Observing and Modeling Earth's Energy Flows, Ten Years Later

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Budapest, Hungary

Earth Radiation Budget Workshop & CERES Science Team Meeting

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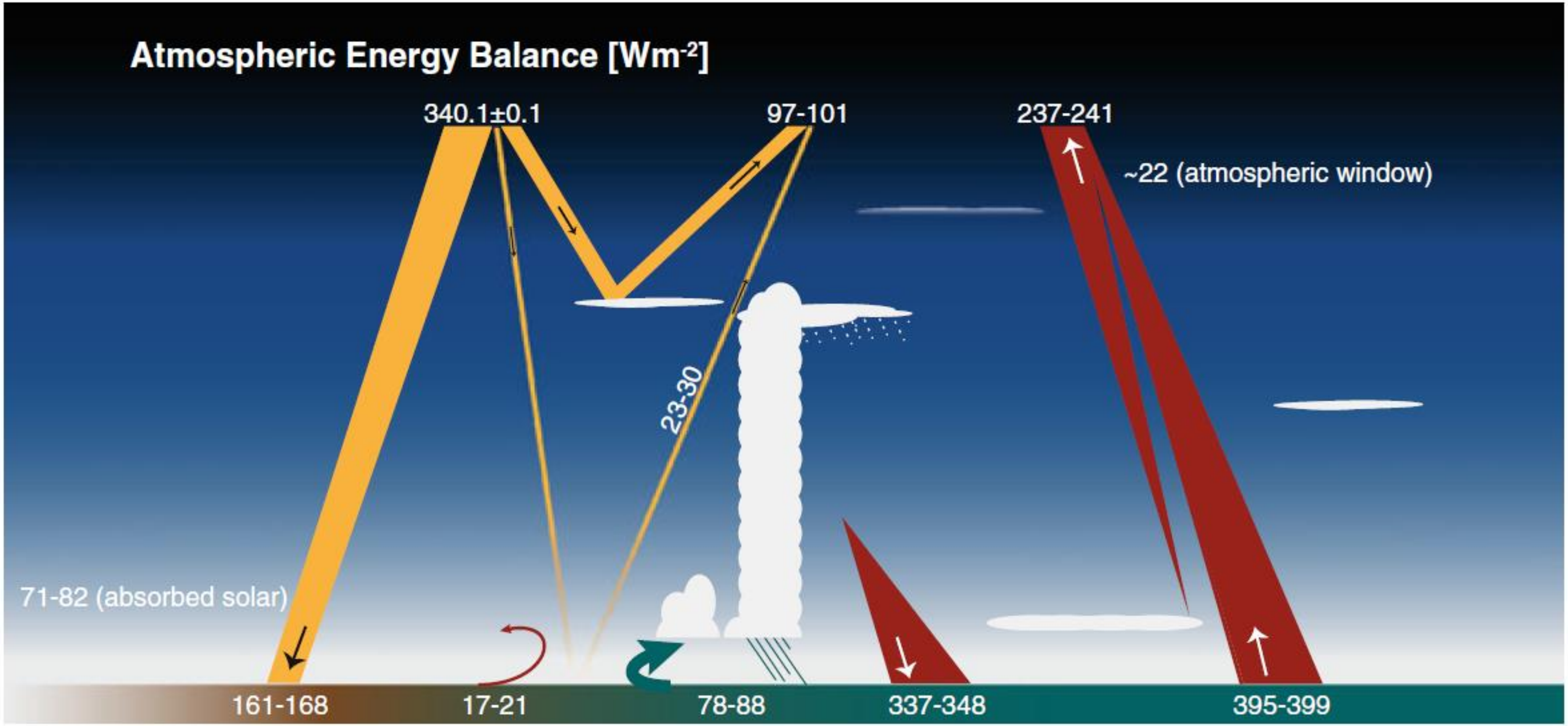
Observing

Observing and Modeling Earth's Energy Flows

Surv Geophys (2012) 33:779–816

Bjorn Stevens • Stephen E. Schwartz



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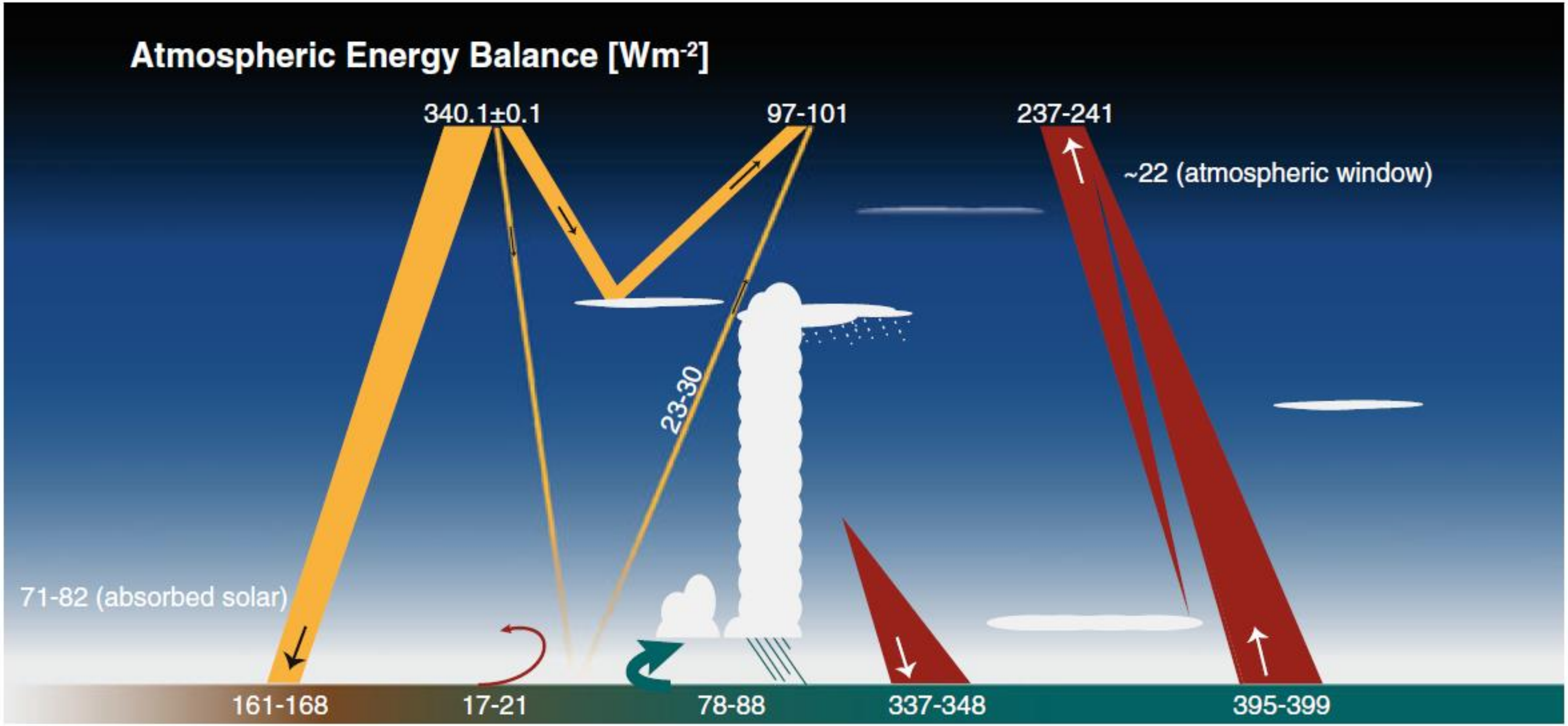
long-wave CRE of +26.5 W m^{-2}



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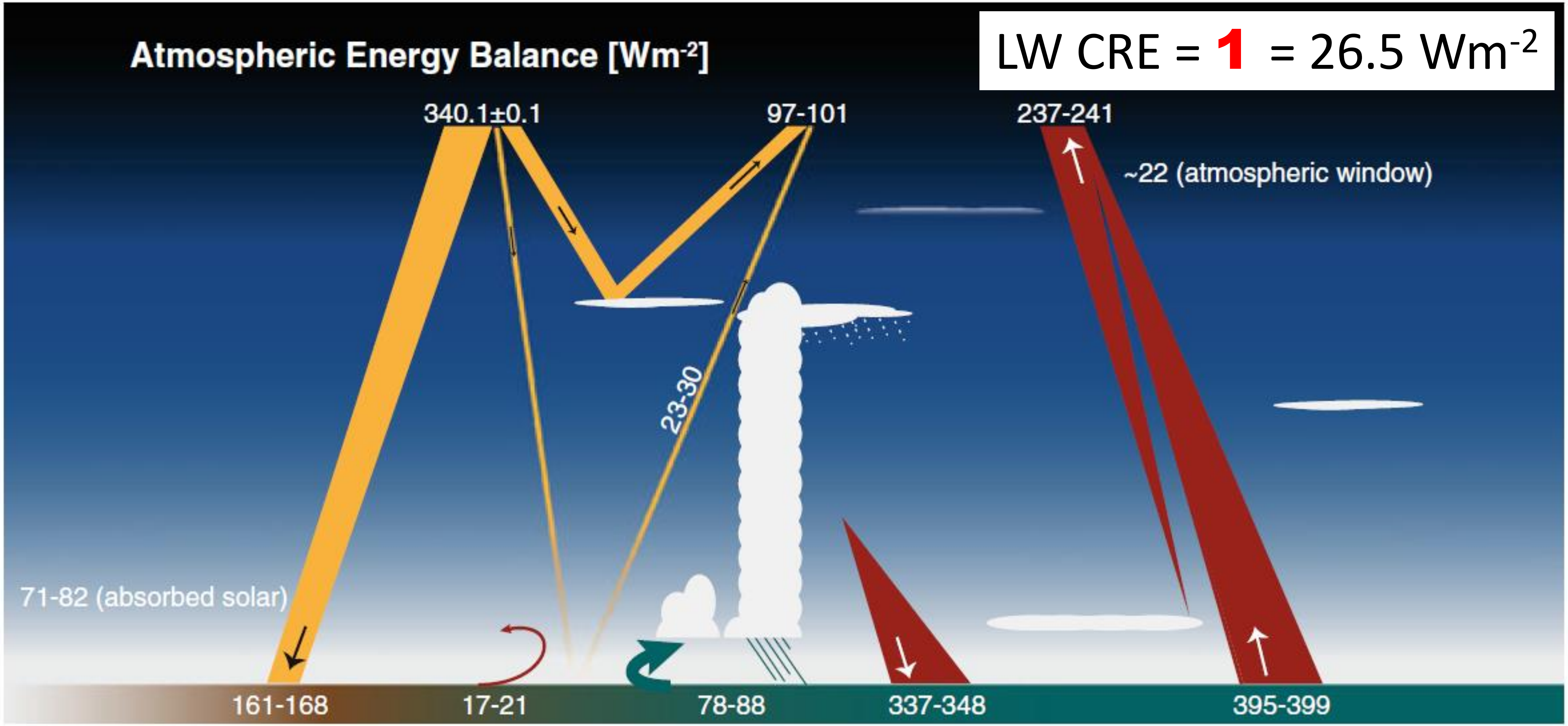

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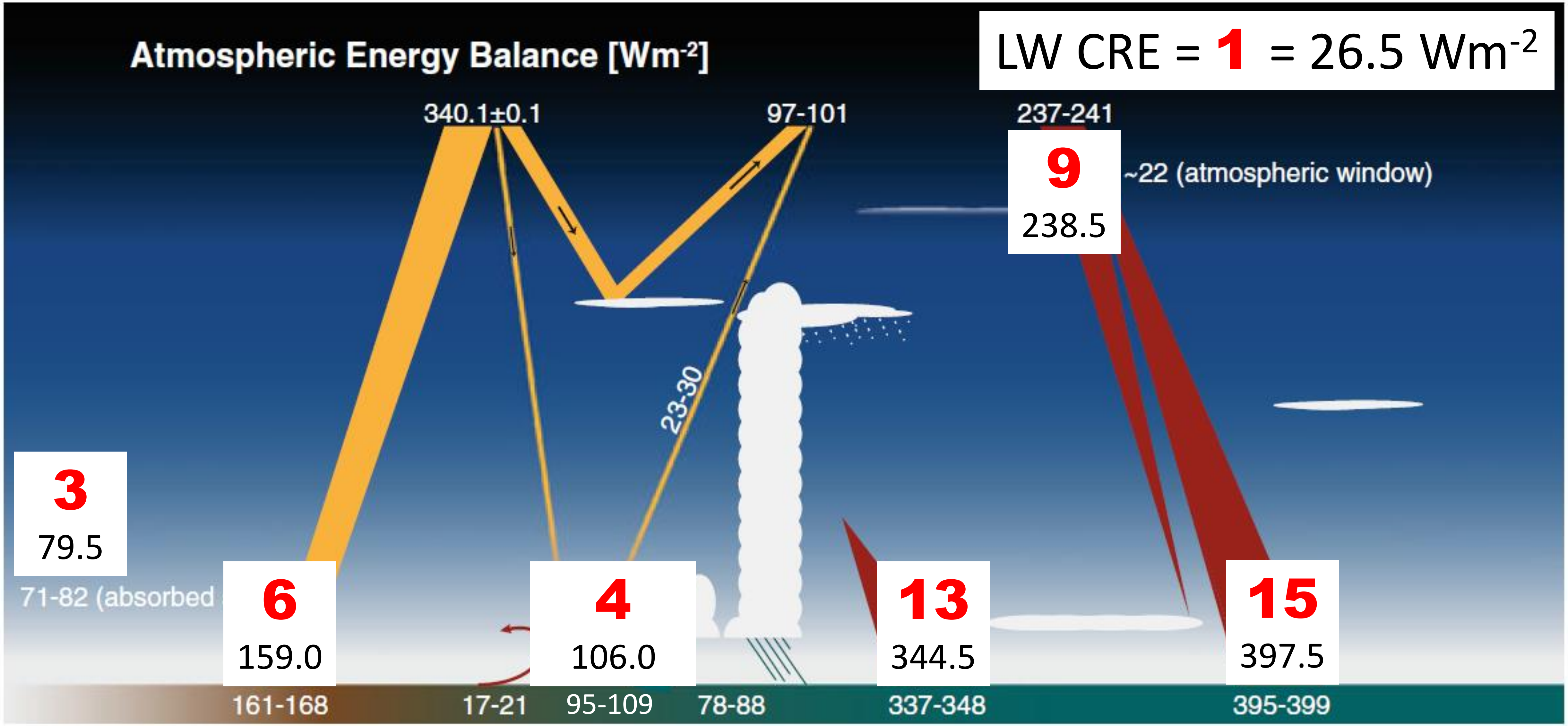
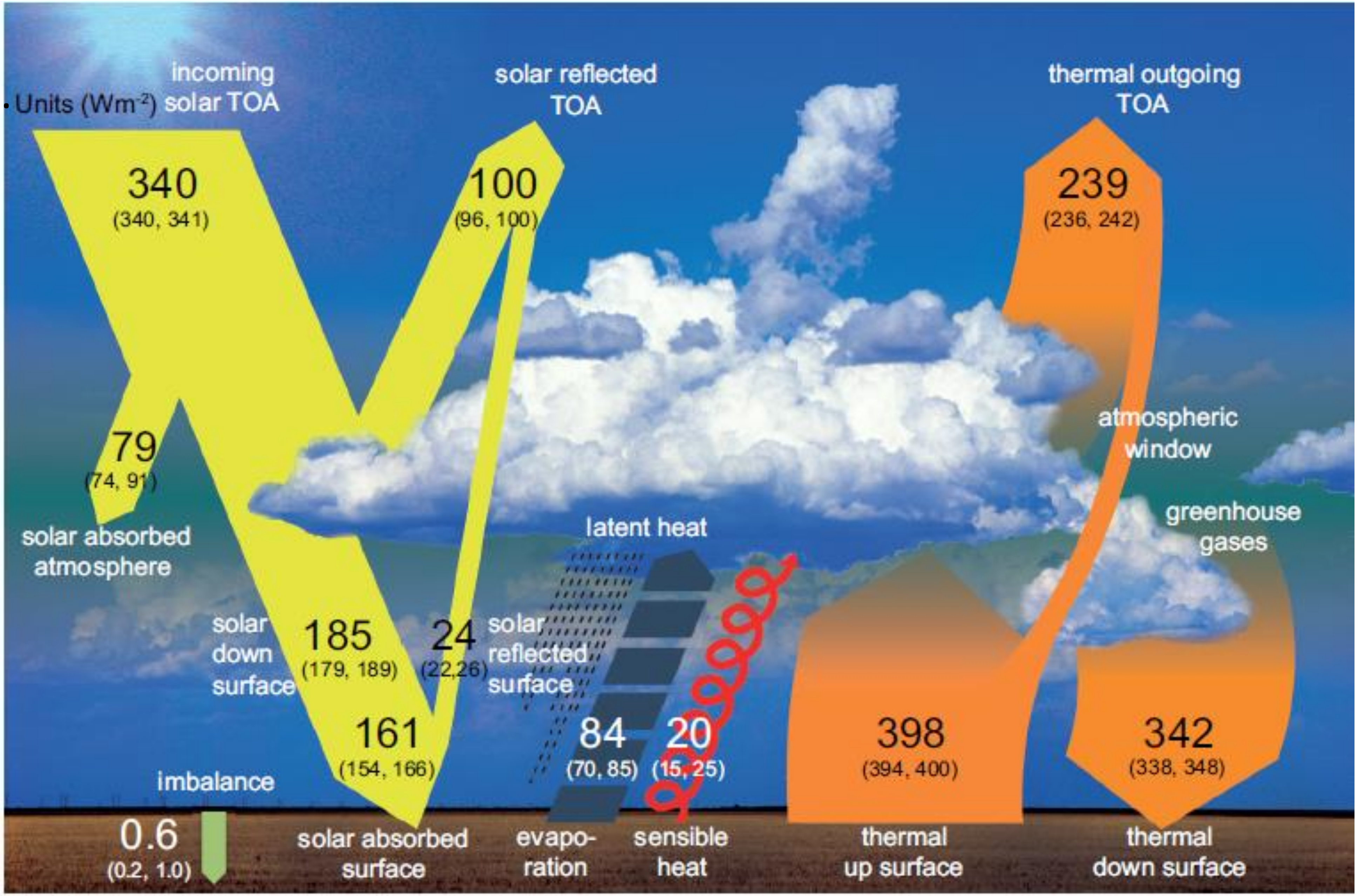


IPCC AR5
Wild et al.
(2013)



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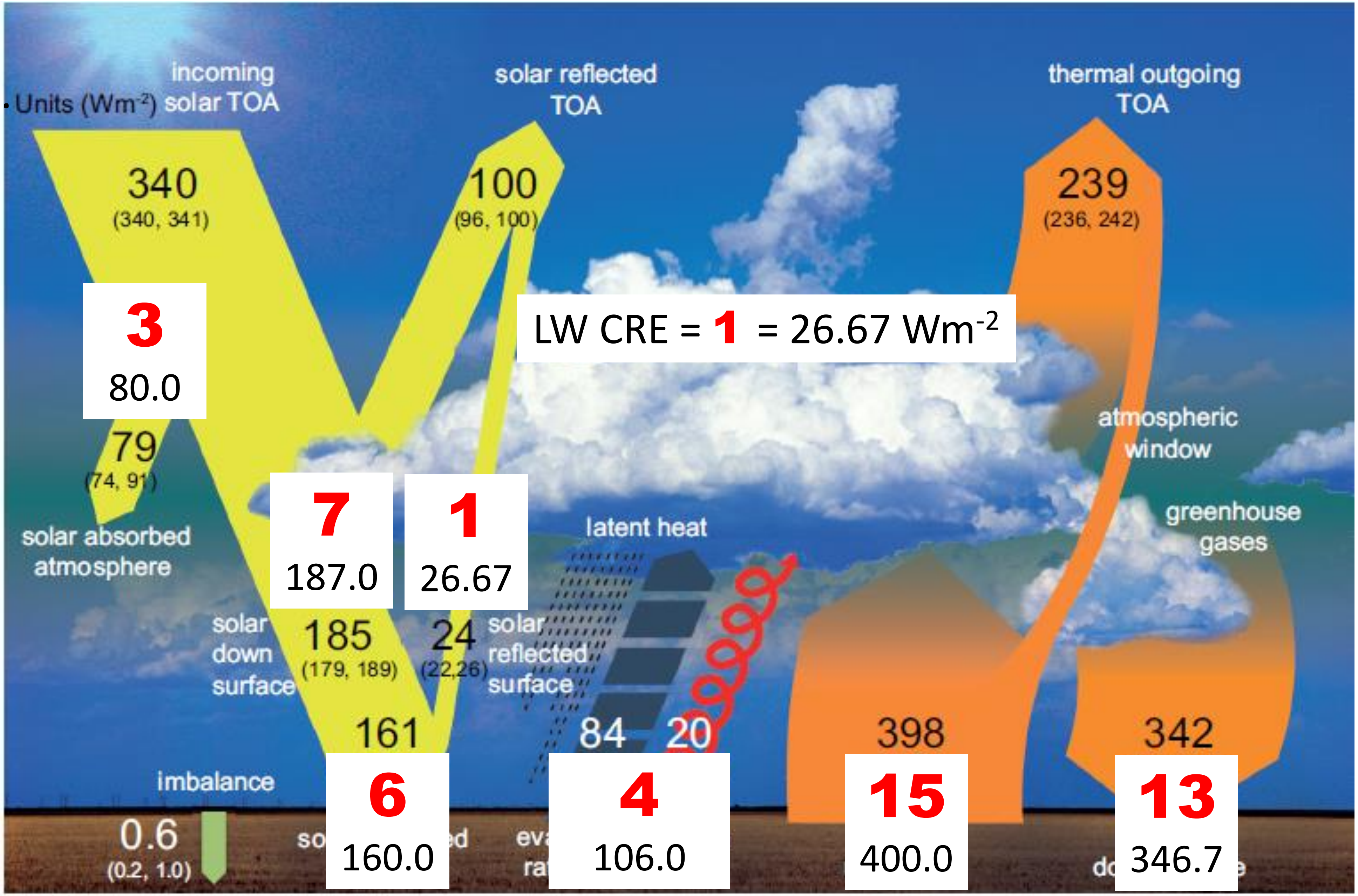

Each **N**-position is within the stated uncer-tainty

IPCC AR5
Wild et al.
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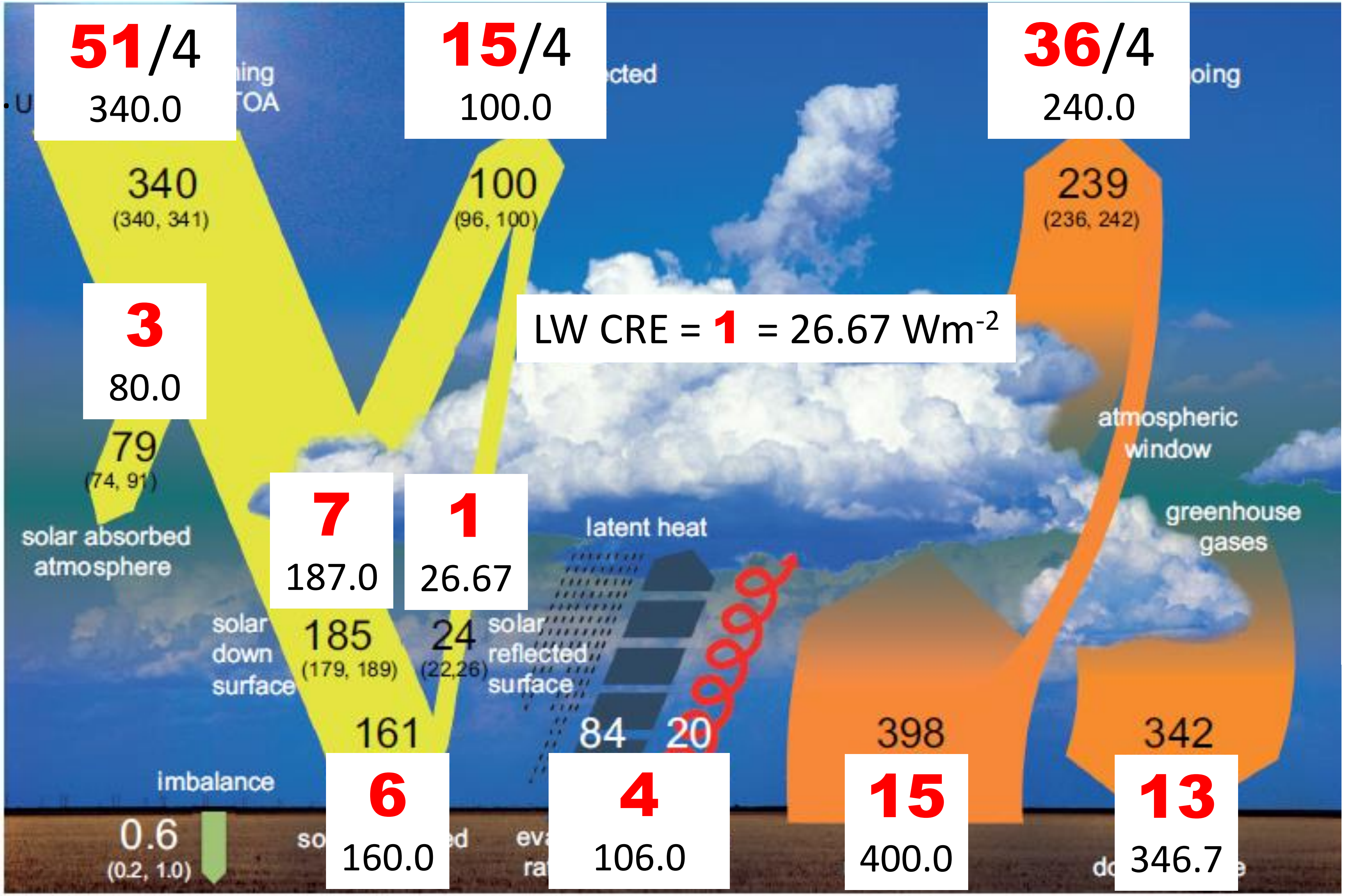

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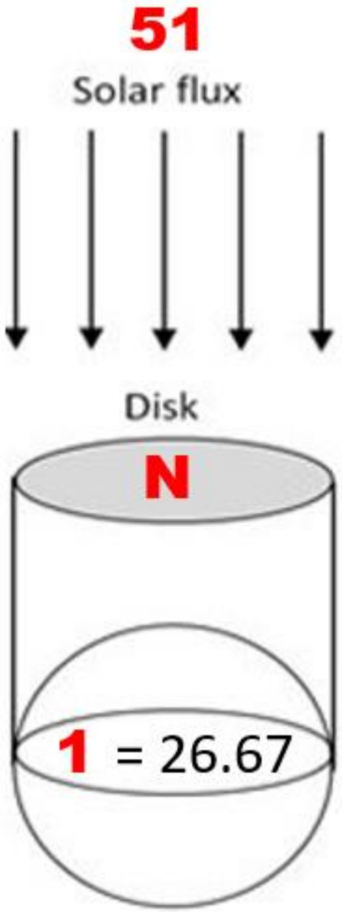
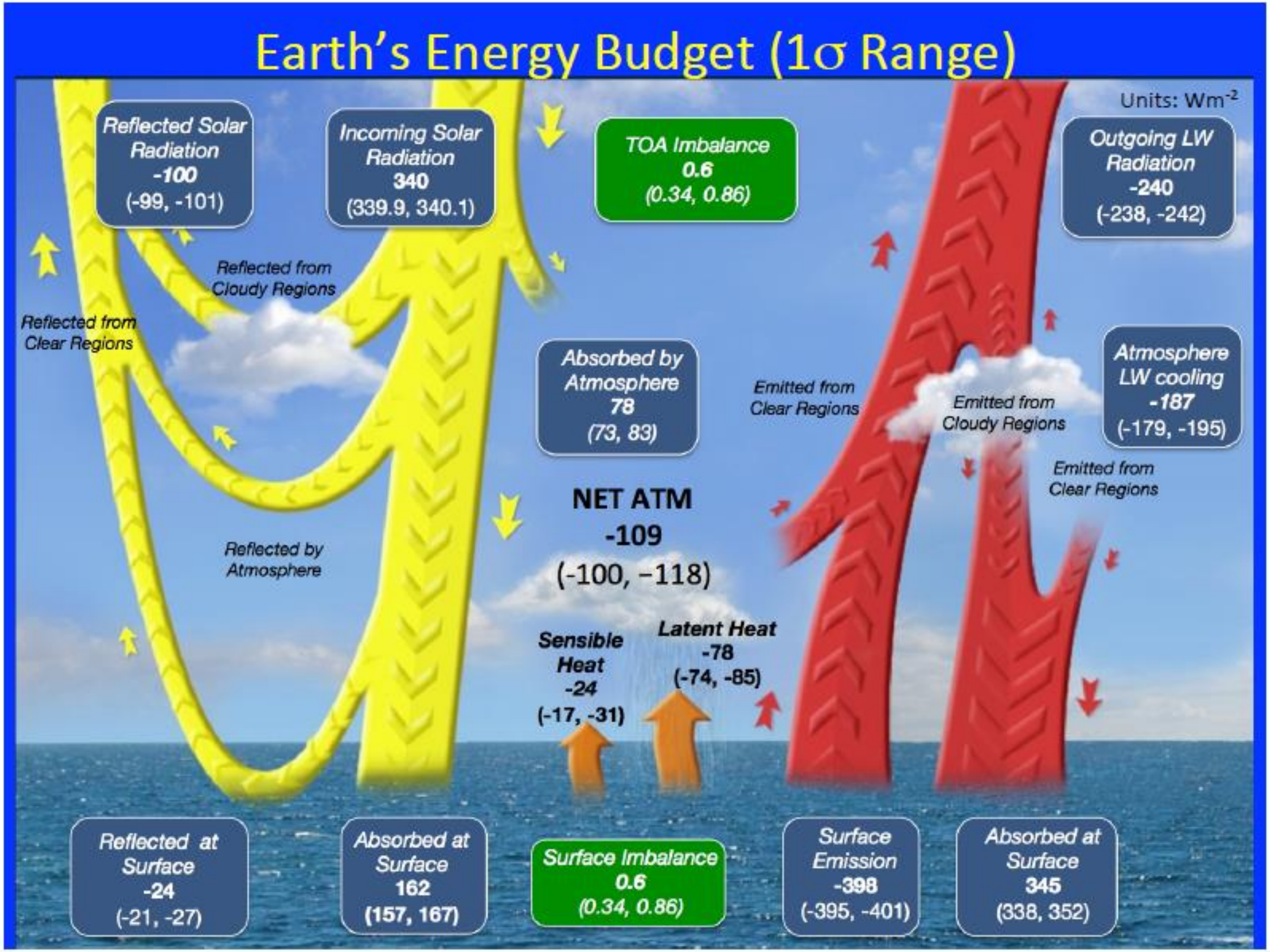


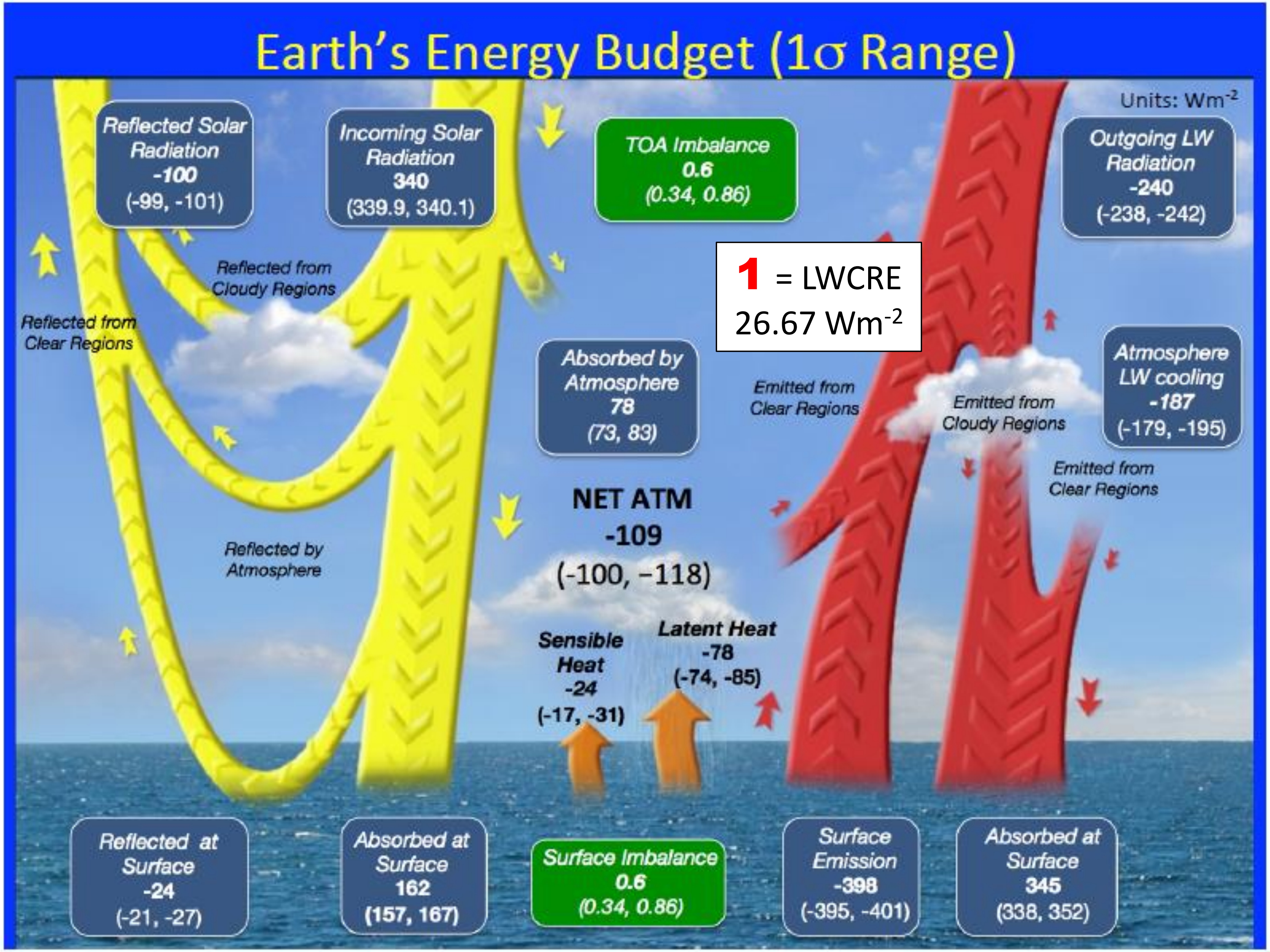
Each flux is integer on the cross-section disk

Loeb
(2014)



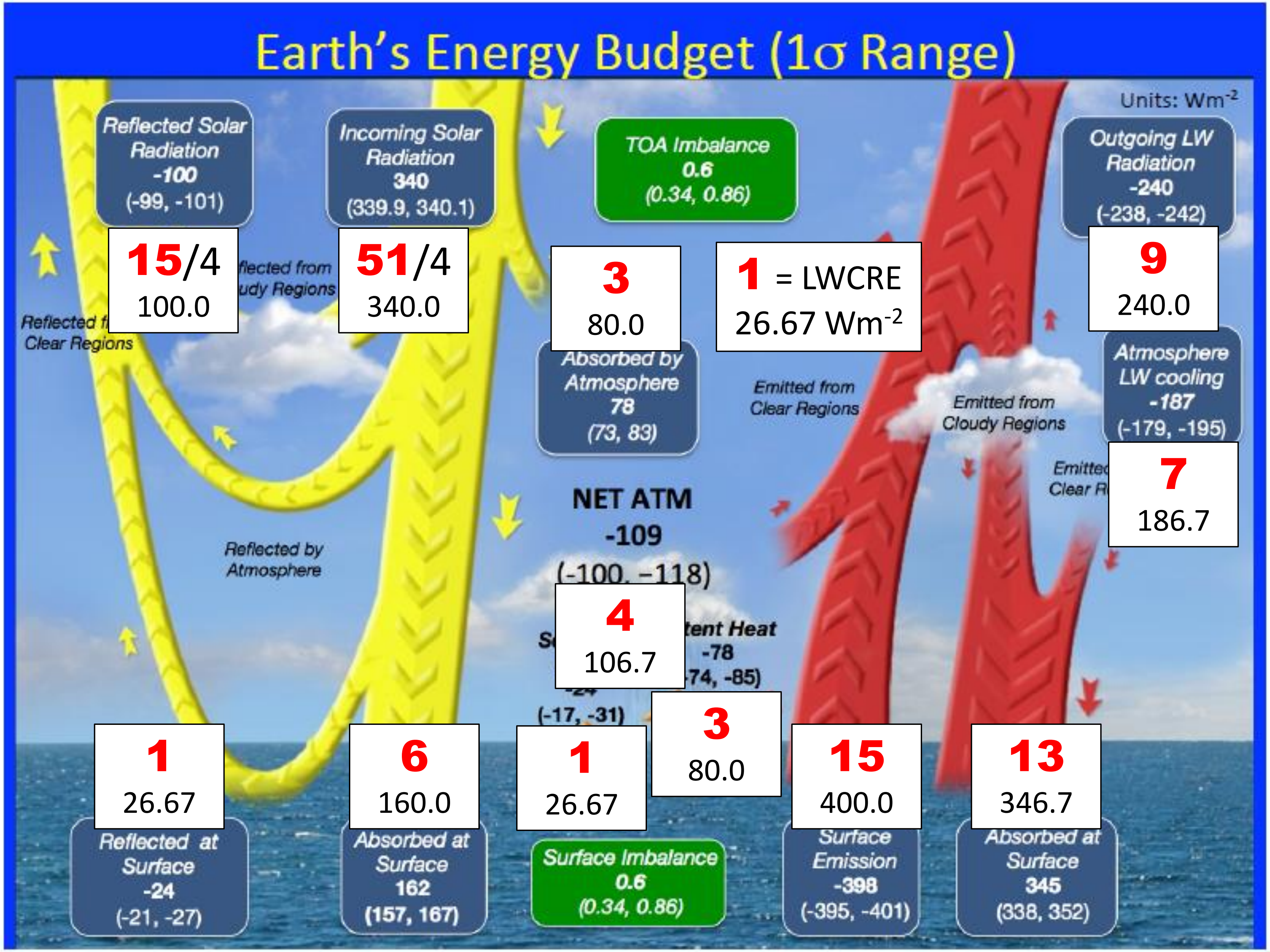
Earth's Energy Budget (1σ Range)
Units: Wm-2
Reflected Solar Radiation
-100
(-99, -101)
Incoming Solar Radiation
340
(339.9, 340.1)
TOA Imbalance
0.6
(0.34, 0.86)
Outgoing LW Radiation
-240
(-238, -242)
Reflected from Cloudy Regions
Reflected from Clear Regions
Absorbed by Atmosphere
78
(73, 83)
Emitted from Clear Regions
Emitted from Cloudy Regions
Atmosphere LW cooling
-187
(-179, -195)
Emitted from Clear Regions
NET ATM
-109
(-100, −118)
Reflected by Atmosphere
Sensible Heat
-24
(-17, -31)
Latent Heat
-78
(-74, -85)
Reflected at Surface
-24
(-21, -27)
Absorbed at Surface
162
(157, 167)
Surface Imbalance
0.6
(0.34, 0.86)
Surface Emission
-398
(-395, -401)
Absorbed at Surface
345
(338, 352)

Loeb (2014)



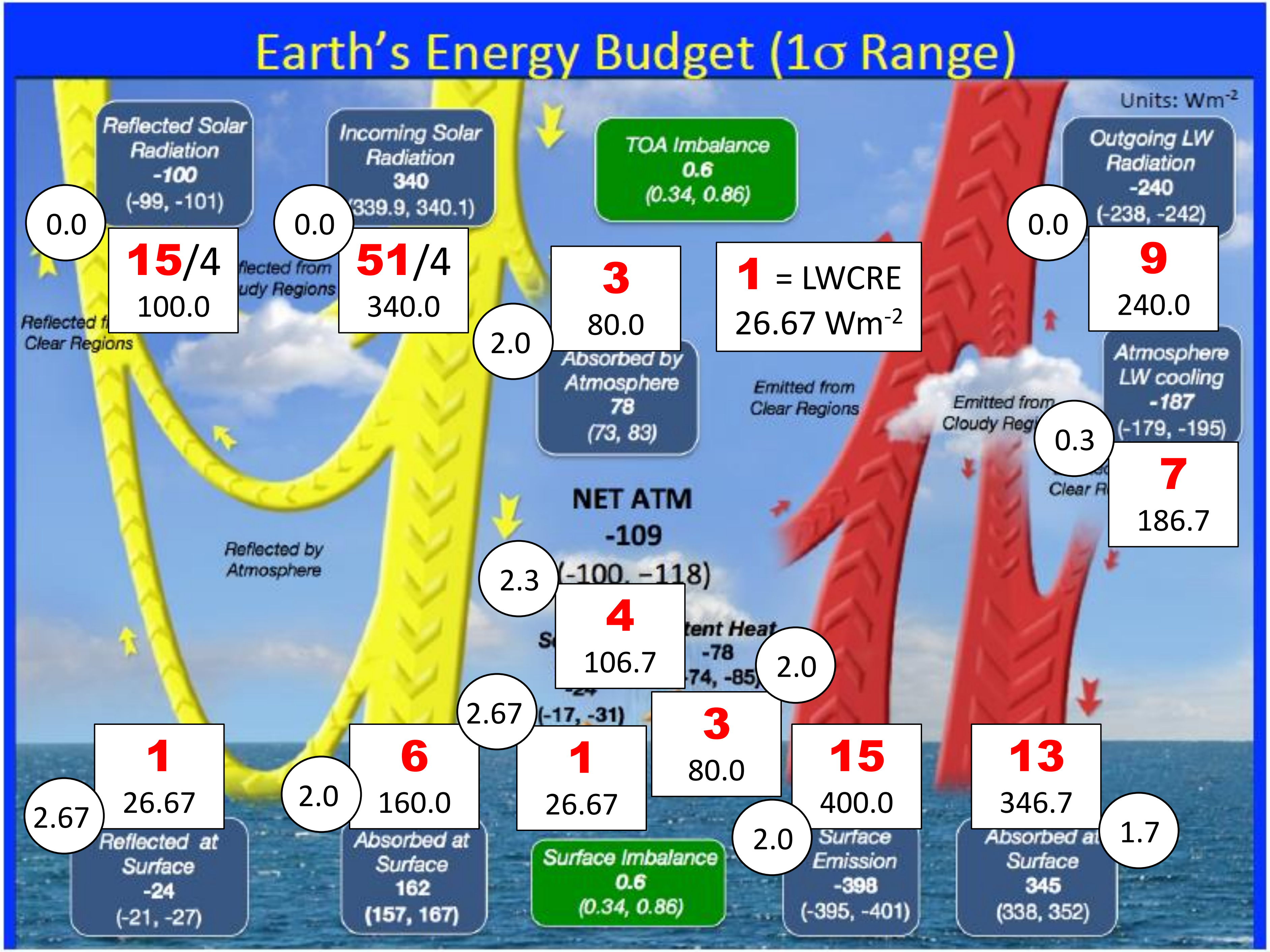
1 = LWCRE
26.67 Wm^{-2}

Loeb (2014)



EACH flux component is within the stated range of uncertainty

Loeb (2014)



EACH flux component is within the stated range of uncertainty

Largest difference

2.67

Wm^{-2}

CERES EBAF Ed.4.1 Data Quality Summary, Table 2-1, clear-sky with Δ^C (July 2005-June 2015) **1** = 26.67 Wm^{-2}, largest difference 2.8 Wm^{-2}

		N	**N** × Unit	Observed Table 2-1	Observed – Modeled
Clear-Sky TOA	LW	**40**/4	266.7	265.9	-0.8
	SW	**8**/4	53.3	53.8	0.5
	Net	**3**/4	20.0	20.3	0.3
Clear-Sky Surface	LW down	**12**	320.0	317.2	-2.8
	LW up	**15**	400.0	398.2	-1.8
	LW Net	**-3**	-80.0	-81.0	-1.0
	SW down	**9**	240.0	240.7	0.7
	SW up	**1**	26.67	29.1	2.4
	SW Net	**8**	213.3	211.6	-1.7
	SW + LW Net	**5**	133.3	130.6	-2.7

CERES EBAF Ed.4.1 Data Quality Summary, Table 4-1, all-sky (July 2005-June 2015) 1 = 26.67 Wm^{-2}, largest difference 3.5 Wm^{-2}

	All-sky	**N**	**N** × Unit	Observed Table 4-1	Observed – Modeled
TOA	SW insolation	**51**/4	340.0	340.0	0.0
	SW up	**15**/4	100.0	99.1	-0.9
	LW up	**36**/4	240.9	240.1	-0.8
	TOT Net	0	0	0.71	0.71
Surface	SW down	**7**	186.7	186.6	-0.1
	SW up	**1**	26.67	23.2	-3.5
	SW Net	**6**	160.0	163.3	3.3
	LW down	**13**	346.7	344.8	-1.9
	LW up	**15**	400.0	398.3	-1.7
	LW Net	**-2**	-53.3	-53.5	-0.2
	TOT Net	**4**	106.7	109.8	3.1
	CRE				
TOA	SW	**-7**/4	-46.7	-45.3	1.4
	LW	**1**	26.67	25.8	-0.9
	TOT	**-3**/4	-20.0	-19.6	0.4

2022 October

CERES EBAF Ed4.1, 264 months (Mar 2000 – Feb 2022)

256		94.4433	242.463	-7.3098	52.1217	268.077	9.3989	-42.3219	25.6142	-16.7077	329.597
257		93.2353	244.019	-8.0008	50.1934	269.585	9.47502	-43.0421	25.5662	-17.4759	329.253
258		91.248	244.527	-4.1457	49.3426	269.337	12.951	-41.9056	24.8092	-17.0964	331.63
259		93.3104	242.53	0.3825	49.7308	267.824	18.668	-43.5796	25.2946	-18.285	336.223
260		98.6329	240.874	2.5279	52.7613	265.929	23.344	-45.8714	25.0554	-20.816	342.035
261		104.357	238.192	4.962	55.9828	263.8	27.7281	-48.3743	25.6082	-22.7661	347.511
262		107.262	237.329	6.3568	56.5185	262.954	31.4748	-50.7431	25.6244	-25.1187	350.948
263		104.735	237.315	9.1884	55.233	262.965	33.0396	-49.5012	25.65	-23.8513	351.238
264	months	100.422	238.699	9.3582	54.2494	263.628	30.6018	-46.1719	24.9286	-21.2433	348.479
	flux	sw-all	lw-all	net-all	sw-cl	lw-cl	net-cl	cre-sw	cre-lw	cre-net	solar
	mean	98.9644	240.2435	0.8122	53.7193	266.0126	20.2881	-45.2451	25.7691	-19.4759	340.0201
	N	**15**/4	**9**		**2**	**10**	**3**/4	**-7**/4	**1**	**3**/4	**51**/4
	N × UNIT	100.04	240.12	0.00	53.36	266.80	20.01	-46.69	26.68	20.01	340.17
	Diff	1.08	-0.12	-0.81	-0.36	0.79	-0.28	1.44	0.91	0.53	0.15

UNIT = **1** = 26.68 Wm^{-2}; Largest difference at TOA = 1.44 Wm^{-2} (SW CRE)

2022 October

CERES EBAF Ed4.1, 264 months (Mar 2000 – Feb 2022)

245	177.5758	228.6707	18.93763	24.55068	354.2381	328.4349	408.9658	408.5872	158.6382	204.1201	-54.7277	-80.1523	103.9105	123.9677
246	180.8253	230.9673	18.07014	23.49308	353.5978	327.5986	408.2481	407.7277	162.7552	207.4742	-54.6504	-80.1291	108.1048	127.3451
247	184.3788	235.0425	19.45713	24.76397	349.9691	323.2565	405.3765	405.008	164.9217	210.2785	-55.4074	-81.7513	109.5143	128.5272
248	188.506	243.9077	23.29836	28.98416	344.4411	316.2766	399.9942	399.627	165.2076	214.9235	-55.5531	-83.3504	109.6545	131.573
249	193.2095	251.2145	27.12736	33.31856	339.3771	310.8441	395.0079	394.4384	166.0821	217.896	-55.6308	-83.5943	110.4514	134.3016
250	193.3444	253.8828	27.05768	33.15158	335.3092	307.3889	390.6691	390.4489	166.2868	220.7313	-55.3599	-83.06	110.9268	137.6713
251	193.3754	252.863	24.7855	30.6412	333.2545	306.3332	389.5119	389.4991	168.59	222.2217	-56.2574	-83.1659	112.3326	139.0558
252	193.1669	249.1837	23.02699	29.04887	334.5251	308.0375	390.5228	390.8333	170.1399	220.1349	-55.9977	-82.7958	114.1422	137.3392
253	192.2169	244.1768	23.10015	28.77468	337.431	311.2424	394.1427	394.4612	169.1167	215.4021	-56.7117	-83.2189	112.405	132.1833
254	190.5441	239.7446	24.84071	30.36777	341.3257	315.4144	399.2494	399.0524	165.7034	209.3769	-57.9237	-83.6382	107.7797	125.7386
255	185.1975	235.3919	24.63445	31.1239	346.8448	320.1824	404.3804	403.388	160.5631	204.268	-57.5356	-83.2056	103.0275	121.0624
256	180.3911	230.664	21.67765	27.87111	351.2243	325.2448	407.6398	406.7827	158.7135	202.7929	-56.4155	-81.5378	102.2979	121.2552
257	177.04	227.3869	18.97621	24.48535	354.9714	329.0909	409.1697	408.7534	158.0638	202.9016	-54.1983	-79.6627	103.8654	123.239
258	180.0347	228.828	17.95136	23.21147	354.0513	327.9114	408.5252	408.038	162.0833	205.6165	-54.4739	-80.1267	107.6095	125.4898
259	184.9359	235.9973	19.39501	24.73351	350.749	323.5717	405.2231	404.6099	165.5409	211.2639	-54.474	-81.0381	111.0669	130.2259
260	189.6486	244.4237	22.766	28.57069	345.0431	317.2519	400.2661	399.7646	166.8826	215.8529	-55.223	-82.5126	111.6596	133.3403
261	193.3337	251.4644	26.30676	32.44175	339.9027	311.4507	395.2095	394.9791	167.027	219.0226	-55.3069	-83.5284	111.7201	135.4942
262	193.129	253.9487	26.3463	32.84708	335.999	308.4004	390.9471	390.9245	166.7827	221.1017	-54.9481	-82.5242	111.8346	138.5777
263	193.8617	252.8522	24.63365	30.87342	333.9135	307.3784	389.8788	390.1137	169.2281	221.9788	-55.9654	-82.7355	113.2627	139.2434
264	193.6417	249.1481	23.08076	29.38704	335.03	308.9401	391.1476	391.3972	170.5609	219.761	-56.1176	-82.4569	114.4433	137.3042
Flux name	sw-dn-all	sw-dn-cl	sw-up-all	sw-up-cl	lw-dn-all	lw-dn-cl	lw-up-all	lw-up-cl	net-sw-all	net-sw-cl	net-lw-all	net-lwcl	net-tot-all	net-tot-cl
22-year mean	186.85	240.87	23.16	29.08	345.01	317.40	398.75	398.51	163.68	211.79	-53.73	-81.11	109.95	130.68
N	7	9	1	1	13	12	15	15	6	8	2	3	4	5
N × unit	186.76	240.12	26.68	26.68	346.84	320.16	400.20	400.20	160.08	213.44	53.36	80.04	106.72	133.40
Difference	-0.09	-0.75	3.52	-2.40	1.83	2.76	1.45	1.69	-3.60	1.65	0.37	1.07	-3.23	2.72

Unit = **1** = 26.68 Wm^{-2}; Largest difference at surface = -3.60 Wm^{-2} (SW Net all-sky)

Modeling

Modeling

Die ganze Betrachtung kann daher keineswegs als abschliessend oder zwingend gelten, doch mag sie weiteren Spekulationen einen Anhalt geben, indem sie einen einfachen Gedanken zunächst in einfachster Form ausführt.

Thus our considerations are neither complete nor compelling, but by explaining a simple idea in its simplest form, they may form the basis for further speculations.

Schwarzschild (1906)

Modeling

- What follows here is my approach
- Neither complete nor compelling
- Explains a simple idea in its simplest form
- Consists of four radiative transfer equations
- Each based on Schwarzschild’s

- But I would be more interested in YOUR thoughts

Vorsitzender Secretar: Hr. Planck.

- Max Planck chaired a meeting in Berlin on Nov. 5, 1914, where Einstein delivered a paper in the absence of the author, Karl Schwarzschild, who served as a soldier in World War I.

Über Diffusion und Absorption in der Sonnenatmosphäre.

Von K. Schwarzschild.

(Vorgelegt von Hrn. Einstein am 5. November 1914 [s. oben S. 979].)

- This is the paper that introduced the equation of radiation transfer.

Liou (1980) An introduction to atmospheric radiation

Hence, the equation of transfer may be written as

$$\frac{dI_\lambda}{k_\lambda \rho \, ds} = -I_\lambda + B_\lambda(T). \tag{1.55}$$

This equation is called Schwarzschild's equation.

Thus, the monochromatic upward and downward flux densities shown in Eqs. (4.12) and (4.13) may be rewritten as

$$F_\nu^\uparrow(\tau) = \{\pi B_\nu(T_s) - \pi B_\nu[T(\tau_1)]\}\mathscr{T}_\nu^f(\tau_1 - \tau) + \pi B_\nu[T(\tau)] + \int_\tau^{\tau_1} \mathscr{T}_\nu^f(\tau' - \tau)\frac{d\pi B_\nu(\tau')}{d\tau'}\,d\tau', \tag{4.79}$$

$$F_\nu^\downarrow(\tau) = \pi B_\nu[T(\tau)] - \pi B_\nu[T(0)]\,\mathscr{T}_\nu^f(\tau) - \int_0^\tau \mathscr{T}_\nu^f(\tau - \tau')\frac{d\pi B_\nu(\tau')}{d\tau'}\,d\tau'. \tag{4.80}$$

In an earlier paper, Schwarzschild (1906) presented the two-stream approximation to the same problem:

Ueber das Gleichgewicht der Sonnenatmosphäre

Von

K. Schwarzschild.

Vorgelegt in der Sitzung vom 13. Januar 1906.

On the Equilibrium of the Sun's Atmosphere

by K. Schwarzschild

(Presented at the meeting of the Berlin Academy of Sciences on January 13, 1906)

$$E = \frac{A_0}{2}(1 + \bar{\tau}), \qquad A = \frac{A_0}{2}(2 + \bar{\tau}), \qquad B = \frac{A_0}{2}\bar{\tau}. \qquad (11)$$

E emission of a layer, A upward beam, B downward beam

A_0 emerging flux at TOA, τ optical depth

$$E = \frac{A_0}{2}(1 + \bar{\tau}), \qquad A = \frac{A_0}{2}(2 + \bar{\tau}), \qquad B = \frac{A_0}{2}\bar{\tau}. \qquad (11)$$

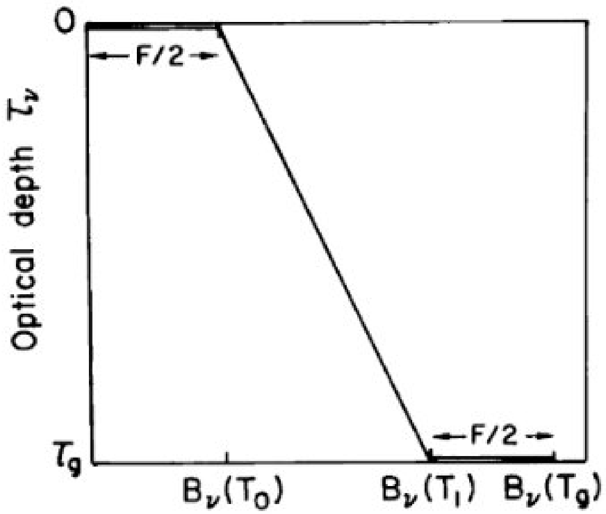
Eq. (1) $A - E = \Delta A = A_0/2$ Net radiation at the surface, independent of τ

Goody (1964, Eq. 2.115) $F_\nu/2\pi = J_\nu(0) - B_\nu^*(0) = B_\nu^*(\tau_\nu^*) - J_\nu(\tau_\nu^*)$.

Houghton (1977, Eq. 2.13)

The Physics of Atmospheres, Cambridge Univ Press

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



Chamberlain (1978, Fig. 1.4)

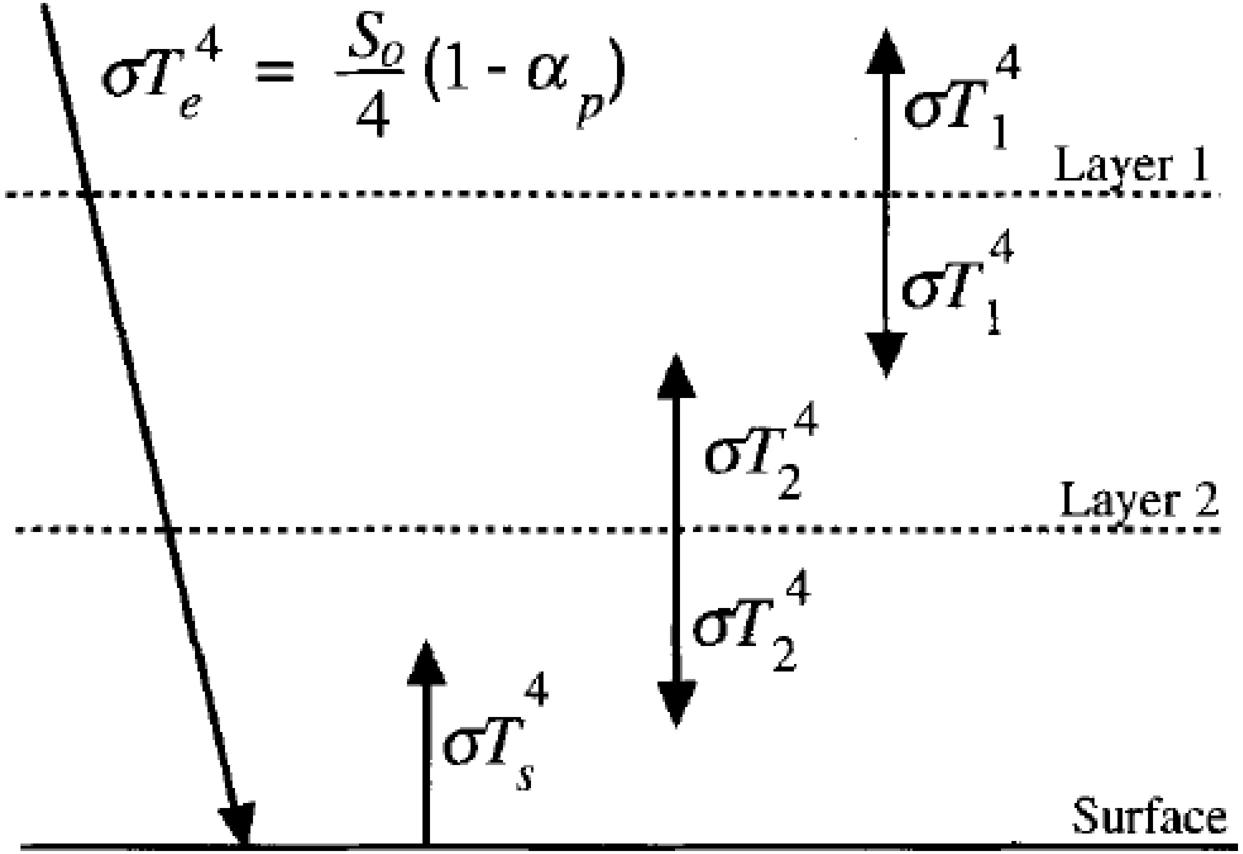
Theory of Planetary Atmospheres, Academic Press

Fig. 1.4 The MRE solution for $T(\tau)$, presented as $B_\nu(T)$ vs. τ_ν. Note the discontinuity at the ground and the finite skin temperature at $\tau = 0$.

$\Delta B_g = B_g - B_0 = B_{eff}/2$ = SFC SW net + LW net = $H_S + H_L$ = OLR/2

- Radiative Equilibrium: Discontinuity; Radiative-Convective Equilibrium: Convection + Evaporation (Emden 1913)
- Net radiation at the surface and the corresponding convective activity are set unequivocaly to OLR/2

Dennis Hartmann (1994) *Global Physical Climatology* pp. 61-63, two-layer radiative equilibrium model



TOA $\frac{S_0}{4}\left(1-\alpha_p\right) = \sigma T_e^4 = \sigma T_1^4$ (3.47)

$\sigma T_2^4 = 2\sigma T_1^4$ (3.48)

$\sigma T_1^4 + \sigma T_s^4 = 2\sigma T_2^4$ (3.49)

$\frac{S_0}{4}\left(1-\alpha_p\right) + \sigma T_2^4 = \sigma T_s^4$ (3.50)

$\varepsilon\sigma T_s^4 + \varepsilon\sigma T_2^4 = 2\varepsilon\sigma T_{SA}^4$ (3.54)

Emission temp T_e = 255 K; Air adjacent to surface T_{SA} = 320 K; Surface temp T_S = 335 K

With Hartmann's data, Eq. (1) is justified within 0.31 Wm^{-2}

Emission temp T_e = 255 K; Air adjacent to surface T_{SA} = 320 K; Surface temp T_S = 335 K

Eq. (1) $\sigma T_S^4 - \sigma T_{SA}^4 = \sigma T_e^4/2$

$5.67\,[(3.35)^4 - (3.20)^4] = 5.67(2.55)^4$

714.11 – 594.54 = 119.56 = 119.87 – **0.31** Wm^{-2}

Simple geometry

Independent of τ

No reference to GHGs

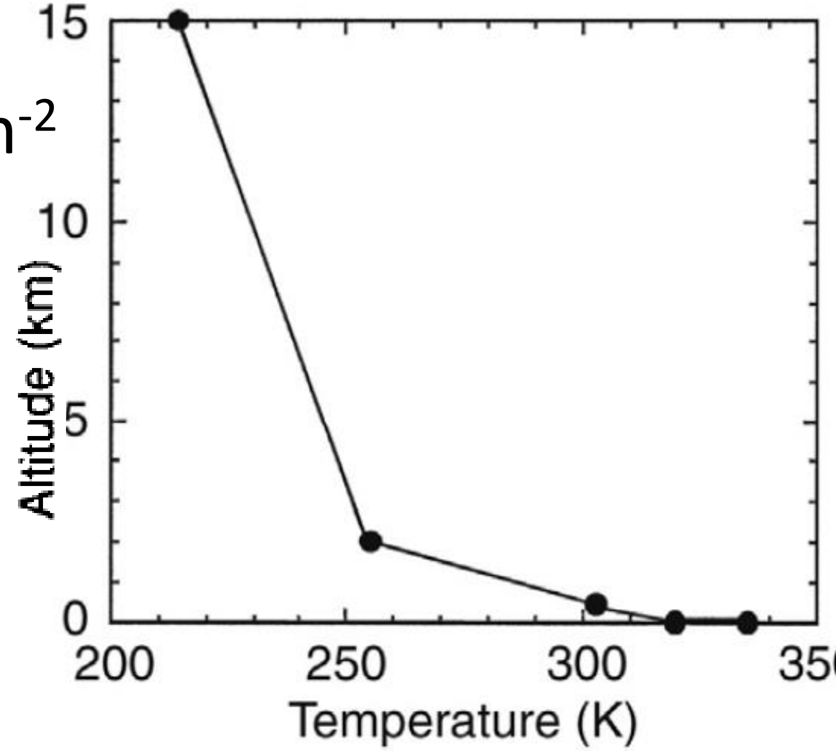


Fig. 3.11

Eq. (1) $A - E = \Delta A = A_0/2$

Is it valid in general?

CERES EBAF Ed2.8, 192 months (Mar 2000 – Feb 2016)
Global means from Rose et al. (2017)

Eq. (1)	$A - E$	$= \Delta A$	$= A_0/2$
	530.59 – 398.40	= 132.19	= 265.59 /2

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Loeb et al. (2012): Earth heat uptake for July 2005–June 2010 is 0.58 ± 0.38 Wm^{-2}

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It is a verified radiative transfer constraint equation from Schwarzschild

- Connects net radiation at the surface and convective activity to OLR/2
- Missing from Manabe-Wetherald (1967) convective adjustment
- Missing from the Charney Report (1979)
- Not there in the IPCC Reports (1990-2022)

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- Not there in the IPCC Reports (1990-2022)
- Ought to be incorporated into the CMIP and ECHAM models …?

Dr. Graeme Stephens wanted to have it thirty years ago:

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. D8, PAGES 15,311–15,324, AUGUST 20, 1991

The Earth's Radiation Budget and Its Relation to Atmospheric Hydrology
1. Observations of the Clear Sky Greenhouse Effect

GRAEME L. STEPHENS AND THOMAS J. GREENWALD

Mihalas, 1978; *Goody and Yung*, 1989]

$$\sigma T_s^4 = \sigma T_e^4 [2 + 3\tau^* / 2] \quad (1)$$

and

$$\sigma T_*^4 = \sigma T_e^4 [1 + 3\tau^* / 2] \quad (2)$$

$$\sigma T_s^4 - \sigma T_*^4 = \sigma T_e^4$$

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$$\sigma T_s^4 - \sigma T_*^4 = \sigma T_e^4 \quad /2$$

$$B^*(\tau_1) = \frac{\sigma \theta_g^4}{\pi} = \frac{-F_S(2 + 3\tau_1/2)}{2\pi},$$

$$B(\tau) = \frac{\sigma \theta(\tau)^4}{\pi} = \frac{-F_S(1 + 3\tau/2)}{2\pi},$$

$$\Delta B = \frac{F_S}{2\pi}$$

(*Goody and Yung*, 1989)

Observations of the Earth's Radiation Budget in relation to atmospheric hydrology
4. Atmospheric column radiative cooling over the world's oceans

Graeme L. Stephens,[1] Anthony Slingo,[2] Mark J. Webb,[2] Peter J. Minnett,[3] Peter H. Daum,[3] Lawrence Kleinman,[3] Ian Wittmeyer,[1] and David A. Randall[1]

which leads to the solution of (3a) and (3b) as

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$$E = \frac{A_0}{2}(1 + \bar{\tau}), \qquad A = \frac{A_0}{2}(2 + \bar{\tau}), \qquad B = \frac{A_0}{2}\bar{\tau}. \qquad (11)$$

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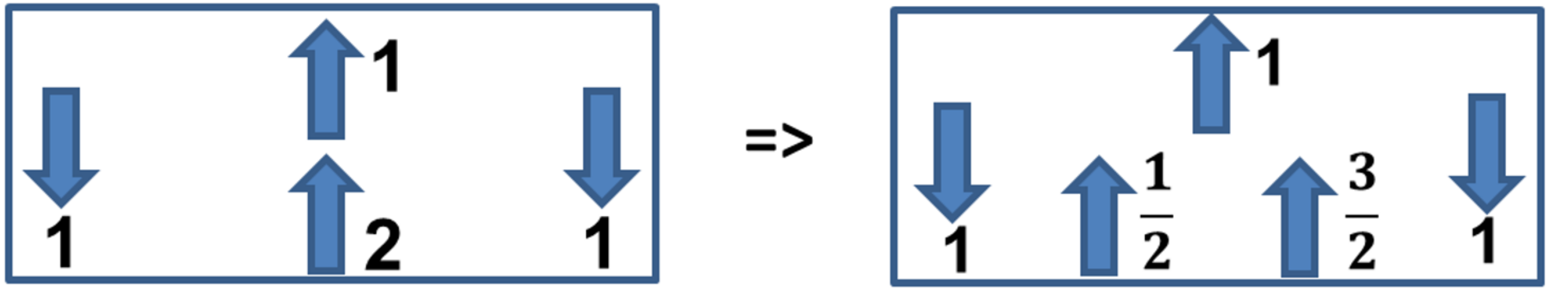
Eq. (1) $\mathbf{A - E = A_0/2}$ (clear-sky, net)

Eq. (2) $\mathbf{A = A_0(2 + \tau)/2}$ (clear-sky, total)

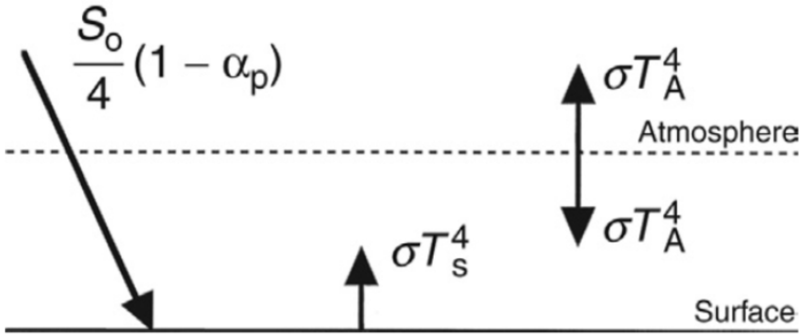
Just realize that if $\tau = 2$

$$E = \frac{A_0}{2}(1 + \bar{\tau}), \qquad A = \frac{A_0}{2}(2 + \bar{\tau}), \qquad B = \frac{A_0}{2}\bar{\tau}. \qquad (11)$$

then **Eq. (2)** $\mathbf{A = 2A_0}$ $\mathbf{E = 3A_0/2;}$ $\mathbf{B = A_0}$



$A = 2A_0$ (Clear-sky) $\Delta A = A - E = A_0/2$



$\sigma T_s^4 = 2\sigma T_A^4$

Hartmann (1994, Fig. 2.3)

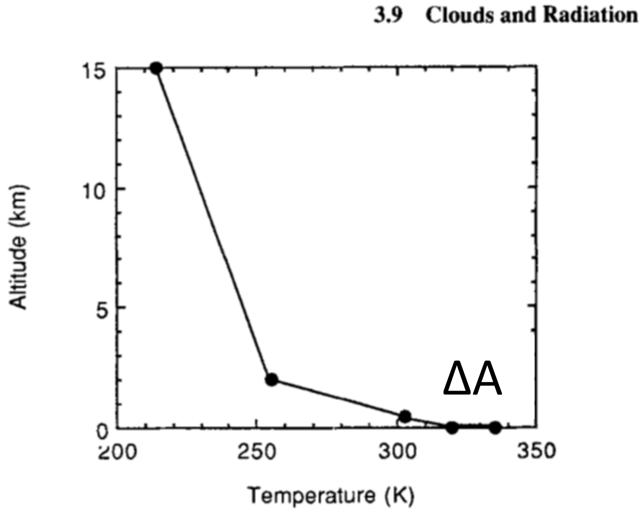


Fig. 3.11

CERES EBAF Ed2.8, 192 months (Mar 2000 – Feb 2016) Global means from Rose et al. (2017), clear-sky

Eq. (1)	$\mathbf{A} - \mathbf{E}$	$= \Delta\mathbf{A}$	$= \mathbf{A_0}/2$	
	530.59 – 398.40	**= 132.19**	**= 265.59 /2**	**–0.60 Wm^{-2}**
Eq. (2)	$\mathbf{A}$		$= 2\mathbf{A_0}$	
	530.59		**= 2 × 265.59**	

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Eq. (2)	$\mathbf{A}$		$= \mathbf{2A_0}$	
	530.59		**= 2 × 265.59**	**–0.59 Wm^{-2}**

CERES EBAF Ed2.8, 192 months (Mar 2000 – Feb 2016) Global means from Rose et al. (2017), clear-sky

Eq. (1)	**$A - E$**	**$= \Delta A$**	**$= A_0/2$**	
	530.59 – 398.40	**= 132.19**	**= 265.59 /2**	**–0.60 Wm^{-2}**
Eq. (2)	**A**		**$= 2A_0$**	
	530.59		**= 2 × 265.59**	**–0.59 Wm^{-2}**

$\Delta A : A_0 : E : A = 1 : 2 : 3 : 4$ (clear-sky) justified within EEI

Creating the all-sky versions

Eq. (1) **SFC Net = $A - E = A_0/2$** (clear-sky, net)

Eq. (2) **SFC Tot = $A = 2A_0$** (clear-sky, total at $\tau = 2$)

Separating atmospheric radiation transfer from the longwave cloud effect (LWCRE):

Eq. (3) **SFC Net = $A - E = (A_0 - L)/2$** (all-sky, net, incl LWCRE)

Eq. (4) **SFC Tot = $A = 2A_0 + L$** (all-sky, total at $\tau = 2$ incl LWCRE)

Verification of the four equations

CERES EBAF Ed4.1 Version 3, 22 years (March 2000 – Feb 2022) (Wm^{-2})

Eq. (1) SFC SW down – SW up + LW down – LW up (clear) = TOA LW (clear)/2

240.8725 – 29.0808 + 317.4004 – 398.5133 = 266.0126 /2

Eq. (2) SFC SW down – SW up + LW down (clear) = 2 × TOA LW (clear)

240.8725 – 29.0808 + 317.4004 = 2 × 266.0126

Eq. (3) SFC SW down – SW up + LW down – LW up (all) = [TOA LW (all) – LWCRE]/2

186.8481 – 23.1638 + 345.0120 – 398.7454 = (240.2435 – 25.7691)/2

Eq. (4) SFC SW down – SW up + LW down (all) = 2 × TOA LW (all) + LWCRE

186.8481 – 23.1638 + 345.0120 = 2 × 240.2435 + 25.7691

4 decimal places from netCDF3

Verification of the four equations

CERES EBAF Ed4.1 Version 3, 22 years (March 2000 – Feb 2022) (Wm^{-2})

Eq. (1)	**SFC SW down – SW up + LW down – LW up (clear)**	**= TOA LW (clear)/2**	
	240.8725 – 29.0808 + 317.4004 – 398.5133	= 266.0126 /2	–2.3275
Eq. (2)	**SFC SW down – SW up + LW down (clear)**	**= 2 × TOA LW (clear)**	
	240.8725 – 29.0808 + 317.4004	= 2 × 266.0126	–2.8332
Eq. (3)	**SFC SW down – SW up + LW down – LW up (all)**	**= [TOA LW (all) – LWCRE]/2**	
	186.8481 – 23.1638 + 345.0120 – 398.7454	= (240.2435 – 25.7691)/2	+2.7139
Eq. (4)	**SFC SW down – SW up + LW down (all)**	**= 2 × TOA LW (all) + LWCRE**	
	186.8481 – 23.1638 + 345.0120	= 2 × 240.2435 + 25.7691	+2.4403

Verification of the four equations

CERES EBAF Ed4.1 Version 3, 22 years (March 2000 – Feb 2022) (Wm^{-2})

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	186.8481 – 23.1638 + 345.0120	**= 2 × 240.2435 + 25.7691**	**+2.4403**

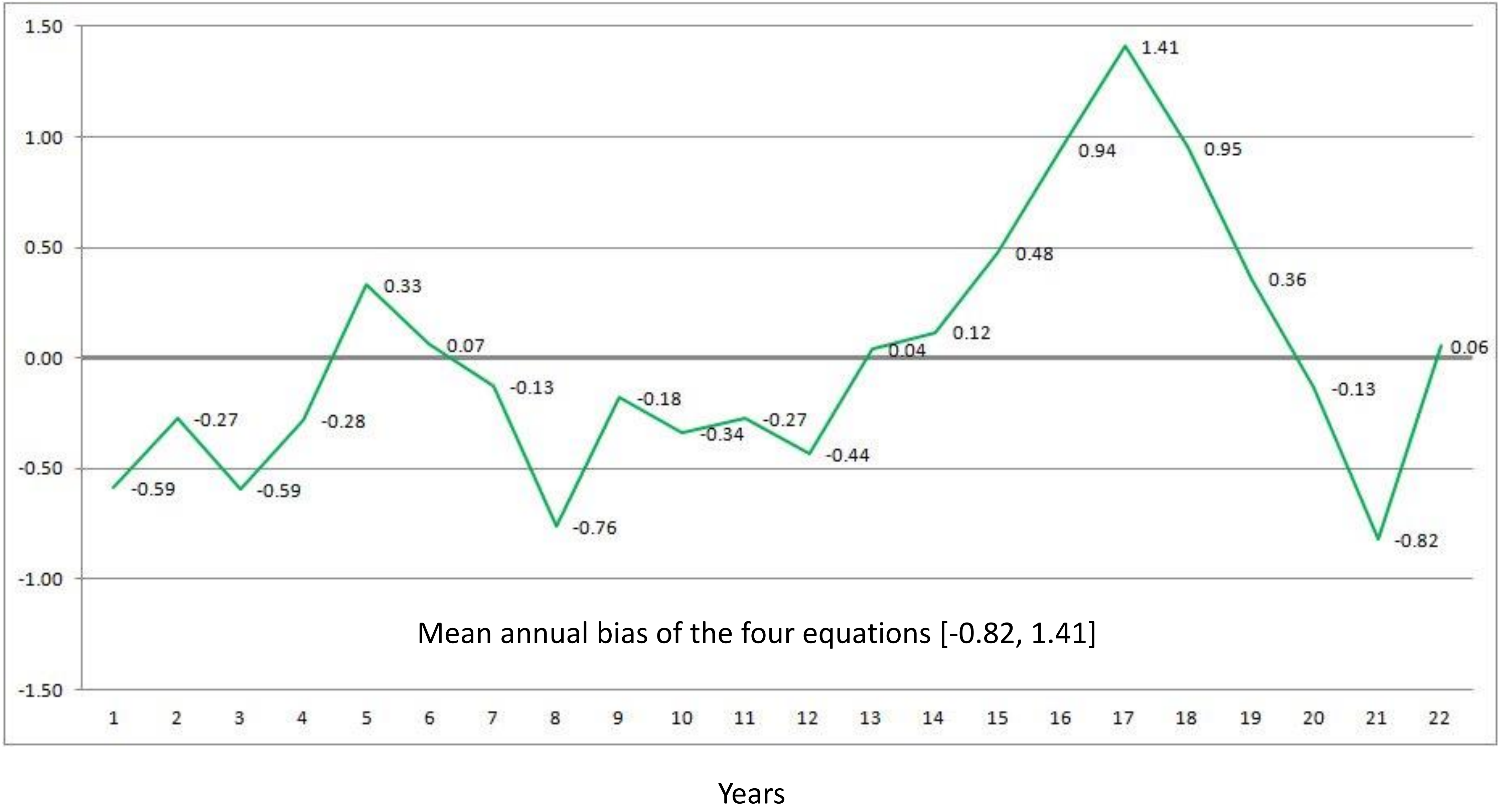
Mean bias of the four equations = –0.0016 Wm^{-2}

Arithmetic identity?

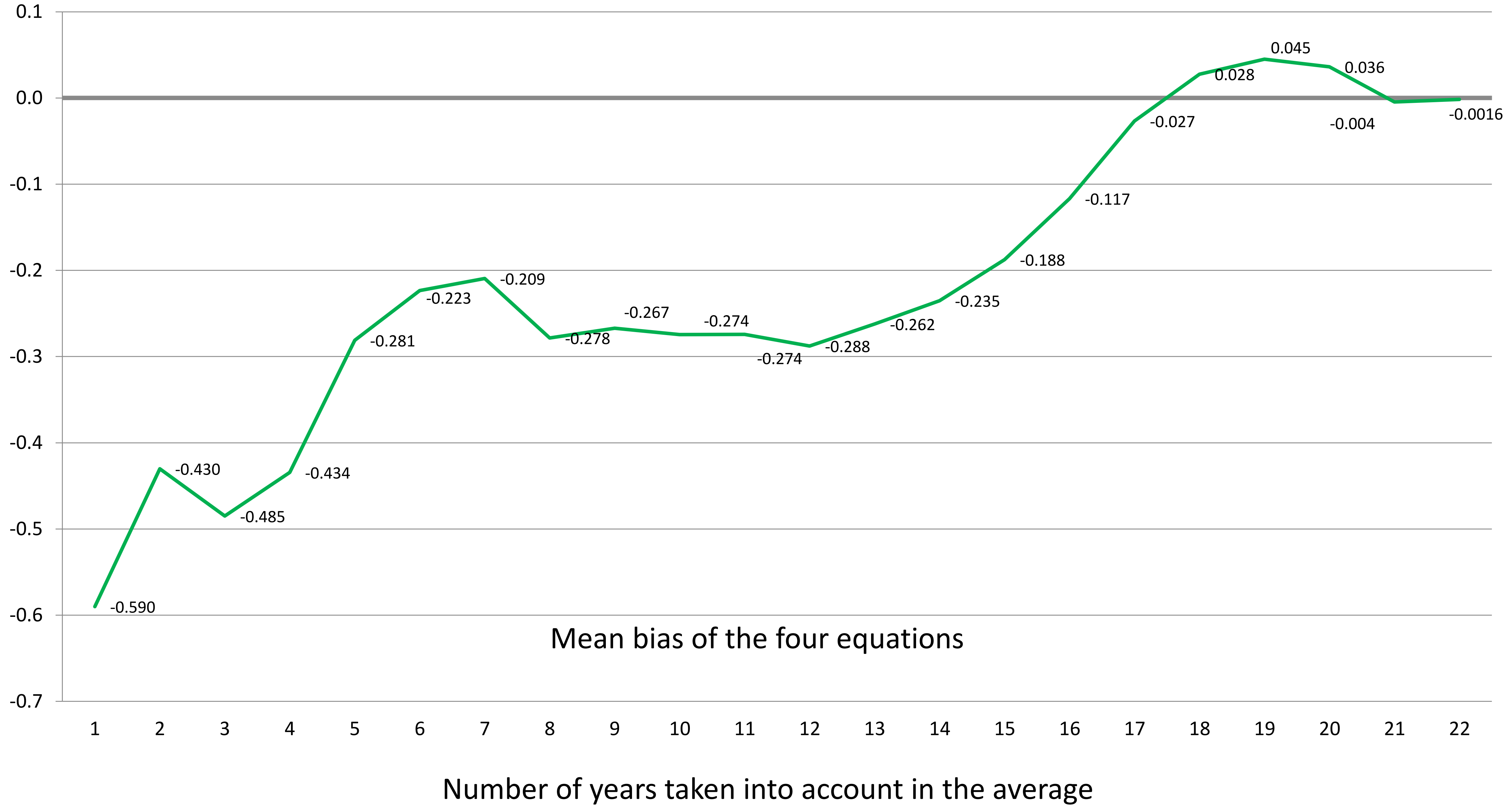
Built-in the CERES data production protocol ?

Months						
253		0.29445	-0.9109	5.96655	4.4427	2.4482
254		-6.44355	-3.9373	1.38395	4.0869	-1.2275
255		-12.2888	-8.9542	-4.11395	0.213	-6.28597
256		-12.7835	-8.1169	-6.12655	-0.6026	-6.90737
257		-11.5535	-7.1773	-5.36085	-0.5684	-6.165
258		-9.1785	-5.1453	-2.2496	2.2706	-3.5757
259		-3.68625	-0.813	2.44935	5.9359	0.9715
260		0.3756	1.246	3.7502	5.1222	2.6235
261		3.59425	2.8735	5.42835	4.9381	4.20855
262		7.10085	3.5947	5.98215	2.4987	4.7941
263		7.76075	3.4266	7.42995	2.8609	5.36955
264		5.4902	1.4451	7.558	3.2636	4.43923
	Min	-14.4605	-12.9035	-7.1828	-4.3878	-9.73365
	Max	8.814	4.329	10.615	7.305	7.76603
	Mean	**-2.3275**	**-2.8332**	**2.7139**	**2.4403**	**-0.0016**
		ΔEq1	ΔEq2	ΔEq3	ΔEq4	Mean

No. There are large interannual fluctuations

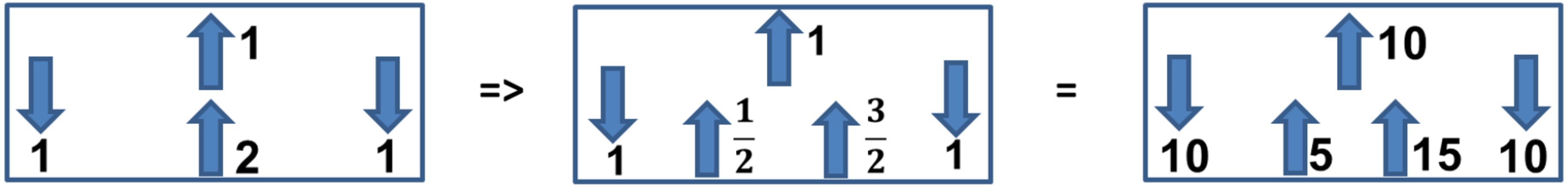


Approaching zero only after 18 years of averaging

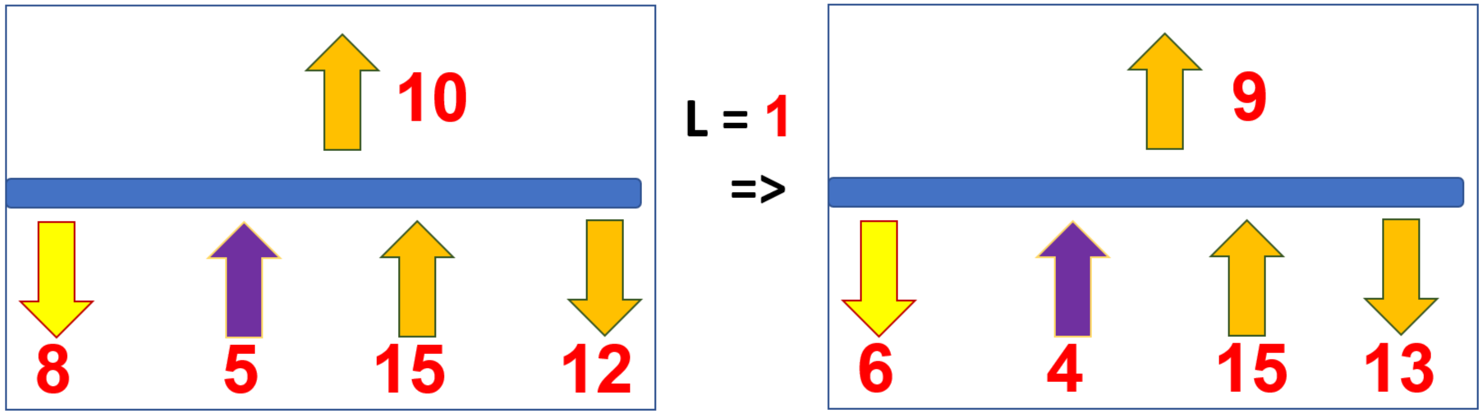


The N-numbers, as solution of the equations

Pure geometry: No reference to GHGs



$A = 2A_0$ (Clear-sky) $\Delta A = A_0/2$, $E = 3A_0/2$



Clear-sky	All-sky
$8 + 12 - 15 = 10\ /\ 2$	$6 + 13 - 15 = (9 - 1)/2$
$8 + 12 = 10 \times 2$	$6 + 13 = 9 \times 2 + 1$
Eq. (1) SFC Net = $A_0/2$	**Eq. (3) SFC Net = $(A_0 - L)/2$**
Eq. (2) SFC Tot = $2A_0$	**Eq. (4) SFC Tot = $2A_0 + L$**
Clear-sky	**All-sky**

The flux components with LWCRE = 1

TOA LW	clear-sky =	10	TOA LW	all-sky =	9
SFC LW up	clear-sky =	15	SFC LW up	all-sky =	15
SFC LW down	clear-sky =	12	SFC LW down	all-sky =	13
SFC LW net	clear-sky =	–3	SFC LW net	all-sky =	–2
SFC SW net	clear-sky =	8	SFC SW net	all-sky =	6
SFC SW+LW net	clear-sky =	5	SFC SW+LW net	all-sky =	4
SFC SW+LW total	clear-sky =	20	SFC SW+LW total	all-sky =	19
G greenhouse effect	clear-sky =	5	G greenhouse effect	all-sky =	6
SWCRE (surface)	=	–2	LWCRE (surface, TOA)	=	1

Fit model to observation

CERES EBAF Ed4.1, 264 months, March 2000 — Feb 2022 data

Best fit: 1 unit = 1 = LWCRE = 26.68 ± 0.02 Wm^{-2}

Observing and Modeling Earth's Energy Flows, 2022

Observed: CERES EBAF Ed4.1 Version 3, March 2000 – February 2022

Modeled: Eq. (1) **8** + **12** – **15** = **10**/2; Eq. (2) **8** + **12** = **10** × 2; **1** = 26.68 Wm^{-2}

Eq. (3) **6** + **13** – **15** = (**9** – **1**)/2; Eq. (4) **6** + **13** = **9** × 2 + **1**

Clear-sky	N	N × Unit (Wm^{-2})	Observed (Wm^{-2})	Difference (Wm^{-2})
TOA LW up	10	266.80	266.01	-0.79
SFC SW net	8	213.44	211.79	-1.65
SFC LW down	12	320.16	317.40	-2.76
SFC LW up	15	400.20	398.51	-1.69
All-sky				
TOA LW up	9	240.12	240.24	0.12
SFC SW net	6	160.08	163.68	3.60
SFC LW down	13	346.84	345.01	-1.83
SFC LW up	15	400.20	398.75	-1.45
			Mean difference	**-0.81**

Earth Radiation Budget Atomium

Summary

- I think one of the greatest achievements of the CERES mission is the accurate verification of the four equations
- They can be deduced without referring to GHGs
- They reproduce the observed global mean CERES fluxes closely

- I do hope Aqua and Terra will continue working until 2026
- I am deeply interested in the development of the mean values
- I expect the difference to remain close to zero

- There are open questions in the theory
- I got my own suggestions (not before Adjourn).
- What are yours? (Send replies to miklos.zagoni@t-online.hu)