Surface Radiative Fluxes over the Pan-Arctic Land Region: Variability and Trends

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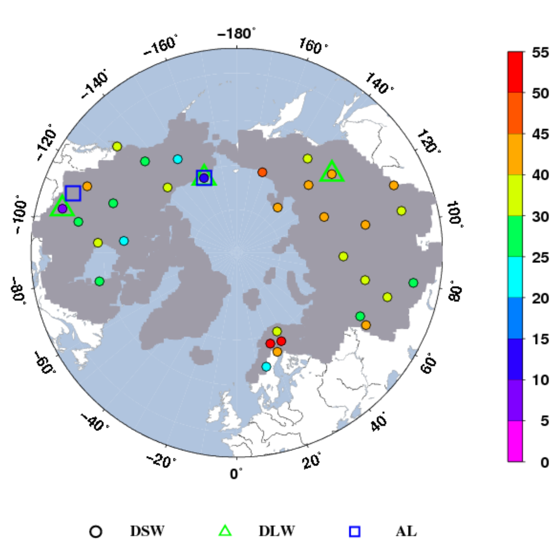
ABSTRACT

Surface radiative fluxes are not only a major component of the surface energy balance, but also control a diverse set of physical-biological processes, including the land surface hydrological cycle and plant photosynthesis. Past studies of the pan-Arctic region have identified changes in land surface hydrological fluxes, but less attention has been focused on the energy inputs to the system. Recent satellite data and atmospheric model reanalysis products have provided several datasets that predict most or all terms in the surface energy budget, and provide the opportunity to investigate the variations in surface radiative fluxes. We analyzed surface downward shortwave and longwave radiation and albedo from the (1) European Centre for Medium-Range Weather Forecast 40-Year Reanalysis (ERA-40), (2) European Centre for Medium-Range Weather Forecast Interim Reanalysis (ERA-Interim), (3) International Satellite Cloud Climatology Project (ISCCP), and (4) an off-line simulation with the Variable Infiltration Capacity (VIC) model for the period from 1984 to 2006 (ERA-40, 1984-2002; ERA-Interim, 1989-2006). In addition, diurnal and mean seasonal cycles were compared with in situ measurements from the Asian Automatic Weather Station Network (AAN), the Baseline Surface Radiation Network (BSRN), the Boreal Ecosystem-Atmosphere Study (BOREAS), the National Solar Radiation Data Base (NSRDB), and the Global Energy Balance Archive (GEBA). At the regional scale, the consistency of dominant spatial, temporal and latitudinal variability of these surface radiative fluxes across different datasets was examined. Also, for a small number of GEBA stations with records spanning the period from the 1950s and 1960s to post-2000, we analyzed long-term trends in surface downward shortwave radiation.

DATASETS

1. In situ data

For purposes of comparison with satellite and model output, we mainly used observations archived in the Global Energy Balance Archive (GEBA), which is a central database for the worldwide instrumentally measured energy fluxes at the surface, located at the Institute for Climate and Atmospheric Sciences of ETH. As shown in the figure **at right**, these observation sites contain monthly surface downward shortwave (32 sites), longwave (3 sites) radiation and albedo (2 sites) (abbreviated as DSW, DLW and AL, respectively, hereinafter) measurements with various record lengths between 1950 and 2006.



2. Satellite data

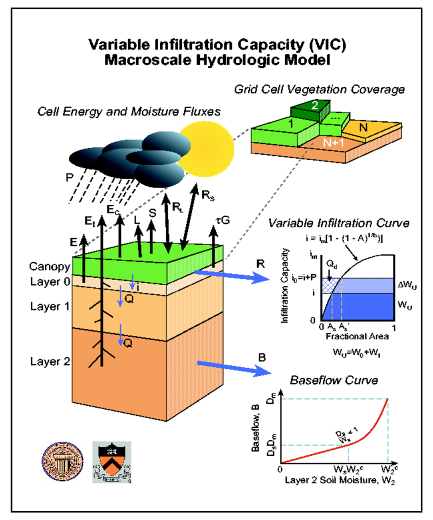
The satellite surface radiative flux data is from the International Satellite Cloud Climatology Project-Flux Data (ISCCP-FD, abbreviated as ISCCP hereinafter) (Zhang et al., 2004), which has a spatial resolution of 2.5 degree with 3-hour time intervals. The period of the ISCCP is from July 1983 to December 2006 (at the time of writing). The ISCCP uses the NASA Goddard Institute for Space Studies (GISS) radiative transfer model, the ISCCP-D1 cloud dataset (Rossow and Schiffer, 1999) and satellite data for temperature and humidity. More information about the ISCCP product can be found at http://isccp.giss.nasa.gov/projects/flux.html.

3. Reanalysis data

Two reanalysis products from the European Centre for Medium-Range Weather Forecasts (ECMWF) numerical weather prediction (NWP) model were used in this study. The ERA-40 reanalysis (Uppala et al., 2005) is from a 3-D variational assimilation system with a spatial resolution of T159 in the horizontal and 60 levels in the vertical, covering the time period from September 1957 to August 2002 with a 6-hour temporal resolution. A new interim global reanalysis product called the ERA-Interim (Simmons et al., 2006) was produced by ECMWF with data publicly available for the period 1989-2009 with a 12-hour temporal resolution. The ERA-Interim, which is a 4-D variational assimilation system at T255 horizontal resolution with the same 60 levels in the vertical, improved the ERA-40 reanalysis with the variational bias correction of satellite observations and a more recent cycle of the ECMWF model (Uppala et al., 2008).

4. Land surface model off-line simulation

The Variable Infiltration Capacity (VIC) model (Liang et al., 1994, 1996; Cherkauer and Lettenmaier, 1999, 2003) was designed not only for off-line simulations of the water and energy budgets in large areas, but also for use in coupled land–atmosphere models to simulate the role of the land surface in partitioning moisture and energy. In this research, the VIC model was used as off-line simulations at a three-hour time step in full energy balance mode, and forced with daily precipitation, maximum and minimum temperatures and wind speed from a high quality gridded dataset with a spatial resolution of 100-km EASE grid, which was constructed using methods outlined in Adam et al. (2007) for the period 1979 to 2007 over the pan-Arctic land region.

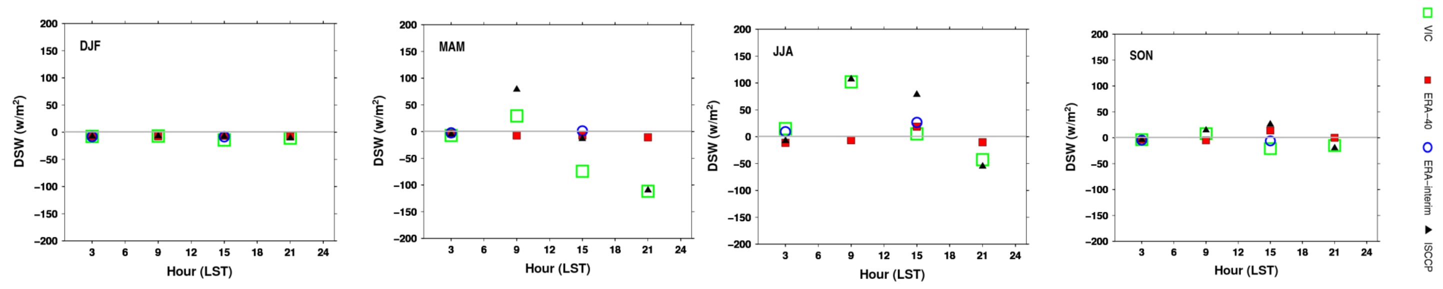


RESULTS

1. Evaluation of datasets using in situ observations

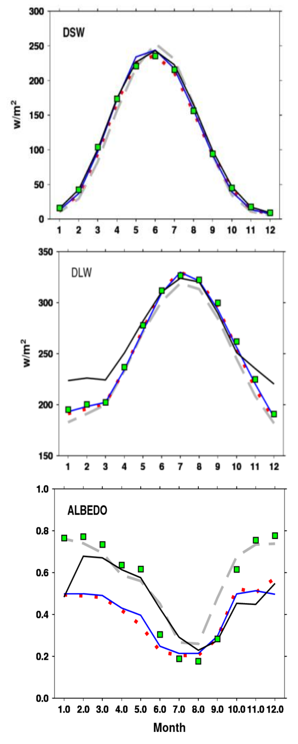
a) Mean diurnal cycle

A comparison of the DSW mean diurnal cycle anomaly from the ERA-40, ERA-Interim, ISCCP and VIC relative to the observed data is shown in the figure **below** (Barrow, Alaska) for winter (DJF), spring (MAM), summer (JJA), and autumn (SON). The differences by time of day for the ISCCP and VIC show a larger variation than the ERA-40 and ERA-Interim, which suggests that the reanalysis products have more accurate mean diurnal cycle of DSW than the satellite product and land surface model off-line simulation.



b) Mean seasonal cycle

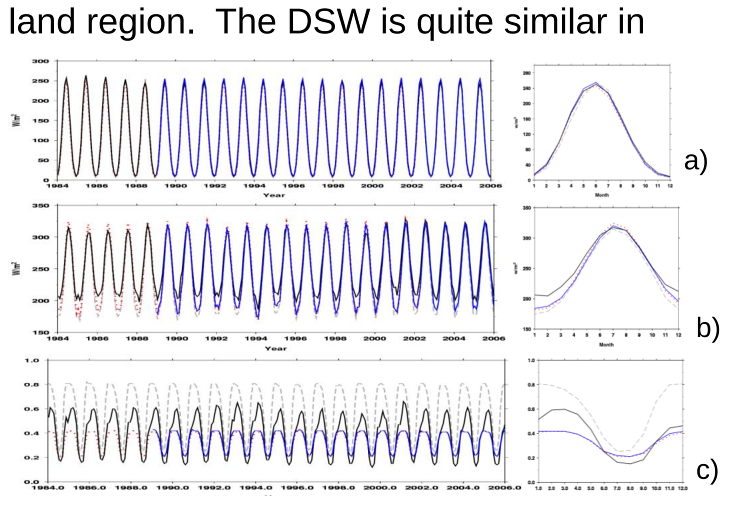
The figure **at upper right** compares the mean seasonal variation of DSW, averaged over 32 sites across the pan-Arctic land region. The ERA-40, ERA-Interim, ISCCP, and VIC all have small, negligible biases (±3.5 W/m2), compared to the in situ observation mean. The small biases in the ISCCP and VIC are actually a cancellation of large positive and negative biases during the time of day. The figure **at middle right** evaluates the mean seasonal cycle of DLW from different datasets with GEBA field measurements averaged at 3 sites. Compared to the in situ data, the ERA-40, ERA-Interim and VIC all have small biases which are less than 10 W/m2. For the ISCCP, DLW is overestimated from November through April that results in a weak seasonal cycle. The figure **at lower right** shows a comparison of mean seasonal cycle of AL from the ERA-40, ERA-Interim, ISCCP, and VIC model with the GEBA data, averaged at 2 sites in the pan-Arctic. Relatively speaking, the VIC matches the observed value very well except the summer time, while the reanalysis products do well only for the summer. The ISCCP AL only shows a good match in the spring.



2. Regional-scale comparisons

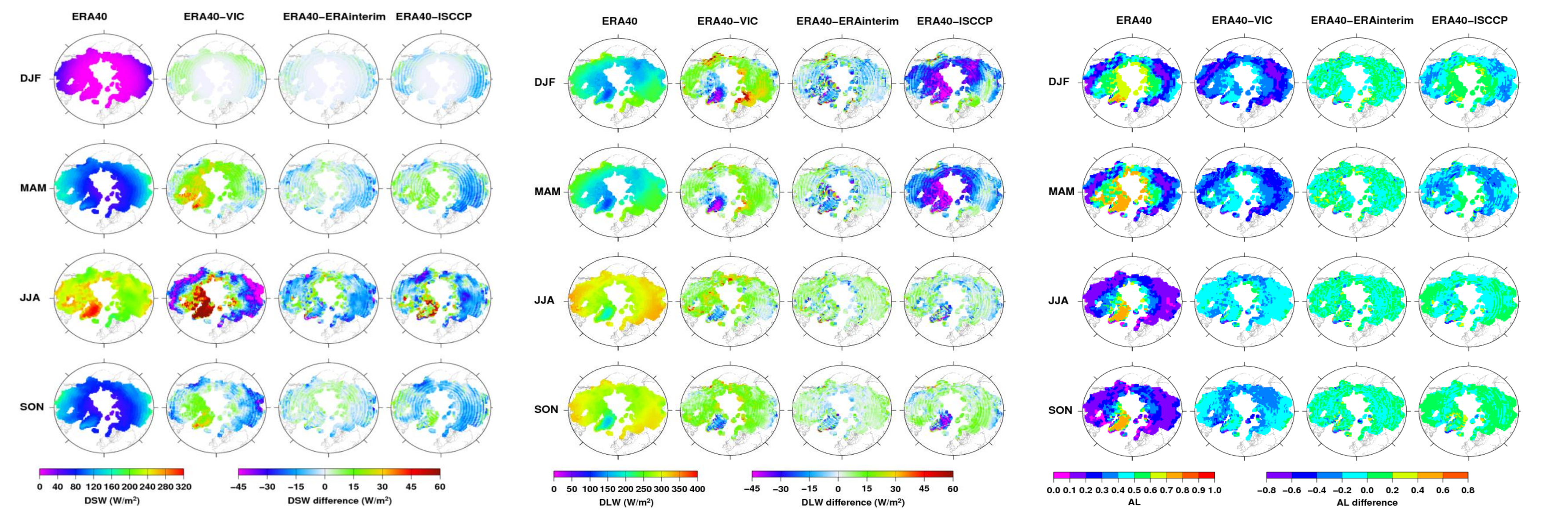
a) Temporal variability

The figure **at right** shows the monthly time series and mean seasonal cycle of DSW, DLW, and AL from the four datasets, averaged across the pan-Arctic land region. The DSW is quite similar in terms of interannual variations (left-hand side of (a)). The DLW has similar monthly and seasonal variations among the four estimates, which are low during October to April and peak in July. The overestimation of DLW during the snow season results in a weak mean seasonal cycle for the ISCCP. There is a considerably large underestimation in the ERA-40 and ERA-Interim which is up to 0.4 during the snow season compared to the VIC model. The snow AL of the ISCCP is higher than the reanalysis products while it is still about 0.1 lower than the VIC estimates.



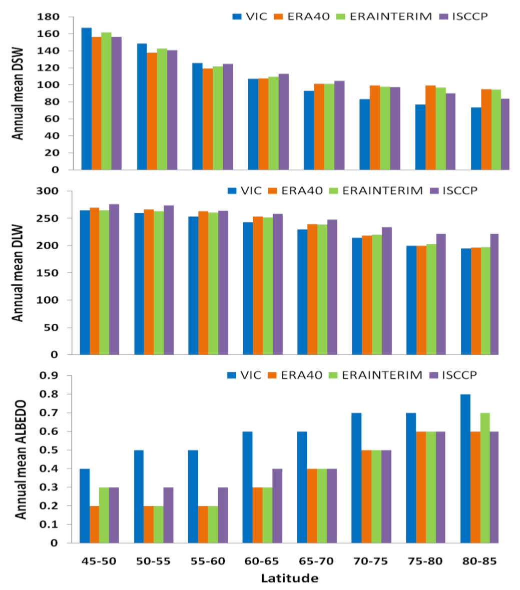
b) Spatial variability

Figures **below** show the spatial distribution of seasonal mean DSW, DLW, and AL from the ERA-40, and the difference between the ERA-40 and VIC, ERA-Interim and ISCCP for winter (DJF), spring (MAM), summer (JJA), and autumn (SON). The ERA-40 and ERA-Interim are quite similar for all the seasons. The VIC and ISCCP agree reasonably well with the ERA-40 reanalysis both in the timing and magnitude of seasonal pattern of DSW, although significant differences are evident in some areas. The bias of DLW in the winter and spring for the VIC, ERA-Interim and ISCCP is higher than the counterpart in the summer and autumn over most land areas of the pan-Arctic. It should be noted that winter and spring DLW from the ISCCP significantly overestimates the ERA-40 for almost all the land areas except southwestern Eurasia and the Norwegian coast. For the VIC, autumn, winter and spring AL is persistently higher than the ERA-40 and the maximum bias is up to 0.8 in the mountains of Eurasia and North America. In the summer, the bias between the ERA-40 and VIC is much smaller. For the ISCCP, the overestimation areas in the winter and spring are similar to the VIC, but relatively smaller.

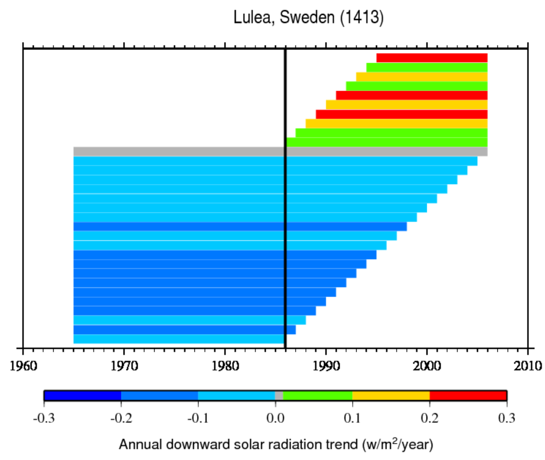


c) Latitudinal variability

The DSW from the VIC, ERA-40, ERA-Interim and ISCCP shows a quite similar latitudinal change which is maximum in the 45-50ºN band, and then decreases sharply with poleward latitude, as shown in the figure **at upper right**. The VIC overestimates the annual mean of DSW from the reanalysis in the lower latitude up to 60-65º N, where they are almost equal, and then underestimates in the higher latitude. The DLW decreases gradually with latitudinal bands from the 45-50ºN to 80-85ºN. Although the ISCCP follows the similar pattern with the other three estimates, it considerably overestimates the annual mean DLW and the bias with the other three datasets generally becomes bigger (at lease in a relative sense) with latitude. From 45-50º N to 60-65º N, the AL (as shown in the figure **at lower right** from the reanalysis products has a significant difference with the VIC and ISCCP. However, it is almost equal to the ISCCP and the difference between the VIC and the reanalysis products is much smaller from 65-70º N.



3. Trend analysis



To examine long-term trends in observed DSW, we used the Mann-Kendall trend (Mann, 1945) test for trend significance (p=0.05, two-tailed). Trend tests were performed for annual DSW at 12 GEBA stations with records spanning the period from the 1950s and 1960s to post-2000. Eight stations have decreasing trends and four in them are significant, while there are three stations with increasing trends and two of them are significant. The figure **at left** (statistical significance not shown) shows that the absence of trend for station 1413 for 1965-2006 results from cancellation of upward and downward trends. Trend slopes for most stations taken over a range of start and end dates showed that there is a turning point between 1985 and 1990. Before that, a dimming period exists, whereas brightening occurred thereafter.

CONCLUSIONS

A number of papers have been published about the above datasets globally (Allan et al., 2004; Betts et al., 2006; Li et al., 1995; Lin et al., 2008; Raschke et al., 2006), and locally, such as Tibet (Yang et al., 2008); the Arctic Ocean (Liu et al., 2005); northern Eurasia (Troy et al., 2009); and the Mackenzie, Mississippi and Amazon river basins (Betts et al., 2009). However, few have focused on the pan-Arctic land region. This study evaluates different surface radiative flux datasets over the pan-Arctic land region which has significant changes in surface air temperature and hydrological cycle, focusing on their variability and trends. Firstly, these data sets were evaluated against the field measurements. According to our validation results, the DSW monthly mean biases are approximately ±3.5 W/m^2 for the ERA-40, ERA-Interim, ISCCP, and VIC. For DLW, the biases for the ERA-40, ERA-Interim and VIC are less than 10 W/m^2. However, large discrepancies (less than 25 W/m^2) in DLW still exist between the ISCCP and GEBA due to the overestimation during the snow season. All data sets have consistent temporal patterns for each radiative flux at the regional scale associated with the monthly, seasonal and annual cycle (except the DLW in the ISCCP and AL during the snow season). In terms of dominant spatial variability, all data sets show large variability in the pan-Arctic. Despite the above encouraging agreements, substantial temporal and spatial discrepancies are still found (a) between these data sets and the GEBA field measurements, and (b) among these data sets. In addition, there is a turning point which is between 1985 and 1990 at the GEBA sites to tell the dimming and brightening period which is consistent with Wild et al. (2005).

REFERENCES

Troy, T.J. and Wood, E.F., (2009) Comparison and evaluation of gridded radiation products across northern Eurasia (in review).

X. Shi, M. Wild, and D. P. Lettenmaier, Surface radiative fluxes over the pan-Arctic land region: variability and trends (to be submitted).

Note: See the author for other references, or www.hydro.washington.edu ("publications").