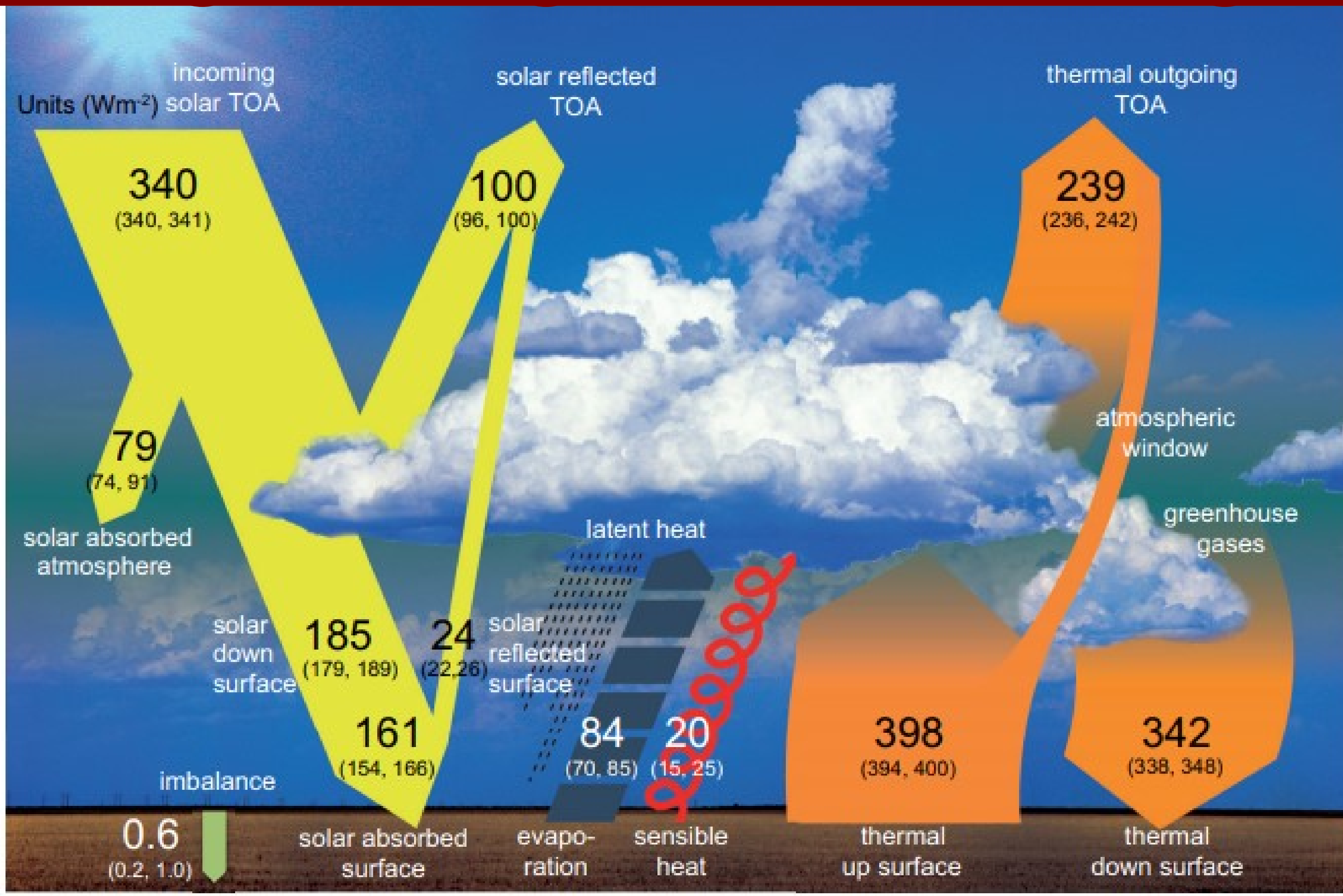
Global Warming Physics for Solar Geoengineering in Albedo Mitigation

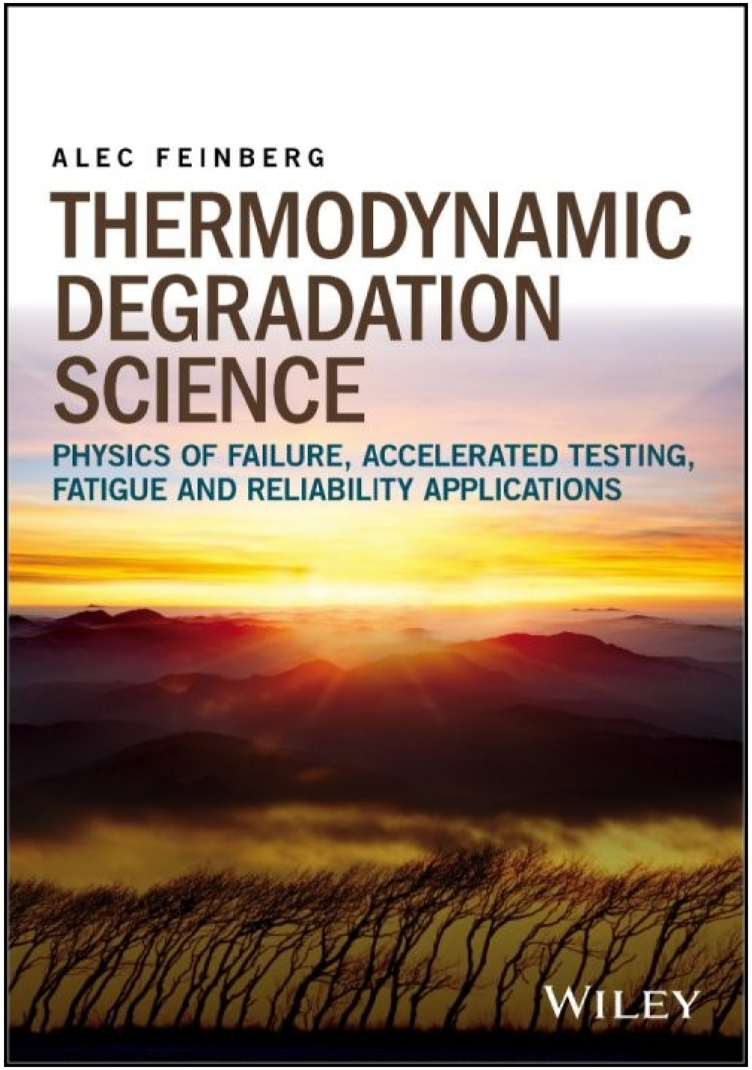


Alec Feinberg, Ph.D., DfRSoft

Outline for Reversing Global Warming

Albedo Work on GW

- Dr. Feinberg's Recent Papers:
- Feinberg, A. **Urban Heat Island Amplification Estimates on Global Warming Using an Albedo Model**. *SN Appl. Sci.* **2,** 2178 (2020). https://doi.org/10.1007/s42452-020-03889-3
- **Currently in Peer Review (References for Slides)**
- Research Gate:
- **On Geoengineering and Implementing an Albedo Solution with Urban Heat Islands Global Warming and Cooling Estimates,**
  - Preprint (submitted) vixra 2006.0198, Research Gate: DOI: 10.13140/RG.2.2.26006.37444/4
- **A Re-radiation Model for the Earth's Energy Budget and the Albedo Advantage in Global Warming Mitigation**
- https://www.researchgate.net/publication/345506635_A_Re-radiation_Model_for_the_Earth's_Energy_Budget_and_the_Albedo_Advantage_in_Global_Warming_Mitigation



Geoengineering Physics Model

- No Forcing

Solar in Absorption

Greenhouse Gas

$$P_{Total\,2019} = P_{\alpha} + P_{GHG} = P_{\alpha}(1+f_1) = \sigma T^4$$

Re-radiation Factor

- Forcing

$$P_{Total\,2019} = P_{\alpha'} + P_{GHG'} = P_{\alpha'}(1+f_2)$$

- Feedback Amplification Factor A_F

$$P_{Total\,2019\,\&\,Feedback} = P_{1950} + \left(P_{2019} - P_{1950}\right)A_F = \sigma T_S^4$$

Physics Modeling on Changes

Basic GW Physics

•<u>1950</u>

- **Average Temp=57F**
- **Earth Albedo 30.08%**
- **57F GHGs**

<u>2019-2020</u>

Average Temp=58.73F

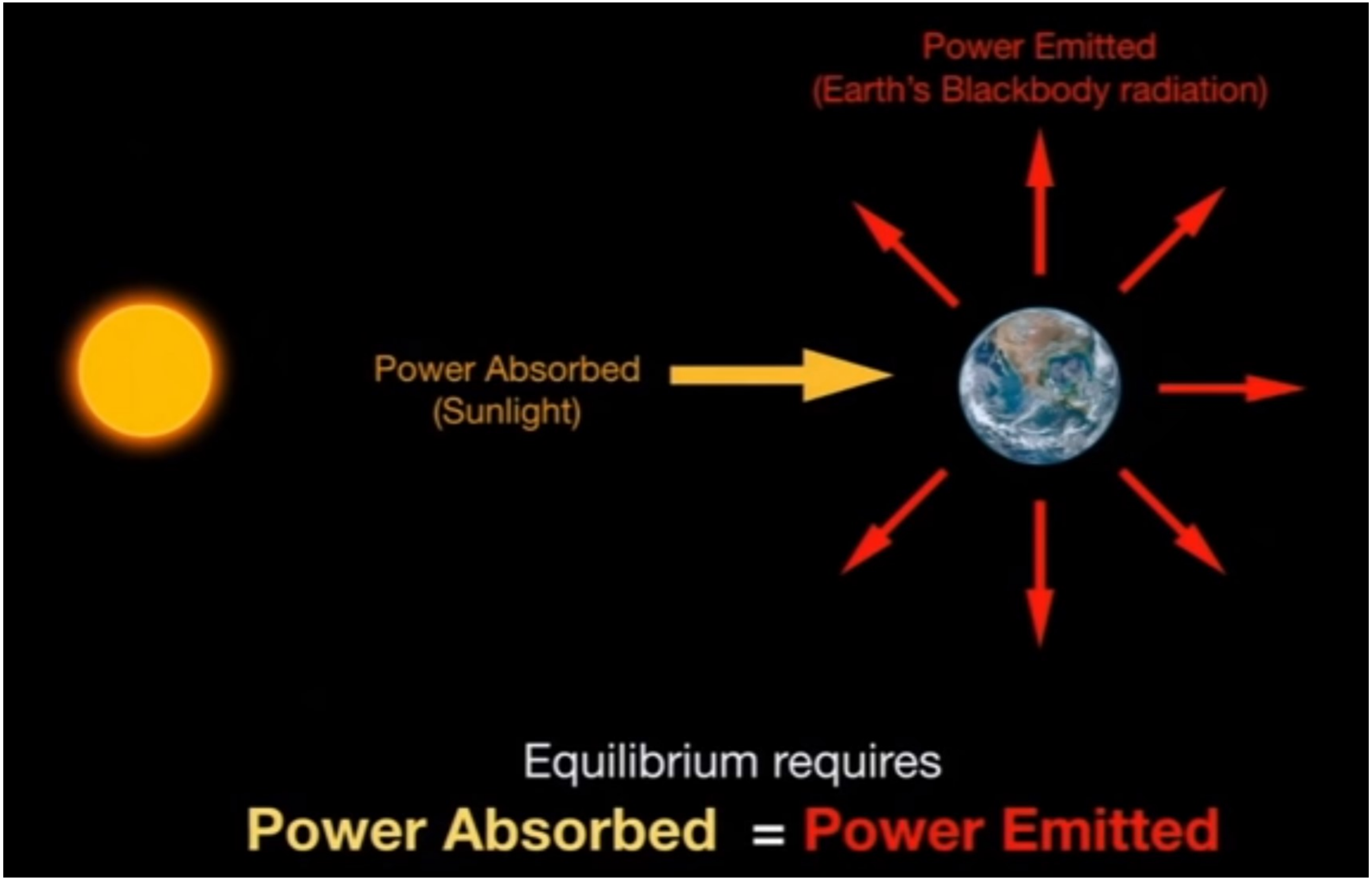
Earth Albedo 30.035%

58.73F GHGs & Feedback

Global Warming Forcing & Feedback 1950 to 2019

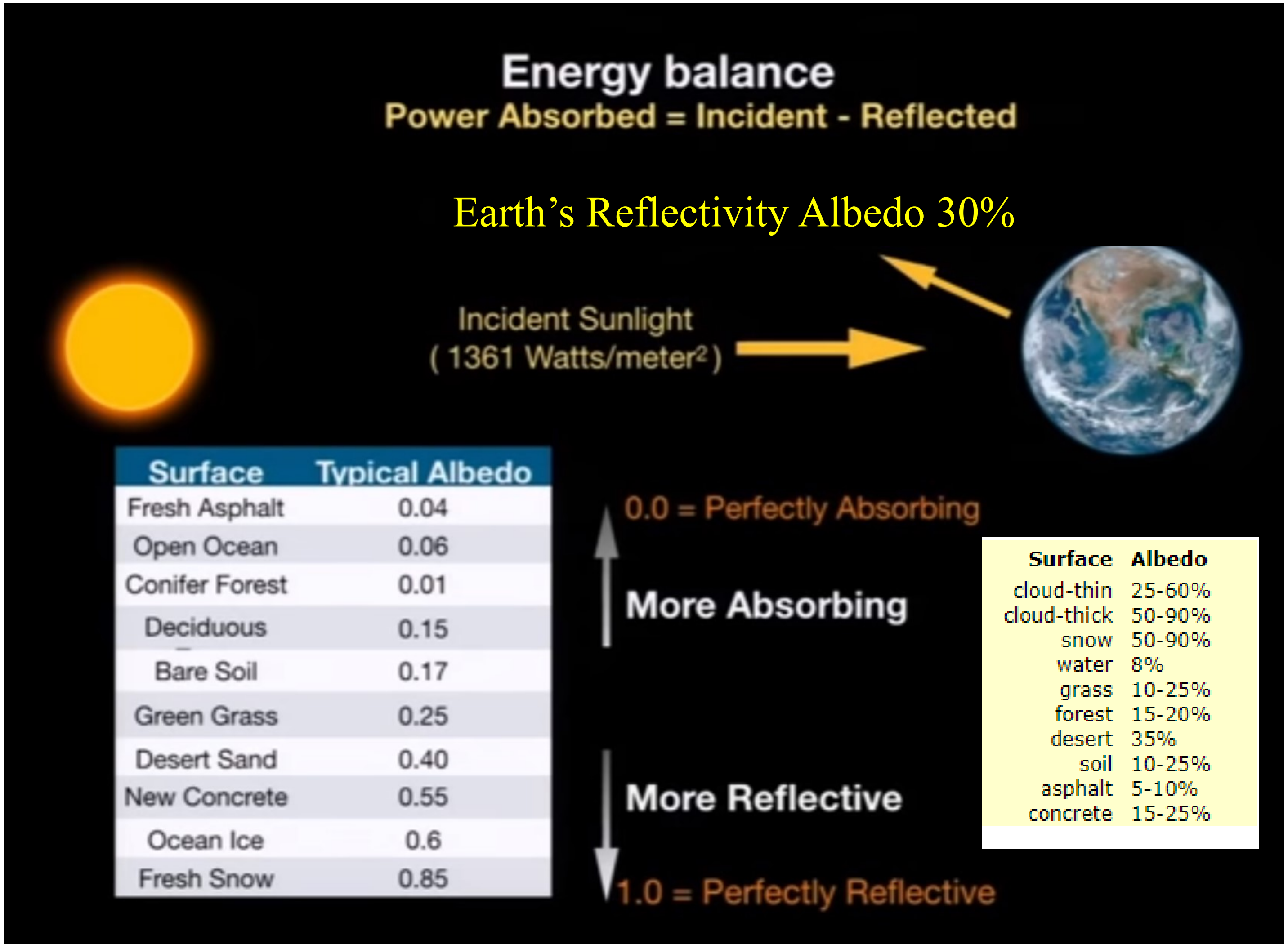
Global Warming Causes →	**Population Increase Causes → Forcing** **Increases in Greenhouse Gas** **Albedo Decrease - Expanding Urban Heat Islands (UHI) & Roads**
Global Warming Feedback Amplification Effects →	Response to forcing: Ice and Snow Melting – Albedo Feedback Water-Vapor Feedback, Lapse Rate Feedback, Cloud Feedback, etc.

Modeling Energy Absorbed



Earth's Albedo Effect

Earth's Albedo Effect - a measure of how much solar radiation is reflected from Earth's surface. Earth Average in 1950 was 30%

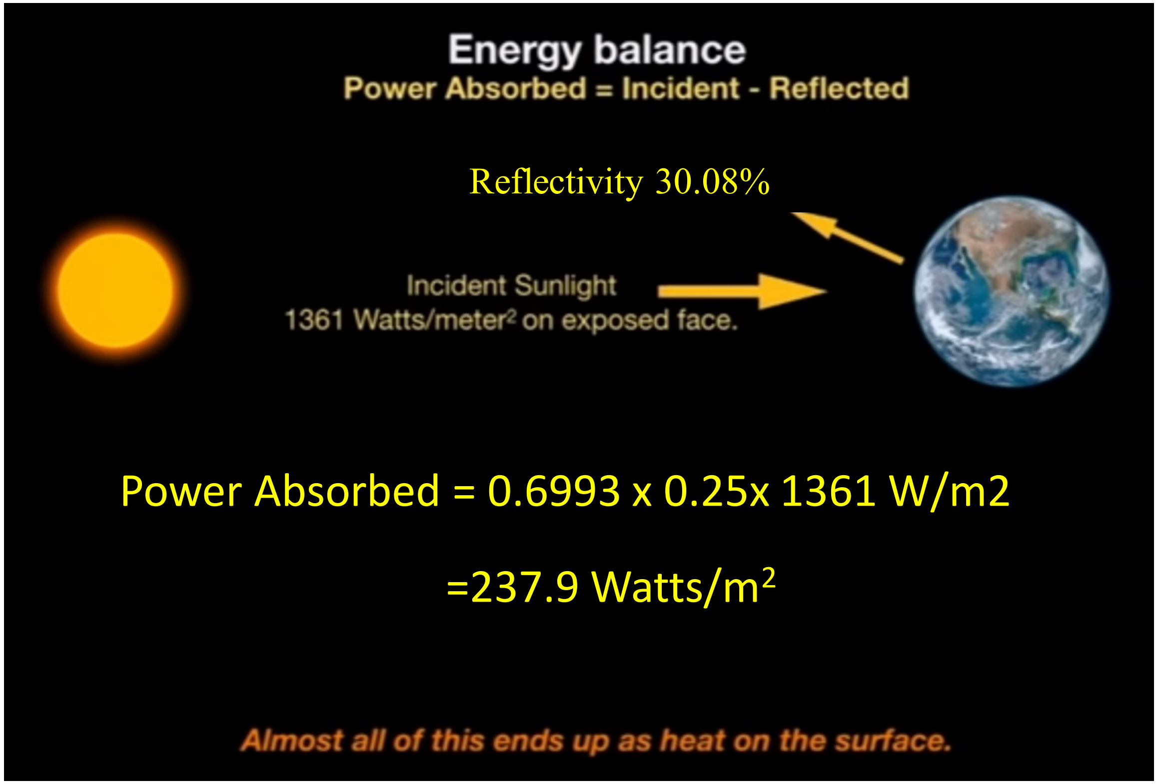


Surface	Typical Albedo
Fresh Asphalt	0.04
Open Ocean	0.06
Conifer Forest	0.01
Deciduous	0.15
Bare Soil	0.17
Green Grass	0.25
Desert Sand	0.40
New Concrete	0.55
Ocean Ice	0.6
Fresh Snow	0.85

Surface	Albedo
cloud-thin	25-60%
cloud-thick	50-90%
snow	50-90%
water	8%
grass	10-25%
forest	15-20%
desert	35%
soil	10-25%
asphalt	5-10%
concrete	15-25%

Energy Balance Calculation 1950

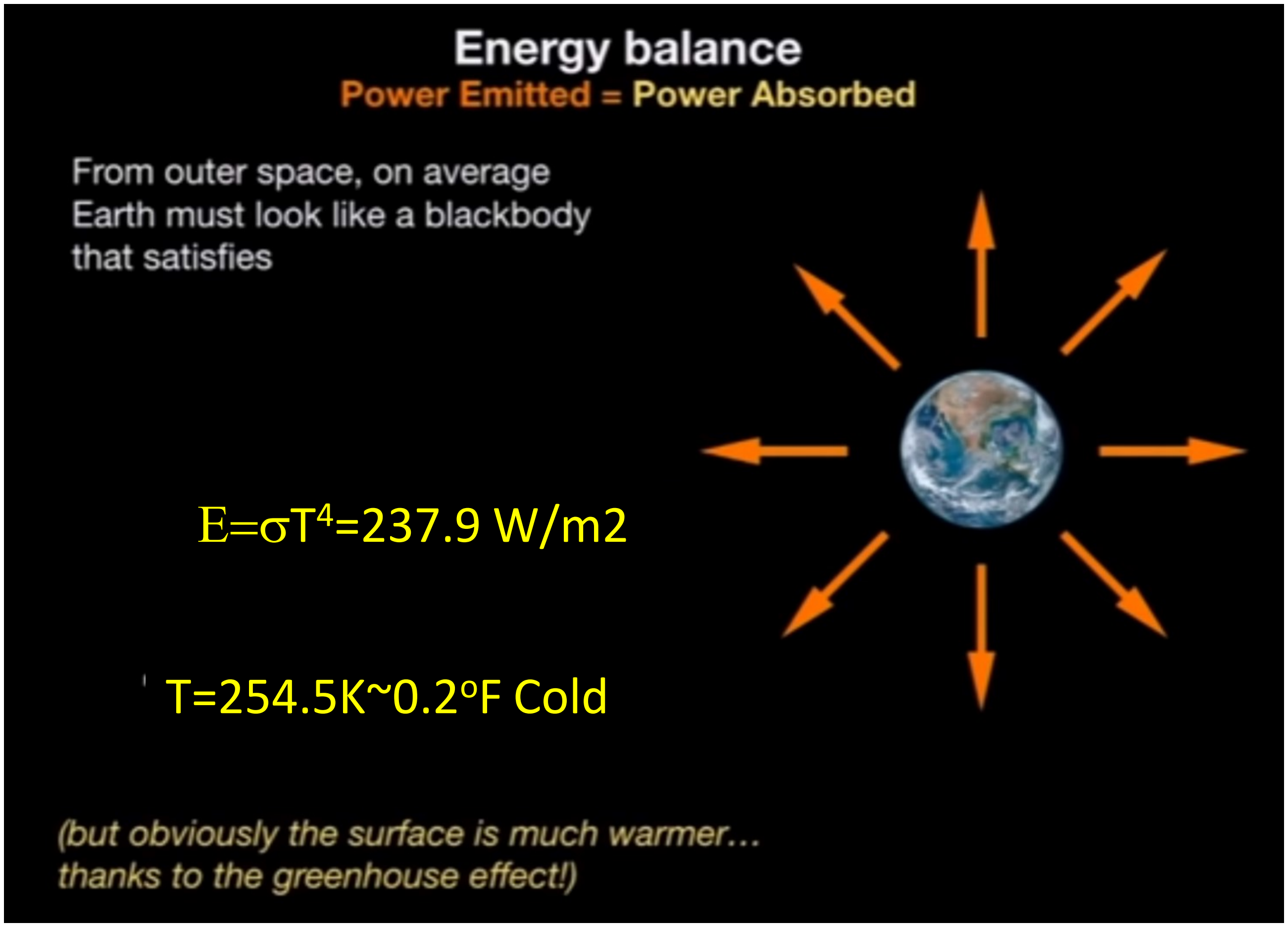
(No Greenhouse Gases)



- ½ of Earth is irradiated, another ½ is lost due to sphere effect
  Percent available for absorbed is then ¼

- Average Earth Albedo is 0.29 – Reflectivity (see References)

Energy Budget Temperature 1950 Without Greenhouse Effect



$E=\sigma T^4=237.9$ W/m2

$\sigma=5.670367\times10^{-8}$ W. $m^{-2}\cdot K^{-4}$

$T^4=237.9$ W/m2/5.67E-8

$T=254.5K\sim0.2^oF$ Cold

Basic Physic Simplified 1950

Earth Heating= $P_{total} = (1+f_1)\, P_\alpha = 1.618\, P_\alpha$

Where (Assume No Global Warming in 1950)

- P_α =absorbed Solar radiation
  =So { 0.25 x (1-Albedo) }=**340.25 W/m²** {(1-0.3008)}=**237.903 W/m²**
- $P_{GHG} = f_1\, P_\alpha$, **f_1 is a re-radiation factor ($0.618=\beta^4$)**
  β=effective emissivity constant of the planetary system
- $P_{total} = (1+f_1)\, P_\alpha = P_\alpha + P_{GHG} = 384.9267 W/m^2 = \sigma T^4$

- **T=287.04°K=13.89°C=57°F for 1950**

$\sigma = 5.670367\times10^{-8}\ W.\ m^{-2}\cdot K^{-4}$

Sun Incoming Energy So=1361 W/m²

Albedo=0.3008 (in 1950, see references at end for this number)

0.25 Average fraction of Sun light illuminating Earth at any time

f= Frac. GHG Power Emitted Back=Obtained at 57°F for 1950

Put this in Excel
1950 Results

Year	Surface Temp (K)	Surface Temp (C)	Surface Temp (F)	f1 f2	Alpha 1950	Power Absorbed 1361/4(1-albedo) W/m^2	Temperature Without GHGs Albedo (K)	GHG Power (W/m^2)	Total Power GHG (W/m^2)
1950	**287.040**	**13.890**	**57.001**	**0.6180**	**0.3008**	**237.9028**	**254.51**	**147.0239**	**384.9267**

Model Constants

f1	0.618
Sigma	5.67E-08
So/4	340.25

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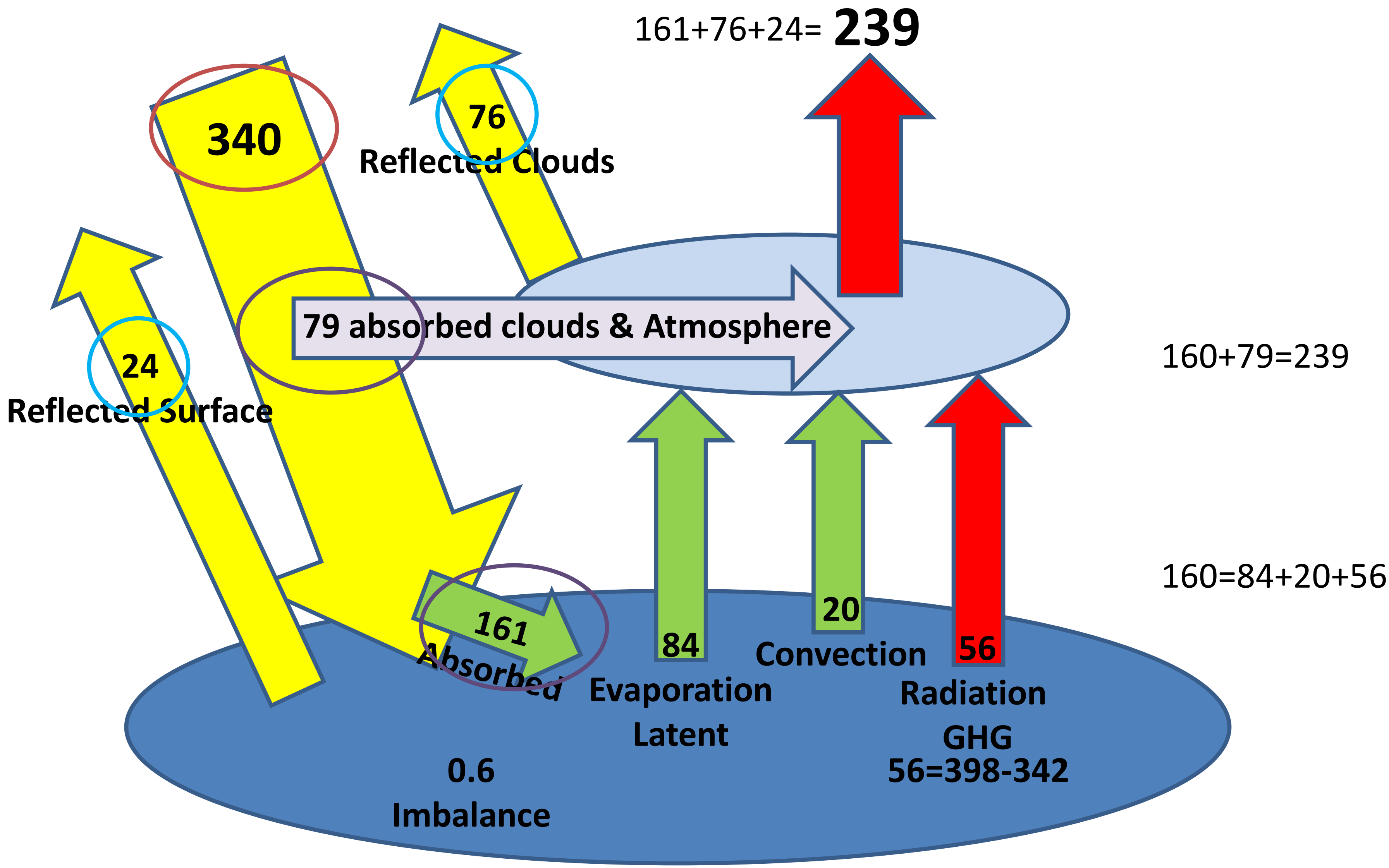
First Look at Some Key IPCC Earth Energy Budget Albedo Values

- 340 W/m^2=1361W/m^2 x 0.25
- Sunlight Reflected = 24 Earth Surface + 76 Clouds

  = 100W/m^2
- Albedo = 100/340=29.4118% √
  - Albedo of Clouds = 76/340 = 22%
  - Albedo of Earth = 24/340= 7%
  - We are using 30% in 1950
- **340-100=240W/m2 is absorbed in & radiated out**

  240 in and 240 out

Simplified Diagram of 2013 IPCC



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Radiation IN = Radiation OUT

- 161 into Earth + 79 Absorbed by Clouds=240
- This is short wavelength solar radiation
- Now it gets absorbed & convert to Long wavelength infrared radiation going out
- $\{84 + 20 + 56 + 79 + 0.6\}_{IN}\ W/m^2 = 239.4\ W/m^2$

Evaporation Latent Heat

Convection

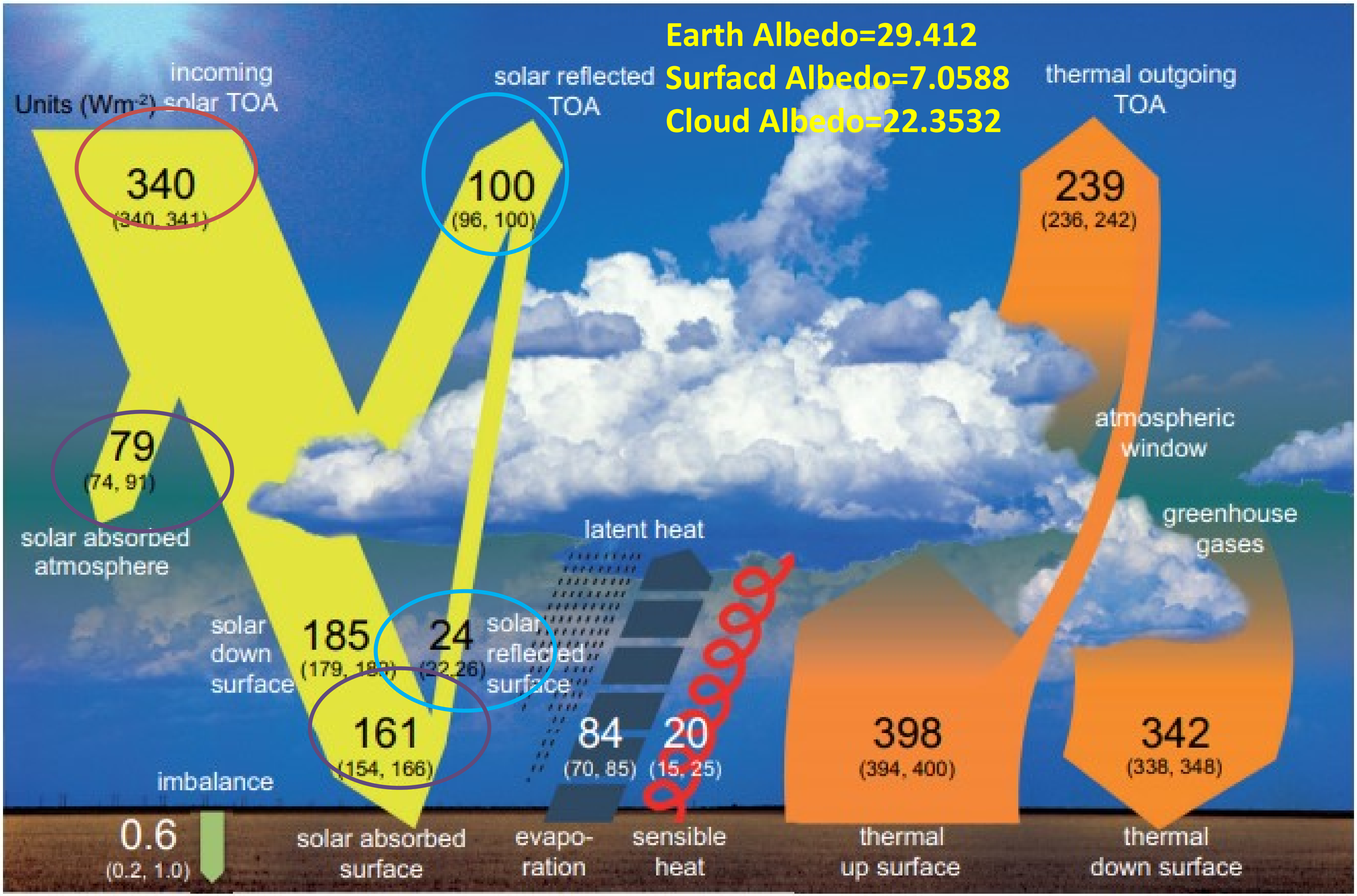
Radiation

Absorbed by Clouds

Imbalance

160 Earth

IPCC Earth Energy Budget 2013 Albedos



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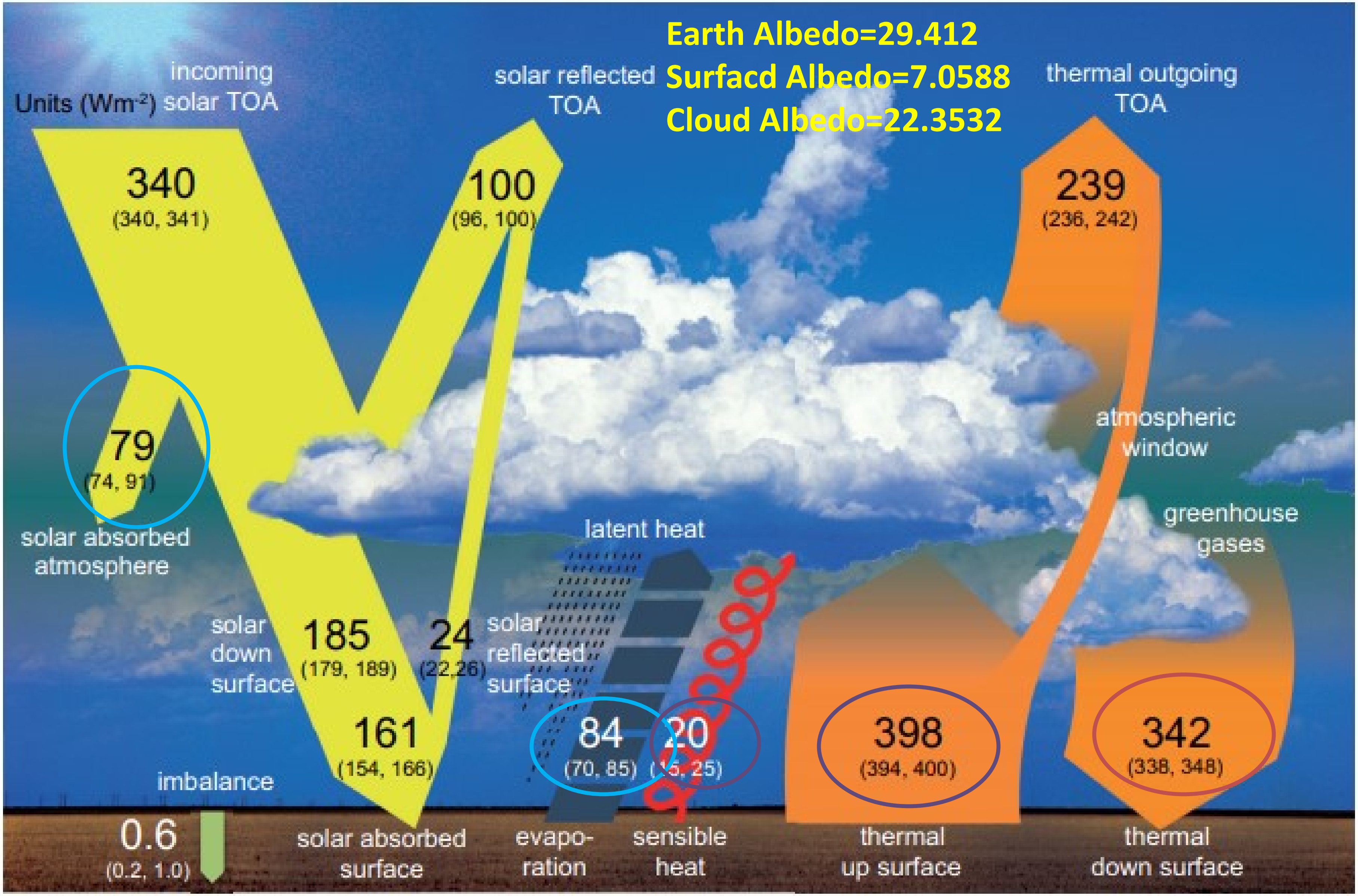
Radiation IN = Radiation OUT

- $OLR = P_{therm\_up} + P_{evap} + P_{sen\_heat} + P_{atm} - P_{therm\ down}$
- 239= 398 + 84 + 20 +79 - 342
- 239= 56 + 84 + 20 +79
- $P_{GHG} = P_{therm\_down} - P_{atm} =$ 342-79=263
- IPCC model GHG power ratio of whole is
- f_{GHG}=263/398=0.66 according to IPCC
- This model ratio of whole where whole is 239
- f_{GHG}=PGHG/OLR=148/239=0.62 This model
- About same but ours is more accurate and has the true physics

IPCC Earth Energy Budget 2013 Albedos



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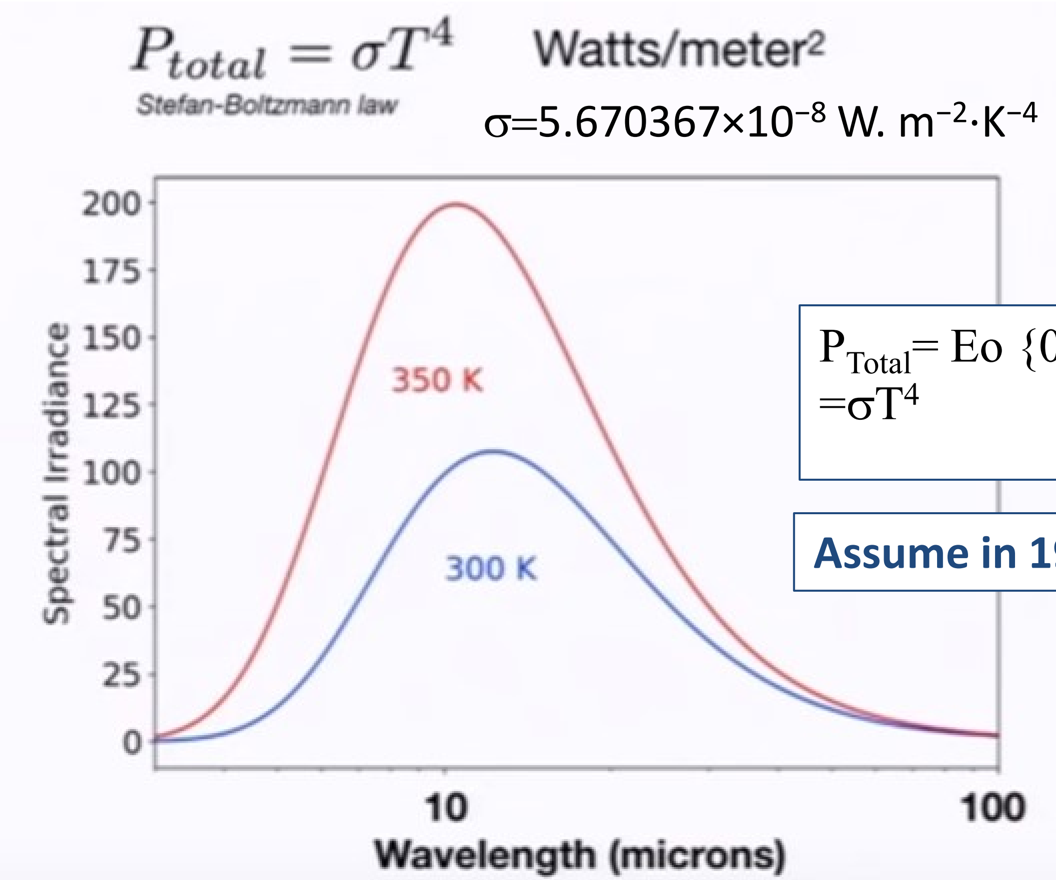
IPCC Albedo & Absorbed Values

IPCC Earth energy budget values (Hartmann et al., 2013)

IPCC Item	Reflected (W/m^2)	Albedo %	Absorbed (W/m^2)
Solar Incident Power		-	
Earth	100/340 (240)	29.4118	240=340x(1-.294)
Atmosphere & Clouds	76/340	22.3529	79* (29.4-22.4)/29.4 x 240=57
Earth Surface Albedo	24/340 (161)	7.0588	161 (29.4-7.1)/29.4 x 240=182

Convert Energy to Temperature Black Body Radiation & DfRSoft Simplified Model

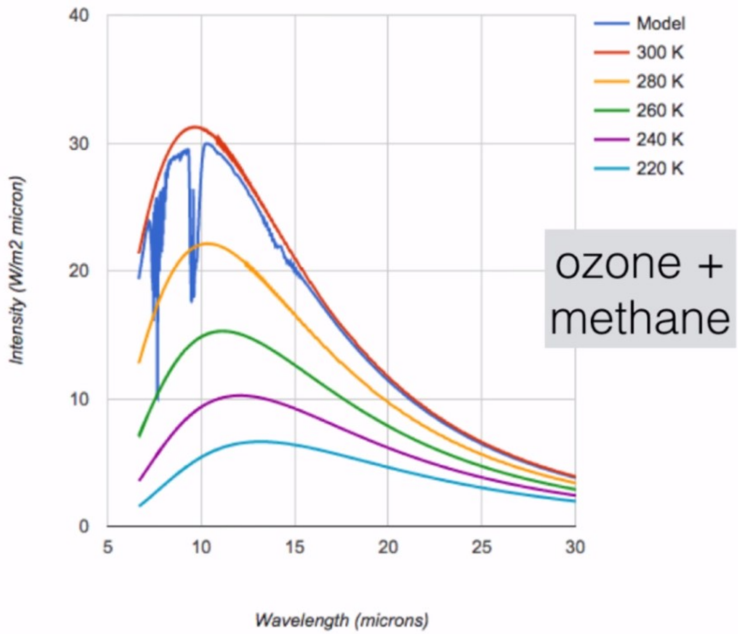


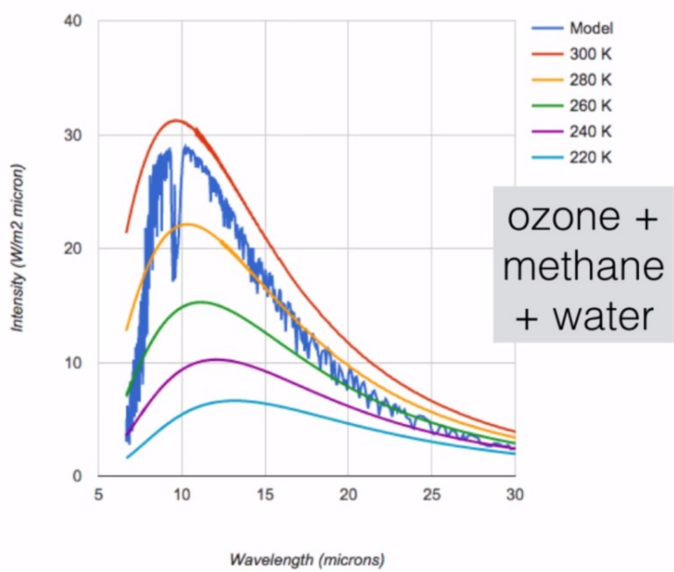
Neglecting Fossil Fuels DfRSoft Model:

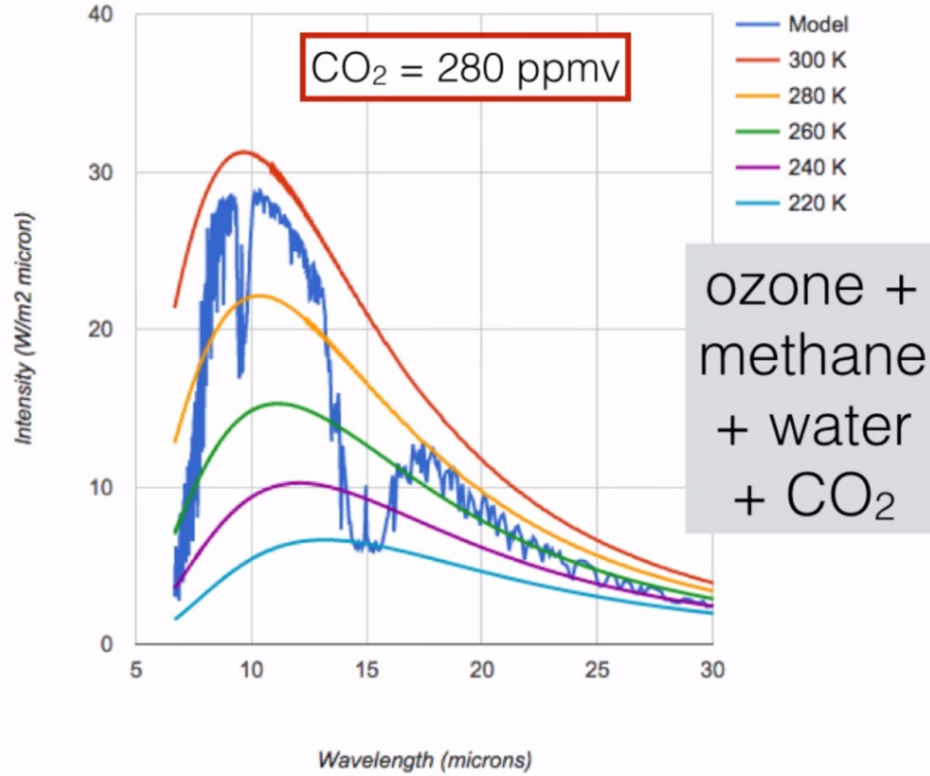
P_{Total}= Eo {0.25 x (1-Albedo)} (1+ $f_{Greenhouse\ Energy}$) =σT^4

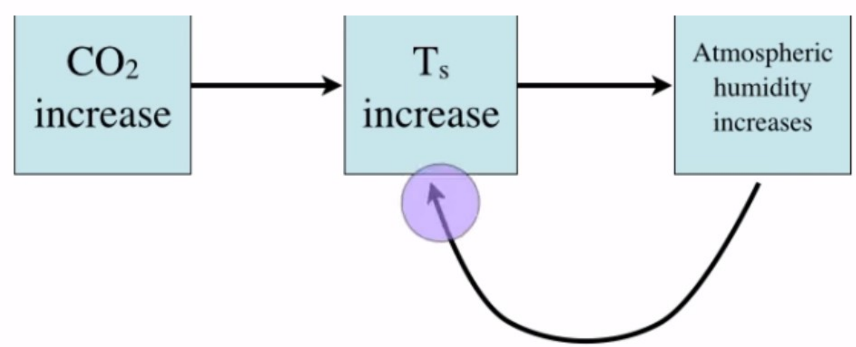
Assume in 1950 No forcing or feedbacks like ice melting

Add Greenhouse Gasses





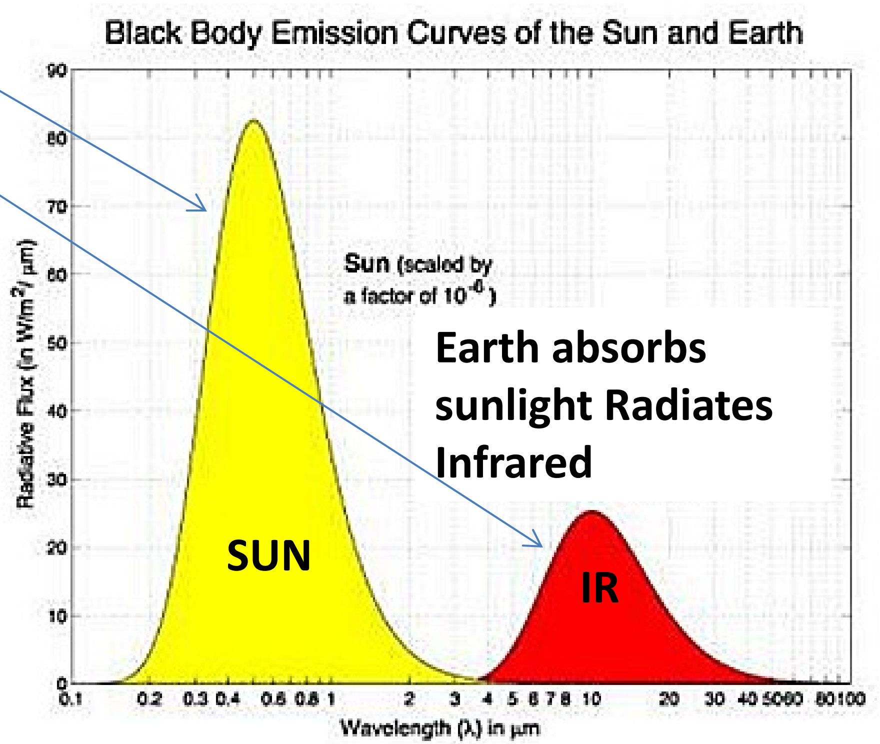




Sun (Solar) Radiation, IR GH gas Absorption

- We note that greenhouse gasses do not absorb sunlight photons, essentially transparent to light.
- However, when the Earth absorbs sunlight, it re-radiates infrared photons (heat), this heat radiation has different wavelengths then the sunlight. In this area.

of the spectrum, the greenhouse gasses can absorb radiation. GH gasses absorb a certain wavelength, then re-emit radiation of the same wavelength in arbitrary directions, some back to Earth and some to outer space.



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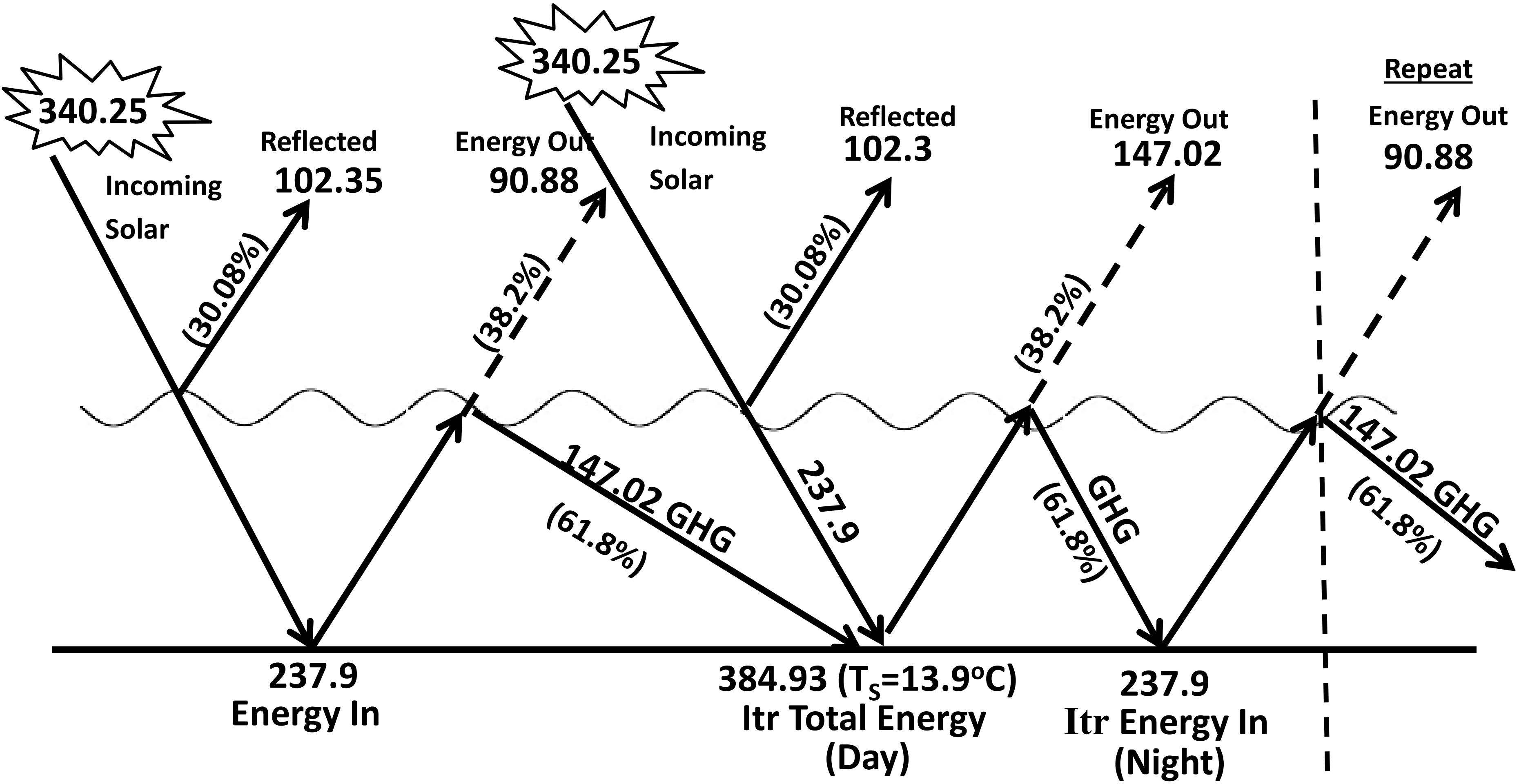
Energy Balance in=Our : 1+f Factor

- Plain Language
- Consider the Earth with a roof. The roof represents the GHGs over the Earth and only allows 40% of any energy leaves with the rest returning to Earth. Sunlight comes in, and some is absorbed and heats the Earth's floor to 255^{o}K (-2.3^{o}F very cold). Let's say it takes 100 units of energy. The heat rises, but only 40 units of energy can leave from the roof, so 60 units come back and warms the Earth's floor to 288^{o}K (57^{o}F average temp of Earth). On average, the Earth's floor is heated by a total of (1+f) 160 units. The sun keeps warming the Earth's floor at 100 units on average, and the roof keeps sending back 60 units. So the roof is responsible for 60 units on average of energy, and the Earth's floor is warmed by 160 units on average.
- How much heat leaves in equilibrium? Of the 100 units of energy absorbed and radiated, the initial 40 units left. As well, the Earth's floor received a total of 160 units, but the roof only let 40% leave that's another 64 (=0.4 x 160) units of energy leaving. The total leaving is 104 units in equilibrium, so roughly 100 units comes in and almost same goes out. This estimate can be refined to f=61.8% . Then, 100 units are absorbed and radiated, so 38.2 units initially leave, and 61.8 units is re-radiated to the Earth's floor which is now heated to 161.8 units of energy. From this 0.382 x 161.8 leaves=61.8 units or energy. The total is 61.8+38.2=100 units of energy leaves and another 100 units, establishing equilibrium. Any eventual difference causes global warming.

1950 Earth's Iterative Energy Balance



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Geoengineering Physics Model

- No Forcing

Solar in Absorption

Greenhouse Gas

$$P_{Total\,2019} = P_{\alpha} + P_{GHG} = P_{\alpha}(1 + f_1) = \sigma T^4$$

Re-radiation Factor

HOW DO WE DETERMINE THE AVERAGE VALUE OF f1=0.618 ?

We use this for 1950, pseudo time where we assume no forcint

Derivation for f_1

The Baseline Steady State Re-radiation Solution-1950

Reference: A Re-radiation Model for the Earth's Energy Budget and the Albedo Advantage in Global Warming Mitigation

We are considering a time when there are ***no forcing issues*** causing warming trends. Then by conservation of energy, the equivalent power re-radiated from GHGs in this model is dependent on P_α with

$$P_{GHG} = P_{Total} - P_\alpha = \sigma T_S^4 - \sigma T_\alpha^4 \tag{6}$$

To be consistent typically $T_\alpha \approx 255°K$ and $T_S \approx 287°K$, (see Table 3 results) then in keeping with a common definition of the global beta (the proportionality between surface temperature and emission temperature) we have $\beta \approx T_\alpha/T_S = T_e/T_S$.

This allows us to write the dependence

$$P_{GHG} = \sigma T_S^4 - \sigma T_\alpha^4 = \frac{\sigma T_\alpha^4}{\beta^4} - \sigma T_\alpha^4 = \sigma T_\alpha^4\left(\frac{1}{\beta^4} - 1\right) = \sigma T_\alpha^4\left(\frac{1}{\bar{f}} - 1\right) \tag{7}$$

Note that if $\beta^4=1$, there would be no GHG effect. Here we set $\bar{f}$, the re-radiation parameter equal to β^4. We can also define the re-radiation similarly by some fraction f_1 such that

$$P_{GHG} = \bar{f}_1 P_\alpha = \bar{f}_1 \sigma T_\alpha^4 \tag{8}$$

According to Equations 7 and 8, we require

$$P_{GHG} = \sigma T_\alpha^4\left(\frac{1}{\bar{f}} - 1\right) = \bar{f}_1 \sigma T_\alpha^4 = \bar{f} \sigma T_\alpha^4 \tag{9}$$

When $\bar{f} = \bar{f}_1$ the solution is derived from the quadratic expression

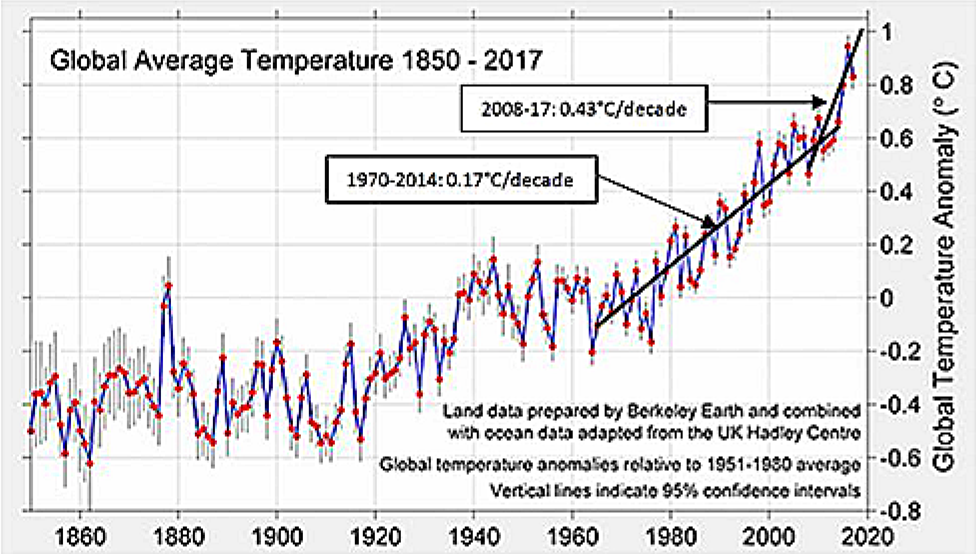
$$\bar{f}^2 + \bar{f} - 1 = 0 \text{ yielding } \bar{f} = 0.618034 = \beta^4,\ \beta = (0.618034)^{1/4} = 0.88664 \tag{10}$$

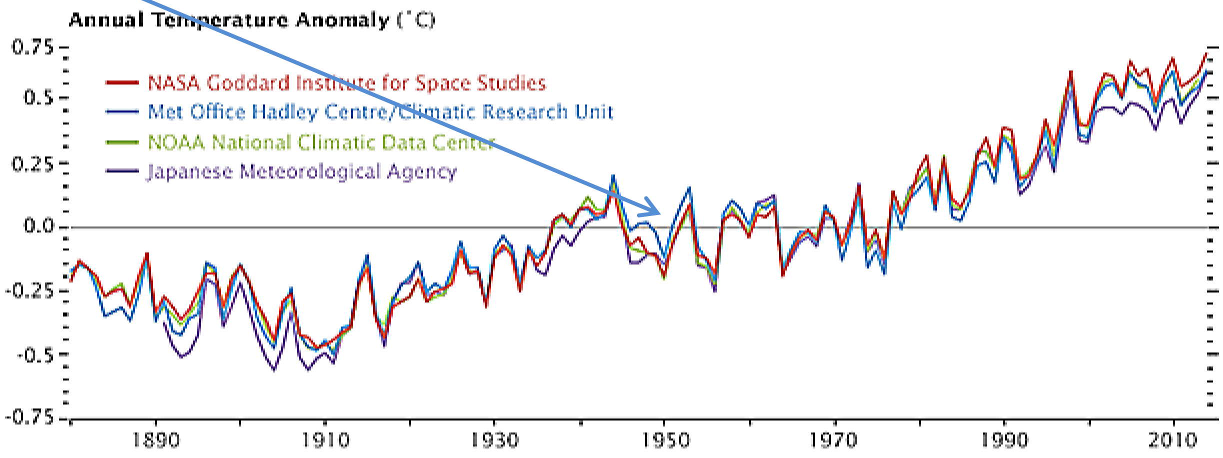
This is very close to the common value estimated for β and it was obtained through energy balance in the planetary system providing a non-series exact solution per Eq. 10. This is the unique stable baseline re-radiation state illustrated in Figure 1. Although the atmosphere is dynamic and other non-forcing alternate states can exist, we use this value for the optimum repeatable baseline steady-state GMEEB re-radiation solution. This steady-state solution may be the lowest thermodynamic re-radiation free energy condition (see next section).

Review Earth Energy Budget and Temperature in 2019

Global Warming Trend

- A 0.95°C Rise Corresponds to a 1.7°F Rise
- 1950 Average Temp 57°F
- 2019-2020 Average Temp=58.73°F





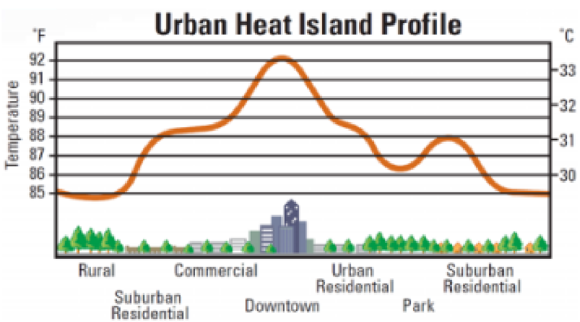
Review Earth Energy Budget and Temperature in 2019 Since industrial revolution

2019 - How do we Know Temperature Has Increased?

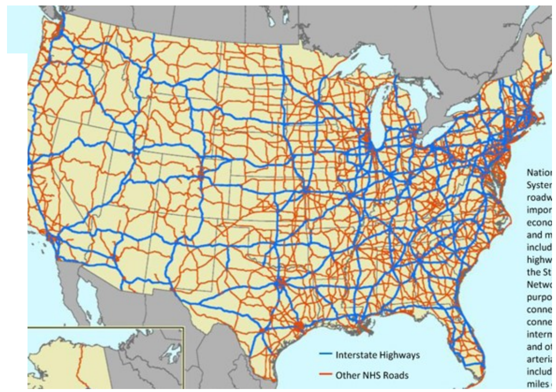
- Surface thermometers
- Satellite temperatures
- Ice is melting
- Ocean heat is increasing
- Sea Levels are Rising

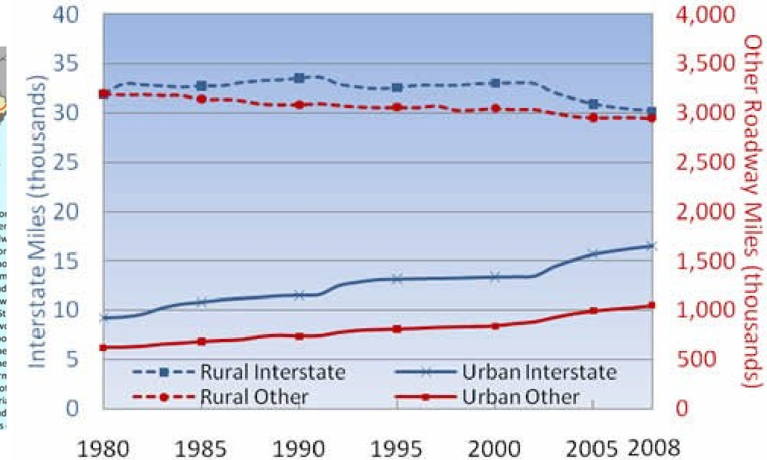
Earth Albedo In Decline

- When cities replace natural vegetation, the area usually becomes much hotter. Climatologists call this effect an **urban heat island**. Other Major factors most obvious is pollution and Asphalt (Albedo=.04) roads, parking lots, buildings etc.



EPA, 2003

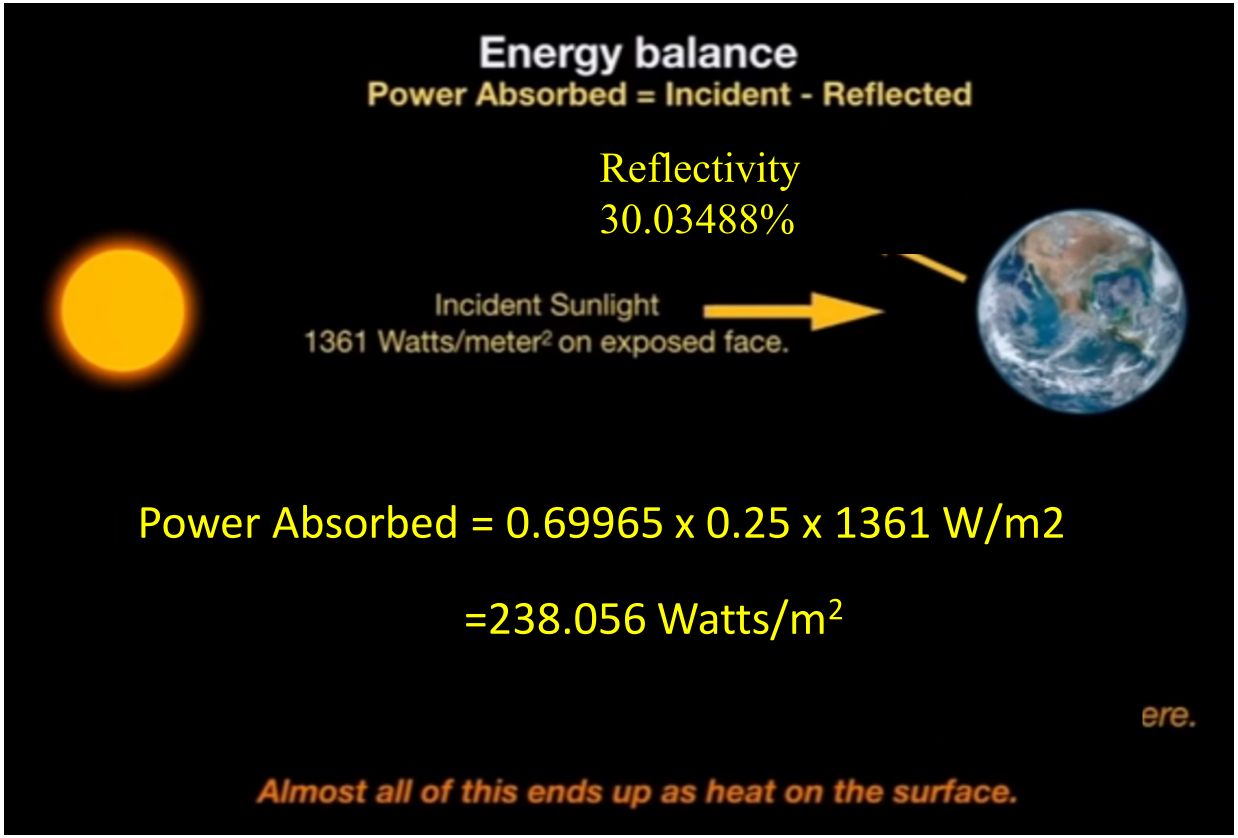




- Cities of > million people can be 1-3^{o}C (1.8-5.4^{o}F) warmer
- Arctic ice is melting about 13% per decade (Albedo=0.6) on the planet is melting to 0.06. Less energy is reflected into space, and the Earth will warm.

Energy Budget Calculation 2019

(First No Greenhouse Gases but Some Albedo Issues)



❖ Here we make add a slight change by decreasing the Average Earth Albedo by 0.15%. There is reason to believe it is less in 2019 compared to 1950 due to ice melting, Cities, Asphalt roads.

2019 More Complex

- 2019 We Have both Forcing & Feedback

Global Warming Causes →	**Population Increase Causes → Forcing** **Increases in Greenhouse Gas** **Albedo Decrease - Expanding Urban Heat Islands (UHI) & Roads**
Global Warming Feedback Amplification Effects →	Response to forcing: Ice and Snow Melting – Albedo Feedback Water-Vapor Feedback, Lapse Rate Feedback, Cloud Feedback, etc.

Physics Model for 2019

- Forcing

$$P_{Total\,2019} = P_{\alpha'} + P_{GHG'} = P_{\alpha'}(1+f_2)$$

- Feedback Amplification Factor A_F

$$P_{Total\,2019\,\&\,Feedback} = P_{1950} + \left(P_{2019} - P_{1950}\right)A_F = \sigma T_S^4$$

Forcing Part 2019

- We assume a small change in the albedo P_{α}'
- α_{2019}=0.3003488, α_{2019}=0.3008
  - This is a 0.15% change, very small
- $P_{\alpha'=1019\alpha}$=(1-0.3003488) x (1361W/m^2 x 0.25)

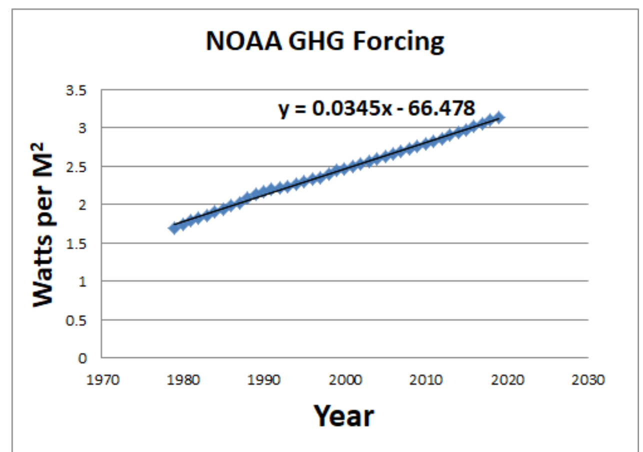
  $P_{\alpha'=1019\alpha}$ =238.056W/m^2

Forcing Part 2019

- Then f_2 is adjusted to the IPCC GHG forcing value estimated between 1950 and 2019 of $2.38W/m^2$.
- How I got the $2.38W/m^2$
  - NOAA Data plotted it and fitted it then extrapolated from 1950 to 2019

Year	PPM
2019	3.1775
1950	0.797
Since 1950	**2.3805**

(https://www.esrl.noaa.gov/gmd/aggi/aggi.html)



Physics Model for 2019

- Forcing

147.0239 + 2.381 = 149.404

$$P_{Total\,2019} = P_{\alpha'} + P_{GHG'} = 238.056 + \left(P_{GHG\_1950} + \Delta P_{GHG\_2019}\right)$$

$$= 238.056 + 149.404 = 387.4605 W/m^2 = P_{\alpha'}(1 + f_2) = 238.056(1 + 0.6276)$$

$$P_{Total\,2019} = 387.4605 W/m^2 \qquad Note \quad f_2 = 0.6276$$

- Feedback Amplification Factor A_f=2.022

$$P_{Total\,2019\,\&\,Feedback} = P_{1950} + \left(P_{2019} - P_{1950}\right) A_F = \sigma T_S^4$$

$$= 384.9267 + (387.4605 - 384.9267)2.022 = 390.0499$$

$$= \sigma T_S^4, \quad T = 287.989°K, \ or \ \Delta T = 0.95°C$$

Basic Physic Simplified 2019

Earth Heating= P_{total} = $(1+f_2)\ P_{\alpha'}$ =1.6271 P_{α}

What is f2 and $P_{\alpha'}$

- $P_{\alpha'}$ =Due to small decrease in Earth albedo (explained soon), Earth absorbs bit more less reflective by only 0.15%
- Here Δf is due to increases in GHGs (primarily CO2)
- How do we find f2=0.6271?
- We use IPCC estimates between 1950 and 2019 for GHG increase in terms of Power.
- PGHG=2.38W/m
- Reference: Butler JH, Montzka SA, (2020) The NOAA Annual Greenhouse Gas Index, Earth System Researh Lab. Global Monitoring Laboratory, https://www.esrl.noaa.gov/gmd/aggi/aggi.html
- Adjust f2 to fit this data
- $P_{\alpha'=}$1361W/m2/4(1-0.3003488)=238.056W/m2

$$P_{Total\,2019} = P_{\alpha'} + P_{GHGin1950} + \Delta P_{GHG'}$$

$$= 238.056 + 147.02 + 2.38 = 387.46 W/m^2$$

$$f_2 = f_{2019} = f_1 + \Delta f = \beta_1^4 + \Delta f \approx \beta_2^4 + \Delta f$$

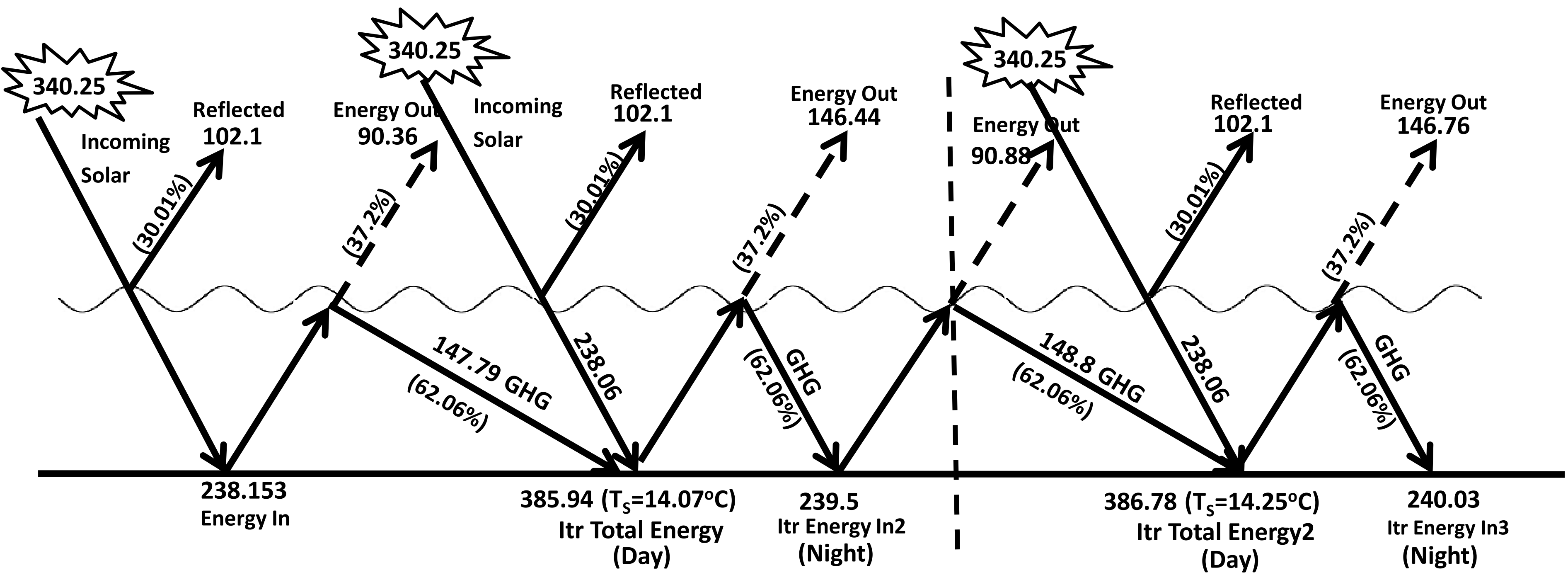
Summary

Year	T_S(°K)	T_α(°K)	f_1, f_2	α, α'	Power Absorbed W/m^2	$P_{GHG'}$ P_{GHG}	P_{Total} W/m^2
2019	287.5107	254.55	0.6276	30.03488	**238.056**	149.4041	387.4605
1950	287.0395	254.51	0.6180	30.08	**237.9028**	147.024	384.9267
Δ2019-1950	**0.471**	**0.041**	**0.0096**	**(0.15%)**	**0.15352**	**2.38**	**2.53**
$\Delta_{Feedback}$ A_F=2.022	**0.95**	**0.083**	-	-	**0.3104**	**4.81**	**5.12**

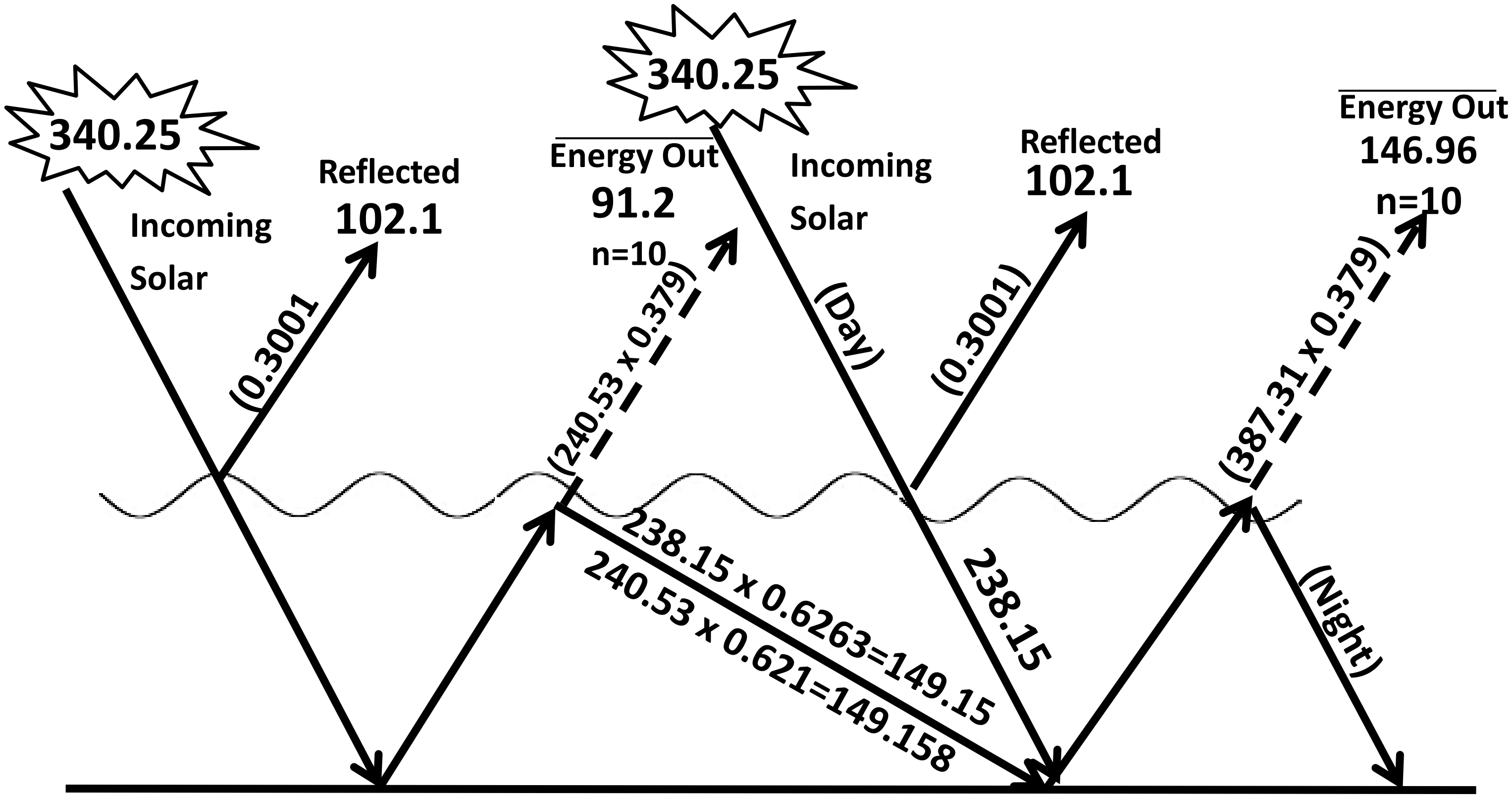
P_{Total}=384.935W/m^2 = σT^4 **$T_{Surface}$=254.51°K=13.89°C=57°F for 1950**

Year	Surface Temp (K)	Surface Temp (C)	Surface Temp (F)	f1 f2	Alpha 1950	Power Absorbed 1361/4(1-albedo) W/m^2	Temperature Without GHGs Albedo (K)	GHG Power (W/m^2)	Total Power GHG (W/m^2)
1950	**287.040**	**13.890**	**57.001**	**0.6180**	**0.3008**	**237.9028**	**254.51**	**147.0239**	**384.9267**
2019	**287.511**	**14.361**	**57.849**	**0.6276**	**0.3003488**	**238.056**	**254.55**	**149.4041**	**387.4605**
Key Deltas	0.47119	0.47119		0.00960	0.15%	0.15	0.041	2.38	2.53
Feedback	**0.9527**	**0.9527**			-	0.3104	0.083	4.81	**5.12**

2019 Earth's Energy Imbalance



2019 Average Earth's Energy Balance



238.15+2.38=240.53
Energy In Itr n=10
Forcing=2.38, Feedback=2.74, 0.5°C
Imbalance Ein-Eout=0

387.308
Avg. Total Energy, n=10
(T_S=14.33°C + Fdbk=0.5°C=14.83°C)
ΔT=0.95°C

240.5

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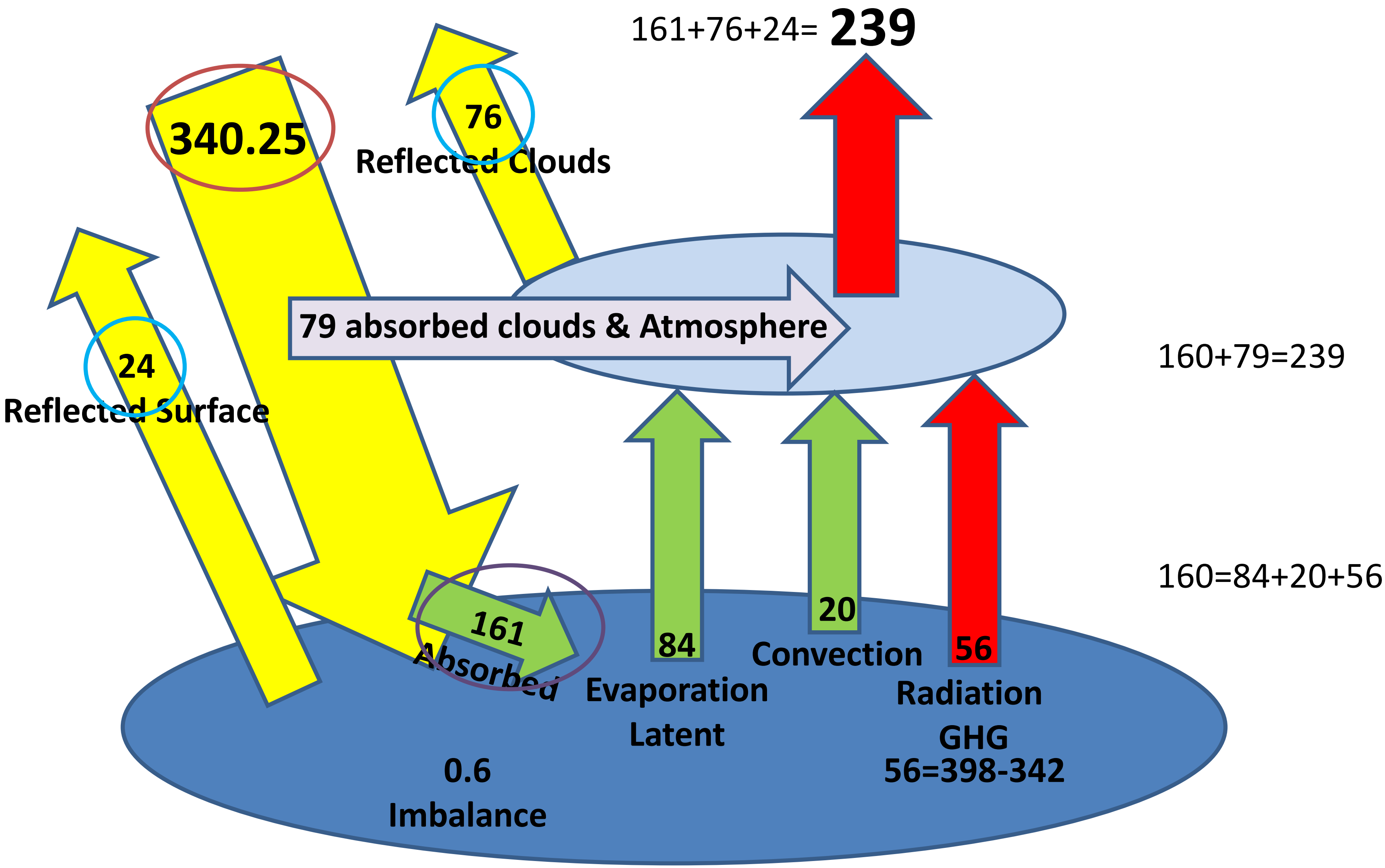
Simplified Diagram of 2013 IPCC



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Part 2
Solar Geoengineering Equation 1

- Note the following important Geoengineering parameter (From Summary Table

$$\gamma_{\%\Delta\alpha\Delta T} \approx \frac{\Delta Power\ Absorbed}{\Delta Albedo\%} = \frac{0.15352}{0.15\%} = 1.02\,W/m^2/\%Albedo$$

- We can prove this as a valid parameter

$$\gamma_{\%\Delta\alpha} = \frac{(\Delta E_o)_\alpha}{\frac{\alpha_1-\alpha_2}{\alpha_1}100} = \frac{E_o(\alpha_1-\alpha_2)}{\frac{\alpha_1-\alpha_2}{\alpha_1}100} = E_o\alpha_1/100 \approx 1W/m^2/\%\Delta albedo$$

E_o=1360W/m^2/4=340W/m^2 and when α_1 is 0.294118, the value is 1.000W/m^2/D%albedo. We note the value 29.4118% (100W/m^2/340W/m^2) and E_o are given in AR5 in their energy budget diagram.

Geoengineering Equation 2

- We can prove this intuitive expression

$$\Delta P_{\text{Re}v\_S} = -\gamma_{\%\Delta\alpha\Delta T} \;\; \%\Delta\alpha \; (1+f_1) \; A_F = -\Delta P_T \, (1+f_Y) \; A_F$$

Here we define

/

ΔP_{Rev_S} is the reverse power per unit area change
$\%\Delta\alpha$ is the percent global albedo change due to modification of a target area
$\gamma_{\%\Delta\alpha\Delta T}$ = Planck-albedo parameter, $1 Watt/m^2/\%\Delta$Albedo
$1+f_1$= the albedo-GHG re-radiation parameter where $f_1=0.618$
A_F is an estimate of the anticipated GW feedback amplification reduction factor
$\Delta P_T = \gamma_{\%\Delta\alpha\Delta T} \;\; \%\Delta\alpha$ is the reverse forcing change from the target area T

Example 1.5% Global Albedo Change

- Consider a 1.5% global geoengineering albedo change, with f_1=0.618 and a decrease in water-vapor climate feedback anticipated, we use the Earlier value of A_F≈2.022.

$$\Delta P_{\mathrm{Re}v\_S} = -1\mathrm{W/m^2/\%} \text{ x } 1.5\% \text{ x } (1+\mathrm{f_1}) \text{ x } 2.022 = -\Delta P_T\,(1+f_Y)\;A_F$$

$$= -1.5\mathrm{W/m^2} x (1+0.618) \text{ x } 2.022 = -4.91 \text{ Watt/m}^2$$

$$Effect = \frac{4.91W/m^2}{5.12W/m^2} = 95.8\% \qquad \Delta P_T = -1.5W/m^2$$

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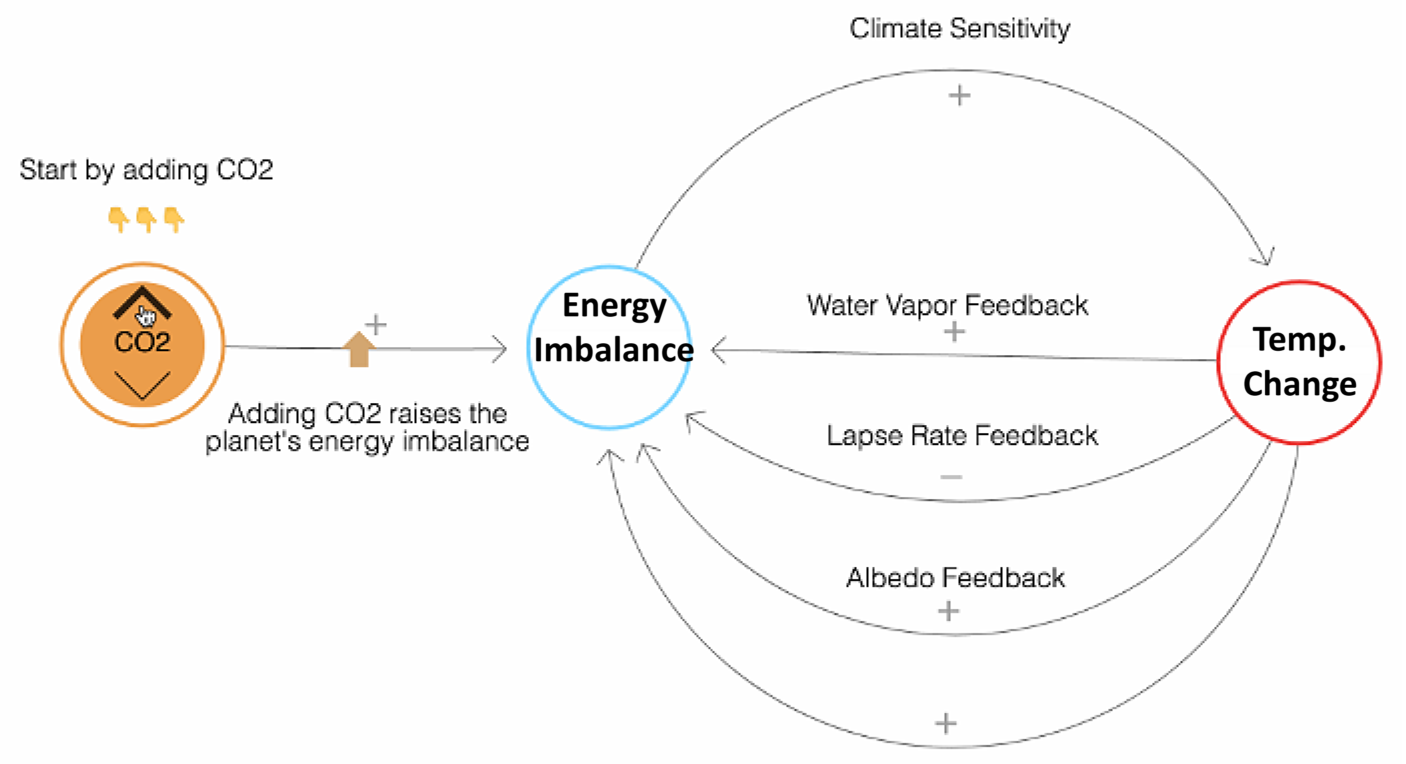
Albedo Model

$$\Delta P_T = \frac{S_o}{4}\frac{0.33 A_T \mathrm{H}_{T-N}}{A_E}\left[(\alpha'_T - \alpha_T)\right] = \Delta P_T$$

- $H_{T\text{-}N}$ hotspot irradiance sensible heat storage potential, a function of the heat capacity, mass, temperature storage, and solar irradiance.
- A_E is the surface area of the Earth
- A_T target effective area
- α_T target albedo, α'_T Modified arget albedo

Feedback – Amplification

- Climatologist View



Feedback – Amplification

- My Suggested Changes