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Lessons from 24 Years of NASA CERES Satellite Observations

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Abstract Text:
The NASA CERES project provides satellite-based observations of the components of Earth's radiant energy flow system. We control four radiative transfer constraint equations on EBAF Ed4.1_V3 and Ed4.2_V4 data products. The first equation is a well-known constraint on the net radiation at the surface, coming directly from Schwarzschild's (1906, Equation 11), reproduced in standard university textbooks like Goody (1964, Eq. 2.115); Houghton (1977, 1986, 2002, Eq. 2.13); Chamberlain (1978, 1987, Eq. 1.2.29 and Fig. 1.4); Goody and Yung (1989, Eq. 2.146); Hartmann (1994, 2016, Eqs. 3.48-3.54); Salby (1996, 2012, Eq. 8.67); Pierrehumbert (2008, Eq. 4.45); Ambaum (2021, Eq. 10.56) and in university lecture notes (Stephens 2003), but notably missing from the climate literature. The equation states that the net radiation at the surface (R_N) — and the corresponding convection—is independent of the optical depth and equals half of the outgoing longwave radiation (OLR) in the clear-sky. The second equation is an application of Schwarzschild's (1906, Eq. 11). The third and fourth equations are simple all-sky versions of the first pair. See the four equations, the data, and the differences, in Fig.1a.

The first equation describes R_N (clear-sky) = SFC (SW net + LW net) (clear-sky) = (SW down – SW up) + (LW down – LW up) (clear-sky), being equal OLR(clear-sky)/2.

The second equation gives the total SW + LW absorbed radiation (R_T) at the surface (SW down – SW up + LW down), as R_T = 2OLR in the clear-sky.

The third and fourth equations are created from the first pair, by separating atmospheric radiation transfer from the longwave effect of clouds (LWCRE) and using all-sky data on both sides: Surface SW net + LW net (all-sky) = [OLR(all-sky) – LWCRE]/2; and Surface (SW + LW) absorbed (all-sky) = (SW down – SW up + LW down) (all-sky) = 2OLR(all-sky) + LWCRE.

The biases of the individual equations are within the range of ± 2.83 Wm^{-2}; the mean bias of the four equations is 0.0007 Wm^{-2} (this justifies the use of four decimal places in the netCDF file).

This unprecedented accuracy of the constraint equations raises a couple of questions. Do these four equations express an arithmetic identity? The answer is no; in the prevailing theory we are not aware of any relationship that would require these couplings between surface and TOA irradiances, without referring to any atmospheric gaseous composition or the optical depth. Further, there are notable differences between the annual values:

the mean bias of the four equations fluctuates between -0.8 and 1.4 [Wm^{-2}] during the years (Fig. 1b). Or, are these four equations built in the CERES data production protocol? No again: the mean bias in the first five years vary between -0.5 and -0.2 [Wm^{-2}] and it approaches zero after including 17 years into the averaging; then it occupies the value of zero and remains there after only two decades (Fig. 1c).

As Terra and Aqua spacecrafts have begun orbital maneuvers in 2021 since their orbits started drifting, a new, adjusted dataset, EBAF Edition 4.2 was introduced. We use Version 4 data, first on the same period (April 2000-March 2022); the differences become as follows: -2.35, -2.70, 3.98, 3.46; the mean bias is 0.60 [Wm^{-2}]. Then we used the extended time period April 2000-March 2024, and have -2.32, -2.50, 4.01, 3.67, with a mean of 0.715 [Wm^{-2}]. As it can be seen, the transition between the platforms led to an increase of the mean bias of about 0.6 Wm^{-2} during the same time period, increasing further over 0.7 Wm^{-2} for the last two years of observations.

Notice that the clear-sky equations prescribe the ratio

R_N : (TOA_LW_up) : (SFC_LW_up) : R_T = 1 : 2 : 3 : 4 ,

resulting in a clear-sky greenhouse factor of

g(clear-sky) = G(clear-sky) / (SFC_LW_up) = [(SFC_LW_up) − (TOA_LW_up)] / (SFC_LW_up) = 1/3.

With CERES EBAF Edition 4.2 V4 (24-yr) data (see Fig.1a), g(clear-sky, CERES) = (398.7742 − 265.9748) / 398.7742 = 0.3330.

Recently, data were published from global energy and water cycle assessments by Stephens et al. (2023, BAMS) on 30 years of the GEWEX mission. Their data are for all-sky, therefore only equations (3) and (4) may be controlled, with LWCRE taken from an earlier study of the same authors (Stephens et al.2012) as 26.7 Wm^{-2}. According to Fig. 2 of the GEWEX study, net radiation at the surface (R_N) equals the sum of the convective fluxes: latent heat (evaporation) and sensible heat. Using data from Fig.SB3,

Eq. (3) R_N = LE + H = "Evaporation" + "Sensible heat" = ("Outgoing LW" − LWCRE)/2

81.1 + 25.4 = (239.5 − 26.7)/2 + 0.1 [Wm^{-2}]

Eq. (4) R_T = "Surface SW" − "Surface Reflection" + "All-sky emission" = 2 × "Outgoing LW" + LWCRE

184.0 − 23.3 + 345.1 = 2 × 239.5 + 26.7 + 0.1 [Wm^{-2}]

On GEWEX data, both all-sky equations are valid within 0.1 Wm^{-2}.

Joint justification of the governing equations by two idependent projects: the global energy-water exchange observation program at the surface and the space-born observations at TOA show the reliability of both the GEWEX assessment and the CERES satellite meteorology mission in one key achievement of recent decades, allowing us to improve and upgrade the climate theory. This accuracy, including a constraint on the clear-sky greenhouse factor, helps explain the observed CERES trend: instead of a reduction, OLR has increased, suggesting that EEI is a time leg between the increased absorbed solar radiation and the increase in OLR as Planck-response. For further details, see References.

References

Stephens, G. (2003) Colorado State University AT622 Section 6, Eqs. (6.10a)-(6.10b), Example 6.3, Fig. 6.3a, https://reef.atmos.colostate.edu/~odell/AT622/stephens_notes/AT622_section06.pdf

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See https://earthenergyflows.com; also the updated Supplementary Material video: https://www.earthenergyflows.com/Zagoni-EGU2024-Trenberths-Greenhouse-Geometry_Full-v03-480.mp4

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CERES EBAF Ed4.1 Version 3, 22 years (April 2000 – March 2022) (Wm^{-2})
CERES EBAF Ed4.2 Version 4, 22 years (April 2000 – March 2022) (Wm^{-2})
CERES EBAF Ed4.2 Version 4, 24 years (April 2000 – March 2024) (Wm^{-2})

Eq. (1)	**SFC SW down – SW up + LW down – LW up (clear)**	**= TOA LW (clear)/2**	
	240.8680 – 29.0724 + 317.4049 – 398.5211	= 266.0122 /2	– 2.3267
	241.0969 – 29.7521 + 317.8744 – 398.5890	= 265.9594 /2	– 2.3495
	241.0514 – 29.7043 + 318.0984 – 398.7742	= 265.9748 /2	– 2.3161
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
	241.0969 – 29.7521 + 317.8744	= 2 × 265.9594	– 2.6996
	241.0514 – 29.7043 + 318.0984	= 2 × 265.9748	– 2.5042
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
	187.1451 – 23.4950 + 346.1057 – 398.4220	= (240.3317 – 25.6277)/2	+ 3.9818
	187.1756 – 23.4607 + 346.3158 – 398.6162	= (240.3894 – 25.5854)/2	+ 4.0126
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
	187.1451 – 23.4950 + 346.1057	= 2 × 240.3317 + 25.6277	+ 3.4647
	187.1756 – 23.4607 + 346.3158	= 2 × 240.3894 + 25.5854	+ 3.6665
		Mean	**0.0007**
			0.5994
(a)			**0.7147**

Fig. 1a Four equations and their validity on CERES EBAF data products

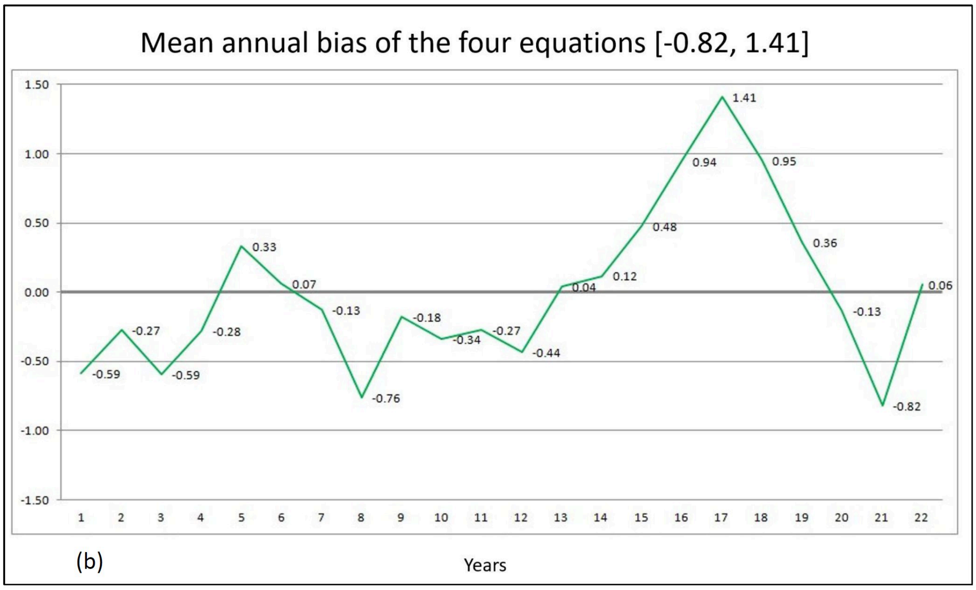

Fig. 1b Annual mean bias of the four equations

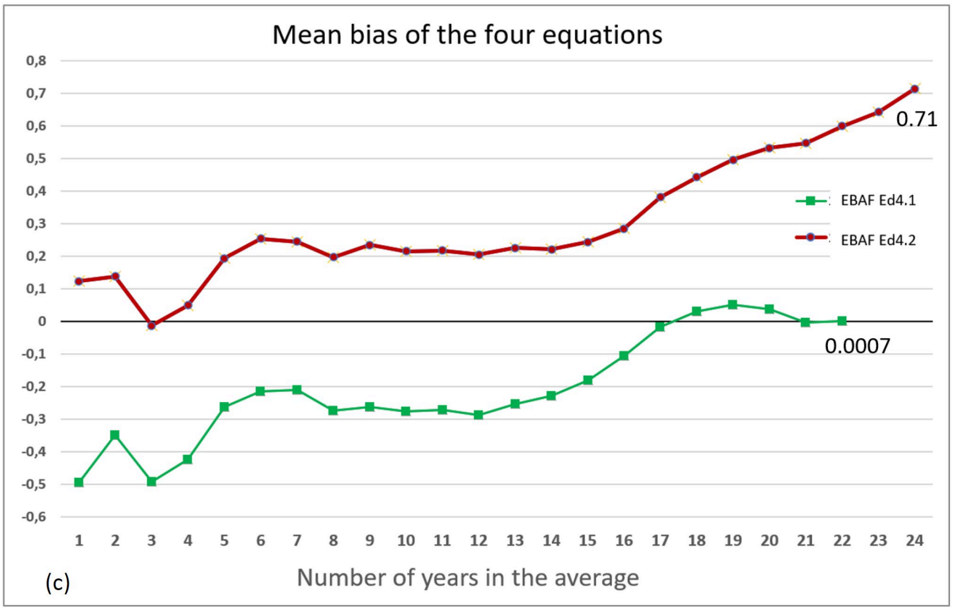

Fig. 1c Mean bias of the four equations as a function of the number of years