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

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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 mi² (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
Buried Supraglacial Lakes

Melt Water → Supraglacial Lake → Drained Lake

Snow → Supraglacial Lake → Drained Lake

Ice → Supraglacial Lake → Drained Lake

Ice Sheet → Supraglacial Lake → Drained Lake

Drainage Path → Drained Lake
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

\[ SD = \frac{\nabla (6.9 \text{ GHz} \ Tb)}{\text{Max}(\nabla (6.9 \text{ GHz} \ Tb))} - \frac{\nabla (10.7 \text{ GHz} \ Tb)}{\text{Max}(\nabla (10.7 \text{ GHz} \ Tb))} \]

- Low frequencies
- Spatial derivative
- Frequency difference
- Scaling

AMSR-E/Aqua Daily EASE-GridBrightnessTemperatures, 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


SD and Subsurface Water Density

SD at Locations with Subsurface Water

Observation Density (per sq km)

SD

Data Source: Miège, pers. comm., Lampkin, pers. comm
Moving SD Regions

Moving SD Regions: 2011 Monthly Averages and PFA Location

SD

-0.08 0 0.08

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