (cm)
0
-20
-40
-60
-80
-100
-120
-2.0
-1.5
-1.0
-0.5
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
0.1
0.2
0.3
0.4
Temperature (C)
Salinity (psu)
Porosity Fraction
6/5/2009
6/9/2009
6/11/2009
6/13/2009


Depth Below Ice Surface (cm)
0
-20
-40
-60
-80
-100
-120
-2.0
-1.5
-1.0
-0.5
1.0
2.0
3.0
4.0
5.0
6.0
0
0.1
0.2
0.3
0.4
Temperature (C)
Salinity (psu)
Porosity Fraction
6/5/2009
6/9/2009
6/11/2009
6/13/2009
6/15/2009


Depth Below Ice Surface (cm)
0
-20
-40
-60
-80
-100
-120
-140
-1.5
-1
-0.5
0
1.0
2.0
3.0
4.0
5.0
0
0.1
0.2
0.3
0.4
Temperature (C)
Salinity (PSU)
Porosity Fraction
6/9/2010
6/12/2010
6/15/2010
6/17/2010
6/19/2010


Porosity of ICESCAPE Cores
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Depth (cm)
0
0.1
0.2
0.3
0.4
0.5
0.6
Porosity Fraction
3b
4b
6c
7c
8b
9b
10b
11c
12b
12e

Permeable?

Percolation Threshold: 5% Brine Volume

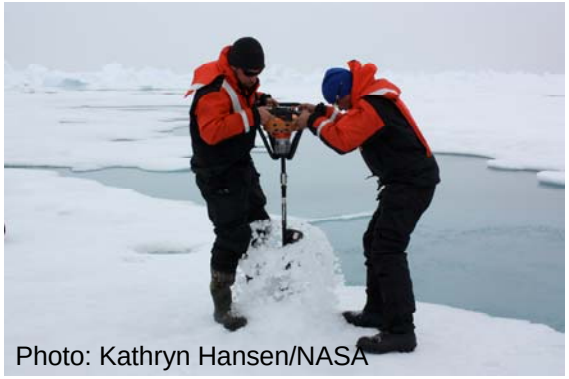
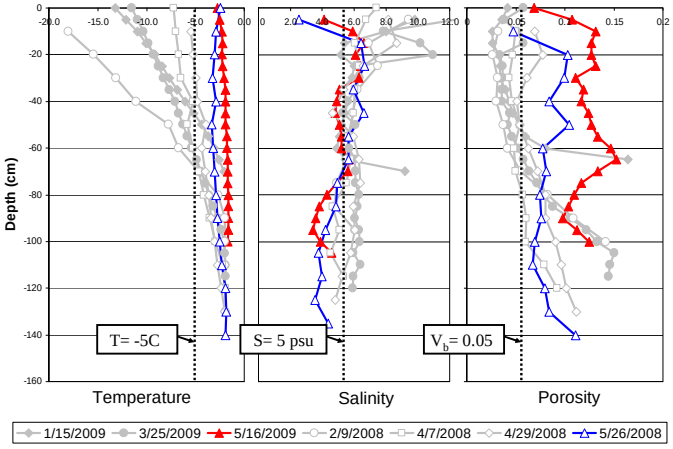
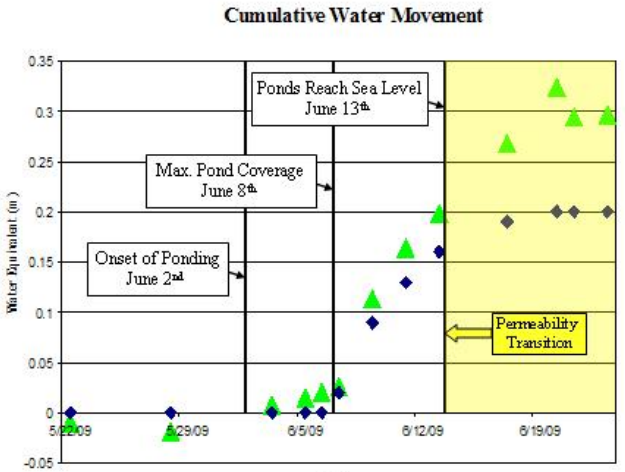


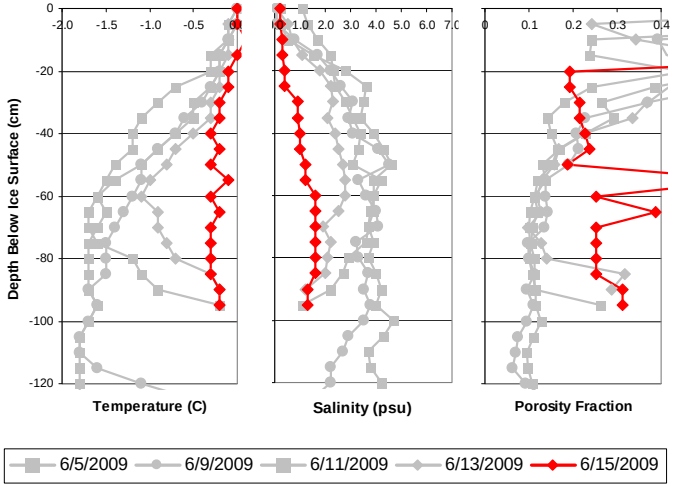
Photo: Kathryn Hansen/NASA

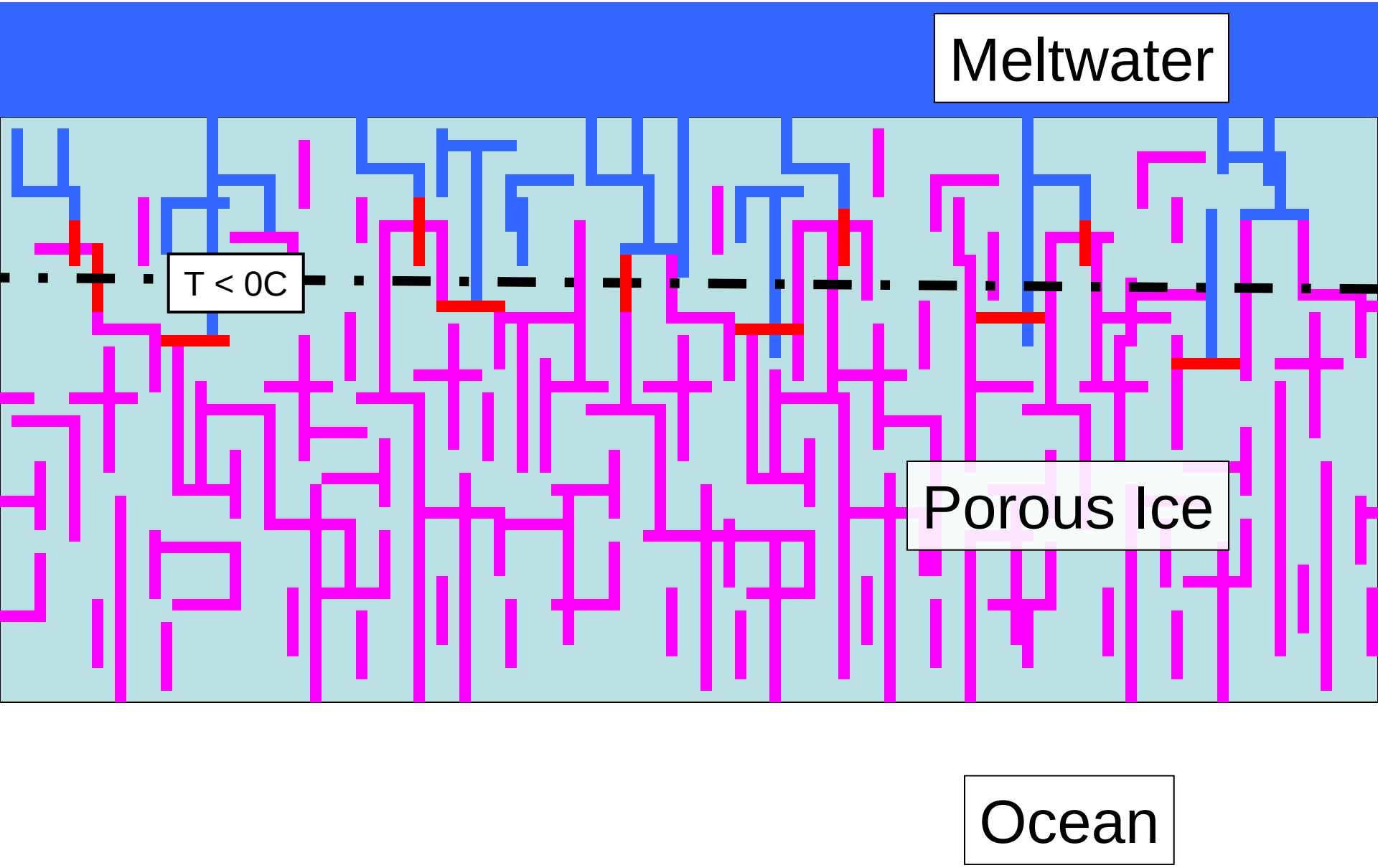
Ice Core Profiles 2008/9 – From Petrich, Eicken, and Druckenmiller

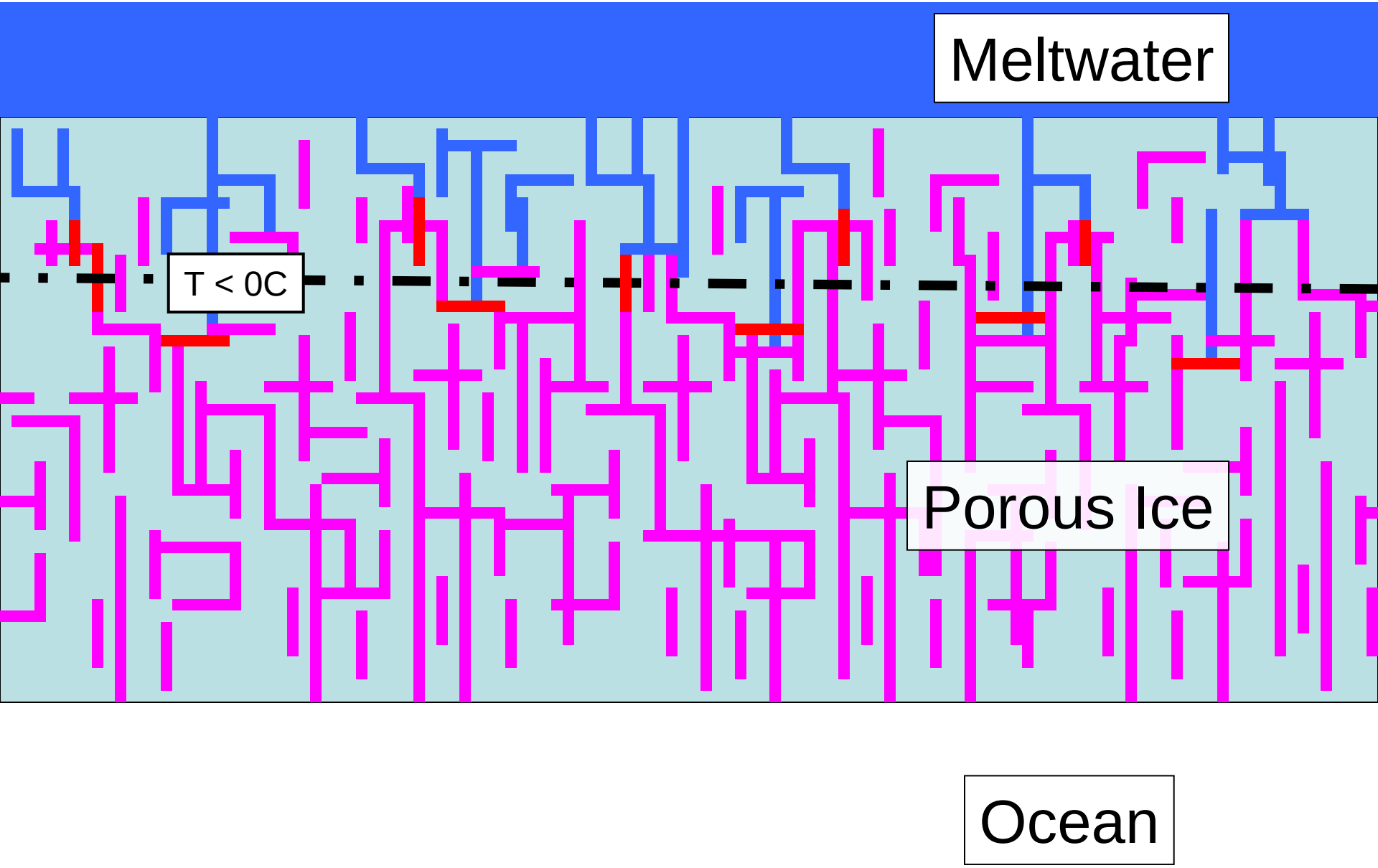


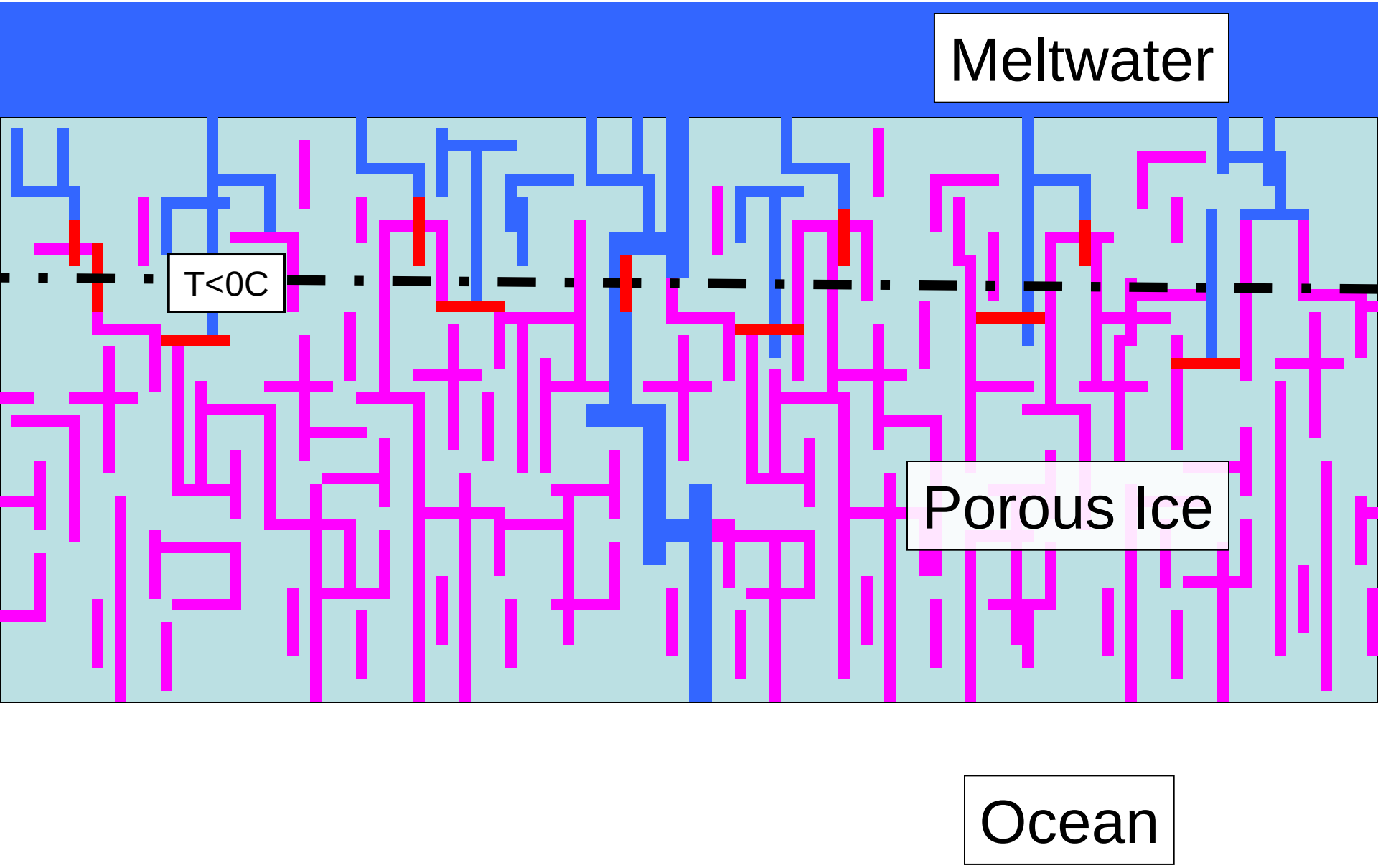
Percolation Threshold: ~20% Brine Volume






Meltwater
T < 0C
Porous Ice
Ocean


Meltwater
T < 0C
Porous Ice
Ocean


Meltwater
T<0C
Porous Ice
Ocean

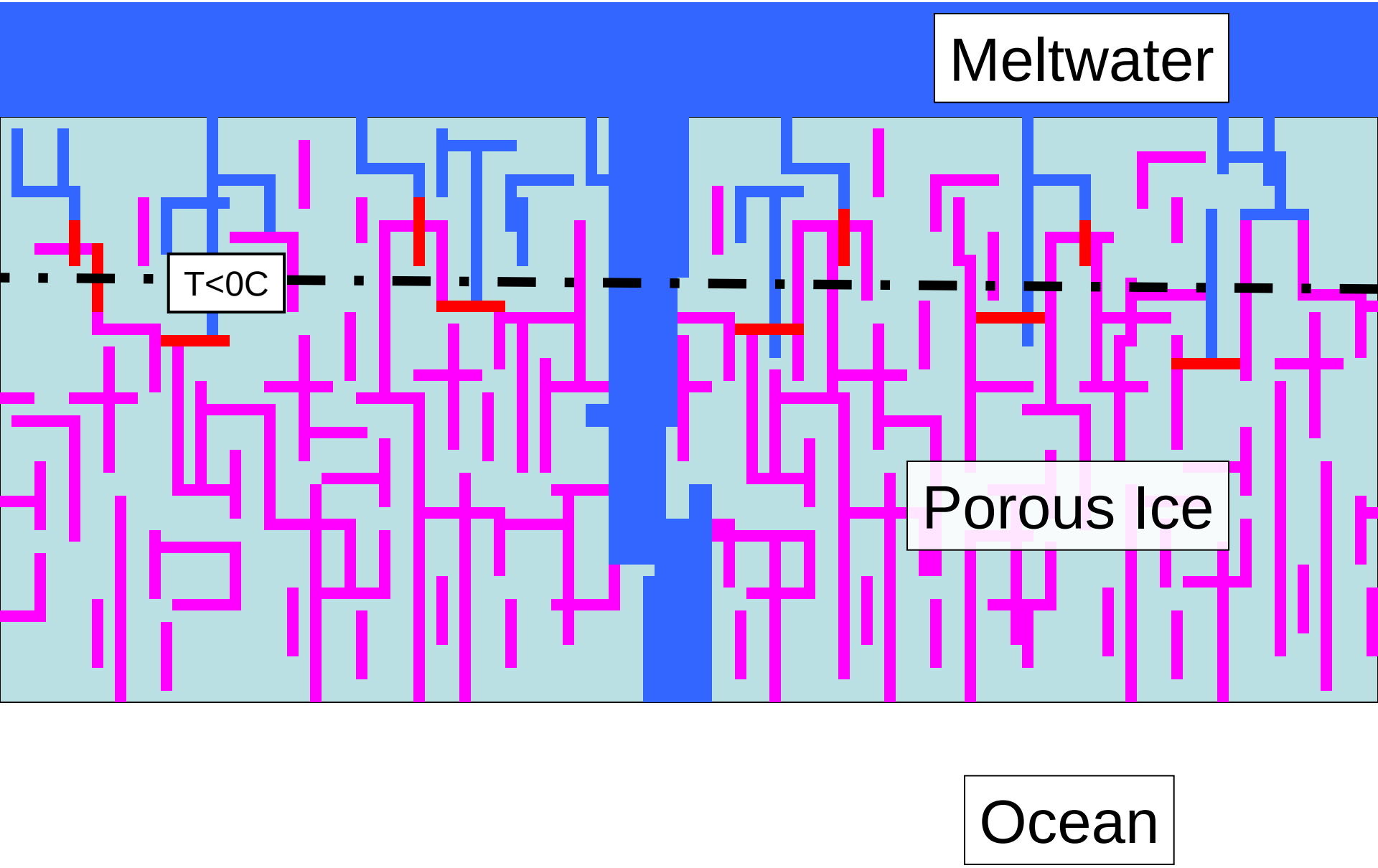
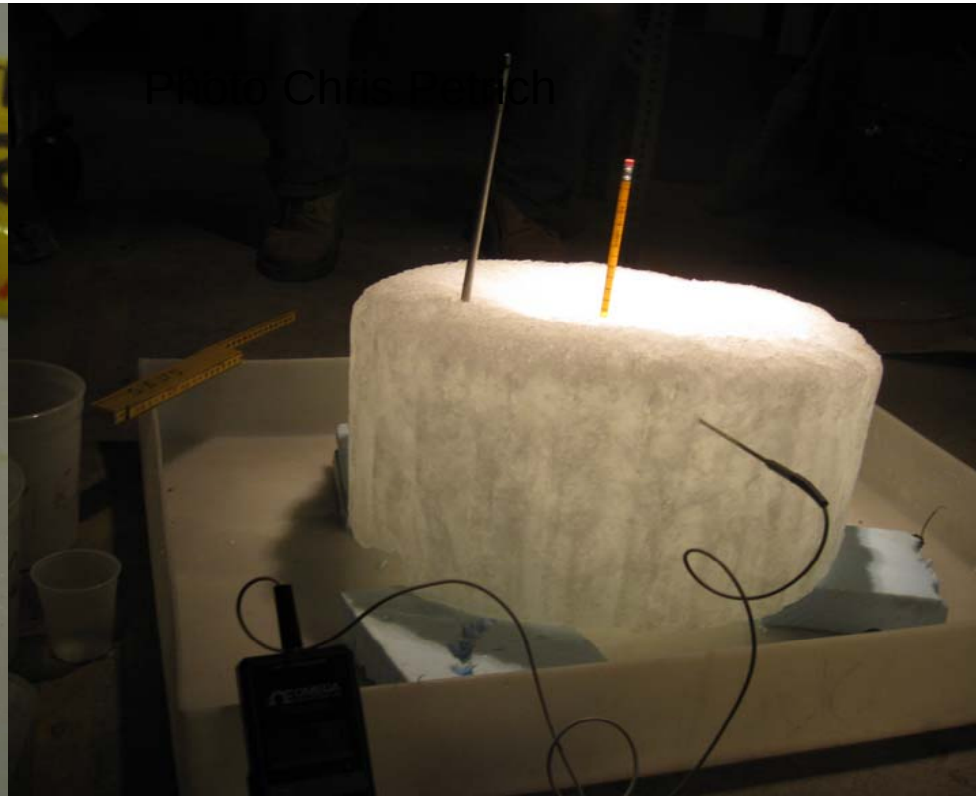
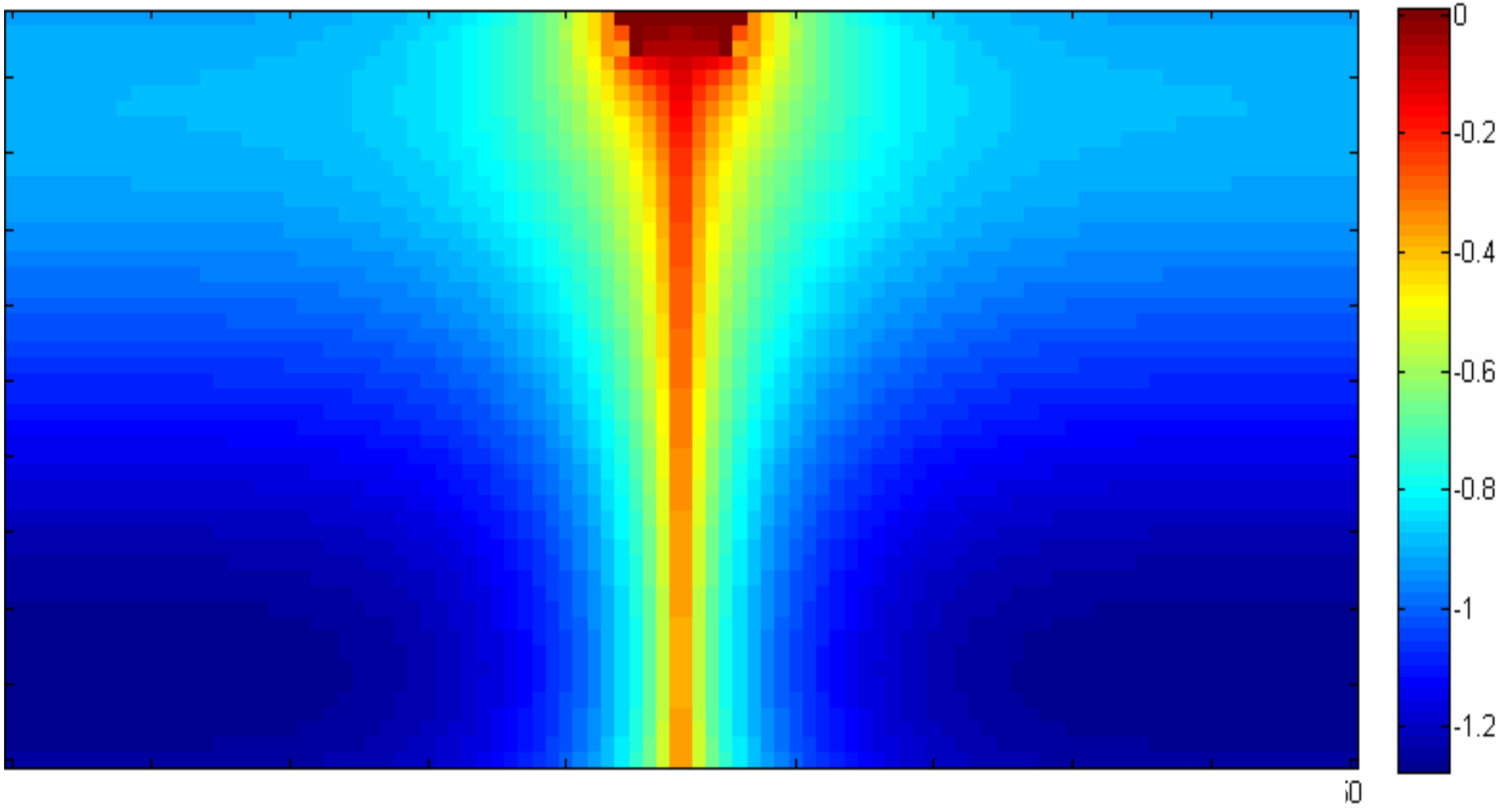
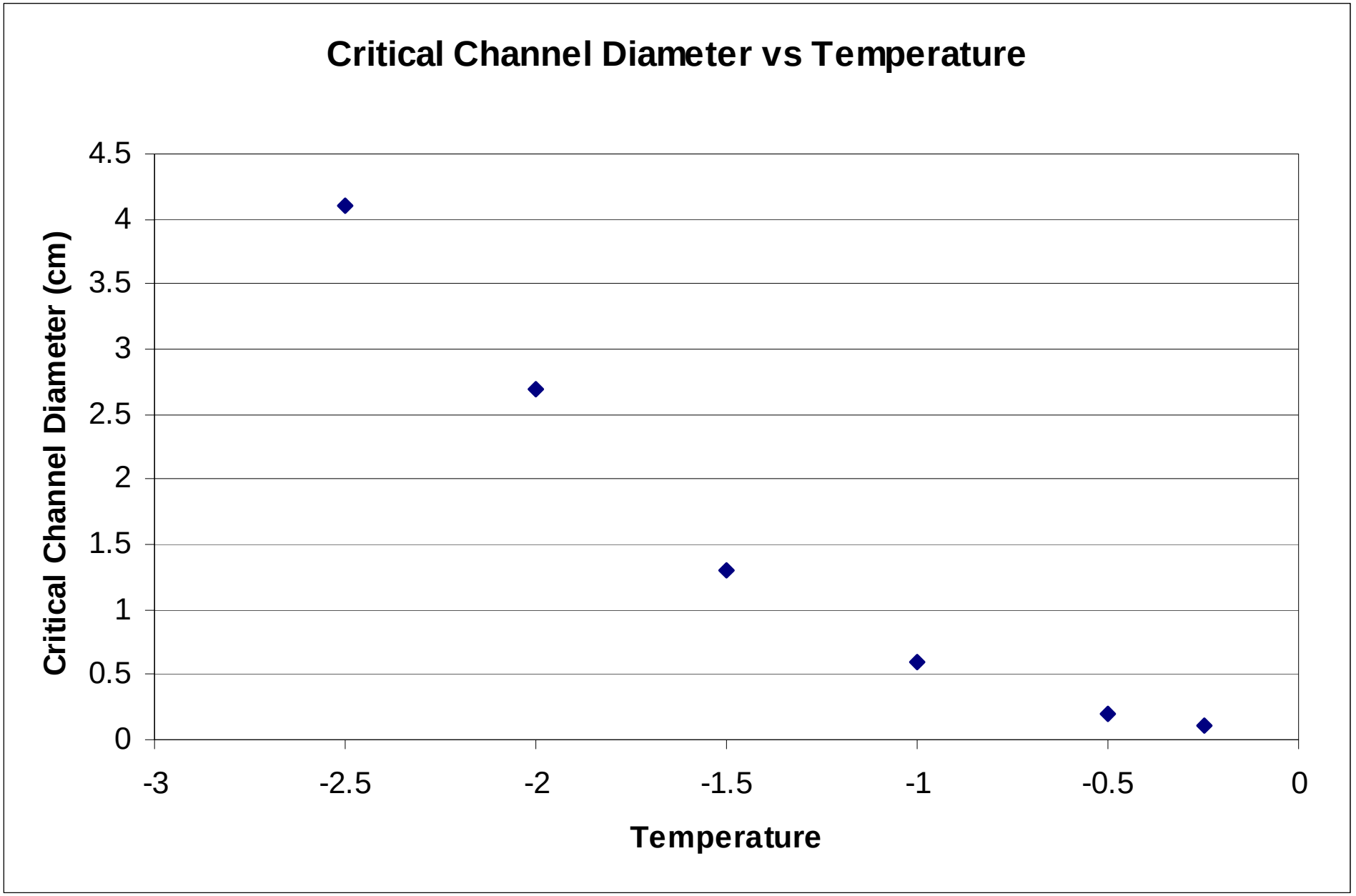

Meltwater
T<0C
Porous Ice
Ocean

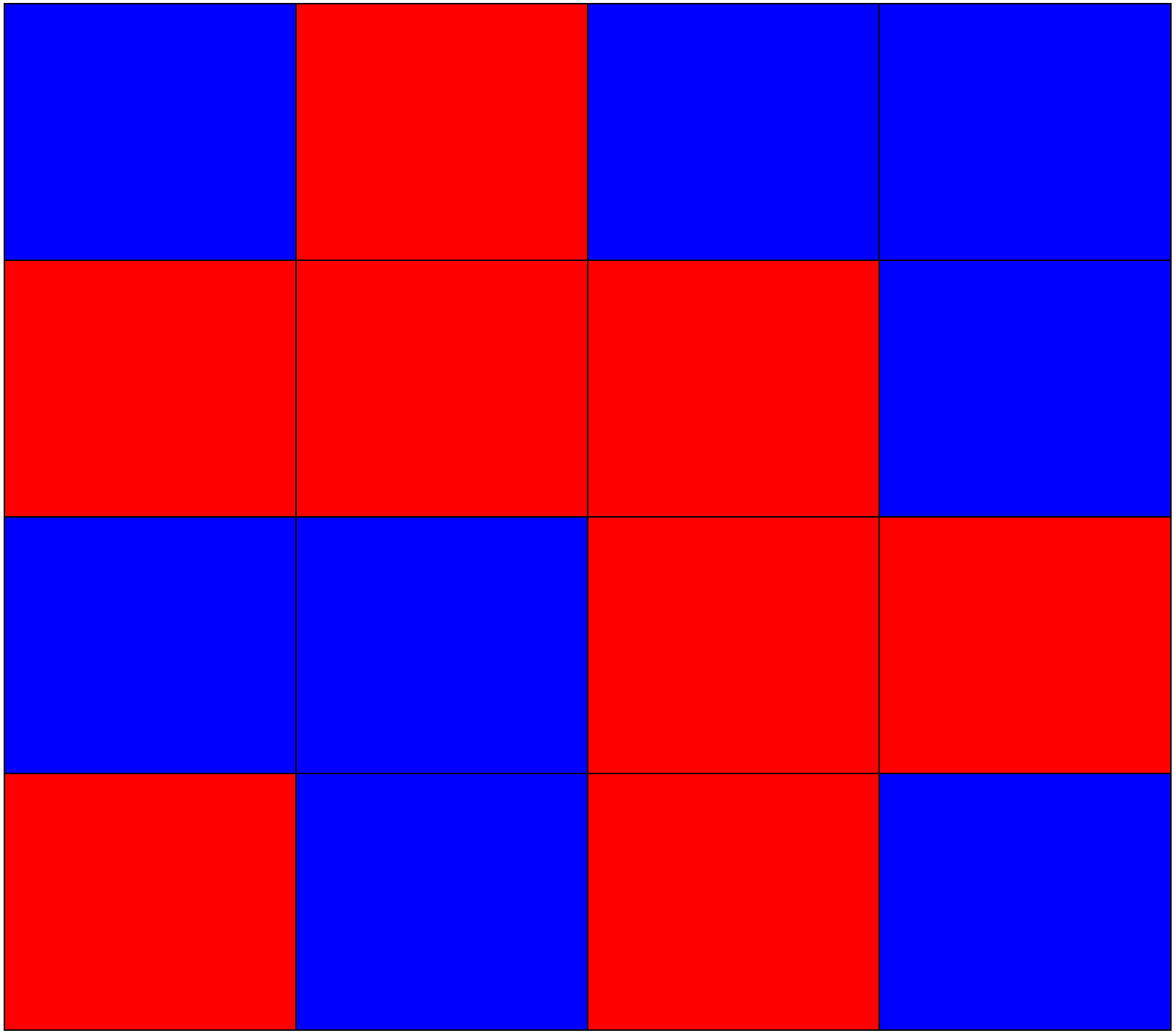

Photo Chris Petrich

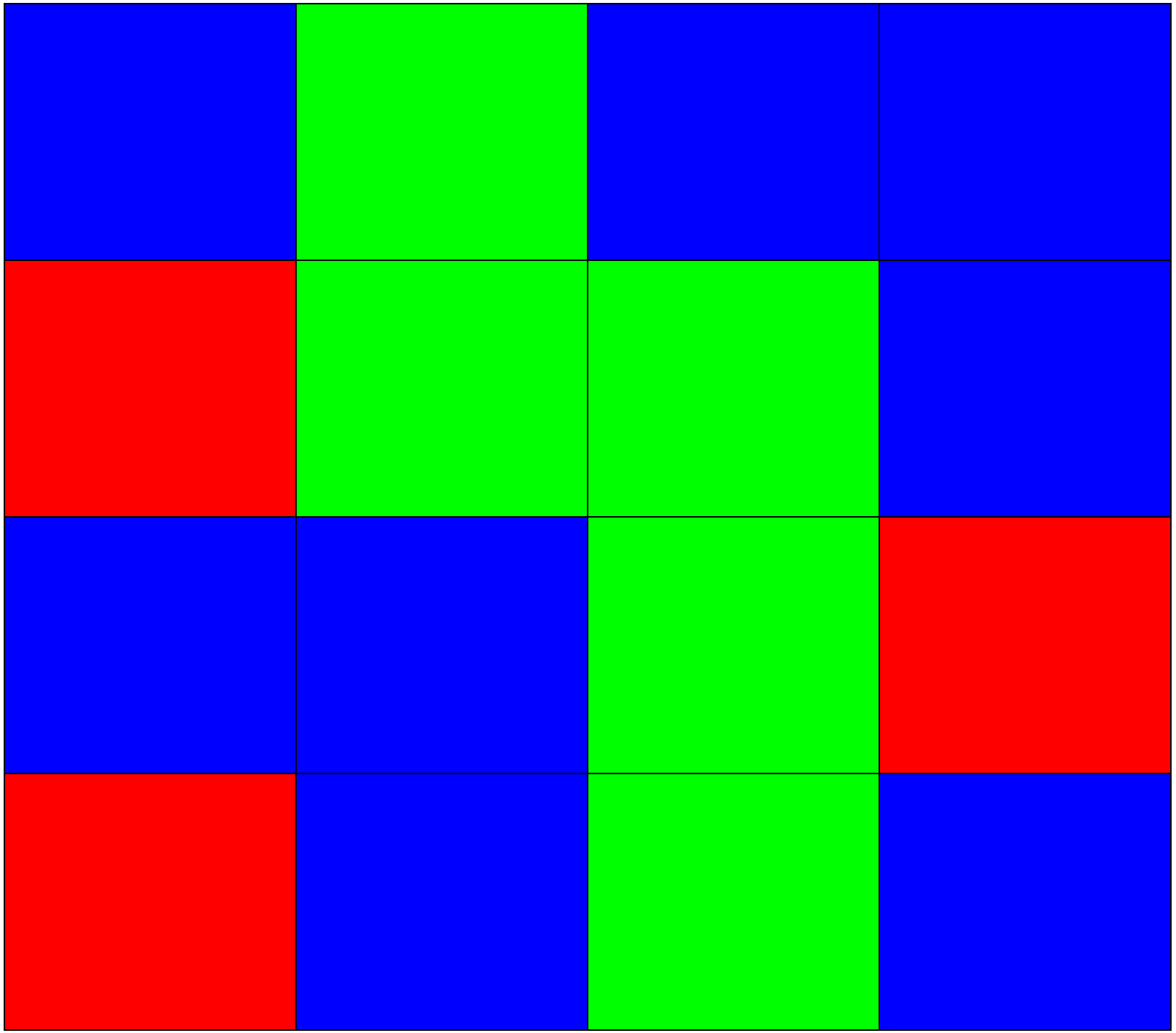


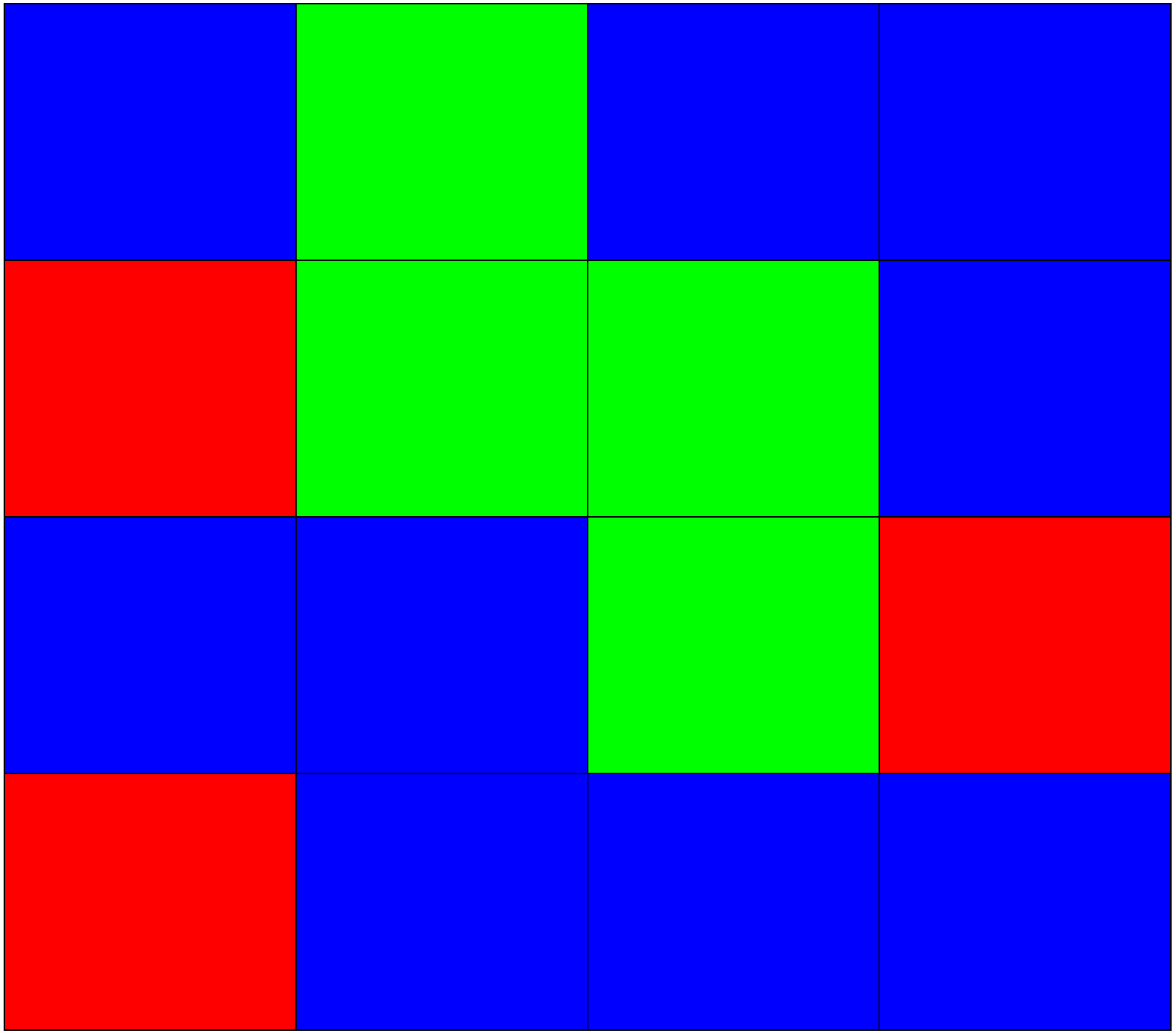
Photos: Becky Niemiec

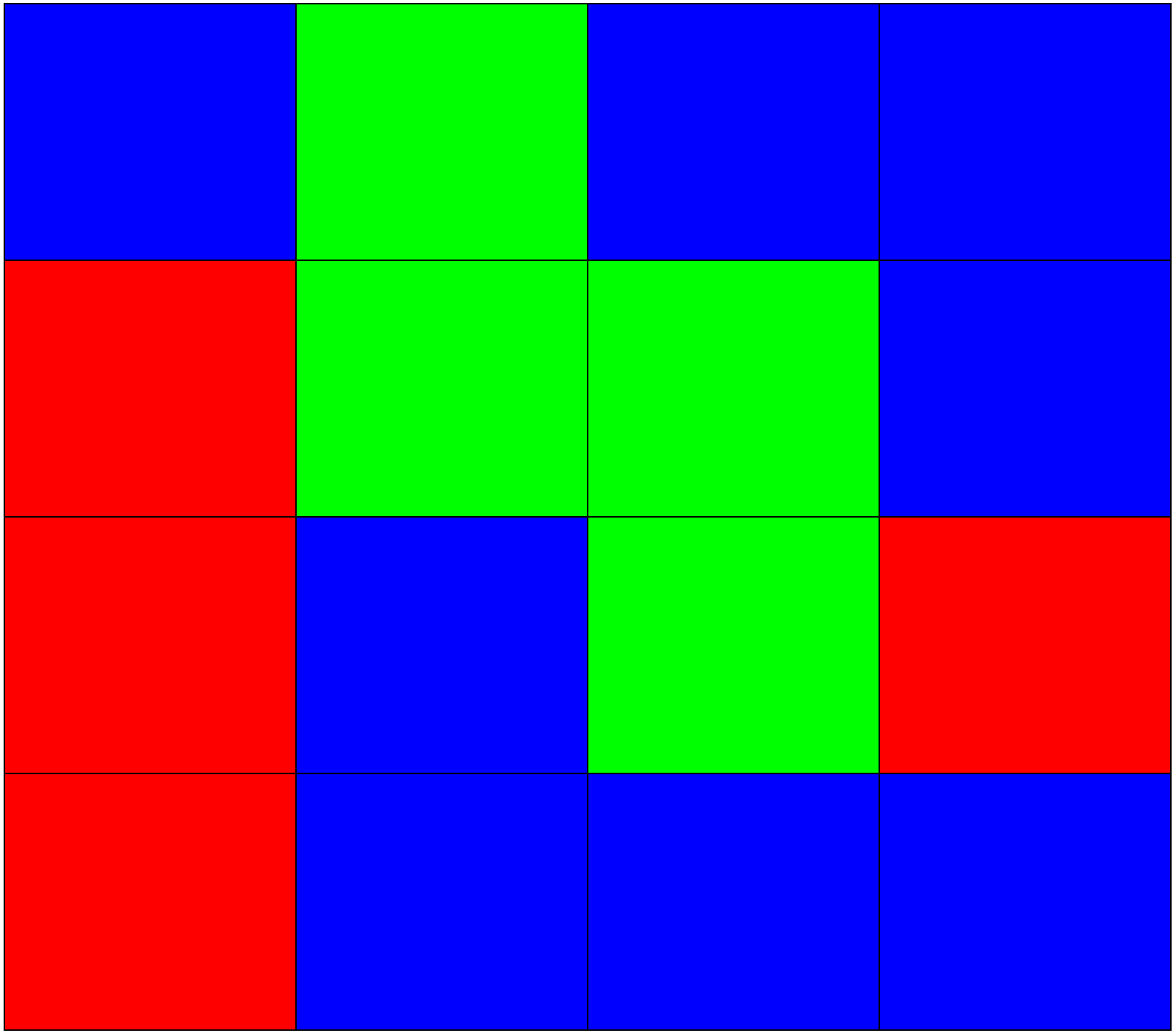

0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
i0

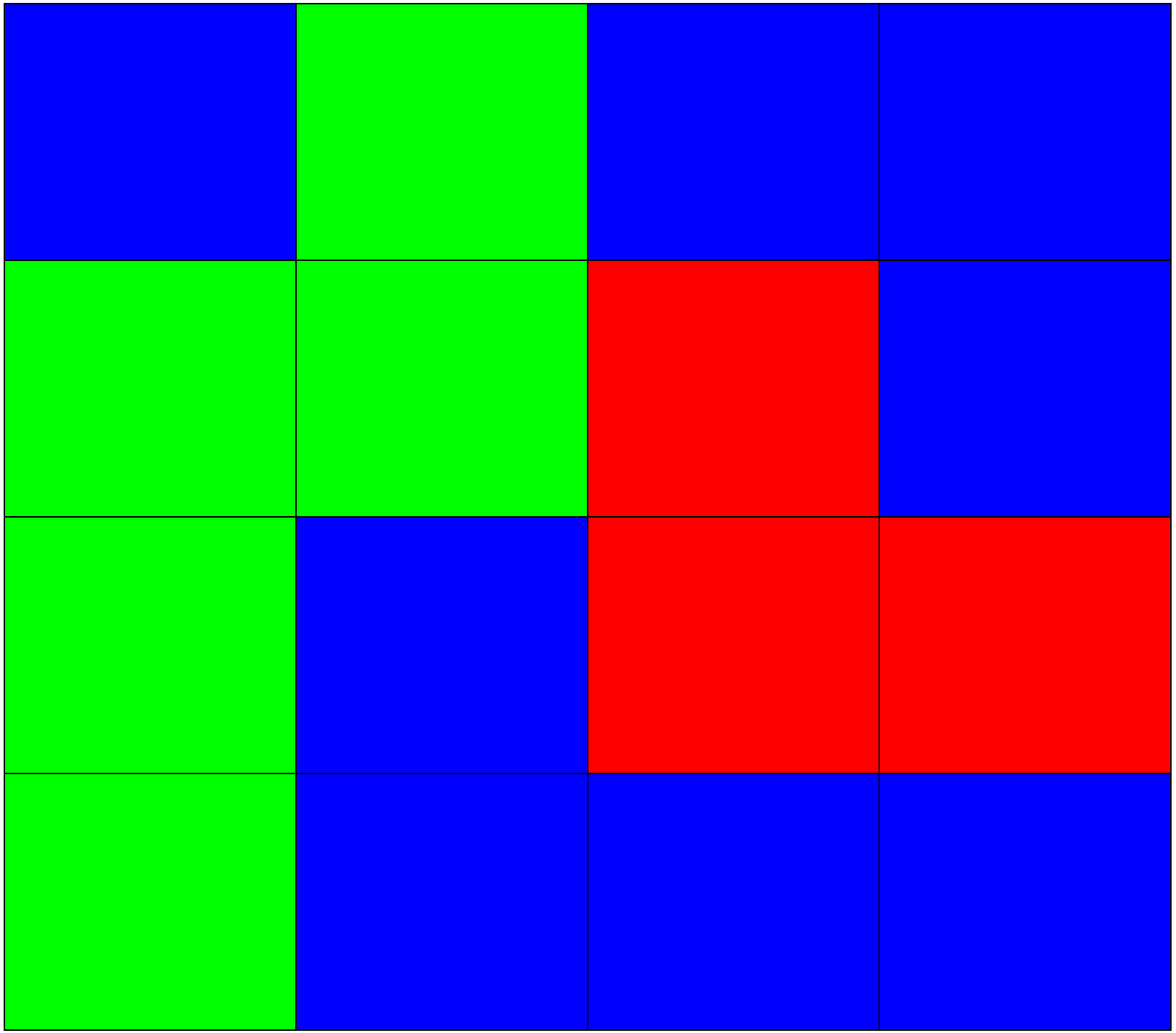

Critical Channel Diameter vs Temperature
Critical Channel Diameter (cm)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-3
-2.5
-2
-1.5
-1
-0.5
0
Temperature

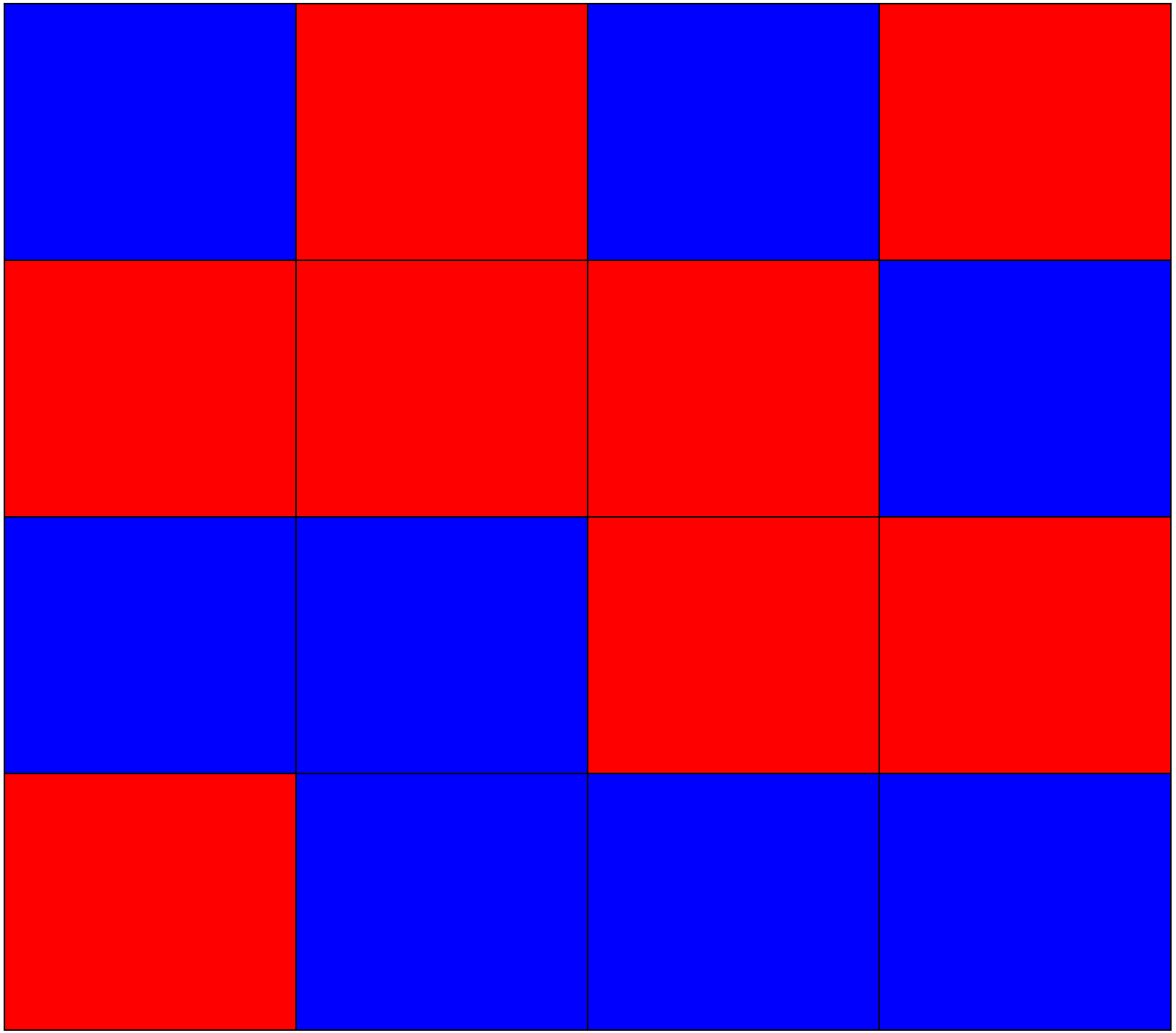


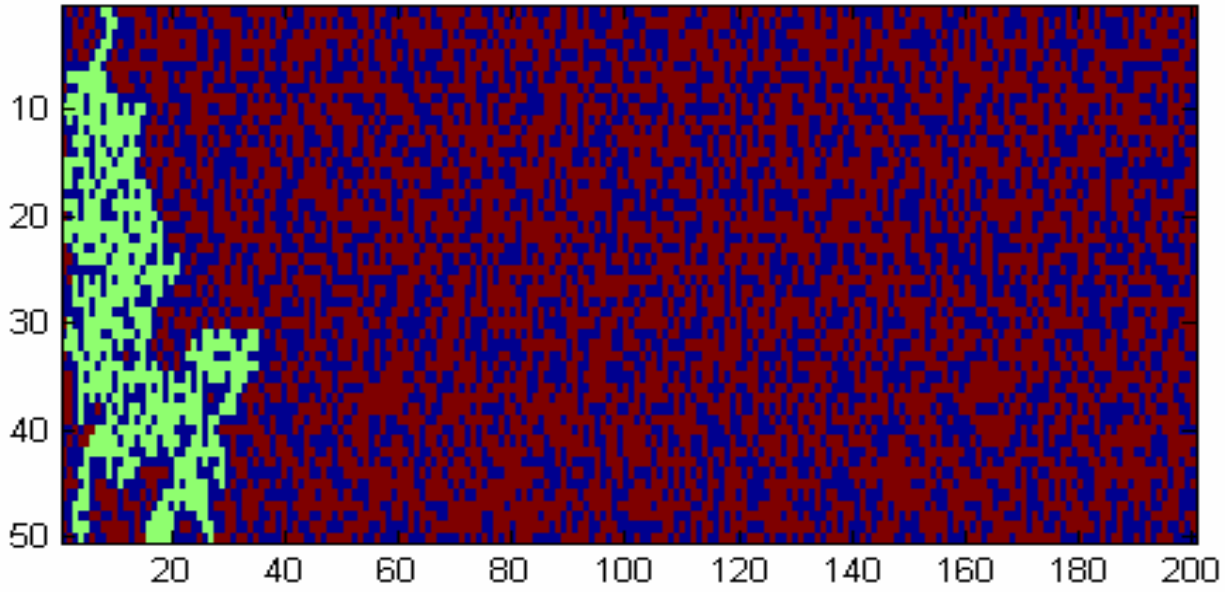


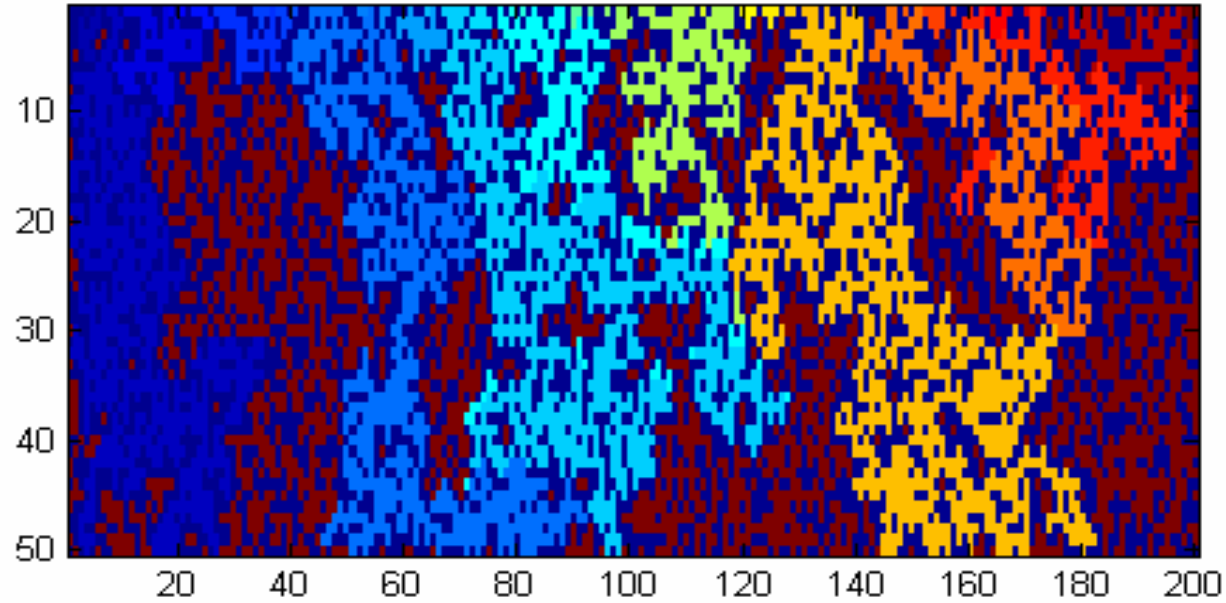


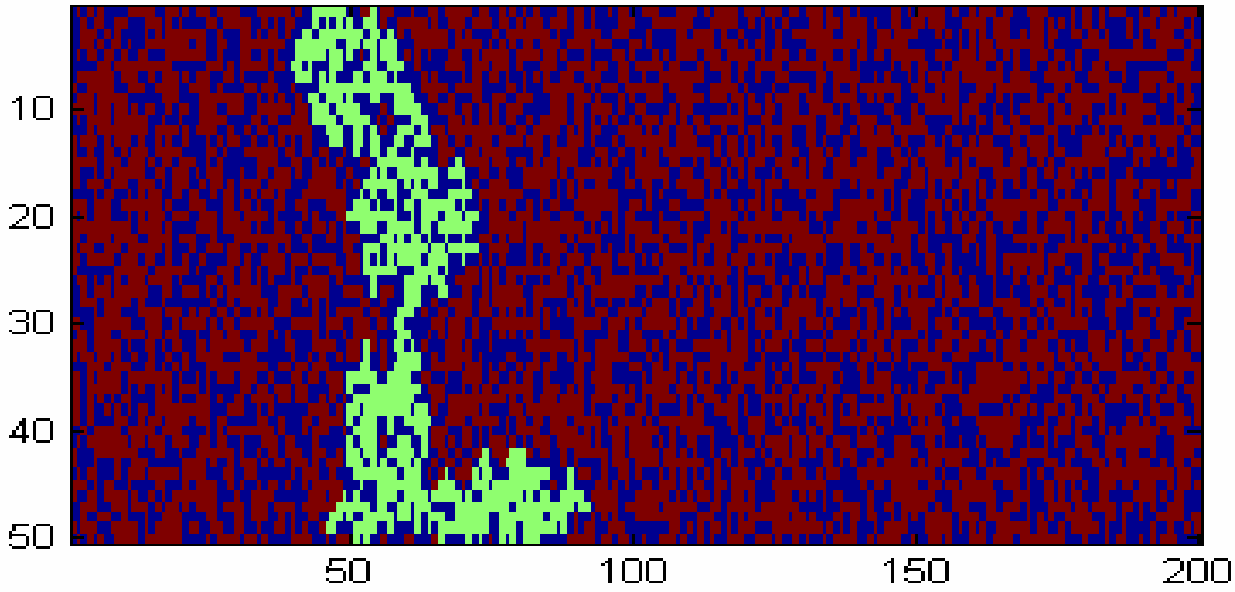


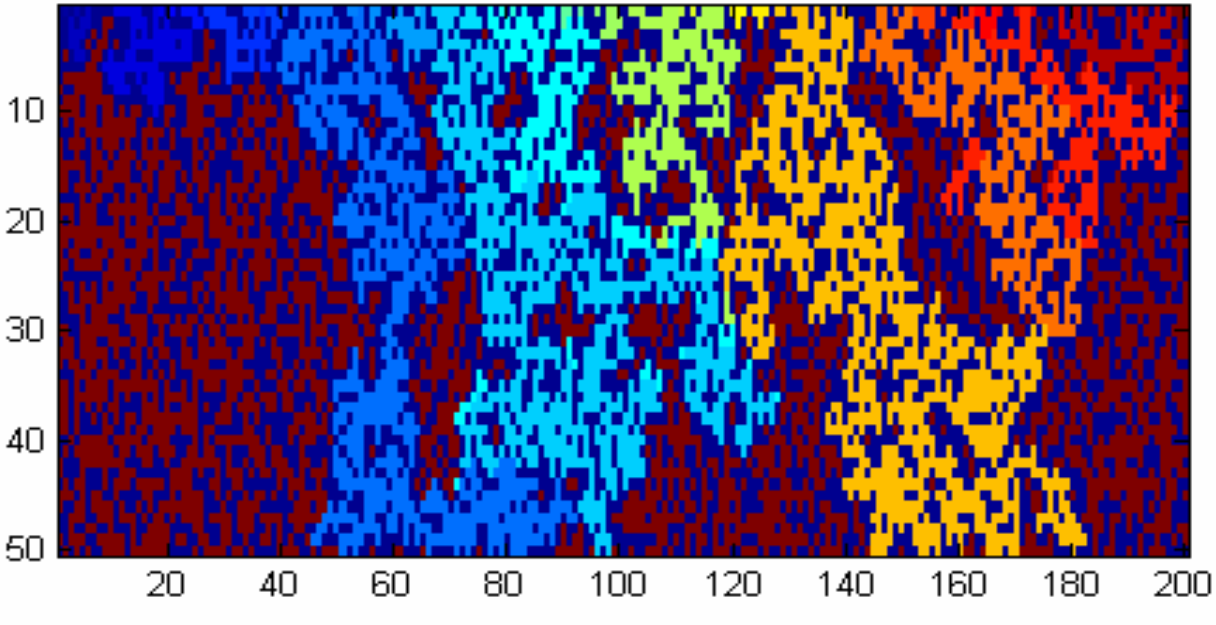


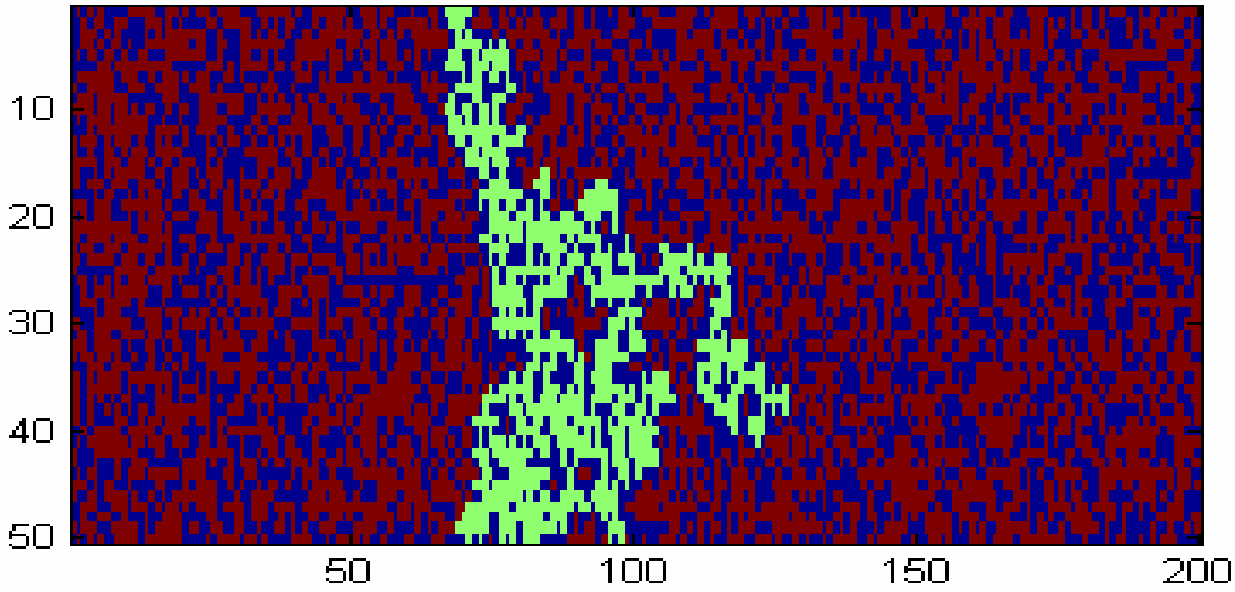


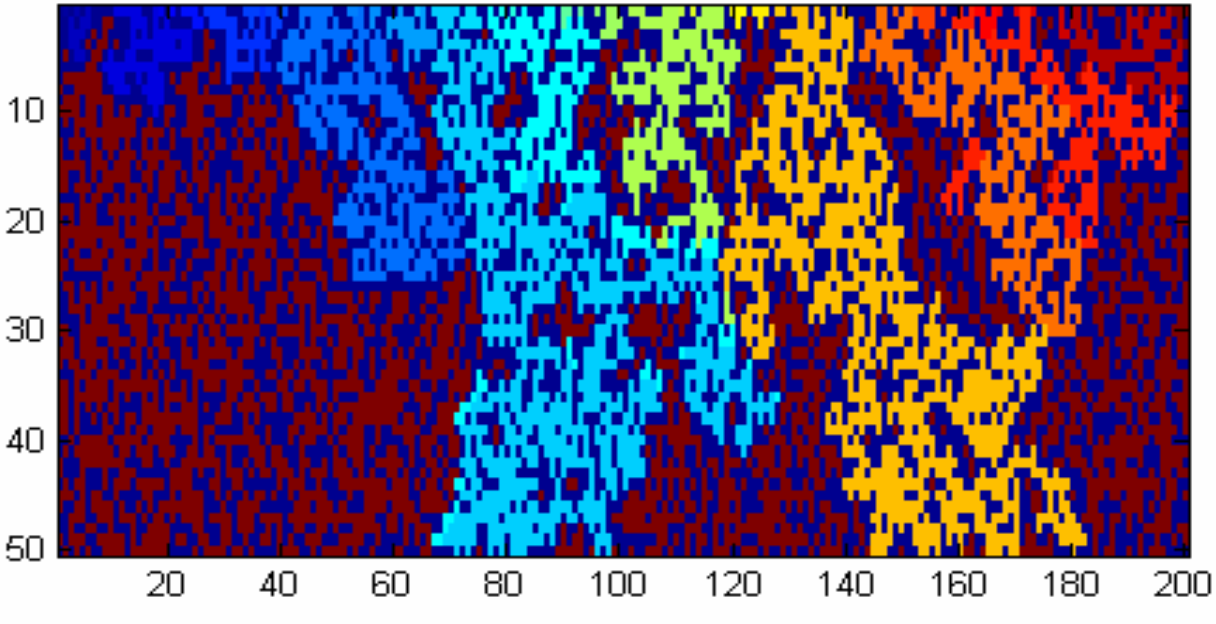

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

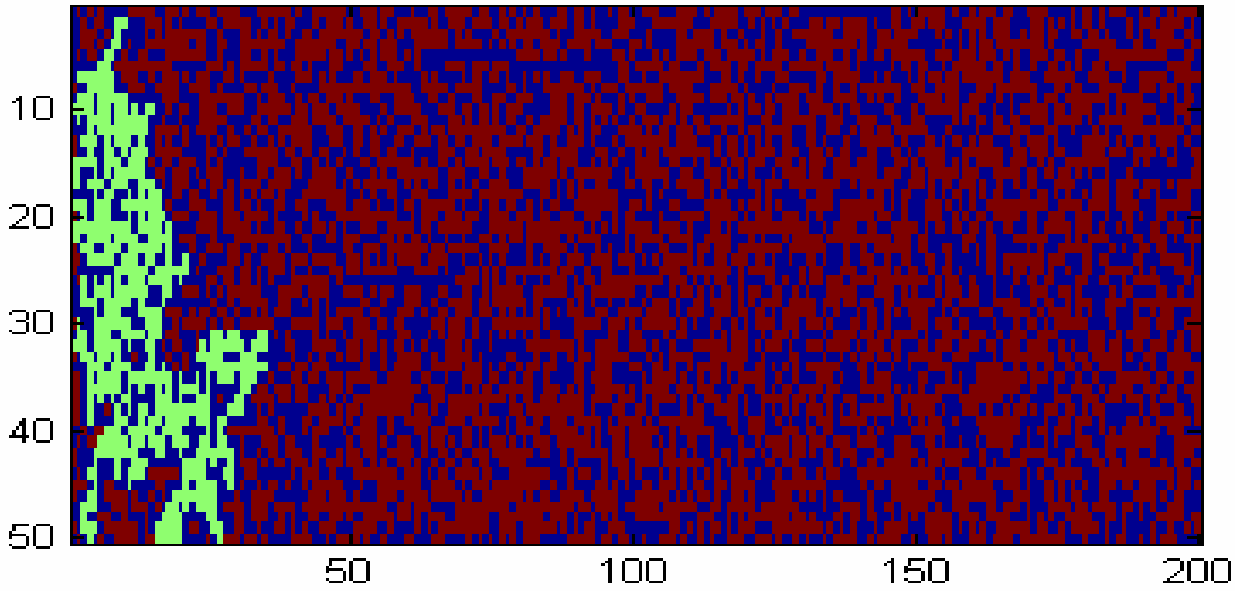

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

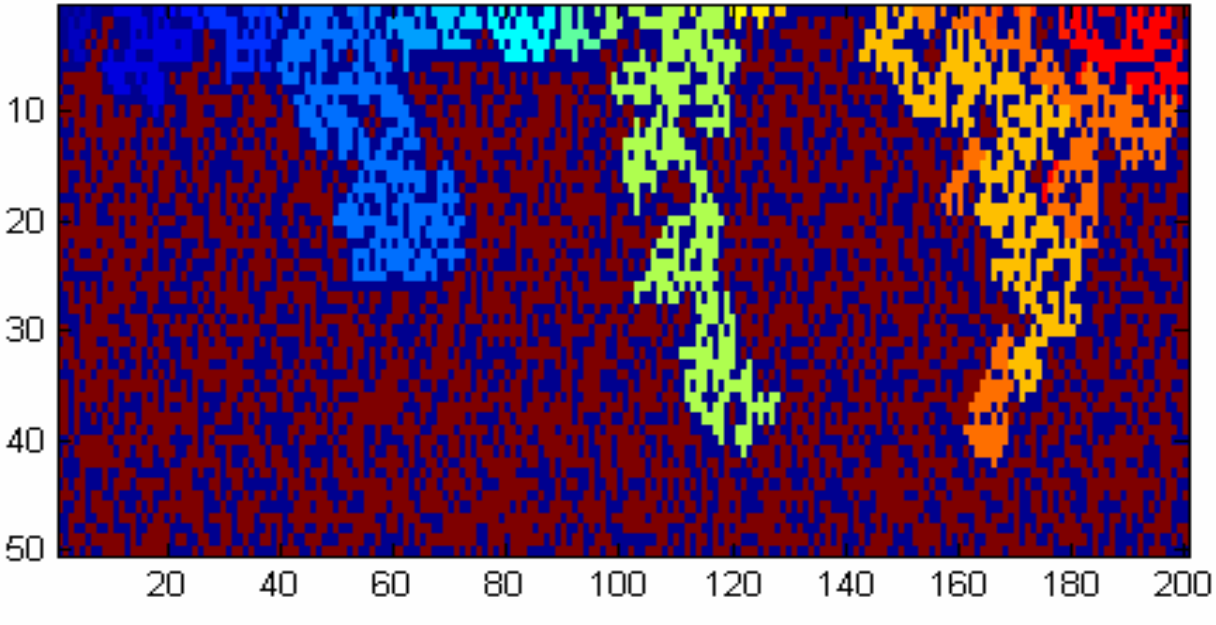

10
20
30
40
50
50
100
150
200

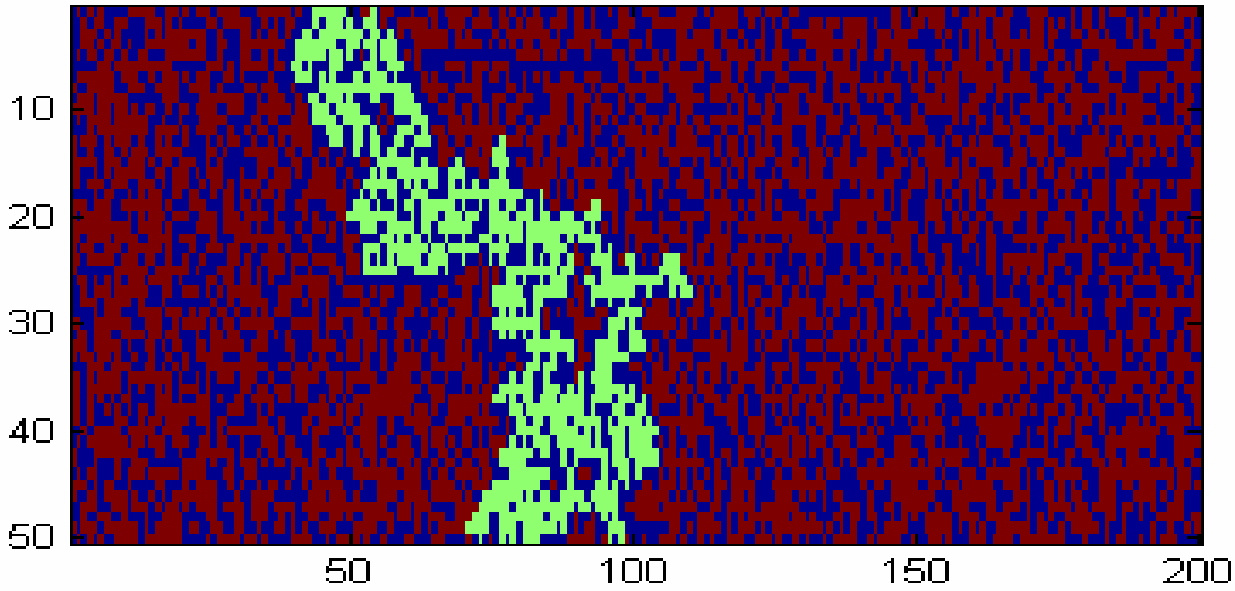

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

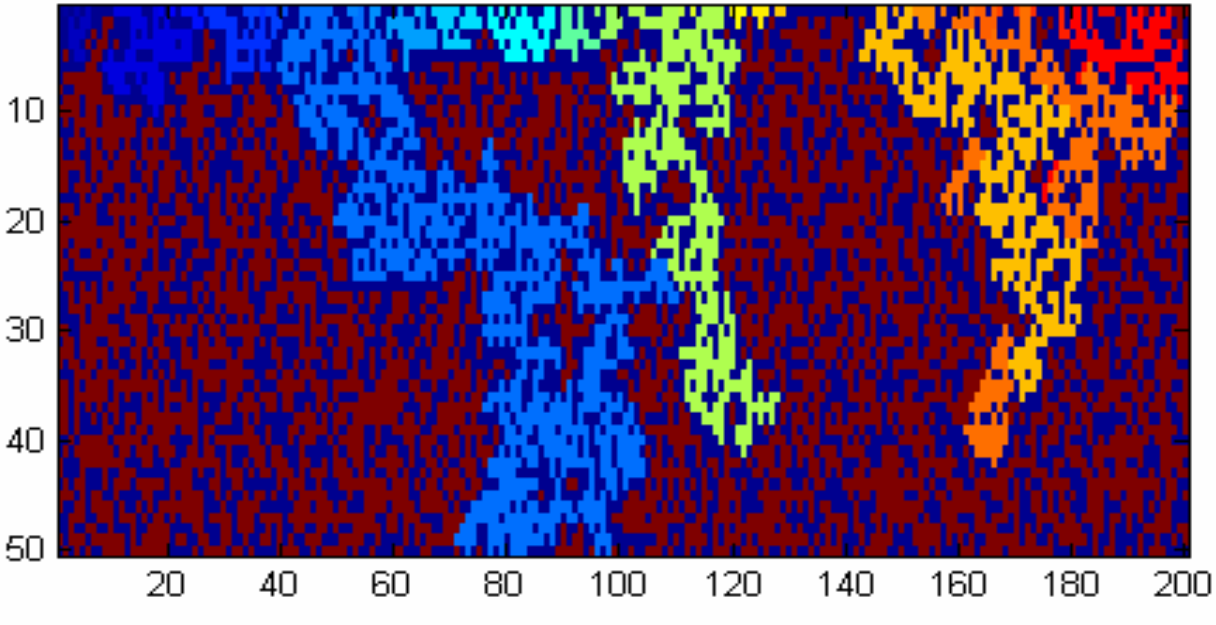

10
20
30
40
50
50
100
150
200

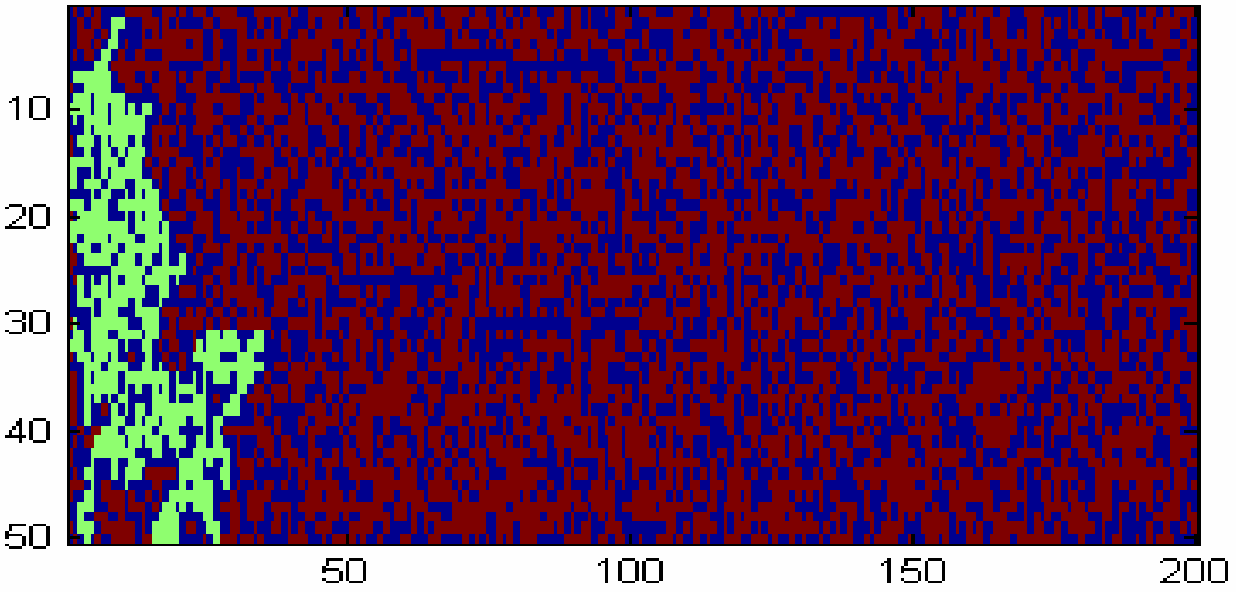

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

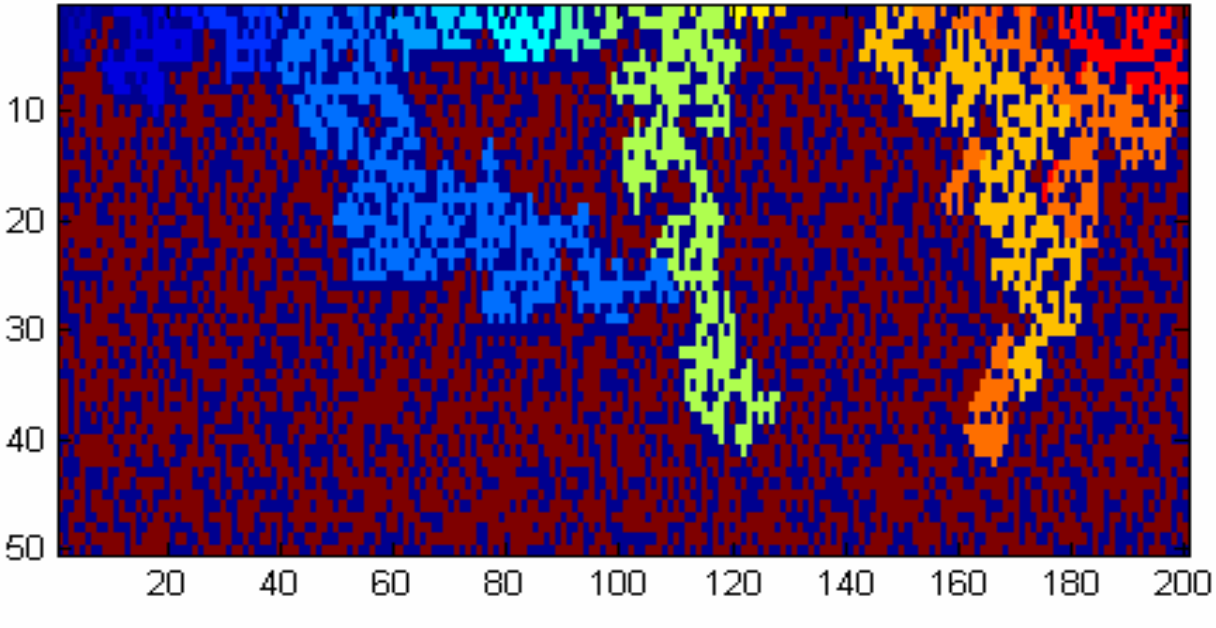

10
20
30
40
50
50
100
150
200

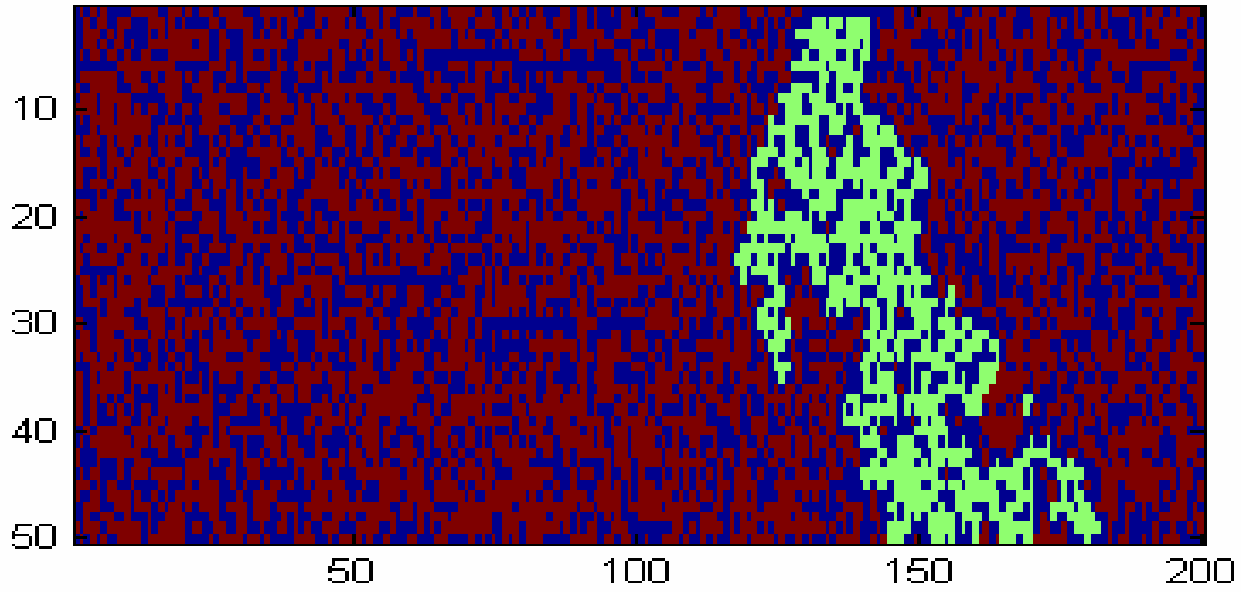

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

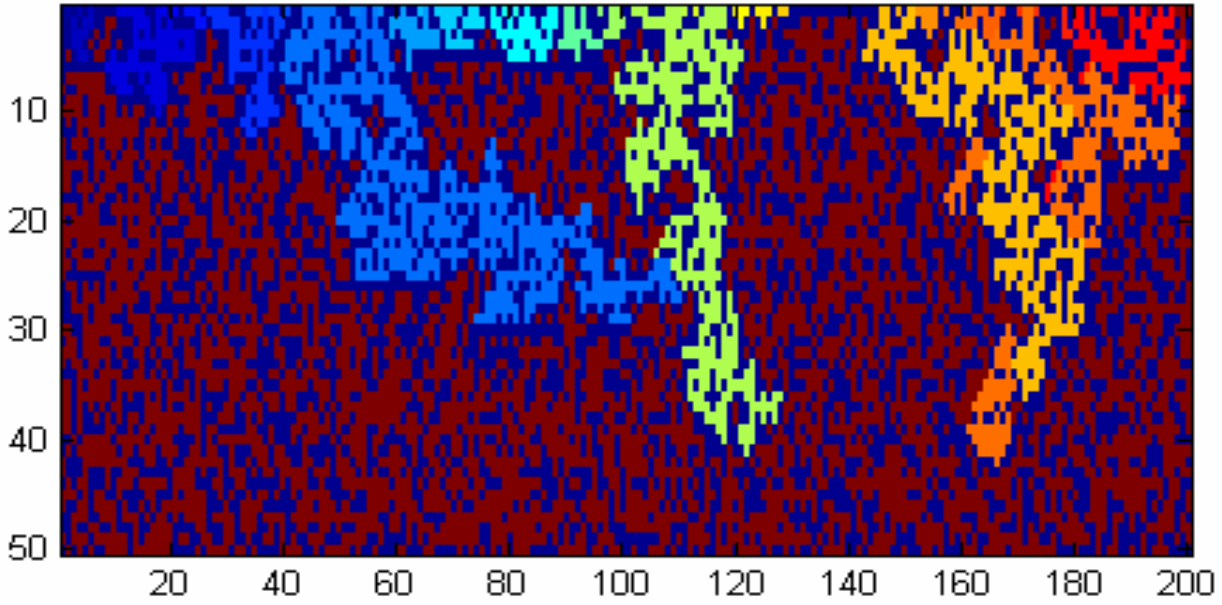

10
20
30
40
50
50
100
150
200

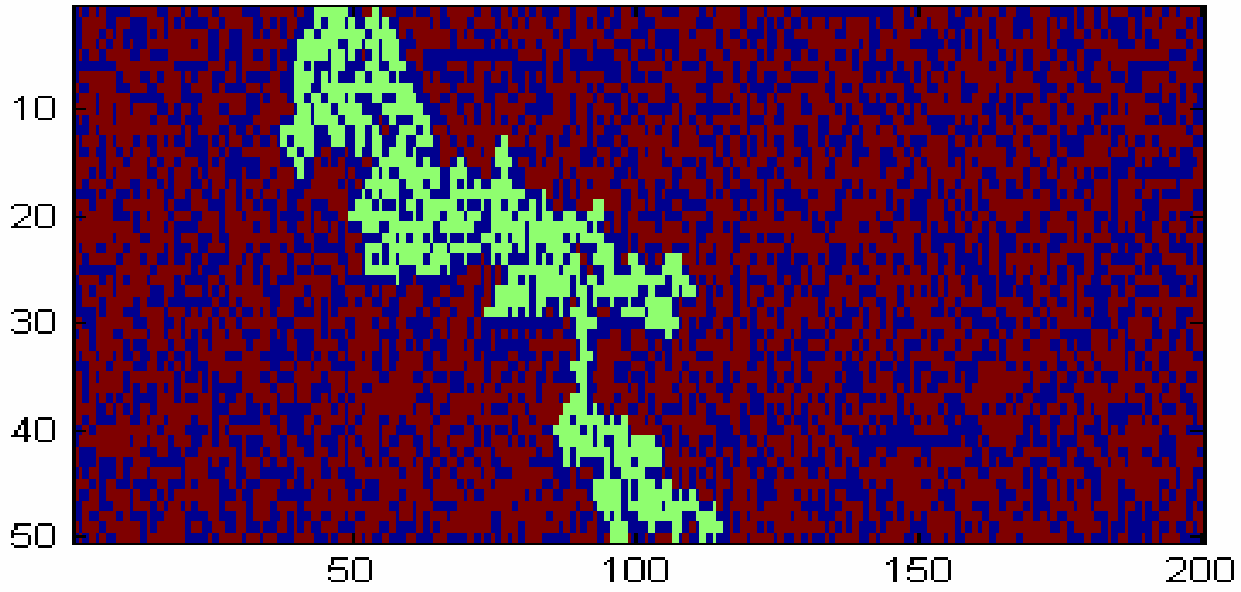

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

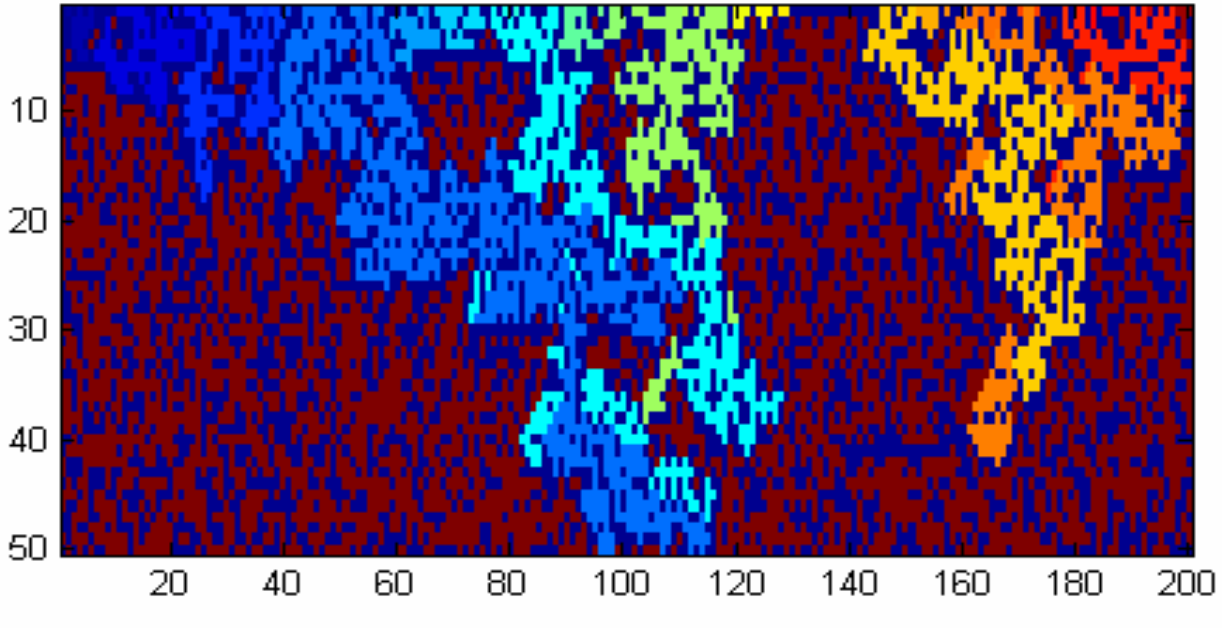

10
20
30
40
50
50
100
150
200

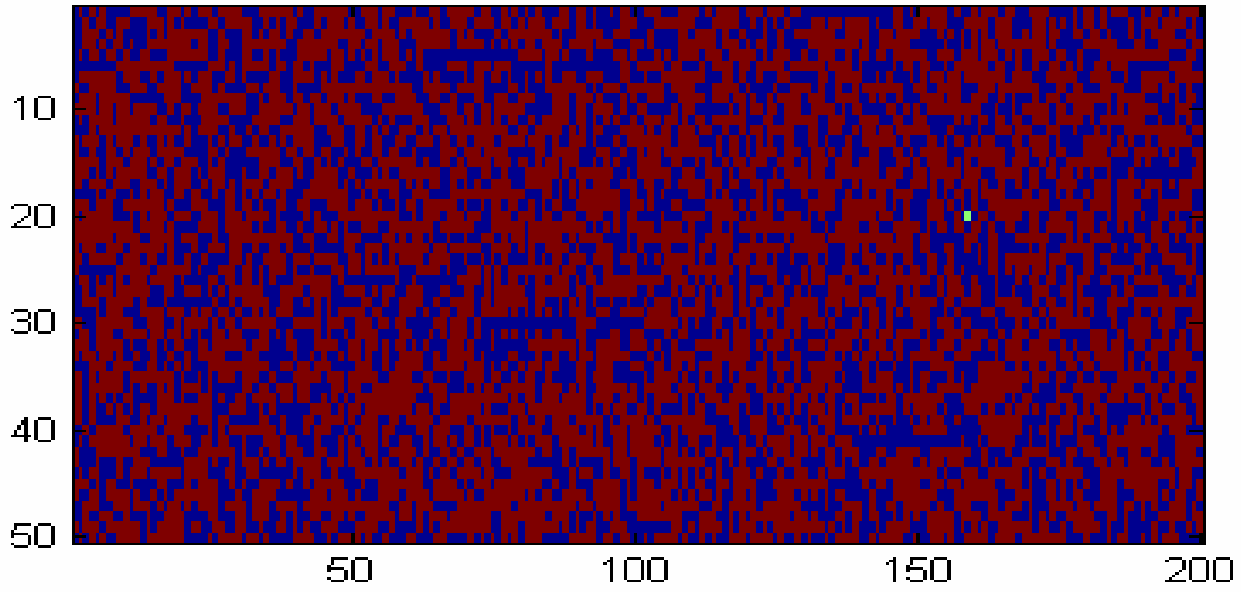

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

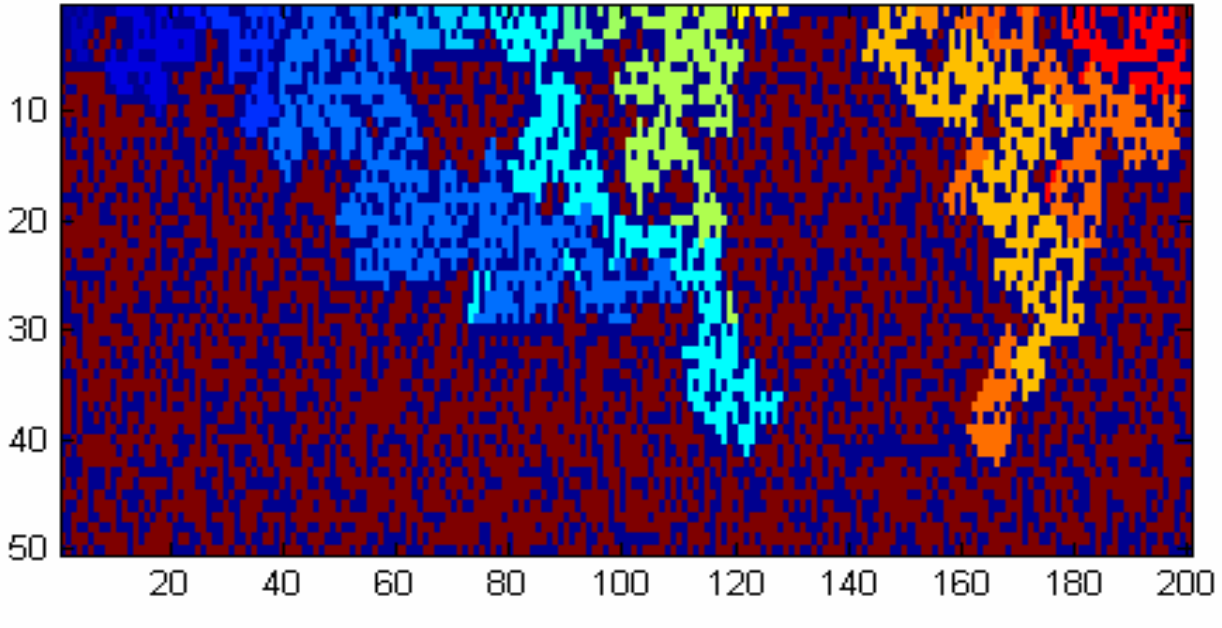

10
20
30
40
50
50
100
150
200

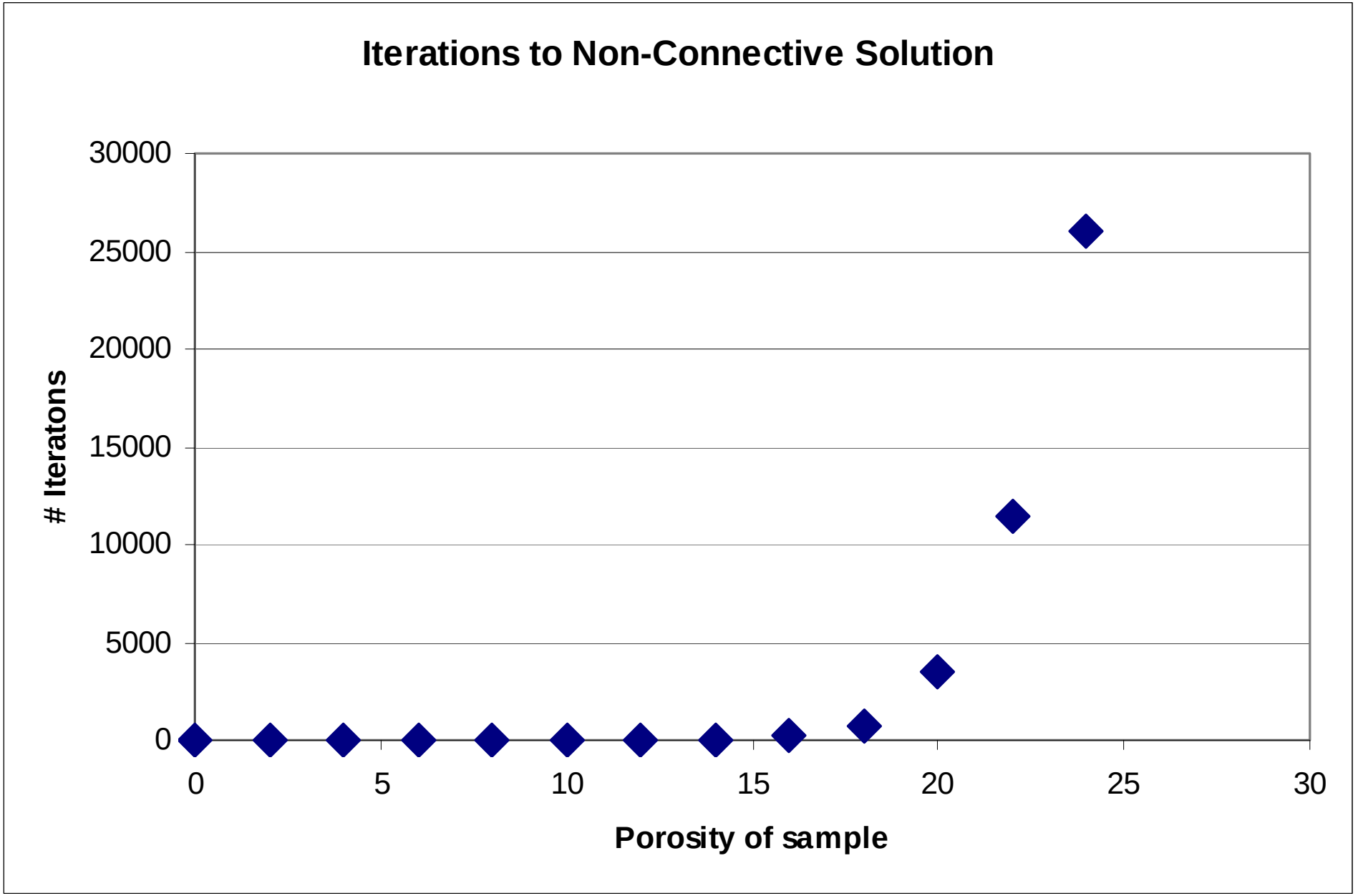

10
20
30
40
50
20
40
60
80
100
120
140
160
180
200

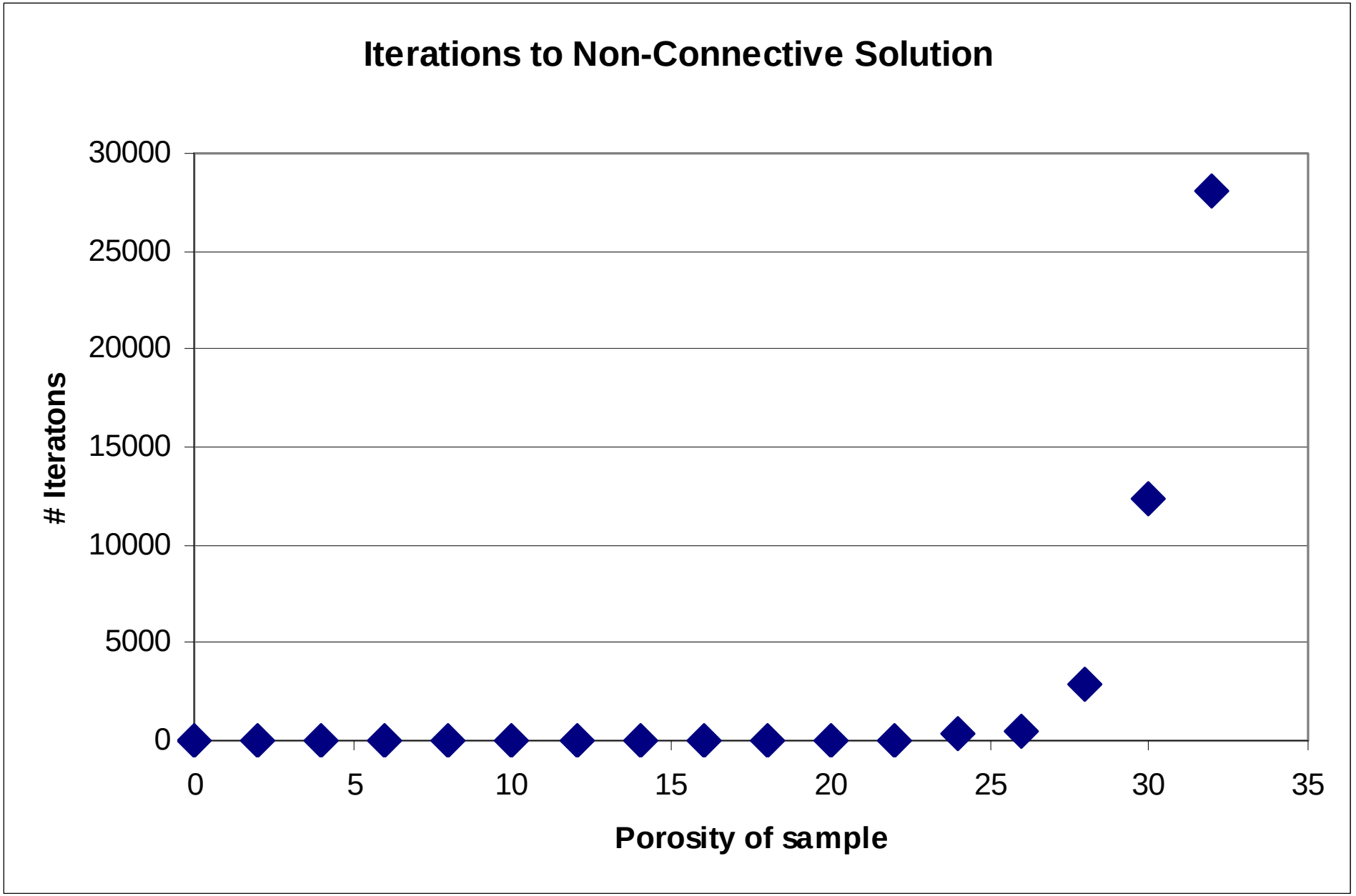

10
20
30
40
50
50
100
150
200


10
20
30
40
50
20
40
60
80
100
120
140
160
180
200


10
20
30
40
50
50
100
150
200


10
20
30
40
50
20
40
60
80
100
120
140
160
180
200


Iterations to Non-Connective Solution
30000
25000
20000
15000
10000
5000
0
Iteratons
0
5
10
15
20
25
30
Porosity of sample


Iterations to Non-Connective Solution
30000
25000
20000
15000
10000
5000
0
Iteratons
0
5
10
15
20
25
30
35
Porosity of sample

Conclusions

- Ice impermeable to fresh water long after pores connective due to fresh meltwater intrusions refreezing in pores.
- Pores (such as brine channels) above critical size cannot be plugged because heat cannot be conducted away quickly enough
- Appears to be temperature (-0.5C) and porosity (20%) thresholds beyond which ice becomes permeable to fresh water.

Thank You

Collaborators

Don Perovich, Kerry Claffey, Zoe Courville, Dave Finnegan, Matthew Druckenmiller, Hajo Eicken, Chris Petrich, Matthew Sturm, Karen Frey, Luke Trusel, and Christie Wood

Barrow Arctic Science Consortium
USCGS Healy Crew

National Science Foundation Grant No. ARC-0454900
NASA ICESCAPE Program