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## PHYSICS OF THE PLANETARY GREENHOUSE EFFECT

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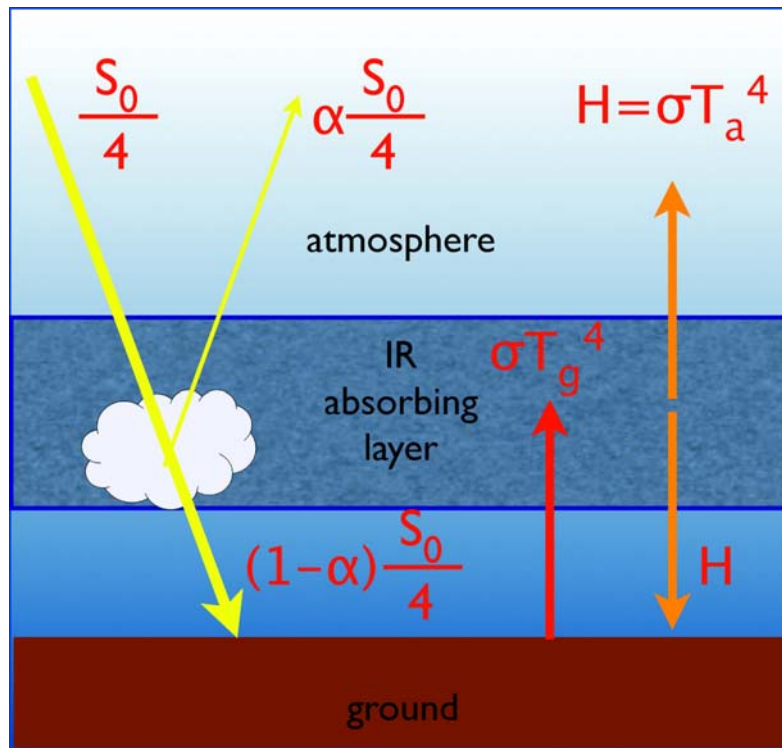
- Recent general view and the semi-infinite atmosphere
- Simple radiative transfer model of the Earth-atmosphere system
- Some facts - results of global scale LBL simulations
- Balance equations - Kirchhoff's law - virial theorem
- Transfer and greenhouse functions
- Radiative equilibrium in bounded atmosphere - correct solution
- Effect of a partial cloud cover – characteristic altitude
- Global average profiles, greenhouse sensitivity
- Planetary greenhouse effect in view of the new theory
- Conclusions

# GENERAL VIEW AND THE SEMI-INFINITE ATMOSPHERE

## RADIATIVE EQUILIBRIUM IN INFINITE MEDIUM (Eddington, 1916)

$$dB(\bar{\tau})/d\bar{\tau} = 3H/(4\pi) \quad B(\bar{\tau}) = 3H\bar{\tau}/(4\pi) + B_0 \quad B(\tilde{\tau}) = H(1 + \tilde{\tau})/(2\pi)$$

### OPAQUE HOMOGENEOUS ABSORBING LAYER



### SURFACE TEMPERATURES

“...Assumption of infinite thickness involves little or no loss of generality...”

(Milne, 1922)

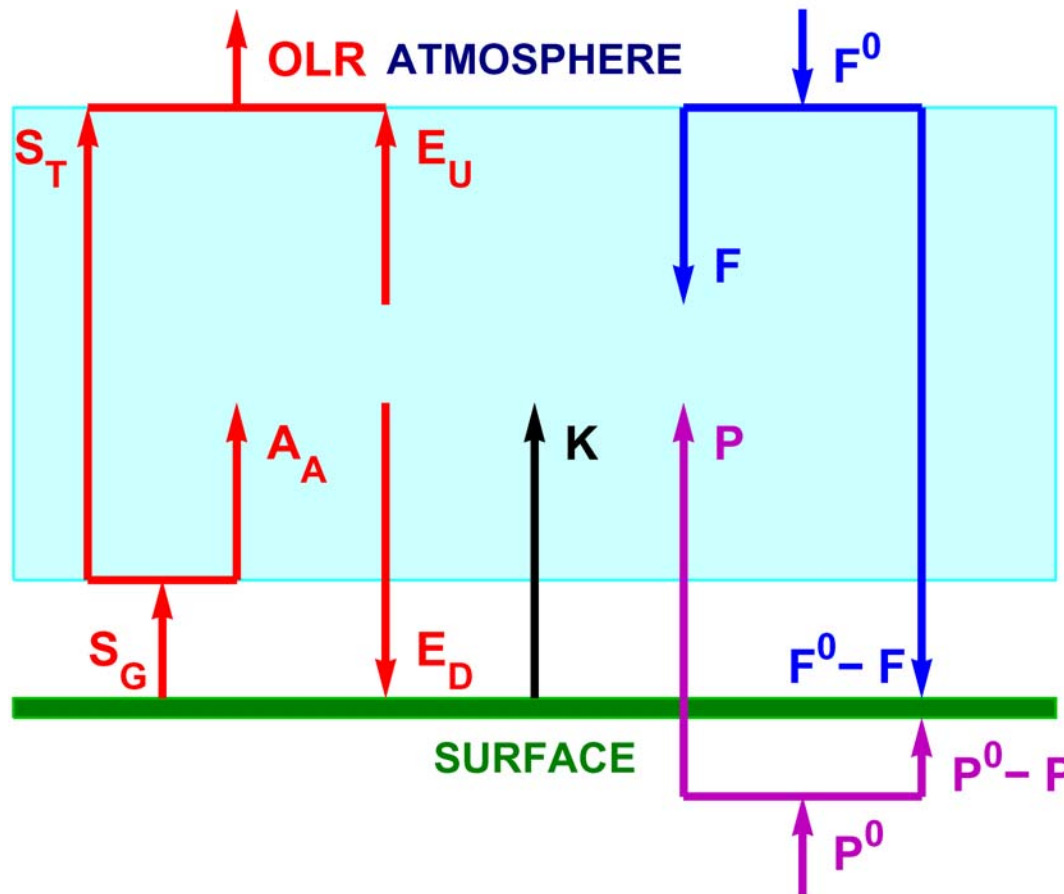
**AIR**  $t_A^4 = t_E^4(1 + \tilde{\tau}_A)/2$

**GROUND**  $t_G^4 = t_E^4(2 + \tilde{\tau}_A)/2$

**THESE SOLUTIONS ARE MATHEMATICALLY INCORRECT**

$\Delta S = 5.35 \cdot \ln[ \text{CO}_2(t)/\text{CO}_2(t_0) ]$  (IPCC, 2001)

# CLEAR-SKY RADIATIVE TRANSFER MODEL



Greenhouse effect:

$$G = S_G - OLR$$

$$G_N = G / S_G$$

All-sky measurements:

$$S_G = 391 \text{ Wm}^{-2}$$

$$OLR = 235 \text{ Wm}^{-2}$$

$$G_N \sim 0.4$$

QUESTIONS:

What are the theoretical relationships among the global average IR flux density terms ?

What can we learn from global scale simulations of IR fluxes ?

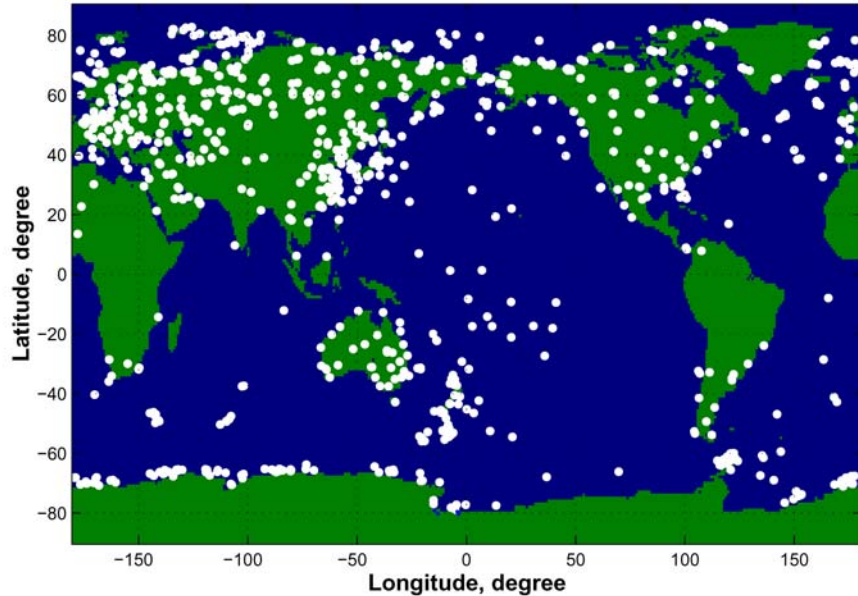
NET ATMOSPHERE (1)  $F + P + K + A_A - E_D - E_U = 0$

NET SURFACE (2)  $F^0 + P^0 + E_D - F - P - K - A_A - S_T = 0$

(3)  $F^0 + P^0 = OLR$

# GLOBAL SCALE LBL SIMULATIONS

Geographical Distribution of the 1761 TIGR Soundings



## INPUT DATA SET

RADIOSONDE OBSERVATIONS ARE FROM A SUB-SET OF THE **TIGR** COMPILATION  
(A. Chedin and N. Scott 1983)

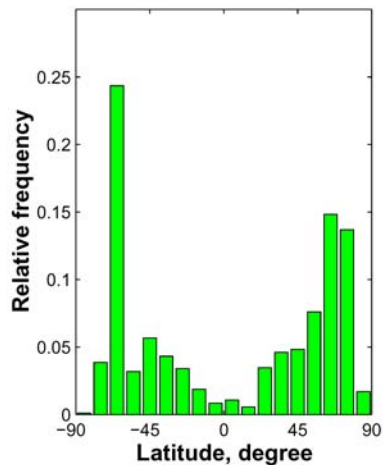
## PROCESSING LBL CODE

High-resolution atmospheric radiative transfer code **HARTCODE**  
(F. Miskolczi, M. Bonzagni and R. Guzzi, 1990)

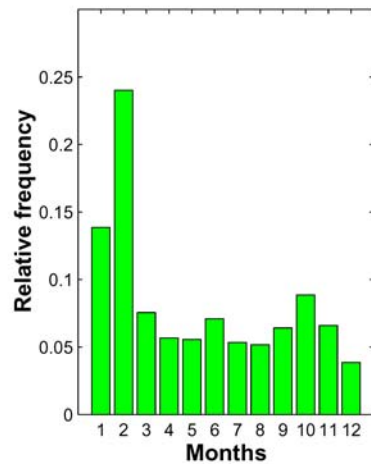
## SPECTROSCOPIC DATA SET

**HITRAN 2K**  
(<http://cfa-www.harvard.edu/HITRAN/hitransdata>)

Latitudinal Distribution

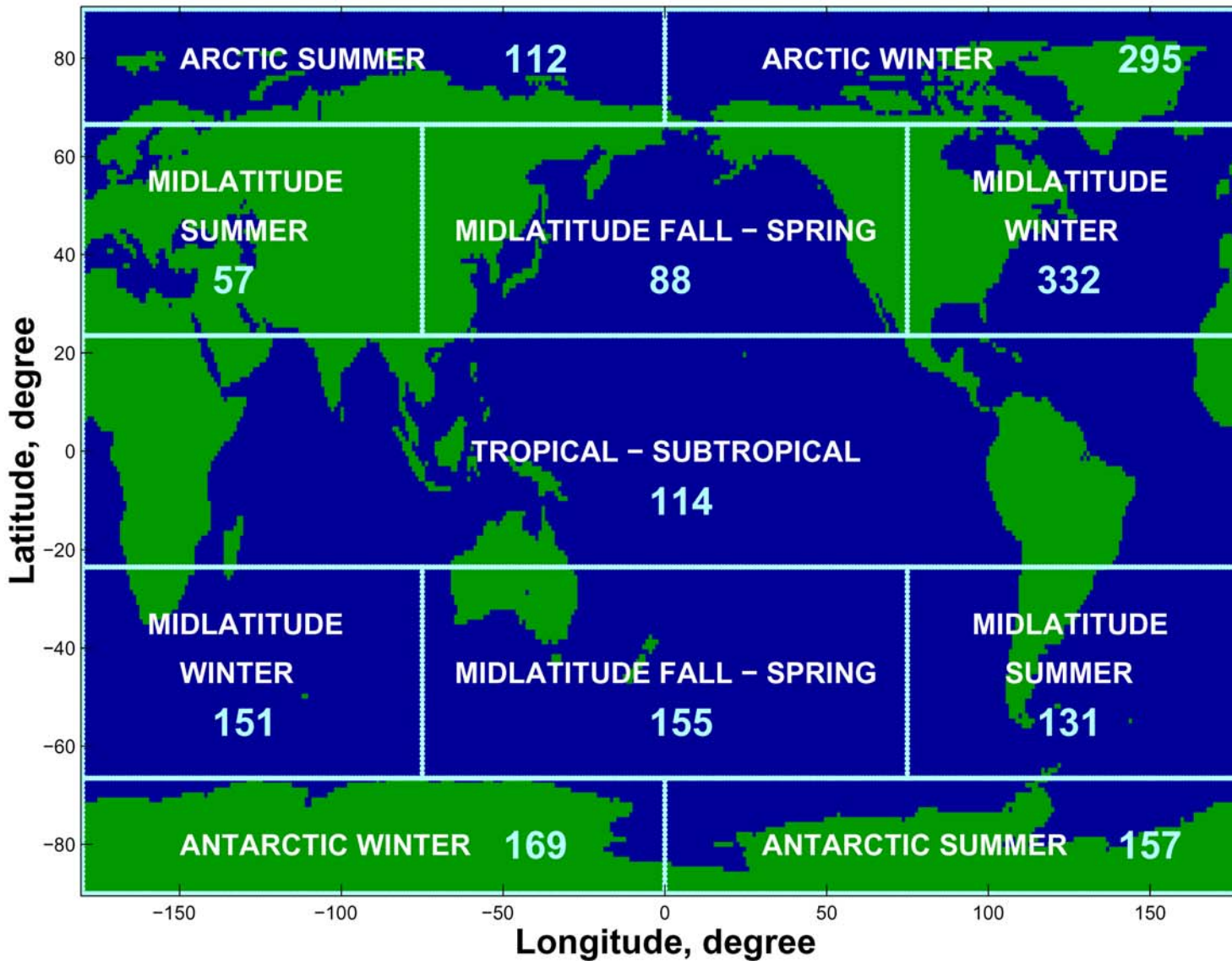


Annual Distribution



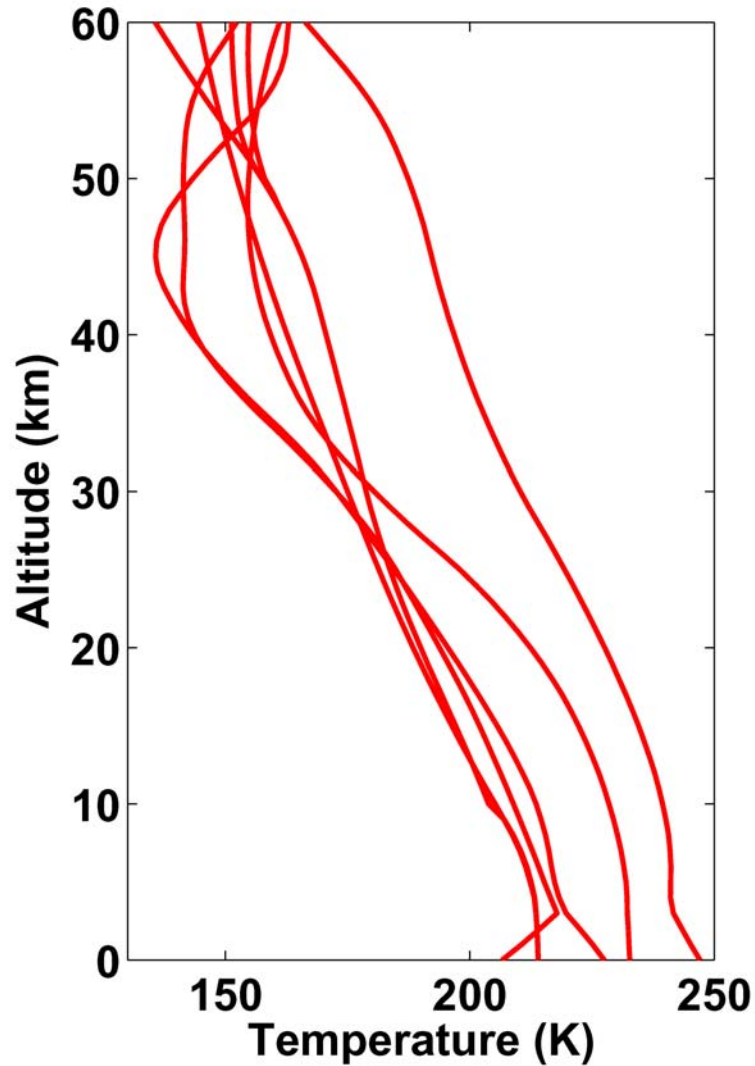
# LBL SIMULATIONS USED 228 TIGR RADIOSONDE OBSERVATIONS

## Grouping of the 1761 TIGR Soundings

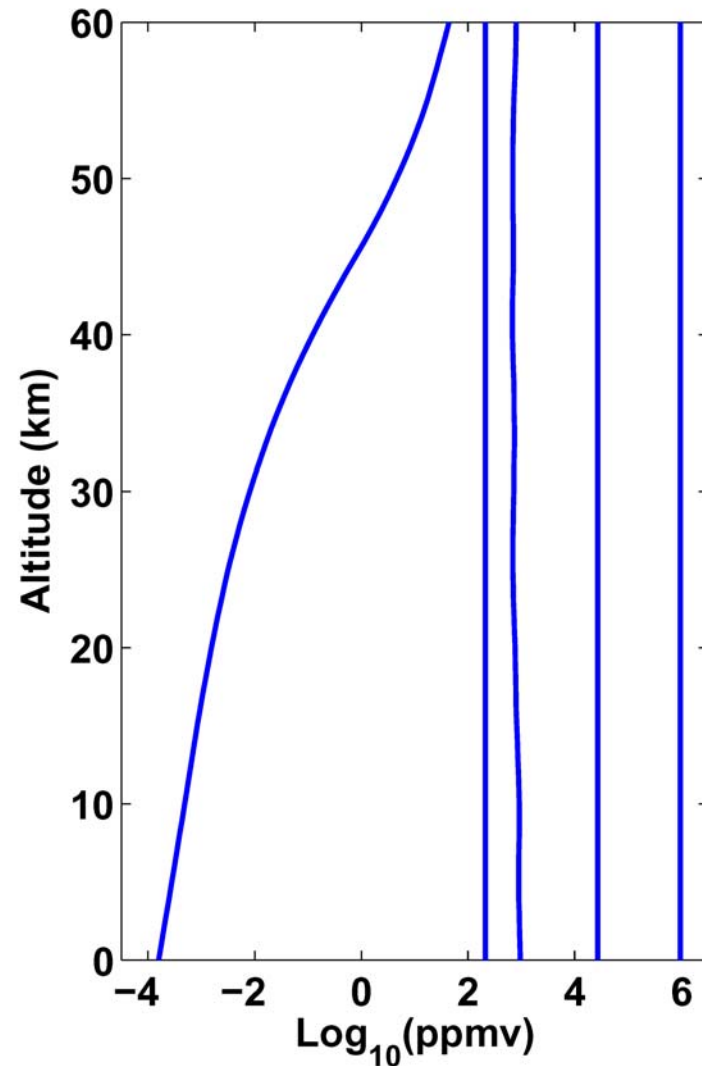


## LBL SIMULATIONS WITH MARTIAN ATMOSPHERES

Standard temperature profiles  
16 set with and without H<sub>2</sub>O

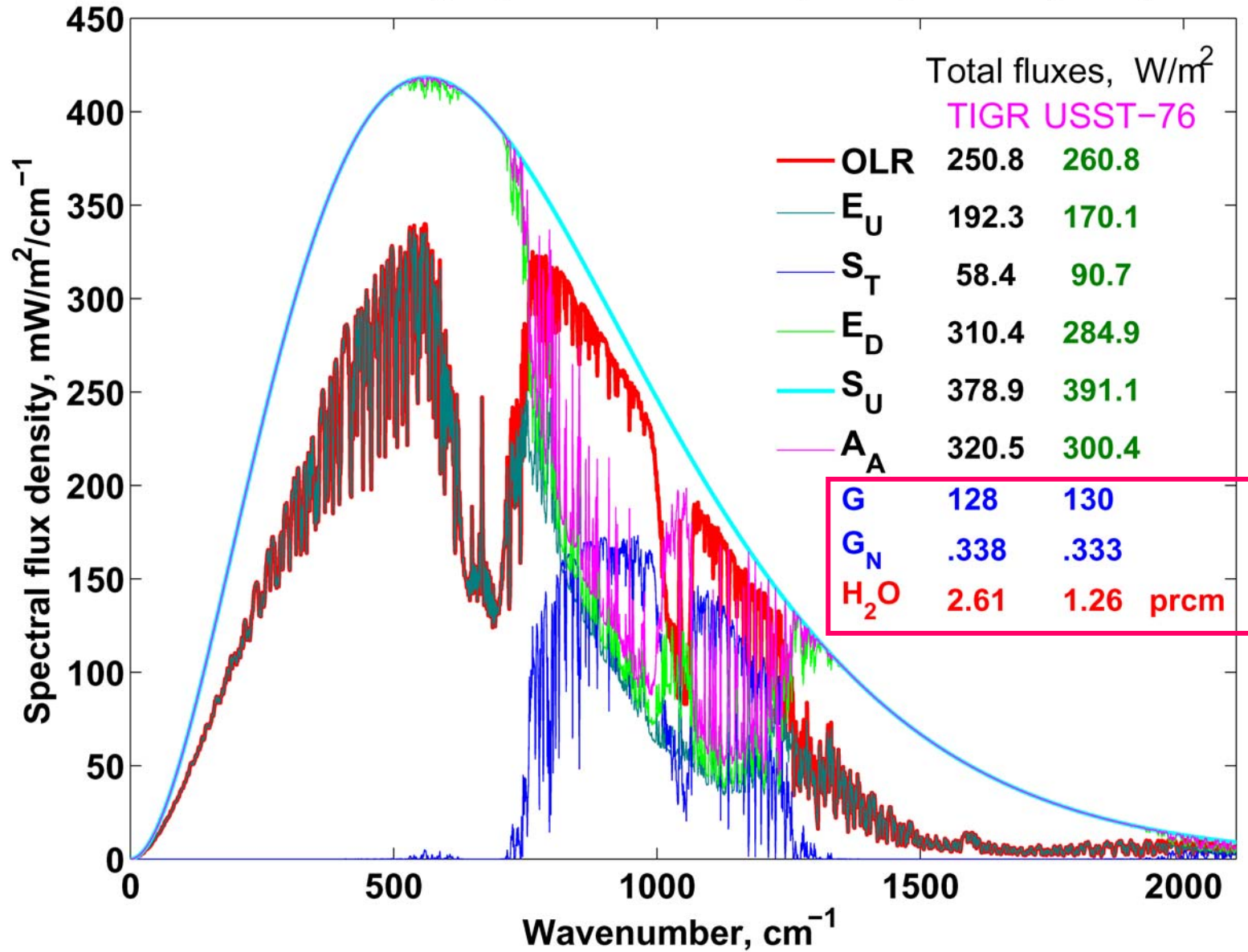


Absorbers from left to right :  
O<sub>3</sub>, H<sub>2</sub>O, CO, N<sub>2</sub>, CO<sub>2</sub>



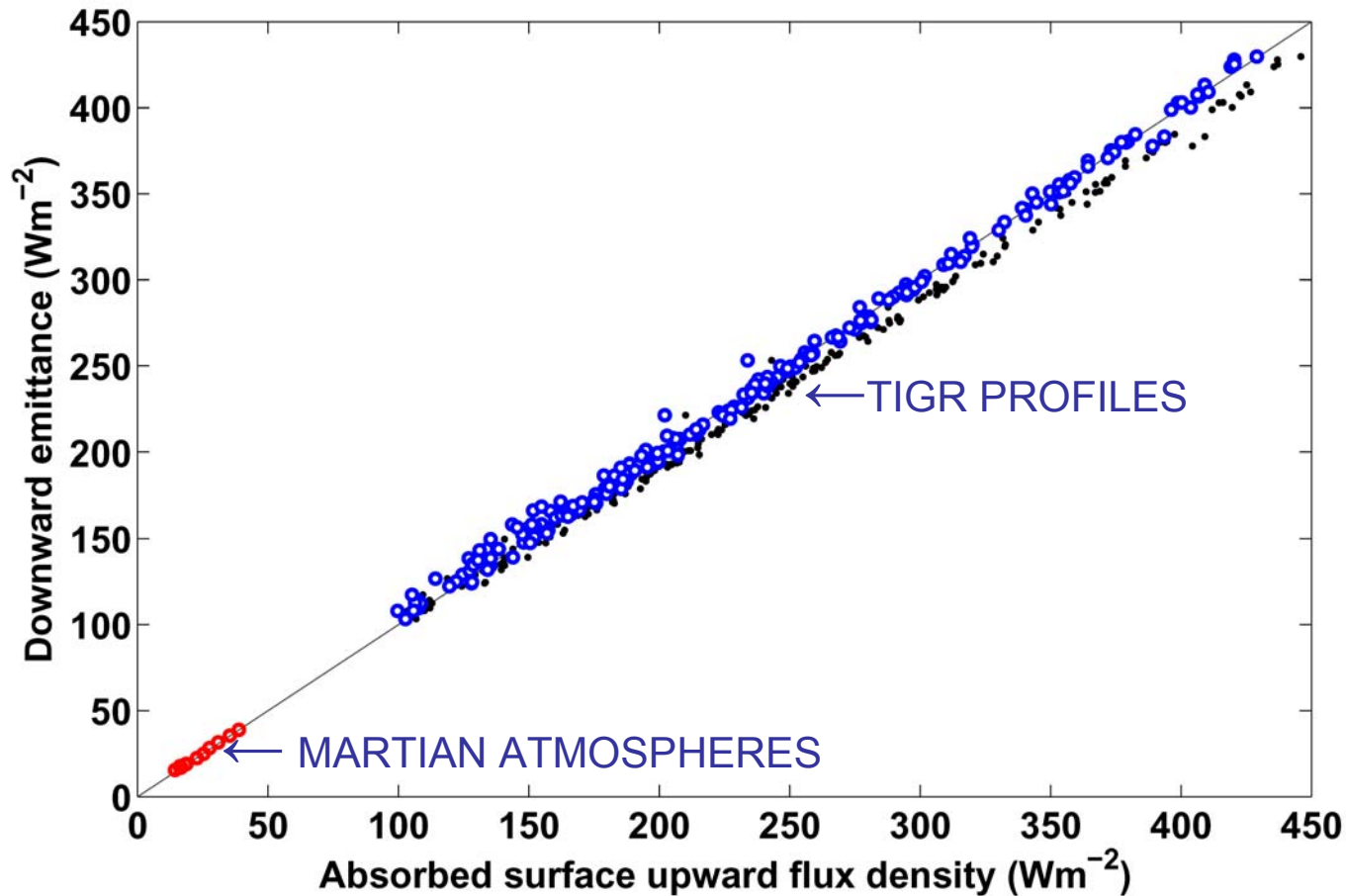
# CLEAR-SKY GREENHOUSE FACTORS

Global average spectral flux density components (TIGR)



?

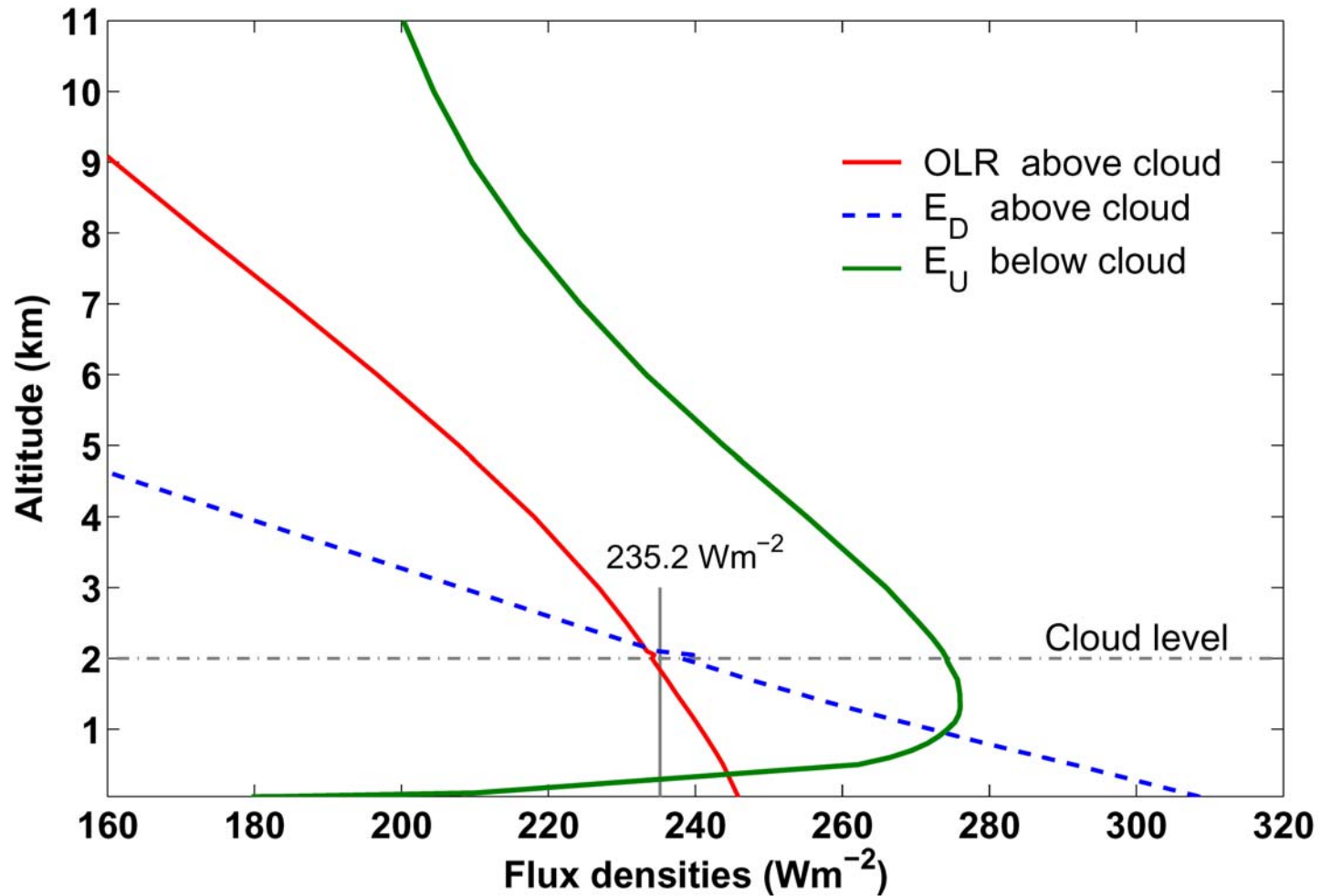
## ABSORBED SURFACE RADIATION AND DOWNWARD ATMOSPHERIC EMITTANCE



$E_D = A_A$  independently of the thermal structure and greenhouse gas content of the atmosphere.

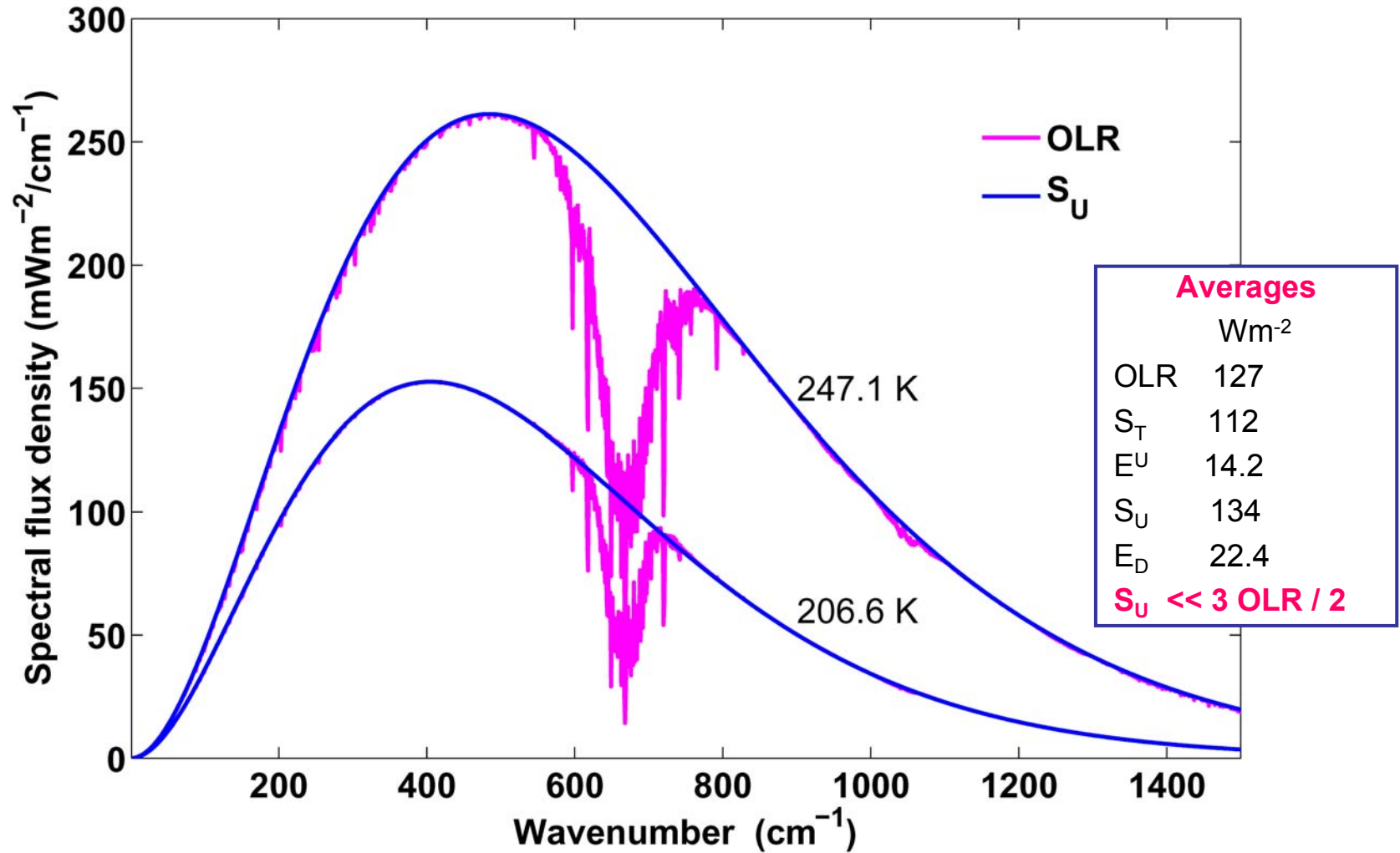
The surface and the atmosphere are in thermal equilibrium (Kirchhoff law).

## SIMULATION OF VERTICAL CLEAR-SKY FLUX DENSITY PROFILES



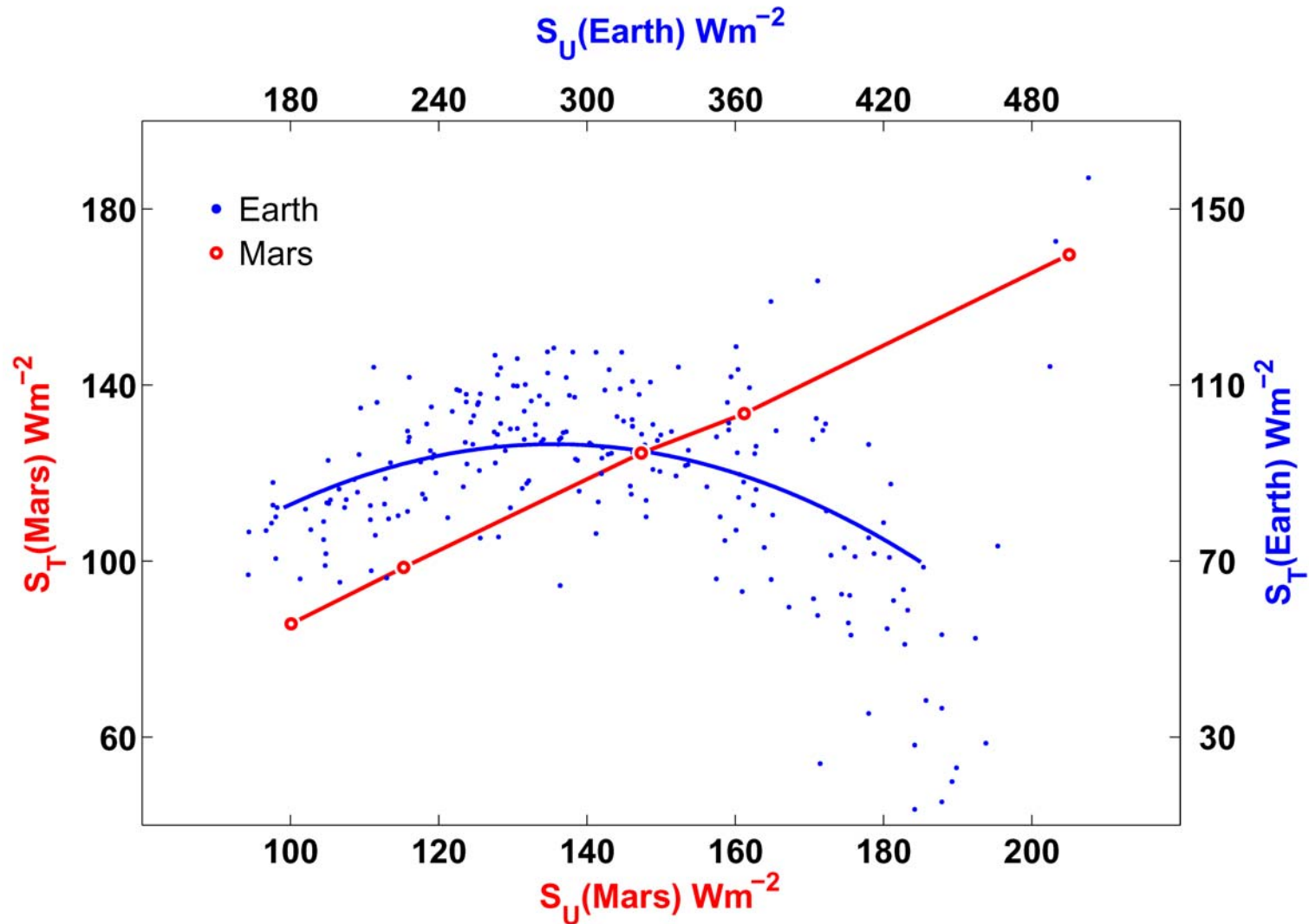
The clear-sky  $\text{OLR}=250 \text{ Wm}^{-2}$  is too large. A partial cloud cover at some altitude may restore the correct global average  $\text{OLR}^A=235 \text{ Wm}^{-2}$ .

## SIMULATIONS OF MARTIAN SPECTRAL FLUX DENSITIES



The clear Martian atmosphere is remarkably transparent, the average flux transmittance is  $\sim 0.84$ , just about the same as the flux absorption on the Earth.

## RELATIONSHIPS BETWEEN $S_U$ AND $S_T$



The broad-band radiative transfer schemes of the two planets are totally different.

## THEORETICAL RELATIONSHIPS BETWEEN THE IR FLUX DENSITIES

- Kirchhoff law:** (4)  $A_A = S_U A = S_U(1 - T_A) = E_D$        $T_A = \frac{S_T}{S_U} = 1 - A = e^{-\tilde{\tau}_A}$
- Consequences:** (5)  $E_U = F + K + P$       **UPWARD EMITTANCE**
- (6)  $S_U - OLR = E_D - E_U = G$       **GREENHOUSE FACTOR**
- (7)  $S_U - OLR + (E_D - E_U) = OLR$       **ENERGY CONSERVATION**
- Virial theorem and radiation pressure:**  $S_U = 2E_U$        $R = \frac{S_U}{3}$

## THEORETICAL TRANSFER AND GREENHOUSE FUNCTIONS

- (8)  $\frac{OLR}{S_U} = \frac{2}{3} \rightarrow f^+ = \frac{2}{3}$        $S_U - OLR = R \rightarrow g^+ = \frac{1}{3}$       **RADIATIVE BALANCE**
- (9)  $\frac{OLR}{S_U} = \frac{3 + 2T_A}{5} \rightarrow f^o = 1 - \frac{2A}{5}$        $S_U - OLR = \frac{6A}{5}R \rightarrow g^o = \frac{2A}{5}$       **GENERAL SOLUTION**
- (10)  $\frac{OLR}{S_U} = \frac{2 + T_A}{3} \rightarrow f^* = 1 - \frac{A}{3}$        $S_U - OLR = AR \rightarrow g^* = \frac{A}{3}$       **THIN ATMOSPHERE**

# TRANSFER FUNCTION IN SEMI-TRANSPARENT BOUNDED RADIATIVE EQUILIBRIUM ATMOSPHERE – GENERAL SOLUTION

## RADIATIVE EQUILIBRIUM IN FINITE MEDIUM

$$dB(\bar{\tau})/d\bar{\tau} = 3H/(4\pi) \quad B(\bar{\tau}) = 3H\bar{\tau}/(4\pi) + B_0 \quad H = \pi \left[ \bar{I}^+(\bar{\tau}) - \bar{I}^-(\bar{\tau}) \right]$$

### Boundary conditions

$$\tilde{\tau}_A \quad \text{and} \quad S_G = \pi B_G$$

$$\pi B_0 = \frac{H}{2} \left[ 1 + \tilde{\tau}_A e^{-\tilde{\tau}_A} + e^{-\tilde{\tau}_A} \right] - \pi B_G e^{-\tilde{\tau}_A}$$

$$1 - e^{-\tilde{\tau}_A}$$

### Transfer function

$$f = 2/(1 + \tau_A + T_A)$$

$$\pi B(\tilde{\tau}) = \frac{H}{2A} \left[ \frac{2}{f} - (\tilde{\tau}_A - \tilde{\tau})A \right] - \frac{\pi B_G T_A}{A}$$

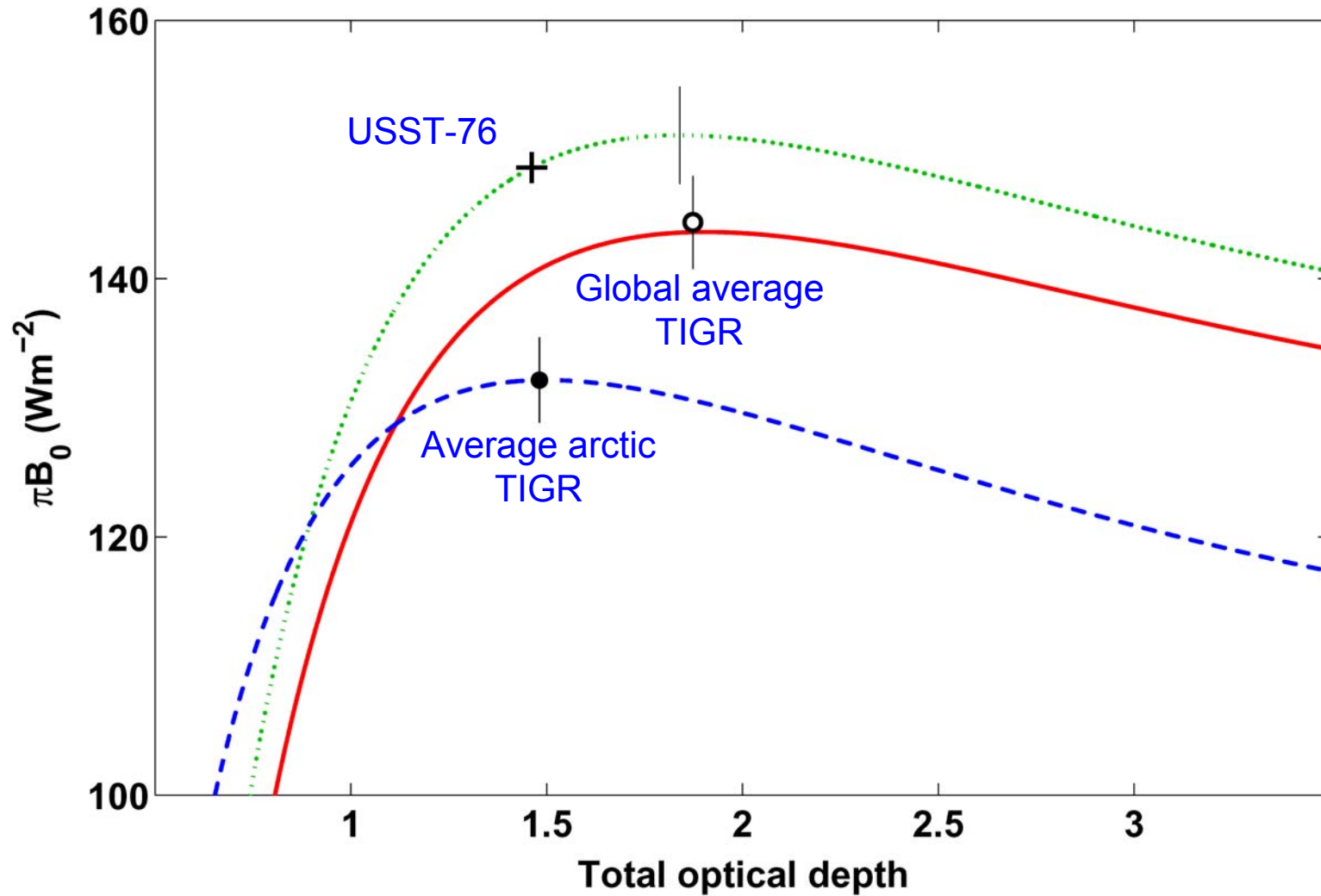
### Energy minimum principle

$$\pi dB_0(\tilde{\tau}_A)/d\tilde{\tau}_A = 0$$

$$S_U = \frac{OLR}{f} \rightarrow t_G^4 = \frac{t_E^4}{2} (1 + \tau_A + T_A)$$

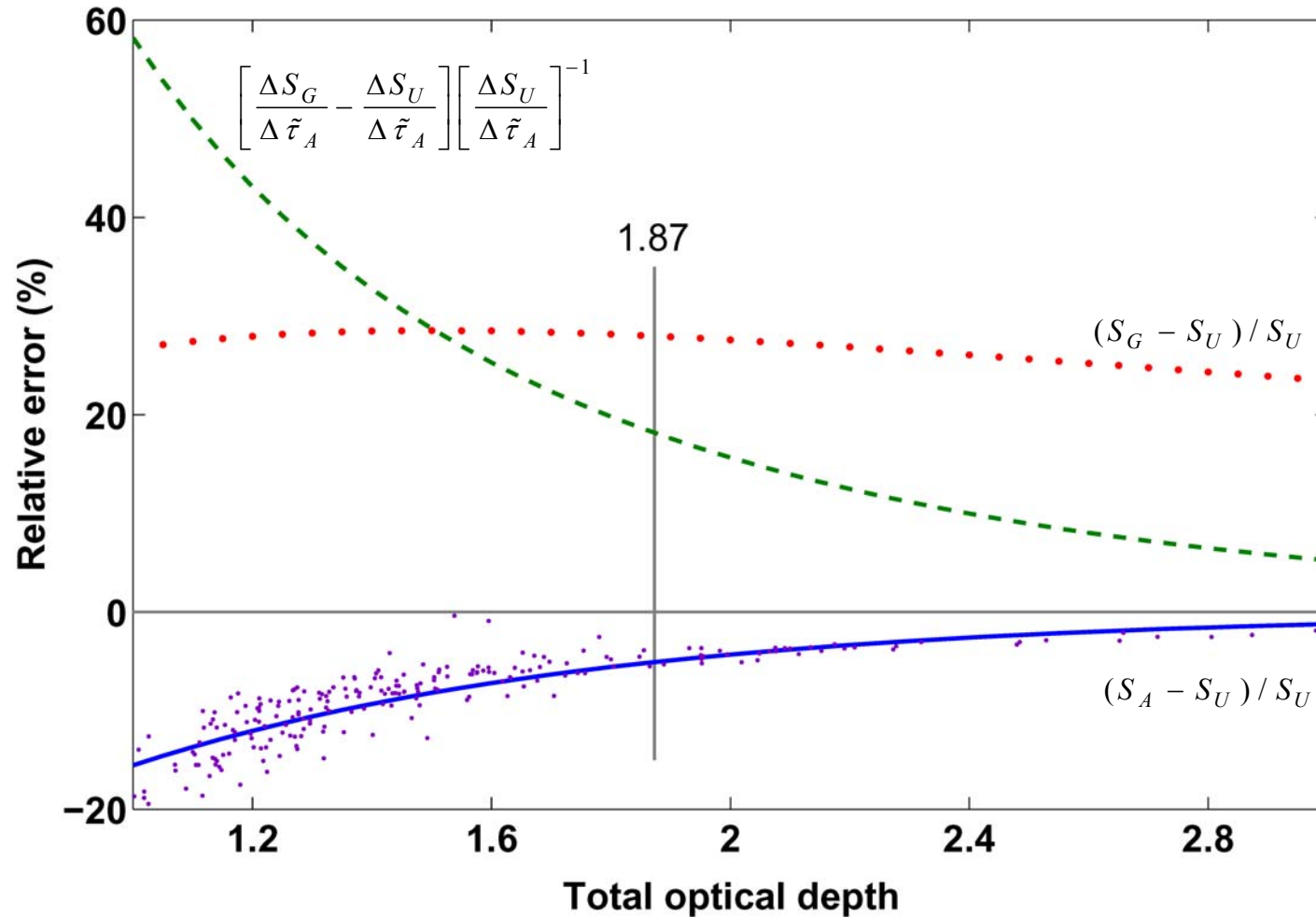
The surface temperature depends also  
on the flux transmittance  $T_A$ .

## SIMULATION RESULTS AND THE ENERGY MINIMUM PRINCIPLE



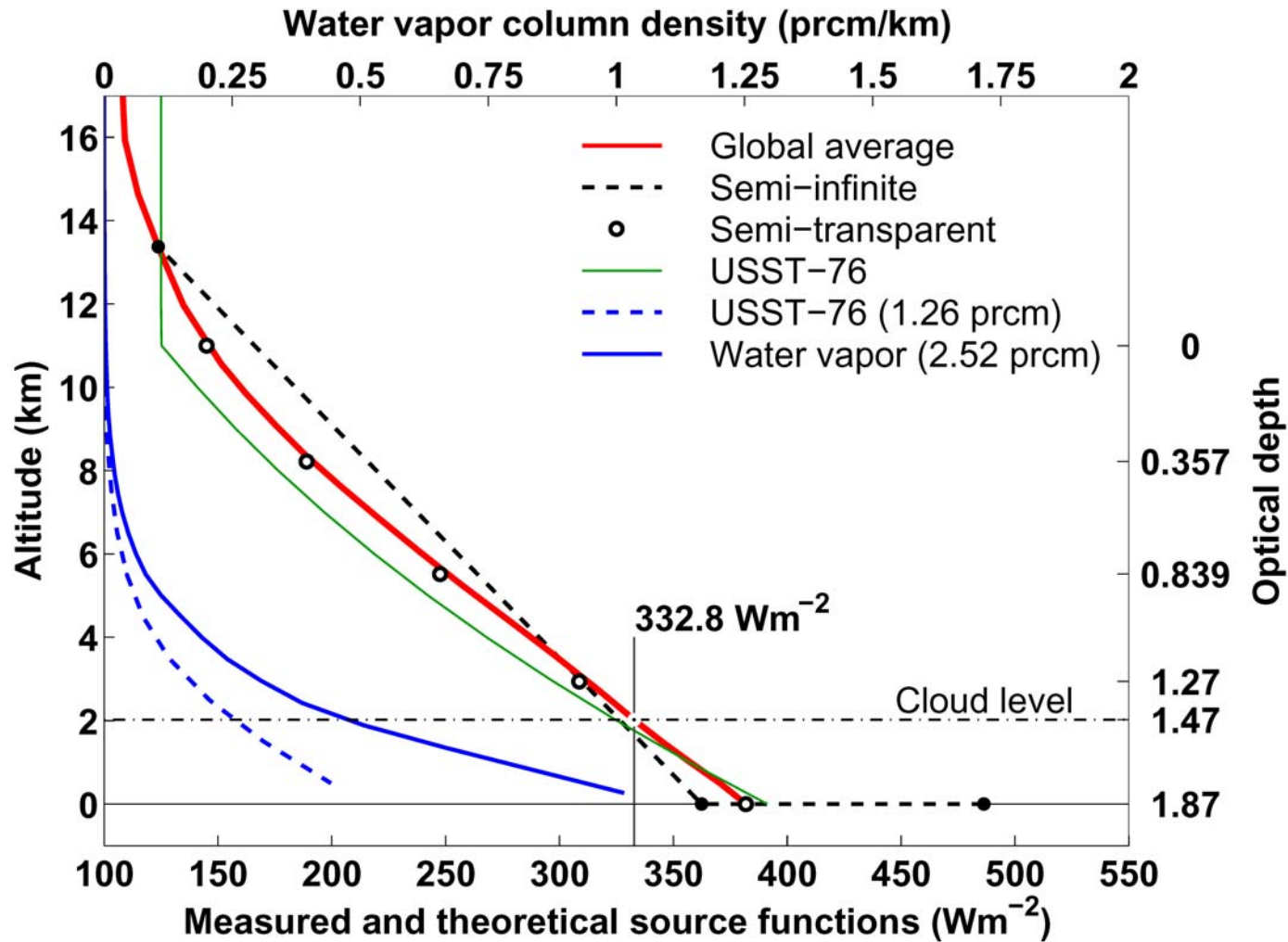
**Radiative equilibrium atmospheres accommodate the optical depth which maximizes  $B_0(\tilde{\tau}_A)$ .**

## FLUX DENSITY ( $S_G$ and $S_A$ ) ERROR ESTIMATES Semi-infinite – semi-transparent



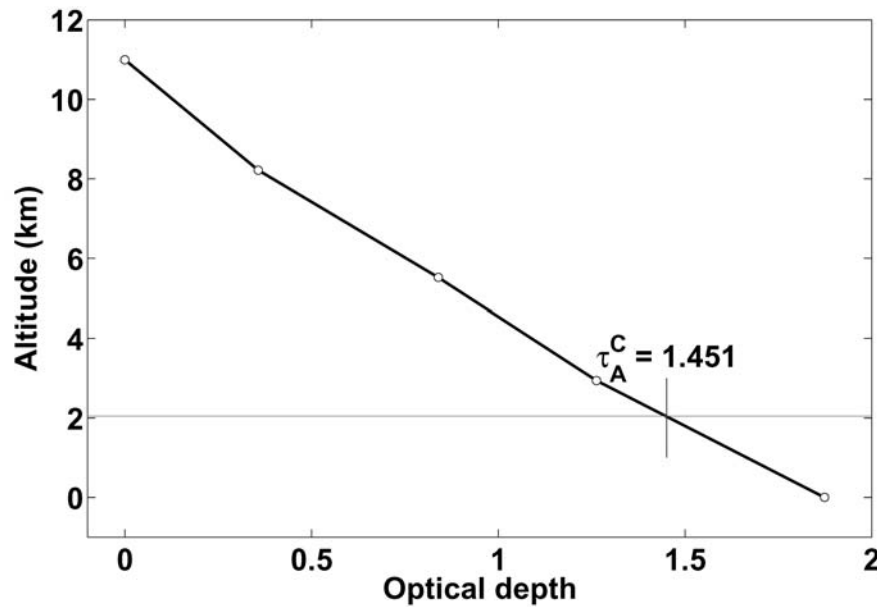
The classic solution overestimates  $S_G$  by 30 % , and underestimates  $S_A$  by 8 % . The sensitivity is off by about 20 % .

# GLOBAL AVERAGE ATMOSPHERES



The USST-76 atmosphere is not adequate for global radiative budget studies.  
 (Not in radiative equilibrium, not in energy balance,  $H_2O$  amount is small)

## GLOBAL AVERAGE TIGR PROFILE – FURTHER RESULTS

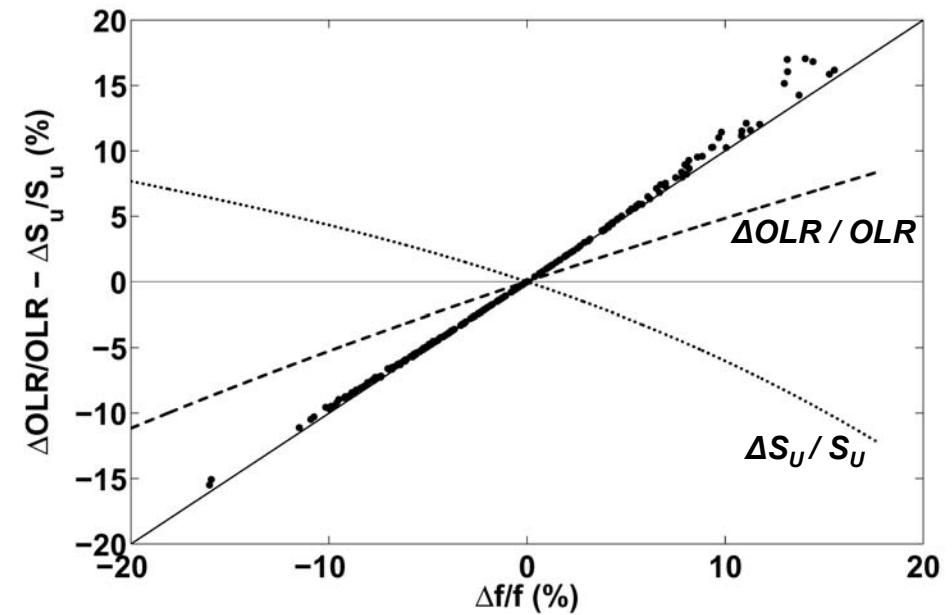


The dynamical flux optical depth is a linear function of the altitude.

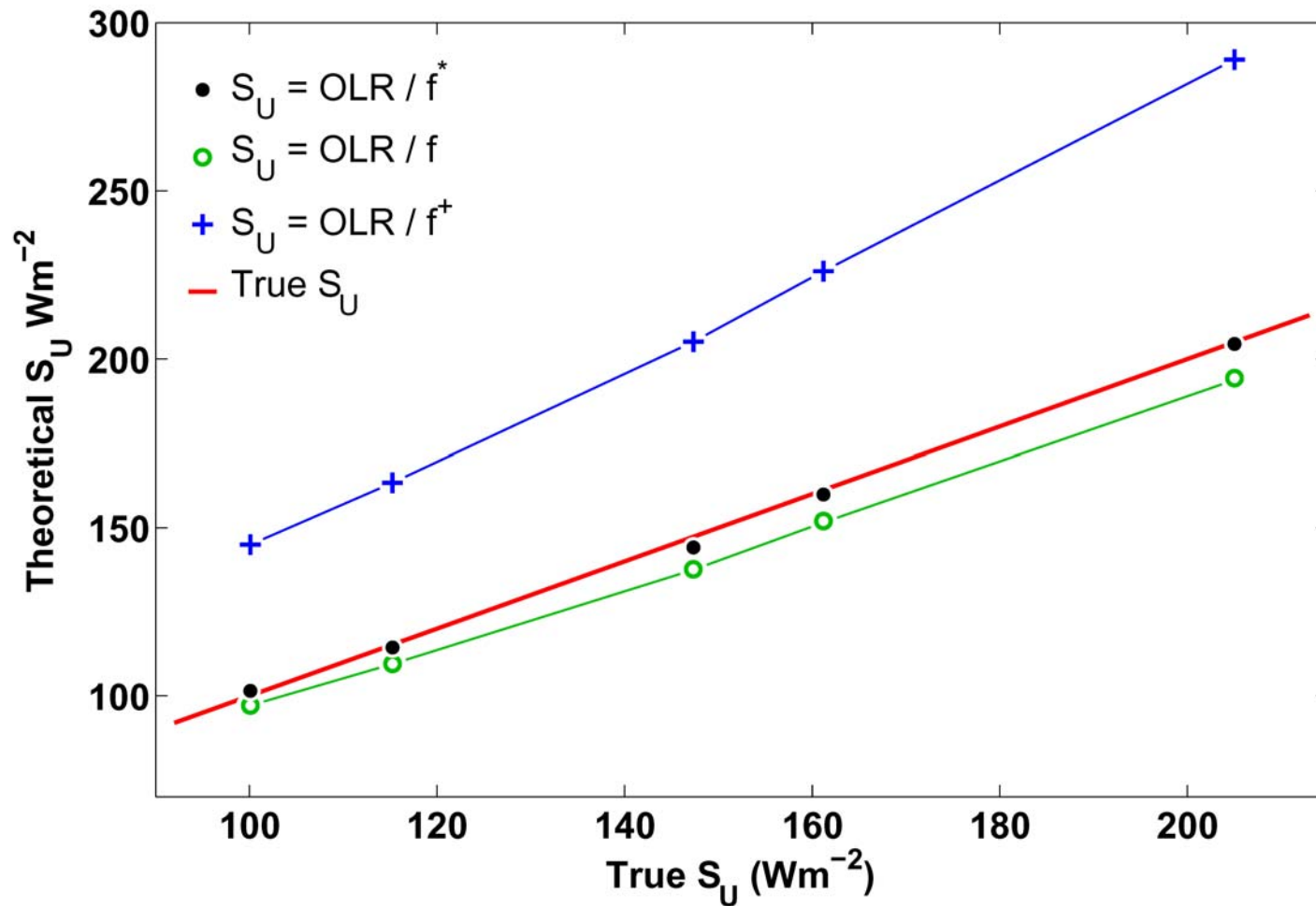


The new radiative equilibrium transfer function is able to account for the stratospheric compensation:

$$\Delta OLR = -f \Delta S_U.$$

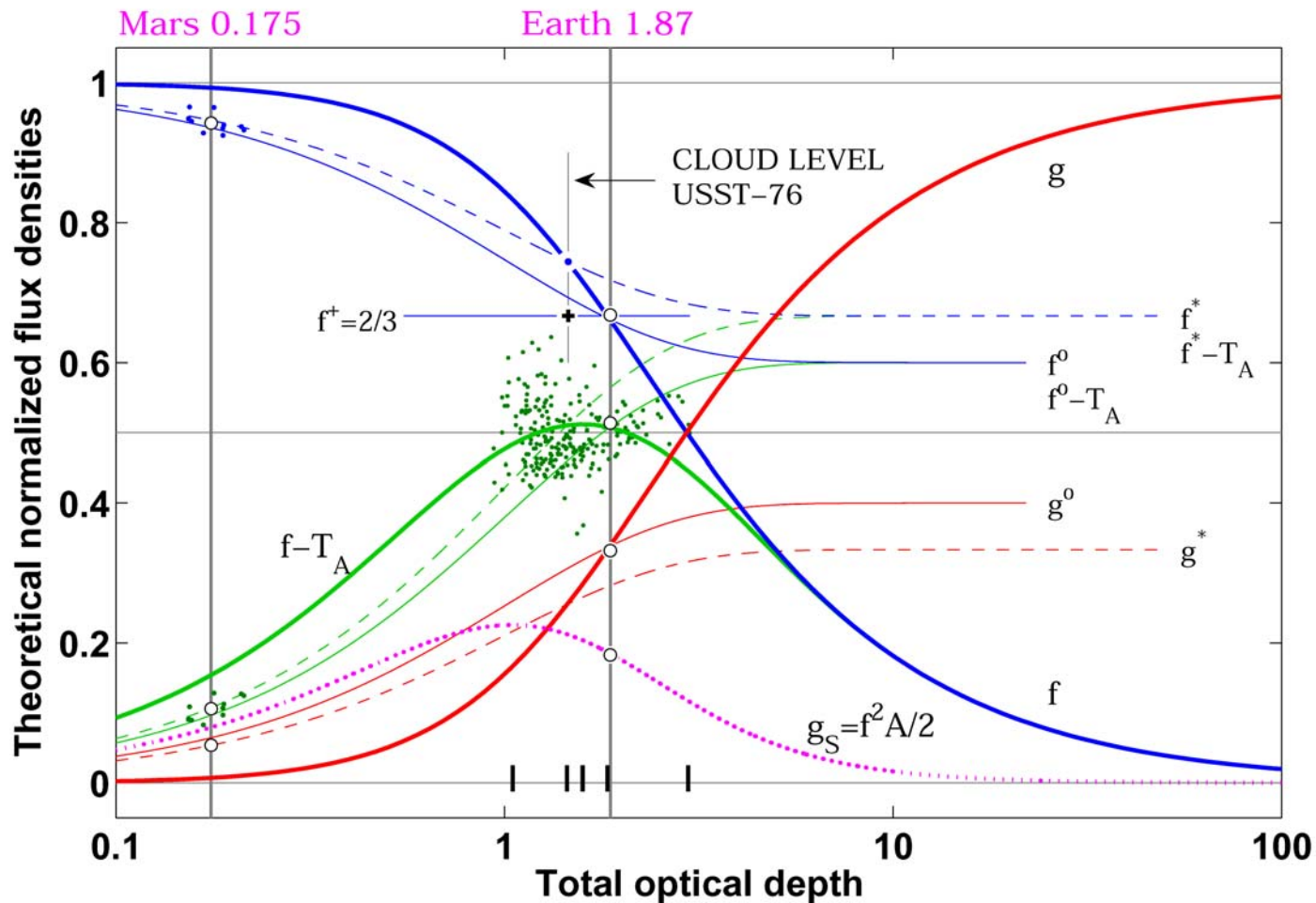


## THEORETICAL TRANSFER FUNCTION FOR THE MARTIAN ATMOSPHERE



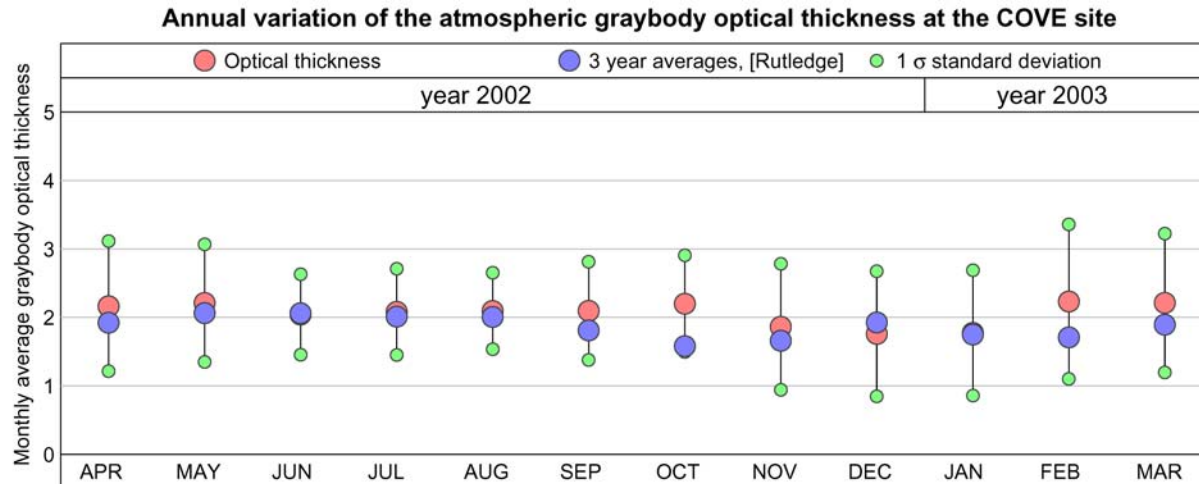
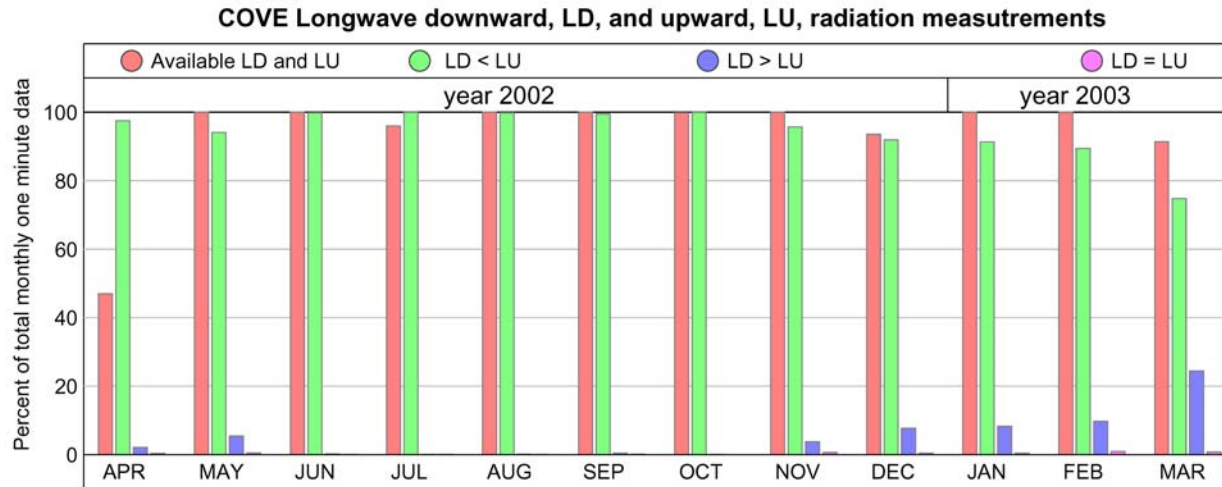
The Martian atmosphere is not in radiative equilibrium. The greenhouse effect is properly described with the  $S_U + S_T / 2 = 3OLR / 2$  balance equation.

# GREENHOUSE EFFECT IN PLANETARY ATMOSPHERES



For the **Earth** and **Mars** the new theory is perfectly supported by simulation results and observations. The greenhouse effect on the **Earth** is locked to the critical optical depth of  $\sim 1.87$  which is maintained by the atmospheric **H<sub>2</sub>O** amount.

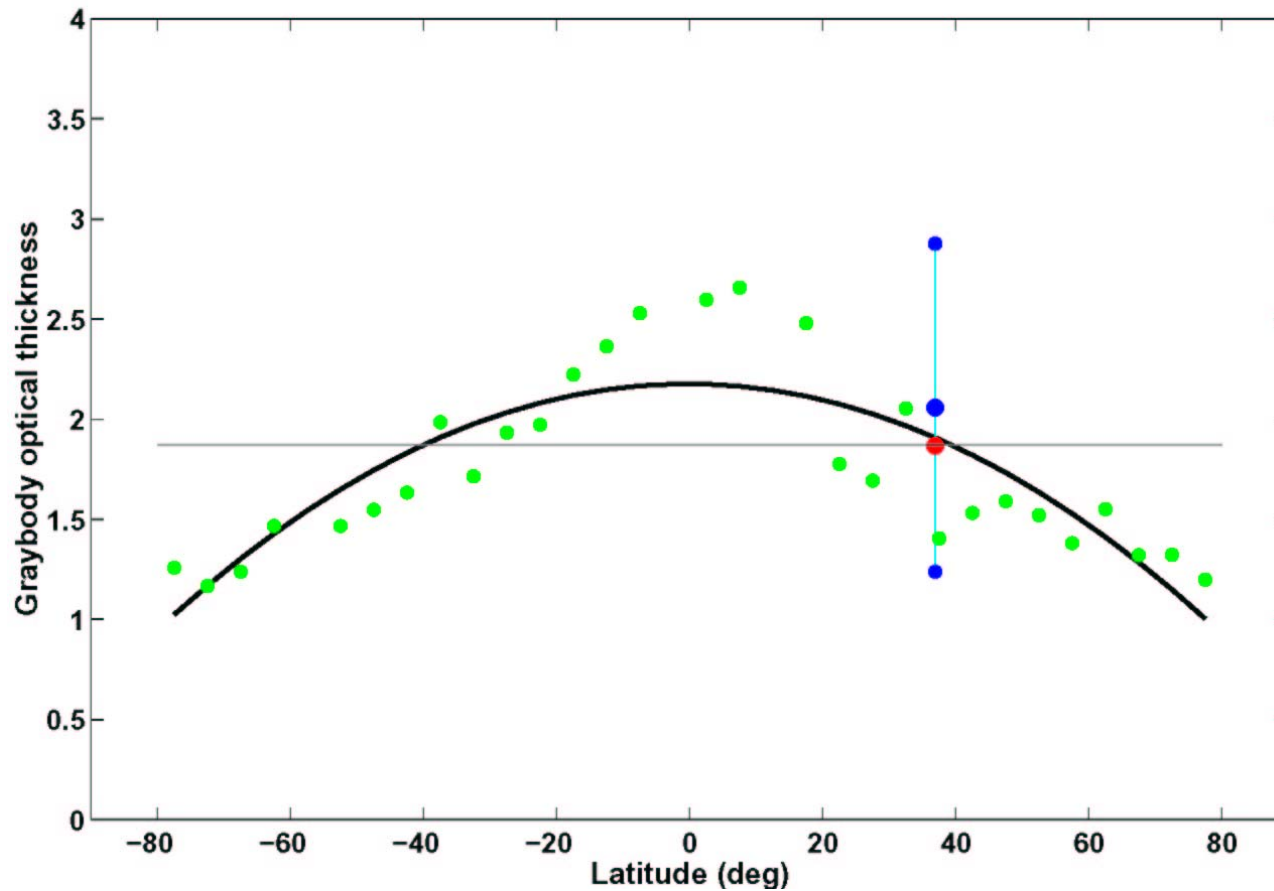
# GROUND MEASUREMENT OF FLUX OPTICAL DEPTH



$$\tilde{\tau}_A = \ln \left[ \frac{S_U}{S_U - E_D} \right]$$

# FLUX OPTICAL DEPTH FROM TIGR DOWNWARD EMITTANCES

$$\tau_A = \log(1/(1-E_D/S_U)) \text{ at the COVE site}$$



A pyrgometer network could be suitable for global-scale monitoring of the spatial and temporal variability of the flux optical depth (from the ground).

## CONCLUSIONS

- Applying Kirchhoff's law,  $E_D=A_A$ , and the virial theorem,  $S_U=2*E_U$ , a general radiative balance equation was established for semi-transparent planetary atmospheres:  $S_U+S_T/2-E_D/10=3OLR/2$ .
- For atmospheres in radiative equilibrium the relationship between the  $OLR$  and  $S_U$  was also established by the correct mathematical solution of the bounded atmosphere problem:  $S_U=OLR/f=OLR/(1-g)$ .
- The runaway greenhouse effect is physically impossible. All normalized greenhouse factors are bounded.
- Large scale simulation results show that the Earth's average clear-sky temperature profile closely satisfies both equations. The average Martian atmosphere is not in radiative equilibrium, it follows only the balance equation for thin atmospheres:  $S_U+S_T/2=3OLR/2$ .
- The Earth's global average flux optical depth is  $1.87$  which is consistent with the theoretical flux optical depth expectations of the energy balance requirement and the requirement of the most efficient cooling of the system,  $1.86$ , and  $1.84$ .
- Planetary radiation budget studies should rely on real global average atmospheres (problems with the USST-76).

## CONCLUSIONS (Cont.)

- With a partial cloud cover the Earth-atmosphere system is in the state of a virtually saturated greenhouse effect without changing the optimal clear-sky flux optical depth and violating the energy balance equation:  $g^0=0.4$  ,  $S_U=5$   $OLR/3\sim 391=5*235/3$   $Wm^{-2}$ .
- The Earth's atmosphere is configured for the most efficient IR cooling of the planet with a critical global average flux optical depth. As long as the Earth has the oceans as unlimited sources and sinks of optical depth, this critical equilibrium optical depth is maintained by the more or less chaotic general circulation of atmosphere and ocean currents. Excess or deficit in the global average optical depth will violate either the energy conservation principle or the energy minimum principle.
- The observed global warming has nothing to do directly with the greenhouse effect, it must be related to changes in the total absorbed solar radiation,  $F^0$ , or the dissipated heat from other natural or anthropogenic sources of thermal energy,  $P^0$ .
- For climate simulations GCMs should be conditioned with the real physical laws of the planetary greenhouse effect.

## References

F. Miskolczi, *Időjárás*, 2007, 111, No. 1 :

Greenhouse effect in semi-transparent planetary atmospheres.

F. Miskolczi and M. Mlynczak, *Időjárás*, 2004, 108, No. 4 :

The greenhouse effect and the spectral decomposition of the clear-sky terrestrial radiation.

F. Miskolczi, *Időjárás*, 2001, 105, No. 4 :

High accuracy skin temperature retrieval from spectral data of multi-channel IR imagers.

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