Global energy budget, flux integer tables and the greenhouse effect of clouds $\mathbf{F} = \mathbf{F}_0 + \Delta \mathbf{F}$ G(all) – G(clear) = OLR(clear) - OLR(all) $= 1 \text{ UNIT} = 26.68 \text{ Wm}^2 \Rightarrow \text{ULW}$ = [] = OLR(clear) – OLR(cloudy) = LWCRE / $\beta_0 \equiv 1$ UNIT = 44.47 Wm⁻² \Rightarrow ULW = G(cloudy) – G(clear) **METRICS** = STI(clear) = 1 UNIT = 66.70 $Wm^{-2} \Rightarrow ULW$ $f_0(all) = 1;$ $1/f_0(\text{clear}) = 1$ UNITS **F**₀ **RELATIONSHIPS** $= 26.68 \text{ Wm}^{-2}$ OLR(all) = 9ASR ⇒ <u>9</u> UNIT + EEI OLR(outgoing LW all • E(SFC, all) =2OLR(all) + LWCRE =EEI = **0.58** 133.4 **99.3** 340.0 $ASR = 240.7 \text{ Wm}^{-2}$ 240.12 **OLR(all) + OLR(clear)** absorbed solar radiation RSR outgoing LW overcast outg E(SFC, cloudy) =reflected **OLR**(cloudy) + **OLR**(clear) $\beta \times OLR(cloudy) = \beta$ + $(1 - \beta) \times$ solar **ISR** $\alpha_0 = 0.293$ radiaincoming E(SFC, clear) =tion solar absorbed by CTS(atm) = 1CTS(all) =solar 2OLR(clear) atmosphere and clouds radiation • Solar absorbed by surface 186.8 SAA = 3213.4 **80.0** serves the energy content of the LW emitted by clouds and at all-sky greenhouse effect. = G(all) • The cloud-covered part of the ULW × β_0 = OLR(all) (STI(all)/S $\beta_{\rm eff} = \beta_{\rm obs} \times \epsilon_{\rm cloud} = 0.60$ surface radiates as much energy as in the outgoing longwave radiation: LWQ DLR(all) G(all) $ULW \times \beta_{eff} = OLR(all)$ 80.0 373.5 26.68 LAA = 1DLR • 'Cooling to space': ensibl latent atmosphere and tmospl All-sky: clouds LWQ + CTS(atm) = 0, $-(LWQ = ULW - OLR - DLR) = \frac{7}{2} = SAA + SH + LH = CTS(atm)$ LAA(all) = 2CTS(atm) = 14 = LWLWQ + CTS(all) = LWCRE.**Cloudy sky:** E(ATM, all) = SAA + SH + LH + LAA = CTS(all) + DLR(all) = 21 = E(SFC) + CTS(all) = 21 = E(SFC) $\beta_{eff} \times [LWQ + CTS(atm, cloudy)]$ = -LWCRE/526.68 **Clear-sky:** 160.7 0.58 53.4 400.2 0.08 $(1 - \beta_{eff}) \times [LWQ + CTS(clear)]$ = LWCRE / 5 EEI LH = 3DLR SAS - IMB = 1SH = 1ULW = <u>15</u> = <u>9</u> = <u>6</u> NSL =• The effective LW-opaque single-layer cloud area fraction solar absorbed surface surfac thermals evaporation surface LW up surface LW net is equal to the all-sky transfer function, $\beta_{\text{eff}} = f_0(\text{all})$, and E(SFC, all) = SAS + DLR = SH + LH + ULW + EEI = 19 + EEI = 20LR(all) + LWCI $f_0(\text{all}) \times f_0(\text{clear}) = g_0(\text{all}).$ • From a surface perspective, **CLEAR-SKY** $f(\text{clear}) = \text{OLR}(\text{clear}) / \text{ULW} = 2/3 \Rightarrow \text{STI}(\text{clear}) = 1; \text{G}(\text{clear}) = 2; \text{CTS}(\text{clear}) = 3; \text{OLR}(\text{clear}) = 3; \text{CTS}(\text{clear}) =$ the energy being lost in the all-sky atmospheric window $(1-\beta) \times G(\text{clear}) = 2;$ $(1-\beta) \times \text{CTS}(\text{clear}) = 3;$ $(1-\beta) \times \text{OLR}(\text{clear}) = 4;$ $(1-\beta) \times \text{LAA}(\text{clear}) = G(1-\beta) \times (1-\beta) \times (1-\beta)$ is gained back by the **CONTRIBUTION** LWQ + CTS(clear) = LWCRE / 2 = + 13.3 Wm⁻²; $(1-\beta) \times [LWQ + CTS(clear)] = LWCRE$ greenhouse effct of clouds: LWCRE = STI(all)= $(1 - \beta_{\text{eff}}) \times \text{STI(clear)}$. $f(\text{cloudy}) = \text{OLR}(\text{cloudy})/\text{ULW} = 5/9 \Rightarrow G(\text{clear}) = 3; \text{CTS}(\text{atm, cloudy}) = G(\text{cloudy}) = 4; \text{OLH}$ **CLOUDY** $\beta \times G(cloudy) = 4$; $\beta \times CTS(atm, cloudy) = 4$; $\beta \times OLR(cloudy) = 5$; $\beta \times LAA(cloudy) = 6$ HTED • A 'grid' albedo position = **CONTRIBUTION** LWQ + CTS(atm, cloudy) = - LWCRE / 3 = -8.86 Wm⁻²; $\beta \times [LWQ + CTS(atm, cloudy)] = \alpha_0 = 1 - \sin 45^\circ = 1 - \sqrt{2}/2$ $LWQ = -186.8 \pm 6$ $SH = 25 \pm 4$ $ULW = 398.3 \pm 4$ Net SFC LW = 53.4 ± 5 DLR • F observed data ⇒ $SAS = 160.1 \pm 5$ $LH = 81 \pm 4$ $OLR(all) = 240.1 \pm 2$ $OLR(clear) = 268.1 \pm 3$ STI(c CERES EBAF Ed4.0 ● Their sources ⇒ CERES EBAF Ed4.0

L'Ecuyer et al. (2015)

Wild et al. (2015)

| 15 $OLR(clear) = 10$ $G(clear) = 5$ $G(clear) = 5$ 9 $OLR(clear) = 6$ $G(clear) = 3$ 6 $OLR(clear) = 4$ $G(clear) = 2$ | | Integer tables of Earth's energy flows. F ₀ values in unit flux: | |
|---|---|--|--|
| elear) = <u>10</u> = <u>6</u> = <u>4</u> | OLR(clear) = 266.8 | ALL-SKY = 2 | 6.68 Wm* |
| 106 7 | CTS(clear) = 200.1 | STI(all) LWCRE | = 1 = 26.68 = 1 = 26.68 |
| bing LW cloudless | STI(clear) = 66.7 | SH NSL(all) | = 1 = 26.68 = 2 = 53.4 |
| OLR(clear) = 4 | CTS(clear)/ULW= <mark>1/2</mark> | LH SAA(all) | = <u>3</u> = 80.0 = <u>3</u> = 80.0 |
| $\Gamma I(all) = 1$ | STI(clear)/ULW=1/6 | G(clear) | $=\frac{5}{5}$ = 133.4 |
| 26.68 | G ≡ ULW – OLR | SAS(all) | = <u>6</u> = 160. |
| TI(a aan) = c(a l) | G(clear) = 133.4 | –LWQ CTS(atm) | = 1 = 186.8 = 1 = 186.8 |
| $\Pi(\text{clear}) = g(\text{all})$ | G(all) = 160.1 | CTS(all) OLR(all) | = $=$ $=$ 213.4 = $=$ 240.7 |
| (all) = <u>13</u> | G(clear) = <u>5</u> = <u>3</u> = <u>2</u> | OLR(clear) DLR(clear) | = 10 $=$ 266.3 $=$ 12 $=$ 320 $=$ |
| clear and cloudy re and clouds | G(all) = 6 | DLR(all) | $= \frac{13}{13} = 346.3$ |
| CRE + DLR | $g \equiv G / ULW$ f = OLP / ULW | LAA(all) ULW | = 14 = 373. = 15 = 400.3 |
| 2I WCRF | $g_0(\text{clear}) = 1/3$ | CLOUDY = 4 | 4.47 Wm ⁻² |
| 2DWCKE | | STI(cloudy) LWCRE / β _{eff} | = <u>0</u> = <u>1</u> = 44.47 |
| 46.8 | $g_0(an) = 2/5$ | (SH+LH)(cloudy) G(clear) | = <u>2</u> = 88.94 = <u>3</u> = 133.4 |
| (all) = <u>13</u> | $f_0(\text{clear}) = 2/3$ | G(cloudy) | $=$ $\frac{4}{4}$ = 177.9 |
| e LW down | $f_0(all) = 3/5$ | CTS(all, cloudy) | $= \frac{1}{5} = 222.3$ |
| RE + EEI | $f_0(\text{all}) = \beta_{\text{eff}}$ | OLR(cloudy) OLR(clear) | $= \frac{5}{2} = 222.3$ $= \frac{6}{2} = 266.8$ |
| lear) = 4; LAA(cl) | lear) = <u>5;</u> ULW = <u>6</u> | LAA(cloudy) ULW | = <u>9</u> = 400.2 = <u>9</u> = 400.2 |
| $f(clear) = \frac{5}{2}; (1 - \beta) \times ULW = G(all) = \frac{6}{2}$ | | CLEAR-SKY= | = 66.7 Wm |
| | | STI(clear) (SH + LH)(clear) | = <u>1</u> = 66.7 = <u>2</u> = 133.4 |
| $C(cloudy) = \frac{5}{2}; OLR(clear) = \frac{6}{2}; ULW = \frac{9}{2}$ $PLR(all) = \frac{9}{2}; \beta \times ULW = OLR(all) = \frac{9}{2}$ | | G(clear) CTS(clear) | = <u>2</u> = 133.4 - <u>3</u> - 200 1 |
| LWCRE / $5 = -\frac{1}{5} = -5.34 \text{ Wm}^{-2}$ | | OLR(clear) | $= \underline{4} = 266.8$ |
| $x = 345.0 \pm 5$ (ear) = 66 + 2 | $\beta_{\rm eff} = 0.58 \pm 0.02$ | LAA(clear) ULW | = 5 = 333.5 = 6 = 400.2 |
| ES EBAF Ed4.0 | CERES SYN1deg Ed4 | ΔF < | ±1σ |
| | Hamananan (2000) | | |

CEF

Costa

Wild et al. (2015)

$\overline{\mathbf{F}}_0 = \mathbf{N} \times \mathbf{UNIT}$