**Surface Temperature**

Temperature evolution from 1 July 2013 – 30 June 2014. Values between the solid horizontal lines indicate surface temperatures $T_{surf}$, the dashed (dashed-dotted) line at 2 m (10 m) level is NOAA/GMD measurements, and from 20 m to 5km above ground level (AGL) is derived from twice-daily soundings. The height scale AGL is logarithmic to emphasize the near-surface values where the atmospheric and GIS are physically coupled. Subsurface temps are on a linear scale.

**Surface Energy Budget**: In the absence of snow melt, the Surface Energy Budget (SEB) is composed of 4 components: Net Radiation (Q), Turbulent Heat Fluxes ($H_{sensible}$ and $H_{latent}$), and a Conductive Heat Flux (C).

$$Q = LW_{down} - LW_{up} + SW_{down} - SW_{up}$$

Surface temperatures are related to the upwelling longwave radiation via the snow emissivity ($\epsilon$): $LW_{up} = \epsilon \sigma T^4$

In order to investigate surface temperature biases in a reanalysis product or global climate model we must first understand the energy exchange processes occurring at the ice/ atmosphere interface. Specifically, how each SEB component responds to atmospheric forcing due to solar and/or cloud occurrence.

**MEASUREMENTS**

- ICECAPS project – Atmospheric state and cloud properties. (Shupe et. al. 2013, BAMS)
- Broadband Radiometers – Upwelling and Downwelling Shortwave and Longwave Radiation
- Bulk Aerodynamic Method – Turbulent sensible heat flux estimates based on differences between the temperatures and wind speeds at 2m and the surface. (Persson et. al. 2002, JGR)
- Gradient 2-level method – Turbulent latent heat flux estimates based upon the gradient of moisture and wind speed between 10m and the surface.
- Thermistor String – Subsurface temperature sensors used to calculate the conductive heat flux.

**RESPONSE TO CLOUD RADIATIVE FORCING**

Clouds and/or insolation radiatively warm the central GIS surface (Miller et. al. 2015, J. Climate) effectively increasing the radiative forcing terms ($LW_{down} + SW_{up}$). The surface energy budget responds to the increase in the radiative forcing by decreasing $H_{sensible}$, $H_{latent}$, and C, while increasing LW↑ (a proxy for surface temperature). Linear regression analysis estimates annual responses to radiative forcing (Figure above).

Due to seasonal changes in near-surface atmospheric stability, available moisture, snow density, and the subsurface temperature gradient the response of the non-radiative terms, and consequently LW↑, changes throughout the year (Figure below).

**A CASE STUDY**

The case study is for the time period: November 10 (12UTC) to November 11 (12 UTC), 2013, illustrates the contrast between a clear-sky scene, a scene containing a liquid-bearing cloud and a scene containing an ice-cloud.

The liquid-bearing cloud increases the downwelling longwave radiation drastically. Consequently, the near surface layer changes from stable to a more neutral situation, as indicated by the gradient richardson number.

The sensible heat flux decreases in the presence of the liquid-bearing cloud and the latent heat flux increases slightly as more mixing occurs during times of near neutral stability.

The conductive heat flux initially warms the surface during the clear-sky period, then has a cooling effect in the presence of the liquid-bearing cloud. Overall, the clouds act to warm the ice sheet.

**ANNUAL CYCLE OF SURFACE FLUX**

The monthly mean values of each of the SEB terms. A positive value represents a warming of the surface and a negative value is a cooling of the surface. The monthly residuals are shown in red at the top of the panel [W m⁻²].

**MONTHLY DIURNAL CYCLES**

Hourly mean values from July 2013 – June 2014. Black contour lines indicate the solar elevation angle. Units on the color bars are all in W m⁻².

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