Contrasting ARM's SRB Measurements with Six SURFRAD Stations

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Introduction

The Surface Radiation Budget Network (SURFRAD) was established in 1993 by the National Oceanic and Atmospheric Administration's (NOAA's) Air Resources Laboratory (ARL). Site selection was a collaborative effort among NOAA, National Aeronautics and Space Administration (NASA), and university scientists; locations were chosen to represent diverse climates of the United States. Four initial SURFRAD stations were installed in late 1994 and 1995 at Bondville, Illinois; Fort Peck, Montana; Goodwin Creek, Mississippi; and Boulder, Colorado (Table Mountain). Two new stations were installed in 1998 at Desert Rock, Nevada, and in central Pennsylvania (Penn State). Information regarding the SURFRAD network and access to its data may be found at http://www.srrb.noaa.gov. The geographically and climatologically diverse SURFRAD network nicely complements a dense grouping of 25 surface radiation budget (SRB) stations at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site in Oklahoma and Kansas. The Baseline Solar Radiation Network (BSRN) station referred to in this work is located at the central facility of the SGP site near Billings, Oklahoma, in a flat agricultural area. These stations sample the SRB for climates ranging from arid to temperate (Table 1). It is the purpose of this paper to compare and contrast their surface radiation characteristics.

Radiation measurements at the BSRN and SURFRAD stations cover the range of the electro-magnetic spectrum that affects the earth/atmosphere system. All four components of the SRB, downwelling and upwelling solar, and downwelling and upwelling infrared (IR), are measured independently. The basis for the comparisons in this work is net radiation, defined as downwelling minus upwelling radiation, and is computed as net IR, net solar, and total net (net solar + net IR). Albedo, defined as upwelling solar divided by downwelling solar, is also compared. Monthly averages are presented. These are computed by averaging 3-minute computed values of net radiation and albedo over the monthly periods. The net radiation averages include nighttime values; whereas the albedo averages only include data for solar zenith angles less than 75°.

Table 1. Station information.

Station Name	Latitude, Longitude	Annual Rainfall (cm)	Elevation (m)	Climate (Köppen-Geiger)
Bondville	40.06°N, 88.37°W	94	213	Cfa (temperate)
Fort Peck	48.31°N, 105.10°W	30	634	Bsk (semiarid)
Goodwin Creek	34.25°N, 89.87°W	145	98	Cfa (temperate)
Table Mountain	40.125°N, 105.237°W	46	1689	Bsk (semiarid)
Desert Rock	36.626°N, 116.018°W	18	1007	BWk (arid)
Penn State	40.72°N, 77.93°W	99	376	Cfa (temperate)
BSRN	36.62°N, 97.50°W	84	318	Cfa (temperate)

Monthly Summaries of Net Radiation

Figure 1 contrasts the mean monthly net radiation of each SURFRAD station with that of the BSRN station for 1998. Upon close inspection, it is evident that variations in moisture availability and clouds account for the disparity in net radiation among the stations; however, differences owing to latitude are also evident. Annual traces of net IR, net solar, and total net radiation for Goodwin Creek, Bondville, and Penn State are similar to those of the BSRN site. The likely reason for this similarity is that all four of these locations are relatively moist. The annual cycle of net solar radiation at the wettest station, Goodwin Creek, is fairly symmetric around the period of high sun in June. High moisture availability and prevalent cloudiness throughout the year are reflected in a relatively flat annual trace of modest net IR. The smallest magnitude of net IR occurs in winter at Goodwin Creek, indicating that the cold season there is a period of increased cloudiness and/or relatively cold ground. Note that the peak in total net radiation is about +175 Wm^{-2} in June of 1998, and that it never goes negative in winter, owing to high moisture and the low latitude of Goodwin Creek. Because the climates of Bondville and Penn State are also moist, their annual traces of surface net IR radiation are similar to Goodwin Creek's, i.e., flat with the least net surface exchange occurring in winter when the ground is cool. Annual variations of net solar and total net radiation at Penn State and Bondville are also similar to Goodwin Creek, although the total net for these two stations goes slightly negative in December. This is most likely because they are well north of Goodwin Creek. Goodwin Creek also appears to be cloudy in the late winter of 1998, as demonstrated by the sharp decrease in the magnitudes of net IR and net solar from October to December. At the BSRN site, the net IR is systematically less, and the net solar is typically higher than those of the three moist SURFRAD stations. This suggests that the BSRN site is on average less cloudy than those stations all year long.

The dry SURFRAD stations (Fort Peck, Table Mountain, and Desert Rock) show the greatest contrast with the BSRN station, especially with regard to net IR. The magnitude of net IR at the dry SURFRAD stations is typically greater than that of the BSRN station throughout the year because the lack of moisture allows for greater radiational cooling. The most pronounced exception to this is in the cold season at Fort Peck where the net IR is greater than that of the BSRN station for several months. This may be caused by more clouds in the winter, very cold surface temperatures, persistent snow cover, or a combination of all of these conditions. The largest magnitudes of net IR in summer at the dry stations correspond to the summer maximum in net solar radiation. It is the relative lack of clouds and high sun

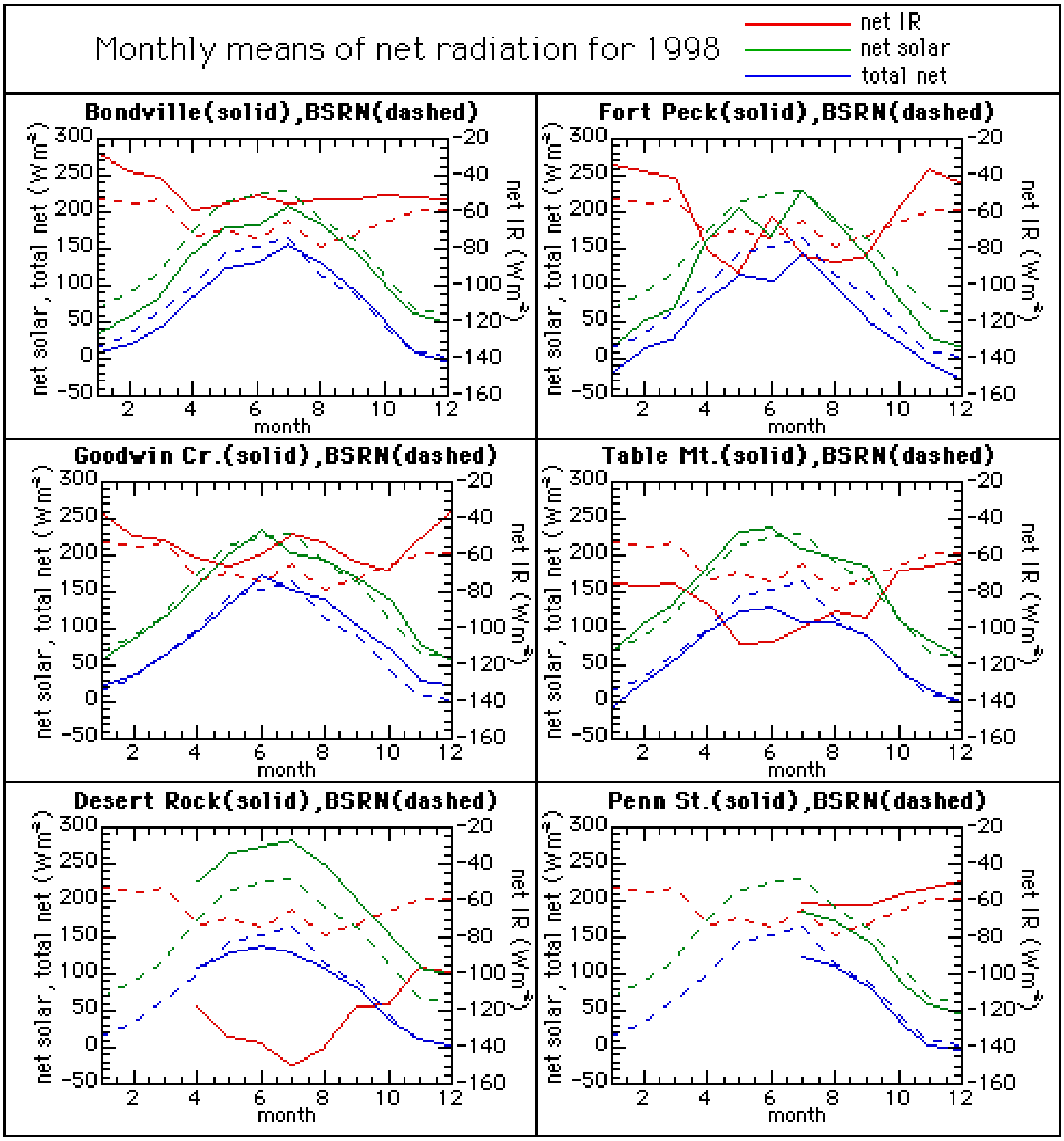

Figure 1. Comparison of mean monthly net solar, net infrared, and total net radiation between SURFRAD stations (solid) and the BSRN station (dashed) for 1998. Note that the scale for net IR is on the right.

during that period that permits more solar energy to reach the surface, however, clear skies and a dry atmosphere also lead to greater radiational cooling. Typical mid-summer differences in net IR between the dry SURFRAD stations and the BSRN station are 20 Wm^{-2} to 40 Wm^{-2}; however, note the near 85-Wm^{-2} difference in July between Desert Rock and the BSRN station. Fort Peck again is the exception, but only for one month. The net solar at Fort Peck slopes anomalously downward from May to June, and there is a corresponding rise in net IR during that period, becoming less than the BSRN's net IR for June. This seemingly anomalous change is most likely due to abnormal cloudiness at Fort Peck during June of 1998.

Considering the differences in climate among the SURFRAD and BSRN stations, their annual traces of total net radiation show remarkably little intra-annual variation (Figure 2). Generally, net radiation minima are near zero in winter and maxima are near +150 Wm^{-2} in summer. At least on the monthly scale, the phases of the annual cycles of the stations' total net radiation are quite similar, with maxima in June/July and minima in December/January. However small anomalies in isolated years at individual stations are evident. Note that the peak in total net radiation in July 1998 at Goodwin Creek (that was discussed earlier) appears to be anomalous, i.e., the July maxima in 1995, 1996, and 1997, are all lower than that of 1998. Another is the anomalously low total net radiation during the January, February, and

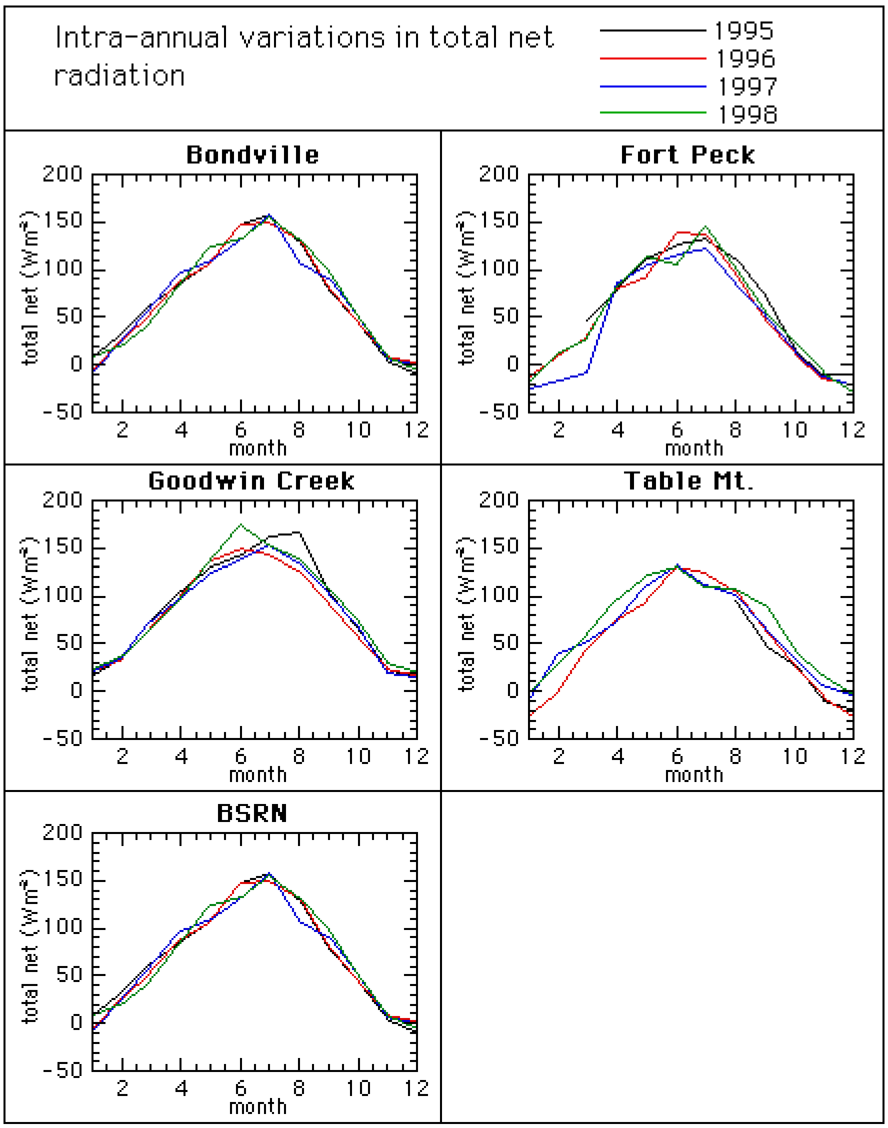

Figure 2. Intra-annual variations of mean monthly total net radiation at four SURFRAD stations and the ARM BSRN station in Oklahoma for 1995, 1996, 1997, and 1998.

March of 1997 at Fort Peck, which corresponds to the last three months of a 5-month period of constant snow cover (see Figure 3). Regardless of these temporary aberrations, it is interesting that the differing effects of latitude, moisture availability, and cloudiness among the stations combine to produce annual total net radiation traces that are similar, in the mean. Table Mountain is somewhat the outlier with consistently less monthly net radiation than the other sites. This is apparently due to its aridity; however, the difference is not great. It is suspected that Desert Rock will exhibit less total net radiation than Table Mountain because of the persistent hot, dry, and cloudless conditions there.

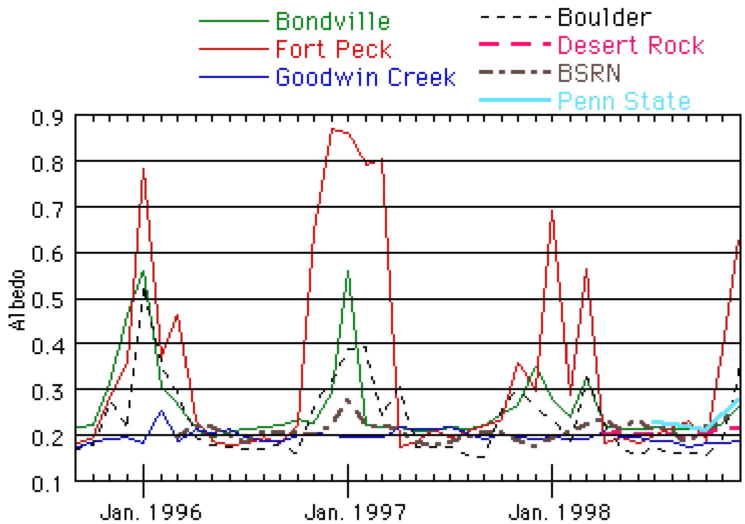

Figure 3. Time series of mean monthly surface albedo at four SURFRAD stations and the ARM BSRN station in Oklahoma from September 1996 through 1998.

Figure 3 presents a time series of mean monthly albedo for the BSRN and SURFRAD stations. These plots show relative stability in the surface albedo during the warm season and high variability in winter. Values range from 0.87 to 0.16, which is acceptable given that the largest values are at Fort Peck in winter—a time of large solar zenith angles and prevalent snow cover. It is interesting that part of the rationale for choosing Fort Peck was its high intra-annual variability of snow cover, which has certainly revealed itself over the station's first four years. Although its record is short, the least annual variation in surface albedo is at Desert Rock where snow is rare and the ground cover changes little throughout the year. The lowest albedo is found at Table Mountain in late summer. There the vegetation undergoes a marked variation through the warm season; it is lush and green in the spring, and by late summer it is sparse and brown. In response, the albedo decreases by 1% to 2% over that period. Evidence of this subtle systematic summertime variation in albedo also shows up at Goodwin Creek where the grass surface also may go through a similar seasonal cycle.

Summary and Conclusions

Six surface radiation budget stations of the SURFRAD network have been operating over the United States since 1995. A BSRN SRB station has also been operating at the central facility of the ARM SGP site in Oklahoma for the same period. Time series of monthly averages of net radiation were computed as a way to compare and contrast the BSRN and SURFRAD stations. They show differences attributable to latitude, moisture availability, ground temperature, snow cover, and cloudiness. Surface radiation characteristics of the Goodwin Creek, Penn State, and Bondville SURFRAD stations compare best to the BSRN station because they share relatively moist conditions, and evince these properties through relatively flat annual cycles of low-magnitude net IR. Although, the BSRN station appears to be less cloudy than the moist SURFRAD stations. The dry SURFRAD stations at Table Mountain, Fort Peck, and Desert Rock show greater net IR losses than the BSRN station, but also exhibit larger net gains of solar radiation owing to less cloudiness. These counteracting effects appear to make the annual cycles of total net radiation similar at all stations. Mean monthly albedos for the warm season range from 16% to 24% among these seven stations, but during the cold season there are large variations in albedo depending on the persistence of snow cover.

With these careful, accurate long term surface radiation measurements of the SRB, a baseline is being established from which regional climate changes may be tracked. This is in addition to these networks' obvious value to satellite and model validation efforts. It is encouraging that the U.S. Department of Energy (DOE) and NOAA have recognized the need for these complementary long-term measurement programs, and continue to support them.