Lecture 3
13 January 2025

CM 615

Climate change Impacts & Adaptation

Climate system, Energy balance, Simple Radiative Models, MODTRAN, Global circulation system, Energy transport

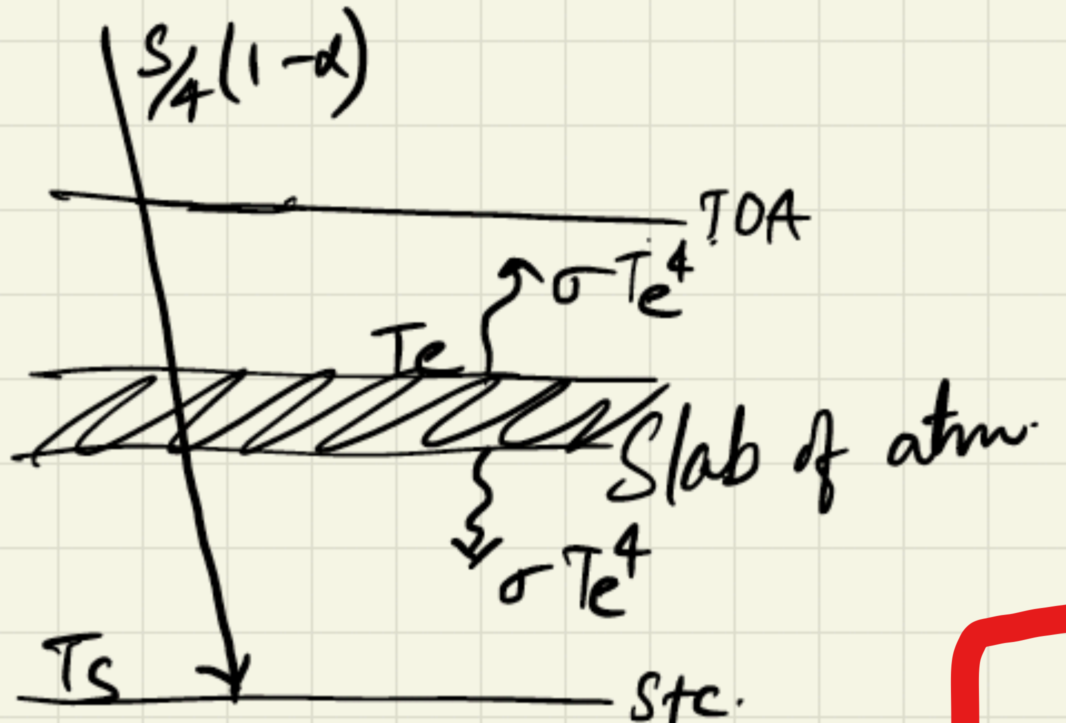
Angshuman Modak
Climate Studies, IIT Bombay

The perfectly absorbing slab atmosphere

1- layer atmosphere

$$N = \frac{S}{4}(1-\alpha) - \sigma T_e^4$$

Earth is considered a black body.



$$\boxed{N_{TOA} = \frac{S}{4}(1-\alpha) - \sigma T_e^4}$$

$$N_{sfc} = \frac{S}{4}(1-\alpha) + \sigma T_e^4 - \sigma T_s^4$$

$$\sigma T_s^4 = \frac{S}{4}(1-\alpha) + \sigma T_e^4$$

$$= \frac{S}{4}(1-\alpha) + \frac{S}{4}(1-\alpha)$$

$$\boxed{T_s = \left[\frac{1}{\sigma} \cdot \frac{S}{2}(1-\alpha)\right]^{1/4}}$$

$$\alpha = 0.3$$

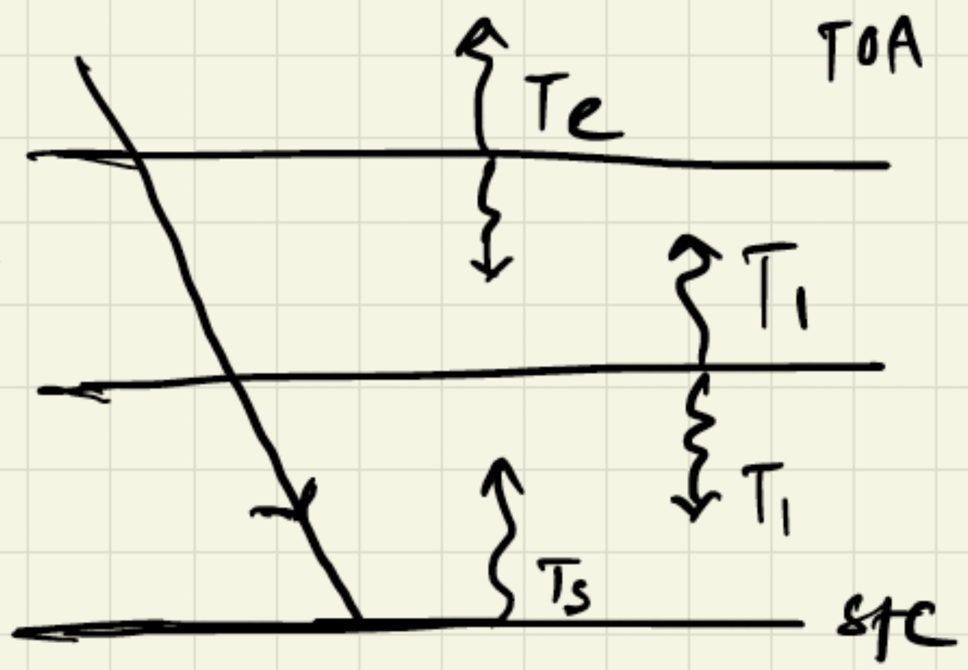
- A slab of perfect greenhouse gas
- Atmosphere is perfectly transmissive to sunlight but a blackbody absorber in the infrared
- $\boxed{T_s = \left(\frac{S(1-\alpha)}{2\sigma}\right)^{\frac{1}{4}}}$

The perfectly absorbing slab atmosphere

2-layer atmosphere

$$N_{TOA} = \frac{S}{4}(1-\alpha) - \sigma T_e^4$$

$$N_{sfc} = \frac{S}{4}(1-\alpha) + \sigma T_1^4 - \sigma T_s^4$$



$$\sigma T_s^4 = \frac{S}{4}(1-\alpha) + \sigma T_1^4 \quad — 1$$

$$= \frac{S}{4}(1-\alpha) + \sigma T_1^4$$

$$2\sigma T_1^4 = \sigma T_e^4 + \sigma T_s^4 \quad — 2$$

$$\Rightarrow \sigma T_1^4 = \frac{1}{2}(\sigma T_e^4 + \sigma T_s^4)$$

$$2\sigma T_s^4 = \frac{S}{2}(1-\alpha) + \sigma T_e^4 + \sigma T_s^4$$

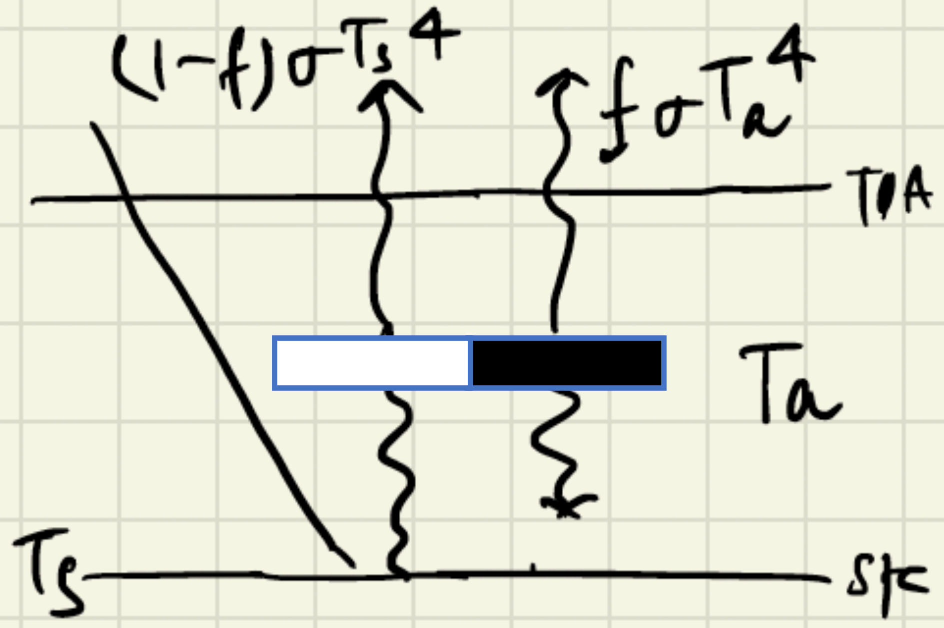
$$\Rightarrow \sigma T_s^4 = \frac{S}{2}(1-\alpha) + \frac{S}{4}(1-\alpha) = \frac{3S}{4}(1-\alpha)$$

$$\Rightarrow T_s = \left[3\,\frac{S}{4\sigma}(1-\alpha)\right]^{1/4}$$

- 2-layers
- A slab of perfect greenhouse gas
- Atmosphere is perfectly transmissive to sunlight but a blackbody absorber in the infrared
- $T_s = \left(\frac{3S(1-\alpha)}{4\sigma}\right)^{\frac{1}{4}}$
- For n-layers what would be Ts ?

The partially absorbing slab atmosphere

$f \rightarrow$ fraction of energy
Atm. emits and absorbs



$$N_{TOA} = \frac{S}{4}(1-\alpha) - f\sigma T_a^4 - (1-f)\sigma T_s^4$$

$$N_{sfc} = \frac{S}{4}(1-\alpha) + f\sigma T_a^4 - \sigma T_s^4$$

$$\boxed{T_s^4 = \frac{S(1-\alpha)}{2\sigma(2-f)}} , \quad \boxed{T_a^4 = \frac{S(1-\alpha)}{4\sigma(2-f)}}$$

$T_s > T_a$ under all conditions.

if $f\uparrow$ $T_s\uparrow$, $T_a\uparrow$

if $f = 1$, $T_a \rightarrow T_e$

$f = 0$, $T_s \rightarrow T_e$

- Atmosphere is transparent to SW
- f - fraction of energy that is absorbed
- How Ts and Ta are related?
- For Ts = 288K, $\alpha = 0.3$
- what is the value of f ?

Radiative convective equilibrium (RCE)

Nobel Prize in Physics 2021

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2021

"for groundbreaking contributions to our understanding of complex physical systems"

with one half jointly to

SYUKURO MANABE
Born 1931 in Shingu, Japan.
Ph.D. 1958 from University of Tokyo, Japan.
Senior Meteorologist at Princeton University, USA.

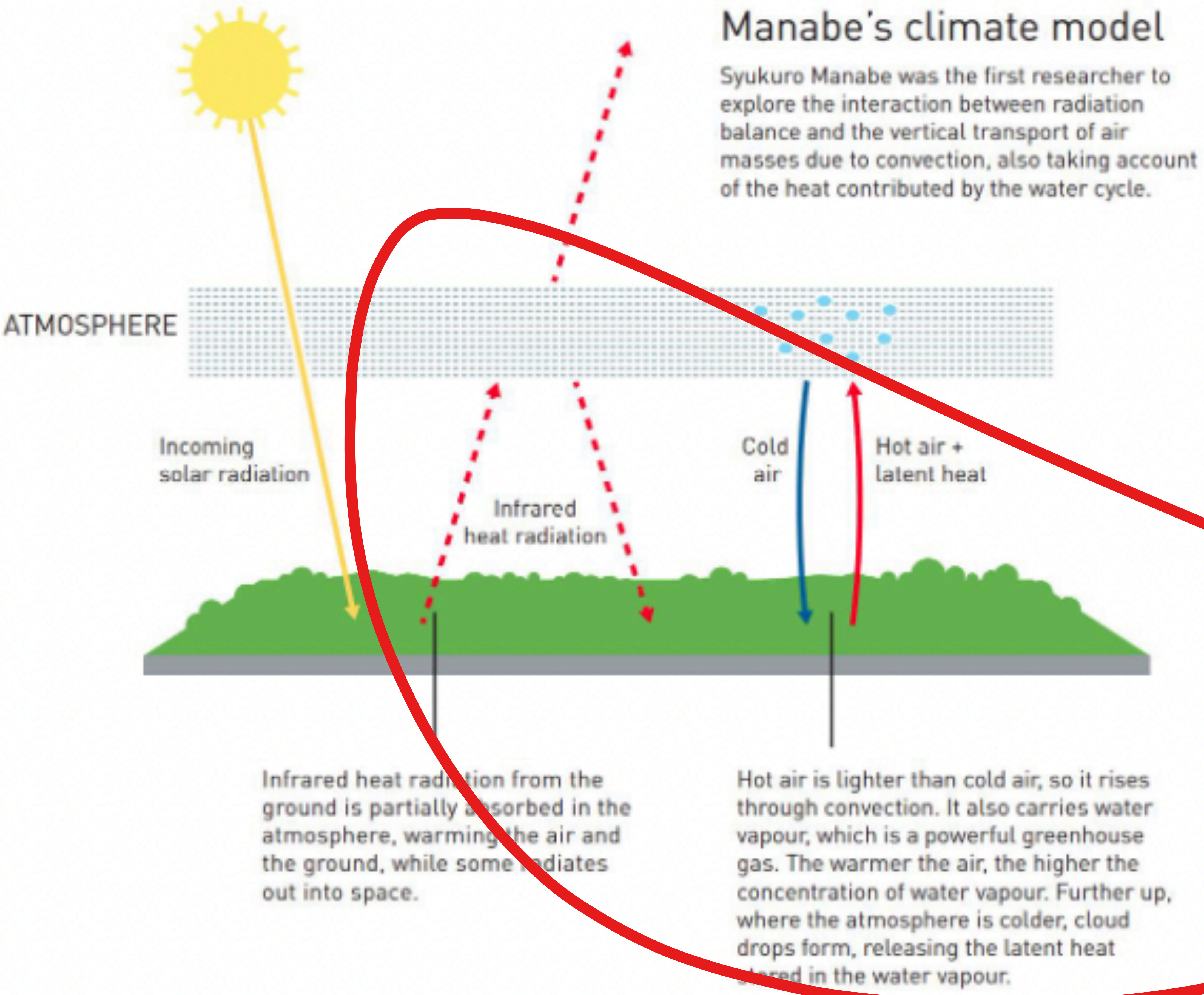
KLAUS HASSELMANN
Born 1931 in Hamburg, Germany.
Ph.D. 1957 from University of Göttingen, Germany. Professor, Max Planck Institute for Meteorology, Hamburg, Germany.

"for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

and the other half to

GIORGIO PARISI
Born 1948 in Rome. Italy. Ph.D. 1970 from Sapienza University of Rome, Italy. Professor at Sapienza University of Rome, Italy.

"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales"



In the 1950s, Japanese atmospheric physicist **Syukuro Manabe** was one of the young and talented researchers in Tokyo who left Japan, which had been devastated by war, and continued their careers in the US. The aim of Manabes's research, like that of Arrhenius around seventy years earlier, was to understand how increased levels of carbon dioxide can cause increased temperatures. However, while Arrhenius had focused on radiation balance, in the 1960s Manabe led work on the development of physical models to incorporate the vertical transport of air masses due to convection, as well as the latent heat of water vapour.

To make these calculations manageable, he chose to reduce the model to one dimension – a vertical column, 40 kilometres up into the atmosphere. Even so, it took hundreds of valuable computing hours to test the model by varying the levels of gases in the atmosphere. Oxygen and nitrogen had negligible effects on surface temperature, while carbon dioxide had a clear impact: when the level of carbon dioxide doubled, global temperature increased by over 2°C.

Source: https://www.nobelprize.org/prizes/physics/2021/popular-information/

IPCC AR6

Energy flows in the climate system