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Modeling and Observing Global Energy and Water Cycles

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Abstract Text:
Stephens et al. (1991-1994) provided a theoretical basis for the GEWEX activity for quantifying Earth's radiation budget and its relation to atmospheric hydrology. The last paper contains the fundamental equations: Eq. (1a) and (1b) describe simple transfer relations in radiative equilibrium with a solution given in Eq. (5a) and (5b) for the upward and downward hemispheric fluxes, resulting in a net radiation at the surface (Rn) being equal to half of the outgoing longwave radiation (OLR),

Rn = OLR/2. (1)

Textbooks derive this constraint from the same principles (e.g. Goody 1964, Eq. 2.115; Houghton 1977, Eq. 2.13).

Using optical depth = 2 in Eq. 5a, we have the total radiation (R_T) at the surface equals twice the Outgoing LW,

R_T = 2OLR, (2)

both for clear-sky conditions.

To check these equations under radiative-convective equilibrium conditions, their all-sky equivalents should be constructed. This creation is easy by separating atmospheric radiation transfer from the longwave cloud radiative effect (LWCRE). The resulting equations, with all-sky flux values on both sides, are these:

Rn = (OLR – LWCRE)/2 (3)

for the net radiation at the surface, and

R_T = 2OLR + LWCRE (4)

for the total radiation at the surface.

In radiative-convective equilibrium, the net radiation at the surface equals the sum of the non-radiative flux components, latent heat flux and sensible heat flux. Using the terminology of Figure 2 of Stephens et al. (2023, BAMS), the relationship on the net radiation at the surface (Rn) for clear sky fluxes looks like this:

Rn = LE + H = OLR/2,

where LE is the latent heat flux (evaporation) and H is the sensible heat flux. With the GEWEX data provided by Fig. SB3 of Stephens et al. (2023, BAMS): LE (Latent heat, Evaporation) = 81.1 Wm^{-2}; H (Sensible heat) = 25.4 Wm^{-2}; OLR (Outgoing LW radiation) = 239.5 Wm^{-2}; and using LWCRE from a previous study of the same authors (Stephens et al. 2012) as 26.7 Wm^{-2}, Eq. (3) looks like this:

81.1 + 25.4 = (239.5 – 26.7)/2 + 0.1,

the constraint equation is satisfied by a difference of 0.1 Wm^{-2}.

In R_T, the total energy absorbed by the surface is the sum of the shortwave and longwave absorption, “Absorbed SW” and “All-sky emission”, so Eq. (4) is:

160.7 + 345.1 = 2 × 239.5 + 26.7 + 0.1.

The equation is satisfied by the same difference of 0.1 Wm^{-2}, proving both the validity of the equations and the accuracy of the GEWEX dataset.

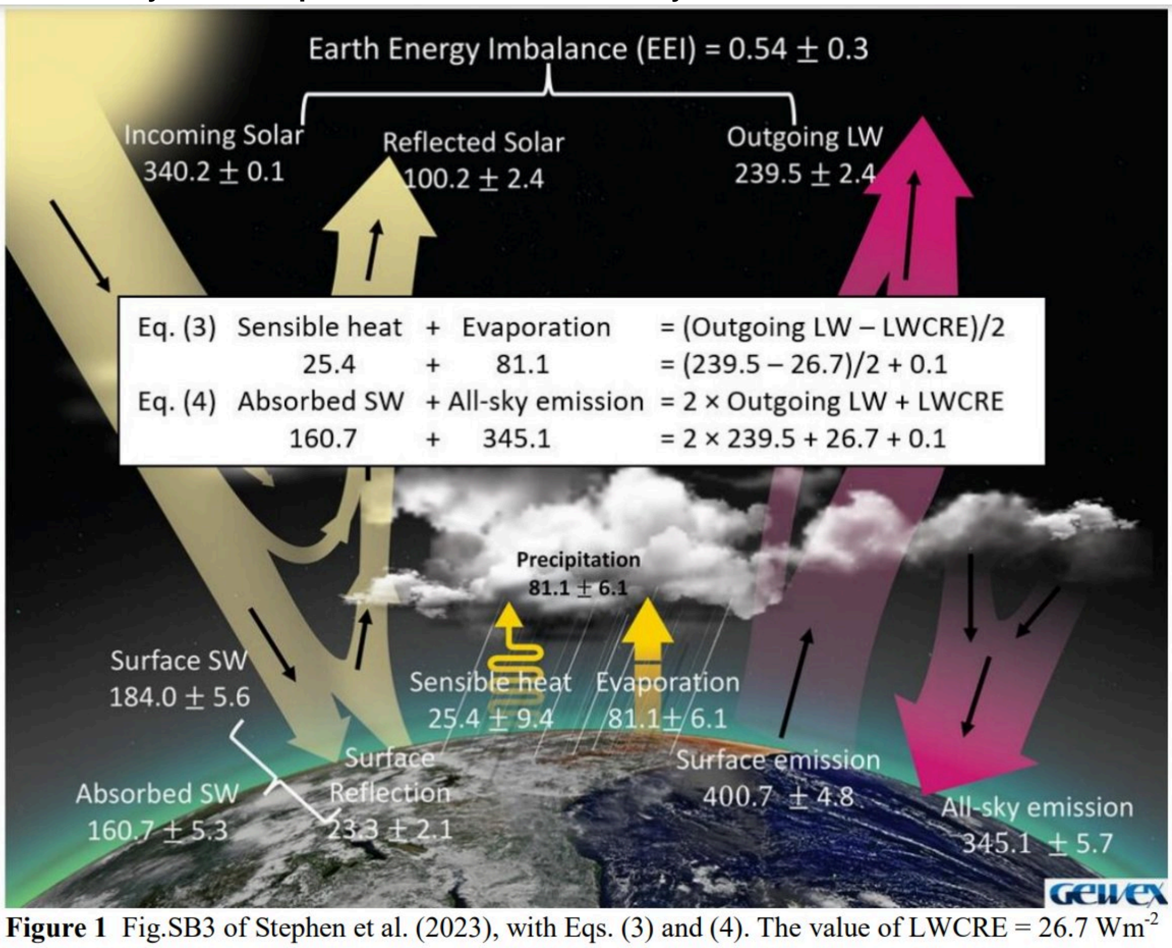

Figure 1 Fig.SB3 of Stephen et al. (2023), with Eqs. (3) and (4). The value of LWCRE = 26.7 Wm^{-2} is taken from Stephens et al. (2012).

Plain-Language Summary:
Quantifying the various ways energy flows through the Earth system has been a foundational activity of GEWEX from the outset. 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 estimate by emphasizing the high degree of accuracy it quantifies the constraints on some global energy and water cycle components, namely, the net radiation at the surface and the sum of the corresponding latent heat (evaporation) and sensible heat. Dr. Graeme Stephens and his coauthors provided the theoretical basis in a series of papers on the Earth's radiation budget and its relation to atmospheric hydrology (1991-1994). Their equations for the upward and downward hemispheric fluxes result in a constrained net radiation at the surface, being equal to half of the outgoing longwave radiation (OLR), and, with a specific optical depth of 2, in a constrained total energy absorption at the surface, being equal to twice of the OLR. After creating their all-sky versions, they are justified within 0.1 Wm^{-2}, proving both the validity of the equations and the accuracy of the GEWEX data.

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