A53G-2367

Defining the Magnitude: Patterns, Regularities and Direct TOA-Surface Flux Relationships in the 15-Year Long CERES Satellite Data — Observations, Model and Theory

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Observations

CERES EBAF TOA and SFC Ed2.8 and Ed4.0 data
Global Means (Mar2000-Feb2016) (Rose et al. 2017)

All Sky	Ed4	Ed2.8
TOA SW Insolation	340.04	339.87
TOA SW Up	*99.23*	*99.62*
TOA LW Up	*240.14*	*239.60*
SFC SW Down	187.04	186.47
SFC SW Up	23.37	24.13
SFC LW Down	344.97	345.15
SFC LW Up	398.34	398.27

Clear Sky	Ed4	Ed2.8
TOA SW Insolation	340.04	339.87
TOA SW Up	*53.41*	*52.50*
TOA LW Up	*268.13*	*265.59*
SFC SW Down	243.72	244.06
SFC SW Up	29.81	29.74
SFC LW Down	314.07	316.27
SFC LW Up	397.59	398.40

There are patterns in these fluxes.

Pattern 1: The SFC absorbed energy (SW down – SW up + LW down) in the clear-sky equals to 2OLR, with a difference of 0.6 Wm^{-2} in Ed2.8 and 8.3 Wm^{-2} in Ed4.0.

Pattern 2: The net (non-radiative) energy at the surface in clear-sky = SFC Net = SW down – SW up + LW down – LW up equals to the G greenhouse effect = SFC LW up – TOA LW up with Diff = -0.6 Wm^{-2} (Ed2.8) and 0.9 Wm^{-2} (Ed4.0)

Pattern 3: Ed 2.8 Clear-sky integer ratios: G = SFC LW up – TOA LW up =132.8 (**1**); TOA LW up = 265.6 (**2**), SFC LW up = 398.4 (**3**); E(SFC) = 530.6 (**4**).

Pattern 4: Pattern 1 is valid for the all-sky by adding surface LW cloud radiative effect: SW net + LW down = 2OLR + SFC LWCRE. Diff = 0.7 (Ed2.8), 0.9 (Ed4) Wm^{-2}

Pattern 5: All-sky integer ratios: with **UNIT** = OLR(all-sky)/9 = 240.1/9 = 26.68 W/m^2 (Ed4)

Clear-sky, Ed2.8, time period 2001-2015, climate year:

	SW down	SW up	SW abs	LW abs	E(SFC)	OLR	2OLR	Diff
CLIM 1	255.35	31.34	224.01	306.27	530.28	262.43	524.86	5.42
CLIM 2	251.86	29.86	222	307.98	529.98	262.78	525.56	4.42
CLIM 3	246.89	30.09	216.8	311.09	527.89	263.42	526.84	1.05
CLIM 4	242.26	31.63	210.63	315.14	525.77	265.01	530.02	-4.25
CLIM 5	237.33	32.21	205.12	320.27	525.39	267.18	534.36	-8.97
CLIM 6	233.41	28.67	204.74	325.70	530.44	269.05	538.1	-7.66
CLIM 7	231.63	25.72	205.91	328.35	534.26	269.75	539.5	-5.24
CLIM 8	233.65	24.42	209.23	327.05	536.28	269.12	538.24	-1.96
CLIM 9	239.24	25.80	213.44	321.82	535.26	267.58	535.16	0.1
CLIM 10	247.06	29.92	217.14	315.28	532.42	265.25	530.5	1.92
CLIM 11	253.97	33.73	220.24	309.57	529.81	263.26	526.52	3.29
CLIM 12	256.35	33.52	222.83	306.74	529.57	262.38	524.76	4.81
Average	244.08	29.74	214.34	316.27	530.61	265.60	531.20	-0.59

214.34 +316.27 = 530.61 = 2 × 265.60 – 0.59 Pattern 1

Clear-sky, Ed2.8, climate year, 2001-2015

	ULW	OLR	G	Net SFC	ULW+G	2OLR	Diff
CLIM 1	388.3	262.43	125.87	141.98	514.17	524.86	10.69
CLIM 2	389.89	262.78	127.11	140.09	517	525.56	8.56
CLIM 3	393.31	263.42	129.89	134.57	523.2	526.84	3.64
CLIM 4	398.51	265.01	133.5	127.26	532.01	530.02	-1.99
CLIM 5	403.29	267.18	136.11	122.09	539.4	534.36	-5.04
CLIM 6	407.64	269.05	138.59	122.8	546.23	538.1	-8.13
CLIM 7	409.1	269.75	139.35	125.17	548.45	539.5	-8.95
CLIM 8	407.83	269.12	138.71	128.46	546.54	538.24	-8.30
CLIM 9	403.85	267.58	136.27	131.41	540.12	535.16	-4.96
CLIM 10	397.76	265.25	132.51	134.65	530.27	530.5	0.23
CLIM 11	392.27	263.26	129.01	137.54	521.28	526.52	5.24
CLIM 12	389.00	262.38	126.62	140.57	515.62	524.76	9.14
average	**398.39**	**265.60**	**132.80**	**132.22**	**531.19**	**531.20**	**0.01**

ULW – G = OLR (def.); **Data**: G = Net SFC (= SH+LH)
ULW + G = 2OLR, Diff = **0.01** (!!!) W/m^2 =>
G = OLR/2 <=> g = G/ULW = 1/3 Pattern 2

Pattern 4	SW abs	LW abs	E(SFC)	OLR(all)	SFC LWCRE	2OLR+LWCRE	Diff
CLIM1	166.42	335.38	501.8	236.84	29.49	503.17	-1.37
CLIM2	167.56	337.14	504.7	237.41	29.51	504.33	0.37
CLIM3	166.66	339.93	506.59	237.72	28.89	504.33	2.26
CLIM4	162.97	344.67	507.64	238.42	29.58	506.42	1.22
CLIM5	157.91	349.22	507.13	240.24	28.64	509.12	-1.99
CLIM6	155.39	353.4	508.79	242.38	28.21	512.97	-4.18
CLIM7	156.73	355.86	512.59	243.71	28.16	515.58	-2.99
CLIM8	160.33	355.23	515.56	243.68	28.2	515.56	0
CLIM9	163.59	350.78	514.37	242.13	28.43	512.69	1.68
CLIM10	164.08	345.39	509.47	239.66	28.98	508.3	1.17
CLIM11	163.66	339.84	503.5	237.19	29.82	504.2	-0.7
CLIM12	164.19	336.4	500.59	236.31	29.75	502.37	-1.78
Average	162.46	345.27	507.73	239.64	28.97	508.25	-0.53

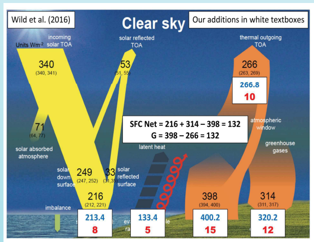
SFC (SW in + LW in) = 2OLR(all) + SFC LWCRE (-0.53 W/m^2)

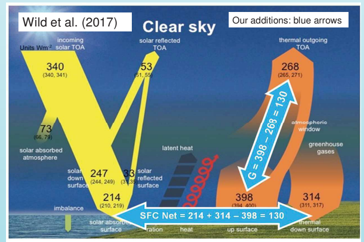
Model

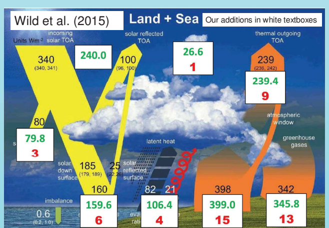
The observed CERES EBAF fluxes can be modeled as integer multiples of a unit flux. The model data set is Edition MZ.

All-sky	Ed4.0	Ed2.8	EdMZ	N	Ed4.0 – EdMZ	Ed2.8 – EdMZ
TOA SW In	340.04	339.87	**340.04**		0.0	-0.27
TOA LW Up	240.14	239.60	**240.14**	**9**	0.0	-0.54
SFC SW In	163.67	162.34	**160.09**	**6**	3.58	2.25
SFC LW Down	344.97	345.15	**346.87**	**13**	-1.90	-1.72
SFC (SW in + LW in)	508.64	507.49	**506.96**	**19**	1.68	0.53
SFC LW Up	398.34	398.27	**400.23**	**15**	-1.89	-1.96
SFC Net	110.30	109.22	**106.73**	**4**	3.57	2.49
G	158.20	158.67	**160.09**	**6**	-1.89	-1.42
2TOA LW Up+LWCRE	511.18	508.08	**506.96**	**19**	4.22	1.12

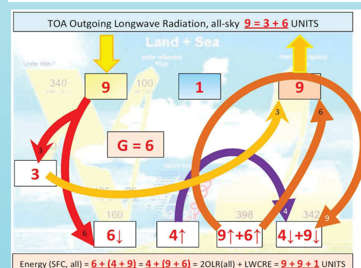
Clear-sky	Ed4.0	Ed2.8	EdMZ	N	Ed4.0 – EdMZ	Ed2.8 – EdMZ
TOA SW in	340.04	339.87	**340.04**		0.0	-0.17
TOA LW up	268.13	265.59	**266.82**	**10**	1.31	-1.23
SFC SW in	213.91	214.32	**213.47**	**8**	0.44	0.85
SFC LW in	314.07	316.27	**320.18**	**12**	-6.11	-3.91
SFC SW + LW in	527.98	530.59	**533.65**	**20**	-5.67	-3.06
SFC LW up	397.59	398.40	**400.23**	**15**	-2.64	-1.83
SFC Net	130.39	132.19	**133.42**	**5**	-3.03	-1.23
G	129.46	132.81	**133.42**	**5**	-3.96	-0.61

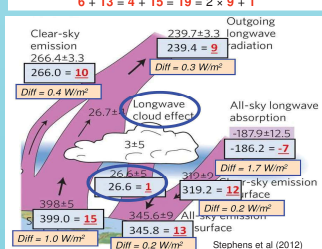


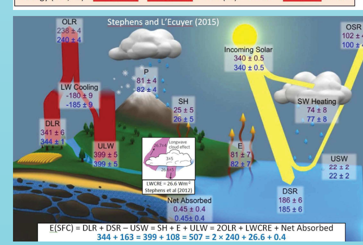




SFC (SW + LW) absorbed, all-sky = 2OLR(all-sky) + LWCRE
6 + 13 = 4 + 15 = 19 = 2 × 9 + 1

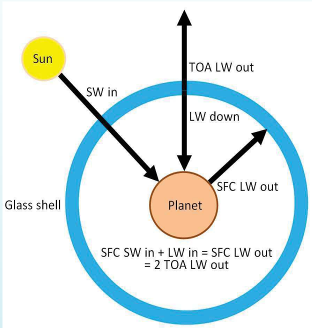


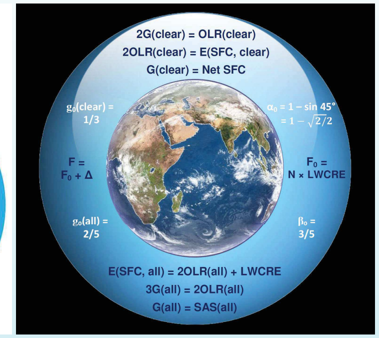




Theory

The simplest greenhouse model: A planet surrounded by an SW-transparent, LW-opaque, non-turbulent "glass shell" atmosphere. Here the total surface absorption is exactly twice the outgoing longwave radiation, because of the geometry.





From here, all the patterns, including the integer ratios, can be deduced by using simple arithmetic relationships.
Clear-sky integer ratios in Costa-Shine (2012) LBL-computation:

	STI	G	ATM	OLR	ULW	2OLR
Costa-Shine (2012):	65	127	194	259	386	518
Pattern:	65 /	130 /	195 /	260 /	390 /	520
Ratios:	**1** /	**2** /	**3** /	**4** /	**6** /	**8**
Difference:	0	3	1	1	4	2 (Wm^{-2})

The patterns as integers:

Pattern1 (clear-sky): SFC (SW + LW) (in) = 2 × OLR
8 + 12 = 2 × 10
Pattern 2 (clear-sky): SFC Net = ULW – OLR = G
20 – 15 = 15 – 10 = 5
8 – 6 = 6 – 4 = 2
Pattern3 (clear-sky): STI / G / ATM / OLR / ULW / E(SFC)
1 / 2 / 3 / 4 / 6 / 8
Pattern4 (all-sky): SFC (SW + LW) (in) = 2OLR + LWCRE
6 + 13 = 2 × 9 + 1
Pattern5 (all-sky): F = **N** × UNIT, UNIT = OLR(all-sky) / 9.

Conclusions

There are robust patterns in the CERES global means. What are they: coincidences? Or conspiracy ☺ ? No; they have sound theoretical basis: integer data set is presented to reproduce the patterns, and a simple greenhouse model (IR-opaque limit, glass shell geometry) offers the physical background for the basic ratios. All fluxes are within 1σ range. Compared to the model data, the difference to Ed4.0 clear-sky SFC SW absorption is only 0.44 Wm^{-2} and to all-sky SFC LW down is -1.9 Wm^{-2}; the clear-sky DLR in Ed4.0 is too low by 6.1 Wm^{-2} and the clear-sky OLR is too high by 1.3 Wm^{-2}.

http://www.globalenergybudget.com

Poster:
AGU 2017 Fall Meeting: A53G-2367
Defining the Magnitude: Patterns, Regularities and Direct TOA-Surface Flux Relationships in the 15-Year Long CERES Satellite Data — Observations, Model and Theory

ePoster:
https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/205884
website: www.globalenergybudget.com
email: miklos.zagoni@t-online.hu

Handout:
28th CERES Science Team Meeting Presentation
2017 September 27, NASA Goddard Space Flight Center
Greenbelt, MD.

Miklos Zagoni

Patterns in the CERES Global Mean Data

*"To search for something – though it be mushrooms –
or some pattern – is impossible, unless you look and try."
Dmitri Mendeleev*

CERES_EBAF-Surface_Ed4.0
Data Quality Summary (May 26, 2017)

Table 5-1. Global mean surface fluxes in W m^{-2} computed from EBAF Ed4.0 and EBAF Ed2.8 for March 2000-February 2016.

All-sky	**Ed4**	**Ed2.8**	**Ed4 – Ed2.8**
TOA SW insolation	340.0	339.9	0.17
SW down	187.0	186.5	0.57
SW up	23.4	24.1	-0.76
SW net[1]	163.7	162.3	1.33
LW down	345.0	345.2	-0.18
LW up	398.3	398.3	0.07
LW net[1]	-53.4	-53.1	-0.25
SW+LW net	110.3	109.2	1.08
Clear-sky			
TOA SW insolation	340.0	339.9	0.17
SW down	243.7	244.1	-0.33
SW up	29.8	29.7	0.07
SW net[1]	213.9	214.3	0.41
LW down	314.1	316.3	-2.20
LW up	397.6	398.4	-0.81
LW net[1]	-83.5	-82.1	1.39
SW+LW net[1]	130.4	132.2	-1.80

[1] Net is computed by downward – upward.

Fred Rose et al 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

Pattern 1. SFC energy in = 2 × TOA LW out

Clear-sky	Ed2.8
TOA SW in	339.87
TOA SW up	52.50
TOA LW up	265.59
SFC SW down	244.06
SFC SW up	29.74
SFC SW in (down – up)	214.32
SFC LW down	316.27
SFC SW + LW absorbed	530.59
SFC LW up	398.40
SFC SW + LW net	132.19
G = SFC LW up – TOA LW up	132.81
2TOA LW up	531.18
Diff	–0.59

Clear-sky, Ed2.8
Surface energy absorbed
SW + LW (Wm^{-2}):

(SW down – SW up) + LW down
= (244.06 – 29.74) + 316.27
= 214.32 + 316.27
= 530.59

TOA LW out = 265.59
2 × TOA LW out =
= 531.18

Diff = –0.59 Wm^{-2}

214.32 + 316.27 = 2 × 265.59 – 0.59

Clear-sky, Ed2.8, time period 2001-2015, climate year:

	SW down	SW up	SW abs	LW abs	E(SFC)	OLR	2OLR	Diff
CLIM 1	255.35	31.34	224.01	306.27	530.28	262.43	524.86	5.42
CLIM 2	251.86	29.86	222	307.98	529.98	262.78	525.56	4.42
CLIM 3	246.89	30.09	216.8	311.09	527.89	263.42	526.84	1.05
CLIM 4	242.26	31.63	210.63	315.14	525.77	265.01	530.02	-4.25
CLIM 5	237.33	32.21	205.12	320.27	525.39	267.18	534.36	-8.97
CLIM 6	233.41	28.67	204.74	325.70	530.44	269.05	538.1	-7.66
CLIM 7	231.63	25.72	205.91	328.35	534.26	269.75	539.5	-5.24
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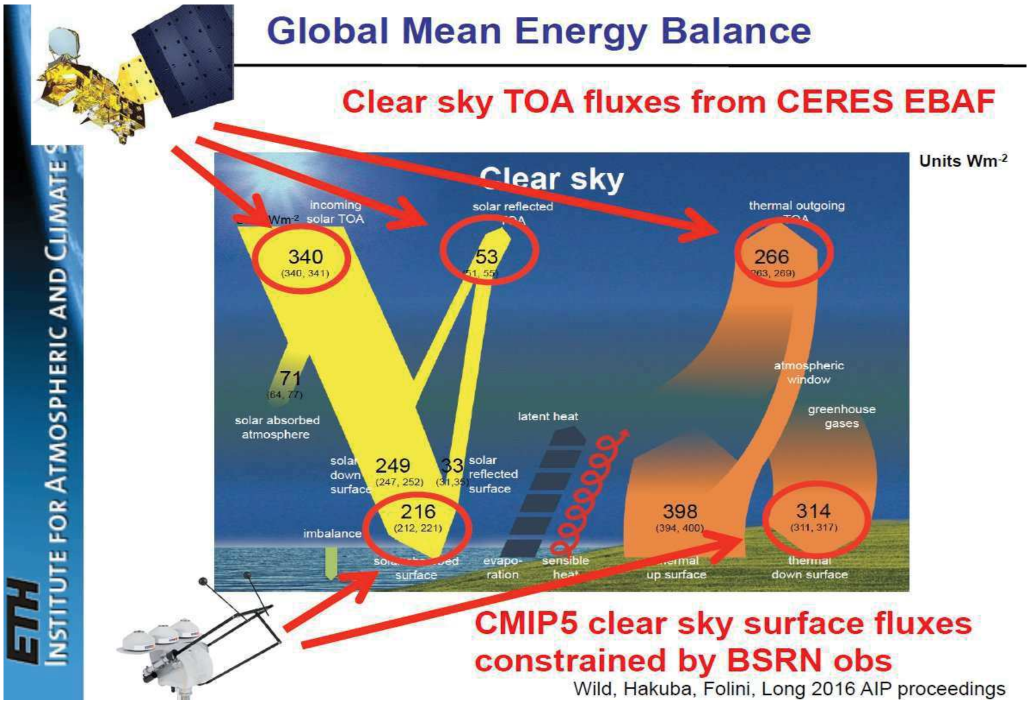
CLIM 9	239.24	25.80	213.44	321.82	535.26	267.58	535.16	0.1
CLIM 10	247.06	29.92	217.14	315.28	532.42	265.25	530.5	1.92
CLIM 11	253.97	33.73	220.24	309.57	529.81	263.26	526.52	3.29
CLIM 12	256.35	33.52	222.83	306.74	529.57	262.38	524.76	4.81
Average	244.08	29.74	214.34	316.27	530.61	265.60	531.20	-0.59

214.34 +316.27 = 530.61 = 2 × 265.60 – 0.59

E(SFC in, clear-sky) = (SW down – SW up) + LW in = 2OLR – EEI

CERES 26th STM October 2016, Martin Wild, slide #36



TOA and SFC fluxes from independent data sources

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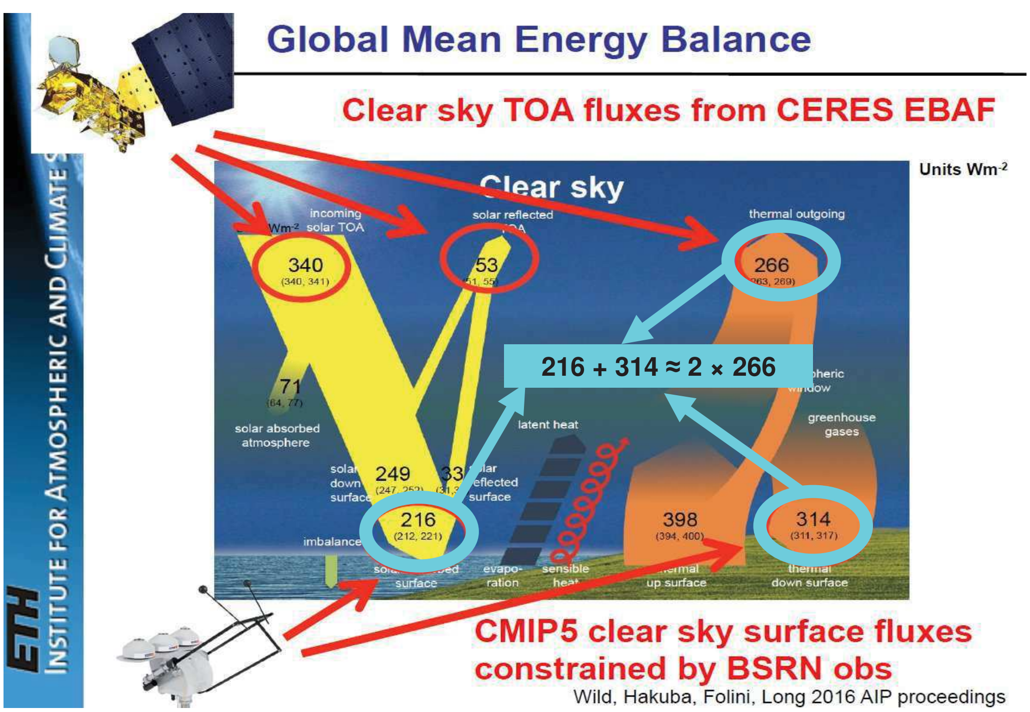
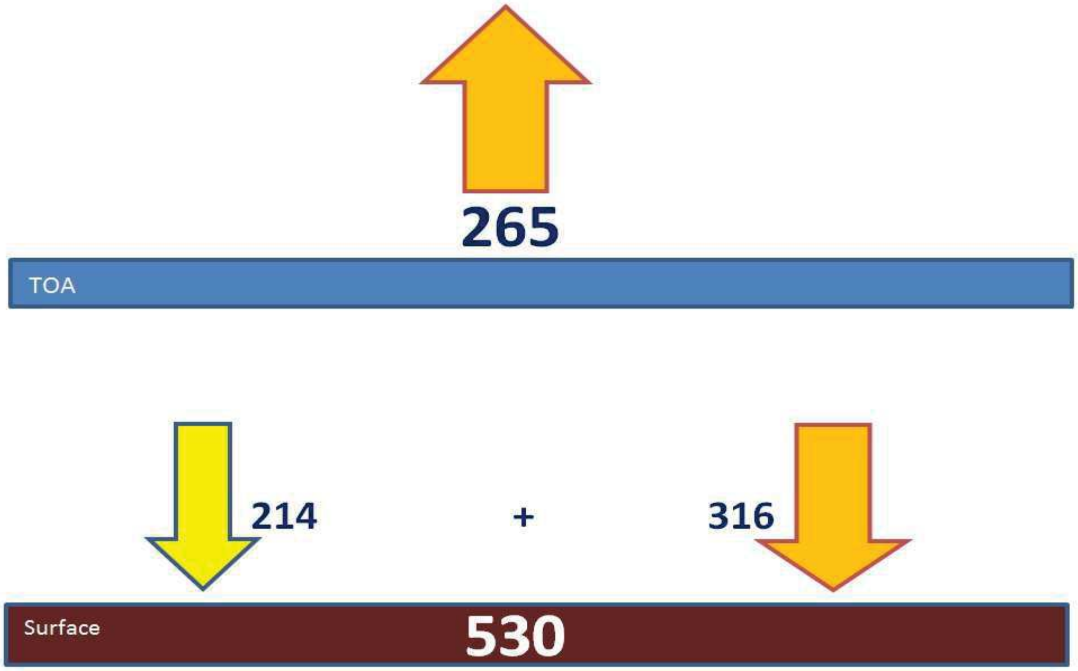
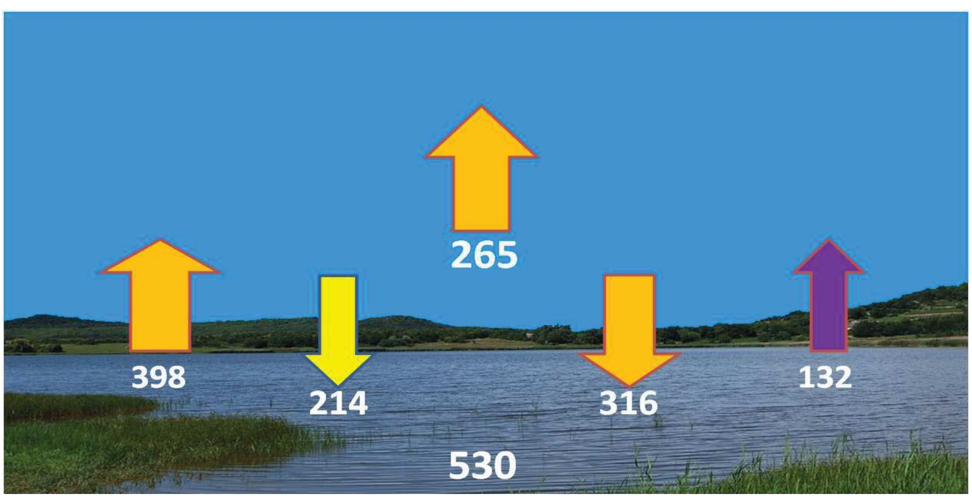


solar absorbed surface + thermal down surface = 2 × thermal outgoing TOA



Energy (surface in, clear sky) = SW↓ abs + LW↓ abs = 2 × OLR



Surface energy budget, clear-sky, CERES EBAF Ed2.8

Solar absorbed + thermal absorbed = 2 outgoing longwave TOA

214.34 + 316.28 = 2 × 265.6 − 0.58 Wm^{-2}

SW abs↓ + LW abs↓ = 2OLR(clear) − 0.58 Wm^{-2}

=> Net planetary imbalance for July 2005-June 2010: 0.58±0.43 Wm^{-2}

Pattern 2. SFC Net = G

Clear-sky	Ed2.8
TOA SW in	339.87
TOA SW up	52.50
TOA LW up	265.59
SFC SW down	244.06
SFC SW up	29.74
SFC SW in	214.32
SFC LW in	316.27
SFC SW + LW absorbed	530.59
SFC LW up	398.40
SFC Net	**132.19**
G	**132.81**
Diff	–0.62

SFC Net Flux (non-radiative)
= SFC (SW in + LW in)
– SFC LW up

SFC Net = 214.32 + 316.27
– 398.40
= **132.19**

G = SFC LW up – TOA LW up
= ULW – OLR =
= **132.81**

Diff (W m^{-2})
= –0.62

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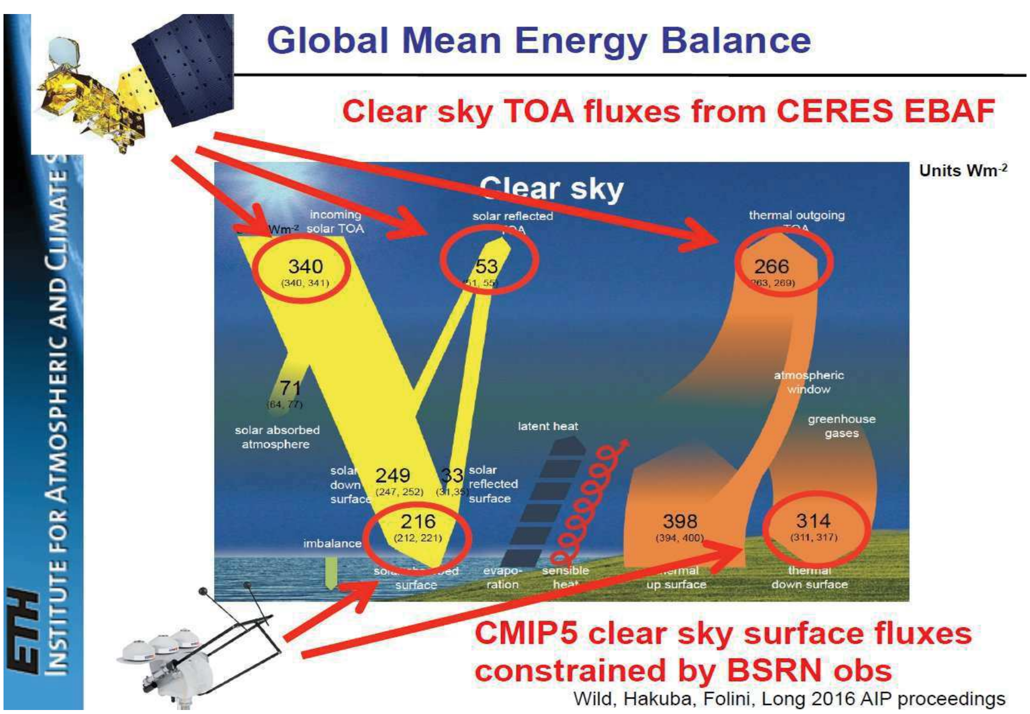
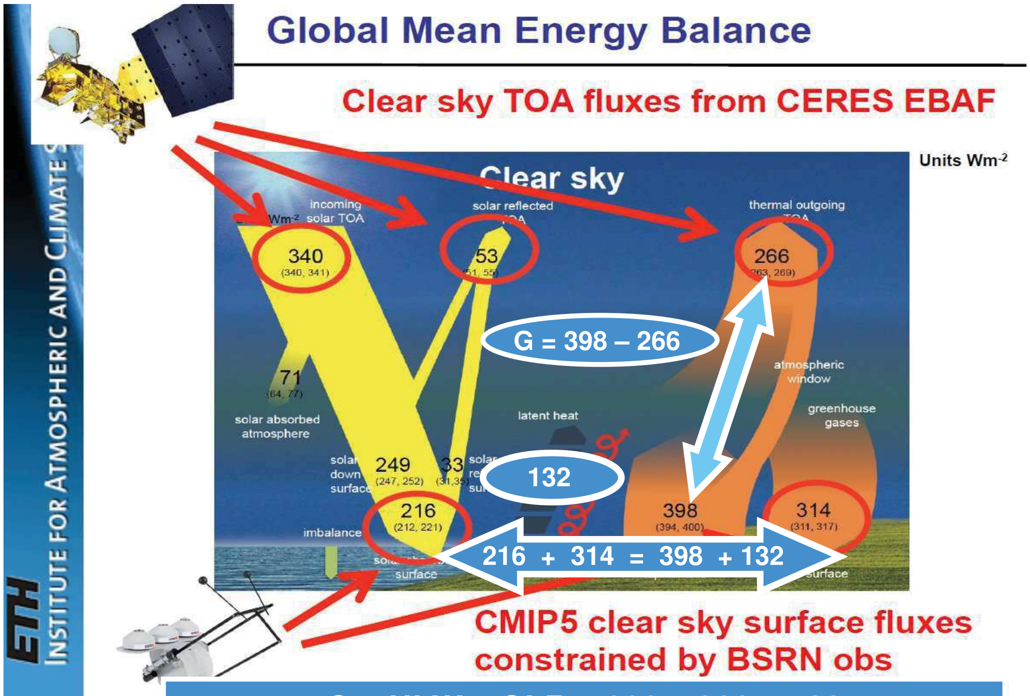


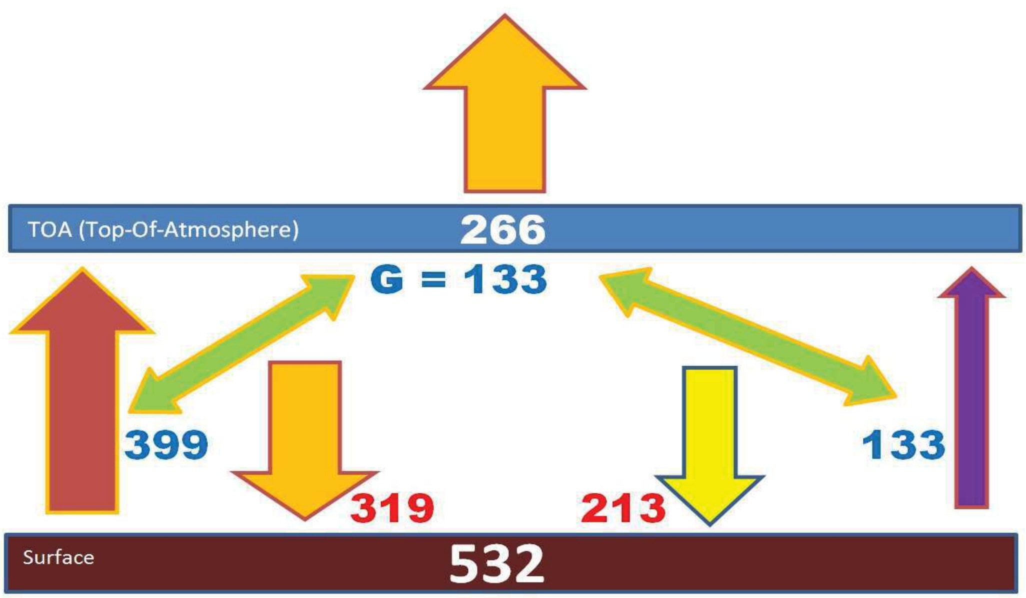
TOA and SFC fluxes from independent data sources

G = SFC Net (turb, non-rad)



G = ULW – OLR = 398 – 266 = 132
SFC Net (SH + LH) = 216 + 314 – 398 = 132

Clear-sky ratios



G / OLR / ULW / E(SFC) = 133 / 266 / 399 / 532 = **1 / 2 / 3 / 4**

Clear-sky, Ed2.8, climate year, 2001-2015

	ULW	OLR	G	Net SFC	ULW+G	2OLR	Diff
CLIM 1	388.3	262.43	125.87	141.98	514.17	524.86	10.69
CLIM 2	389.89	262.78	127.11	140.09	517	525.56	8.56
CLIM 3	393.31	263.42	129.89	134.57	523.2	526.84	3.64
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CLIM 6	407.64	269.05	138.59	122.8	546.23	538.1	-8.13
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CLIM 8	407.83	269.12	138.71	128.46	546.54	538.24	-8.30
CLIM 9	403.85	267.58	136.27	131.41	540.12	535.16	-4.96
CLIM 10	397.76	265.25	132.51	134.65	530.27	530.5	0.23
CLIM 11	392.27	263.26	129.01	137.54	521.28	526.52	5.24
CLIM 12	389.00	262.38	126.62	140.57	515.62	524.76	9.14
average	**398.39**	**265.60**	**132.80**	**132.22**	**531.19**	**531.20**	**0.01**

ULW **–** G = OLR (def.); **Data**: G = Net SFC (= SH+LH)
ULW + G = 2OLR, Diff = **0.01** (!!!) W/m^2 =>
G = OLR/2 <=> g = G/ULW = 1/3

Greenhouse effect and normalized greenhouse factors,

years 2001 – 2015, g = G/ULW.

Integer ratios: **g(all)** = 6/15 = 2/5 = **0.4; g(clear)** = 5/15 = **1/3**

g(all-sky) and g(clear-sky), CERES EBAF Edition 2.8 (March 27, 2015), monthly mean

Theoretical lattice state at g(all-sky) = 6/15 = 2/5 =**0.4** and g(clear-sky) = 5/15 = 1/3 =**0.3333**

Best fit: g(all-sky) = **0.40006** (in year 2015), g(clear-sky) = **0.33338** (in year 2011)

Increase: g(all-sky) from 0.397 to 4.000; g(clear-sky) from 0.3313 to 0.3355

2001		G = ULW - OLR	g = G/ULW		
ULW	OLR(all-sky)	G(all-sky)	g(all-sky)	OLR(clear-sky)	g(clear-sky)
386.52	236.38	150.14	0.378000	262.3	0.321381
387.61	236.47	151.14	0.375000	262.54	0.32267
391.6	236.94	154.66	0.381000	263.06	0.328243
397.01	237.91	159.1	0.390000	265.06	0.332359
402.96	240.44	162.52	0.399000	267.65	0.33579
405.53	241.76	163.77	0.406000	268.82	0.337114
407.84	243.54	164.3	0.413000	269.85	0.338343
407.41	244.1	163.31	0.416000	269.77	0.337841
403.6	241.67	161.93	0.417000	267.36	0.337562
398.07	239.21	158.86	0.399000	265.59	0.332806
392.62	237.55	155.07	0.395000	264.09	0.327365
388.71	236.21	152.5	0.392000	262.55	0.324561
Average 239.35		**158.11**	**0.396754**	**265.72**	**0.331336**

2010	OLR(all)	G	g(all)	OLR(clear)	g(clear)
388.1	237.59	150.51	0.387812	262.85	0.322726
389.76	237.47	152.29	0.390728	262.85	0.325611
393.82	238.31	155.51	0.394876	264.01	0.329618
399.41	238.16	161.25	0.40372	264.94	0.336672
404.04	240.59	163.45	0.404539	267.39	0.338209
407.37	242.28	165.09	0.405258	268.59	0.340673
408.44	243.36	165.08	0.404172	269.23	0.340833
407.45	243.86	163.59	0.401497	268.8	0.340287
403.91	242.07	161.84	0.400683	267.34	0.33812
398.44	239.44	159	0.399056	265.16	0.334505
392.67	237.56	155.11	0.395014	263.27	0.329539
387.61	236.18	151.43	0.390676	261.87	0.324398
			0.398169		**0.333433**

2011	OLR(all)	G	g(all)	OLR(clear)	g(clear)
386.56	235.86	150.7	0.389849	261.37	0.323857
388.4	237.52	150.88	0.388465	262.45	0.324279
392.56	237.85	154.71	0.394105	262.84	0.330446
398.11	238.17	159.94	0.401748	264.42	0.335812
403.06	239.29	163.77	0.406317	266.37	0.339131
407.06	241.97	165.09	0.405567	268.68	0.33995
408.41	243.95	164.46	0.402684	269.79	0.339414
407.51	244.05	163.46	0.401119	268.91	0.340114
403.66	242.92	160.74	0.398206	267.47	0.337388
398.28	239.02	159.26	0.399869	264.73	0.335317
391.79	236.81	154.98	0.395569	262.76	0.329335
388.35	235.99	152.36	0.392327	261.92	0.325557
			0.397985		**0.33338**

Pattern 3. Clear-sky integer ratios

Costa and Shine (2012) Line-By-Line

- ULW = 386 Wm^{-2}
- OLR = 259 Wm^{-2}
- ATM = 194 Wm^{-2}
- G = 127 Wm^{-2}
- STI = 65 Wm^{-2}

JUNE 2012 COSTA AND SHINE 1867

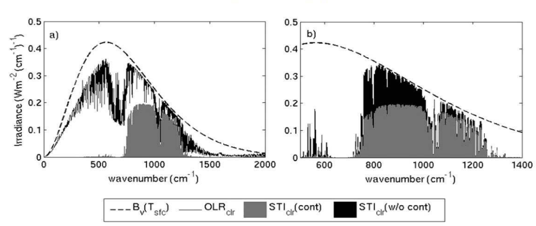


FIG. 1. Spectral distribution of the clear-sky Earth Radiation Budget components [$W\ m^{-2}\ (cm^{-1})^{-1}$] using a global-mean atmosphere. (a) Longwave irradiance emitted by surface $B_\nu(T_{sfc})$ assuming it to be a blackbody, the outgoing longwave radiation (OLR_{clr}), and surface transmitted irradiance including the water vapor continuum [STI_{clr} (cont)]. (b) As in (a), over a smaller wavenumber interval, but includes, instead of OLR_{clr}, the surface transmitted irradiance when the water vapor continuum is excluded [STI_{clr}(w/o cont)].

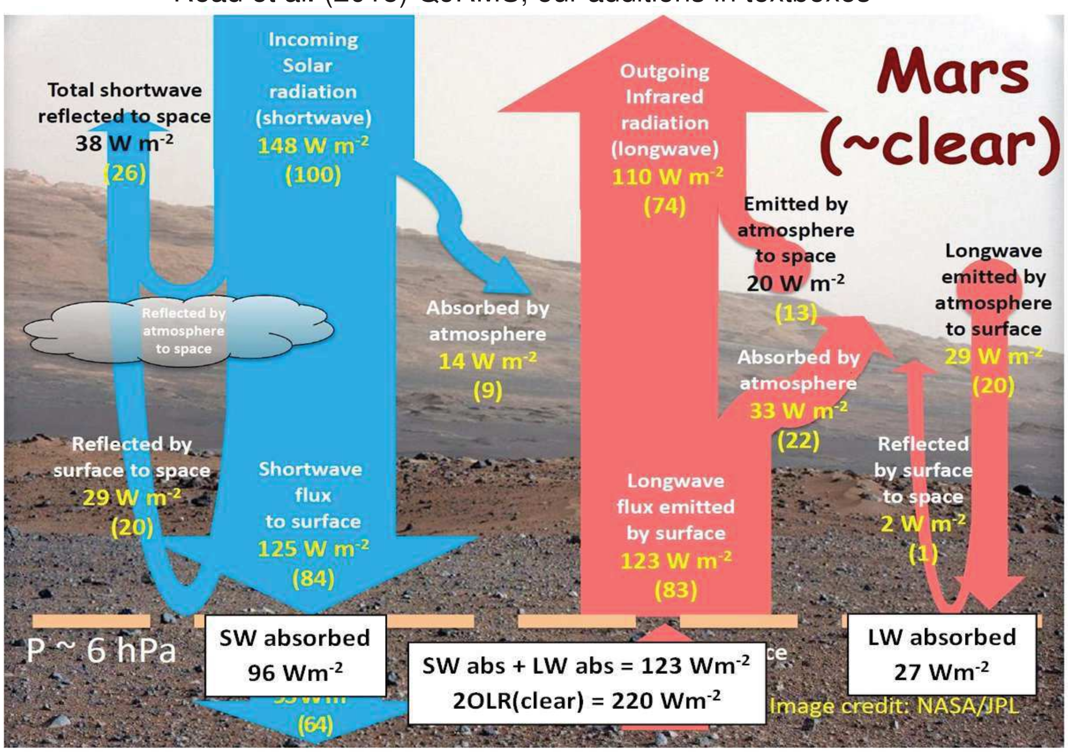
	STI	G	ATM	OLR	ULW	2OLR
CS12 =	65	127	194	259	386	518
Pattern	65 /	130 /	195 /	260 /	390 /	520
Ratios	**1** /	**2** /	**3** /	**4** /	**6** /	**8**
Diff	0	3	1	1	4	2 (Wm^{-2})

1.	E(SFC, clear) = 2OLR(clear)
2.	G(clear) = SFC Net (clear)
3.	G(clear) = OLR(clear)/2

These are **NOT** universal planetary rules.

- They cannot be deduced from the known *energy in = energy out* balance requirements
- They describe a unique, very specific state
- They are far from being valid, for example, on the Mars:
- The Martian ULW is 123 Wm^{-2},
  OLR = 110, G = 13 Wm^{-2}, therefore
  ULW + G << 2OLR
  ULW – OLR << 2OLR – ULW
  G << OLR/2.

Read et al. (2015) QJRMS, our additions in textboxes



Energy (surface, Mars) = SW in + LW in << 2OLR; 2G = 26 W/m² << OLR

They belong to a specific geometry

- It is like the **IR-opaque limit**:
  a planet surrounded by a

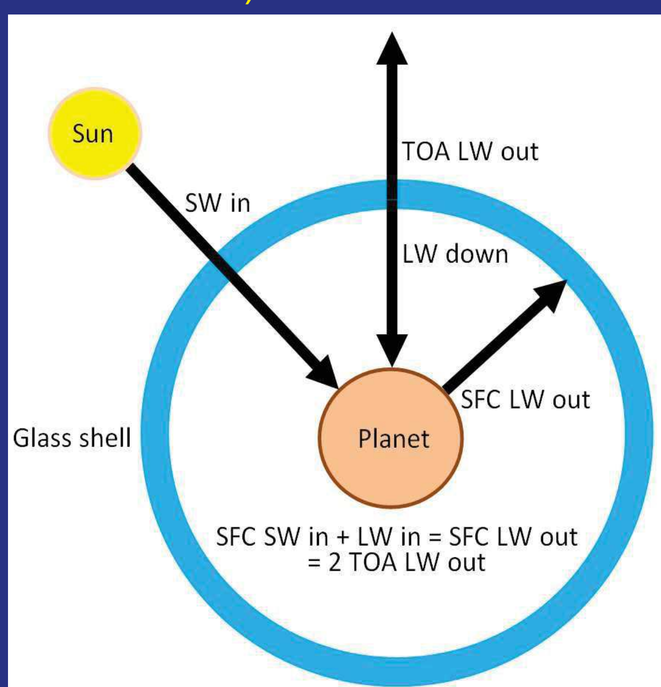
  SW-transparent
  LW-opaque
  non-turbulent

  "**glass-shell**" atmosphere.

- The surface radiation here is exactly **twice** the outgoing longwave radiation because of the construction:

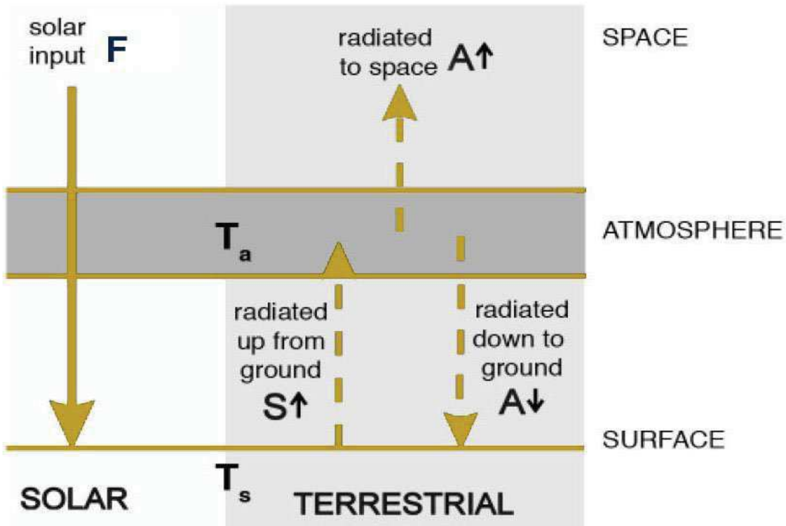
Model: an idealized **glass-shell** geometry

SFC (SW in + LW in) = SFC LW out = 2 TOA LW out



After Mashall and Plumb (2008, Fig. 2.7)

SW-transparent, LW-opaque, non-turbulent



$$F(SW) + A(LW) = S(LW) = 2A(LW)$$

$$G = S - A = A = F$$

All-sky

All-sky	Ed2.8
TOA SW in	339.87
TOA SW up	99.62
TOA LW up	239.60
SFC SW down	186.47
SFC SW up	24.13
SFC SW in	162.34
SFC LW down	345.15
SFC SW + LW absorbed	**507.49**
SFC LW up	398.27
SFC Net	109.22
G	158.67
SFC LWCRE	28.88
2TOA LW Up + SFC LWCRE	**508.08**
Diff	–0.59

Ed2.8

SFC energy in:

SW in = 162.35 W/m^2
LW in = 345.15 W/m^2
SFC (SW in + LW in)
= **507.5**

SFC energy out:

LW up + Net =
= **398.3 + 109.2**

2OLR = 2 × 239.6
= **479.2** W/m^2

Diff = 507.5 – 479.2
= **28.3** W/m^2

28 W/m² difference…

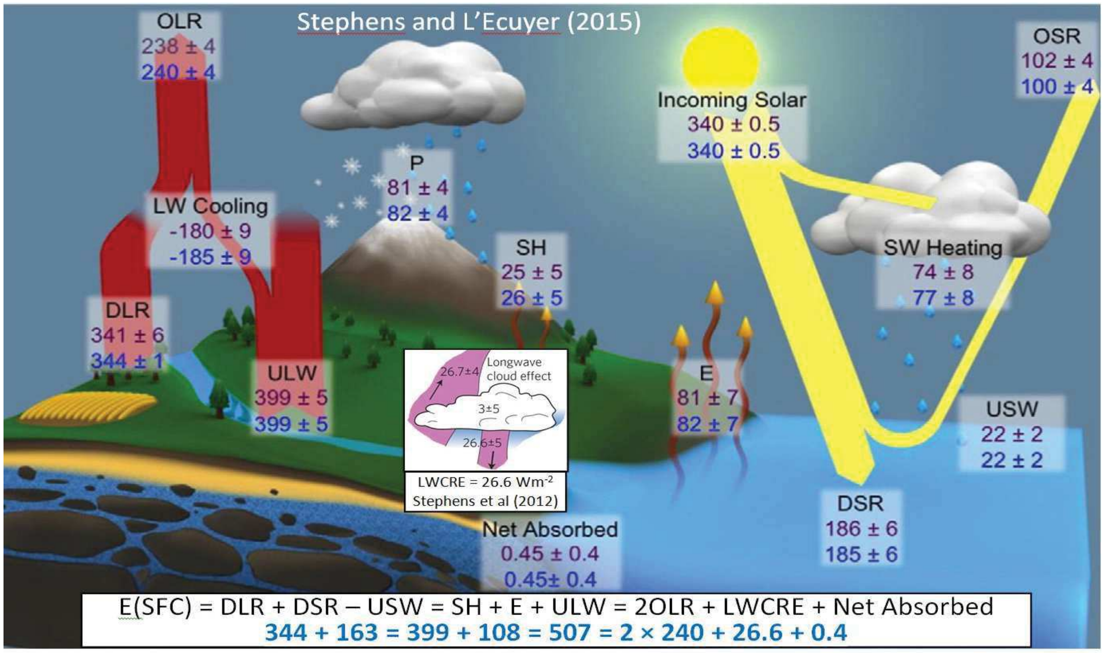
- How much was the cloud longwave radiative effect (LWCRE)?
- LWCRE = 28 W/m².
- What we have here it is this:
  SFC energy in (SW + LW) =
  = 2OLR(all) + SFC LWCRE.
- *Now THAT might be meaningful* :
- **The surface energy budget in the all-sky has the same form as in the clear-sky case, PLUS one LW cloud radiative effect.**

Pattern 4. E(SFC) = 2OLR(all) + LWCRE

CLIMYEAR	SW abs	LW abs	E(SFC)	OLR(all)	LWCRE	2OLR+LWCRE	Diff
CLIM 1	166.24	335.34	501.58	236.77	29.51	503.05	-1.47
CLIM 2	167.41	337.07	504.48	237.35	29.58	504.28	0.2
CLIM 3	166.63	339.65	506.28	237.72	28.92	504.36	1.92
CLIM 4	162.87	344.47	507.34	238.42	29.61	506.45	0.89
CLIM 5	157.84	349.06	506.9	240.24	28.64	509.12	-2.22
CLIM 6	155.25	353.3	508.55	242.38	28.25	513.01	-4.46
CLIM 7	156.65	355.73	512.38	243.71	28.18	515.6	-3.22
CLIM 8	160.25	355.1	515.35	243.66	28.23	515.55	-0.2
CLIM 9	163.49	350.65	514.14	242.11	28.5	512.72	1.42
CLIM 10	163.98	345.31	509.29	239.61	28.98	508.2	1.09
CLIM 11	163.53	339.77	503.3	237.15	29.86	504.16	-0.86
CLIM 12	164.09	336.33	500.42	236.28	29.75	502.31	-1.89
average	162.35	345.15	507.50	239.62	29.00	508.23	-0.73

SFC (SW in + LW in) = 2OLR(all) + LWCRE (-0.73 W/m²)

Stephens and L'Ecuyer 2015, Atmos Res
(my additions in white textboxes).



E(SFC, all) = LW in + SW in = 2OLR(all) + LWCRE + IMB - **0.05** (!!!) W/m^2

344 + 163 = 2 x 240 + 26.6 + 0.45 - 0.05

All-sky

All-sky	Ed2.8
TOA SW in	339.87
TOA SW up	99.62
TOA LW up	239.60
SFC SW down	186.47
SFC SW up	24.13
SFC SW in	162.34
SFC LW down	345.15
SFC SW + LW absorbed	**507.49**
SFC LW up	398.27
SFC Net	109.22
G	158.67
SFC LWCRE	28.88
2TOA LW Up + SFC LWCRE	**508.08**
Diff	–0.59

Ed2.8

SFC energy in

(SW + LW) =

= 162.34 + 345.15

= **507.49**

=

2 x TOA LW out

+ SFC LWCRE

= 2 x 239.6 + 28.88 =

508.08

Diff =

–0.59 W m^{-2}

Ed4.0

All-sky	Ed4.0
TOA SW in	340.04
TOA SW up	99.23
TOA LW up	240.14
SFC SW down	187.04
SFC SW up	23.37
SFC SW in	163.67
SFC LW down	344.97
SFC SW + LW absorbed	**508.64**
SFC LW up	398.34
SFC Net	110.30
G	158.20
SFC LWCRE	30.90
2TOA LW Up + SFC LWCRE	**511.18**
Diff	–2.54

All-sky, Ed4.0

Energy absorbed SFC ($W\ m^{-2}$):

SW in + LW in =
163.67 + 344.97 =
508.64

2 x OLR + SFC LWCRE =
2 x 240.14 + 30.90 =
511.18

Diff = **–2.54 W m^{-2}**

Ed4.0

Clear-sky	Ed4.0
TOA SW in	340.04
TOA SW up	53.41
TOA LW up	268.13
SFC SW down	243.72
SFC SW up	29.81
SFC SW in	213.91
SFC LW down	314.07
SFC SW + LW Absorbed	527.98
SFC LW Up	397.59
SFC Net	**130.39**
G	**129.46**
Diff	0.93

Clear-sky, Ed4.0
SFC Net = G

SFC Net =
SW in + LW in – LW up
= 528.0 – 397.6
= **130.4** W m^{-2}

G = ULW – OLR =
397.6 – 268.1
= **129.5** W m^{-2}

Diff = **0.9** W m^{-2}.

Ed4.0

Clear-sky: SFC Net = G

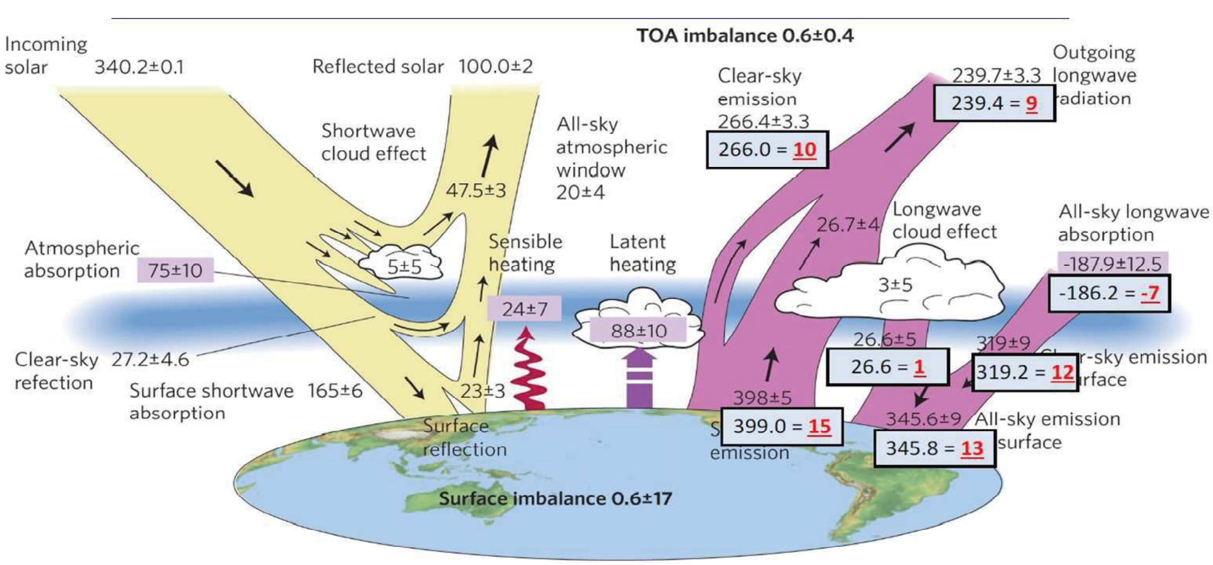
G =SFC Net - Diff	ULW clear	OLR clear	G clear	SFC Net	Diff
CLIM 1	388.08	265.08	123	139.01	16.01
CLIM 2	389.63	265.27	124.36	137.49	13.13
CLIM 3	393.06	266.02	127.04	132.44	5.4
CLIM 4	397.64	267.04	130.6	126.25	-4.35
CLIM 5	402.18	268.99	133.19	121.41	-11.78
CLIM 6	405.9	271	134.9	122.11	-12.79
CLIM 7	407.29	272	135.29	124.59	-10.7
CLIM 8	406.4	271.71	134.69	127.49	-7.2
CLIM 9	402.83	270.36	132.47	129.98	-2.49
CLIM 10	397.57	268.14	129.43	132.33	2.9
CLIM 11	392	265.95	126.05	134.61	8.56
CLIM 12	388.69	264.91	123.78	137.19	13.41
Average	397.606	268.039	129.57	130.41	0.84

SFC Net = SW in + LW in – LW up = 213.9 + 314.1 – 397.6 = **130.4** W m^{-2}

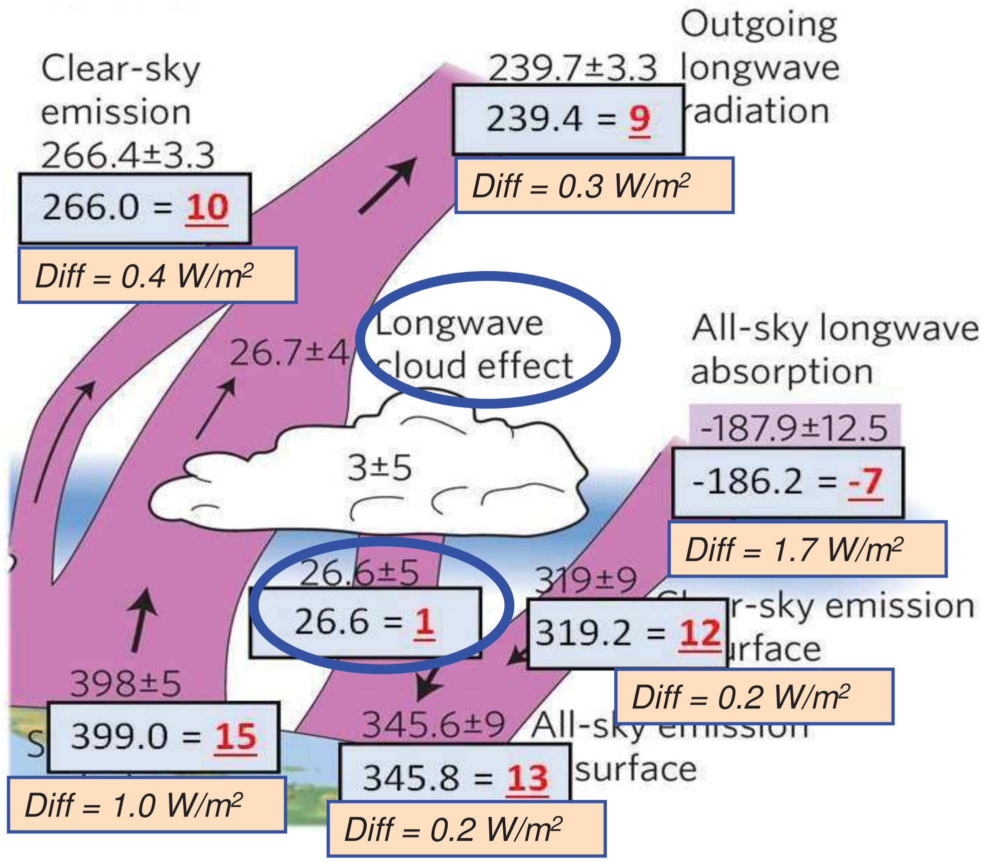
G = ULW – OLR = 397.6 – 268.0 = **129.6** W m^{-2}

Diff = = **0.8 W m^{-2}**

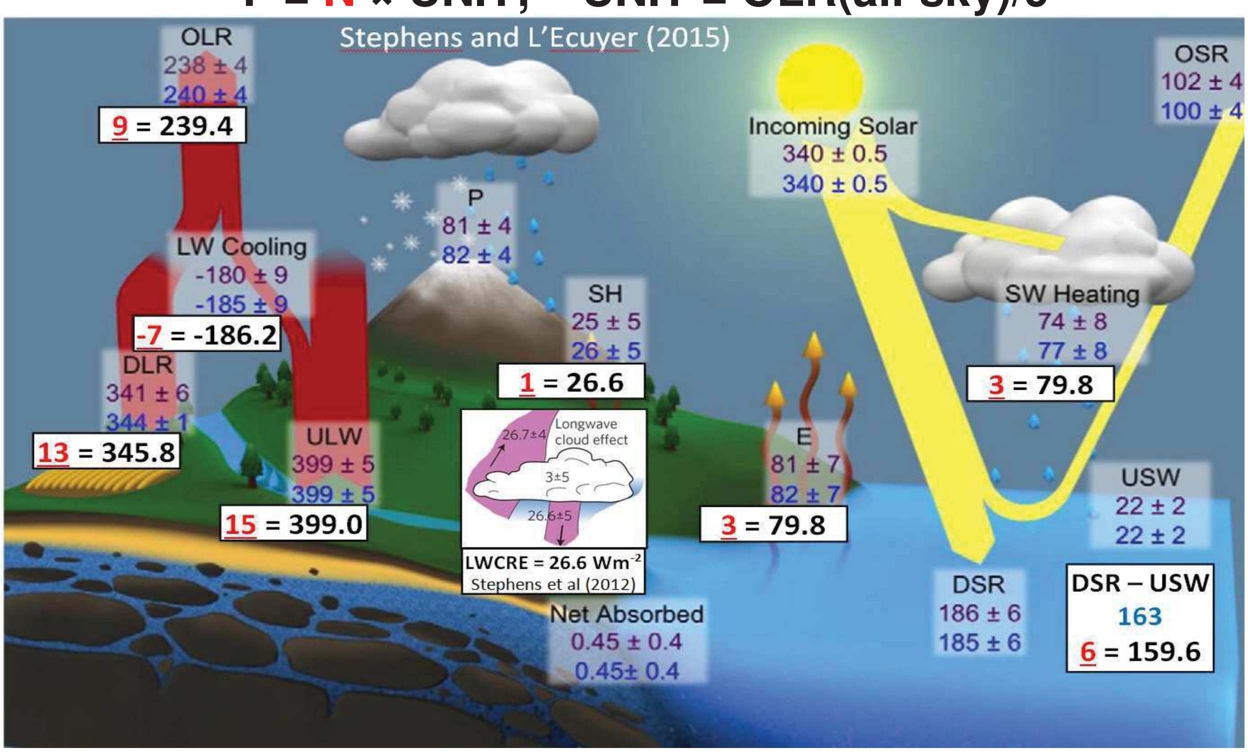
Pattern 5. All-sky integer ratios



Stephens et al. (2012)



$F = N \times \text{UNIT}$; $\text{UNIT} = \text{OLR(all-sky)}/9$



Is it possible
to satisfy all the patterns
with one data set?

Let's try.

Model data set: EdMZ
All-sky pattern positions

All-sky	Ed4.0	Ed2.8	EdMZ	Ed4.0 – EdMZ	Ed2.8 – EdMZ
TOA SW In	340.04	339.87	**340.04**	0.0	-0.27
TOA LW Up	240.14	239.60	**240.14**	0.0	-0.54
SFC SW In	163.67	162.34	**160.09**	3.58	2.25
SFC LW Down	344.97	345.15	**346.87**	-1.90	-1.72
SFC (SW in + LW in)	508.64	507.49	**506.96**	1.68	0.53
SFC LW Up	398.34	398.27	**400.23**	-1.89	-1.96
SFC Net	110.30	109.22	**106.73**	3.57	2.49
G	158.20	158.67	**160.09**	-1.89	-1.42
2TOA LW Up+LWCRE	511.18	508.08	**506.96**	4.22	1.12

EdMZ all-sky integer ratios

F = N × UNIT

UNIT = OLR(all-sky)/9

All-sky Flux	EdMZ	N
TOA SW In	**340.04**	
TOA SW Up	**99.60**	
TOA LW Up	**240.14**	**9**
SFC SW In	**160.09**	**6**
SFC LW Down	**346.87**	**13**
SFC (SW in + LW in)	**506.96**	**19**
SFC LW Up	**400.23**	**15**
SFC Net	**106.73**	**4**
G	**160.09**	**6**
SFC LWCRE	**26.68**	**1**
2 × TOA LW Up + LWCRE	**506.96**	**19**

Model data set: EdMZ
Clear-sky pattern positions

Clear-sky	Ed4.0	Ed2.8	EdMZ	Ed4.0 – EdMZ	Ed2.8 – EdMZ
TOA SW in	340.04	339.87	**340.04**	0.0	-0.17
TOA LW up	268.13	265.59	**266.82**	1.31	-1.23
SFC SW in	213.91	214.32	**213.47**	0.44	0.85
SFC SW + LW in	527.98	530.59	**533.65**	-5.67	-3.06
SFC LW up	397.59	398.40	**400.23**	-2.64	-1.83
SFC Net	130.39	132.19	**133.42**	-3.03	-1.23
G	129.46	132.81	**133.42**	-3.96	-0.61

EdMZ clear-sky integer ratios

F = N × UNIT

UNIT = OLR(clear-sky)/4

Clear-sky Flux	EdMZ	N
TOA SW In	340.04	
TOA LW Up	266.82	4
ATM emitted Up	200.11	3
STI	66.7	1
SFC (SW + LW) In	533.65	8
SFC LW Up	400.23	6
SFC Net	133.42	2
G	133.42	2

Clear-sky fluxes in all-sky units

F = N × UNIT(all-sky)

Clear-sky Flux	EdMZ	N
TOA SW In	340.04	
TOA LW Up	266.82	10
SFC SW In	213.47	8
SFC LW Down	320.18	12
SFC (SW + LW) In	533.65	20
SFC LW Up	400.23	15
SFC Net	133.42	5
G	133.42	5
TOA LWCRE (UNIT)	26.68	1

The patterns as integers

Pattern1 (clear-sky): SFC (SW + LW) (in) = 2 × OLR
8 + **12** = 2 × **10**

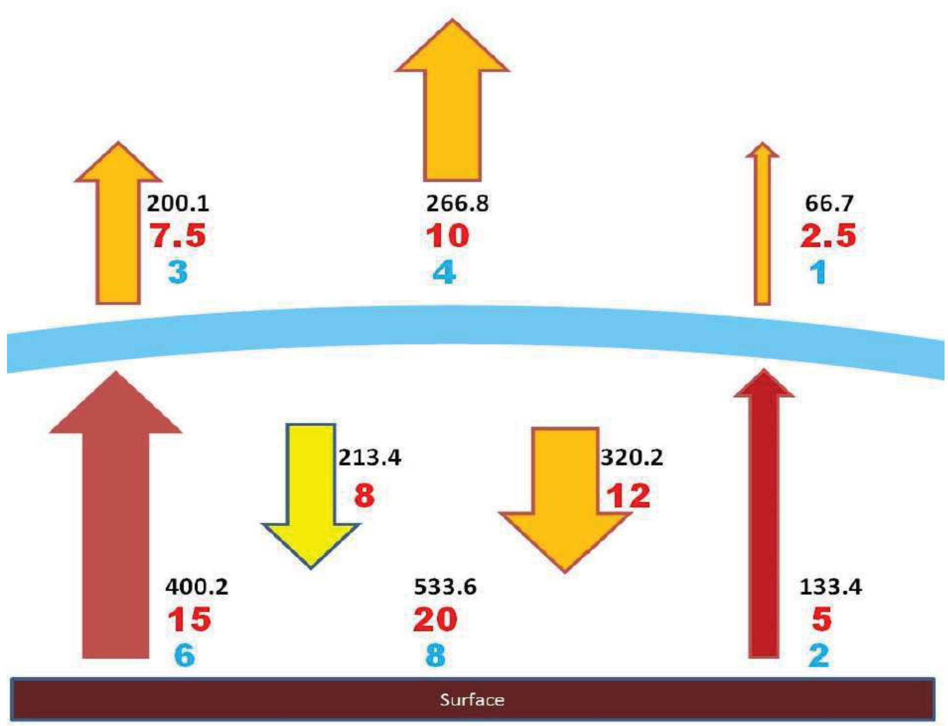
Pattern 2 (clear-sky):SFC Net = ULW – OLR = G
20 – **15** = **15** – **10** = **5**
8 – **6** = **6** – **4** = **2**

Pattern3 (clear-sky): STI / G / ATM / OLR / ULW / E(SFC)
1 / **2** / **3** / **4** / **6** / **8**

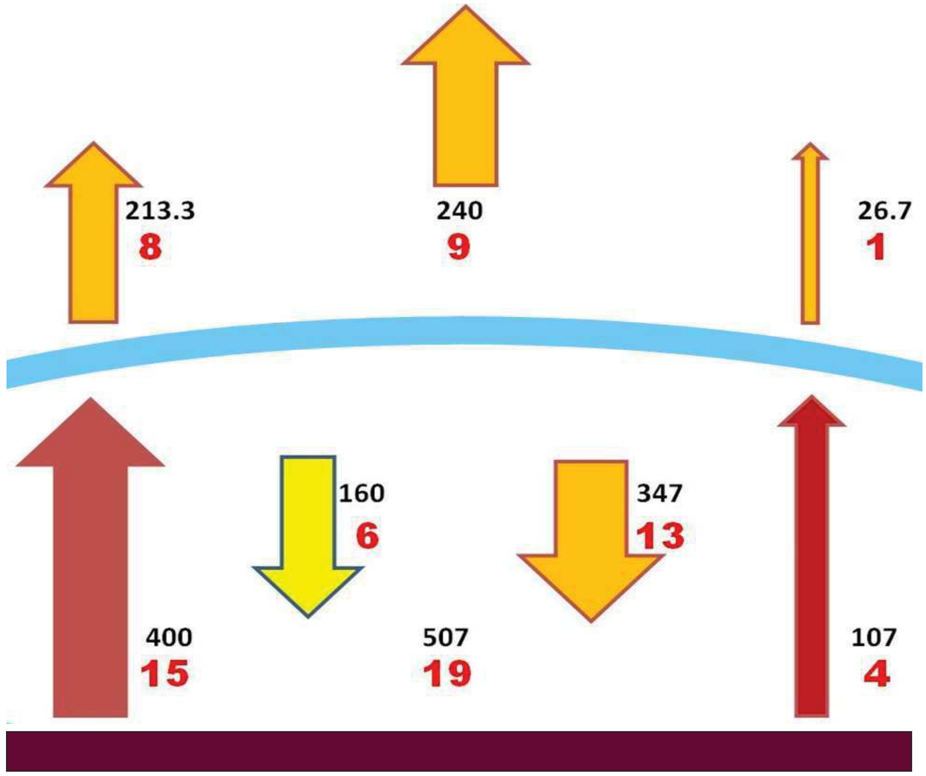
Pattern4 (all-sky): SFC (SW + LW) (in) = 2OLR + LWCRE
6 + **13** = 2 × **9** + **1**

Pattern5 (all-sky): F = **N** × UNIT, UNIT = OLR(all-sky) / 9.

CLEAR SKY basics: g = (15 – 10) /15 = **5/15** = 1/3



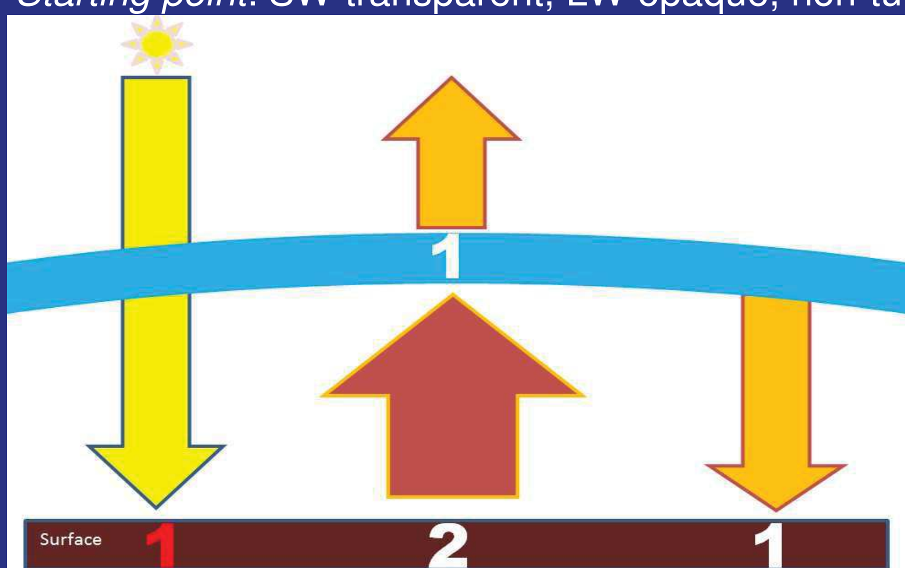
ALL SKY basics: g = (15 – 9) /15 = **6/15** = 0.4



Deduction of EdMZ

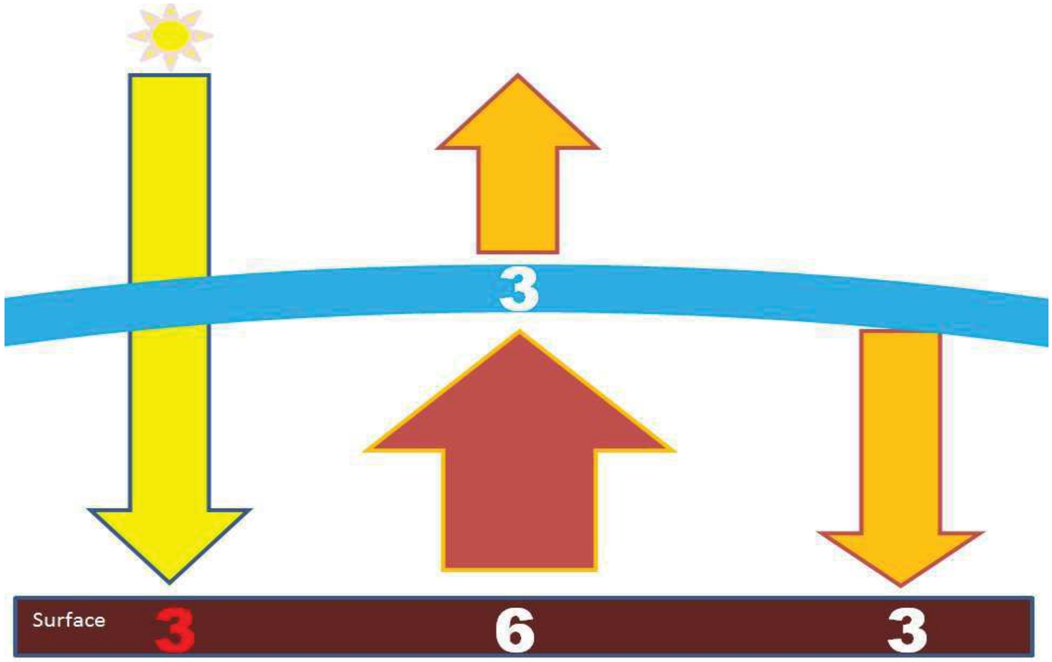
from the Closed Shell Geometry

Step 0 *Starting point*: SW-transparent, LW-opaque, non-turbulent



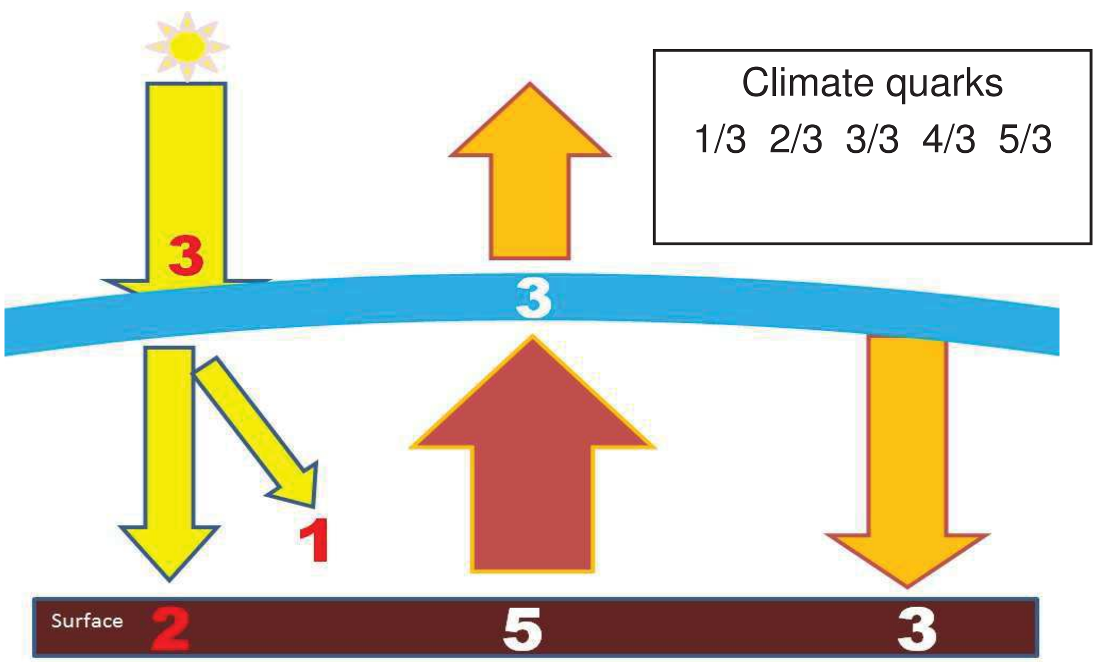
Solar Absorbed Surface (SAS) = 1 goes into G = ULW – OLR = 1

Step 1 *Unit change*: 1 => 3



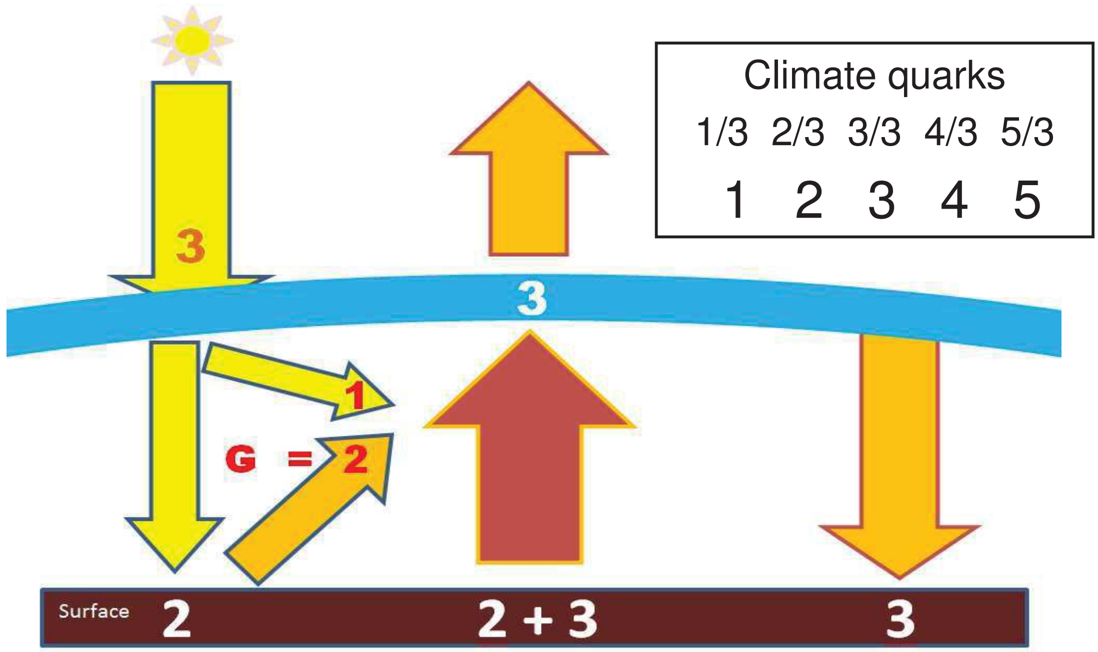
Solar Absorbed Surface (SAS) = 3 goes into G = ULW – OLR = 3

Step 2 *Allow* **ONE** *atmospheric SW-absorption: SAA = 1, SAS = 2*



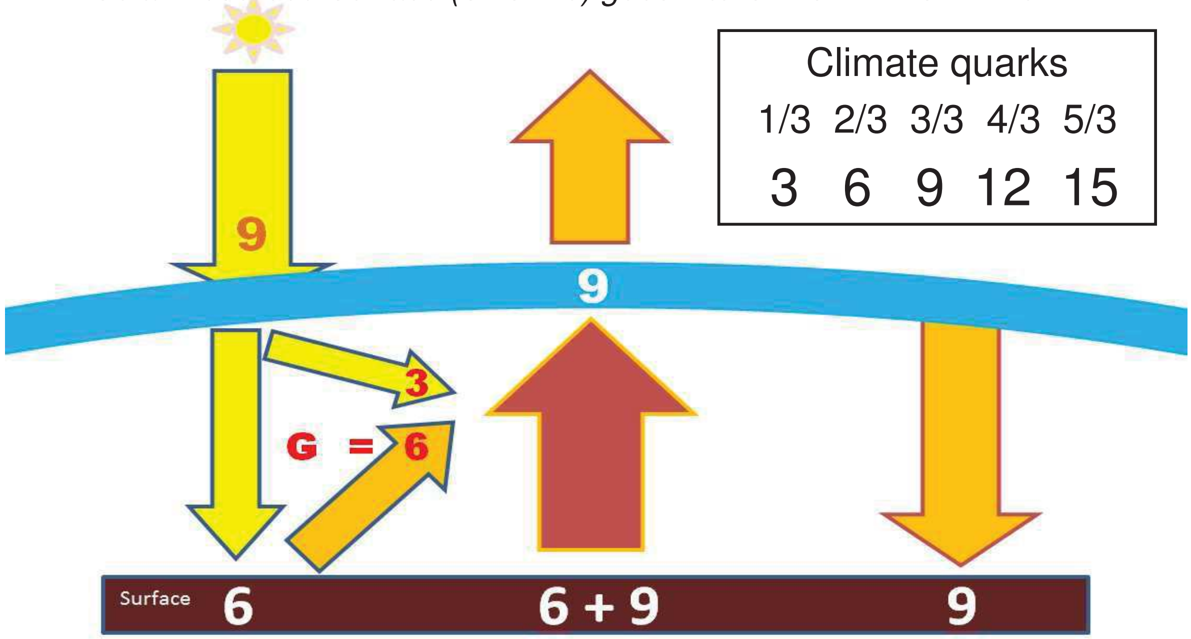
Solar Absorbed Atmosphere (SAA) = 1, Solar Absorbed Surface (SAS) = 2

Step 3 *Solar Absorbed Surface (SAS = 2) goes into **G** = ULW – OLR = 2*



'SAS = G' property kept

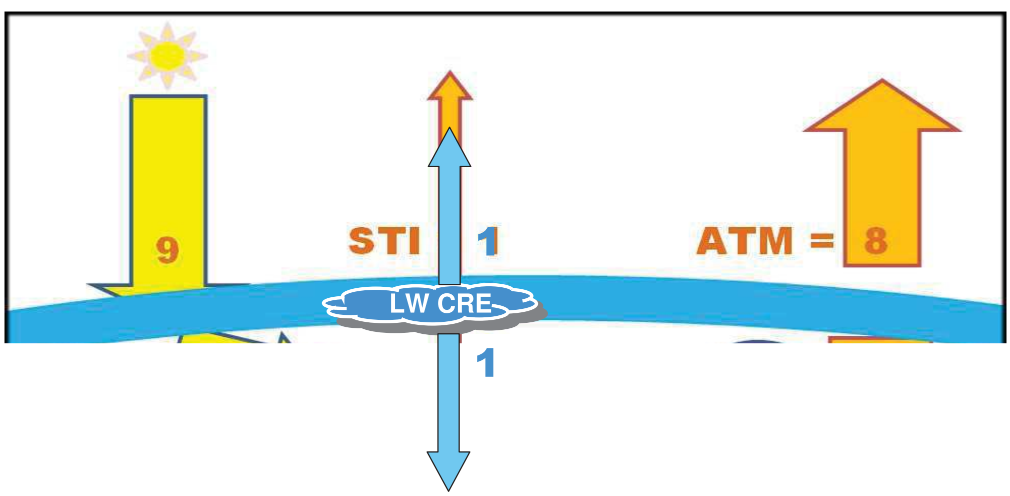
Step 4 *Unit change: 3 => 9.*
*Solar Absorbed Surface (SAS = 6) goes into **G** = ULW – OLR = 6*



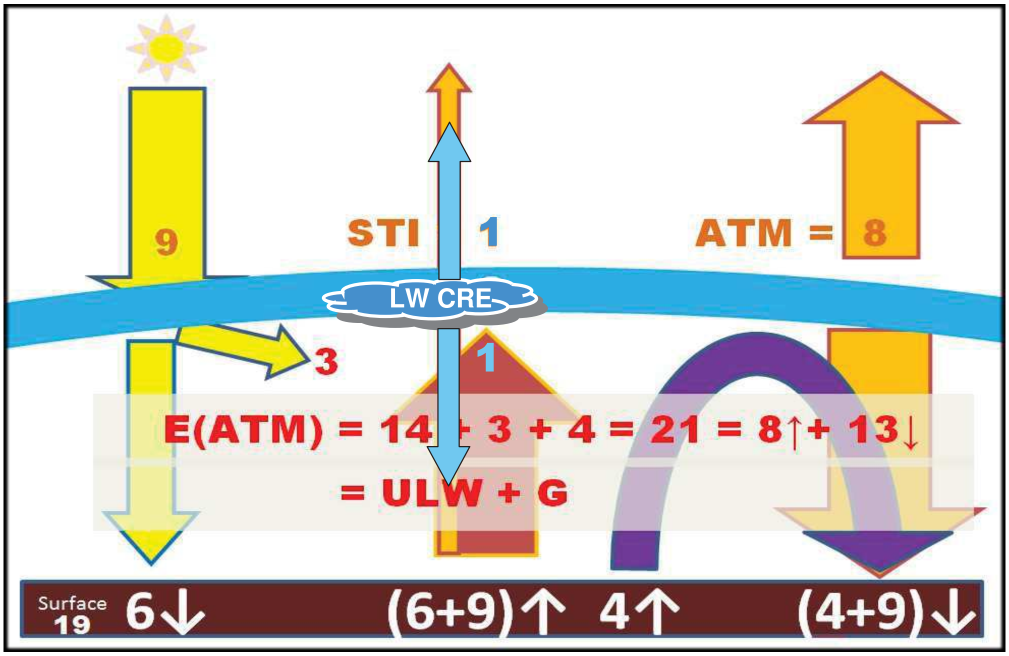
SAS (6) = G (6)

Step 5 *Allow* **ONE** *partial LW-transparency …*

Step 6 *… fade the window with* **ONE** *up and down LW cloud effect*

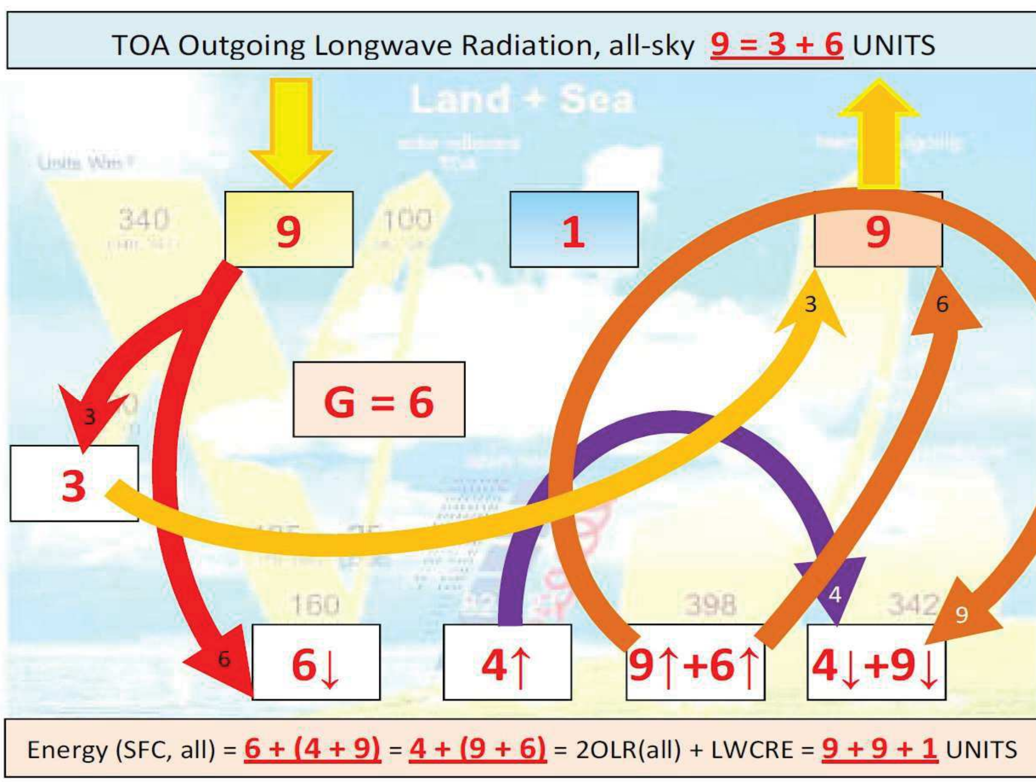


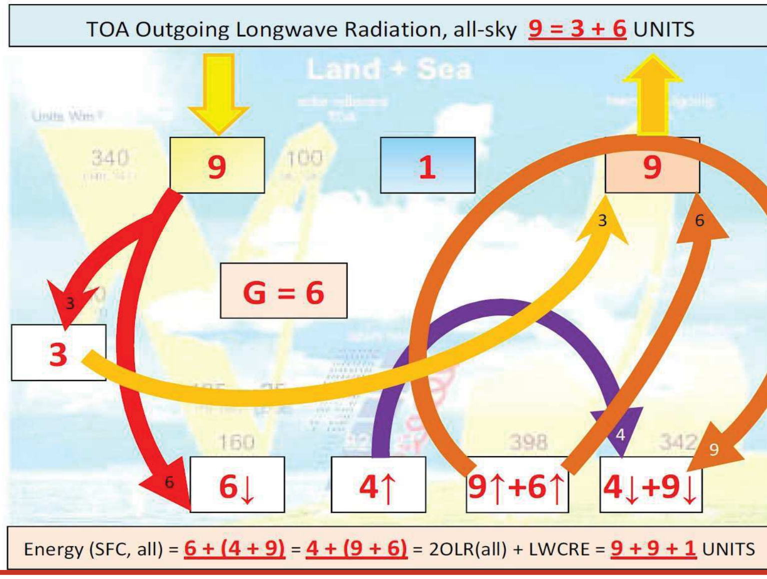
Step 7 *… and close the balance with turbulence*.
Atmosphere: E(SFC) + 2 UNITS = 21 = emitted up (8) + down (13)



Surface: E(SFC) = 2 OLR + 1 UNIT = 19

The pattern. *Basic energy flow routes and integer rates*.



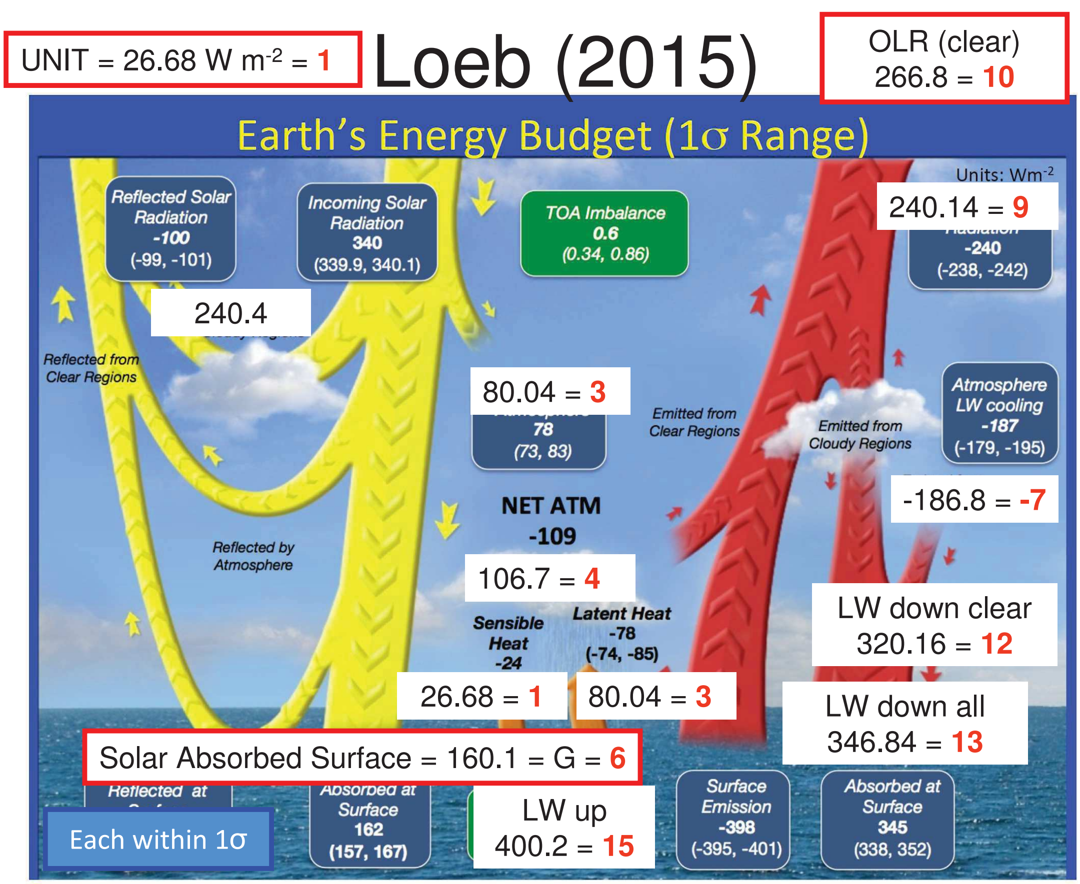


ASR = OLR = **9** = 240, SAA = **3** = 80, SAS = **6** = 160

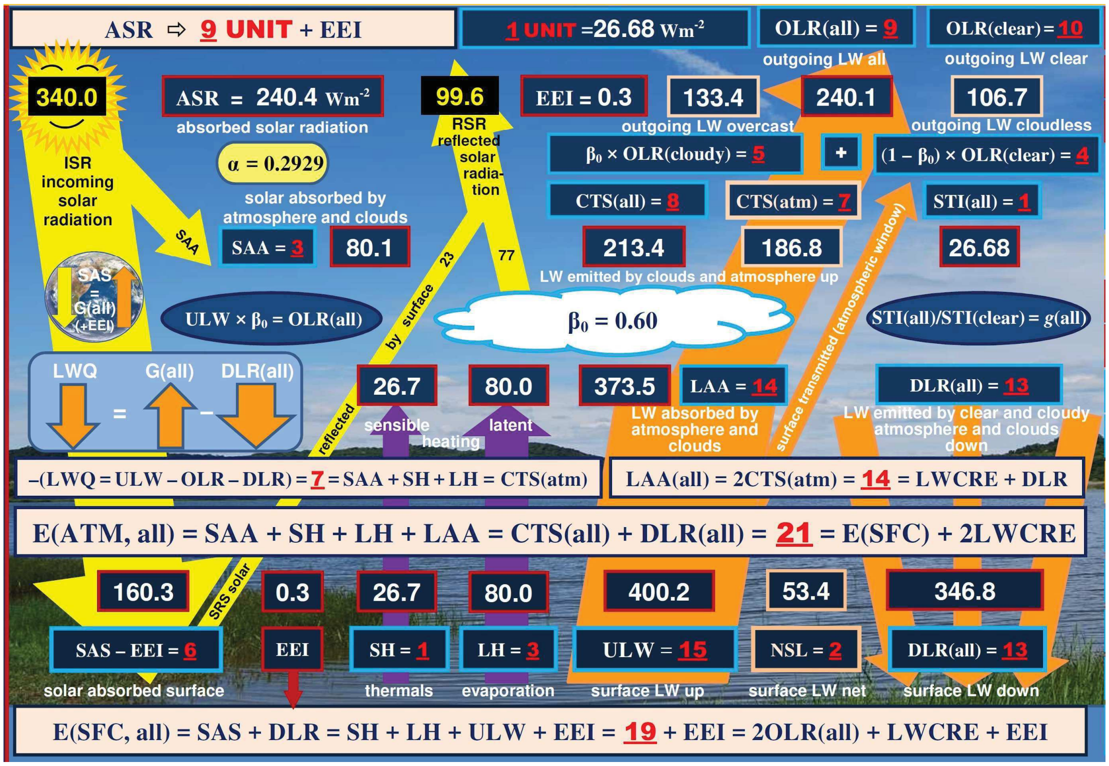
ULW = **15** = 400, G = **6** = 160, SFC Net = **4** = 107

DLR = **13** = 346, LW Cooling = **-7** = -187

1 = UNIT = 26.68 (W m^{-2})



EdMZ with ISR = 340.0 and OLR = 240.1 Wm^{-2}



Specific geometries

Moon (zero)		
ULW – G = OLR	G = 0	g = 0
ULW + G = OLR	ULW = OLR	t = 1
Mars (intermediate, free)		
ULW – G = OLR	G = 0.118 OLR	g = 0.106
ULW + G = 1.236 OLR	ULW = 1.118 OLR	t = 0.732
Earth (clear-sky) (level one)		
ULW – G = OLR	G = (1/2) OLR	g = 1/3
ULW + G = 2OLR	ULW = (3/2) OLR	t = 1/6
Earth (all-sky) (level two)		
ULW – G = OLR	G = (2/3) OLR	g = 2/5
ULW + G = (7/3) OLR	ULW = (5/3) OLR	t = 1/15
Shield (level three)		
ULW – G = OLR	G = OLR	g = 1/2
ULW + G = 3OLR	ULW = 2OLR	t = 0

t = STI/ULW, atmospheric LW transmittance

SW

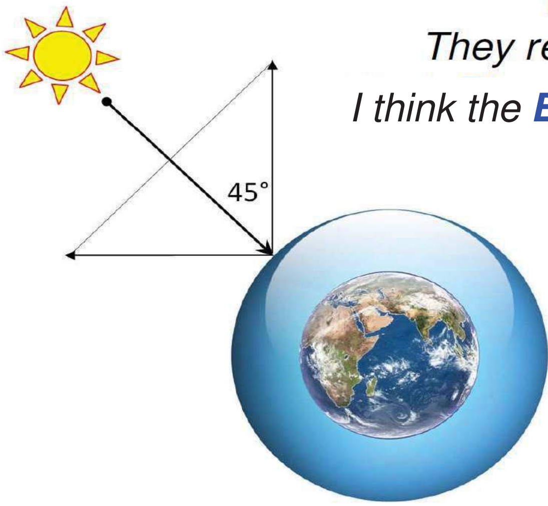
The albedo of Earth

Reviews of Geophysics

Graeme L. Stephens[1,2,3], Denis O'Brien[4], Peter J. Webster[5], Peter Pilewski[6,7], Seiji Kato[8], and Jui-lin Li[1]

"surprising" hemispheric symmetry and
"remarkable" interannual stability
of the system albedo.
Why?
*They refer to **Gaia**.*

*I think the **Blue Marble** (Glass Shell) is better:*

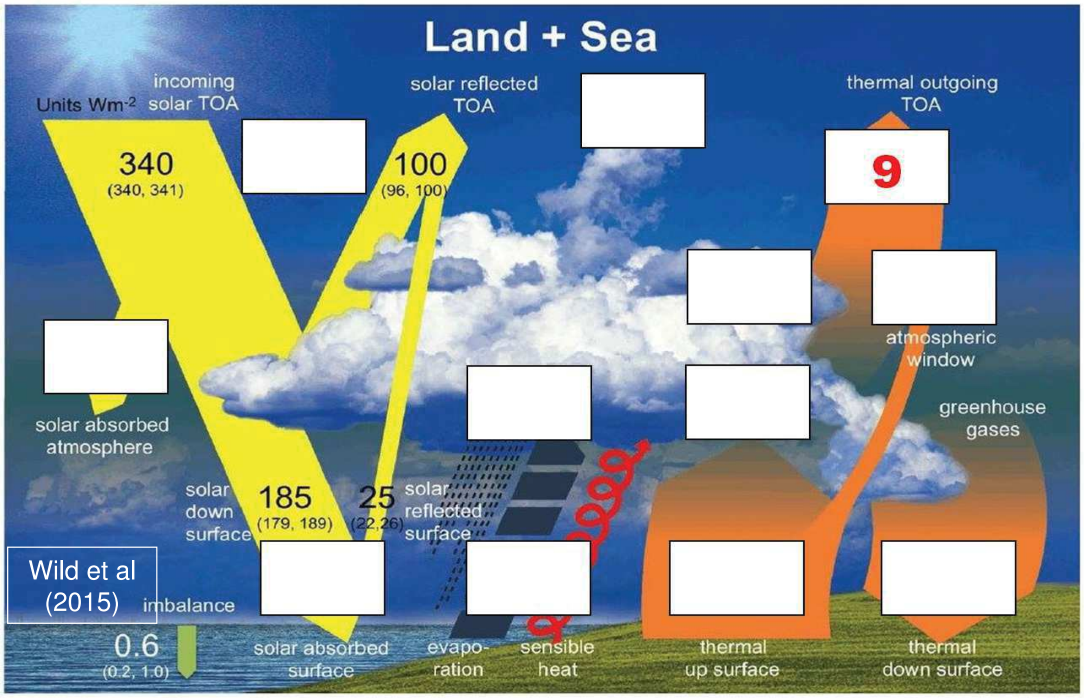


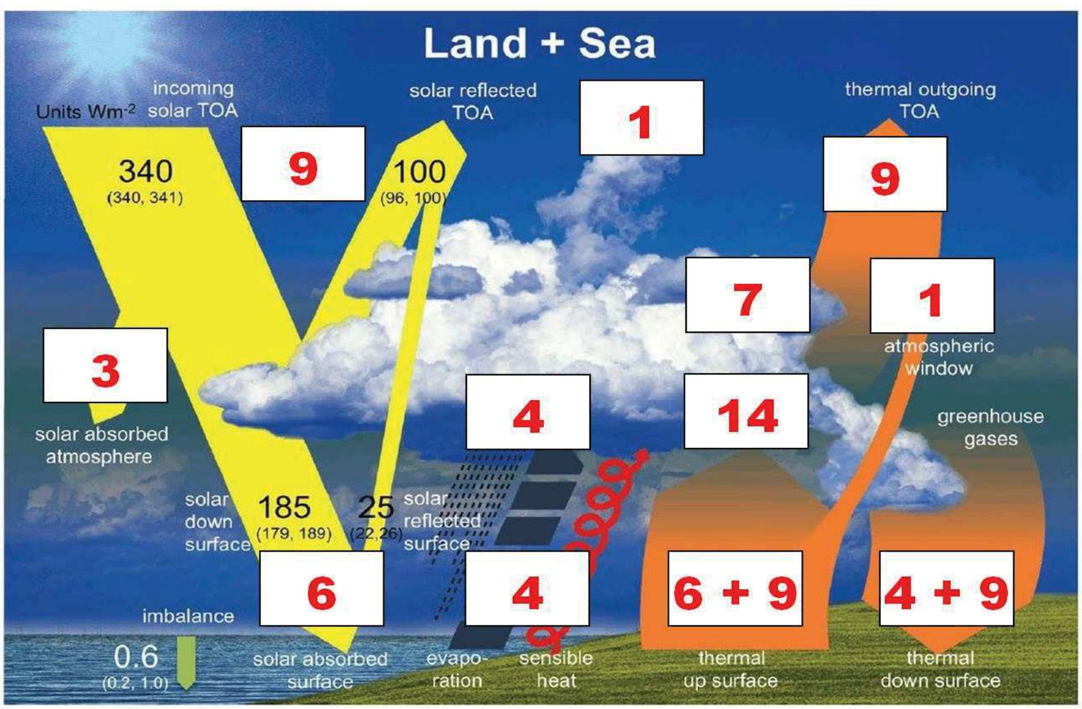
$$\alpha_0 = 1 - \sin 45°$$
$$= 1 - \sqrt{2}/2$$
$$= 0.292893$$

CERES - EBAF Data
Time Range: January to December - CLIMATE YEAR
Time Resolution: CLIM
Valid Range: 0 - 800

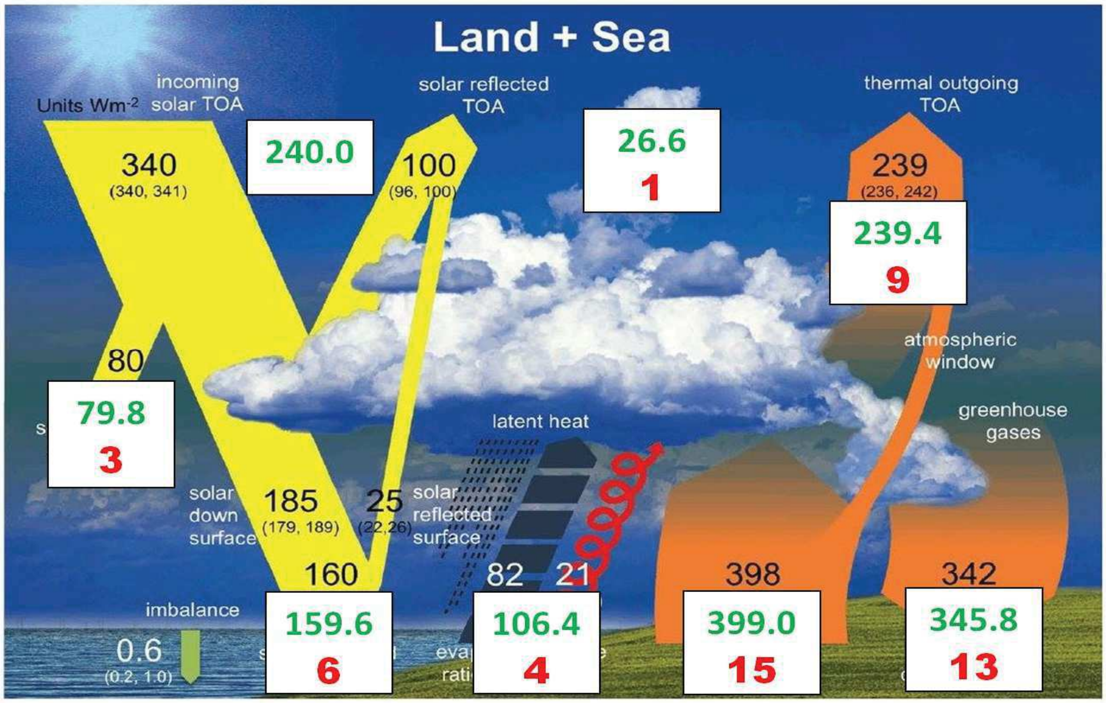
Incoming Solar Flux (W m-2)		TOA Shortwave Flux All-Sky (W m-2)	Albedo
CLIM 1	350.69	106.26	0.30300265
CLIM 2	348.15	102.27	0.29375269
CLIM 3	343.98	99.31	0.28870865
CLIM 4	337.54	97.44	0.2886769
CLIM 5	332.3	97.45	0.2932591
CLIM 6	329.24	96.39	0.29276516
CLIM 7	328.89	93.93	0.28559701
CLIM 8	331.43	92.62	0.27945569
CLIM 9	336.78	94.79	0.28145971
CLIM 10	342.04	100.24	0.29306514
CLIM 11	347.05	106.18	0.30595015
CLIM 12	350.34	108.29	0.30909973
AVERAGE	339.8692	99.5975	**0.29289938**

Climate sudoku





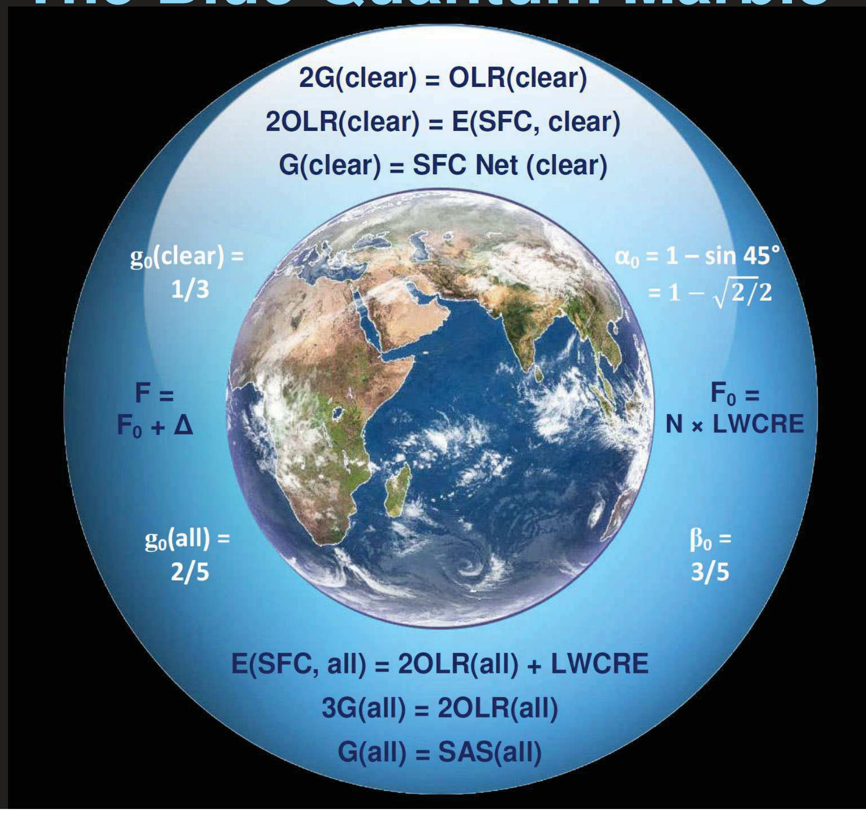
$\mathbf{1}$ = 26.6 W/m^2, Δmax(Wild-EdMZ) = -3.8 W/m^2 (DLR)

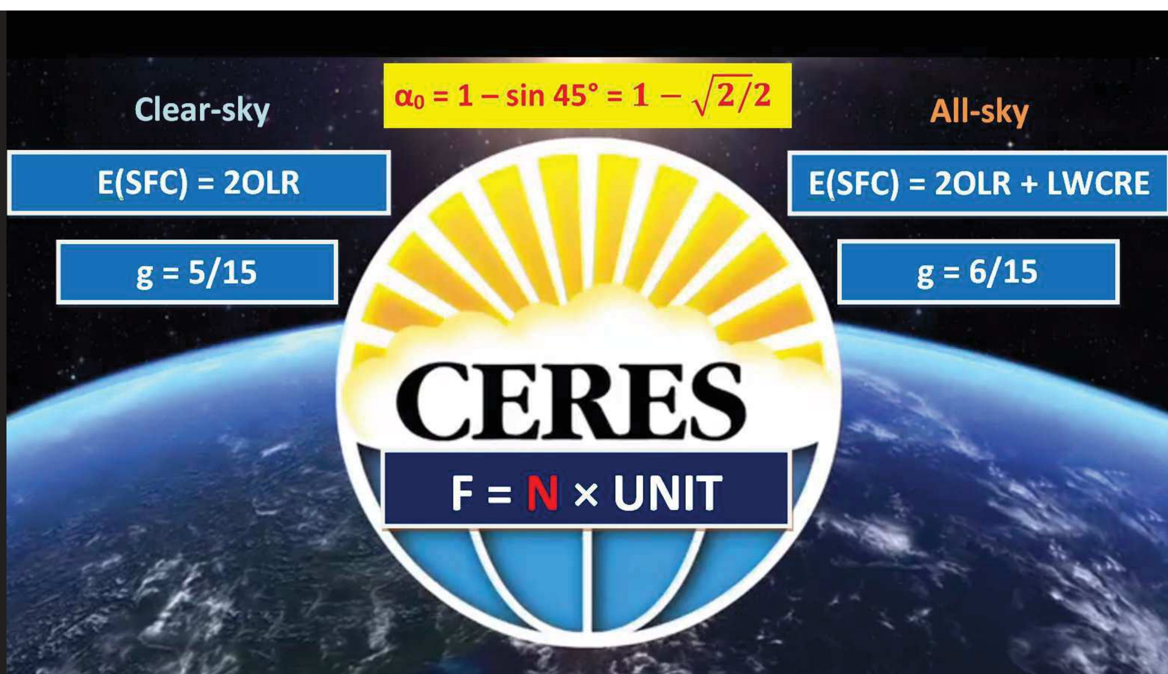


Summary

- There are robust patterns in the annual global means.
- EdMZ is an idealized data set representing the pattern, belonging to a time-independent geometry.
- The integer ratios follow from the closed-shell geometry.
- The corresponding physical state has some reasonable theoretical basis.
- The largest bias between Ed4.0 and EdMZ is -6.1 Wm^{-2} (2%) in DLR(clear) and 3.6 Wm^{-2} (2.2%) in SFC SW(all).
- Size and time-scale of fluctuations around — or systematic deviations from — the pattern positions are not yet known.

The Blue Quantum Marble





Thank you CERES Science and Data Teams!

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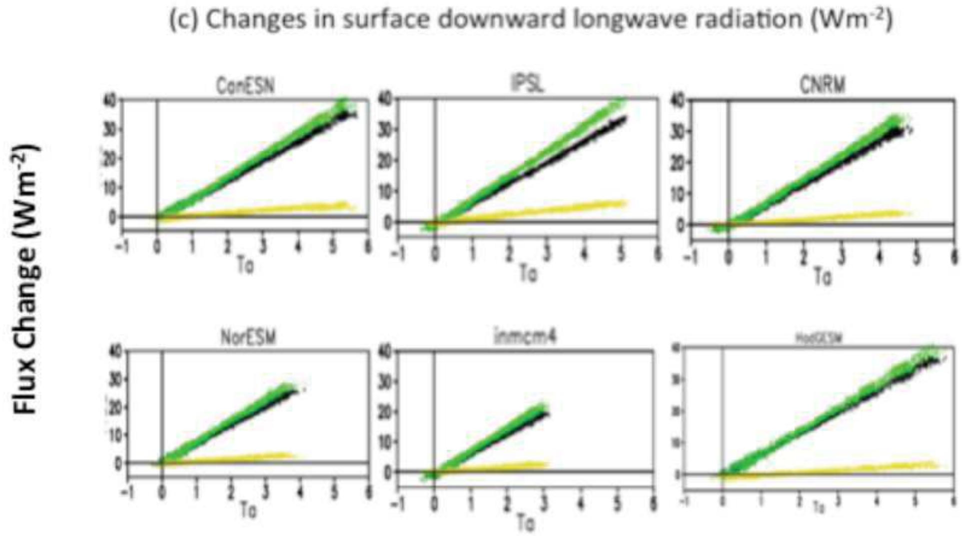
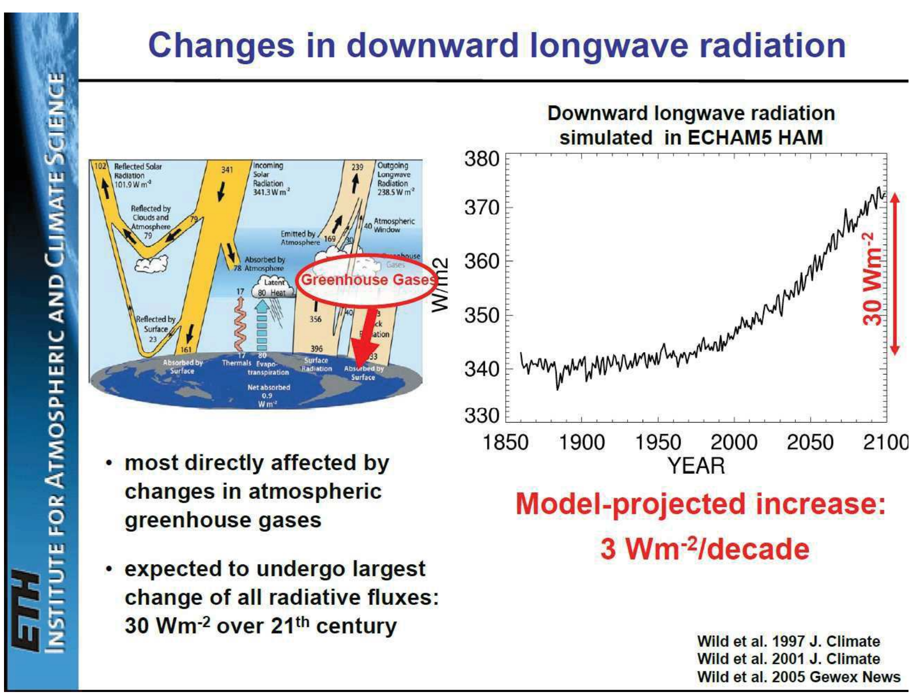
Backup slides

30 Wm^{-2} CMIP5 model projected increase in DLR



Stephens et al. (2012) Nat Geosci Suppl Fig S2 (c)

30 Wm^{-2} increase in DLR would falsify EdMZ



$F = F_0 + \Delta F$ Global energy budget, flux integer tables and the greenhouse effect of clouds $F_0 = I \times UNIT$

GREENHOUSE METRICS UNITS

G(all) – G(clear) = OLR(clear) – OLR(all) = LWCRE ≡ 1 UNIT = 26.6 Wm^{-2} ⇨ ULW = 15 OLR(clear) = 10 G(clear) = 5

G(cloudy) – G(clear) = OLR(clear) – OLR(cloudy) = LWCRE / β_0 ≡ 1 UNIT = 44.33 Wm^{-2} ⇨ ULW = 9 OLR(clear) = 6 G(clear) = 3

1 / f_0(all) = 1 ; 1 / f_0(clear) = 1 = STI(clear) ≡ 1 UNIT = 66.5 Wm^{-2} ⇨ ULW = 6 OLR(clear) = 4 G(clear) = 2

Integer tables of Earth's energy flows. F_0 values in unit flux:

F_0 RELATIONSHIPS

- E(SFC, all) = 2OLR(all) + LWCRE = 2OLR(clear) – STI(all)

E(SFC, cloudy) = OLR(cloudy) + OLR(clear)

E(SFC, clear) = 2 OLR(clear)

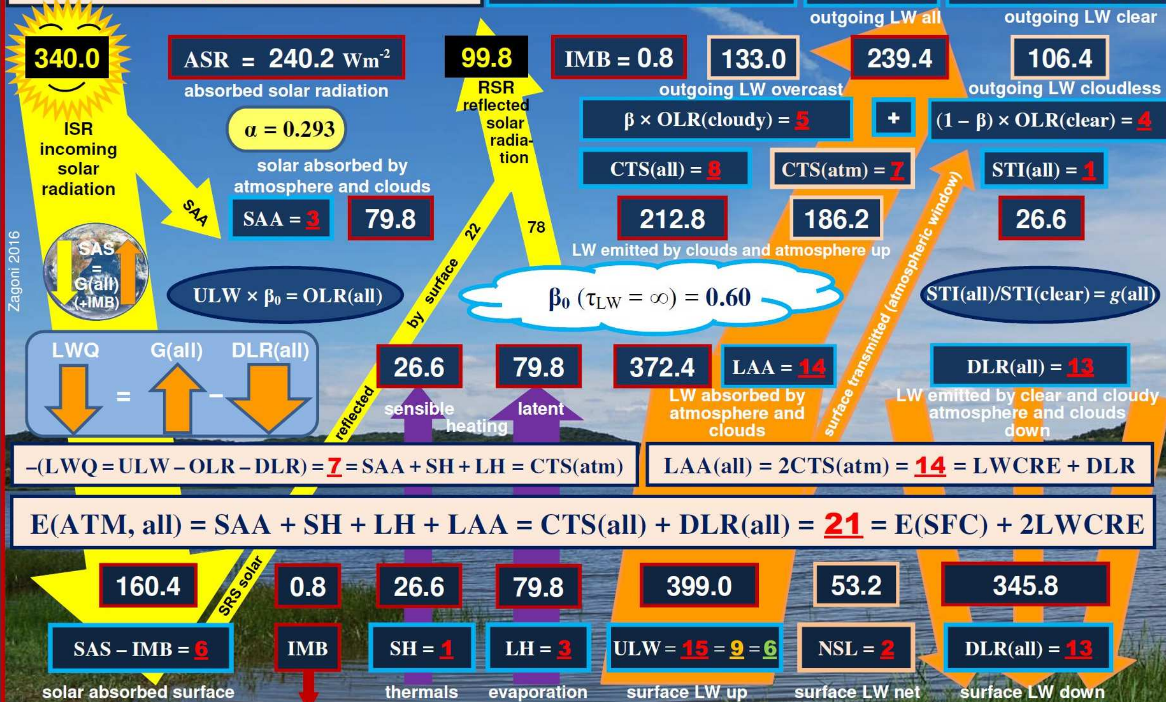
- Solar absorbed by surface serves the energy content of the all-sky greenhouse effect.
- The cloud-covered part of the surface radiates as much energy as in the outgoing longwave radiation: ULW × β = OLR(all)
- 'Cooling to space':

All-sky: LWQ + CTS(atm) = 0, LWQ + CTS(all) = LWCRE.

Cloudy sky: β × [LWQ + CTS(atm, cloudy)] = –LWCRE /5

Clear-sky: (1 – β) × [LWQ + CTS(clear)] = LWCRE / 5

- The effective LW-opaque single-layer cloud area fraction is equal to the all-sky transfer function, f_0(all) = β_0, and f_0(all) × f_0(clear) = g_0(all).
- Clouds cool the surface in the SW, warm it in the LW. The warming effect, LWCRE, is compensated by an equivalent amount of energy being lost in the open atmospheric window: LWCRE = (1 – β) × STI(clear).
- A 'grid' albedo position is $\alpha_0 = 1 - \sqrt{2}/2$
- F observed data ⇨
- Their sources ⇨



E(SFC, all) = SAS + DLR = SH + LH + ULW + IMB = 19 + IMB = 2OLR(all) + LWCRE + IMB

OLR(clear) = 266.0	
CTS(clear) = 199.5	
STI(clear) = 66.5	
CTS(clear)/ULW=1/2	
STI(clear)/ULW=1/6	
G ≡ ULW – OLR	
G(clear) = 133.0	
G(all) = 159.6	
G(clear) = 5 = 3 = 2	
G(all) = 6	
g ≡ G / ULW, f ≡ OLR / ULW	
g_0(clear) = 1/3	
g_0(all) = 2/5	
f_0(clear) = 2/3	
f_0(all) = 3/5	
f_0(all) = β_0	

ALL-SKY: 26.6 Wm^{-2}

STI(all)	= 1	= 26.6
LWCRE	= 1	= 26.6
SH	= 1	= 26.6
NSL(all)	= 2	= 53.2
LH	= 3	= 79.8
SAA(all)	= 3	= 79.8
G(clear)	= 5	= 133.0
G(all)	= 6	= 159.6
SAS(all)	= 6	= 159.6
–LWQ	= 7	= 186.2
CTS(atm)	= 7	= 186.2
CTS(all)	= 8	= 212.8
OLR(all)	= 9	= 239.4
OLR(clear)	= 10	= 266.0
DLR(clear)	= 12	= 319.2
DLR(all)	= 13	= 345.8
LAA(all)	= 14	= 372.4
ULW	= 15	= 399.0

CLOUDY: 44.33 Wm^{-2}

STI(cloudy)	= 0	
LWCRE / β_0	= 1	= 44.33
(SH+LH)(cloudy)	= 2	= 88.66
G(clear)	= 3	= 133.0
G(cloudy)	= 4	= 177.33
CTS(atm, cloudy)	= 4	= 177.33
CTS(all, cloudy)	= 5	= 221.66
OLR(cloudy)	= 5	= 221.66
OLR(clear)	= 6	= 266.0
LAA(cloudy)	= 9	= 399.0
ULW	= 9	= 399.0

CLEAR-SKY: 66.5 Wm^{-2}

STI(clear)	= 1	= 66.5
(SH + LH)(clear)	= 2	= 133.0
G(clear)	= 2	= 133.0
CTS(clear)	= 3	= 199.5
OLR(clear)	= 4	= 266.0
LAA(clear)	= 5	= 332.5
ULW	= 6	= 399.0

CLEAR-SKY WEIGHTED CONTRIBUTION

f(clear) = OLR(clear) / ULW = 2/3 ⇨ STI(clear) = 1; G(clear) = 2; CTS(clear) = 3; OLR(clear) = 4; LAA(clear) = 5; ULW = 6

(1–β) × G(clear) = 2; (1–β) × CTS(clear) = 3; (1–β)×OLR(clear) = 4; (1–β) × LAA(clear)=G(clear) = 5 ; (1 – β) × ULW = G(all) = 6

LWQ + CTS(clear) = LWCRE / 2 = + 13.3 Wm^{-2}; (1–β) × [LWQ + CTS(clear)] = LWCRE / 5 = 1 / 5 = + 5.32 Wm^{-2}

CLOUDY WEIGHTED CONTRIBUTION

f(cloudy) = OLR(cloudy)/ULW = 5/9 ⇨ G(clear) = 3; CTS(atm, cloudy)= G(cloudy)= 4; OLR(cloudy)= 5; OLR(clear)= 6; ULW = 9

β × G(cloudy) = 4 ; β × CTS(atm, cloudy) = 4 ; β × OLR(cloudy) = 5 ; β × LAA(cloudy) = OLR(all) = 9 ; β × ULW = OLR(all) = 9

LWQ + CTS(atm, cloudy) = – LWCRE / 3 = – 8.86 Wm^{-2}; β × [LWQ + CTS(atm, cloudy)] = – LWCRE / 5 = – 1 / 5 = – 5.32 Wm^{-2}

LWQ = – 186.3 ± 6 SAS = 160.1 ± 6	SH = 25 ± 4 LH = 81 ± 4	ULW = 398.8 ± 4 NSL = 53.5 ±5 OLR(all) = 239.8 ± 2 OLR(clear) =266.4 ± 4	DLR = 345.3 ± 5 STI(clear) = 66 ± 2	β = 0.605 ± 0.01 g(clear) = 1/3
CERES EBAF Ed2.7 Wild et al. 2015	L'Ecuyer et al. 2015	CERES EBAF Ed2.7 Wild et al. 2015	CERES EBAF Ed2.7 Costa and Shine 2012	CERES SYN1deg Ed3A Ramanathan-Inamdar 2006

$\Delta F < \pm 1\sigma$