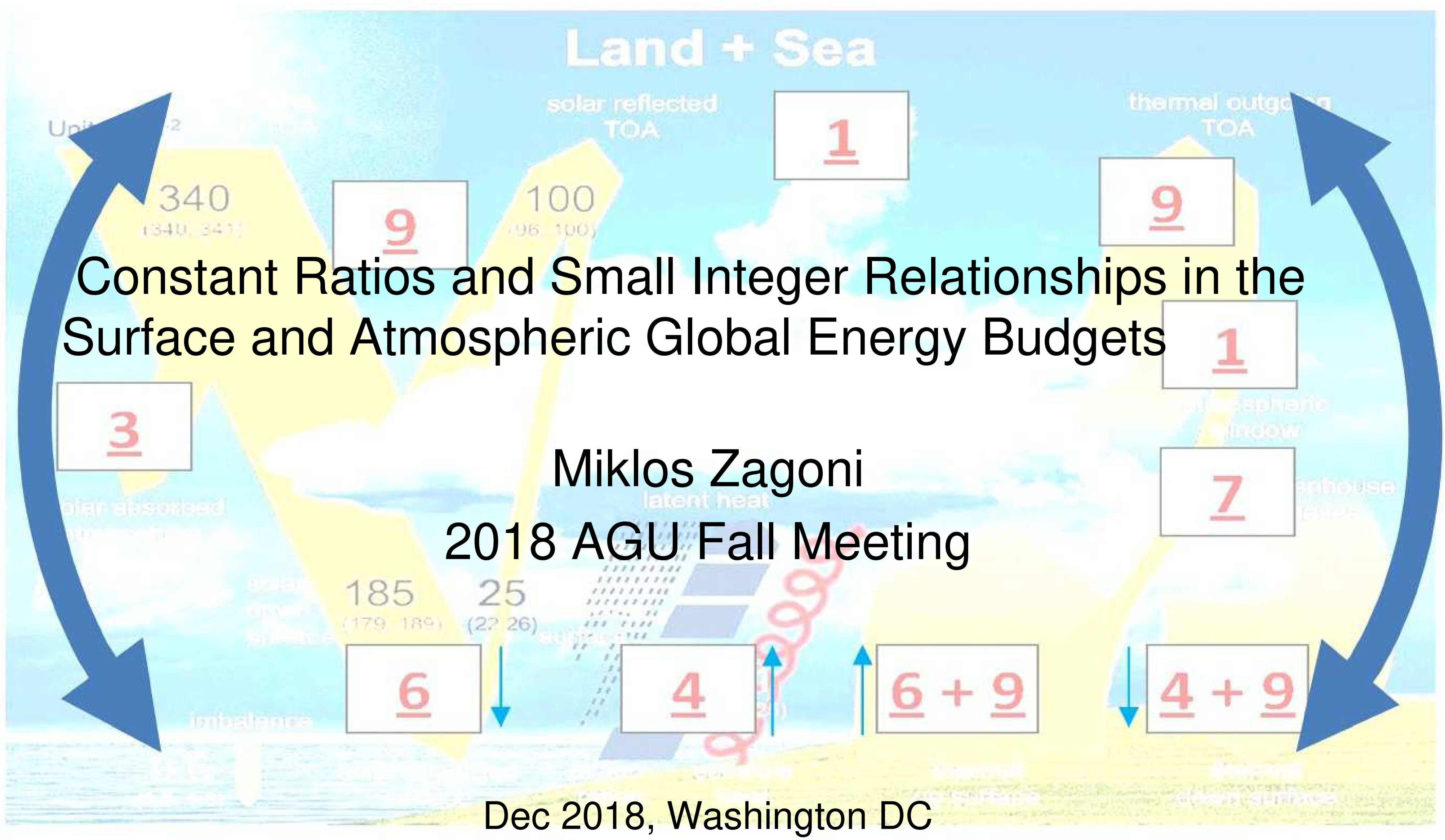
Let’s talk about DLR



Constant Ratios and Small Integer Relationships in the Surface and Atmospheric Global Energy Budgets

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2018 AGU Fall Meeting

Dec 2018, Washington DC

$F = N \times \text{UNIT}$

- One of the most interesting discoveries in the recent years at NASA is the quantal structure of the fluxes in the annual global mean.
- It is documented in several CERES data sets (EBAF Ed2.8, Ed4.0), and can be revealed also in other, independent global energy budget estimates such as Stephens et al. (2012), Wild et al. (2015), Stephens and L'Ecuyer (2015); Clear-sky: Costa and Shine (2012) computation, Wild et al. (2018), etc.

Energy SFC (SW in + LW in)

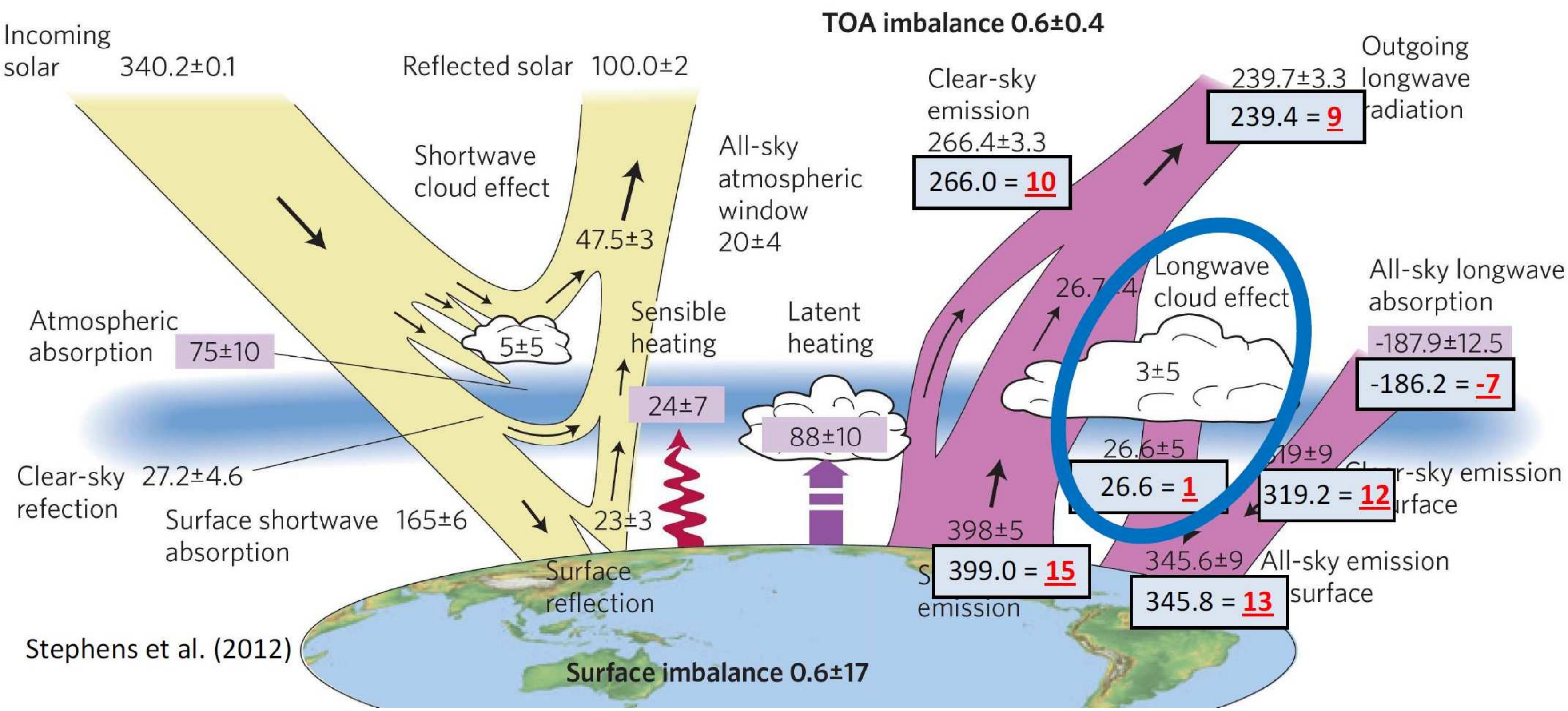
- This small integer system is not the deepest level of reality, only the *facet* of something more fundamental:
- Direct surface/TOA energetic relationships exist, expressing the following constraints:
- Energy SFC (SW + LW) in = 2OLR in the clear-sky, and
- = 2 OLR + LWCRE in the all-sky mean.

Stephens et al. (2012)

ATM + DLR = ASR + OLR(all) + 2LWCRE = 2OLR(clear) + IMB

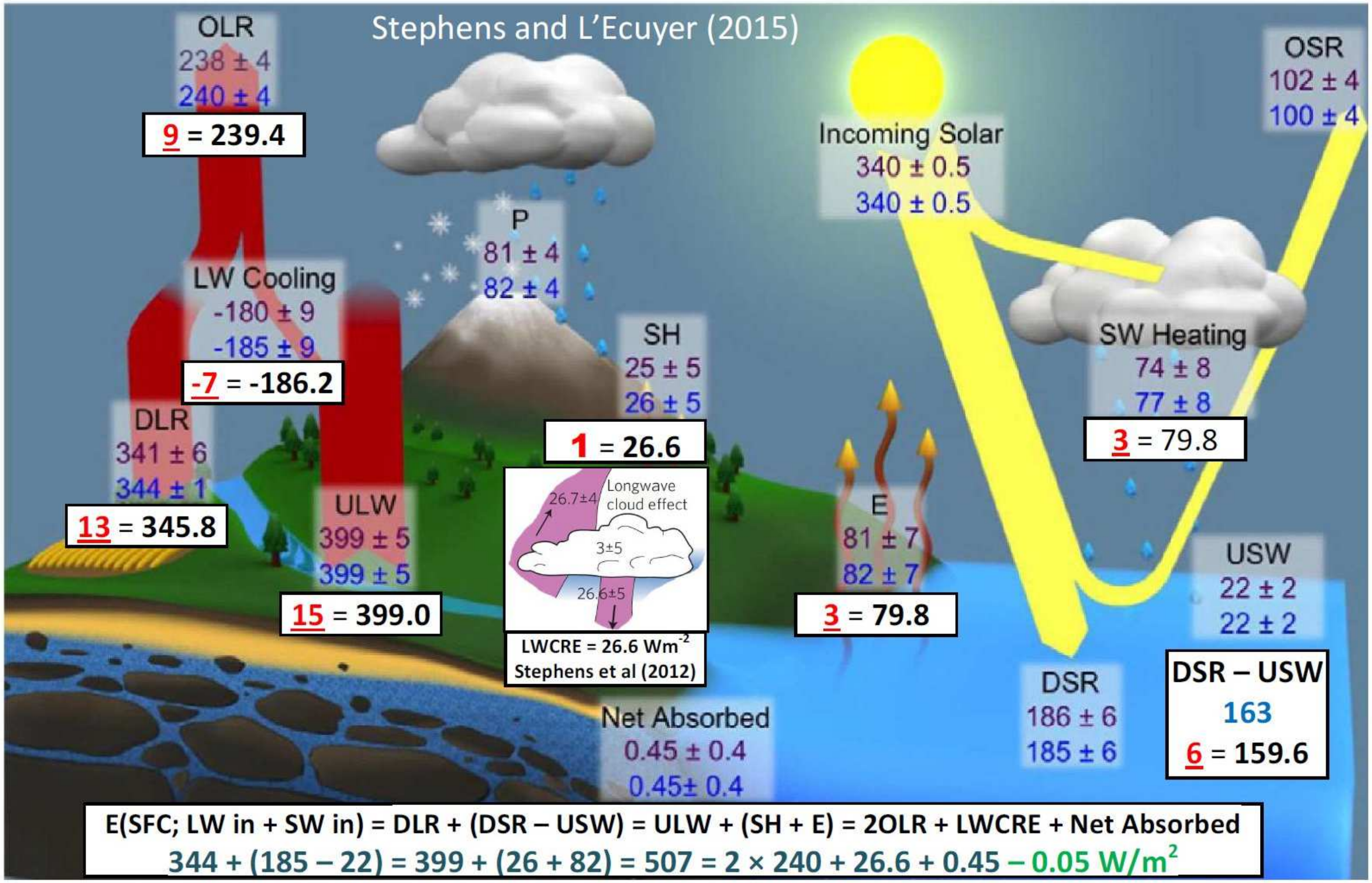
187.9 + 345.6 = 240.2 + 239.7 + 2 × 26.7 (+ 0.2) = 2 × 266.4 + 0.6 (+ 0.1)

7 + **13** = **9** + **9** + 2 × **1** = 2 × **10** + imbalance (+ 0.1 W/m^2)



Notice the role of LWCRE = 26.6 W/m^2 as ONE UNIT

Stephens and L'Ecuyer (2015)

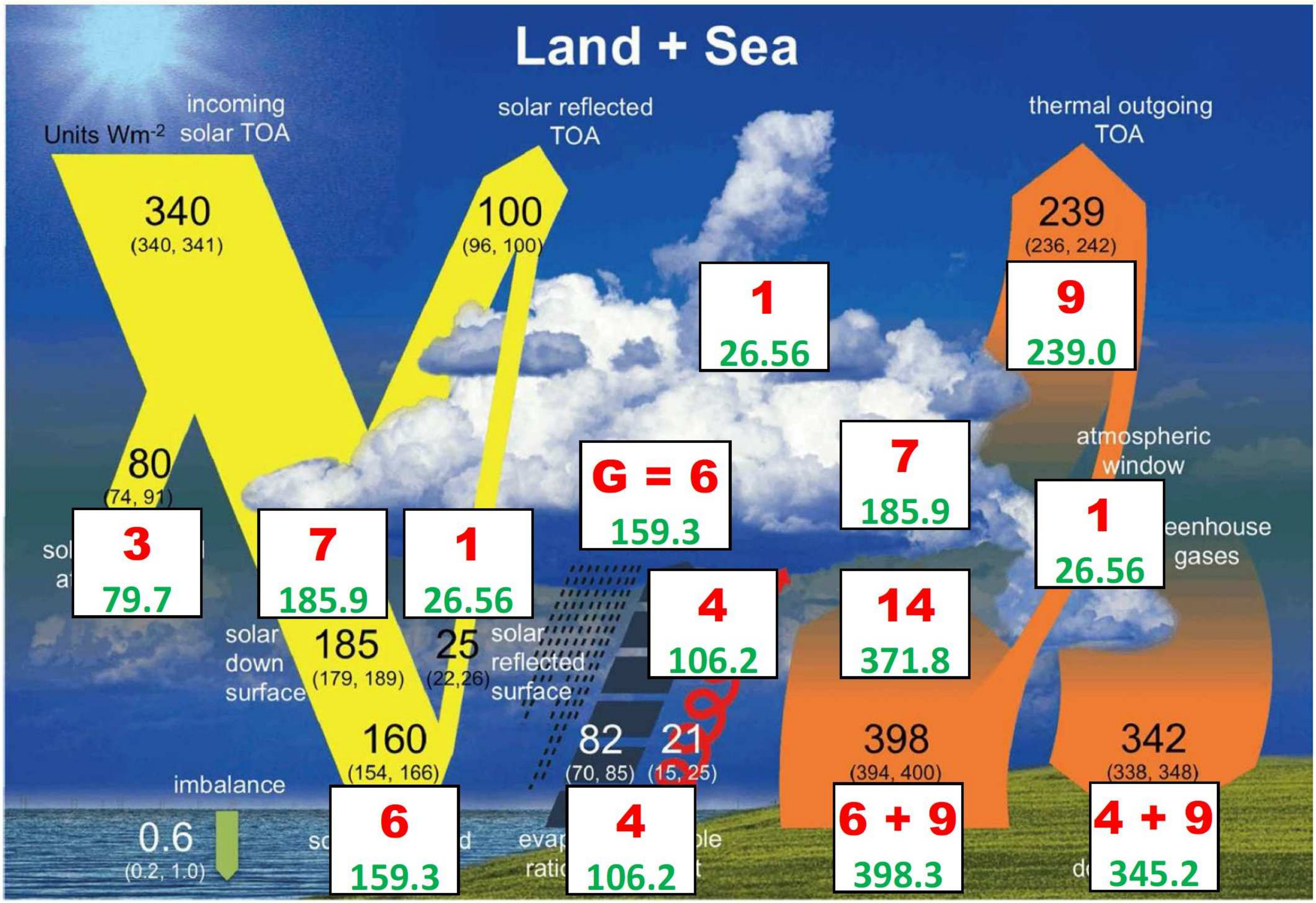


$E(SFC) = LW\downarrow + SW\downarrow = LW\uparrow + turb\uparrow = 2OLR + LWCRE$

$\underline{13} + \underline{6} = \underline{15} + \underline{4} = \underline{19} = 2 \times \underline{9} + \underline{1}$

Constraint equation of E(SFC) = SW in + LW in = 2OLR+LWCRE valid 0.05 W/m^2

Wild et al. (2015) all-sky



SW ↓ + LW ↓ = 6 + (4 + 9) = non-rad ↑ + LW ↑ = 4 + (6 + 9) = 19 = 2 × 9 + 1

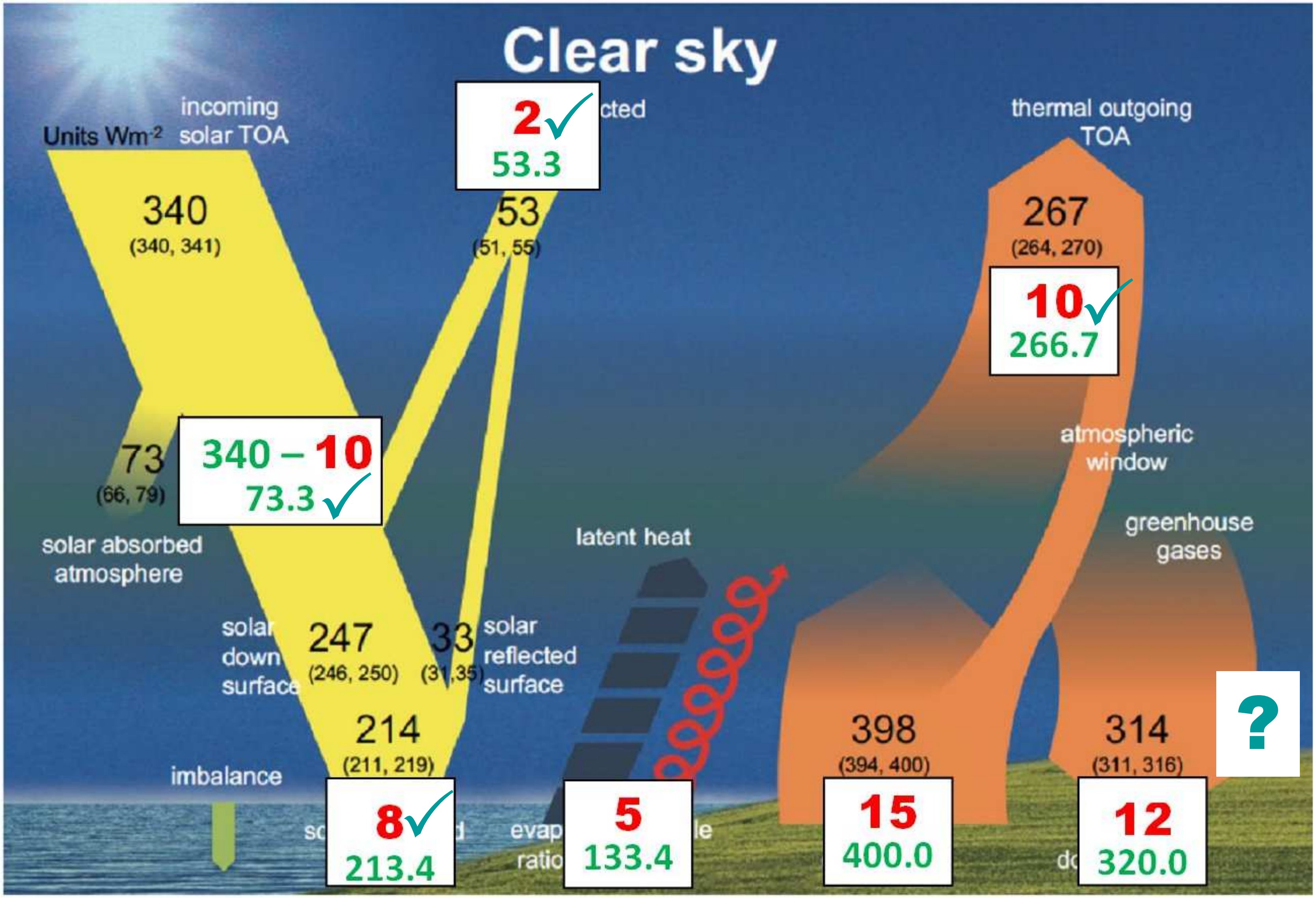
Energy SFC (SW + LW) in = 2 × TOA LW out + LW CRE

Kato et al. (2018) Table 5 all-sky, CERES EBAF Ed4, July 2005 – June 2005

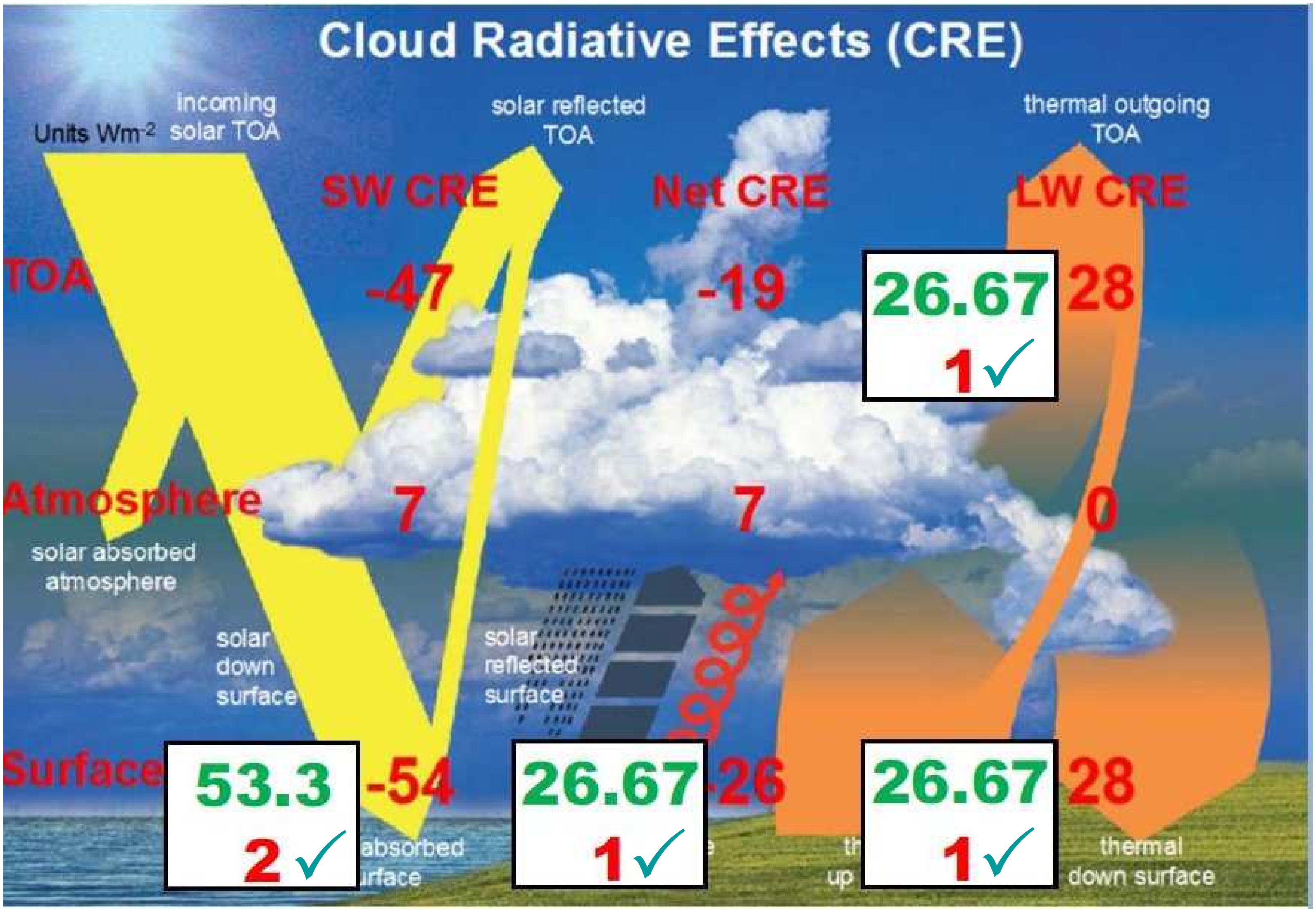
1 ≡ TOA LW up / 9 = 240.0/9 = 26.67 W m^{-2}, Δmax = 4.0 W m^{-2} (E(SFC))

Flux name All-sky	Ed4 (W m^{-2})	N (integer)	EdMZ (W m^{-2})	Ed4 – EdMZ (W m^{-2})
TOA SW insolation	340.0			
TOA SW up	99.1			
TOA LW up	240.0	9	240.0	0.0
SW down	187.1	7	186.7	0.4
SW up	23.3	1	26.67	-3.4
SW net	163.8	6	160.0	3.8
LW down	344.7	13	346.7	-2.0
LW up	398.3	15	400.0	-1.7
LW net	-53.6	2	-53.3	-0.3
SW + LW net	110.2	4	106.7	3.5
Atm SW net	77.1	3	80.0	-2.9
Atm LW net	-186.5	7	-186.7	0.2
Atm SW + LW net	-109.4	4	-106.7	-2.7
G greenhouse effect	158.3	6	160.0	-1.7
SFC SW in + LW in	508.5	19	506.7	1.8
2 TOA LW up + LWCRE	510.7	19	506.7	4.0

Wild et al. (2018) clear-sky



Wild et al. (2018) CRE



Surv Geophys (2012) Spec Issue

Flux name All-sky	**Source**	**Value W m^{-2}**			
SFC LW Up	Kato et al.	398 ± 3			
SFC LW Dn	Kato et al.	345 ± 7			
SFC Net	Kato et al.	106 ± 12			
TOA LW Up	Trenberth and Fasullo	238.5			
Solar Abs Atm	Trenberth and Fasullo	78			
Solar Abs SFC	Trenberth and Fasullo	161			
LW CRE	Stevens and Schwartz	26.5			
ATM LW net	Kato, Trenberth	185.5			
G greenhouse effect	Kato, Trenberth	159.5			

Surv Geophys (2012) Spec Issue

Flux name All-sky	Source	Value W m^{-2}	N	N × UNIT W m^{-2}	Diff W m^{-2}
SFC LW Up	Kato et al.	398 ± 3	15	397.5	0.5
SFC LW Dn	Kato et al.	345 ± 7	13	344.5	0.5
SFC Net	Kato et al.	106 ± 12	4	106.0	0.0
TOA LW Up	Trenberth and Fasullo	238.5	9	238.5	0.0
Solar Abs Atm	Trenberth and Fasullo	78	3	79.5	-1.5
Solar Abs SFC	Trenberth and Fasullo	161	6	159.0	2.0
LW CRE	Stevens and Schwartz	26.5	1	26.5	0.0
ATM LW net	Kato, Trenberth	185.5	7	185.5	0.0
G greenhouse effect	Kato, Trenberth	159.5	6	159.0	0.5

Costa and Shine (2012) clear-sky

Costa and Shine (2012) clear-sky 3D LBL RT	**Value W m^{-2}**			
STI (WIN)	65			
G	127			
Atm LW up	194			
TOA LW up	259			
Surface LW up	386			
2 × TOA LW up	518			

Costa and Shine (2012) radiative transfer LBL clear-sky

Costa and Shine (2012) clear-sky 3D LBL RT	**Value W m^{-2}**	**N integer**	**N × UNIT W m^{-2}**	**Diff W m^{-2}**
STI (WIN)	65	**1**	65	0
G	127	**2**	130	3
Atm LW up	194	**3**	195	1
TOA LW up	259	**4**	260	1
Surface LW up	386	**6**	390	4
2 × TOA LW up	518	**8**	520	2

CERES EBAF 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}

$$\boxed{214.32 + 316.27 = 2 \times 265.59 - 0.59}$$

CERES EBAF Ed2.8 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

CERES EBAF Ed2.8 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

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

All-sky

Ed2.8

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

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}

CERES EBAF 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

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 $W\ m^{-2}$**

EBAF 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

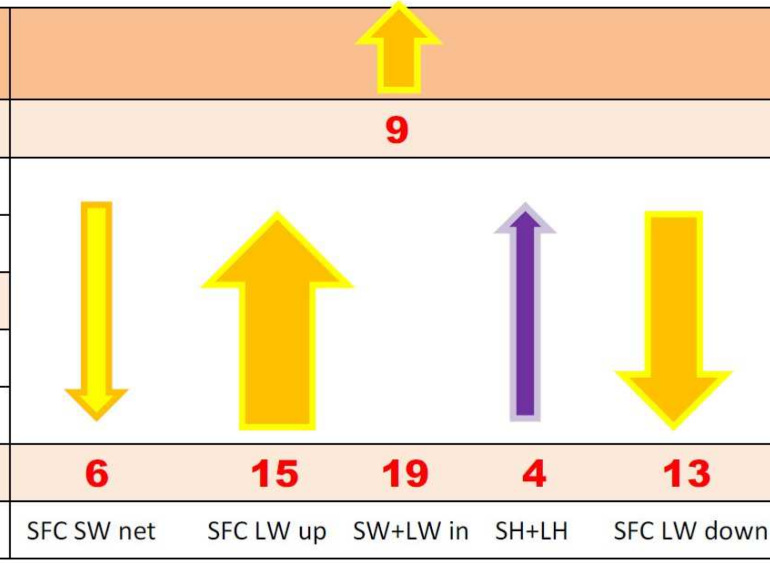
SFC Net =
SW in + LW in – LW up
= 528.0 – 397.6
= **130.4** W m^{-2}

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

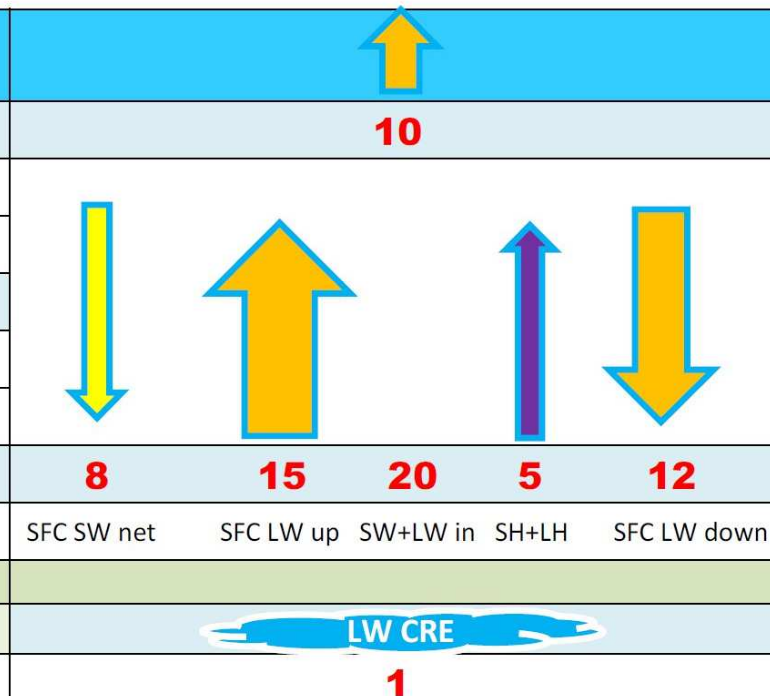
Diff = **0.9** W m^{-2}.

We present a complete set of SW, LW, and non-radiative fluxes in the global energy budget for all-sky and clear-sky conditions

All-sky CERES EBAF	Edition 2.8	Edition 4.0	Edition MZ	UNITS N	Ed MZ – Ed 4.0
TOA LW	239.6	240.1	240.1	9	0.0
SFC SW net	162.3	163.7	160.1	6	-3.6
SFC LW down	345.2	345.0	346.8	13	1.8
SFC (SW+LW) in	507.5	508.7	506.9	19	-1.8
SFC LW up	398.3	398.3	400.2	15	1.9
SFC (SW+LW) net	109.2	110.3	106.7	4	-3.6
2OLR + LWCRE	508.1	511.1	506.9	19	-4.2
G	158.7	158.2	160.1	6	1.9

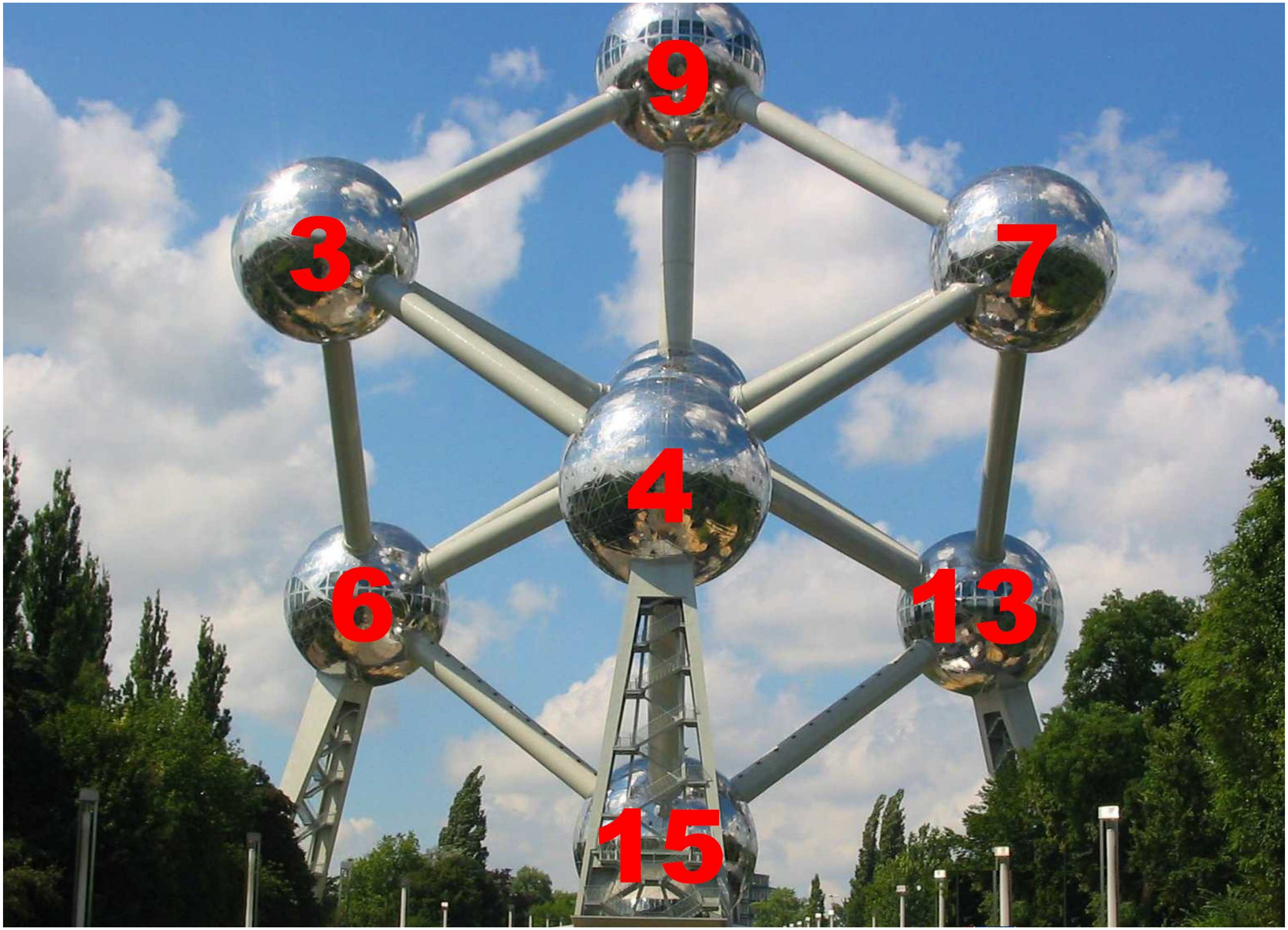


Clear-sky CERES EBAF	Edition 2.8	Edition 4.0	Edition MZ	UNITS N	Ed MZ – Ed 4.0
TOA LW	265.4	268.1	266.8	10	-1.3
SFC SW net	214.3	213.9	213.4	8	-0.5
SFC LW down	316.3	314.1	320.2	12	6.1
SFC (SW+LW) in	530.6	528.0	533.6	20	5.6
SFC LW up	398.4	397.6	400.2	15	2.6
SFC (SW+LW) net	132.2	130.4	133.4	5	3.0
2OLR	530.8	536.2	533.6	20	-2.6
G	133.0	129.5	133.4	5	3.9
LW CRE					
TOA	25.8	28.0	26.68	1	-1.3
SFC	28.9	30.9	26.68	1	-4.2

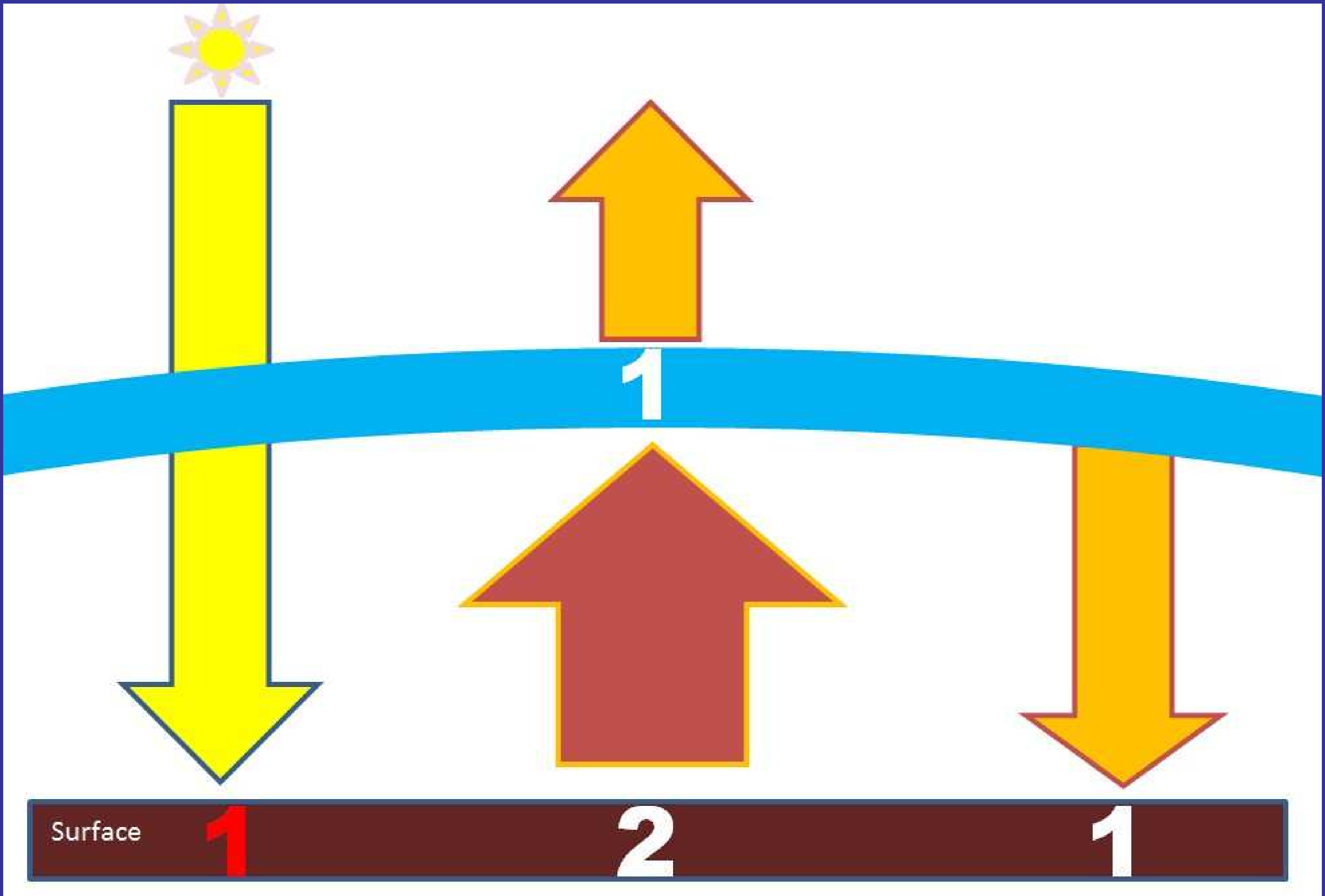


This is not a mess of small integer numbers; this is a meaningful energetic system.

You may call it atom, or quanta…



A Conceptual Approach:
Closed Shell Geometry

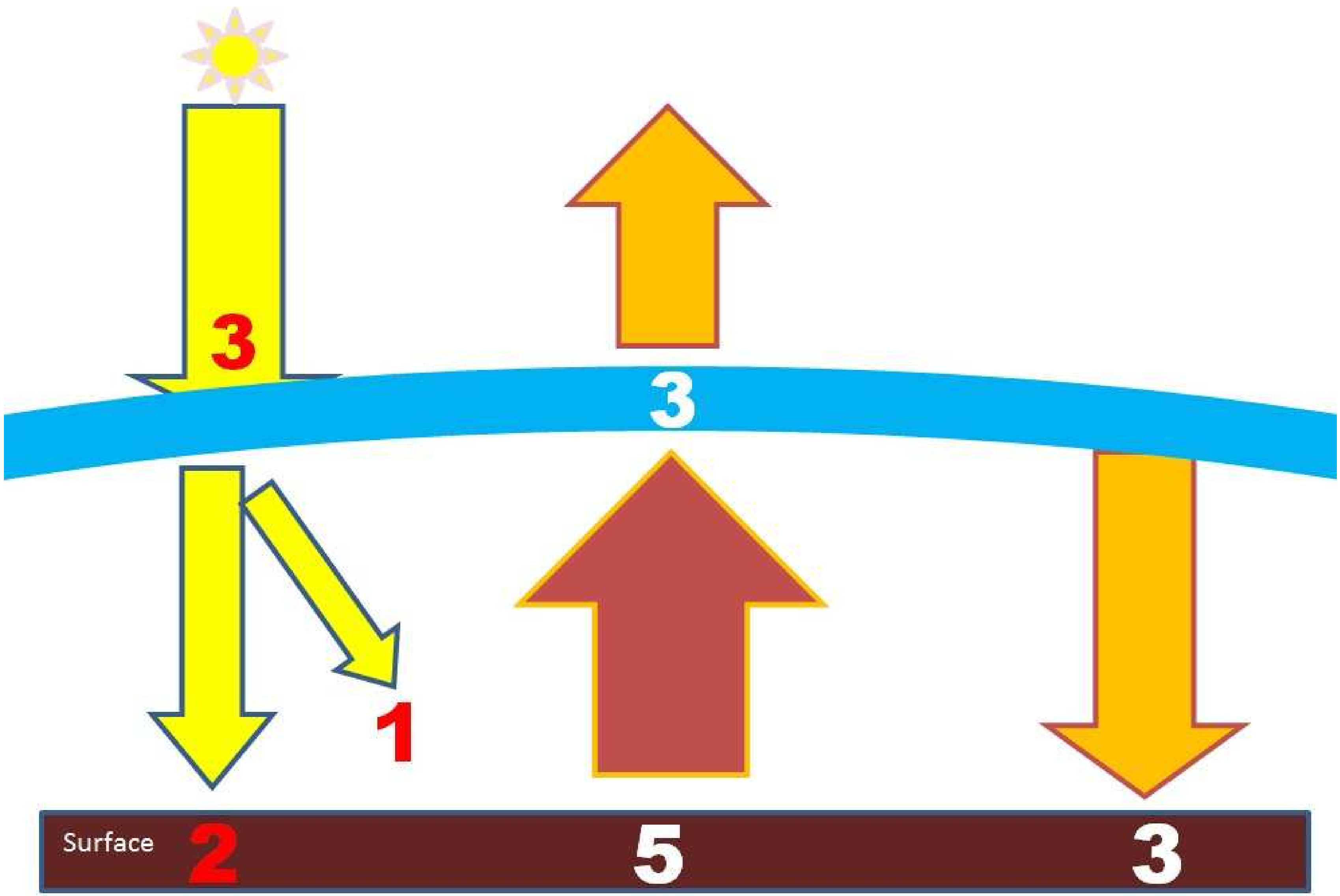


SW-transparent, LW-opaque, non-turbulent

Deduction, Step 1. UNIT change 1 => 3

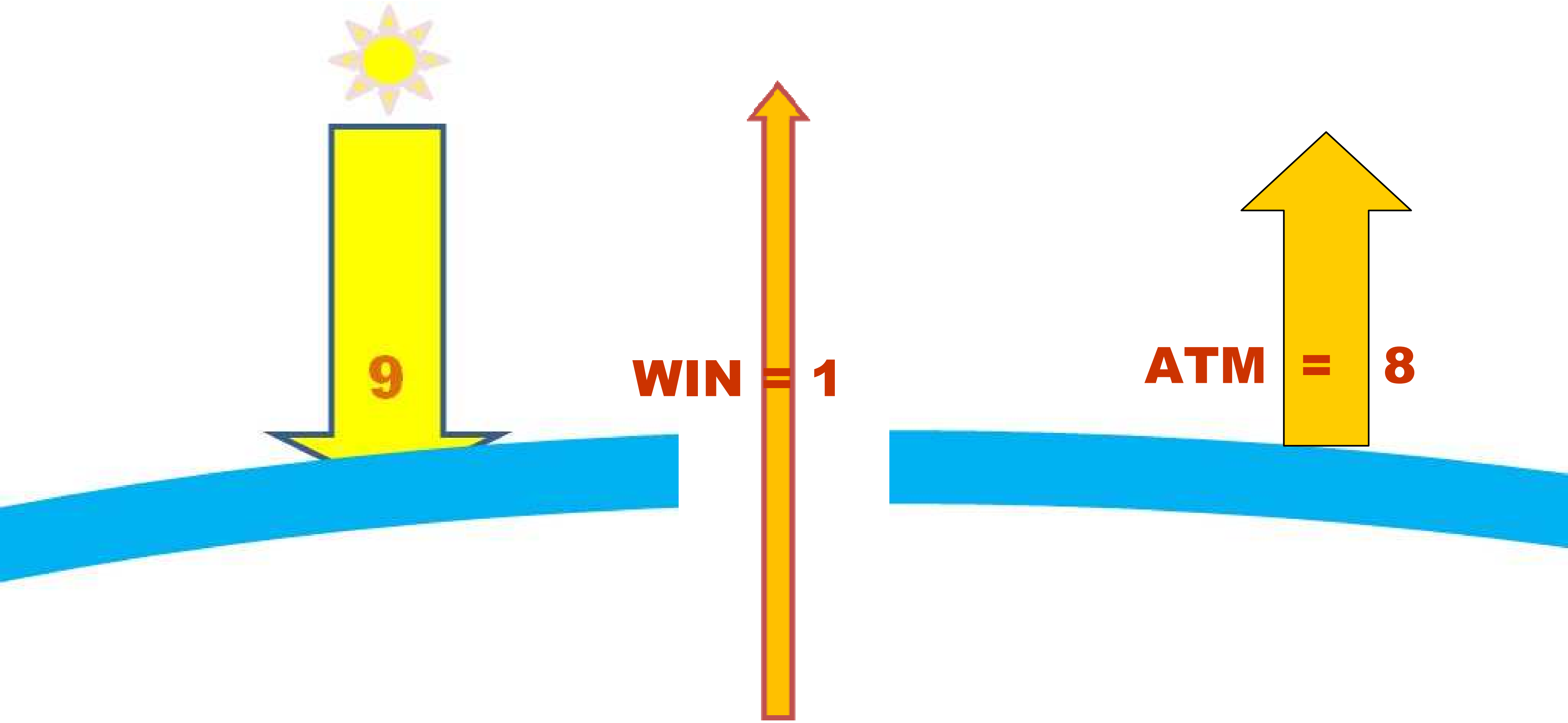
Allow **ONE** *unit of atmospheric SW-absorption*:

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

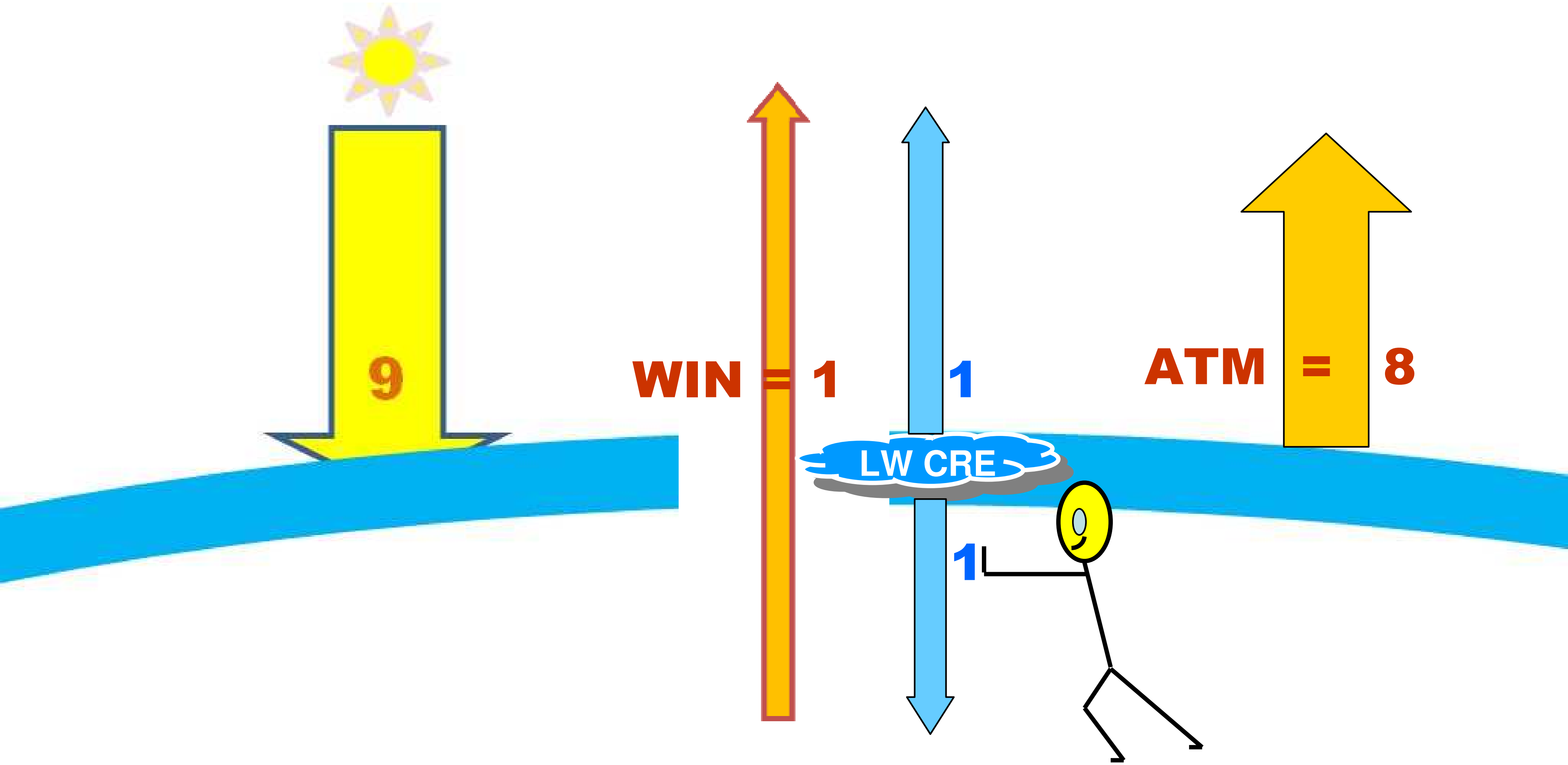


After unit change 3 => 9

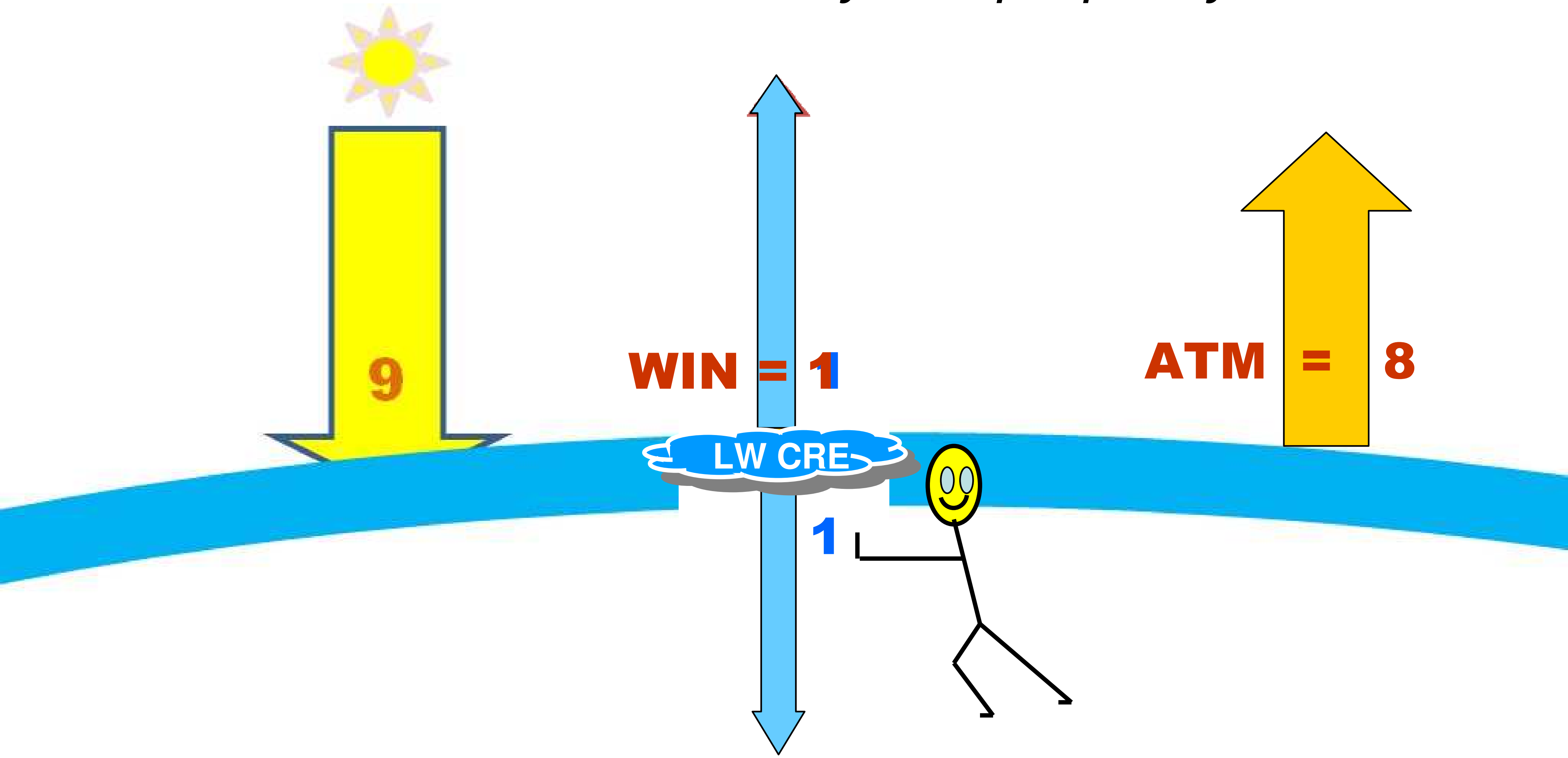
… allow **ONE** *unit for partial atmospheric LW-transparency…*



… introduce **ONE** *unit for cloud LW radiative effect…*



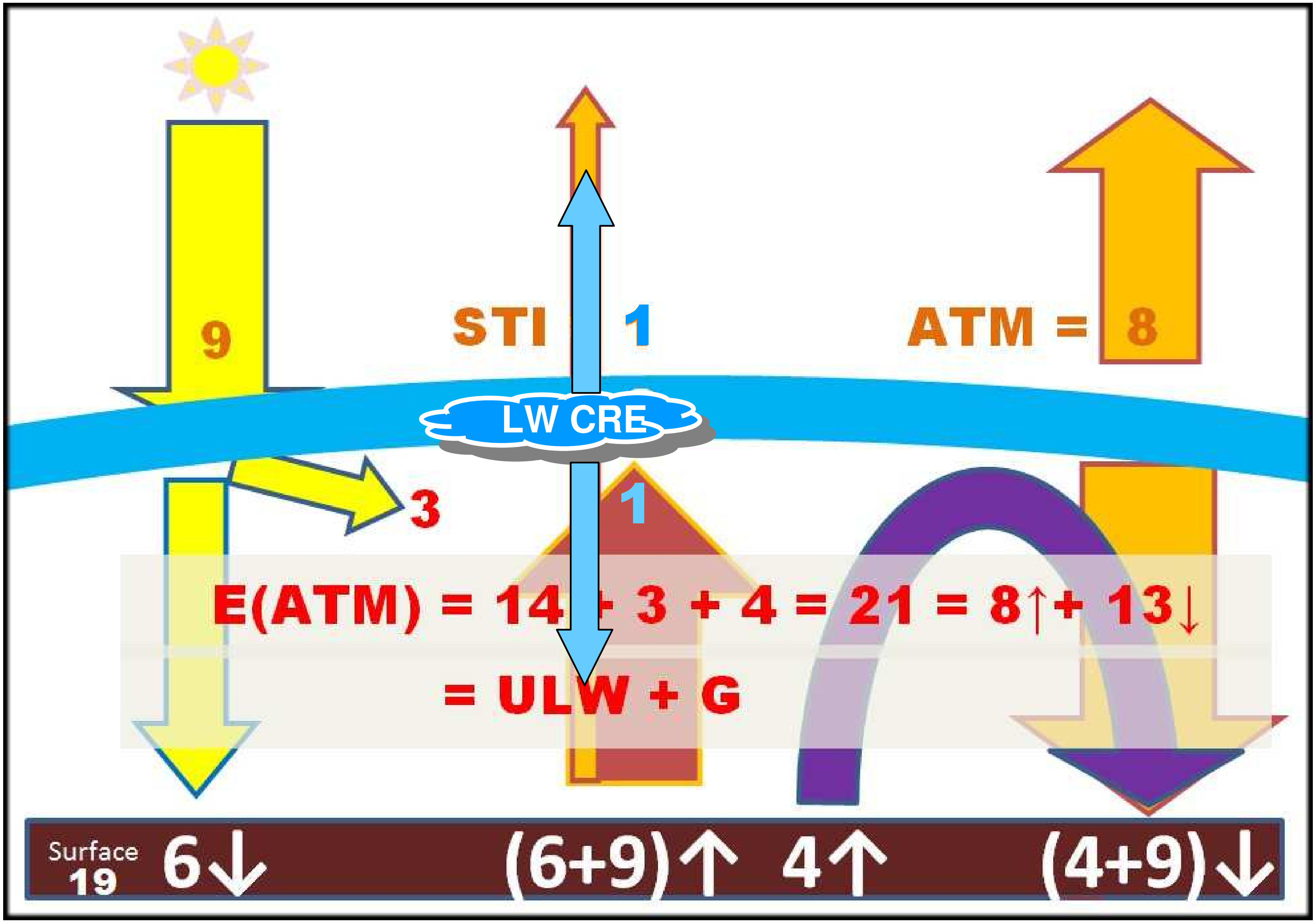
… and close the window with it !
The result is an effectively IR-opaque system.



From a surface perspective:
what is lost in the window is gained back
by the greenhouse effect of clouds

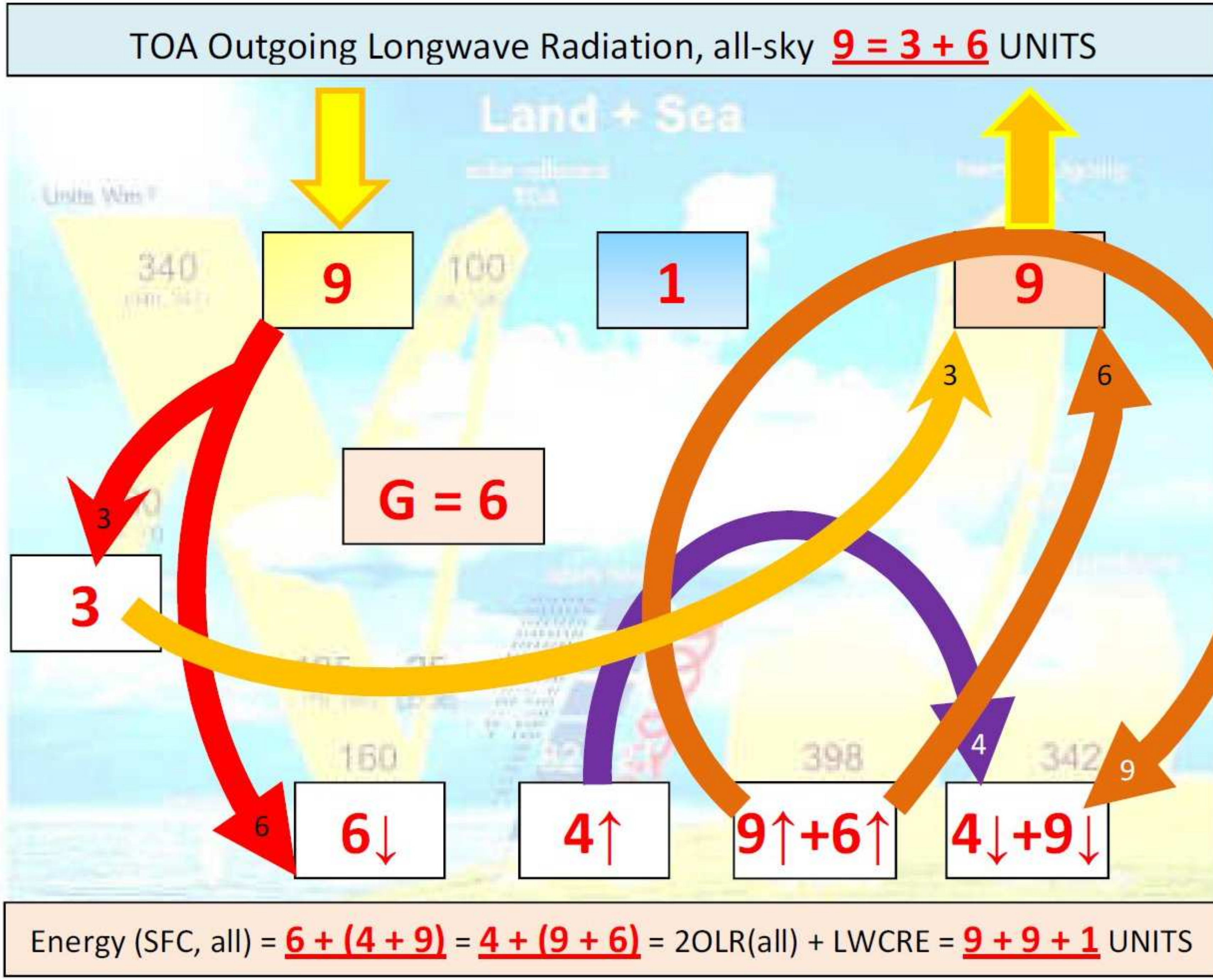
*Finsally, close the balance with turbulence***.**

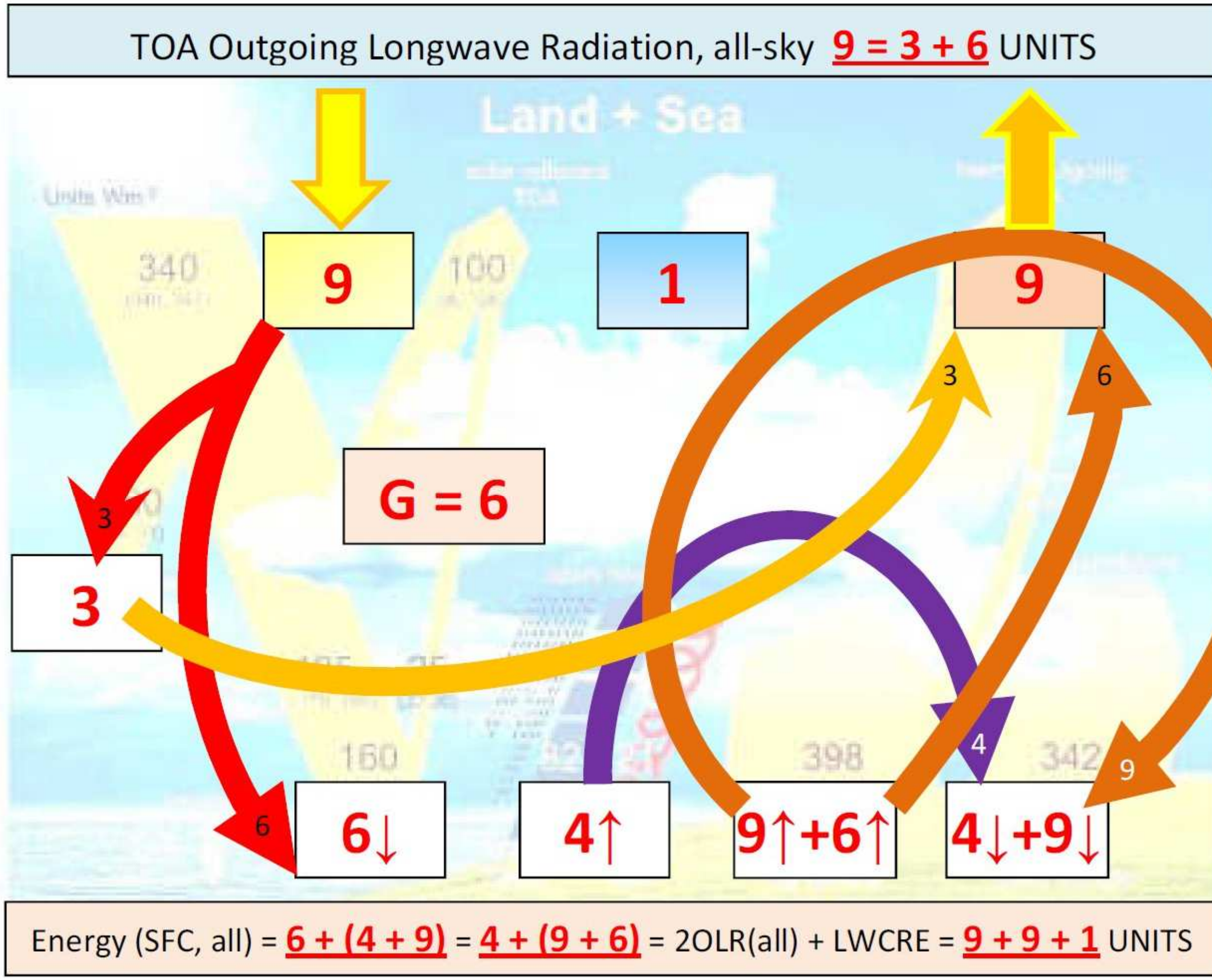
Atmosphere: E(SFC) + **2** UNITS = **21** = emitted up (**8**) + down (**13**)



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

The structure. *Basic energy flow routes and rates*.





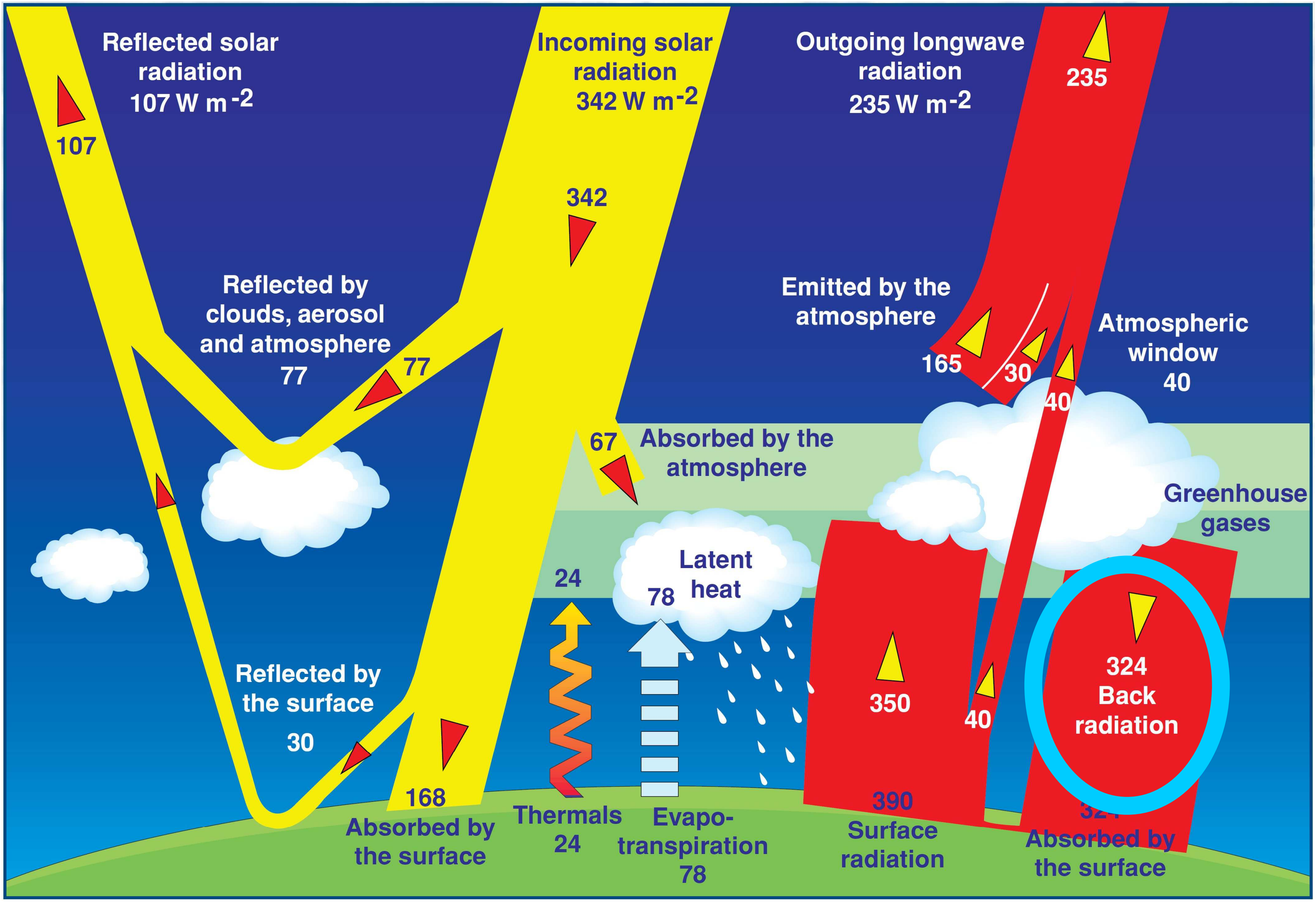
ASR = OLR = **9** = 240, SAA = **3** = 80, SAS = **6** = 160

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

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

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

Example:
Downward Longwave Radiation at surface



Kiehl and Trenberth (1997)

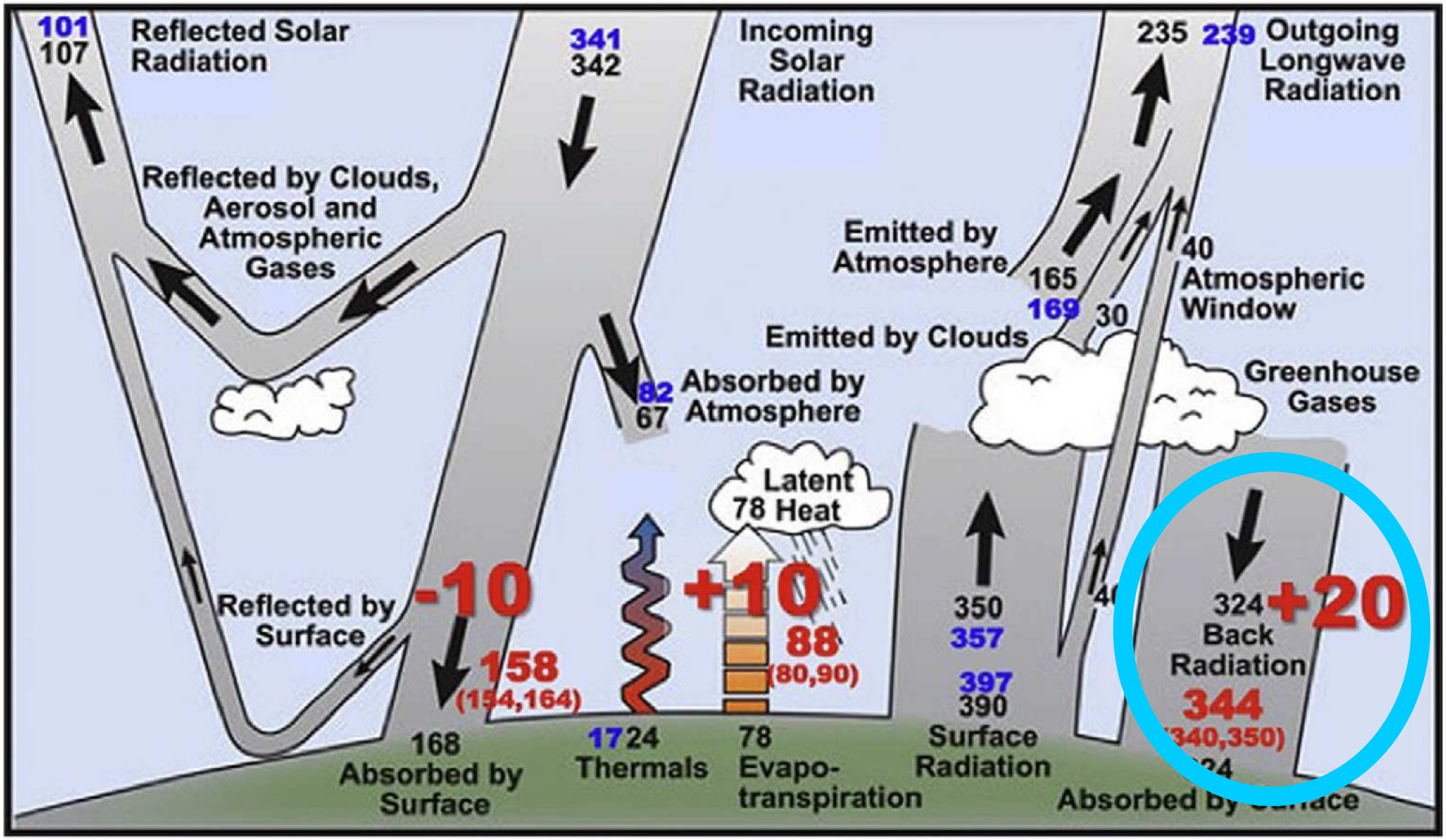
Wild (1997) – excellent job

Clear-sky ATM SW abs	72 ✓
Clear-sky SFC SW abs	214 ✓
Clear-sky SFC LW dn (DLR)	321 ✓
All-sky SFC LW dn (DLR)	345 ✓
All-sky ATM SW abs	85 ✓
All-sky SFC SW abs	154 ✓
All-sky SFC net LW	51 ✓
SFC LW up	396 ✓
SFC LW CRE	24 ✓

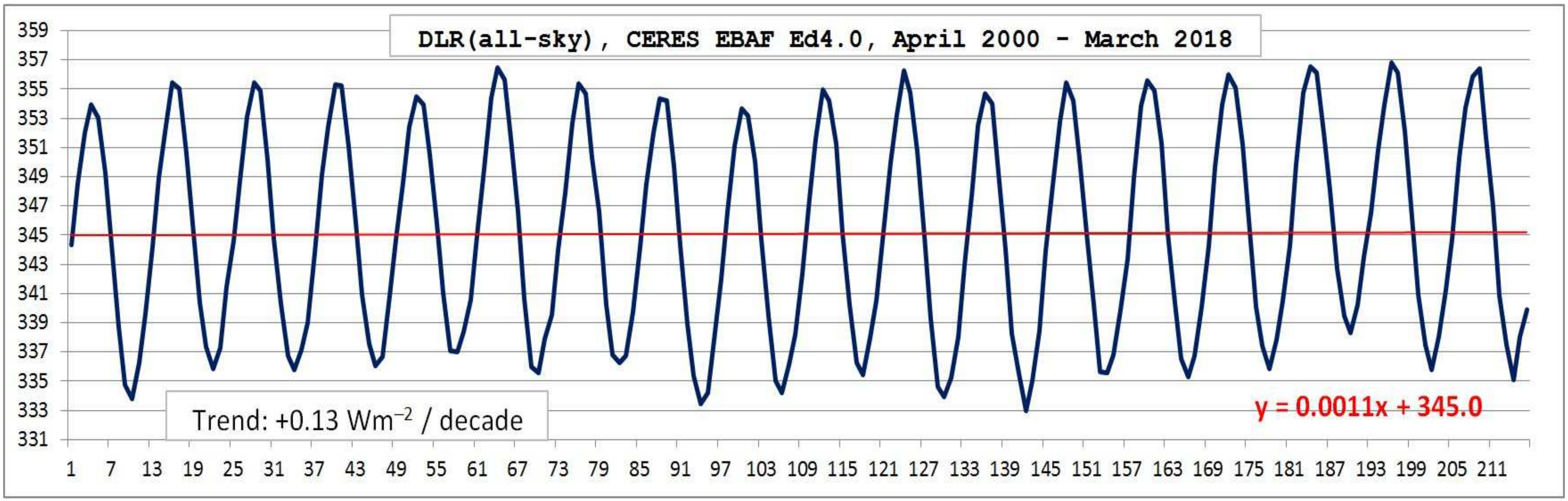
Wild et al. (1998) Clim Dyn

Surface (Wm^{-2}):	
SW downward all-sky	170
SW absorbed all-sky	147
SW absorbed clear-sky	214
SW cloud radiative forcing	– 67
$\boxed{\text{LW downward all-sky}}$	344
LW downward clear-sky	323
LW upward	397
Net LW all-sky	– 53
LW cloud radiative forcing	– 21
Surface net radiation	94

Wild (2012) Facelift



DLR Trend, CERES EBAF Ed4.0



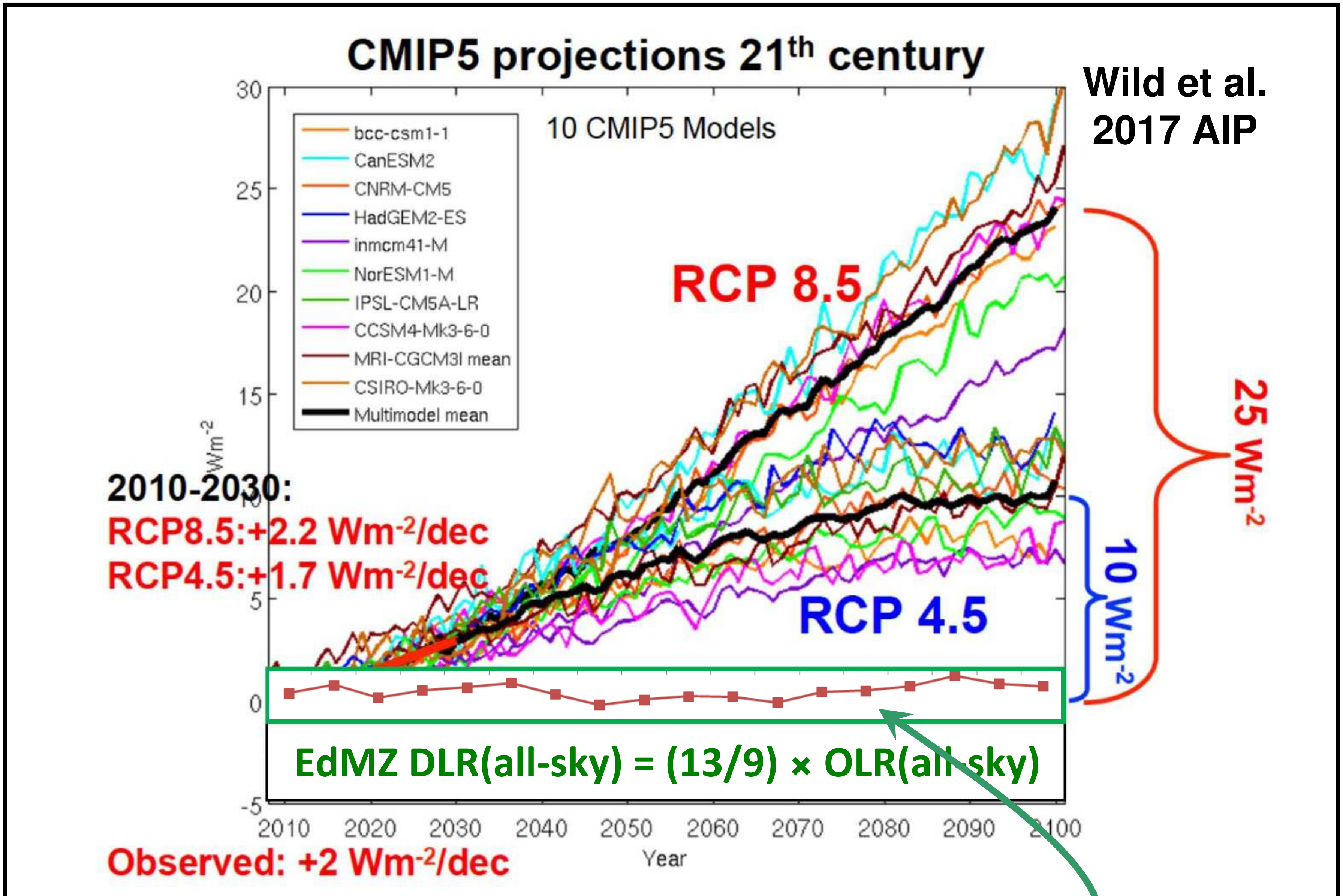
Stability: DLR fluctuates around its lattice position of

13 UNITS = (13/9) × OLR = 345 Wm^{-2}

with an increasing trend of 0.13 Wm^{-2} per decade.

DLR Trend

- Uncertainty in the trend is ten times smaller (0.5 Wm^{-2}) than the uncertainty in the absolute value (5 Wm^{-2}) (Kato 2018).
- Increasing carbon dioxide concentration from 360 to 720 ppm increases the DLR about 1.5 Wm^{-2};
- This gives about 0.08 Wm^{-2} DLR change per decade, with 20 ppm / dec (IPCC AR5).
- It takes about 50 years for the signal (not including feedback) to become greater than the uncertainty in DLR.
- To have +2 Wm^{-2} per decade increase in DLR as projected by CMIP5, an amplifying feedback multiplication factor of 25 would be needed.
- In contrast, the CERES observed trend in DLR is about +0.13 Wm^{-2}, corresponding to a feedback factor of +1.5.
- Further, the CERES observed trend of DLR follows the observed trend in OLR, fluctuating around its integer position of 13 UNITS (= 13/9 × OLR).



EdMZ projection 21st century:

DLR = OLR × 13/9 = 13 UNITS

Further reading

Theory, physical basis, deduction etc:

28th and 29th CERES meetings:

https://ceres.larc.nasa.gov/science-team-meetings2.php

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Supporting website: www.globalenergybudget.com