VIC / GOES Radiation Evaluation

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Abstract

A recently published paper by Roads et al (2003) describing the GCIP Water and Energy Balance Synthesis (WEBS) showed that the Variable Infiltration Capacity model (VIC) model under-simulates “observations” of net solar radiation by an average of 50 w/m² in the summer months of 1996-1999 over the Mississippi basin. The net solar radiation “observations” used by Roads et al (2003) are a GOES-based satellite data set produced by the University of Maryland. The “VIC” values were in fact produced by Maurer et al (2002) as VIC model forcings (hence are unrelated to the VIC model) using the algorithm of Thornton and Running (1999), which is based on the daily temperature range (we nonetheless refer herein to the Thornton and Running values as “VIC” as do Roads et al). This note diagnoses downward shortwave and net shortwave radiation values over the Mississippi basin and at the six SURFRAD locations across the U.S. Averaged over the Mississippi in June, July, and August of 1998 we found a 40 to 50 w/m² net radiation deficit between VIC and GOES, as did Roads et al (2003). However, for downward shortwave radiation, the difference on average was about 20 w/m²; the balance of the difference was attributed to a large (factor of 2) difference in albedo between that used by GOES and VIC. A comparison of GOES albedos with SURFRAD observations, and values used in the LDAS versions of the NOAH, and Mosaic models, indicates that the GOES albedo is low relative to both observations and other models. Both VIC and GOES downward solar radiation values were compared to SURFRAD measurements, which showed that VIC was closer to the observed daily averages (especially for summer 1998), while GOES better reproduced daily peaks.
Introduction / Approach

Roads et al (2003) compare various predictions of water and energy budget terms over the Mississippi River basin produced by coupled land-atmosphere models, and uncoupled runs of the VIC model, the latter described by Maurer et al (2002). This note focuses on differences noted by Roads et al (2003) between VIC solar radiation (actually predicted downward solar radiation based on the temperature range-based algorithm of Thornton and Running (1999), a satellite-based (GOES) product from the University of Maryland, and direct observations at SURFRAD sites, all during the time period 1996-1999. For the VIC and GOES products, the domain is the Mississippi basin. Figure 1 shows the study domain as well as the locations of the six U. S. SURFRAD stations, of which five lie within the Mississippi basin.

![Figure 1: Mississippi River Basin as represented by VIC 1/8 degree grid with locations of SURFRAD stations](image)

The basis of the analysis conducted here is Figure 7.4 of Roads et al (2003), reproduced here as Figure 2 (taken from [http://ecpc.ucsd.edu/gcip/webs.htm](http://ecpc.ucsd.edu/gcip/webs.htm)), which compares net solar radiation from the GOES product (from Rachel Pinker and colleagues at the University of Maryland). The Pinker et al product is labeled in Roads et al (2003) as “observations”. The apparent low bias of VIC is important, as the Maurer et al (2002) data are for a 50-year simulation over the period 1950-2000, most of which predates the availability of satellite solar radiation data. If the source of biases in the VIC forcing data can be identified, it might be possible to adjust them to improve model simulations over the entire 50 year period.
The data used in Figure 2 is identical to that used by Roads et al (2003). The GOES data are from (http://ecpc.ucsd.edu/gcip/data/obs/pinker/nswsfc.dat). The VIC data are from the Maurer et al (2002) 1/8’ LDAS retrospective (http://ecpc.ucsd.edu/gcip/data/models/vic/summary/mongrid.ts) archive.

The above archive of the data used by Roads et al (2003) includes only GOES net shortwave radiation for the period 1996 - 1999. Because we are also interested in downward shortwave radiation, we tried to first recreate the Roads et al (2003) GOES net shortwave radiation values based on GOES data extracted from the University of Maryland web site www.atmos.umd.edu/~srb/gcip/ (hereafter referred to as UMD GOES). If we can do this accurately, we then have confidence that the other data we want to examine (other than net shortwave) are consistent with the Roads et al (2003) data. We did this for June, July, and August (JJA) 1998 by multiplying the UMD GOES monthly incoming shortwave radiation by one minus the UMD GOES monthly albedo. We chose this period because we were interested in summertime values when solar radiation is most significant and because the UMD albedo values are only available for 1997 and 1998.

Figure 3 shows average JJA 1998 net shortwave radiation for a) 1/8 degree VIC from the retrospective LDAS archive described by Maurer et al (2002), b) ½ degree GOES from Roads et. al (2003) and c) ½ degree UMD GOES incoming monthly shortwave multiplied by one minus UMD GOES monthly albedo.
The VIC LDAS data have a daily basin average of 198 w/m², the GOES data from Roads et al (2003) paper have an average of 245 w/m², and the GOES data extracted from the UMD web site have an average of 239 w/m². The difference between the Roads et al and the UMD GOES data is most likely attributable to the non-linear effects in the temporal averaging of the product of albedo and incoming shortwave radiation. The two GOES products are close enough to give us confidence that differences in the satellite extraction algorithms (which we are aware have changed several times) are minor enough not to have a major effect on our analysis.

Figure 3: JJA 1998 net shortwave radiation from Maurer et al (2002), Roads et al (2003) and inferred from GOES U. of Maryland data (w/m²).
The differences between the VIC and GOES net solar radiation values could stem either from different albedos and/or different downward shortwave radiation values. Because no downward shortwave radiation or albedo values were reported by Roads et al. (2003) paper, we based our comparisons on the UMD GOES data (from their web site) and our archives of the Maurer et al. (2002) VIC data.

Figure 4 shows downward shortwave radiation values for the same domain in the same time period as Figure 3. The spatial patterns are similar, however, VIC has a daily basin average of 245 w/m² while the mean of the UMD GOES data is 264 w/m² – a difference of 19 w/m², as compared with a 41 or 47 w/m² difference (depending on the source of the data) in the net solar radiation. An obvious question is, why is the difference in net solar so much larger than in downward solar?

Figure 4: JJA 1998 downward shortwave radiation from Maurer et al and GOES product from University of Maryland data (w/m²).
Clearly, the difference has to do with albedo, which is much smaller for the GOES product than for VIC (see below).

**Downward Shortwave Radiation**

The most reliable source of measured incoming (downward) and net shortwave radiation in the U.S. is the SURFRAD network. It consists of six sites, five of which are in the Mississippi basin, and four of which have complete records for JJA 1998. We compared the average diurnal cycle (3 hr time-step) for VIC-simulated, UMD GOES, and SURFRAD observations at these four locations (Figure 5).

![Figure 5: Comparison of mean diurnal cycle of downward and net solar radiation for JJA 1998 at four SURFRAD sites in Mississippi River basin from observations, and overlying grid cell from VIC and GOES. SURFRAD data taken from http://www.srrb.noaa.gov/surfrad/index.html](image-url)
As shown in Maurer et al (2002), VIC underestimates daily peaks of incoming and net radiation but represents the daily average quite well. The UMD GOES product estimates the downward daily shortwave peak quite well but overestimates the daily average. The UMD GOES product significantly overestimates both the net solar radiation peak and daily average. Table 1 shows the average of the daily average of net and downward shortwave for JJA 1998 averaged over the four sites.

We performed a similar analysis for JJA of 1999 (Table 2). For this period, data were available for all six SURFRAD stations. However, UMD GOES albedo is available for only 1997 and 1998, so we were unable to back out net shortwave from the downward. Looking at 1999, we see that the VIC averages are again quite similar to the SURFRAD observations. The average UMD GOES downward shortwave values in 1998 were 17 w/m² high in 1998 and 3 w/m² low in 1999 relative to SURFRAD. If we make the assumption that the GOES albedo at each station did not change much and apply the 1998 values (Table 3) to this incoming shortwave, we get a GOES net shortwave radiation of 240 w/m². Even though the downward GOES shortwave matches well with the SURFRAD stations for 1999, the albedo difference would still cause an overestimation of daily average net shortwave of 24 w/m².

Table 1  Average of SURFRAD stations (fpk, gwn, bon, tbl) daily average incoming and net shortwave radiation for JJA 1998.

<table>
<thead>
<tr>
<th>w / m²</th>
<th>SURFRAD</th>
<th>VIC</th>
<th>GOES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward SW</td>
<td>248</td>
<td>249</td>
<td>265</td>
</tr>
<tr>
<td>Net SW</td>
<td>204</td>
<td>201</td>
<td>238</td>
</tr>
</tbody>
</table>

Table 2  Average of all SURFRAD stations (fpk, gwn, bon, tbl, psu, dra) daily average incoming and net shortwave radiation for JJA 1999.

<table>
<thead>
<tr>
<th>w / m²</th>
<th>SURFRAD</th>
<th>VIC</th>
<th>GOES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward SW</td>
<td>269</td>
<td>260</td>
<td>266</td>
</tr>
<tr>
<td>Net SW</td>
<td>216</td>
<td>211</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Albedo

For comparison purposes, we extracted from the LDAS archive at NCEP albedo from the NOAH and Mosaic models as run in LDAS, along with the VIC and UMD GOES values. As for VIC, we inferred albedo by taking the ratio of upward to downward solar radiation. It should be noted that there is a subtle difference between the values for VIC and the other two models – VIC inferred albedos were averaged over the diurnal cycle, whereas for the other two models we took the average of the values for 11 AM and 1 PM local time, on selected days of the month. For VIC, we know that there is no variation in albedo over the day, so this averaging makes no difference. We are not aware of whether there are diurnal differences in albedo in the other two models, although we think it likely that there are not. In any event, Figure 6 shows the resulting average albedo values for the Mississippi for JJA of 1998. The VIC and UMD GOES values are averages from all days during the period while the NOAH and Mosaic values are the average of the June 1, 15, July 1, 15, and August 1, 15, 30 values. These days were chosen to reduce the data processing time yet still give the comparable average to VIC and UMD GOES by being centered on July 15.

Figure 6: JJA 1998 Albedo from VIC, NOAH, and Mosaic models compared with GOES
The albedo patterns for VIC and NOAH are quite similar while Mosaic has the same basin average but much more spatial variability. The three models have JJA 1998 basin average albedos of 0.19, 0.20, and 0.18 for VIC, NOAH, and Mosaic, respectively. On the other hand, the UMD GOES albedo has a basin average of only 0.09. Dingman (1994) states that very few earth materials have albedos below 0.1 and that the soils and grasses that comprise the land cover of much of the Mississippi basin should have albedos more on the order of 0.2.

The most reliable in situ measurements of albedo in the U.S. should be the SURFRAD network. We compared the VIC, NOAH, and Mosaic simulated and UMD GOES average JJA 1998 albedos at the five SURFRAD sites within the Mississippi basin (Table 3).

Table 3  Simulated and measured albedo values at SURFRAD locations

<table>
<thead>
<tr>
<th></th>
<th>FPK</th>
<th>TBL</th>
<th>PSU</th>
<th>BON</th>
<th>GWN</th>
<th>AVG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFRAD</td>
<td>.21</td>
<td>.17</td>
<td>.22</td>
<td>.23</td>
<td>.18</td>
<td>.20</td>
</tr>
<tr>
<td>GOES</td>
<td>.1</td>
<td>.1</td>
<td>.1</td>
<td>.07</td>
<td>.1</td>
<td>.09</td>
</tr>
<tr>
<td>VIC</td>
<td>.20</td>
<td>.19</td>
<td>.18</td>
<td>.20</td>
<td>.19</td>
<td>.19</td>
</tr>
<tr>
<td>NOAH</td>
<td>.2</td>
<td>.2</td>
<td>.2</td>
<td>.2</td>
<td>.2</td>
<td>.20</td>
</tr>
<tr>
<td>MOSAIC</td>
<td>.24</td>
<td>.21</td>
<td>.10</td>
<td>.20</td>
<td>.20</td>
<td>.20</td>
</tr>
</tbody>
</table>

VIC, NOAH, and Mosaic match the SURFRAD measurements quite closely. The SURFRAD average of the 5 stations is .20, which compares with VIC, NOAH, and Mosaic values at the stations (overlying grid cells) of 0.19, 0.20, and 0.20, respectively. As suggested by the basin-wide comparisons, the UMD GOES albedo is apparently low by a factor of about two.
Conclusions

Although Roads et al imply that the VIC (actually Thornton et al, rescaled to the diurnal cycle) solar radiation is biased downward, this analysis suggests otherwise. Specifically:

1) The UMD GOES albedo appears to be unrealistically low (about 0.09 averaged over the Mississippi River basin, compared with about 0.19 averaged over SURFRAD sites, which quite closely matches prescribed values for summer in VIC, and inferred albedo from two other LDAS land surface schemes. Slightly more than half of the difference between VIC net solar radiation and UMD GOES reported in Roads et al is attributable to the low UMD GOES albedo;

2) For summer 1998, UMD GOES downward solar radiation exceeds the average of five SURFRAD sites by about 16 w/m², which is equivalent to most of the difference between VIC and UMD GOES net solar radiation not accounted for by the difference in albedo. The VIC daily average values match the average of the SURFRAD sites quite closely. For 1999, UMD GOES downward solar radiation is slightly less than the average of the SURFRAD sites (by 3 w/m²), but VIC is only about 6 w/m² less than UMD GOES (and 9 w/m² less than the average of the SURFRAD sites, as compared with a 16 w/m² difference between VIC and UMD GOES in 1998;

3) The VIC peak daily values do appear to be biased down somewhat; the method of rescaling the daily average predicted by Thornton and Running (1999) to the clear sky diurnal cycle bears closer scrutiny. It should be recognized though, that the Thornton and Running algorithm uses only the daily temperature range, hence no information about diurnal patterns of cloud cover (which strongly affect the diurnal patterns of solar radiation over much of the Mississippi basin in summer) is incorporated.
References;


