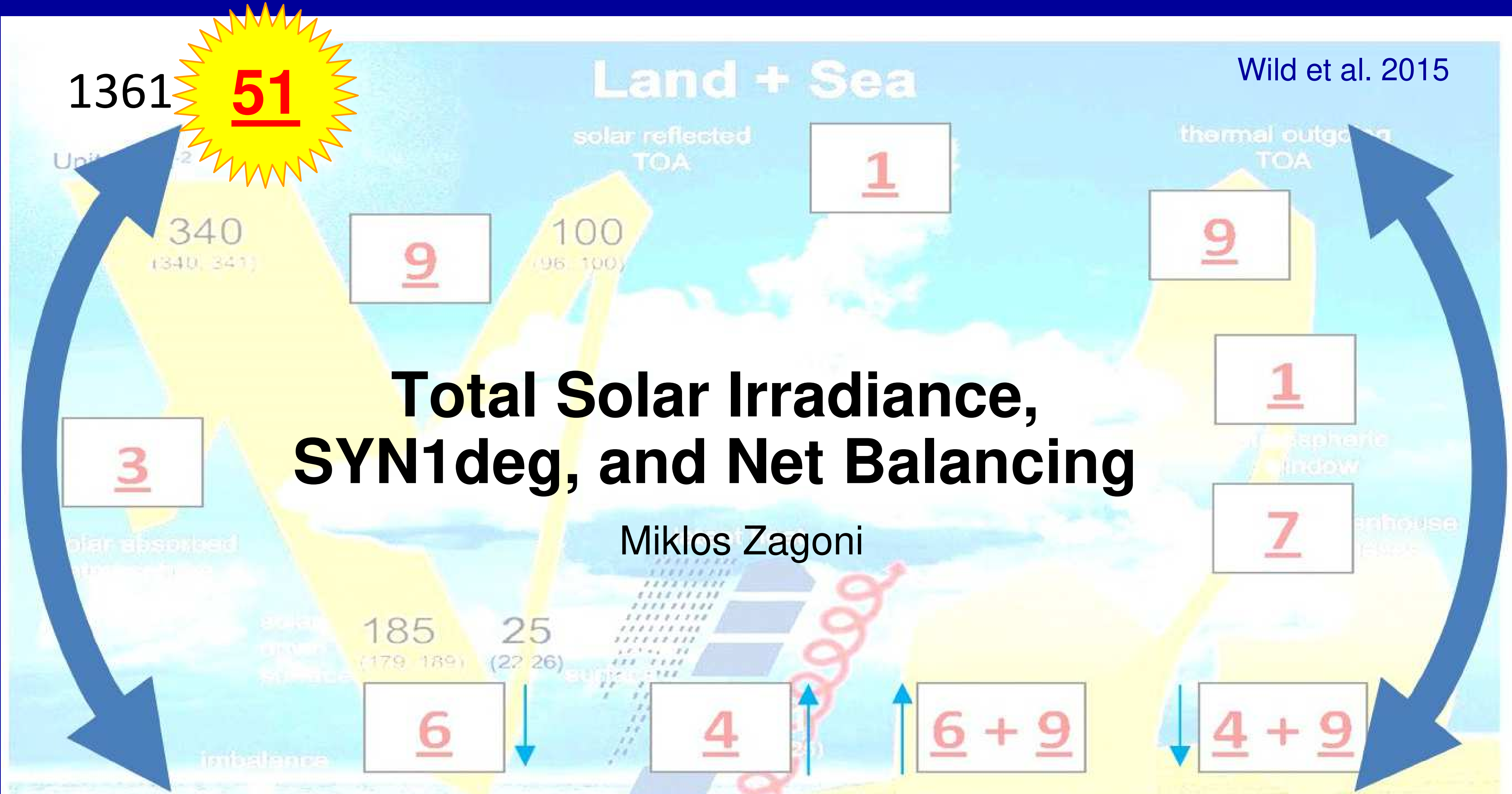
Patterns in the CERES Global Mean Data, Part 3.



Total Solar Irradiance, SYN1deg, and Net Balancing

Miklos Zagoni

31st CERES Science Team Meeting, May 9, 2019, Hampton, VA

"Instead of the traditional paradigm of properties define processes, study how processes define property" — *Graeme Stephens*

DATA: CERES SYN1deg Ed4A TOA

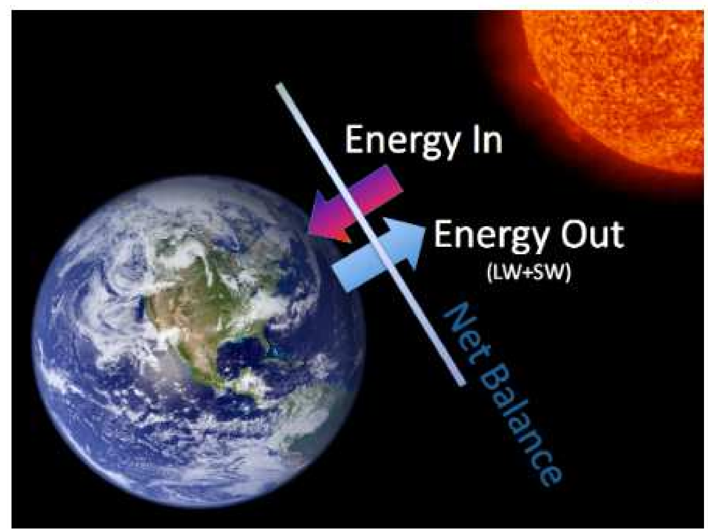
All-sky, Oct 2000 – Sep 2018 (216 months)

• TSI	= 1360.9 ± 0.5			
• TOA SW in	= **340.0**		**EBAF Ed4.0**	
• TOA LW	= **238.6**	**+1.5**	**240.1**	
• TOA SW up	= **97.1**	**+2.0**	**99.1**	
• Net	= **4.3**			

Constraint I

TOA E in = TOA E out

CERES Earth's Radiation Budget



Loeb et al. (2018) J Clim, Table 5

	EBAF Ed2.8		EBAF Ed4.0	
	Unadjusted	With constraint	Unadjusted	With constraint
Incoming Solar	339.8	339.8	340.0	340.0
All-sky LW	238.7	239.6	238.6	240.1
All-sky SW	97.9	99.6	97.1	99.1
All-sky net	3.2	0.63	4.3	0.71
Clear-sky LW	264.5	265.4	266.3	268.1
Clear-sky SW	51.5	52.5	52.3	53.3
Clear-sky net	23.8	21.9	21.4	18.6
LW CRE	25.8	25.8	27.7	27.9
SW CRE	−46.4	−47.1	−44.8	−45.8
Net CRE	−20.6	−21.3	−17.1	−17.9

A NEW Constraint
in CERES SYN1deg Ed4A SFC + TOA
Clear-sky Oct 2000 – Sep 2018

	SFC SW down	=	242.65
–	SFC SW up	=	– 28.40
=	SFC SW net	=	214.25
	SFC LW down	=	317.77
–	SFC LW up	=	– 397.23
=	SFC LW net	=	– 79.46
	SFC SW+LW net	**=**	134.79
	TOA LW	=	268.15
	TOA LW / 2	**=**	134.08
	Diff	**=**	– 0.71

Constraint II

SFC SW+LW net

= TOA LW / 2

What Does Constraint II Mean?

As an illustration, consider the case of radiative equilibrium with black bodies emitting $B^*(0)$ or $B^*(\tau_1)$ at the two boundaries. The third terms on the right-hand side of (2.144) and (2.145) are now zero and

$$F/2\pi = B(0) - B^*(0) = B^*(\tau_1) - B(\tau_1). \qquad (2.146)$$

Equation (2.146) requires a discontinuity in the Planck function, implying a discontinuity of temperature, at the boundary.

The class of approximation of which (2.140) is representative is extensive and a large number of different names and terms are used to describe members of the class: the *Schwarzschild–Schuster* approximation, the *Eddington* approximations, *Chandrasekhar's first*

Discontinuity in the Planck function at the boundary = *F/2π*

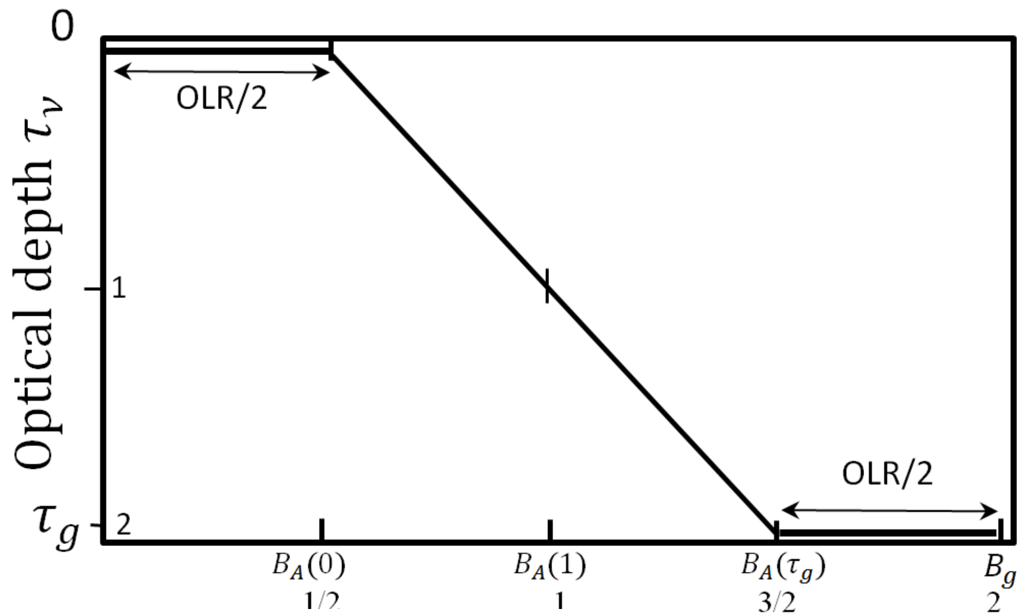
Goody and Yung (1989)

Discontinuity at the ground = OLR/2, independent of the optical thickness

Several textbooks, lecture notes (Grant Petty, Visconti, Chamberlain,Pierrehumbert)

$$\sigma {T_A}^4 = OLR(1+\tau)/2$$

$$\sigma {T_g}^4 = OLR(2+\tau)/2$$



$$\sigma T_g(\tau_g)^4 - \sigma T_A(\tau_g)^4 = OLR/2 \text{ independent of } \tau_g$$

The temperature at the bottom of the atmosphere at τ^* is given by Equation (3.47), so that we have a discontinuity between the air temperature and that of the surface

$$T_s^4 - T(\tau^*) = T_e^4/2 \qquad (3.49)$$

Discontinuity at the ground: SFC SW+LW net = OLR/2

Long-known theoretical requirement

Constraint II
in CERES EBAF Ed2.8 & Ed4.0
Clear-sky, CLIM YEAR

SFC SW+LW Net	**= 132.71**
TOA LW	= 265.82
(TOA LW) / 2	**= 132.91**
(TOA LW) / 2 – SFC Net	= **0.2**

SFC SW+LW Net	**= 130.41**
TOA LW	= 268.15
(TOA LW) / 2	**= 134.07**
(TOA LW) / 2 – SFC Net	= **3.7**

My Net Balancing II

Your (Constr I)

- SW gain = 1.7
- LW gain = 2.5

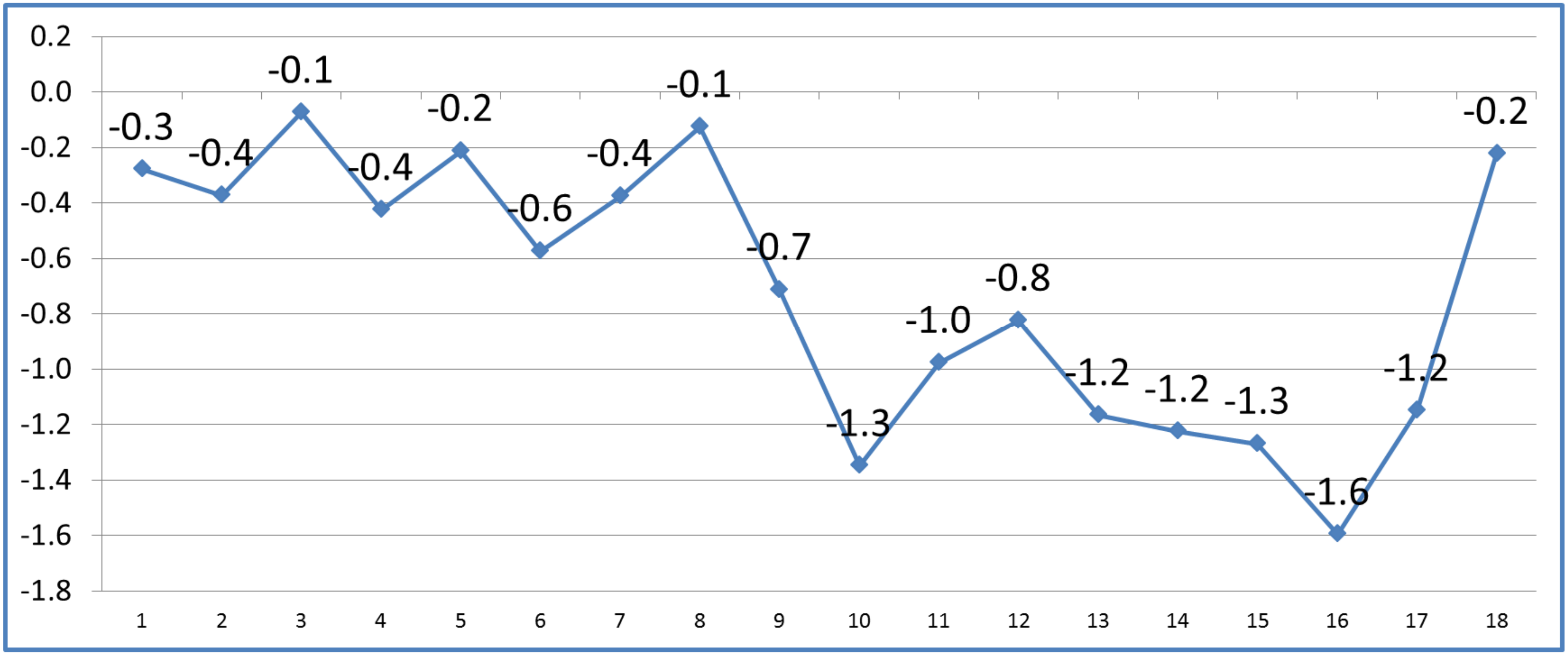
Parameter	TOA Flux adjustment (W/m^2)
Total SW	1.7
Total LW	2.5
Total Net	-4.2

Mine (Constr II)		SYN	My		EdMZ	Integers
SFC SW net	=	214.25	– 0.81	=	213.44	8
SFC LW net	=	–79.46	– 0.58	=	– 80.04	– 3
SFC SW+LW net	**=**	134.79	– 1.39	**=**	133.40	5
TOA LW	=	268.15	– 1.35	=	266.80	10
TOA LW/2	**=**	134.08	– 0.68	**=**	133.40	5
Diff	**=**	– 0.71			0.0	

Earth's Energy Imbalance of the Second Kind

EEI_2 = TOA LW/2 – SFC SW+LW net

18 years, Oct 2000-Sep 2018

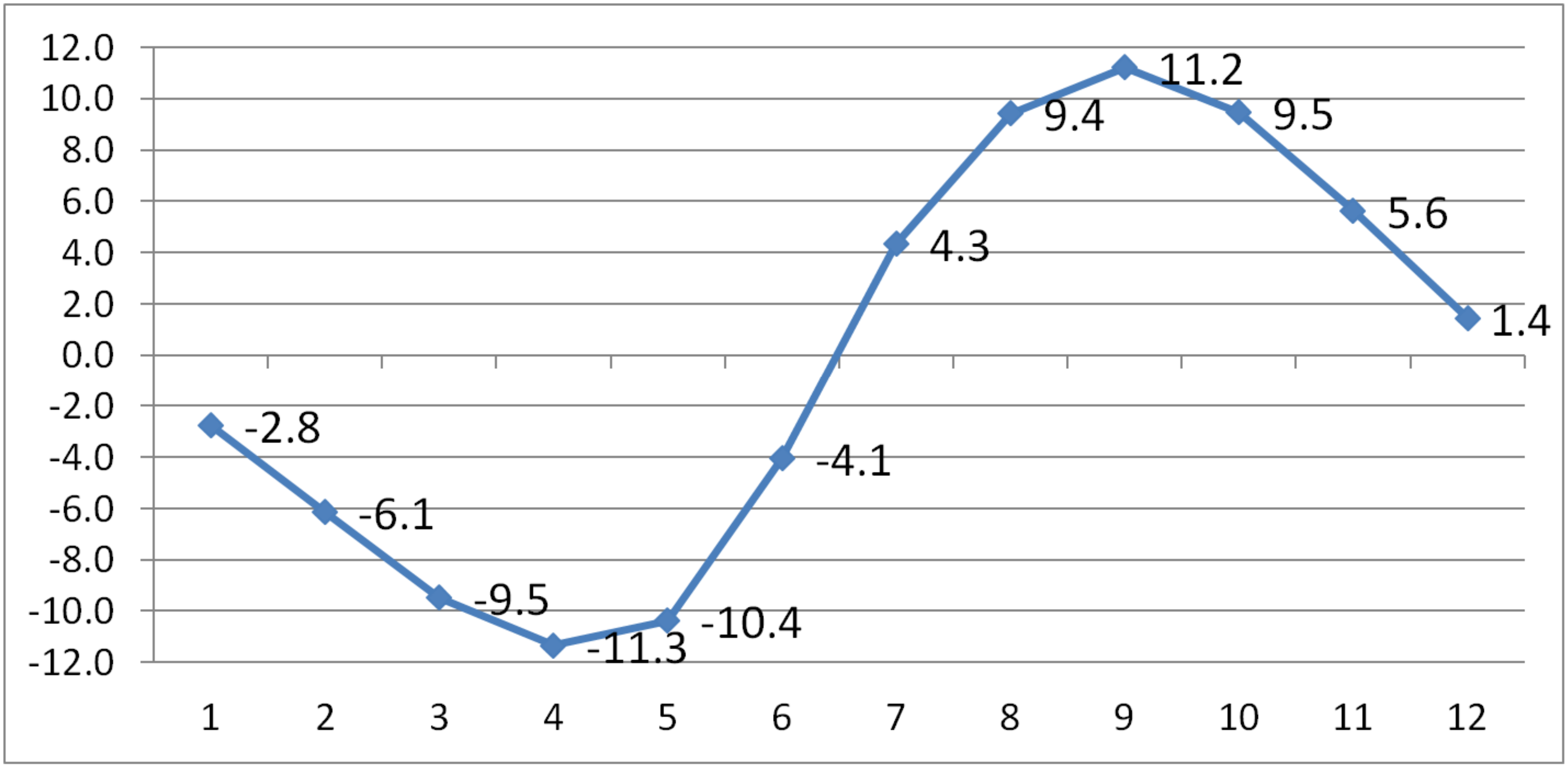


SYN1deg Ed4A 18-years

max –0.07, min –1.60, mean = – 0.72 Wm^{-2}

EEI_2 = TOA LW/2 – SFC SW+LW net

12 months, Oct 2017-Sep 2018



SYN1deg Ed4A 12-months

max 11.21, min –11.34, mean = – 0.22 Wm^{-2}

EEI_2 = TOA LW/2 – SFC SW+LW net

Area-weighted zonal means from N Pole to the Equator

Degree	SW net	LW net	SW + LW net	TOA LW	TOA LW/2	Area-weighted difference
80 – 90	6.3	– 12.9	– 6.7	35.6	17.8	24.5
70 – 80	16.3	– 26.6	– 10.3	72.6	36.3	46.6
60 – 70	54.4	– 39.3	15.1	111.8	55.9	40.8
50 – 60	112.3	– 53.1	59.2	153.6	76.8	17.6
40 – 50	159.7	– 66.9	92.8	196.2	98.1	5.4
30 – 40	204.5	– 79.5	125.0	238.2	119.1	– 5.9
20 – 30	239.8	– 80.1	159.7	273	136.5	– 23.2
10 – 20	264.4	– 71.7	192.7	289.4	144.7	– 48.0
0 – 10	270.6	– 61.3	209.3	286.6	143.3	– 66.0
Hemispheric mean	**213.7**	**– 79.1**	**134.6**	**266.6**	**133.3**	**– 1.3**

A THIRD constraint in CERES SYN1deg Ed4A SFC + TOA Clear-sky Oct 2000 – Sep 2018

	SFC SW down	=	242.65
–	SFC SW up	=	– 28.40
=	SFC SW net	=	214.25
+	SFC LW down	=	317.77
=	**SFC SW+LW abs**	**=**	532.02
	TOA LW	=	268.15
	2 × (TOA LW)	**=**	536.30
	Diff	**=**	4.28

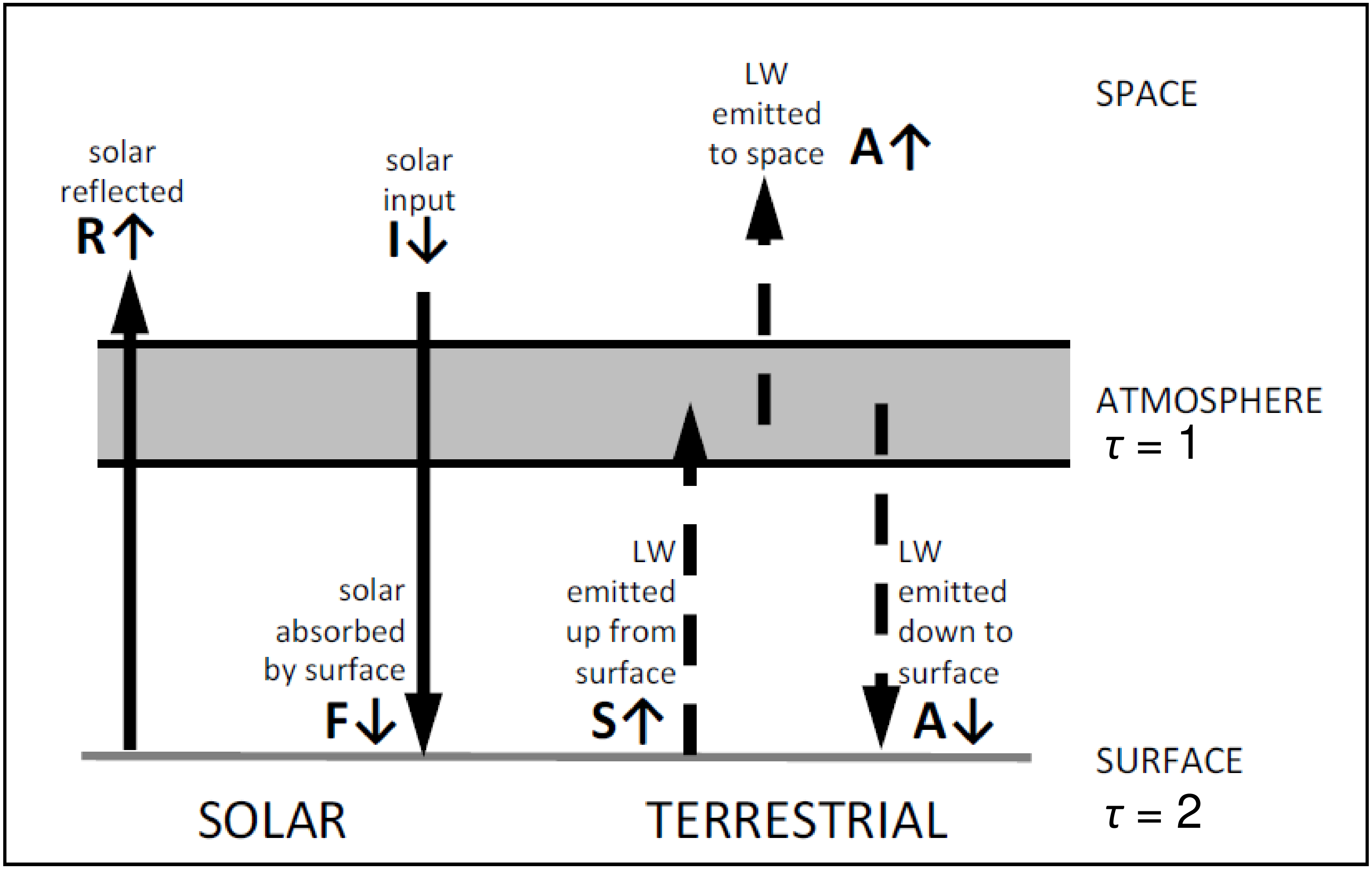
Constraint III

SFC SW+LW abs

= 2 TOA LW

Same confidence as Constraint I.

What Does Constraint III Mean?



S = 2A = 2F

Modified from
Marshall-Plumb (2008)

Liou (1980)

Fig. 8.20, we may write down the energy balance equations at the top of the atmosphere and the surface, respectively, in the forms

$$Q(1-\bar{r}) - \bar{\varepsilon}\sigma T_a^4 - (1-\bar{\varepsilon})\sigma T^4 = 0, \quad (8.31)$$

$$Q(1-\bar{r}-\bar{A}) + \bar{\varepsilon}\sigma T_a^4 - \sigma T^4 = 0, \quad (8.32)$$

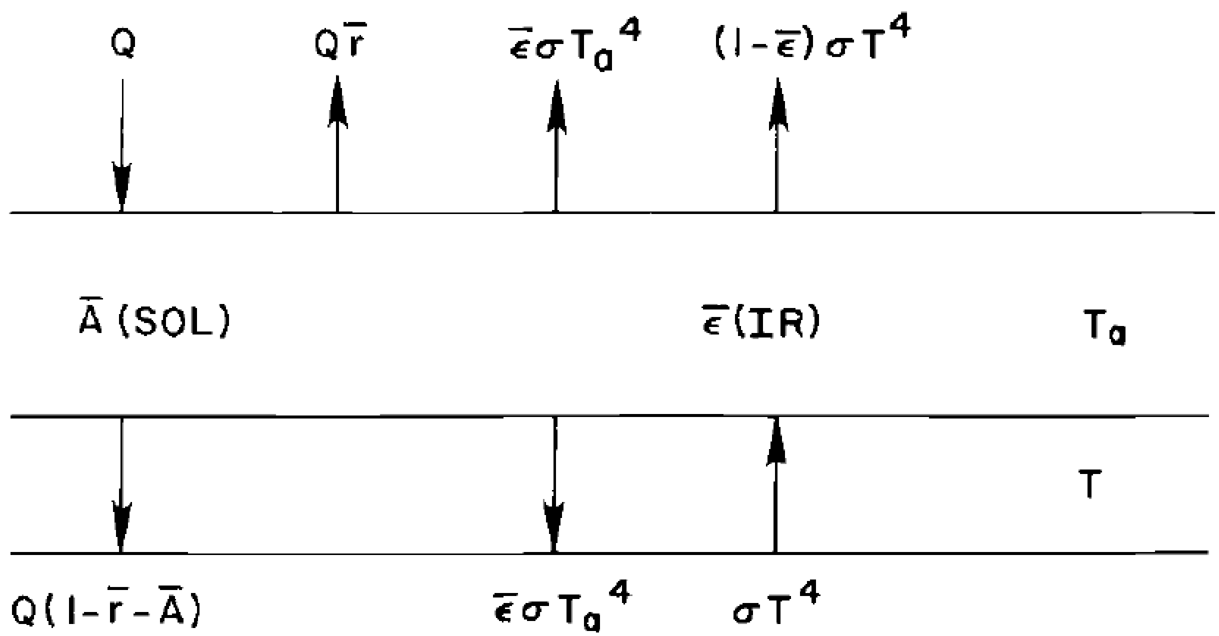


Fig. 8.20 Two-layer global radiative budget model.

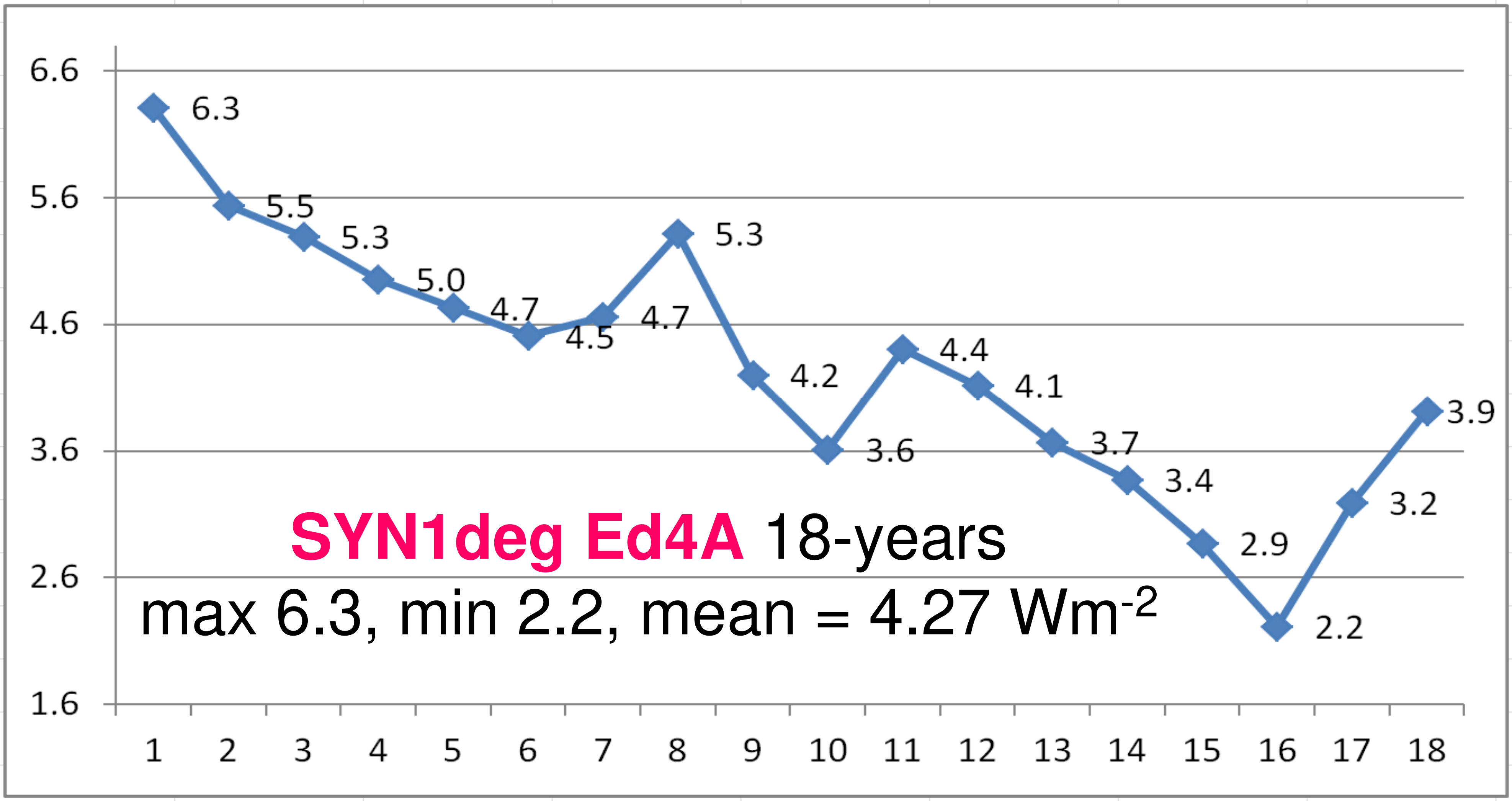
Trivial solution to the radiative transfer problem

with $\bar{A}=0$ and $\bar{\varepsilon}=1$, $\sigma T^4 = 2\sigma T_a{}^4$

Earth's Energy Imbalance of the Third Kind

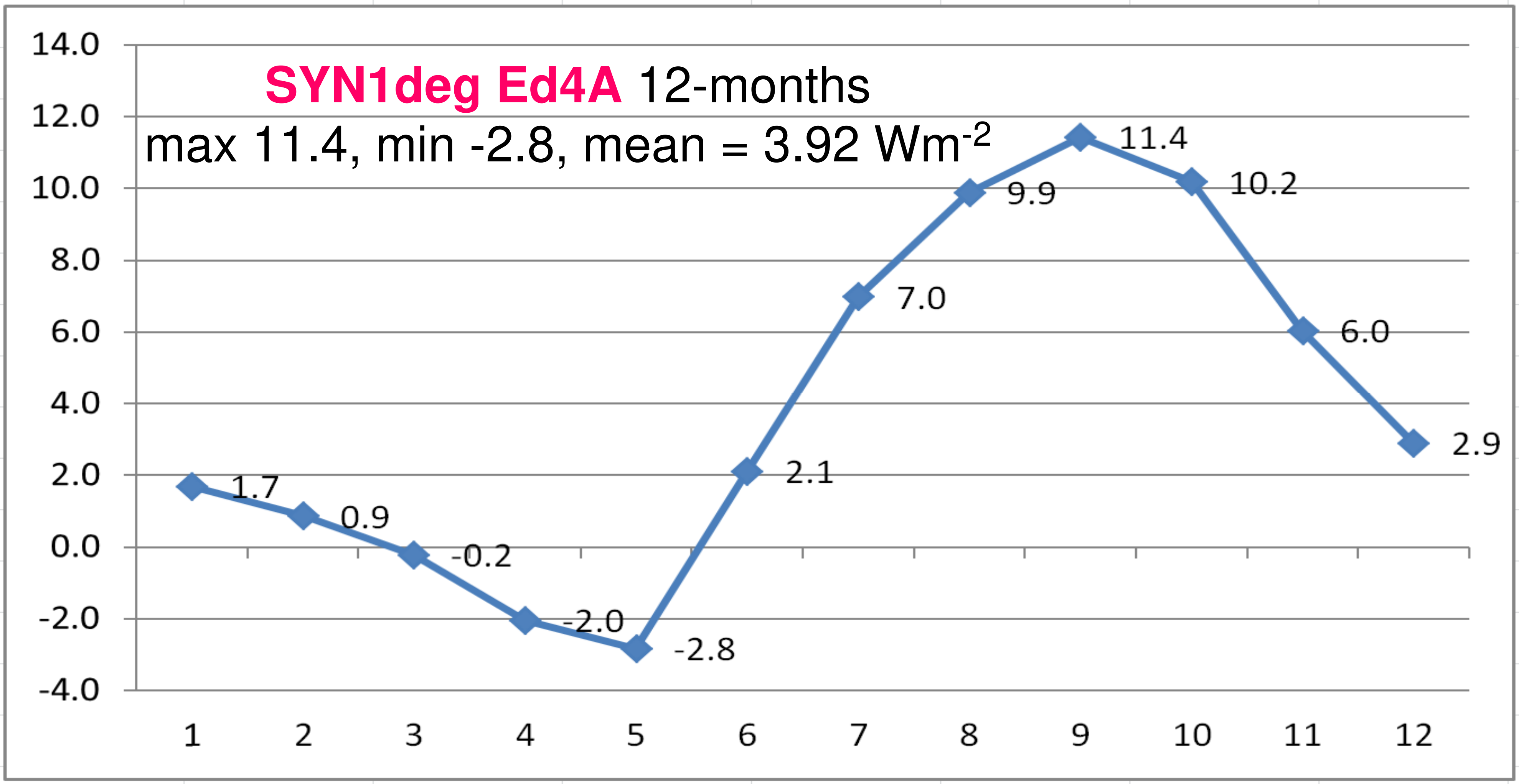
EEI_3 = 2TOA LW – SFC SW+LW

18 years, Oct 2000-Sep 2018



EEI_3 = 2TOA LW – SFC SW+LW

12 months, Oct 2017-Sep 2018



Constraint III
in CERES EBAF Ed2.8
Clear-sky, CLIM YEAR

	SYN1deg		EBAF **Ed2.8**
SFC SW net	**214.25**	+ 0.09	= 214.34
SFC LW down	**317.77**	– 1.49	= 316.28
SW+LW gross	532.02	**– 1.40**	**= 530.62**
TOA LW	**268.15**	– 2.55	= 265.60
2(TOA LW)	**536.30**	**– 5.10**	**= 531.20**
DIFF	**4.28**		**0.58**

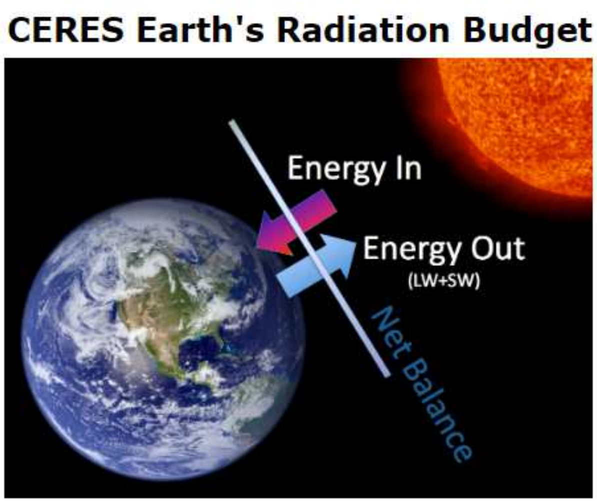
Constraint III
in CERES EBAF Ed4.0
Clear-sky, CLIM YEAR

	Ed4.0		SYN	My	EdMZ	N
SFC SW net	= 213.99 + 0.26	<=	214.25	– 0.81	= 213.44	**8**
SFC LW down	= 314.02 + 3.75	<=	317.77	+ 2.39	= 320.16	**12**
SW+LW abs	**= 528.01 + 4.01**	<=	**532.02**	**+ 1.58**	**= 533.60**	**20**
TOA LW	= 268.04 + 0.11	<=	268.15	– 1.35	= 266.80	**10**
2(TOA LW)	**= 536.08 + 0.22**	<=	**536.30**	**– 2.70**	**= 533.60**	**20**
DIFF	= **8.1**		**4.28**		**0.0**	

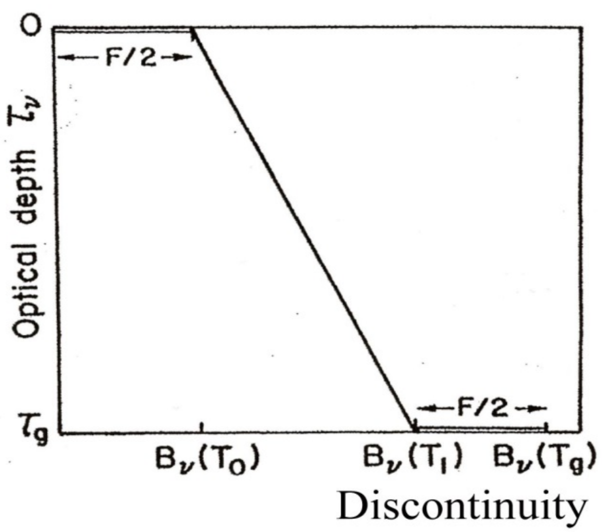
The Three Musketeers: Truth, Law and Order

The One, The Half and The Double

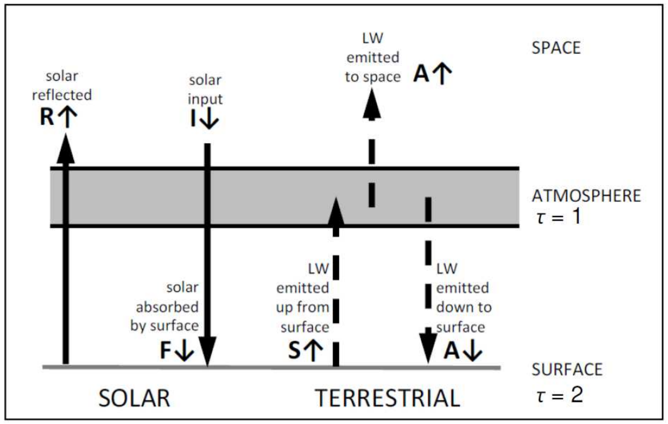
ASR	SFC Net	SFC Gross
= OLR	= OLR/2	= 2OLR



Universal necessity



Theoretical requirement



Simplest geometry

One for all, all for one

My Net Balancing I

Total Solar Irradiance = **1360.68** Wm^{-2} = **51** units

1 unit = TSI / **51** = **26.68** Wm^{-2}

Reflected all-sky, cross-section disk	= **15** units	
Absorbed all-sky, cross-section disk	= **36** units	
Reflected SW clear-sky, disk	= **8** units	
Absorbed SW clear-sky, disk	= **43** units	
Incoming Solar Radiation, sphere	= **51** / 4	= **340.17**
Reflected SW all-sky, sphere	**= 15 / 4 units**	**= 100.05**
Absorbed SW all-sky, sphere	**= 36 / 4 = 9 units**	**= 240.12**
Emitted LW all-sky, sphere	**= 36 / 4 = 9 units**	**= 240.12**
Reflected SW clear-sky, sphere	**= 8 / 4 = 2 units**	**= 53.36**
Absorbed SW clear-sky, sphere	**= 43 / 4 units**	**= 286.81**
Emitted LW clear-sky, sphere	**= 40 / 4 = 10 units**	**= 266.80**
TOA net CRE	**= – 3 / 4 units**	**= –20.01**

My Net Balancing I-II-III & CRE

1 UNIT = 26.68 Wm^{-2}		SYN	My		N × UNIT	N
Total Solar Irradiance	=	1360.9	– 0.22	=	1360.68	51
TOA SW up all	=	97.32	+ 2.73	=	100.05	15 / 4
TOA LW up all	=	238.63	+ 1.49	=	240.12	36 / 4
TOA SW up clr	=	51.38	+ 1.98	=	53.36	8 / 4
TOA LW up clr	=	268.15	– 1.35	=	266.80	40 / 4
SFC SW+LW net clr	=	134.79	– 1.39	=	133.40	5
(TOA LW)/2 clr	=	134.08	– 0.68	=	133.40	5
SFC SW net clr	=	214.25	– 0.81	=	213.44	8
SFC LW down clr	=	317.77	+ 2.39	=	320.16	12
SFC SW+LW abs clr	=	532.02	+ 1.58	=	533.60	20
2 × (TOA LW) clr	=	536.30	– 2.70	=	533.60	20
LW CRE SFC, TOA	=	29.52	– 2.84	=	26.68	1
SW CRE SFC	=	– 52.60	– 0.76	=	– 53.36	2
SW CRE TOA	=	– 45.93	– 0.76	=	– 46.69	7 / 4

Bonus: The Greenhouse Effect

G = SFC LW up – TOA LW

I ❤ SYN1deg

	SYN	My	EdMZ	N
SFC LW up all-sky	397.96	+ 2.24	400.20	15
TOA LW all-sky	238.63	+ 1.49	240.12	9
G all-sky	159.33	+ 0.75	160.08	6
SFC LW up clear-sky	397.23	+ 2.97	400.20	15
TOA LW clear-sky	268.15	– 1.35	266.80	10
G clear-sky	129.08	+ 4.32	133.40	5

Understanding how the Sun's energy drives Earth's climate system