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

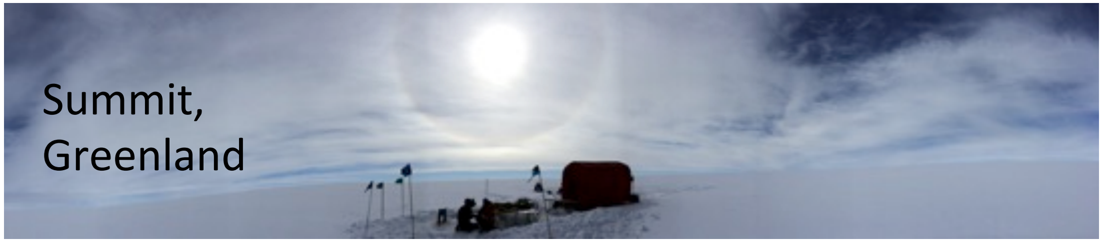
Charles N. Long[1,2], Christopher J. Cox[1,2], IASOA Radiation Working Group

[1] Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO

[2] NOAA Earth System Research Laboratory (ESRL) Boulder, CO

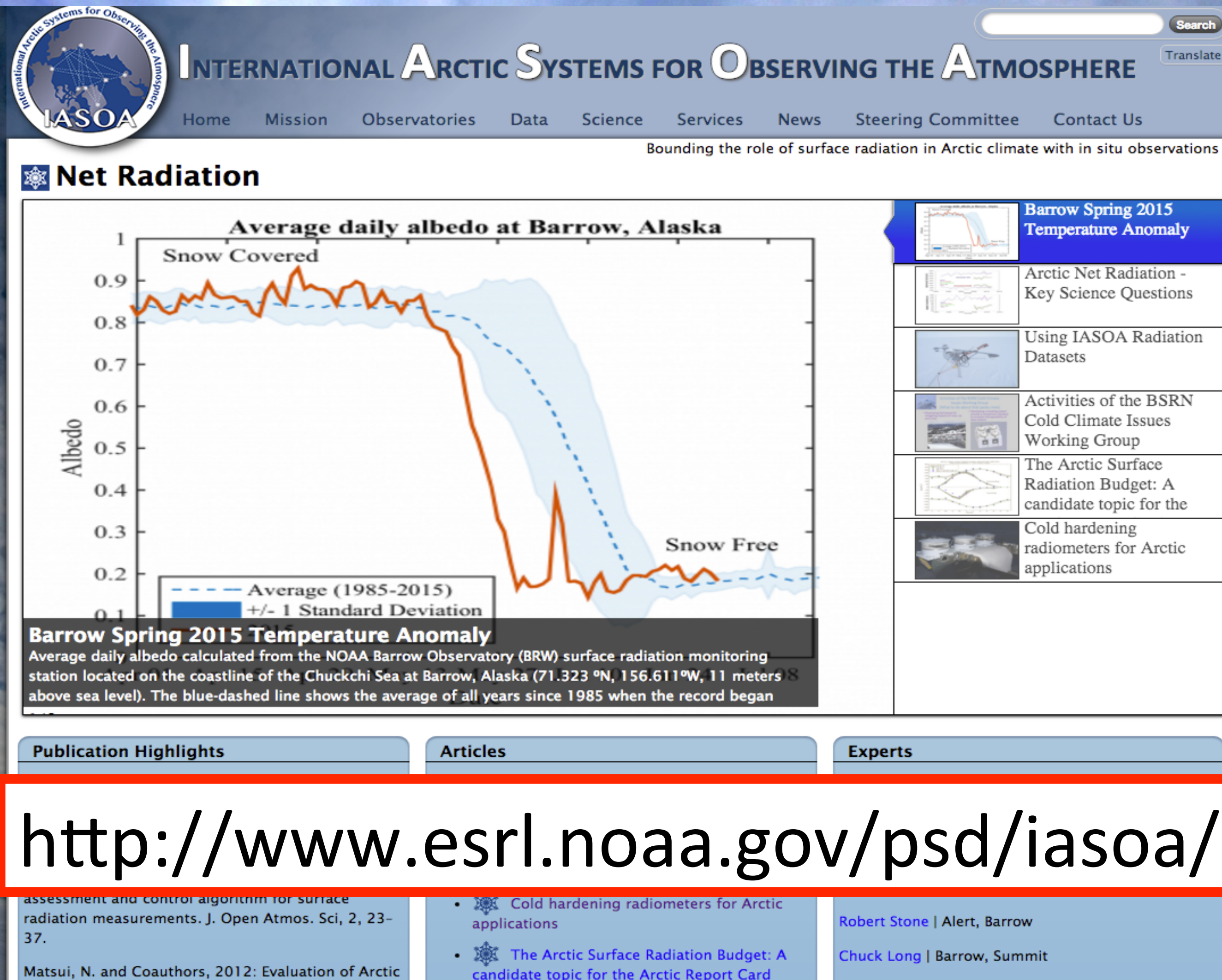
AOOSM – Seattle 2015

The Arctic looks like this…



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), Yoshihiroo Iijima (JAMSTEC), Nathaniel Miller (CIRES)



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

International Arctic Systems for Observing the Atmosphere

IASOA

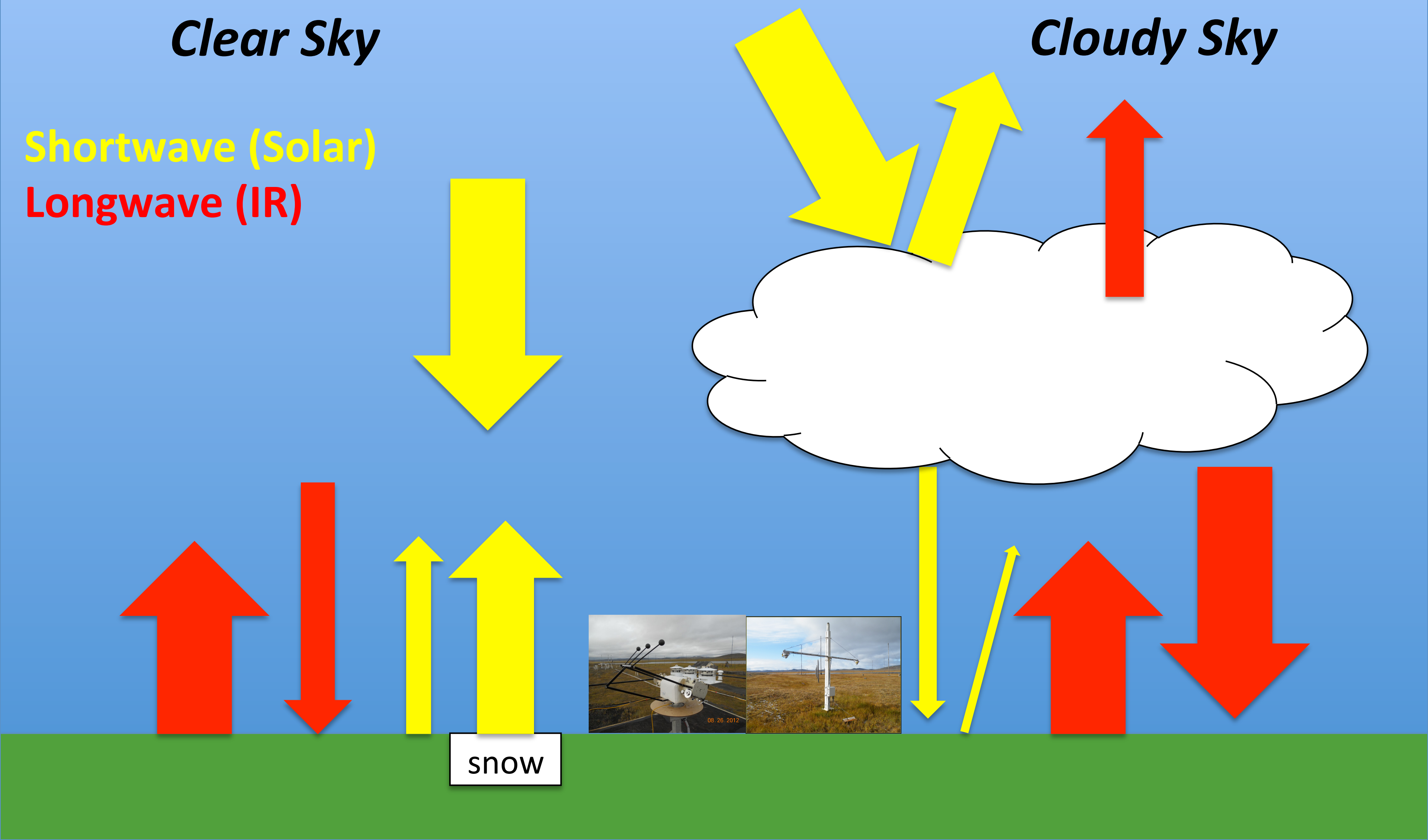
This analysis

Forthcoming

Cloud Radiative Forcing at the surface

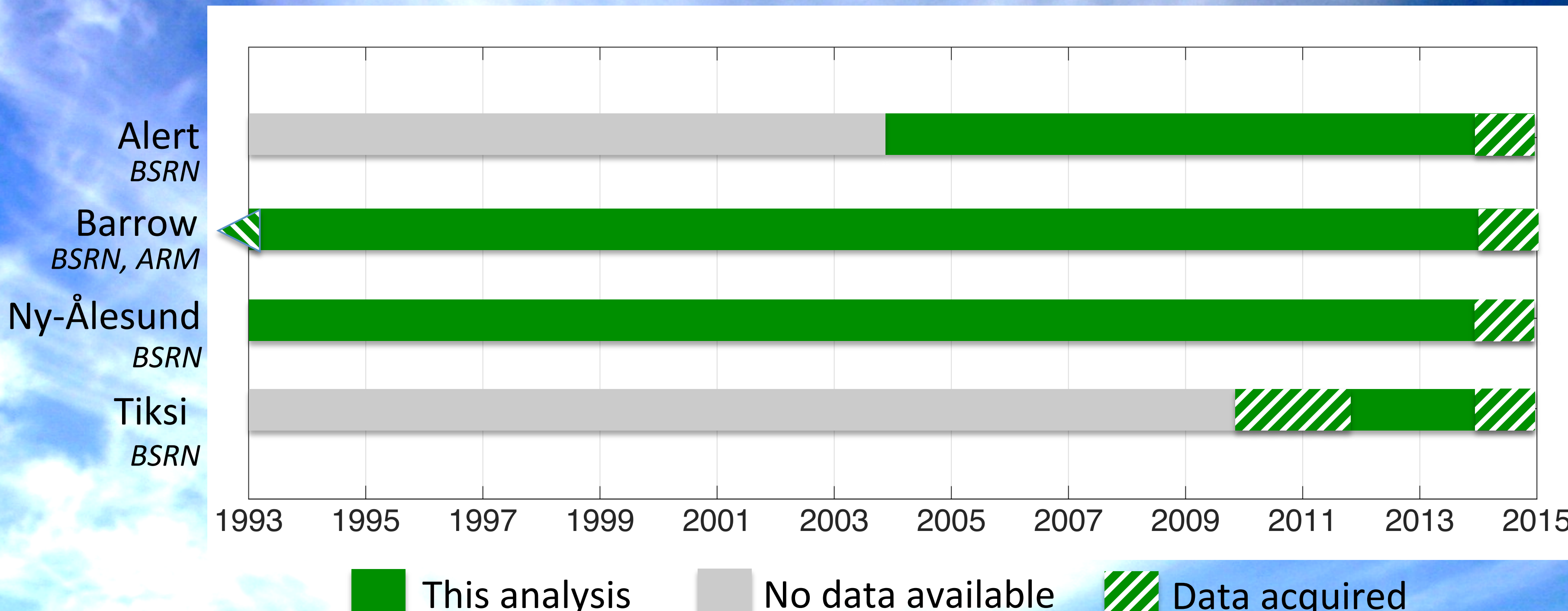
Quantifying the perturbation to the net surface radiation budget caused by clouds

Cloud Radiative Effect Downwelling only

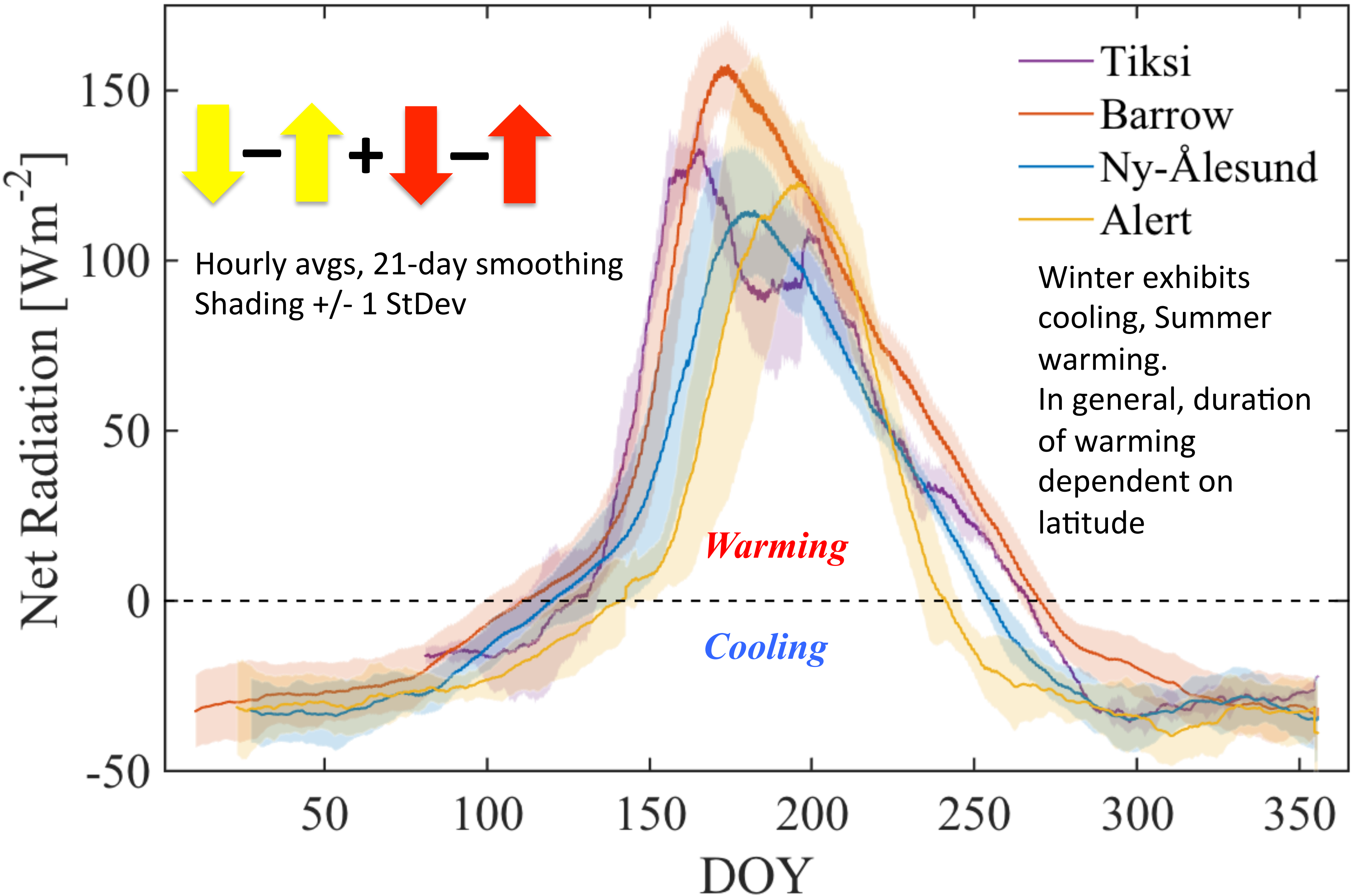


Data Record

(Need SW Total, diffuse and direct components)



Net All Wave Radiation



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

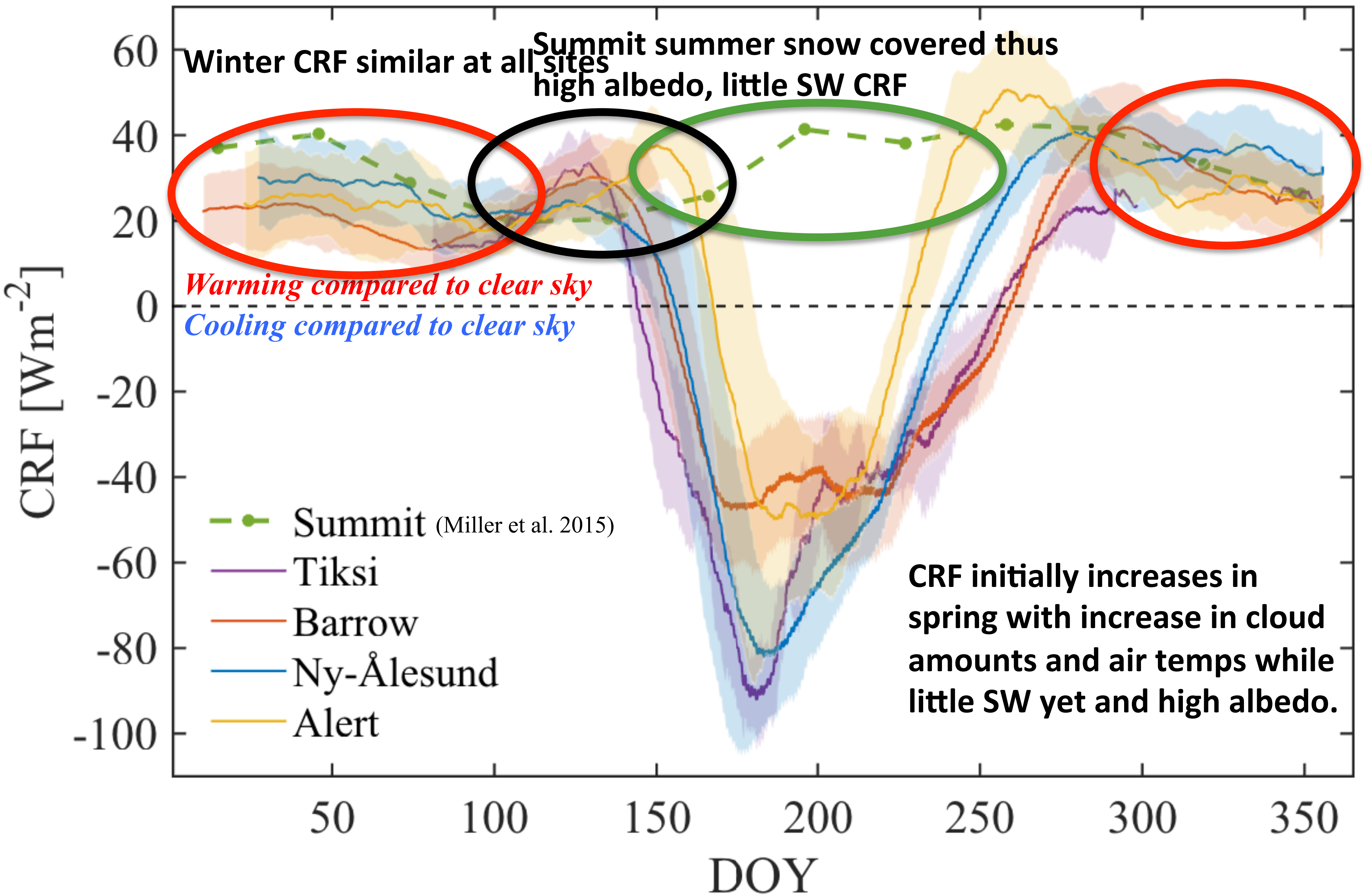
RadFlux Outputs

Parameter	Meas./Retr.	Comments
Downwelling Total SW	Measured	Unshaded Pyranometer
Clear-sky Total SW	Retrieved	Long and Ackerman, 2000, JGR
Diffuse SW	Measured	Shaded Pyranometer
Clear-sky diffuse SW	Retrieved	Long and Ackerman, 2000, JGR
Direct SW	Measured	Sun Tracking Perheliometer
Clear-sky direct SW	Retrieved	Long and Ackerman, 2000, JGR
Upwelling SW	Measured	Pyranometer
Clear-sky Upwelling SW	Retrieved	Long, 2005, ARM
Downwelling LW	Measured	Pyrgeometer
Clear-sky Downwelling LW	Retrieved	Long and Turner, 2008, JGR
Upwelling LW	Measured	Pyrgeometer
Clear-sky Upwelling LW	Retrieved	Long, 2005, ARM
Clear-sky periods	Retrieved	Long and Ackerman, 2000, JGR [daylight only]
Air Temperature	Measured	Temperature sensor
Relative Humidity	Measured	Humidity sensor
Total Sky Cover	Retrieved	Long et al., 2006, JGR [daylight only]
LW Effective Sky Cover	Retrieved	Long and Turner, 2008, JGR; Durr and Philipona, 2004, JGR [low/mid cloud only]
Cloud Vis optical depth	Retrieved	Barnard and Long, 2004, JAM; Barnard et al., 2008, TOASJ [Skycover>90% only]
Cloud SW transmissivity	Retrieved	Long and Ackerman, 2000, JGR [daylight only]
sky brightness temperature	Retrieved	Long, 2004, ARM
cloud radiating temperature	Retrieved	Long, 2004, ARM [LW Scv>50% only]
clear-sky LW emissivity	Retrieved	Marty and Philipona, 2000, GRL; Long, 2004, ARM

Complete Net surface radiative cloud forcing and cloud macrophysical properties without using any measurements typically used as input for model calculations

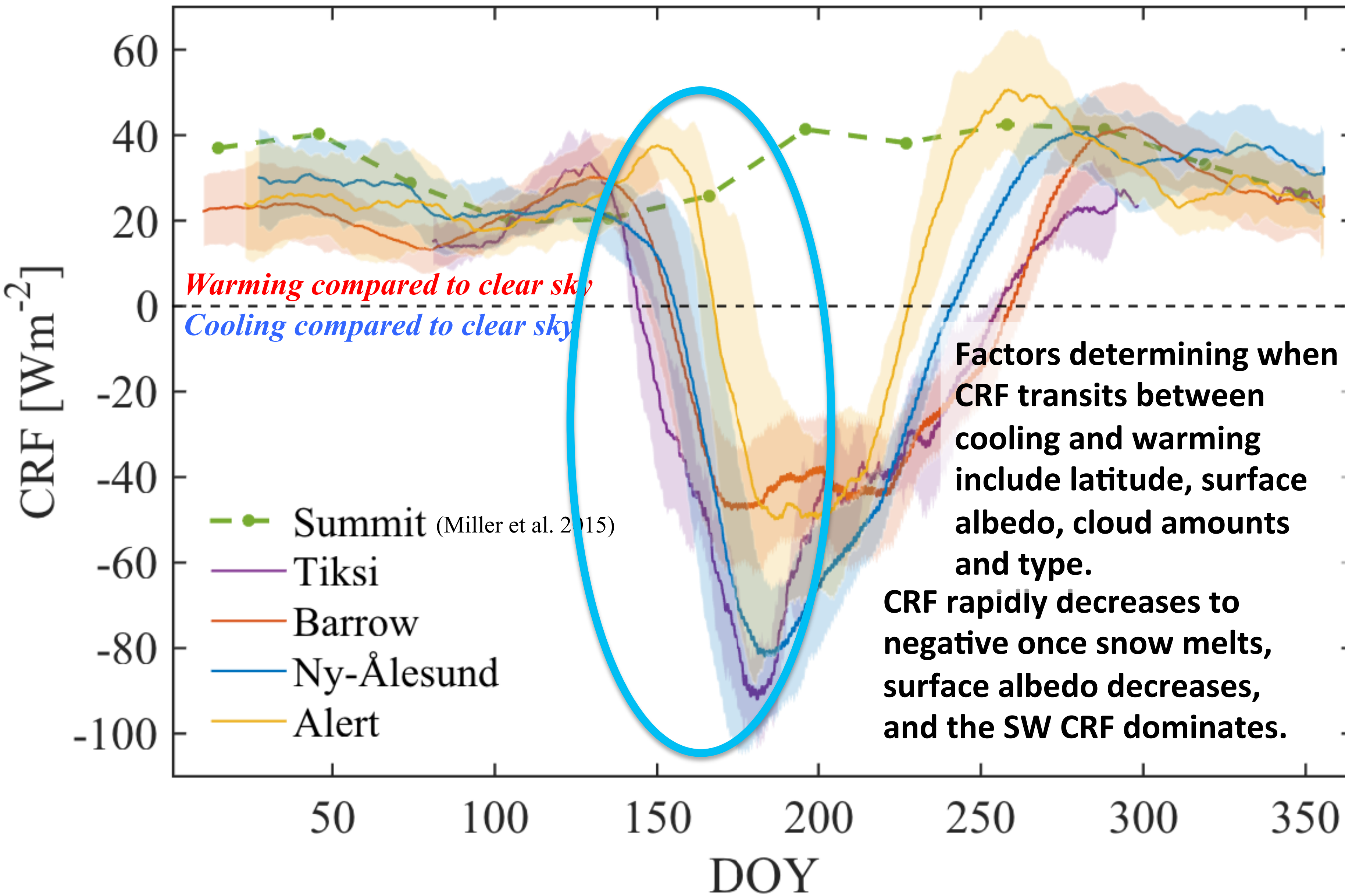
Cloud Radiative Forcing (CRF) Seasonal Cycle

[21-day smoothed hourly averages]



Cloud Radiative Forcing (CRF) Seasonal Cycle

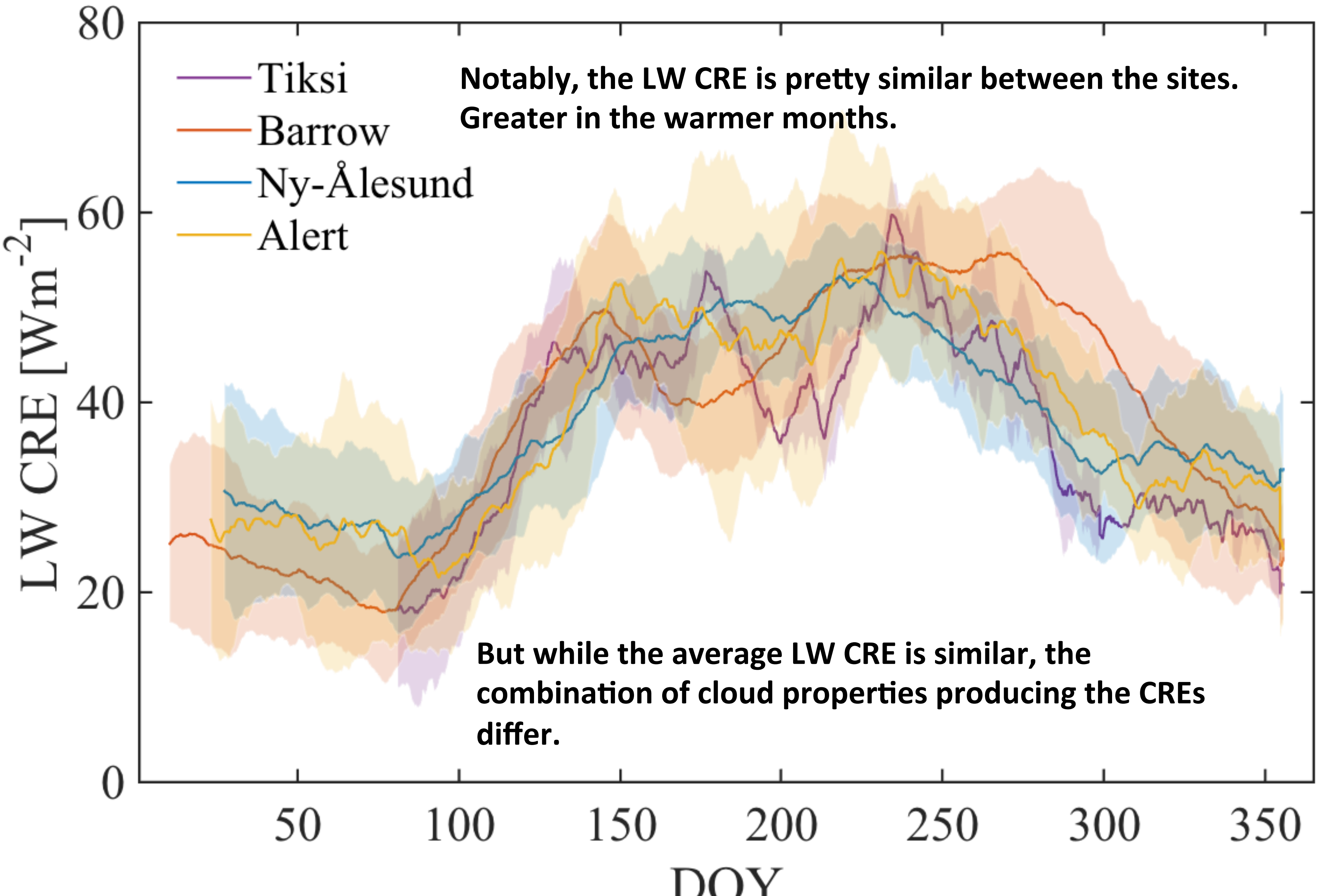
[21-day smoothed hourly averages]

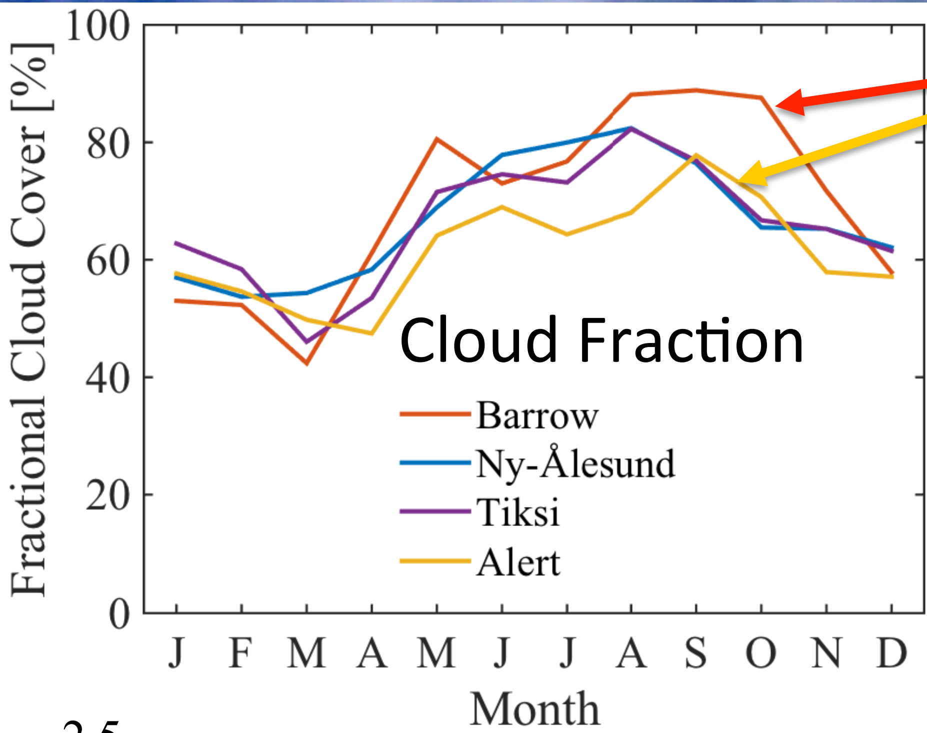


Factors determining when CRF transits between cooling and warming include latitude, surface albedo, cloud amounts and type.

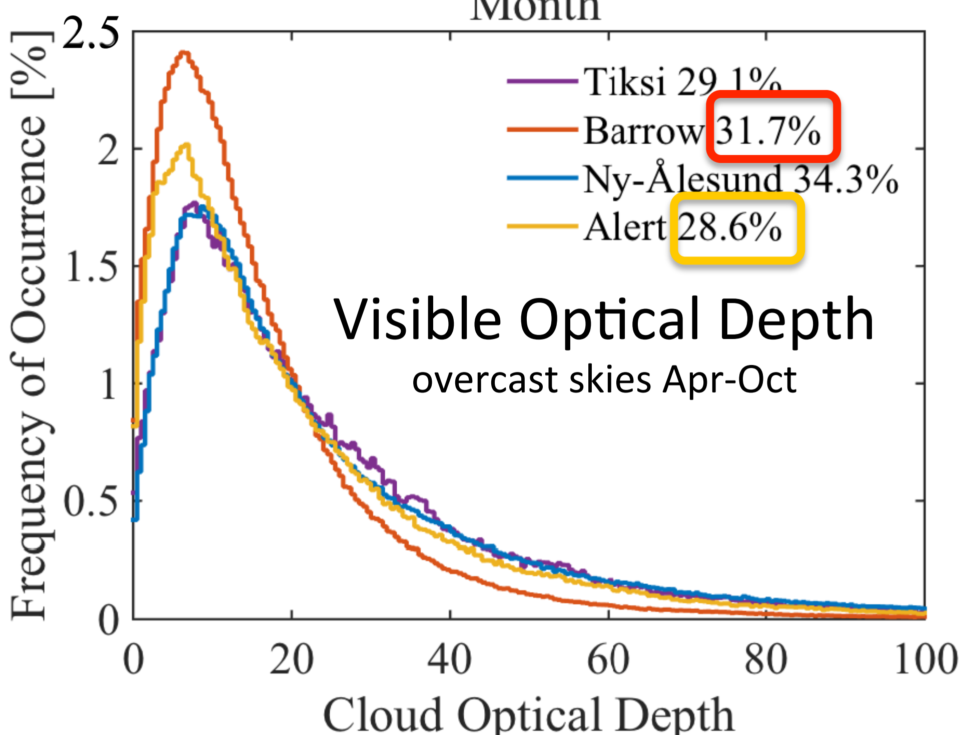
CRF rapidly decreases to negative once snow melts, surface albedo decreases, and the SW CRF dominates.

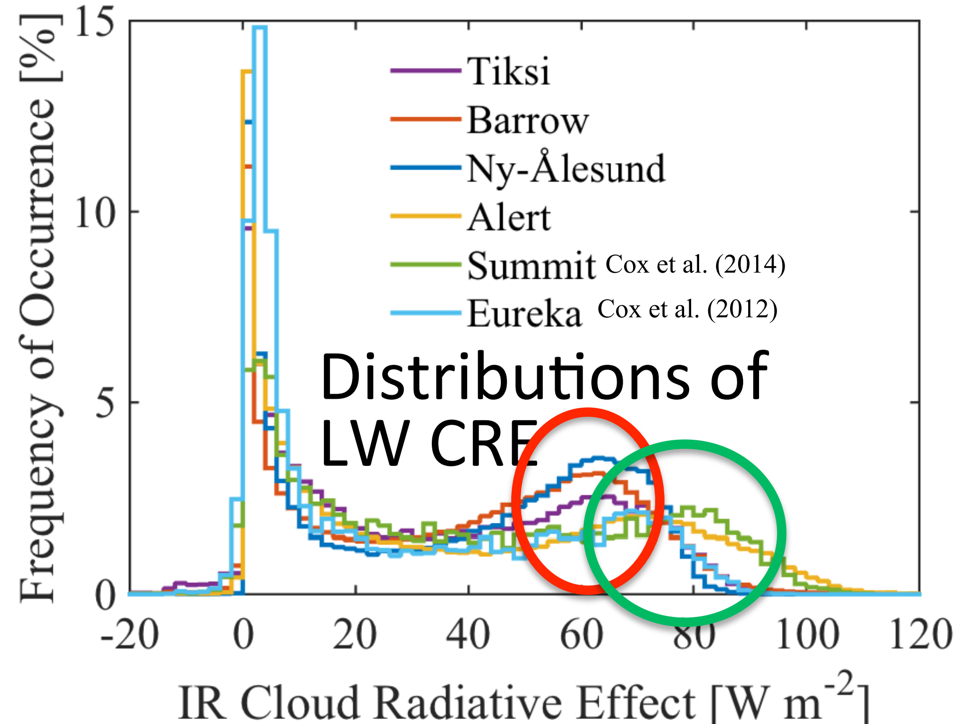
Longwave Cloud Radiative Effect (LW CRE)





- Cloud amounts and OVC occurence 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}





Thanks!

- **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_{SW} differs between sites due to differences in cloud fraction and available sunlight. Conversely, average CRE_{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.**

References

Cox, C. J., Walden, V. P., Compo, G. P., Rowe, P. M., Shupe, M. D., & Steffen, K. (2014). Downwelling longwave flux over Summit, Greenland, 2010–2012: Analysis of surface-based observations and evaluation of ERA-Interim using wavelets. J. Geophys. Res., 119(21), 12-317.

Cox, C. J., Walden, V. P., & Rowe, P. M. (2012). A comparison of the atmospheric conditions at Eureka, Canada, and Barrow, Alaska (2006–2008). J. Geophys. Res., 117(D12).

Hinkel, K.M. & Nelson, F.E. (2003). Spatial and temporal patterns of active layer thickness at Circumpolar Active Layer Monitoring (CALM) sites in northern Alaska, 1995-2000. J. Geophys. Res., 108(D2), 8168.

Long, C. N., & Shi, Y. (2008). An automated quality assessment and control algorithm for surface radiation measurements. Op. Atmos. Sci. J., 2(1).

Long, C. N., & Turner, D. D. (2008). A method for continuous estimation of clear-sky downwelling longwave radiative flux developed using ARM surface measurements. J. Geophys. Res., 113(D18).

Long, C. N., & Ackerman, T. P. (2000). Identification of clear skies from broadband pyranometer measurements and calculation of downwelling shortwave cloud effects. J. Geophys. Res., 105(D12), 15609-15626.

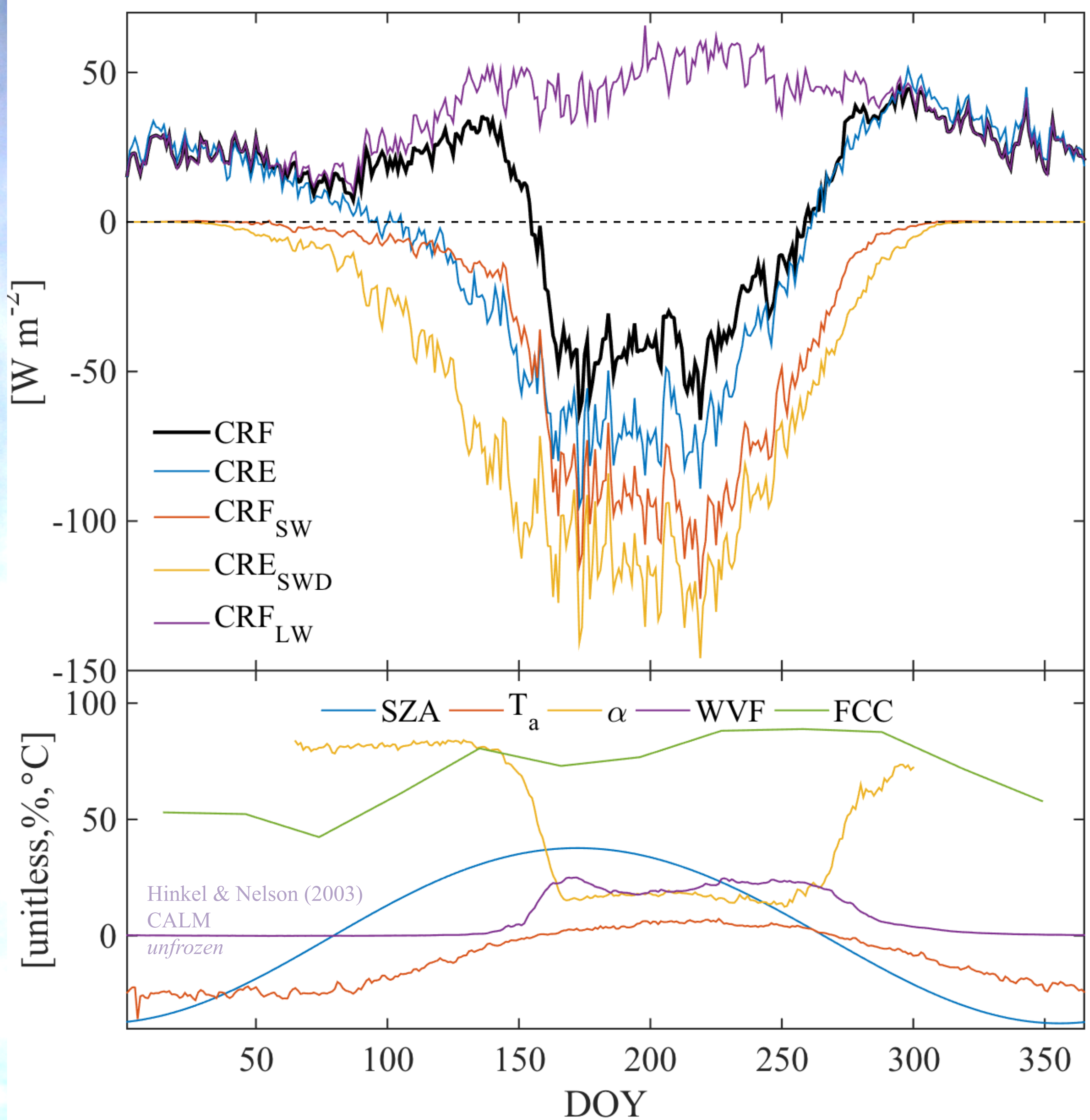
Miller, N. B., Shupe, M. D., Cox, C. J., Walden, V. P., Turner, D. D., & Steffen, K. (2015). Cloud radiative forcing at Summit, Greenland. J. Clim., 28, 6267-6280.

Outcalt, S. I., Nelson, F. E., & Hinkel, K. M. (1990). The zero-curtain effect: Heat and mass transfer across an isothermal region in freezing soil. Wat. Resour. Res., 26(7), 1509-1516.

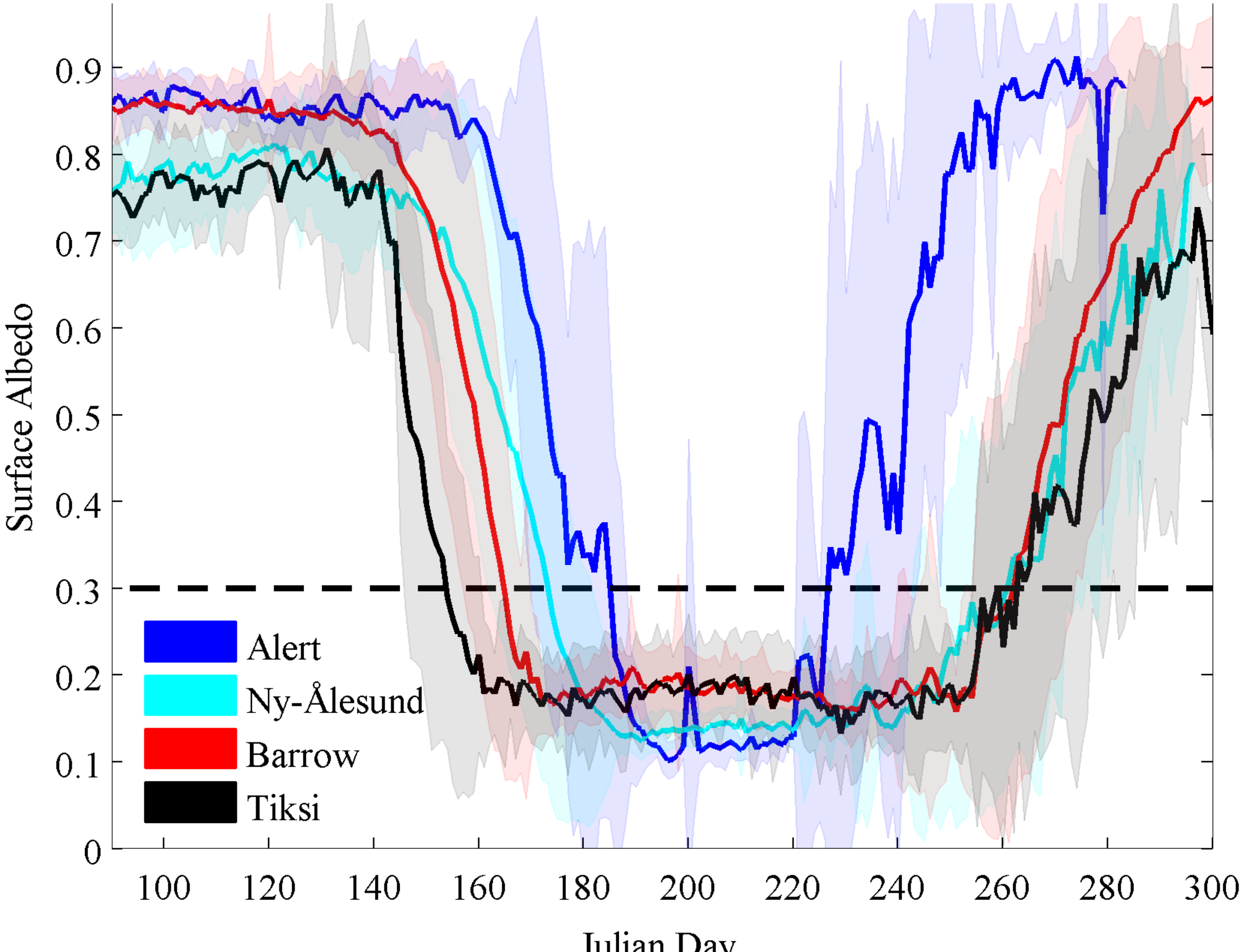
Barrow 1996-2011

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

Hinkel, K.M. & Nelson, F.E. (2003). Spatial and temporal patterns of active layer thickness at Circumpolar Active Layer Monitoring (CALM) sites in northern Alaska, 1995-2000. J. Geophys. Res., 108(D2), 8168.

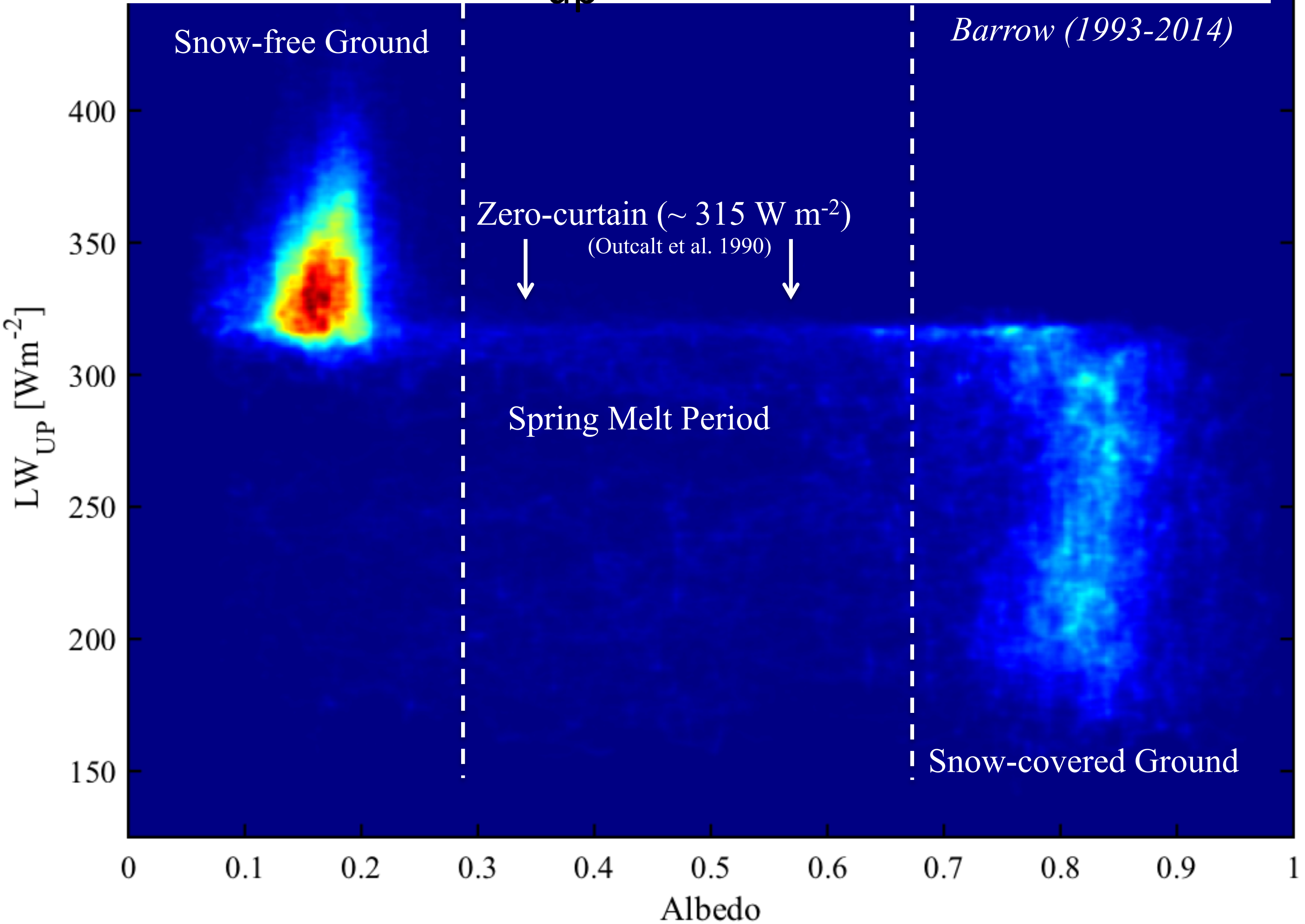


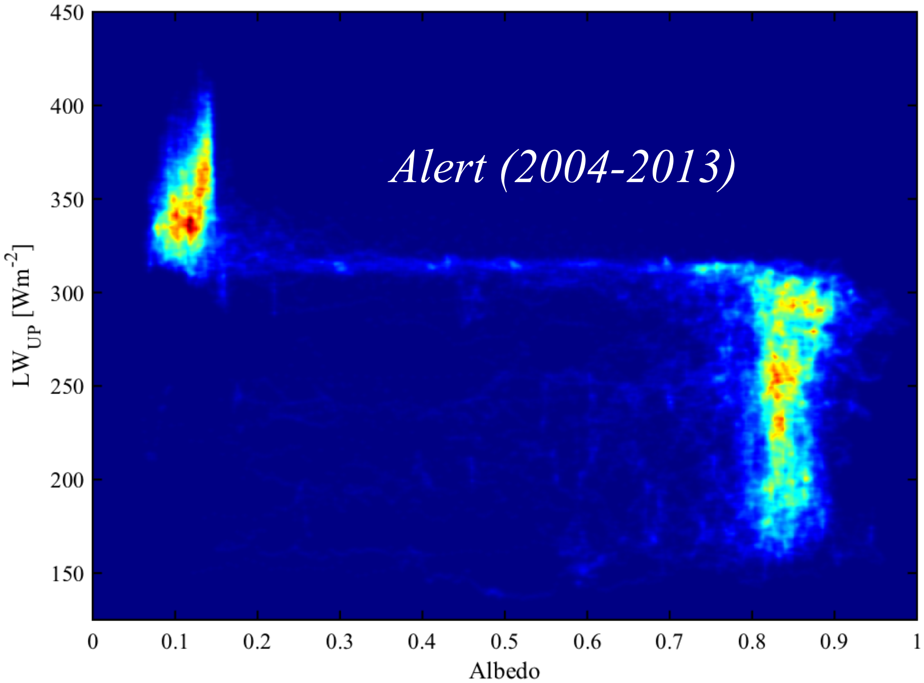
Albedo

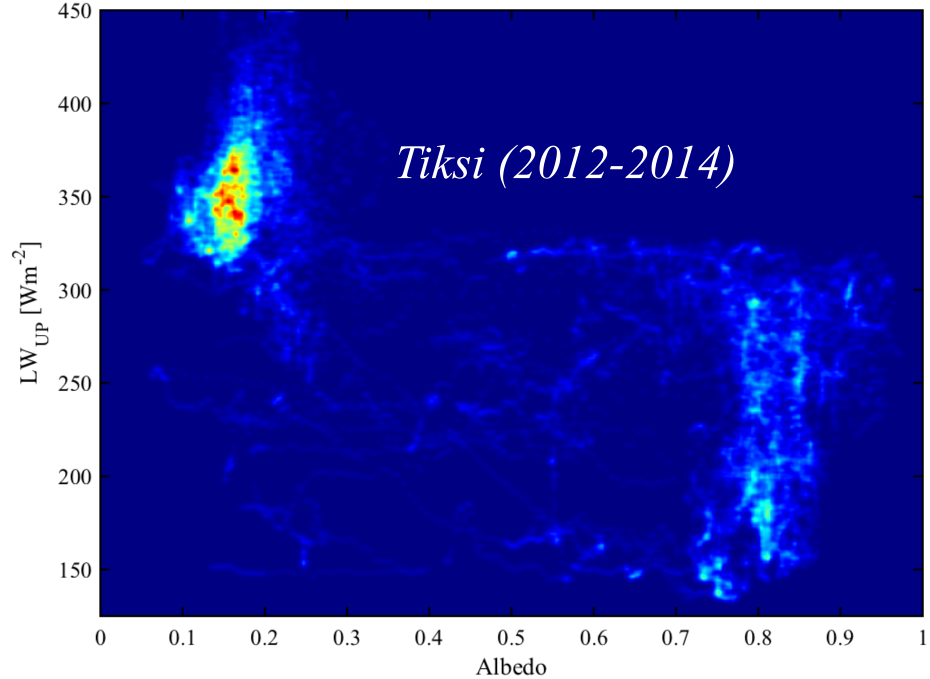


Surface Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
120
140
160
180
200
220
240
260
280
300
Alert
Ny-Ålesund
Barrow
Tiksi
Julian Day

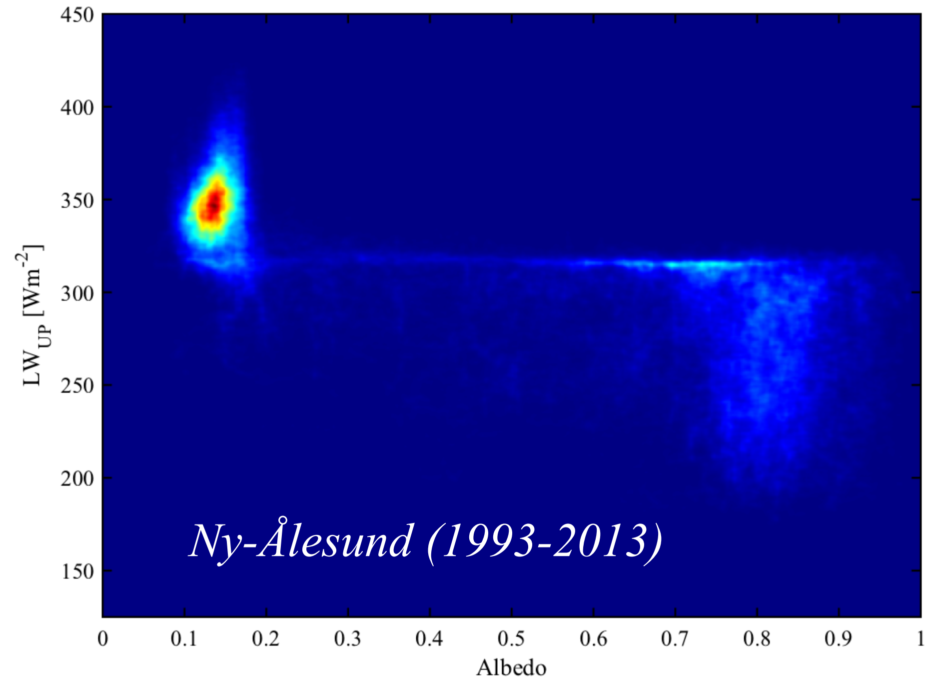
Spring LW_{up} “Zero Curtain”



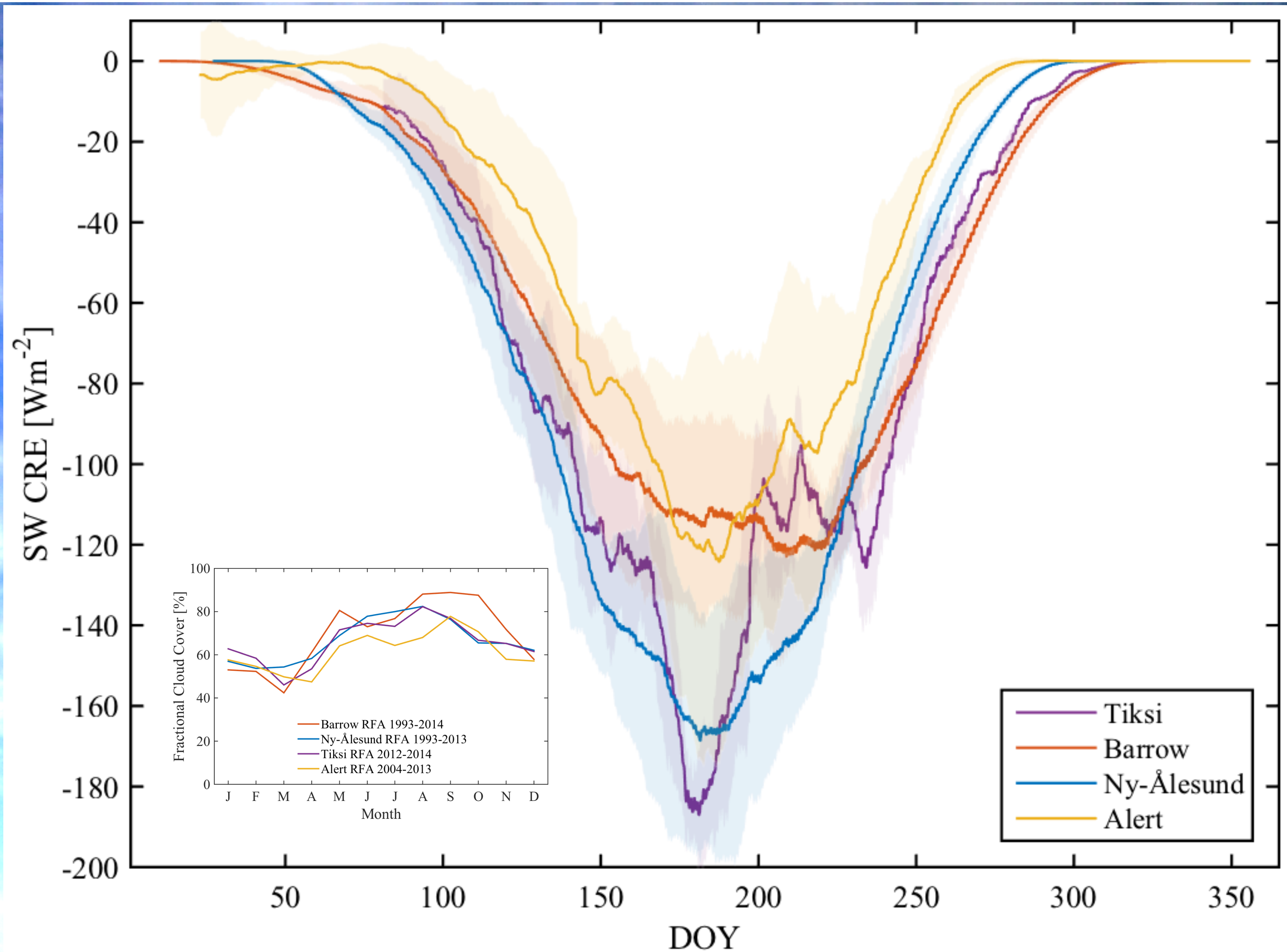

Alert (2004-2013)
LW_UP [Wm^-2]
Albedo
450
400
350
300
250
200
150
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Tiksi (2012-2014)
LW_UP [Wm^-2]
Albedo
450
400
350
300
250
200
150
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Continued…


Ny-Ålesund (1993-2013)
LW_UP [Wm^-2]
Albedo
450
400
350
300
250
200
150
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Shortwave Cloud Radiative Effect (SW CRE)



Monthly Mean Cloud Radiative Forcing (CRF)