Assessing satellite-derived net surface radiative flux in the Arctic

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ABSTRACT

Satellite-derived surface radiative fluxes have been recently improved and extended. However, the accuracy of recent satellite-derived surface radiative fluxes in the Arctic is not well characterized. Here, the authors assess the accuracy of the net surface radiative flux (NETSRF) in the Arctic, focusing on the ice-covered ocean, for three satellite products against four in situ measurements collected from different areas in the Arctic. The three satellite products are the Surface Radiation Budget project (SRB), the International Satellite Cloud Climatology Project (ISCCP), and the Extended AVHRR Polar Pathfinder version-2 (APP-x). Our comparisons suggest that: (1) in terms of the overall bias, root-mean-square error, and correlation, the NETSRF of ISCCP is closer to in situ observations than that of SRB and APP-x; (2) in terms of the diurnal variation of the biases, it is not very clear which satellite product is superior to the others; and (3) in terms of the interannual variability of the bias, the NETSRF of ISCCP is more accurate than that of SRB and APP-x. This comparison may provide useful guidance to the community as to which data-set may provide the smallest bias in NETSRF.

1. Introduction

Accurate knowledge of net radiative flux at the surface is critical for understanding and simulating climate variations. This is particularly true in the Arctic, where significant changes are occurring (e.g. Richter-Menge, Overland, and Mathis, 2016). The Arctic has seen amplified warming associated with a rapid decline in sea ice since the satellite era (e.g. Cavalieri and Parkinson 2012; Stroeve et al. 2012). The net surface radiative flux (NETSRF) in the Arctic differs from that in extratropical regions. The absorbed solar radiation at the surface is strongly influenced by the presence of seasonal sea ice. Sea ice has a high albedo, which reflects most of the incoming solar radiation. Changes in sea-ice albedo in turn affect the surface energy budget, as well as sea-ice coverage. The sea-ice-albedo–temperature feedback is considered to be a dominant contributor to the rapid decline in Arctic sea ice (e.g. Curry, Schramm, and Ebert 1995). The Arctic has frequent and extensive clouds, especially mixed-phase clouds, which have a net heating effect at the surface by altering downward longwave radiation (e.g. Curry et al. 1996; Wang and Key 2003). Cloud-related processes have been also linked to the recent decline in Arctic sea ice, i.e. increased cloud cover contributes to increased downward longwave radiation (e.g. Kay and Gettelman 2009; Kim et al. 2017).

Satellite observations have greatly improved our ability to estimate NETSRF in the Arctic, although they rely on indirect determination via calculations using a radiative transfer model and input variables derived from satellite observations. However, the accuracy of satellite-based NETSRF over the Arctic is not well-characterized compared to that of extrapolar regions. This contributes to large uncertainty in estimates of surface energy budgets...
and climate variability in the Arctic. Some progress has been made in determining the accuracy of surface radiative fluxes in the Arctic. Studies in the late 1990s suggested that the range of surface radiative fluxes among different datasets is very large (e.g. Serreze et al. 1998). Liu et al. (2005) showed that satellite-derived products might provide downward shortwave and longwave radiation with a mean bias of ~40 W m⁻² and ~30 W m⁻², respectively. The satellite-derived downward shortwave radiation is more accurate than that of numerical weather prediction reanalysis, because better cloud properties are used in the satellite-based products relative to the reanalysis. Niu, Pinker, and Cronin (2010) evaluated the shortwave radiative flux derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) at the land surface in the northern high latitudes, and indicated that the shortwave radiation of MODIS is in better agreement with observations than that of numerical models.

Recently, with the efforts of several research groups, improved and extended satellite-derived products of surface radiative fluxes have been released (e.g. Key et al. 2016; Stackhouse Jr. et al. 2011; Zhang et al. 2004). The purpose of this paper is to extend previous studies to evaluate the accuracy and uncertainty of NETSRF over the Arctic for recent satellite-derived products using assembled in situ measurements.

2. Data

2.1. Satellite data

The NETSRF over the Arctic is calculated for the following three satellite-based products using their surface downward and upward shortwave and longwave radiative fluxes (surface radiative fluxes for all-sky conditions are used in this study):

- **Surface Radiation Budget project (SRB):** The shortwave and longwave radiative fluxes are calculated using a radiative transfer model (Fu et al. 1997; Pinker and Laszlo 1992), with cloud parameters from the International Satellite Cloud Climatology Project (ISCCP), meteorological variables from the Goddard Earth Observing System of NASA’s Global Modeling and Assimilation Office, ozone fields from the Total Ozone Mapping Spectrometer (TOMS), and other ancillary datasets. SRB provides data at 3-h intervals on a 1° latitude–longitude grid from July 1983 to December 2007 (https://eosweb.larc.nasa.gov/project/srb/srb_table).

- **ISCCP:** Improved shortwave and longwave radiative fluxes (named ISCCP-FD) are calculated by employing a radiative transfer model, with improved global data of cloud and surface properties from ISCCP, atmospheric temperature and humidity from the Television Infrared Observation Satellite Operational Vertical Sounder, column ozone from TOMS, and climatological aerosols from GISS (Zhang et al. 2004). ISCCP provides data at 3-h intervals from July 1983 to December 2009 on an equal-area projection with a 2.5° latitude–longitude spatial resolution (http://isccp.giss.nasa.gov/outgoing/FLUX/SRF/).

   Extended AVHRR Polar Pathfinder (APP-x) version-2: The APP-x data-set has been extended to include retrievals of surface radiative fluxes, cloud information and its radiative effects (cloud forcings). The shortwave and longwave radiative fluxes are calculated in the Cloud and Surface Parameter Retrieval using FluxNet, which is a neural network version of a radiation transfer model named Streamer (Key et al. 2002). Calculations also use the atmospheric temperature and humidity from the NCEP–NCAR reanalysis, as well as ISCCP ozone data. APP-x provides twice-daily data at local solar times of 0400 and 1400 for the period 1982–2014 at a spatial resolution of 25 km on the EASE (Equal-Area Scalable Earth) grid (ftp://stratus.APP-x.wisc.edu/pub/ncdc/appx/data/Polar-APP-X_v01r01_C_1982-2014/).

2.2. In-situ measurements

To assess in detail the differences in regional and high-frequency representations of NETSRF over the Arctic, the following four in situ datasets are used to evaluate the above three satellite products:

- **Surface Heat Budget of the Arctic Ocean (SHEBA):** SHEBA is a year-long field campaign from October 1997 to October 1998 in the Beaufort and Chukchi seas, in which the Canadian icebreaker DesGroseilliers drifted from (75.42°N, 144.42°W) to (80.33°N, 166.02°W) (Figure 1). SHEBA provides a comprehensive observational data-set
Arctic Ocean Experiment in 2001 (AOE01): Surface meteorological measurements were made during the AOE01 field campaign in July–August 2001 in the central Arctic Ocean, in which the Swedish icebreaker Oden was moored to an ice floe and drifted from near (89°N, 1.8°E) to (88.2°N, 9.4°W) (Figure 1) (Tjernström et al. 2004). Surface shortwave and longwave radiative fluxes at 5-min intervals during 3–19 August 2001 are obtained to generate hourly averages.

Arctic Summer Cloud Ocean Study in 2008 (ASCOS): Extensive measurements were taken during the ASCOS project in the central Arctic Ocean when an ice camp was set up on 12 August at (87.4°N, 1.5°W) and remained in operation through to 1 September, associated with ice drifting (Figure 1) (Tjernström et al. 2014). Surface shortwave and longwave radiative fluxes at 10-min intervals from 13 August to 1 September 2008 are obtained to generate hourly averages.

Barrow Alaska Observatory (BRW): Measurements close to sea ice have been maintained at the northernmost point of the United States (71.32°N, 156.61°W) (Figure 1) since a weather observing facility was established in 1973 in Barrow (Druckenmiller et al. 2009). Hourly surface shortwave and longwave radiative fluxes from 26 April 1993 to 31 December 2013 are available (http://www.esrl.noaa.gov/gmd/obop/brw/summary.html).

3. Results

Figure 2 shows the spatial distribution of the climatology of NETSRF during summer (May, June, July, and August) and autumn-to-winter (September, October, November, and December) for the period 1984–2007. During the melting period, SRB shows that there is a net radiation surplus, which decreases poleward by ~50–60 W m⁻² in the central Arctic Ocean (except a relatively high-value area near the pole with ~55–75 W m⁻²); ~50–85 W m⁻² over an arc around the periphery of the Arctic basin, extending from north of Alaska to north of western Siberia; and ~90–170 W m⁻² in the sea-ice edge zone (Figure 2(a)). The pattern of ISCCP’s NETSRF also shows a net radiation surplus decreasing poleward, but the magnitude of the ISCCP’s NETSRF is 10 W m⁻² less than that of SRB over much of the Arctic Ocean.
of the Arctic Ocean (Figure 2(b)). The two-time average of PP-x also shows a similar NETSRF distribution, but with a larger magnitude of NETSRF than that of SRB and ISCCP (Figure 2(c)). During the freeze-up period, SRB exhibits a net radiation deficit of ~10–25 W m⁻² in the Arctic Ocean and ~30–50 W m⁻² in the sea-ice edge zone (Figure 2(d)). ISCCP's NETSRF is similar to that of SRB in terms of both the magnitude and pattern, although ISCCP's NETSRF is ~10–20 W m⁻² larger in the ice-edge zone, especially the North Atlantic sector (Figure 2(e)). The two-time average of APP-x shows a net radiation deficit of ~15–25 W m⁻² in the central Arctic, but a smaller radiation loss in the southern Beaufort, Chukchi and eastern Siberia seas (~0–10 W m⁻²; Figure 2(f)). The SRB and ISCCP data have a 3-h temporal resolution, which can capture the daily cycle. The averaged net surface radiative flux of SRB and ISCCP in Figure 2(a) and (b) is calculated using 3-h data, which represents the daily mean. Unfortunately, the APP-x product provides twice-daily data at 0400 and 1400, local time (LT), which cannot capture the daily cycle. The averaged net surface radiative flux of APP-x in Figure 2(c) is calculated based on the two-time average, which cannot be considered as the daily mean. So, the two-time average of APP-x shows much larger (smaller) values of NETSRF in May–August (September–December) than those of SRB and ISCCP.

Statistical comparisons between the satellite-derived and in situ measured NETSRF, as well as each flux component, are presented in Table 1, including the bias, root-mean-square error (RMSE), and correlation. The bias, RMSE, and correlation between the satellite products and in situ observations are calculated for the time periods that the in situ observations are available (see Figure 3 for further detail). The locations for the comparisons are shown in Figure 1.

Table 1. Comparisons between the satellite-derived and in situ-measured NETSRF, as well as each flux component, including bias, RMSE, and correlation (bold denotes correlation that is statistically significant at the >99% confidence level).

|                  | SWD | SWU | LWD | LWU | netSW | netLW | NETSRF |
|------------------|-----|-----|-----|-----|-------|-------|--------|
| SHEBA Bias SRB   | 3.3 | −18.1 | −3.1 | −0.1 | 21.4   | −3.0  | 18.4   |
|                  | ISCCP | 2.4 | −10.2 | 9.4  | 4.8    | 12.6  | 4.6    |
|                  | APP-x | 10.2 | −6.7  | −7.4 | −1.1   | 16.9  | −6.3   |
| RMSE SRB 66.8    | 54.7 | 43.4 | 16.5 | 41.3 | 35.1   | 43.1  |
|                  | ISCCP | 54.6 | 44.4 | 22.5 | 30.0   | 27.1  | 34.9   |
|                  | APP-x | 75.7 | 50.9 | 15.4 | 43.0   | 28.3  | 38.2   |
| Corr SRB 0.89     | 0.88 | 0.74 | 0.96 | 0.83 | −0.02  | 0.75  |
|                  | ISCCP | 0.93 | 0.92 | 0.75 | 0.93   | 0.86  | 0.81   |
|                  | APP-x | 0.9  | 0.91 | 0.82 | 0.96   | 0.83  | 0.86   |
| AOE01 Bias SRB   | 30.1 | −20.1 | −33.5 | −14.8 | 50.2   | −18.7 | 31.5   |
|                  | ISCCP | 29.3 | 5.9  | −26.0 | −17.6  | 23.4  | −8.4   |
|                  | APP-x | 23.9 | −31.9 | −16.9 | 0.9    | 55.8  | −17.9  | 37.9   |
| RMSE SRB 72.5     | 50.1 | 41.8 | 16.7 | 58.3 | 32.1   | 44.7  |
|                  | ISCCP | 55.5 | 39.5 | 30.5 | 18.3   | 27.1  | 21.3   |
|                  | APP-x | 68.5 | 50.3 | 29.5 | 5.6    | 63.8  | 27.9   | 43.3   |
| Corr SRB 0.42     | 0.38 | 0.34 | 0.59 | 0.39 | 0.27   | 0.28  |
|                  | ISCCP | 0.48 | 0.43 | 0.56 | 0.46   | 0.52  | 0.46   | 0.16   |
|                  | APP-x | 0.28 | 0.27 | 0.04 | 0.13   | 0.2   | 0.16   | 0.22   |
| ASCOS Bias ISCCP | 27.6 | 5.3  | −25.4 | −9.6  | 22.3   | −15.8 | 6.5    |
|                  | APP-x | 25.1 | −8.8 | −15.3 | 33.1   | −26.8 | 7.0    |
| RMSE ISCCP 54.3   | 32.1 | 35.7 | 14.6 | 29.9 | 24.5   | 19.2  |
|                  | APP-x | 55.5 | 30.6 | 56.6 | 18.1   | 42.0  | 21.4   | 22.5   |
| Corr ISCCP 0.37   | 0.35 | 0.28 | 0.3  | 0.24  | 0.15   | 0.57  |
|                  | APP-x | 0.13 | 0.2  | 0.41 | 0.66   | −0.09 | 0.19   | 0.56   |
| BRW Bias SRB 7.9  | −7.9 | 0.3  | −2.5  | 15.8  | 2.8    | 18.6  |
|                  | ISCCP | 7.0  | 2.4  | 8.2   | 4.6    | 7.3   | 11.9  |
|                  | APP-x | 20.55 | −0.2 | 1.3 | −9.9   | 20.8  | 11.2   | 32.0   |
| RMSE SRB 70.6     | 74.6 | 36.5 | 21.7 | 57.6 | 33.3   | 58.9  |
|                  | ISCCP | 61.1 | 53.5 | 41.3 | 22.2   | 44.4  | 31.7   | 45.9   |
|                  | APP-x | 85.8 | 79.6 | 43.4 | 28.5   | 72.1  | 36.2   | 74.7   |
| Corr SRB 0.71     | 0.6  | 0.54 | 0.59 | 0.66 | 0.24   | 0.61  |
|                  | ISCCP | 0.93 | 0.87 | 0.75 | 0.93   | 0.90  | 0.24   | 0.88   |
|                  | APP-x | 0.92 | 0.80 | 0.72 | 0.92   | 0.87  | 0.35   | 0.86   |

Notes: The bias, RMSE and correlation between the satellite products and in situ observations are calculated for the time periods that the in situ observations are available (see Figure 3 for further detail). The locations for the comparisons are shown in Figure 1. SWD, downward shortwave flux; SWU, upward shortwave flux; LWD, downward longwave flux; LWU, upward longwave flux; netSW, net shortwave flux (SWD minus SWU); netLW, net longwave flux (LWD minus LWU); NETSRF, net surface radiative flux (netSW plus netLW). Units: W m⁻².

Comparison with the SHEBA observations shows that the overall bias of SRB’s NETSRF is 18.4 W m⁻² (RMSE of
43.1 W m⁻²). The large positive bias is primarily contributed by a large positive bias in the net shortwave flux (21.4 W m⁻²; Table 1). ISCCP’s NETSRF has a mean bias of 17.1 W m⁻² (RMSE of 34.9 W m⁻²), which results from positive biases of both the net shortwave flux (netSW) and net longwave flux (netLW). APP-x’s NETSRF yields a mean bias of 10.6 W m⁻² (RMSE of 38.2 W m⁻²). Although the overall bias of APP-x is smaller than those of SRB and ISCCP, it results from a cancelling out of large positive netSW bias (16.9 W m⁻²) and small-to-moderate negative netLW bias (−6.3 W m⁻²). Figure 3 is a scatterplot between the satellite-based and in situ measured NETSRF. We note that, for SRB, there is a spike near 0 W m⁻² on the x-axis (Figure 3(a)). This means that SRB has a problem capturing the observed small values of NETSRF, and this is also reflected slightly in ISCCP and APP-x (Figure 3(b) and (c)). In addition, APP-x clearly overestimates observed net surface radiative flux greater than ~80 W m⁻² (Figure 3(c)). Overall, from the aspect of bias, RMSE and correlation, the NETSRF of ISCCP and APP-x are relatively closer to that from SHEBA observations.

Compared with the AOE01 observations, the overall biases of NETSRF for both SRB and APP-x are very large, at 31.5 W m⁻² for SRB and 37.9 W m⁻² for APP-x (RMSE of 44.7 W m⁻² for SRB and 43.3 W m⁻² for APP-x). Moreover, the very large positive biases result from a cancelling out of excessively large positive net shortwave flux (50.2 W m⁻² for SRB and 55.8 W m⁻² for APP-x) and large negative net longwave flux (~18.7 W m⁻² for SRB and ~17.9 W m⁻² for APP-x). The overall bias of ISCCP’s NETSRF (15.0 W m⁻², with an RMSE of 21.3 W m⁻²) is about two times smaller than those of SRB and APP-x, which results from the cancelling out of large (absolute value greater than 20 W m⁻²) positive net shortwave flux and moderate (absolute value between 10 W m⁻² and 20 W m⁻²) negative net longwave flux. As shown in Figure 3(d), SRB’s NETSRF tends to cluster around 30.0 W m⁻² on the x-axis for almost all y values, which is not present in ISCCP and APP-x. The NETSRF of both ISCCP and APP-x correlates weakly with AOE01, but ISCCP has much higher correlations for both netSW and netLW than those of SRB and APP-x. Overall, the NETSRF of ISCCP is closer to that from AOE01 observations.

Comparison with ASCOS observations shows that ISCCP has a small-to-moderate mean bias of 6.5 W m⁻² (RMSE of 19.2 W m⁻²), which is due to the cancelling out of large positive bias in netSW and moderate negative bias in netLW. The mean bias and RMSE of APP-x’s NETSRF are comparable to those of ISCCP, and the mean bias is also derived from the cancelling out of large positive netSW and negative netLW, which are larger than those of ISCCP. The NETSRF of ISCCP and APP-x has similar correlation with ASCOS. Overall, the NETSRF of ISCCP is closer to ASCOS observations in terms of the bias magnitude of each flux component.

SHEBA, AOE01, and ASCOS only provide NETSRF for short-term periods. Therefore, we further assess the accuracy of NETSRF for the three satellite products against the long-term continuous observations of BRW, which is very close to sea ice. Compared with the BRW observations, all three datasets are highly correlated with respect to NETSRF. SRB has a moderate mean bias of 18.6 W m⁻², which is primarily derived from the netSW bias. APP-x has a large mean bias of 32.0 W m⁻², which is due to the combined biases of netSW and netLW. ISCCP’s NETSRF, meanwhile, has the smallest mean bias (11.9 W m⁻²) and RMSE (45.9 W m⁻²) relative to those of SRB and APP-x. Overall, ISCCP gives the best statistics for NETSRF.

Next, we examine the bias by time of day for the satellite-based NETSRF (eight times for SRB and ISCCP; two times for APP-x). Compared to SHEBA, the NETSRF differences by time of day for SRB and ISCCP both show clear diurnal variation, with a large difference between 0400 LT and 1400 LT for APP-x. As shown in Figure 4(a), the largest bias occurs in the early afternoon (32.8 W m⁻² for SRB, 28.7 W m⁻² for ISCCP, and 21.6 W m⁻² for APP-x), while the smallest bias occurs after midnight (2.0 W m⁻² for SRB, 8.0 W m⁻² for ISCCP, and −0.5 W m⁻² for APP-x). Thus, the range of the bias diurnal variation for SRB is ~10 W m⁻² larger than that of ISCCP and the two-time difference of APP-x. As shown in Figure 4(b), the large diurnal variation of the netSW bias plays a dominant role in the NETSRF bias diurnal variation for SRB and ISCCP; plus, the two-time large difference of the NETSRF bias also originates from the netSW bias for APP-x. Overall, ISCCP and APP-x are relatively closer to the SHEBA observations.

When compared with AOE01, the NETSRF bias also shows a large diurnal variation for SRB and a large two-time difference for APP-x; whereas, the diurnal variation of the bias is not obvious in ISCCP (Figure 4(d)). For SRB, it is mainly modulated by the large diurnal variation of the netLW bias (Figure 4(f)). For APP-x, it is due to the unbalanced two-time bias for both netSW and netLW (Figure 4(e) and (f)). The range of the bias remains at ~20 W m⁻² for APP-x (from 27.5 W m⁻² to 49.9 W m⁻²), but is greatly enhanced for SRB, reaching ~58 W m⁻² (from ~9.3 W m⁻² to 48.2 W m⁻²). By contrast, the bias of ISCCP varies from 7.0 W m⁻² to 20.8 W m⁻². Thus, ISCCP is more accurate for NETSRF against AOE01 observations.

Compared to ASCOS, the NETSRF bias diurnal variation is evident in ISCCP with a range of ~32 W m⁻², which primarily results from the large diurnal variation of the netSW bias (Figure 4(h)). By contrast, the bias of APP-x is ~7 W m⁻² at both times (Figure 4(g)), which is due to the bias balance from netSW and netLW (Figure 4(h) and (i)). Thus, APP-x is in better agreement with ASCOS observations.

As shown in Figure 4(j), the NETSRF bias diurnal variation is also present in ISCCP and SRB, and the two-time
Figure 3. Scatterplots of the satellite-derived NETSRF (y-axis; units: W m$^{-2}$) against in situ measured net surface radiative flux (x-axis; units: W m$^{-2}$). (a) SRB vs. SHEBA; (b) ISCCP vs. SHEBA, using data at 3-h intervals; and (c) APP-x vs. SHEBA, using data at 0400 and 1400 LT 31 October 1997 to 28 September 1998. (d) SRB vs. AOE01; (e) ISCCP vs. AOE01, using data at 3-h intervals; and (f) APP-x vs. AOE01, using data at two LTs for 3–19 August 2001. (g) ISCCP vs. ASCOS, using data at 3-h intervals; and (h) APP-x vs. ASCOS, using data at two LTs for 15 August to 1 September 2008. (i) SRB vs. BRW; (j) ISCCP vs. BRW, using data at 3-h intervals; and (k) APP-x vs. BRW, using data at two LTs for 26 April 1993 to 31 December 2007.
difference in the NETSRF bias for APP-x is large, when compared with the long-term BRW observations. The range of the diurnal variation remains at ~20 W m$^{-2}$ for ISCCP, but is enhanced for SRB (47.6 W m$^{-2}$), which mainly results from the large variation in netSW bias. Also, the two-time difference is large for APP-x (34.4 W m$^{-2}$), which is modulated by the large bias of netSW (Figure 4(k)). Overall, ISCCP is closer to the BRW observations.

Finally, we examine interannual variability of the NETSRF bias for the three satellite products by taking advantage of more than 20 years of records from the BRW site (1993–2007). The average standard deviations of SRB and ISCCP are close to that of the in situ data in general, and is larger for APP-x when compared to the in situ data. More specifically, the standard deviations of the interannual biases for BRW and the corresponding satellite-derived datasets and their ratios are as follows: BRW, 88.48 W m$^{-2}$; SRB, 84.70 W m$^{-2}$; ratio of SRB and BRW, 0.957; BRW, 92.01 W m$^{-2}$; ISCCP, 89.09 W m$^{-2}$; ratio of ISCCP and BRW, 0.968; BRW, 101.79 W m$^{-2}$; APP-x, 128.91 W m$^{-2}$; ratio of APP-x and BRW, 1.267. Moreover, the bias between ISCCP and BRW shows a relatively steady variability (Figure 5), with a standard deviation of 9.59 W m$^{-2}$ for the period 1993–2007. This compares to a standard deviation of 18 W m$^{-2}$ for the SRB and BRW bias, and 14.85 W m$^{-2}$ for the APP-x and BRW bias. On the whole, the NETSRF of ISCCP is more accurate than that of SRB or APP-x.

4. Discussion and conclusion

Recently, a merged data-set containing a suite of satellite, reanalysis, and in situ products from 1979 to the present has been released. From this, a schematic diagram of the energy budget for the Arctic was produced (Christensen et al. 2016), but with no detailed bias information. In this study, we set out to identify which satellite product is best, which would be useful when employing the datasets to evaluate NETSRF over the Arctic Ocean in Coupled Model Intercomparison Project simulations. This evaluation provides a snapshot of the accuracy and uncertainty of NETSRF over the Arctic, focusing on the ice-covered ocean for three current-day satellite-derived products (SRB, ISCCP and APP-x). These satellite flux products are widely used to force coupled sea-ice–ocean models, evaluate the simulation of fully coupled climate system models, understand physical processes, and study climate variability and change. Owing to temporal and spatial limitations, the datasets used in this study are insufficient. Therefore,
we collected related in situ data to cover as many Arctic areas and time periods as possible.

The three satellite products are evaluated against four sets of in situ measurements obtained from different locations in the Arctic, including SHEBA, AOE01, ASCOS, and BRW. Our comparisons suggest that the NETSRF of ISCCP is closer to in situ observations relative to SRB and APP-x, based on the statistics of overall bias, RMSE, and correlation. It is not very clear, however, which satellite product is superior to the others from the perspective of the diurnal variation of the averaged bias. Nonetheless, based on the interannual variability of the averaged bias, the NETSRF of ISCCP is more accurate than that of SRB or APP-x.

Although the results of this study indicate ISCCP might agree better with in situ measurements relative to SRB or APP-x, it is not entirely clear to what extent this can be generalized to the entire ice-covered Arctic. More in situ measurements over the ice-covered ocean are needed to validate satellite flux products. Nevertheless, our results provide useful information to the community (e.g. the Arctic System reanalysis project (Lindsay et al. 2014)) as to which data-set may provide the smallest bias in NETSRF, as well as its four components (Table 1).

Recently, an overview of the challenges involved in obtaining high-latitude ocean and sea-ice surface flux data was provided by the U.S. CLIVAR Working Group on High-Latitude Surface Fluxes Workshop (Bourassa et al. 2013; Gille, Bourassa, and Clayson 2010). The workshop summarized key needs for improving high-latitude fluxes—particularly, developing improved satellite flux observations. The workshop also recommended accuracy requirements for surface fluxes related to spatial and temporal scales for high-latitude processes, i.e. for sea ice, a 1 W m⁻² flux imbalance equates to a 10 cm ice melt in a year (a significant fraction of the ice budget). To improve our understanding and ability to model feedback mechanisms in the Arctic, a heat-flux accuracy of 10 W m⁻² is desirable. Our evaluation shows that substantial discrepancies remain between the studied satellite products and in situ measurements, and among the satellite products. For example, compared to in situ measurements, all three satellite-derived products show diurnal variation in the NETSRF bias, with the largest bias in early afternoon and the smallest before or after midnight. Clearly, the input data into the radiative transfer calculations for the three satellite-derived products, including cloud and surface properties, as well as thermodynamic profiles, have critical impacts on the radiative flux estimates. Further investigations of these properties (i.e. cloud fraction, surface albedo) are needed to better understand the causes leading to the discrepancies between these satellite products and in situ measurements, and among the satellite products, to reduce the levels of uncertainty. Additionally, more in situ measurements over the ice-covered ocean are needed to validate satellite flux products and support continuing algorithm improvements.

**Acknowledgments**

We thank Ola PERSSON and Chris FAIRALL for providing the SHEBA and AOE01 data, and Ian BROOKS for providing the ASCOS data.

**Funding**

This research is supported by the National Major Research High Performance Computing Program of China [grant number 2016YFB0200800]; the National Natural Science Foundation of China [grant number 41676185]; and the NOAA Climate Program Office [grant number NA14OAR4310216].

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