The Arctic Surface Radiation Budget:

A candidate topic for the Arctic Report Card

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Introduction

The surface energy budget is a major driver of many important processes in the Arctic. Ultimately, the energy balance determines the growth and decay of sea ice, as well as the melting and freezing of permafrost and snow cover. All of these processes are inextricably linked with changing climatic conditions as the Arctic warms at a faster rate than elsewhere on Earth. The surface albedo can also be very sensitive to changes in the surface energy budget if melting or freezing is occurring. Long-term changes in the surface albedo are contributing to positive feedbacks in the Arctic climate system.

Despite its importance the surface energy budget is not routinely measured. On occasion, it is fully characterized during field programs (such as SHEBA). And because of this, researchers rely heavily on estimates of the surface energy balance from both models and satellite instruments. This is partly due to the fact that the measurements of the individual components of the energy balance are difficult; this is especially true for the latent and sensible heat fluxes.

The surface energy balance is typically written as:

$$F_{total} = (F_{SW}^{\downarrow} - F_{SW}^{\uparrow}) + (F_{LW}^{\downarrow} - F_{LW}^{\uparrow}) + H_L + H_S + H_G + \varepsilon$$
$$F_{total} = F_{SW}^{net} + F_{LW}^{net} + H_L + H_S + H_G + \varepsilon$$

This equation shows that the total flux into the surface is a combination of the four radiative fluxes (both shortwave/solar and longwave/infrared), plus the fluxes of latent heat (H_L), sensible heat (H_S), and the geothermal heat (H_G). The sign convention is positive fluxes are into the surface. Therefore, if F_{total} is positive, melting will occur for a frozen surface. Note that ε represents the total error associated with the flux measurements or estimates.

The Baseline Surface Radiation Network (BSRN) measures the four components of the surface radiation at many sites around the world (Ohmura et al, 1998). This includes six stations at latitudes greater than 60 N: Barrow, Alaska, Ny-Ålesund, Norway, Eureka, Canada (candidate), Alert, Canada (candidate), Summit Station, Greenland (candidate), and Tiksi, Russia (candidate). The last four stations listed are still not officially BSRN sites, but are making routine measurements of all four components of the surface radiation budget (Matsui et al, 2012). Each of these stations has a different period of record, with Barrow and Ny-Ålesund being the longest. Note that the BSRN officially recommends that sites measure both diffuse and direct solar radiation, however most sites in the Arctic are simply measuring the sum of both, which is termed global radiation.

Long and Shi (2008) have provided a comprehensive approach for providing quality control for surface broadband radiation measurements. Matsui et al (2012) (and references therein) document the significant issues that arise when making these types of measurements in the Arctic. These most commonly includes calibration errors and riming/frosting of the instrument domes.

Approach for use in the Arctic Report Card

Here we focus on the four components of the surface radiation budget because they are routinely measured at the two BSRN sites and four candidate sites across the Arctic. There are various approaches for how to incorporate knowledge of the surface radiation budget into the Arctic Report Card. We suggest the following approach:

1) Determine the level of quality control that has been performed on both the archived measurements and the real-time measurements for a particular year.

2) Present the climatology of surface radiation budget measurements at each of the six sites.

3) Use the current year's measurements to place that year in context of the sites climatology. The time scale over which these comparisons are made will likely be important (annual vs. seasonal vs. monthly).

4) Compare the monthly average radiation component values to reanalyses data products (such as ECMWF and/or NCEP).

5) Use the reanalyses data products to provide spatial information about anomalies in the different components of the surface radiation budget.

6) Based on the analyses above, provide a list of highlights for the past year at the individual sites and a summary of key results from the reanalyses.

This is simply a *draft approach*. Other ideas and approaches are encouraged. It is also recognized that any approach that is adopted should evolve in subsequent years as additional measurements and data products become available.

Potential Drawbacks

The most obvious drawbacks in providing a "chapter" for the Arctic Report Card on the surface radiation budget are the potential errors associated with the measurements. How long does it currently take each site to perform adequate quality control [such as Long and Shi (2008)] on their data? Does it make sense to proceed using data that hasn't been quality-controlled?

A second issue involves potential biases in the reanalyses products. The idea for the Report Card is to provide an idea of how the Arctic "functioned" during the most recent year. Since there are measurements at only six sites, it is essential to use reanalyses to provide spatial context of the surface radiation budget. Are the uncertainties and biases small enough in the reanalyses to use them confidently? What other reanalyses validation activities are underway? Can this "chapter" of the Arctic Report Card be used as a source of validation?

A very important topic is how to errors in both the measurements and reanalyses products limit what we can conclude for the Arctic Report Card. Are the surface radiation budget measurements and the Arctic reanalyses of high enough quality to proceed with formulating general conclusions about the current year?

Sample Highlights and Graphics

We used data from Barrow, Alaska to generate some sample graphics to consider for the Arctic Report Card. It is anticipated that similar graphics can be generated for each of the other five Arctic sites, but using different time periods for their "climatologies". **Figure 1** shows data from the DOE ARM SKYRAD measurements. The gray areas represent the $\pm$ 1-sigma values about the monthly means from 1998-2012. The green symbols show the monthly average values for 2012. The blue symbols show the monthly average values derived from the ECMWF reanalyses (ERA-Interim); the uncertain bars indicate $\pm$ 1-sigma variation about the monthly means over the time period 1998-2012. [ERA-Interim was used because it was determined by Cox et al (2012) to be the most accurate reanalyses product for Barrow, Alaska.] Note that the most significant differences between ERA-I and the measurements is in the spring in the upwelling shortwave component.

Figure 2 shows the 2012 anomalies in the four surface radiation components, plus the net radiation anomaly. The anomalies are computed versus the 1998-2012 average from ERA-Interim. The net radiation shows slightly positive anomalies across the Arctic, with the largest anomaly occurring over the Beaufort Sea and into the northwestern Canadian Archipelago. There are also some smaller positive anomalies in the Barents and Kara Seas near Novaya Zemlya. All of these anomalies seem to be associated with negative anomalies in these areas in the upwelling shortwave flux. Both the downwelling and upwelling longwave flux anomalies for 2012 are large and positive for much of the Arctic, especially over the Barents and Kara Seas, but these two components largely cancel each other in the net radiation anomaly.

Finally, **Figure 3** provides plots of each of the four components and the net radiation for all seasons from 1998 through 2012. There appear to be increasing trends in the annual downwelling and upwelling longwave fluxes as a function of time, and perhaps decreases in the two shortwave components and the net radiation. However, note that only 15 years of data are plotted, so long-term trends may not be statistically significant.

References

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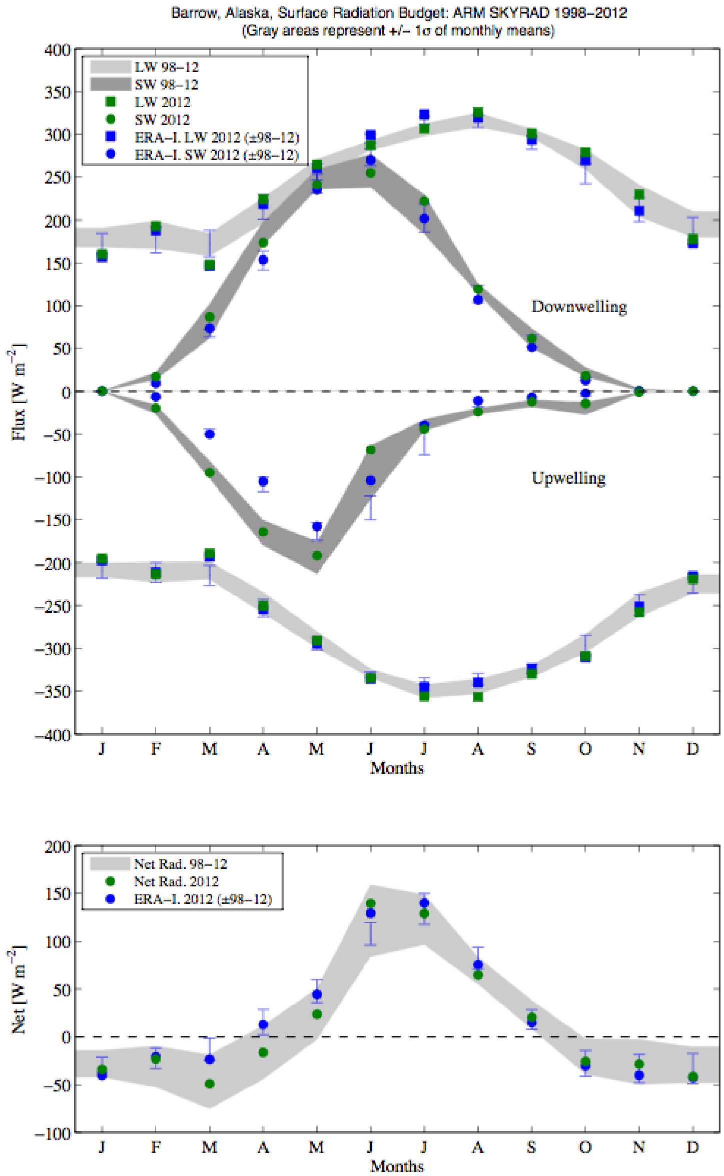
Barrow, Alaska, Surface Radiation Budget: ARM SKYRAD 1998–2012
(Gray areas represent +/– 1σ of monthly means)
LW 98–12
SW 98–12
LW 2012
SW 2012
ERA–I. LW 2012 (±98–12)
ERA–I. SW 2012 (±98–12)
Downwelling
Upwelling
Flux [W m^-2]
Months
Net Rad. 98–12
Net Rad. 2012
ERA–I. 2012 (±98–12)
Net [W m^-2]
Months

Figure 1.

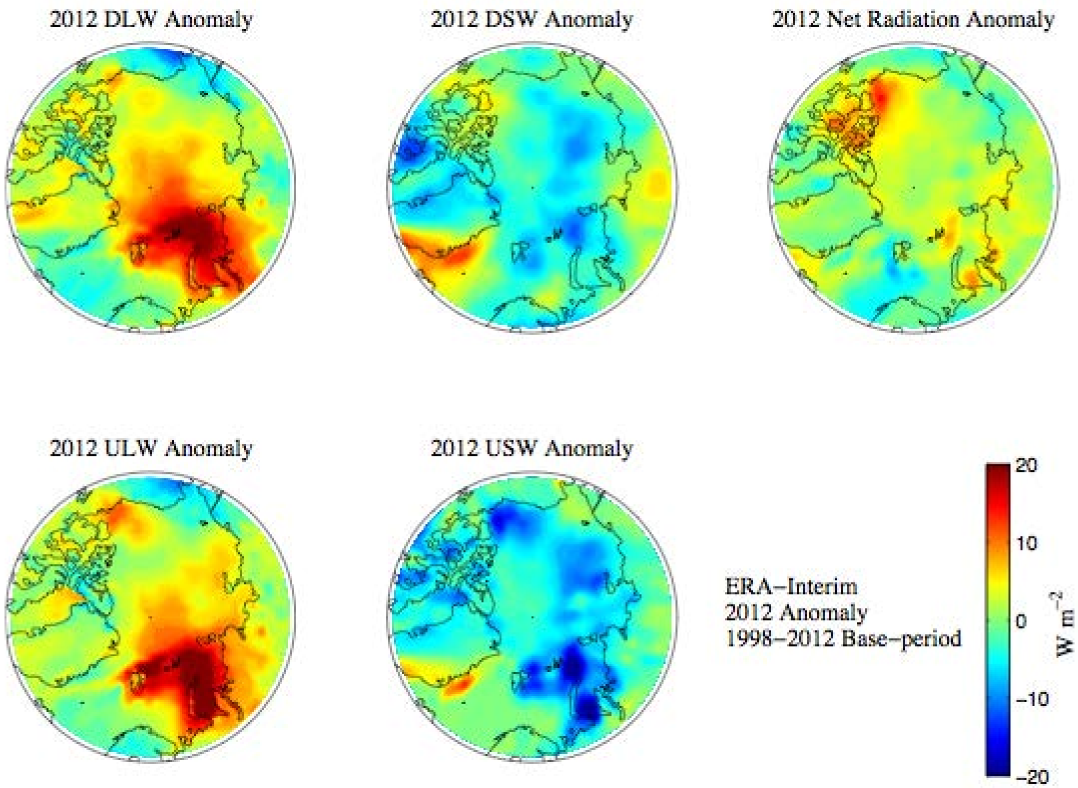
2012 DLW Anomaly
2012 DSW Anomaly
2012 Net Radiation Anomaly
2012 ULW Anomaly
2012 USW Anomaly
ERA−Interim
2012 Anomaly
1998−2012 Base−period
20
10
0
−10
−20
W m^-2

Figure 2.

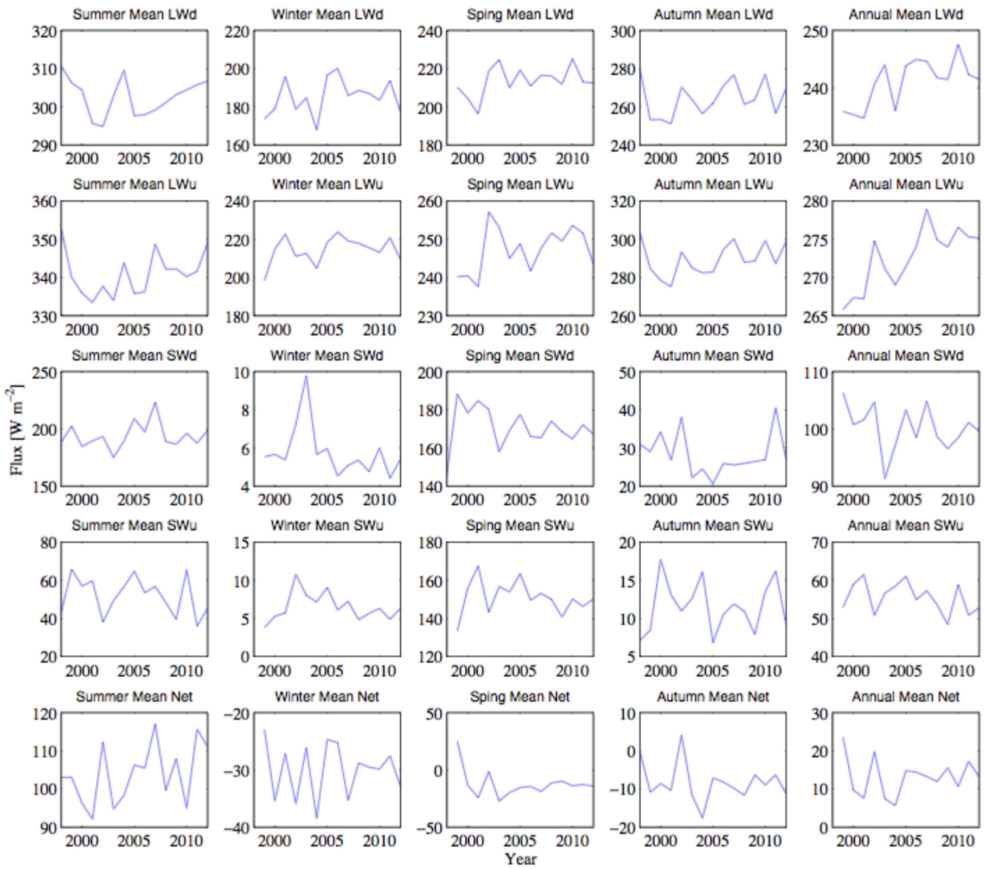
Summer Mean LWd
Winter Mean LWd
Sping Mean LWd
Autumn Mean LWd
Annual Mean LWd
Summer Mean LWu
Winter Mean LWu
Sping Mean LWu
Autumn Mean LWu
Annual Mean LWu
Summer Mean SWd
Winter Mean SWd
Sping Mean SWd
Autumn Mean SWd
Annual Mean SWd
Summer Mean SWu
Winter Mean SWu
Sping Mean SWu
Autumn Mean SWu
Annual Mean SWu
Summer Mean Net
Winter Mean Net
Sping Mean Net
Autumn Mean Net
Annual Mean Net
Flux [W m^-2]
Year

Figure 3.