Identifying CESM cloud and surface biases at Summit, Greenland

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CESM Ice Sheet Surface Biases Cross Working Group Session
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ICECAPS
Mobile Science Facility

Precip Sensor: Snowfall rate

Microwave Radiometers: PWV, LWP, T

Sodar: Boundary layer depth

Cloud Radar: Cloud macrophysics, phase, microphysics, dynamics

Ceilometer: Cloud base

Depolarization Lidars: Cloud base, phase, microphysics, orientation

Spectral Infrared Interferometer: Cloud phase, microphysics, LW radiation

Shupe et. al. BAMS 2013

Elevation 3255m
72°35’ N
38°25’ W
• Ground-based Radiation Measurements
  – Swiss Federal Institute, Zürich (ETH)
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)
Annual Cycle of Cloud Radiative Forcing

[Graph showing monthly variability of SW and LW CRF and the net effect across the year.]
Surface albedo important for CRF

Central Greenland is a unique Arctic location

Miller et. al. J. Climate [in press]
Dong et. al. 2010, JGR
Shupe and Intrieri 2004, J. of Climate
Kay and L’Ecuyer 2013, JGR
- High year round cloud fraction – 86%
- Cloud phase is important for magnitude of LW CRF
Lidar scattering ratio (SR) threshold of 5 = LWP sensitivity of 0.1 – 0.2 g/m²

Figure by Line Bourdages

(see poster [J. Kay] for more COSP simulator comparisons)
Cloud liquid water path at Summit, Greenland

![Graph showing cloud liquid water path from January to December with data points and box plots for observed and CESM-CAM5 cloud liquid water path.](image)

- **X-axis**: Months from January to December
- **Y-axis**: CESM-CAM5 cloud liquid water path (gm^-2)
- **Right Y-axis**: Observed cloud liquid water path (gm^-2)
CAM 5.4
+ changes to the aerosol mode widths =
  runs M1 and M2

• New version of cloud microphysics (MG2)
  – Prognostic precipitation, New activation
    (Gettelman and Morrison 2015, J. Climate)

• New mixed phase ice nucleation
  – Mixed phase a function of Aerosols
a) SW CRF

- Observations
- CESM – CAM5
- CESM-M1
- CESM-M2

b) LW CRF

c) Total CRF

<table>
<thead>
<tr>
<th></th>
<th>Monthly CRF [W m⁻²]</th>
<th>Observations</th>
<th>CESM – CAM5</th>
<th>CESM-M1</th>
<th>CESM-M2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>CRF</td>
<td>0.80</td>
<td>0.85</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>Annual CRF</td>
<td>30 Wm⁻²</td>
<td>12 Wm⁻²</td>
<td>29 Wm⁻²</td>
<td>34 Wm⁻²</td>
<td>8 Wm⁻²</td>
</tr>
<tr>
<td>Summer CRF</td>
<td>34 Wm⁻²</td>
<td>8 Wm⁻²</td>
<td>24 Wm⁻²</td>
<td></td>
<td></td>
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</tbody>
</table>
Flux $[\text{Wm}^{-2}]$

- **a) SW down**
- **b) LW down**

Observations

- CESM-M1
- CESM-M2

Month of Year

Albedo

- 0.80
- 0.85
- 0.90
- 0.95
- 1.00
Observations
CESM-M1

Albedo

Month
Cloud Influence on other surface energy budget terms

\[ SEB = SW_{\text{net}} + LW_{\text{net}} + H_{\text{sensible}} + H_{\text{latent}} + G_{\text{storage}} - \text{Melt} \]

- **Turbulent Fluxes (H)**
  - Sensible and Latent Heat Fluxes
    - Eddy Covariance method
    - Bulk Aerodynamic method

- **Heat Storage (G)**
  - Thermistor String
Thank you

• This research is supported by the National Science Foundation under grants PLR1303879 and PLR1314156.

• Thanks to the Swiss Federal Institute for providing the ETH broadband radiometer measurements.

• Additional broadband radiation measurements, ozonesonde soundings, CO₂ measurements, and near-surface meteorological tower data are provided by the National Oceanic and Atmospheric Administration’s Global Monitoring Division.

• Thanks to Polar Field Services and the various science technicians for their excellent support of the field experiments at Summit Station.
Summer Daily Maximum Temperatures

- Summer maximum temperatures are critical to represent because they have the greatest impact on melt extent.

- In order to accurately represent surface temperatures → need to capture the frequency of occurrence and phase of clouds above the GIS.

Daily Max 2m temp [C] 2008-2014 (Jun-Aug)
Other factors effect upwelling radiation:

- Albedo 2-5% too low
- Temperature inversion strength too weak?
For elevated sun angles (low SZA) the optimal LWP = 10-40 gm$^{-2}$ for maximum surface warming.
Clear-Sky Estimate via Rapid radiative transfer model (RRTM)

Inputs:

- Merged temperature profiles
  - ECMWF, twice daily radiosondes, MWR derived boundary layer profiles
- Merged moisture profiles
  - ECMWF, twice daily radiosondes, scaled by MWR derived PWV
- Snow emissivity = 0.985
- Clear-sky snow albedo →
- CO$_2$ mixing ratio
- Standard subarctic winter
  - N$_2$O, CO, CH$_4$ and O$_2$
- Ozone sonde profile
- Surface temperature
  - derived from LW measurements

\[
y = 0.74715 + 0.00145x
\]
Clear-Sky Residuals

a) LW↑
clear-sky & no rime

b) LW↓

c) SW↑
clear-sky SZA < 90 & no rime

d) SW↓
The physical depth of an ice-cloud influences the optical depth.

Linear relationship between cloud thickness and LW CRF.
The shift from cloud warming to cooling occurs at about 80°, which may explain the statement made by Minnett (1999) that the cloud SW cooling effect decreases as the sun rises in the sky. At the highest cloud heights, the LWP crossover point also increases to values that are unreasonably high. These decreases in turn cause the LWP crossover point to become insensitive to sun angle. For SHEBA, the crossover point becomes insensitive to sun angle as well. For Arctic clouds (i.e., typical clouds will have a warm-surface cloud cooling effect). Interestingly, at low cloud temperatures or higher optical depth, the cloud SW cooling effect may increase to levels that are unreasonably high. The LWP crossover value increases as both the cloud SW cooling effect and the LWP increase. At some LWP, the cloud SW cooling effect surpasses the LW warming effect for a given combination of parameters because it influences both of the competing effects. At some LWP, the cloud SW cooling effect becomes dominant over the LW warming effect as a function of solar zenith angle and CF. Thus, as the surface bed decreases, the solar zenith angle rapidly decreases. According to Fig. 7, this is true for the cases for Minnett's observations in an ocean environment with broken sea ice. As the sun becomes higher in the sky, and/or the clouds become more sensitive to cloud microphysical composition, the cloud SW cooling effect becomes dominant over the LW warming effect for at least one-half of the day for Greenland. If the transition from cloud warming to cooling occurred at 80°, which was likely for Arctic summer northeast values reported here would have been, the case for Minnett's observations in an ocean environment with broken sea ice. As the average CF increases, the cross-over of the LWP directly is difficult. Equations (5) and Fig. 6b suggest that this sensitivity is insensitive to surface cloud cooling effect becomes dominant over the LW warming effect.

Fig. 7. Contours of the cloud LWP value at which point the SW surface cloud cooling effect becomes dominant over the LW warming effect as a function of $\theta$ and $\alpha_s$. The following parameters are assumed: $T_c = -10^\circ C$, $z_c = 1$ km, $t_{al} = 0.9$, and $t_{as} = 0.75$. 

Contour levels are LWP in g m$^{-2}$.
Greenland Ice Sheet

The GIS is over 3.2 km deep at Summit Station.

Observed increase in GIS melt rate and extent (Mernild et. al. 2011, J. Glac.) has global and regional impacts.

For surface temperatures close to 273K a small change in the surface energy budget can have substantial implications for the surface mass balance.

CESM-LE, J. Kay