Surface Atmosphere Radiation Budget (SARB) working group update

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Work done after the spring 2018 CERES meeting

• Extended Ed4 EBAF-surface and SYN1deg through March 2018.
• Started MATCH aerosol processing with MODIS collection 6.1.
• Continue collaborating with GMAO in developing a new version of GEOS reanalysis for Ed5 CERES products.
• Estimated uncertainty in net surface and atmosphere irradiances.
• Evaluated Collection 6.1 MODIS aerosols.
• Estimated the effect of partly cloudy MODIS pixels to computed irradiances.
• Sea ice nadir view reflectance as a function of sea ice fraction.
• Continue revision C3M with new CALIPSO, CloudSat, CERES, and MODIS data.
Edition 4 EBAF-surface

• Uncertainty
  • Uncertainty in up and downward surface shortwave and longwave irradiances are estimated (Kato et al. 2018)
  • Error covariance matrix is needed to estimate net surface and atmosphere irradiance uncertainty
  • Uncertainty in irradiance differences between two time periods

• Plan for Ed 4.1
  • Revision is required due to MODIS calibration (6.7 and 8.6 μm channels) and aerosol issues
### Satellite derived global annual mean energy fluxes

<table>
<thead>
<tr>
<th>Flux</th>
<th>Global mean (Wm(^{-2}))</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface net shortwave</td>
<td>164</td>
<td>Ed4 EBAF</td>
</tr>
<tr>
<td>Surface net longwave</td>
<td>-54</td>
<td>Ed4 EBAF</td>
</tr>
<tr>
<td>Latent heat fluxes =</td>
<td>-78</td>
<td>GPCP version 2.3</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensible heat</td>
<td>-23</td>
<td>SeaFlux, Princeton ET</td>
</tr>
<tr>
<td>Sum</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Ocean heating rate</td>
<td>Less than 1</td>
<td>0.68 Wm(^{-2}) + 0.03 Wm(^{-2}) (ice warming and melt + etc.)</td>
</tr>
<tr>
<td>Energy flux associated</td>
<td>Less than 1</td>
<td>0.8 Wm(^{-2}) over ocean</td>
</tr>
<tr>
<td>with mass (water) transfer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Fluxes are defined positive downward

**What is the uncertainty in net irradiance?**
Surface validation sites

46 buoys (blue diamond) and 36 land surface sites (white diamond)
Validation of monthly mean downward surface irradiances over ocean

RMS difference is used for the uncertainty in monthly regional means.
### Downward irradiance uncertainty

<table>
<thead>
<tr>
<th></th>
<th>Mean irradiance</th>
<th>Estimated uncertainty (Wm⁻²)</th>
<th>Monthly gridded</th>
<th>Monthly zonal</th>
<th>Monthly global</th>
<th>Annual global</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downward longwave</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean+Land</td>
<td>345</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>364</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Land</td>
<td>333</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Arctic</td>
<td>183</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Antarctic</td>
<td>183</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Downward shortwave</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean+Land</td>
<td>187</td>
<td>13</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>191</td>
<td>11</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>195</td>
<td>12</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>119</td>
<td>14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Antarctic</td>
<td>119</td>
<td>21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Upward irradiance uncertainty is estimated from bias errors in cloud fraction, surface skin temperature. Need to estimate the uncertainty in net irradiance.
Error covariance estimated from surface irradiance adjustments in the EBAF-surface process

We adjust cloud, surface and atmospheric properties to match TOA irradiances. We then use Jacobians to adjust surface irradiances. Global annual mean adjustments are used to estimate error covariance.
## Uncertainty in surface net irradiance

<table>
<thead>
<tr>
<th></th>
<th>Downward (Wm(^{-2}))</th>
<th>Upward (Wm(^{-2}))</th>
<th>Correlation coefficient</th>
<th>Net uncertainty (Wm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortwave</td>
<td>4</td>
<td>3</td>
<td>-0.29</td>
<td>5.7</td>
</tr>
<tr>
<td>Longwave</td>
<td>5</td>
<td>3</td>
<td>-0.36</td>
<td>6.7</td>
</tr>
<tr>
<td>SW+LW</td>
<td>5.7</td>
<td>6.7</td>
<td>0.26</td>
<td>9.8</td>
</tr>
</tbody>
</table>

\[x = u \pm v\]

\[\text{uncertainty}(x) = V(u) + V(v) \pm 2 \text{Cov}(u, v) = V(u) + V(v) \pm 2 r(u, v) S(u) S(v)\]

- \(V\): Variance
- \(\text{Cov}\): Covariance
- \(S\): Standard deviation
- \(r\): Correlation coefficient (estimated from surface irradiance adjustments)

When the uncertainty is estimated by including error correlation, the uncertainty is larger than the uncertainty computed with independent error assumption (7.7 Wm\(^{-2}\)).

Uncertainty in global mean precipitation is 9% (Adler et al. 2012), which is about 7 Wm\(^{-2}\).
• Relatively large uncertainty exists in net surface irradiance.
• How much does the uncertainty in mean irradiiances affect the uncertainty in estimating irradiance change?
• Uncertainty in irradiance anomalies and uncertainty in detecting surface irradiance change.
Anomaly time series comparison

What is the uncertainty in estimating downward irradiance change?
Uncertainty in detecting surface irradiance change from the difference of surface irradiances averaged over two time periods

The error in the downward shortwave or longwave irradiance difference from two time periods is

\[
\Delta F = \left( \frac{1}{N_2} \sum_{i=2}^{N_2} F_{\text{comp}} \right) - \left( \frac{1}{N_1} \sum_{i=1}^{N_1} F_{\text{comp}} \right) - \left( \frac{1}{N_2} \sum_{i=2}^{N_2} F_{\text{obs}} \right) + \left( \frac{1}{N_1} \sum_{i=1}^{N_1} F_{\text{obs}} \right)
\]

Rewriting this

\[
\Delta F = \left( \frac{1}{N_2} \sum_{i=2}^{N_2} F_{\text{comp}} - F_{\text{obs}} \right) - \left( \frac{1}{N_1} \sum_{i=1}^{N_1} F_{\text{comp}} - F_{\text{obs}} \right)
\]

Compute standard deviation of \( \Delta F \)
Time series of computed (red) and observed (black) downward shortwave irradiance averaged over 36 sites over lands are available.

Randomly select $N_1$ observed and computed irradiances.

Randomly select $N_2$ observed and computed irradiances from remaining $192 - N_1$ months.

Compute $\Delta F$

Repeat 100 times and compute standard deviation of $\Delta F$.

$$\Delta F = \frac{1}{N_2} \sum_{N_2} \downarrow F_{\text{comp}} - \frac{1}{N_1} \sum_{N_1} \downarrow F_{\text{comp}} - \left( \frac{1}{N_2} \sum_{N_2} \uparrow F_{\text{obs}} - \frac{1}{N_1} \sum_{N_1} \uparrow F_{\text{obs}} \right)$$
Downward shortwave irradiance change

\[ \Delta F = \left( \frac{1}{N_{\downarrow 2}} \sum_{N_{\downarrow 2}} \uparrow F_{\text{comp}} \right) - \left( \frac{1}{N_{\downarrow 1}} \sum_{N_{\downarrow 1}} \uparrow F_{\text{obs}} \right) \]
\[ \Delta F = \left( \frac{1}{N_{\downarrow 2}} \sum_{N_{\downarrow 2}} \uparrow \uparrow F_{\text{comp}} \right) - \left( \frac{1}{N_{\downarrow 1}} \sum_{N_{\downarrow 1}} \uparrow \uparrow F_{\text{comp}} \right) - \left( \frac{1}{N_{\downarrow 2}} \sum_{N_{\downarrow 2}} \uparrow \uparrow F_{\text{obs}} \right) - \left( \frac{1}{N_{\downarrow 1}} \sum_{N_{\downarrow 1}} \uparrow \uparrow F_{\text{obs}} \right) \]
Summary: uncertainty

• Even when the uncertainty in the global annual mean downward shortwave and longwave irradiances is, respectively, 4 Wm$^{-2}$ and 5 Wm$^{-2}$, the uncertainty in the difference of downward irradiances from two time periods is about one order of magnitude smaller.

• According to the IPCC report (WG1AR5, Hartmann et al. 2013), the carbon dioxide concentration is increasing with the rate about 2 ppm per year or 20 ppm per 10 years.

• Increasing the carbon dioxide concentration from 360 ppm to 600 ppm increases the surface downward longwave irradiance about 1 Wm$^{-2}$.

• This gives about 0.08 Wm$^{-2}$ surface downward longwave irradiance change caused by an increase of the carbon dioxide concentration by 20 ppm (i.e. 0.08 Wm$^{-2}$ increase per decade).

• It takes about 50 years for the signal (not including feedback) to become greater than the uncertainty in downward longwave.
Contribution to anomalies

Thorsen et al. (2018)
Issues affecting edition 4.0 EBAF-surface

• Large changes occur in polar night cloud fraction after March 2016 due to MOIDS instrument issues

• A bug in MODIS aerosol algorithm causes large difference in the aerosol optical thickness over land between collection 5 and collection 6.1.

• These problems do not affect observed TOA irradiances, but affect computed surface irradiances.

• Edition 4 EBAF-surface is available from March 2000 through March 2018.

• Edition 4.1 EBAF-surface will replace Ed4 for the entire record in spring 2019.
Polar nighttime cloud issue

Maximum surface downward longwave irradiance changes for February 2017

Actual changes between Ed4 and Ed4.1 EBAF-surface is smaller

Trade off between best cloud properties at any given time vs. continuity with no significant artifacts
Aerosol issue

Collection 6.1 aerosol optical depth is approximately 10% larger than Collection 5 aerosol optical depth.

Clear-sky downward shortwave irradiance difference for February 2017
Edition 4.1 EBAF-surface

• Nighttime polar cloud fraction bias correction is applied from January 2008 through February 2016 to correct Terra cloud fraction. No correction is applied to Terra after March 2016 (when SSF is processed with MODIS Collection 6.1).

• New Himawari 8 clouds is processed with correct input including corrected collocation of IR and VIS from July 2015.

• MODIS collection 6.1 aerosol optical thickness (and new surface albedo history map) is used for the entire time period.
Results from CERES-GMAO collaboration

• Polar surface skin temperature
  • Compare MODIS derived skin temperature and GEOS skin temperature
  • MODIS skin temperatures are derived when CALIPSO and CloudSat do not detect clouds
  • Cases when GEOS reanalyses have clouds are excluded
Geographical Distribution of $\Delta T_s$ over the Arctic when Both CALIPSO-CloudSat (CC) and GMAO Indicate Clear
Skin Temperature Comparison Over The Arctic When CC cloud fraction = 0%

Greenland + snow over land

Day+Night

Sea Ice

Open water

Day

Day (SZA < 90°)

Night

Night (SZA ≥ 90°)
Skin Temperature Comparison Over The Arctic When CC cloud fraction = 0% and GMAO cloud fraction = 0%
Sea ice reflectance as a function of sea ice fraction

SZA: 60 through 70 deg

- 0.469 um
- 0.555 um
- 0.645 um
- 0.8585 um
- 1.24 um
- 1.64 um
Summary

• Ed 4.0 EBAF-surface is released through March 2018.
• Ed 4.1 EBAF-surface will replace Ed4 in spring 2019.
  • Clear-sky irradiances and nighttime polar longwave irradiances are affected
• The uncertainty in the difference of downward irradiance averaged over two time periods is one order magnitude smaller than the uncertainty in the downward irradiance.
• An improvement of surface skin temperature in polar regions are expected in the next generation of GMAO-CERES reanalysis
List of publications


• Saito, M., P. Yang, N. G. Loeb, and S. Kato, 2018: A parameterization of surface snow albedo based on two-layer snow model in conjunction with a mixture of grain habits, to be submitted to Journal of the Atmospheric Sciences.
Surface and atmosphere net anomalies

![Graph of surface net anomalies from 03/2000 to 03/2018]

Selected Region: [-90.0 to 90.360]

![Graph of surface net longwave flux from 03/2000 to 03/2018]

Selected Region: [-90.0 to 90.360]