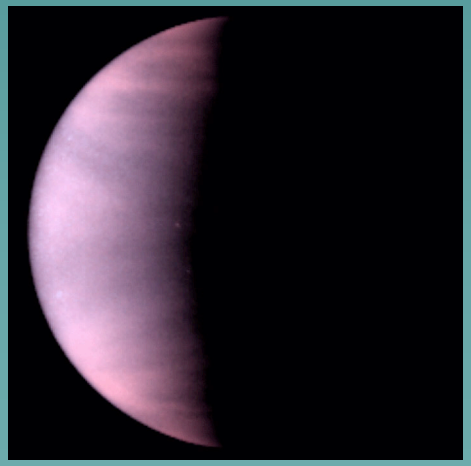
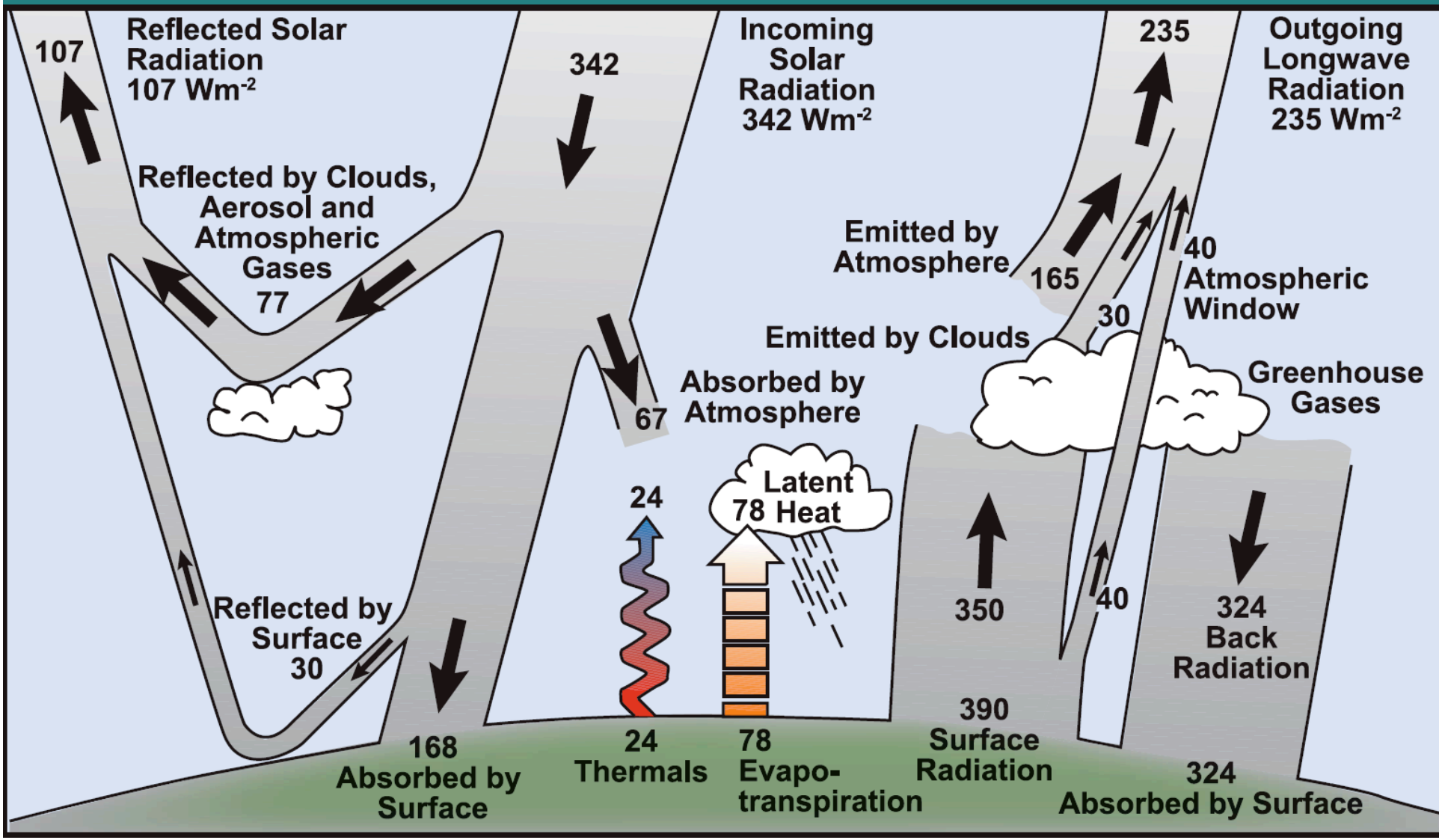
Climate Sensitivities of Venus and Earth

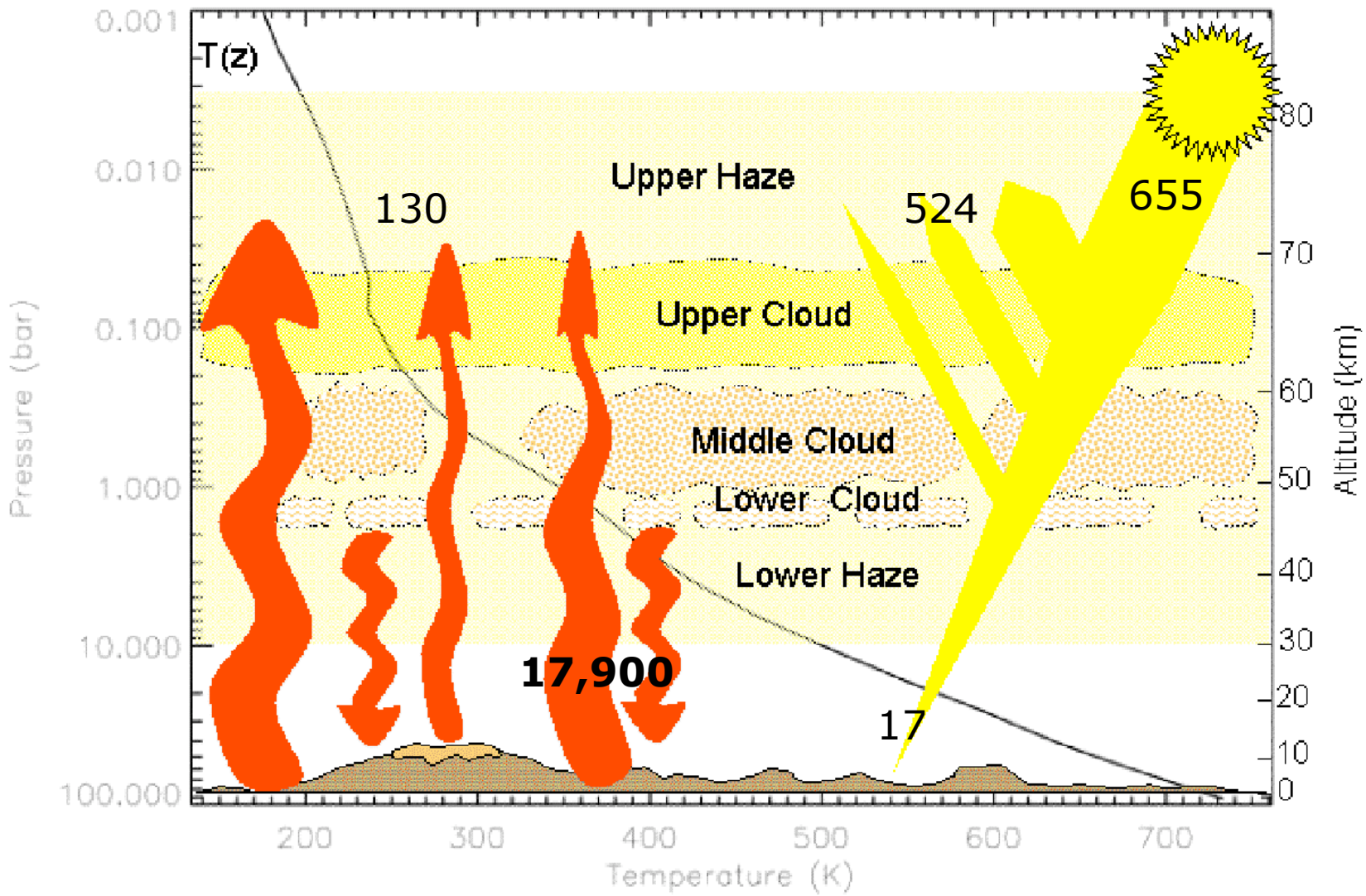
Mark Bullock
Southwest Research Institute



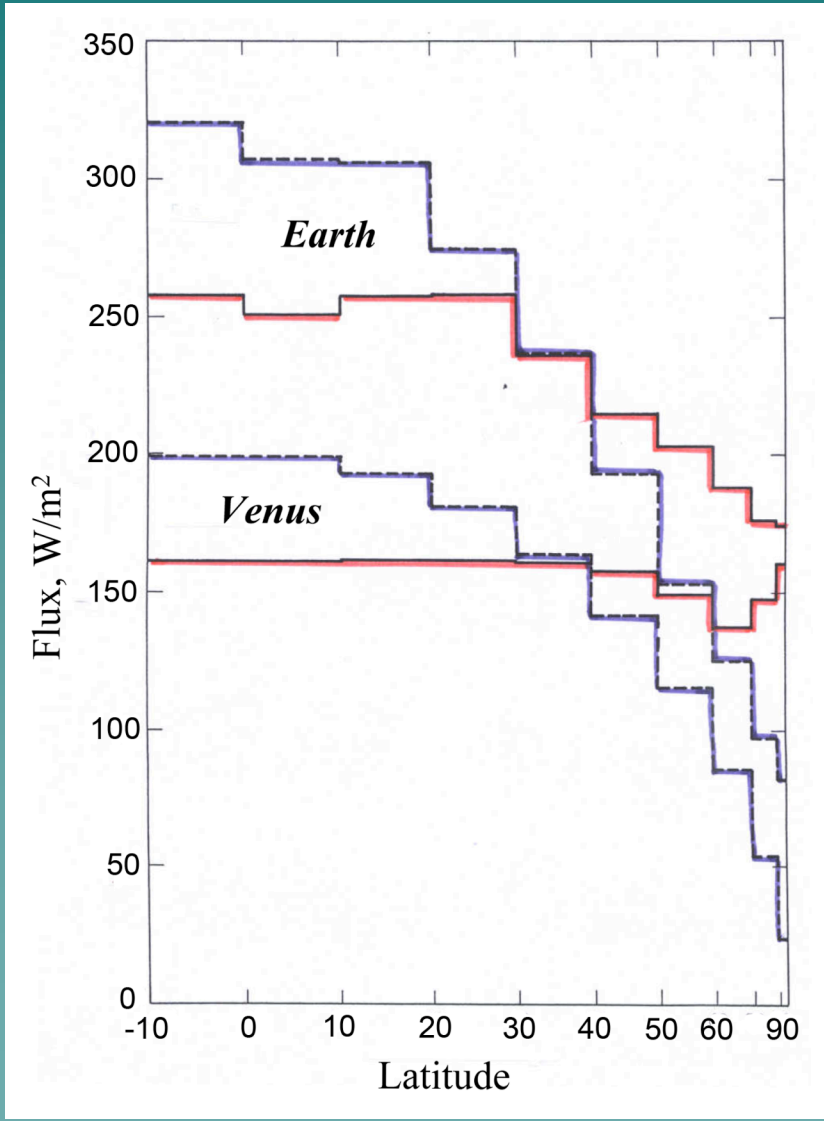
Earth Atmosphere Energy Balance



Venus Atmosphere Energy Balance

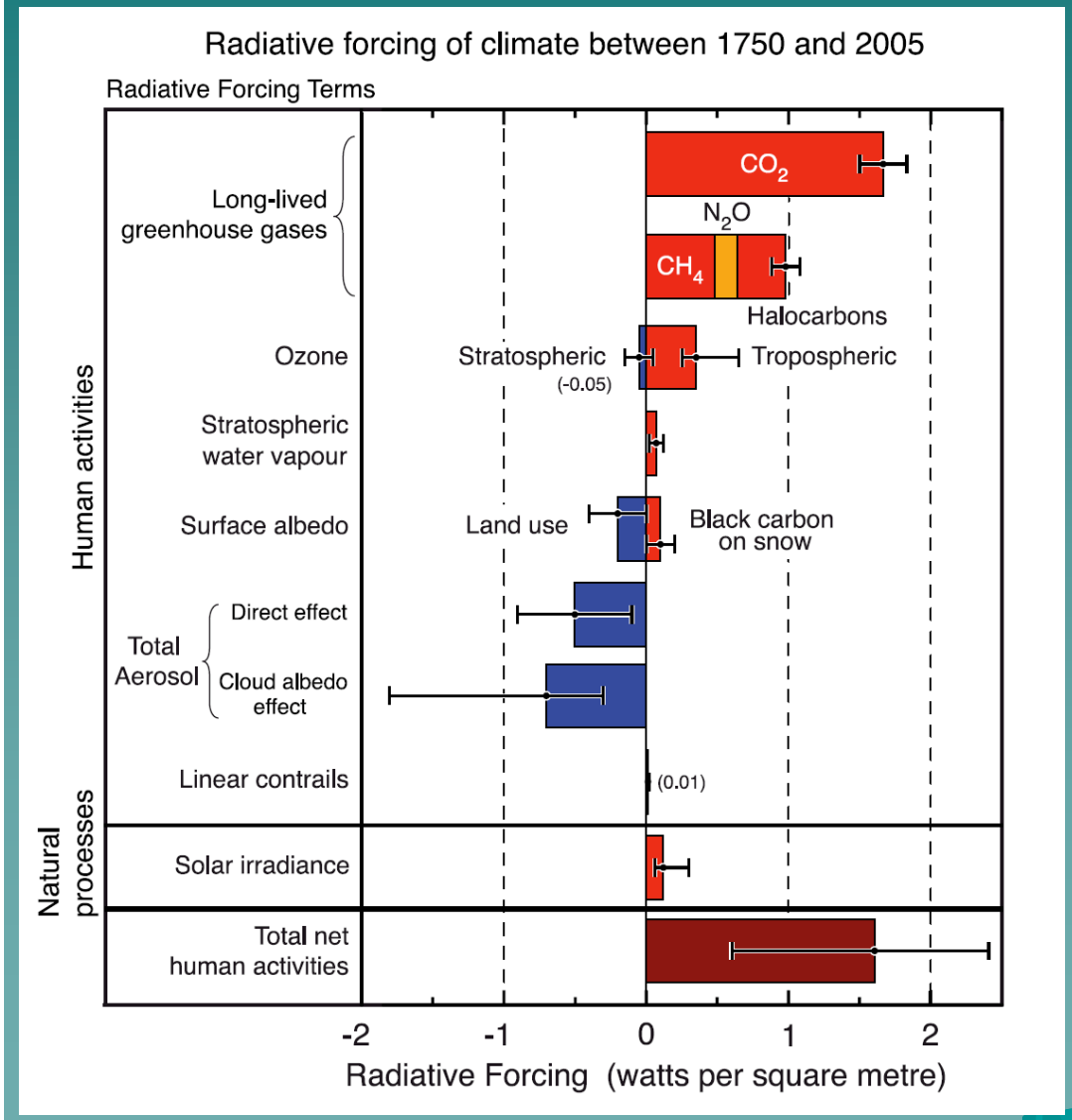


Energy Distribution



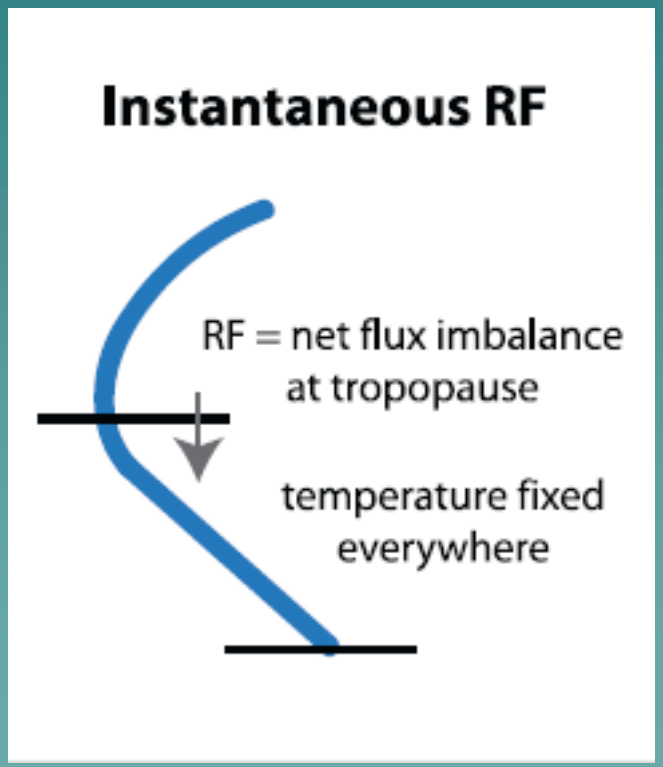
- Blue – Solar
- Red – Thermal
- Outgoing thermal energy almost constant with latitude

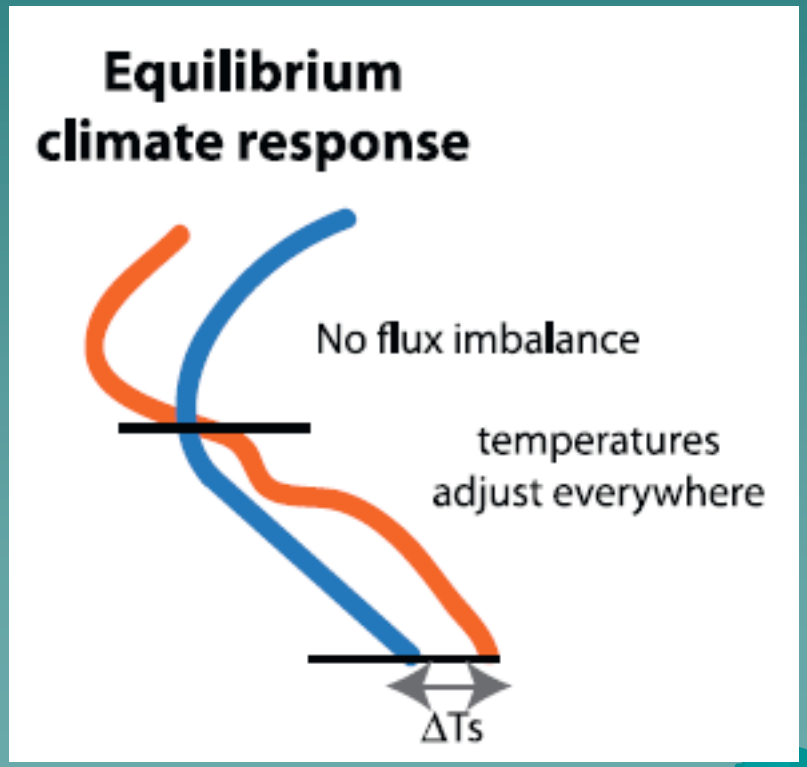
IPCC – Terrestrial Radiative Forcing



- 250 years of industrial activity
- Greenhouse gas forcing increased 3 W/m^2
- Aerosols 1.25 W/m^2

Radiative Forcing and Response





Climate Forcing and Response

$$F = F\left(\left[CO_2\right], T\right)$$

$$\Delta F = \frac{\partial F}{\partial\left[CO_2\right]}\Delta\left[CO_2\right] + \frac{\partial F}{\partial T}\Delta T$$

Forcing Term Response Term

Doubling CO_2 without Feedbacks

$$\Delta T = \frac{-\dfrac{\partial F}{\partial [CO_2]}}{\dfrac{\partial F}{\partial T}} \Delta [CO_2]$$

For Earth, doubling CO_2

$$\frac{\partial F}{\partial [CO_2]} \Delta [CO_2] = -4 \frac{W}{m^2}$$

Water Vapor Feedback

$$F = F\left(\left[CO_2\right],\left[H_2O\right]T\right)$$

$$\Delta F = \frac{\partial F}{\partial\left[CO_2\right]}\Delta\left[CO_2\right] + \frac{\partial F}{\partial T}\Delta T + \frac{\partial F}{\partial\left[H_2O\right]}\frac{\partial\left[H_2O\right]}{\partial T}\Delta T$$

Forcing Response Feedback

Include Albedo Feedback

$$\frac{S_o}{4}\left(\frac{d\alpha}{dT}\right)$$

-4 W/m²

Forcing

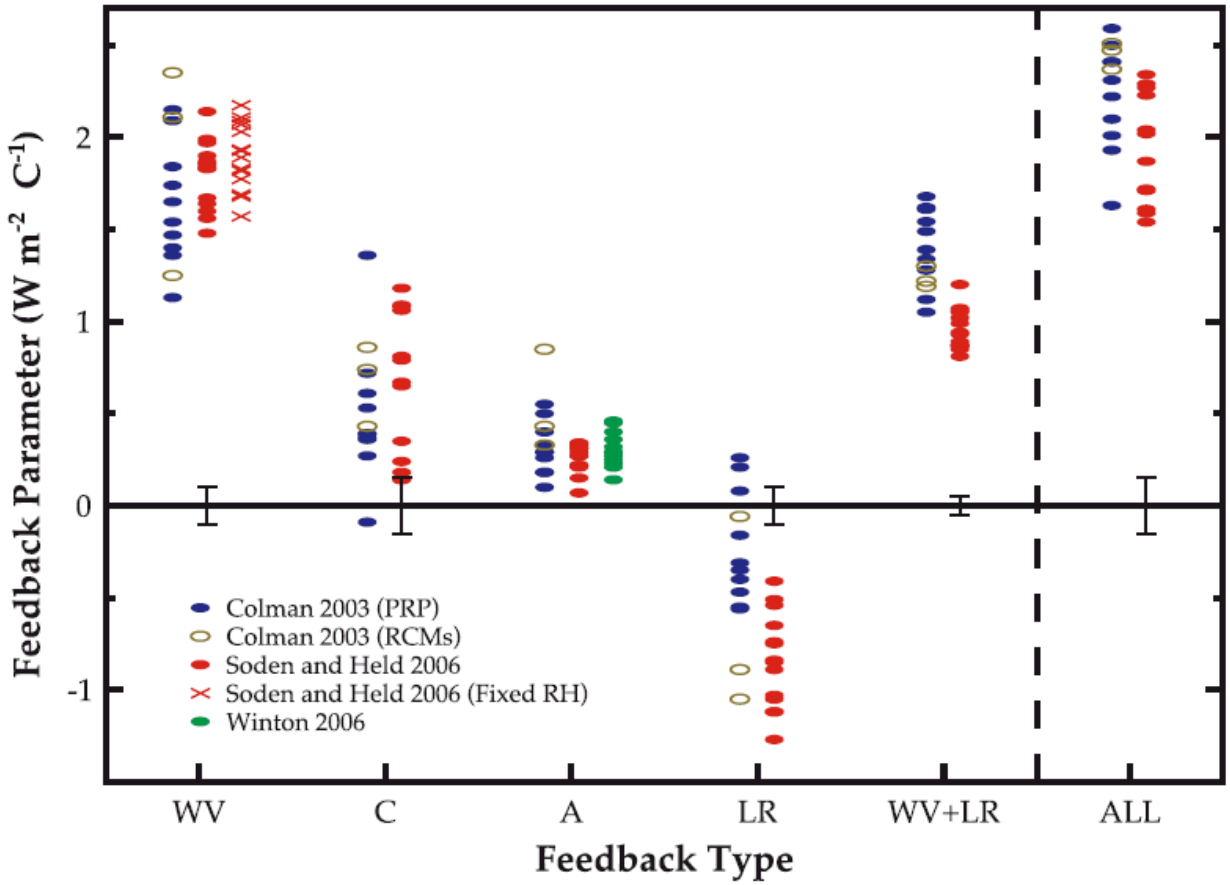
$$\Delta T = \frac{-\frac{\partial F}{\partial [CO_2]}\Delta[CO_2]}{\frac{\partial F}{\partial T} + \frac{\partial F}{\partial [H_2O]}\frac{\partial [H_2O]}{\partial T} + \frac{S_o}{4}\left(\frac{d\alpha}{dT}\right)} = \frac{\Delta Q}{\lambda}$$

Feedback

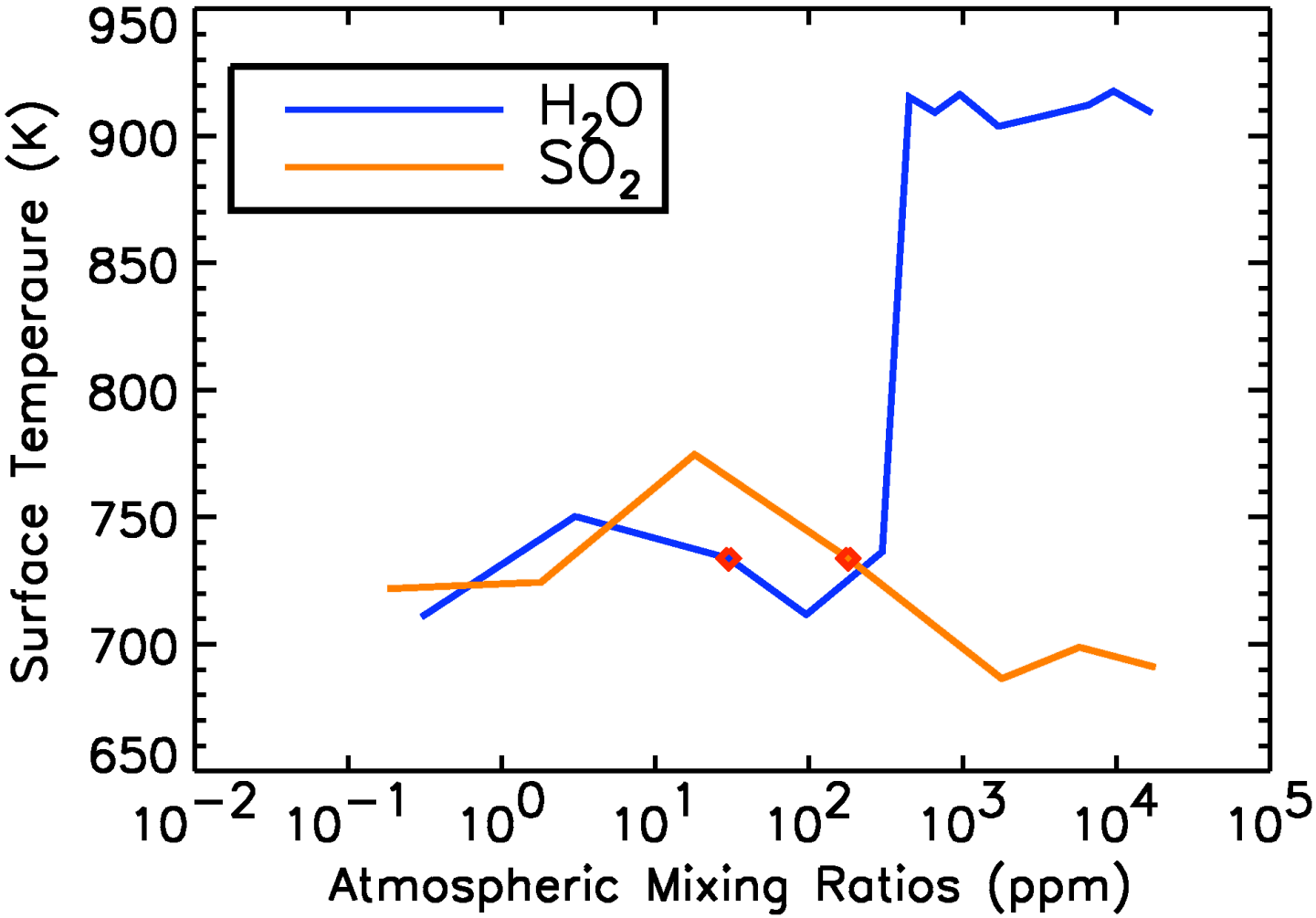
3.5 W/m² -1.6 W/m² -0.5 W/m²

Earth Atmosphere Sensitivity

$$\Delta T = \frac{\Delta Q}{\lambda} = \frac{4}{1.4} = 2.9^{o}C$$



Venus Model – Surface Temperatures



Venus Climate Sensitivity Doubling H_2O

-24.1 W/m²

$$\Delta T = \frac{-\frac{\partial F}{\partial [H_2O]}\Delta[H_2O]}{\frac{\partial F}{\partial T} + \frac{S_o}{4}\left(\frac{\partial \alpha}{\partial T}\right)_{H_2O}} = \frac{\Delta Q}{\lambda} = -2.9K$$

2.8 W/m² K -11.1 W/m² K

Venus Climate Sensitivity Doubling SO_2

-1.2 W/m²

$$\Delta T = \frac{-\frac{\partial F}{\partial [SO_2]}\Delta [SO_2]}{\frac{\partial F}{\partial T} + \frac{S_o}{4}\left(\frac{\partial \alpha}{\partial T}\right)_{SO_2}} = \frac{\Delta Q}{\lambda} = -8.0K$$

2.8 W/m² K -2.95 W/m² K

Summary
Climate Sensitivity to Doubling

	Earth CO_2	Venus H_2O	Venus SO_2
Forcing (W/m^2)	-4	-24.1	-1.2
Response (W/m^2-K)	3.5	2.8	2.8
Feedback (W/m^2-K)	-2.1	-11.1	-2.9
ΔT (K)	2.9	-2.9	-8.0