Activity

We will use a simple linear climate model to estimate how much the world will warm in response to a doubling of CO_2 assuming:

(i) No feedbacks (apart from "black body" response)

(ii) Positive water vapour feedback

$$\Delta R = \Delta Q + Y \Delta T_s$$

- ΔR: Net top of atmosphere radiation
- ΔQ: Radiative forcing
- Y: Climate feedback parameter

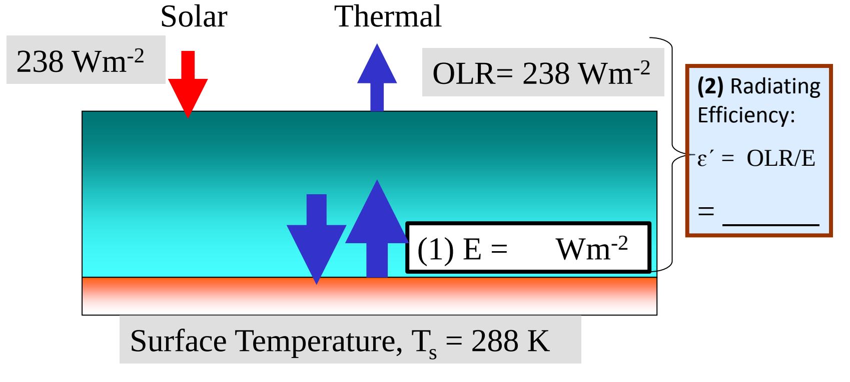
At equilibrium:

$$\Delta Q = -Y \Delta T_s$$

Solve for surface temperature

We will estimate the rise in global mean temperature on doubling CO_2 without feedbacks

1) Fill in the surface upward longwave emission, $E=\sigma T_s^4$
where $\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$ is the Stefan-Boltzmann constant
2) Calculate the radiating efficiency, $\varepsilon' = OLR/E$



Above: Present day global annual mean energy balance

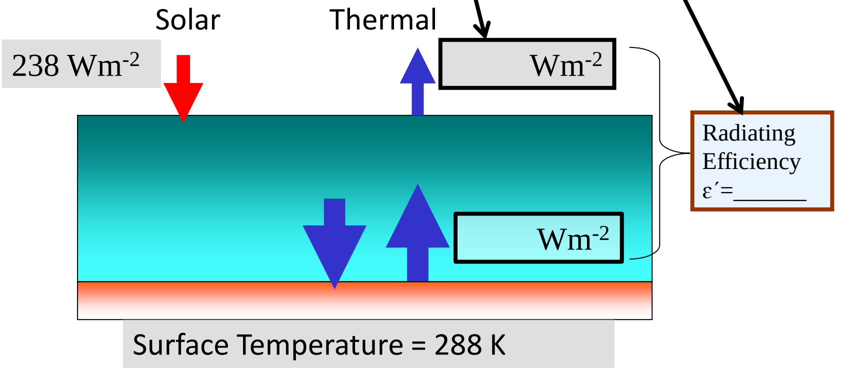
We now introduce a radiative forcing…

(3) calculate the radiative forcing of doubling CO_2 (ΔQ_{CO2}) using this formula:

$\Delta Q_{CO2} = 5.35\ln(CO_2/CO_{2}\_base)$

ΔQ_{CO2} = ______**Wm^{-2}**

(4) enter the new top of atmosphere thermal emission & radiating efficiency



How much will the surface temperature have to rise to restore radiative balance at the top of the atmosphere?

The rate of change of thermal emission to space with temperature, $\partial R/\partial T_S$ (the black-body/no feedback sensitivity, Y_{BB}) can be assumed to vary as: $\partial R/\partial T_S = -\partial OLR/\partial T_S$ where $OLR = \varepsilon'\sigma T_S^4$.

5) Differentiate the above to give a formula for $Y_{BB} = \partial R/\partial T_S = -\partial OLR/\partial T_S =$

6) Using the value of ε′ calculated in (4) and present day surface temperature (T_s=288 K), calculate Y_{BB} from the formula in (5).

7) Using the relationship, $\Delta Q = -Y_{BB}\Delta T_S$, estimate the surface temperature response to a doubling of CO_2 (ΔQ_{CO2})

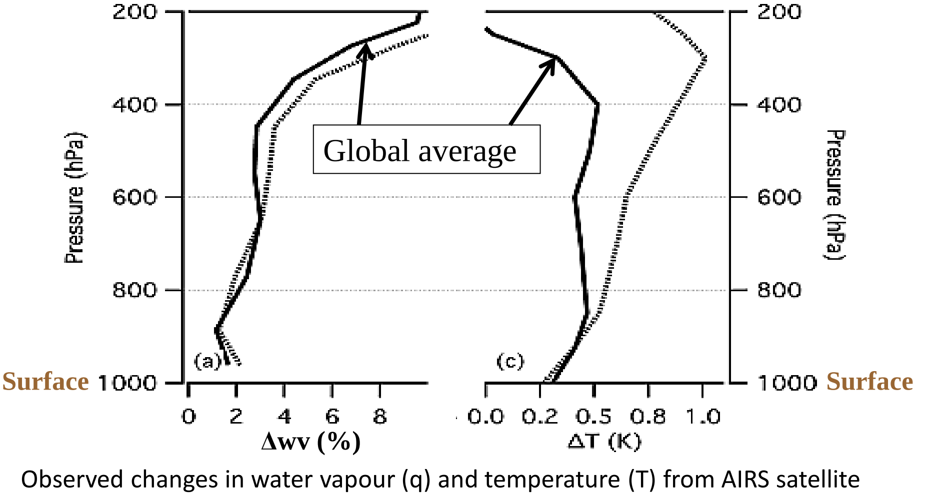
We will now estimate the temperature change when water vapour feedback is included

- To do this we will first estimate, from observations, what change in water vapour, wv (in %), is associated with a 1K change in surface temperature (T_s) change, dwv/dTs (% per K)
- Next we will estimate, from radiative transfer model results, what the sensitivity of the radiation budget is to a 10% increase in water vapour to calculate $\partial R/\partial wv$ (in Wm^{-2} per %)
- This information will be used to estimate the water vapour feedback climate sensitivity, $Y_{WV} = (\partial R/\partial wv)(dwv/dTs)$.
- Finally, the equilibrium surface temperature response will be estimated from: $\Delta Q_{CO2} = -Y\Delta T_S$, $Y = Y_{BB} + Y_{WV}$

We want to find out how the ΔT_S with water vapour feedback included compares with the ΔT_S calculated without…

(8) Using the graph below, estimate (roughly) the observed response of water vapour (wv) to surface temperature:

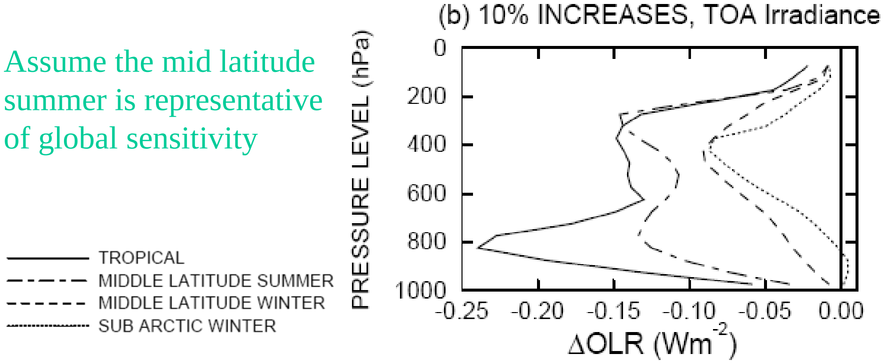
$\Delta wv/\Delta T_s \approx dwv/dT_s =$ [ ] (in %/K)



Observed changes in water vapour (q) and temperature (T) from AIRS satellite instrument (Dessler et al., 2008, Geophys. Res. Lett.)

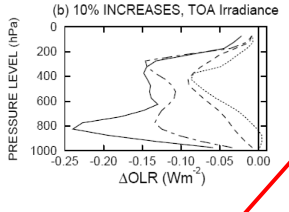
(9) Using the graph below, approximate (**roughly)** the sensitivity of R to a change in water vapour: $\partial R/\partial wv \approx$ ☐ (in Wm^{-2} per %)

Assume the mid latitude summer is representative of global sensitivity

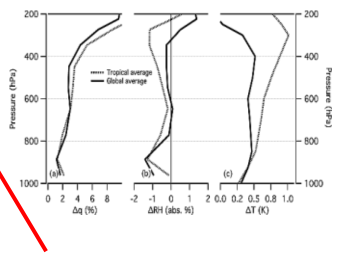


Calculated sensitivity of outgoing longwave radiation ($\Delta OLR \approx -\Delta R$) to a 10% increase in water vapour concentrations in <u>twenty</u> 50 mb thick vertical slabs (roughly sum up the total contribution to ΔOLR).

(10) Climate sensitivity including water vapour feedback



$$\frac{\partial R}{\partial wv}\frac{\partial wv}{\partial T_s}$$



~______ $Wm^{-2}\%^{-1}$ ~_____ $\%K^{-1}$

$Y_{WV} = (\partial R/\partial wv)(dwv/dTs) =$ ______ $Wm^{-2}K^{-1}$

$Y = Y_{WV} + Y_{BB} =$

$$\Delta Q = -Y\Delta T_S$$

ΔT_s = _____ **K**

How does the ΔT_S compare to the “no feedback” case?