How Much CO_2 and the Sun Contribute to Global Warming?

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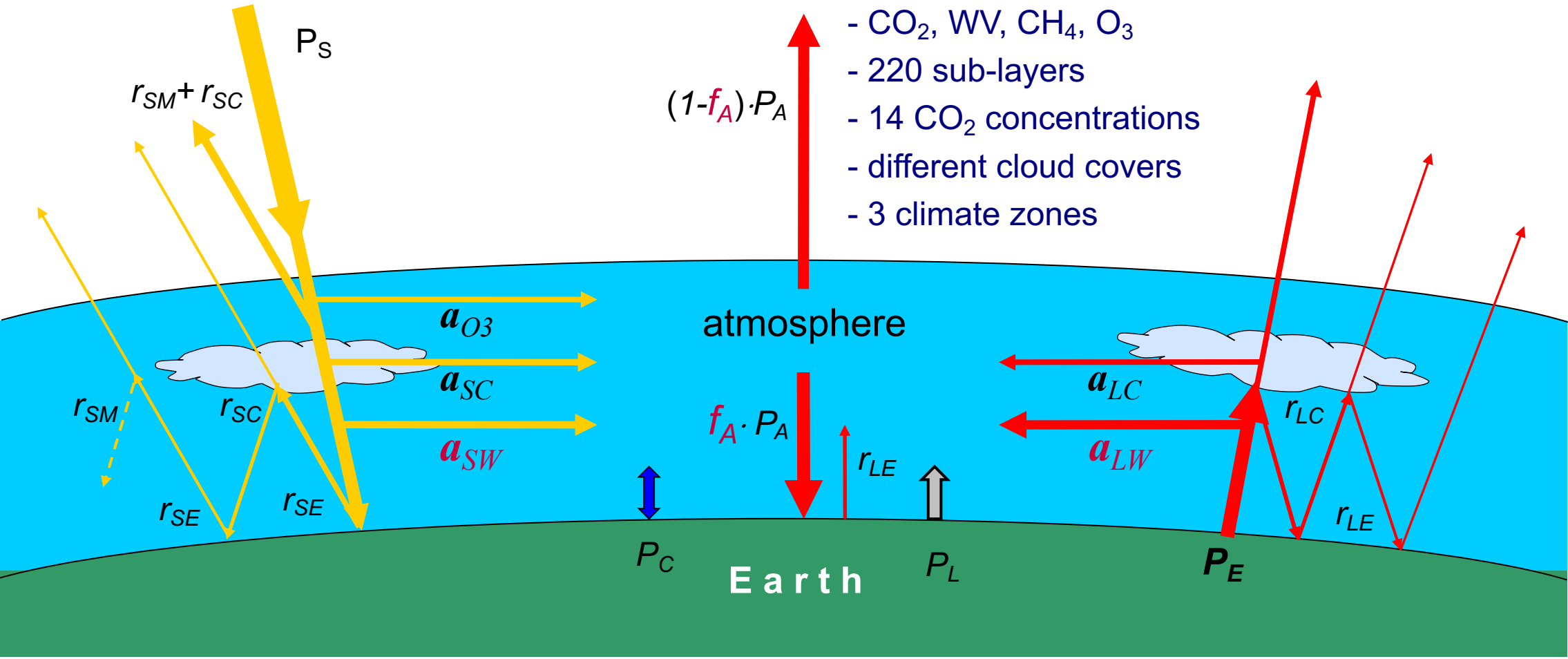
IPCC declares:

- *Observed warming is predominantly caused by CO_2*
- *Increasing CO_2 is only man-made*

Two-Layer Climate Model – *2LCM*

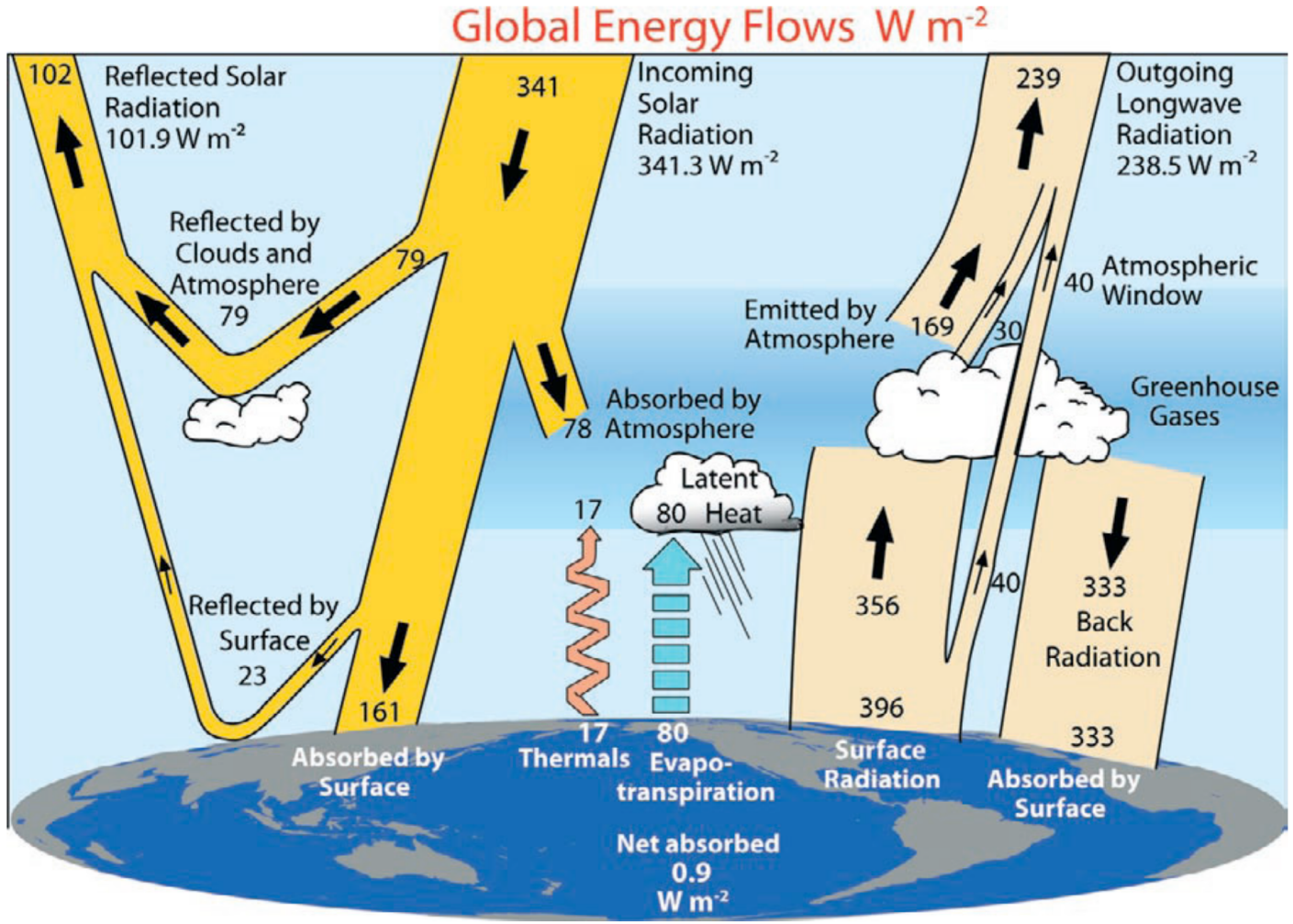
LBL-RT calculations for 900.000 lines of GH-gases

- CO_2, WV, CH_4, O_3
- 220 sub-layers
- 14 CO_2 concentrations
- different cloud covers
- 3 climate zones



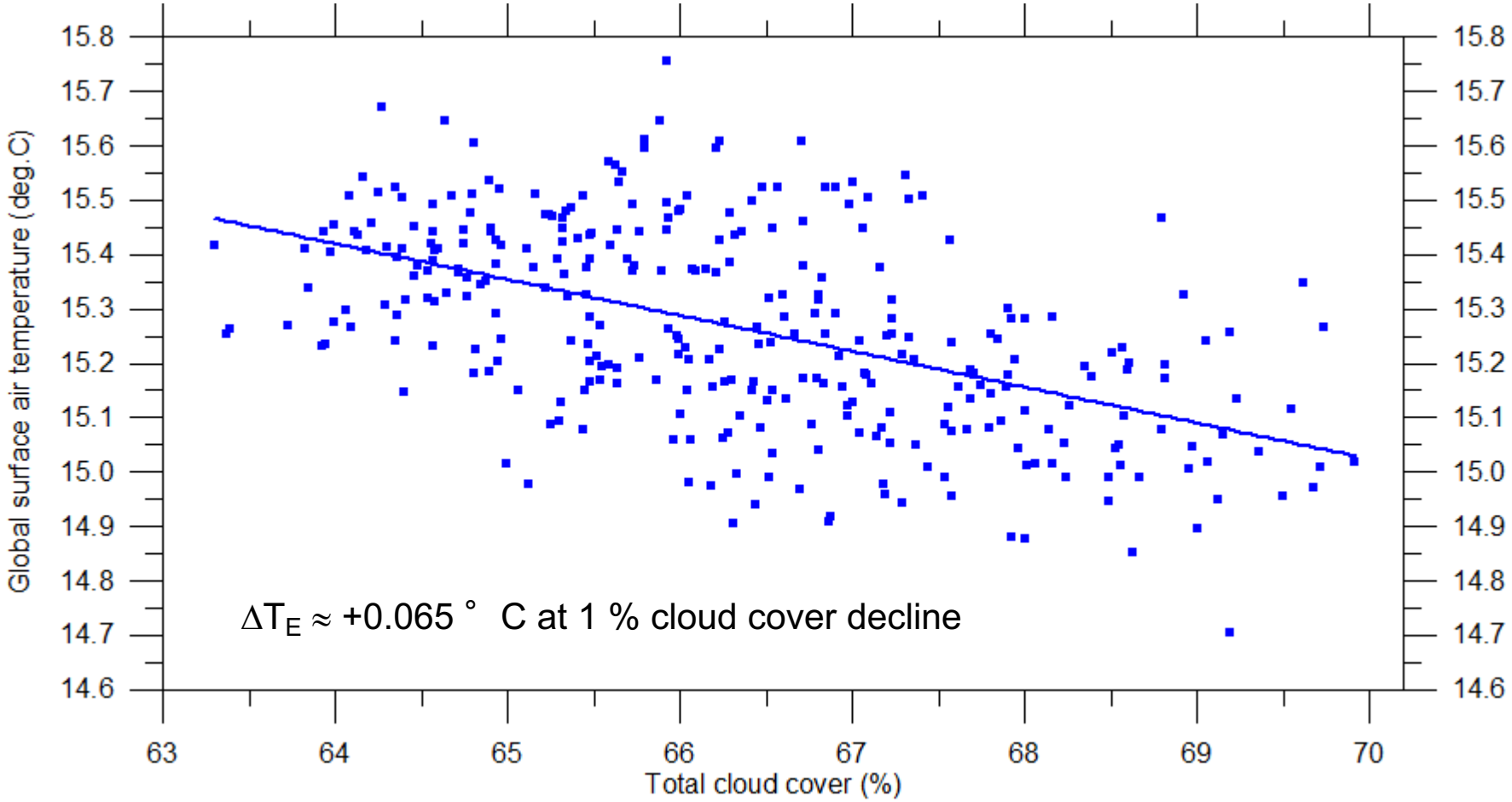
Symbols: P – power; r – reflectivity (scattering).; a – absorptivity; f_A – asymmetry factor

Comparison with measured energy and radiation budget



Energy and radiation budget after Tremberth, Fassulo and Kiehl

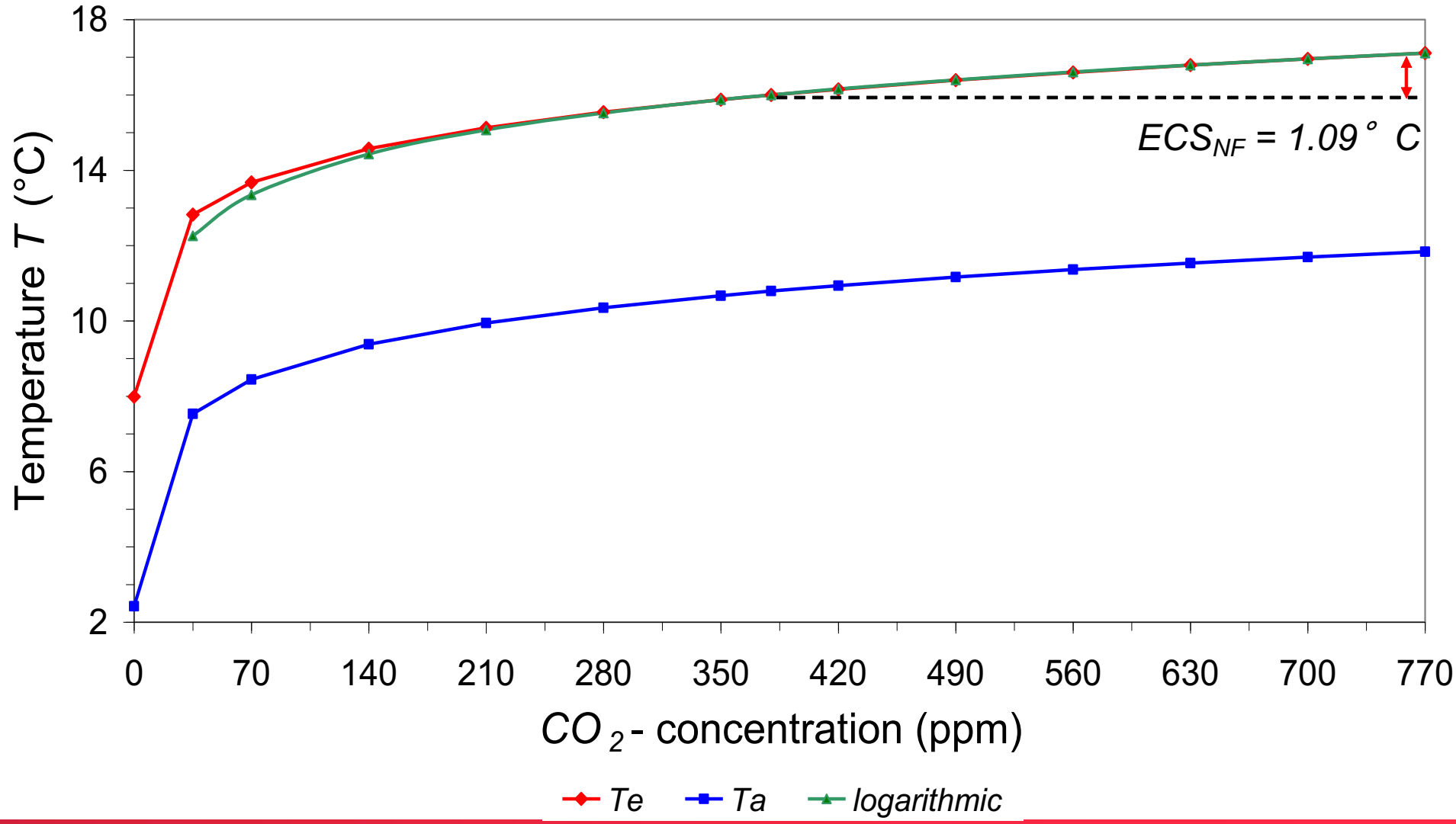
International Satellite Cloud Climatology Project - *ISCCP*



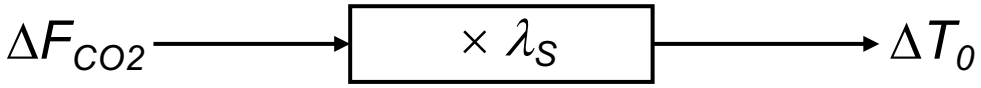
http://www.climate4you.com/index.htm

Direct CO_2 Influence on the climate

Earth's temperature T_E and lower atmospheric temperature T_A at 66 % cloud cover



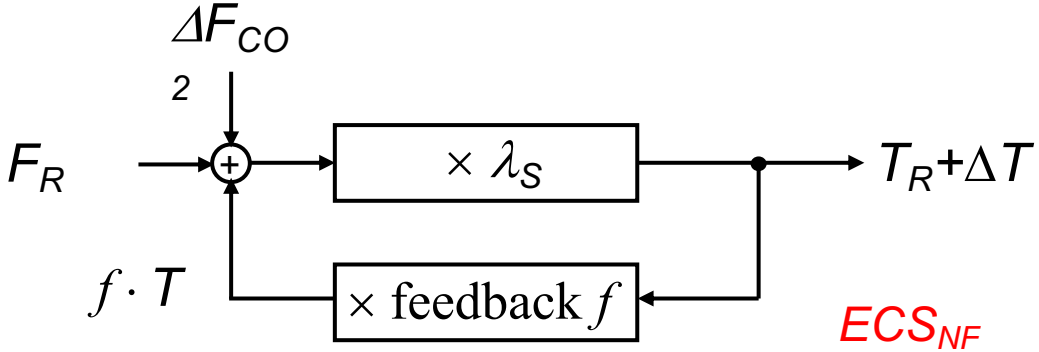
- **Feedback Processes:**
  - many scientists agree: increasing CO_2 absorption causing a forcing ΔF_{CO2} should only moderately contribute to an additional warming ΔT_0



$$\Delta T_0 = \lambda_S \cdot \Delta F_{CO_2}$$

with λ_S – Planck sensitivity

  - greater worry: smaller perturbations might initiate a feedback f [$W/m^2/^\circ C$], could significantly amplify the primary perturbation



$$T = T_R + \Delta T$$
$$= \lambda_S \cdot (F_R + \Delta F_{CO_2} + f \cdot (T_R + \Delta T))$$
$$= \frac{1}{1 - f \cdot \lambda_S} \cdot \lambda_S \cdot F_T$$

  - doubled CO_2: $ECS = \frac{1}{1 - f \cdot \lambda_s} \lambda_S \cdot \Delta F_{2xCO_2}$ (ECS_{NF})

amplification: $A = \frac{1}{1 - f \cdot \lambda_s}$

Feedback Effects

- **Well known feedbacks:**
  - water vapor feedback
  - lapse rate feedback
  - albedo feedback
  - cloud feedbacks

- **Additional feedbacks:**
  - convection feedback
  - evaporation feedback
  - solar induced cloud feedback

Feedback Effects (Hardy, 2017)

- **Water Vapor Feedback:**
  - From LBL-RT calculations for 3 climate zones → diff. T → diff. humidity:

    clear sky: f_{WV} = *1.10 W/m²/° C* → ***A = 1.57*** *or* ***+ 57%***

    66% clouds: f_{WV} = *0.43 W/m²/° C* → ***A = 1.14*** *or* ***+ 14%***

  - IPCC (AR5): f_{WV} = *1.6 W/m²/° C* → ***A = 2.0*** *or* ***+100%***

Reasons for the discrepancy:

- My calculations also consider sw absorptivity → negative feedback
- IPCC neglects changing absorption cross-section with surface temperature
- Main differences: Calculation of a_{LW} with temperature & humidity:
  - IPCC uses only clear sky for WV calculations and
  - emanates from a WV concentration for mid- latitudes half of the global mean

Feedback Effects

- **Lapse Rate Feedback:**
  - in agreement with AR5:

$$f_{LR} = -0.6\ W/m^2/^\circ C \rightarrow \mathbf{A = 0.85} \quad or \quad \mathbf{-15\%}$$

- **Surface Albedo Feedback:**
  - from AR5: $f_{SA} = 0.3\ W/m^2/^\circ C \rightarrow \mathbf{A = 1.11}$ *or* **+11%**

- **Convection Feedback:**
  - atmospheric temperature T_A responds less sensitively to CO_2 changes

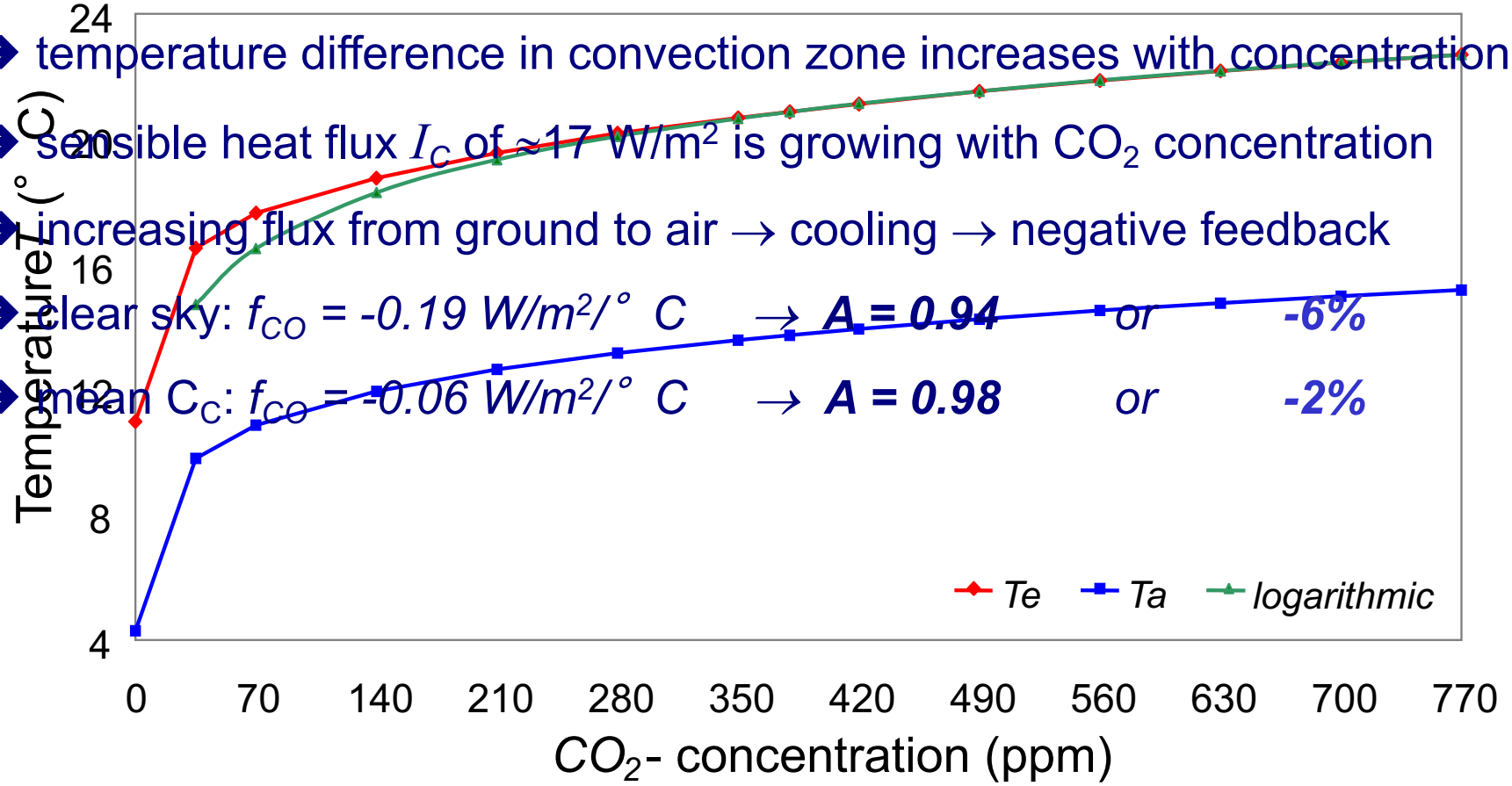
➔ temperature difference in convection zone increases with concentration

➔ sensible heat flux I_C of ≈17 W/m² is growing with CO_2 concentration

➔ increasing flux from ground to air → cooling → negative feedback

➔ clear sky: f_{CO} = *-0.19 W/m²/° C* → ***A = 0.94*** *or* ***-6%***

➔ mean C_C: f_{CO} = *-0.06 W/m²/° C* → ***A = 0.98*** *or* ***-2%***



- **Evaporation Feedback:**
  - evaporation of water and sublimation of ice contribute to cooling of surface
  - an increasing Earth-temperature forces these processes and results in negative feedback → evaporation feedback
  - latent heat:

$$I_L = l_H \cdot (T_E - T_0)$$

l_H = 5 W/m²/° C – heat transfer coefficient; T_0 – freezing point

  - clear sky: f_{EV} = -2.1 W/m²/° C → **A = 0.59** or **- 41%**
  - mean C_C: f_{EV} = -2.76 W/m²/° C → **A = 0.56** or **- 44%**

Feedback Effects

- **Cloud feedback**
  - Reduced cloudiness $\rightarrow$ increased temperature:
    What controls cloud cover?
  - Some observations: increasing *T* and *humidity* $\rightarrow$ increasing cloud cover C_C
    negative **Thermally Induced Cloud Feedback (TICF)**,
  - Other observations: just opposite
  - IPCC assumes: positive TICF initiated by CO_2
    specifies in AR5: feedback f_{CT} = ***0.3 W/m²/° C*** *(-0.2 – 2.0 W/m²/° C)*

- **Equilibrium Climate Sensitivity at Mean Cloud Cover:**

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	CMIP5	f [W/m²/° C]	A	2LCM	f [W/m²° C]	A
ECS_{NF}	1.16 – **1.06 ° C**			**1.09 ° C**		
+ water vapor	1.06 ° C	1.6	2.00	0.15 ° C	0.43	1.14
+ albedo	0.11 ° C	0.3	1.10	0.11 ° C	0.3	1.10
- lapse rate	0.16 ° C	- 0.6	0.85	0.16 ° C	- 0.6	0.85
- convection	-		-	0.02 ° C	- 0.06	0.98
- evaporation	-		-	0.48 ° C	- 2.76	0.56
+ therm. clouds	1.51 ° C	2.0	2.43	1.44 ° C	2.0	2.33
ECS	**15.5 ° C**	**3.0**	**14.6**	**1.22 ° C**	**0.37**	**1.12**

$$ECS = \frac{1}{1 - f \cdot \lambda_S} \lambda_S \cdot F_{2\times CO2} = \frac{1.06\,°C}{0.5} = 2.12\,°C$$

Solar Influence

- **Strong indication for other mechanisms contributing**
  - to cloud changes
  - to additional warming

- **Solar Cloud Changes:**

  The amount of clouds varies over the solar cycle:
  is an indication that solar activities also modulate the cloud cover

  - **Cosmic Rays** – Henrik Svensmark, Shaviv et al.:
    increasing TSI reduces the cosmic flux via solar magnetic field →
    reduces formation of water droplets in the lower atmosphere
  - **Hyper-sensitivity to UV-Rays** – Joanna Haigh:
    increased UV-radiation activates ozone production and heat transfer →
    acts back on cloud formation

- **Solar Cloud Changes**
  - Over last century: Modern Grand Solar Maximum with ΔTSI of $\approx$ *3 ‰* (e.g. Shapiro et al. 2011, Scafetta&Willson 2014)
  - From ERBS (Willson&Mordvinov, 2003): $\delta TSI \approx$ *1‰* over the 80s and 90s
  - When solar anomaly responsible for cloud changes:
    - contributes to direct solar heating with same feedbacks as *GH*-gases
    - additionally amplified by solar cloud changes

      $\Rightarrow$ **Solar Induced Cloud Feedback (*SICF*)**

      $\Rightarrow$ **Solar Sensitivity S_S = *0.17° C* for *1‰ TSI variation***

Global Warming Over Last Century

- **Total Temperature Balance:**
  - **Solar warming over last century**:
    for solar anomaly $\Delta TSI = 2.6‰ \rightarrow \Delta T_{Sun} = \Delta TSI \times S_S = 0.44^\circ C \rightarrow 60\%$
  - **CO_2 warming over last century**:
    100 ppm CO_2 at *ECS* $= 0.70^\circ C \rightarrow \Delta T_{CO2} =$ **$0.30^\circ C \rightarrow 40\%$**
  - **Full agreement with observed temperature increase: $0.74^\circ C$**
  - **Full agreement with observed cloud cover changes**

CO_2 increase over Industrial Era man-made?

removal: > 100,000 yr

CO_2 increase from 280ppm (1850) → 393 ppm (av. 10yr)

AF ~ 2.1 %

air-sea gas exchange

human emission
~ 4.7 %

respiration + decomposition

CO_2

CO_2

photosynthesis

CO_2 increase over Industrial Era man-made?

~~absorption ~ influx → unphysical~~

~~$\Delta F \sim 2.1\ \%$~~

air-sea gas exchange

human emission
4.7 %

respiration +
decomposition

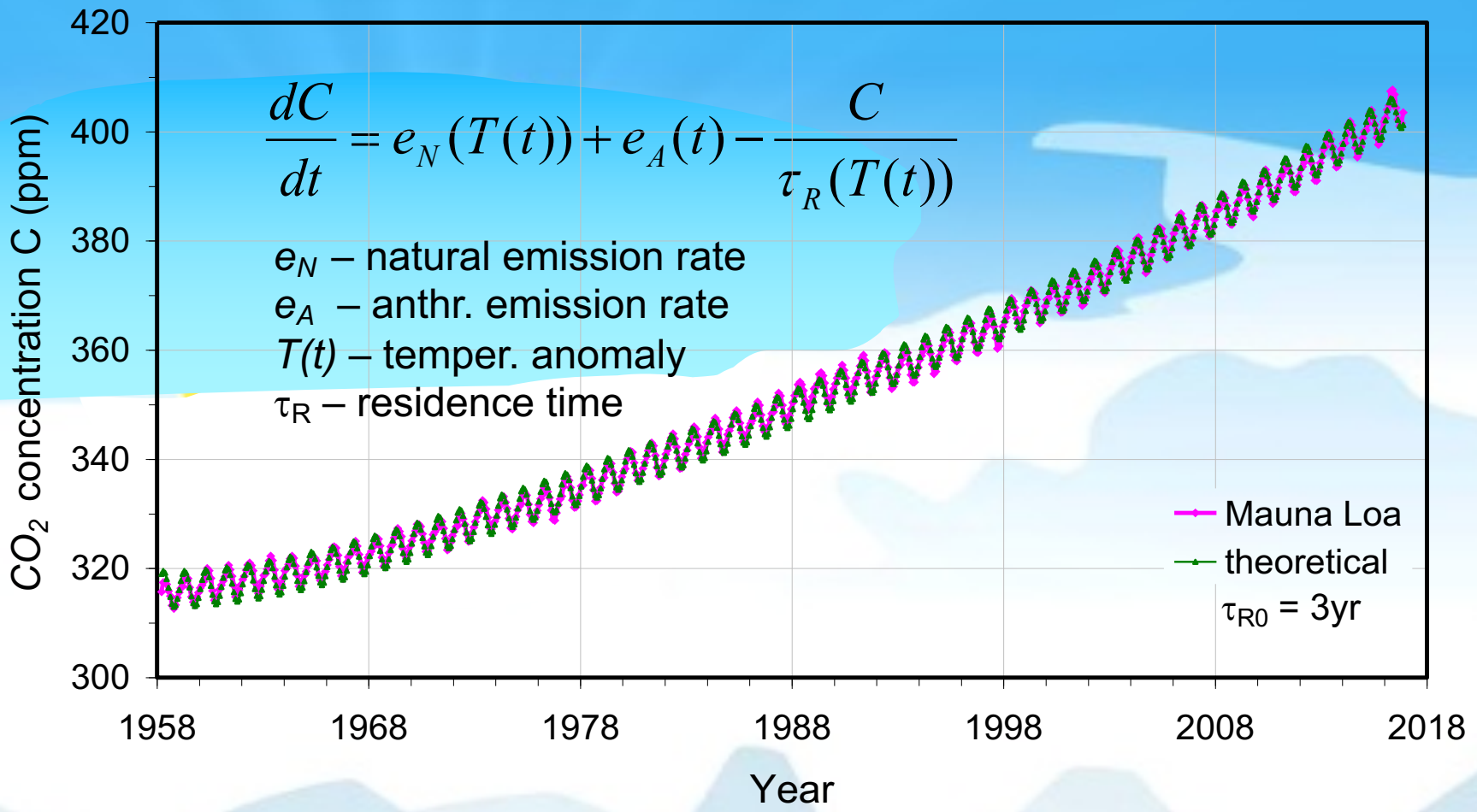
CO_2

CO_2

$$\text{absorption rate} = \frac{C_{CO2}}{\tau_R}$$

photosynthesis

CO_2 increase over Industrial Era man-made?



human emissions: 16 % of 113 ppm CO_2 increase

contribution to warming over last century:

16% of 0.3° C ⇒ 0.05° C

Summary

- Detailed *LBL*-radiation transfer calculations for the absorptivities and back-radiation of the greenhouse gases H_2O, CO_2, CH_4 and O_3 in the atmosphere
- Two-layer climate model especially appropriate to calculate the influence of an increasing CO_2-concentration, and a varying solar activity on global warming
- We consider all relevant feedback processes: water vapor, lapse-rate, surface albedo, convection and evaporation
- Influence of clouds with thermally and solar induced feedback
- Equilibrium climate sensitivity ECS = *0.7 ° C* almost *5* times smaller than IPCC value
- Dominant warming over last century caused by the Sun with *0.44 ° C (60%)*
- CO_2 only contributes to *0.3 ° C (40%)*
- With 16% human CO_2 emissions $\rightarrow$ anthropogenic contribution to warming is *0.05 ° C*