Cloud radiative forcing from pan-Arctic BSRN stations:
Applications for climate monitoring and sea ice forecasting

Christopher J. Cox¹,², Charles N. Long¹,², Taneil Uttal², Sandy Starkweather¹,², Sara Crepinsek¹,², Marion Maturilli³, Allison McComiskey², Nathaniel B. Miller¹,², Elena Konopleva-Akish⁴, Vasily Kustov⁵, Matthew D. Shupe¹,², Konrad Steffen⁶, Diane Stanitski², Robert Stone⁷, Von P. Walden⁸

¹ Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO
² NOAA Earth System Research Laboratory (ESRL) Boulder, CO
³ Alfred Wegener Institute (AWI) Hemholtz Centre for Polar and Marine Research, Postdam
⁴ Science and Technology Corporation (STC), Boulder, CO
⁵ Arctic and Antarctic Research Institute (AARI), St. Petersburg
⁶ Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürich
⁷ Cooperative Institute for Research in Environmental Sciences (CIRES), retired
⁸ Washington State University (WSU), Pullman, WA

christopher.j.cox@noaa.gov

14th BSRN Workshop, Canberra, Australia, 2016
The Arctic looks like this...

Summit, Greenland

Eureka, Canada

Alert, Canada

Tiksi, Russia

Barrow, Alaska

coastal Greenland

Alert, Canada

SHEBA

Tiksi, Russia

Barrow, Alaska

(photo V. Walden)

(photo V. Albee)

(photo V. Kustov)

(photo NOAA-PSD)

(photo V. Kustov)
International Arctic Systems for Observing the Atmosphere (IASOA)

BSRN status

BSRN
Closed (meas. continue)
Candidate

Also, DOE-ARM obs. at Oliktok and Barrow

http://www.esrl.noaa.gov/psd/iasoa/

Uttal et al. in press BAMS doi: 10.1175/BAMS-D-14-00145.1
IASOA Radiation Working Group (RWG)

Sandy Starkweather (CIRES), Taneil Uttal (NOAA), Matthew Shupe (CIRES), Diane Stanitski (NOAA), Thomas Haiden (ECMWF), Von Walden (WSU), Allison McComiskey (NOAA), Rigel Kivi (FMI), Marion Maturilli (AWI), Elena Konopleva-Akish (STC), Sara Crepinsek (CIRES), Joseph Sedlar (Stockholm), Amy Solomon (CIRES), Janet Intrieri (NOAA), Ola Persson (NOAA), Robert Stone (NOAA, retired), Jeff Key (NOAA), Charles Long (CIRES), Christopher Cox (CIRES), Vasily Kustov (AARI), Hironori Yabuki (JAMSTEC), Yoshihiro Iijima (JAMSTEC), Nathaniel Miller (CIRES)
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)

**Measured Variables**

\[ \text{LW} \downarrow \quad \text{LW} \uparrow \quad \text{SW}_{\text{GLOB}} \downarrow \quad \text{SW}_{\text{DIFF}} \downarrow \quad \text{SW}_{\text{DIR}} \downarrow \quad \text{SW} \uparrow \]

Relative Humidity, Temperature

**Quality Control**

Remove suspect data, IR loss correction

*Long and Shi 2008*

**Calculated Variables**

Clear-sky SW & LW, total sky cover, LW effective sky cover, cloud optical depth, cloud transmissivity, sky brightness temperature, cloud radiative temperature, LW clear sky emissivity

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
Cloud Radiative Forcing (CRF) Seasonal Cycle
[21-day smoothed hourly averages]

Warming compared to clear sky
Cooling compared to clear sky

CRF [Wm⁻²]

Summit (Miller et al. 2015)
Tiksi
Barrow
Ny-Ålesund
Alert
Cloud Radiative Forcing (CRF) Seasonal Cycle
[21-day smoothed hourly averages]

- Warming compared to clear sky
- Cooling compared to clear sky

Winter CRF similar at all sites

CRF [Wm$^{-2}$]

Summit (Miller et al. 2015)
Tiksi
Barrow
Ny-Ålesund
Alert

DOY
Cloud Radiative Forcing (CRF) Seasonal Cycle
[21-day smoothed hourly averages]

- Warming compared to clear sky
- Cooling compared to clear sky

CRF initially increases in spring with increase in cloud amounts and SZA: still high albedo.
Cloud Radiative Forcing (CRF) Seasonal Cycle
[21-day smoothed hourly averages]

Warming compared to clear sky
Cooling compared to clear sky

Summit summer snow covered: high albedo, dominated by LW warming (Miller et al. 2015)

SW cooling at other sites during snow-free season.
Distributions of cloud radiative effect are different at some sites because of different T/PWV climates. CRE in far-IR and atmospheric window compensate at constant RH.

The longwave analogue to the affects of albedo on SW CRF...
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, T and q.

(Miller et al. 2015)
Cloud Radiative Forcing (CRF) Seasonal Cycle

[21-day smoothed hourly averages]

Warming compared to clear sky
Cooling compared to clear sky

Intersite differences large compared to interannual variability in autumn.
Longwave Cloud Radiative Effect (LW CRE)

LW CRE is pretty similar between the sites.

LW CRE is pretty similar between the sites.
Cloud properties vary between sites e.g.,
• Cloud occurrence greater at Barrow than other sites in autumn.
Applications – seasonal sea ice forecasting

- Autumn sea ice conditions are thought to be affected by radiative conditioning of the ice in spring.

- Springtime downwelling all-wave at Barrow, Alaska, well-correlated with autumn sea ice extent.
The observed correlation is driven in part by clouds.

Increased CRF during spring supported by positive cloud cover anomaly early followed by negative anomaly late.

The subtleties of the CRF transition in spring appear to be important!

Cox et al. *submitted* J. Climate, 2016
Conclusions

- Working to leverage Arctic BSRN observations collectively to advance process understanding.

- Properties of the environment that are not cloud properties (e.g., surface cover, T,q profiles) are among the largest sources of variability in CRF.

- Interannual variability in CRF is similar to differences between sites except in autumn. *Intra-site characterization is needed.*

- On average, CRE_{LW} is similar between the sites, but this is from different combinations of cloud properties and interaction with T/q. Analyzing components of SEB and understanding how balance is reached through compensation is a priority.

- BSRN observations may be useful in advancing seasonal-scale sea ice forecasting. Working on a multi-site empirical-statistical methodology.
Thanks!

References:


Albedo

Surface Albedo

Julian Day

Alert
Ny-Ålesund
Barrow
Tiksi
Snow-free Ground

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

Spring Melt Period

Snow-covered Ground

Spring LW$_{up}$ “Zero Curtain”
Monthly Mean Cloud Radiative Forcing (CRF)

- Greenland icy year round
- Brief ice-free Period at Alert

Ice-covered

Ice-free

CRF [W m$^{-2}$]

Month

J F M A M J J A S O N D