Potency of Greenhouse Molecules

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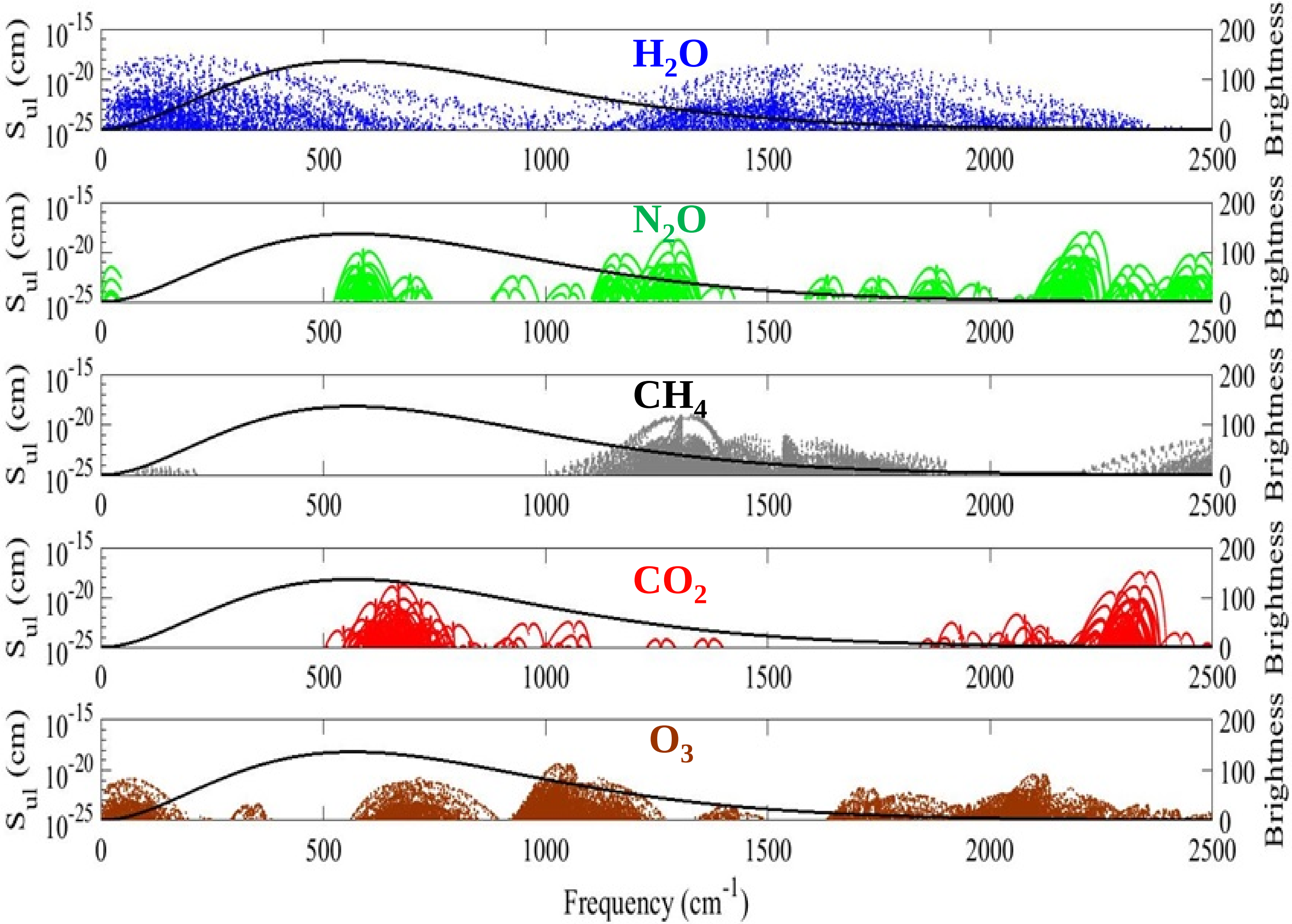
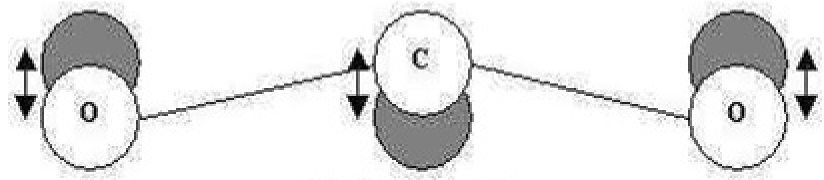
Greenhouse Gas Transitions

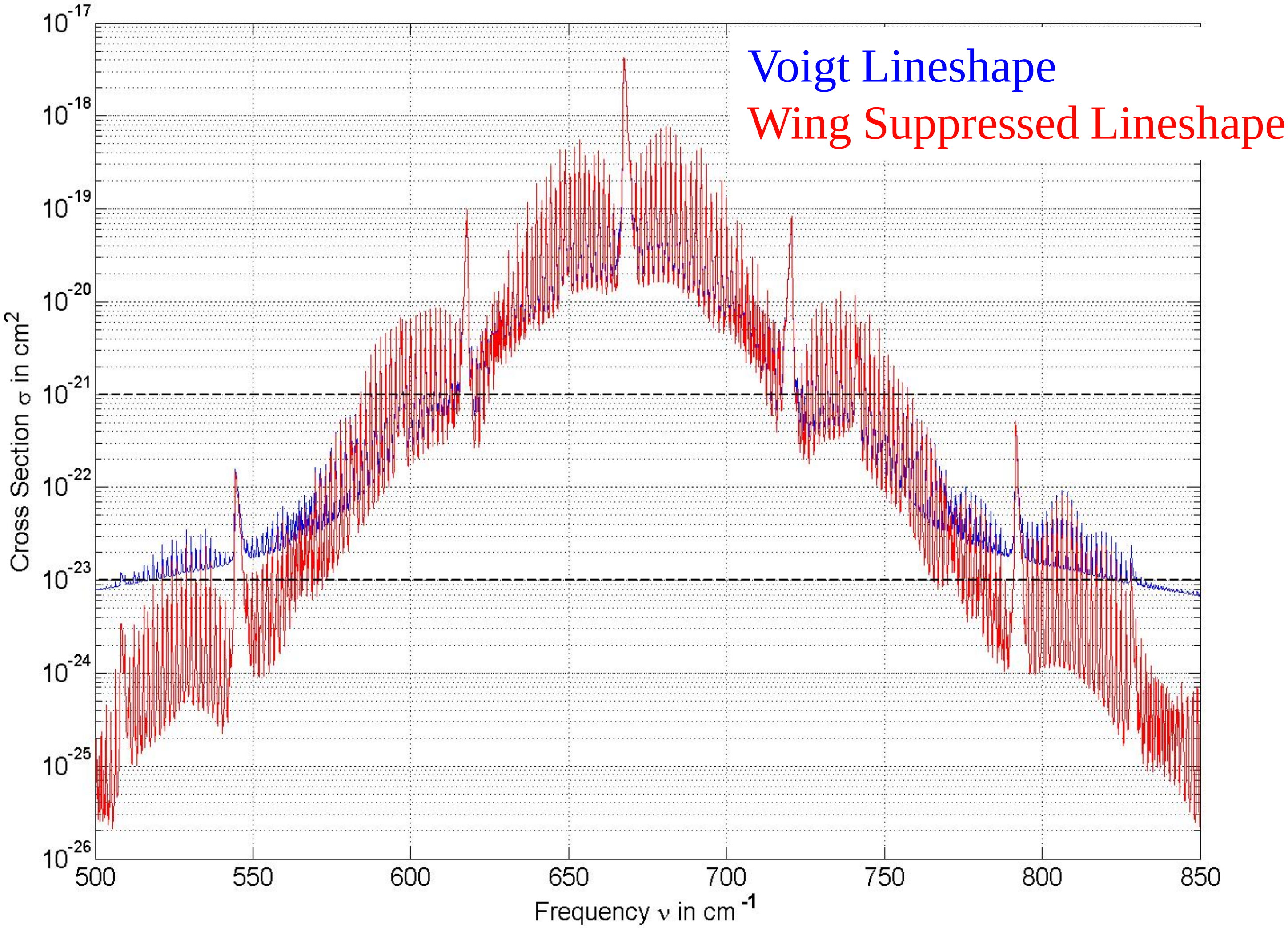
Line Strengths from Hitran Database



CO_2 Bending Mode
at T = 300 K & P = 1 atm.

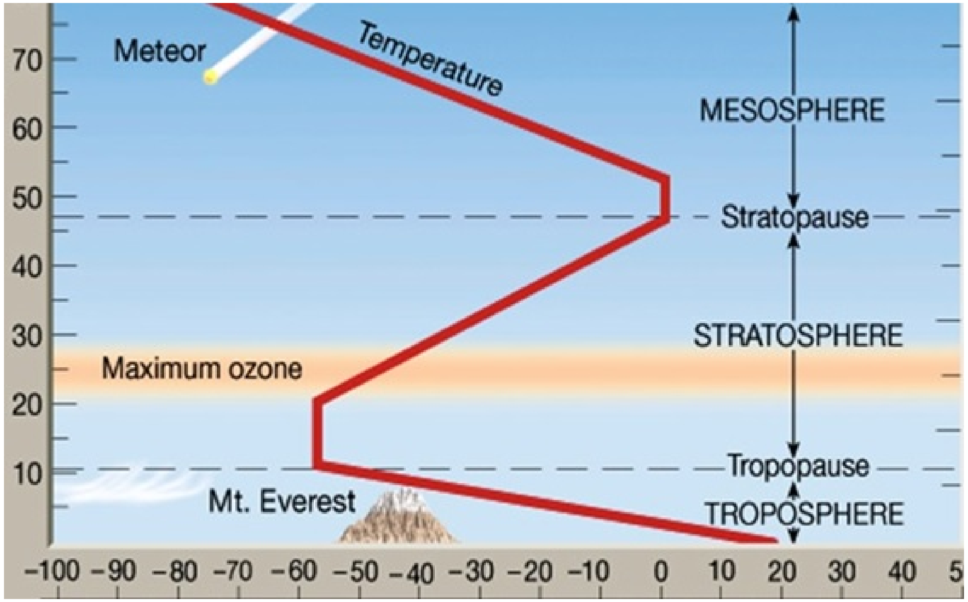


- Atmosphere opaque at line center → global warming driven by far wings of lineshape
- Far wings fall off faster than Voigt profile due to Dicke narrowing & collisions

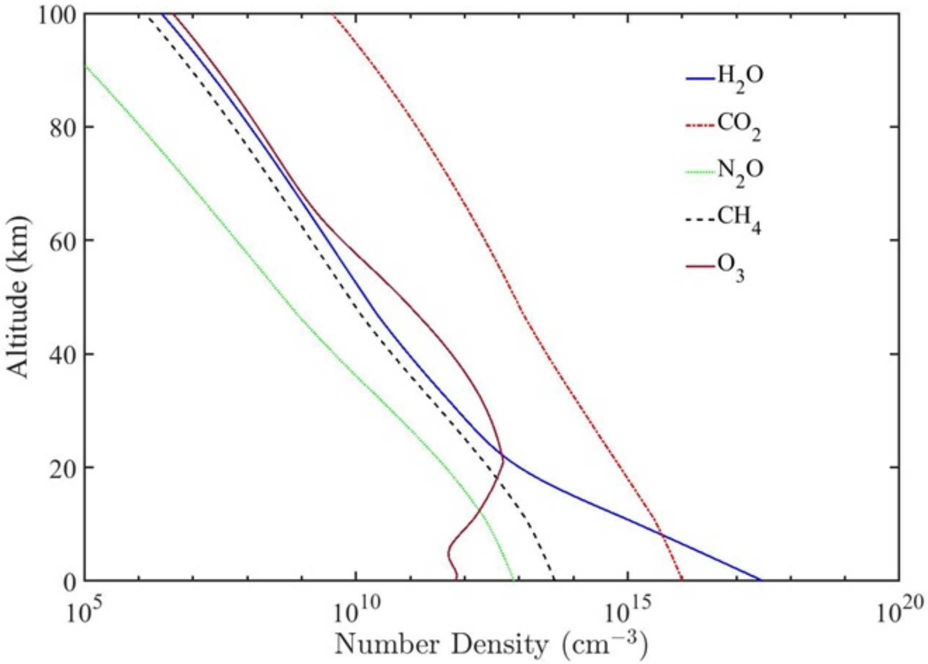


Altitudinal Dependence

Temperature



Number Density



Schwarzschild Equation

S. Chandrasekhar, *Radiative Transfer*, Dover, New York (1960)

Upward infrared heat intensity I(ν, z) at frequency ν & height z given by

$$\frac{\partial I(\nu, z)}{\partial z} = \kappa(B - I)$$

where attenuation $\kappa = \sum_i N_i(z) \quad \sigma_i(\nu, z)$

↑

CO_2, N_2O, CH_4, H_2O, O_3

Planck Brightness $B = \frac{2hc^2\nu^3}{e^{\nu/\nu_T} - 1} \qquad \nu_T = \frac{kT}{hc}$

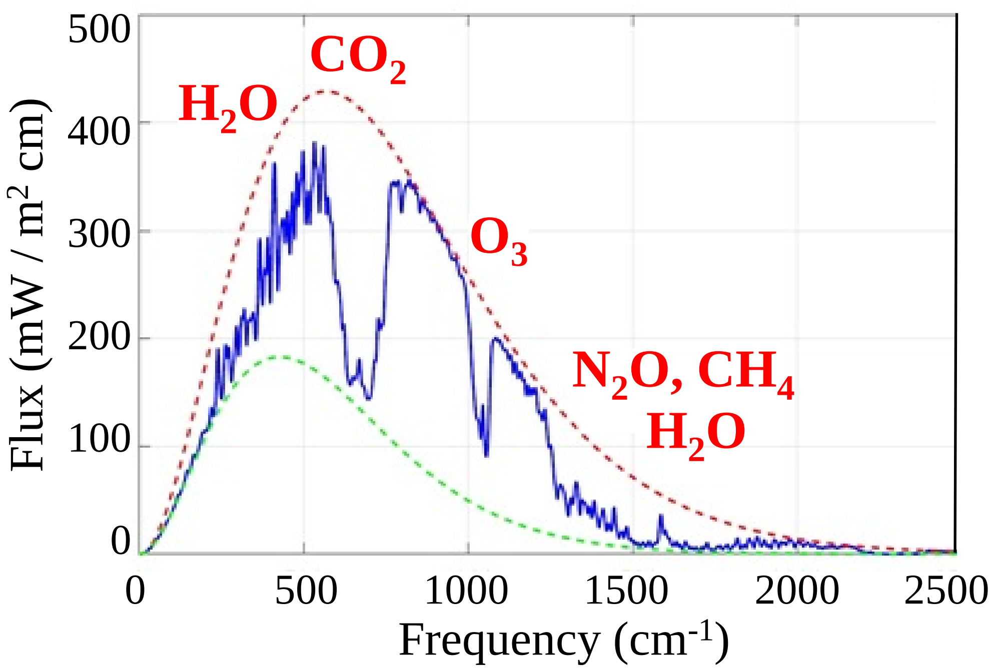
$\pi \int_0^\infty B d\nu = \sigma T^4$ Stefan Boltzmann Law

Comparison of Calculated Flux to Satellite Data

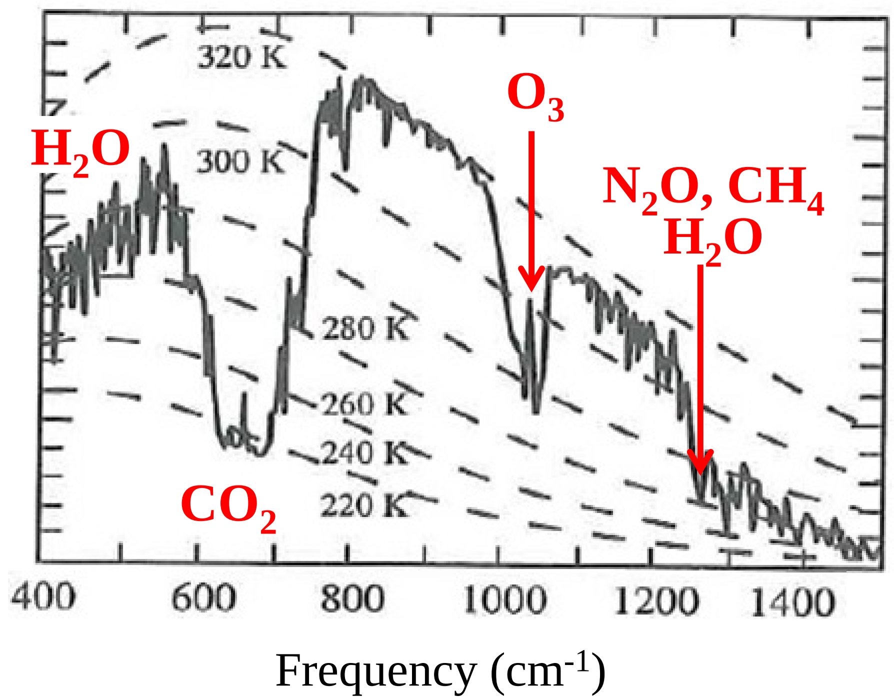
R. Hanel et al, *Geophys. Res*. **77**, 2629 (1972)

- Flux calculation for ambient levels of CO_2, CH_4, N_2O, O_3 & H_2O

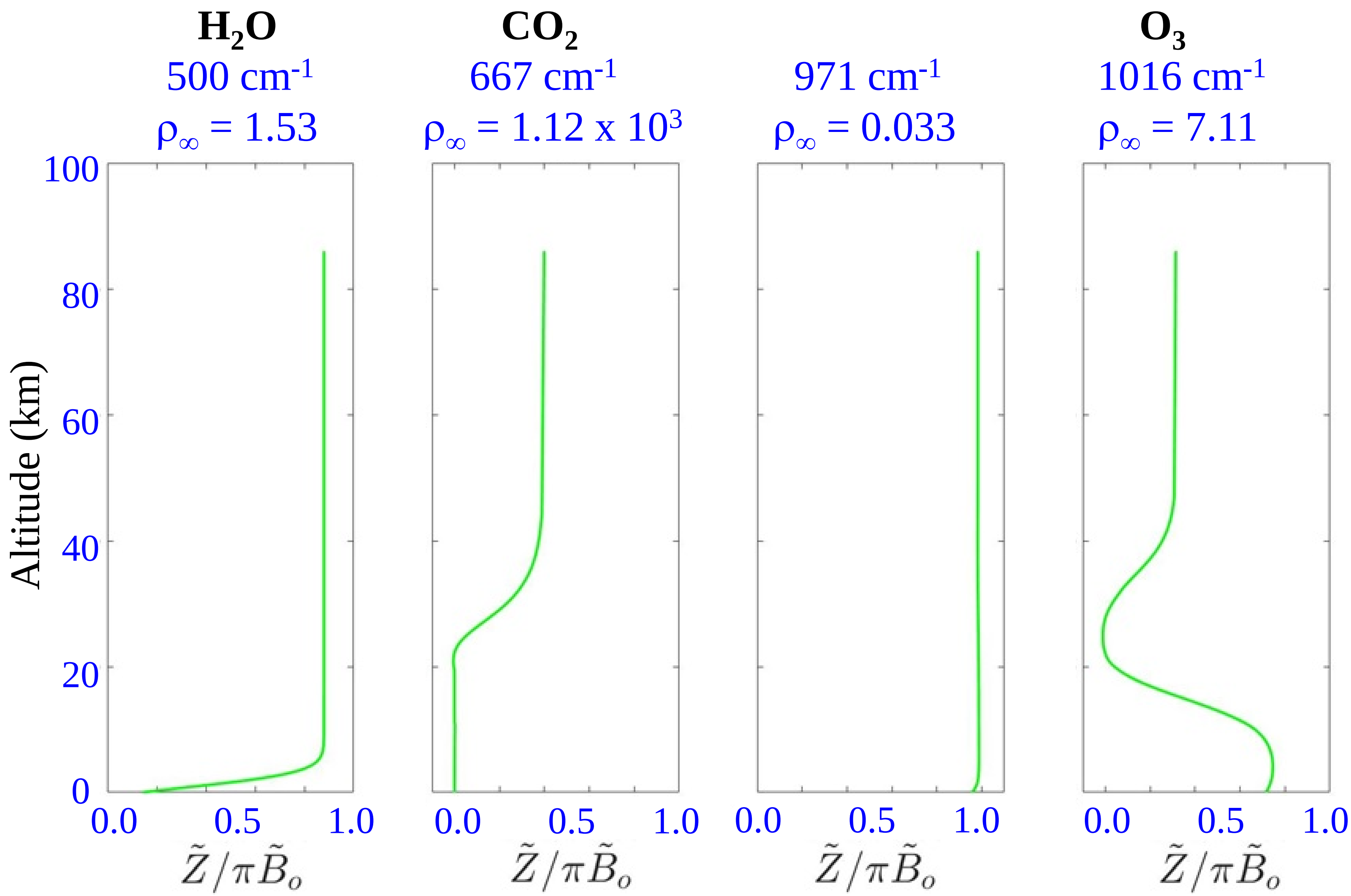
Calculation



Satellite Intensity Observations

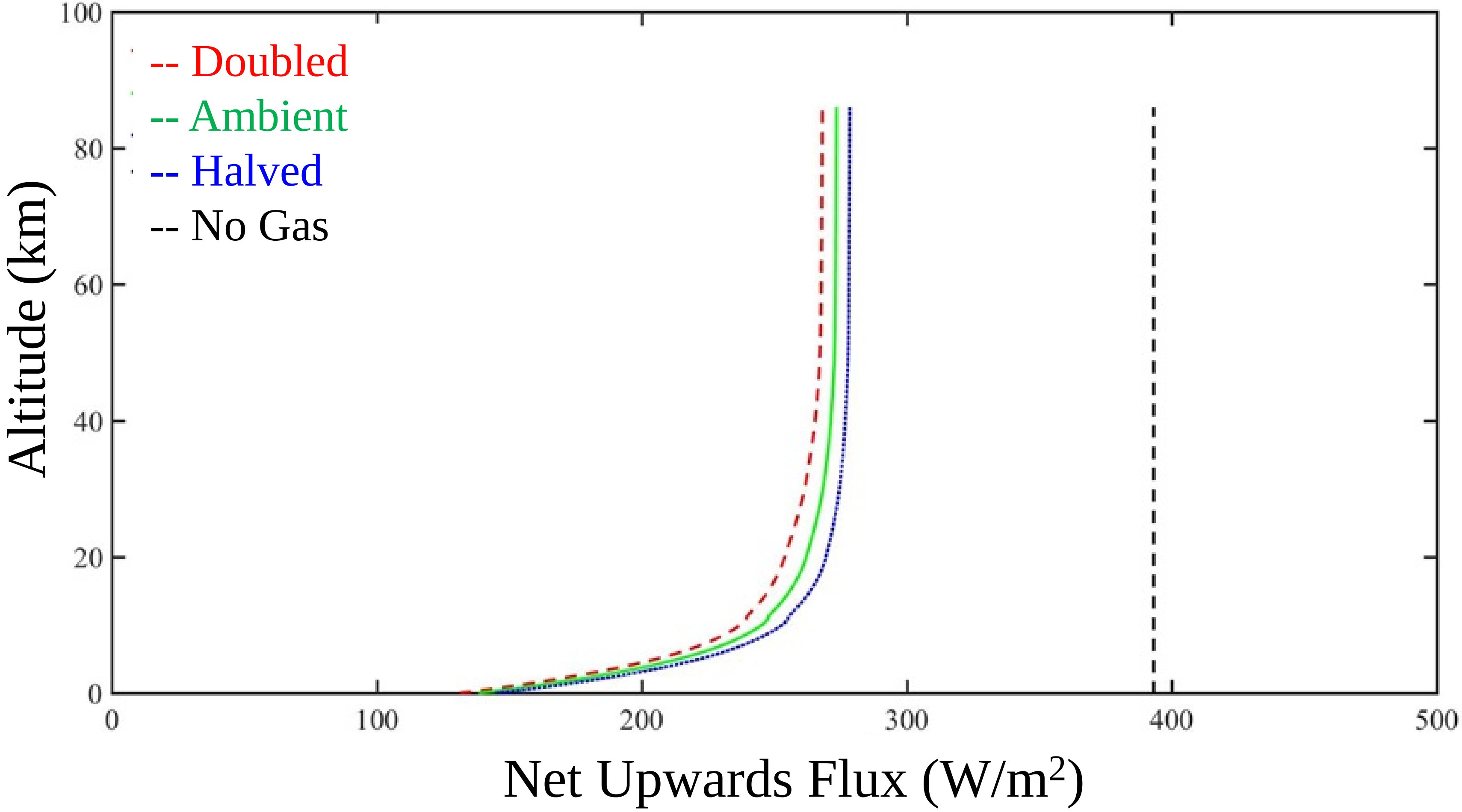


Upwards Flux at various Frequencies



Radiative Forcing

- Fluxes computed for surface at 288.7 K & standard atmosphere temperature profile
- Ambient Surface Levels: CO_2 (400 ppm), CH_4 (1.8 ppm), N_2O (0.32 ppm)
- Ambient Surface H_2O (12,400 ppm due to 70% relative humidity) varied ±6%
- O_3 (7.8 ppm at 35 km) kept constant



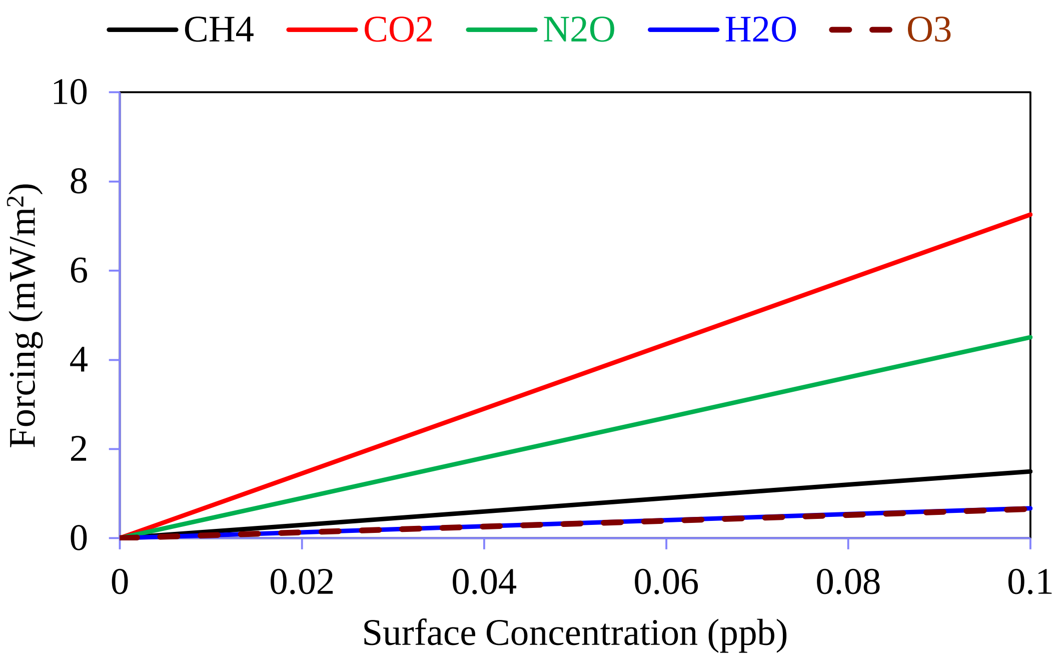
Temperature Change due to Forcing

Forcing: $\Delta J = J(\text{Ambient}) - J(\text{Doubled})$

Temperature Increase: $\dfrac{\Delta T}{T} = \dfrac{\Delta J}{4\,J}$

Gas	Concentration Change	Top of Atmosphere Forcing (W/m^2)
H_2O CO_2 CH_4 N_2O O_3	+6% at 70% relative humidity $400 \rightarrow 800$ ppm $1.8 \rightarrow 3.6$ ppm $0.32 \rightarrow 0.64$ ppm No Change	1.0 4.0 1.5 2.2
Total	All of above	5.3 $\Rightarrow \Delta T = +1.4\ ^{o}C$
Plus	Clouds, Aerosols	????

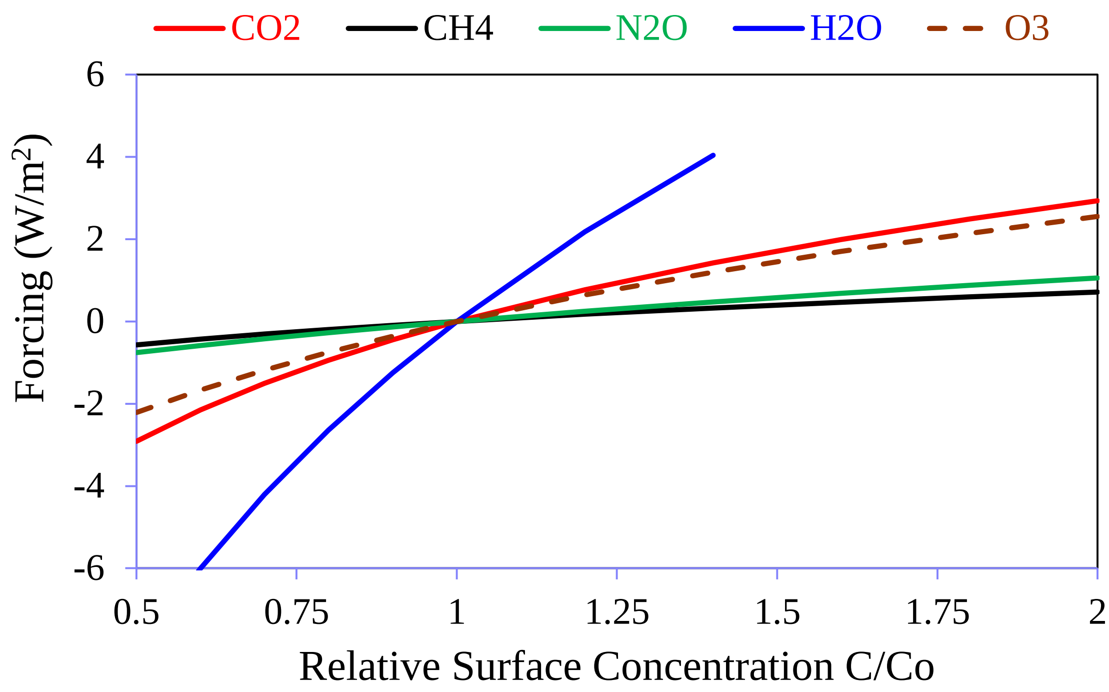
Greenhouse Gas Potency for Barren Earth



Gas	0.1 ppb Forcing (mW/m^2)	Column Density (10^{19} m^{-2})	Power/Molecule = Forcing/Col. Density (10^{-22} W)
CO_2	7.3	2.16	3.5
N_2O	4.5	2.07	2.2
CH_4	1.5	2.09	0.7
H_2O	0.7	0.50	1.4
O_3	0.7	0.12	5.7

Greenhouse Gas Potency for existing Atmosphere

Increase each greenhouse gas keeping other gas concentrations at ambient levels C_o.



Gas	0.1 ppb Forcing (mW/m^2)	Column Density (10^{19} m^{-2})	Power/Molecule = Forcing/Col. Density (10^{-22} W)
CO_2	1.1×10^{-3}	2.16	4.9×10^{-4}
N_2O	4.1×10^{-1}	2.07	2.0×10^{-1}
CH_4	5.1×10^{-2}	2.09	2.4×10^{-2}
H_2O	9.8×10^{-5}	0.50	2.0×10^{-4}
O_3	4.4×10^{-2}	0.12	3.8×10^{-1}

Greenhouse Gas Potency Summary

WvW & W. Happer, submitted for publication

Molecule	Optically Thin Limit		Ambient Atmosphere	
	Power per Molecule (10^{-22} W)	Power rel. CO_2	Power per Molecule (10^{-22} W)	Power rel. CO_2
CO_2	3.45	1	4.91×10^{-4}	1
N_2O	2.24	0.65	1.96×10^{-1}	400
CH_4	0.71	0.21	2.44×10^{-2}	50
H_2O	1.38	0.40	1.96×10^{-4}	0.40
O_3	5.67	1.64	3.77×10^{-1}	770

Conclusions

1. Radiative Forcing

Doubling CO_2, CH_4, N_2O & increasing H_2O gives 5.3 W/m^2 forcing $\Rightarrow$ ~1.5 ^oC temperature increase. Uncertainty primarily due to clouds.

2. Greenhouse Potency

- At very low concentrations, CO_2, CH_4, N_2O & H_2O have comparable forcings

- At ambient levels CH_4 & N_2O have greater per molecule forcing because CO_2 & H_2O more strongly saturated due to 100-10,000 higher concentration

More Info: **www.wvanwijngaarden.info.yorku.ca**