Surface radiation budget and cloud radiative forcing from pan-Arctic Baseline Surface Radiation Network (BSRN) stations

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The Arctic looks like this...

- Summit, Greenland
- Alert, Canada
- Tiksi, Russia
- Barrow, Alaska
- Eureka, Canada
- Coastal Greenland

(photo V. Walden)
(photo R. Albee)
(photo V. Kustov)
(photo NOAA-PSD)
(photo R. Albee)
(photo V. Kustov)
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http://www.esrl.noaa.gov/psd/iasoa/
Cloud Radiative Forcing at the surface
Quantifying the perturbation to the net surface radiation budget caused by clouds

Cloud Radiative Effect Downwelling only

Clear Sky

Cloudy Sky

Shortwave (Solar)
Longwave (IR)
Data Record
(Need SW Total, diffuse and direct components)
Net All Wave Radiation

Hourly avgs, 21-day smoothing
Shading +/- 1 StDev

Winter exhibits cooling, Summer warming.
In general, duration of warming dependent on latitude
Radiative Flux Analysis (RadFlux)

- **RadFlux methodology**
  - Time series analyses of surface broadband radiation and meteorological measurements (T/RH)
    - Need at least 5-minute resolution
  - Detect clear-sky (cloud free) periods
  - Use detected clear sky data to fit functions
  - Interpolate coefficients to produce continuous estimate of clear-sky irradiances
  - Use clear-sky and measured irradiances to infer cloud forcing and cloud properties
RadFlux Outputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meas./Retr.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downwelling Total SW</td>
<td>Measured</td>
<td>Unshaded Pyranometer</td>
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<tr>
<td>Clear-sky Total SW</td>
<td>Retrieved</td>
<td>Long and Ackerman, 2000, JGR</td>
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<tr>
<td>Diffuse SW</td>
<td>Measured</td>
<td>Shaded Pyranometer</td>
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<tr>
<td>Clear-sky diffuse SW</td>
<td>Retrieved</td>
<td>Long and Ackerman, 2000, JGR</td>
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<tr>
<td>Direct SW</td>
<td>Measured</td>
<td>Sun Tracking Perheliometer</td>
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<tr>
<td>Clear-sky direct SW</td>
<td>Retrieved</td>
<td>Long and Ackerman, 2000, JGR</td>
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<tr>
<td>Upwelling SW</td>
<td>Measured</td>
<td>Pyranometer</td>
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<tr>
<td>Clear-sky Upwelling SW</td>
<td>Retrieved</td>
<td>Long, 2005, ARM</td>
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<td>Downwelling LW</td>
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<td>Pyrgeometer</td>
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<tr>
<td>Upwelling LW</td>
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<td>Clear-sky Upwelling LW</td>
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<td>Long, 2005, ARM</td>
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<tr>
<td>Clear-sky periods</td>
<td>Retrieved</td>
<td>Long and Ackerman, 2000, JGR [daylight only]</td>
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<tr>
<td>Air Temperature</td>
<td>Measured</td>
<td>Temperature sensor</td>
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<tr>
<td>Relative Humidity</td>
<td>Measured</td>
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<tr>
<td>Total Sky Cover</td>
<td>Retrieved</td>
<td>Long et al., 2006, JGR [daylight only]</td>
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<tr>
<td>Cloud Vis optical depth</td>
<td>Retrieved</td>
<td>Barnard and Long, 2004, JAM; Barnard et al., 2008, TOASJ [Skycover&gt;90% only]</td>
</tr>
<tr>
<td>Cloud SW transmissivity</td>
<td>Retrieved</td>
<td>Long and Ackerman, 2000, JGR [daylight only]</td>
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<td>sky brightness temperature</td>
<td>Retrieved</td>
<td>Long, 2004, ARM</td>
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<tr>
<td>cloud radiating temperature</td>
<td>Retrieved</td>
<td>Long, 2004, ARM [LW Scv&gt;50% only]</td>
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</table>

Complete Net surface radiative cloud forcing and cloud macrophysical properties without using any measurements typically used as input for model calculations.
Cloud Radiative Forcing (CRF) Seasonal Cycle  
[21-day smoothed hourly averages]

Winter CRF similar at all sites high albedo, little SW CRF

Summit summer snow covered thus
cooling compared to clear sky

CRF initially increases in spring with increase in cloud amounts and air temps while little SW yet and high albedo.
Cloud Radiative Forcing (CRF) Seasonal Cycle

[21-day smoothed hourly averages]

Warming compared to clear sky
Cooling compared to clear sky

Factors determining when CRF transits between cooling and warming include latitude, surface albedo, cloud amounts and type.

CRF rapidly decreases to negative once snow melts, surface albedo decreases, and the SW CRF dominates.

Summit (Miller et al. 2015)
Tiksi
Barrow
Ny-Ålesund
Alert
Notably, the LW CRE is pretty similar between the sites. Greater in the warmer months.

But while the average LW CRE is similar, the combination of cloud properties producing the CREs differ.
Cloud Fraction

- Cloud amounts and OVC occurrence greater at Barrow than Alert.
- CRE of each cloud likely greater at Alert due to drier atmosphere (less greenhouse effect at given temperature).
- Barrow, Tiksi, and Eureka LW CRE mode centered on ~60 Wm$^{-2}$.
- Alert and Summit centered on 80 Wm$^{-2}$
Conclusions

• Properties of the environment that are not cloud properties (e.g., surface cover) are among the largest levers in variability in CRF (and sometimes magnitude too).

• CRE\textsubscript{sw} differs between sites due to differences in cloud fraction and available sunlight. Conversely, average CRE\textsubscript{lw} is similar between the sites, but this average comes from different combinations of cloud properties. Analyzing components of SEB and understanding how balance is reached through compensation is a priority.

• Interannual variability in CRF annual cycle is nearly as large at each site as differences between sites – we hypothesize that intra-site variability might be as large as inter-site variability (with notable exceptions, e.g., Summit in all months and Aug./Sept. at all sites when cloud fractions differ between sites the most).

Given initial analyses,

• What improvements to the arctic surface radiation network?
  – Multiple upwelling radiation measurements at each site to complement 1 downwelling set - site selection in collaboration with studies/IASOA working groups
  – Need to make intersite comparisons more robust with comparability metrics – “traveling comparison standard system”

• Next steps
  – Already analyzing what CRF observations at Barrow can tell us about interannual variability in sea ice.
  – Assessing capabilities of long-term Arctic radiation measurements for trend detection.
  – Understanding the influence of atmospheric dynamics and low-frequency variability in modulating CRF.

Thanks!
References


All data RFA, except unfrozen soil water volume fraction (WVF)

Spring LW

Snow-free Ground

Zero-curtain (~ 315 W m\(^{-2}\))
(Outcalt et al. 1990)

Spring Melt Period

Snow-covered Ground

Barrow (1993-2014)

Spring LW\(_{up}\) “Zero Curtain”
Ny-Ålesund (1993-2013)

Alert (2004-2013)

Tiksi (2012-2014)

Continued...

Ny-Ålesund (1993-2013)
Monthly Mean Cloud Radiative Forcing (CRF)

- Ice-covered
- Ice-free

Legend:
- Summit (2011-2013, Miller et al. [2015])
- Arctic Ocean (2006-2011, Kay & L'Ecuyer [2013])
- Barrow (1993-2014, RFA)
- Ny-Ålesund (1993-2013, RFA)
- Tiksi (2012-2014, RFA)
- Alert (2004-2013, RFA)