How transparent is the Earth's atmosphere for the terrestrial radiation?

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Abstract

Surveys in Geophysics published a special issue in 2012, titled 'Observing and Modeling Earth's Energy Flows'. Kato et al. give uncertainty estimate of surface irradiances, computed with MODIS-, Calipso- and CloudSat-Derived properties. The best value and uncertainty (1σ) of the annual global mean surface Downward Longwave Radiation is DLR = 345 ± 7 W/m2; and of the annual global mean surface Upward LongWave radiation is ULW = 398 ± 3 W/m2. Trenberth and Fasullo, while tracking Earth's energy, give a mean value of Outgoing Longwave Radiation as OLR = 238.5 W/m2. Stevens and Schwartz refer to the data of NASA CERES (Clouds and the Earth's Radiant Energy System) EBAF (Energy Balanced and Filled) product, which gives a Long-Wave Cloud Radiative Effect, LWCRE of +26.5 W/m2. — First we observe here that the above-given mean values of DLR, ULW and OLR are integer multiples of the referred LWCRE, far within to their 1σ uncertainty range: DLR = 13LWCRE (+0.5 W/m2), ULW = 15LWCRE (+0.5 W/m2), OLR = 9LWCRE (+ 0.0 W/m2). — In the light of latest observations, Stephens et al. (2012, Nature Geoscience) give an update on Earth's energy balance, with very similar mean flux values (ULW = 398, DLR = 345.6, OLR = 239.7 W/m2), with higher uncertainties (±5, 9, 3 W/m2, respectively), and present also clear-sky values as OLR(clear) = 266.4 W/m2 and DLR(clear) = 319 W/m2; LWCRE is 26.7 ± 4 W/m2 there. — Based on the same satellite product, Wild et al. (2015) tabulate the CERES values as ULW = 398.8, DLR = 345.3 and OLR = 239.8 W/m2, and propose estimate of the absorbed shortwave fluxes as Absorbed Solar Radiation, ASR = 240 ± 2 W/m2; Solar Absorbed by Atmosphere, SAA = 80 ± 6 W/m2, and Solar Absorbed by Surface as SAS = 160 ± 6 W/m2. Loeb et al. (2015), reviewing a longer time period of CERES observations, suggest again practically the same values. — We realize that SAA = 3LWCRE (+0.5 W/m2) and SAS = 6LWCRE (+1 W/m2); both are again far within to the given uncertainty ranges. — With special focus on the NASA Energy and Water Cycle Study (NEWS), Stephens and L'Ecuyer (2015) present an objectively optimized estimate of the turbulent heat flows of the energy budget: Sensible Heat (SH) and Latent heat (LH) fluxes are given as SH = 26 ± 5 W/m2 and LH = 82 W/m2. — We recognize that both of these fluxes fit into the structure as SH = 1LWCRE (– 0.5 W/m2) and LH = 3LWCRE (+2.5 W/m2), again with a much smaller difference than the acknowledged uncertainty estimates. — In our study we show that all the atmospheric energy flow elements F can be written as $F = F_0 + \Delta F$, where $F_0 = I \times U$; here I is an integer, U is a unit flux, and ΔF is a deviation of the observed F flux value from its prescribed F_0 position. We present the F_0 flux values in three different units: (i) for the global average all-sky fluxes, the unit flux is the Long-Wave Cloud Radiative Effect, LWCRE (termed also the greenhouse effect of clouds); (ii) the cloudy unit is LWCRE/β, where β is cloud area fraction; and (iii) the clear-sky unit is the atmospheric window radiation (called also surface transmitted irradiance, STI(clear)). The ΔF values are well within the ±1σ range. — We point out definite internal relationships between these energy flows; the primary relations indicate: (a) the sum of the energy flows at the atmosphere's lower boundary (Earth's surface) appear to be unequivocally connected to the energy flows at the atmosphere's upper boundary (top of the atmosphere), separately to the clear-sky and the all-sky case; (b) the greenhouse factor has a given position in the structure at g(clear) = 1/3 and g(all) = 2/5; (c) the total cloud area fraction seems to be constrained at the value of the planetary emissivity at 3/5; and (d) even Earth's planetary albedo appears to have a preferred value of $\alpha = 1 - \sqrt{2}/2 = 1 - \sin 45°$. We start our study with a preliminary hypothetical explanation on the possible physical mechanism. Note that the validity of the found relationships does not depend on the validity of the proposed conceptual framework. Our results are compiled into a new energy budget diagram and poster.

1. § Global warming is the consequence of more infrared absorption in the atmosphere by more CO_2. More absorption means less escaping surface emission in the "atmospheric window". Recent longwave radiative transfer computations clearly show the role of these atmospheric infrared-absorbing gases:

When the so-called water vapor continuum is included in the computation, the longwave emission reaching to top of the atmosphere from the surface through the mid-infrared window of the cloudless atmosphere, in global and annual mean, is 66 W/m2; and it is 99 W/m2 when the continuum is excluded. This is the numerical result of Costa and Shine (2012); they use the term "surface transmitted irradiance", STI, for the atmospheric window radiation.

Clouds are not transparent in the infrared, therefore the global average "all-sky" radiation in the window is STI(all) = STI(clear) × (1 – β); having the real case with the water vapor continuum absorption and with the observed cloud area fraction of β ~ 60%, we have for the all-sky atmospheric window radiation a value of STI(all) = 26.4 W/m2.

With this, they updated the result of Kiehl and Trenberth (1997) (which served the basis for the 2001 and 2007 IPCC reports), who used 99 W/m2 clear-sky and 40 W/m2 all-sky atmospheric window radiation in their famous diagram; Trenberth and Fasullo (2012), and all other energy budget studies published later, accepted this update:

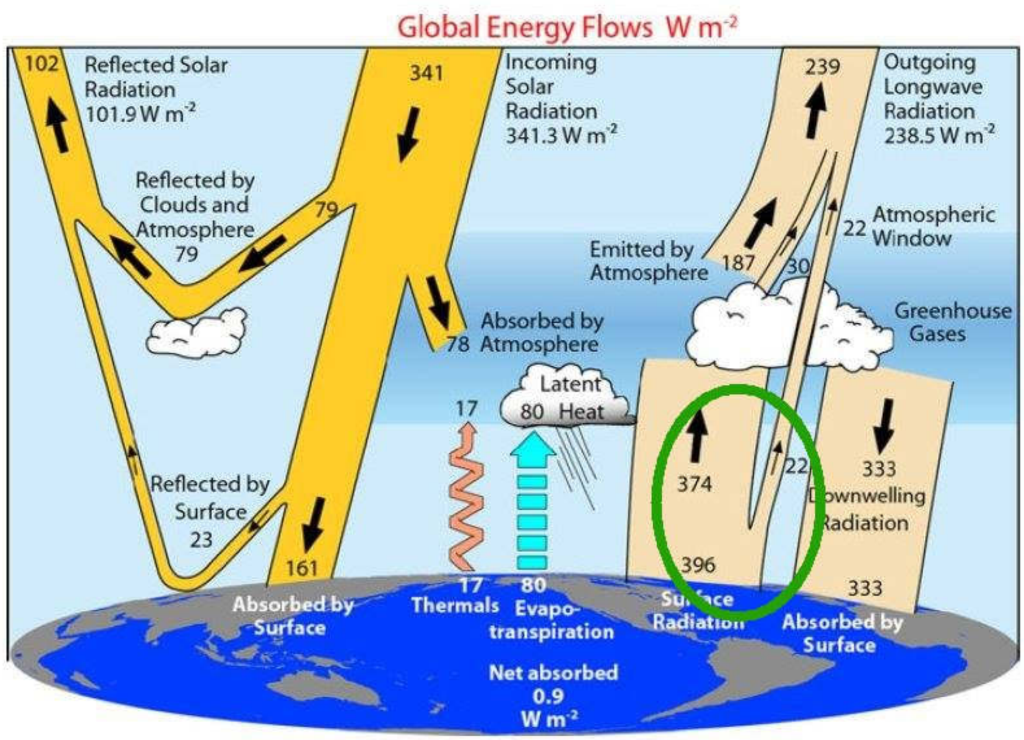

Fig. 1 The global annual mean earth's energy budget for 2000–2005 (W m^{-2}). The *broad arrows* indicate the schematic flow of energy in proportion to their importance. Adapted from Trenberth et al. (2009) with changes noted in the text

Trenberth and Fasullo (2012) Fig. 1. 374 W/m2 is absorbed by the atmosphere and clouds from 396 W/m2 upward longwave surface radiation, and only 22 W/m2 escapes to space through the atmospheric window.

Costa and Shine (2012) noted about their result that about "one-tenth of the OLR originates directly from the surface". We can add: this also means that only one-fifteenth of the surface emission can get through the atmosphere in the window without being absorbed, since the upward longwave (ULW) emission from the surface is about 398 W/m2. Data uncertainties are about ± 5 W/m2. (TF2012 use 22 W/m2 for all-sky atmospheric window, based on slightly higher cloud area fraction from another data set. We will examine this question later in detail.)

Our atmosphere is really not very transparent in the infrared; or, from the other hand, it is rather close to being completely opaque.

For terrestrial (surface) longwave radiation,
the Earth's atmosphere is partially transparent,
but it is not too far from being entirely closed.

94 % of the surface longwave emission
is absorbed by the greenhouse gases
(H_2O, CO_2, CH_4, ozone etc.), and only
6 % gets through and reaches the
top-of-the-atmosphere (TOA) in the 'window'.

If there is more CO_2 (or H_2O or methane) in the air, the longwave absorption will increase hence the surface transmitted longwave irradiance is expected to decrease: the window becomes even tighter, so our atmosphere becomes even less infrared-transparent.

This is the best explanation science can offer today: we should take care of the window, we must keep it open.

If this is so, the concerns about the increasing atmospheric CO_2-content should be taken seriously.

*

But.

The gap between the 'closed' model and the actual situation of Earth's atmosphere is so narrow that the following approach does not seem implausible: just for curiosity, let us try to understand this '94 % closed' atmosphere from the 'end of the road', when the gap is completely filled; when the whole spectrum of the terrestrial emission is covered; that is, when 100 % of the upward longwave surface radiation is blocked by the atmosphere and 0 % is transmitted from the surface to space (STI = 0).

This imagined state can easily be treated by a simple greenhouse model of a planet closed into a 'glass-shell'. A basic textbook example for this case is Figure 2.7 from *John Marshall and Alan Plumb: Atmosphere, Oceans and Climate Dynamics, Elsevier 2008, Chapter 2: The global energy balance*.

Here it is assumed that all the incoming solar radiation gets through the atmosphere and reaches the surface (that is, the 'shell' is completely transparent in the shortwave); and all the longwave surface emission is absorbed by the atmosphere (that is, the shell is 100 % opaque in the longwave). It is also assumed that no turbulent heat is transferred from the surface to the atmosphere: sensible and latent heating (SH and LH) is zero.

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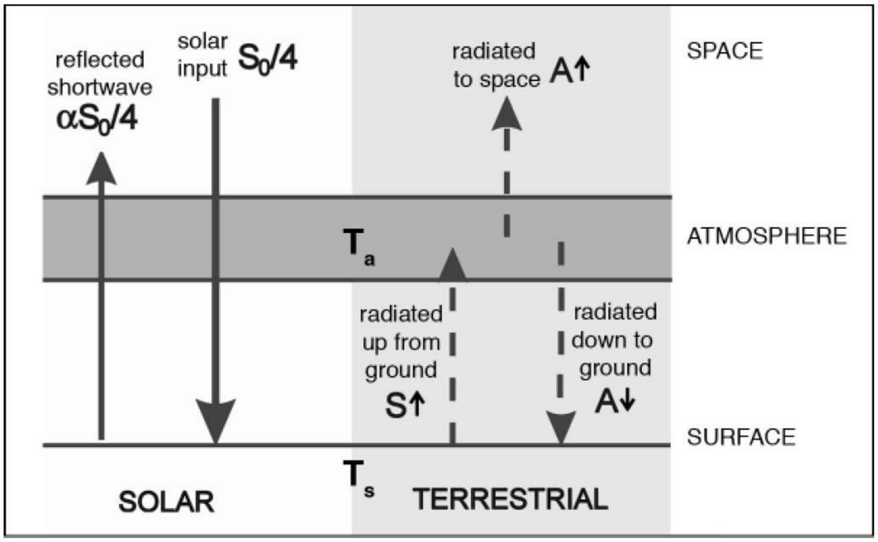

FIGURE 2.7. The simplest greenhouse model, comprising a surface at temperature T_s, and an atmospheric layer at temperature T_a, subject to incoming solar radiation $S_0/4$. The terrestrial radiation upwelling from the ground is assumed to be completely absorbed by the atmospheric layer.

A single-layer SW-transparent, LW-opaque, non-turbulent 'glass-shell' greenhouse model.
Marshall-Plumb 2008, Fig. 2.7.

At the surface the energy balance equation is given in Marshall and Plumb Eq. (2-8):

$$S\uparrow = \frac{1}{4}\left(1-\alpha_p\right)S_0 + A\downarrow,$$

whence

$$\sigma T_s^4 = \frac{1}{4}\left(1-\alpha_p\right)S_0 + \sigma T_e^4 = 2\sigma T_e^4, \qquad \text{(2-8)}$$

In our notation system:

Absorbed Solar Radiation (ASR) + Downwelling Longwave Radiation (DLR) is balanced by the Upwelling Long Wave (ULW) terrestrial emission:

ASR + DLR = ULW.

This 'glass shell atmosphere' is assumed to be entirely transparent to the solar flux, but absorbs the longwave upward radiation from the ground completely. As a single-layer shell, it will then radiate the absorbed energy upward and downward equally:

OLR = DLR

The constraint here is that in equilibrium the Absorbed Solar Radiation is balanced by the Outgoing Longwave Radiation (OLR):

$$ASR = OLR$$

Therefore the surface energy balance equation for the glass-shell model, simply from geometrical reasoning, is:

$$\mathbf{E(SRF) = ULW = ASR + DLR = 2OLR}.$$

The planetary emissivity of the closed model, defined as the ratio of outgoing longwave radiation and surface longwave emission, is therefore OLR/ULW = 0.5.

The greenhouse effect, defined as surface upward longwave radiation (ULW) less outgoing longwave radiation (OLR) as

$$G = ULW – OLR$$

is then equal to OLR in this model; therefore the normalized greenhouse function, g = G/ULW is also equal to g = 0.5.

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How does this all looks like on Earth?

Here the case is different. Our atmosphere is only partially transparent to the solar flux: Solar Absorbed by Atmosphere (SAA) is not zero, therefore Solar Absorbed by Surface (SAS) is less than the total solar absorption: SAS = ASR – SAA. Also, our atmosphere is leaky, that is, only partially opaque to the terrestrial flux, as we have seen above.

Let us check first the clear-sky part of the atmosphere. We cite here the data from the most recent NASA CERES (Clouds and the Earth's Radiant Energy System) satellite observations, as presented in the EBAF (Energy Balanced And Filled) products, see the latest editions Ed2.7 and Ed2.8 on the NASA CERES website. For the ten-year period 2000 - 2010:

SAS(clear) = SW down – SW up = 243.9 – 29.7 = 214.2 W/m2

DLR(clear) = 316.8 W/m2

OLR(clear) = 265.8 W/m2

E(SRF, clear) = SAS(clear) + DLR(clear) = 531.0 W/m2.

Now let us compare it with two OLR :

2OLR(clear) = 2 × 265.8 = 531.6 W/m2.

Now **THAT** is a surprise!

Hard to believe, but according to the observed data, the same 'closed model geometry' works in the clear-sky part of the Earth's atmosphere as in the glass-shell model !

The difference is only 0.6 W/m2, much smaller than the error of observation (typically about ±3 W/m2):

E(SRF, Earth, clear) = 2OLR(clear).

The validity of the closed-model analogy is so shocking that we start a new paragraph here.

II. Checking the closed model on all-sky CERES data

2. §. “Dear Dr. Zagoni, this is completely impossible, nonsense, lunatic. The clear-sky part of the Earth CANNOT follow the glass-shell closed model, since – as you yourself pointed out above – there is an escaping part of the surface radiation through the clear-sky atmospheric window, with a value of STI(clear) = 66 W/m2. This is so because of very simple spectral reasons. “*As humans emit greenhouse gases, it’s causing the Earth to warm. That’s indisputable and proven*.” – as The Guardian itself says. So your model is wrong.”

Well, sorry, we didn't say that the clear-sky atmosphere in itself is 'closed'; we only *observe*, based on the CERES data, that the surface energy flows follow the equivalent model of a glass-shell geometry, being double of the clear-sky OLR.

But all right, if this is so ‘indisputable’, let us check it on further numbers of average clear and cloudy conditions on Earth: the so-called all-sky case.

Citing again NASA CERES data:

SAS(all) = SW down – SW up = 186.4 – 24.1 = 162.3 W/m2

DLR(all) = 345.1 W/m2

OLR(all) = 239.6 W/m2

E(SRF, all) = SAS(all) + DLR(all) = 507.4 W/m2.

To compare it with 2×OLR(all), the difference is +28.2 W/m2, and to compare it with 2OLR(clear), the difference is -24.2 W/m2.

But wait ... aren't these values similar to what is *lost in the all-sky atmospheric window*?

Very close to it indeed — far within to the measurement uncertainties.

So let us accept for a moment, at least numerically, that

E(SRF, all) = 2OLR(clear) – STI(all).

Now **THIS** relationship would be intelligible.

It would mean that:

The Earth's all-sky atmosphere works like an LW-opaque closed shell,
except one-fifteenth of the surface irradiance,
which is escaping to space through the all-sky atmospheric window.

As Marshall and Plumb (2008) show in the model:

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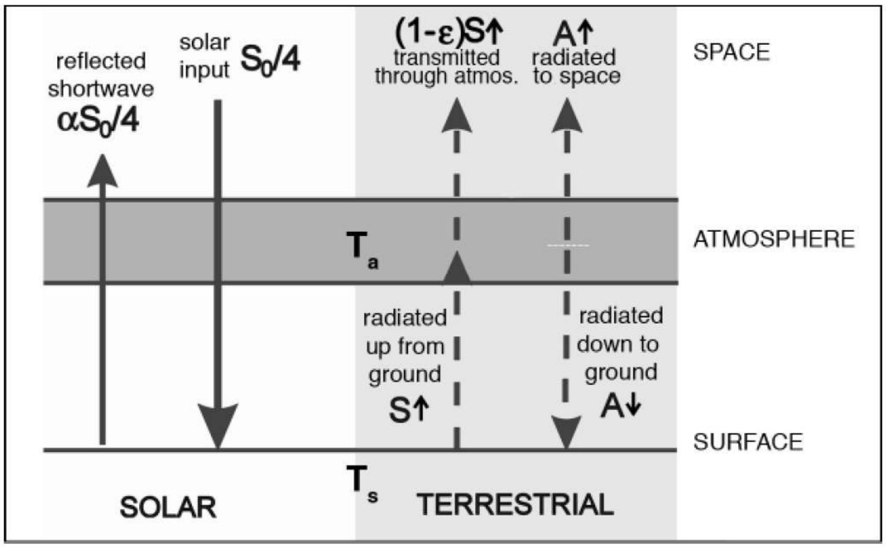

FIGURE 2.8. A leaky greenhouse. In contrast to Fig. 2.7, the atmosphere now absorbs only a fraction, ε, of the terrestrial radiation upwelling from the ground.

Here we know from the data that the fraction of terrestrial radiation upwelling from the ground which is absorbed by the atmosphere is ε ~ 14/15; that is, only 1/15 of the terrestrial LW emission is transmitted through the atmosphere.

To close our atmosphere in the LW, only 6.6 % of the surface black-body radiation must be grabbed at.

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Here another quantity will be taken into account: the difference of clear-sky and all-sky outgoing radiations, OLR(clear) – OLR(all), called the Long Wave Cloud Radiative Effect, LWCRE; it is known also as the 'blanketing effect' of the clouds (in contrast to their shielding effect in the shortwave).

According to the CERES EBAF Ed2.8 data again:

OLR(clear) – OLR(all) = LWCRE = 26.2 ± 0.5 W/m2.

Let us compare it to the atmospheric window value:
Window radiation was STI(all) = 26.4 W/m2.

From here an idea arises.

Could we state that: the longwave radiative effect of clouds is the same as the all-sky atmospheric window?

Could we state that

the role of the partial cloud cover in the longwave is
TO FILL THE GAP?
TO CLOSE THE ATMOSPHERIC WINDOW?

This would explain the similar behavior of a closed shell model and the (seemingly) open atmospheric model of the partially cloud-covered Earth as shown in our two figures below:

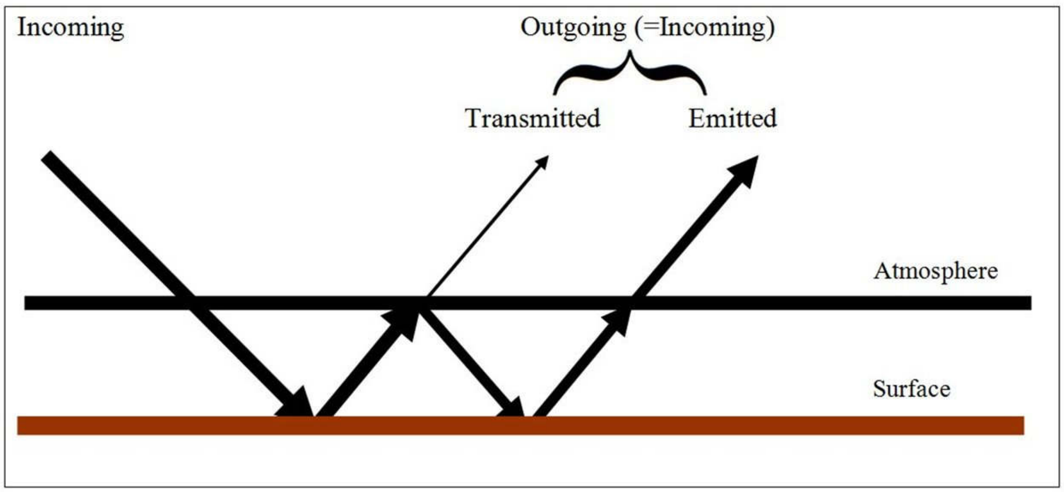

Figure 1. Schematic view representing the concept of a 'leaky' atmosphere. Surface transmitted irradiance, STI(all) is lost in space through the open mid-infrared atmospheric window.

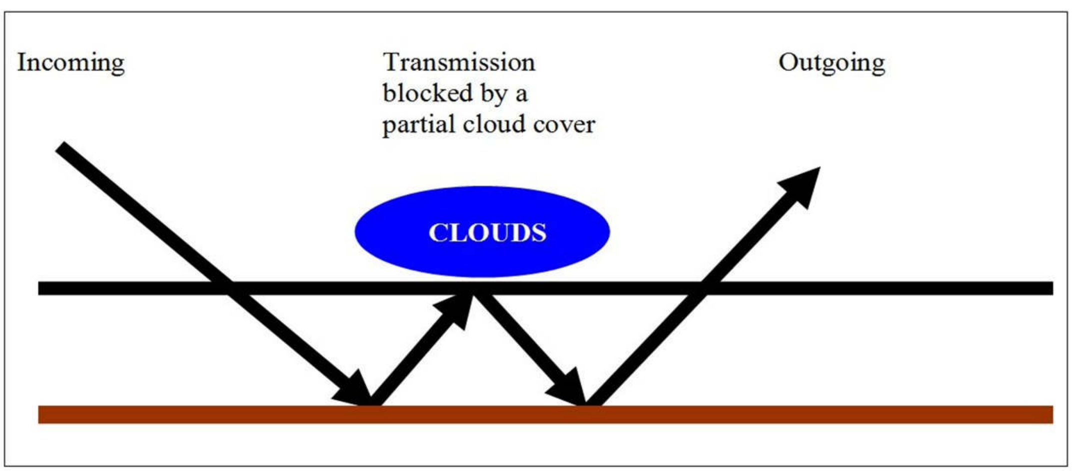

Figure 2. Schematic view representing the concept that the all-sky atmospheric window is closed by the longwave cloud radiative effect, LWCRE.

If so, starting from the glass-shell geometry and the clear-sky case of Earth, we could write the surface energy balance equation of the all-sky case of Earth as:

Energy (SRF, shell) = 2OLR(shell)

Energy (SRF, Earth, clear) = 2OLR(clear)

Energy (SRF, Earth, all) =

= 2OLR(clear) – STI(all)

= 2OLR(all) + LWCRE.

Then the analogy leads to this statement:

The surface energy being lost in the all-sky atmospheric window, STI(all),
is gained back by the longwave cloud radiative effect, LWCRE.

We apologize for the tabloid manner, but the symmetry of this equation must be expressed somehow.

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But it is evident that there are a lot of differences between the shell-model and the Earth.

For example,

Downward longwave radiation is not equal to outgoing longwave radiation: DLR ≠ OLR;

There is solar absorption in the atmosphere: SAA ≠ 0, therefore SAS ≠ ASR;

and the turbulent heat does not zero: SH + LH ≠ 0.

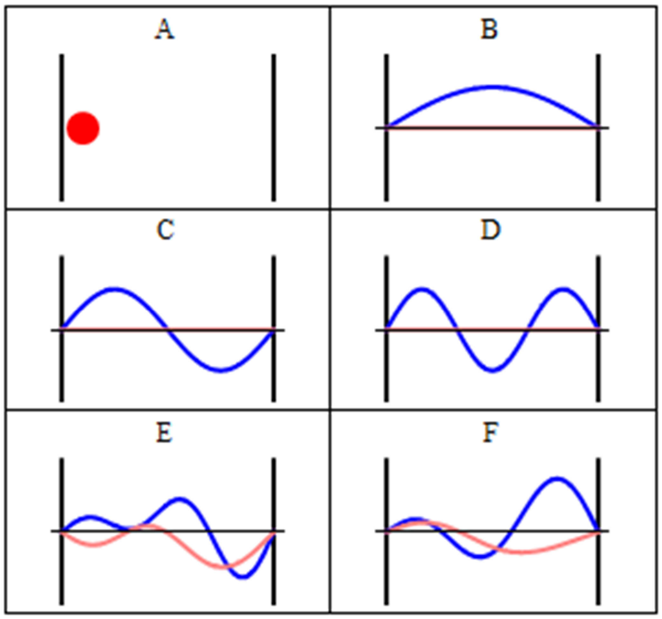
Further, in the clear-sky Earth, the absorbed solar radiation is not equal to the outgoing radiation: ASR(clear) ≠ OLR(clear).

Contrary to all of these internal differences, from an outer-boundary perspective,
the above-said logic still might work.

Though this be madness, yet there is method in't.

How the internal energy flows ('waves') would behave in this closed-box model?

It wouldn't be a big surprise (actually, it could even be anticipated) if they showed a periodic character with 'wave numbers' which are **integer multiples of the unit flux of LWCRE**, when propagating in the 'box' between the two boundaries; like in the animation below:

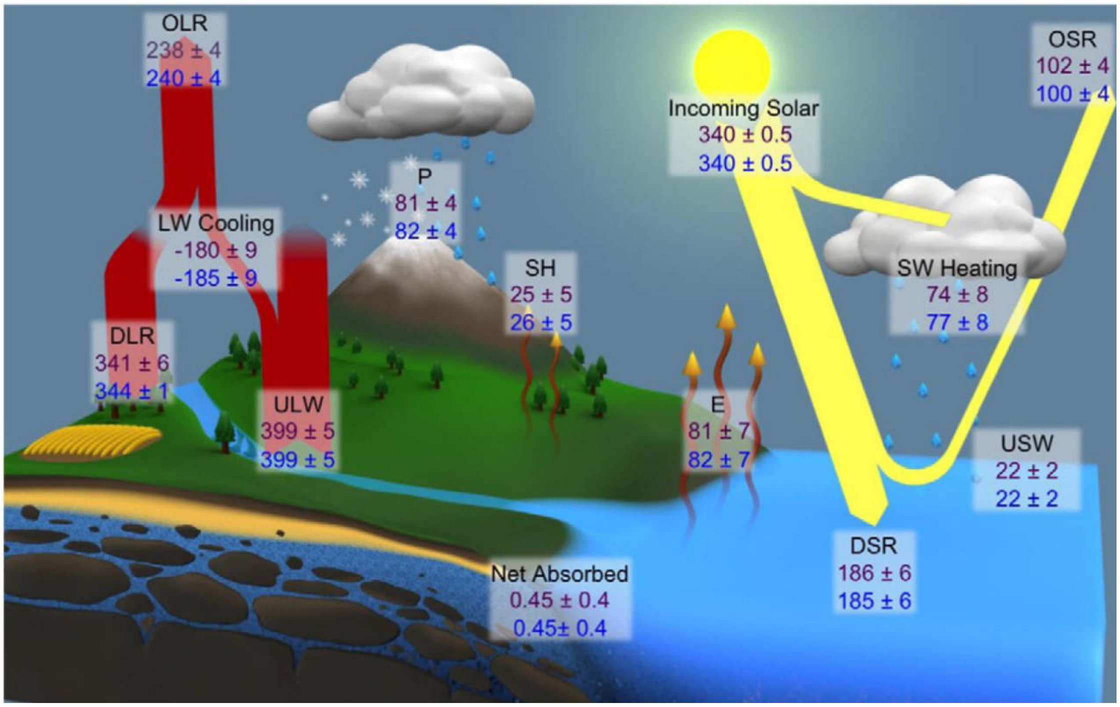


Left border: Lower boundary (surface)
Right border: Upper boundary (TOA, closed by LWCRE = STI(all))

(Animation is from Wikipedia: https://en.wikipedia.org/wiki/Particle_in_a_box)

III. Checking the model on the latest published energy budget diagram

3. §
We check the fluxes from the latest published global energy balance diagram:
Stephens and L'Ecuyer (2015): The Earth's energy balance.
(Atmospheric Research 166: 195–203)



The flux components given in the diagram with uncertainties (all in W/m2):

ULW (Upward surface Longwave Radiation) = 399 ± 5
DLR (Downward Longwave Radiation) = 344 ± 1 (?)
ISR (Incoming Solar Radiation) = 340 ± 0.5
OSR (Outgoing Solar Radiation) = 100 ± 4
ASR (Absorbed Solar Radiation) = 240 ± 4
OLR (Outgoing Longwave Radiation) = 240 ± 4
LW Cooling (LWQ = ULW – DLR – OLR) = – 185 ± 9
SH (Sensible Heating) = 26 ± 5
E (Evaporation, called also Latent Heating) = 82 ± 7
SW Heating (SAA, Solar Absorption by Atmosphere) = 77 ± 8
DSR (Downward Solar Radiation) = 185 ± 6
USW (Upward Solar Radiation) = 22 ± 2
DSR – USW (SAS, Solar Absorption by Surface) = 163 ± 6.

An important energy flow component, clear-sky outgoing radiation, OLR(clear) is not displayed here, but we recall the earlier published energy balance diagram by the same authors (Stephens et al. 2012: An update on Earth's energy balance in light of the latest observations, Nature Geoscience 5: 691-696), where the quantity is presented as:
OLR(clear) (Clear-sky emission) = 266.4 ± 3.3 W/m2

Another fundamental components presented in the Stephens et al. (2012) diagram are cloud longwave effect at top-of-atmosphere and at surface:

LWCRE (TOA) = 26.7 ± 4 W/m2
LWCRE (SRF) = 26.6 ± 5 W/m2

On comparison, we see that the following F flux mean values are **INTEGER MULTIPLES OF LWCRE** (the relative uncertainty and the difference is also shown):

Table I. Observed fluxes

F	W/m2	1σ (W/m2)	F_0 = **I** × LWCRE (W/m2)	Δ (W/m2)	σ / LWCRE (%)	Δ / LWCRE (%)
ULW	399	± 5	**15** × 26.6	+ 0.0	18.8	0.0
DLR	344	± 1 (?)	**13** × 26.6	– 1.8	3.8	6.8
OLR	240	± 4	**9** × 26.6	+ 0.6	15.0	2.2
LWQ	–185	± 9	**– 7** × 26.6	+ 1.2	33.8	4.5
SH	26	± 5	**1** × 26.6	– 0.6	18.8	2.2
E	82	± 7	**3** × 26.6	+ 2.2	26.3	8.3
SAA	77	± 8	**3** × 26.6	– 1.8	30.0	6.8
SAS	163	± 6	**6** × 26.6	+ 3.4	22.5	12.8

Each of these values appear well within the respective uncertainty range; the only exception is DLR, but the displayed ±1 W/m2 uncertainty in the Stephens-L'Ecuyer 2015 diagram seems wrong, far too narrow (in the 2012 diagram of the same authors a much more realistic error range of ± 9 W/m2 was attached to this quantity; the mean value there was 345.6 W/m2; our **13** × 26.6 = 345.8 W/m2 differs from this only by 0.2 W/m2).

Six of these observed quantities are independent: Longwave cooling (LWQ) is a linear combination other flux components. The sum of solar absorption by the atmosphere and solar absorption by the surface, SAA + SAS, is equal to the total Absorbed Solar Radiation, ASR. At equilibrium, this, in turn, is equal to OLR. These are currently balanced within 1 W/m2 (±0.45 W/m2).

We construct further quantities as linear combinations of the above, e.g: OLR(clear) = OLR + LWCRE; The Net Surface Longwave (NSL) cooling is defined as NSL = ULW – DLR; and the clear-sky and all-sky greenhouse effects, G(clear) and G(all) are defined as the difference of surface upward longwave radiation and outgoing longwave radiation: G(clear) = ULW – OLR(clear), and G(all) = ULW – OLR(all).

Consequently, these flux components also have values that are multiples of the unit flux as: OLR(clear) = **10** × 26.6 W/m2, NSL = **2** × 26.6 W/m2, G(clear) = **5** × 26.6 W/m2, and G(all) = **6** × 26.6 W/m2.

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So far we were talking about the *observable* flux components of the global energy budget. But will the non-observable flux components like atmospheric window radiation, which can only be computed, fit into this whole-number structure?

From the most recent independent detailed line-by-line computation on realistic atmospheric profiles presents, a result of STI(clear) = 66 W/m2 was published (Costa and Shine 2012).

NASA CERES satellite observations show a total cloud area fraction of $\beta \sim 0.605$ for the past seven years. For an IR-opaque single-layer effective cloud area fraction we use $\beta = 0.6$. The resulted all-sky window radiation is then STI(all) = $(1 - \beta) \times$ STI(clear) = $0.4 \times 66 = 26.4$ W/m2. If we used the observed mean value of $\beta \sim 0.605$, we would have STI(all) = $0.395 \times 66 = 26.1$ W/m2.

Remember, these values are from CERES data; the CERES LWCRE was 26.2 W/m2. Our supposed

$$\text{LWCRE} = (1 - \beta) \times \text{STI(clear)} = \text{STI(all)}$$

equality seems working well.

So we accept STI(all) as a further independent element in the table, with a value of STI(all) = **1** × LWCRE, and with a deviation of about ± 0.5 W/m2 or less.

Using STI(all), we create two more important flux components as linear combinations of others: atmospheric upward longwave emission (also called Cooling To Space, CTS); for clear and all-sky conditions is defined as: CTS(clear) = OLR(clear) – STI(clear), CTS(all) = OLR(all) – STI(all). Separating the cloud effect from the latter, CTS(atm) = OLR(all) – STI(all) – LWCRE.

Assuming that STI(all) = **1**, these components in turn will be: CTS(all) = **8**, and CTS(atm) = **7**. Finally, for clear and all-sky conditions, the portion of surface upward LW emission (ULW) which is absorbed in the atmosphere is the Longwave Atmospheric Absorption (LAA). LAA(all) = ULW – STI(all) = **14**.

Summarizing these all observable and non-observable fluxes into a table, they form an arithmetic sequence with a common difference of LWCRE:

Table II. All fluxes, $F_0 = I \times LWCRE$ (W/m2)

Flux	Name	I	F_0
LongWave Cloud Radiative Effect	LWCRE	**1**	26.6
Sensible Heating, all-sky	SH(all)	**1**	26.6
Surface Transmitted Irradiance, all-sky	STI(all)	**1**	26.6
Net Surface Longwave radiation, all-sky	NSL(all)	**2**	53.2
Evaporation (Latent Heating), all-sky	LH(all)	**3**	79.8
Solar Absorbed by Atmosphere, all-sky	SAA(all)	**3**	79.8
Turbulent heat flux, all-sky	(SH + LH)(all)	**4**	106.4
Greenhouse effect, clear-sky	G(clear)	**5**	133.0
Greenhouse effect, all-sky	G(all)	**6**	159.6
Solar Absorbed by Surface, all-sky	SAS(all)	**6**	159.6
LongWave Cooling, all-sky	LWQ(all)	**–7**	-186.2
Cooling-To-Space, atmosphere	CTS(atm)	**7**	186.2
Cooling-To-Space, all-sky	CTS(all)	**8**	212.8
Outgoing Longwave Radiation, all-sky	OLR(all)	**9**	239.4
Outgoing Longwave Radiation, clear-sky	OLR(clear)	**10**	266.0
Downward Longwave Radiation, clear-sky	DLR(clear)	**12**	319.2
Downward Longwave Radiation, all-sky	DLR(all)	**13**	345.8
Longwave Atmospheric Absorption, all-sky	LAA(all)	**14**	372.4
Upward LongWave emission by the surface	ULW	**15**	399.0

all within about $\Delta F = \pm 3$ W/m2.

Now the F radiative and non-radiative, observable and only-computable energy flows in Earth's surface and atmosphere seem to follow the "wave-in-a-box" model: they are integer multiples of a unit flux of LWCRE:

$$\mathbf{F = I \times LWCRE + \Delta F}$$

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When we settled STI(all) as **1** in the table of integer relationships, the following condition was true:

$(1 - \beta) \times STI(clear)/ULW = 1/15$.

The observed total cloud area fraction, in the average of the past seven years, is $\beta \sim 0.605$. The ratio STI(clear)/ULW ~ 1/6 is a result of the radiative transfer computation, as we have seen above; so we have, for the 'grid' (F_0)values, $2/5 \times 1/6 = 1/15$ — again, within the observational uncertainties: the cloud area fraction seems to be part of the game as well.

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Really, the observed cloud area fraction beta is very close to the planetary emissivity (defined as the ratio between outgoing LW radiation, OLR(all) and surface upward LW radiation, ULW, see e.g Bengtsson 2012), called also all-sky transfer function, *f*(all). Again, with the F_0 quantities,

β = OLR(all) / ULW = *f*(all) = **9**/**15** = 0.6.

Formally, the all-sky transfer function *f*(all) is equal to 1 – *g*(all), where *g*(all) is the normalized all-sky greenhouse function, defined as

g(all) = G(all)/ULW = (ULW – OLR(all)) / ULW = **6**/**15** = 0.4.

Consequently, the cloudless area of the surface, (1 – β), would be numerically equal to the all-sky greenhouse function *g*(all).

Remember: both the planetary emissivity (transfer function) and the greenhouse function of the closed-shell model were 0.5.

On Earth, where 1/10 of the clear-sky emission is lost-in-space through the open all-sky atmospheric window, we are not surprised to have

f(all) = 5/10 + 1/10 = 0.6
g(all) = 5/10 – 1/10 = 0.4

The sharp values of these quantities are extremely implausible, unless some planetary-level determinations work in the physical background — or in the geometry. We should regard them annual global mean 'preferred' values, around which oscillations (vibrations, fluctuations, natural or triggered variations) are possible — unknown in size and time-scale.

But according to the above-cited, observed and published data, these equalities stand very precisely — at least far within to the accuracy of the observations. This forces us to take our box model seriously.

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We will see that several interesting internal relationships show themselves in the box-model. Here we show only one:

The cloud-covered part of the surface, β, radiates the amount of energy β × ULW, which is equal to the all-sky outgoing LW radiation OLR(all):

β × ULW = OLR(all)

IV. Checking the constraint relationship on the latest published diagram

4. § Here we point out that the relationship, which connects unequivocally the energy budget of the lower boundary (surface) to the energy flows at the upper boundary (TOA), is THERE in the Stephens and L'Ecuyer (2015) diagram.

The surface energy balance equation:

Energy (SRF, in) = Solar Absorbed by the Surface + Downward Longwave Radiation =
Energy (SRF, out) = Upward Longwave radiative cooling (ULW) and non-radiative (Sensible plus Latent) cooling.

With the numbers of the diagram:

Energy (SRF, in) = SAS + DLR = 163 + 344 = 507 W/m2
Energy (SRF, out) = ULW + SH + E = 399 + 26 + 82 = 507 W/m2

Note that:
Energy (SRF) = 507 W/m2 = 2 × 240 + 26.6 + 0.4 W/m2.

Energy (SRF) = 2OLR + LWCRE

with an imbalance of only 0.4 W/m2, which is also indicated in the diagram (under the name Net Absorbed).

The relationship in this diagram is exact — which is intriguing.

We can therefore establish E(SRF) as element **19 = 2 × 9 + 1** in our table.

According to these data sets, the energy flows at the lower boundary of the box (surface) really appear to equilibrate to the energy flows at the upper boundary (TOA).

V. An almost-conclusive deduction of the fluxes from the box model

5. § Let us survey what we already know about the fluxes in our specific leaky-but-still-closed box model, based on Table II.

At the upper boundary (top-of-atmosphere, TOA) there are NINE units in the all-sky outgoing radiation, from which EIGHT units are emitted upward from the atmosphere and clouds, and ONE unit is transmitted from the surface. This ONE unit is gained back by ONE unit of longwave cloud effect.

At the lower boundary (surface, SRF) there are TWO units of net surface longwave (NSL) radiative cooling and FOUR units of non-radiative cooling (sensible + latent heat release, SH + LH) (with an internal distribution of ONE thermals and THREE units of evaporation). The surface *net* radiative and *non*-radiative cooling is then, together, SIX units.

These SIX units of surface net and non-radiative cooling are equal to the SIX units of solar radiation absorbed by the surface (SAS), which serves the SIX units of longwave energy content of the greenhouse effect (G).

These SIX units of the greenhouse effect, added to the net NINE units coming back from the atmosphere, form the FIFTEEN units of *gross* surface radiative cooling (ULW).

This FIFTEEN units of the gross surface radiative cooling, with the FOUR units of surface non-radiative cooling form the NINETEEN units of the total energy flow content of the surface E(SRF) = ULW + SH + LH.

Having FIFTEEN units of surface upward longwave (ULW) radiation and TWO units in net surface longwave radiation, we must have THIRTEEN units in downward longwave radiation (DLR).

This THIRTEEN units in downward longwave radiation, added to the SIX units of solar radiation absorbed by the surface form the NINETEEN units of the total energy income of the surface E(SRF) = DLR + SAS.

Having FIFTEEN units of surface upward longwave (ULW) radiation and ONE unit in surface transmitted radiation (STI), we must have FOURTEEN units for longwave atmospheric absorption: LAA = ULW – STI.

Having FOURTEEN units of longwave atmospheric absorption and SEVEN units in non-longwave atmospheric absorption, we have TWENTY ONE units for the total atmospheric absorption.

From these TWENTY ONE units of atmospheric energy income, EIGHT units are emitted upward by the atmosphere and clouds, and THIRTEEN units are emitted downward to the surface.

This means that SEVEN units are emitted upward by the atmosphere only, and TWELWE units are emitted downward without the cloud longwave effect, leaving TWO units of LWCRE up and down.

The TWENTY ONE units in the gross atmospheric energy absorption is then equal to NINETEEN units coming from the surface, plus THREE units coming from solar atmospheric absorption, less ONE unit of surface radiation, as STI is running through the atmosphere without being captured.

The TWENTY ONE units in the atmospheric energy content are then equal to NINETEEN units of the gross surface energy content plus ONE up and ONE down longwave cloud radiative effect.

This TWENTY ONE units of atmospheric energy content act like a shield of TWO times TEN units of OLR(clear), plus ONE unit of LWCRE.

The NINETEEN units of surface energy content is equal to TWO times TEN units of OLR(clear), less ONE unit escaping in the all-sky atmospheric window.

The NINETEEN units of surface energy content is equal to TWO times NINE units of OLR(all), plus ONE unit of longwave cloud effect.

Having FIFTEEN units of surface upward longwave radiation, NINE units in outgoing longwave radiation and THIRTEEN units in downward longwave radiation, we must have minus SEVEN units in the net atmospheric longwave cooling: LWQ = ULW – OLR – DLR .

This SEVEN units in the net atmospheric longwave cooling is supplied by SEVEN units of non-longwave atmospheric heating: solar absorbed by atmosphere (THREE units), plus sensible and latent heating (ONE plus THREE units).

The SEVEN units of net atmospheric longwave cooling joins to TWO units of net longwave cooling coming from the surface, to form the NINE units of the total thermal cooling of the system: the outgoing longwave radiation.

*

NINE units of outgoing longwave radiation and FIFTEEN units of surface upward longwave radiation then define a proper fraction of 9/15 = 0.6 for planetary emissivity, called also transfer function, f(all).

SIX units of the greenhouse effect and FIFTEEN units of ULW define a proper fraction of 6/15 = 0.4 for the normalized greenhouse function, g(all).

NINE units of outgoing longwave radiation plus ONE unit of longwave cloud radiative effect defines TEN units for the clear-sky outgoing radiation.

TEN units of clear-sky outgoing radiation then lead to TWENTY units for the clear-sky surface energy budget, E(SRF, clear) = 2OLR(clear).

From this TWENTY units of clear-sky surface energy flows ONE unit is lost in the all-sky mean, leaving NINETEEN units for the all-sky surface energy budget: E(SRF, all) = 2OLR(clear) – STI(all), gained back by ONE unit of the longwave cloud effect: E(SRF, all) = 2OLR(all) + LWCRE.

The cooperation between the clear-sky part and the all-sky part is created by a partial cloud cover; with a total single-layer IR-opaque effective cloud area fraction β = (NINE units of OLR) / (FIFTEEN units of ULW) = 9/15 = 0.6 = planetary emissivity.

TEN units of clear-sky outgoing longwave radiation contributes to the all-sky global average with an area-weighted value of (1 – β) × OLR(clear) = FOUR units. Therefore, the cloudy part contributes to the NINE units of all-sky OLR with FIVE units, having a nominal outgoing longwave radiation above clouds OLR(cloudy) = FIVE / β .

NINE units of OLR(all) is therefore being partitioned as

OLR(all) = $(1 - \beta) \times$ OLR(clear) + $\beta \times$ OLR(cloudy) = FOUR + FIVE.

Hence, the cloudy unit is ONE/β, and the clear-sky unit is ONE / $(1 - \beta)$.

Numerically:

ONE = UNIT(all) = OLR(clear) / 10 = 26.6 W/m2, then

ONE / β = UNIT(cloudy) = 26.6 / 0.6 = 44.33 W/m2, and

ONE / $(1 - \beta)$ = UNIT(clear) = 26.6 / 0.4 = 66.5 W/m2.

The surface energy budget under clouds is given then:

E(SRF, cloudy) = 2OLR(cloudy) + UNIT(cloudy) = 2OLR(clear) – UNIT(cloudy).

Okay then, but we said at the beginning of this paper: "If there is more CO2 in the air, both the clear-sky and the all-sky surface transmitted longwave radiation is expected to decrease: the window becomes even tighter."

What's happening with the window if there is more CO2 in the air? The latest NASA AIRS instrument has actually measured the decrease in IR energy from the Earth as CO2 in the atmosphere has increased. This is observational evidence that increased CO2 reduces the rate of loss of IR energy to outer space. But we have also observational evidence that the whole flux structure still maintains the integer ratio system and that the greenhouse effect keeps its narrow value at its required position. What's going on?

It seems that the overall planetary-level energetic control, which determine the closed-model geometry, pose effective constraints on the entire radiative transfer process, and it can be anticipated that the most powerful greenhouse gas, water vapor could play the leading role, through evaporation, precipitation, cloud formation and greenhouse effect-regulation. The given energy flow structure belongs to a very specific, unique annual global mean vertical temperature distribution. Though one element is perturbed by anthropogenic emissions, all the other elements together seem to be able to act as an effective stabilizing feedback network.

*

We do not have enough data to talk about these fluxes and their relationships during transient climatic conditions, under glacial and interglacial circumstances. We can only say what we see: that these identities and integer ratios are there in the data covering the recent decades of accurate satellite observations; some of them are almost exact, and all of them are surprisingly close.

It is remarkable that contrary to the above-referred AIRS observations, the two substantial radiative boundary fluxes, OLR and ULW still fit the best: with 0.6 W/m2 and 0.0 W/m2 deviation, according to the Stephens and L'Ecuyer (2015) data. We regard this as a strong indication that the box model might be valid.

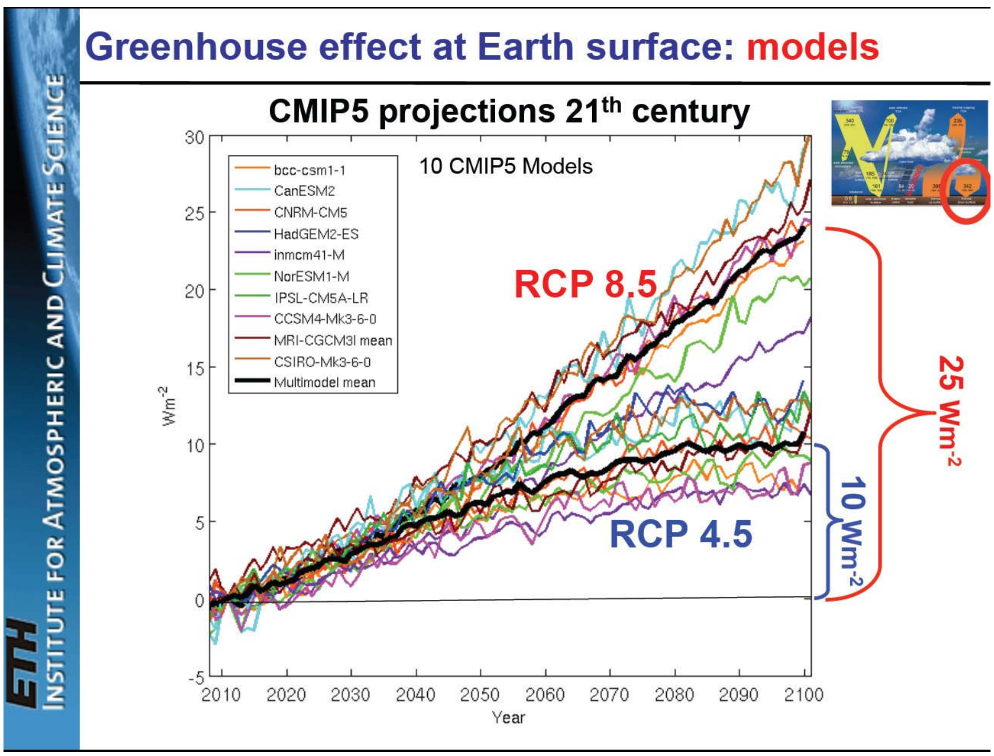
It is to be emphasized also that we are finding ratios and relationships between energy flows, not absolute values of flows: the all-sky unit is relative to OLR(all), the clear-sky unit is relative to OLR(clear).

So we state three substantial findings:

I. The surface energy budget is constrained to the energy flows at TOA
II. There is a discrete pattern in the fluxes
III. The above two features can be explained by a specific closed-model analogy.

These three, inter-related results give us enough confidence to state the followings:

This particular, constrained and quantized characteristic of the atmospheric energy flow system is a completely different paradigm from the prevailing climate theory, which expects increased greenhouse effect from the increased CO2 content of the atmosphere.



From: Wild M (2015a) Energy cycles in the global climate system.

If the above-presented numerical relationships are long-standing and valid
and the Earth really maintains the said closed-system character,
then this increase in the greenhouse effect cannot happen.

Let this justifiable forecast be the bottom line of this paper.