12.842 / 12.301 Past and Present Climate
Fall 2008

Climate Physics and Chemistry

Role of the Atmosphere in Climate

(Read Hartmann, Chapters 1 and 2)

Ways by which the atmosphere influences climate:

- Strong effects on radiative transfer, including filtering of ultraviolet radiation
- Large advective and convective heat transfer
- Main driver of ocean circulation
- Important role in biogeochemical cycles

Atmospheric Composition

Gas Name	Chemical Formula	Percent Volume
Nitrogen	N_2	**78.08%**
Oxygen	O_2	**20.95%**
***Water**	H_2O	**0 to 4%**
Argon	Ar	**0.93%**
***Carbon Dioxide**	CO_2	**0.0360%**
Neon	Ne	**0.0018%**
Helium	He	**0.0005%**
***Methane**	CH_4	**0.00017%**
Hydrogen	H_2	**0.00005%**
***Nitrous Oxide**	N_2O	**0.00003%**
***Ozone**	O_3	**0.000004%**

*** variable gases**

Carbon Dioxide Measurements

NOAA CMDL Carbon Cycle Greenhouse Gases

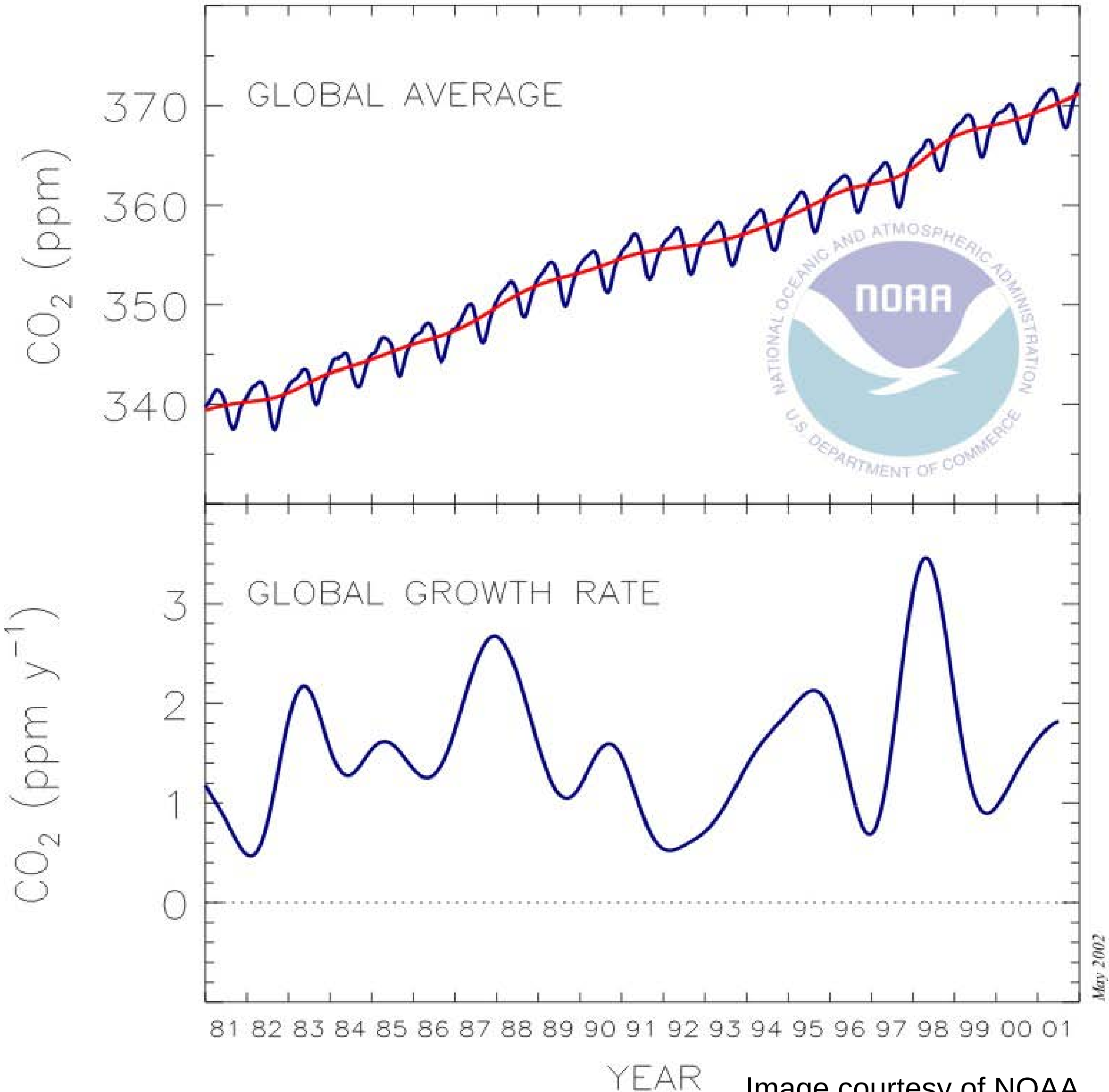


Image courtesy of NOAA.

Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for carbon dioxide. Principal investigator: Dr. Pieter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6278 (ptans@cmdl.noaa.gov, http://www.cmdl.noaa.gov/ccgg).

Methane Measurements

NOAA CMDL Carbon Cycle Greenhouse Gases

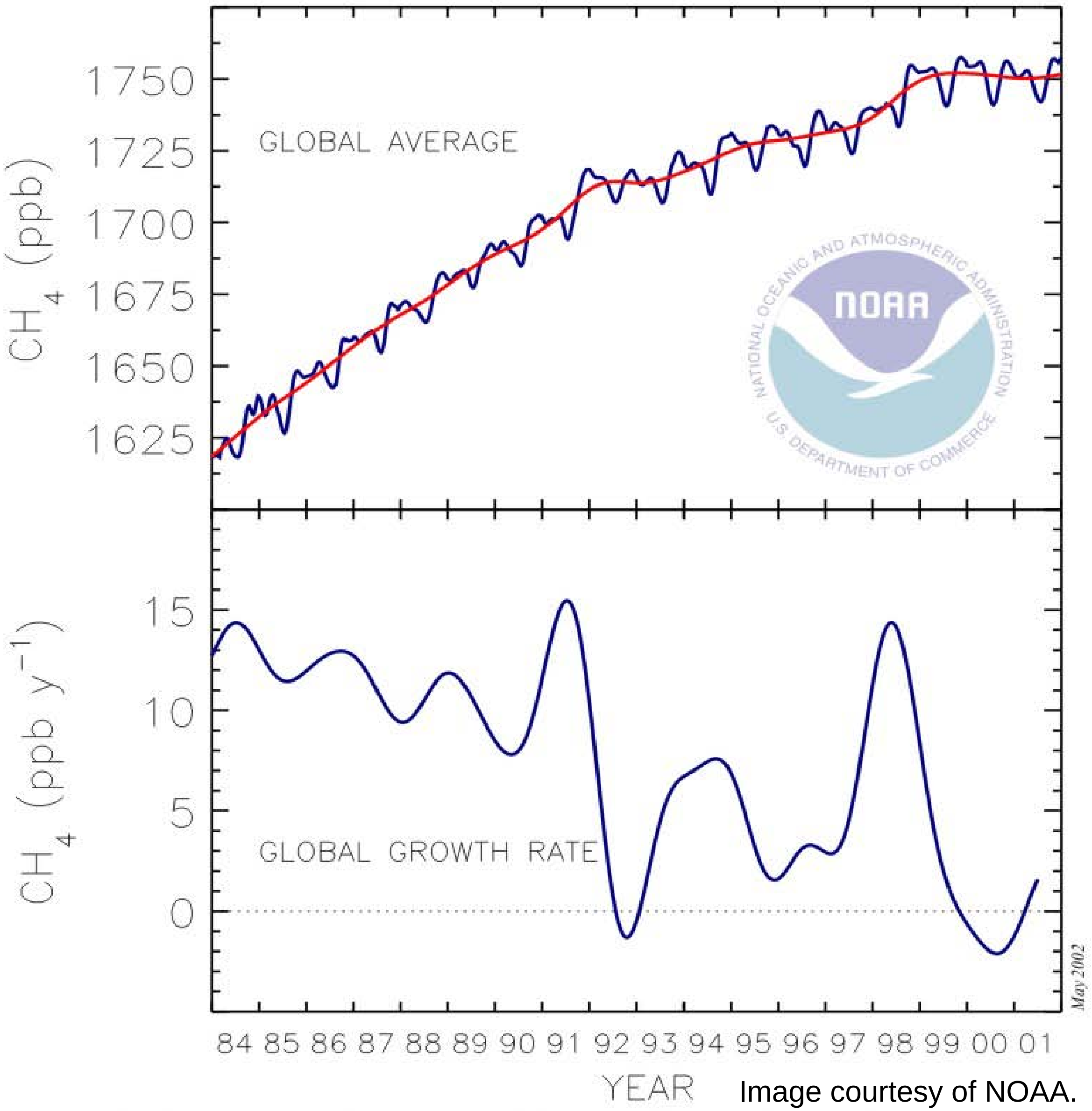
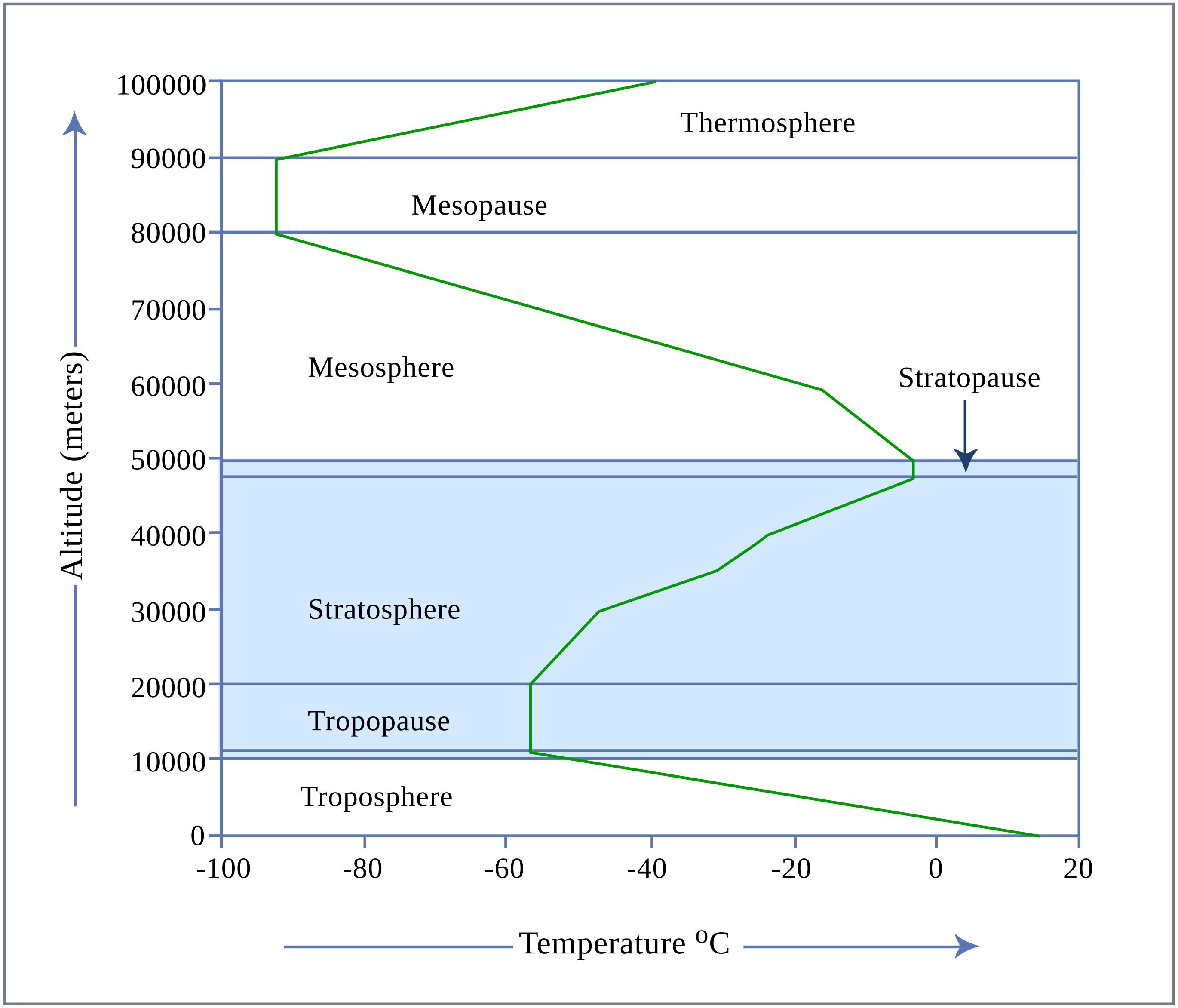


Image courtesy of NOAA.

Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for methane. Principal investigator: Dr. Ed Dlugokencky, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6228 (edlugokencky@cmdl.noaa.gov, http://www.cmdl.noaa.gov/ccgg).



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See Figure 1.6 and Figure 1.7 in Hartmann, Dennis L. *Global Physical Climatology*. Reading, MA: Academic Press, p.411. ISBN: 0123285305.

Elements of Thermal Balance: Solar Radiation

- Luminosity: 3.9×10^{26} J s^{-1} = 6.4×10^{7} Wm^{-2}
  at top of photosphere

- Mean distance from earth: 1.5×10^{11} m
- Flux density at mean radius of earth

$$S_0 \equiv \frac{L_0}{4\pi d^2} = 1370\,Wm^{-2}$$

Stefan-Boltzmann Equation: $F = \sigma T^4$

$\sigma = 5.67 \times 10^{-8}\ Wm^{-2} K^{-4}$

Sun: $\sigma T^4 = 6.4 \times 10^7\ Wm^{-2}$

$\rightarrow \quad T \simeq 6{,}000\, K$

Disposition of Solar Radiation:

$$\text{Total absorbed solar radiation} = S_0\left(1-a_p\right)\pi r_p^{\,2}$$

$$a_p \equiv \text{planetary albedo}\left(\simeq 30\%\right)$$

$$\text{Total surface area} = 4\pi r_p^{\,2}$$

$$\text{Absorption per unit area} = \frac{S_0}{4}\left(1-a_p\right)$$

Absorption by clouds, atmosphere, and surface

Terrestrial Radiation:

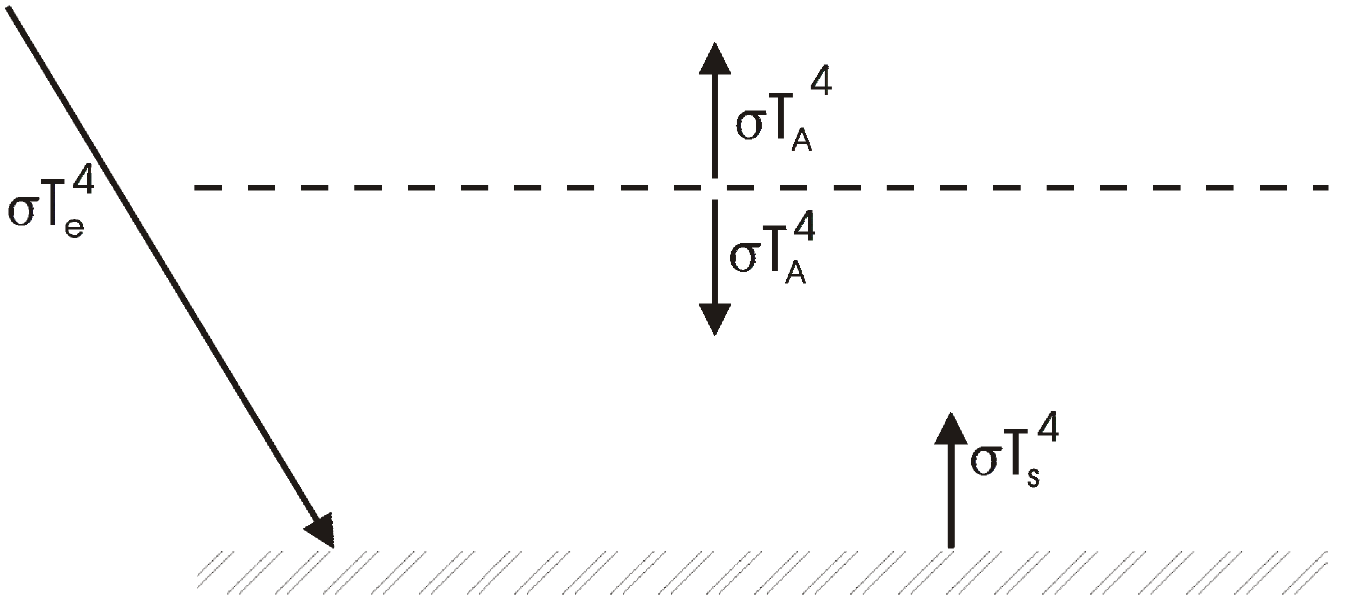
Effective emission temperature:

$$\sigma T_e^{\,4} \equiv \frac{S_0}{4}\left(1 - a_p\right)$$

Earth: $T_e = 255K = -18°C$

Observed average surface temperature $= 288K = 15°C$

Highly Reduced Model



- Transparent to solar radiation
- Opaque to infrared radiation
- Blackbody emission from surface and each layer

Radiative Equilibrium:

Top of Atmosphere:

$$\sigma T_A^{\,4} = \frac{S_0}{4}\left(1 - a_p\right) = \sigma T_e^{\,4}$$

$$\rightarrow \quad \boxed{T_A = T_e}$$

Surface:

$$\sigma T_s^{\,4} = \sigma T_A^{\,4} + \frac{S_0}{4}\left(1 - a_p\right) = 2\sigma T_e^{\,4}$$

$$\rightarrow \boxed{T_s = 2^{1/4} T_e} = 303\,K$$

Surface temperature too large because:

- Real atmosphere is not opaque
- Heat transported by convection as well as by radiation

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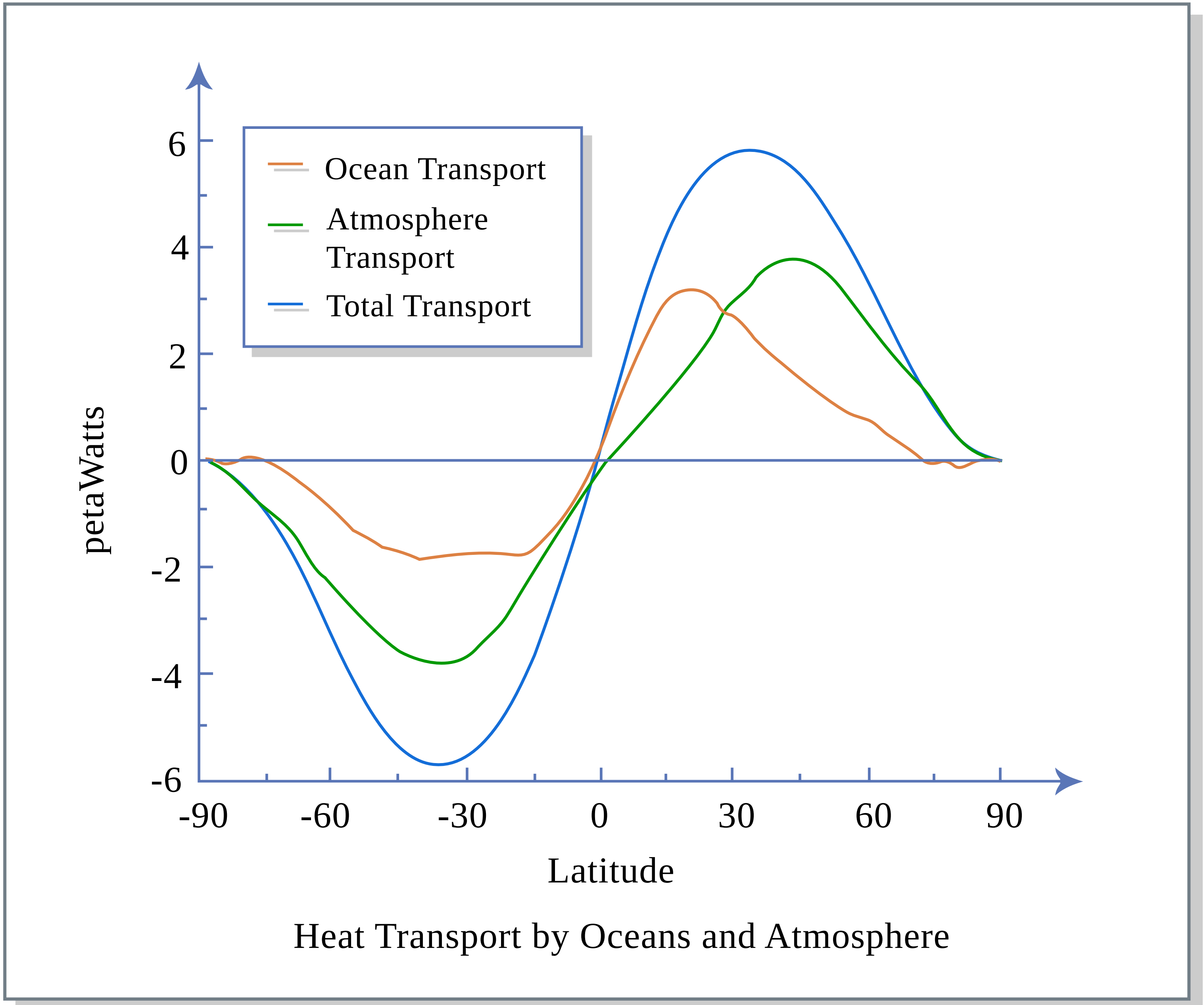

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