Behavior and fate of Oil in Ice-Covered water: How does it move upwards ?

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UAF UNIVERSITY OF ALASKA FAIRBANKS

IARC

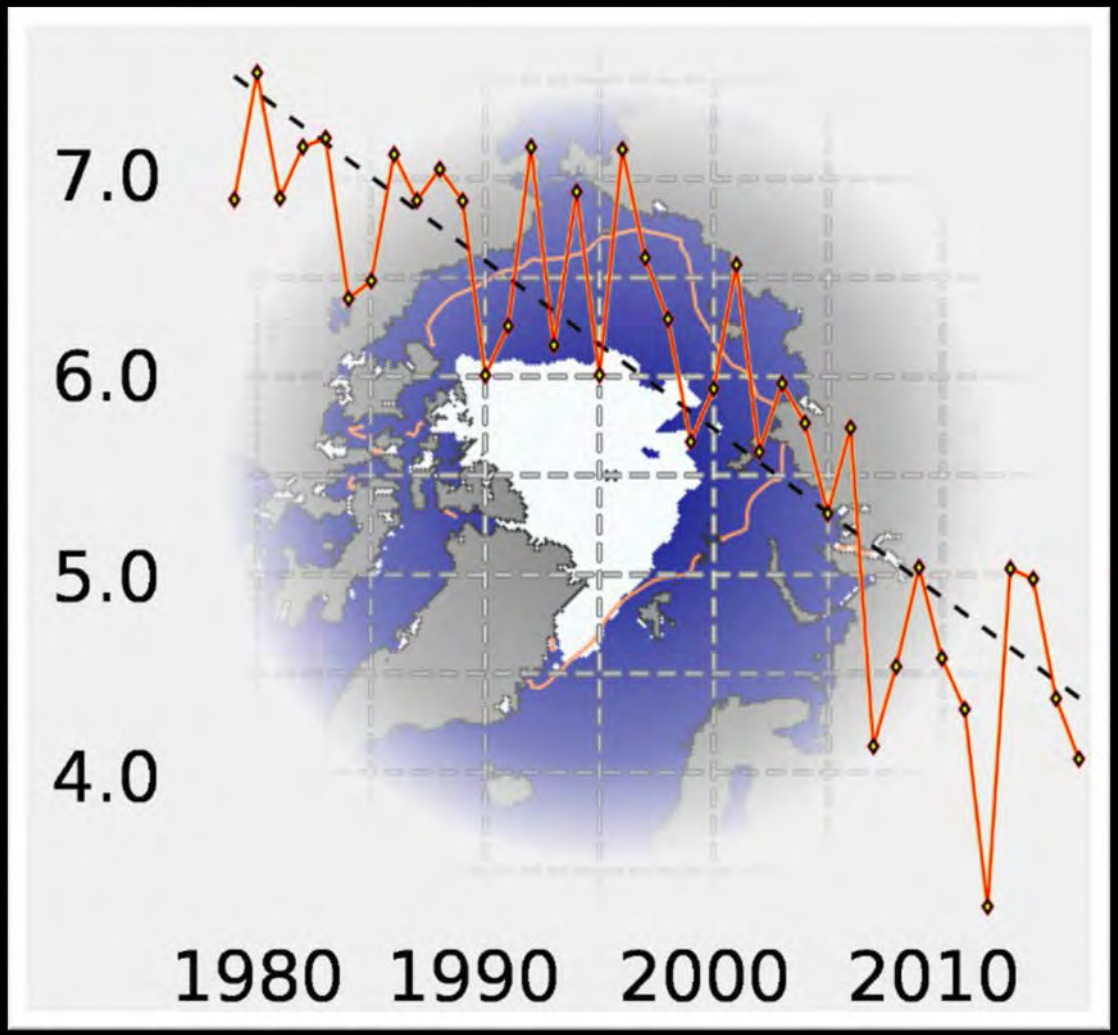
- Sea Ice group at UAF
  - Hajo Eicken
  - Daniel Pringle
  - Kyle Dilliplaine …
- RSOI team
  - Scott Pegau
  - Jessica Garron
  - Jeremy Wilkinson …
- MOSIDEO
  - Chris Petrich …

… other collaborators

The Research Council of Norway

CIRFA

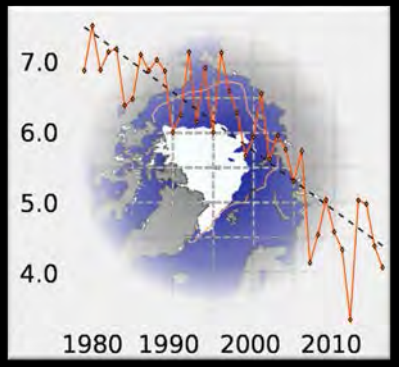
NSF



Data from
National Snow and Ice Data Center

NSIDC
National Snow and Ice Data Center

Sea ice extent
(10^6 km^2)

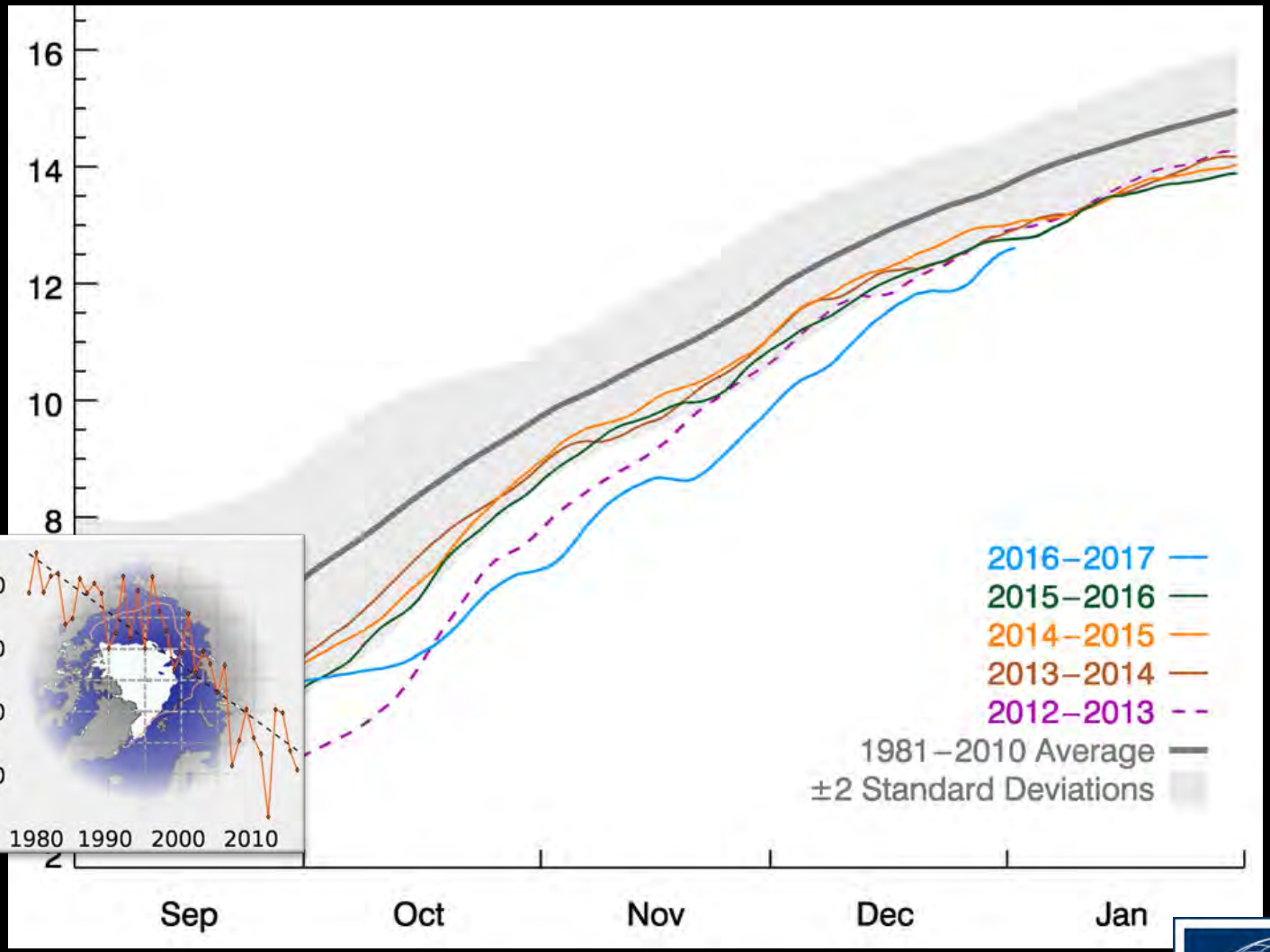


Year

Data from
National Snow and Ice Data Center

NSIDC
National Snow and Ice Data Center

There will be ice



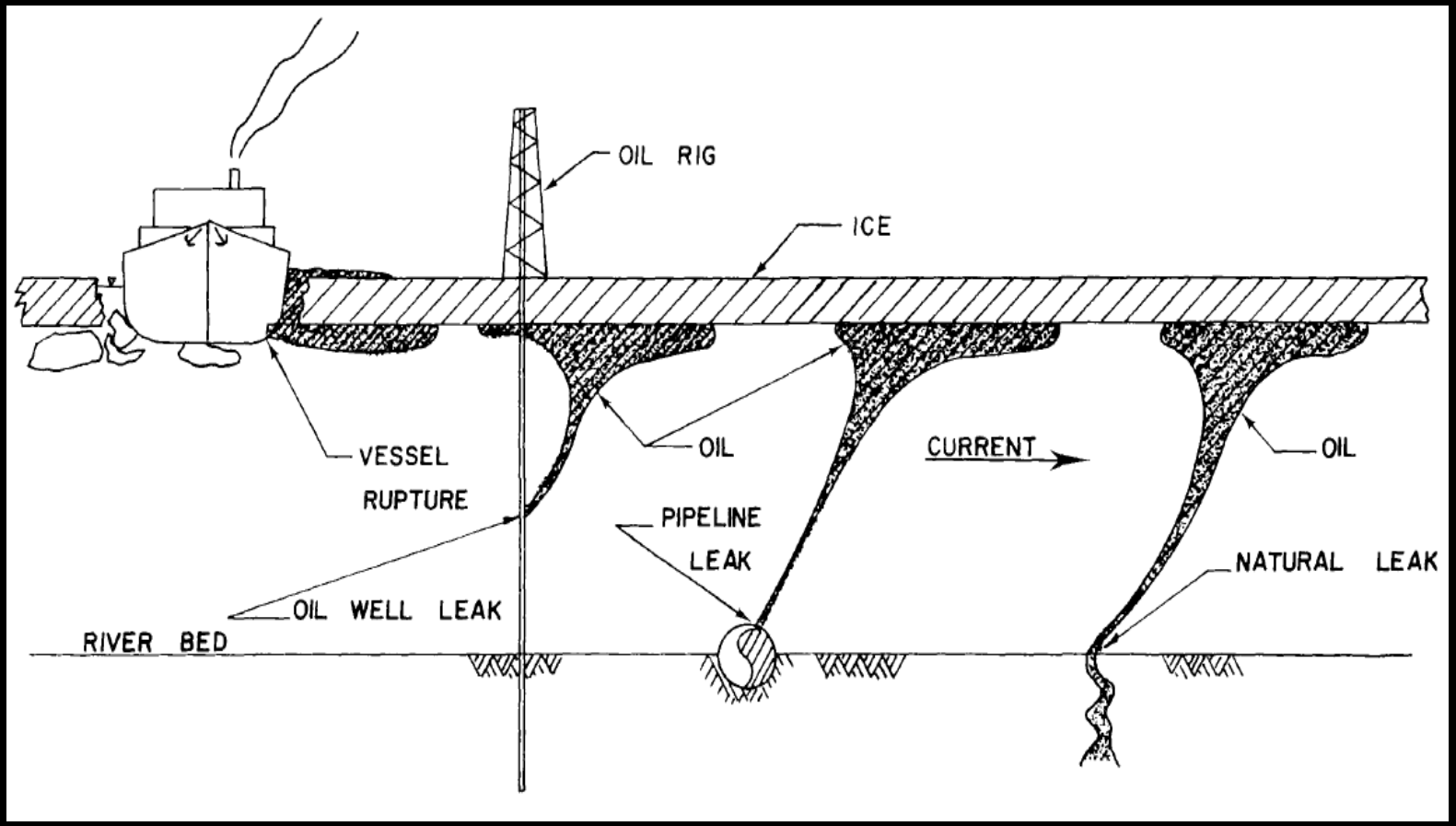
Sea ice extent (10^6 km^2)

Year

Data from National Snow and Ice Data Center

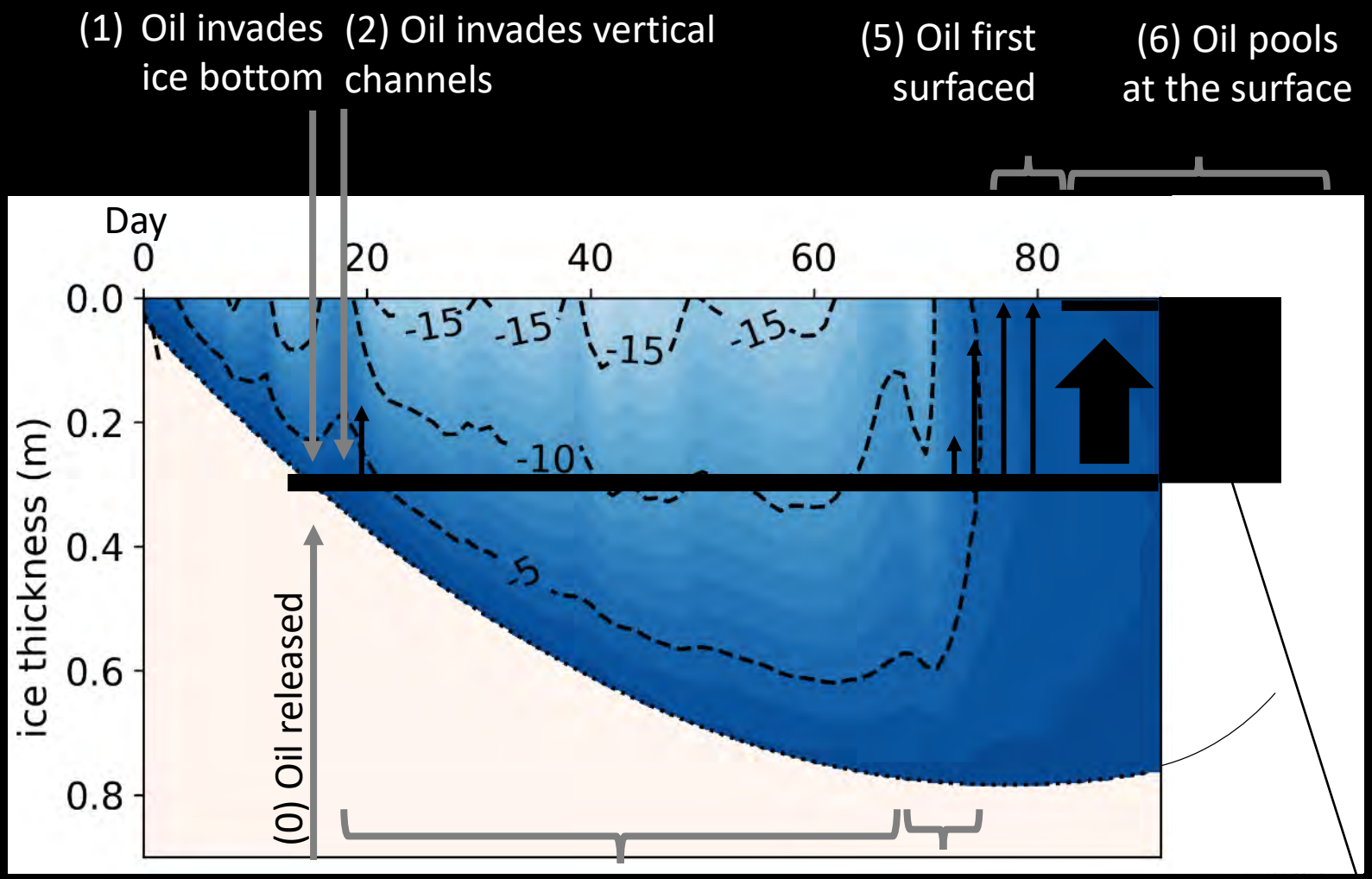
NSIDC
National Snow and Ice Data Center

There may be oil



[Uzuner et al. (1979)]

There may be oil under-, in- and on the ice



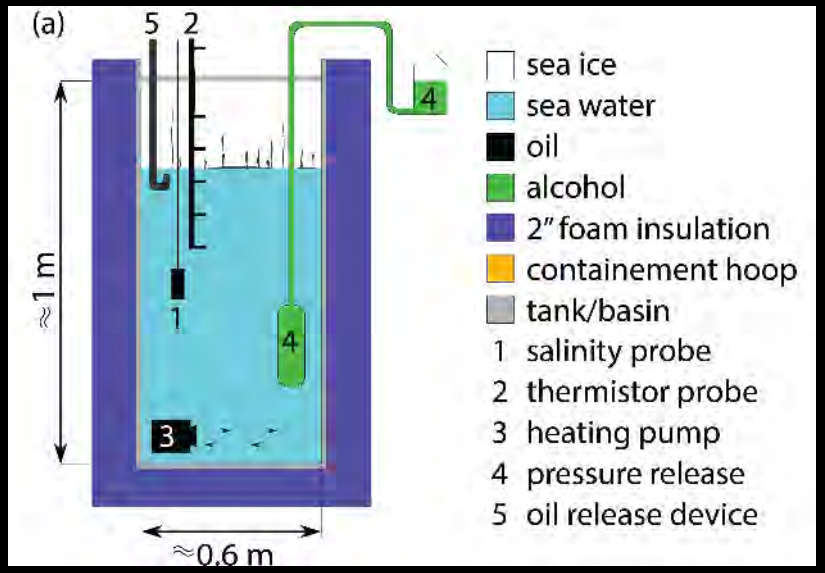
How to respond to an oil spill in the sea ice ?

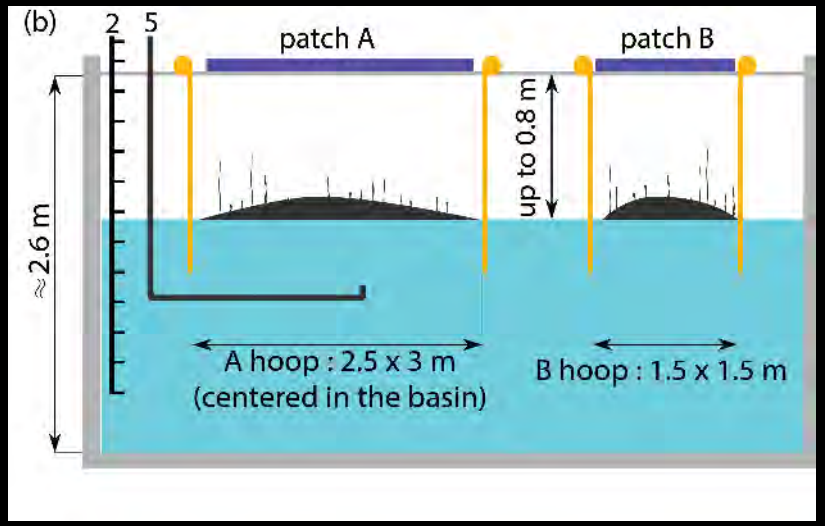
[CRREL]

1. How do the ice stratigraphy and pore microstructure control the migration rate and surfacing of oil
2. What is the influence of oil properties and thickness of the under-ice oil layer on the migration

3. Integration in a simple model to predict oil distribution for guiding clean-up effort

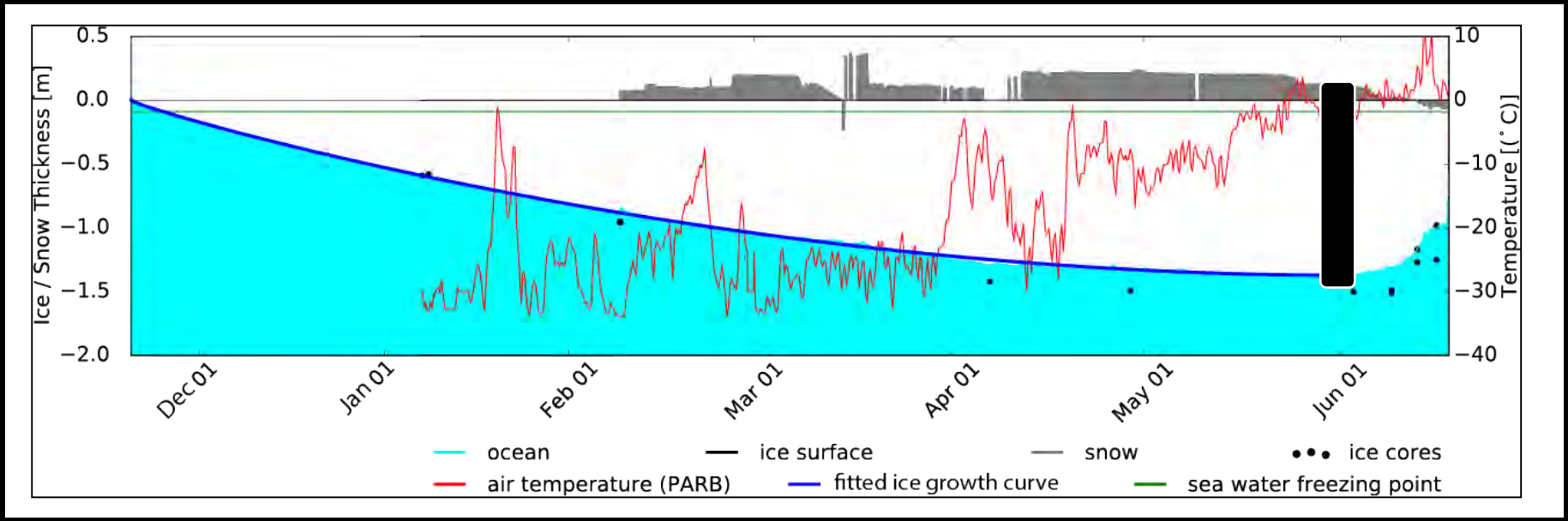
- 3 experiments
  - UAF
  - RSOI @ CRREL, Hanover, NH
  - MOSIDEO @ HSVA, Hamburg, Germany
- Different types of oil
  - Alaska North Slope
  - Troll B, Norway
  - $0.5 < h_o < 10$ cm
- Different ice thickness
  - $20 < h_i < 70$ cm
- Different ice stratigraphy
  - Columnar
  - Granular/columnar
- Mimic seasonal cycle
  - Growth and melt period





Sea ice Seasonal cycle

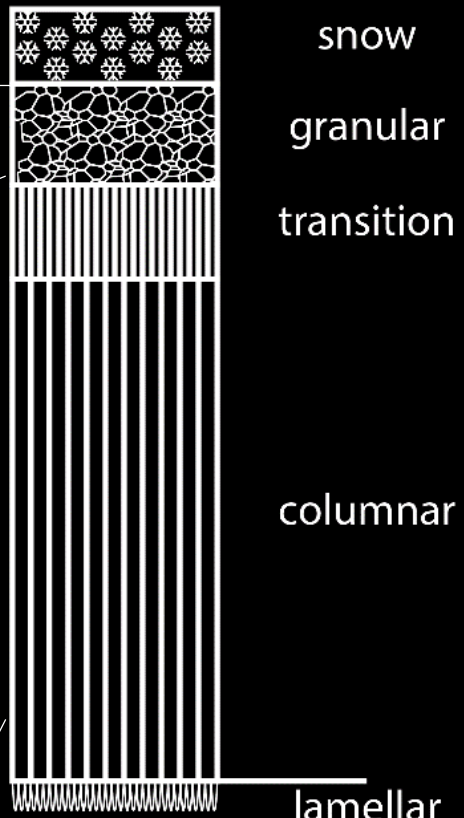
- Strong seasonal cycle

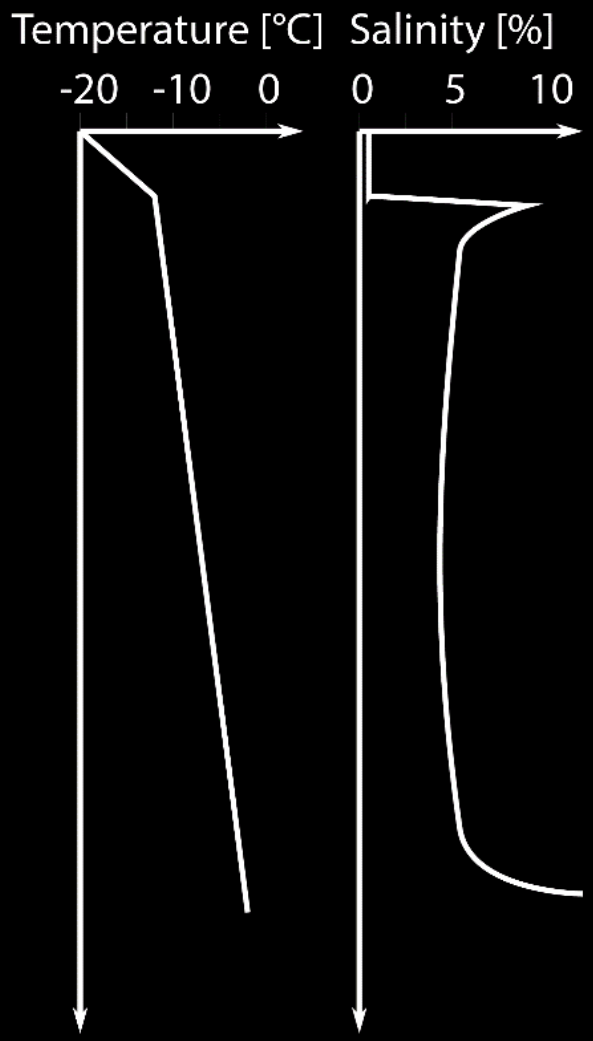


Data obtained from Barrow Sea Ice Observatory, operated by University of Alaska Fairbanks (Druckenmiller et al., 2009, http://doi.org/10.1016/j.coldregions.2008.12.003)

Sea ice

Stratigraphy



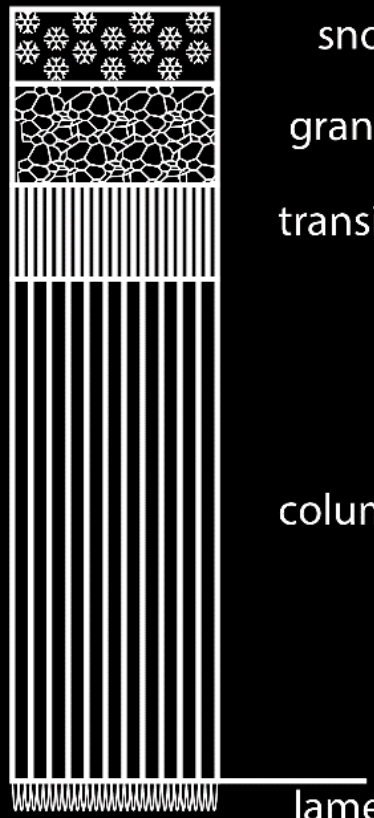


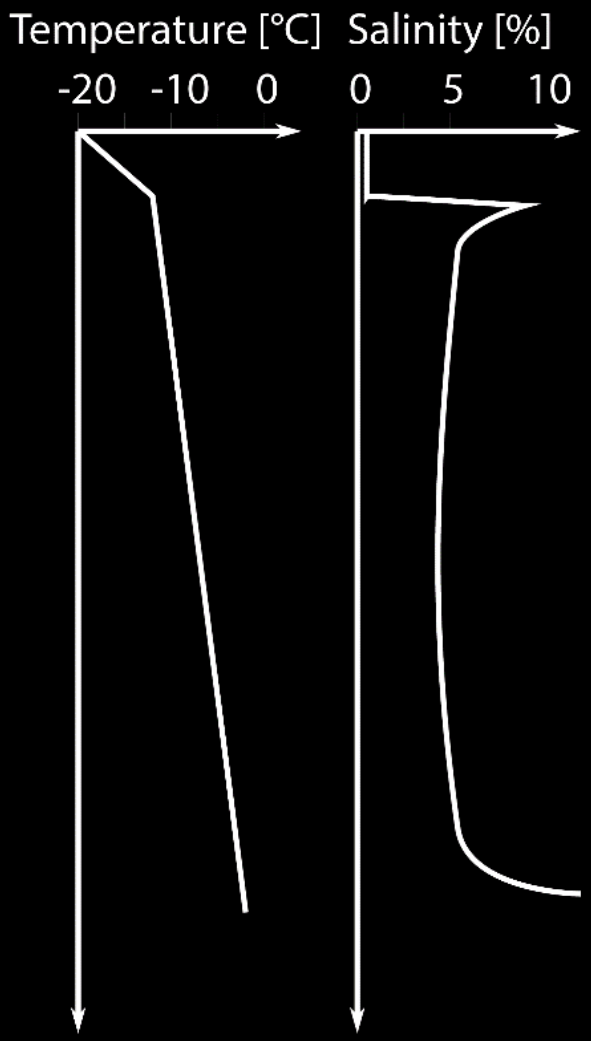
[After Petrich and Eicken, 201

Sea ice

Biota

[Eric Collins]



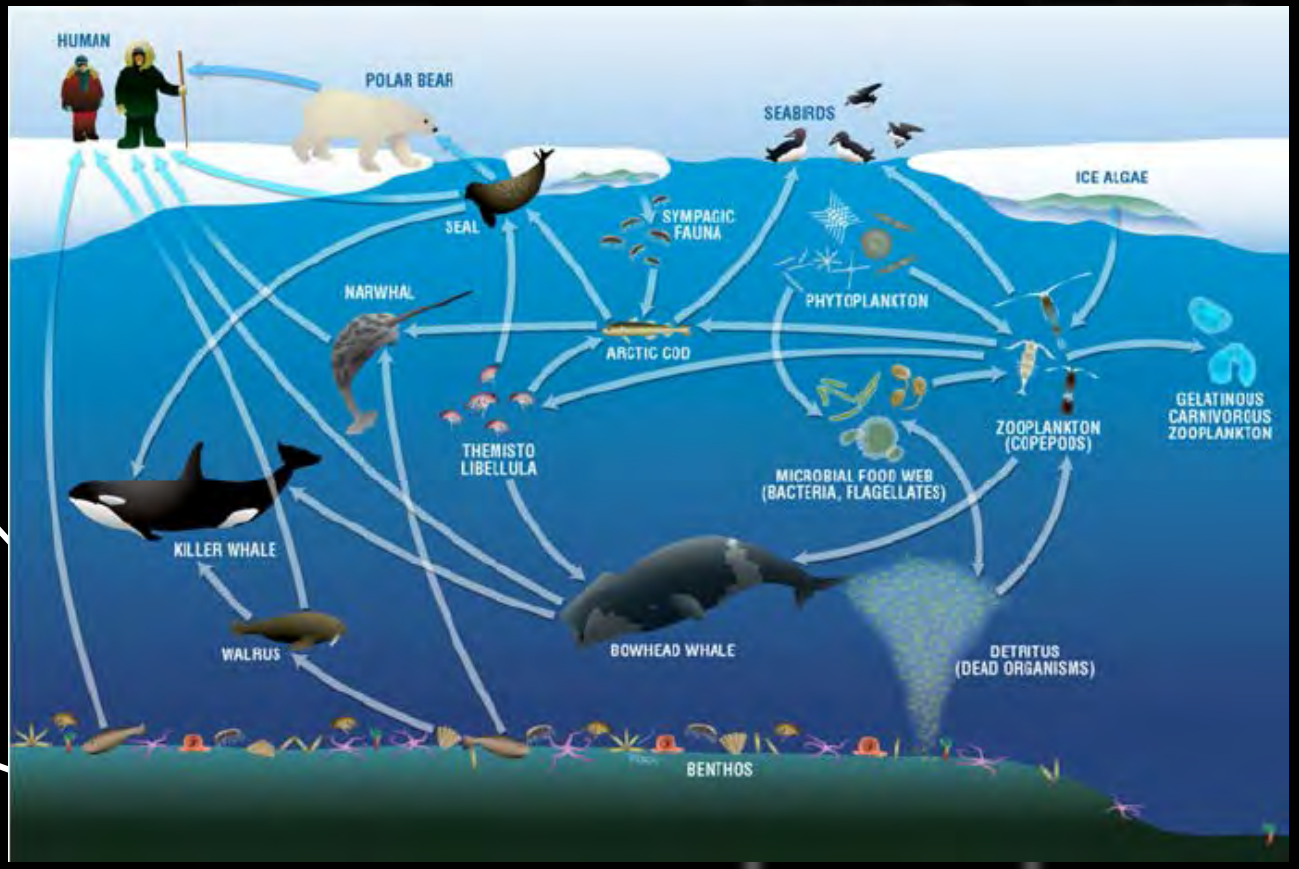


[After Petrich and Eicken, 201

Sea ice Biota

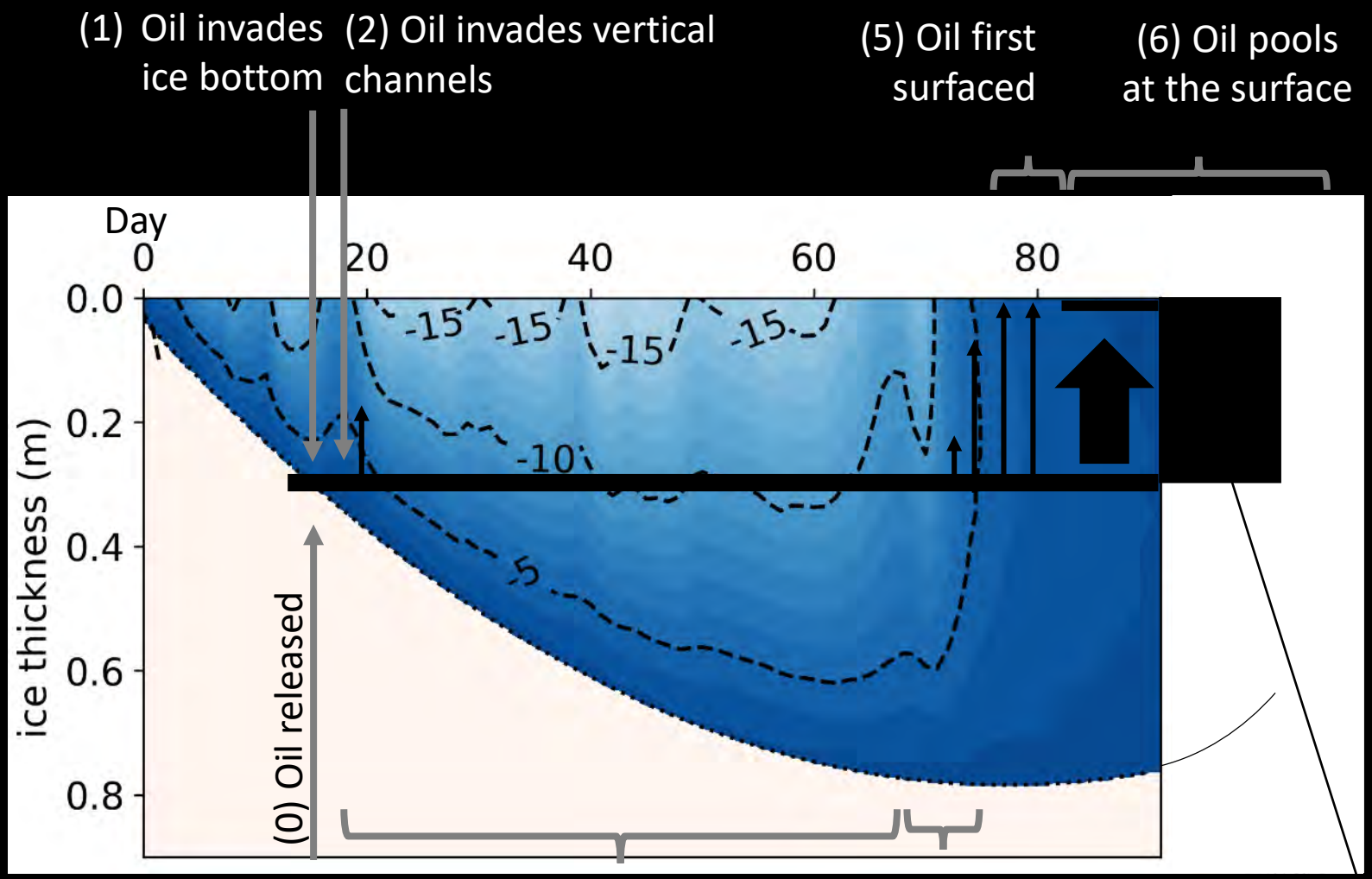
- Ice-associated biota sustain Arctic food webs

[Eric Collins]



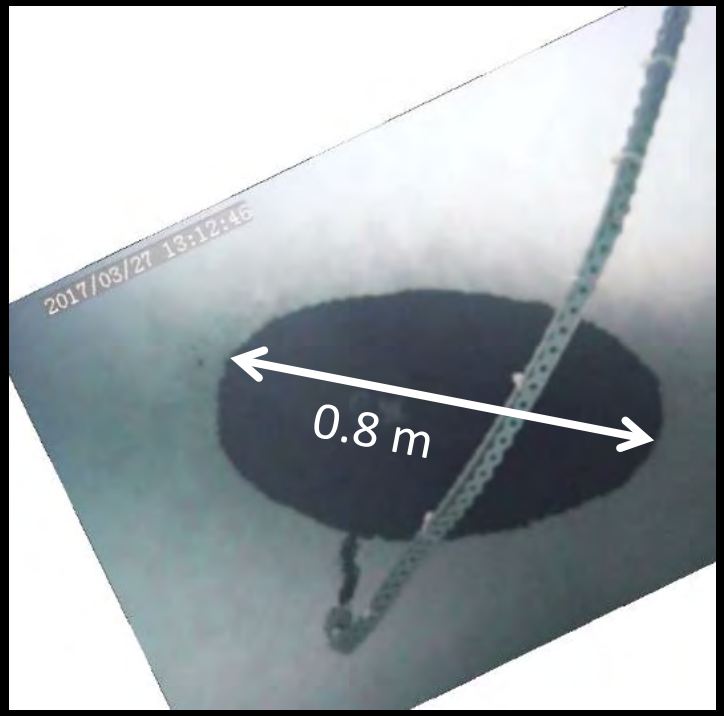
[Darnis G. et al, 2012; doi:10.1007/s10584-012-0483-8]

There may be oil under-, in- and on the ice



Oil/ice (0) Oil release

- Pooling in under-ice cavities
- Spreading by underwater currents

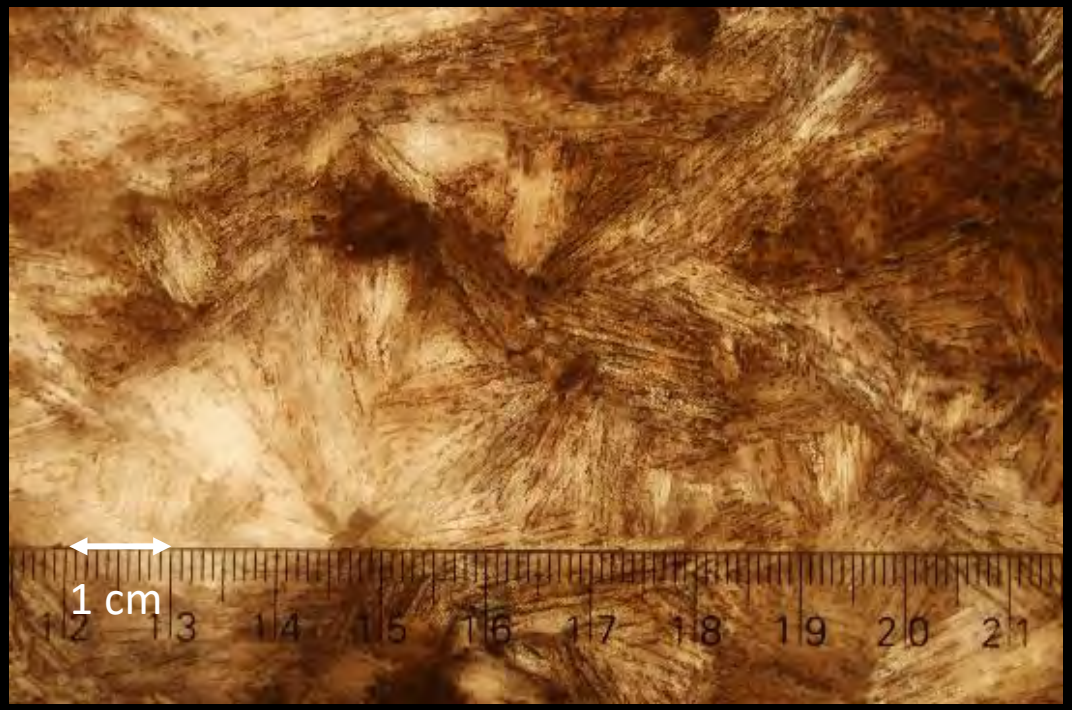


[MOSIDEO]

Oil/ice (1) Skeletal layer invasion

- Oil quickly invades the skeletal layer [Martin 1979]
- Oil movement threshold: 10 % porosity [Karlsson J., 2009]

[Karlsson J., 2009]

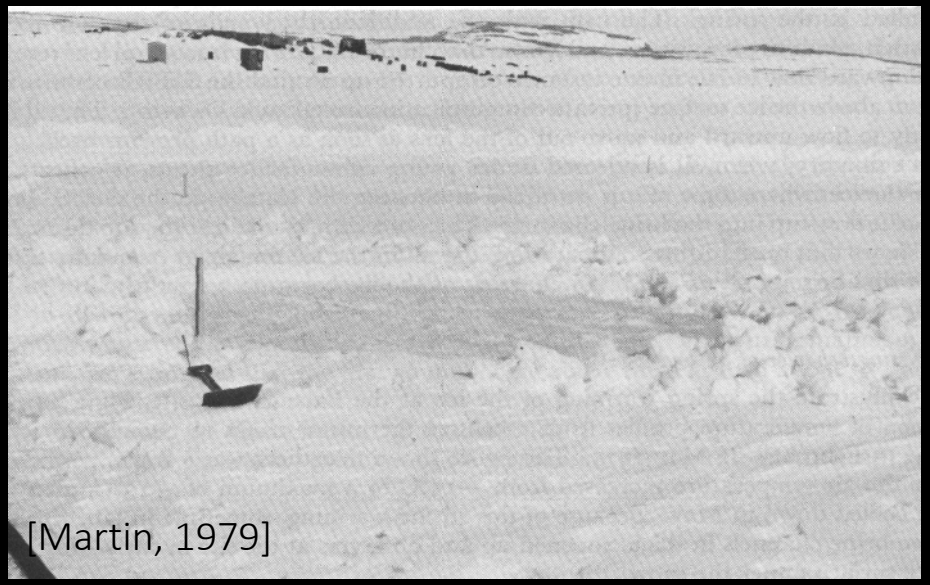


[MOIIDEO]

Oil/ice (2) Encapsulation

- Encapsulated oil lens
  - Depending of
    - Ice growth rate
    - Oil lens size
  - Up to several days

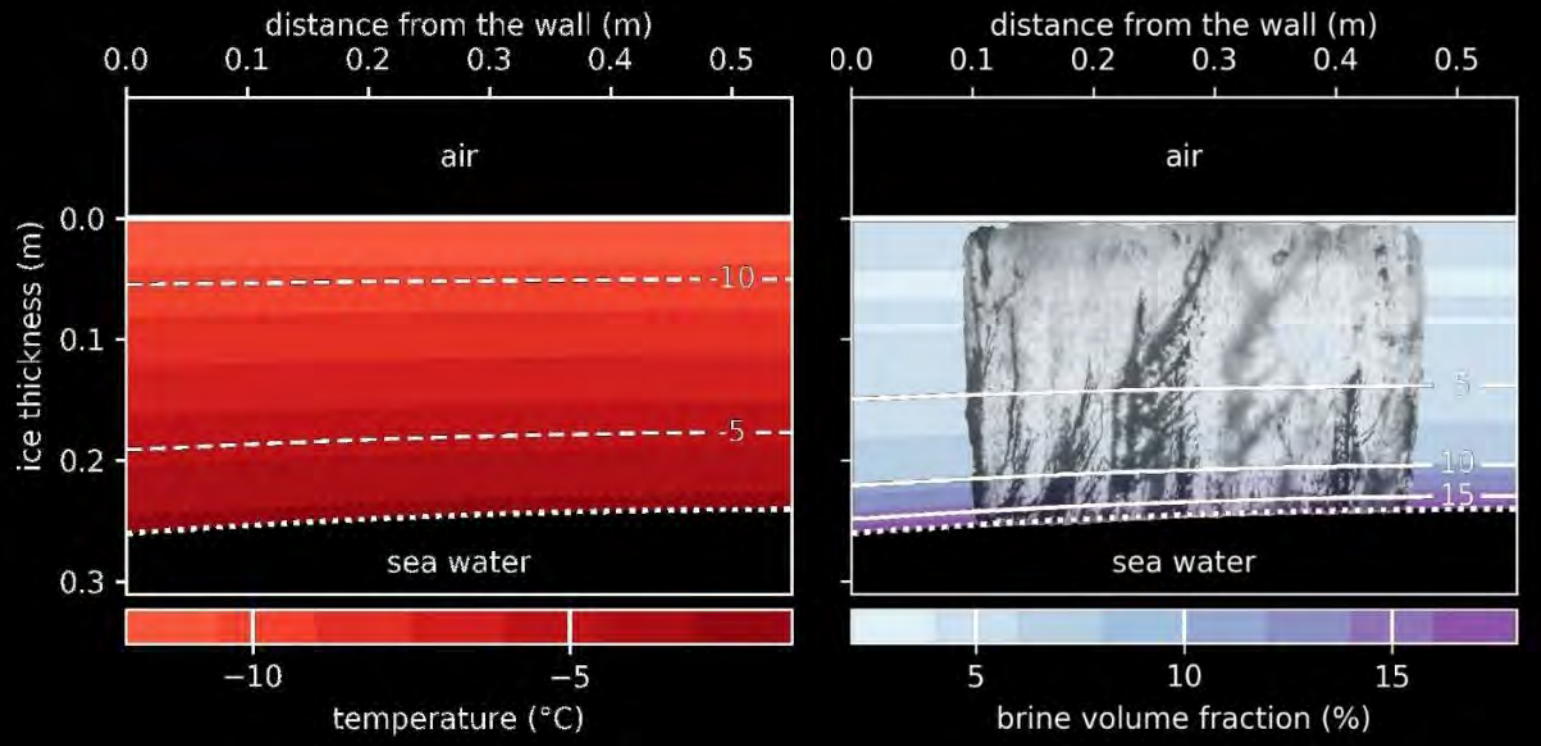
- Oil is immobilized until warming


[Martin, 1979]


[A. Allen]

Oil/ice (3) Brine channel invasion

- Oil surfacing when
  - Cold ice T < -5 °C → ϕ < 10%
  - Within 24 hours
  - Various oil and ice thickness



Why are there no prior observations of oil moving in cold ice?

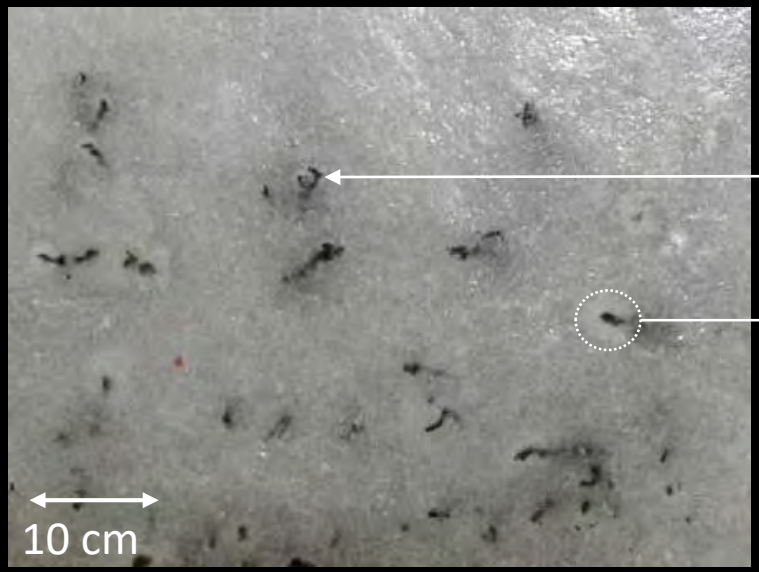
Oil/ice

Condition for surfacing

1. Ice microstructure:
   - Connection between ice bottom and ice surface
   - Geometry allow oil to flow: channel diameter

2. Space available for brine pushed out by the oil
   - Exchange oil/brine in the channel
   - Brine expelled at the surface

[CRREL]



[CRREL]

Oil/ice

Condition for surfacing

- Stratigraphy
  - Granular 1-3 cm
  - Columnar 20-70 cm
  - Lamellar: 2-5 cm
- Columnar
  - Vertical brine channel
  - Large diameter

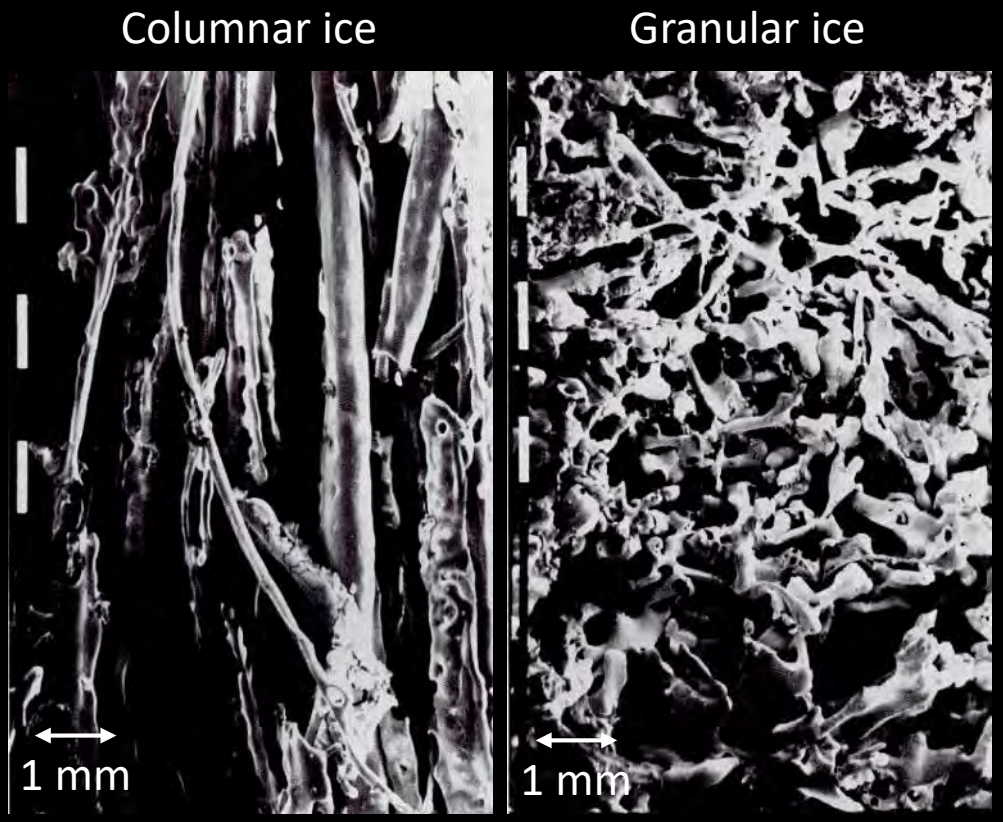
Columnar ice

[Weissenberger , 1992]

Oil/ice

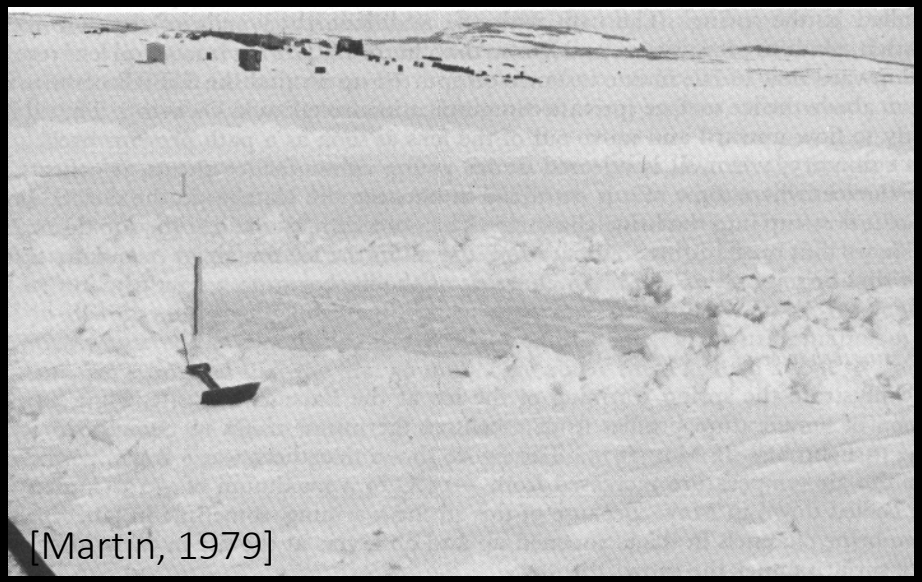
Condition for surfacing

- Stratigraphy
  - Granular 1-3 cm
  - Columnar 20-70 cm
  - Lamellar: 2-5 cm
- Columnar
  - Vertical brine channel
  - Large channel diameter
- Granular
  - Refined texture
  - Smaller pore diameter
  - Tortuous and longer path



[Weissenberger , 1992]

Oil/ice … a long and cold winter …



[Martin, 1979]

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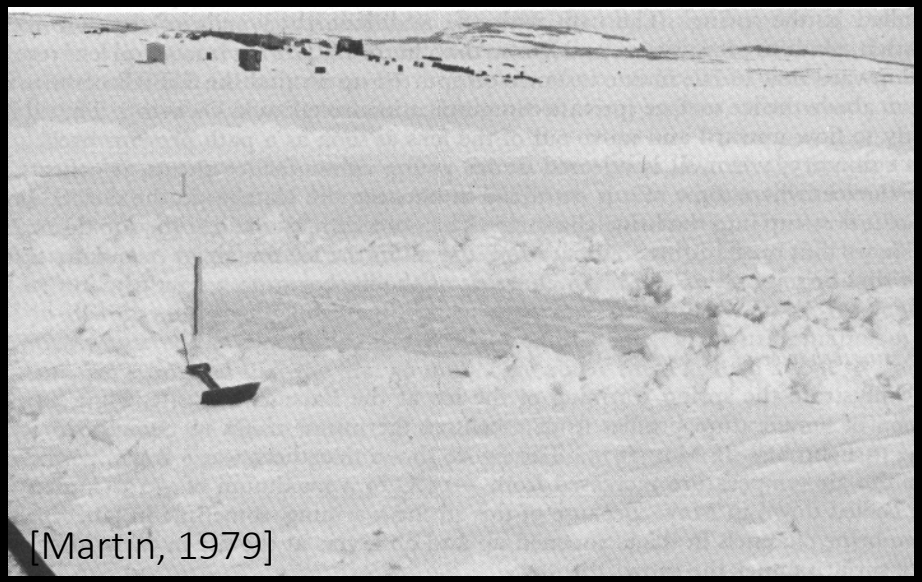
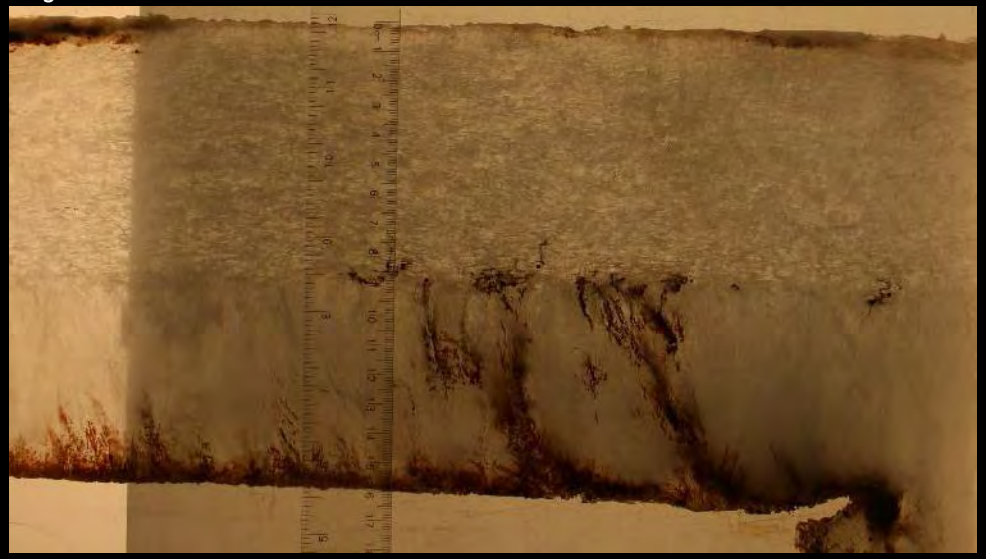


[Martin, 1979]

T_s = -7.0 °C

≈20 cm



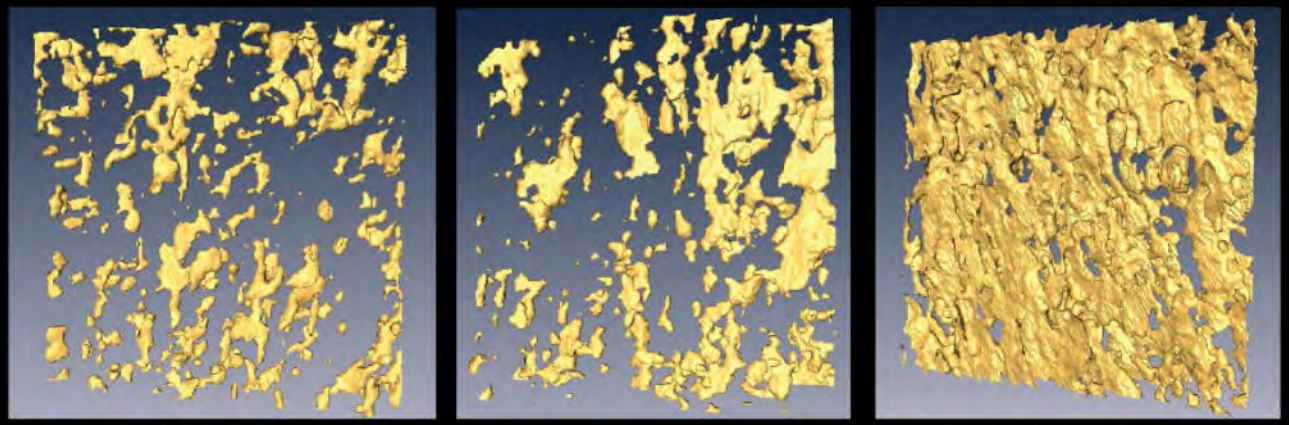
T_{sw} = -2.1 °C

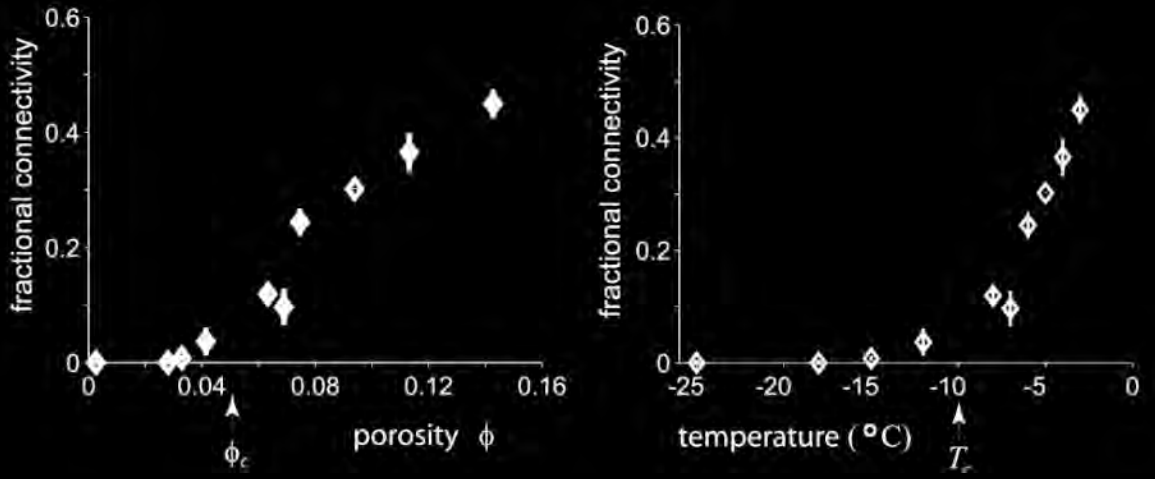
[MOSIDEO]

[MOSIDEO]

Oil/ice (4) Spring warming

- Increase in porosity and connectivity in sea ice
- Brine convection if $\phi > 5\%$



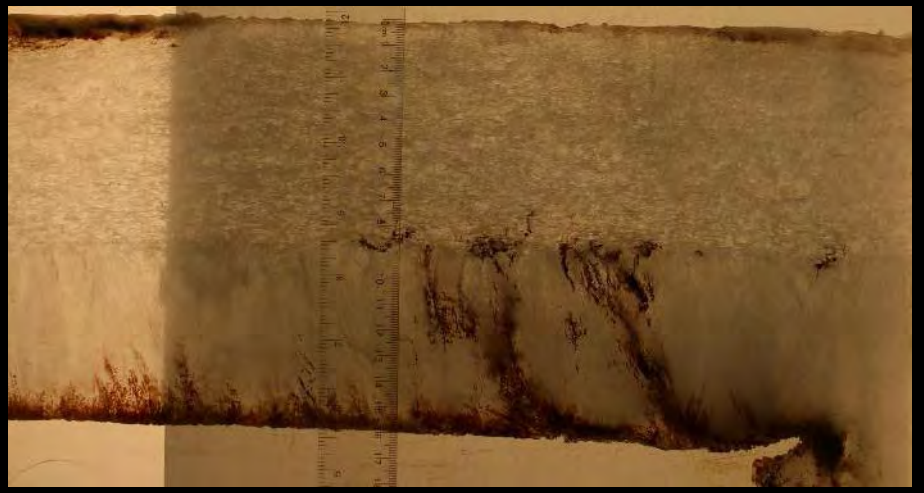


[Golden et al. , 2007, doi.org/10.1029/2007GL030447]

Oil/ice (4) Spring warming

- When, T > -5 °C, ϕ > 5% potential for brine movement
- Oil invades opening pore space
- Oil migration function of:
  - Brine channel diameter
  - Pore volume fraction

T_s = -7.0 °C [MOSIDEO]



T_s = -4.5 °C

[MOSIDEO]

Oil/ice (5) First surfacing

- Vertical movement
- Horizontal spreading
  - Granular ice
  - Sea water level
    Less buoyancy

T_s = -4.5 °C [MOSIDEO]

T_s = -3.5 °C

[MOSIDEO]

Oil/ice (5) First surfacing

- Vertical movement
- Horizontal spreading
  - Granular ice
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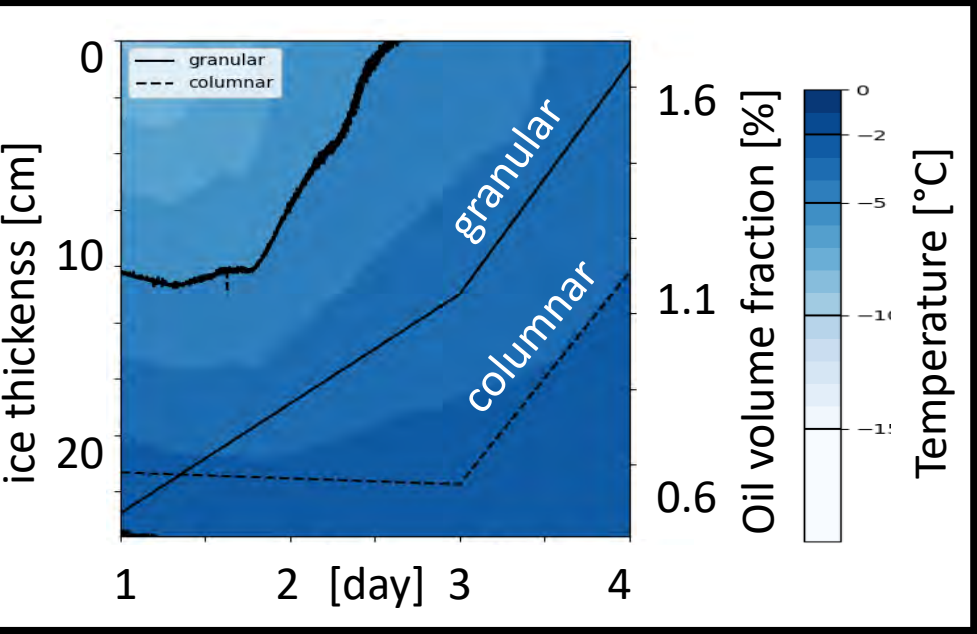
    Less buoyancy



T_s = -4.5 °C [MOSIDEO]

T_s = -3.5 °C

[MOSIDEO]

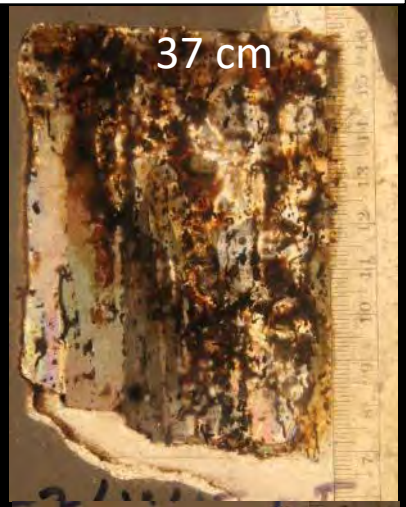
Oil/ice (6) Oil pooling at the surface

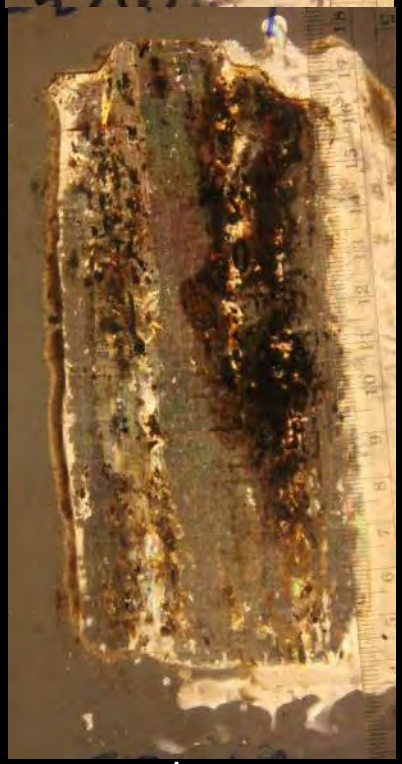
- Lateral spreading and pooling
- Solar warming of oil
  - Increase surface melt
  - Pool in oil pond, rather than melt pond

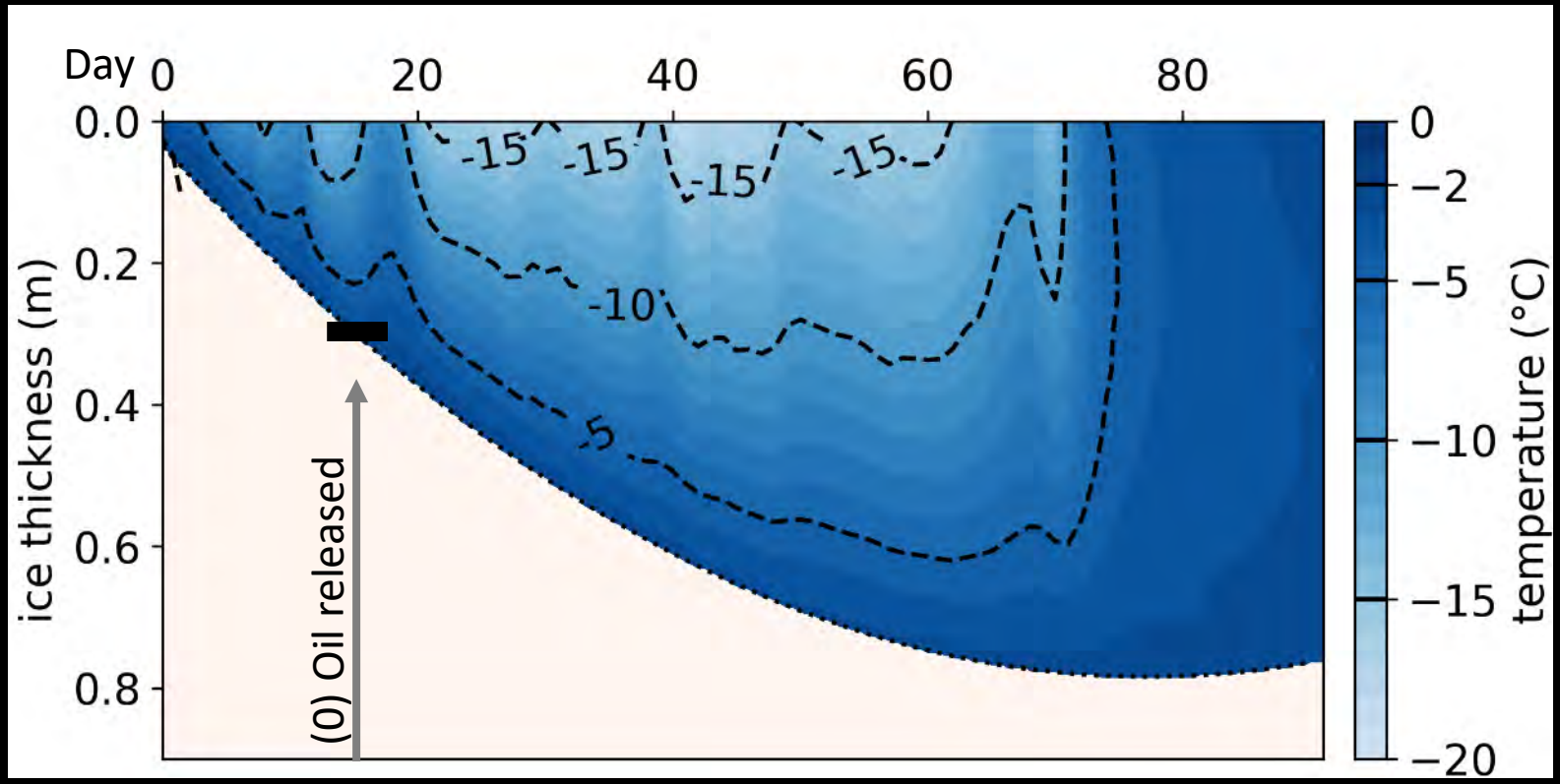
[UAF]

Oil/ice (7) Oil occupies ice porosity

- Late melt season
- Complex oil distribution



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ice thickness (m)
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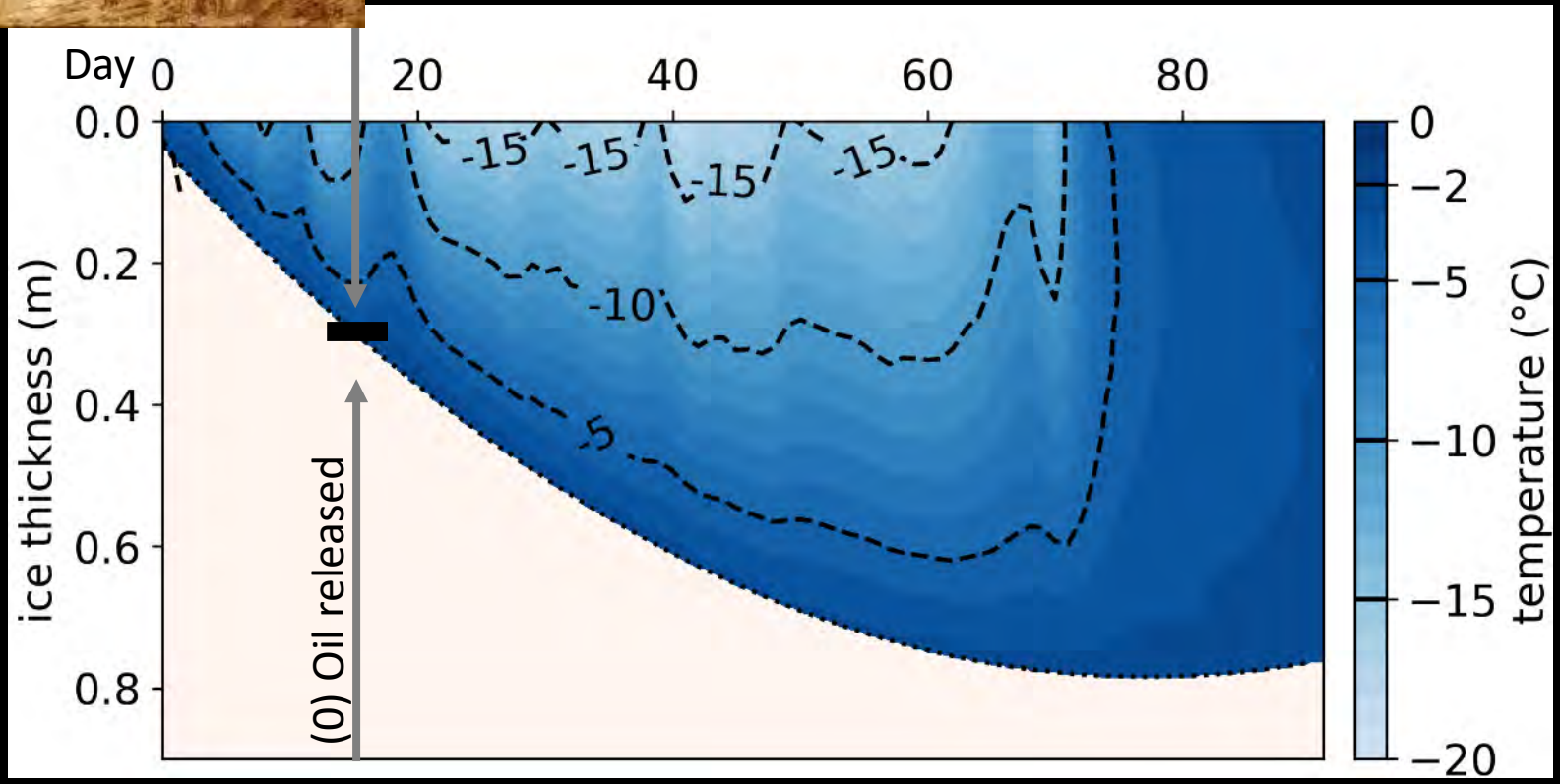
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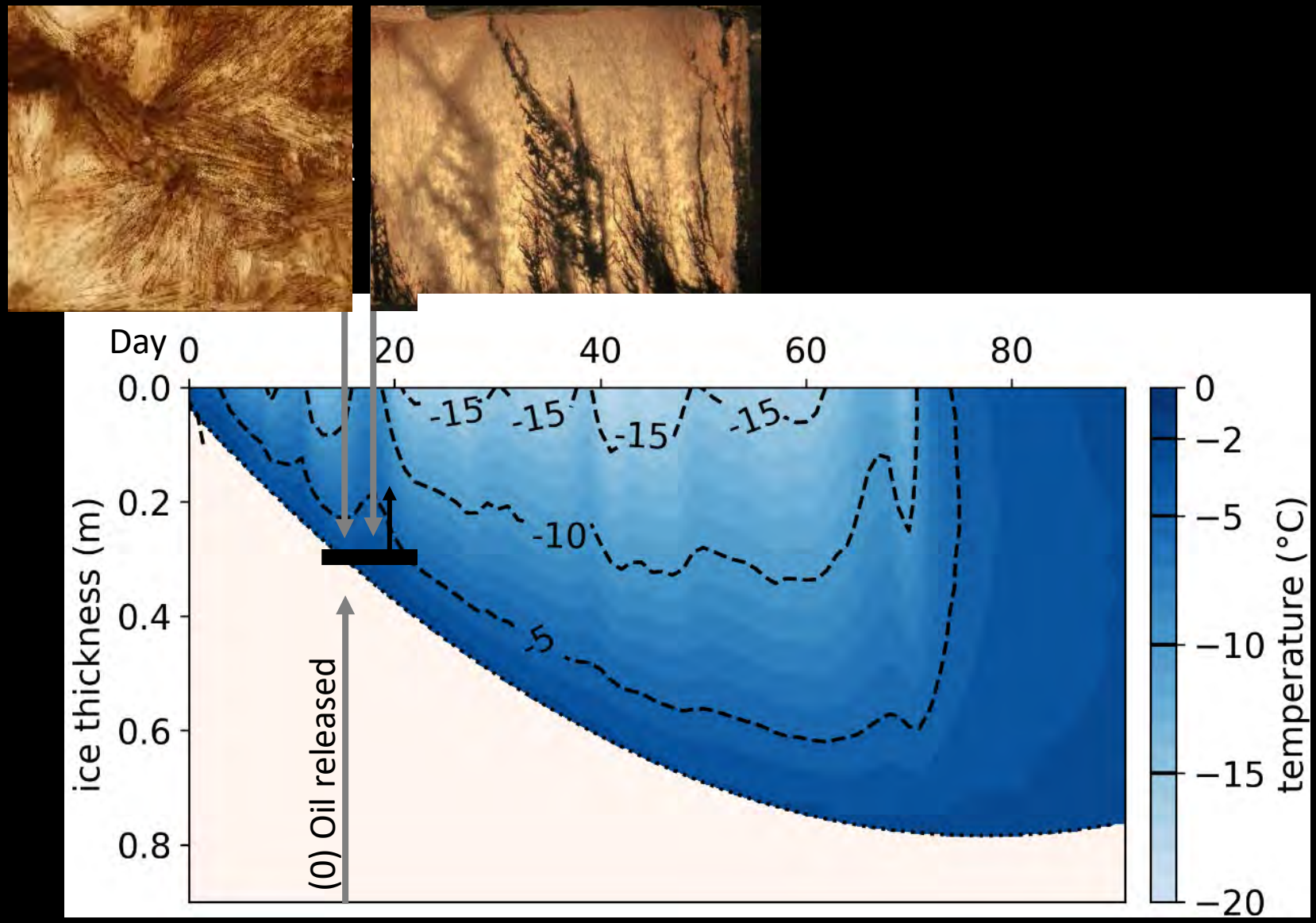
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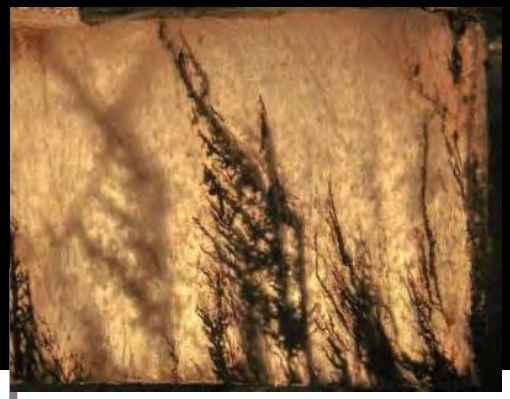

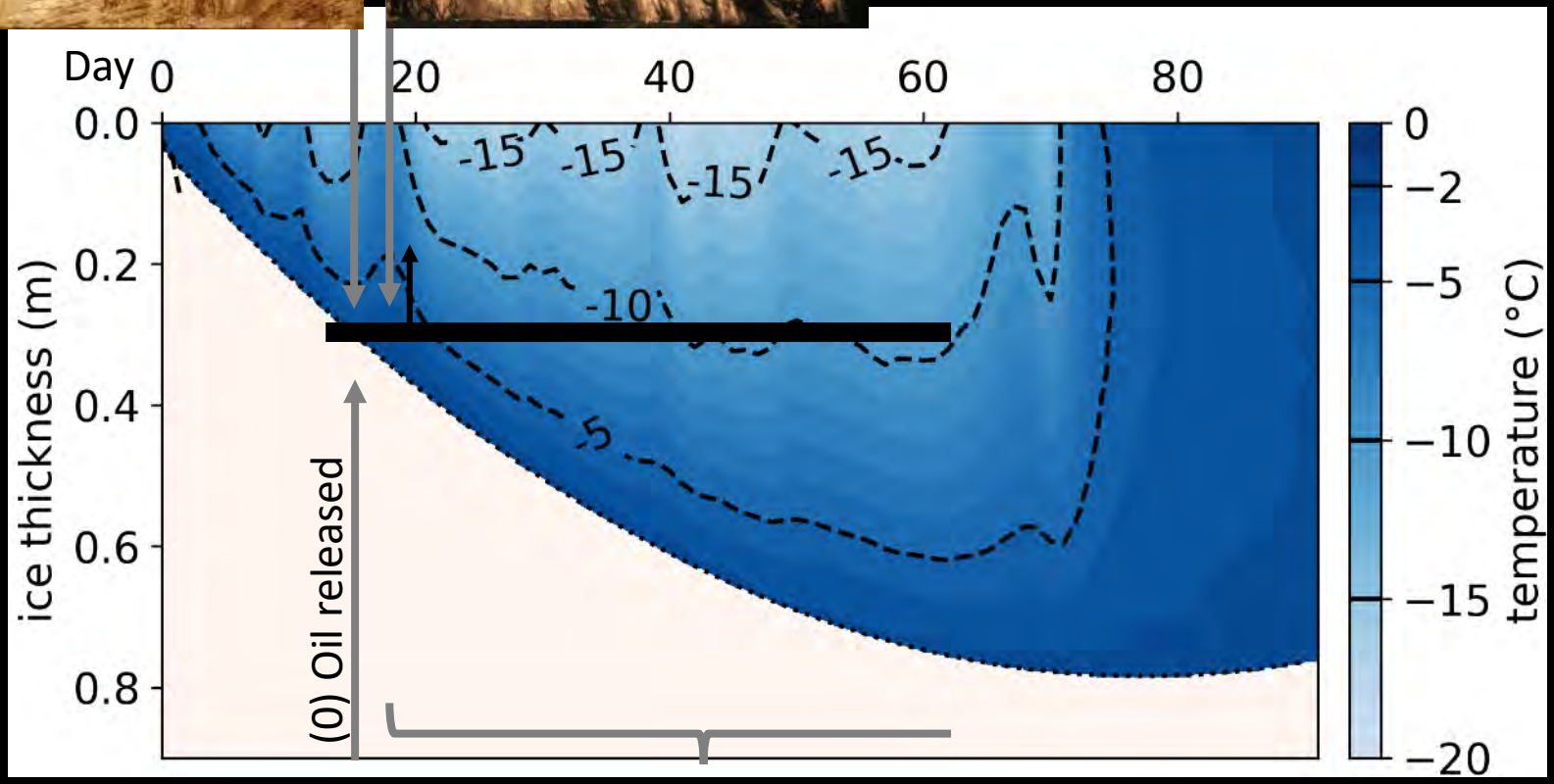
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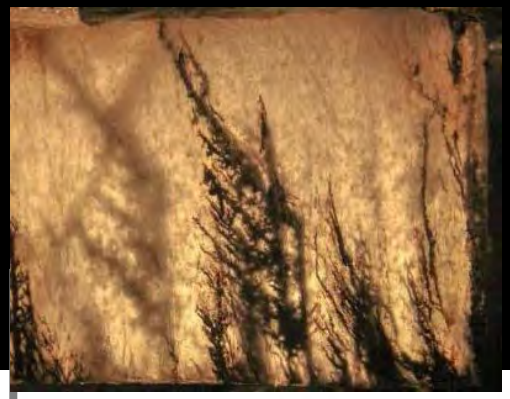
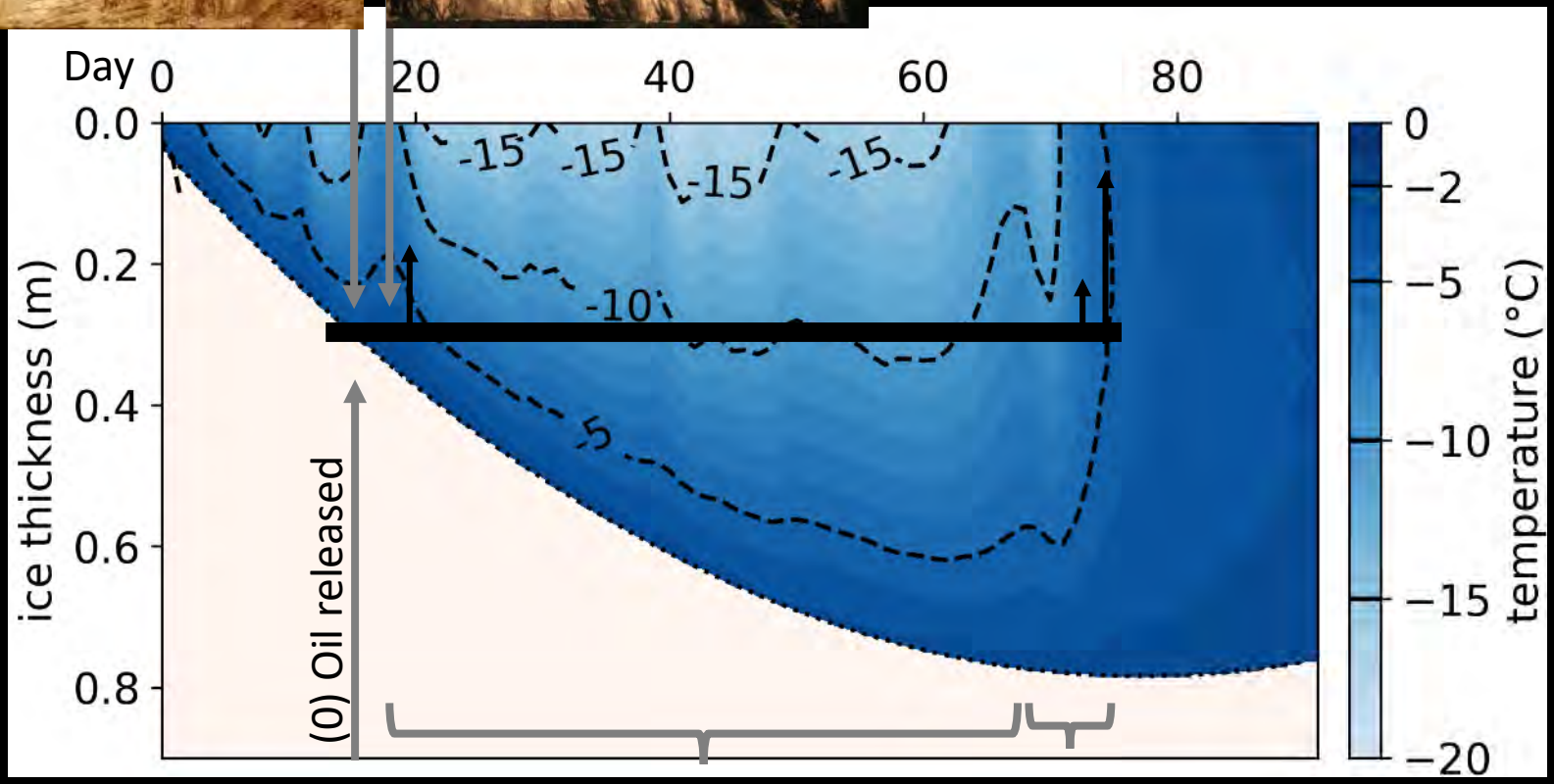
Oil lens

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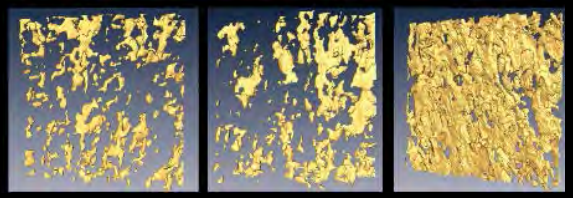

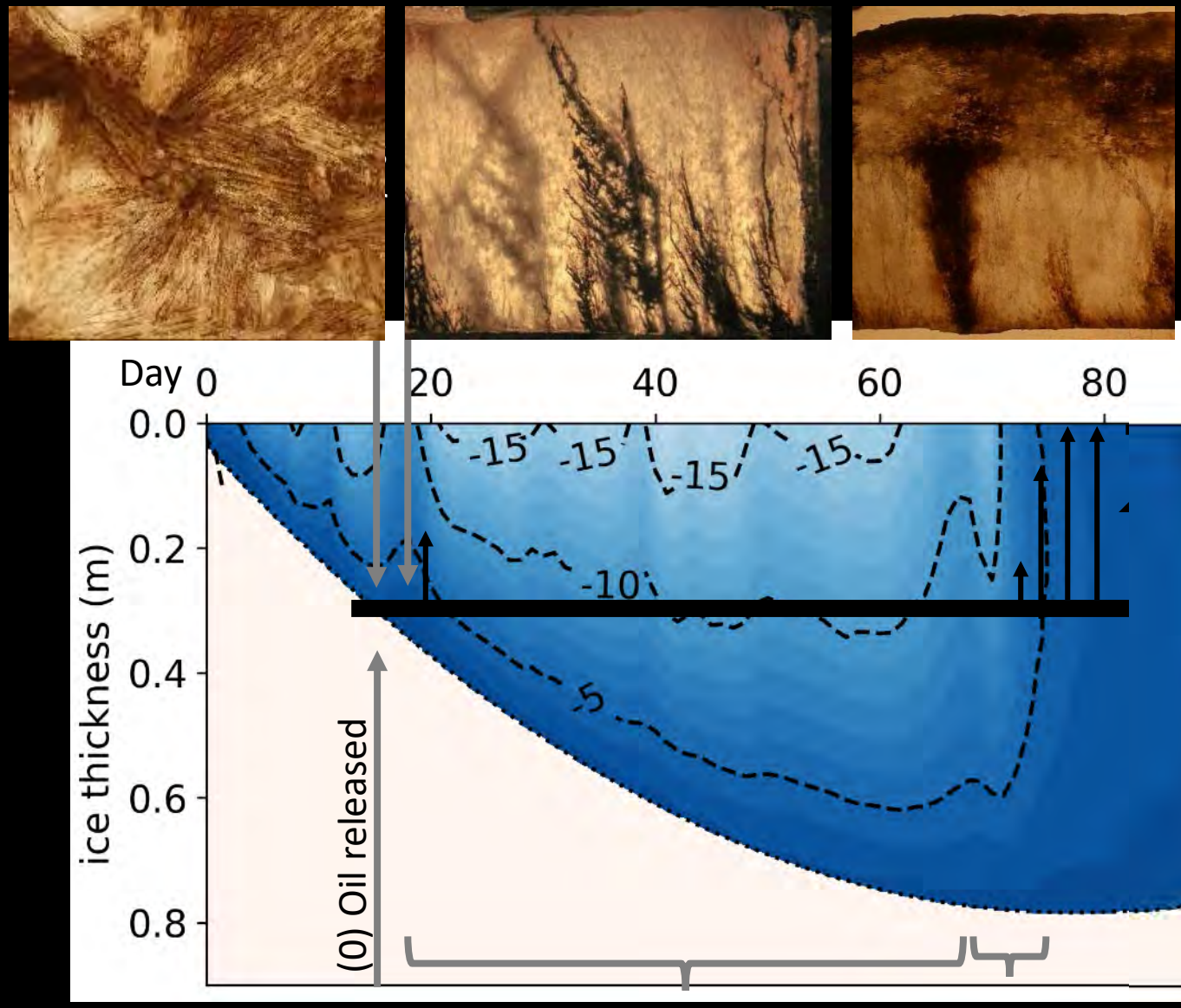
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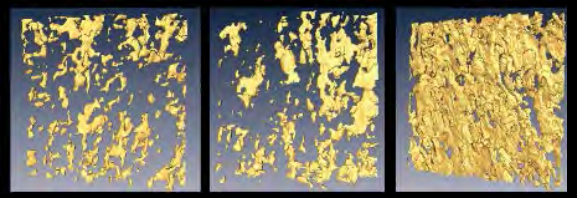


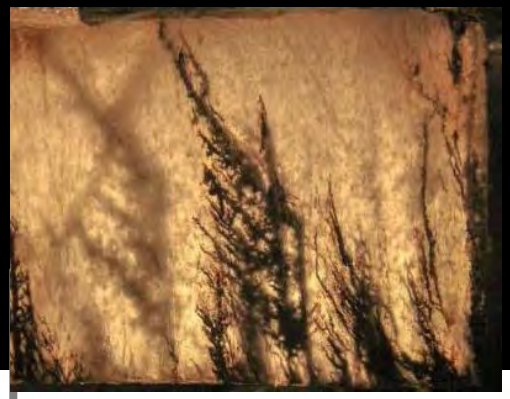


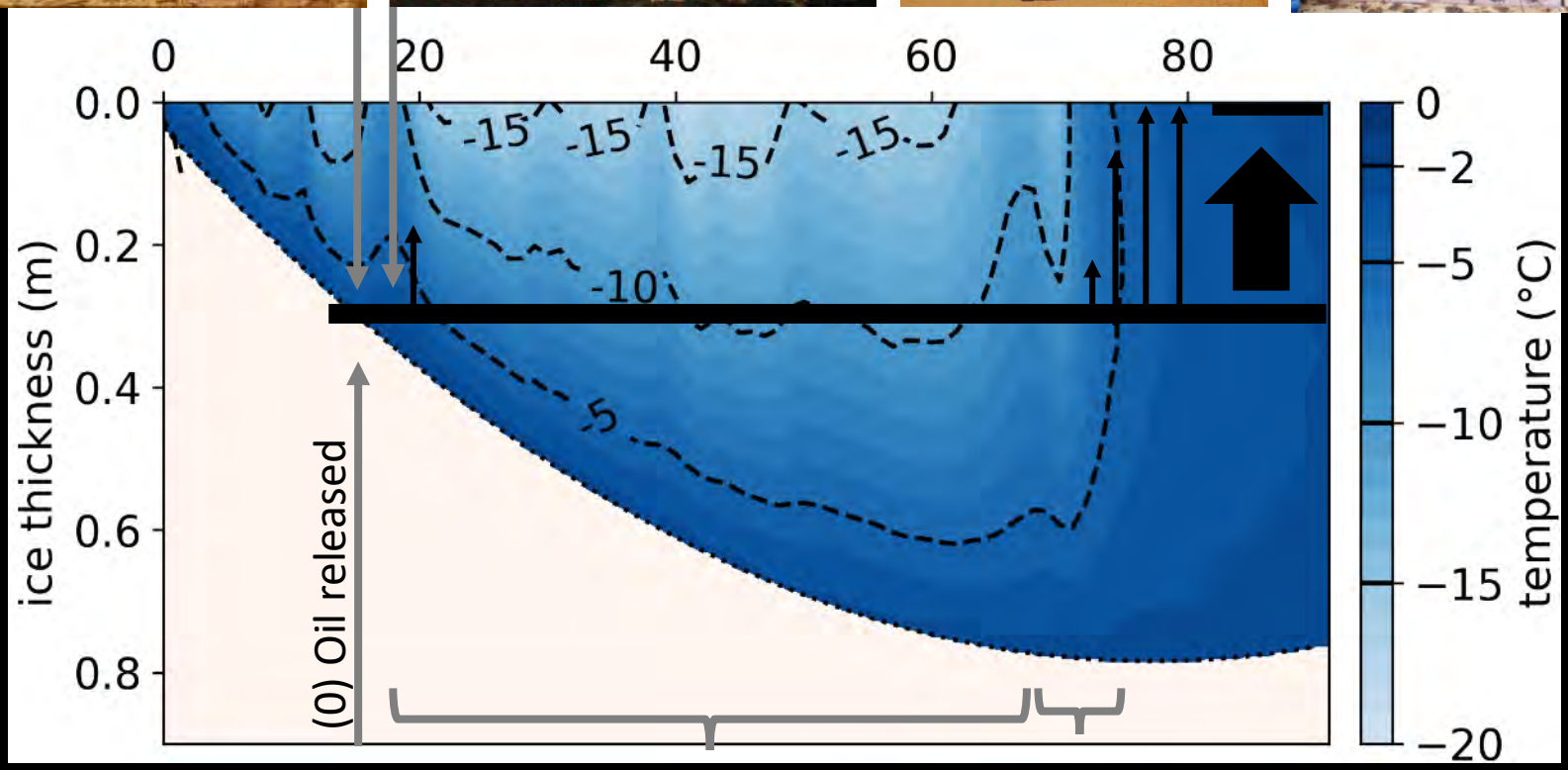
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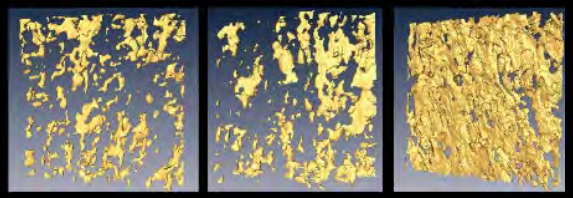
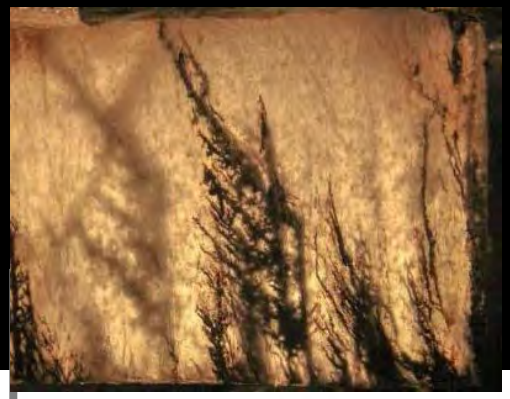
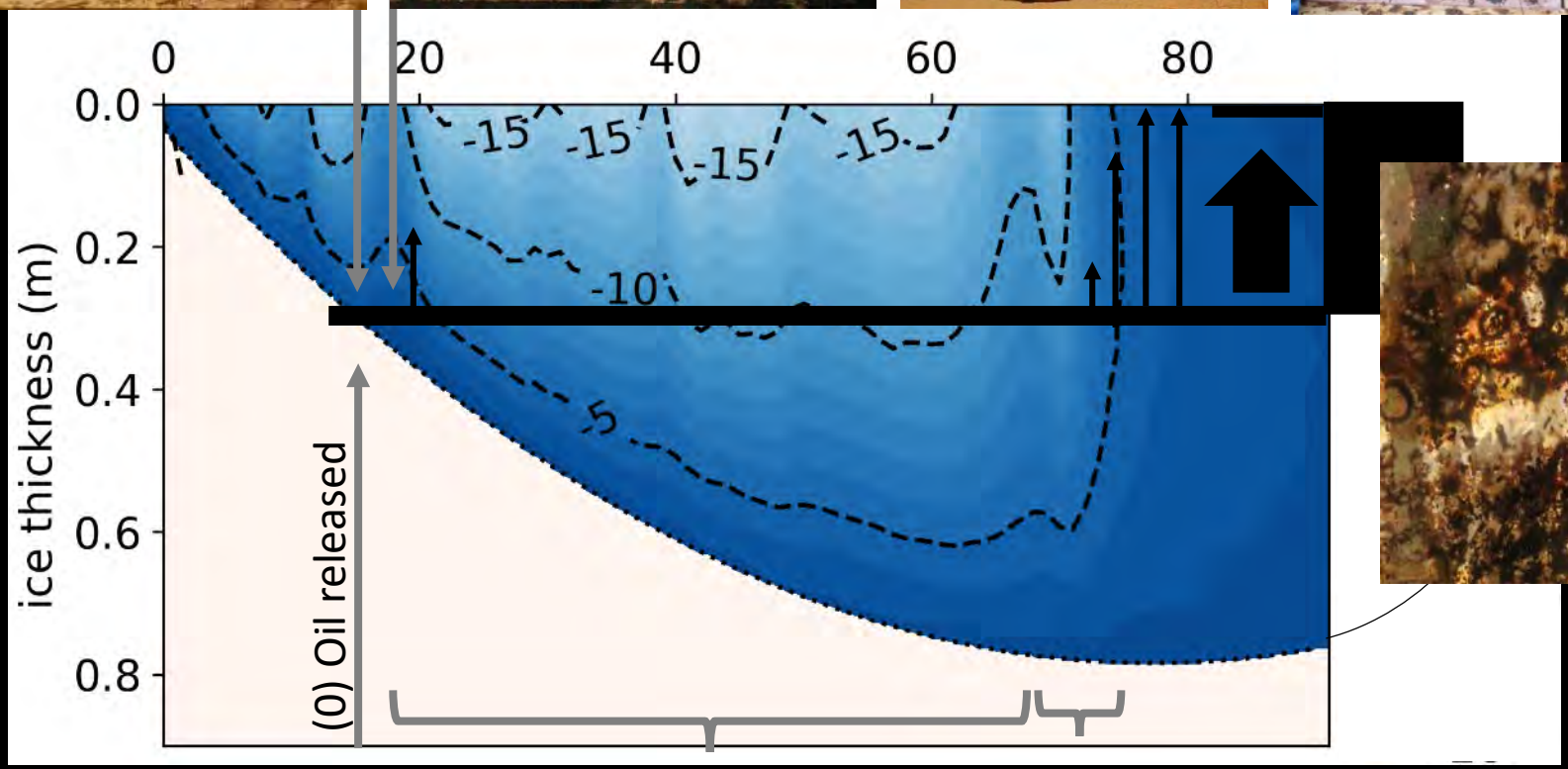
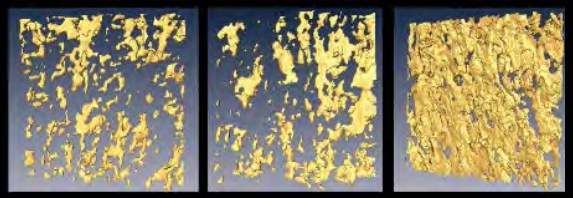
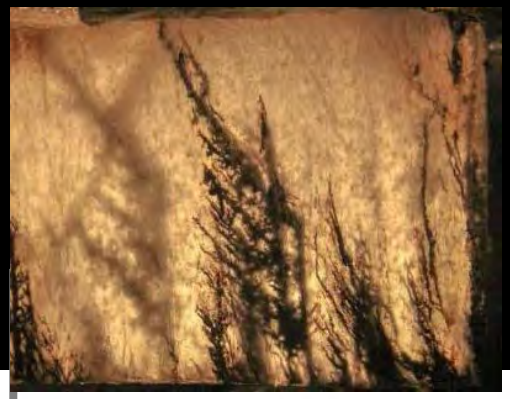
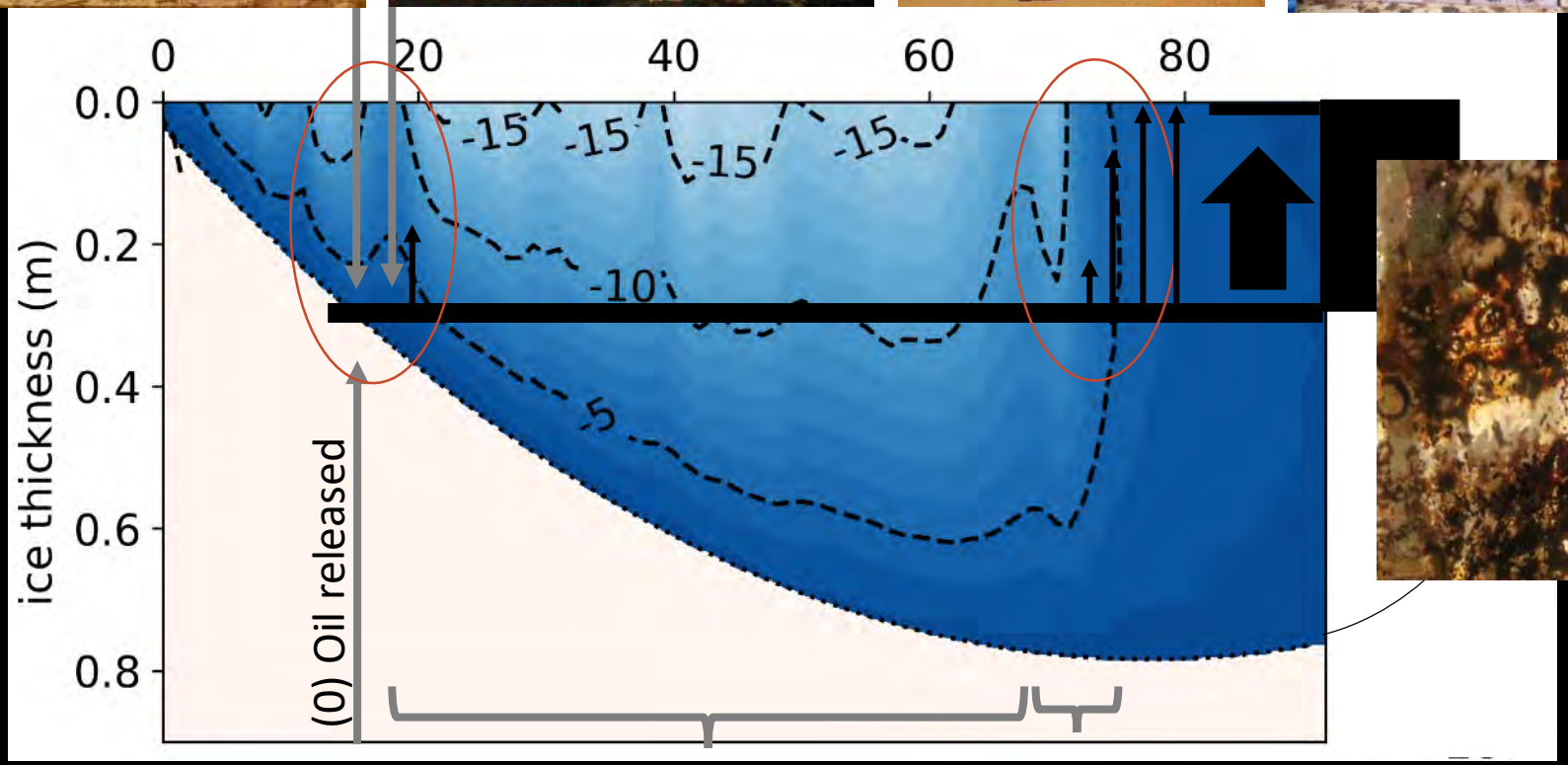
Oil lens




0
20
40
60
80
0.0
0.2
0.4
0.6
0.8
ice thickness (m)
-15
-15
-15
-15
-10
-5
(0) Oil released


Oil lens
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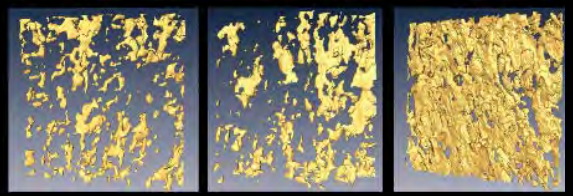
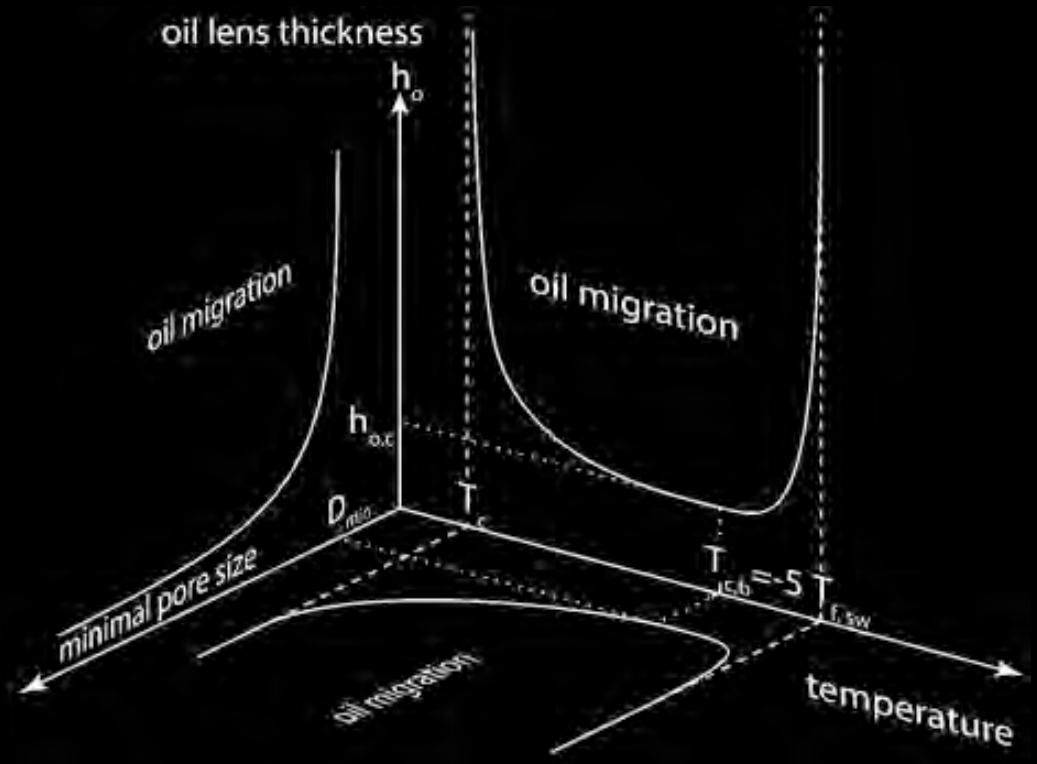


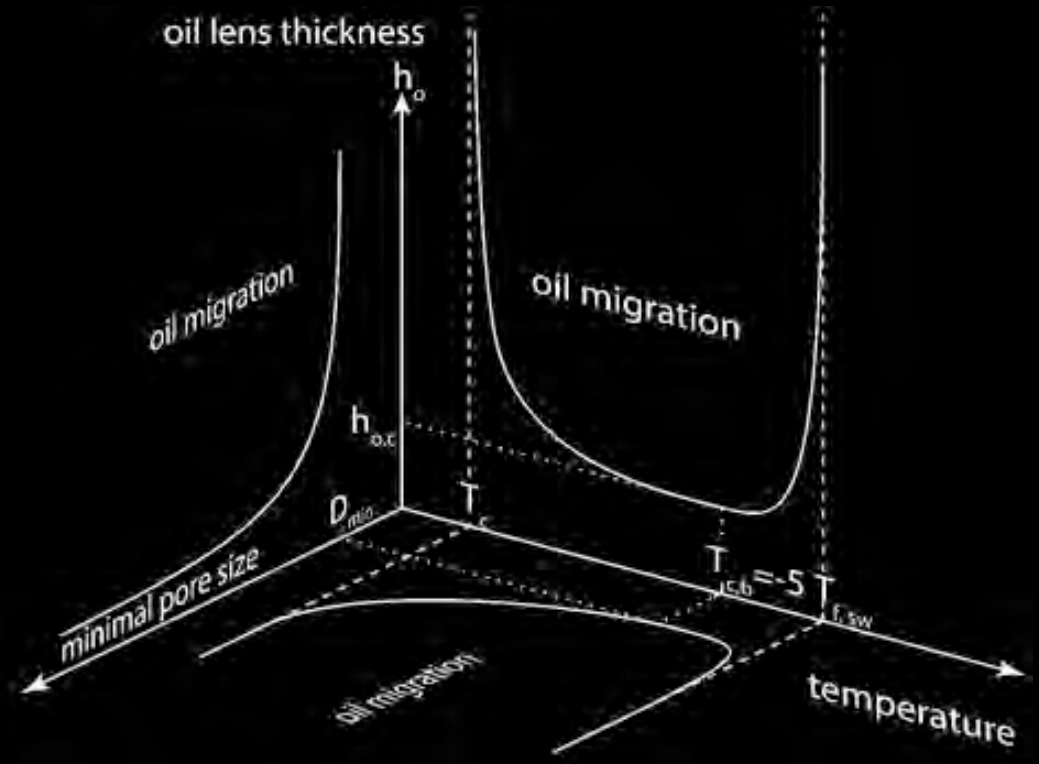
What's next

- Quantifying constraining factor for oil migration
  - Sea ice microstructure and stratigraphy
  - Oil properties



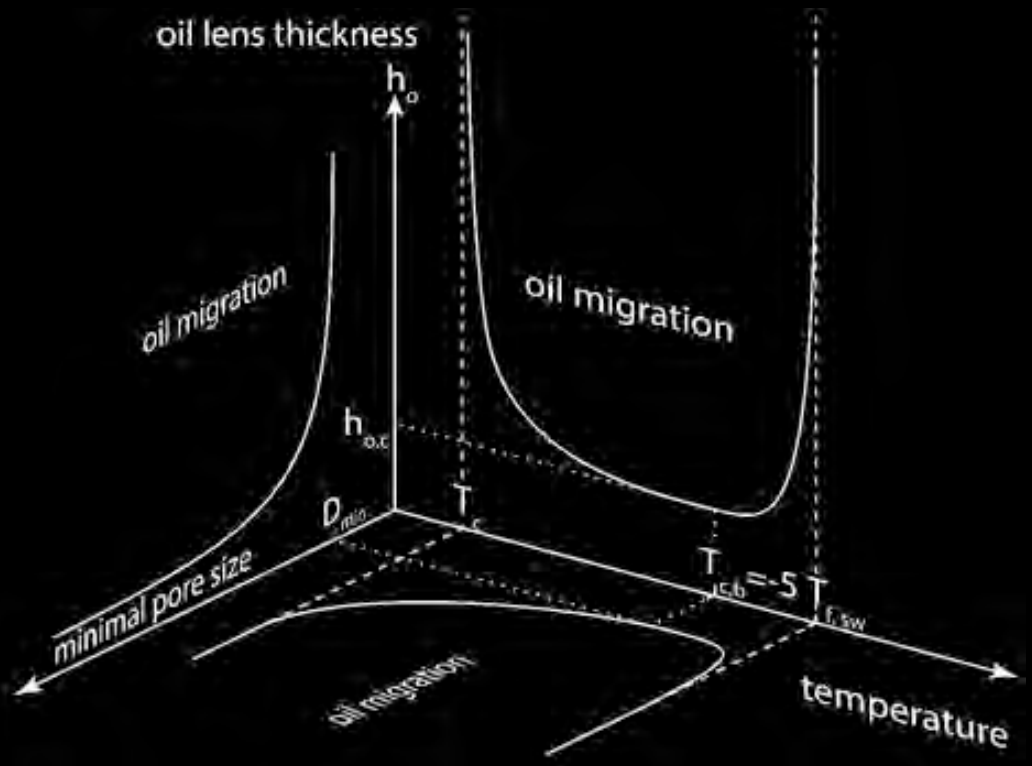
What's next

- Quantifying constraining factor for oil migration
  - Sea ice microstructure and stratigraphy
  - Oil properties
- Oil migration model
  - No model today
    - When and how much
  - Supports oil spill response



What's next

- Quantifying constraining factor for oil migration
  - Sea ice microstructure and stratigraphy
  - Oil properties
- Oil migration model
  - No model today
    - T, S, time
    - When and how much
  - Supports oil spill response
- **What are you need ?**
  - NOAA, with NRDA
  - ACS, with oil removal
  - Large-scale model



Thank you