EBAF Ed4.2 vs 4.1 & TOA SW Up

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(Remote Presentation)
\[ E = \frac{A_0}{2} (1 + \tau), \quad A = \frac{A_0}{2} (2 + \tau), \quad B = \frac{A_0}{2} \tau. \]  

Schwarzschild (1906, Eq. 11)

- \( E \) emission of a layer
- \( A \) upward beam at the given layer
- \( B \) downward beam at that layer
- \( A_0 \) emerging beam at the upper boundary
- \( \tau \) optical depth

Net radiation at the surface:

Eq. (1) \( A - E = SH + LH = A_0/2 \)  

Liou (2002, Fig. 8.9)  
Hartmann (2016, Fig. 3.16)

May be derived from first principles (Milne 1930, Handbook of Astrophysics)

**Represented in:** Ostriker (1963, Eq. 15); Goody (1964, Eq. 2.115); Houghton (1977, Eq. 2.13); Chamberlain (1978, Eq. 1.2.29); Goody and Yung (1989, 2.146); Stephens (1991, Eq. 1 & 2; 1994, Eq. 5a & 5b); Hartmann (1994, Fig. 3.10-3.11); Liou (2002, Fig. 8.9); Pierrehumbert (2010, Eq. 4.44-4.45); Hartmann (2016, Fig. 3.16) ...

I think my study is the first that controls it on global mean observed data.
Total radiation at the surface if $\epsilon = 1$:

\[ E = \frac{A_0}{2} \left( I + \tau \right), \quad A = \frac{A_0}{2} \left( 2 + \tau \right), \quad B = \frac{A_0}{2} \tau. \] (II)

Eq. (2) \( A = 2A_0 \) at \( \tau = 2 \)

2.5 Greenhouse Effect

\[ \frac{S_0}{4} \left( 1 - \alpha_p \right) \]

\[ \sigma T_s^4 \downarrow \]

\[ \sigma T_A^4 \downarrow \]

Atmosphere

\[ \sigma T_A^4 \uparrow \]

\[ \sigma T_s^4 \uparrow \]

Hartmann (1994, Fig. 2.3) \( \sigma T_s^4 = 2\sigma T_A^4 \)

\[ \tilde{\epsilon} \sigma T_a^4 \]

\[ (1-\tilde{\epsilon}) \sigma T^4 \]

\[ \tilde{\epsilon} (IR) \]

\[ T_a \]

\[ \tilde{\epsilon} (SOL) \]

\[ \tilde{\epsilon} (IR) \]

\[ T \]

Liou (1980, Fig. 8.20) \( \epsilon = 1 \Rightarrow \sigma T^4 = 2\sigma T_a^4 \)

Fig. 8.20 Two-layer global radiative budget model.

Total radiation at the surface if $\epsilon = 1$:

\[ Eq. (2) \quad A = 2A_0 \]
Entropy export to space by radiation (Eq. 5), entropy produced within the atmosphere (Eq. 6), and the total entropy produced by the Earth system (Eq. 7), as a function of $\varepsilon$, is at maximum if $\varepsilon = 1$. 

Kato and Rose (2020, Fig. 1)
Eq. (1) SFC SW+LW Net (clear) = A − E = A₀/2
Eq. (2) SFC SW+LW Total (clear) = A = 2A₀

Creating the all-sky versions (including LWCRE):

Eq. (3) SFC SW+LW Net (all) = A − E = (A₀ − L)/2
Eq. (4) SFC SW+LW Total (all) = A = 2A₀ + L

Eq. (1) SFC (SW down − SW up + LW down − LW up) (clear) = TOA LW (clear) /2
Eq. (2) SFC (SW down − SW up + LW down) (clear) = TOA LW (clear) × 2
Eq. (3) SFC (SW down − SW up + LW down − LW up) (all) = TOA [LW (all) − LWCRE]/2
Eq. (4) SFC (SW down − SW up + LW down) (all) = TOA LW (all) × 2 + LWCRE
Four Equations, EBAF Edition 2.8
(March 2000 – Feb 2016) (Rose et al. 2017, 27th CERES STM)

Eq. (1)  \[ SFC \ SW \ down - SW \ up + LW \ down - LW \ up \ (\text{clear}) = \frac{TOA \ LW \ (\text{clear})}{2} \]

Eq. (2)  \[ SFC \ SW \ down - SW \ up + LW \ down \ (\text{clear}) = 2 \times TOA \ LW \ (\text{clear}) \]

Eq. (3)  \[ SFC \ SW \ down - SW \ up + LW \ down - LW \ up \ (\text{all}) = \frac{[TOA \ LW \ (\text{all}) - LWCRE]}{2} \]

Eq. (4)  \[ SFC \ SW \ down - SW \ up + LW \ down \ (\text{all}) = 2 \times TOA \ LW \ (\text{all}) + LWCRE \]
Four Equations, EBAF Edition 2.8
(March 2000 – Feb 2016) (Rose et al. 2017, 27th CERES STM)

| Eq. (1) | SFC  SW down – SW up + LW down – LW up (clear) = TOA LW (clear)/2 | Diff |
| Ed2.8 | 244.06 – 29.74 + 316.27 – 398.40 | = 265.59 /2 | –0.60 |

| Eq. (2) | SFC  SW down – SW up + LW down (clear) = 2 × TOA LW (clear) |
| Ed2.8 | 244.06 – 29.74 + 316.27 | = 2 × 265.59 | –0.59 |

| Eq. (3) | SFC  SW down – SW up + LW down – LW up (all) = [TOA LW (all) – LWCRE]/2 |
| Ed2.8 | 186.47 – 24.13 + 345.15 – 398.27 | = (239.60 – 25.99)/2 | +2.41 |

| Eq. (4) | SFC  SW down – SW up + LW down (all) = 2 × TOA LW (all) + LWCRE |
| Ed2.8 | 186.47 – 24.13 + 345.15 | = 2 × 239.60 + 25.99 | +2.30 |
Four Equations, EBAF Edition 4.1
CERES EBAF Ed4.1 & Ed4.2, 22 years (April 2000 – March 2022) (Wm$^{-2}$)

Eq. (1)  \[ \text{SFC SW down} - \text{SW up} + \text{LW down} - \text{LW up (clear)} = \frac{\text{TOA LW (clear)}}{2} \]
\[ \text{Ed4.1} \]
\[ 240.8680 - 29.0724 + 317.4049 - 398.5211 \]
\[ = \frac{266.0122}{2} \]
\[ \text{Diff} \]
\[ -2.3267 \]
\[ \}

Eq. (2)  \[ \text{SFC SW down} - \text{SW up} + \text{LW down (clear)} = 2 \times \frac{\text{TOA LW (clear)}}{} \]
\[ \text{Ed4.1} \]
\[ 240.8680 - 29.0724 + 317.4049 \]
\[ = 2 \times 266.0122 \]
\[ -2.8238 \]
\[ \}

Eq. (3)  \[ \text{SFC SW down} - \text{SW up} + \text{LW down (all)} = \frac{[\text{TOA LW (all)} - \text{LWCRE}]}{2} \]
\[ \text{Ed4.1} \]
\[ 186.8544 - 23.1629 + 345.0108 - 398.7454 \]
\[ = \frac{(240.2450 - 25.7672)}{2} \]
\[ +2.7083 \]
\[ \}

Eq. (4)  \[ \text{SFC SW down} - \text{SW up} + \text{LW down (all)} = 2 \times \frac{\text{TOA LW (all)} + \text{LWCRE}}{} \]
\[ \text{Ed4.1} \]
\[ 186.8544 - 23.1629 + 345.0108 \]
\[ = 2 \times 240.2450 + 25.7672 \]
\[ +2.4450 \]

\[ \text{Ed4.1} \]
\[ \text{Mean} \]
\[ +0.0007 \]
The four equations are intimately connected
Decrease TOA LW(clear) by 1 Wm⁻²

Eq. (1)  SFC  SW down – SW up + LW down – LW up (clear) = TOA LW (clear)/2
Ed4.1  240.8680 – 29.0724 + 317.4049 – 398.5211 = 266.0122 /2
Diff
–2.3267
–1.8267

Eq. (2)  SFC  SW down – SW up + LW down (clear) = 2 × TOA LW (clear)
Ed4.1  240.8680 – 29.0724 + 317.4049
= 2 × 266.0122
–2.8228
–0.8228

Eq. (3)  SFC  SW down – SW up + LW down – LW up (all) = [TOA LW (all) – LWCRE]/2
= 2 × 240.2450 + 25.7672 +2.7083
= 2 × 240.2450 + 24.7672 +2.2083

Eq. (4)  SFC  SW down – SW up + LW down (all) = 2 × TOA LW (all) + LWCRE
Ed4.1  186.8544 – 23.1629 + 345.0108 = 2 × 240.2450 + 25.7672 +2.4450

Ed4.1  Mean +0.0007
Ed4.1  Mean +0.7507
Four Equations, EBAF Edition 4.1 & 4.2
CERES EBAF Ed4.1 & Ed4.2, 22 years (April 2000 – March 2022) (Wm\(^{-2}\))

Eq. (1) \[ SFC \text{ SW down} - \text{SW up} + \text{LW down} - \text{LW up (clear)} = \text{TOA LW (clear)}/2 \]
\[ \begin{align*}
\text{Ed4.1} & : 240.8680 - 29.0724 + 317.4049 - 398.5211 = 266.0122/2 \quad -2.3267 \\
\text{Ed4.2} & : 241.1519 - 29.7397 + 317.8570 - 398.6099 = 266.1348/2 \quad -2.4081
\end{align*} \]

\[ \text{Diff} \]
\[ \begin{align*}
\text{Ed4.1} & : 266.0122/2 - 2.3267 \\
\text{Ed4.2} & : 266.1348/2 - 2.4081
\end{align*} \]

\[ \text{Mean} +0.0007 \]

Eq. (2) \[ SFC \text{ SW down} - \text{SW up} + \text{LW down (clear)} = 2 \times \text{TOA LW (clear)} \]
\[ \begin{align*}
\text{Ed4.1} & : 240.8680 - 29.0724 + 317.4049 = 2 \times 266.0122 \quad -2.8238 \\
\text{Ed4.2} & : 241.1519 - 29.7397 + 317.8570 = 2 \times 266.1348 \quad -3.0005
\end{align*} \]

\[ \text{Bias} \]
\[ -2.7043 \]

Eq. (3) \[ SFC \text{ SW down} - \text{SW up} + \text{LW down (all)} = \frac{[\text{TOA LW (all)} - \text{LWCRE}]}{2} \]
\[ \begin{align*}
\text{Ed4.1} & : 186.8544 - 23.1629 + 345.0108 - 398.7454 = (240.2450 - 25.7672)/2 + 2.7083 \\
\text{Ed4.2} & : 187.0918 - 23.4436 + 346.1147 - 398.4220 = (240.3317 - 25.8032)/2 + 4.0766
\end{align*} \]

\[ \text{Bias} \]
\[ +3.6865 \]

Eq. (4) \[ SFC \text{ SW down} - \text{SW up} + \text{LW down (all)} = 2 \times \text{TOA LW (all)} + \text{LWCRE} \]
\[ \begin{align*}
\text{Ed4.1} & : 186.8544 - 23.1629 + 345.0108 = 2 \times 240.2450 + 25.7672 + 2.4450 \\
\text{Ed4.2} & : 187.0918 - 23.4436 + 346.1147 = 2 \times 240.3317 + 25.8032 + 3.2963
\end{align*} \]

\[ \text{Mean} +0.4911 \]

Bias, or Ed4.2 captured something physical that Ed4.1 missed?
EBAF Edition 4.2
22 years (Apr 2000 – Mar 2022)
22 years (Jan 2001 – Dec 2022)

Eq. (1)  \[ \text{SFC} \ SW \ down - SW \ up + LW \ down - LW \ up \ (\text{clear}) = \frac{\text{TOA} \ LW \ (\text{clear})}{2} \]

<table>
<thead>
<tr>
<th></th>
<th>Apr-March</th>
<th>Jan-Dec</th>
</tr>
</thead>
</table>

\[ \{ \text{Diff} \} = -2.7043 \]
\[ \{ \text{Diff} \} = -2.6234 \]

Eq. (2)  \[ \text{SFC} \ SW \ down - SW \ up + LW \ down \ (\text{clear}) = 2 \times \text{TOA} \ LW \ (\text{clear}) \]

<table>
<thead>
<tr>
<th></th>
<th>Apr-March</th>
<th>Jan-Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>241.1519 – 29.7397 + 317.8570</td>
<td>= 2 \times 266.1348</td>
</tr>
<tr>
<td></td>
<td>241.1085 – 29.7012 + 317.9809</td>
<td>= 2 \times 266.1207</td>
</tr>
</tbody>
</table>

\[ \{ \text{Diff} \} = -3.0005 \]
\[ \{ \text{Diff} \} = -2.8533 \]

Eq. (3)  \[ \text{SFC} \ SW \ down - SW \ up + LW \ down - LW \ up \ (\text{all}) = \frac{[\text{TOA} \ LW \ (\text{all}) - \text{LWCRE}]/2}{2} \]

<table>
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<tr>
<th></th>
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\[ \{ \text{Diff} \} = +4.0766 \]
\[ \{ \text{Diff} \} = +4.0463 \]

Eq. (4)  \[ \text{SFC} \ SW \ down - SW \ up + LW \ down \ (\text{all}) = 2 \times \text{TOA} \ LW \ (\text{all}) + \text{LWCRE} \]

<table>
<thead>
<tr>
<th></th>
<th>Apr-March</th>
<th>Jan-Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>187.0918 – 23.4436 + 346.1147</td>
<td>= 2 \times 240.3317 + 25.8032</td>
</tr>
<tr>
<td></td>
<td>187.0941 – 23.4179 + 346.2001</td>
<td>= 2 \times 240.3606 + 25.7601</td>
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</tbody>
</table>

\[ \{ \text{Diff} \} = +3.6865 \]
\[ \{ \text{Diff} \} = +3.7206 \]

<table>
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<tr>
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<th>Jan-Dec</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>+0.4911</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>+0.5486</td>
</tr>
</tbody>
</table>
Annual mean bias of the 4Eqs, Ed4.1, Ed4.2
Mean bias of the 4Eqs, Ed4.1, Ed4.2

Number of years in the average
Libera Science Goals & Objectives

Overarching goals:

1) Provide seamless continuity of the ERB measurement with characteristics identical to CERES
   - Prevents gap in ERB data record critical for studies of global climate change
   - Tied to **Science objective 1**: Use extended record to identify and quantify processes responsible for the instantaneous to decadal variability of ERB

2) Develop a self-contained, innovative, affordable observing system
   - Novel, miniaturized detectors greatly improve accuracy & stability and pave way toward smaller & cost-effective follow-on mission.
   - **Science objective 2** Libera tests a miniature wide field-of-view camera to provide scene & angular context crucial for radiative flux retrieval

3) Provide new and enhanced capabilities that support extending ERB science goals
   - Employ Split-Shortwave channel to derive SW VIS and NIR fluxes and quantify SW energy disposition
   - Tied to **Science objective 3**: Revolutionize understanding of spatio-temporal variations in SW, VIS & NIR irradiance
Eq. (3) Sensible heat + Evaporation = (Outgoing LW − LWCRE)/2

Eq. (4) Absorbed SW + All-sky emission = 2 × Outgoing LW + LWCRE
Eq. (3) Sensible heat + Evaporation = (Outgoing LW – LWCRE)/2

Eq. (4) Absorbed SW + All-sky emission = 2 × Outgoing LW + LWCRE
Eqs. (3) and (4) express fundamental physical requirements, verified by 30 years of GEWEX.

Any future global energy flow estimate, climate report, sensitivity study, water change prediction, cloud forcing and CRE-feedback assessment should strictly satisfy these constraints with this examplary accuracy.
The **N**-numbers, as solution of the equations

Pure geometry, no reference to GHGs

![Diagram](image)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Expression</th>
<th>Clear-sky</th>
<th>All-sky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (1)</td>
<td>$\Delta A = A_0/2$, $E = 3A_0/2$</td>
<td>$SFC_{Net} = A_0/2$</td>
<td>$SFC_{Net} = (A_0 - L)/2$</td>
</tr>
<tr>
<td>Eq. (2)</td>
<td>$A = 2A_0$</td>
<td>$SFC_{Tot} = 2A_0$</td>
<td>$SFC_{Tot} = 2A_0 + L$</td>
</tr>
</tbody>
</table>

**Calculations**

- Clear-sky:
  - $8 + 12 - 15 = 10 / 2$
  - $8 + 12 = 10 \times 2$

- All-sky:
  - $6 + 13 - 15 = (9 - 1)/2$
  - $6 + 13 = 9 \times 2 + 1$
Ed4.2 is better (closer to N) in most flux components in the clear-sky

<table>
<thead>
<tr>
<th></th>
<th>Clear-sky</th>
<th>N</th>
<th>N × Unit</th>
<th>Ed4.1</th>
<th>Diff</th>
<th>Ed4.2</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOA</td>
<td>LW</td>
<td>10</td>
<td>266.80</td>
<td>266.01</td>
<td>-0.79</td>
<td>266.13</td>
<td>-0.67</td>
</tr>
<tr>
<td></td>
<td>SW Net</td>
<td>8</td>
<td>213.44</td>
<td>211.80</td>
<td>-1.64</td>
<td>211.41</td>
<td>-2.03</td>
</tr>
<tr>
<td></td>
<td>LW down</td>
<td>12</td>
<td>320.16</td>
<td>317.40</td>
<td>-2.76</td>
<td>317.86</td>
<td>-2.30</td>
</tr>
<tr>
<td></td>
<td>LW up</td>
<td>15</td>
<td>400.20</td>
<td>398.52</td>
<td>-1.68</td>
<td>398.61</td>
<td>-1.59</td>
</tr>
<tr>
<td></td>
<td>LW Net</td>
<td>-3</td>
<td>-80.04</td>
<td>-81.12</td>
<td>-1.08</td>
<td>-80.75</td>
<td>-0.71</td>
</tr>
<tr>
<td></td>
<td>TOT Net</td>
<td>5</td>
<td>133.40</td>
<td>130.68</td>
<td>-2.72</td>
<td>130.66</td>
<td>-2.74</td>
</tr>
</tbody>
</table>
No significant difference, Ed4.1 is a bit better

<table>
<thead>
<tr>
<th></th>
<th>All-sky</th>
<th>N</th>
<th>N × Unit</th>
<th>Ed4.1</th>
<th>Diff</th>
<th>Ed4.2</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LW</td>
<td></td>
<td>9</td>
<td>240.12</td>
<td>240.25</td>
<td>0.13</td>
<td>240.33</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW Net</td>
<td></td>
<td>6</td>
<td>160.08</td>
<td>163.69</td>
<td>3.61</td>
<td>163.65</td>
<td>3.57</td>
</tr>
<tr>
<td>LW down</td>
<td></td>
<td>13</td>
<td>346.84</td>
<td>345.01</td>
<td>-1.83</td>
<td>346.11</td>
<td>-0.73</td>
</tr>
<tr>
<td>LW up</td>
<td></td>
<td>15</td>
<td>400.20</td>
<td>398.75</td>
<td>-1.45</td>
<td>398.42</td>
<td>-1.78</td>
</tr>
<tr>
<td>LW Net</td>
<td></td>
<td>-2</td>
<td>-53.36</td>
<td>-53.74</td>
<td>-0.38</td>
<td>-52.31</td>
<td>1.05</td>
</tr>
<tr>
<td>TOT Net</td>
<td></td>
<td>4</td>
<td>106.73</td>
<td>109.95</td>
<td>3.22</td>
<td>111.34</td>
<td>4.61</td>
</tr>
<tr>
<td>LW CRE</td>
<td></td>
<td>1</td>
<td>26.68</td>
<td>25.77</td>
<td>-0.91</td>
<td>25.80</td>
<td>-0.88</td>
</tr>
</tbody>
</table>
But what about $\alpha$ and $\beta$?

Kato and Rose (2020)
Starting point: The simplest greenhouse model

\[ \alpha = \beta = 0 \]
\[ \varepsilon = 1 \]
\[ \sigma_{\text{sfc}}^4 = 2\sigma_a^4 \]
\[ F_{\text{tur}} = 0 \]
Starting point: The simplest greenhouse model

Solar Absorbed Surface (SAS)  Upward LongWave (ULW)  Downward Longwave Radiation (DLR)
Introduce 1 unit RSR at TOA; $\alpha = 1/5$
Allow 1 unit solar absorption in atmosphere; $\beta = 1/5$
Add 2 units turbulence to satisfy Eqs. (1) and (2)

Eq. (1): $2 = \frac{4}{2}$
Eq. (2): $2 + 6 = 4 \times 2$
Calibrate to TSI: 1 (black) unit is 10 (red) units

TSI
5+1
1360.68

RSR
1

OLR
4

Clear-sky Net TOA IMB
3

Eq.(1) 2 = 4/2
Eq.(2) 2 + 6 = 4 x 2

1 = 10 = 266.80 Wm⁻²

I created 2 (red) units hiatus
Solution: Reflect 2 (red) units less

Absorption will be 3 (red) units more
Re-distribute the absorption: 1 in ATM, 2 at SFC

Ready. My clear-sky on the disk.
Transform to red units

The only input parameter is TSI

TSI
5+1 (51)
1360.68

ASR
4+3 (43)

SAA
1+1 (11)

SAS
3+2 (32)

RSR
1–2 (8)

OLR
4 (40)

Clear-sky Net TOA IMB

1 = 10 = 266.80 Wm⁻²
Divide by 4

\[
\begin{align*}
\text{ISR} & = \frac{51}{4} = 340.17 \\
\text{ASR} & = \frac{43}{4} \\
\text{RSR} & = \frac{8}{4} \\
\text{OLR} & = \frac{40}{4} = \frac{3}{4}
\end{align*}
\]

\[10 = 266.80 \text{ Wm}^{-2}\]

\[\text{LWCRE} = 1\]

\[
\begin{align*}
\text{Eq.(1)} & \quad 5 = \frac{10}{2} \\
\text{Eq.(2)} & \quad 5 + 15 = 10 \times 2
\end{align*}
\]

My clear-sky on the sphere.
The only input parameter is TSI

\[\text{Eq.}(1) \quad 5 = \frac{10}{2} \]
\[\text{Eq.}(2) \quad 5 + 15 = 10 \times 2\]

Clear-sky Net TOA IMB

ISR 51/4 340.17
ASR 43/4 286.81
RSR 8/4 53.36
OLR 40/4 266.80
SAA 11/4 73.37
LW CRE 1 26.68
LW net 3 80.04
SAS 8
TUR 5
ULW 15
DLR 12

213.44 133.40 400.20 320.16
Theory vs EBAF Ed4.2, clear-sky

- **OLR**: 40/4
  - 266.80
  - 266.13
- **ISR**: 51/4
  - 340.17
  - 340.18
- **ASR**: 43/4
  - 286.81
  - 286.42
- **RSR**: 8/4
  - 53.36
  - 53.76
- **OLR**: 40/4
  - 266.80
  - 266.13
- **Clear-sky Net TOA IMB**: 3/4
  - 20.01
  - 20.29
- **SAA**: 11/4
  - 73.37
  - 75.01
- **SAS**: 8
  - 73.37
  - 75.01
- **TUR**: 5
  - LW net
  - 80.04
  - 80.75
- **ULW**: 15
  - LWnet
  - 26.68
  - 25.80
- **LWCRE**: 1
  - 26.68
  - 25.80
- **ISR**: 51/4
  - 340.17
  - 340.18
- **ASR**: 43/4
  - 286.81
  - 286.42
- **RSR**: 8/4
  - 53.36
  - 53.76
- **OLR**: 40/4
  - 266.80
  - 266.13
- **Clear-sky Net TOA IMB**: 3/4
  - 20.01
  - 20.29
- **SAA**: 11/4
  - 73.37
  - 75.01
- **SAS**: 8
  - 73.37
  - 75.01
- **TUR**: 5
  - LW net
  - 80.04
  - 80.75
- **ULW**: 15
  - LWnet
  - 26.68
  - 25.80
- **LWCRE**: 1
  - 26.68
  - 25.80

Theory vs EBAF Ed4.2, clear-sky

- **Eq.(1)**: \(5 = \frac{10}{2}\)
- **Eq.(2)**: \(5 + 15 = 10 \times 2\)
OLR $10 \rightarrow 9$, My all-sky system on the sphere

The only input parameter is TSI
Theory vs Ed4.2, all-sky, $\alpha = 15/51 = 5/17$, $\beta = 12/51 = 4/17$

Diff in ASR = 1.01 Wm\(^{-2}\), in OLR = 0.21 Wm\(^{-2}\), EEI = 0.80 Wm\(^{-2}\)
Table 2-1. Theory vs observation for global mean clear-sky fluxes for April 2000-March 2022 (W m\(^{-2}\))

<table>
<thead>
<tr>
<th>Clear-Sky TOA</th>
<th>Clear-sky</th>
<th>(N)</th>
<th>(N \times \text{Unit})</th>
<th>EBAF Ed4.2</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW insolation</td>
<td>51/4</td>
<td>340.17</td>
<td>340.18</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>LW</td>
<td>40/4</td>
<td>266.80</td>
<td>266.13</td>
<td></td>
<td>-0.67</td>
</tr>
<tr>
<td>SW</td>
<td>8/4</td>
<td>53.36</td>
<td>53.76</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Net</td>
<td>3/4</td>
<td>20.01</td>
<td>20.29</td>
<td></td>
<td>0.28</td>
</tr>
<tr>
<td>Clear-sky Surface</td>
<td>LW down</td>
<td>12</td>
<td>320.16</td>
<td>317.86</td>
<td>-2.30</td>
</tr>
<tr>
<td></td>
<td>LW up</td>
<td>15</td>
<td>400.20</td>
<td>398.61</td>
<td>-1.59</td>
</tr>
<tr>
<td></td>
<td>LW Net</td>
<td>-3</td>
<td>-80.04</td>
<td>-80.75</td>
<td>-0.71</td>
</tr>
<tr>
<td></td>
<td>SW Net</td>
<td>8</td>
<td>213.44</td>
<td>211.41</td>
<td>-2.03</td>
</tr>
<tr>
<td></td>
<td>SW + LW Net</td>
<td>5</td>
<td>133.40</td>
<td>130.66</td>
<td>-2.74</td>
</tr>
</tbody>
</table>
**Table 4-1. Theory vs observation for global mean TOA and surface fluxes and CREs for EBAF Edition 4.2 for April 2000 to March 2022 (W m\(^{-2}\)).**

<table>
<thead>
<tr>
<th></th>
<th>All-sky</th>
<th>N</th>
<th>N \times Unit</th>
<th>EBAF Ed4.2</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW insolation</td>
<td>51/4</td>
<td></td>
<td>340.17</td>
<td>340.18</td>
<td>0.01</td>
</tr>
<tr>
<td>SW up</td>
<td>15/4</td>
<td></td>
<td>100.05</td>
<td>99.05</td>
<td>-1.00</td>
</tr>
<tr>
<td>LW up</td>
<td>36/4</td>
<td></td>
<td>240.12</td>
<td>240.33</td>
<td>0.21</td>
</tr>
<tr>
<td>TOT Net</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0.8</td>
<td>0.80</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW Net</td>
<td>6</td>
<td></td>
<td>160.08</td>
<td>163.65</td>
<td>3.57</td>
</tr>
<tr>
<td>LW down</td>
<td>13</td>
<td></td>
<td>346.84</td>
<td>346.11</td>
<td>-0.73</td>
</tr>
<tr>
<td>LW up</td>
<td>15</td>
<td></td>
<td>400.20</td>
<td>398.42</td>
<td>-1.78</td>
</tr>
<tr>
<td>LW Net</td>
<td>-2</td>
<td></td>
<td>-53.36</td>
<td>-52.31</td>
<td>1.05</td>
</tr>
<tr>
<td>TOT Net</td>
<td>4</td>
<td></td>
<td>106.72</td>
<td>111.34</td>
<td>4.62</td>
</tr>
<tr>
<td><strong>CRE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td>-7/4</td>
<td></td>
<td>-46.69</td>
<td>-45.28</td>
<td>1.41</td>
</tr>
<tr>
<td>LW</td>
<td>1</td>
<td></td>
<td>26.68</td>
<td>25.80</td>
<td>-0.88</td>
</tr>
<tr>
<td>Net</td>
<td>-3/4</td>
<td></td>
<td>-20.01</td>
<td>-19.48</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Concluding

• **My talk:** TOA SW Up is part of the \( N \)-system

• **EEI:** Not only ASR – OLR, but \( \Delta \text{ASR}(N) – \Delta \text{OLR}(N) \)

• **The meeting:** EBAF Ed4.2 is closer to \( N \) in most components

• **Earth Energy Budget:** Eqs. (1) — (4) are compulsory
Last minute: extras, comments
• Observed:
  • ISR = 340.19 Wm\(^{-2}\)
  • TSI = 4.0034 \times 340.19 = 1361.92 Wm\(^{-2}\)

• Theory with geodetic weighting:
  • LWCRE = TSI/51 \times (4/4.0034) = 1 = 26.68 Wm\(^{-2}\)
  • LWCRE (with spherical weighting) = 26.70 Wm\(^{-2}\)
It is frequently stated that
Net CRE = SW CRE + LW CRE

Yes, but by def.:
• TOA Net CRE ≡ RSR(clear) – RSR(all) + OLR(clear – OLR(all) =
• TOA Net CRE = ISR – ASR(clear) – [ISR – ASR(all)] + LWCRE =
• TOA Net CRE = ASR(all) – ASR(clear) + [OLR(clear) – OLR(all)] =
• TOA Net CRE = – [ASR(clear) – OLR(clear)] + EEI(all) = EEI(all) – EEI(clear).

In equilibrium (EEI (all) = 0):
• TOA net CRE = – EEI(clear) = – 3/4 = – 20.01 Wm\(^{-2}\)
• TOA clear IMB = EEI(clear) = ASR – OLR = 43/4 – 40/4 = 3/4 = 20.01 Wm\(^{-2}\)

To understand the global character of TOA Net CRE, no clouds are needed.
It depends only on clear-sky values: SW absorption and LW emission (and EEI(all)).
Clear-Sky Greenhouse Effect at GFDL

LWCRE (theory) = 1 = 26.68 ± 0.01 Wm$^{-2}$

G (clear, theory) = 15 − 10 = 5 = 133.40 ± 0.05 Wm$^{-2}$

G (GFDL AM4) = 133.4 ± 0.6 Wm$^{-2}$

Shiv Priyam Raghuraman, David Paynter, V. Ramaswamy (JGR 2019)

Table 2
Global Mean and Time Mean G Comparison Between Observational, Reanalysis, and Modeling Data Sets Over March 2000 to August 2016

<table>
<thead>
<tr>
<th>Quantity</th>
<th>ERBE</th>
<th>CE 4.1 “c”</th>
<th>CE 4.1 “t”</th>
<th>ERA-Interim</th>
<th>GFDL AM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{Oceans}$</td>
<td>146 ± 7</td>
<td>131.3 ± 0.5</td>
<td>134.1 ± 0.5</td>
<td>134.8 ± 0.6</td>
<td>135.0 ± 0.5</td>
</tr>
<tr>
<td>G</td>
<td>−</td>
<td>129.7 ± 0.6</td>
<td>132.4 ± 0.6</td>
<td>133.1 ± 0.7</td>
<td>133.4 ± 0.6</td>
</tr>
</tbody>
</table>
Overall conclusion

This is not a 'just-so' world.

Not “If this goes up, than that goes down” world.

This is a principled world.