Hidden meltwater in the ice: Extending Greenland Ice Sheet subsurface meltwater records with satellite remote sensing

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EARTH AND ENVIRONMENTAL SCIENCE

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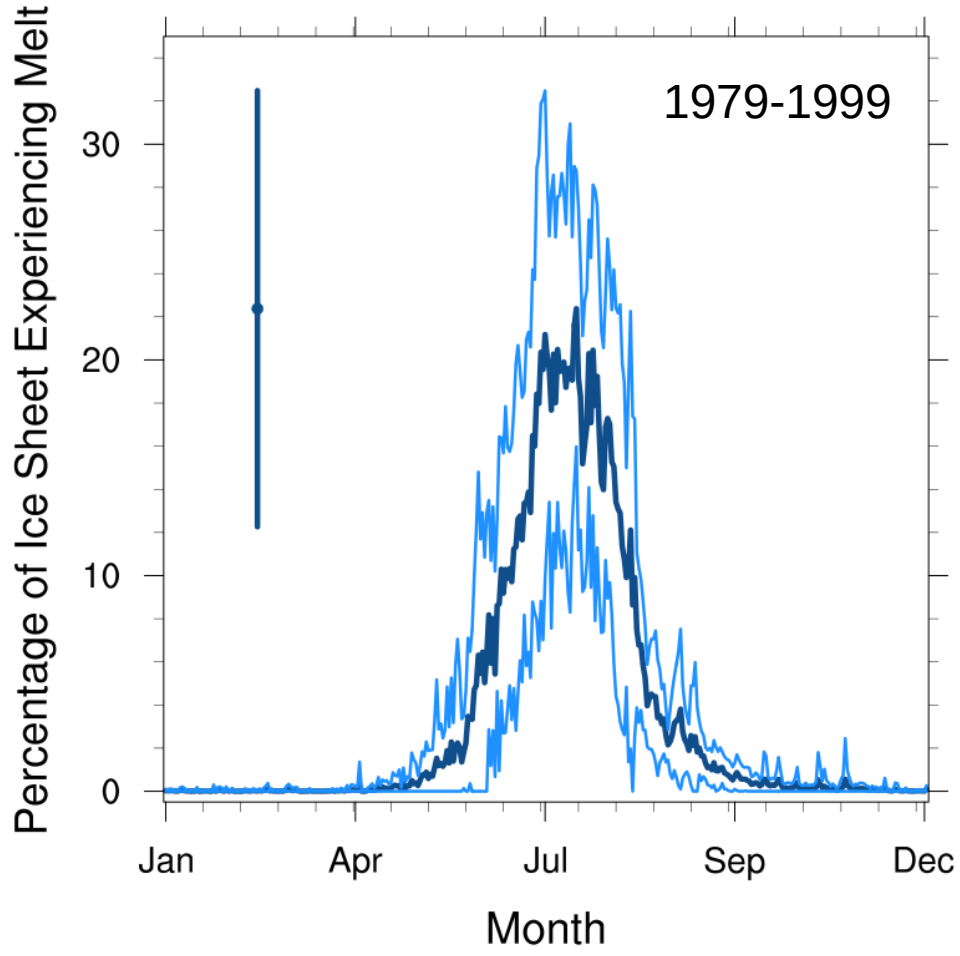
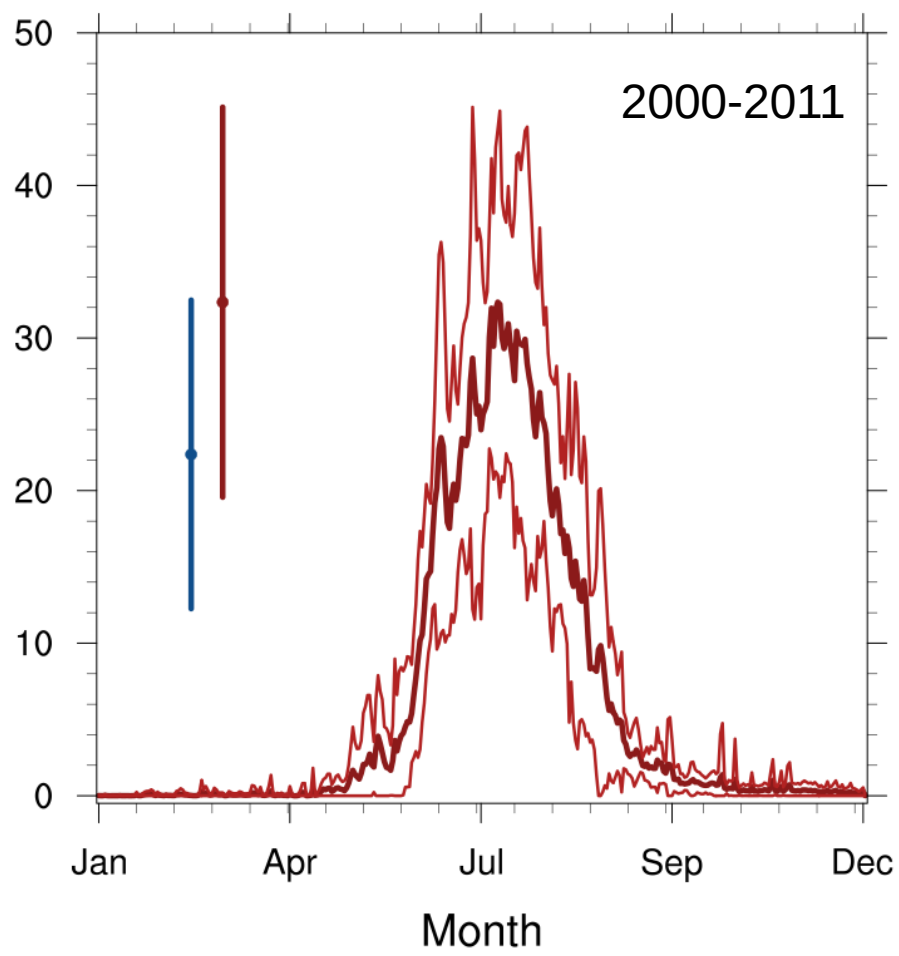
Increasing Melt in Greenland

Greenland Surface Melt

1979-1999
Average
+/- 1σ
2000-2011
Average
+/- 1σ



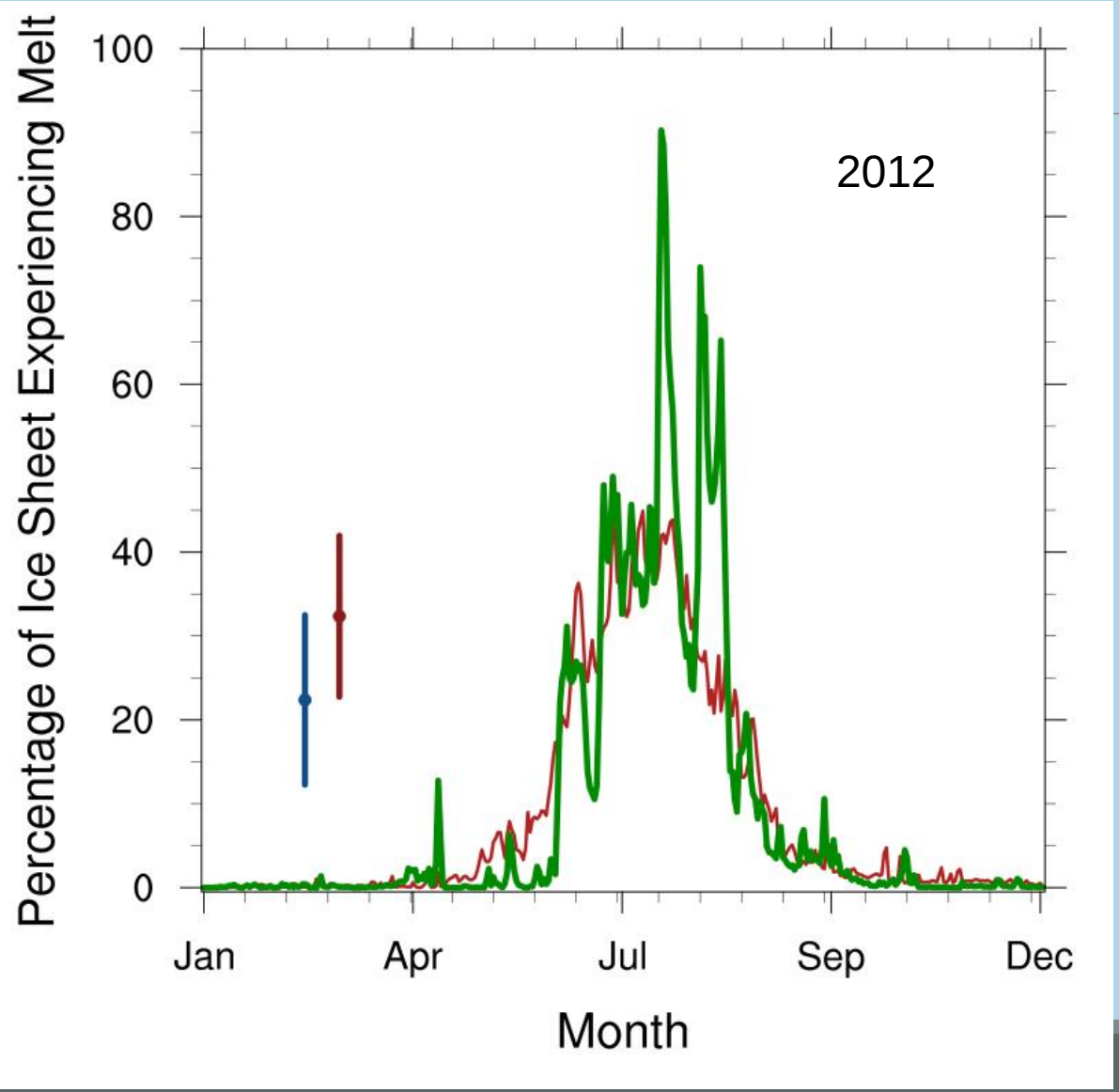


Data Source:
Mote (2014)

Increasing Melt in Greenland

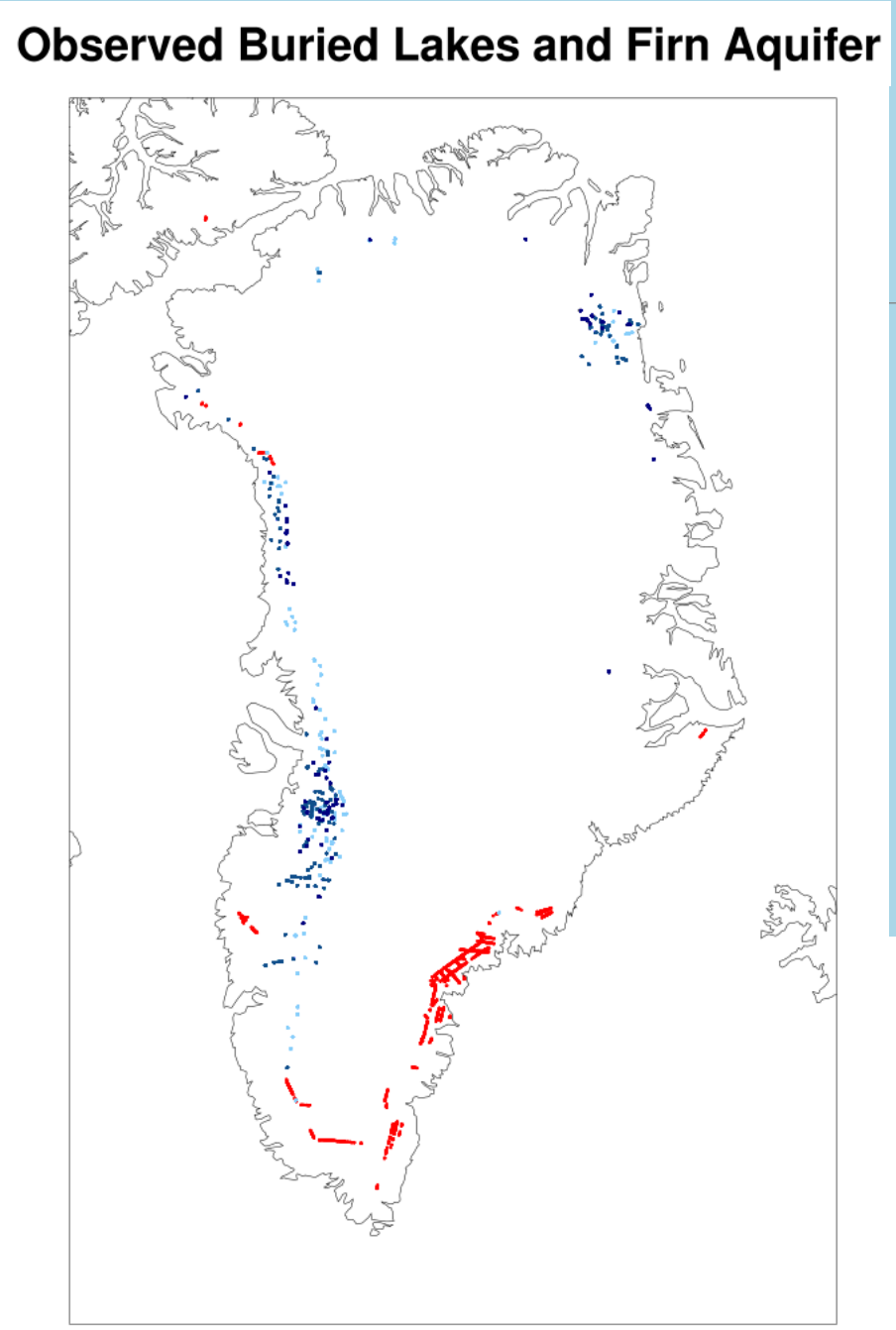
Greenland Surface Melt

1979-1999 Average
+/- 1σ
2000-2011 Average
+/- 1σ
2012



Data Source: Mote (2014)

Greenland Hydrology in a Changing Climate



Perennial Firn Aquifers (PFAs)

- Discovered April 2011
- Estimated 70,000 mi^2 (Forster et. al. 2013)
- Estimated 140 Gt, (Koenig et. al. 2014)

Buried Supraglacial Lakes (BSLs)

- Estimated 1.5 Gt in 2011 (Koenig et. al. 2015)

Data Source: Miège, pers. comm., Lampkin, pers. comm

Perennial Firn Aquifers

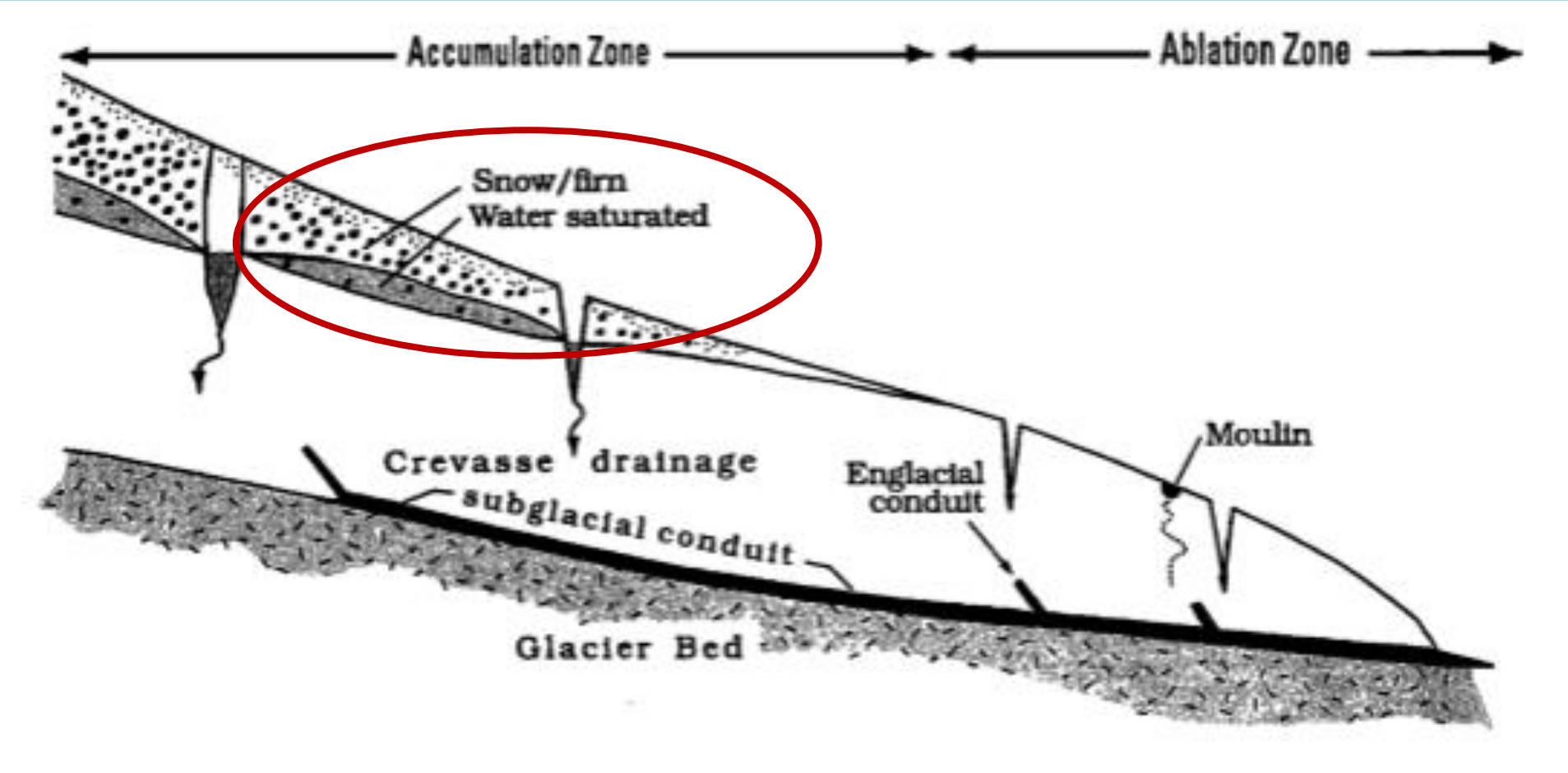
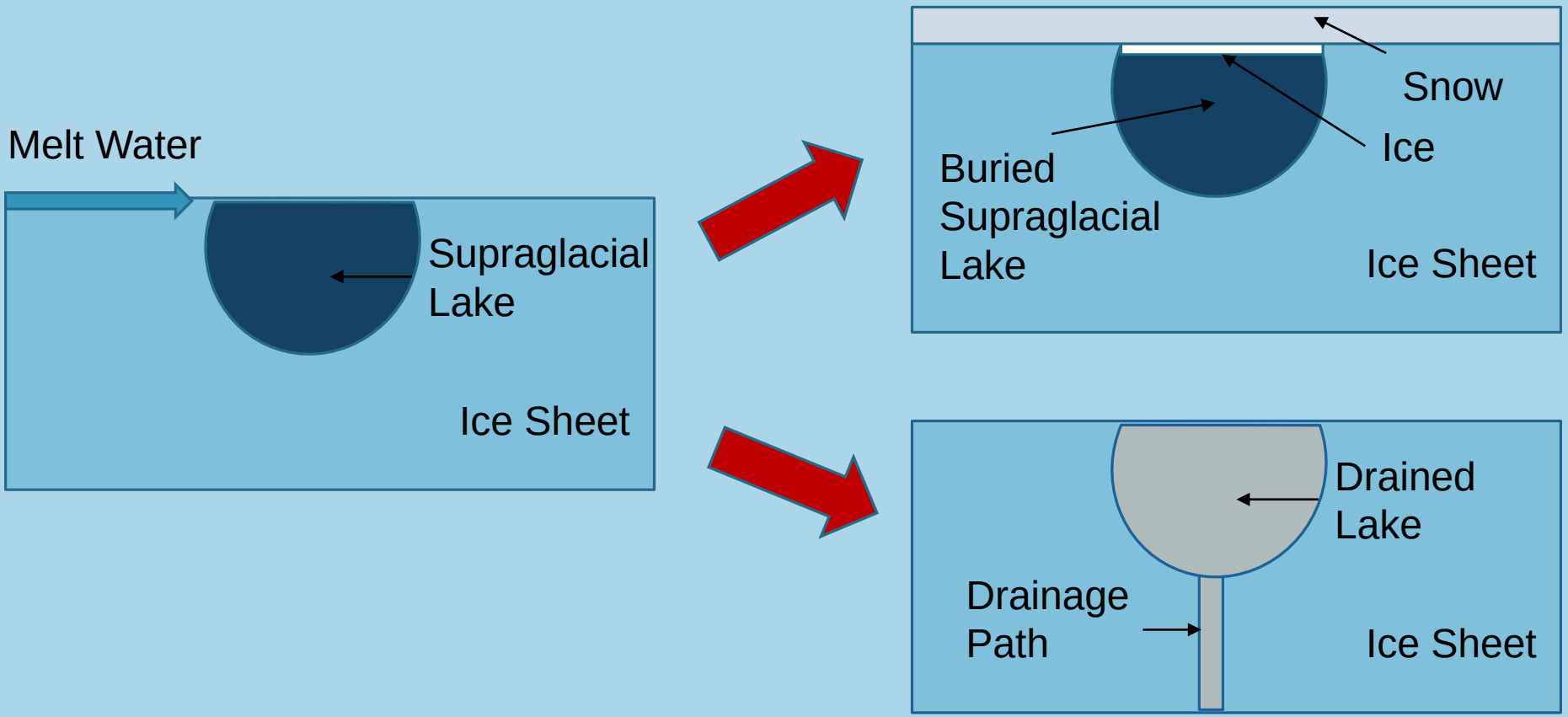
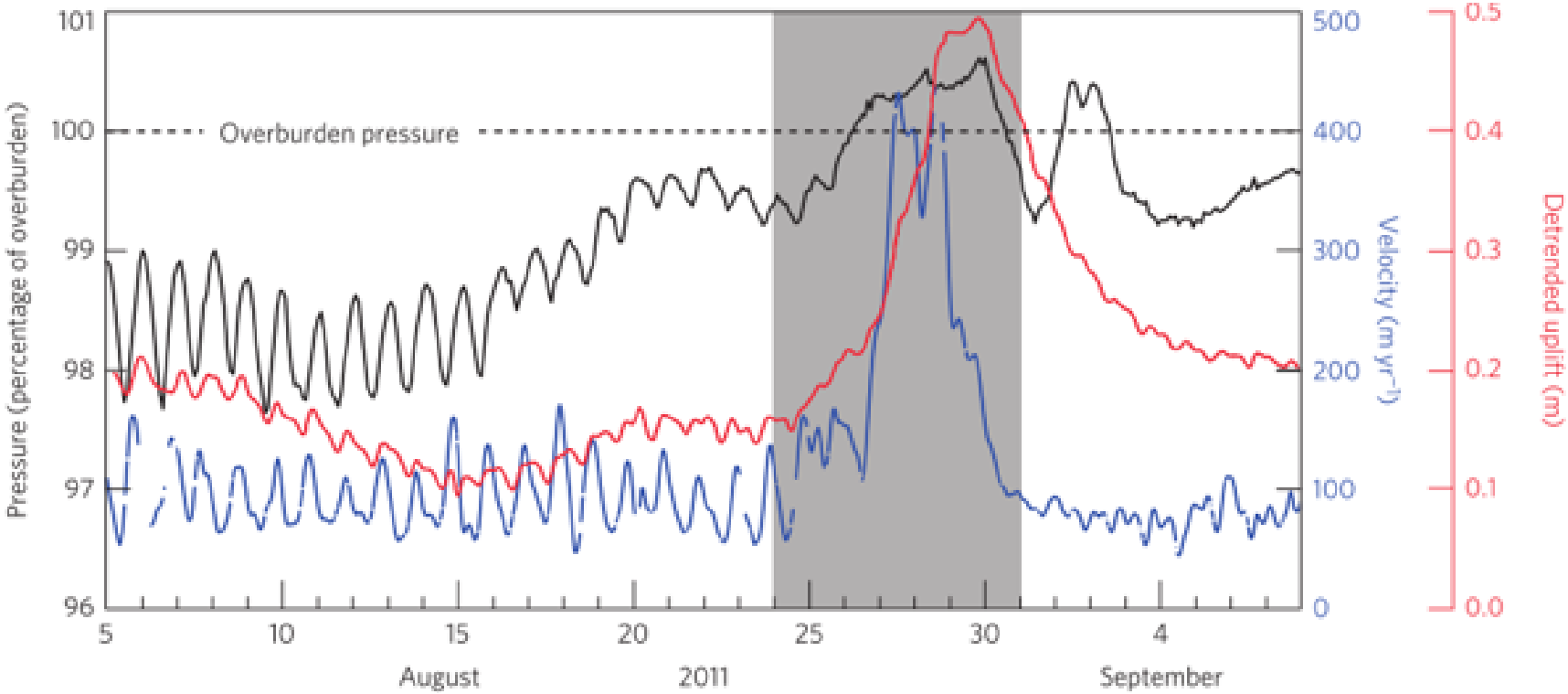


Image from Fountain and Walders (1998)

Buried Supraglacial Lakes



Impact of Retained Water



- **Delayed water drainage**
  - **PFA ~0.04 mm slr**
  - **Glacier outlet velocity**
  - **Catastrophic drainage**

Image from Doyle et. al. (2015)

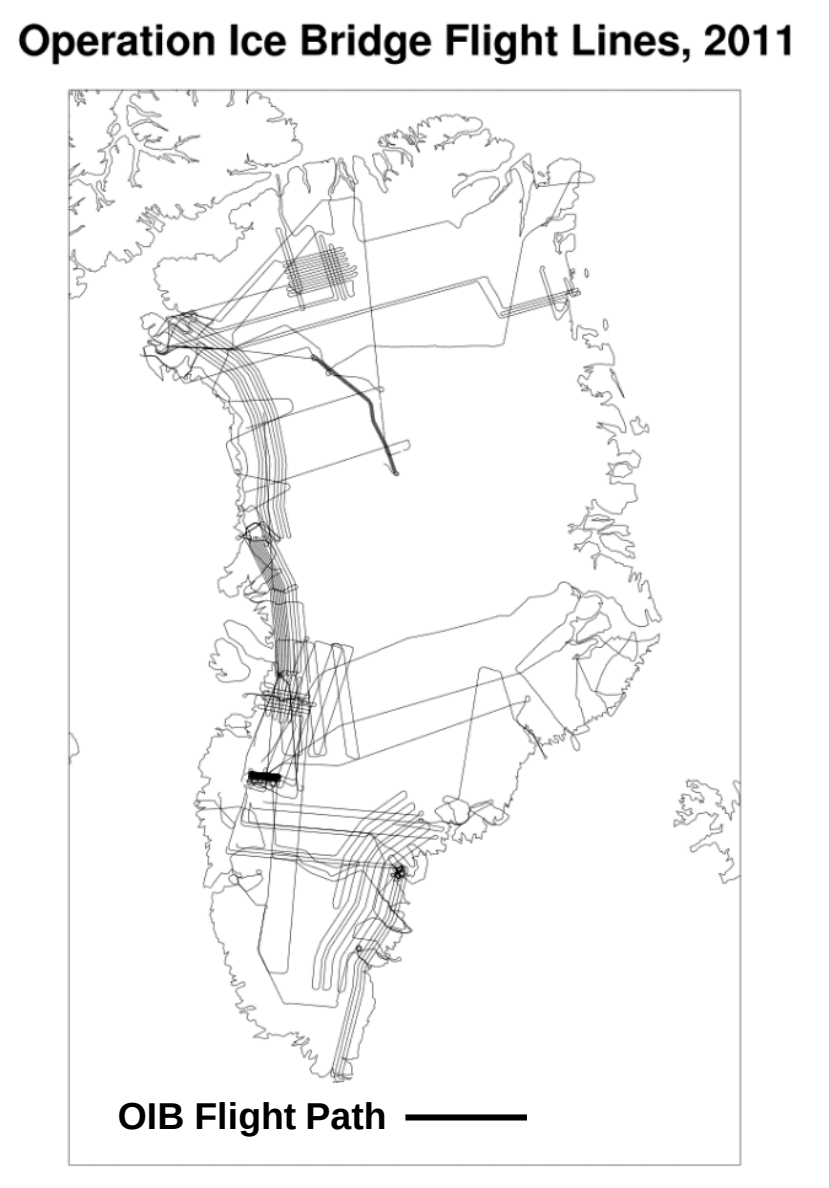
Satellite Observation Potential

Current Observations: Operation Ice Bridge (OIB)

- 2009-present
- Limited flight paths
- Melt season only

Satellite Observations: AMSR-E

- 2002-2011
- Very similar frequencies
- Entire ice sheet daily
- Low spatial resolution



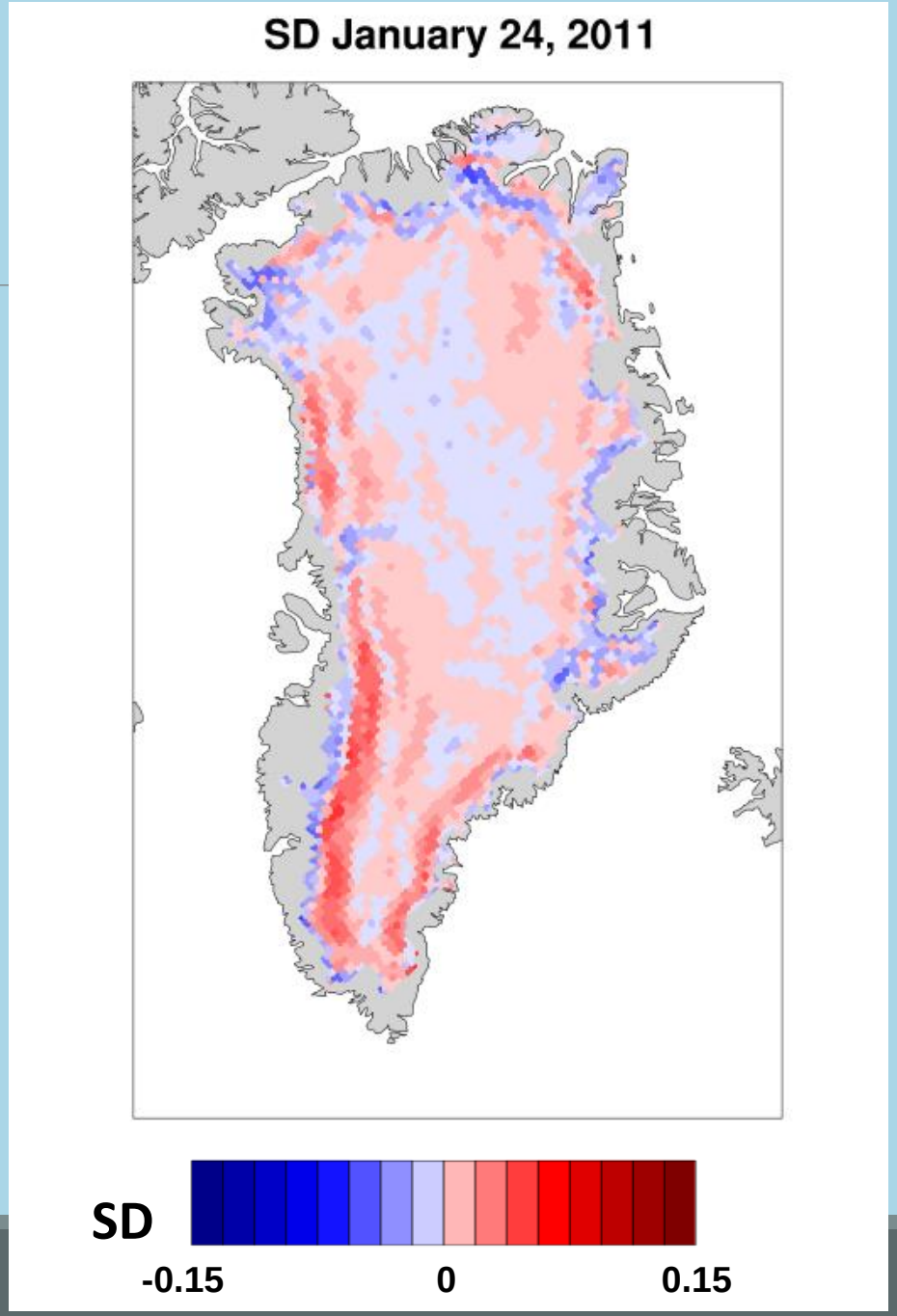
Data Source: Miège, pers. comm.

Method

$$SD = \frac{\nabla(6.9\,GHz\,Tb)}{Max(\nabla(6.9\,GHz\,Tb)} - \frac{\nabla(10.7\,GHz\,Tb)}{Max(\nabla(10.7\,GHz\,Tb)}$$

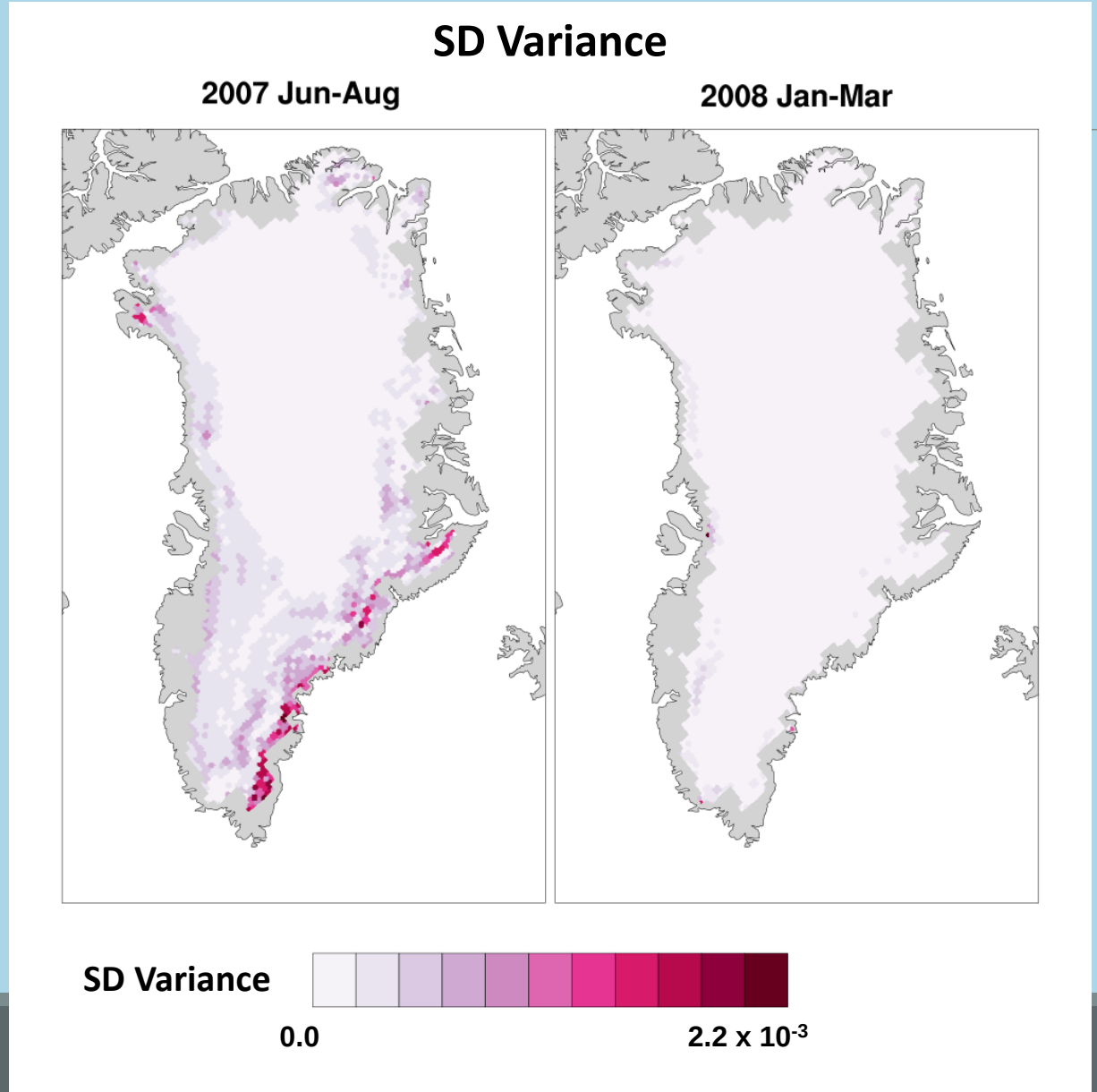
- Low frequencies
- Spatial derivative
- Frequency difference
- Scaling

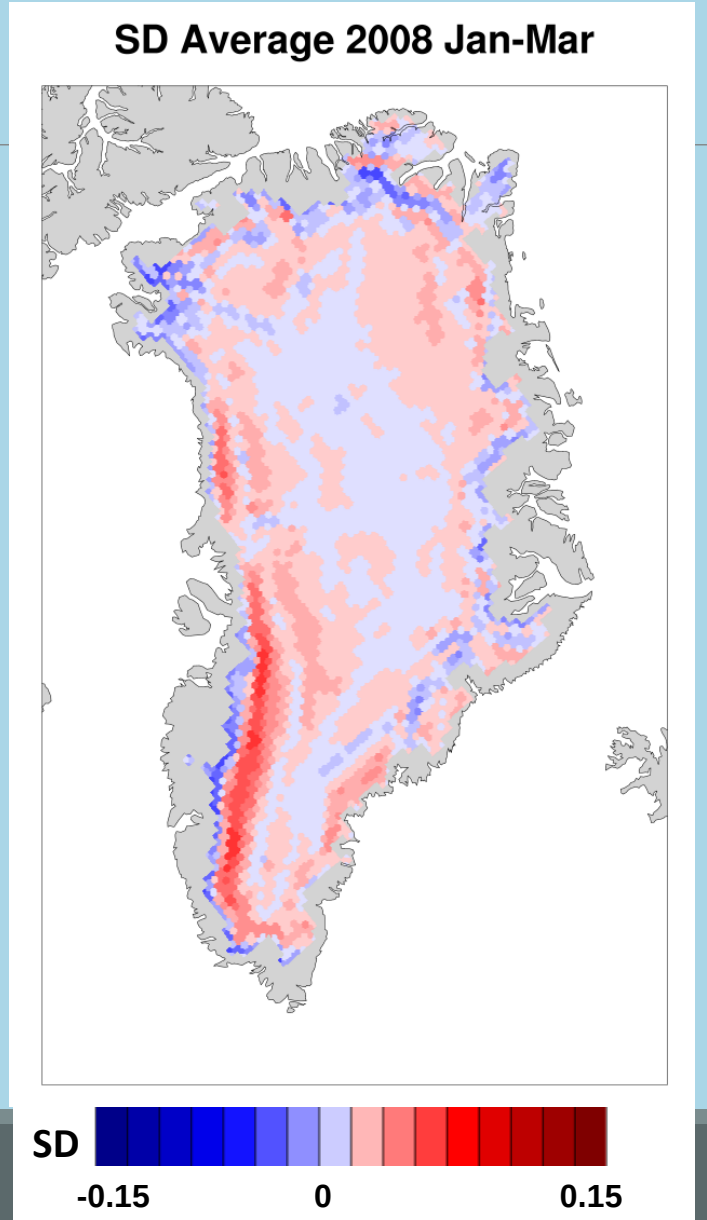
AMSR-E/Aqua Daily EASE-Grid Brightness Temperatures, Version 1
NASA NSIDC Distributed Archive Data Center
Knowles et. al. (2006)



Results

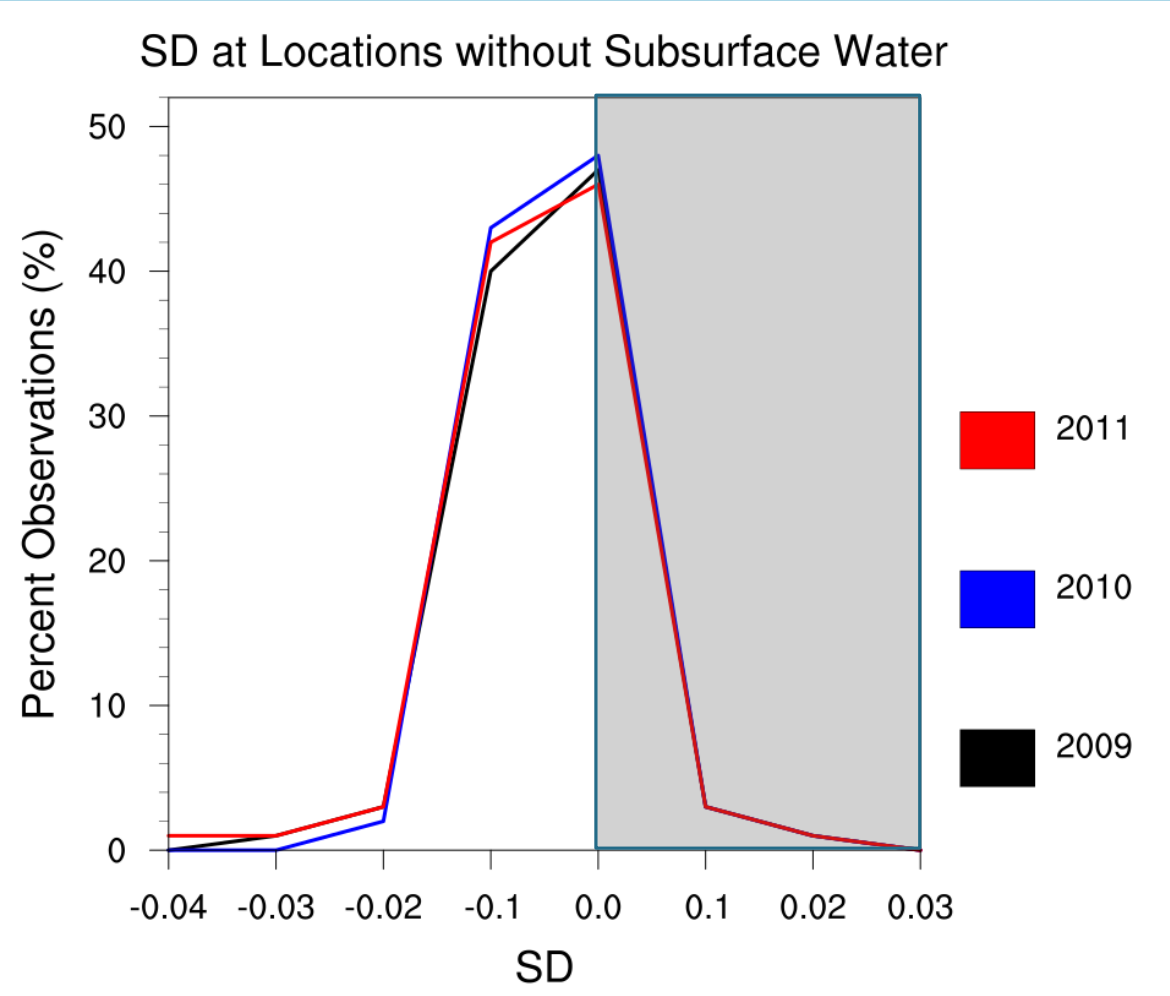
Summer SD is inconsistent due to surface melt interference.
Winter SD is temporally consistent.





Results

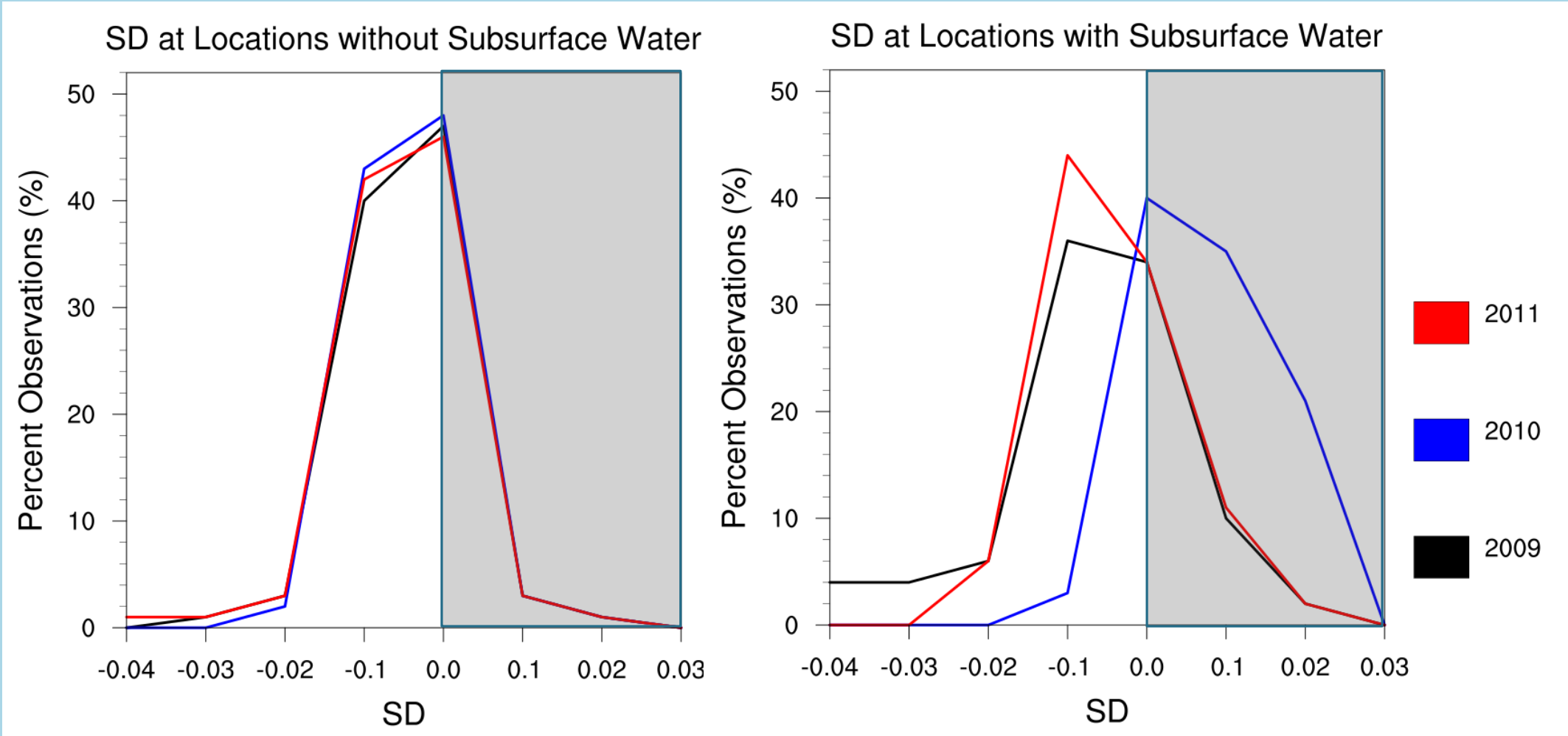
Consistent profile for locations without observed subsurface water.



Data Source: Miège, pers. comm. , Lampkin, pers. comm

Results

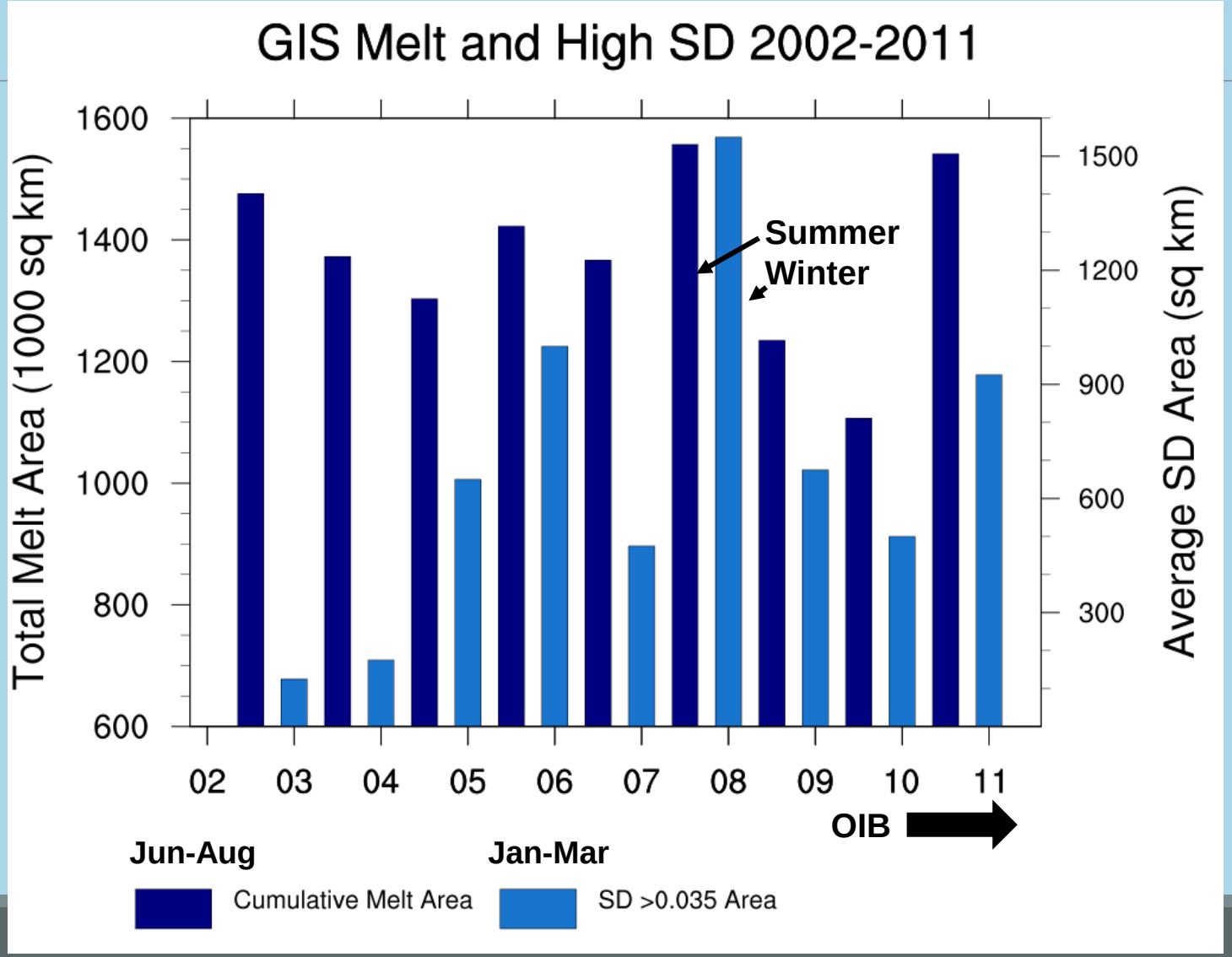
Consistent profile for locations without observed subsurface water.
Inconsistent profile for locations with subsurface water.
Comparison Points = 2861
Points with Subsurface Water = 2009: 46, 2010: 60, 2011: 144



Data Source: Miège, pers. comm., Lampkin, pers. comm

Results

Winter high SD area trails melt season cumulative area



Data Source:
Mote (2014)

Conclusions

Retained Meltwater Record Extension

- **Increased spatial coverage (full ice sheet)**
- **Increased temporal coverage (2002-2011, 7 years pre-OIB)**
- **Observation based**

Inconsistent Identification

- **True negatives**
- **True positives**
- **False positives and negatives**

Future Work

Brightness Temperature Emission Model

- **Develop Tb for known subsurface conditions**
- **Test and refine SD**

Testing meteorological drivers of PFA

- **Locations identified by SD**
- **Accumulation, melt intensity**

Moving SD regions

Additional record extensions, SMMR 1978-1987

Questions?

References

- Forster, R. R. and Coauthors , 2013: Extensive liquid meltwater storage in firn within the Greenland ice sheet. *Nat. Geosci.*, **7,** 95-98, doi:10.1038/NGEO2043.
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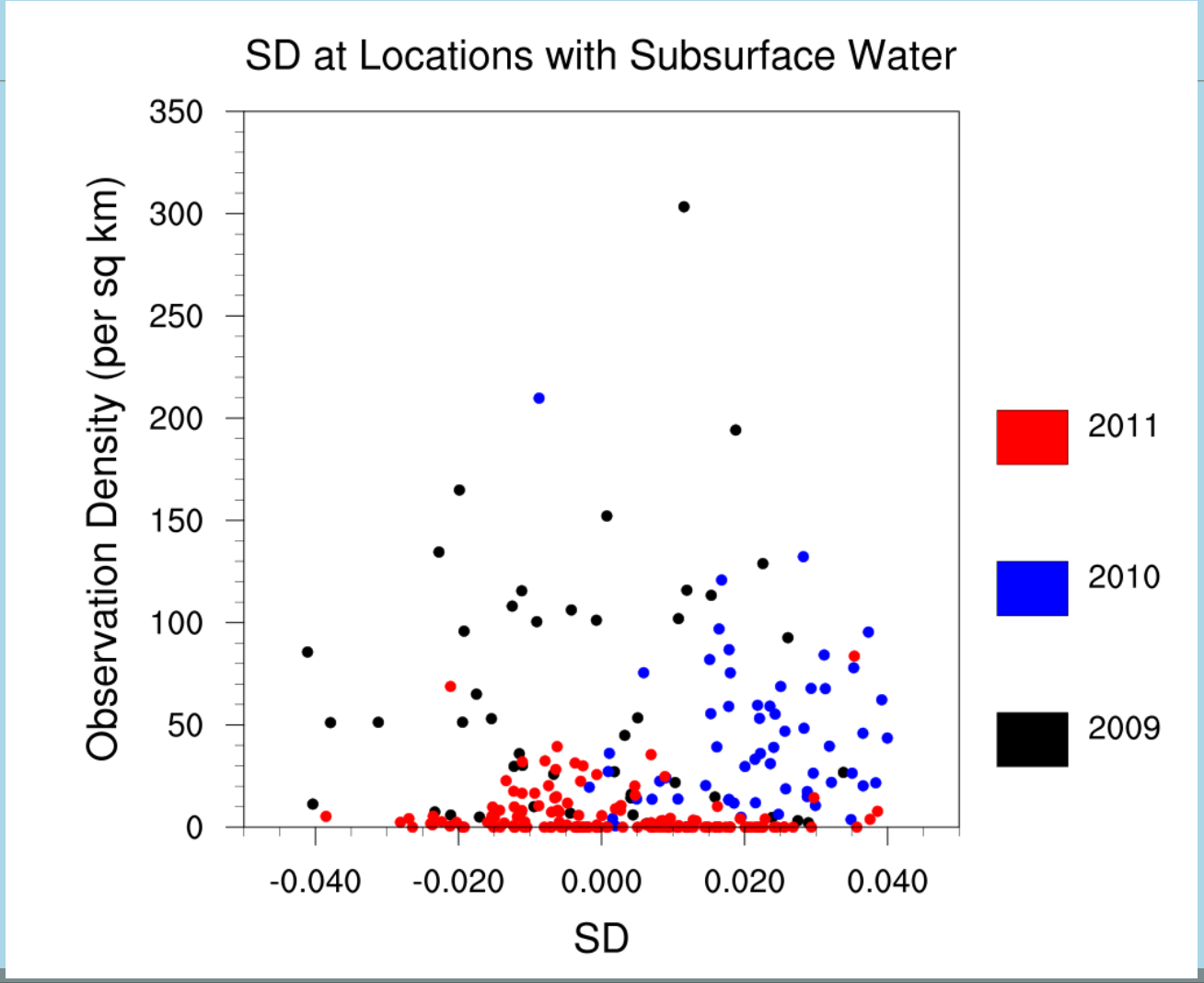
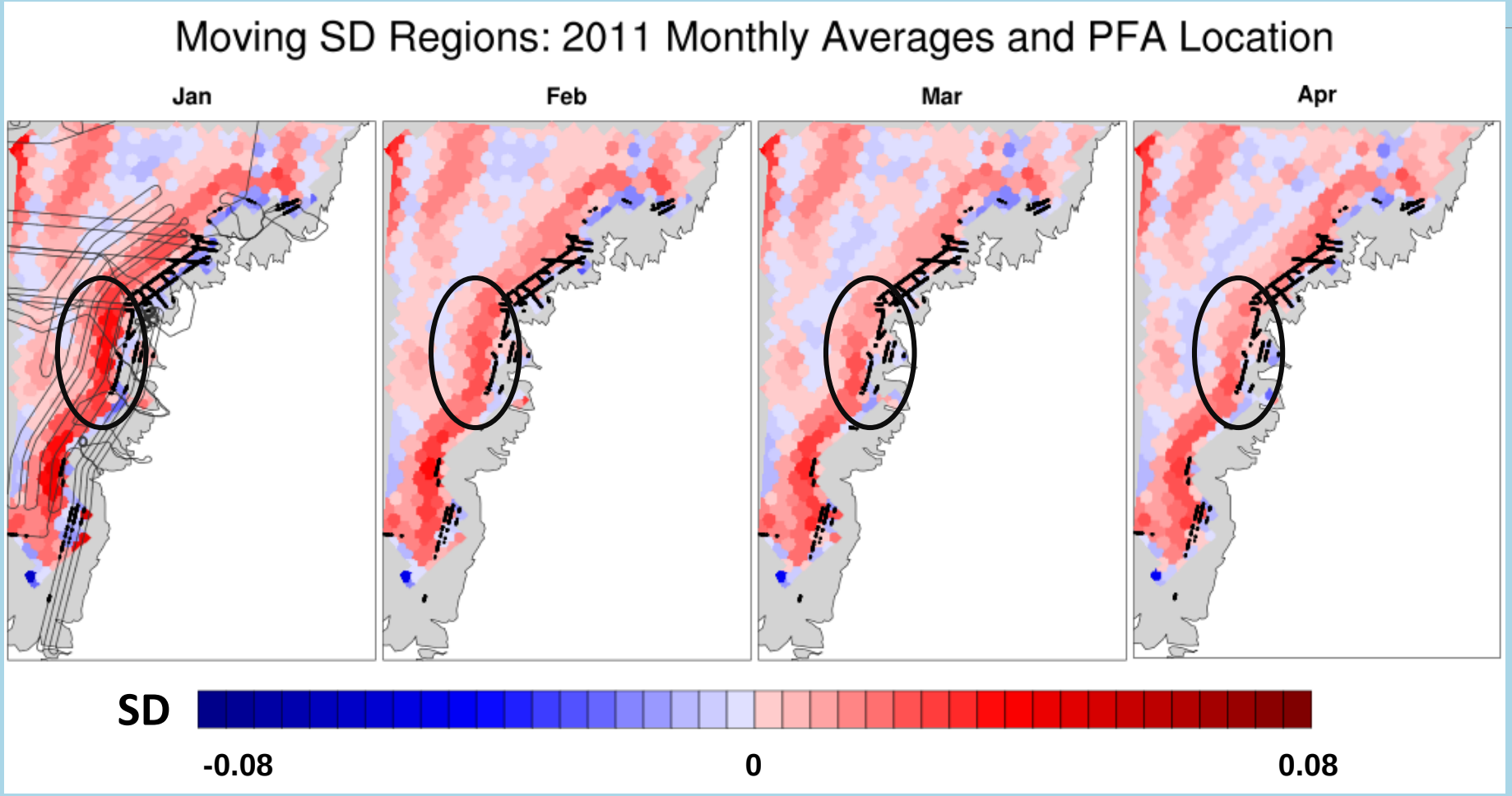
SD and Subsurface Water Density



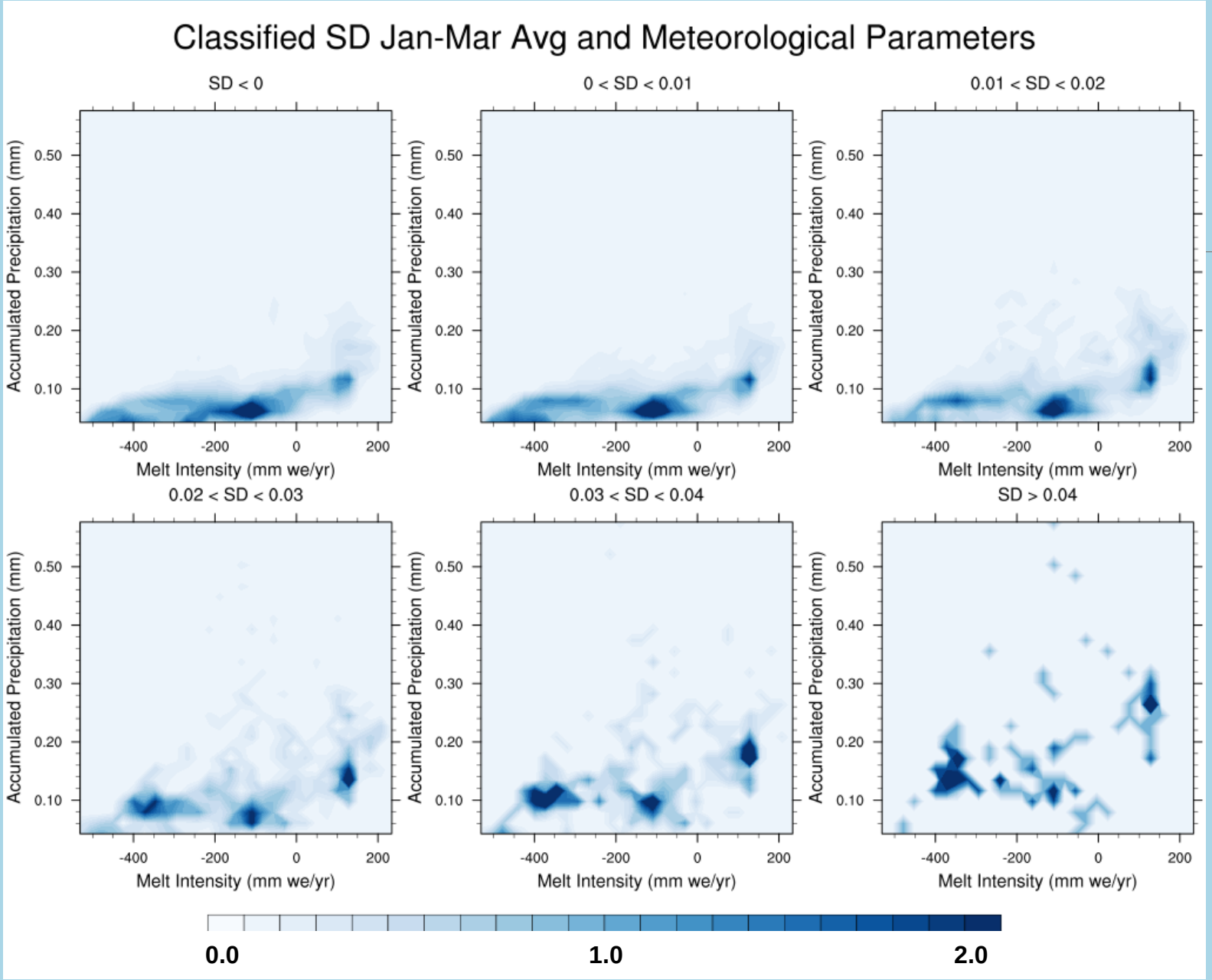
Data Source: Miège, pers. comm., Lampkin, pers. comm

Moving SD Regions



OIB Flight Path
Observed PFA

Data Source:
Miège, pers. comm.



Meteorological Drivers

Subsurface liquid water

- **High accumulation**
- **High melt intensity**
- **Forster et. al. (2014)**
- **Munneke (2014)**

Data Source: Bromwich et. al. (2012) Arctic System Reanalysis