The surface energy budget and the influence of clouds at Summit Greenland

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Nathaniel Miller – University of Colorado (ATOC, CIRES)
Matthew Shupe (CIRES, NOAA)
Christopher Cox (CIRES, NOAA)
David Noone (Oregon State University)
Konrad Steffen (Swiss Federal Research Institute, WSL)
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Greenland Ice Sheet

The GIS is over 3.2 km deep at Summit Station

http://www.nasa.gov/topics/earth/features/greenland-melt.html

Observed and simulated increases in melt extent impacts fresh water input to regional seas and has implications for global sea level rise.

Mernild et. al. 2011, J. Glac

For surface temperatures close to 0°C a small change in the surface energy budget can have substantial implications for the melt extent of the GIS.
SEB = \( SW_{\text{down}} - SW_{\text{up}} + LW_{\text{down}} - LW_{\text{up}} \)
\[ + H_{\text{sensible}} + H_{\text{latent}} + G_{\text{conductive}} \]

All components available for 1 year
July 2013 – June 2014

- **Broadband Radiation** - Swiss Federal Institute (ETH)
- **Sensible heat Flux** - Bulk Aerodynamic method (Persson et. al. 2002, JGR)
- **Latent Heat Flux** - Gradient 2-level method
- **Conductive Heat Flux** - Thermistor String

Define a positive flux as warming the surface
Monthly Mean SEB values

Percentage of all available 30 min data for a given month
Diurnal Cycle

Total Radiative Flux

Hour of the Day [UTC]

Month of Year

Solar Elevation Angle

Wm$^{-2}$
How do clouds effect the SEB?

Primarily through influencing the downwelling radiation.

Cloud radiative forcing (CRF) is an estimation of a cloud’s impact on the radiative flux at the surface.

\[ \text{CRF} = \text{Flux}_{\text{all-sky, measured}} - \text{Flux}_{\text{clear-sky, modeled}} \]

Best estimate atmospheric profiles

Rapid Radiative Transfer Model (RRTM)
January 2011 – October 2013  (Miller et. al. 2015, J. Climate)

- Clouds act to radiatively warm the surface throughout the year
  - due to high surface albedo throughout the year
Clouds are common at Summit. The annual average cloud fraction is 86%.
- Ice-clouds are important to CRF
- LW CRF magnitude corresponds to the presence of liquid-bearing clouds
Response to Radiative Warming

For a 10 Wm$^2$ increase in net radiation

~ 3 Wm$^2$ decrease in Sensible Heat Flux
Summary

• Clouds act to warm the surface of central Greenland
  – Presence of liquid-bearing clouds control the magnitude

• An increase in Net Radiation leads to:
  – Cooling response of the sensible heat flux
  – Cooling response of the conductive heat flux

• A net positive total cloud forcing warms the surface, propagating heat into the Greenland Ice Sheet
  – or this energy contributes to melting snow/ice
Thank you

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Response to Radiative Warming

For a 10 Wm\(^2\) increase in net radiation

\(~ 3 \text{ Wm}^2\) decrease in Sensible Heat Flux
The physical depth of ice clouds influences the magnitude of CRF.

Liquid-bearing clouds become opaque to LW radiation $\sim 30$ gm$^{-2}$. 
Liquid-bearing clouds change the boundary-layer structure.

Liquid-bearing clouds become opaque to LW radiation ~ 30 gm$^{-2}$

Surface-based inversion (SBI) intensity decreases in the presence of liquid-bearing clouds.