Theoretical Determination of the Greenhouse Effect and its Verification on 240 Months of EBAF Ed4.1 Data

Miklos Zagoni (Budapest, Hungary)
CERES Science Team Meeting, September 17, 2020

“Denn in der steten Wechselwirkung zwischen experimenteller und theoretischer Forschung, die immer zugleich Antrieb und Kontrolle ist, wird auch in Zukunft die sicherste, die einzige Gewähr liegen für den gedeihlichen Fortschritt der physikalischen Wissenschaft.” — Max Planck

“Because the constant interaction between experimental and theoretical research, which is always inspiration and control, is the safest, the only guarantee of the prosperous progress of physical science.” — Max Planck
Einstein read a paper at the meeting of the Berlin Academy of Sciences on November 5, 1914 (chair: Max Planck) in the absence of the author, Karl Schwarzschild, who served as a soldier in World War I. The paper introduced the equation of radiation transfer:
1.4.3 Schwarzschild's Equation and Its Solution

Hence, the equation of transfer may be written as

\[
\frac{dI_\lambda}{k_\lambda \rho \, ds} = -I_\lambda + B_\lambda(T).
\]  \hspace{1cm} (1.55)

This equation is called Schwarzschild's equation. The first term in the right-hand side of Eq. (1.55) denotes the reduction of the radiant intensity due to absorption, whereas the second term represents the increase of the radiant intensity arising from blackbody emission of the material. To seek a solution

\[
- \frac{1}{e_{\nu, \nu}} \frac{dI_\nu(P, s)}{ds} = I_\nu(P, s) - J_\nu(P, s).
\]  \hspace{1cm} (2.17)

Equation (2.17) is known as the equation of transfer, and was first given in this form by Schwarzschild.
Schwarzschild (1906, Eq. 11): Two-stream approximation to the same problem

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

\[ A - E = \frac{A_0}{2} \text{ constant net flux independent of } m. \]

On Earth, in radiative-convective equilibrium: surface net radiation (non-radiative fluxes: latent + sensible) constrained to OLR/2.

At the bottom of the atmosphere where $\chi^* = \chi_0^*$, $F^\dagger = \pi B_g$, $B_g$ being the black-body function at the temperature of the ground. It is easy to show that there must be a temperature discontinuity at the lower boundary, the black-body function for the air close to the ground being $B_0$, and

$$B_g - B_0 = \frac{\phi}{2\pi}$$

(Eq. 1) $B_g - B_0 = B_{\text{eff}}/2$

In the specific case of optical depth $\chi_0^* = 2$,

My Eq. (3) Surface gross (total) absorption: $B_g = 2B_{\text{eff}}$

But why optical depth $\chi_0^* = 2$? Can it be real? A first check:
<table>
<thead>
<tr>
<th>All Sky</th>
<th>Ed4</th>
<th>Ed2.8</th>
<th>Ed4 – Ed2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOA SW Insolation</td>
<td>340.04</td>
<td>339.87</td>
<td>0.17</td>
</tr>
<tr>
<td>TOA SW Up</td>
<td>99.23</td>
<td>99.62</td>
<td>-0.39</td>
</tr>
<tr>
<td>TOA LW Up</td>
<td>240.14</td>
<td>239.60</td>
<td>0.54</td>
</tr>
<tr>
<td>SFC SW Down</td>
<td>187.04</td>
<td>186.47</td>
<td>0.57</td>
</tr>
<tr>
<td>SFC SW Up</td>
<td>23.37</td>
<td>24.13</td>
<td>-0.76 (3.1%)</td>
</tr>
<tr>
<td>SFC LW Down</td>
<td>344.97</td>
<td>345.15</td>
<td>-0.18</td>
</tr>
<tr>
<td>SFC LW Up</td>
<td>398.34</td>
<td>398.27</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clear Sky</th>
<th>Ed4</th>
<th>Ed2.8</th>
<th>Ed4 – Ed2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOA SW Insolation</td>
<td>340.04</td>
<td>339.87</td>
<td>0.17</td>
</tr>
<tr>
<td>TOA SW Up</td>
<td>53.41</td>
<td>52.50</td>
<td>0.91 (1.73%)</td>
</tr>
<tr>
<td>TOA LW Up</td>
<td>268.13</td>
<td>265.59</td>
<td>2.54</td>
</tr>
<tr>
<td>SFC SW Down</td>
<td>243.72</td>
<td>244.06</td>
<td>-0.33</td>
</tr>
<tr>
<td>SFC SW Up</td>
<td>29.81</td>
<td>29.74</td>
<td>0.07</td>
</tr>
<tr>
<td>SFC LW Down</td>
<td>314.07</td>
<td>316.27</td>
<td>-2.20</td>
</tr>
<tr>
<td>SFC LW Up</td>
<td>397.59</td>
<td>398.40</td>
<td>-0.81</td>
</tr>
</tbody>
</table>
Data from Rose et al (2017, Ed2.8)

- TOA LW up (clear) = 265.59  \( \Delta \text{Eq.(1)} = -0.60 \)
- SFC SW down (clear) = 244.06  \( \Delta \text{Eq.(3)} = -0.59 \)
- SFC SW up (clear) = 29.74
- SFC SW net (clear) = 214.32
- SFC LW down (clear) = 316.27
- SFC LW up (clear) = 398.40

\[
\text{Eq.(3) Surface gross (total) absorption} = 2 \text{OLR}
\]

\[
\text{SFC SW net + LW down} = 214.32 + 316.27 = 2 \times 265.59 - 0.59 \text{ Wm}^{-2}
\]

Loeb et al. (2013):

\[
\Rightarrow \text{Net planetary imbalance for July 2005-June 2010: 0.58±0.43 Wm}^{-2}
\]

What does Eq. (3) mean?
A theory / explanation / interpretation
The simplest greenhouse model

2.3. THE GREENHOUSE EFFECT

Figure 2.7. The simplest greenhouse model, comprising a surface at temperature $T_s$, and an atmospheric layer at temperature $T_a$, subject to incoming solar radiation $S_o/4$. The terrestrial radiation upwelling from the ground is assumed to be completely absorbed by the atmospheric layer.

Further, $G = S - A = A = S_o(1 - \alpha)/4$, solar absorbed surface
Hartmann (1994, Fig. 2.3)

Global Physical Climatology

\[
\frac{S_0}{4} (1 - \alpha_p) = \sigma T_A^4
\]

\[
G = \sigma (T_S^4 - T_A^4) = \sigma T_A^4 = \frac{S_0(1 - \alpha_p)}{4} \text{ solar absorbed surface}
\]

Fig. 2.3 Diagram of the energy fluxes for a planet with an atmosphere that is transparent for solar radiation but opaque to terrestrial radiation.

\[
\sigma T_S^4 = 2\sigma T_A^4 \quad (\text{Eq}3)
\]

and, of course,
In the case of $A = 0$ and $\varepsilon = 1$, it follows that $\sigma T^4 = 2\sigma T_a^4$, and

$$G = \sigma T^4 - (\varepsilon \sigma T_a^4 + (1 - \varepsilon)\sigma T^4) = Q(1 - r - A) \text{ even if } A \neq 0$$
If (hypothesis) on Earth we have \( \text{LWCRE} \approx \text{WIN(all)} \),

**clouds might compensate for the lost energy.**

K. Shine (2012): \( \text{WIN (clear)} = 66 \text{ Wm}^{-2} \)

Their computed \( \text{WIN(all)} = 22 \text{ Wm}^{-2} \) with \( \beta_{\text{obs}} = 0.67 \) and IR-opaque clouds

\( \text{WIN(all)} = \text{WIN(clear)} \times (1 - \beta_{\text{eff}}) = 26.4 \text{ Wm}^{-2} \) with \( \beta_{\text{eff}} = 0.6 \)

At least, not impossible.

Further details in [Zagoni EGU 2020](http://example.com) and forthcoming AGU2020.

**What does it follow from Eq. (1) and Eq. (3)?**
Theory: clear-sky, net and gross

Eq. (1) \( B_g - B_0 = \frac{B_{\text{eff}}}{2} \)

Eq. (3) \( B_g = 2B_{\text{eff}} \)

\[ B_g : B_0 : B_{\text{eff}} : B_{\text{Green}} = 4 : 3 : 2 : 1 \]

where \( B_{\text{Green}} = B_0 - B_{\text{eff}} \) (\( G = \text{ULW} - \text{OLR} \))

\[ 4 : 3 : 2 : 1 = 20 : 15 : 10 : 5, \text{ “all-sky units”} \]

Theory:

\[ g \text{ normalized greenhouse effect (greenhouse factor)} = \]

\[ = B_{\text{Green}} / B_0 = (\text{ULW} - \text{OLR}) / \text{ULW} = \frac{5}{15} = \frac{1}{3}. \]
Creating the all-sky version (Eq2) from Eq1
Houghton (2002, Fig. 2.4)

\[ \text{Eq1 (clear-sky)} \]
\[ B_g - B_0 = \frac{B_{\text{eff}}}{2} \]

\[ \text{My Eq2 (all-sky)} \]
\[ B_g - B_0 = (B_{\text{eff}} - L)^2 \]

Separating atmospheric radiation from longwave cloud effect (L):

\[ \text{Eq2} \quad B_g - B_0 = \frac{(B_{\text{eff}} - L)}{2} \quad \text{(surface net, all-sky)} \]
Creating the all-sky version (Eq4) from Eq3
Hartmann (1994, Fig. 2.3)

\[ \frac{S_0}{4} (1 - \alpha_p) \overset{\text{Atmosphere}}{=} \sigma T_A^4 \]
\[ \overset{\text{Surface}}{=} \sigma T_s^4 \]

\[ \sigma T_s^4 = 2 \sigma T_A^4 \quad \Rightarrow \quad \sigma T_s^4 = 2 \sigma T_e^4 \quad (2.12) \]

and the surface energy balance is consistent:

\[ \frac{S_0}{4} (1 - \alpha_p) + \sigma T_A^4 = \sigma T_s^4 \quad \Rightarrow \quad \sigma T_s^4 = 2 \sigma T_e^4 \quad (2.13) \]

**Eq3** Surface total (gross) SW + LW energy income: \( B_g = 2B_{\text{eff}} \)

**Eq4** Adding cloud effect, the surface absorption is: \( B_g = 2B_{\text{eff}} + L \)
The equations and their integer solution

Global mean $F = F_0 + \Delta F$, where $F_0 = N \times \text{UNIT}$; UNIT = 1 = LWCRE

$\Delta F$ = observation uncertainty + natural fluctuation + systematic deviation

Eq. (1)  Surface SW net + LW net (clear) = $\frac{\text{TOA LW(clear)}}{2}$

Eq. (2)  Surface SW net + LW net (all) = $\frac{\text{TOA LW(all)} - \text{LWCRE}}{2}$

Eq. (3)  Surface SW net + LW down (clear) = $2\text{TOA LW(clear)}$

Eq. (4)  Surface SW net + LW down (all) = $2\text{TOA LW(all)} + \text{LWCRE}$

Surface LW up, clear-sky = 15  Surface LW up, all-sky = 15
Surface SW net, clear-sky = 8  Surface SW net, all-sky = 6
Surface LW net, clear-sky = -3  Surface LW net, all-sky = -2
Surface SW+LW net, clr-sky = 5  Surface SW+LW net, all-sky = 4
Surface SW+LW gross, clear = 20  Surface SW+LW gross, all = 19
Surface LW down, clear-sky = 12  Surface LW down, all-sky = 13
OLR clear-sky = 10  OLR all-sky = 9
G greenhouse effect, clear-sky = 5  G greenhouse effect, all-sky = 6
SWCRE (surface) = -2  LWCRE (surface, TOA) = 1
$g(\text{clear-sky}) = \frac{5}{15} = \frac{1}{3}$  $g(\text{all-sky}) = \frac{6}{15} = 0.4$

Best fit 1 = 26.68 Wm$^{-2}$

So much about theory. And now, the experimental research.
Data from Rose et al (2017, Ed2.8)

- TOA LW up(clear) = 265.59 Wm\(^{-2}\)
- SFC LW up(clear) = 398.40 Wm\(^{-2}\)
- G (clear) = 132.81 Wm\(^{-2}\)

\[ g(\text{clear}) = \frac{G(\text{clear})}{\text{SFC LW up}} = \frac{132.81}{398.40} = 0.3333 \]

- g(clear, theory) = 1/3.
Celebrating 20 years of CERES Data
EBAF Ed4.1, April 2000 — March 2020

Eq. (1) SFC SW+LW net (clear-sky) = OLR(clear-sky)/2

Schwarzschild (1906, Eq. 11), net, clear-sky

<table>
<thead>
<tr>
<th>CERES 20-yr</th>
<th>F</th>
<th>N × UNIT</th>
<th>F₀</th>
<th>ΔF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC SW net</td>
<td>211.73</td>
<td>8 × 26.68</td>
<td>213.44</td>
<td>−1.71</td>
</tr>
<tr>
<td>SFC LW down</td>
<td>317.44</td>
<td>12 × 26.68</td>
<td>320.16</td>
<td>−2.72</td>
</tr>
<tr>
<td>SFC LW up</td>
<td>398.44</td>
<td>15 × 26.68</td>
<td>400.20</td>
<td>−1.76</td>
</tr>
<tr>
<td>TOA LW up</td>
<td>266.02</td>
<td>10 × 26.68</td>
<td>266.80</td>
<td>−0.78</td>
</tr>
<tr>
<td>SW+LW net</td>
<td>130.73</td>
<td>5 × 26.68</td>
<td>133.40</td>
<td>−2.67</td>
</tr>
<tr>
<td>G</td>
<td>132.42</td>
<td>5 × 26.68</td>
<td>133.40</td>
<td>−0.98</td>
</tr>
</tbody>
</table>

Eq. (1) 8 + 12 − 15 = 5 = 10/2

g(clear-sky, theory) = 5/15 = 1/3.
g(clear-sky) = 132.43/398.44 = 0.3323
Eq. (2) SFC SW+LW net = (OLR – LWCRE)/2, all-sky

<table>
<thead>
<tr>
<th>CERES 20-yr</th>
<th>F</th>
<th>N × UNIT</th>
<th>F₀</th>
<th>ΔF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC SW net</td>
<td>163.57</td>
<td>6 × 26.68</td>
<td>160.08</td>
<td>3.49</td>
</tr>
<tr>
<td>SFC LW down</td>
<td>345.13</td>
<td>13 × 26.68</td>
<td>346.84</td>
<td>-1.71</td>
</tr>
<tr>
<td>SFC LW up</td>
<td>398.66</td>
<td>15 × 26.68</td>
<td>400.20</td>
<td>-1.54</td>
</tr>
<tr>
<td>TOA LW up</td>
<td>240.21</td>
<td>9 × 26.68</td>
<td>240.12</td>
<td>0.09</td>
</tr>
<tr>
<td>LWCRE</td>
<td>25.81</td>
<td>1 × 26.68</td>
<td>26.68</td>
<td>-0.87</td>
</tr>
<tr>
<td>SW+LW net</td>
<td>110.04</td>
<td>4 × 26.68</td>
<td>106.72</td>
<td>3.32</td>
</tr>
<tr>
<td>(OLR – LWCRE)/2</td>
<td>107.20</td>
<td>4 × 26.68</td>
<td>106.72</td>
<td>0.48</td>
</tr>
<tr>
<td>G</td>
<td>158.45</td>
<td>6 × 26.68</td>
<td>160.08</td>
<td>-1.63</td>
</tr>
</tbody>
</table>

Eq. (2) \(6 + 13 - 15 = 4 = (9 - 1)/2\)
\(g(\text{all-sky, theory}) = 6/15 = 0.4.\)
\(g(\text{all-sky}) = (398.66 - 240.21)/398.66 = 0.3975\)

\(\Delta \text{SFC SW net} = 3.49\) Wm\(^{-2}\) the largest individual bias on the whole data set
Eq. (3)  SFC SW net + LW down (clear) = 2OLR(clear)

\[
\frac{S_0}{4} (1 - \alpha_p) = \sigma T_A^4 + \sigma T_s^4
\]

\[
\sigma T_s^4 = 2\sigma T_A^4
\]

<table>
<thead>
<tr>
<th>CERES 20-yr</th>
<th>F</th>
<th>(N \times \text{UNIT} )</th>
<th>(F_0)</th>
<th>(\Delta F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC SW net</td>
<td>211.73</td>
<td>8 \times 26.68</td>
<td>213.44</td>
<td>–1.71</td>
</tr>
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<td>317.44</td>
<td>12 \times 26.68</td>
<td>320.16</td>
<td>–2.72</td>
</tr>
<tr>
<td>SW net + LW down</td>
<td>529.17</td>
<td>20 \times 26.68</td>
<td>533.60</td>
<td>–4.43</td>
</tr>
<tr>
<td>TOA LW up</td>
<td>266.02</td>
<td>10 \times 26.68</td>
<td>266.80</td>
<td>–0.72</td>
</tr>
</tbody>
</table>

\[\text{Eq. (3) } 8 + 12 = 20 = 2 \times 10 \]

\[\Delta SFC \text{ SW net + LW down} = -4.43 \text{ Wm}^{-2} \text{ the largest composite bias on the whole data set}\]
Eq. (4)  SFC SW net + LW down (all) = 2OLR(all) + LWCRE

\[
\frac{S_0}{4} (1 - \alpha_p) = \sigma T_A^4 + \sigma T_s^4
\]

\[\text{LWCRE}\]

<table>
<thead>
<tr>
<th>CERES 20-yr</th>
<th>F</th>
<th>N \times \text{UNIT}</th>
<th>F_0</th>
<th>\Delta F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC SW net</td>
<td>163.57</td>
<td>6 \times 26.68</td>
<td>160.08</td>
<td>3.49</td>
</tr>
<tr>
<td>SFC LW down</td>
<td>345.13</td>
<td>13 \times 26.68</td>
<td>346.84</td>
<td>-1.71</td>
</tr>
<tr>
<td>TOA LW up</td>
<td>240.21</td>
<td>9 \times 26.68</td>
<td>240.12</td>
<td>0.09</td>
</tr>
<tr>
<td>LWCRE</td>
<td>25.81</td>
<td>1 \times 26.68</td>
<td>26.68</td>
<td>-0.87</td>
</tr>
<tr>
<td>SW net + LW down</td>
<td>508.70</td>
<td>19 \times 26.68</td>
<td>506.92</td>
<td>1.78</td>
</tr>
<tr>
<td>2OLR + LWCRE</td>
<td>506.23</td>
<td>19 \times 26.68</td>
<td>506.92</td>
<td>-0.69</td>
</tr>
</tbody>
</table>

Eq. (4)  \textbf{6 + 13} = \textbf{19} = 2 \times 9 + 1  \quad 2.46
Mean bias of the four equations

- Net (clear-sky) \( \Delta Eq1 = -2.28 \) \( \{ \) 0.28 \)
- Net (all-sky) \( \Delta Eq2 = 2.84 \) \( \} \)
- Gross (clear-sky) \( \Delta Eq3 = -2.88 \) \( \} \) -0.21
- Gross (all-sky) \( \Delta Eq4 = 2.46 \) \( \} \)

mean = 0.035 Wm\(^{-2}\)

- Clear-sky (net) \( \Delta Eq1 = -2.28 \) \( \} \) -2.58
- Clear-sky (gross) \( \Delta Eq3 = -2.88 \) \( \} \)
- All-sky (net) \( \Delta Eq2 = 2.84 \) \( \} \) 2.65
- All-sky (gross) \( \Delta Eq4 = 2.46 \) \( \} \)

mean = 0.035 Wm\(^{-2}\)
Extension to Total Solar Irradiance

S. Gupta, D. Kratz, P. Stackhouse, A Wilber: On Continuation of the Use of Daily TSI for CERES Processing

CERES 33rd Science Team Meeting, April 28, 2020

Straight Line Fit to SORCE TSI - Jan2018-Dec2019

- $N = 594$
- Mean TSI = 1360.670 Wm$^{-2}$
- Slope = -0.0160 Wm$^{-2}$/year
- Uncertainty on slope = 0.0043

Value at 2018 = 1360.6861
Value at 2020 = 1360.6541

$TSI = 1360.670 \text{ Wm}^{-2}$, value at 2018 = 1360.686 Wm$^{-2}$
# Accuracy of TOA Fluxes

*clear-sky for total area, EBAF Ed4.1, 04/2000 – 03/2020*

<table>
<thead>
<tr>
<th>Flux name, F</th>
<th>$N$</th>
<th>$F = F_0 + \Delta F$</th>
<th>$F_0 = N \times \text{UNIT}$</th>
<th>$\Delta F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW clear-sky</td>
<td>8 / 4</td>
<td>53.76</td>
<td>53.36</td>
<td>0.40</td>
</tr>
<tr>
<td>LW clear-sky</td>
<td>40 / 4</td>
<td>266.02</td>
<td>266.80</td>
<td>-0.78</td>
</tr>
<tr>
<td>SW all-sky</td>
<td>15 / 4</td>
<td>99.04</td>
<td>100.05</td>
<td>-1.01</td>
</tr>
<tr>
<td>LW all-sky</td>
<td>36 / 4</td>
<td>240.21</td>
<td>240.12</td>
<td>0.09</td>
</tr>
<tr>
<td>TOA LW CRE</td>
<td>4 / 4</td>
<td>25.81</td>
<td>26.68</td>
<td>-0.87</td>
</tr>
<tr>
<td>TOA SW CRE</td>
<td>-7 / 4</td>
<td>-45.28</td>
<td>-46.69</td>
<td>1.41</td>
</tr>
<tr>
<td>TOA Net CRE</td>
<td>-3 / 4</td>
<td>-19.47</td>
<td>-20.01</td>
<td>0.54</td>
</tr>
<tr>
<td>Albedo, clear</td>
<td>8 / 51</td>
<td>0.158</td>
<td>0.157</td>
<td>0.001</td>
</tr>
<tr>
<td>Albedo, all</td>
<td>15 / 51</td>
<td>0.291</td>
<td>0.294</td>
<td>-0.003</td>
</tr>
</tbody>
</table>

Each flux is an **integer** on the intercepting cross-section disk

Mean TSI = $51 = 1360.68 \pm 0.5 \text{ Wm}^{-2}$ => UNIT = $1 = 26.68 \pm 0.01 \text{ Wm}^{-2}$

Clear-sky: SW up = 8  SW in = 43  LW up = 40  Net CRE = -3

All-sky: SW up = 15  SW in = 36  LW up = 36
The Clear-Sky Greenhouse Effect at GFDL

\[ \text{SORCE TSI} = 51 = 1360.68 \pm 0.5 \text{ Wm}^{-2} \]

\[ \Rightarrow G(\text{clear-sky}) = 5 = 133.40 \pm 0.05 \text{ Wm}^{-2} \]

\[ G(\text{GFDL AM4}) = 133.4 \pm 0.6 \text{ Wm}^{-2} \Delta F = 0.0 \]


Shiv Priyam Raghuraman\(^1\), David Paynter\(^2\), and V. Ramaswamy\(^2\) (2019)

\(^1\)Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, USA, \(^2\)Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, NJ, USA

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_{\text{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>
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<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>
The Greenhouse Effect of Clouds, $\Delta F(\text{CERES}) = 0.06 \text{ Wm}^{-2}$

<table>
<thead>
<tr>
<th></th>
<th>OLR all-sky</th>
<th>LWCRE at TOA</th>
<th>OLR clear-sky</th>
<th>LWCRE Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>240.21</td>
<td>25.81</td>
<td>266.02</td>
<td>26.68</td>
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<tr>
<td>CERES LWCRE mean</td>
<td></td>
<td>26.74</td>
<td></td>
<td></td>
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<tr>
<td>LWCRE at surface</td>
<td></td>
<td>27.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLR all-sky</td>
<td>345.13</td>
<td></td>
<td>317.44</td>
<td></td>
</tr>
<tr>
<td>DLR clear-sky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stephens et al. (2012)

- LWCRE mean = 26.65 Wm$^{-2}$
- $\Delta F(\text{Stephens}) = -0.03 \text{ Wm}^{-2}$

LWCRE Theory

$$1 = \frac{\text{TSI/51}}{51} = \frac{1360.68}{51} = 26.68 \text{ Wm}^{-2}$$

CERES – Theory: $0.06 \text{ Wm}^{-2}$
The global energy balance as represented in CMIP6 climate models, Clim Dyn
Wild (2020) The global energy balance as represented in CMIP6 climate models, Clim Dyn

All sky

Incoming solar TOA

340 341 340 340

51/4
17/4
340.17

36/4
12/4
240.12

101
102
100
99

15/4
5/4
100.05

1 26.68

CMIP6

CMIP5

G 6 2
240.12

238 238 239 240

thermal outgoing TOA

9 3

1 26.68

G(0.4) = wireless 0.4

0.4050 0.4035

0.3995 0.3970

SFC SW net + LW net = (OLR - LWCRE)/2 (4; 1+1); SFC SW net + LW down = 2OLR + LWCRE (19; 6+1)
Your recent approach to imbalance: EEI = f(GHG, LW)

LW is precise

TOA LW up
ΔF = 0.09 Wm^(-2)

Atm LW cooling
ΔF = 0.08 Wm^(-2)

CERES 20-yr
LW up
240.21

CERES 20-yr
SW reflected
99.04

CERES 20-yr
SFC SW down
186.76

I propose to consider EEI = f(SW)
## Understanding 20 Years of CERES Data

### Clear-sky

<table>
<thead>
<tr>
<th>Flux</th>
<th>ISR</th>
<th>TOA SW up</th>
<th>TOA LW up</th>
<th>Net CRE</th>
<th>SFC SWnet</th>
<th>SFC LW dn</th>
<th>SFC LW up</th>
<th>g clear</th>
<th>albedo clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>340.02</td>
<td>53.76</td>
<td>266.02</td>
<td>-19.47</td>
<td>211.73</td>
<td>317.44</td>
<td>398.44</td>
<td>0.3323</td>
<td>0.158</td>
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<td>F₀</td>
<td>340.17</td>
<td>53.36</td>
<td>266.80</td>
<td>-20.01</td>
<td>213.44</td>
<td>320.16</td>
<td>400.20</td>
<td>1/3</td>
<td>0.157</td>
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<tr>
<td>ΔF</td>
<td>-0.15</td>
<td>0.40</td>
<td>-0.78</td>
<td>0.54</td>
<td>-1.71</td>
<td>-2.72</td>
<td>-1.76</td>
<td>-0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>N</td>
<td>51/4</td>
<td>8/4</td>
<td>40/4</td>
<td>3/4</td>
<td>8</td>
<td>12</td>
<td>15</td>
<td>5/15</td>
<td>8/51</td>
</tr>
</tbody>
</table>

ΔEq1 (clear, net) = -2.28

### All-sky

<table>
<thead>
<tr>
<th>Flux</th>
<th>TOA SW up</th>
<th>TOA LW up</th>
<th>SFC SW dn</th>
<th>SFC SWnet</th>
<th>SFC LW dn</th>
<th>SFC LW up</th>
<th>ATM LW cooling</th>
<th>g all-sky</th>
<th>albedo all-sky</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>99.04</td>
<td>240.21</td>
<td>186.76</td>
<td>163.57</td>
<td>345.13</td>
<td>398.66</td>
<td>-186.68</td>
<td>0.3974</td>
<td>0.291</td>
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<tr>
<td>F₀</td>
<td>100.05</td>
<td>240.12</td>
<td>186.76</td>
<td>160.08</td>
<td>346.84</td>
<td>400.20</td>
<td>-186.76</td>
<td>0.4</td>
<td>0.294</td>
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<tr>
<td>ΔF</td>
<td>-1.01</td>
<td>0.09</td>
<td>0.00</td>
<td>3.49</td>
<td>-1.71</td>
<td>-1.54</td>
<td>0.08</td>
<td>-0.003</td>
<td>-0.003</td>
</tr>
<tr>
<td>N</td>
<td>15/4</td>
<td>36/4</td>
<td>7</td>
<td>6</td>
<td>13</td>
<td>15</td>
<td>-7</td>
<td>6/15</td>
<td>15/51</td>
</tr>
</tbody>
</table>

ΔEq2 (all, net) = 2.84

ΔEq3 (clear, gross) = -2.88

ΔEq4 (all, gross) = 2.46
Conclusions / 1

- **Eq1** is a standard textbook formula; it may be derived from first principles; its validity was expected, and proved by CERES within 2.3 Wm$^{-2}$. It constrains the global hydrological cycle to OLR/2.

- Yet it is missing from the Charney Report’s “principal premises”. It is missing from the climate models, sensitivity studies, forcing and feedback estimates, imbalance computations and climate change assessments.

- **Eq2** is its evident all-sky extension, valid within the same range of uncertainty.

- **Eq3** and **Eq4** describe a particular state with specific determinations, justified within the same difference.

- The $g$ greenhouse factors come from the equations without reference to the atmospheric trace-gas composition. They do not show any enhancement or deviation from their theoretical position during these 20 years.

- The extension of the $N$ system to TSI is unexpected but extremely accurate, providing us with the correct albedos. Identifying the all-sky unit as the greenhouse effect of clouds gives $1 = \text{LWCRE}$, with a best fit of 26.68 Wm$^{-2}$.

- We can see variations in the $F$ values during these two decades, but they might be fluctuations around, rather than permanent deviations from the $F_0$ positions, where for each flux $\Delta F$ is within the known observation uncertainty.

- I expect $\Delta \text{LW} < \pm 3 \text{ Wm}^{-2}$ for the next decades as well.
As the last speaker of this conference, I took the liberty of concluding from my point of view.

I wish to say thank you to the CERES Science Team for their endless effort for better and better accuracy.

Without that high level of data quality, my theoretical considerations would not have been possible.

I hope my theory justified your data and your data verified my theory, for the benefit of both of us.