Why Has Global Warming Paused?

Physics Department Colloquium
Princeton University
October 10, 2013

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Princeton University

Will Happer, Climate Scientist, 1982

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THE LONG-TERM IMPACTS OF INCREASING ATMOSPHERIC CARBON DIOXIDE LEVELS

Edited by
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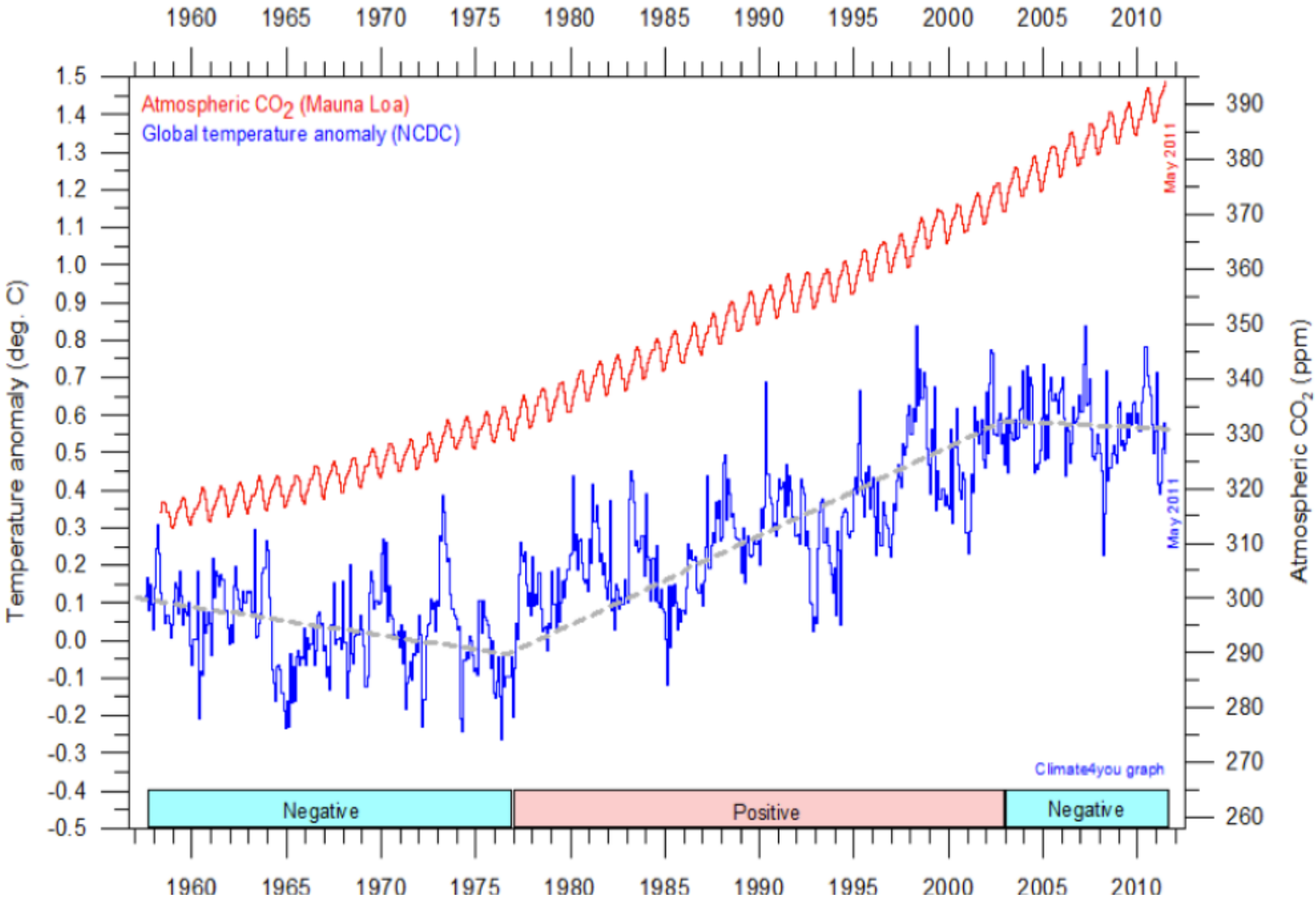
BALLINGER PUBLISHING COMPANY
Cambridge, Massachusetts
A Subsidiary of Harper & Row, Publishers, Inc.

What is all the fuss about?



Climate Models Don't Work; Red is Observed; Bars are Models

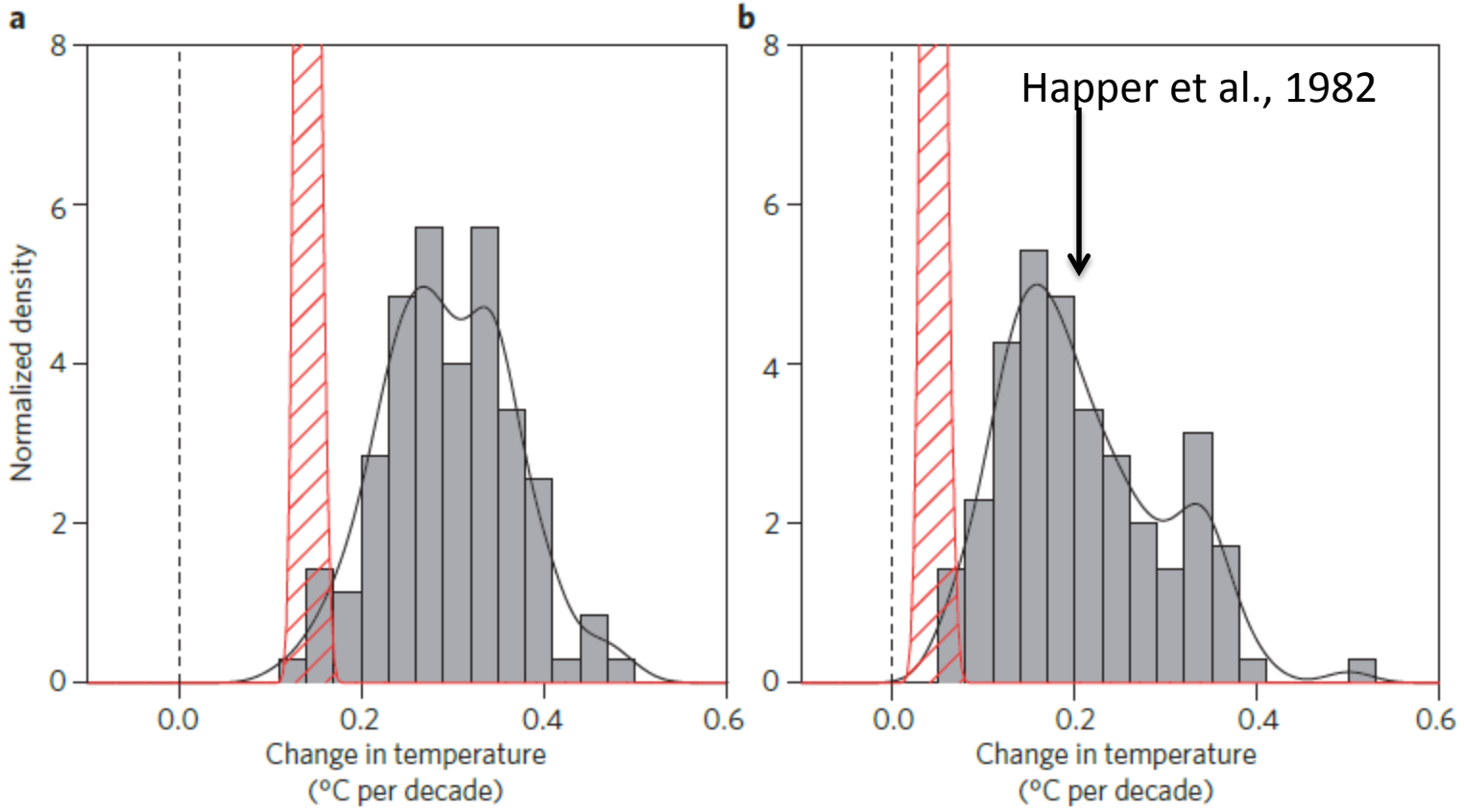


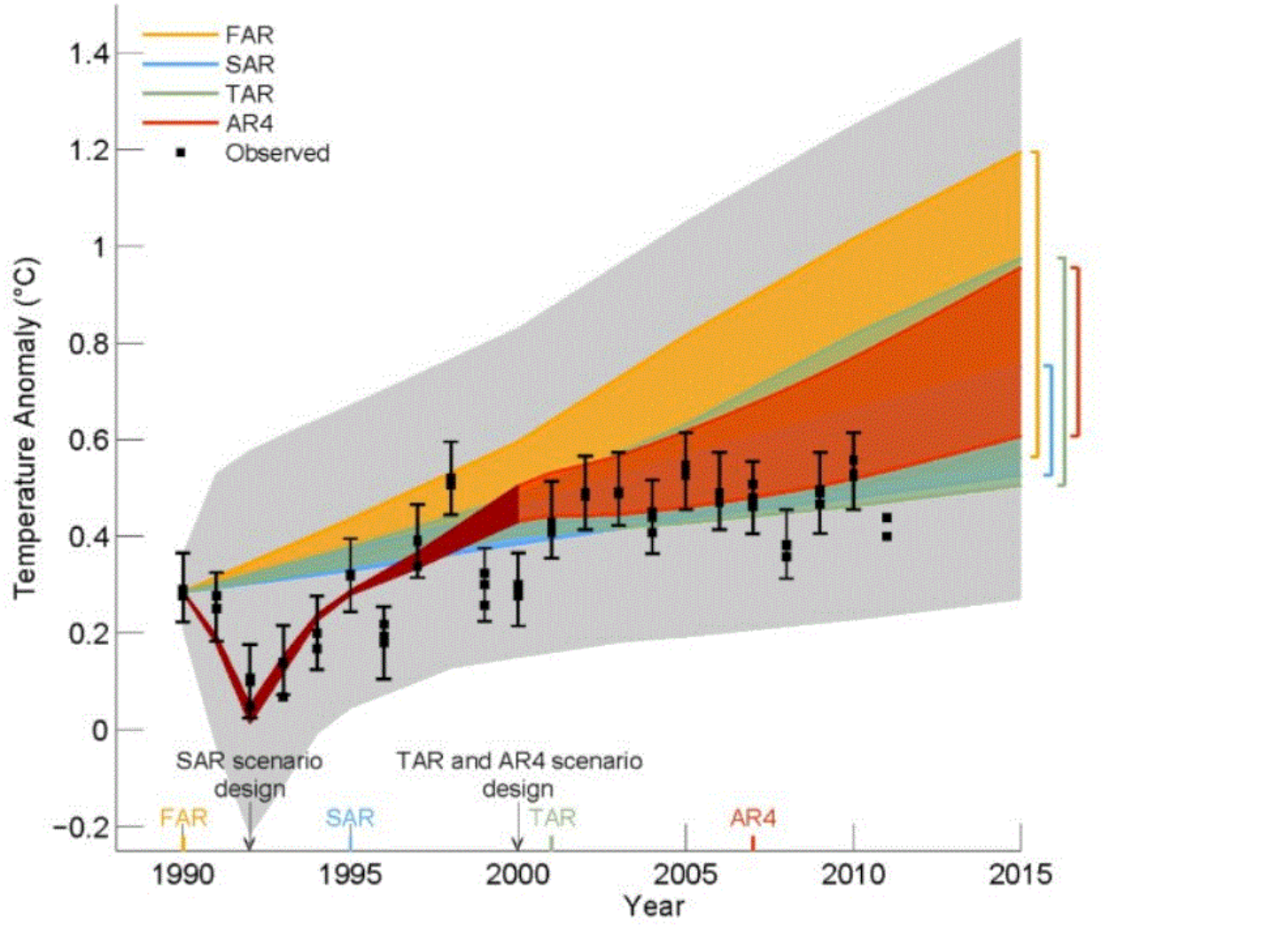
Figure 1 | Trends in global mean surface temperature. **a**, 1993–2012. **b**, 1998–2012. Histograms of observed trends (red hatching) are from 100 reconstructions of the HadCRUT4 dataset[1]. Histograms of model trends (grey bars) are based on 117 simulations of the models, and black curves are smoothed versions of the model trends. The ranges of observed trends reflect observational uncertainty, whereas the ranges of model trends reflect forcing uncertainty, as well as differences in individual model responses to external forcings and uncertainty arising from internal climate variability.

Nature Climate Change, Vol 3, p. 767, September 2013.

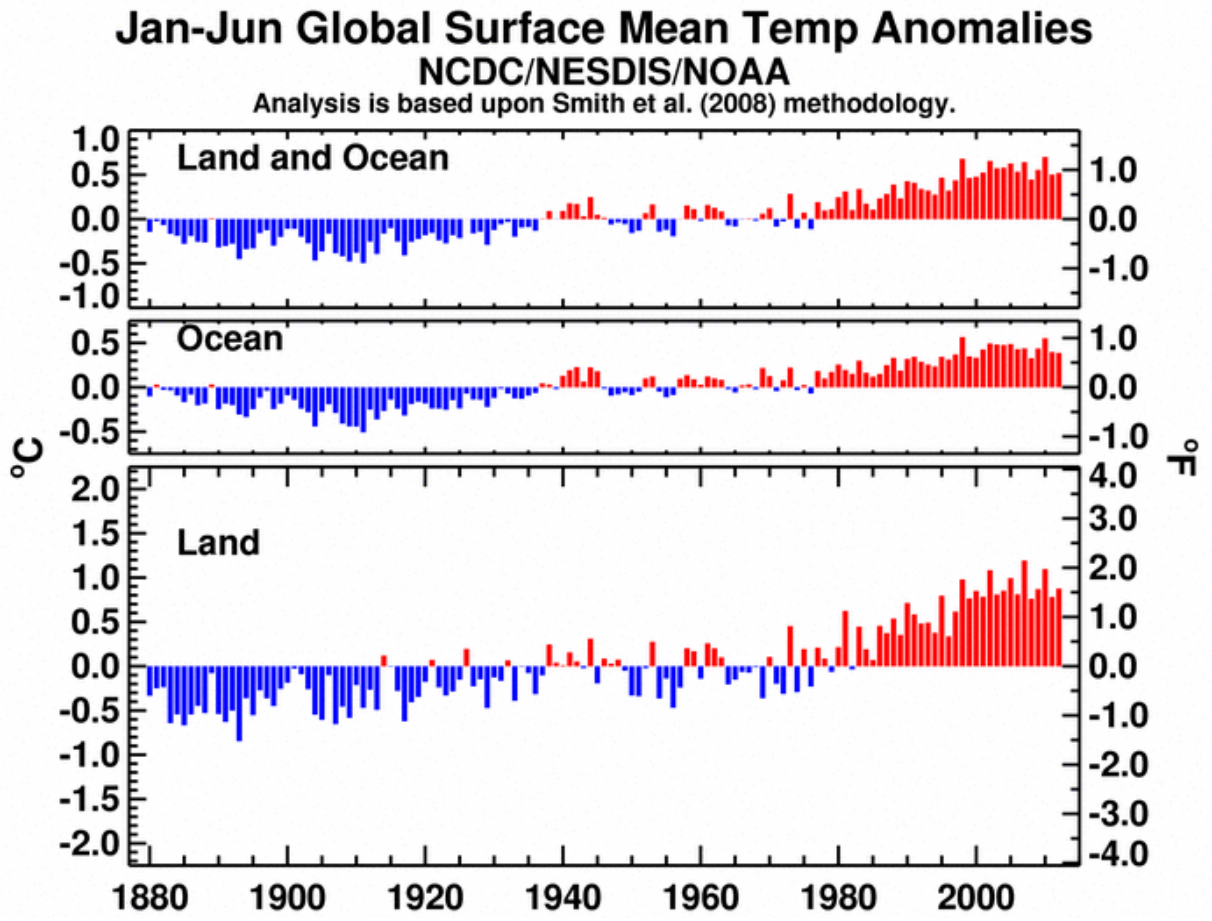
Der Spiegel, Jan. 2013

The press is beginning to notice!

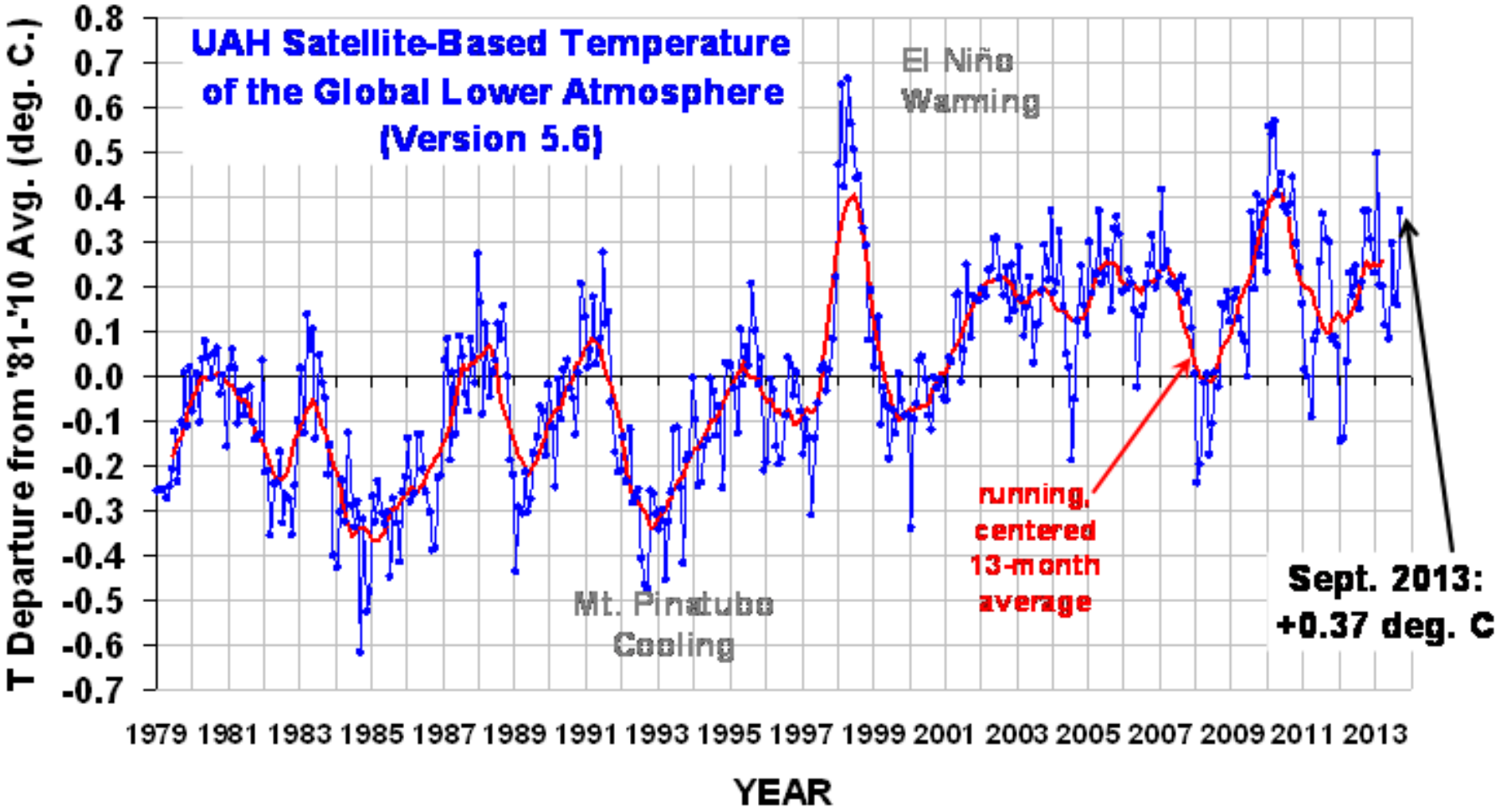
Klimawandel: Forscher rätseln über Stillstand bei Erderwärmung



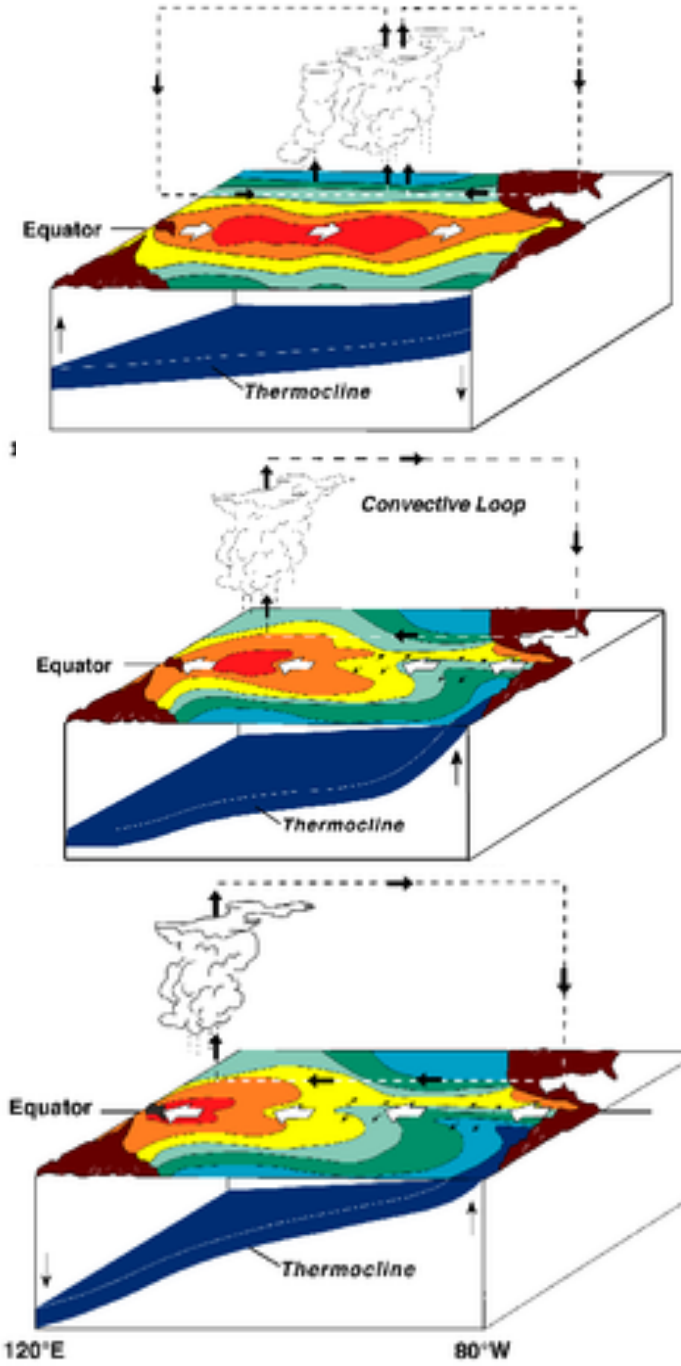
•After a long pause, or slight decline from the dust bowl maximima of the 1930's, temperatures started to rise rapidly in the 1980's.
•Temperatures have been stable since about 1998, although CO2 levels have continued to rise.



Satellite temperature measurements of lower atmosphere show little warming



http://www.drroyspencer.com/latest-global-temperatures/

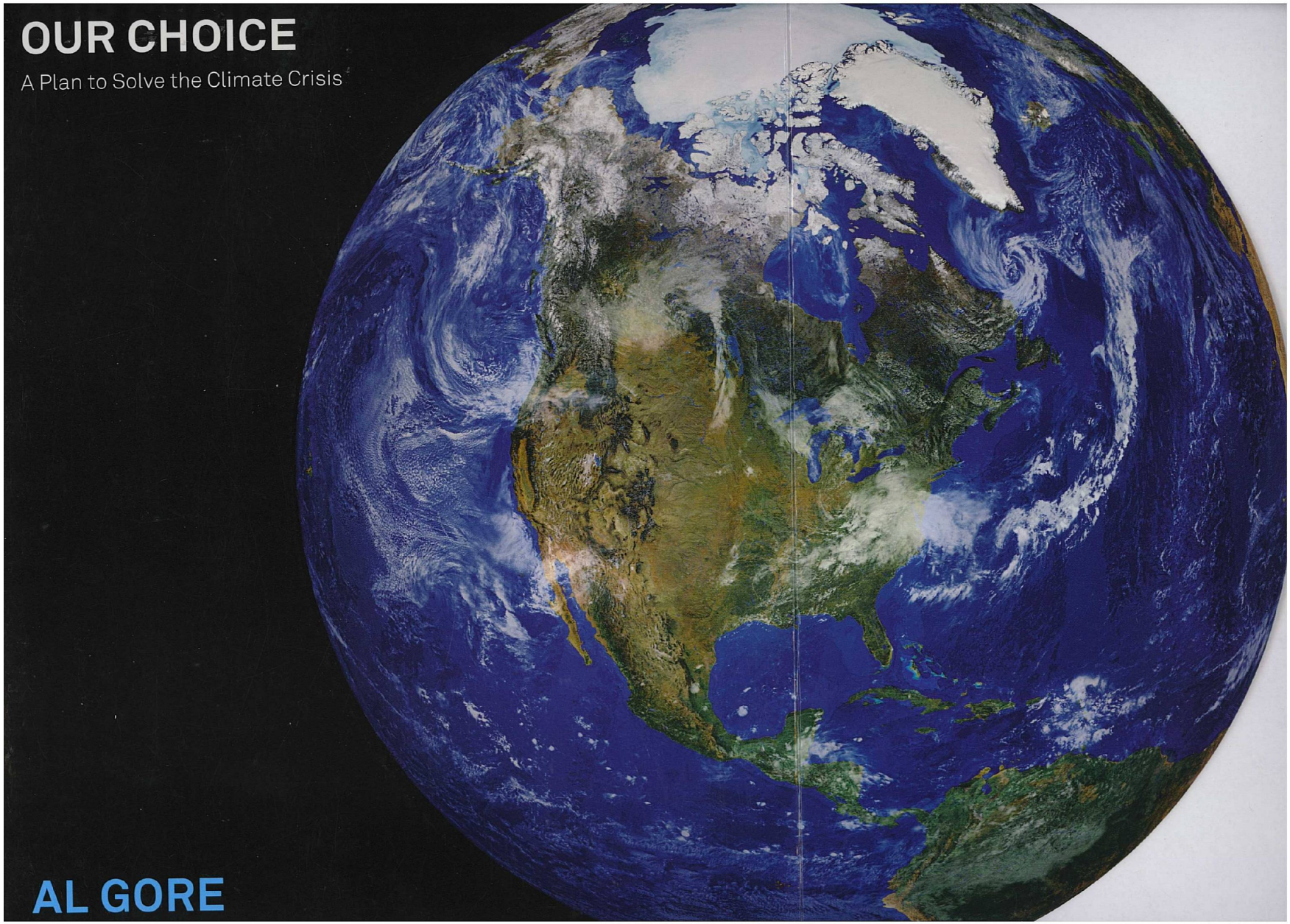


El Nino

Normal

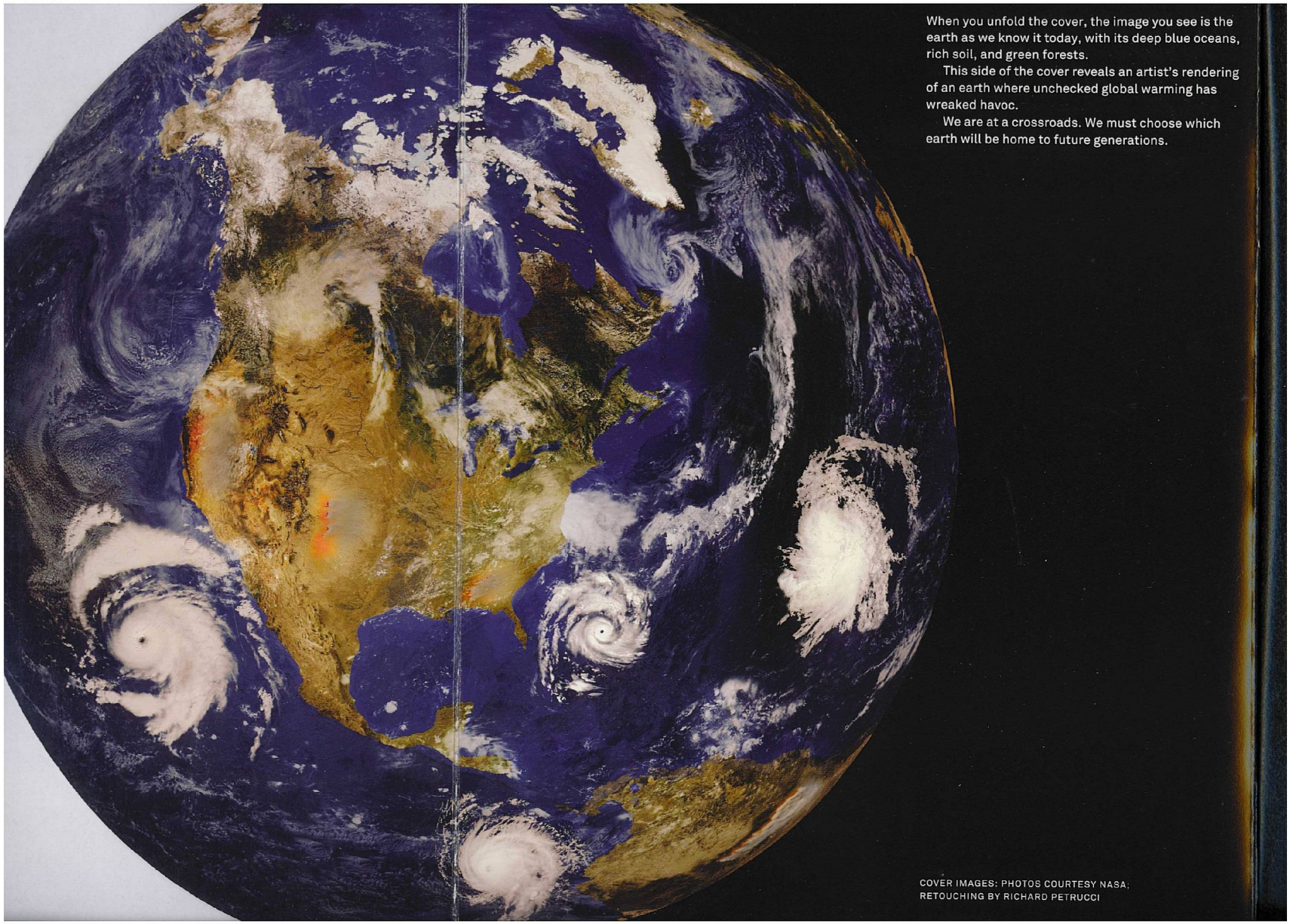
La Nina

Al Gore, Climate Scientist, Nobel Laureate.

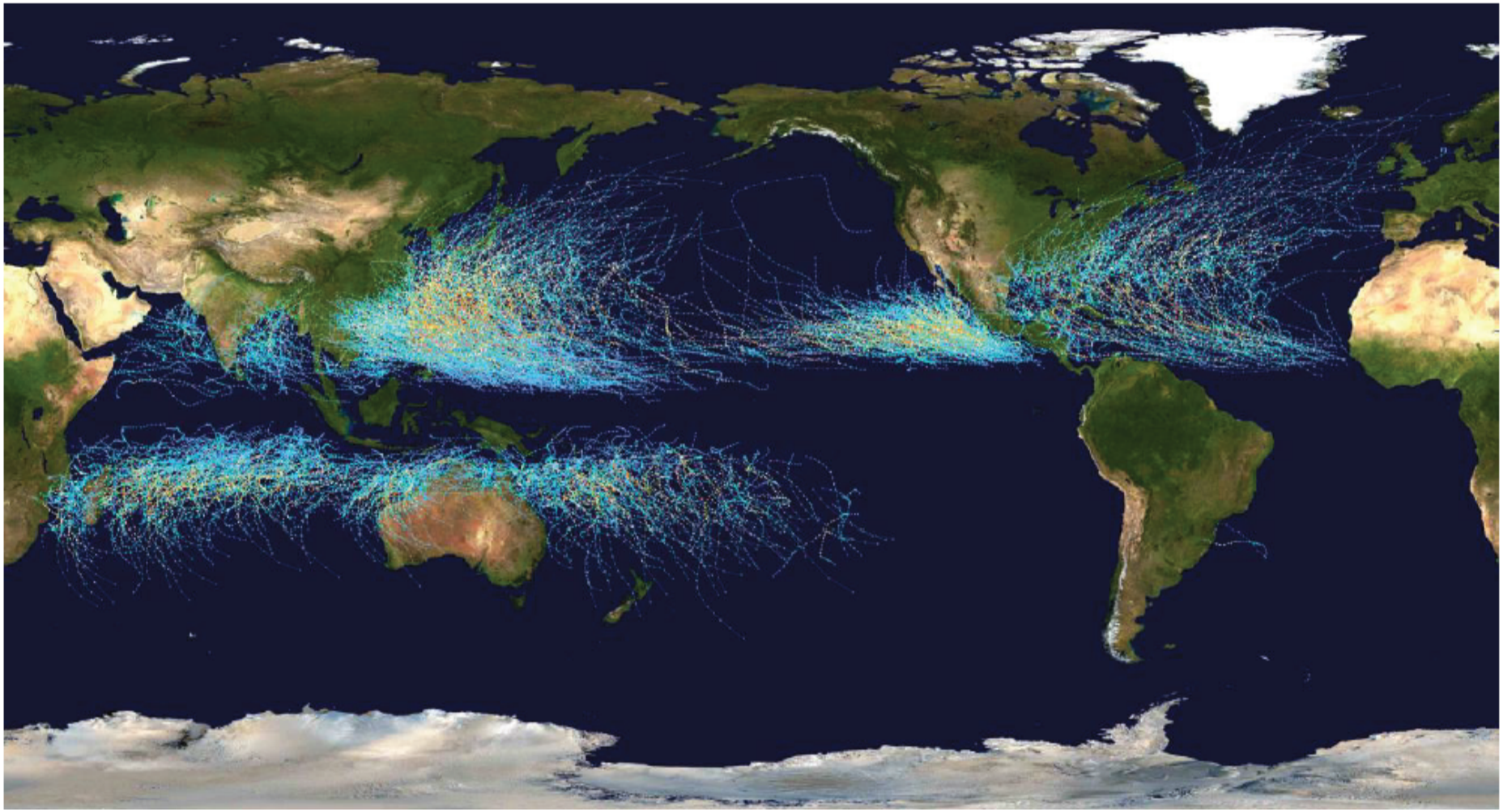


The Original for the Image on the Book's Cover.

The Image on the Inner Cover Showing the Lamentable Effects of More CO2

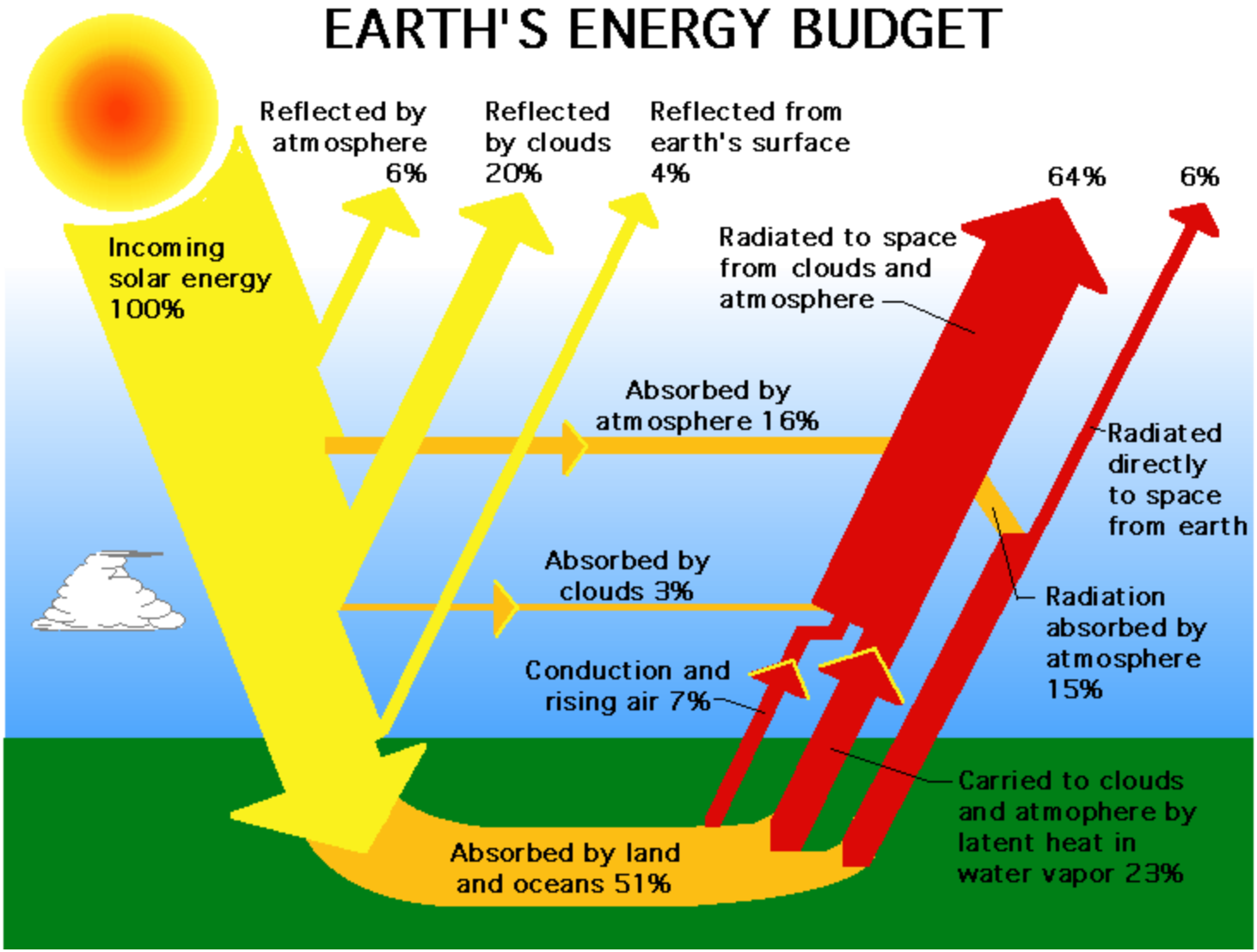


Hurricane (Tropical Cyclone) Tracks; 1985-2005; (Wikipedia)

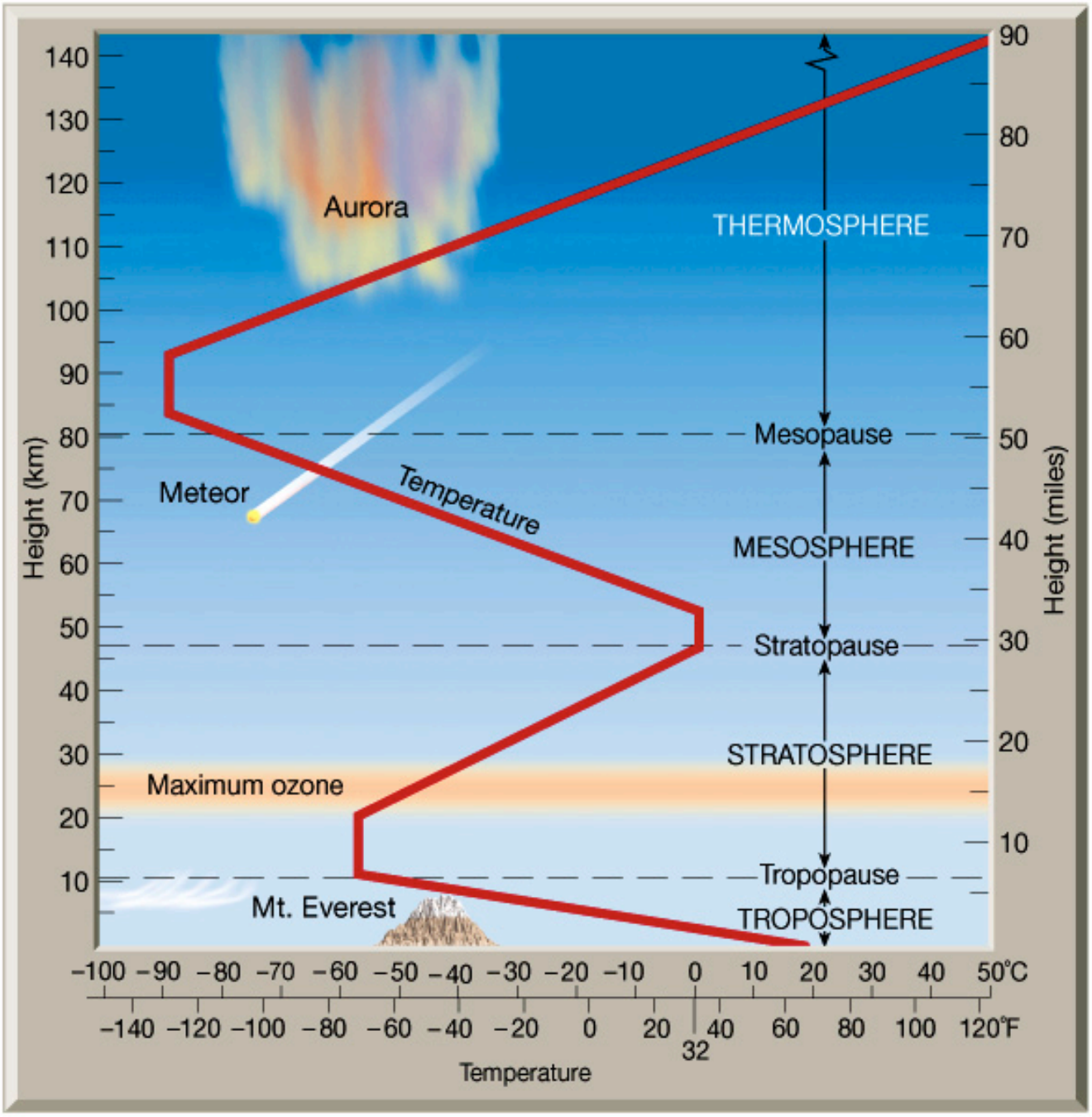


No Coriolis force at equator → No hurricanes

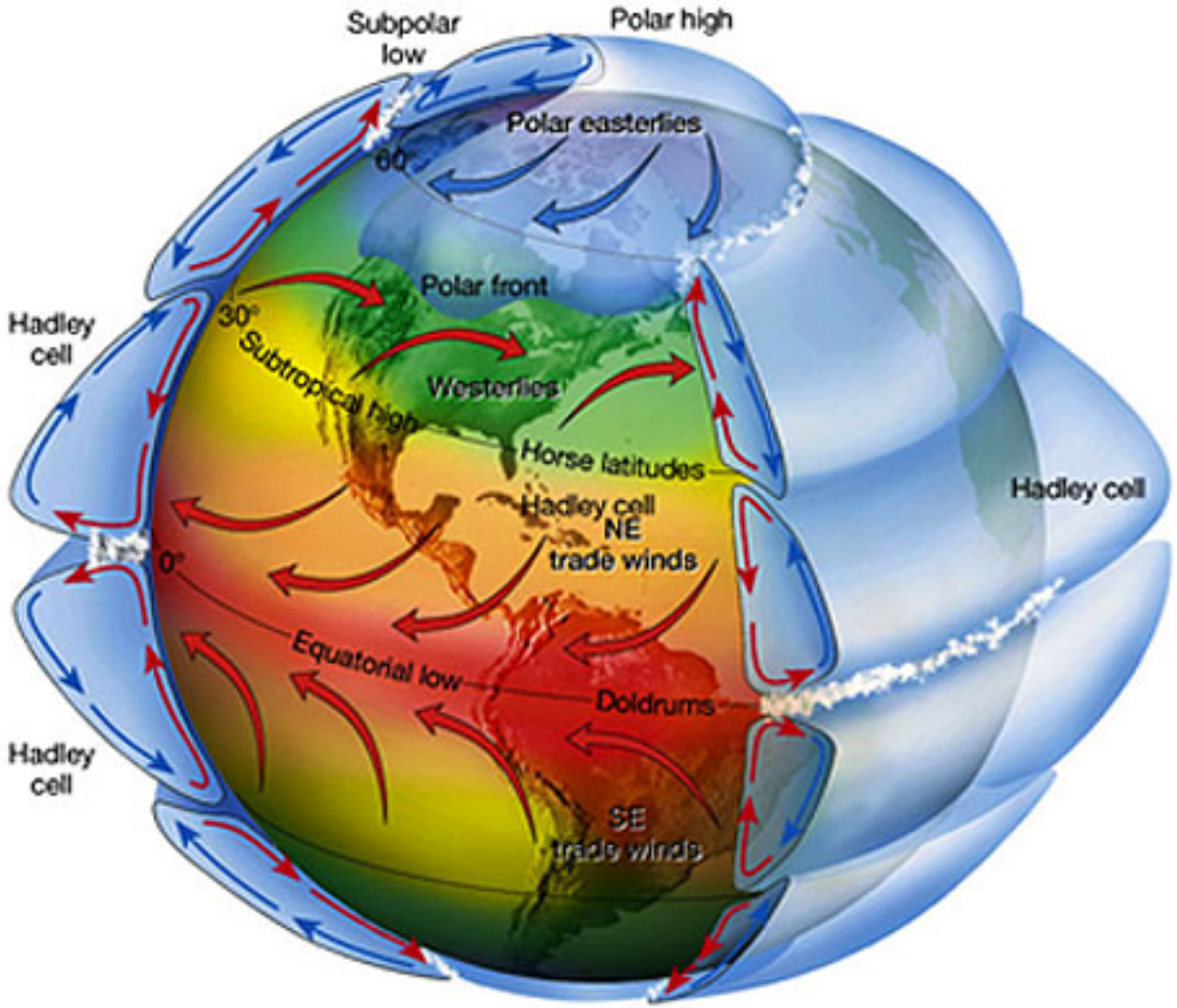
Low clouds spiral in counterclockwise in North; clockwise in South

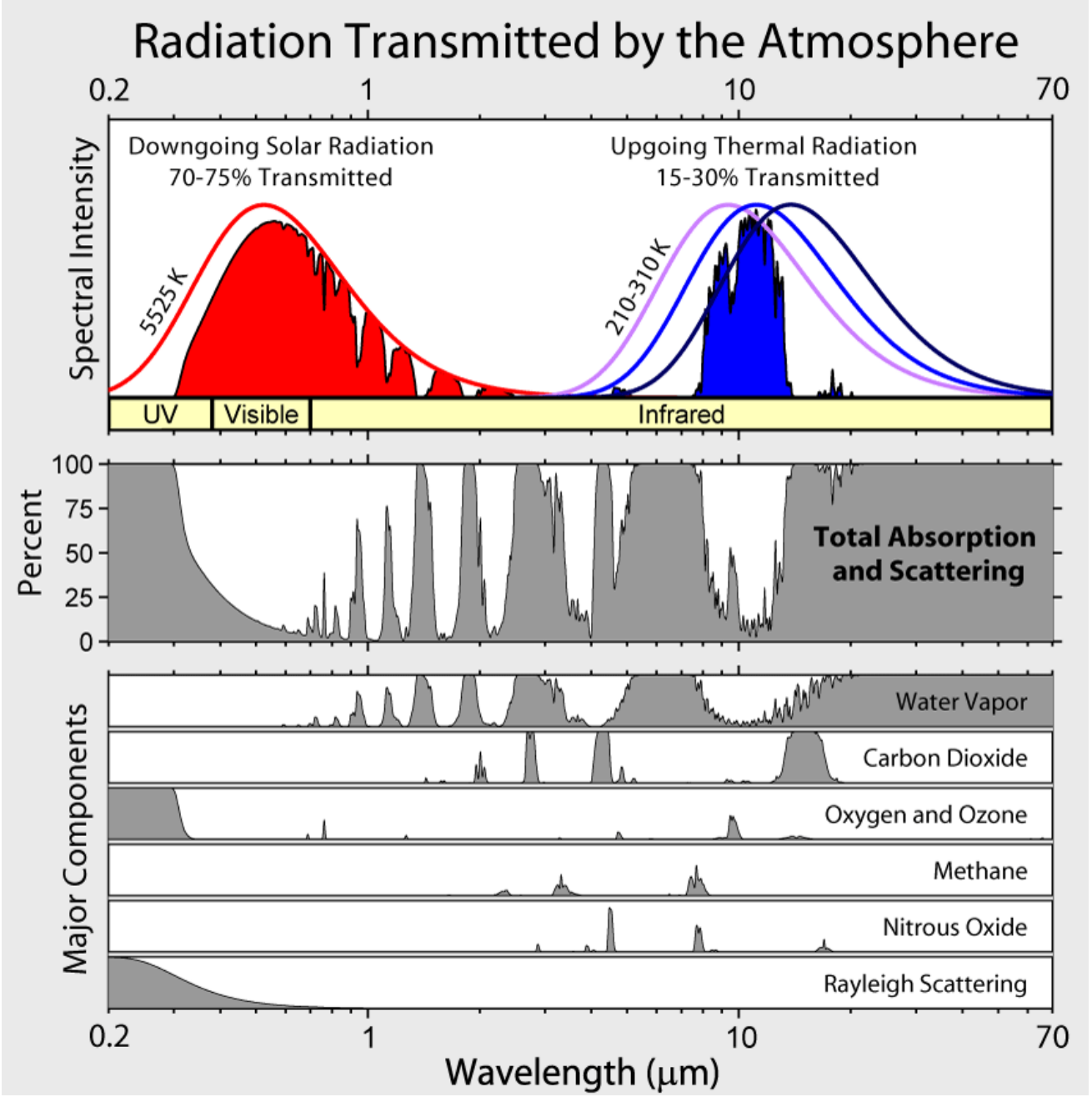


A NASA Website

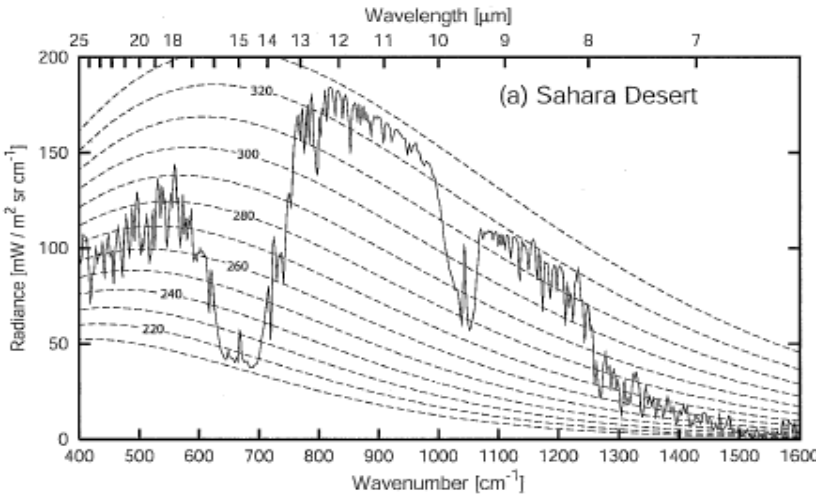

Aurora
THERMOSPHERE
Mesopause
Meteor
Temperature
MESOSPHERE
Stratopause
STRATOSPHERE
Maximum ozone
Tropopause
Mt. Everest
TROPOSPHERE
Height (km)
Height (miles)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
90
80
70
60
50
40
30
20
10
−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50°C
−140 −120 −100 −80 −60 −40 −20 0 20 32 40 60 80 100 120°F
Temperature

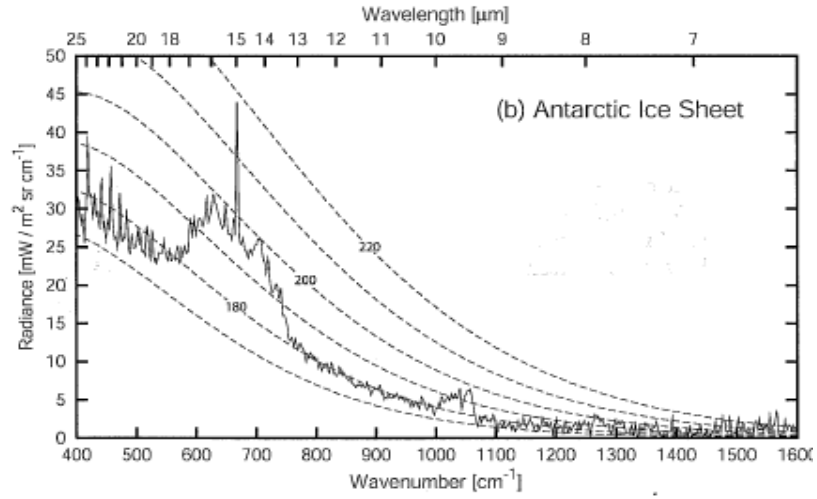
Atmospheric Circulation

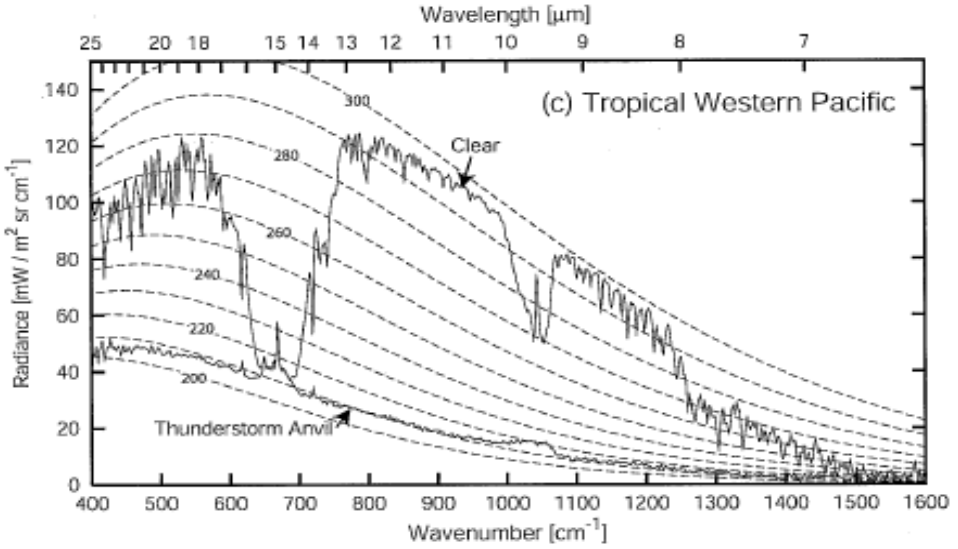



Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

Examples of FTIR Data from a Satellite







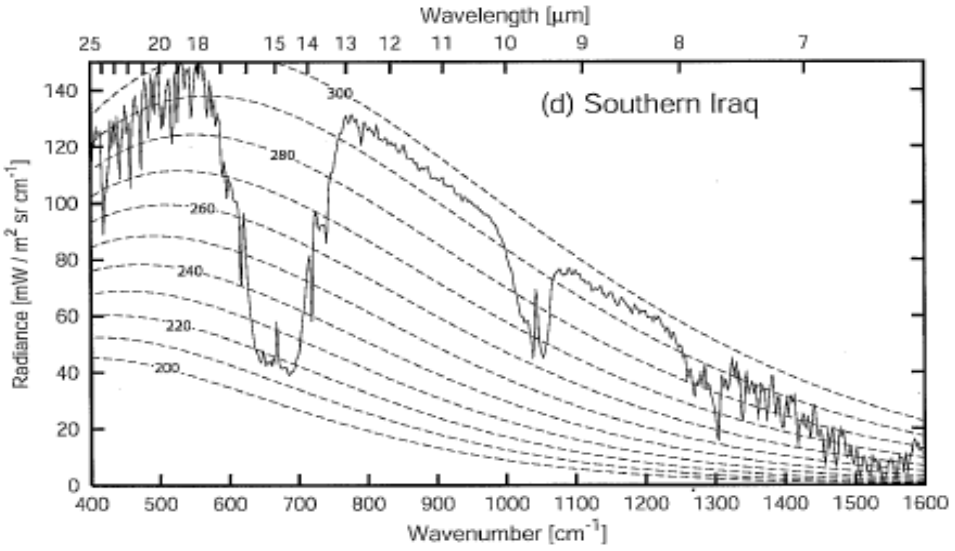


Fig. 8.3: Examples of moderate resolution IR spectra observed by a satellite spe
trometer. Except for the curve labeled "thunderstorm anvil" in panel (c), all spect
were obtained under cloud-free conditions. *(Nimbus-4 IRIS data courtesy of the Go*
dard EOS Distributed Active Archive Center (DAAC) and instrument team leader I
Rudolf A. Hanel.)

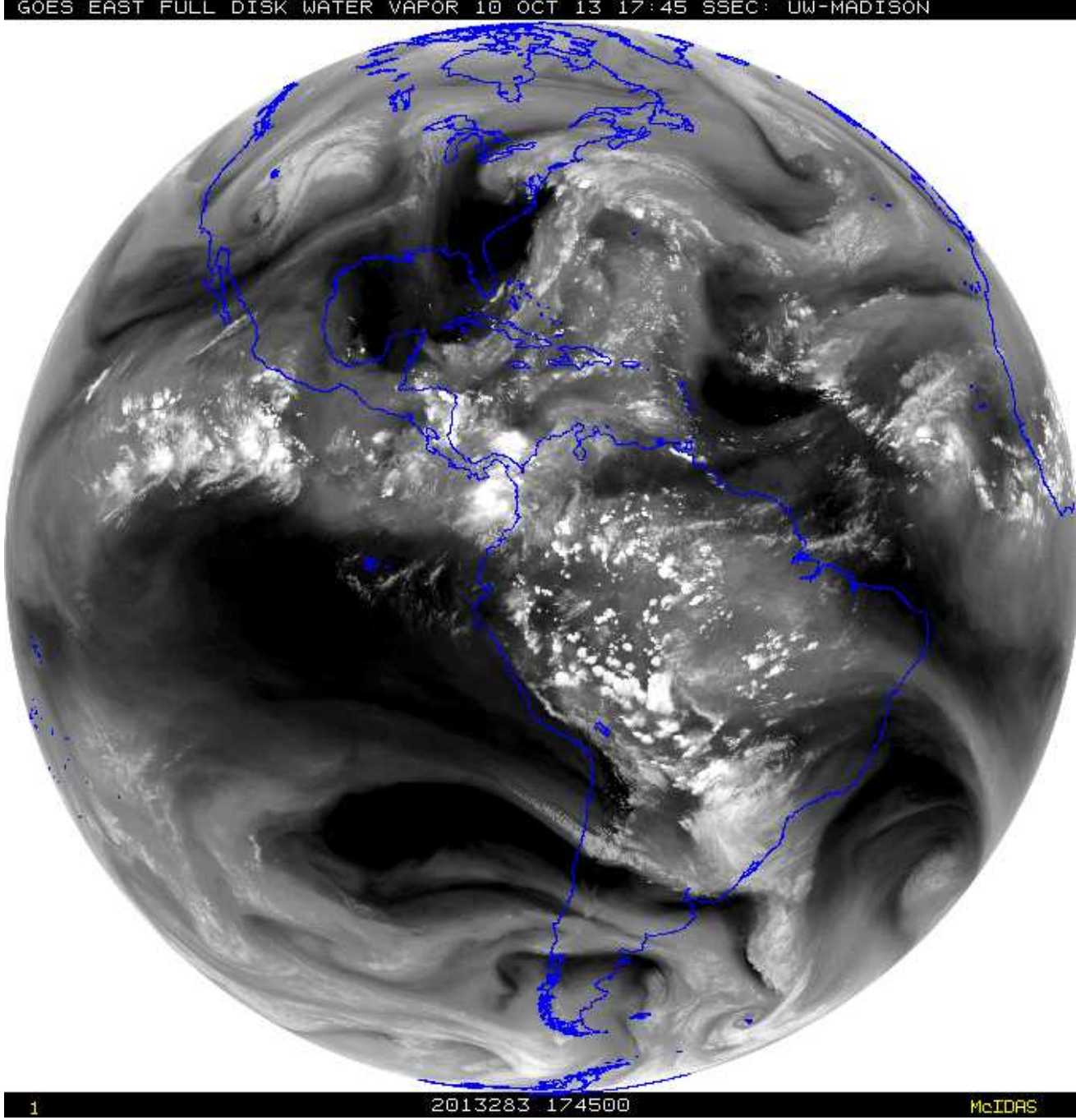
Water vapor

6.5 micrometers
(H_2O bending-mode).

Very optically thick,
emission from high
altitudes,
(mid troposphere).

Dark is relatively low,
warm water vapor.

Light is higher, cold
vapor near cloud tops
and cloud tops.
(deep convection).



http://www.ssec.wisc.edu/data/geo/index.php

Longwave IR

10.7 micrometers
(middle of IR “window”)

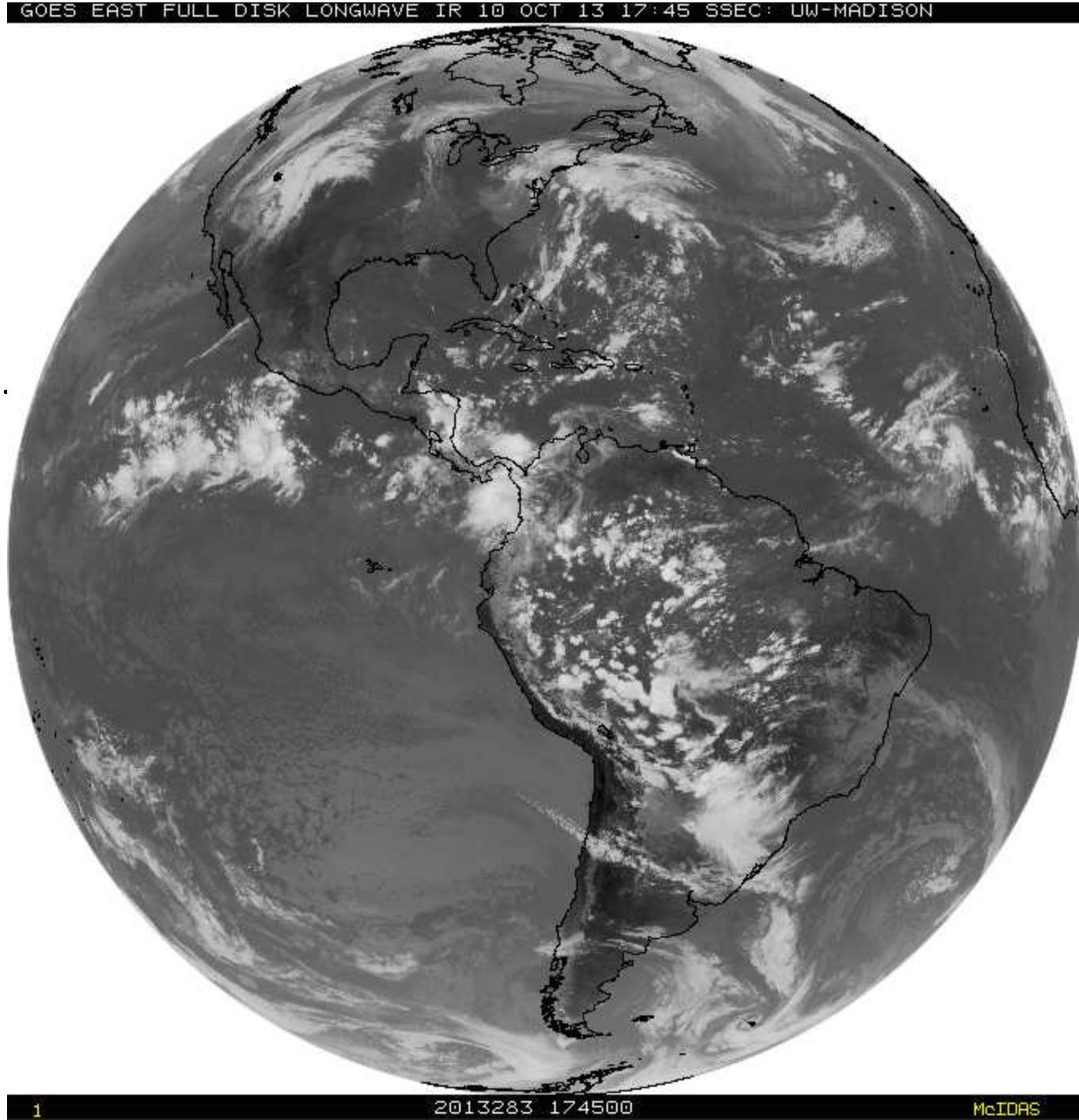
Negligible radiation from greenhouse gases, almost all from surface and clouds.

White, cold cloud tops.

Darker features are low, warm cloud tops **or** cold, semi-transparent cirrus.

Small fraction of surface is free of clouds.

Bottom line:
Clouds are 800 lb Gorilla!



One Slide Summary of Global Warming Theory
Key Parameters: forcing ΔQ_2 and feedback f

Steady-State Temperature Change for Doubled CO2

$$\Delta T = \frac{T_e \Delta Q_2}{4Q_e(1-f)} = \frac{0.30\,\Delta Q_2}{1-f}\ \mathrm{K\ m^2\ W^{-1}} = 3.4\ \mathrm{K} = \frac{1.1\ \mathrm{K}}{(1-2/3)}.$$

$Q_e = (1-\alpha_e)F_e/4 = \sigma\epsilon_e T_e^4 = 236\ \mathrm{W\ m^{-2}}$ = mean radiation of earth to space.

$\alpha_e = 0.306$ albedo (mostly clouds).

$F_e = 1361\ \mathrm{W\ m^{-2}}$ = mean solar flux at earth's orbit.

$T_e = 288\ \mathrm{K}$ = mean surface temperature of Earth.

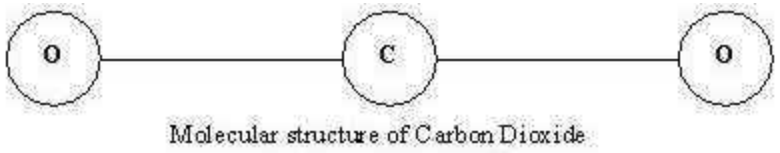
$\epsilon_e = 0.606$ = effective (contrived) emissivity of Earth for T_e.

$f = 0.25\,T_e\ \partial \ln(1-\alpha_e)/\partial T - T_e\ \partial \ln \epsilon_e/\partial T = 2/3$ (per IPCC) = feedback.

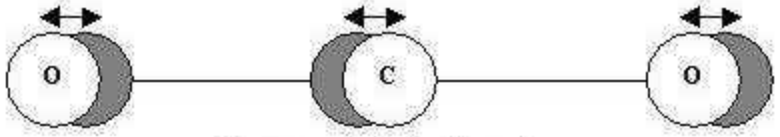
$\Delta Q_2 = 3.7\ \mathrm{W\ m^{-2}}$ (per IPCC) = radiative forcing for doubled CO2.

IPCC values of f and ΔQ_2 give far (at least a factor of 3) too much warming.
Both probably wrong in a way that exaggerates warming!

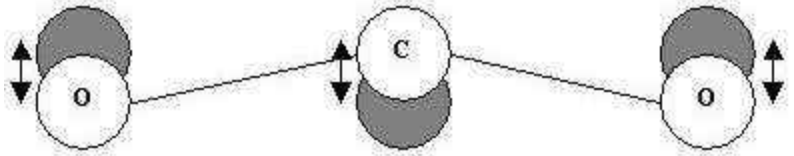
The Villain!



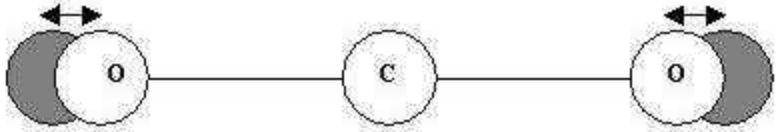
Molecular structure of Carbon Dioxide



The asymmetric stretch mode



The bending mode



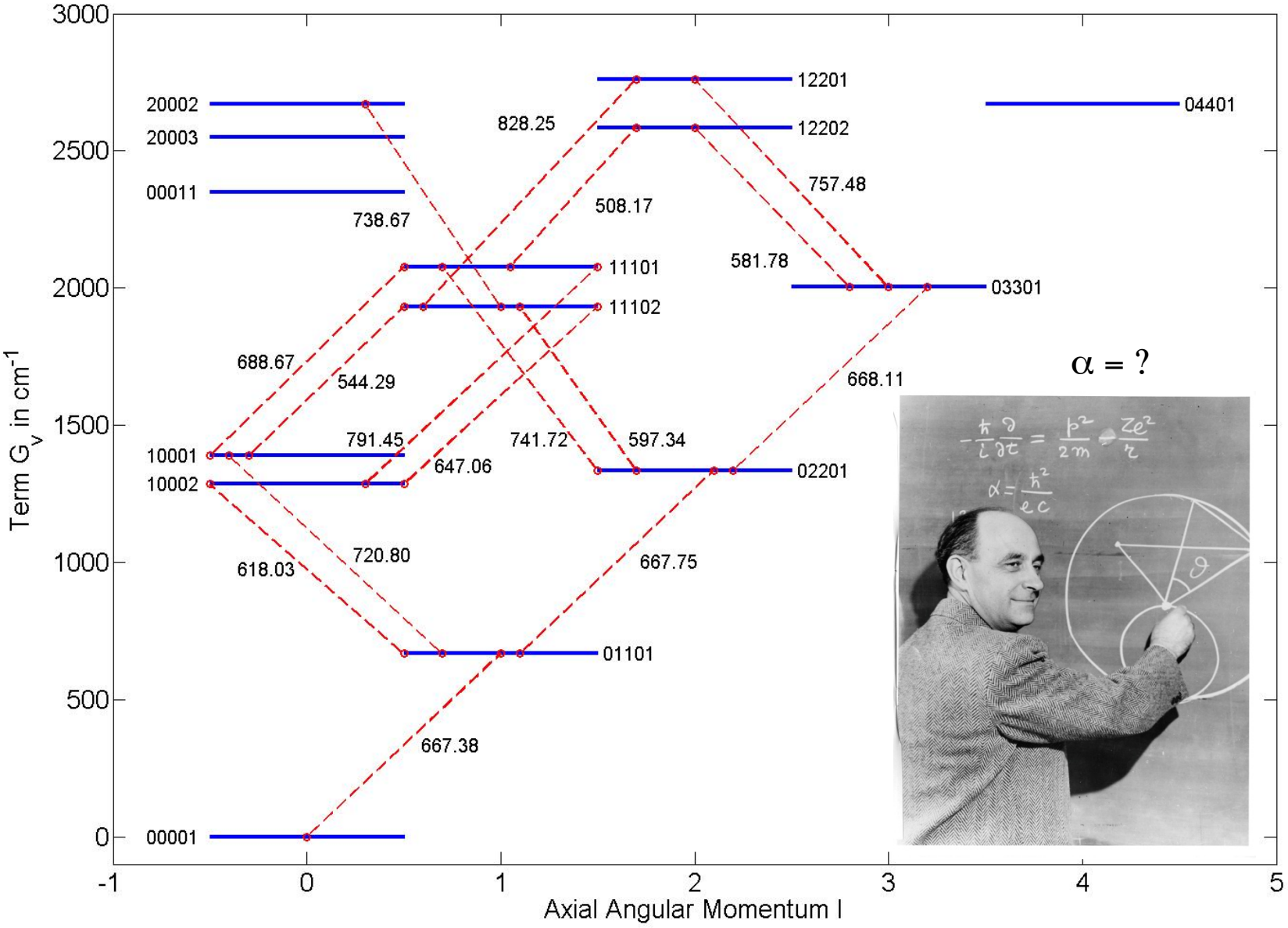
The symmetric stretch mode

2349 cm $^{-1}$
frequency too high for greenhouse warming

666 cm $^{-1}$ (Satan's number)
greenhouse warming

1388 cm^{-1}
no changing dipole moment,
no absorption or emission

Fermi Resonances



What is wrong with this slide?

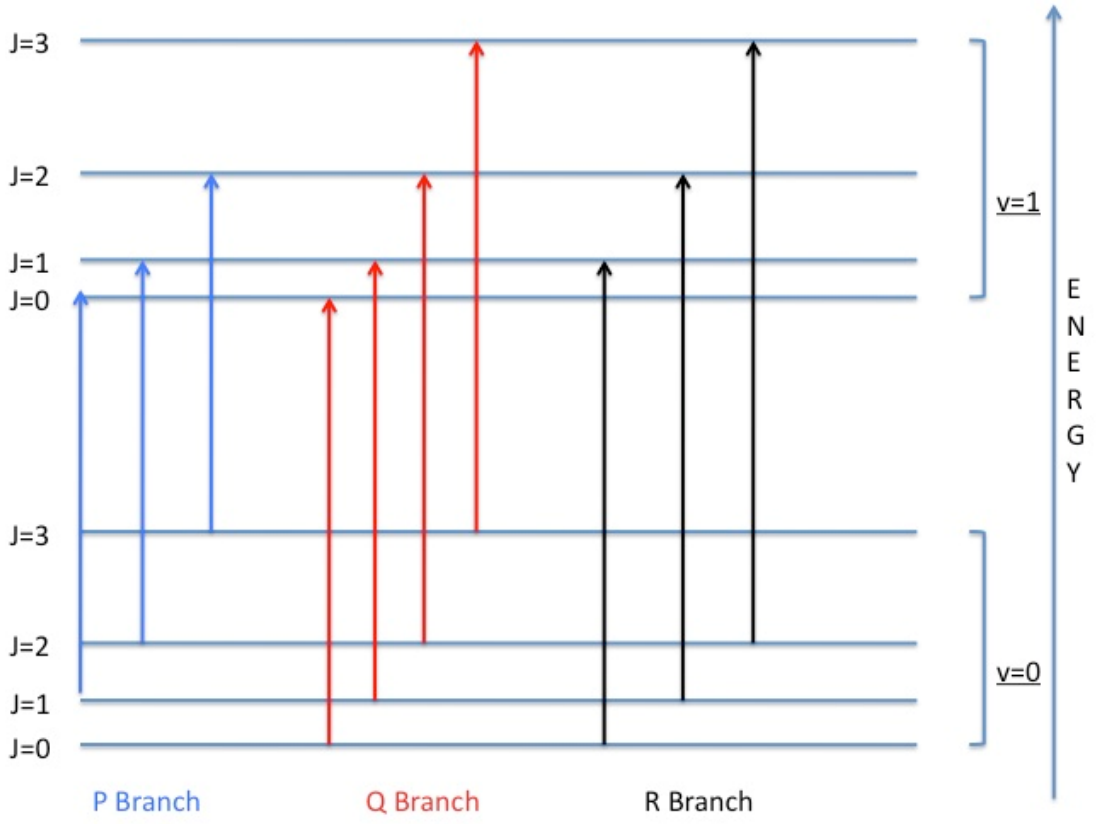


Fig. 6 Schematic diagram of P, Q, and R branch transitions

Attenuation Coefficient (e-foldings / length)

$$\kappa = N \sum_{eg} \sigma_{eg} = N \sum_{eg} S_{eg} G_{eg}$$

Line shape

N is the number density of CO_2 molecules, and σ_{eg} is the cross section of the transition from a lower state g to an upper state e; G_{eg} is the lineshape function.

Line strength (in cm)

$$S_{eg} = \frac{8\pi^3 \nu_{eg} |D_{eg}|^2 e^{-E_g/kT} \left(1 - e^{-hc\nu_{eg}/kT}\right)}{hcZ}$$

ν_{eg} = frequency (in cm^{-1}) of the transition, D_{eg} = the electric dipole matrix element, E_g = lower-state energy, T = absolute temperature, k = Boltzmann's constant, h = Planck's constant, c = speed of light, T = absolute temperature.

Partition function

$$Z = \sum_j e^{-E_j/kT}$$

Normalized line shapes

$$\int_0^\infty G_{eg} d\nu = 1$$

A Lorentzian line shape

$$G_{eg} = \frac{\mu_{eg}/\pi}{\mu_{eg}^2 + (\nu - \nu_{eg})^2}$$

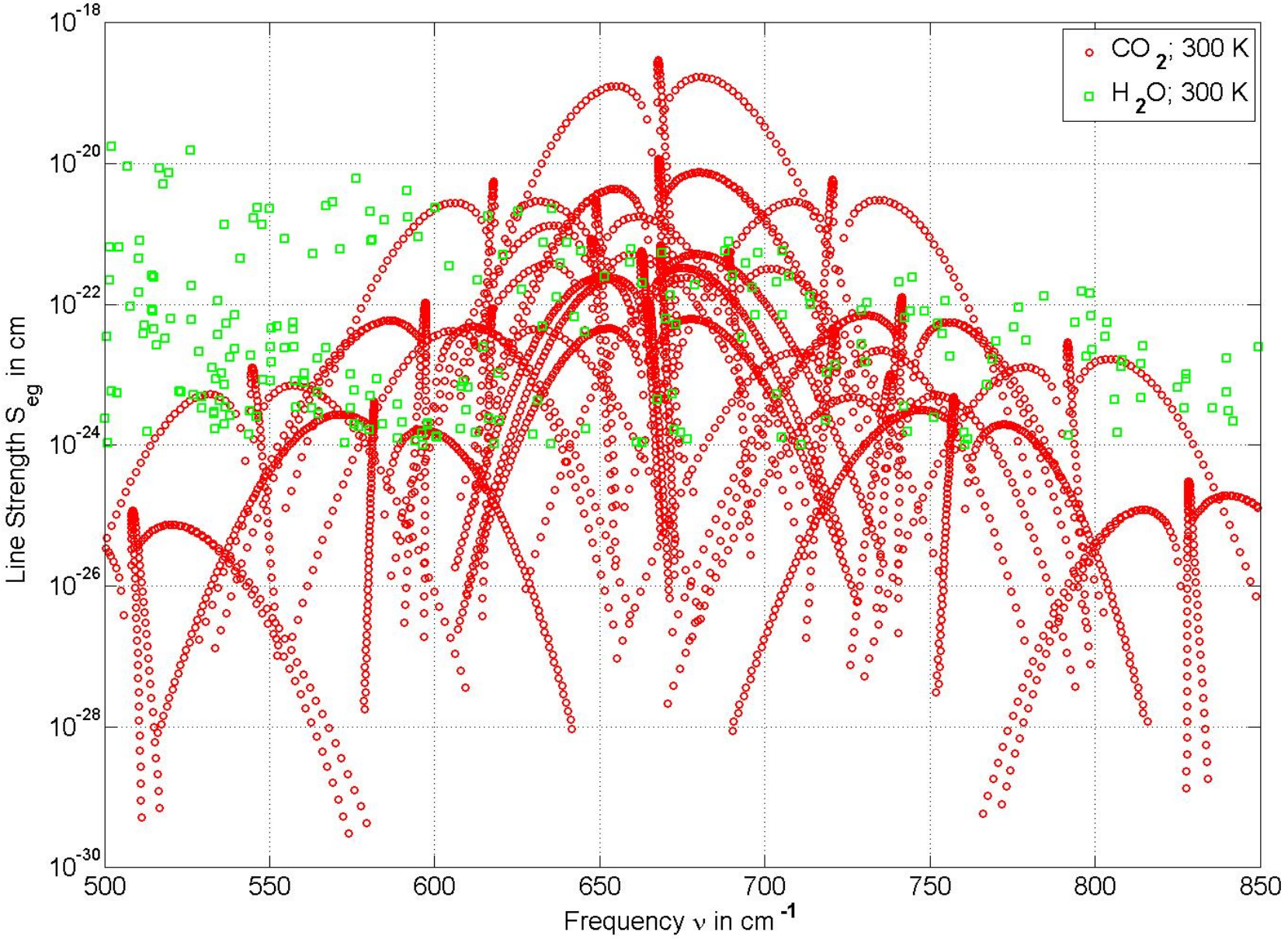
μ_{eg} = broadening; ν = frequency; ν_{eg} = resonance.

A Voigt line shape

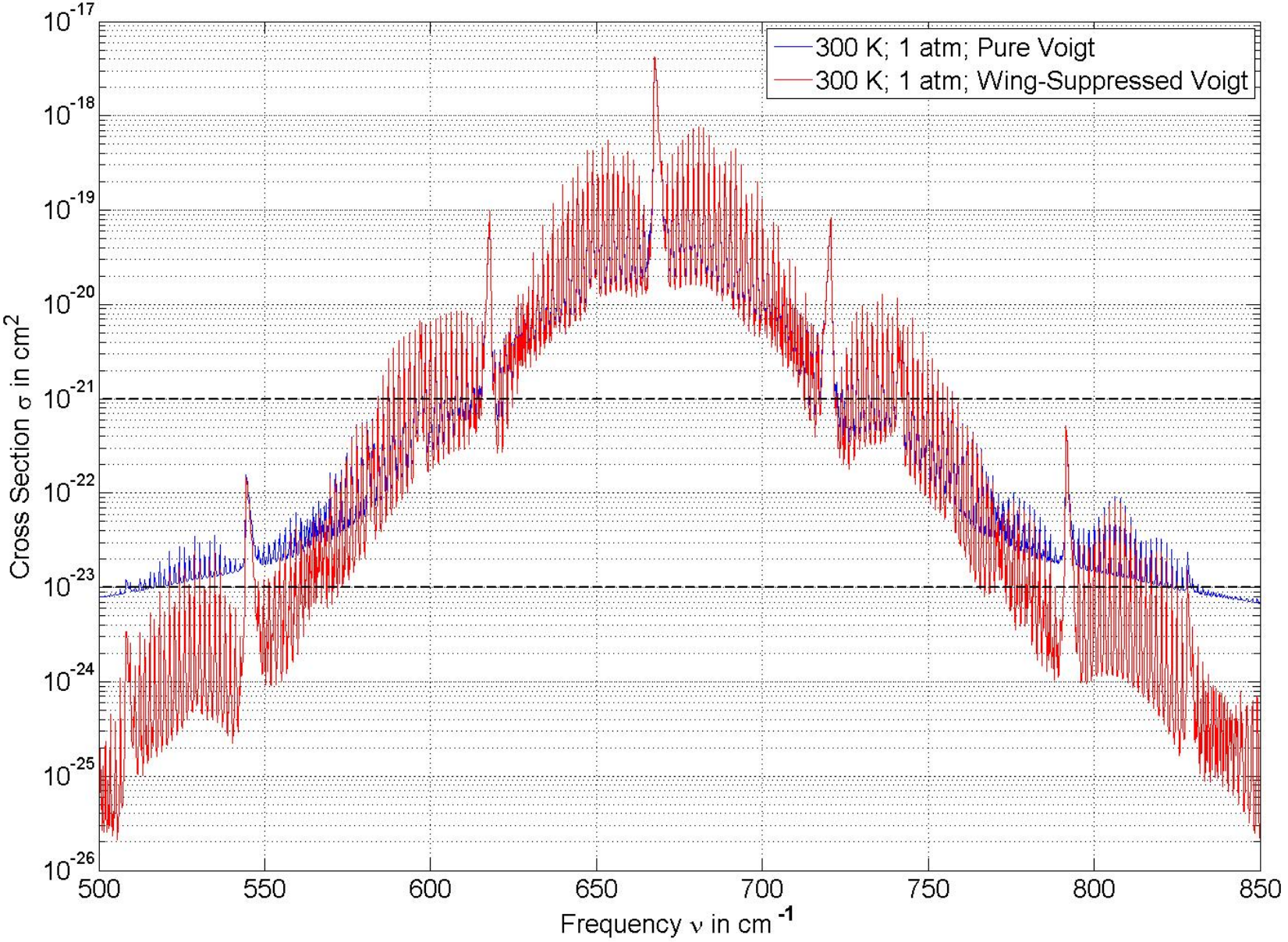
$$G_{eg} = \frac{\mu_{eg}}{\pi}\sqrt{\frac{m}{2\pi kT}}\int_{-\infty}^{\infty} \frac{e^{-mv^2/2kT}\,dv}{\mu_{eg}^2 + (\nu - \nu_{eg}[1 + v/c])^2}$$

Neither Lorentzian nor Voigt line shapes are correct in the far wings!

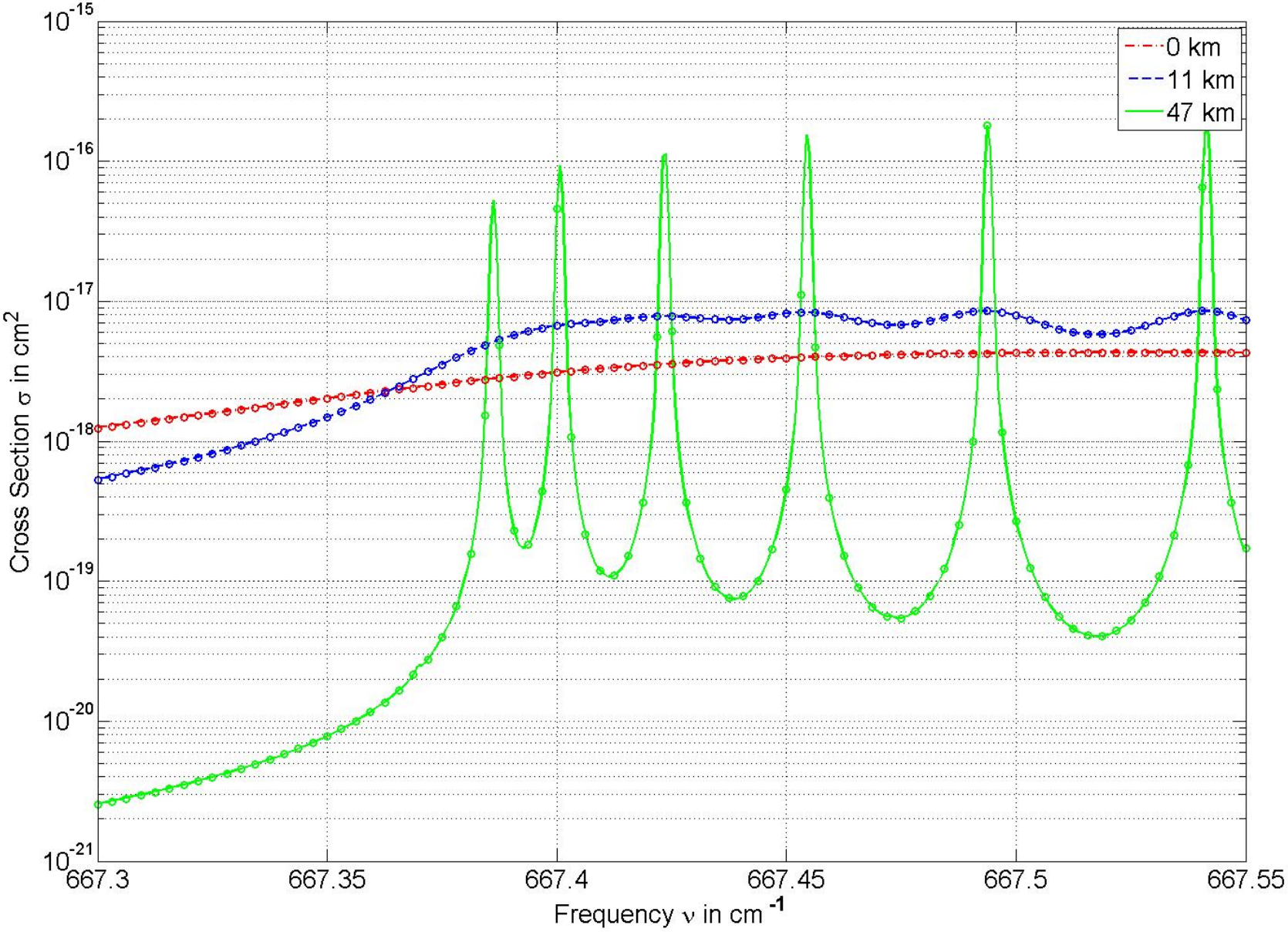
Thousands of lines! Linestrengths vary by 10 orders of magnitude.



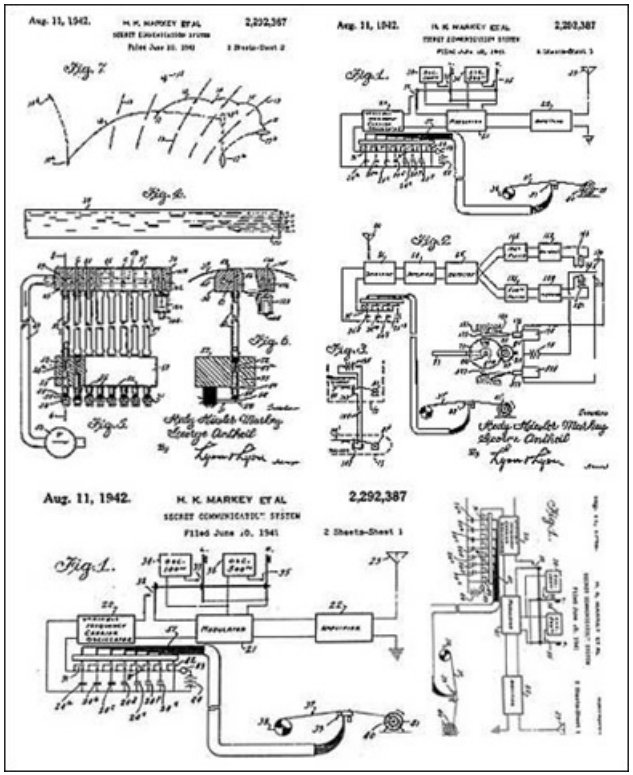
Cross sections depend on far-wing lineshape at band edges which drive warming!



Less pressure broadening of cross sections at high altitude. Q-branch lines.



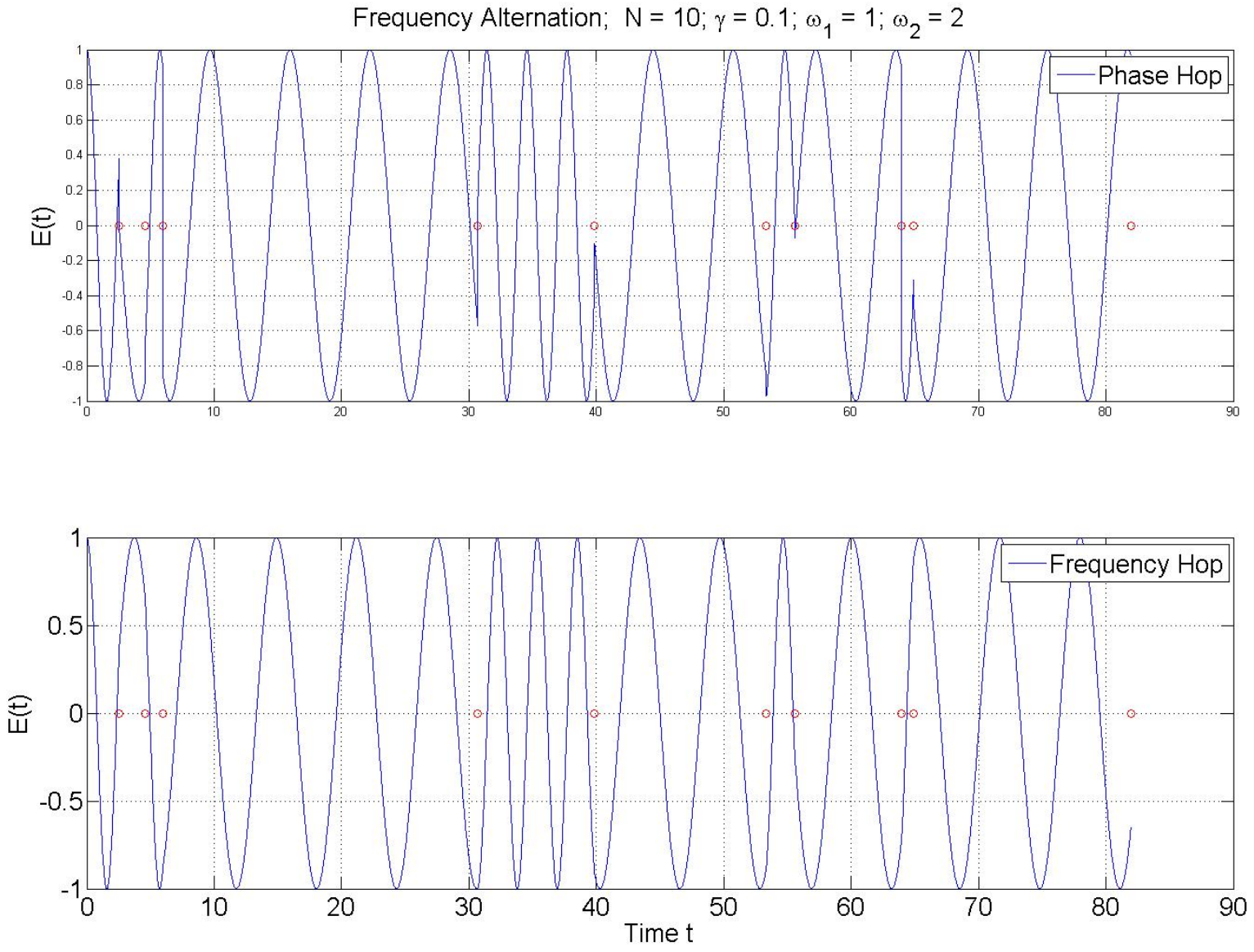
CO_2 molecules work like Hedy Lamarr's Frequency-Hopping torpedo link (WWII).



- Lamarr-Anthiel system hopped over 88 frequencies (piano keyboard). US Patent 2,292,387

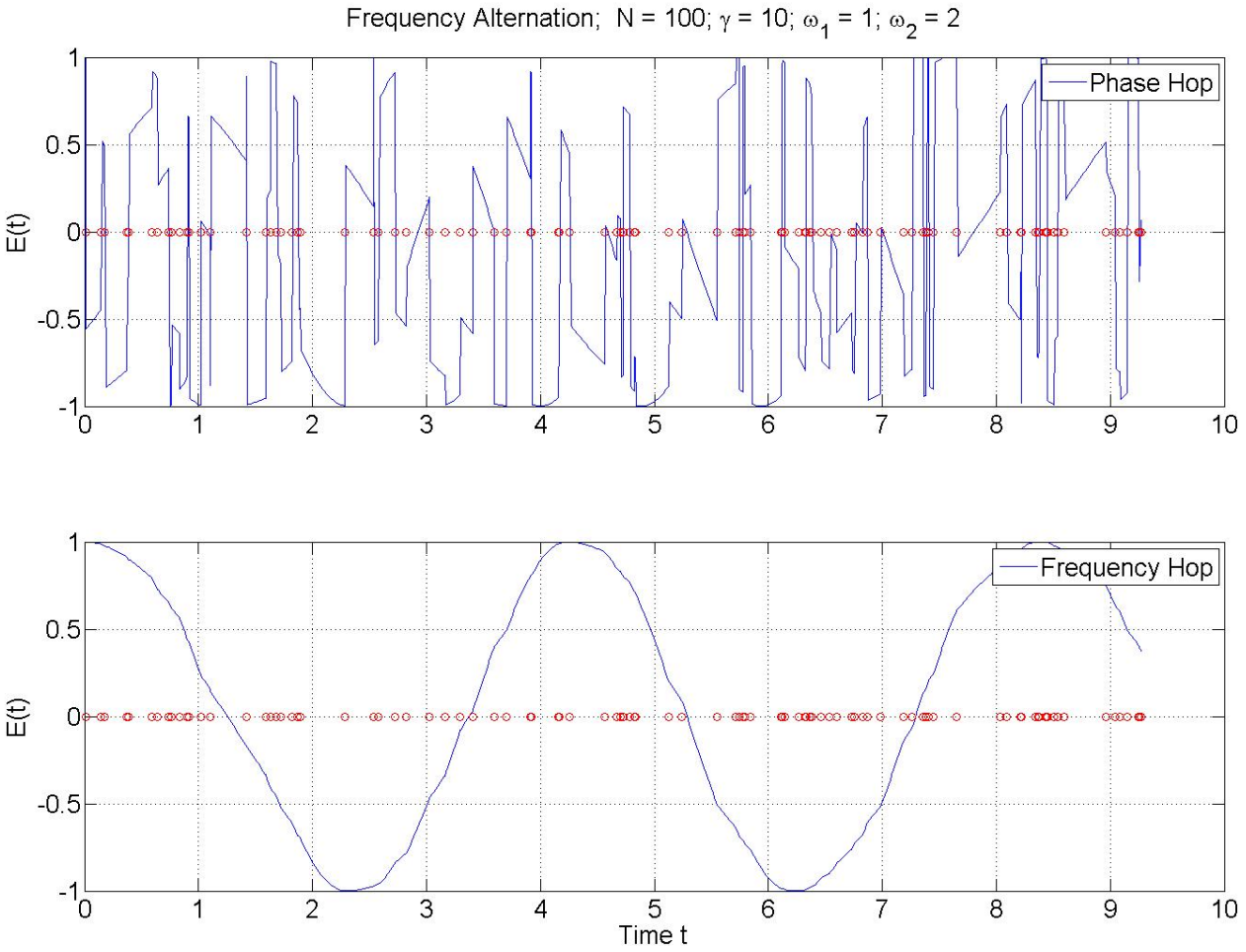
- CO_2 can hop to any of several thousand vibration-rotation frequencies at each collision.

Details of collisional frequency change control far-wing lineshapes.

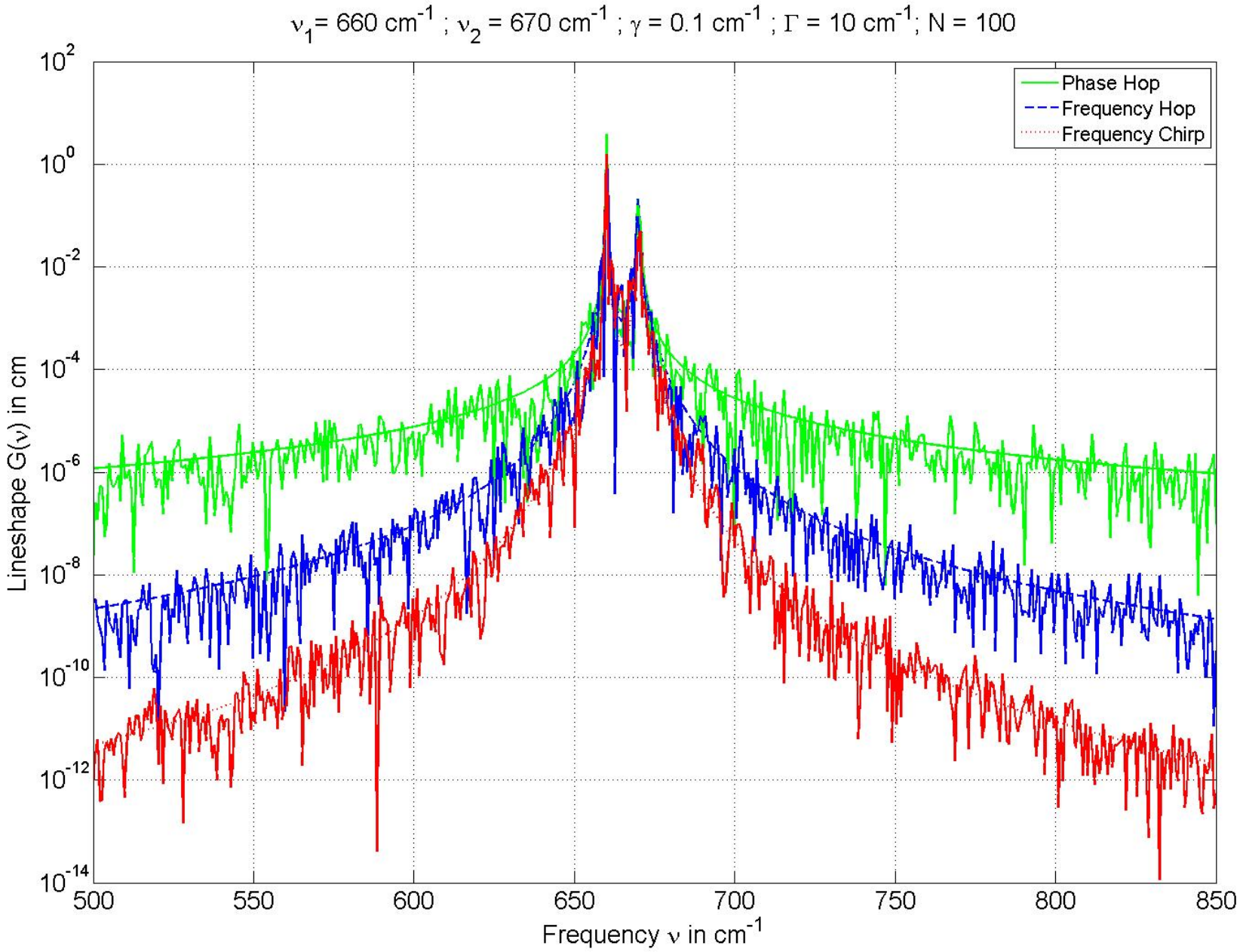


Two extremes for fast collisions: Lorentz broadening (phase hop) and Dicke narrowing (frequency hop)

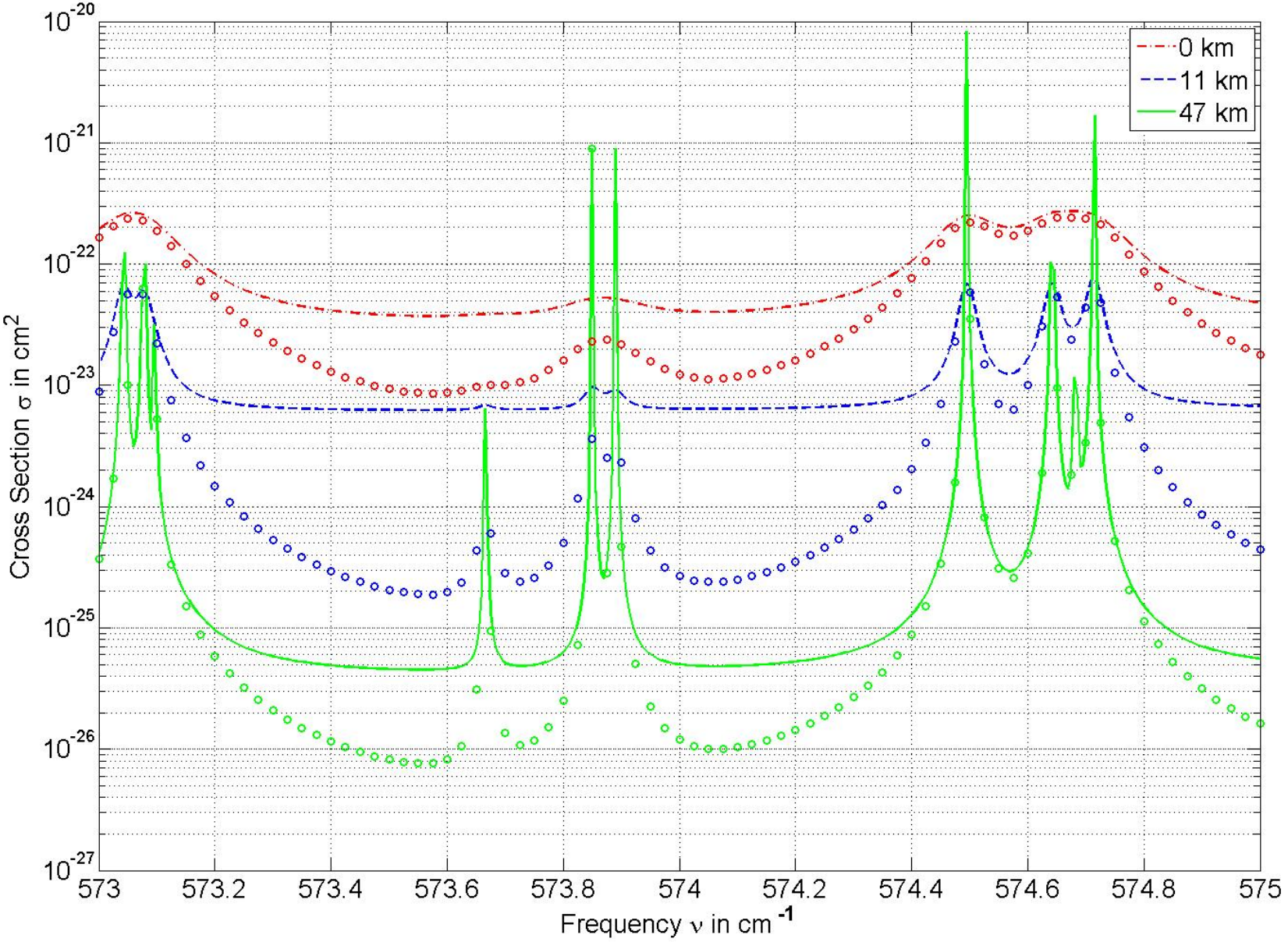
Robert Dicke



Numerical models: more analytic frequency change gives less far-wing broadening.



Far-wing (global warming) cross sections much bigger with Lorentz broadening (lines) than with realistic far-wing broadening (circles).



Downwelling Flux at the Surface

$$J(0) = \int_0^\infty \kappa(z) B(z) e^{-\rho(z)} dz$$

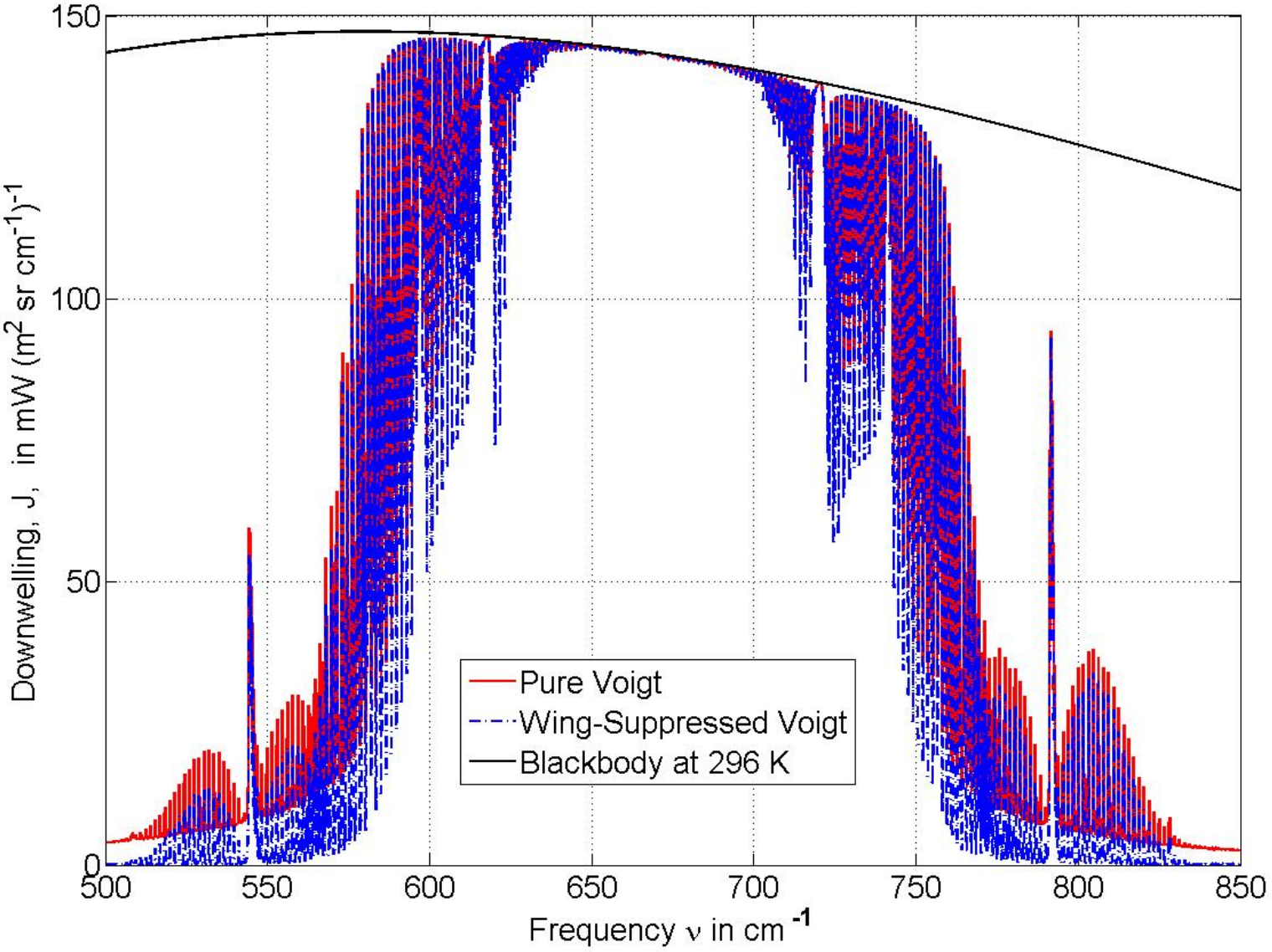
Planck Brightness

$$B = \frac{2hc^2\nu^3}{e^x - 1}, \quad \text{where} \quad x = \frac{hc\nu}{kT}$$

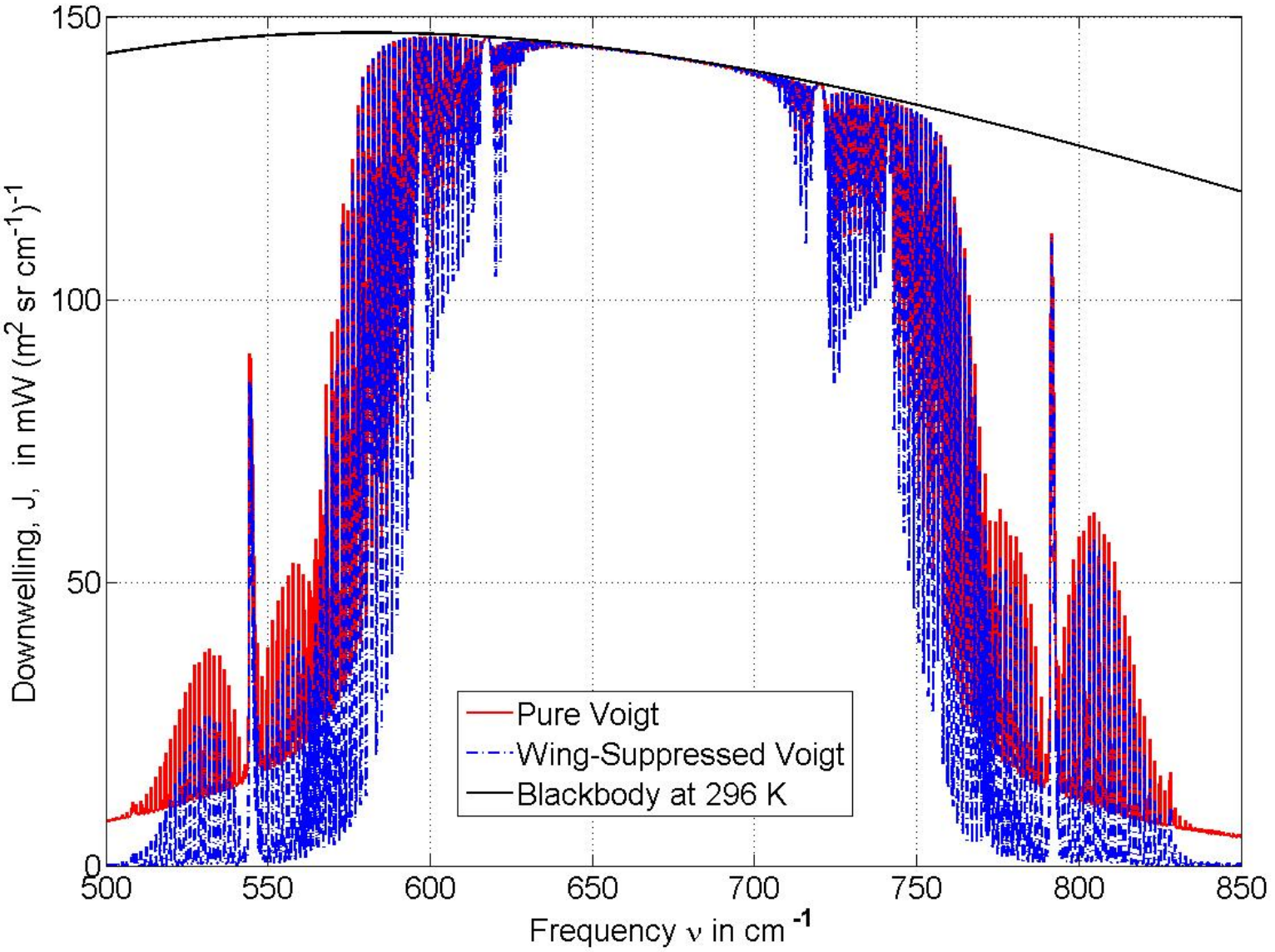
Optical Depth from Surface to Altitude z

$$\rho(z) = \int_0^z \kappa(z') dz'$$

390 ppm CO_2


150
100
50
0
500
550
600
650
700
750
800
850
Downwelling, J, in mW (m2 sr cm-1)-1
Frequency ν in cm -1
Pure Voigt
Wing-Suppressed Voigt
Blackbody at 296 K

780 ppm CO_2


150
100
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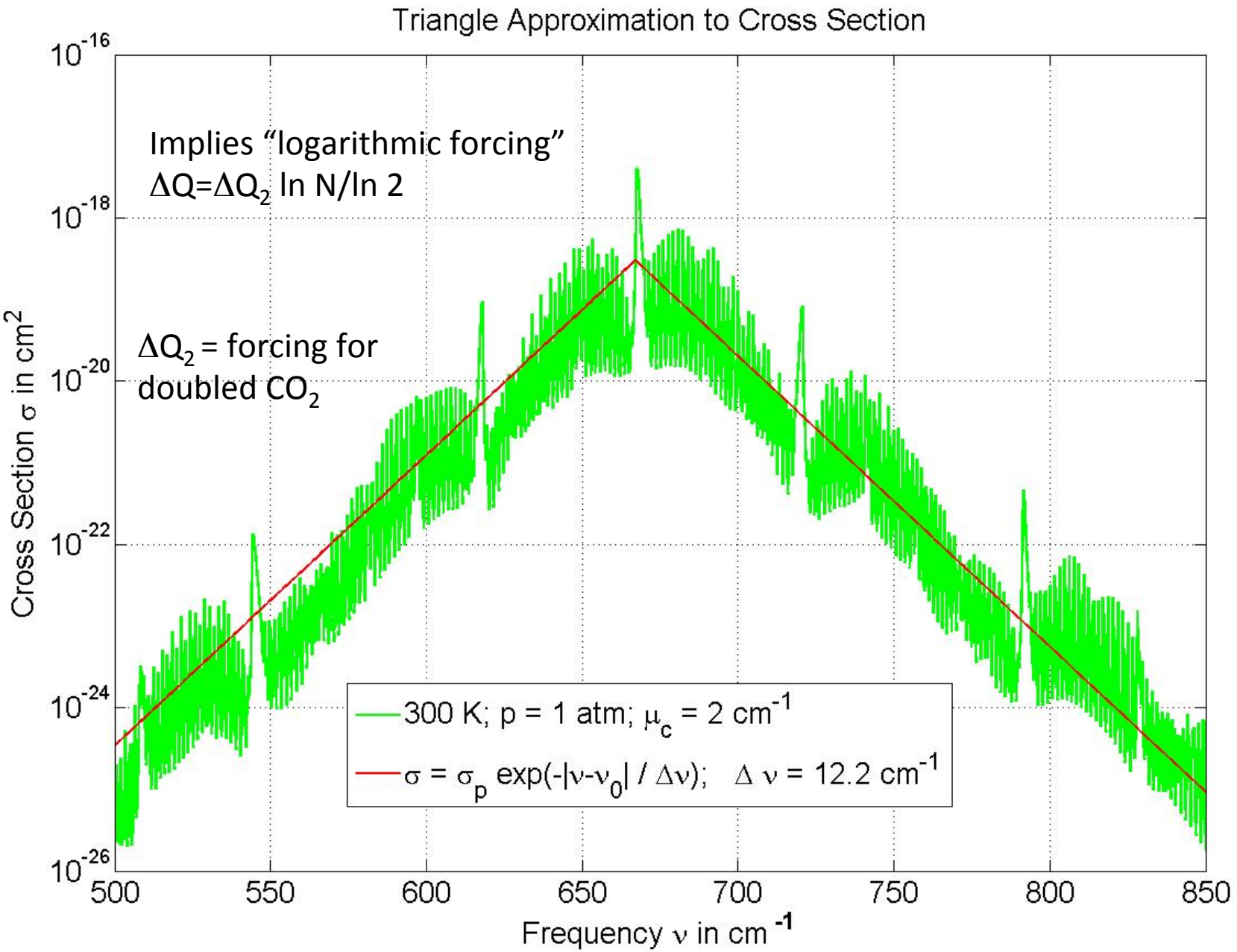
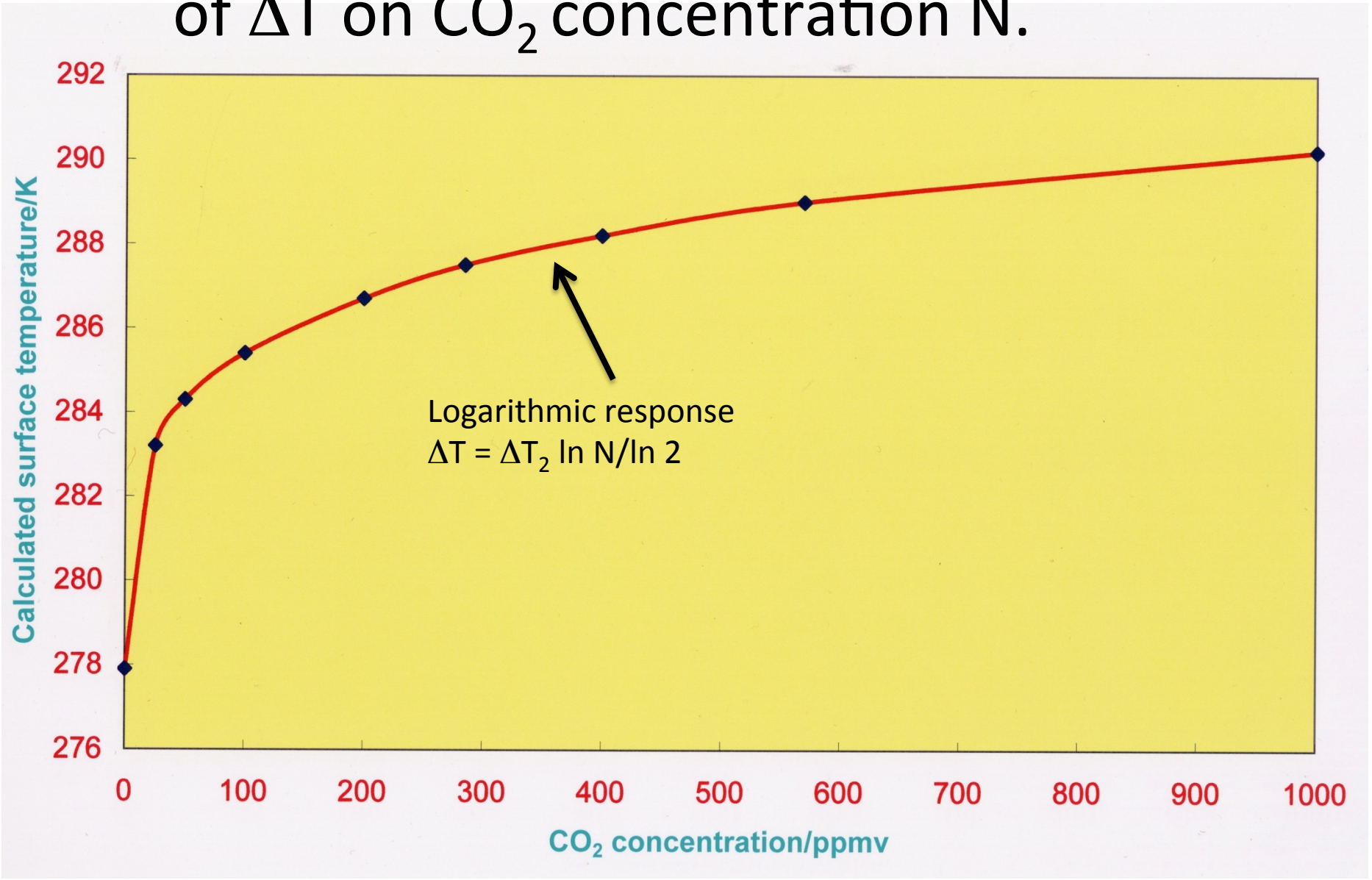
Downwelling, J, in mW (m2 sr cm-1)-1
Frequency ν in cm -1
Pure Voigt
Wing-Suppressed Voigt
Blackbody at 296 K


Triangle Approximation to Cross Section
Implies "logarithmic forcing"
ΔQ=ΔQ2 ln N/ln 2
ΔQ2 = forcing for doubled CO2
300 K; p = 1 atm; μc = 2 cm-1
σ = σp exp(-|ν-ν0| / Δν); Δ ν = 12.2 cm-1
Cross Section σ in cm2
Frequency ν in cm -1
10-16
10-18
10-20
10-22
10-24
10-26
500
550
600
650
700
750
800
850

Representative logarithmic response of ΔT on CO_2 concentration N.



LOGARITHMIC RESPONSE TO CO2 COLUMN DENSITY N

Surface back-radiation from CO2 is very nearly blackbody at surface temperature T_e between upper and lower band limits $\nu_\pm$. Multiplying by π for solid angle we find:

$$Q = \pi \int_{\nu_-}^{\nu_+} B(\nu) d\nu \approx \pi(\nu_+ - \nu_-) B_0, \quad \text{with} \quad B_0 = B(\nu_0).$$

Band-edge frequencies $\nu_\pm$ are where optical depth to space =1.

$$N\sigma(\nu_\pm) = 1 = N\sigma_p e^{-|\nu_\pm - \nu_0|/\Delta\nu}.$$

Take logarithms of both sides of equation to find:

$$\nu_+ - \nu_- = 2\Delta\nu \ln N\sigma_p.$$

Radiative forcing Q and increment ΔQ for doubling N are:

$$Q = 2\pi B_0 \Delta\nu \ln N\sigma_p, \quad \text{and} \quad \Delta Q = 2\pi B_0 \Delta\nu \ln 2 = 7.4 \text{ W m}^{-2}.$$

Numbers are $B_0 = 0.14$ **W m^{-2} str^{-1}**, $\Delta\nu = 12.2$ **cm^{-1}**. Overlap with the pure-rotational band of water vapor eliminates most of the response from the lower band edge, and IR from clouds further reduces the reponse to more CO2. The true response is likely less than half the ideal limit or:

$$\Delta Q \leq 3.7 \text{ W m}^{-2}.$$

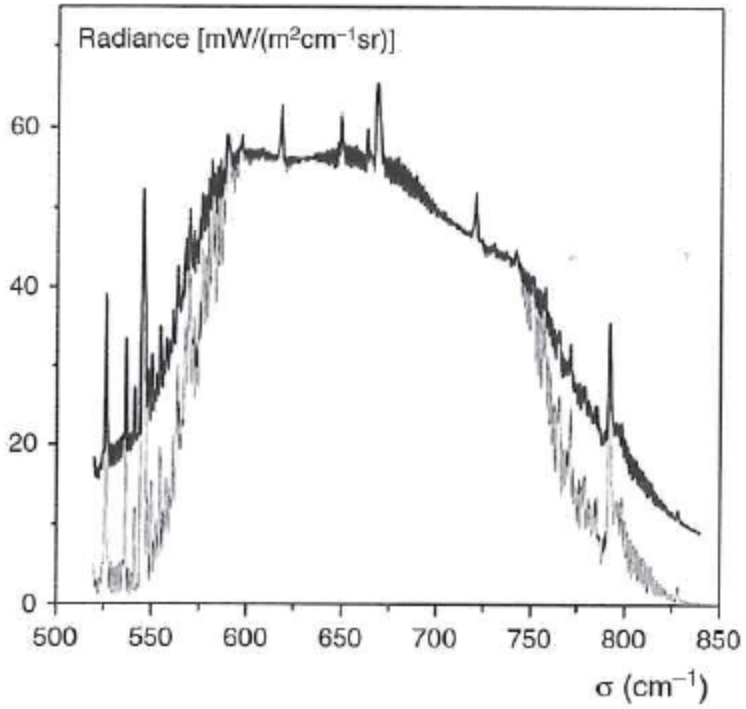
Using Voigt profiles increases the radiative-forcing increment from doubling CO_2 by a factor

~1.4

But far wing absorption from Voigt profiles does not exist!

Need experimental measurements!

Voigt Line Shapes Don't Work in Far Wings!



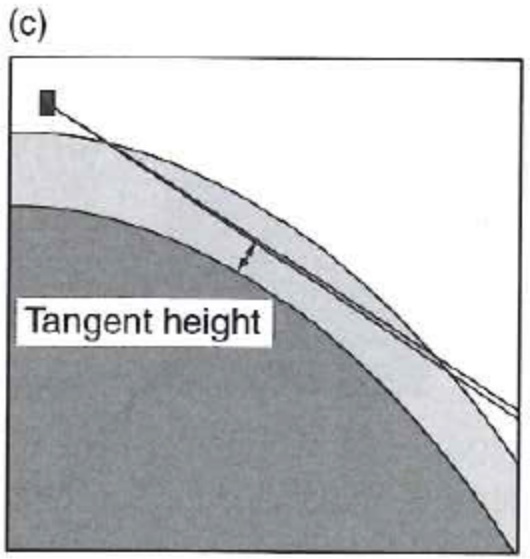


Fig. VII.15: Radiance emitted by the Earth atmosphere in the region of the ν_2 CO_2 band for a 1 cm^{-1} resolution. The thin line gives measured values obtained by a balloon-borne instrument[29] at 40 km altitude looking down to a tangent height of 10 km. The thick line corresponds to predictions using purely Voigt line shapes. After Ref. 603.

Hartmann, Boulet and Robert, *Collisional Effects on Molecular Spectra, Elsevier, 2008*

Climate models are not working! Far-wing lineshapes (forcing ΔQ_2) are one of many possible causes. Clouds (feedback f) probably even more important

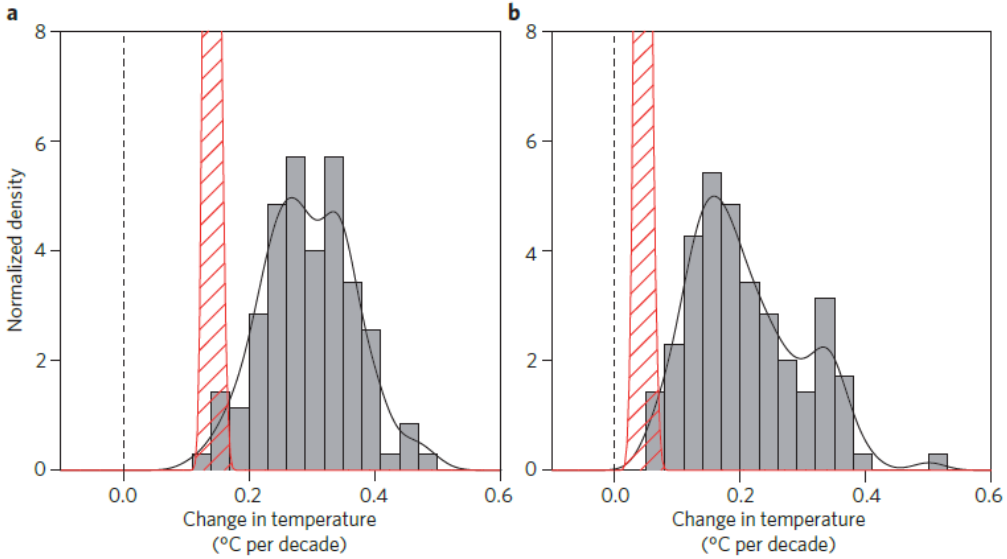


Figure 1 | Trends in global mean surface temperature. **a**, 1993–2012. **b**, 1998–2012. Histograms of

"Science is the belief in the ignorance of experts."

Richard Feynman