Variability of the total surface radiation budget and its components over the U.S. from 1996 through 2011

John A. Augustine and Ellsworth Dutton
NOAA Earth System Research Laboratory
Global Monitoring Division

Boulder, Colorado, USA
The SURFRAD Network
SURFRAD stations

Sioux Falls, SD

Desert Rock, NV

Fort Peck, MT

Penn State, PA
Analysis

• 16 years of continuous minute-scale Surface Radiation Budget and support data (1996-2011)

• Monthly averages were computed for all measured and derived quantities for each station

• Annual averages computed from monthly means

• We normalized the annual averages by computing anomalies from the long-term means
Total net surface radiation

\[ SW\downarrow - SW\uparrow + LW\downarrow - LW\uparrow \]

\[ y = 0.8171x - 1638 \]
\[ R^2 = 0.7897 \]

Total net radiation annual anomaly (Wm\(^{-2}\))


-15 -10 -5 0 5 10 15

bon_totalnet
fpk_totalnet
gwn_totalnet
tbl_totalnet
dra_totalnet
psu_totalnet
sxf_totalnet
Average TotalNet

+8.2 Wm\(^{-2}\)/decade
Net Solar and Net Longwave

Average NetSolar

+5.6 Wm$^{-2}$/decade

+2.3 Wm$^{-2}$/decade
Shortwave–down (SW↓)

+6.6 Wm⁻²/decade
+10 Wm⁻² over 16 years
Shortwave–up (SW↑)

+1.1 Wm$^{-2}$/decade

\[ y = 0.1068x - 213.96 \]

\[ R^2 = 0.0971 \]
500 nm Aerosol optical depth

\[
\text{SW RF}_{\text{aerosols}} = -S_o \ (1-\alpha) \ (1-\exp(-\Delta \tau)) \ (1-g) \ \omega_o
\]

For: \( S_o = 343 \ \text{Wm}^{-2}, \ \alpha = 0.252, \ \Delta \tau = -0.025 \ (16 \ \text{years}), \ g = 0.87, \ \text{and} \ \omega_o = 0.97 \)

Direct SW RF_{aerosols} = +0.82 Wm\(^{-2}\) over 16 years

Small compared to the +10 Wm\(^{-2}\) increase in SW-down

-0.016/decade
LW-up annual anomaly (Wm$^{-2}$)

Net LW $+2.3$ Wm$^{-2}$/decade

LW$\uparrow$

-0.9 Wm$^{-2}$/decade

LW$\downarrow$

+1.5 Wm$^{-2}$/decade

30 ppm increase in CO$_2$ (1996-2011) explains only $+0.09$ Wm$^{-2}$/decade

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No trend in Air Temperature

Specific humidity 
-0.17g/Kg / decade
LW-down and ENSO

Average IR down

ENSO index (1-yr. lag) x 10

Linear (Average IR down)
ENSO index vs. U.S. LW-down

\[ y = 0.1973x + 0.0418 \]
\[ R^2 = 0.497 \]
Summary

- Detected a +8.2 Wm⁻²/decade trend in U.S. total net radiation from 1996 to 2011
- Solar brightening of is the dominant contributor to the SRB increase
- Decreasing cloud cover was mostly responsible for the observed brightening; decreasing aerosols had only a minor effect
- Net LW shows a +2.3 Wm⁻²/decade increase, but with high interannual variability – not statistically significant
- Variability of LW↑ well explained by the surface air temperature variability
- The small increase in LW↓, if real, is not consistent with the flat trend in surface air temperature, decreasing specific humidity, or decreasing cloud cover
- The variability in LW↓ does appear to be modulated by ENSO
- Coincident surface heat flux measurements would have been useful to help explain how the surplus surface net radiation of 12 Wm⁻² was utilized
END
Monthly coverage of radiation measurements

<table>
<thead>
<tr>
<th>Station</th>
<th>quantity</th>
<th>100% coverage</th>
<th>≥95% coverage</th>
<th>70-94% coverage</th>
<th>&lt;70% coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bondville</td>
<td>NetSW</td>
<td>83.8%</td>
<td>96.4%</td>
<td>2.1%</td>
<td>1.6%</td>
</tr>
<tr>
<td>1996-2011</td>
<td>NetIR</td>
<td>76.6%</td>
<td>93.8%</td>
<td>5.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td>192 months</td>
<td>TotalNet</td>
<td>75.0%</td>
<td>93.8%</td>
<td>4.2%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Fort Peck</td>
<td>NetSW</td>
<td>77.6%</td>
<td>94.3%</td>
<td>1.6%</td>
<td>4.2%</td>
</tr>
<tr>
<td>1996-2011</td>
<td>NetIR</td>
<td>72.9%</td>
<td>90.1%</td>
<td>6.3%</td>
<td>3.6%</td>
</tr>
<tr>
<td>192 months</td>
<td>TotalNet</td>
<td>67.2%</td>
<td>88.5%</td>
<td>6.8%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Goodwin Cr.</td>
<td>NetSW</td>
<td>76.1%</td>
<td>92.2%</td>
<td>5.6%</td>
<td>2.2%</td>
</tr>
<tr>
<td>1996-2011</td>
<td>NetIR</td>
<td>73.9%</td>
<td>91.7%</td>
<td>5.0%</td>
<td>3.3%</td>
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<tr>
<td>180 months</td>
<td>TotalNet</td>
<td>70.6%</td>
<td>88.9%</td>
<td>7.8%</td>
<td>3.3%</td>
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<td>Table. Mt.</td>
<td>NetSW</td>
<td>71.9%</td>
<td>97.9%</td>
<td>2.1%</td>
<td>0.0%</td>
</tr>
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<td>1996-2011</td>
<td>NetIR</td>
<td>64.6%</td>
<td>93.2%</td>
<td>4.7%</td>
<td>2.1%</td>
</tr>
<tr>
<td>192 months</td>
<td>TotalNet</td>
<td>56.3%</td>
<td>92.7%</td>
<td>5.2%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Desert Rock</td>
<td>NetSW</td>
<td>75.6%</td>
<td>93.0%</td>
<td>6.4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>1999-2011</td>
<td>NetIR</td>
<td>67.3%</td>
<td>89.2%</td>
<td>5.1%</td>
<td>5.8%</td>
</tr>
<tr>
<td>156 months</td>
<td>TotalNet</td>
<td>65.4%</td>
<td>87.2%</td>
<td>6.4%</td>
<td>6.4%</td>
</tr>
<tr>
<td>Penn State</td>
<td>NetSW</td>
<td>78.9%</td>
<td>97.4%</td>
<td>1.3%</td>
<td>1.3%</td>
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<tr>
<td>1999-2011</td>
<td>NetIR</td>
<td>82.1%</td>
<td>96.2%</td>
<td>1.3%</td>
<td>2.6%</td>
</tr>
<tr>
<td>156 months</td>
<td>TotalNet</td>
<td>94.9%</td>
<td>94.9%</td>
<td>2.6%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Sioux Falls</td>
<td>NetSW</td>
<td>83.3%</td>
<td>99.0%</td>
<td>1.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2004-2011</td>
<td>NetIR</td>
<td>56.3%</td>
<td>97.9%</td>
<td>2.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>96 months</td>
<td>TotalNet</td>
<td>55.2%</td>
<td>96.9%</td>
<td>3.1%</td>
<td>0.0%</td>
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</tbody>
</table>
# Mann Kendall results for trend significance (95% level)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MK median trend</th>
<th>95% lower limit trend</th>
<th>95% upper limit trend</th>
<th>MK significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total surface net</td>
<td>+0.86</td>
<td>+0.57</td>
<td>+1.08</td>
<td>significant</td>
</tr>
<tr>
<td>Net SW</td>
<td>+0.53</td>
<td>+0.27</td>
<td>+1.08</td>
<td>significant</td>
</tr>
<tr>
<td>Net LW</td>
<td>+0.20</td>
<td>-0.05</td>
<td>+0.49</td>
<td>not significant</td>
</tr>
<tr>
<td>SW-down</td>
<td>+0.72</td>
<td>+0.26</td>
<td>+1.11</td>
<td>significant</td>
</tr>
<tr>
<td>SW-up</td>
<td>+0.07</td>
<td>-0.09</td>
<td>+0.29</td>
<td>not significant</td>
</tr>
<tr>
<td>LW-down</td>
<td>+0.26</td>
<td>-0.13</td>
<td>+0.52</td>
<td>not significant</td>
</tr>
<tr>
<td>LW-up</td>
<td>-0.08</td>
<td>-0.43</td>
<td>+0.30</td>
<td>not significant</td>
</tr>
<tr>
<td>Temperature</td>
<td>-0.001</td>
<td>-0.07</td>
<td>0.07</td>
<td>not significant</td>
</tr>
<tr>
<td>Specific humidity</td>
<td>-0.01</td>
<td>-0.03</td>
<td>0.01</td>
<td>not significant</td>
</tr>
<tr>
<td>Sky cover</td>
<td>-0.002</td>
<td>-0.004</td>
<td>0.0009</td>
<td>not significant</td>
</tr>
</tbody>
</table>
Consistency among SRB variables

Table Mountain

-20 0 20 40 60 80 100 120 140 160 180

Monthly average NetLW + average NetSW (Wm$^{-2}$)

Average monthly totalnet (Wm$^{-2}$)
Monthly gap filling

1. Empirical methods

2. Physical relationships
   e.g., $\text{SW-down} = \frac{\text{SW-up}}{\text{albedo}}$

3. Collocated data

4. Other sources (e.g., http://weather-warehouse.com)

5. NCEP Reanalysis (Temp., RH)