EBAF Ed4.2.1 Data vs. Theory

Miklos Zagoni

Budapest, Hungary

Spring CERES Science Team Meeting

May 13-15, 2025, NASA LaRC, Hampton, VA.

Remote presentation

Outline of this talk

- I read on your website (ceres.larc.nasa.gov/science):

  ”Globally averaged, the surface has a net surplus of radiant energy while the atmosphere has a net loss. To make up for this imbalance, sensible (conduction & convection) and latent heat (evaporation) are transferred from the surface to the atmosphere.”

- How much is the surplus?
- In the literature, there is an expectation for that.
- I control it on your data.

Liou (2002)

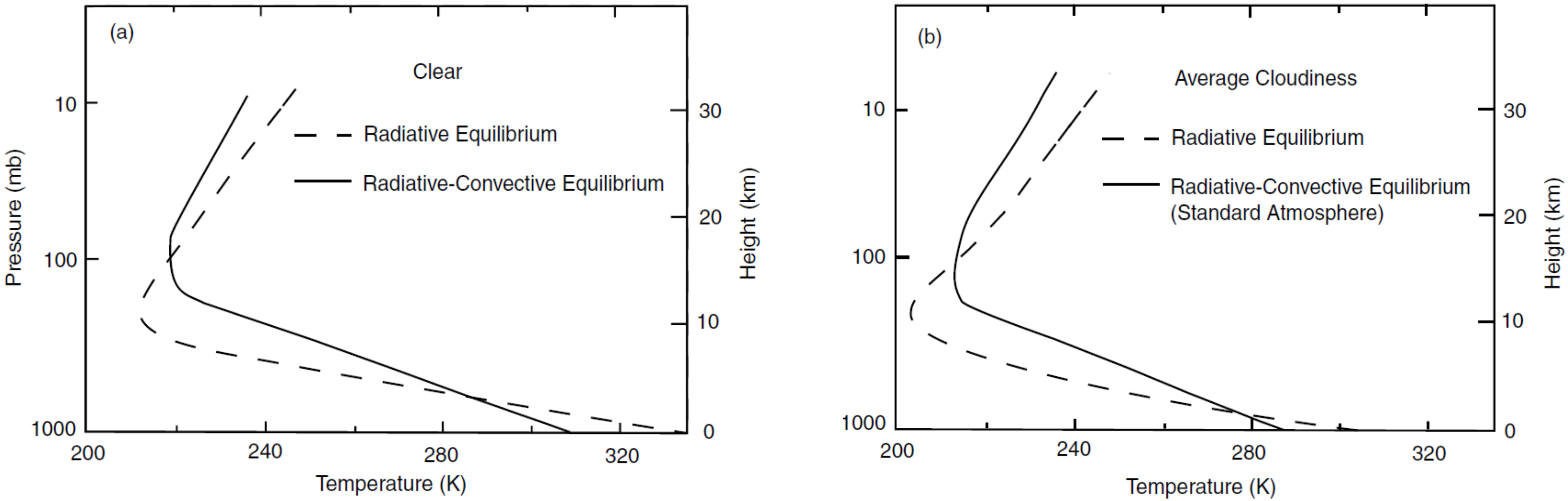


Figure 8.9 Vertical distributions of radiative and radiative–convective equilibrium temperatures in clear (a) and average cloud (b) conditions, simulated from a one-dimensional radiative–convective climate model.

Emden (1913)

Sitzungsberichte

der

mathematisch-physikalischen Klasse

der

K. B. Akademie der Wissenschaften

Über Strahlungsgleichgewicht und atmosphärische Strahlung.

Ein Beitrag zur Theorie der oberen Inversion.

Von **R. Emden.**

Vorgelegt von S. Finsterwalder in der Sitzung am 1. Februar 1913.

89) $$T_{\text{Erde}} = 254^0 \sqrt[4]{2{,}2} = 309^0 = +36^0.$$

An der Berührungsfläche Atmosphäre und Erde ergibt sich somit ein Temperatursprung von 20° C, der in Wirklichkeit durch äußere Wärmeleitung stark herabgesetzt wird, namentlich auf Wasser, wo der Wasserdampf mit der Temperatur der Oberfläche in die Atmosphäre übertritt. Auch diese Strahlungstemperatur der Erdoberfläche hat einen durchaus annehmbaren Wert.

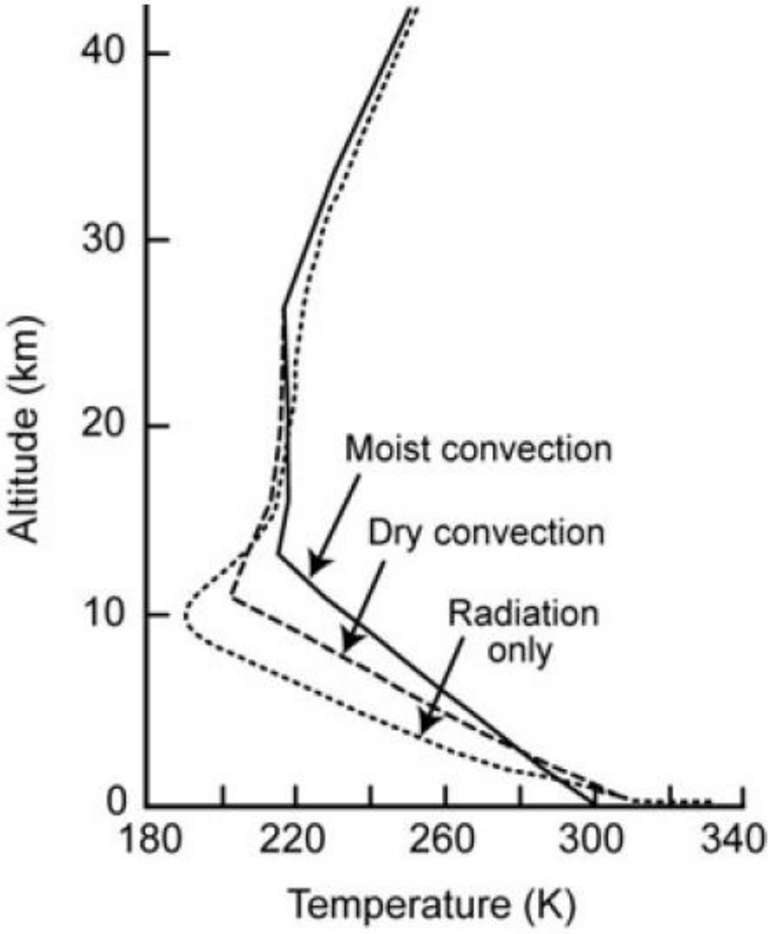
MONTHLY WEATHER REVIEW. AUGUST, 1916

RADIATION EQUILIBRIUM AND ATMOSPHERIC RADIATION.[1]

[1] *Emden, Robert*, in Sitzungsb., K. bayerische Akad. d. Wissens., Munchen, 1913, 43:55–142.

Emden also calculates from equations (4) and (5) that the temperature of the lowest atmospheric layer is 15.8°C and that the temperature of the ground is 36°C. The discontinuity in temperature of 20 degrees is in reality greatly diminished by conduction of heat and evaporation.

Discontinuity = 20 °C = Convection



Radiation and Climate

Vardavas and Taylor

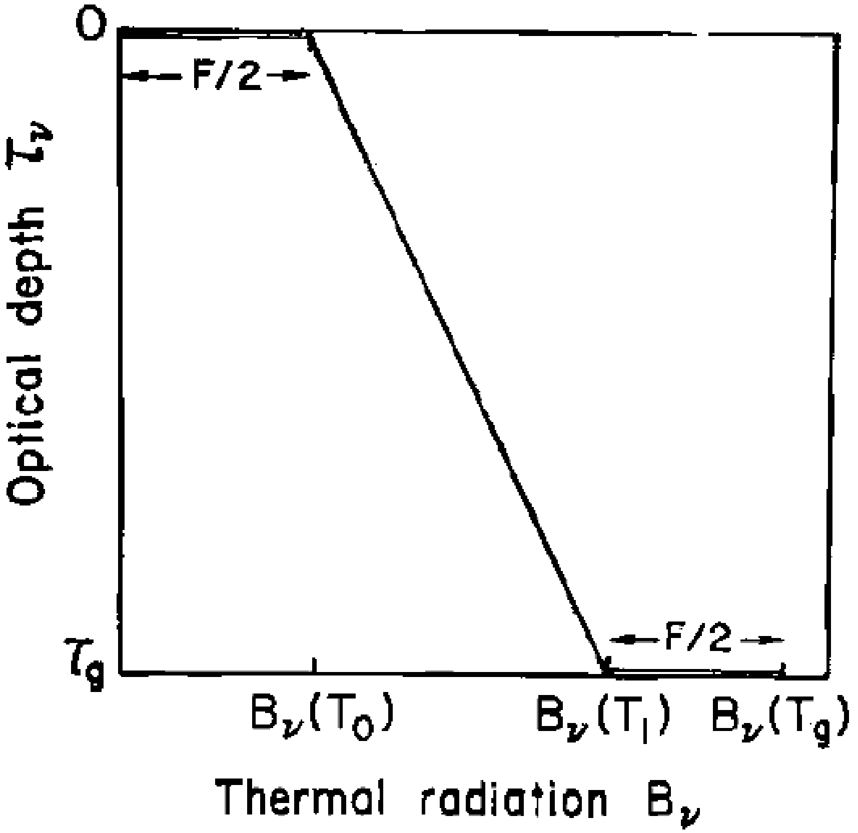
Oxford Univ Press (2007)

An atmosphere in radiative equilibrium (see Fig. 2.11) produces essentially a discontinuity (of about 20 K) between the Earth's surface temperature and the near–surface atmospheric temperature.

the mean intensity can be expressed as

$$J = I^{+} - f/2\pi.$$

FIG. 2.11. Representative vertical temperature profiles calculated assuming (top curve) convective equilibrium in a moist atmosphere, (middle) convective equilibrium in a dry atmosphere, and (bottom) radiative equilibrium. (See Manabe and Wetherald 1967)

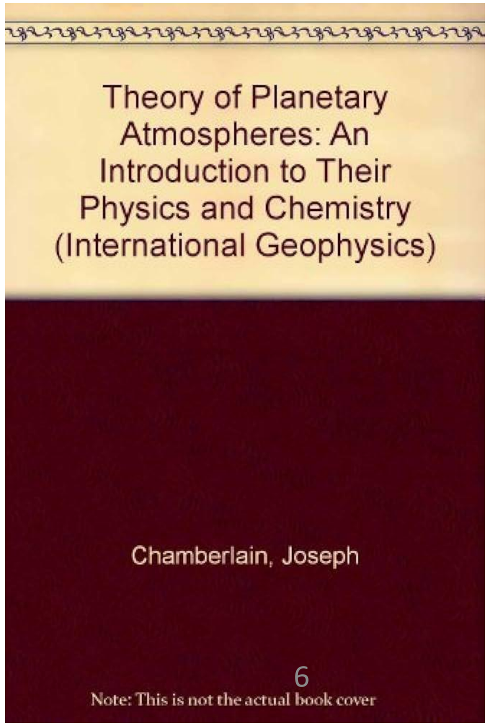


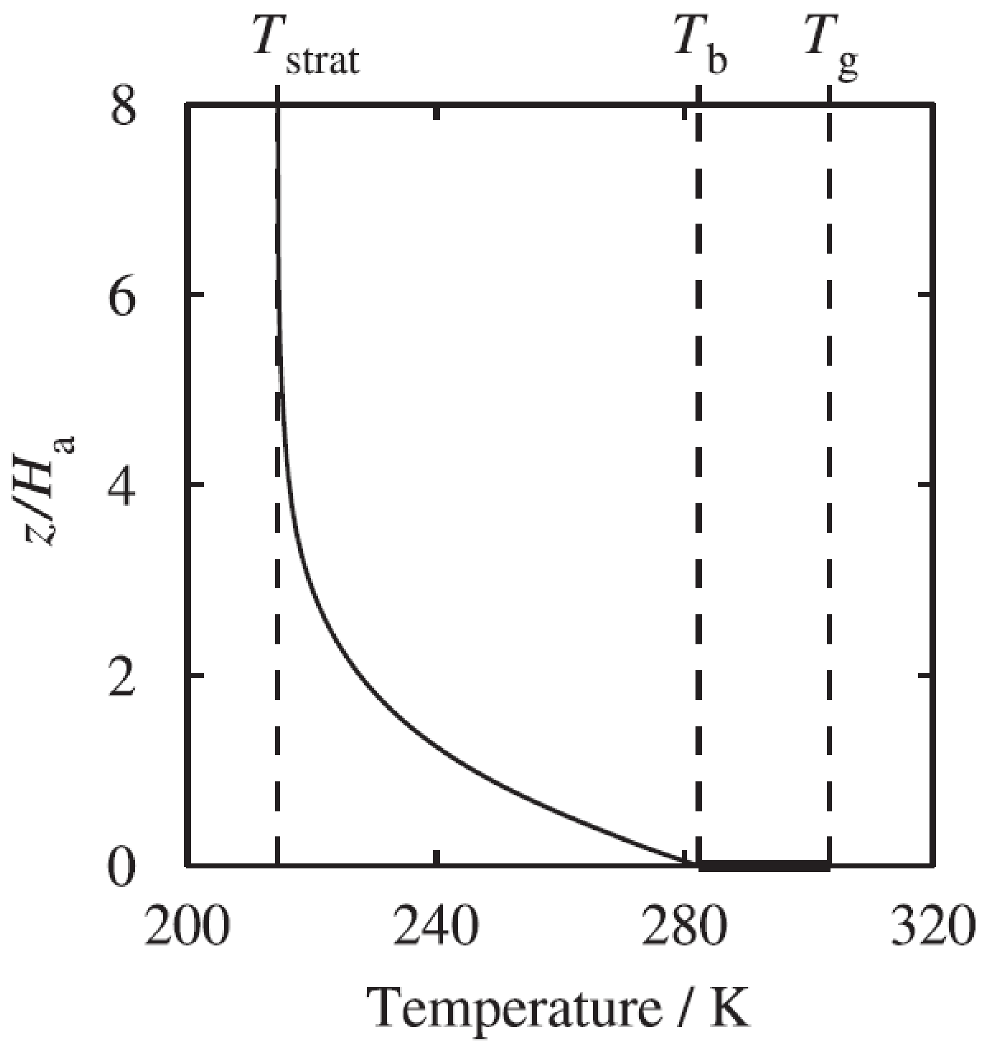
Joseph Chamberlain
Theory of Planetary Atmospheres (1978, 1987)
Academic Press, Fig. 1.4, Eq. 1.2.29

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

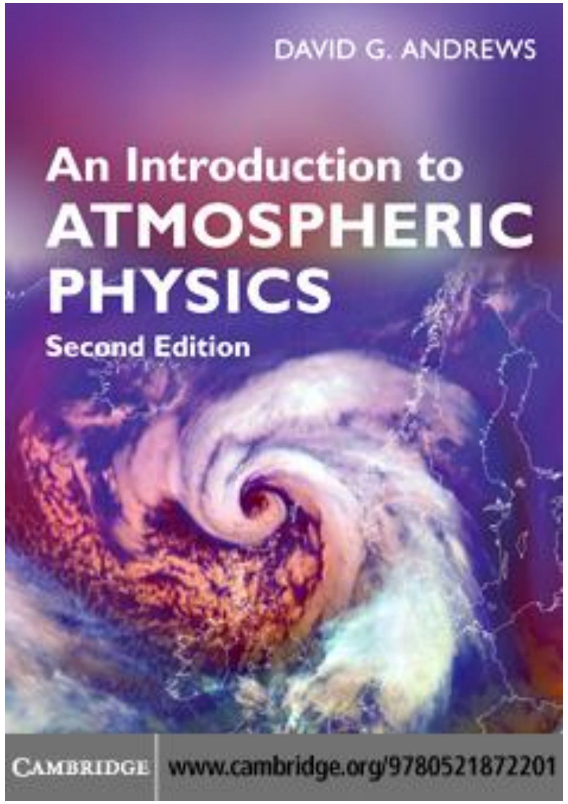
Hence the upward intensity at the ground is

$$I_g^{\,+} \equiv B_\nu(T_g) = B_\nu(T_1) + \tfrac{1}{2}F_\nu \qquad (1.2.29)$$





Andrews: An Introduction to Atmospheric Physics
Cambridge (2010), pp 85-86.



$$T_b \equiv T_e \left(\frac{1 + \chi_g^*}{2} \right)^{1/4}$$

$$T_g \equiv T_e \left(\frac{2 + \chi_g^*}{2} \right)^{1/4}$$

$$T_g^4 - T_b^4 = T_e^4/2$$

discontinuity between the bottom of the atmosphere and the ground.

Inclusion of convection in the model removes the temperature discontinuity

University Lecture Notes

Harvard (2018)

We have got the temperature structure in the atmosphere as a function of τ. Now consider energy balance at the surface (looks familiar?),

$$B(T_s) = F_0 + F^{\downarrow}(\tau_s)$$

From their definitions, we have

$$F^{\downarrow} = \frac{1}{2}\left(\bar{F} - F\right)$$

As the net flux F is constant and equal to F_0, and use Eq. (14), we have:

$$B(T_s) = B(\tau_s) + \frac{F_0}{2}$$

Note the jump at the surface.

惑星大気学_放射
(2022-05-02)
University of Tokyo

(3.10)(3.11)より

$$\underbrace{B^*(T_S)}_{\text{地表面}} = \underbrace{B^*(\tau_s^*)}_{\text{大気下端}} + \frac{F^0}{2}$$

放射平衡では大気下端の温度と地表面温度は不連続になる。($B^* = \sigma T^4$ に注意)

From (3.10)(3.11)

$$\underbrace{B^*(T_S)}_{\text{surface}} = \underbrace{B^*(\tau_s^*)}_{\text{bottom of atmosphere}} + \frac{F^0}{2}$$

A temperature discontinuity exists at the surface. (Note that $B^* = \sigma T^4$)

University exam task for A+

PHY2505S - Lecture 6 page 14

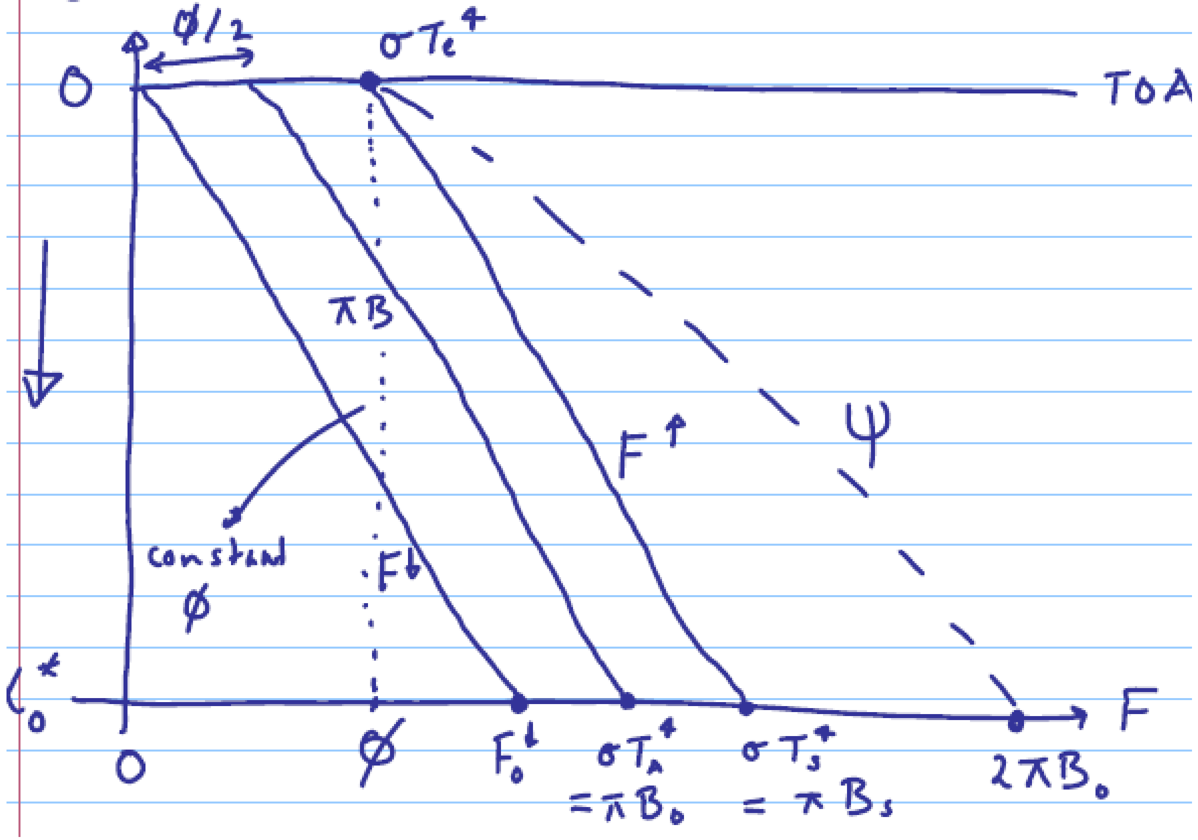
$$\phi = F^{\uparrow} - F^{\downarrow} = \sigma T_e^4$$

$$F^{\uparrow} = \frac{\phi}{2}(\chi^* + 2)$$

$$F^{\downarrow} = \frac{\phi}{2}\chi^*$$

$$\pi B = \frac{\phi}{2}(\chi^* + 1)$$

Let's plot these with χ^* on the y axis.



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, NO. D6, PAGES 11,585–11,591, JUNE 20, 1995

Deductions from a simple climate model: Factors governing surface temperature and atmospheric thermal structure

C. P. Weaver and V. Ramanathan

Center for Clouds, Chemistry and Climate, Scripps Institution of Oceanography, La Jolla, California

Temperature discontinuity. Equations (6a) and (6b) predict a temperature jump at the surface:

$$\sigma T_g^4 - \sigma T(\tau^*)^4 = \frac{f_0}{2} \tag{7}$$

Graeme L. Stephens: Radiative Transfer Notes AT 622

Colorado State Univ (1992-2013)

https://reef.atmos.colostate.edu/~odell/AT622/stephens_notes/AT622_section06.pdf

Example 6.3: Skin temperatures and temperature discontinuities

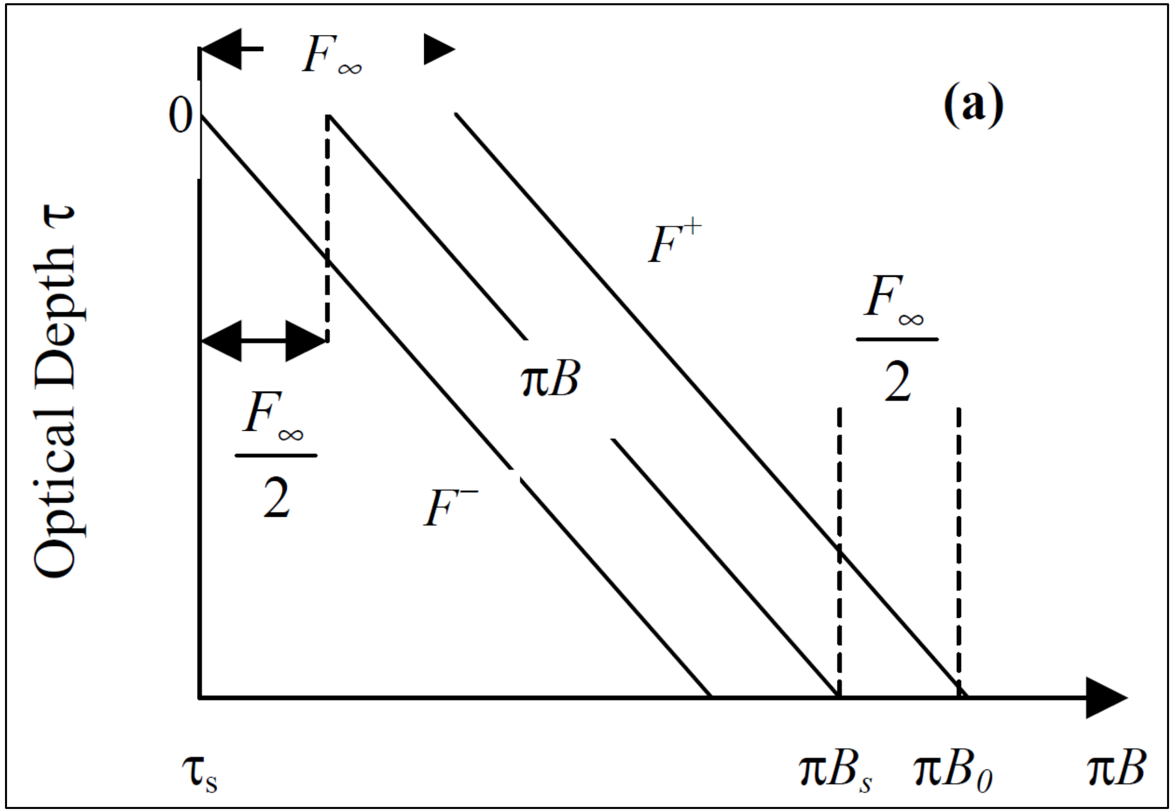
The solutions represented by Eqns. (6.10a) and (6.10b) provide rather interesting insights into the temperature profiles that are predicted by these equations. One of the results of this model is an estimate of the 'skin' temperature, which we think of as a measure of the stratospheric temperature. We obtain this using Eqn. (6.10a) with $\tilde{\tau} = 0$

$$\sigma T^4(\tilde{\tau} = 0) = \frac{F_\infty}{2}$$

and with $F_\infty \approx 235$ Wm^{-2}, it follows that this temperature is $T_{skin} = [117.5/5.68 \times 10^{-8}]^{0.25} = 213$ K.

The solutions in Eqns. (6.10a) and (6.10b) predict a discontinuity between the surface temperature T_s and the air temperature just above the ground $T(\tilde{\tau}_s)$. Differencing these equations and with $\tilde{\tau} = \tilde{\tau}_s$,

$$\sigma T_s^4 - \sigma T^4(\tilde{\tau}_s) = \frac{F_\infty}{2}.$$



"This radiative equilibrium profile is unstable w.r.t. vertical motion and is destroyed by convection"

Net surplus of radiant energy at the surface = Convection = $\frac{F_\infty}{2}$

Data

CERES EBAF Ed2.8, Ed4.2.1

CERES EBAF-Surface Ed2.8 Data Quality Summary (March 27, 2015)

Table 4-1. Global annual mean fluxes using data from March 2000 through February 2010 ($W\ m^{-2}$).

	Flux Component	Ed3A SYN1deg -Month	EBAF-Surface Ed2.6r	EBAF-Surface Ed2.7	EBAF-Surface Ed2.8	EBAF-TOA Ed2.8
TOA	Incoming solar	339.9	339.9	339.9	339.8	339.8
	LW (all-sky)	237.3	239.7	239.6	239.6	239.6
	SW (all-sky)	98.5	99.6	99.6	99.6	99.6
	Net (all-sky)	4.06	0.64	0.69	0.63	0.59
	LW (clear-sky)	263.7	265.8	265.7	265.7	265.8
	SW (clear-sky)	52.5	52.5	52.6	52.6	52.6
	Net (clear-sky)	23.6	21.6	21.6	21.6	21.5
Surface	LW down (all-sky)	341.8	343.7	345.1	345.1	
	LW up (all-sky)	397.6	398.1	398.1	398.0	
	SW down (all-sky)	187.2	186.7	186.5	186.4	
	SW up (all-sky)	23.3	24.1	24.1	24.1	
	Net (all-sky)	108.1	108.3	109.4	109.4	
	LW down (clear-sky)	313.5	314.1	315.8	316.0	
	LW up (clear-sky)	396.6	398.3	398.4	398.0	
	SW down (clear-sky)	242.4	243.4	244.1	243.9	
	SW up (clear-sky)	28.7	29.6	29.7	29.7	
	Net (clear-sky)	130.6	129.6	131.8	132.2	

Eq. (1) Surface Net (clear-sky) = TOA LW (clear-sky) /2

132.2 = 265.7 /2

CERES EBAF-Surface Ed2.8 Data Quality Summary (March 27, 2015)

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	Net (all-sky)	108.1	108.3	109.4	109.4	
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	SW down (clear-sky)	242.4	243.4	244.1	243.9	
	SW up (clear-sky)	28.7	29.6	29.7	29.7	
	Net (clear-sky)	130.6	129.6	131.8	132.2	

Eq. (1) Surface Net (clear-sky) = TOA LW (clear-sky) /2 – TOA Net (all-sky)

132.2 = 265.7 /2 – 0.65 Wm^{-2}

CERES EBAF Ed2.8, 192 months (Mar 2000 – Feb 2016)
F. Rose et al., 27th STM (2017)

Clear Sky	Ed2.8
TOA SW Insolation	339.87
TOA SW Up	*52.50*
TOA LW Up	*265.59*
SFC SW Down	244.06
SFC SW Up	29.74
SFC LW Down	316.27
SFC LW Up	398.40

Eq. (1) Surface Net (clear-sky) = TOA LW (clear-sky) /2

SFC SW dn – SW up + LW dn – LW up = TOA LW /2

244.06 – 29.74 + 316.27 – 398.40 = 265.59/2

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Eq. (1) Surface Net (clear-sky) = TOA LW (clear-sky) /2

SFC SW dn – SW up + LW dn – LW up = TOA LW /2 within TOA Net (all-sky)

244.06 – 29.74 + 316.27 – 398.40 = 265.59/2 – 0.60 Wm^{-2}

Eq. (1) Summary

Globally averaged, the surface has a net surplus of radiant energy and it equals TOA LW /2 in the clear-sky.

It follows that …

- The net surplus of radiant energy at the surface, **compared to the TOA,** called the **greenhouse effect**, G = Surface LW up – TOA LW up,
- is also balanced by convection in the atmosphere, CONV = G (clear).

  => Surface Net = **G = TOA LW/2 (clear)**.

- Since Surface LW up $\equiv$ TOA LW up + G =>

Surface LW up (clear-sky) = (3/2) TOA LW up (clear-sky).

- Let's see on your data.

Table 4-1. Global annual mean fluxes using data from March 2000 through February 2010 (W m^{-2}).

	Flux Component	Ed3A SYN1deg -Month	EBAF-Surface Ed2.6r	EBAF-Surface Ed2.7	EBAF-Surface Ed2.8	EBAF-TOA Ed2.8
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	SW (clear-sky)	52.5	52.5	52.6	52.6	52.6
	Net (clear-sky)	23.6	21.6	21.6	21.6	21.5
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Surface Net (clear-sky) = 132.2 = SFC LW up – TOA LW up ≡ G = 398.0 – 265.7 = 132.3, difference 0.1 Wm^{-2}

Table 4-1. Global annual mean fluxes using data from March 2000 through February 2010 ($W\ m^{-2}$).

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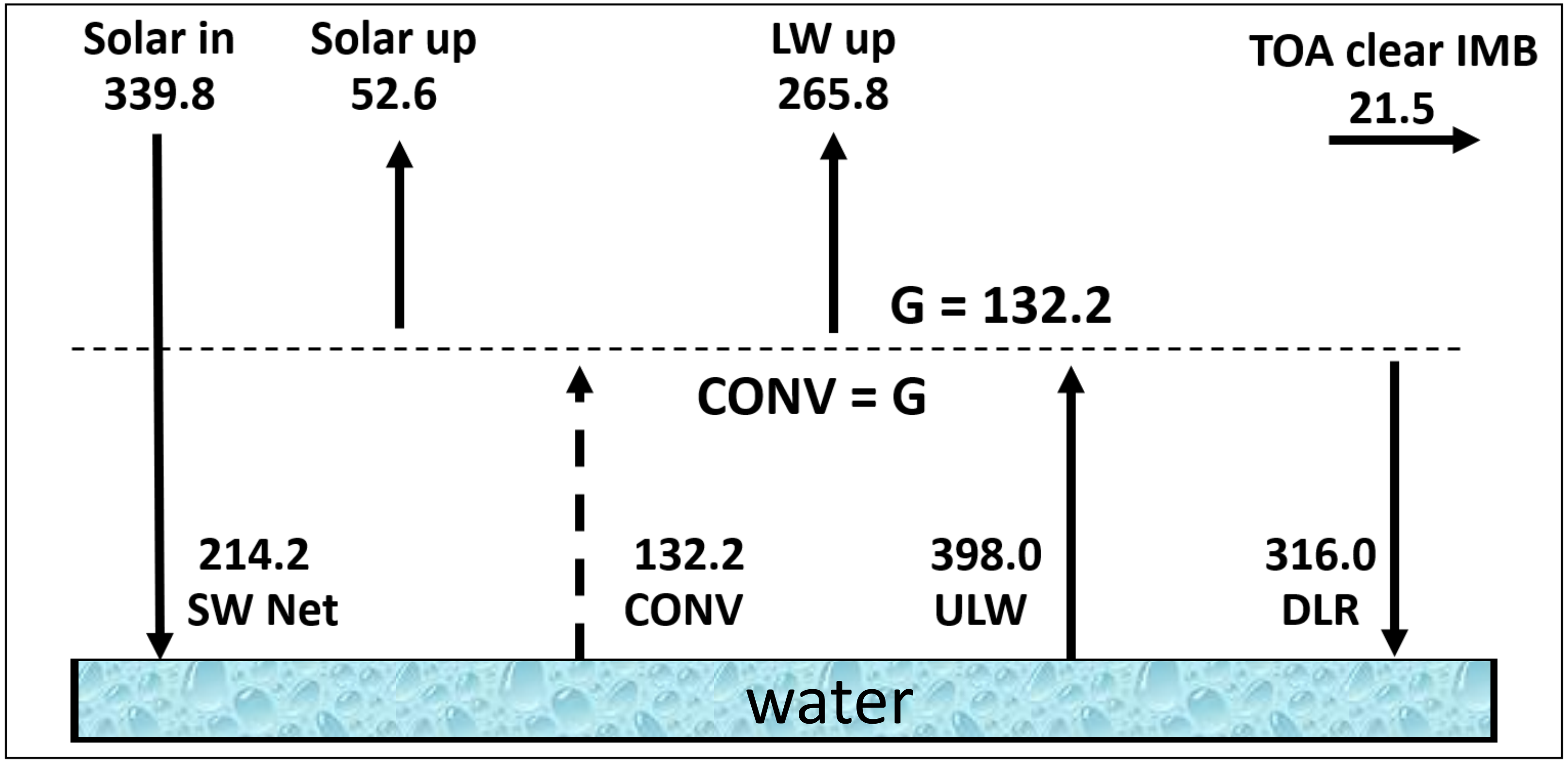
Surface Net (clear-sky) = 132.2 = SFC LW up – TOA LW up ≡ G = 398.0 – 265.7 = 132.3, difference 0.1 Wm^{-2}

But the EBAF-TOA LW up is 265.8 Wm^{-2}; using this value, G = 132.2 Wm^{-2}, the difference is 0.0

Surface Net (clear-sky) = G (clear-sky).

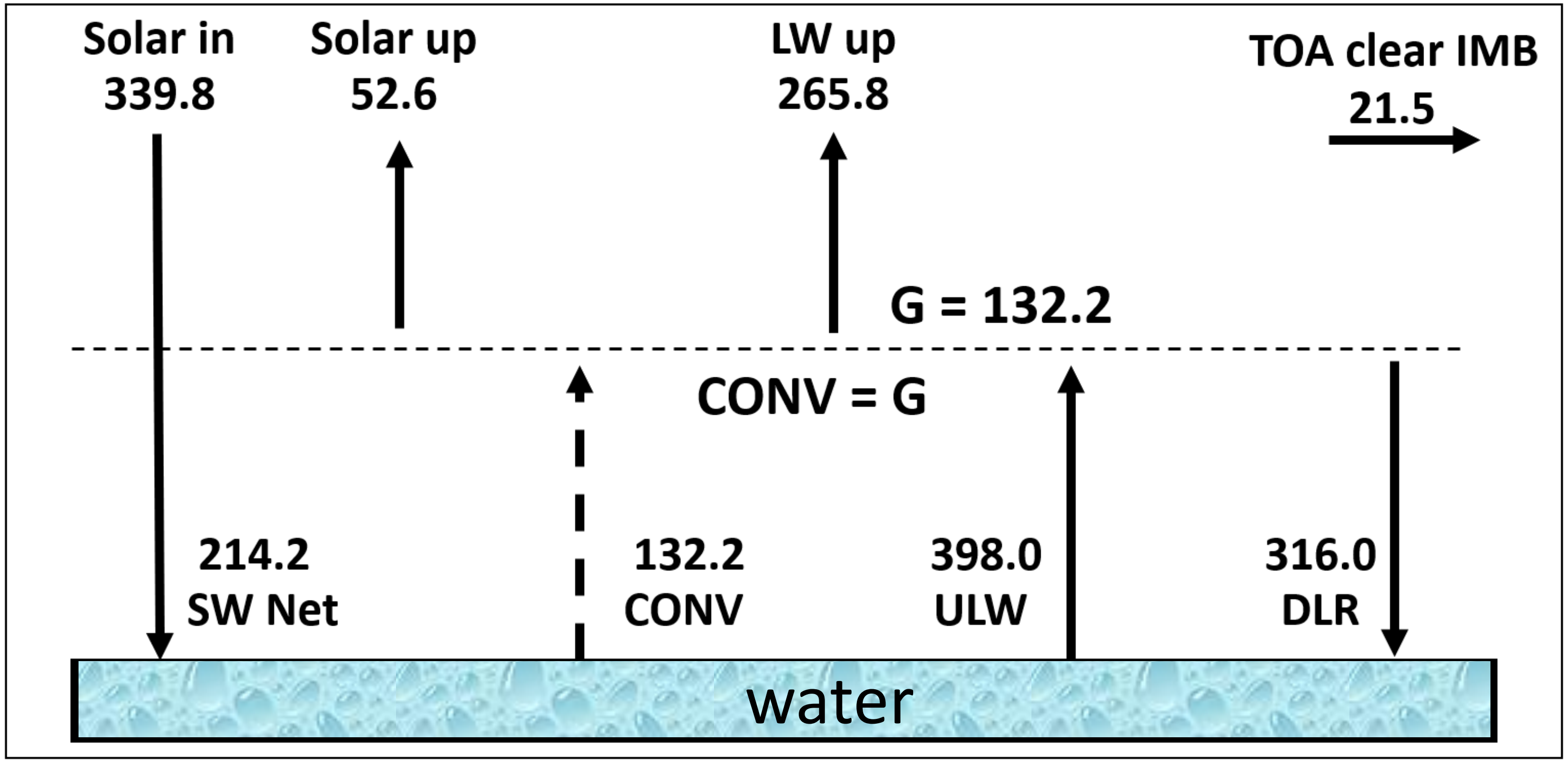


CONV = G = TOA LW/2

=> ULW = (3/2) TOA LW

Surface Net (clear-sky) = 132.2 = SFC LW up – TOA LW up ≡ G (clear-sky) = 398.0 – 265.8 = 132.2 Wm^{-2}

=> Surface LW up ≡ TOA LW up (clear-sky) + G (clear-sky) = (3/2) TOA LW up (clear-sky)



CONV = G = TOA LW/2

=> ULW = (3/2) TOA LW

=> ULW + CONV = 2 TOA LW (Eq.2)

Surface Net (clear-sky) = 132.2 = SFC LW up – TOA LW up ≡ G (clear-sky) = 398.0 – 265.8 = 132.2 Wm^{-2}

=> Surface LW up ≡ TOA LW up (clear-sky) + G (clear-sky) = (3/2) TOA LW up (clear-sky)

=> Surface LW up + Surface Net (clear-sky) = **Surface Total (clear-sky) = 2 × TOA LW up (clear-sky) (Eq.2)**

CERES EBAF Ed2.8 Global means (Mar 2000 – Feb 2016) Clear-sky

Rose et al., 27th STM (2017)

Eq. (1) Surface Net = TOA LW Up /2

244.06 – 29.74 + 316.27 – 398.40 = 265.59 /2 – 0.60 Wm^{-2}

Eq. (2) Surface Total = 2 × TOA LW Up

244.06 – 29.74 + 316.27 = 2 × 265.59

Clear Sky	Ed2.8
TOA SW Insolation	339.87
TOA SW Up	*52.50*
TOA LW Up	*265.59*
SFC SW Down	244.06
SFC SW Up	29.74
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CERES EBAF Ed2.8 Global means (Mar 2000 – Feb 2016) Clear-sky

Rose et al., 27th STM (2017)

Eq. (1) Surface Net = TOA LW Up /2

244.06 – 29.74 + 316.27 – 398.40 = 265.59 /2 – 0.60 Wm^{-2}

Eq. (2) Surface Total = 2 × TOA LW Up

244.06 – 29.74 + 316.27 = 2 × 265.59 – 0.59 Wm^{-2}

=> Surface LW Up = 3 × TOA LW Up /2

398.40 = 1.5 × 265.59 – 0.01 Wm^{-2}

Clear Sky	Ed2.8
TOA SW Insolation	339.87
TOA SW Up	*52.50*
TOA LW Up	*265.59*
SFC SW Down	244.06
SFC SW Up	29.74
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CERES EBAF Ed2.8 Global means (Mar 2000 – Feb 2016)

Clear-sky

Rose et al., 27th STM (2017)

Eq. (1) Surface Net = TOA LW Up /2

244.06 – 29.74 + 316.27 – 398.40 = 265.59 /2 – 0.60 Wm^{-2}

Eq. (2) Surface Total = 2 × TOA LW Up

244.06 – 29.74 + 316.27 = 2 × 265.59 – 0.59 Wm^{-2}

=> Surface LW Up = 3 × TOA LW Up /2

398.40 = 1.5 × 265.59 – 0.01 Wm^{-2}

Surface Net : TOA LW Up : SFC LW Up : Surface Total

1 : 2 : 3 : 4

For example

133 : 266 : 399 : 532 (Wm^{-2})

Clear Sky	Ed2.8
TOA SW Insolation	339.87
TOA SW Up	*52.50*
TOA LW Up	*265.59*
SFC SW Down	244.06
SFC SW Up	29.74
SFC LW Down	316.27
SFC LW Up	398.40

CERES_EBAF_Ed4.2.1_Subset_200101-202412.nc

283	411,5403	270,6774	140,8629	0,34228
284	410,9629	270,4989	140,464	0,34179
285	407,6057	268,9713	138,6344	0,34012
286	402,3427	266,4363	135,9064	0,33779
287	396,1337	264,3171	131,8166	0,33276
288	392,9634	263,6637	129,300	0,32904
289	sfc-lw-up-cl	toa-lw-cl	G	g
290	**398,9818**	**265,9905**	**132,9913**	**0,33333**

Clear-sky	N	Geometry	CERES
Surface LW up	3	399	398.9818
TOA LW up	2	266	265.9905
G	1	133	132.9913
g	1/3	1/3	0.33333

V. Ramanathan and Anand Inamdar

The radiative forcing due to clouds and water vapor

in: *Frontiers of Climate Modeling*
eds. J. T. Kiehl and V. Ramanathan (Cambridge 2006)

"The global average G_a is 131 Wm^{-2} or the normalized g_a is 0.33, i.e., the atmosphere reduces the energy escaping to space by 131 Wm^{-2} (or by a factor of 1/3)."

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“The global average G_a is 131 Wm^{-2} or the normalized g_a is 0.33, i.e., the atmosphere reduces the energy escaping to space by 131 Wm^{-2} (or by a factor of 1/3).”

This is a “truth”, even a “groundtruth”.

Implications

=> Eqs. (3) and (4): all-sky versions of Eqs. (1) and (2).

=> Integer solution of the four equations.

=> Extended set of integers incl. components not involved in the eqs.

Verification of the four equations

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

Eq. (1)	**SFC SW down – SW up**	**+ LW down**	**– LW up**	**(clear)**	**= TOA LW (clear)/2**		**Difference**
	240.8680 – 29.0724	+ 317.4049	– 398.5211		= 266.0122 /2		– 2.3267
Eq. (2)	**SFC SW down – SW up**	**+ LW down**		**(clear)**	**= 2 × TOA LW (clear)**		
	240.8680 – 29.0724	+ 317.4049			= 2 × 266.0122		– 2.8238
Eq. (3)	**SFC SW down – SW up**	**+ LW down**	**– LW up**	**(all)**	**= [TOA LW (all) – LWCRE]/2**		
	186.8544 – 23.1629	+ 345.0108	– 398.7550		= (240.2450 – 25.7672)/2		+ 2.7083
Eq. (4)	**SFC SW down – SW up**	**+ LW down**		**(all)**	**= 2 × TOA LW (all) + LWCRE**		
	186.8544 – 23.1629	+ 345.0108			= 2 × 240.2450 + 25.7672		+ 2.4450
						Mean	0.0007

Verification of the four equations

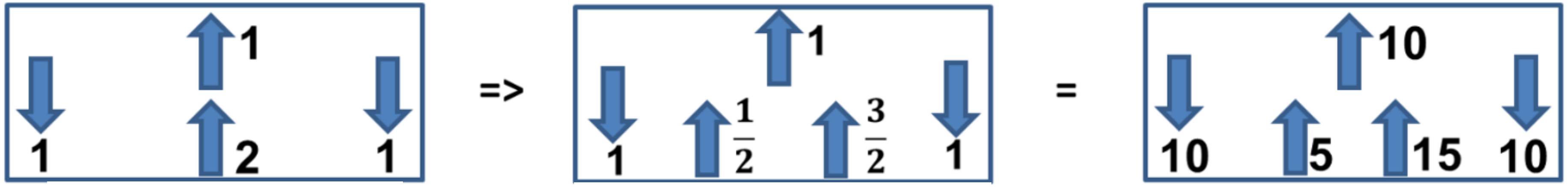
CERES EBAF Ed4.1 Version 3, 22 years (April 2000 – March 2022) (Wm^{-2})

CERES EBAF Ed4.2.1 Version 1, 24 years (April 2000 – March 2024) (Wm^{-2})

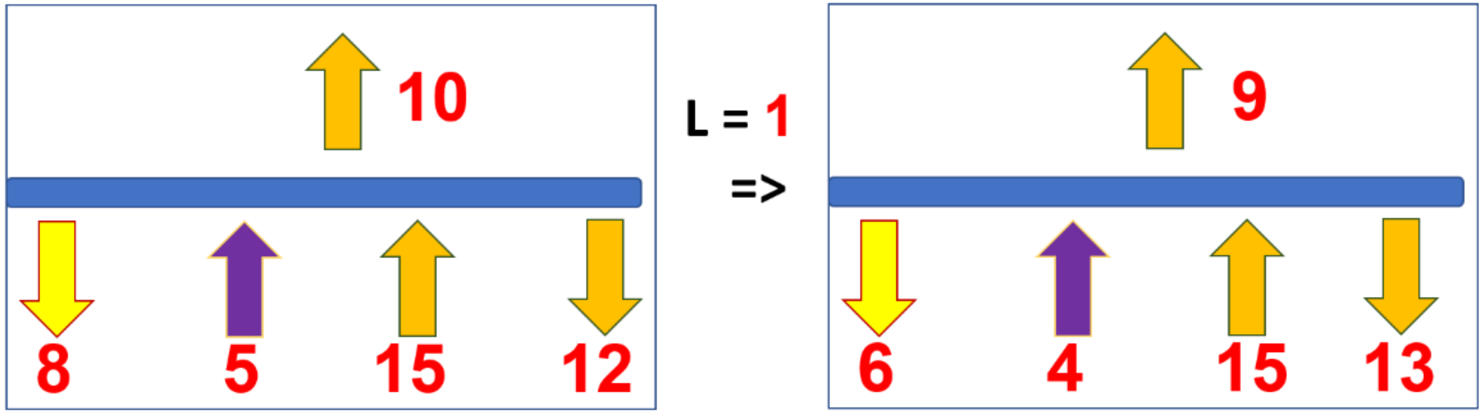
Eq. (1)	SFC SW down	– SW up	+ LW down	– LW up	(clear)	= TOA LW (clear)/2	Difference
	240.8680	– 29.0724	+ 317.4049	– 398.5211		= 266.0122 /2	– 2.3267
	241.0362	– 29.6972	+ 318.1063	– 398.8026		= 265.9732/2	– 2.3439
Eq. (2)	SFC SW down	– SW up	+ LW down		(clear)	= 2 × TOA LW (clear)	
	240.8680	– 29.0724	+ 317.4049			= 2 × 266.0122	– 2.8238
	241.0362	– 29.6972	+ 318.1063			= 2 × 265.9732	– 2.5012
Eq. (3)	SFC SW down	– SW up	+ LW down	– LW up	(all)	= [TOA LW (all) – LWCRE]/2	
	186.8544	– 23.1629	+ 345.0108	– 398.7550		= (240.2450 – 25.7672)/2	+ 2.7083
	187.1513	– 23.4547	+ 346.3226	– 398.6131		= (240.3894 – 25.5835)/2	+ 4.0032
Eq. (4)	SFC SW down	– SW up	+ LW down		(all)	= 2 × TOA LW (all) + LWCRE	
	186.8544	– 23.1629	+ 345.0108			= 2 × 240.2450 + 25.7672	+ 2.4450
	187.1513	– 23.4547	+ 346.3226			= 2 × 240.3894 + 25.5835	+ 3.6565
						Mean	0.0007
							0.7036

The N-numbers as solution of the equations

Pure geometry 1 : 2 : 3 : 4 No reference to GHGs



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



$8 + 12 - 15 = 10\ /\ 2$ $6 + 13 - 15 = (9 - 1)/2$

$8 + 12 = 10 \times 2$ $6 + 13 = 9 \times 2 + 1$

Eq. (1) SFC Net = $A_0/2$
Eq. (2) SFC Tot = $2A_0$

Clear-sky

Eq. (3) SFC Net = $(A_0 - L)/2$
Eq. (4) SFC Tot = $2A_0 + L$

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 Ed4.2.1 V1, 288 months, Jan 2001 — Dec 2024 data

Best fit: 1 unit = 1 = LWCRE = 26.683 ± 0.01 Wm^{-2}

CERES EBAF Edition 4.2.1, 24 years
January 2001 – December 2024, 1 = 26.683 Wm^{-2}

$$G = TOA\ LW/2 - 0.004\ Wm^{-2}$$

$$Surface\ LW\ up = 3\ TOA\ LW/2 - 0.004\ Wm^{-2}$$

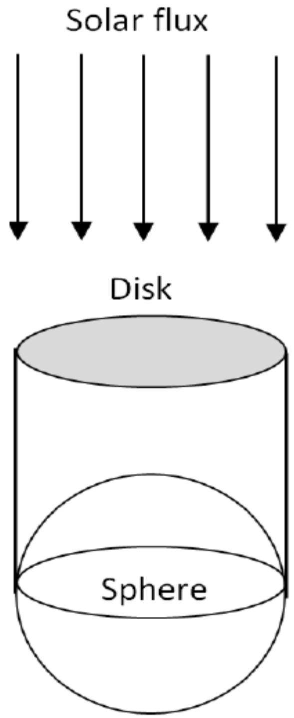
		N	N × Unit	EBAF Ed4.2.1	Difference (Wm^{-2})
Clear-Sky TOA	LW	40/4	266.83	265.9905	-0.84
	SW	8/4	53.37	53.7494	0.38
	Net	3/4	20.01	20.4678	0.46
Clear-Sky Surface	LW down	12	320.20	318.3238	-1.88
	LW up	15	400.25	398.9818	-1.27
	LW net	–3	–80.05	–80.6580	0.62
	SW down	9	240.15	240.9545	0.80
	SW up	1	26.683	29.6533	2.97
	SW net	8	213.46	211.3012	-2.16
	SW + LW net	5	133.42	130.6432	-2.78

CERES EBAF Edition 4.2.1, 24 years; **1** = 26.683 Wm^{-2}

	All-sky	**N**	**N** × Unit	EBAF Ed4.2.1	Difference (Wm^{-2})
TOA	SW insolation	**51**/4	340.21	340.21	0.00
	SW up	**15**/4	100.06	98.98	-1.18
	LW up	**36**/4	240.15	240.45	0.30
	TOT net	0	0	0.88	0.88
Surface	SW down	**7**	186.78	187.11	0.33
	SW up	**1**	26.683	23.42	-3.26
	SW net	**6**	160.10	163.69	3.59
	LW down	**13**	346.88	346.50	-0.38
	LW up	**15**	400.25	398.78	-1.47
	LW net	**–2**	–53.37	-52.28	1.09
	TOT net	**4**	106.73	111.41	4.68
	CRE				
TOA	SW	**–7**/4	-46.70	-45.13	1.57
	LW	**1**	26.683	25.54	-1.14
	TOT	**–3**/4	-20.01	-19.59	0.42

CERES EBAF Edition 4.2.1, 24 years
January 2001 – December 2024, **1** = 26.683 Wm^{-2}

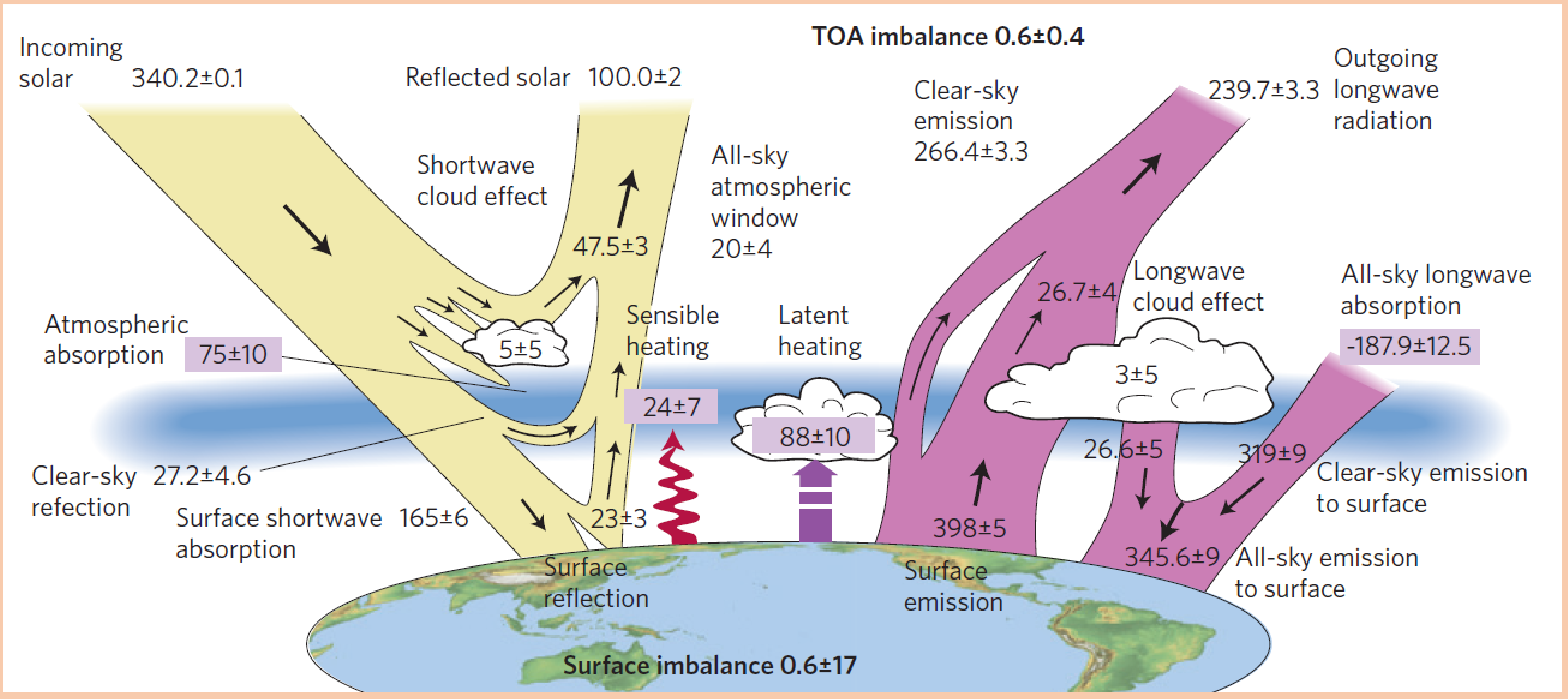
TSI
51

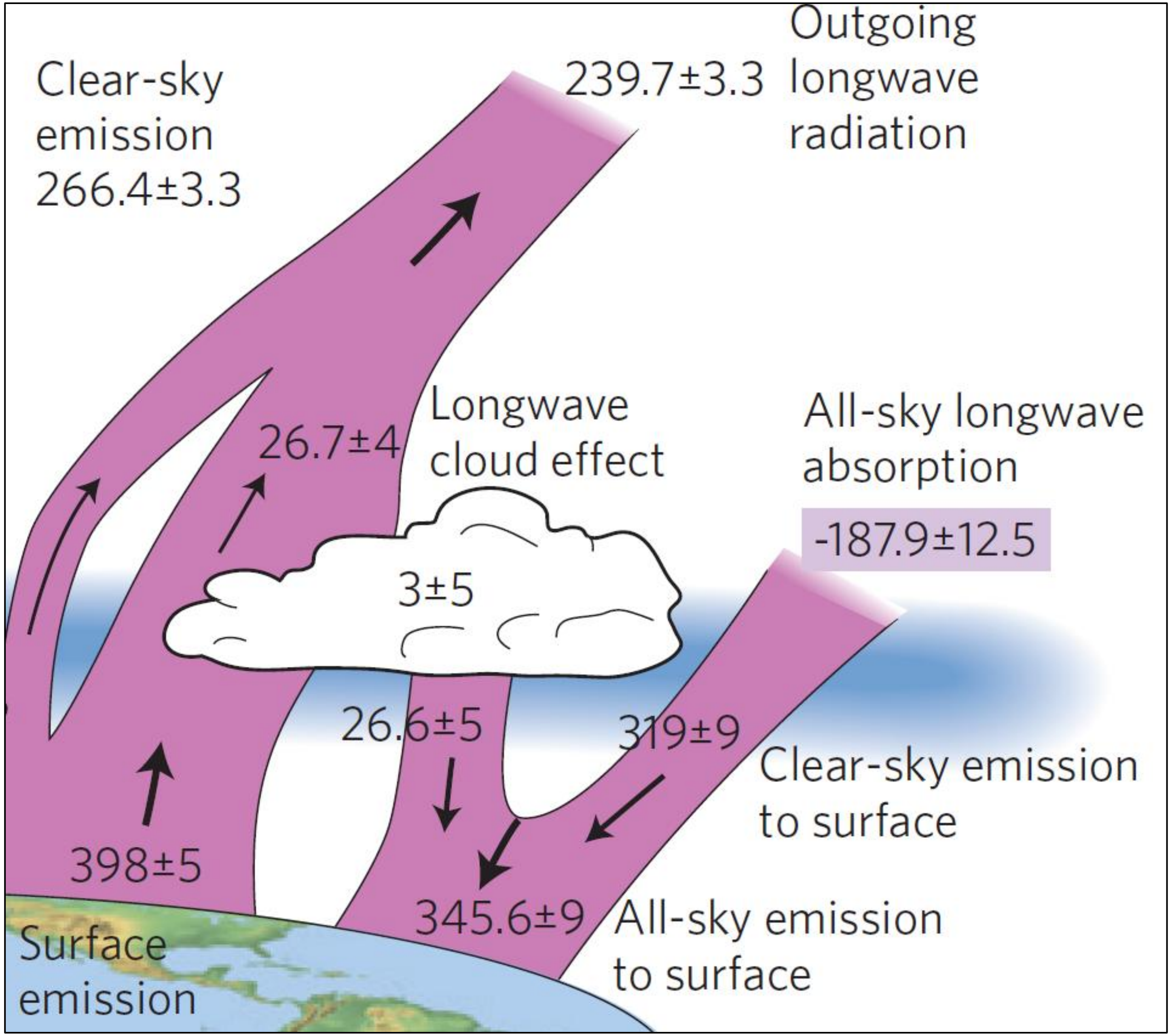


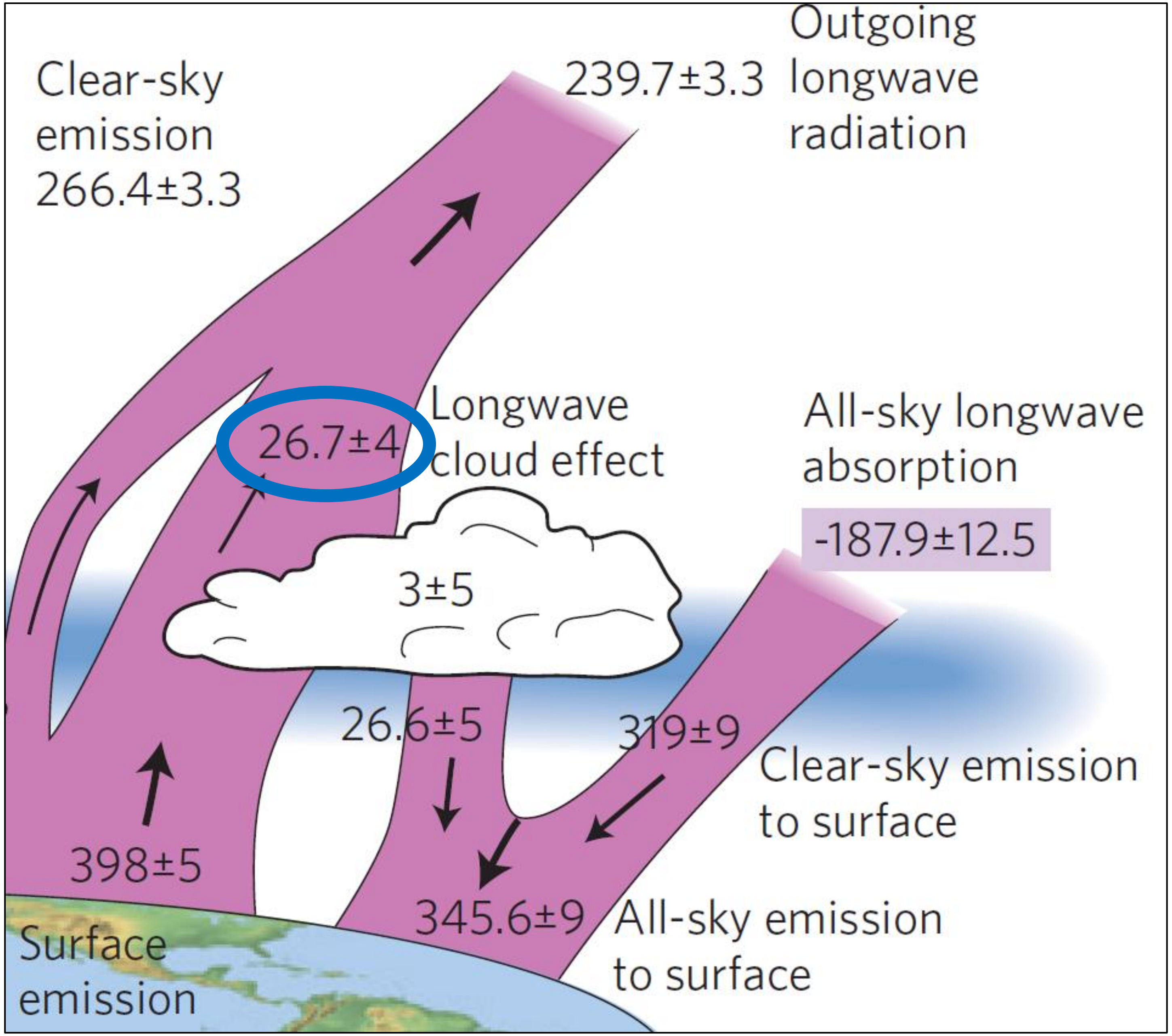
TOA	**N**	**N** × Unit	EBAF Ed4.2.1	Difference (Wm^{-2})
Solar	**51**/4	340.21	340.21	0.00
SW up clear	**8**/4	53.37	53.75	0.38
LW up clear	**40**/4	266.83	265.99	-0.84
Net clear	**3**/4	20.01	20.47	0.46
SW up all	**15**/4	100.06	98.88	-1.18
LW up all	**36**/4	240.15	240.45	0.30
Net all	**0**	0	0.88	0.88
SW CRE	**–7**/4	-46.70	-45.13	1.57
LW CRE	**4**/4	26.683	25.54	-1.14
Net CRE	**–3**/4	-20.01	-19.59	0.42

An update on Earth's energy balance in light of the latest global observations

Graeme L. Stephens[1]*, Juilin Li[1], Martin Wild[2], Carol Anne Clayson[3], Norman Loeb[4], Seiji Kato[4], Tristan L'Ecuyer[5], Paul W. Stackhouse Jr[4], Matthew Lebsock[1] and Timothy Andrews[6]




Clear-sky emission 266.4±3.3
239.7±3.3
Outgoing longwave radiation
26.7±4
Longwave cloud effect
All-sky longwave absorption
-187.9±12.5
3±5
26.6±5
319±9
Clear-sky emission to surface
398±5
345.6±9
All-sky emission to surface
Surface emission


Clear-sky
emission
266.4±3.3
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Outgoing
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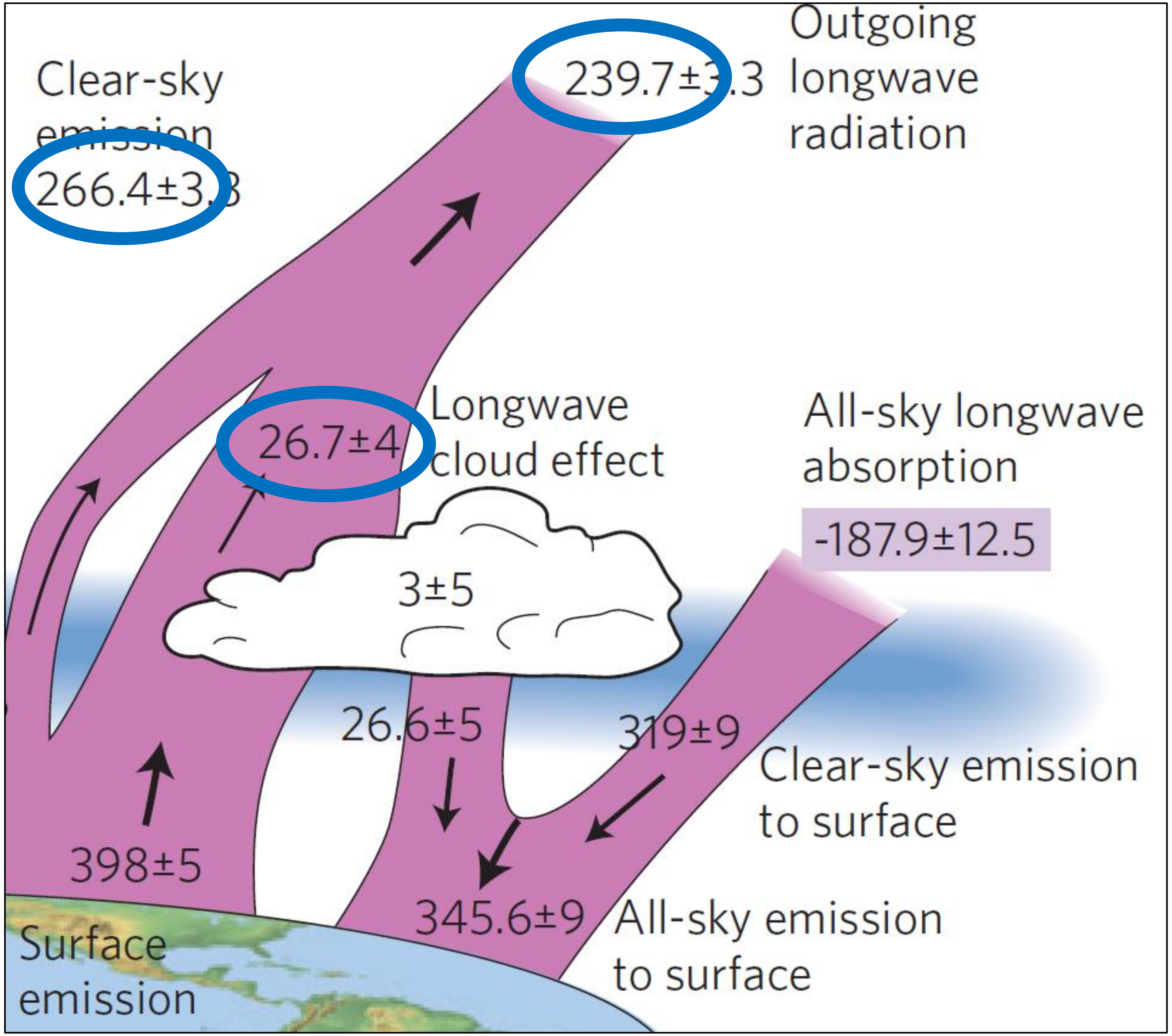
to surface
Surface
emission



Outgoing longwave radiation
239.7±3.3
Clear-sky emission
266.4±3.3
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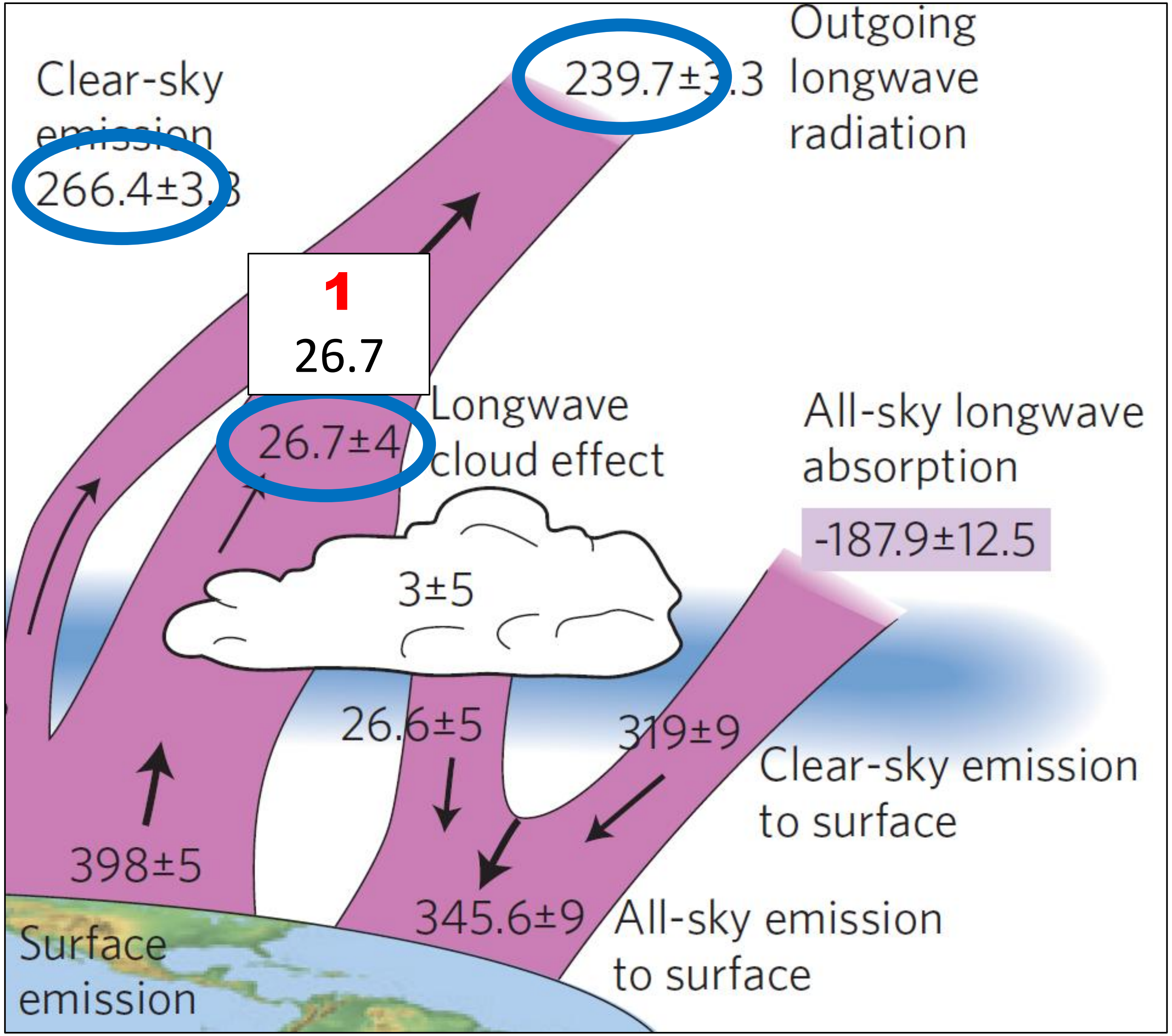

Clear-sky emission
266.4±3.3
239.7±3.3
Outgoing longwave radiation
1
26.7
26.7±4
Longwave cloud effect
All-sky longwave absorption
-187.9±12.5
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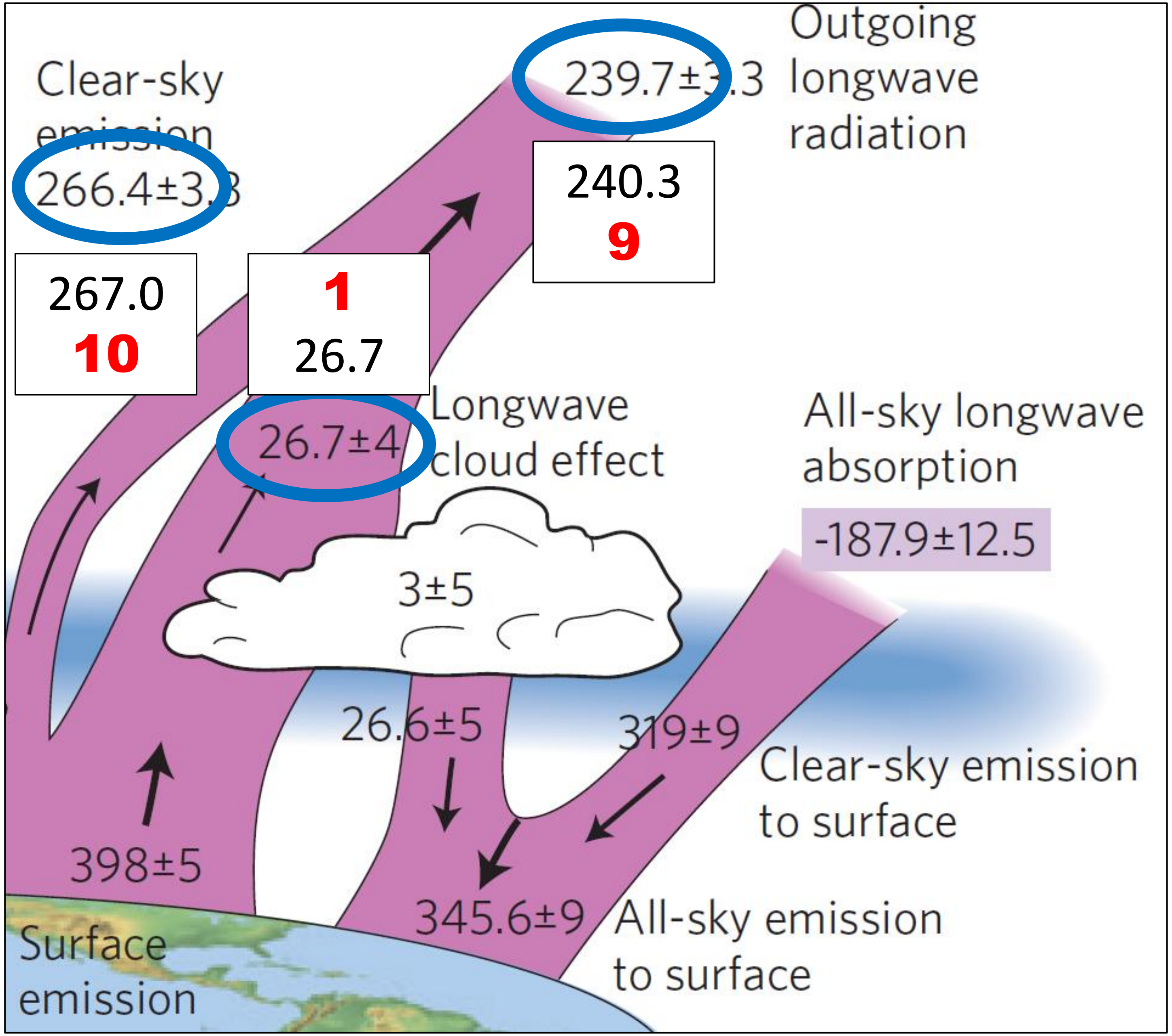
Clear-sky emission
266.4±3.3
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239.7±3.3
240.3
9
Outgoing longwave radiation
Longwave cloud effect
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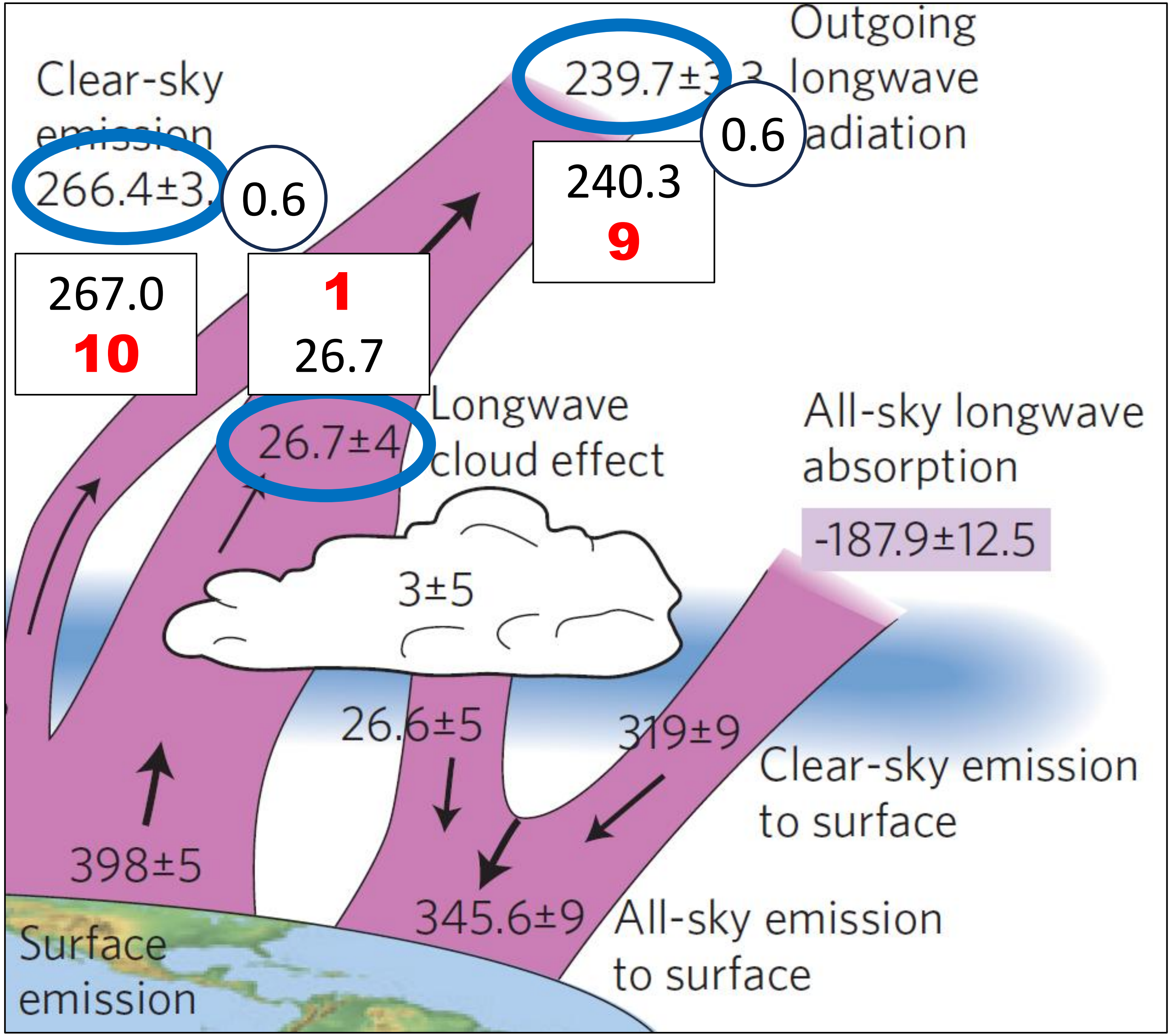
Outgoing longwave radiation
239.7±3.3
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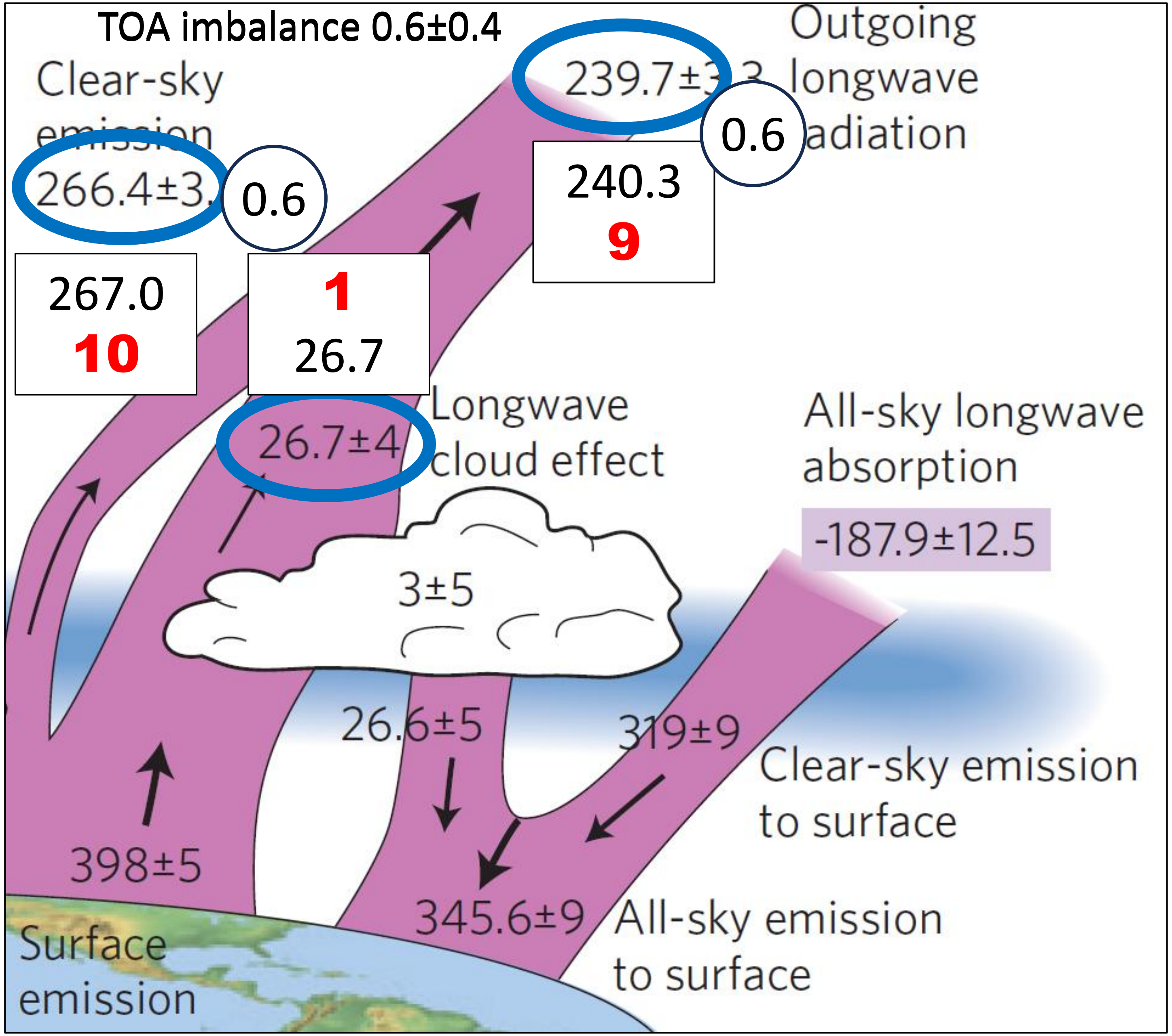

TOA imbalance 0.6±0.4
Clear-sky emission
266.4±3.
0.6
267.0
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Outgoing longwave radiation
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State of the Climate 2023 – August 2024 – BAMS

1. EARTH RADIATION BUDGET AT TOP-OF-ATMOSPHERE

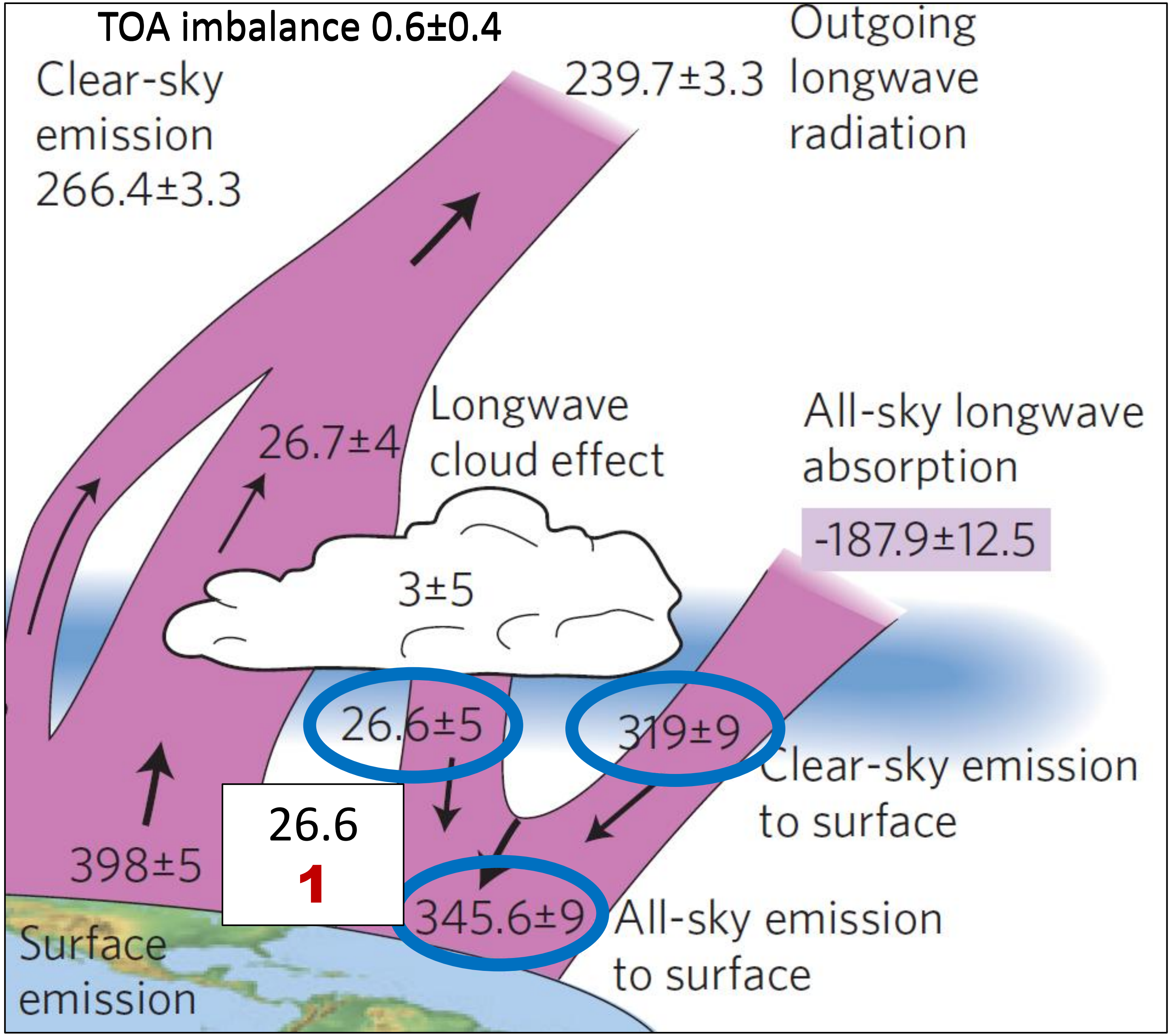
—P. W. Stackhouse Jr., T. Wong, P. Sawaengphokhai, J. Garg, and N. G. Loeb

Table 2.9. Global annual mean top-of-atmosphere (TOA) radiative flux changes between 2022 and 2023, the 2023 global annual mean radiative flux anomalies relative to their corresponding 2001–22 mean climatological values, the mean 2001–22 climatological values, and the 2-sigma interannual variabilities of the 2001–22 global annual mean fluxes (all units in W m^{-2}) for the outgoing longwave radiation (OLR), total solar irradiance (TSI), reflected shortwave (RSW), absorbed solar radiation (ASR, determined from TSI – RSW), and total net fluxes. All flux values have been rounded to the nearest 0.05 W m^{-2} and only balance to that level of significance.

Global	One Year Change (2023 minus 2022) (W m^{-2})	2023 Anomaly (Relative to 2001–22) (W m^{-2})	Climatological Mean (2001–22) (W m^{-2})	Interannual Variability (2001–22) (W m^{-2})
OLR	+0.60	+0.85	240.35	±0.65
TSI	+0.10	+0.25	340.20	±0.15
RSW	–0.80	–1.50	99.00	±1.05
ASR	+0.90	+1.75	241.20	±1.05
Net	+0.30	+0.90	0.85	±0.85

- **36**/4 = 240.15
- **51**/4 = 340.20
- **15**/4 = 100.05

- ΔOLR = 0.20
- ΔTSI = 0.00
- ΔRSW = –1.05
- ΔASR = +1.05
- Net = +0.85


TOA imbalance 0.6±0.4
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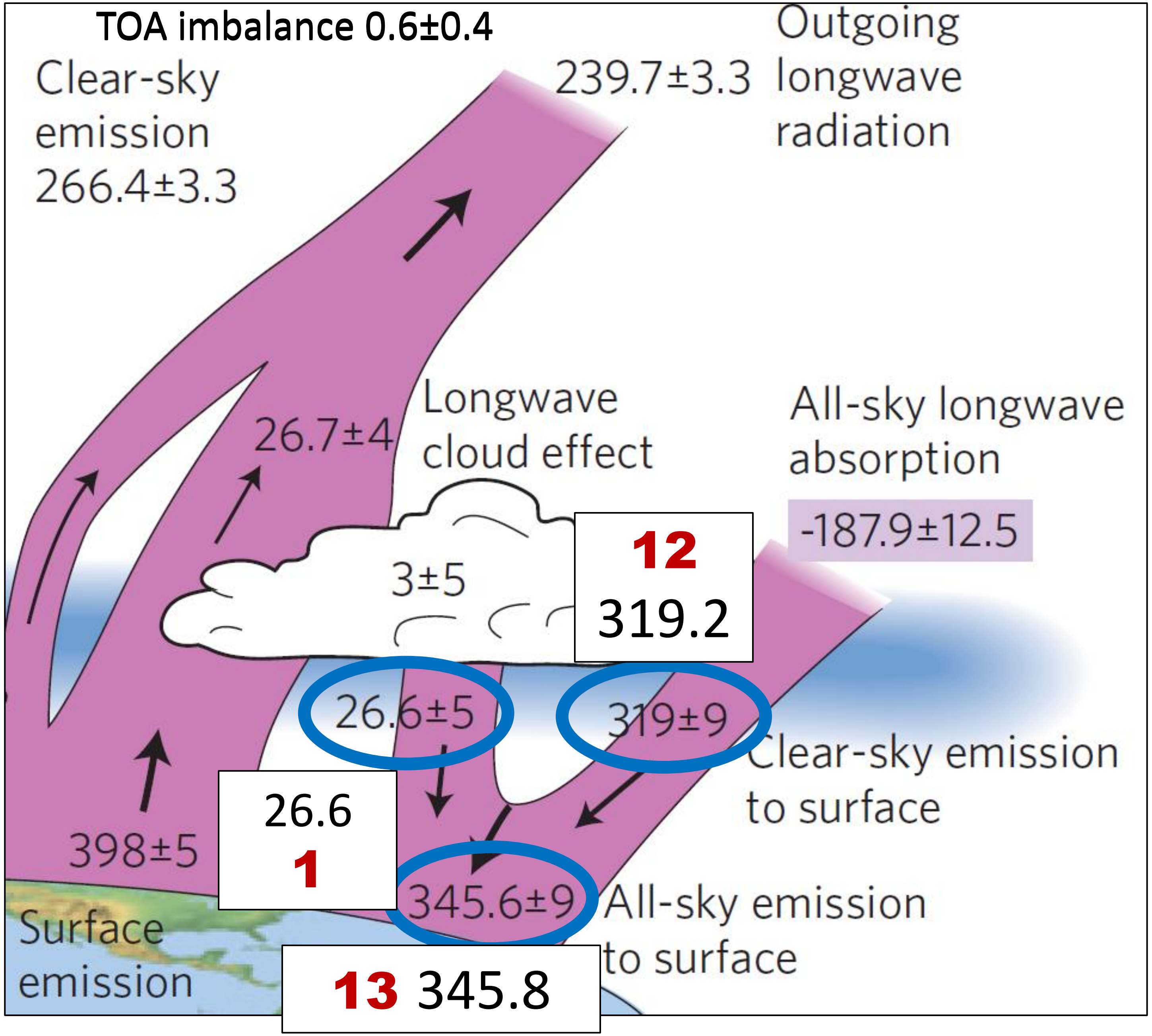

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1
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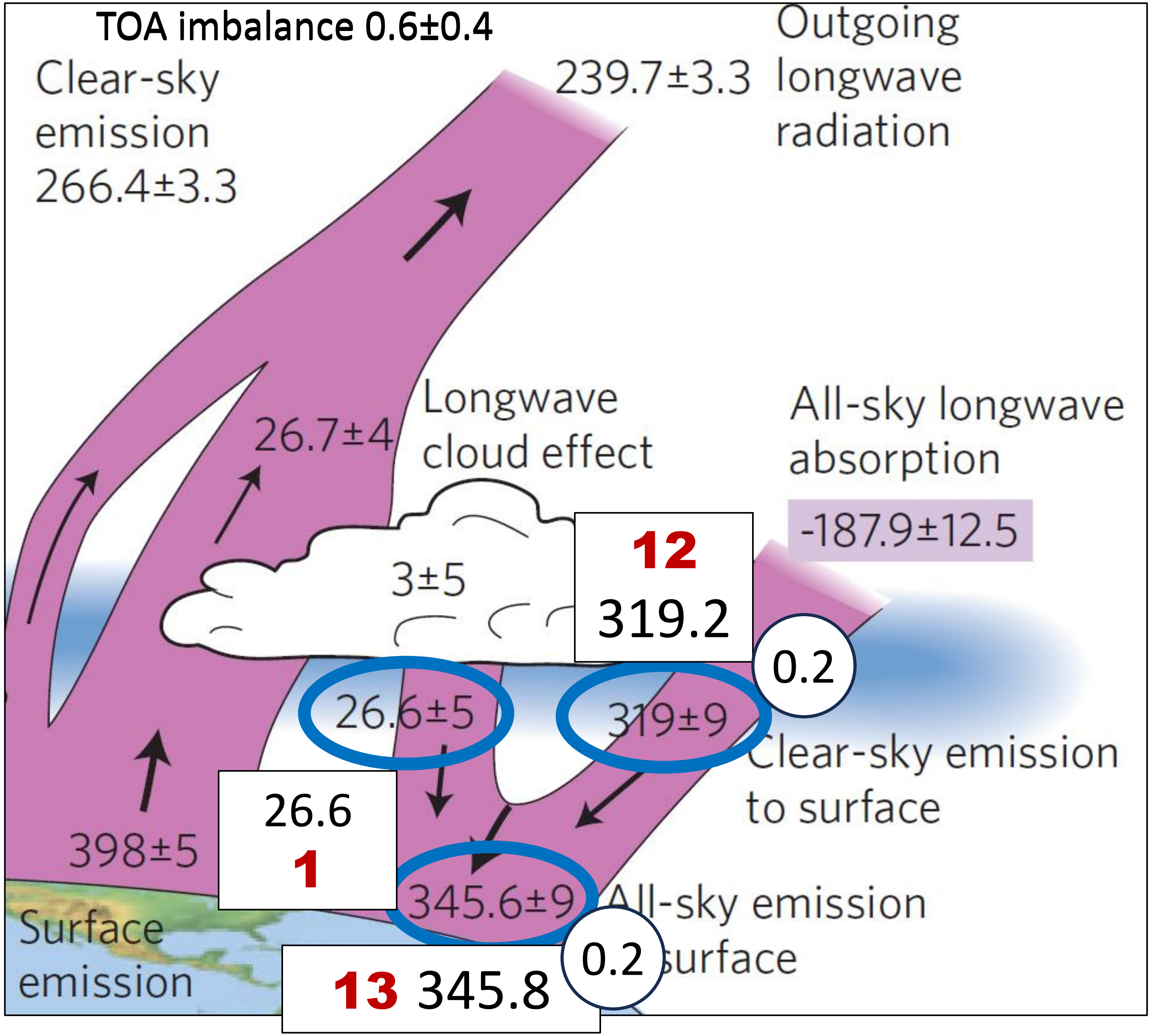
Surface emission
13 345.8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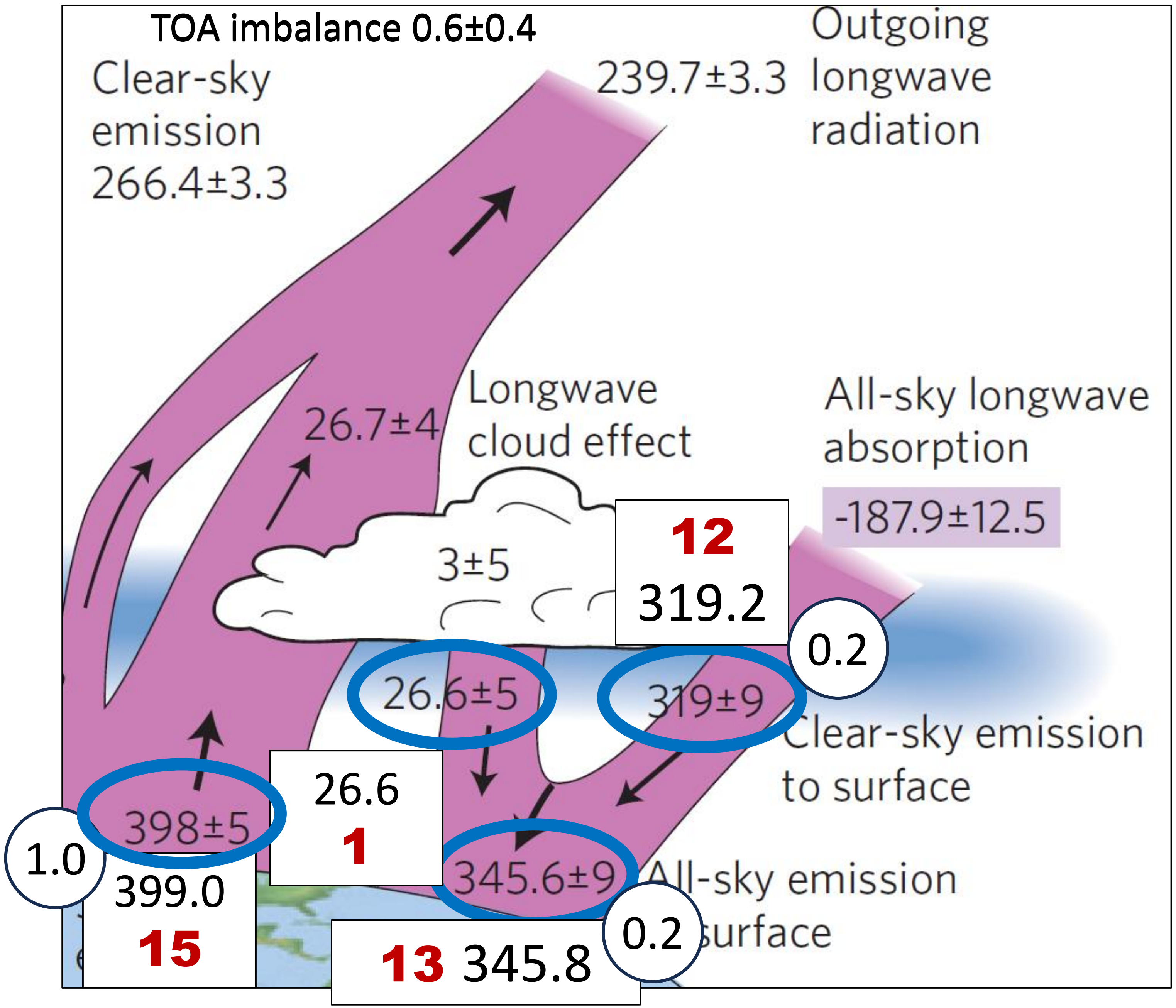
0.2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All-sky emission surface
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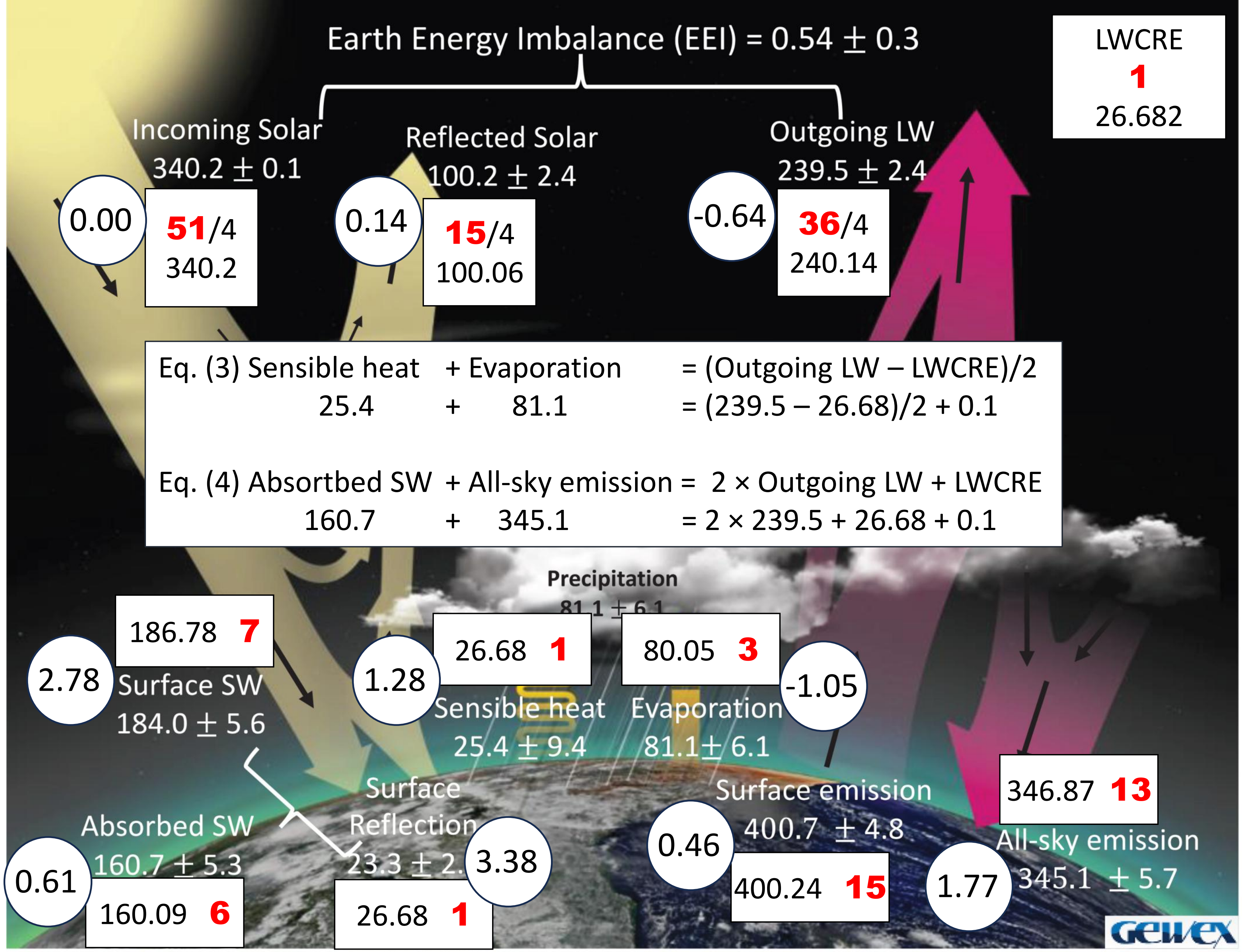
Stephens et al.
(2023, BAMS)



CERES EBAF Edition 4.2.1, 24 years
January 2001 – December 2024, 1 = 26.683 Wm^{-2}

Surface	N	N × Unit	EBAF Ed4.2.1	Difference (Wm^{-2})
SW down clear	9	240.15	240.95	0.80
SW up clear	1	26.68	29.65	2.97
SW net clear	8	213.46	211.30	-2.16
LW down clear	12	320.20	318.32	-1.88
LW up clear	15	400.25	398.98	-1.27
LW net clear	-3	-80.05	-80.66	-0.61
Total net clear	5	133.42	130.64	-2.78
SW down all	7	186.78	187.11	0.33
SW up all	1	26.68	23.42	-3.26
SW net all	6	160.10	163.69	3.59
LW down all	13	346.84	346.50	-0.34
LW up all	15	400.20	398.78	-1.42
LW net all	-2	-53.37	-52.28	1.09
Total net all	4	106.73	111.41	4.68 (largest)

TABLE 2. Global mean irradiances averaged from July 2005 through June 2015 in watts per square meter.

Kato et al. (2025)

	Edition 4.2	Edition 4.1	Edition 4.2–edition 4.1	N	N×unit	ΔEd4.2	ΔEd4.1
All-sky irradiances (W m^{-2})							
TOA insolation	340.1	340.0	0.2	**51**/4	340.10	0.00	0.10
Sfc SW down	187.0	186.6	0.4	**7**	186.72	-0.28	0.12
Sfc SW up	23.5	23.2	0.3	**1**	26.675	3.17	3.47
Sfc SW net	163.5	163.4	0.1	**6**	160.05	-3.45	-3.35
Sfc LW down	345.6	344.8	0.9	**13**	346.77	1.17	1.93
Sfc LW up	398.0	398.3	−0.3	**15**	400.12	2.12	1.82
Sfc LW net	−52.4	−53.5	1.1	**-2**	-53.35	-0.95	0.15
Sfc SW + LW net	111.1	109.8	1.2	**4**	106.70	**-4.40** largest	-3.10
Atm SW net	77.4	77.5	−0.1	**3**	80.02	2.62	2.52
Atm LW net	−187.8	−186.6	−1.1	**-7**	-186.72	1.08	-0.12
Atm SW + LW net	−110.3	−109.1	−1.2	**-4**	-106.70	3.60	2.40
Clear-sky (total area) irradiances (W m^{-2})							
Sfc SW down	241.1	240.7	0.4	**9**	240.07	-1.03	-0.63
Sfc SW up	29.8	29.1	0.7	**1**	26.675	-3.12	-2.42
Sfc SW net	211.3	211.6	−0.2	**8**	213.40	2.10	1.80
Sfc LW down	317.4	317.2	0.2	**12**	320.09	2.69	2.89
Sfc LW up	398.3	398.2	0.1	**15**	400.12	1.82	1.92
Sfc LW net	−80.9	−81.0	0.1	**-3**	-80.02	0.88	0.98
Sfc SW + LW net	130.5	130.6	−0.2	**5**	133.37	2.87	2.77
Atm SW net	75.0	74.6	0.4	**11**/4	73.35	-1.65	-1.25
Atm LW net	−185.2	−184.9	−0.3	**-7**	-186.72	-1.52	-1.82
Atm SW + LW net	−110.2	−110.3	0.1	**-4**	-106.70	-3.50	-3.60

within uncertainty

Congratulations CERES Team! A 25 Year ERB Record!!!

- Your Science-page: „Globally averaged, the surface has a net surplus of radiant energy"

Ramanathan (1995): … and it equals OLR/2 in the clear-sky $\sigma T_g^4 - \sigma T(\tau^*)^4 = \frac{f_0}{2}$

- Inamdar and Ramanathan (2006): „The global average normalized g_a is 0.33, i.e., the atmosphere reduces the energy escaping to space by a factor of 1/3."

g(clear, theory) = 1/3; g(clear, CERES 24-yr) = 0.33333

- Theory: Surface LW up (clear) = (3/2) TOA LW up (clear)

CERES 24-yr: 398.9818 = (3/2) 265.9905 – 0.004 Wm^{-2}.

=> T_G (all, theory) = 34.76°C, T_G(all, CERES) = 34.41°C

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  g(clear, theory) = 1/3; g(clear, CERES 24-yr) = 0.33333

- Theory: Surface LW up (clear) = (3/2) TOA LW up (clear)

  CERES 24-yr: 398.9818 = (3/2) 265.9905 – 0.004 Wm^{-2}.

  => T_G (all, theory) = 34.76°C, T_G(all, CERES) = 34.41°C

  => EBAF Ed4.2.1 DATA vs. THEORY consistent within uncertainty