IRS 2024 Abstract Book

Miklos Zagoni

Content

1. Integer Ratios in Earth's Global Mean Energy Flow System, Clear-Sky

Integer ratios may be recognized among the components of the global mean energy flow system. Here we show the clear-sky structure; in Table 1 from the recent CERES EBAF Edition 4.2, Version 2 (release date: 2 January, 2024) 23 full running years (from October 2000 through September 2023) dataset, and Figure 1 shows a graphical representation of them. The unit flux is 26.68 Wm^{-2}, total solar irradiance is 51 units = 1360.68 Wm^{-2}. Two radiative transfer equations are also presented, from Schwarzschild (1906, Eq. 11), or Houghton (1977 Eq. 2.13), and also Houghton (1977, Eq. 2.15) at an optical depth of 2.

Table 1. Integer positions versus clear-sky global mean data from EBAF Ed4.2 Version 2. Unit = 26.68 Wm^{-2}

Eq. (1) SFC SW+LW Net = OLR/2 **8** + **12** – **15** = **10**/2 (Schw 1906, Eq.11; Houghton 1977, Eq. 2.13)
Eq. (2) SFC SW+LW Tot = 2OLR **8** + **12** = 2 × **10** (Schw 1906, Eq.11; Houghton 1977, Eq. 2.15 at τ = 2)

	Clear-sky	N	N × Unit	EBAF Ed4.2	Difference
Clear-Sky TOA	SW insolation	**51**/4	340.17	340.20	0.03
	LW	**40**/4	266.80	265.95	-0.85
	SW	**8**/4	53.36	53.78	0.42
	Net	**3**/4	20.01	20.42	0.41
Clear-sky Surface	LW down	**12**	320.16	318.06	-2.10
	LW up	**15**	400.20	398.75	-1.45
	LW Net	**-3**	-80.04	-80.69	-0.65
	SW Net	**8**	213.44	211.33	-2.11
	SW + LW Net	**5**	133.40	130.64	-2.76

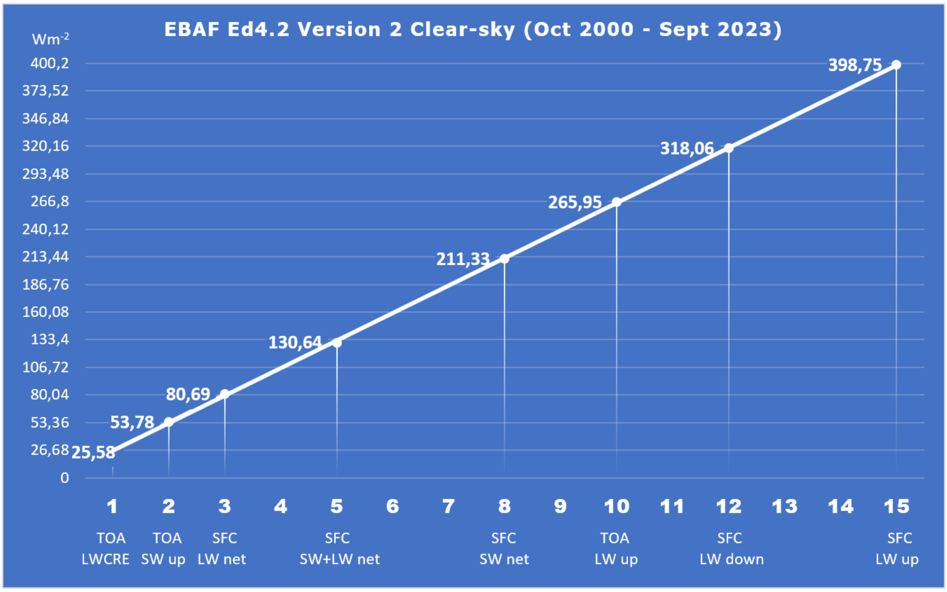


Figure 1 Graphical representation of the above data (except TOA SW insolation and TOA net). These data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.

To indicate accuracy, the greenhouse effect is G = Surface LW up – TOA LW up; in the integer structure G(clear) = 15 – 10 = 5 units, and the normalized greenhouse factor is g = G / Surface LW up = 5/15 = 1/3; with the CERES values from Table 1, g(clear) = (398.75 – 265.95)/398.75 = 0.333.

2. Integer Ratios in Earth's Global Mean Energy Flow System, All-Sky

Integer ratios may be recognized among the components of the global mean energy flow system. Here we show the all-sky structure, in Table 1 from the recent CERES EBAF Edition 4.2, Version 2 (release date: 2 January, 2024) 23 full running years (from October 2000 through September 2023) dataset, and in Figure 1 projected on the most up-to-date Gewex data. The unit flux is 26.68 Wm^{-2}, total solar irradiance is 51 units = 1360.68 Wm^{-2}. Two radiative transfer equations are also presented as the all-sky versions of Houghton (1977) Eq. 2.13, and Eq. 2.15 at an optical depth of 2.

Table 1. Integer positions versus all-sky global mean data from EBAF Ed4.2 Version 2. Unit = 26.68 Wm^{-2}

Eq. (3) SFC SW+LW Net = (OLR – LWCRE)/2 **6** + **13** – **15** = (**9** – **1**)/2 (Schw 1906, Eq.11; Houghton 1977, Eq. 2.13 incl L)
Eq. (4) SFC SW+LW Tot = 2OLR + LWCRE **6** + **13** = 2 × **9** + **1** (Schw 1906, Eq.11; Houghton 1977, Eq. 2.15 at τ = 2 incl L)

TSI = **51**	All-sky	**N**	**N** × Unit	EBAF Ed4.2	Diff
TOA	SW insolation	**51**/4	340.17	340.20	0.03
	SW up	**15**/4	100.05	98.95	-1.10
	LW up	**36**/4	240.12	240.37	0.25
	TOT Net	0	0	0.88	0.88
Surface	SW Net	**6**	160.08	163.71	3.63
	LW down	**13**	346.84	346.25	-0.59
	LW up	**15**	400.20	398.58	-1.62
	LW Net	-**2**	-53.36	-52.33	1.03
	TOT Net	**4**	106.72	111.38	4.66
	CRE				
TOA	SW	-**7**/4	-46.69	-45.17	1.52
	LW	**1**	26.68	25.58	-1.10
	Net	-**3**/4	-20.01	-19.59	0.42

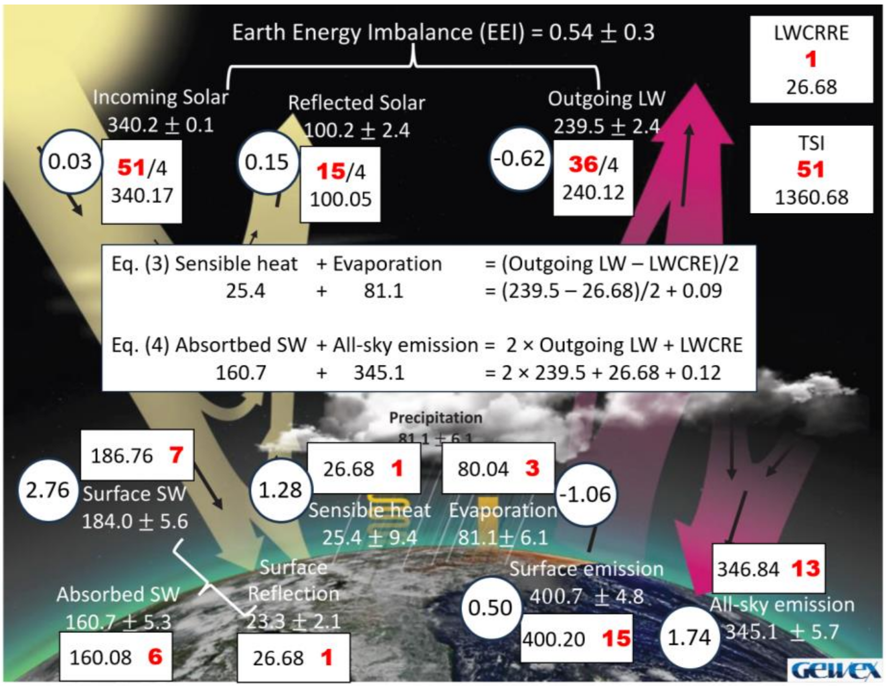


Figure 1. The integer structure on the Gewex energy flow distribution (Stephens et al. 2023, Fig. SB3). Differences from the integer positions in circles (Wm^{-2}). The validity of the two equations is also indicated.

3. Determination of Total Solar Irradiance from the Integer Structure

An unexpected recognition a decade ago was the integer ratio system in the longwave part of the updated global mean energy flow system (Stephens et al. 2012). Using longwave cloud radiative effect (LWCRE) as unit 1 = 26.7 Wm^{-2} in the diagram, it is evident that clear-sky and all-sky outgoing longwave radiation at the top-of-atmosphere (TOA) differ by 1 unit, as it follows from the definition of LWCRE. Similarly, all-sky and clear-sky emission to surface differ by 1 unit, since LWCRE at the surface (26.6 Wm^{-2}) is almost the same as at the TOA. However, the fact that not only their differences are equal to LWCRE, but these irradiances themselves, including surface emission, are integer multiples of the longwave cloud effect, far within the stated ranges of uncertainty, is really a remarkable observation. The largest difference (shown in the circles) is 2.5 Wm^{-2} in "Surface emission", see Figure 1.

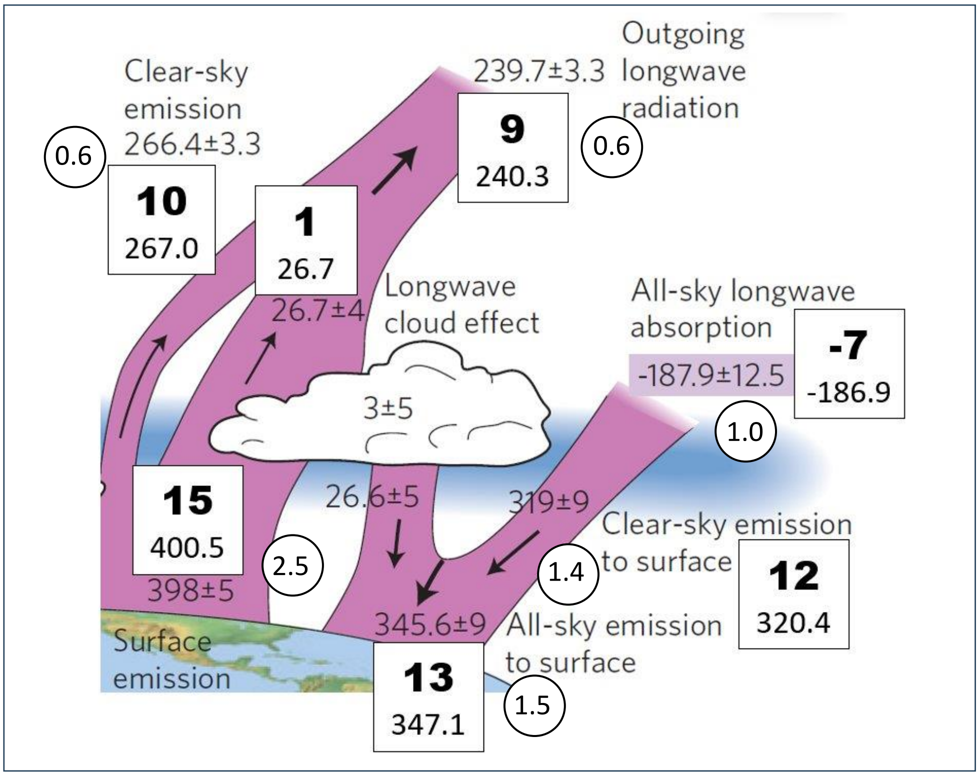


Figure 1. Integer multiple ratio structure can be recognized among the longwave fluxes in the energy flow distribution of Stephens et al. (2012). The unit flux is 1 LWCRE. Textboxes projected on the diagram with the integer positions in black bold typeface and the flux values as integer multiples of 1 unit = 26.7 (Wm^{-2}). The differences of the observed values and the integer multiple positions are given in circles (Wm^{-2})

Including incoming (340.2 ± 0.1 Wm^{-2}) and reflected solar radiation (100.0 ± 2 Wm^{-2}) from the original diagram into the system, it is easy to recognize that they have integer positions as well on the intercepting cross-section disk to solar radiation (that is, before division by 4 for spherical weighting), as 51/4 units = 340.42 Wm^{-2} and 15/4 units = 100.12 Wm^{-2}. After a refinement of the unit flux from 26.7 Wm^{-2} to 26.68 Wm^{-2}, incoming solar is 340.17 Wm^{-2} and reflected solar is 100.05 Wm^{-2}. Now let us recall that EBAF uses geodetic weighting, with a factor of 4.0034, instead of division by 4 for spherical weighting. Accepting the integer structure with the refined unit flux and the geodetic weighting factor, it can be stated that to maintain the Earth's global mean energy flow system, the required total solar irradiance is TSI = 51 × 26.68 × (4.0034/4) = 1361.84 Wm^{-2}.

4. The Clear-Sky Greenhouse Effect as the Unit of the Integer Ratio System

Integer ratios may be recognized among the components of the global mean energy flow system, and the unit flux may be identified as the longwave cloud radiative effect (LWCRE), with a best fit of 1 unit = 26.68 Wm^{-2}. Here we show that the clear-sky greenhouse effect, G(clear), identified as 5 units = 133.4 Wm^{-2} in the integer system, plays also the role of "pacemaker" for the fundamental flux components in the clear-sky global mean energy flow system. (Note that an independent estimate, GFDL Atmospheric Model 4 finds G = 133.4 ± 0.6 Wm^{-2}, Raghuraman et al. 2019, Table 2). With this G-unit, total solar irradiance is 10G + 1 unit = 1334.0 + 26.68 Wm^{-2}, outgoing longwave radiation OLR = 2G, surface upward LW radiation ULW = 3G, and the total SW+LW absorbed energy at the surface is TOT = 4G. Downscaling ULW from its integer position of 15 units = 400.2 Wm^{-2} to the most recent CERES EBAF Edition 4.2, Version 2 (release date: 2 January, 2024) 23 full running years (October 2000 — September 2023) data of ULW = 398.75 Wm^{-2}, the corresponding unit becomes 26.58 Wm^{-2}, and the ratios give for G, OLR, and TOT the values of 132.92, 265.83 and 531.67 Wm^{-2}, respectively, while the CERES EBAF dataset gives 132.80, 265.95 and 531.55 Wm^{-2}, resp.; the differences are 0.12 Wm^{-2}, see Table 1.

Table 1. Clear-sky flux components G = OLW – OLR, outgoing LW radiation, surface upward LW radiation and total SW+LW absorption at the surface (first row); their ratio (second row); expressed in N-units (third row); with 1 unit = 26.68 Wm^{-2} (fourth row); scaling down to the EBAF ULW (fifth row); the downscaled values (sixth row); EBAF values (seventh row); and their differences (last row).

	G	OLR	ULW	TOT
Ratio (clear-sky)	**1**	**2**	**3**	**4**
N	**5**	**10**	**15**	**20**
Theory [26.68]	133.40	266.80	400.20	533.60
Scaling down to			398.75	
Theory [26.58]	132.92	265.83	398.75	531.67
EBAF Ed4.2	132.80	265.95	398.75	531.55
Difference	0.12	-0.12		0.12

EBAF data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.

Reference

Raghuraman, Shiv P., David J Paynter, and V Ramaswamy, November 2019: Quantifying the Drivers of the Clear Sky Greenhouse Effect, 2000-2016. JGR Atmospheres, 124(21), DOI:10.1029/2019JD031017.

5. What is the Unit of the Integer Ratio System?

Integer ratios may be recognized among the components of the global mean energy flow system, and the unit flux may be identified as the longwave cloud radiative effect (LWCRE), with a best fit of 26.68 Wm^{-2}. However, this flux component shows marked decreasing trend in the past two decades, according to the most recent CERES EBAF Edition 4.2, Version 2 (release date: 2 January, 2024) 23 full running years (from October 2000 through September 2023) dataset. On the other hand, shortwave cloud radiative effect, SWCRE, exhibits an opposite (increasing) trend with the same magnitude, therefore their sum, Net CRE at the top of atmosphere, is surprisingly constant, see Figure 1. Importantly, the fundamental flux components in the all-sky global mean energy flow system (TSI, RSR, ASR, OLR, ULW and the greenhouse effect G) may be expressed using Net CRE = 3/4 LWCRE = 20.01 Wm^{-2} as the unit flux; and also with its quadruple, 4 Net CRE = 3 LWCRE = 80.04 Wm^{-2}, see Table 1.

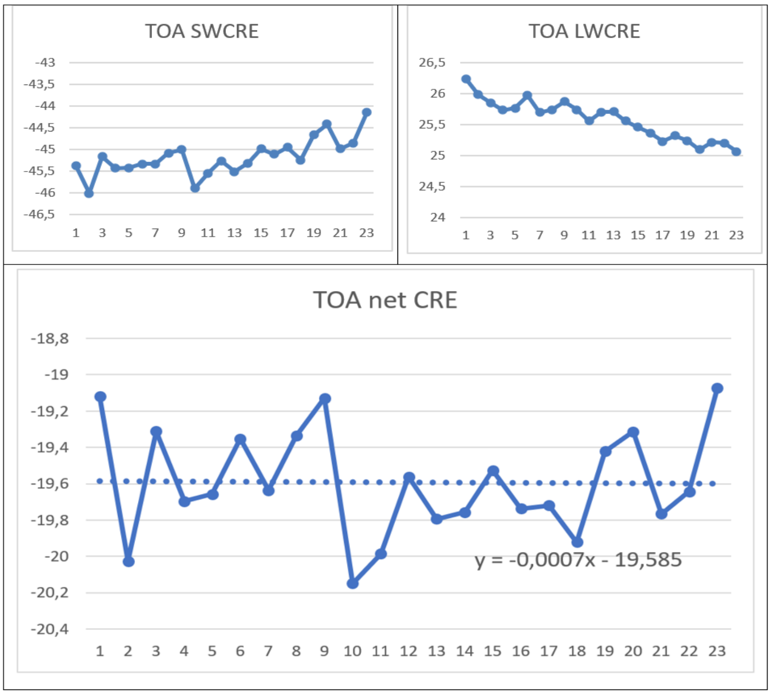


Figure 1 TOA shortwave, longwave and Net CRE in the past 23 full running years (Oct2000-Sept2023).

Table 1 Basic all-sky fluxes in LWCRE (26.68), Net CRE (20.01) and 4 Net CRE (80.04) units (Wm^{-2})

Flux (all-sky)	Value (Wm^{-2})	LWCRE = **1**	TOA Net CRE = **1**	4 Net CRE = **1**
TSI	1360.68	**51**	**68**	**17**
ISR	340.17	**51**/4	**17**	**17**/4
RSR	100.05	**15**/4	**5**	**5**/4
ASR = OLR	240.12	**36**/4 = **9**	**12**	**3**
ULW	400.20	**15**	**20**	**5**
G	160.08	**6**	**8**	**2**

6. What Are the Drivers of Earth's Energy Imbalance?

Stephens et al. (2022) assess data from 20 years of CERES observations (March 2000 to March 2020) to find the trend in Earth's energy imbalance (EEI) and the components of it, and shows the imbalance being positive, appearing largely from reductions in the amount of sunlight reflected by Earth to space. The study identifies the largest contribution as the increasing rate of reflection from Earth's atmosphere, due to a reduction to the aerosol particle concentration. Their Figure 1 shows global net shortwave, longwave, and shortwave + longwave (EEI) anomaly. Here we use the extended and updated dataset, CERES EBAF Edition 4.2, Version 2 (release date 2 January 2024), covering 23 full years (from October 2000 to September 2023). These 276 monthly means show a slight increasing trend in incoming solar radiation, a marked decrease in reflected solar radiation, and as their sum, a robust increasing trend in absorbed solar radiation; and, further, a pronounced increase in surface upward longwave radiation, representative of the known global warming. We relate the global mean absorbed solar radiation by the planet to the surface upward longwave emission and find a strictly linear relationship in the examined period on the said dataset, supporting the claim of Stephens et al. (2022) that by far the largest driver of the changes in Earth's energy imbalance is the amount of absorbed solar radiation in the climate system.

Figure 1 shows the ratio of all-sky surface longwave upward radiation to all-sky absorbed solar radiation within the climate system. The direct coupling of the warming trend to the increase in absorbed solar radiation is expressed by the equation for the trendline, y = 1E-06x + 1,6522.

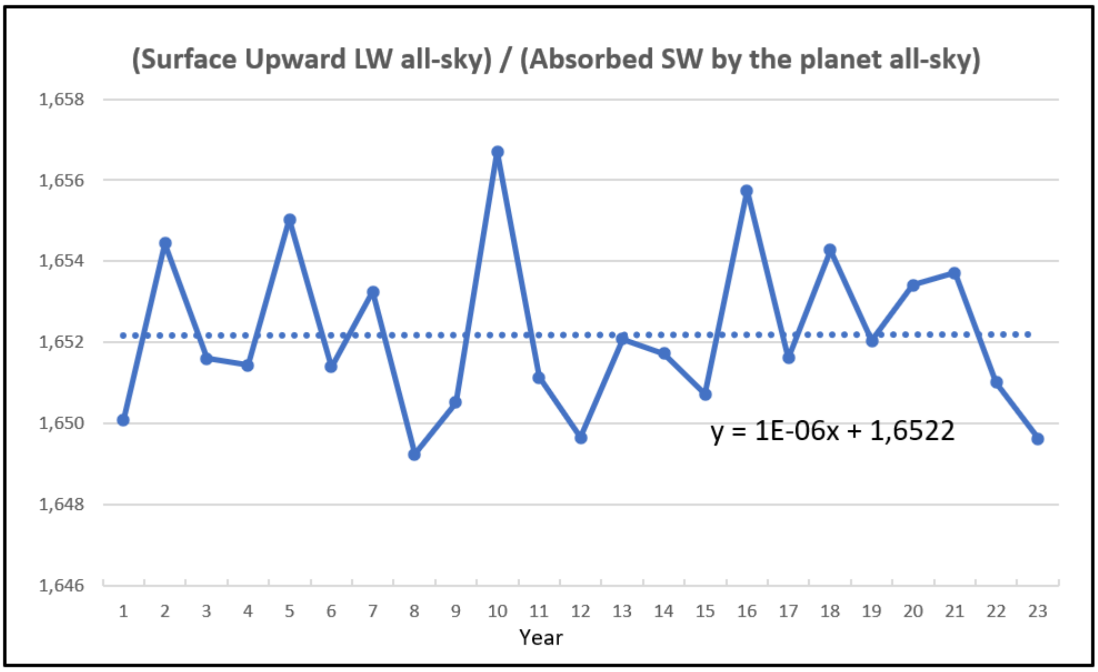


Figure 1. Virtually zero trend can be seen in the ratio of all-sky surface upward longwave radiation to the all-sky absorbed solar radiation by the climate system during the past 23 years, according to CERES EBAF Ed4.2 V2 dataset. Horizontal axis: running years (from October to September). These data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.

Reference

Stephens GL, Hakuba MZ, Kato S, Gettelman A, Dufresne J-L, Andrews T, Cole JNS, Willen U, Mauritsen T. 2022 The changing nature of Earth's reflected sunlight. Proc. R. Soc. A 478: 20220053. https://doi.org/10.1098/rspa.2022.0053

7. Trenberth's Greenhouse Geometry Satisfied by Real Earth Data

"How Does a Greenhouse Effect Work?" asks Kevin Trenberth in his new book [1] (Chapter 3, Sidebar 3.2). The answer is two plates in space, with sunlight shining on the first at a rate of 480 Wm^{-2} (page 30, Fig. 3.3, panel 5); and four equations are presented to describe the resulting energy flow system (480, 320, and 160 Wm^{-2}), see our Fig. 1.

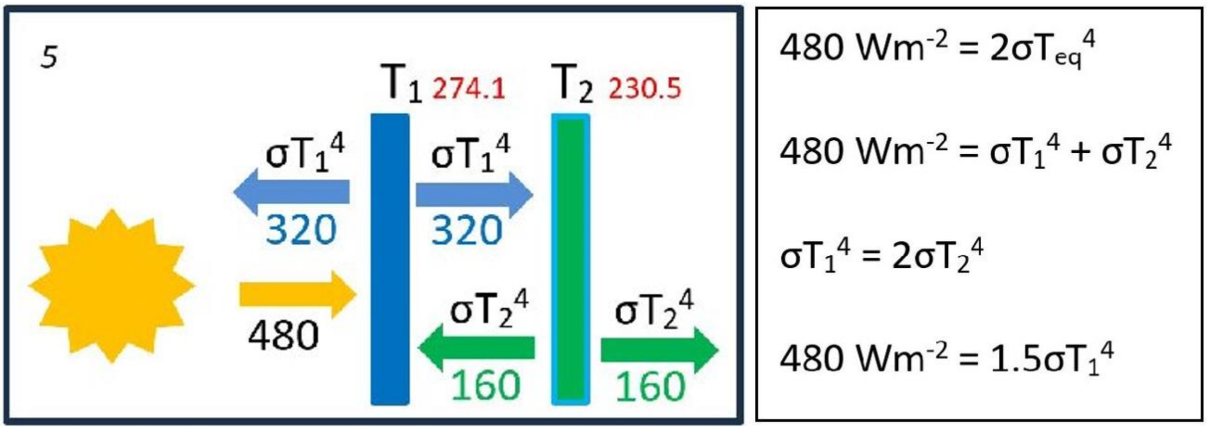


Figure 1 Trenberth's greenhouse geometry, consisting of two plates in space, the first is illuminated by the Sun. The final state is described by four equations. The second, "green" plate (representing an atmosphere with GHGs) elevates the equilibrium temperature belonging to 240 Wm^{-2} to a temperature defined by 320 Wm^{-2}.

Since this structure is open at both sides, to apply it for Earth-like conditions a planetary surface should be introduced, and the equations have to be slightly modified to describe the surface-atmosphere geometry. After doing so, we have an energy flow system with incoming solar radiation = 480 Wm^{-2}, outgoing longwave radiation OLR = 480 Wm^{-2}, and surface upward LW radiation ULW = 720 Wm^{-2} = 1.5OLR. The greenhouse effect is G = ULW–OLR = 240 Wm^{-2} = OLR/2, and the geometric greenhouse factor is g = G/ULW = 1/3. Here we show that these relationships are accurately satisfied by the Earth's clear-sky energy flow system. With the most recent CERES EBAF Edition 4.2 Version 2 data (global means, October 2000 to September 2023): OLR = 265.95 Wm^{-2}, hence 1.5OLR = 398.92 Wm^{-2}, while ULW = 398.75 Wm^{-2} (0.17 Wm^{-2} difference); the greenhouse effect is G = 398.75 – 265.95 = 132.80 Wm^{-2}, while OLR/2 = 132.97 Wm^{-2} (0.17 Wm^{-2} difference). The normalized greenhouse factor is g = 132.80/398.75 = 0.333. This parameter is one of the most stable from all climate data: its value was estimated as 0.33 in 1989 and determined as 1/3 in 2008 (Ramanathan); another decade later CERES EBAF Edition 2.8 (2017) found g = (398.40 – 265.59)/398.40 = 0.33336.

CERES EBAF data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.

Reference:

Trenberth, K. E. (2022), The Changing Flow of Energy Through the Climate System. Cambridge University Press

8. Earth's Annual Global Mean Energy Budget

The first reliable estimate of the Earth annual global mean energy flow system, presented in the landmark study of Kiehl and Trenberth (1997), was based primarily on the ERBE data. In the next year, Wild et al. (1998) showed a disposition of radiative energy in the global climate system from general circulation models and direct surface observations, exhibiting remarkable differences; the largest is in all-sky downward longwave radiation (DLR), 344 Wm^{-2}, compared to 324 Wm^{-2} of Kiehl and Trenberth (1997). This 20 Wm^{-2} discrepancy remained unresolved for more than a decade, when Wild (2012) offered a facelift for the picture of the global energy balance, reinforcing to increase DLR by 20 Wm^{-2} and suggesting a +10 Wm^{-2} change in non-radiative fluxes (up to a value of 105 Wm^{-2}) and a 10 Wm^{-2} decrease in solar radiation absorbed by the surface (down to 158 Wm^{-2}), together yielding a 7 Wm^{-2} increase in surface upward longwave (ULW) radiation (397 Wm^{-2}). With these changes, the mean values in the global energy flow system have occupied their position within typically ±3 Wm^{-2} as to we know them today. Figure 1 shows Earth's global mean energy budget derived primarily from CERES EBAF Edition 4.2 Version 2 data (10/2000 – 09/2023), projected on the integer ratio system. The integer structure provides us with a stationary global mean energy flow system against which temporal variations, permanent (systematic) deviations and anthropogenic perturbations might be considered.

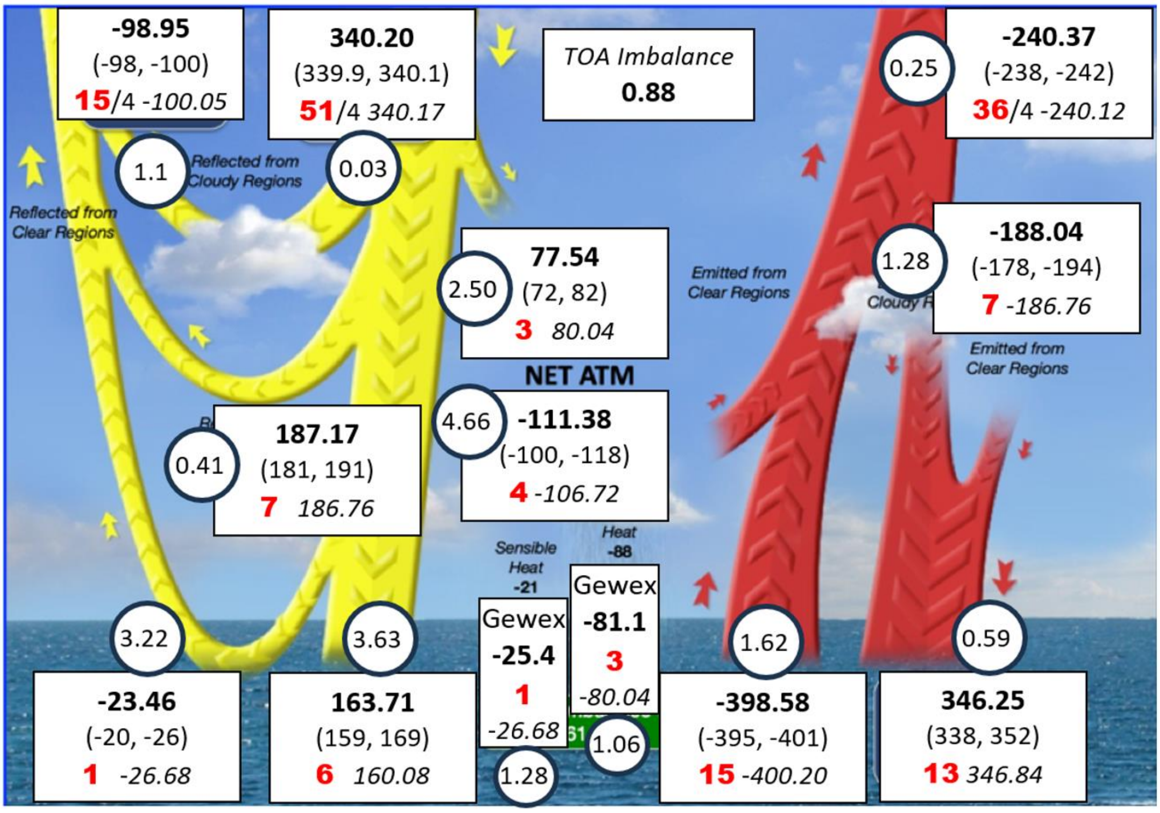


Figure 1 NASA CERES global mean energy flow system as determined by the CERES team. Black bold typeface (upper line in the textboxes): EBAF Ed4.2 V2 data, 23-yr mean, middle line: uncertainty range, bottom line: integer position in red bold typeface and its value in Wm^{-2} with the unit flux of 26.68 Wm^{-2}. Non-radiative flux components from the most recent Gewex dataset (Stephens et al. 2023). Differences in circles (Wm^{-2}).

CERES EBAF data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.

9. The Global Character of TOA Net Cloud Radiative Effect

IPCC First Assessment Report (1990) says: „The presence of clouds heats the climate system by 31 Wm^{-2} through reducing the TOA infrared emission. They also produce a cooling through the reflection of solar radiation. As demonstrated in Table 3.1 [showing Solar CRF = – 44 Wm^{-2}], the latter process dominates over the former, so that the net effect of clouds on the annual global climate system is a 13 Wm^{-2} radiative cooling. *Cloud-radiative forcing is an integrated effect governed by cloud amount, cloud vertical distribution, cloud optical depth and possibly the cloud droplet distribution*."

Wild et al. (2018) follow a similar logic. „The TOA shortwave absorption under all-sky and clear-sky conditions (…) differs by 47 Wm^{-2}. This suggests that the overall effect of clouds is to reduce the absorption of shortwave radiation in the climate system by –47 Wm^{-2} (TOA shortwave cloud radiative effect). (…) Accordingly, the longwave cloud radiative effect at the TOA, as the difference between the outgoing longwave radiation under all-sky and clear-sky conditions becomes positive at 28 Wm^{-2} (…) The net (shortwave and longwave combined) cloud radiative effect at the TOA then results in an overall energy loss of –19 Wm^{-2}."

Here we show that to determine the net cloud radiative effect (CRE) at TOA no need for all-sky fluxes. According to the definition of TOA net CRE, it depends solely on clear-sky fluxes: reflected solar radiation, RSR (clear-sky) and outgoing longwave radiation, OLR (clear-sky). Let us start with the traditional definition, as the sum of shortwave and longwave cloud radiative effects:

TOA net CRE = Shortwave CRE + Longwave CRE. Substitute the definitions:

Shortwave CRE = RSR (clear-sky) – RSR (all-sky),
Longwave CRE = OLR (clear-sky) – OLR (all-sly).

Then:

TOA net CRE = RSR (clear) – RSR (all) + OLR (clear) – OLR (all).

Again, the definition of reflection is incoming minus absorbed solar radiation (RSR = ISR – ASR),

TOA net CRE = [ISR – ASR (clear)] – [ISR – ASR (all)] + OLR (clear) – OLR (all).

ISR cancels out, and what remains is:

TOA net CRE = ASR (all) – ASR (clear) + OLR (clear) – OLR (all).

On a planet in equilibrium, ASR (all-sky) – OLR (all-sky) = 0. Therefore,

TOA net CRE = OLR (clear-sky) – ASR (clear-sky) = –TOA Net Imbalance (clear-sky).

On Earth, if an energy imbalance exists, ASR (all-sky) – OLR (all-sky) = EEI, thus

TOA net CRE = EEI – TOA Net IMB (clear-sky).

The governing principles of the phenomenon of global mean TOA net Cloud Radiative Effect may be understood and its magnitude may be determined solely by knowing clear-sky fluxes: absorbed solar radiation in clear-sky and outgoing longwave radiation in clear-sky, without reference to any cloud property. With CERES EBAF Ed4.2 data: TOA Net CRE = –(ASR–OLR) (clear) = – (286.42 – 265.95) = – 20.47 Wm^{-2}. If an imbalance is estimated (from an increase of ocean heat content) of, say, 1 Wm^{-2}, then TOA Net CRE = – 19.47 Wm^{-2}.

10. In Memoriam Sir John Houghton (1931 – 2020)

The Sixth Assessment Report of the IPCC Working Group I (2021) was dedicated to the memory of Sir John Houghton, who served as their Chair and Co-Chair from 1988 to 2002. Here we assess two equations from his book The Physics of Atmospheres (Cambridge University Press 1977, 1986, 2002), Chapter 2: A radiative equilibrium model. The equation for radiation transfer through an absorbing and emitting slab atmosphere is given in Schwarzschild's (1906, Eq. 11), consisting of three terms: the black-body emission of a layer, the upward beam, and the downward beam at the given layer, as a function of the emerging flux at top-of-atmosphere and the optical depth. "It is easy to show that there must be a temperature discontinuity at the lower boundary", $B_g - B_0 = \Phi/2\pi$ (Eq. 2.13), B_g being the black-body function at the temperature of the ground and B_0 the black-body function for the air close to the ground, and Φ is the incoming and outgoing radiation; but this discontinuity is "destroyed by the process of *convection*". We chose Eq. (2.13) the first equation to be controlled. — The second equation is the greenhouse equation, $B_g = \Phi(\chi_o^* + 2)/2\pi$ where χ_o^* is the optical depth at the bottom of the atmosphere (Eq. 2.15). $\chi^* = 0$ defines TOA; $\chi^* = 1$ is where OLR is generated; we try the equation for the surface at $\chi_o^* = 2$. These two equations will be regarded for clear-sky; we create their all-sky versions by separating atmospheric radiation transfer from the longwave effect of clouds (LWCRE, simply denoted here by L).

Then the four equations to be verified on CERES EBAF data:

$B_g - B_0 = \Phi/2\pi$	(I)	[surface net, clear-sky]	(Houghton 1977, Eq. 2.13)
$B_g = 2\Phi/\pi$	(II)	[surface tot, clear-sky]	(Houghton 1977, Eq. 2.15 with $\chi_0^* = 2$)
$B_g - B_0 = (\Phi - L)/2\pi$	(III)	[surface net, all-sky]	(Houghton 1977, Eq. 2.13 including L)
$B_g = (2\Phi + L)/\pi$	(IV)	[surface tot, all-sky	(Houghton 1977, Eq. 2.15 w $\chi_0^* = 2$ incl L)

Writing the terms into CERES notation, and substituting data from EBAF Edition 4.1 and Edition 4.2 (April 2000 – March 2022):

Eq. (1)	SFC SW down – SW up + LW down – LW up	(clear)	= TOA LW (clear)/2		Diff
Ed4.1	240.8680 – 29.0724 + 317.4049 – 398.5211		= 266.0122 /2		–2.3267
Ed4.2	241.1519 – 29.7397 + 317.8570 – 398.6099		= 266.1348 /2		–2.4081
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		–2.8238
Ed4.2	241.1519 – 29.7397 + 317.8570		= 2 × 266.1348		–3.0005
Eq. (3)	SFC SW down – SW up + LW down – LW up	(all)	= [TOA LW (all) – LWCRE]/2		
Ed4.1	186.8544 – 23.1629 + 345.0108 – 398.7454		= (240.2450	– 25.7672)/2	+2.7083
Ed4.2	187.0918 – 23.4436 + 346.1147 – 398.4220		= (240.3317	– 25.8032)/2	+4.0766
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
Ed4.2	187.0918 – 23.4436 + 346.1147		= 2 × 240.3317	+ 25.8032	+3.2963
Ed4.1				Mean	+0.0007
Ed4.2				Mean	+0.4911

The clear-sky pair of equations is justified within -3 Wm^{-2}, the all-sky pair within +4.1 Wm^{-2}, with a mean difference of 0.0007 Wm^{-2} for Ed4.1 and +0.49 Wm^{-2} for Ed4.2; supporting the choice of $\chi_o^* = 2$.

11. The Integer System as Solution of the Four Houghton-Equations

Four equations were proposed to describe Earth's global mean energy flow system. The first is Houghton's (1977) Eq. 2.13; the second is Eq. 2.15 at an optical depth of 2; these for the clear-sky. The third and fourth are their all-sky pair, including L for LWCRE, using πB_g for the total SW+LW absorbed energy at the surface, πB_0 for surface upward LW and Φ for outgoing LW at TOA:

$B_g - B_0 = \Phi/2\pi$ (I) [surface net, clear-sky] (Houghton 1977, Eq. 2.13)
$B_g = 2\Phi/\pi$ (II) [surface tot, clear-sky] (Houghton 1977, Eq. 2.15 w $\chi_0^* = 2$)
$B_g - B_0 = (\Phi - L)/2\pi$ (III) [surface net, all-sky] (Houghton 1977, Eq. 2.13 incl L)
$B_g = (2\Phi + L)/\pi$ (IV) [surface tot, all-sky (Houghton 1977, Eq. 2.15 w $\chi_0^* = 2$ incl L)

The clear-sky pair was verified within -3 Wm^{-2}, and the all-sky pair within +4.1 Wm^{-2}; the four equations have a mean difference of 0.0007 Wm^{-2} on the CERES EBAF Ed4.1 dataset and 0.5 Wm^{-2} on the Ed4.2 dataset (22 years). Since the equations are accurate, it is expected that their solution will also be accurate. The flux ratios are shown in Figure 1, the corresponding values in Table 1 for clear-sky and all-sky.

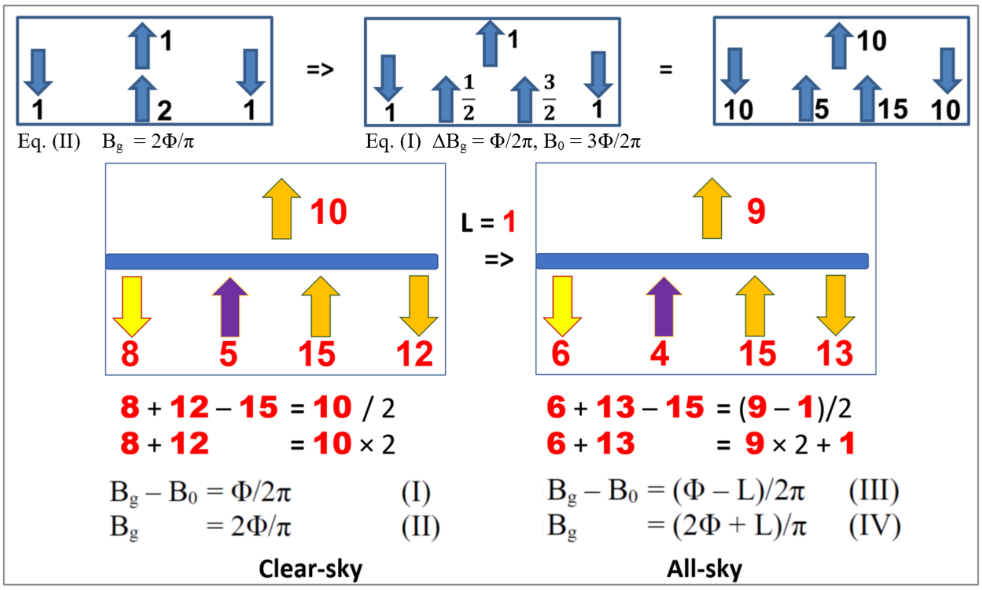


Figure 1. Graphical representation of the four equations with integer solution, the unit flux is one LWCRE.

1 = 26.68	Clear	N	N×unit	EBAF	Diff	All	N	N×unit	EBAF	Diff
TOA	SW in	51/4	340.17	340.20	0.03	SW in	51/4	340.17	340.20	0.03
	LW up	40/4	266.80	265.95	-0.85	LW up	36/4	240.12	240.37	-0.25
	SW up	8/4	53.36	53.78	0.42	SW up	15/4	100.05	98.95	-1.10
	Net	3/4	20.01	20.47	0.46	Net	0	0	0.88	0.88
Surface	LW dn	12	320.16	318.06	-2.10	LW dn	13	346.84	346.25	-0.59
	LW up	15	400.20	398.75	-1.45	LW up	15	400.20	398.58	-1.62
	LW net	-3	-80.04	-80.69	-0.65	LW net	-2	-53.36	-52.33	-1.03
	SW net	8	213.44	211.33	-2.11	SW net	6	160.08	163.71	3.63
	Tot net	5	133.40	130.64	-2.76	Tot net	4	106.72	111.38	4.66

Table 1 Integer values calculated with unit flux of 26.68 Wm^{-2}. Data: EBAF Ed4.2, 23 running years

12. Earth's Radiation Budget and its Relation to Atmospheric Hydrology

Quantifying the various ways energy flows through the Earth system has been a foundational activity of GEWEX from the outset and the latest version of the annual global mean depiction is presented in Figure SB3 of Stephens et al. (2023) based on the most up-to-date GEWEX data records. Here we show the importance of this energy flow depiction by emphasizing the high degree of accuracy in quantifying the constraints on some global energy and water cycle components, namely, on the net radiation at the surface, being equal to the sum of the corresponding non-radiative fluxes: latent heat plus sensible heat.

Stephens and coauthors provided a theoretical basis for this activity at the very beginning of GEWEX in a series of papers on the Earth's radiation budget and its relation to atmospheric hydrology (Stephens et al. 1991a, 1991b, 1993, 1994). The last paper contained the equations of fundamental importance. Their Eq. (1a) and (1b) describe simple transfer equations in radiative equilibrium (the model being equivalent to the two-stream approximation of Schwarzschild 1906, Eq. 11), with a solution given in their Eq. (5a) and (5b) for the upward and downward hemispheric fluxes,

$$F\uparrow(\tau_S) = \sigma T_S^4 = F_\infty (2 + \tau_S)/2 \qquad \text{(Stephens et. al 1994, 5a)}$$
$$F\downarrow(\tau_S) = F_g \quad = F_\infty \tau_S/2 \qquad \text{(Stephens et. al 1994, 5b)}$$

These relationships, with $F_0(\tau_S) = \sigma T_0^4 = F_\infty(1 + \tau_S)/2$ are equivalent to the three terms in Schwarzschild's (1906, Eq. 11); hence the net radiation at the surface, $\Delta\sigma T_S^4 = \sigma T_S^4 - \sigma T_0^4 = F_\infty/2$, where F_∞ = OLR. Atmospheric radiation textbooks like Houghton (1977, Eq. 2.13) or Goody and Yung (1989, Eq. 2.146) have already derived this constraint from the same radiative transfer principles, proving the direct connection between the net radiation at the surface and half of the outgoing longwave radiation.

In radiative-convective equilibrium, the net radiation at the surface is equal to the sum of the non-radiative flux components: latent heat plus sensible heat. Using the terminology of Figure 2 of Stephens et al. (2023), the relationship on the net radiation (Rn) at the surface for clear sky fluxes therefore looks like this: Rn = LE + H = OLR/2, where LE is the latent heat flux and H is the sensible heat flux.

As a first check for the validity of the Rn = OLR/2 equality under pure radiative equilibrium conditions in clear-sky, Hartmann (1994) has a two-layer radiative scheme (pp. 61-63, Figs. 3.10-3.11), where the equality is precisely satisfied. With its data, the effective emission Fe (at the temperature at TOA of Te = 255 K), the surface emission Fs (at a temperature Ts = 335 K), and the atmospheric upward emission Fsa (at a temperature of the air adjacent to the surface Tsa = 320 K) results in Fs – Fsa = Fe/2, with a difference of –0.31 Wm^{-2}, coming simply from the rounding of temperature values.

To check this constraint on published global energy budgets, its all-sky equivalent should be constructed. This creation is easy by separating atmospheric radiation transfer from the longwave cloud radiative effect (LWCRE). The resulting equation, with all-sky flux values on both sides, is this:

$$Rn = LE + H = (OLR - LWCRE)/2$$

With the GEWEX data provided by Figure SB3 of Stephens et al. (2023), LE = 81.1 Wm^{-2}, H = 25.4 Wm^{-2}, OLR = 239.5 Wm^{-2} and using LWCRE from a previous study by the same authors (Stephens et al. 2012) as 26.7 Wm^{-2}, the equation looks like this:

$$81.1 + 25.4 = (239.5 - 26.7)/2 + 0.1.$$

The equation is satisfied by a difference of 0.1 Wm^{-2}. This extreme accuracy on the most up-to-date GEWEX dataset shows the power of utilizing radiative transfer theory in understanding Earth's global mean energy and water cycle system.

13. Surface – Top-Of-Atmosphere Direct Coupling Verified by GEWEX Data

Stephens at al. (1994) presented a simple radiative transfer model in radiative equilibrium (being equivalent to the two-stream approximation of Schwarzschild 1906, Eq. 11). Their Eq. (1a) and (1b) describe transfer equations, with a solution given in Eq. (5a) and (5b) for the upward and downward hemispheric fluxes,

$$F\uparrow(\tau_S) = \sigma T_S^4 = F_\infty (2 + \tau_S)/2 \qquad \text{(Stephens et. al 1994, 5a)}$$
$$F\downarrow(\tau_S) = F_g \quad = F_\infty \tau_S/2 \qquad \text{(Stephens et. al 1994, 5b)}$$

Atmospheric radiation textbooks like Houghton (1977, Eq. 2.15) or Goody and Yung (1989, Eq. 9.5) give the same relationships. Trying Eq. (5a) at the surface with an optical depth of 2, we have $\sigma T_S^4 = 2F_\infty$. The left-hand side is the total SW+LW energy absorption at the surface, the right-hand side is 2OLR. We tried this equation seven years ago on the then-available CERES EBAF Edition 2.8 (March 2000 – February 2016) global mean clear-sky dataset (Rose et al. 2017 CERES STM talk), and found:

Surface SW down – SW up + LW down = 2OLR
244.06 – 29.74 + 316.27 = 2 × 265.59 – 0.59 (Wm^{-2}),

that is, the equation is satisfied by a difference of 0.59 Wm^{-2}, in a time when Earth's energy imbalance was regarded 0.58 Wm^{-2}.

Recently, CERES EBAF Ed4.2 V2 dataset (Oct 2000 – Sept 2023) global mean clear-sky has

241.04 – 29.71 + 318.06 = 2 × 265.95 – 2.51 (Wm^{-2}),

still far within the stated ranges of uncertainty.

To check this constraint on published global energy budgets, its all-sky equivalent should be constructed. This creation is easy by separating atmospheric radiation transfer from the longwave cloud radiative effect (LWCRE). The resulting equation, with all-sky flux values on both sides, is this:

Surface SW down – SW up + LW down = 2OLR + LWCRE.

With the GEWEX data provided by Figure SB3 of Stephens et al. (2023): Surface SW = 184.0 ± 5.6, Surface Reflection = 23.3 ± 2.1, All-sky emission (from the atmosphere to the surface) = 345.1 ± 5.7, Outgoing LW (at TOA) = 239.5 ± 2.4 [each in Wm^{-2}], and using LWCRE from a previous study by the same authors (Stephens et al. 2012) as 26.7 Wm^{-2}, the equation looks like this:

184.0 – 23.3 + 345.1 = 2 × 239.5 + 26.7 + 0.1.

The equation is satisfied by a difference of 0.1 Wm^{-2}. This extreme accuracy on the most up-to-date GEWEX dataset reinforces the choice of $\tau_S = 2$; this is certainly one of the most remarkable results of the first 30 years of GEWEX.

Reference

Stephens, G. and coauthors, 1994: Observations of the Earth's Radiation Budget in relation to atmospheric hydrology, 4. Journal of Geophysical Research, 99, D9, 18585-18604.

14. Global Mean Shortwave, Longwave and Net CREs at TOA, within the Atmosphere and at the Surface

Wild et al. (2018) provide estimates of the global mean shortwave, longwave and net cloud radiative effects at the top-of-atmosphere, within the atmosphere and at the surface. Here we place the integer ratio system on these values, and project their positions on Fig. 15 of Wild et al. (2018).

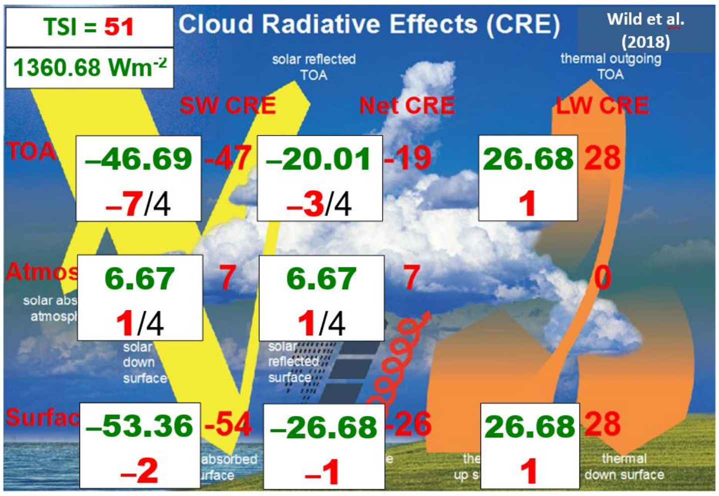


Fig. 1 Cloud Radiative Effects from the integer ratio system projected on Fig. 15 of Wild et al. (2018)

By definition, TOA SW CRE is the difference of clear-sky and all-sky SW reflection, 53 – 100 = –47 Wm^{-2} in the diagram (using data from Fig. 14 of Wild et al. (2018); **8**/4 units – **15**/4 units = – **7**/4 units in the integer system. TOA LW CRE is the difference of outgoing thermal emissions, 267 – 239 = 28 Wm^{-2} in the diagram; **10** units – **9** units = **1** unit in the integer system. At the surface, SW CRE is 160 – 214 = – 54 Wm^{-2} in the diagram; **6** units – **8** units = –**2** units in the integer system. LW CRE is 342 – 314 = 28 Wm^{-2} in the diagram; **13** units – **12** units = **1** unit in the integer system. Each value is integer on the cross-section disk to incoming solar radiation (before division by 4 for spherical weighting). Total solar irradiance is **51** units = 1360.68 Wm^{-2} (note, the most accurate value of Kopp and Lean, 2011, is TSI = 1360.8 ± 0.5 Wm^{-2}).

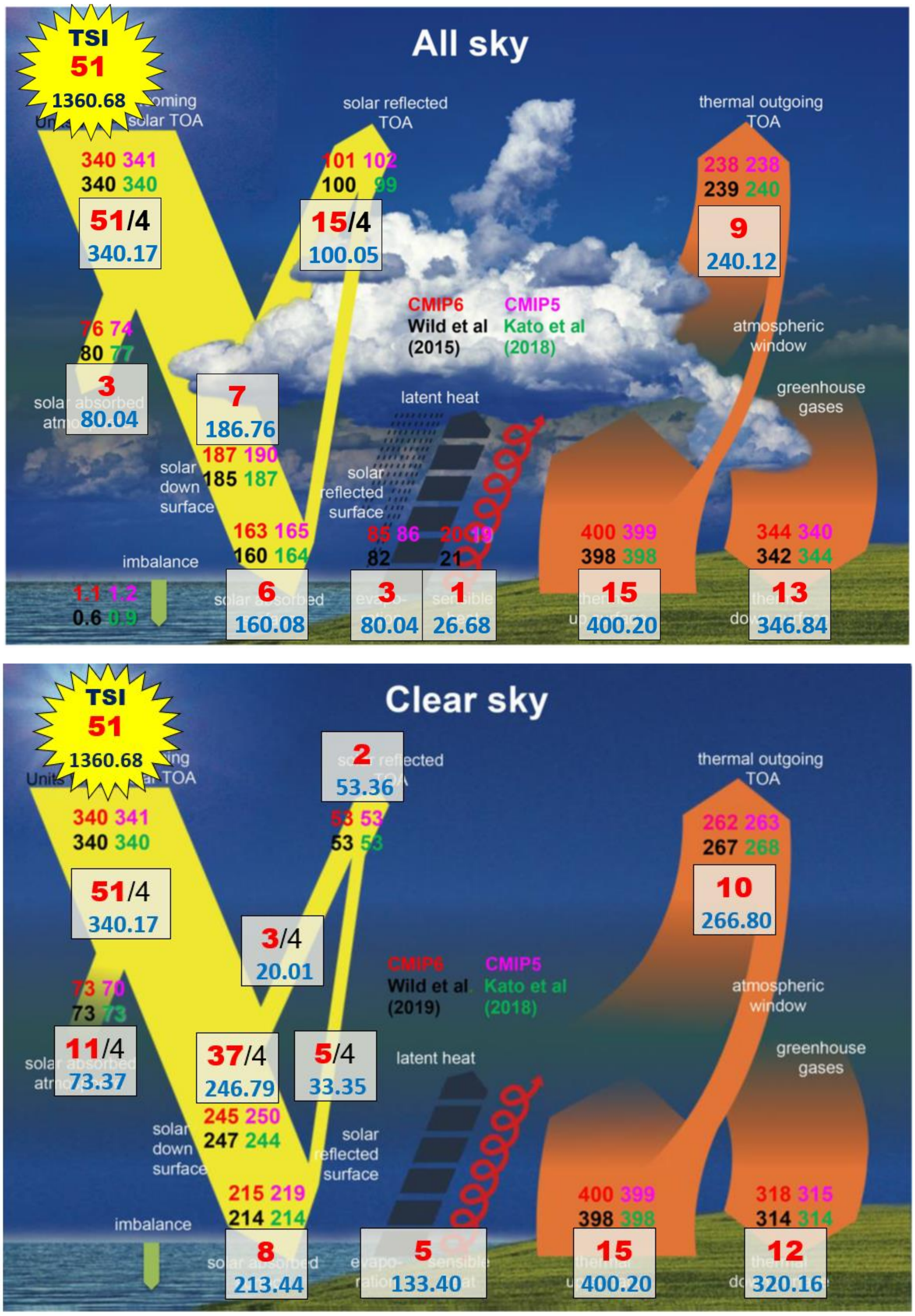
The difference in TOA SW CRE is 0.31 Wm^{-2}; in Net CRE 1.01 Wm^{-2}; in LW CRE is 1.32 Wm^{-2}. Within the atmosphere, both in SW CRE and Net CRE, the difference is 0.33 Wm^{-2}; in LW CRE the difference is zero. At the surface, the difference is 0.64 Wm^{-2} in SW CRE, 0.68 Wm^{-2} in Net CRE, and 1.32 Wm^{-2} is LW CRE. Each difference is far within the stated ranges of uncertainty of the flux components as shown in Fig. 14 of Wild et al. (2018).

The TOA Net CRE from the definition is Net CRE = SW CRE + LW CRE, being arithmetically equivalent to – [TOA Clear-sky Imbalance] + EEI. Using the values from Fig. 14 of Wild et al. (2018), TOA Net CRE = – 20 + 1 = – 19 (Wm^{-2}), and in the integer system, OLR (clear-sky) – ASR (clear-sky) = **40**/4 – **43**/4 = –**3**/4.

Reference

Wild., M et al. (2018), The cloud-free global energy balance and inferred cloud radiative effects: an assessment based on direct observations and climate models. Climate Dynamics https://doi.org/10.1007/s00382-018-4413-y.

15. Integer Structure in Wild (2020, Fig. 13)



Reference

Wild., M. (2020), The global energy balance as represented in CMIP6 climate models. Climate Dynamics (2020) 55:553–577. https://doi.org/10.1007/s00382-020-05282-7.

16. Integer Structure in CMIP6

Global annual mean estimates of energy balance components in Table 1 of Wild (2020).

TOA	Reference estimates	N	N × unit	CMIP6 mean
SW down TOA	340[a], 340[b], 340[c]	51/4	340.17	**340.2**
SW up all-sky TOA	– 99[a,] – 100[b], – 102[c]	-15/4	-100.05	**– 100.6**
SW absorbed all-sky TOA	241[a,] 240[b], 238[c]	36/4	240.12	239.5
SW up clear-sky TOA	– 53[a], – 53[b]	-8/4	-53.36	– 53.0
SW absorbed clear-sky TOA	287[a], 287[b]	43/4	286.81	**287.3**
SW CRE TOA	– 46[a], – 47[b]	-7/4	-46.69	– 47.8
LW up (OLR) all-sky TOA	– 240[a], – 239[b], – 238[c]	-9	-240.12	– 238.3
LW up (OLR) clear-sky TOA	– 268[a], – 267[b]	-10	-266.80	– 262.4
LW CRE TOA	28[a], 28[b]	1	26.68	24.1
Net CRE TOA	– 18[a], – 19[b]	-3/4	-20.01	– 23.6
Imbalance TOA	0.7[a]			1.1
Atmosphere				
SW absorbed all-sky atmos.	80[b]. 74[c], 77[d]	3	80.04	**76.0**
SW absorbed clear-sky atmos.	73[b], 73[d]	11/4	73.37	**72.8**
SW CRE atmos.	7[b], 4[d]	1/4	6.67	**3.2**
LW net all-sky atmos.	– 183[b], – 180[c], – 187[d]	-7	-186.76	**– 182.1**
LW net clear-sky atmos.	– 183[b,] – 184[d]	-7	-186.76	**– 180.9**
LW CRE atmos.	0[b], – 3[d]			– 1.3
Net CRE atmos.	7[b], 1[d]	1/4	6.67	**1.9**
Surface				
SW down all-sky surface	185 [b], 186 [c], 187[d]	7	186.76	**187.4**
SW up all-sky surface	– 25[b], – 22[c], – 23[d]	-1	-26.68	– 23.9
SW absorbed all-sky surface	160[b], 164[c], 164[d]	6	160.08	**163.4**
SW down clear-sky surface	247[b], 244[d]	37/4	246.79	**244.8**
SW up clear-sky surface	33[b], 30[d]	5/4	33.35	30.2
SW absorbed clear-sky surface	214[b], 214[d]	8	213.44	**214.6**
SW CRE surface	– 54[b], – 50[d]	-2	-53.36	**– 51.2**
LW down all-sky surface	342[b], 341[c], 344[d]	13	346.84	**343.8**
LW up all-/clear-sky surface	398[b], 399[c], 398[d]	15	400.20	– 399.9
LW net all-sky surface	– 56[b], – 58[c], – 54[d]	-2	-53.36	**– 56.2**
LW down clear-sky surface	314[b], 314[d]	12	320.16	**318.0**
LW net clear-sky surface	– 84[b], – 84[d]	-3	-80.04	**– 81.7**
LW CRE surface	28[b], 30[d]	1	26.68	25.5
Net CRE surface	– 26[b],– 20[d]	-1	-26.68	**– 25.4**
Net radiation surface	104[b], 106[c], 110[d]	14	106.72	107.2
Latent heat flux	– 82[b], – 81[c]	-3	-80.04	– 85.3
Sensible heat flux	– 21[b], – 25[c]	-1	-26.68	**– 20.1**
Surface Imbalance	0.6[b], 0.5[c]			1.5

Reference

Wild., M. (2020), The global energy balance as represented in CMIP6 climate models. Climate Dynamics (2020) 55:553–577. https://doi.org/10.1007/s00382-020-05282-7.

17. Atmospheric Window Radiation in the Clear-Sky Integer Ratio System

It was shown that integer ratios can be observed in the annual global mean energy flow system, both for clear-sky and all-sky. The clear-sky system with a unit flux of 26.68 Wm^{-2}, versus the CERES EBAF Edition 4.2 Version 2 (October 2000 – September 2023) dataset looks like this (Table 1):

Table 1. Integer positions versus clear-sky global mean data from CERES EBAF Ed4.2 V2. Unit = 26.68 Wm^{-2}

TSI = **51**	Clear-sky	N	N × Unit	EBAF Ed4.2	Difference
Clear-Sky TOA	SW insolation	**51**/4	340.17	340.20	0.03
	LW	**40**/4	266.80	265.95	-0.85
	SW	**8**/4	53.36	53.78	0.42
	Net	**3**/4	20.01	20.42	0.41
Clear-sky Surface	LW down	**12**	320.16	318.06	-2.10
	LW up	**15**	400.20	398.75	-1.45
	LW Net	-**3**	-80.04	-80.69	-0.65
	SW Net	**8**	213.44	211.33	-2.11
	SW + LW Net	**5**	133.40	130.64	-2.76

An interesting question is whether the atmospheric window radiation (surface transmitted irradiance, STI) fits into the system. Costa and Shine (2012) performed a detailed radiative transfer computation of this component, using a line-by-line radiation code and 3D climatologies of temperature, humidity, etc. No assumption was made as to the wavelengths at which radiation from the surface can reach the top of the atmosphere. The clear-sky STI was found 65 Wm^{-2}, with their model-OLR of 259 Wm^{-2}. Using EBAF clear-sky OLR = 265.95 Wm^{-2} and assuming proportionality, the corresponding STI would be 66.74 Wm^{-2}. Notice that 66.70 Wm^{-2} is an integer position: 10/4 units, that is, on the cross-section disk to incoming solar radiation (before division by 4) it is 10 units, out of 40 units of OLR (clear), indicating a 200.10 Wm^{-2} atmospheric upward emission (ATM) to space (30 units on the disk, 30/4 units after spherical weighting). Including these components, the TOA part of Table 1 will look like this:

TSI = **51**	Clear-sky	N	N × Unit	EBAF & CS12	Difference
Clear-Sky TOA	SW insolation	**51**/4	340.17	340.20	0.03
	LW	**40**/4	266.80	265.95	-0.85
	STI	**10**/4	66.70	66.74	0.04
	ATM	**30**/4	200.10	199.21	-0.89
	SW	**8**/4	53.36	53.78	0.42
	Net	**3**/4	20.01	20.42	0.41

Reference

Costa, S.M., K. Shine, (2012), Outgoing Longwave Radiation due to Directly Transmitted Surface Emission. Journ Atmos Sci. 69: 1865-1870.

18. Heuristic Approach to Determine Absorbed Solar Radiation in Clear-Sky

Absorbed solar radiation (ASR) in the clear-sky has a definite position in the integer system: regarding 51 units for TSI, incoming solar radiation (ISR) is 51/4 units, and, with reflected solar radiation (RSR) in the clear-sky 8/4 units, ASR (clear) = 43/4 units. With TSI = 1361.68 Wm^{-2}, RSR (clear) = 53.36 Wm^{-2}, thus ASR (clear) = 286.81 Wm^{-2}. Wild (2020) has 53 Wm^{-2} and 287 Wm^{-2}; CERES EBAF Ed4.2 V2 (23-yr global mean) has 53.78 Wm^{-2} and 286.42 Wm^{-2}.

Here we offer a heuristic approach to determine clear-sky absorbed solar radiation in the integer system without referring to reflected solar radiation.

Houghton (1977, Eq. 2.15), the greenhouse relationship, $B_g = \Phi(\chi_0^* + 2)/2\pi$, was controlled on observed data with a choice of $\chi_0^* = 2$, resulting in $\pi B_g = 2\Phi$. Here πB_g is the total SW+LW radiation absorbed at the surface, Φ is outgoing longwave radiation, both for clear-sky. When we first encountered this relationship seven years ago, CERES EBAF Edition 2.8 was available (16 running years). Substituting their data from Rose et al. (2017), Surface SW down = 244.06, Surface SW up = 29.74, Surface LW down = 316.27, TOA LW up = 265.59 (each Wm^{-2}), we have

$$244.06 - 29.74 + 316.27 = 2 \times 265.59 - 0.59 \ (Wm^{-2}),$$

at a time when Earth's energy imbalance was regarded 0.58 Wm^{-2}.

The most recent CERES EBAF Ed4.2 V2 (23-yr) dataset gives

$$241.04 - 29.71 + 318.06 = 2 \times 265.95 - 2.51 \ (Wm^{-2}).$$

CMIP6 models, according to Wild (2020), have $245 - 30 + 318 = 2 \times 267 - 1$ (W^{-2}).

In Houghton's (1977) model it is evident that Φ equals to both the incoming and outgoing radiation. But we know that at Earth this is true only in the all-sky. In the clear-sky, there a sizeable difference, ~20 Wm^{-2} exists between the incoming and outgoing radiation. The question arises: why do we use OLR on the right-hand side, instead of ASR?

The answer may lay in the fact that Earth's atmosphere is partially transparent in the longwave: there is an atmospheric window radiation (WIN) which is lost in space from a surface perspective, and only LWCRE is gained back in the all-sky. Hence, the total energy absorbed (and emitted) by the surface cannot be equal to 2ASR, only to 2ASR – WIN + LWCRE, and this could be equal to 2OLR. Thus

$$2ASR - WIN + LWCRE = 2OLR.$$

This may be the relationship we were looking for: ASR = (2OLR + WIN – LWCRE)/2.

Using the integer positions provided before to the fluxes on the right-hand side: OLR (clear) = 10 units, WIN(clear) = 10/4 units and LWCRE = 1 unit, it follows that ASR(clear) = (20 + 10/4 – 1)/2 = 43/4 units; Q.E.D. With 1 unit = 26.68 Wm^{-2}, we have ASR (clear-sky) = 286.81 Wm^{-2}.

It follows that TOA Clear-sky Imbalance = ASR(clear-sky) – OLR(clear-sky) = 3/4 unit = 20.01 Wm^{-2}, and, in equilibrium, TOA Net CRE = – TOA Clear-sky Imbalance = –3/4 unit = –20.01 Wm^{-2}.

Reference

Wild., M. (2020), The global energy balance as represented in CMIP6 climate models. Climate Dynamics (2020) 55:553–577. https://doi.org/10.1007/s00382-020-05282-7.

19. A Hypothesis on the All-sky Atmospheric Window

An equation was proposed to determine clear-sky absorbed solar radiation (ASR) without reference to reflected solar radiation (RSR) in [1]:

$$2\text{ASR (clear)} = 2\text{OLR (clear)} + \text{WIN (clear)} – \text{LWCRE}.$$

OLR(clear) is known from the integer system as 10 units = 266.80 Wm^{-2} (its most recent CERES EBAF Ed4.2 V2, 23-yr global mean value is 265.95 Wm^{-2}); WIN (clear) has an integer position in the system as 10/4 units = 66.70 Wm^{-2} (10 units on the cross-section disk where OLR(clear) = 40 before division by 4; its computed value by Costa and Shine, 2012, is 66 Wm^{-2}); and LWCRE = 1 unit = 26.68 Wm^{-2}, yielding ASR (clear) = 43/4 units = 286.81 Wm^{-2} (Wild, 2020, has 287 Wm^{-2}; EBAF Ed4.2 V2, 23-yr global mean has 286.42 Wm^{-2}).

Using the equation in the all-sky,

$$2\text{ASR (all)} = 2\text{OLR (all)} + \text{WIN (all)} – \text{LWCRE}.$$

In equilibrium, ASR (all)=OLR (all), therefore WIN (all) = LWCRE, suggesting WIN (all) = 26.68 Wm^{-2}. Costa and Shine have 20 ± 4 Wm^{-2}. With the assumption that clouds are infrared-opaque and a global mean cloud amount of 67%, WIN (clear) = 66 Wm^{-2} would lead to WIN (all) = (1 – 0.67) × 66 = 21.78 Wm^{-2}; with an assumed effective cloud area fraction of 60%, the resulted WIN (all) would be 26.4 Wm^{-2}, indicating that the opportunity of WIN (all) = 26.68 Wm^{-2} is at least not impossible.

Thus, developing further the hypothesis, the corresponding effective cloud area fraction β_{eff} = 0.6 would lead to a global mean cloudy OLR (with ‘cloudy’ referring to an effective IR-opaque geometric cloud are fraction of 60%), from OLR(all) = (1 – β_{eff}) × OLR (clear) + β_{eff} × OLR(cloudy) as OLR(cloudy) = (9 – 0.4×10)/0.6 = 8.33 units = 222.33 Wm^{-2}, defining a ‘total’ LW cloud radiative effect $LWCRE_{tot}$ = OLR (clear) – OLR (cloudy) = LWCRE/β_{eff} = 26.68/0.6 = 44.47 Wm^{-2}.

This hypothetical result is consistent with the cloudy form of the examined equation,

$$2\text{ASR (cloudy)} = 2\text{OLR (cloudy)} + \text{WIN (cloudy)} – \text{LWCRE},$$

where WIN (cloudy) = 0 by def., hence ASR (cloudy) = OLR(cloudy) – LWCRE/2. The difference, LWCRE/2 is being transported from the clear-sky part of the atmosphere as TOA Clear-sky Imbalance = 3/4 units = 20.01 Wm^{-2}, weighted by the clear/cloudy area fractions of 0.4/0.6 = 2/3 = 1/2 unit = LWCRE /2 = 13.34 Wm^{-2}.

To control the hypothesis on the CERES Flux-By-Cloud-Type product, it should be taken into account that solar absorption in the cloudy area is not proportional to the effective cloud area fraction β_{eff} = 0.6.

Note that effective cloudy DLR can be determined as DLR(clear-sky) + $LWCRE_{tot}$ = 320.16 + 44.47 = 364.63 Wm^{-2} (to be controlled again on CERES FluxByCldTyp).

Reference

[1] Zagoni, M. (2024), Heuristic Approach to Determine Absorbed Solar Radiation in Clear-Sky. Abstract submitted to International Radiation Symposium 2024, Hangzhou, China

20. Defining a Global Mean Cloudy Energy Flow System with β_{eff} = 0.6

Equation (5): 2ASR = 2OLR + WIN – LWCRE defines an effective cloud area fraction.

With WIN (cloudy) = 0 by def., it follows that ASR (cloudy) = OLR (cloudy) – LWCRE/2; that is, the TOA Cloudy Imbalance is –**1**/2 unit = –13.34 Wm^{-2}, with **1** unit = 26.68 Wm^{-2}. With known OLR (clear) = 266.80 Wm^{-2} = **10** units and the computed value of WIN (clear) = 66.70 Wm^{-2} = **10**/4 units we had ASR (clear) = [2 × 10 + 10/4 – 1]/2 = **43**/4 units = 286.81 Wm^{-2}, thus TOA Clear-sky Imbalance = 20.01 Wm^{-2} = **3**/4 units. Hence the clear/cloudy area ratio is (1/2) / (3/4) = 2/3, that is, the effective cloud area fraction is β_{eff} = 0.6.

Using the evident weighting equation: F(all) = (1 – β_{eff}) × F(clear) + β_{eff} × F(cloudy), the flux values weighted to an effective cloud area fraction of 60% can be determined, keeping in mind that SW fluxes should further be weighted by the effective/observed cloudy area fraction of about 0.6/0.67 (not performed).

Since LWCRE (clear-sky) is zero, $LWCRE_{tot}$ (cloudy) = OLR (clear) – OLR (cloudy) = LWCRE (all) / β_{eff} = 26.68/0.6 = 44.47 Wm^{-2}, hence OLR (cloudy) = OLR (clear) – $LWCRE_{tot}$ (cloudy) = 222.33 Wm^{-2}.

The cloudy forms of Eq. (3) and Eq. (4), with $LWCRE_{tot}$ = **1** (shown in brown typeface in the diagram) are

Eq. (3) (SW + LW) net (cloudy) = [OLR(cloudy) – $LWCRE_{tot}$]/2; **2** = (**5** – **1**)/2
Eq. (4) (SW + LW) net (cloudy) + SFC LW up = 2OLR(cloudy) + $LWCRE_{tot}$; **2** + **9** = 2 × (**5** + **1**).

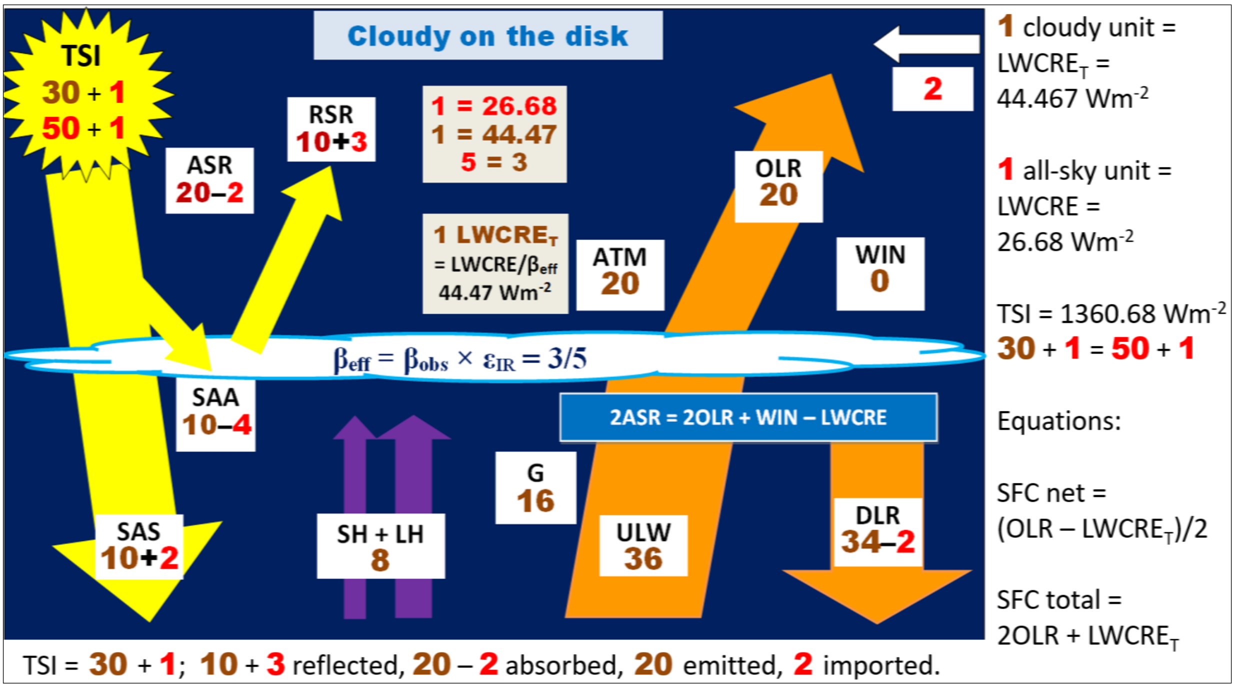


Figure 1 Global mean cloudy energy flow system on the disk, with Eq. (5) and β_{eff} = 0.6, in mixed units. ULW is regarded the same as in clear-sky and all-sky, after spherical weighting 9 cloudy = 15 all-sky units=400.20 Wm^{-2}.

21. The All-Sky Energy Flow System as the Weighted Sum of the Clear-Sky and Cloudy Structures

The cloudy energy flow system was derived from the known clear-sky and all-sky integer ratio solutions of the four Houghton-type equations and an effective cloud area fraction from Eq. (5) as $\beta_{eff} = 0.6$.

Eq. (1) $\Delta\pi B_g = \pi(B_g - B_0) = \Phi/2$ (Houghton 1977, Eq. 2.13, net, clear-sky)
Eq. (2) $\pi B_g = 2\Phi$ (Houghton 1977, Eq. 2.15, total, at $\chi_0^* = 2$, clear-sky)
Eq. (3) $\Delta\pi B_g = \pi(B_g - B_0) = (\Phi - L)/2$ (Houghton 1977, Eq. 2.13, net, including L, all-sky)
Eq. (4) $\pi B_g = 2\Phi + L$ (Houghton 1977, Eq. 2.15, total, at $\chi_0^* = 2$, incl. L, all-sky)
Eq. (5) 2ASR = 2OLR + WIN – LWCRE.

We reconstruct the three structures and their inter-relations by expressing the fundamental components (OLR, ATM, WIN, ULW, G and the convective fluxes) in their own units. The unit of the clear-sky integer system is WIN (clear) = 66.70 Wm^{-2} (shown in blue typeface); the unit of the cloudy system is the total $LWCRE_{Tot}$ = OLR (clear) – OLR (cloudy) = $LWCRE/\beta_{eff}$ = 44.4667 Wm^{-2} (brown); and the unit of the all-sky system is LWCRE = 26.68 Wm^{-2} (red). Cloudy SW fluxes should be weighted further by $\beta_{eff} / \beta_{obs}$.

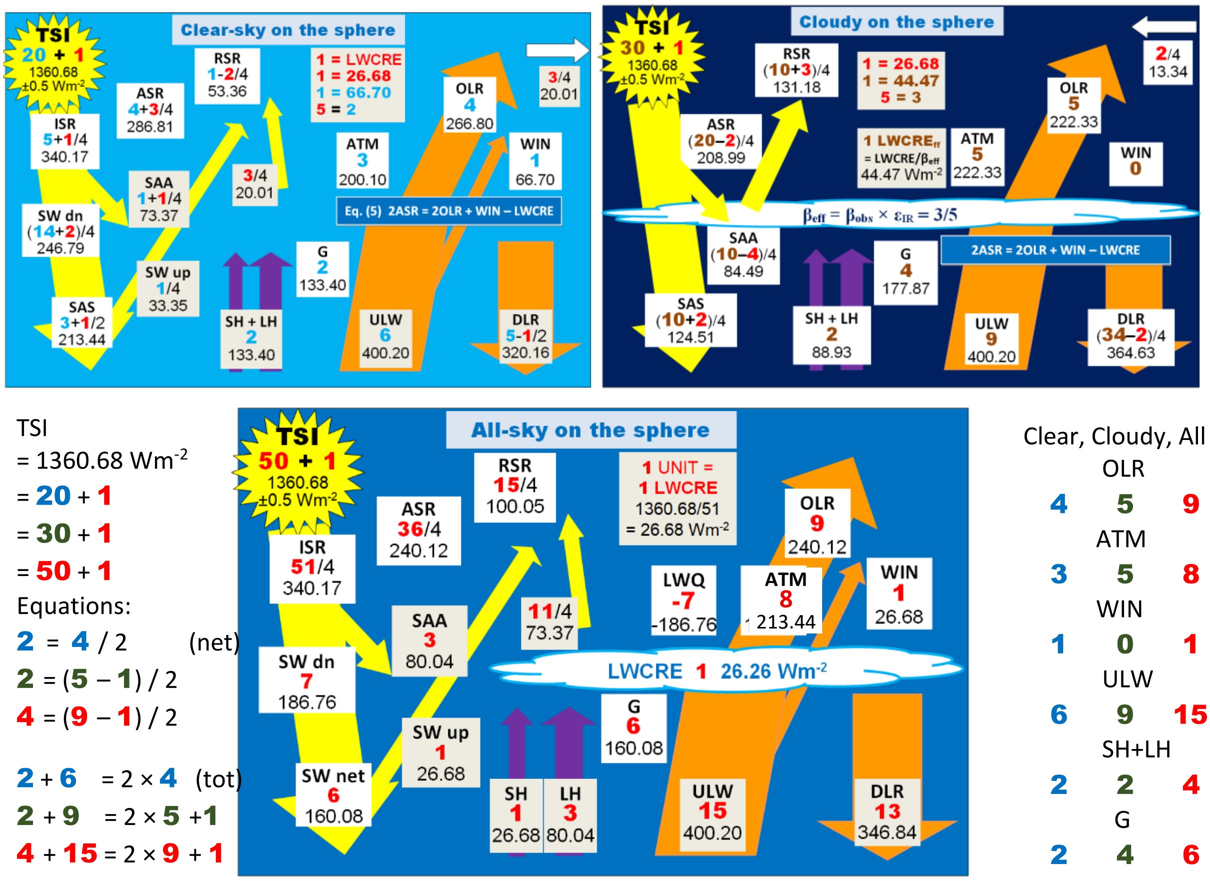


Figure 1 The clear-sky, the all-sky and the cloudy energy flow systems expressed in integer ratios.

22. Three Fundamental Parameters of the Earth's Climate

Bengtsson (2012) says: "The Earth's climate, as well as planetary climates in general, is broadly regulated by three fundamental parameters: the total solar irradiance, the planetary albedo and the planetary emissivity." The most accurate value for the total solar irradiance is 1360.8 ± 0.5 Wm^{-2} (Kopp and Lean 2011); the albedo is determined by the ratio of reflected solar radiation of 100 Wm^{-2} and incoming solar radiation of 340 Wm^{-2} as 100/340 (IPCC WGI AR6, 2021, Fig. 7.2); and the planetary emissivity (the ratio between the radiation to space and the radiation from the surface of the Earth) is given by TOA LW up = 239 Wm^{-2} and surface LW up = 398 Wm^{-2} as 239/398 (*ibid*.). It can be shown that these numbers fit into an integer ratio system; the unit flux is 26.68 ± 0.01 Wm^{-2}. The integer positions for the TOA fluxes are given on the intercepting cross-section disk, their value for the Earth can be given after spherical or geodetic weighting (division factor 4, or 4.0034). Incoming solar radiation is 51/4 units, reflected solar radiation = 15/4 units, TOA LW up = 36/4 units, and surface LW up = 15 units in the integer system. With these values, the arithmetic integer ratio positions for the three fundamental parameters are: TSI = 51 = 1360.68 Wm^{-2}; the albedo is 15/51, arithmetically identical to 100/340; and the planetary emissivity is 9/15 = 0.6 (compared to 239/398 = 0.6005). Here we show that these fundamental ratios follow from elementary geometric considerations, without any reference to the gaseous composition of the atmosphere.

The quote from Bengtsson (2012) continues: "these three quantities are generally very stable. The only exception is a minor decrease in the planetary emissivity." The case is even more interesting. There is a marked, if not unprecedented, decrease in the planetary emissivity during these two decades, but its mean value (0.603) approaches the theoretical requirement (3/5 = 0.6) by exactly this decrease; see Figure 1.

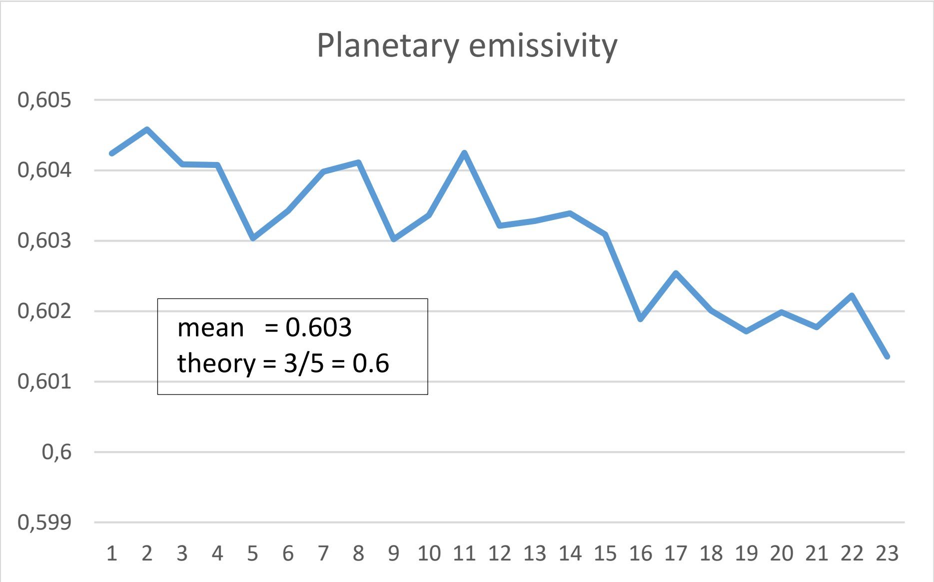


Figure 1 CERES EBAF Ed4.2 planetary emissivity decreases in the past 23 years, with a mean value of 0.603.

Reference

Bengtsson, L. (2012), Foreword: International Space Science Institute (ISSI) Workshop on Observing and Modeling Earth's Energy Flows. Surv Geophys (2012) 33:333–336, DOI 10.1007/s10712-012-9194-y

23. Three Regions Defining Earth's Global Mean Energy Flow System

The first equation we used to describe Earth's global mean energy flow system (Houghton 1977, Eq. 2.13) was independent of the optical depth. The second (Houghton 1977, Eq. 2.15) was taken at an optical depth of two, representative of a single-slab infrared-opaque atmosphere. Together with their all-sky versions, these four equations define an integer ratio system where outgoing LW at TOA (OLR) is 9 units; surface upward LW (ULW) is 15 units and the clear-sky OLR is 10 units. With 1 unit = LWCRE = 26.68 Wm^{-2}, their values are 240.12 Wm^{-2}, 400.20 Wm^{-2} and 266.80 Wm^{-2}, respectively. The clear-sky greenhouse effect is then G(clear) = 15 – 10 = 5 units = 133.40 Wm^{-2}, same as the net radiation at the surface in the clear-sky. The net radiation at the surface in the all-sky is 4 units 106.72 Wm^{-2} = 3 + 1 units for latent heat and sensible heat. Applying a fifth equation, we succeeded to determine an effective (infrared-opaque) geometric cloud area fraction as β_{eff} = 0.6, being equivalent to the all-sky transfer function, defined as *f*(all) = TOA LW / surface upward LW = 9/15 = 0.6.

From this equivalence it follows that the surface upward LW radiation emitted by the cloud-covered are of the surface equals to the outgoing LW radiation at TOA, since β_{eff} × ULW = OLR (all); and the surface upward LW radiation emitted by the clear-sky regions equal to the greenhouse effect, since (1 – β_{eff}) × ULW = 0.4 × 15 = 6 units = G(all). — Equation (5) also implies that the clear-sky window radiation, WIN(clear) = 10/4 units = 66.70 Wm^{-2} serves as the own unit for the fundamental flux ratios in the clear-sky region (shown in blue bold typeface), while WIN(all) = LWCRE plays the regulatory role of the unit in the all-sky region (shown in red bold typeface). The own unit of the cloudy region is the 'total' longwave cloud radiative effect (show in brown bold typeface), defined as the difference of the clear-sky and cloudy outgoing LW radiation, $LWCRE_{tot}$ = OLR(clear) – OLR(cloudy) = LWCRE/β_{eff} .

Hence the fundamental regions defining Earth's global mean climate system might be arranged into three geometric areas: an IR-opaque area by clouds; an IR-opaque area by the greenhouse gases in the clear-sky; and a transparent region in the clear-sky. Their intricate intercommunication provides the overall energetic stability of the global mean radiation structure; see Figure 1.

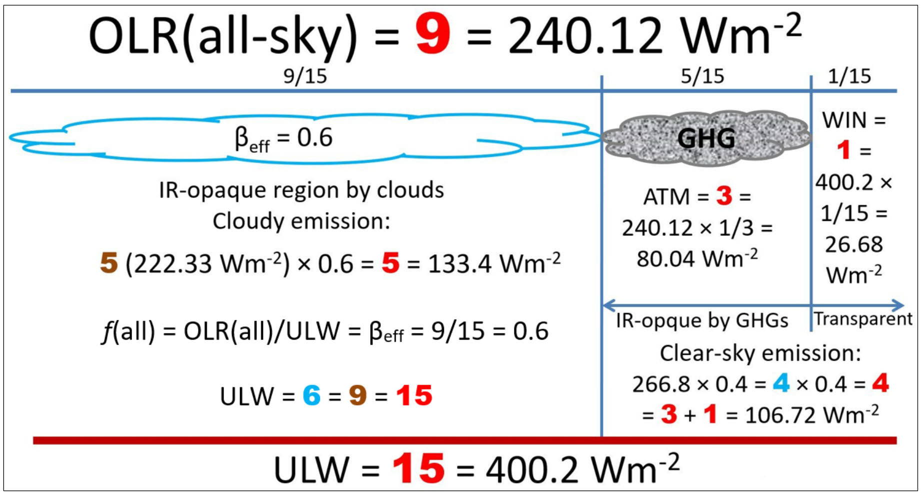


Figure 1 Three regions and their geometric arrangement define Earth's global mean energy flow system: an infrared-opaque by clouds, an infrared opaque by GHGs in the clear-sky, and a transparent in the clear-sky.

24. On the Longwave Cloud Radiative Effect (LWCRE) at the TOA and at the Surface

Longwave cloud radiative effect (LWCRE) serves as a unit flux in the all-sky and clear-sky integer systems, with the same value at the top-of-atmosphere (TOA) and at the surface, as a best fit on more than two decades of observations by both the GEWEX and the CERES missions as 26.68 ± 0.02 Wm^{-2}. In a single-layer geometric atmospheric model it is reasonable to have only one value. But what is the case in the real Earth's atmosphere?

In the global energy budget of Stephens et al. (2012), its value at TOA is 26.7±4 Wm^{-2}, at the surface 26.6 ±5 Wm^{-2}. The CERES EBAF Ed4.1, (12/2000 – 11/2019) dataset gave LWCRE at TOA = 25.79 Wm^{-2} and at the surface 27.67 Wm^{-2}, with a mean value of 26.73 Wm^{-2}. The most recent EBAF Ed4.2 V2 (23-yr mean) has a lower value at TOA, 25.58 Wm^{-2} and a higher, 28.36 Wm^{-2} at the surface, with a mean value of 26.97 Wm^{-2}. L'Ecuyer et al. (2019) have the opposite difference: 27.1 ± 3.7 Wm^{-2} at TOA, and 26.3 ± 3.8 Wm^{-2} at the surface (mean = 26.7 Wm^{-2}). Wild et al. (2018) have the same value, 28 Wm^{-2} for both.

"I see that these two quantities are almost equal. But I don't see any reason why they must be equal."

Here we show an argument pointing to their equality.

The longwave cooling of the atmosphere is defined as LWQ = ULW – DLR – OLR, that is, the difference of LW cooling at the surface (ULW – DLR), and the LW cooling at TOA (OLR).

Now by definition,

OLR (all-sky) = OLR (clear-sky) – LWCRE (TOA),
DLR (all-sky) = DLR (clear-sky) + LWCRE (surface).

Thermodynamics dictates the maximum possible cooling rate of the atmosphere. If the cooling rate were different between cloudy and clear skies, the region with the higher cooling rate would be favored over the other, destabilizing the radiative system. In EBAF Ed4.2, LWQ (clear) = –185.26, LWQ (all) = –188.04 Wm^{-2}, mean = –186.65 Wm^{-2}. In Wild et al. (2018), LWQ (clear) = LWQ (all) = –183 Wm^{-2}.

As surface upward LW (ULW) is regarded the same in all-sky and in the clear-sky, if LWCRE (TOA) = LWCRE (surface), then LWQ (all-sky) = LWQ (clear-sky).

Therefore, the equality should hold: LWQ (cloudy-sky) = LWQ (clear-sky) = LWQ (all-sky), hence

$$\text{OLR (clear)} - \text{OLR (cloudy)} = \text{DLR (cloudy)} - \text{DLR (clear)} = \text{LWCRE (total)} = \text{LWCRE}/\beta_{\text{eff}},$$

having one common value for both at the TOA and at the surface. With an assumed β_{eff} = 0.6, LWCRE (total) = 44.47 Wm^{-2}; OLR (clear) [266.80] – LWCRE (total) = OLR (cloudy) = 222.33 Wm^{-2}; DLR (cloudy) = DLR (clear) [320.16] + LWCRE (total) = 364.63 Wm^{-2}; and, with ULW = 400.20 Wm^{-2}, LWQ (clear) = LQW (cloudy) = –186.76 Wm^{-2}.

25. The Foundations of Quantum Climate Dynamics, Part 1. TSI and RSR Data

What happens to incoming solar radiation in the Earth's climate system? How much is reflected?

In the all-sky annual global mean, from 17 quanta of total solar irradiance 5 quanta bounce back, 12 quanta are absorbed in the disk (planetary albedo = 5/17, arithmetically equivalent to 100/340 of the IPCC AR6 Fig. 7.2). After they spread across the globe as a surface-atmosphere radiation system, the 3 absorbed quanta produce 2 quanta of greenhouse effect, hence 5 quanta of surface upward emission; finally, the incoming 3 quanta leave the system as outgoing 3. With 1 quantum = 80.04 Wm^{-2}, absorbed SW = outgoing LW = 3 quanta = 240.12 Wm^{-2}, surface upward emission is 5 quanta = 400.20 Wm^{-2} and the greenhouse effect is G(all) = 2 quanta = 160.08 Wm^{-2}. Total solar irradiance (TSI) = 17 quanta = 1360.68 Wm^{-2}. In more detail:

The incoming beam encounters a clear-sky area on the disk of 40% and a cloud-covered area of 60% (if IR-opacity is assumed). In the clear-sky, from the incoming beam of 17 quanta, 2 quanta decays into 6 quarks. Now 2 quanta + 2 quarks bounce back to space, 3 quarks are transported to the cloudy area, the remaining 13 quanta + 1 quark melt together into forming 16 balls to spread across the clear-sky part of the spherical surface of the globe. The 4 balls generate 2 balls of greenhouse effect, therefore 6 balls upward emission at the surface. 1 ball = 66.70 Wm^{-2}; the clear-sky greenhouse effect G (clear) = 2 balls = 133.40 Wm^{-2}. Surface LW emission of 6 balls = 400.20 Wm^{-2}; the absorbed 4 balls leave the system as OLR = 266.80 Wm^{-2}. Reflection was 2 quanta + 2 quarks on the disk = 160.08+53.36=213.44 Wm^{-2}, that is, 53.36 Wm^{-2} = 2 quarks on the sphere. TSI = 20 balls + 1 quark = 1334.0 + 26.68 Wm^{-2} = 1360.68 Wm^{-2}.

In the cloudy part (with 60% effective area fraction), the incoming beam is 17 quanta, + the 3 quarks sent from the clear-sky area of 40% arrive to the cloudy part as 2 quarks per unit area. Now 5 quanta melt together and form 9 bullets, 6 quanta and 1 bullet reflect back, the remaining 6 quanta, 8 bullets and 2 quarks are absorbed, melt together, and form 20 bullets. After spherical weighting, the 5 bullets create 4 bullets of greenhouse effect, thus 9 bullets of surface upward emission, then leave the cloudy system as 5 bullets in form of LW radiation. 1 bullet = 44.467 Wm^{-2}, OLR = 5 = 222.33 Wm^{-2}, G = 4 = 177.87 Wm^{-2} and surface upward LW = 9 bullets = 400.20 Wm^{-2}, same as in the cloudless part. SW fluxes are computed for β_{eff} and should be weighted to β_{obs}. TSI = 30 bullets + 1 quark = 1334.0 + 26.68 = 1360.68 Wm^{-2}.

The units: 1 quantum=80.04 Wm^{-2}; 1 ball=66.70 Wm^{-2}; 1 bullet = 44.47 Wm^{-2}; 1 quark = 26.68 Wm^{-2}.

The total reflected radiative energy is 2 quanta + 2 quarks = 160.08 + 53.36 = 213.44 Wm^{-2} in the clear-sky part, contributing to all-sky solar reflection by 0.4 × 213.44 = 85.37 Wm^{-2}; and from the cloudy part, the 6 quanta + 1 bullet = 480.24 + 44.47 = 524.71 Wm^{-2} give 0.6 × 524.71 = 314.83 Wm^{-2}; together 400.20 Wm^{-2} on the disk = 5 quanta = 6 balls = 9 bullets = 15 quarks, equal to 100.05 Wm^{-2} on the all-sky sphere.

The theory of the Earth's global mean electromagnetic radiation system will be based on these data.

Clear-sky (area fraction = 0.4)	Cloudy-sky (area fraction = 0.6)	All-sky
TSI = **17** = **20** + **1** = 1334.0 + 26.68	TSI = **17** = **30** + **1** = 1334.0 + 26.68	TSI = **17** = **50** + **1** = 1334.0 + 26.68
RSR = **2** + **2** = 160.08 + 53.36 = 213.44	RSR = **6** + **1** = 480.24+44.47 = 524.71	RSR = 85.37 + 314.83 = 400.20 Wm^{-2}
On the sphere = 53.36 Wm^{-2}	On the sphere = 131.18 Wm^{-2}	RSR = **5** = **6** = **9** = **15**
Contribution = 0.4 × 53.36 = 21.344	Contribution = 0.6 × 131.18 = 78.708	On the sphere = 100.05 Wm^{-2}

Fig. 1 Clear-sky and cloudy solar reflection on the disk and on the sphere and their contribution to the all-sky RSR. Cloudy RSR is calculated for β_{eff}. For comparison to observations, β_{obs} should be taken into account.

26. The Foundations of Quantum Climate Dynamics, Part 2. ASR from TSI

What happens to incoming solar radiation in the Earth's climate system, after reflection was performed?

In the all-sky annual global mean, from total solar irradiance TSI = 17 quanta, 5 quanta bounce back, 12 quanta are absorbed in the disk (planetary albedo = 5/17, arithmetically equivalent to 100/340 of the IPCC AR6 Fig. 7.2). All-sky global mean TOA reflection on the disk (before spherical weighting), expressed in different units is 5 quanta = 6 clear-sky units (balls) = 9 cloudy units (bullets) = 15 all-sky units (LWCRE). The remaining 12 quanta are absorbed in the annual global all-sky mean. Its distribution between the clear-sky and the cloudy part could be determined only by knowing the clear/cloudy area ratio and by knowing the energy transport between these regions. We succeeded to derive an equation which gives both an infrared-opaque cloud area fraction and an amount and direction of the energy transport.

One of the most intriguing recognitions was the validity of Houghton (1977, Eq. 2.15), the 'greenhouse equation' (same as the second term in Schwarzschild's 1906, Eq. 11) at an optical depth of 2, describing a single-slab SW-transparent, IR-opaque atmospheric layer without clouds:

$$\pi B_g = 2\Phi.$$

On the right-hand side of the equation, Φ equals both the absorbed solar and the emitted longwave radiation, which, on Earth, valid only in the all-sky. But we justified this relationship with clear-sky data. Why do we use OLR on the right-hand side, instead of ASR (absorbed solar radiation)?

The answer is because the Earth's atmosphere is not IR-opaque; there is a window, where energy escapes to space without taking part in the greenhouse-generating atmospheric absorption, and only LWCRE is gained back. Hence the total energy absorbed at the surface (the left-hand side) cannot be equal to 2ASR, since WIN is lost and LWCRE is gained back, and that should be equal to 2OLR:

$$2ASR – WIN + LWCRE = 2OLR \qquad \text{(Eq. 5)}$$

In the clear-sky, a line-by-line computation by Costa and Shine (2012) found WIN (clear) = 65 Wm^{-2}, for their OLR (clear) of 259 Wm^{-2}. Assuming proportionality, for CERES EBAF Ed4.2 of OLR (clear) = 265.95 Wm^{-2}, WIN (clear) would be 66.74 Wm^{-2}. Notice that 66.70 Wm^{-2} is an integer position on the sphere, 1 clear-sky unit = WIN(clear) = 1 ball = 10LWCRE/4. From here, TOA Clear-sky Imbalance is

$$ASR\ (clear) – OLR\ (clear) = [WIN\ (clear) – LWCRE] / 2 = 3\ LWCRE/2.$$

This energy is being transported to the cloudy part, where WIN (cloudy) = 0, by def., therefore

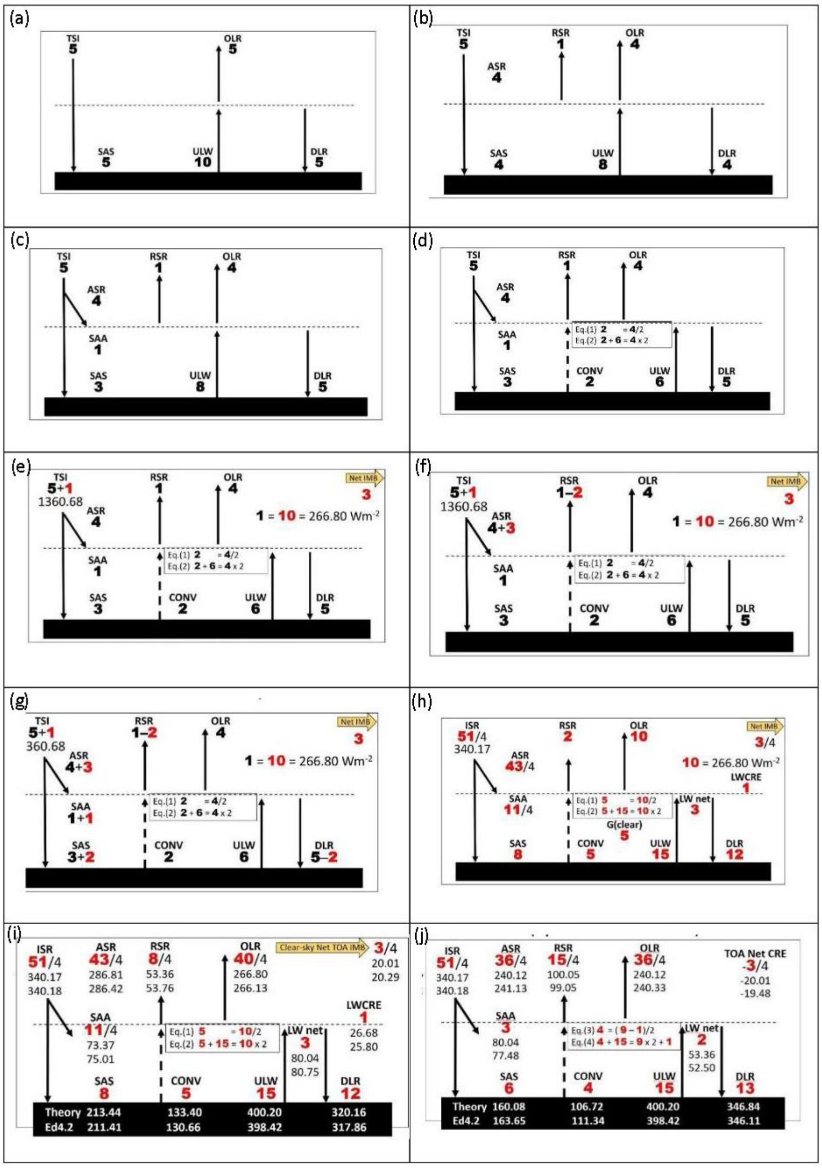
$$ASR\ (cloudy) – OLR\ (cloudy) = LWCRE/2,$$

defining an effective clear/cloudy area ratio as 2/3 = 0.4 /0.6, that is, $\beta_{eff} = 0.6$. Then ASR (cloudy) = 5 bullets – LWCRE/2, ASR (clear) = 4 balls + 3LWCRE/2, and ASR (all) = 3 quanta = 9 LWCRE. All-sky:

RSR = 5 quanta = 6 balls = 9 bullets = 15 LWCRE on the disk;
ASR = 3 quanta = 9 LWCRE on the sphere.
G = 2 quanta = 6 LWCRE, and, for each region:
ULW = 5 quanta = 6 balls = 9 bullets = 15 LWCRE on the sphere, with
TSI = 17 quanta = 20 balls + 1 LWCRE = 30 bullets + 1 LWCRE = 51 LWCRE = 1360.68± 1Wm^{-2}.

27. Geometric Deduction of the Clear-sky and All-sky Integer Flow Systems

Here we offer a geometric deduction of the integer ratios, starting from the simplest 1:2:1 geometry. First, multiply the unit by 5 (a panel); then allow 1 unit of solar reflection at TOA (b); allow 1 unit of solar absorption in the atmosphere (c); introduce convection by Eqs. (1) and (2) (d); calibrate to TSI by adding one red unit and apply a clear-sky imbalance at TOA of 3 red units (e); restore the balance at TOA by reflecting 2 red units less and absorbing 3 red units more (f); re-distribute the absorbed red three surplus as 1 in the atmosphere and 2 at the surface (g); transform the data into red units and divide by 4 for spherical geometry (h); substitute the numbers (theory above, CERES EBAF Ed4.2 below), clear-sky (i); change OLR (clear) from 10 units to 9 units of OLR(all) and perform the corresponding redistribution; all-sky (j).



28. IPCC WGI AR6 Chapter 8: Water Cycle Changes

"The assessment includes the physical basis for water cycle changes"
"Overview of the Global Water Cycle in the Climate System"
"Understanding the interactions between the water and energy cycles is one of the four core projects of the World Climate Research Programme (WCRP). Latent heat fluxes, released by condensation of atmospheric water vapour and absorbed by evaporative processes, are critical to driving the circulation of the atmosphere".
"Water vapour is the most important gaseous absorber in the Earth's atmosphere, playing a key role in the Earth's radiative budget"
"It is well understood that global precipitation and evaporation changes are determined by Earth's energy balance"

The assessment introduces precipitation (P) in the framework of atmospheric energy budget. It is true that atmospheric longwave radiative cooling is defined as S + H + E, that is, the sum of absorbed sunlight (S), sensible heat (H) and evaporation (E), being equal to the difference of surface LW cooling (Net LW) and TOA LW cooling, see Fig. 1.

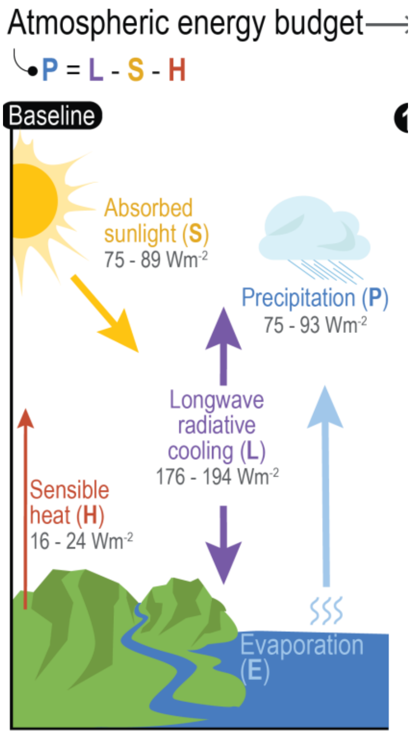


Figure 1 First panel of Figure 8.3 of IPCC WGI AR6 (2021) Chapter 8.

Another, equally important constraint (missing from the IPCC assessments) is that the convective fluxes (H + E) are generated by the energy content of net radiation at the surface, which is the sum of Net (LW + SW), which, further, equals to half of outgoing LW flux at TOA in clear-sky (Houghton's (1977, Eq. 2.13), and Surface Net (SW + LW) = S + E = (TOA LW out – LWCRE)/2 in all-sky, LWCRE being the longwave cloud radiative effect at TOA. This constraint is satisfied by the GEWEX global mean energy budget with 0.1 Wm^{-2} accuracy, where H = 25.4 Wm^{-2}, E = 81.1 Wm^{-2}; Outgoing LW at TOA = 239.5 Wm^{-2} and LWCRE from Stephens et al. (2012) is 26.7 Wm^{-2}.

$$\text{Sensible heat} + \text{Evaporation} = (\text{Outgoing LW} - \text{LWCRE}) / 2$$
$$25.4 + 81.1 = (239.5 - 26.7) / 2 + 0.1\ (Wm^{-2})$$

This equivalence should be taken into account in every reliable water cycle change assessment.

29. CERES EBAF Edition 2.8 (2017) Special Features

Rose et al. (2017):

Global Means(Mar2000-Feb2016)

All Sky	Ed4	Ed2.8	Ed4 –Ed2.8
TOA SW Insolation	340.04	339.87	0.17
TOA SW Up	*99.23*	*99.62*	*-0.39*
TOA LW Up	*240.14*	*239.60*	*0.54*
SFC SW Down	187.04	186.47	0.57
SFC SW Up	23.37	24.13	-0.76 (3.1%)
SFC LW Down	344.97	345.15	-0.18
SFC LW Up	398.34	398.27	0.07
Clear Sky	**Ed4**	**Ed2.8**	**Ed4 –Ed2.8**
TOA SW Insolation	340.04	339.87	0.17
TOA SW Up	*53.41*	*52.50*	*0.91 (1.73%)*
TOA LW Up	*268.13*	*265.59*	*2.54*
SFC SW Down	243.72	244.06	-0.33
SFC SW Up	29.81	29.74	0.07
SFC LW Down	314.07	316.27	-2.20
SFC LW Up	397.59	398.40	-0.81

Houghton (1977, Eq. 2.13; Eq. 2.15 at $\chi_0* = 2$)

(1) Surface (SW down – SW up + LW down – LW up) clear-sky = TOA LW up / 2
244.06 – 29.74 + 316.27 – 398.40 = 265.59/2 – 0.605

(2) Surface (SW down – SW up + LW down) clear-sky = 2 × TOA LW up
244.06 – 29.74 + 316.27 = 2 × 265.59 – 0.59

Loeb et al. (2012): Earth heat uptake for July2005–June 2010 is 0.58 ± 0.38 Wm^{-2}

G (clear) = SFC LW up – TOA LW up = 398.40 – 265.59 = 132.81 Wm^{-2};
g (clear) = G/SFC LW up = 132.81 / 398.40 = 0.333358
g (theory) = (**15** – **10**)/**15** = 1/3.

All-sky: Houghton (1977, Eq. 2.13 incl L; Eq. 2.15 at $\chi_0* = 2$ incl L); L for LWCRE

(3) Surface (SW down – SW up + LW down – LW up) all-sky = (TOA LW up – LWCRE) / 2
186.47 – 24.13 + 345.15 – 398.27 = (239.60 – 25.99) /2 + 2.415

(4) Surface (SW down – SW up + LW down) all-sky = 2 × TOA LW up + LWCRE
186.47 – 24.13 + 345.15 = 2 × 239.60 + 25.99 + 2.3

EBAF Ed4.0 was adjusted: ΔEq1 = -3.675; ΔEq2 = -8.28; ΔEq3 = 4.225; ΔEq4 = 0.37 (Wm^{-2})

EBAF Ed4.1: ΔEq1 = -2.3267; ΔEq2 = -2.8238; ΔEq3 = 2.7083; ΔEq4 = 2.4450, mean = 0.0007.

30. Radiative Forcing of Climate (Ramaswamy et al. 2019)

Ramaswamy et al. (2019) say: "Arrhenius (1896) made the quantitative connection to estimate the surface temperature increase due to increases in CO_2. (…) Arrhenius' systematic investigation and inferences have proven to be pivotal in shaping the modern-day thinking and computational modeling of the climate effects due to CO_2 radiative forcing."

As a contemporary global energy budget estimate, they refer to L'Ecuyer et al. (2015), without realizing that this distribution satisfies two all-sky radiative transfer equations connecting surface fluxes to top-of-atmosphere fluxes, casting strict constraints of climate sensitivity and the effects due to CO_2 forcing.

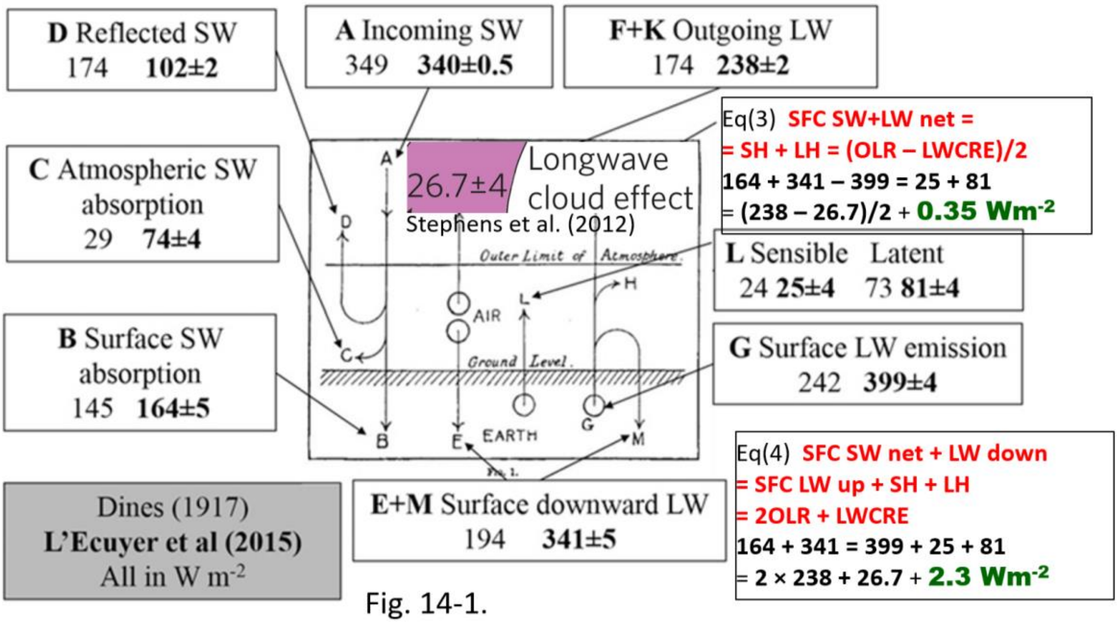


FIG. 14-1. Comparison of one early estimate of Earth's global-average energy budget (Dines 1917) with the contemporary estimates of L'Ecuyer et al. (2015) by annotating the original figure from Dines (1917). All values are given in Wm^{-2}, with Dines's values in plain font, and L'Ecuyer et al. in bold font. Our Eq. (3) [equivalent to Houghton 1977, Eq. 2.13, with all-sky data, including LWCRE], and Eq. (4) [equivalent to Houghton 1977, Eq. 2.15 at $\chi_0^* = 2$ with all-sky data, including LWCRE] are projected on the diagram. Eq. (3) is valid with a difference of 0.35 Wm^{-2}; Eq. (4) with a difference of 2.3 Wm^{-2}. LWCRE = 26.7 Wm^{-2} is taken from Stephens et al. (2012).

Reference

Ramaswamy, V. et al. (2015) Radiative Forcing of Climate: The Historical Evolution of the Radiative Forcing Concept. AMS Monographs Series, DOI: 10.1175/AMSMONOGRAPHS-D-19-0001.1