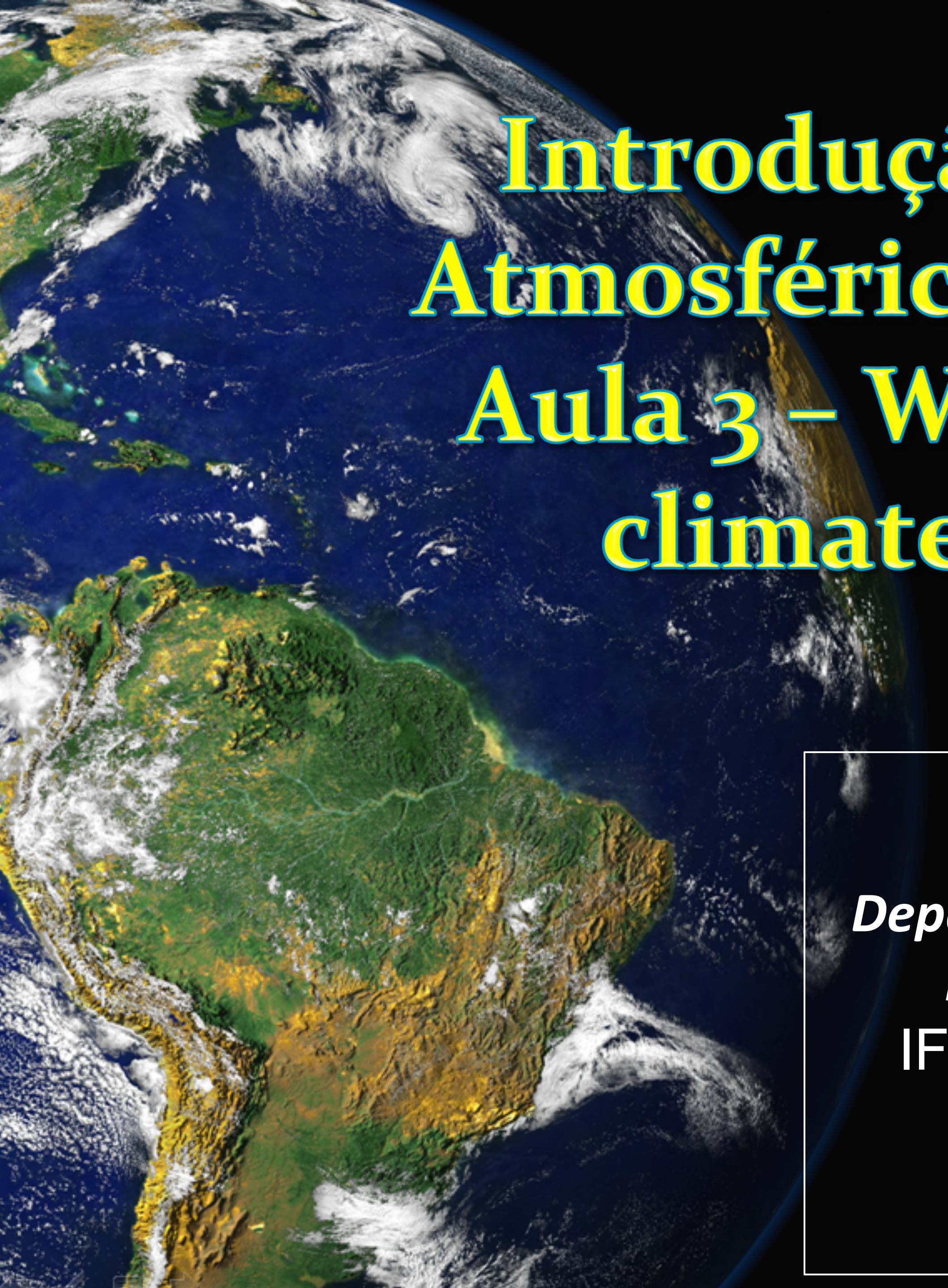

# Introdução a Física Atmosférica - PGF-3521 Aula 3 – Water in the climate system


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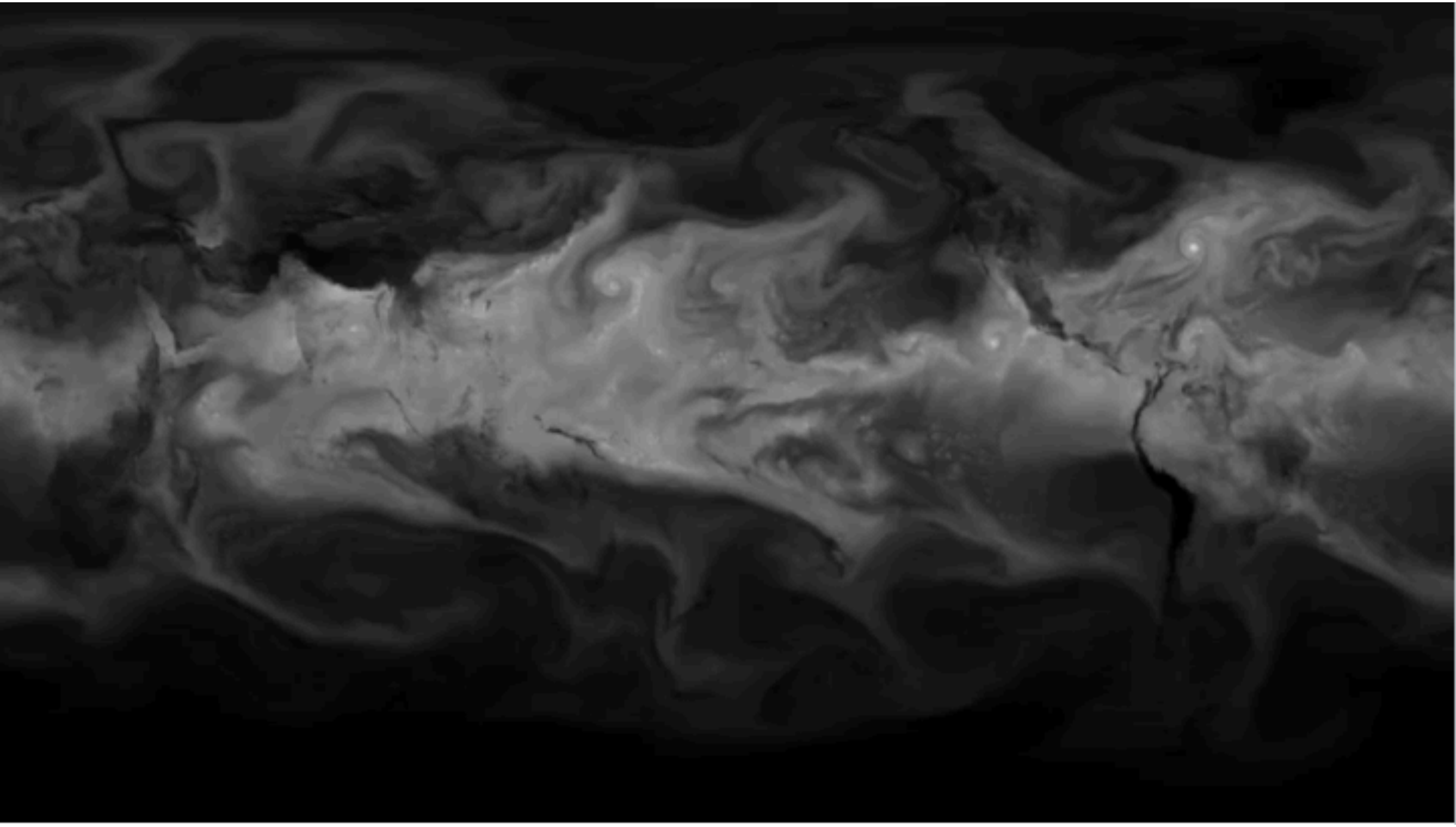
# Water in the climate system

Its physical properties determine

- How strong greenhouse effect is;
- Planetary albedo;
- Thermodynamic structure of the troposphere;
- Large scale circulation;
- Hydrological cycle;

# Total column water vapor



GEOS-5 http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=3811

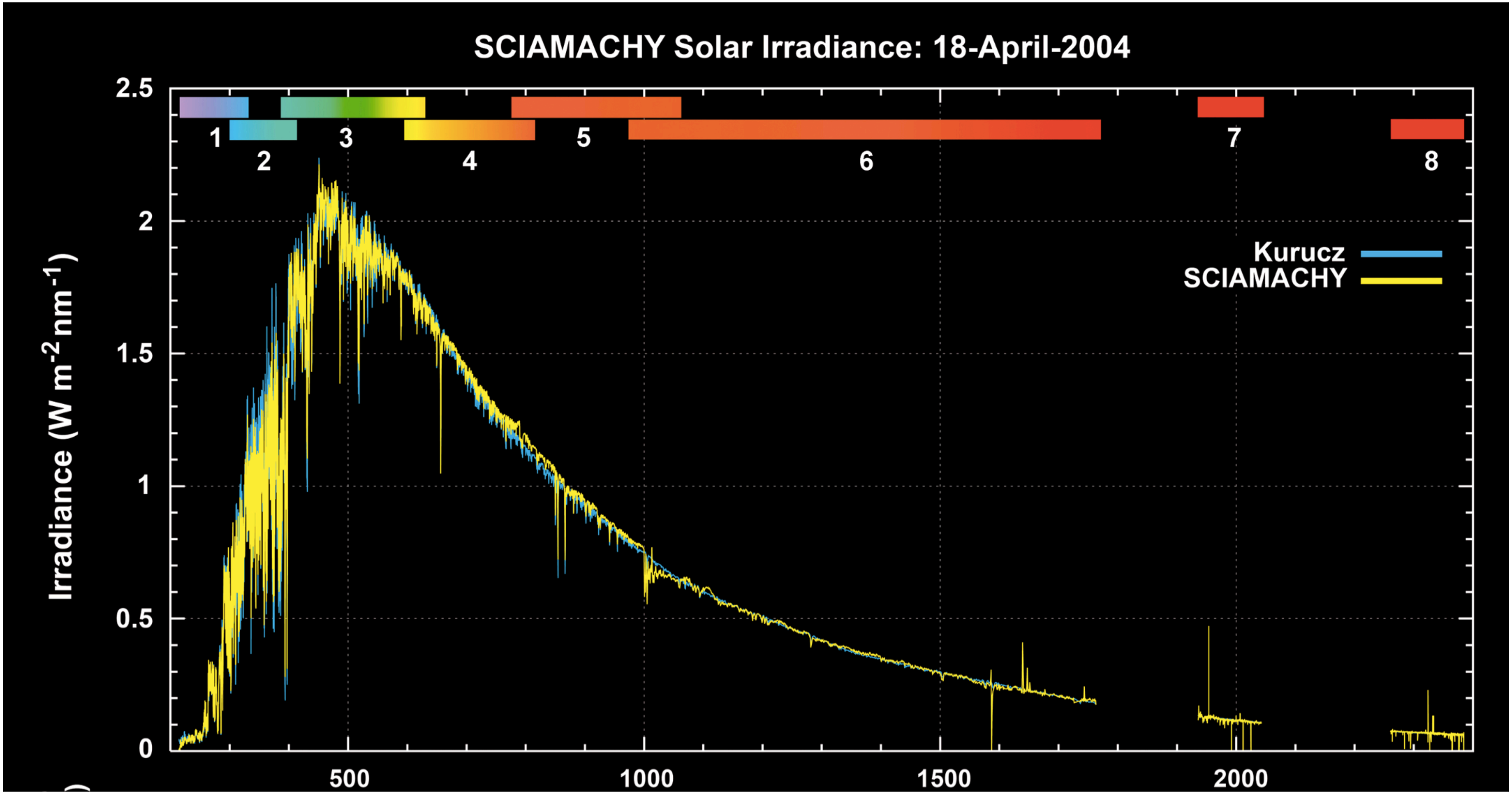
# Water is rare

Water in the atmosphere, be it vapor, liquid or solid, is the least likely place to find a water molecule in the climate system.

| $H_2O$ | Equivalent in meters |
|---|---|
| Liquid or solid water in the atmosphere | 0.0001 m |
| Vapor in the atmosphere | 0.025 m |
| Water in soil, lakes, rivers and glaciers | 50 to 75 m |
| Oceans | 2800 m |

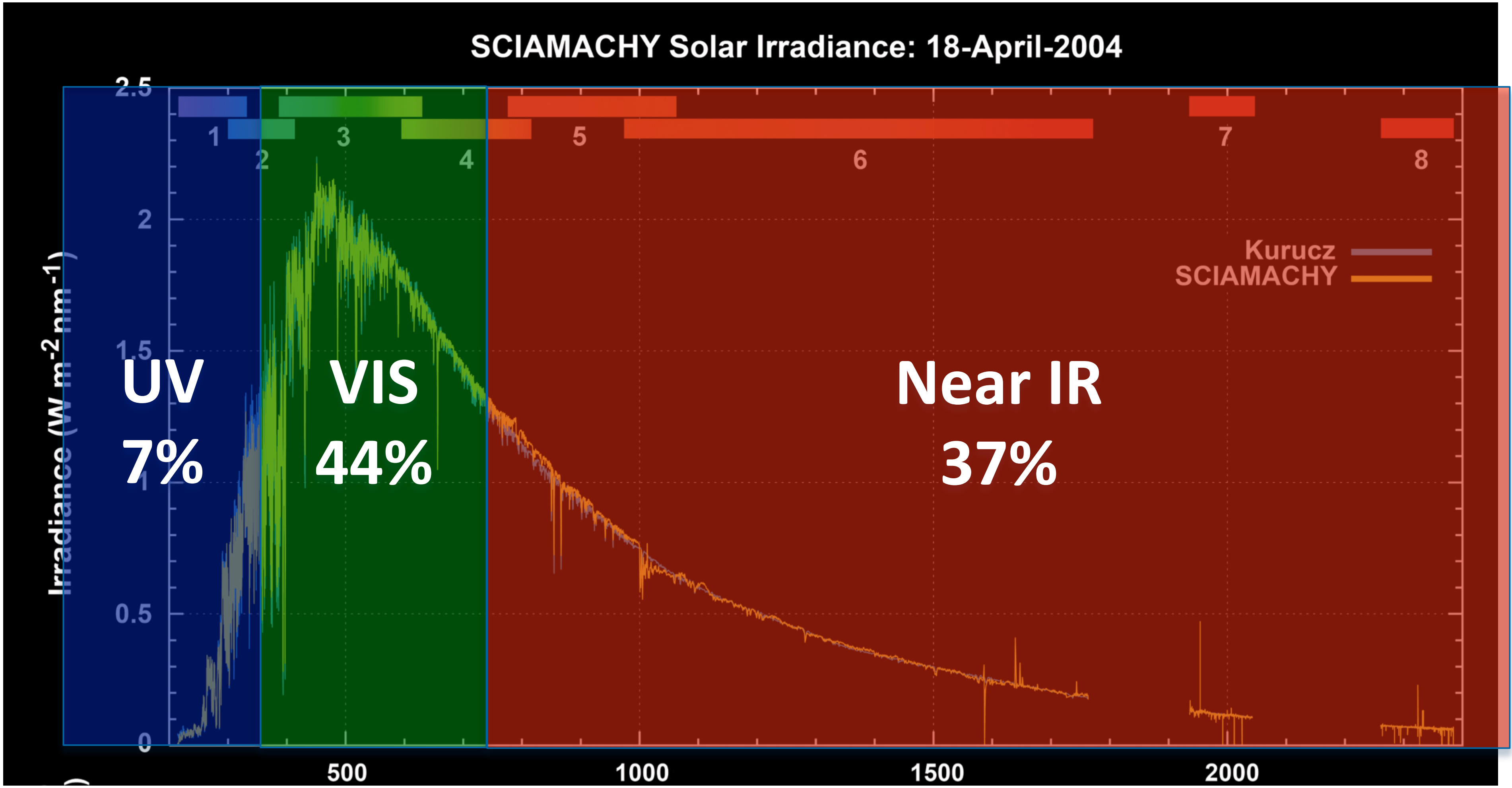
Its important role steams from its radiative properties

# Observed Solar Spectrum




BOOK: SCIAMACHY - Exploring the Changing Earth's Atmosphere
http://atmos.caf.dlr.de/projects/scops/

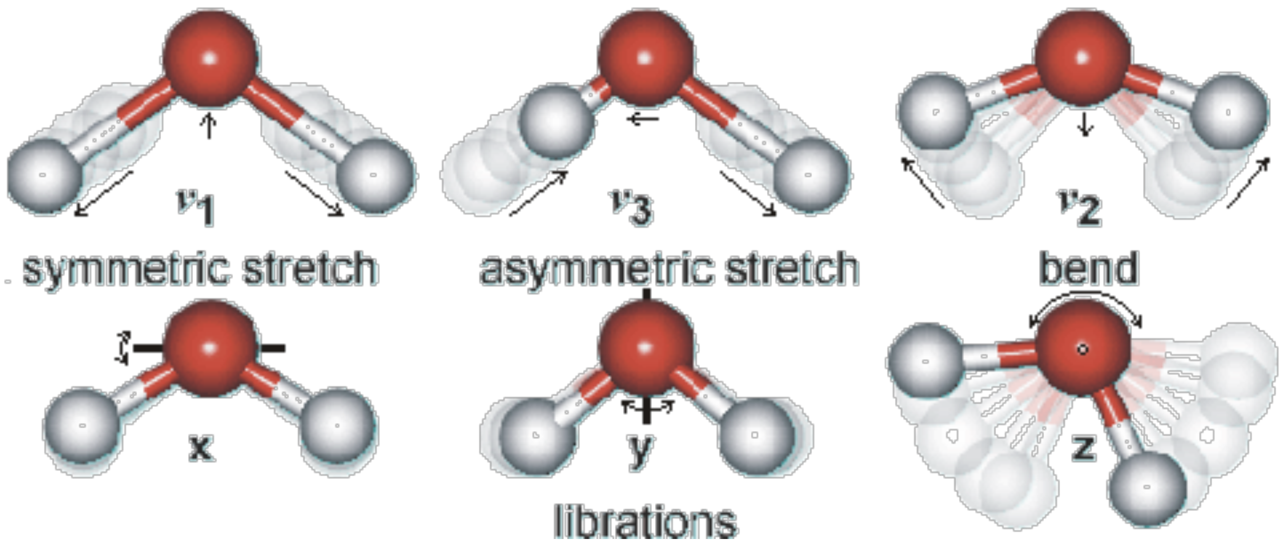
# $S_0 \sim 1365\ W/m^2$




BOOK: SCIAMACHY - Exploring the Changing Earth's Atmosphere
http://atmos.caf.dlr.de/projects/scops/

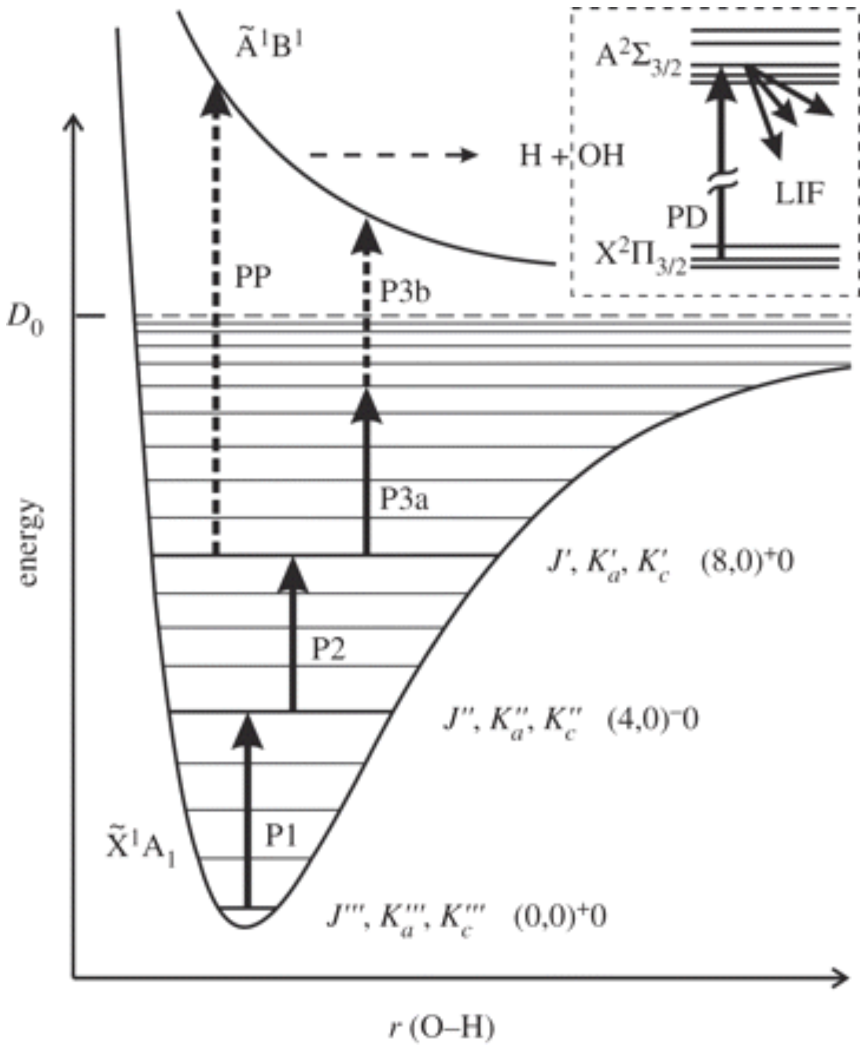
# $H_2O$ vibration and rotation

- The water molecule has a very small moment of inertia on rotation which gives rise to rich combined vibrational-rotational spectra in the vapor containing tens of thousands to millions of absorption lines.




http://www1.lsbu.ac.uk/water/water_vibrational_spectrum.html

# Energy levels




- Energy-level diagram of double- and triple-resonance vibrational overtone excitation (photons P1–P3a) followed by photodissociation (dashed arrows, photons P3b or PP) and OH fragment

MAKSYUTENKO, Phil. Trans. R. Soc. A (2012) doi:10.1098/rsta.2011.0277

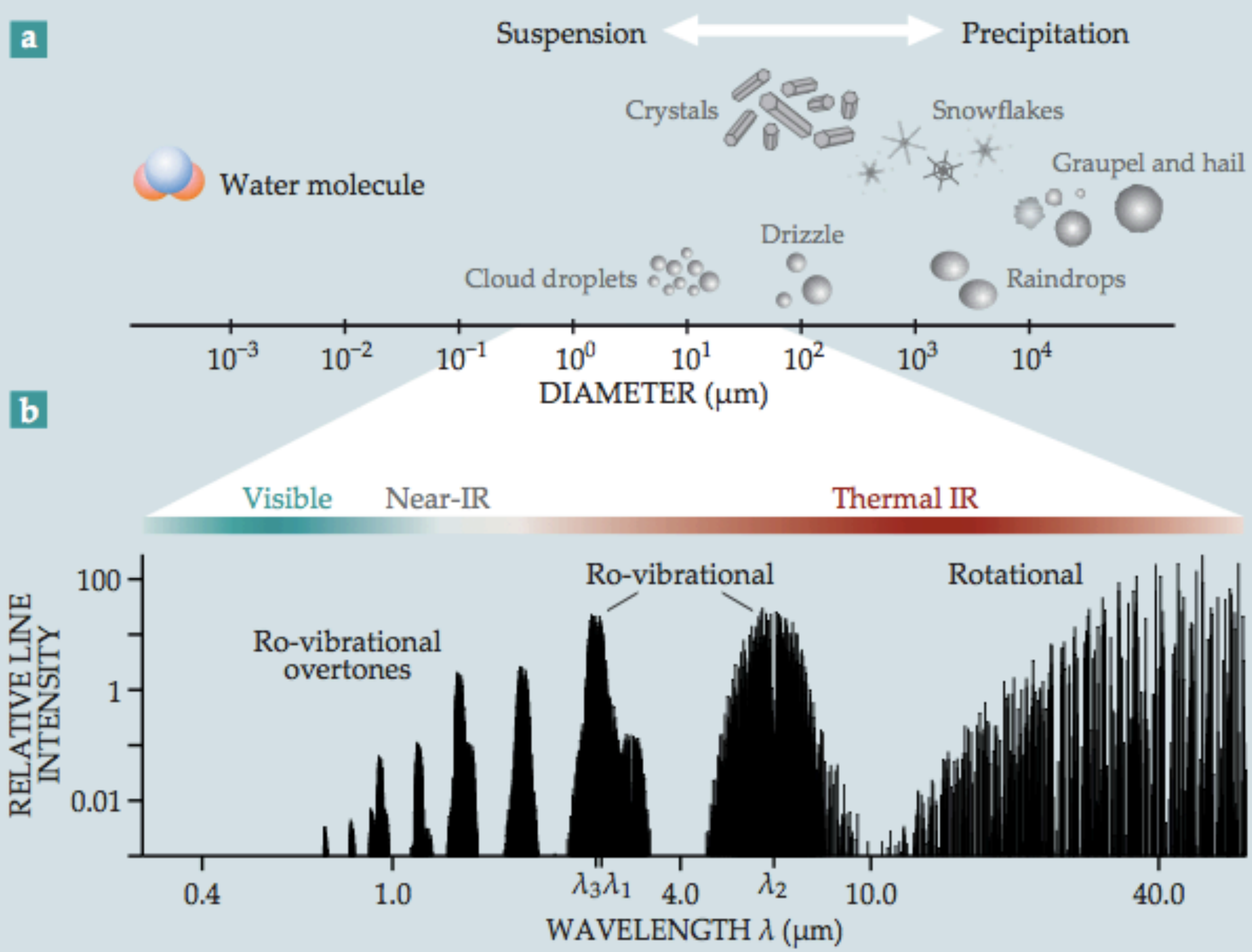



**Figure 1. Hydrometeors (a)**, the condensed forms of water in the atmosphere, come in several sizes. They mostly scatter visible light but absorb over a broad range of the IR. **(b)** The near- and thermal-IR regions of the spectrum excite the molecule and produce its rotational–vibrational (or ro-vibrational) and rotational bands. Specific lines $\lambda_1$, $\lambda_2$, and $\lambda_3$ mark the symmetric stretching mode, bending mode, and asymmetric stretching mode, respectively.

Stevens & Bony, Physics Today 2013

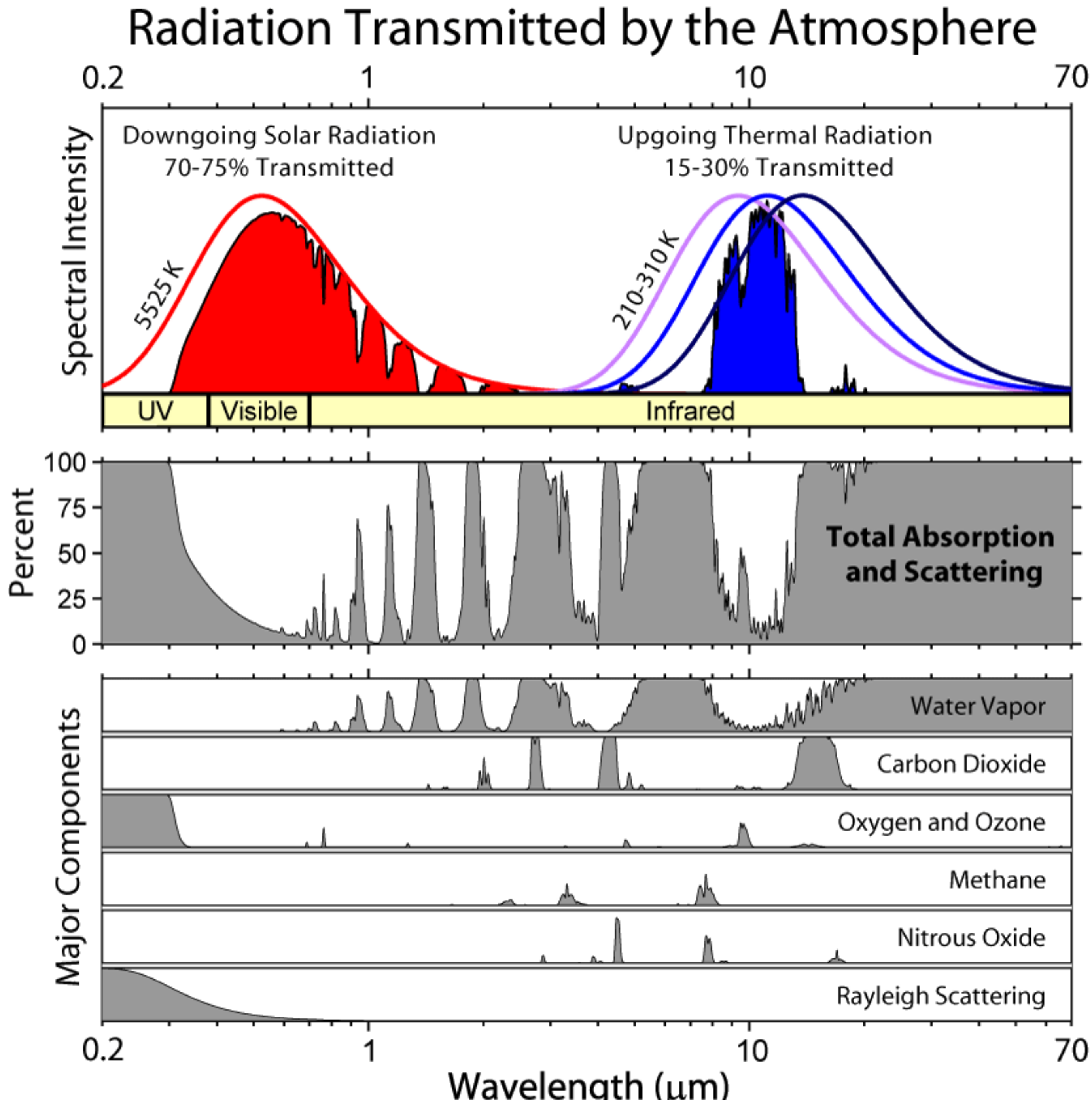
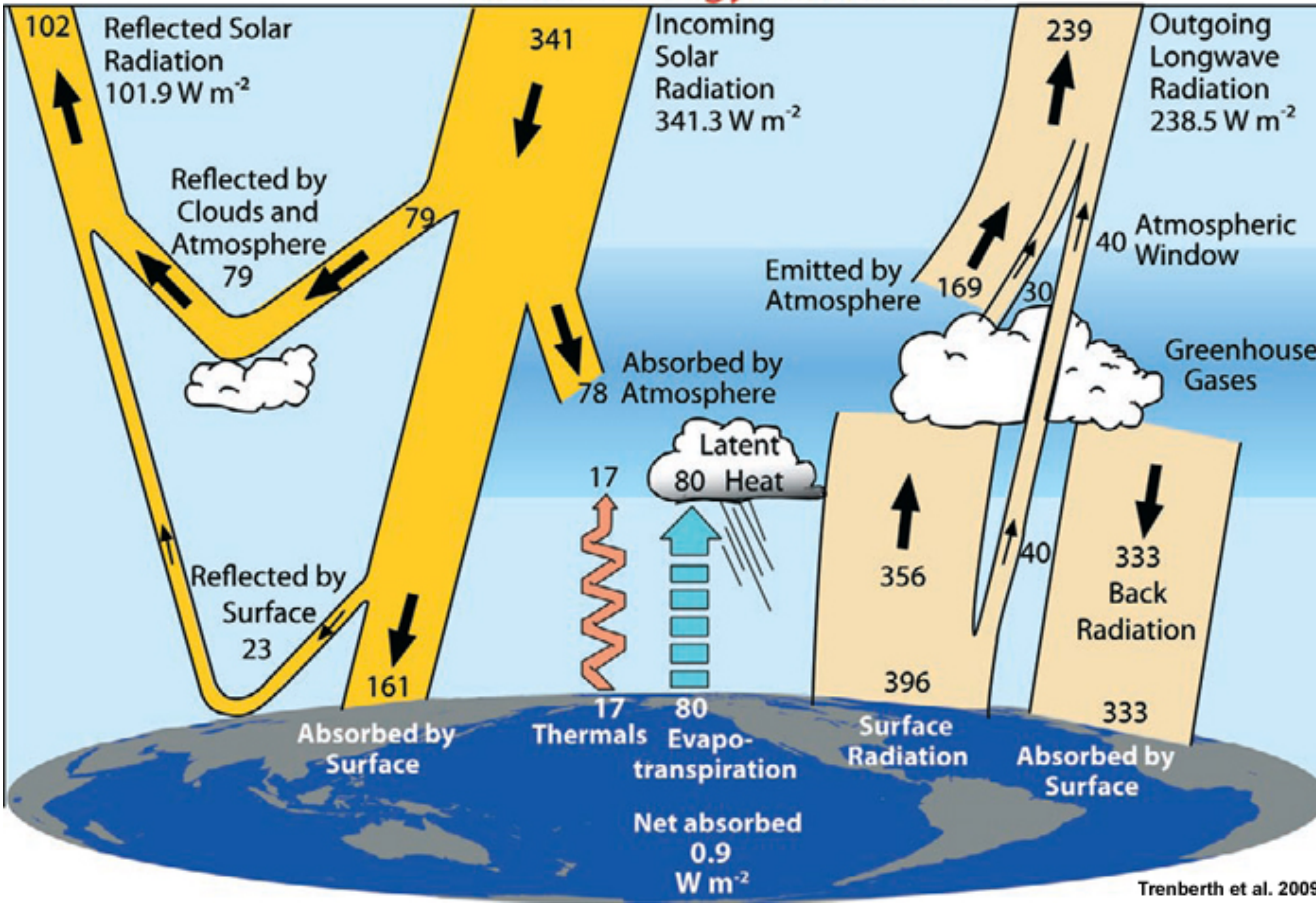



Image by:
Robert A. Rohde
Global Warming Art.

# Global Energy Flows W m$^{-2}$

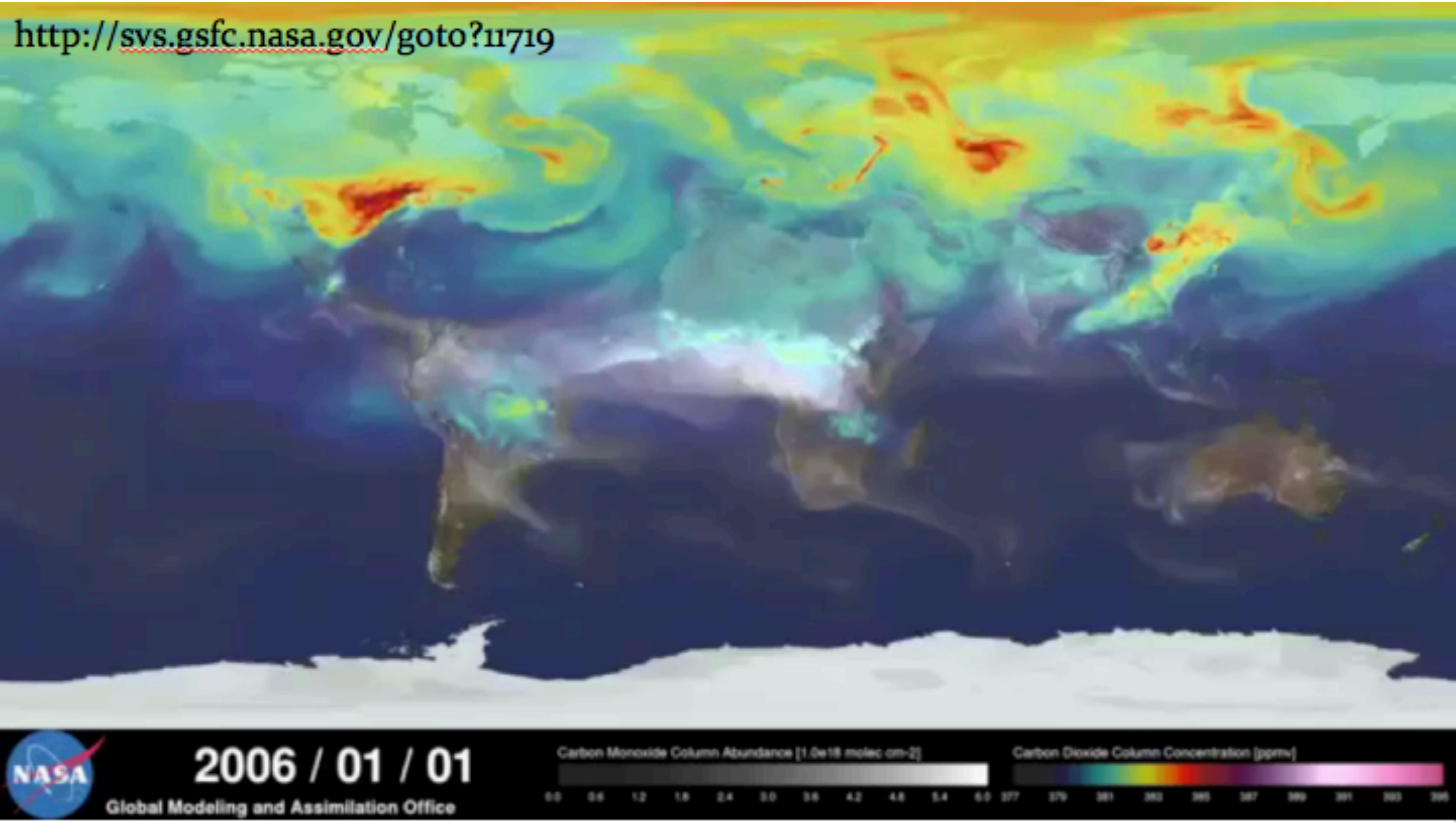


# Natural Greenhouse effect

| | Radiative efficiency (W m$^{-2}$/ppb) | Pre industrial conc. | Natural Greenhouse effect (W m$^{-2}$) | | Concentration in 2011 | Antrop. Forcing (W m$^{-2}$) |
|---|---|---|---|---|---|---|
| $H_2O$ | | | 75 | **51** | | |
| $CO_2$ | $1.37\ 10^{-5}$ | 278±2 ppm | 32 | **24** | 390.4±0.2 ppm | 1.82 |
| $O_3$ | | | 10 | **7** | | 0.35 |
| $CH_4$ | $3.63\ 10^{-4}$ | 722±25 ppb | 8 | **4** | 1803.2±1.2 ppb | 0.48 |
| $N_2O$ | $3.03\ 10^{-3}$ | 270±7 ppb | | | 324.3±0.1 pbb | 0.17 |
| $CF_4$ | 0.1 | 34.7±0.2 ppt | | | 79.0±0.1 ppt | 0.0041 |
| Outros | | | | | | 0.01 |
| Total | | | 125 | **86** | | 2.83 |

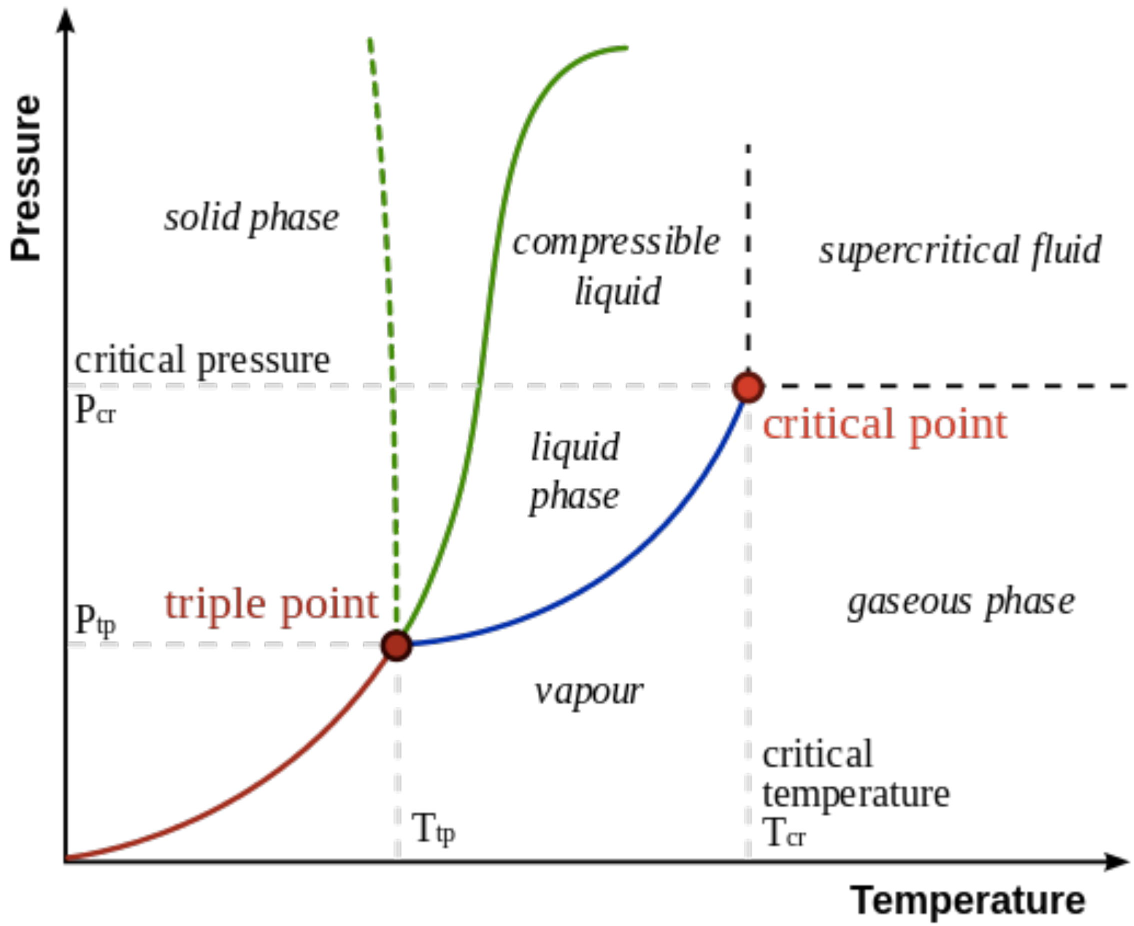
Hartmann et al, IPCC (WG-I) 2013
Kiehl and Trenberth, BAMS, 1997

# $H_2O$ is not a forcing because it is not directly emitted as $CO_2$



# Vapor phase diagram

- Vapor refers to a gas phase at a temperature where the same substance can also exist in the liquid or solid state, below the critical temperature of the substance.
- $T_{cr}(H_2O) = 374$ °C
- $T_{tp}(H_2O)=0.01$ °C



# Water vapor partial pressure

Clausius-Clapeyron:

$$\frac{\mathrm{d}e_s}{\mathrm{d}T} = \frac{L_v(T)e_s}{R_v T^2}$$

Saturation vapor pressure:

$$e_s(T) = 6.1094 \exp\left(\frac{17.625T}{T + 243.04}\right)$$

http://earthsci.org/processes/weather/weaimages/weaimages.html

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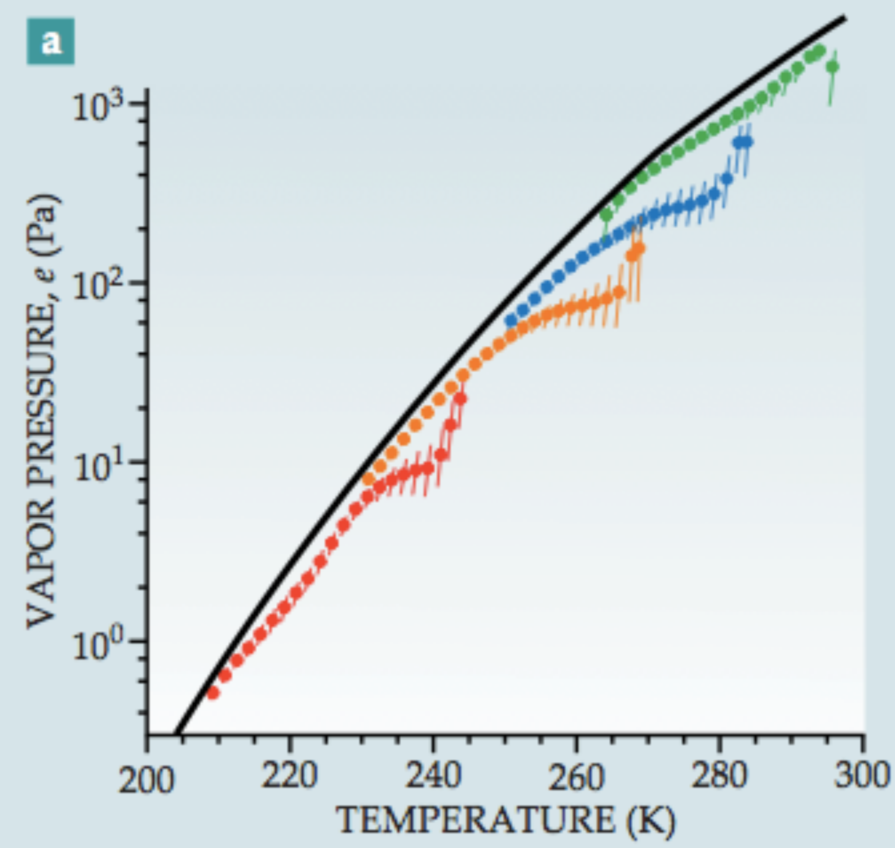
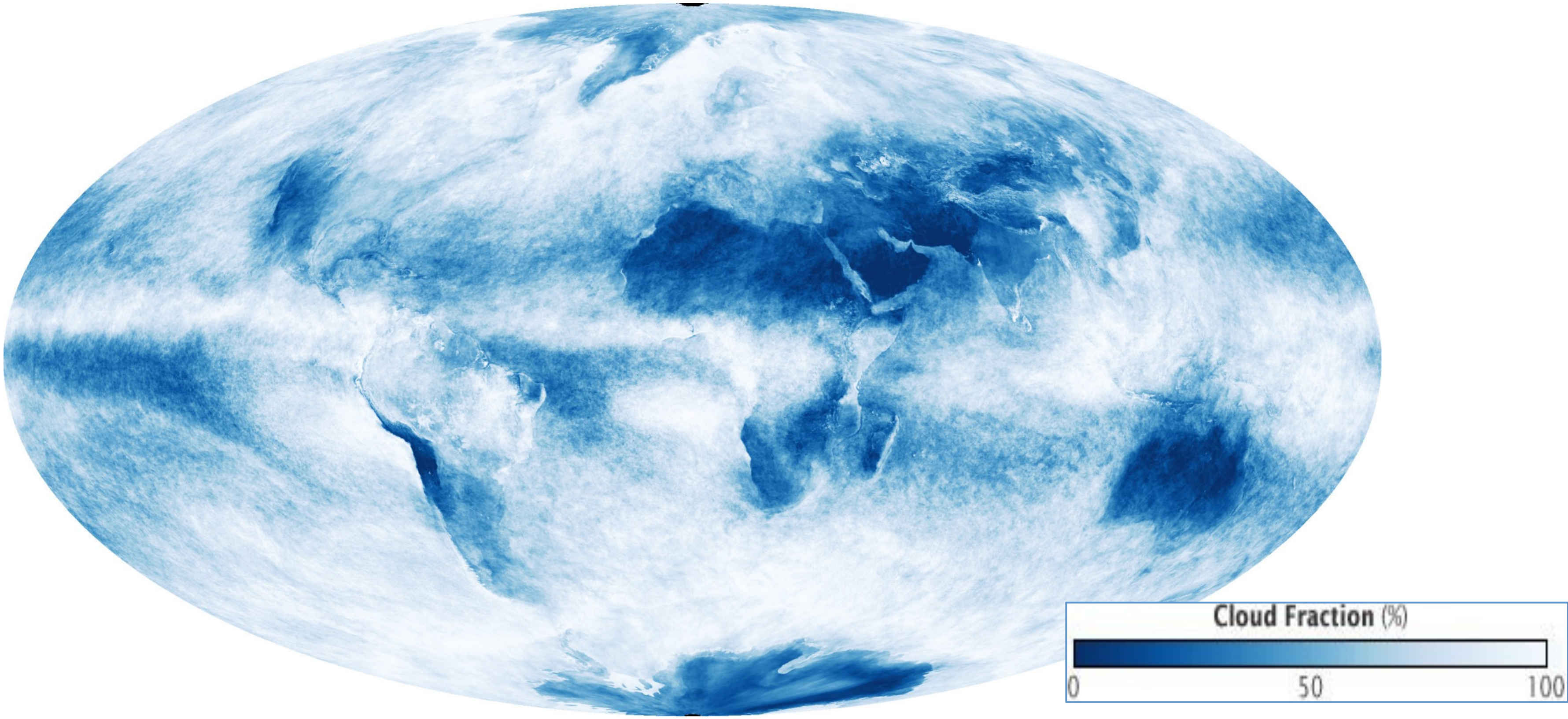



**Figure 2. The atmospheric vapor pressure** as a function of temperature **(a)** is bounded by the atmosphere's vapor pressure when saturated with water (solid line). The data are shown as the median (dot) and range (error bar) of 228 monthly values at different isobaric levels—900 hPa (green), 700 hPa (blue), 500 hPa (orange), and 300 hPa (red). (Data are provided by the European Centre for Medium-Range Weather Forecasts.) **(b)** Based on satellite measure-

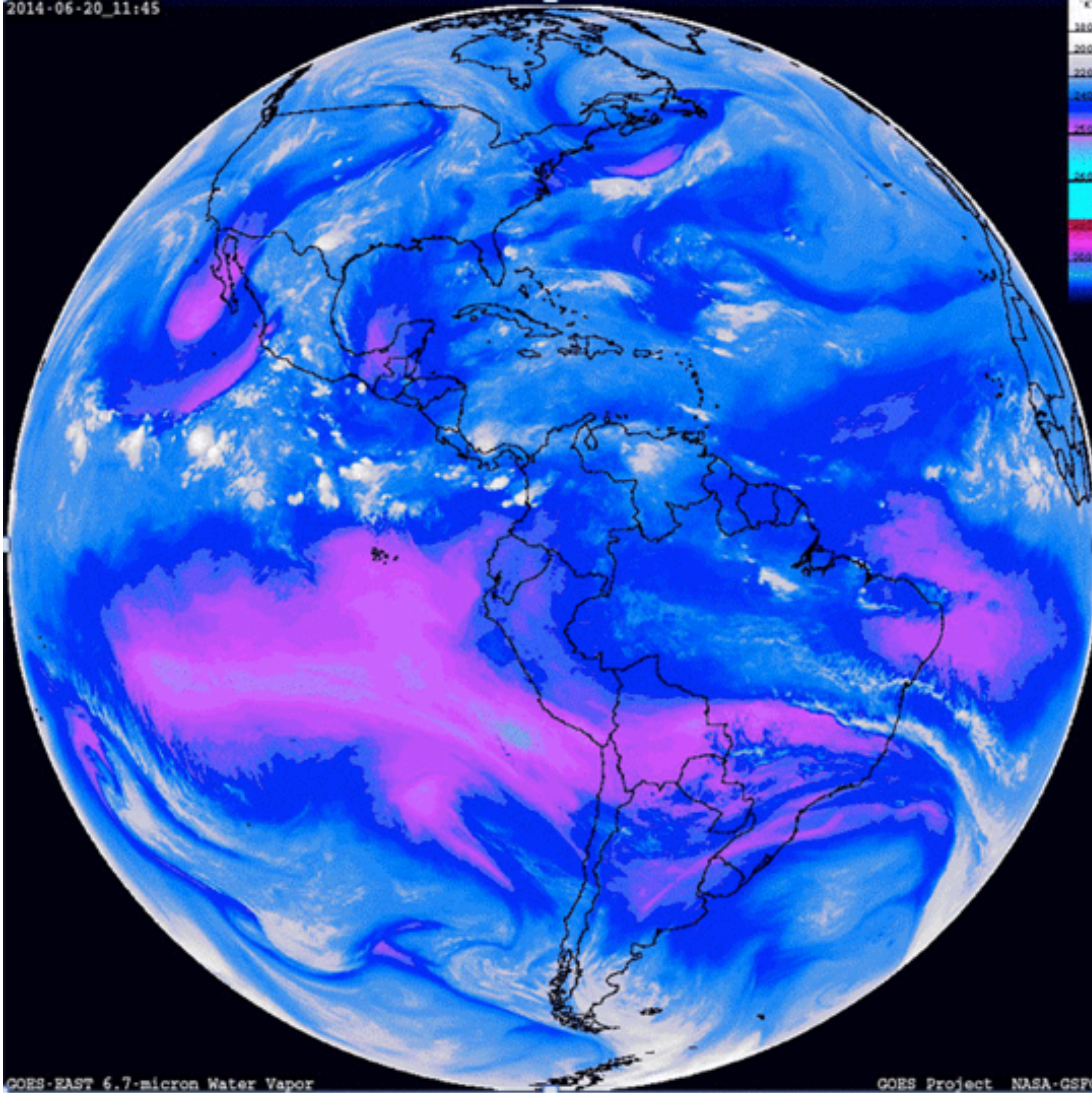
Stevens & Bony, Physics Today 2013

http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MODAL2_M_CLD_FR

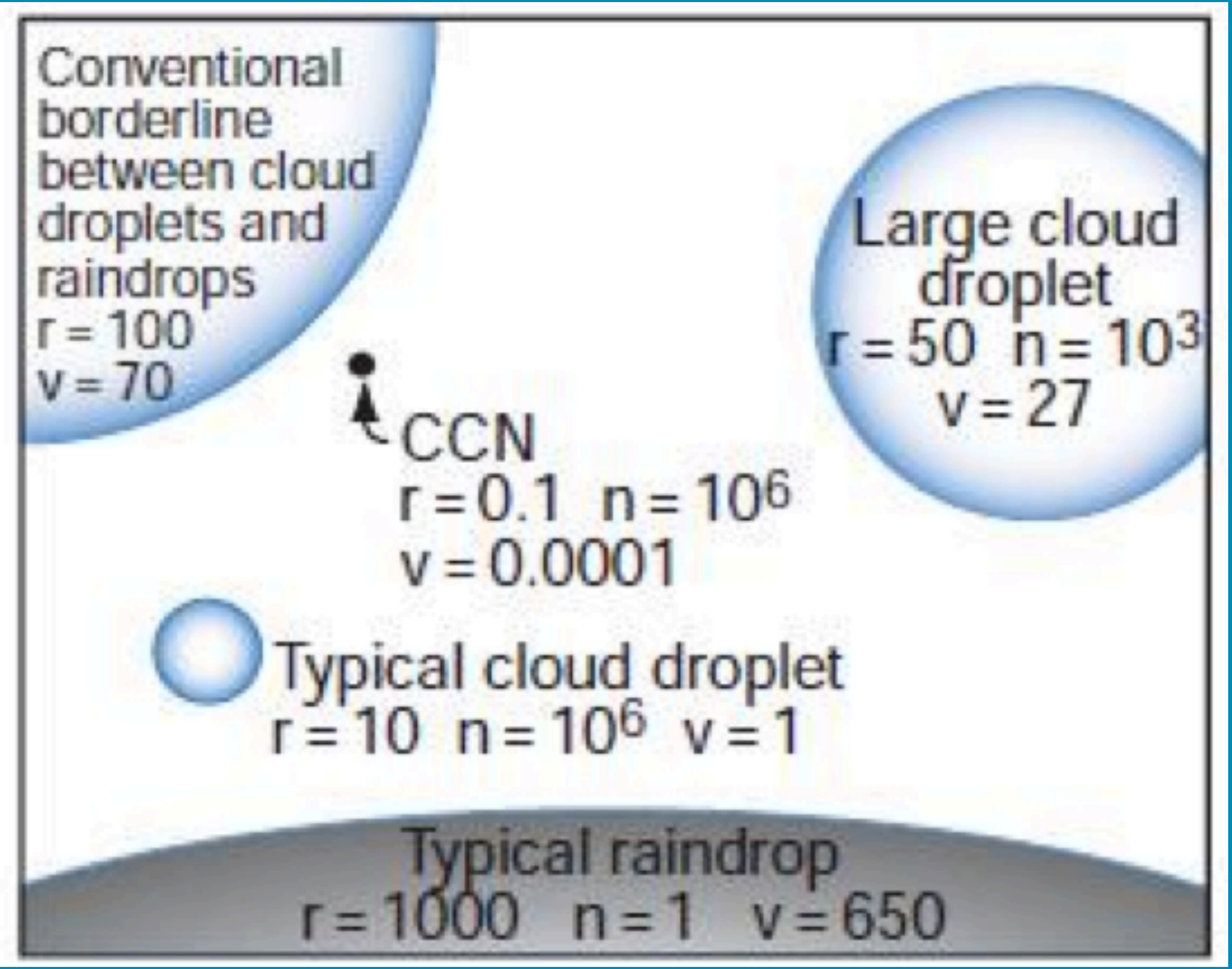



| | Cloud density | | | |
|---|---|---|---|---|
| | Thin | Thick | Opaque | |
| Cloud level | $N\varepsilon < 0.5$ | $0.5 < N\varepsilon < 0.95$ | $N\varepsilon > 0.95$ | All densities |
| | $\sigma_{vis} < 1.4$ | $1.4 < \sigma_{vis} < 6$ | $\sigma_{vis} > 6$ | |
| High (<440 mb) | 15% | 15% | 3% | 33% |
| Middle (440–700 hPa) | 7% | 10% | 9% | 26% |
| Low (>700 hPa) | | 2% | 47% | 49% |
| Total | 20% | 23% | 32% | 75% |

NOAA HIRS 1979-2001, Wylie et al, J. Clim. 2005 http://www.nasa.gov/content/goddard/a-new-view-nasanoaa-water-vapor-animations-over-oceans



# 6 orders of magnitude in volume



# Clouds (liq/ice) strongly interact with SW and LW radiation

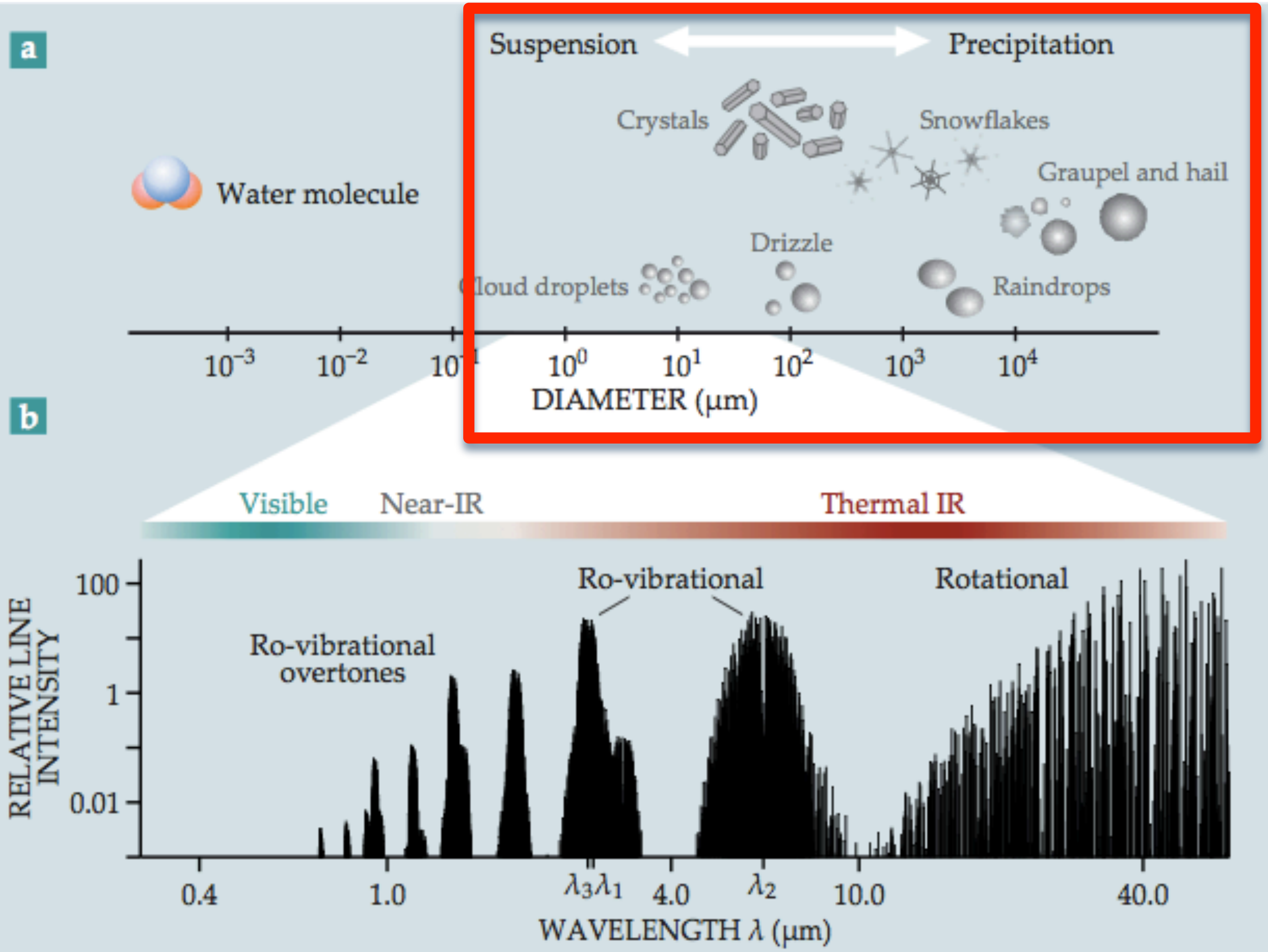
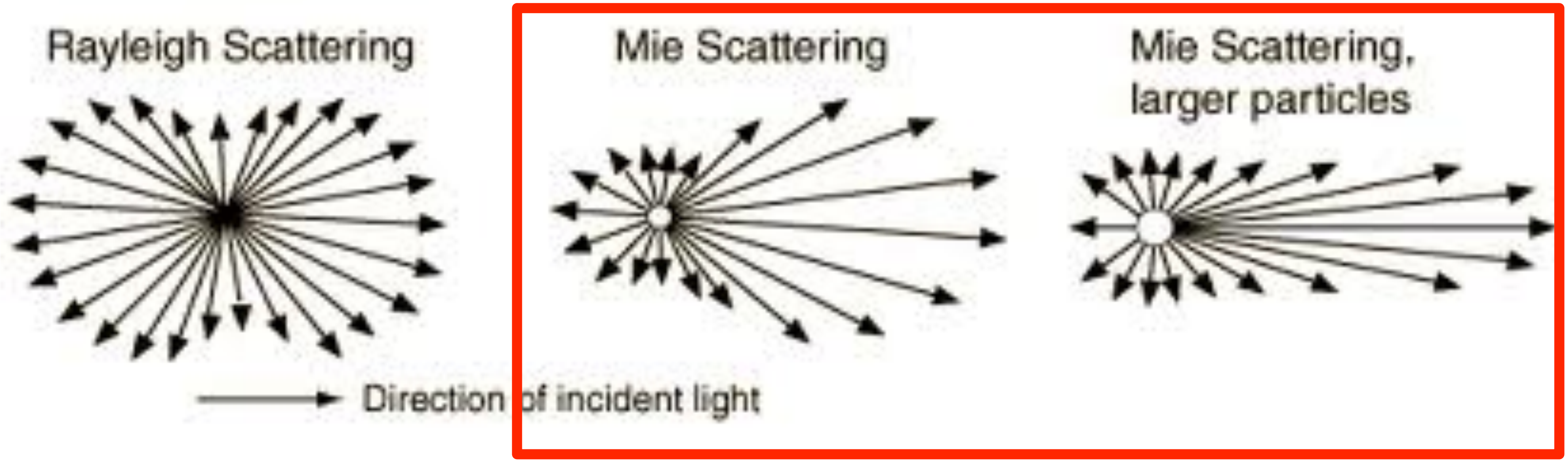



**Figure 1. Hydrometeors (a)**, the condensed forms of water in the atmosphere, come in several sizes. They mostly scatter visible light but absorb over a broad range of the IR. **(b)** The near- and thermal-IR regions of the spectrum excite the molecule and produce its rotational–vibrational (or ro-vibrational) and rotational bands. Specific lines $\lambda_1$, $\lambda_2$, and $\lambda_3$ mark the symmetric stretching mode, bending mode, and asymmetric stretching mode, respectively.

Stevens & Bony, Physics Today 2013

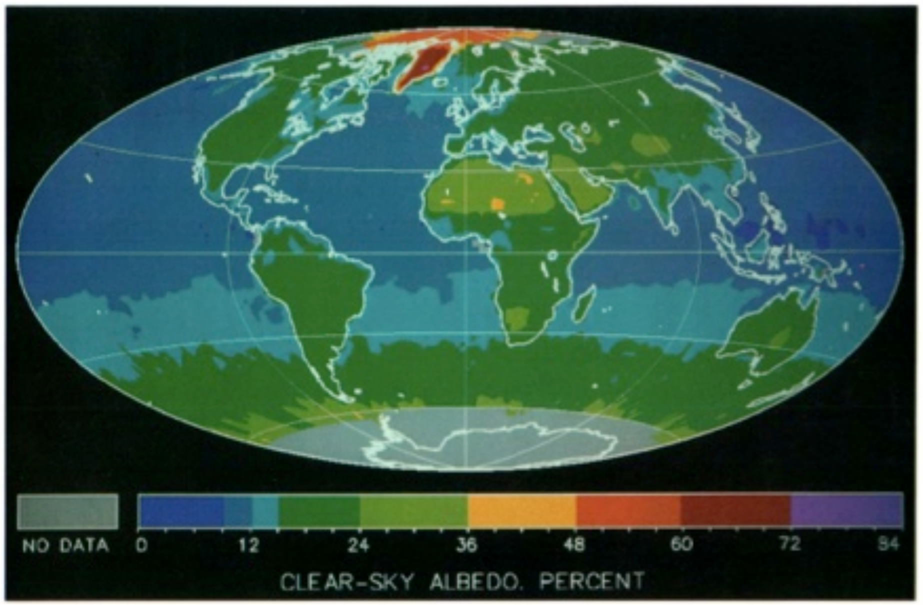
# Particles are very complicated

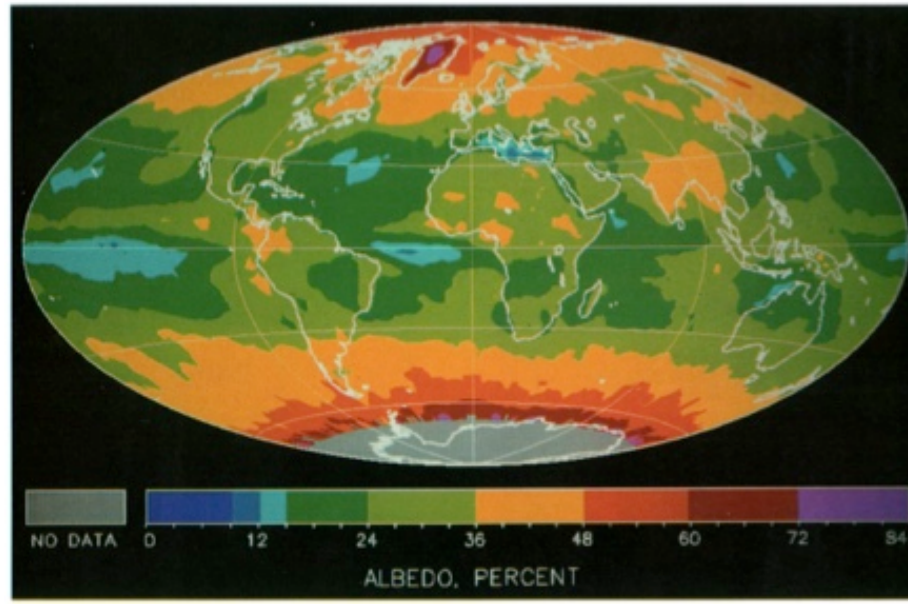
- Classical electromagnetism
  - Rayleigh scattering - molecules
  - Mie scattering – aerosol and droplets




**Size << λ** **Size ≈ λ** **Size > λ**

# Effects on SW radiation



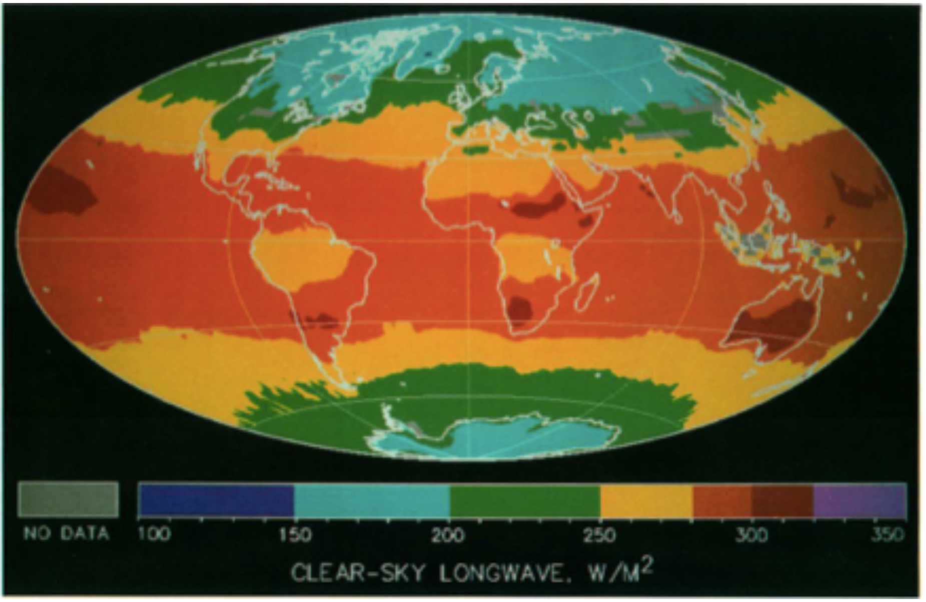



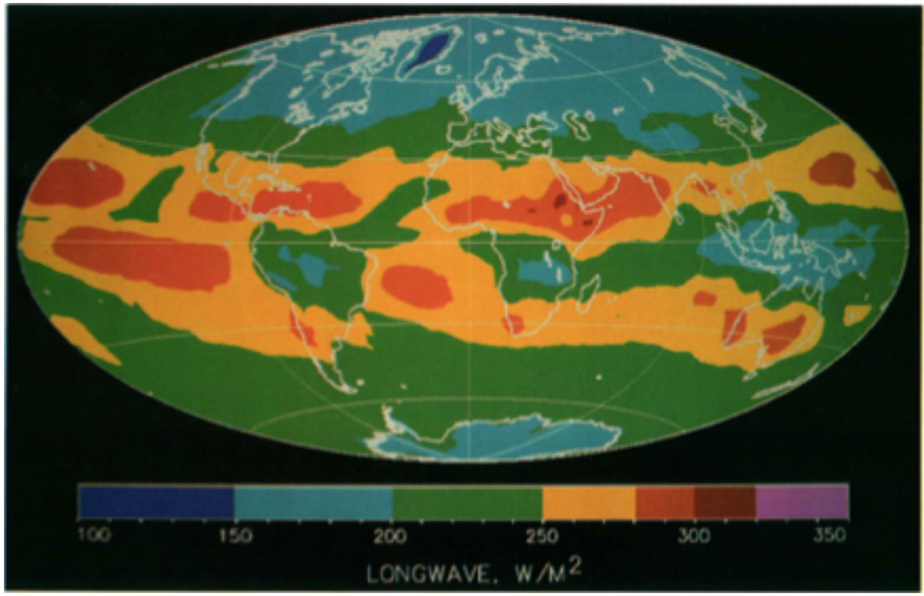

Harrison et al, JGR 1990

TABLE 1. Summary of Cloud Radiative Forcing Parameters ($W/m^2$)

| Date | Longwave | Clear-Sky Longwave | Longwave Cloud Forcing | Shortwave Absorbed | Clear-Sky Shortwave Absorbed | Shortwave Cloud Forcing | Net Cloud Forcing |
|---|---|---|---|---|---|---|---|
| April 1985 | 234.5 | 265.8 | 31.3 | 236.5 | 281.6 | −45.1 | −13.8 |
| July 1985 | 237.5 | 267.6 | 30.1 | 234.4 | 281.1 | −46.7 | −16.6 |
| Oct. 1985 | 234.1 | 266.3 | 32.2 | 243.0 | 293.1 | −50.1 | −17.9 |
| Jan. 1986 | 231.9 | 262.5 | 30.6 | 243.3 | 295.0 | −51.7 | −21.1 |
| Annual | 234.5 | 265.6 | 31.1 | 239.3 | 287.7 | −48.4 | −17.3 |

# Effects on LW radiation




Harrison et al, JGR 1990

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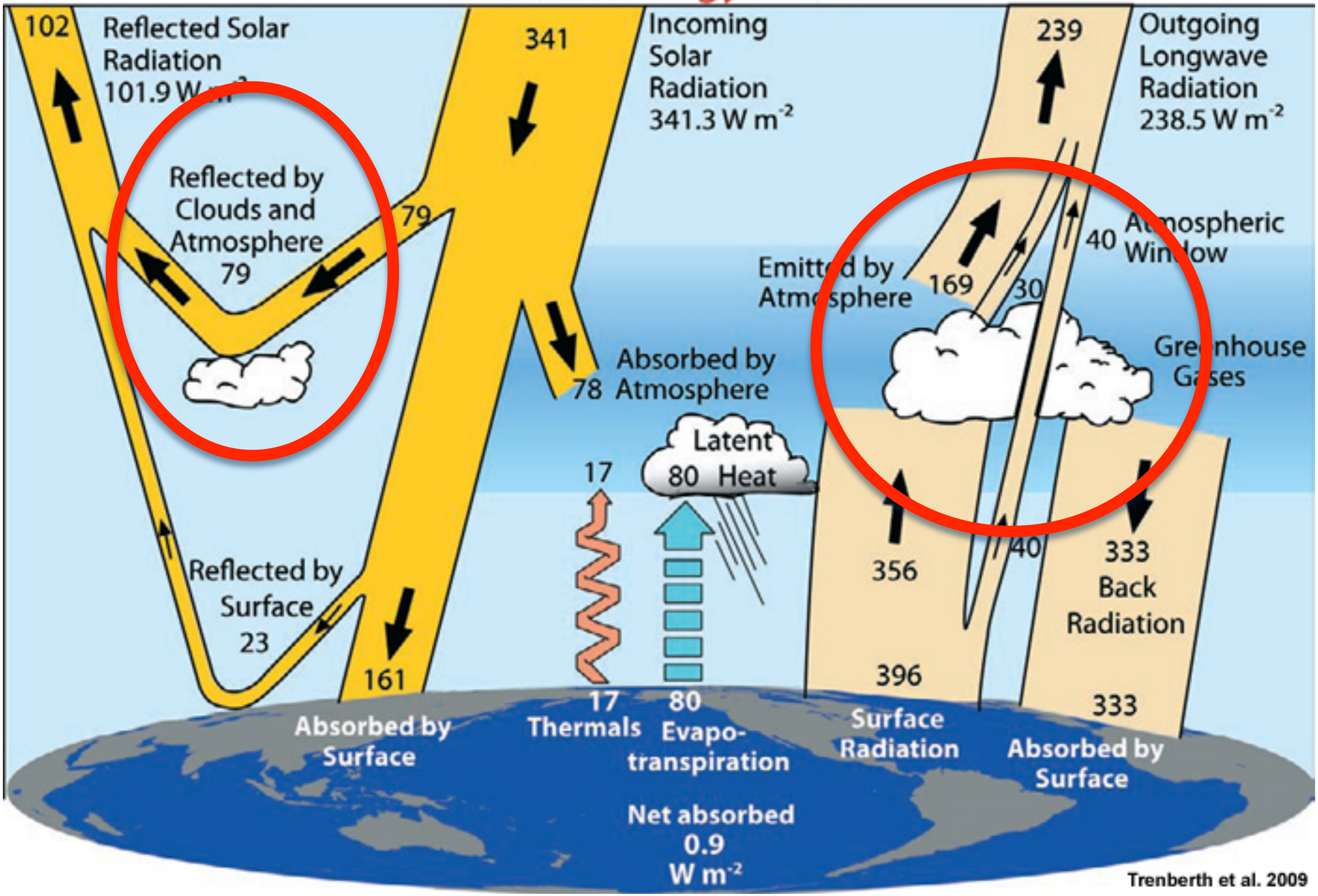
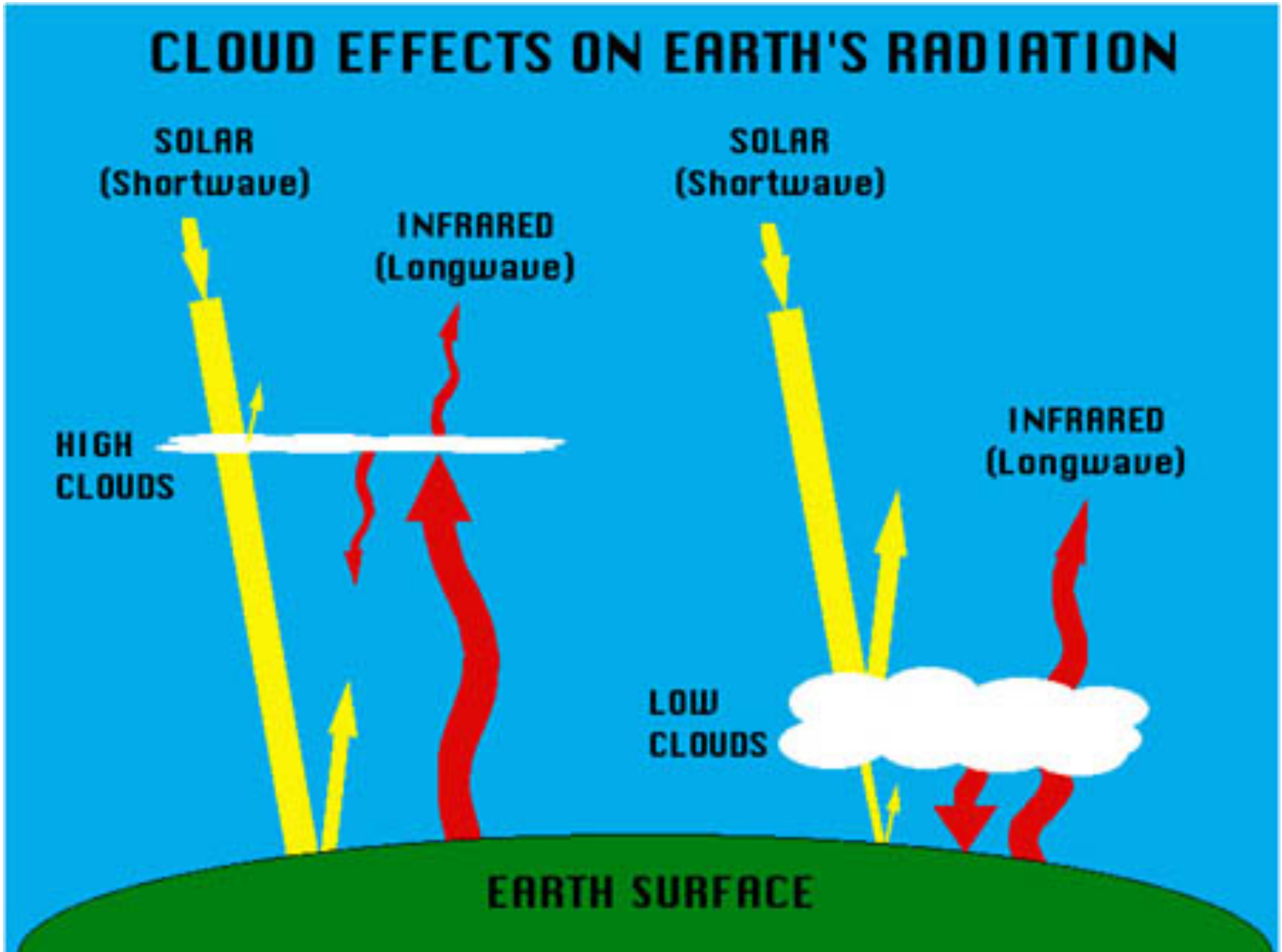
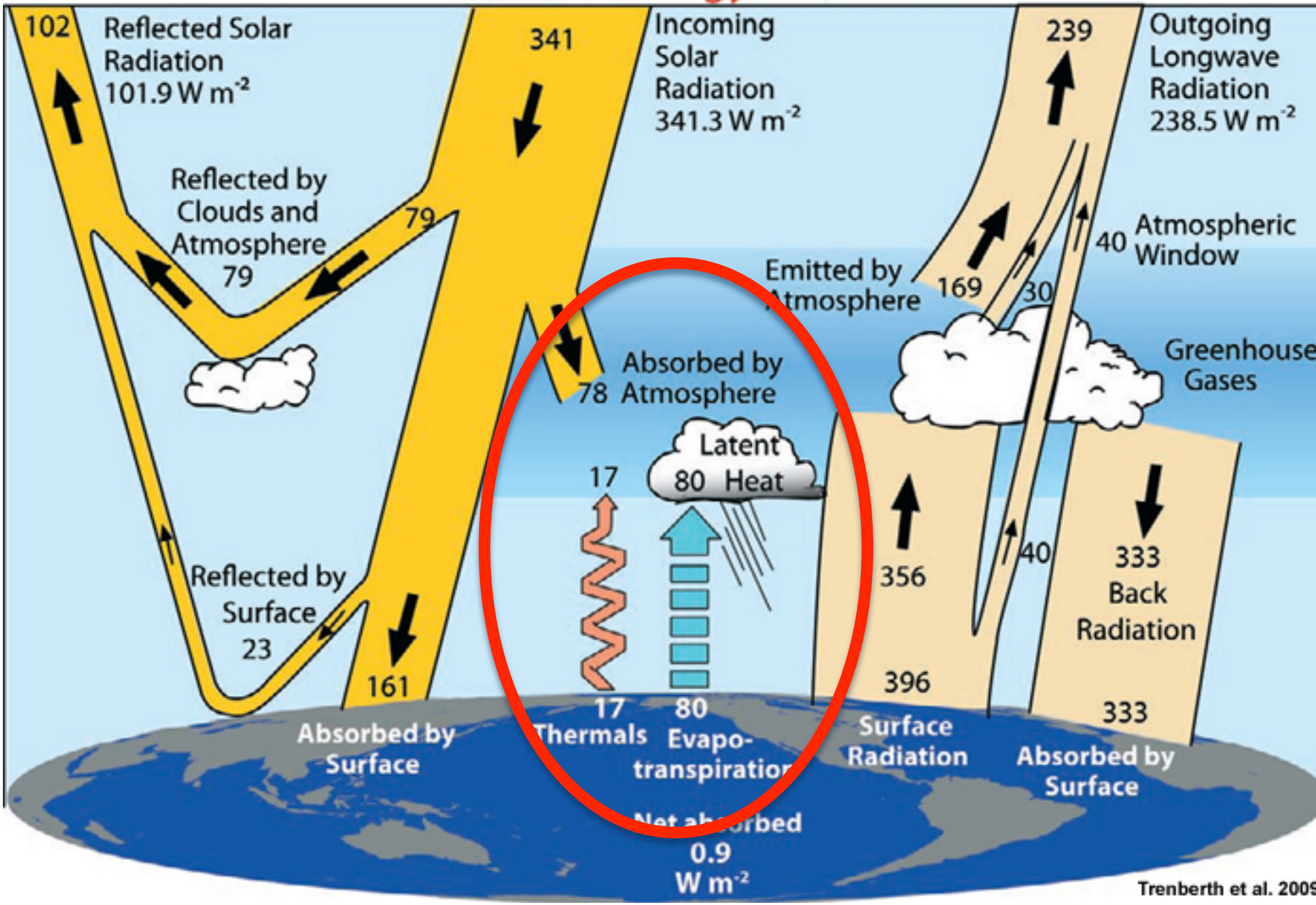
# Global Energy Flows W $m^{-2}$



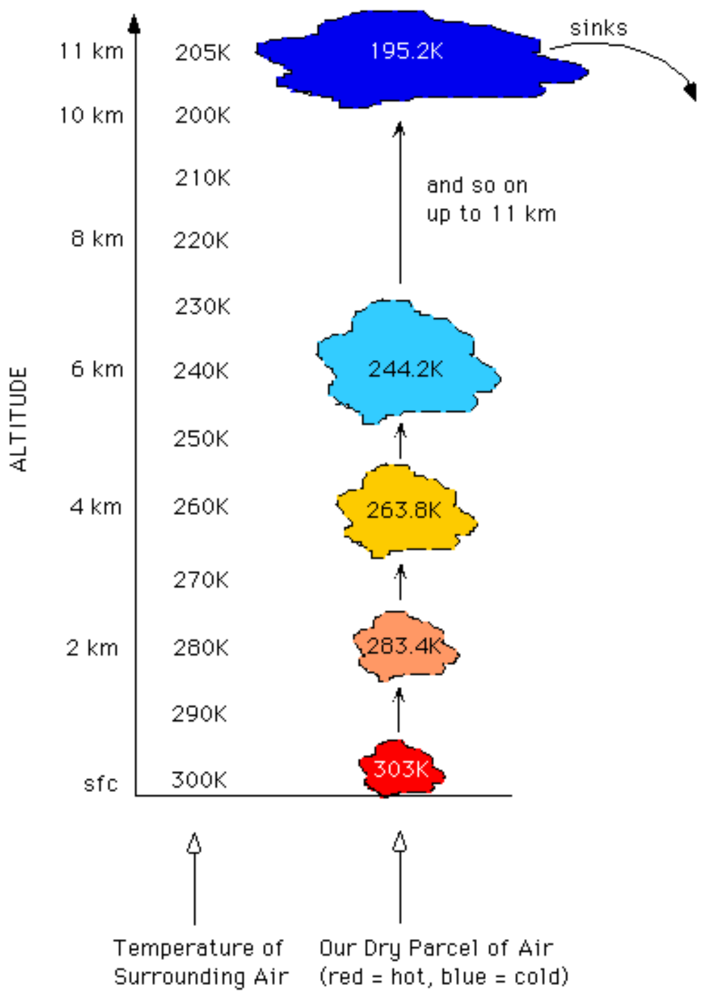

CLOUD EFFECTS ON EARTH'S RADIATION
SOLAR
(Shortwave)
INFRARED
(Longwave)
HIGH
CLOUDS
SOLAR
(Shortwave)
INFRARED
(Longwave)
LOW
CLOUDS
EARTH SURFACE

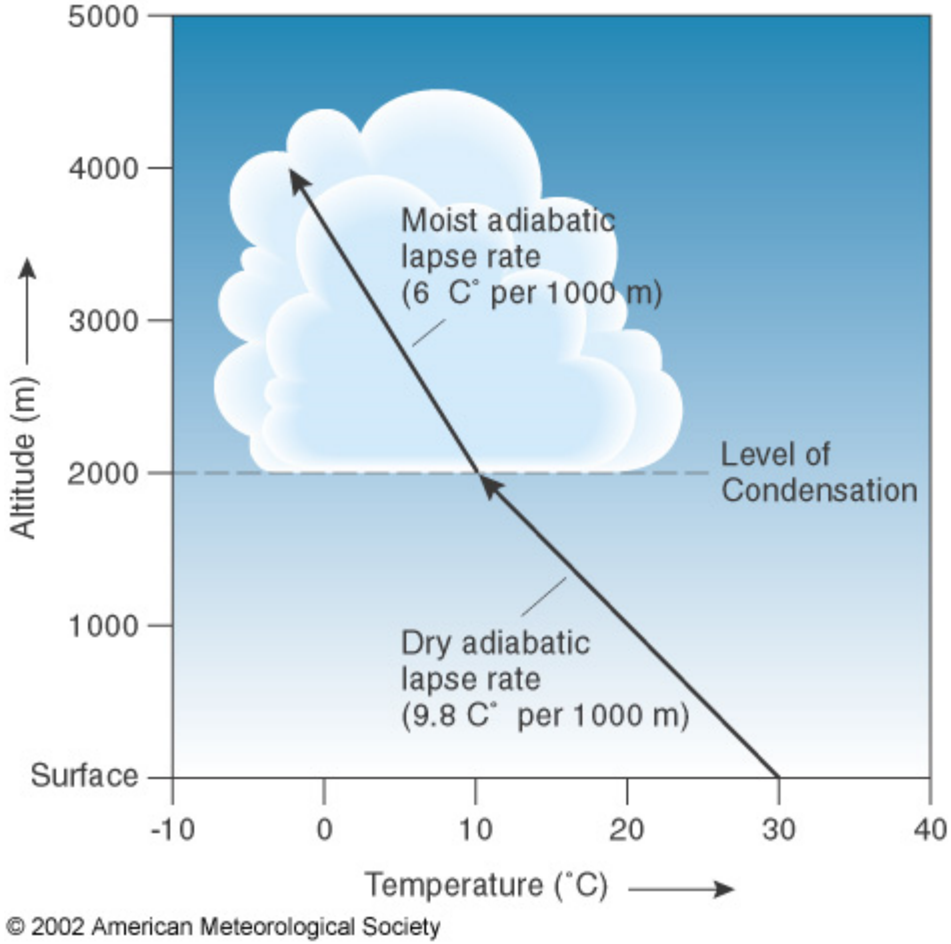
# Global Energy Flows W m$^{-2}$

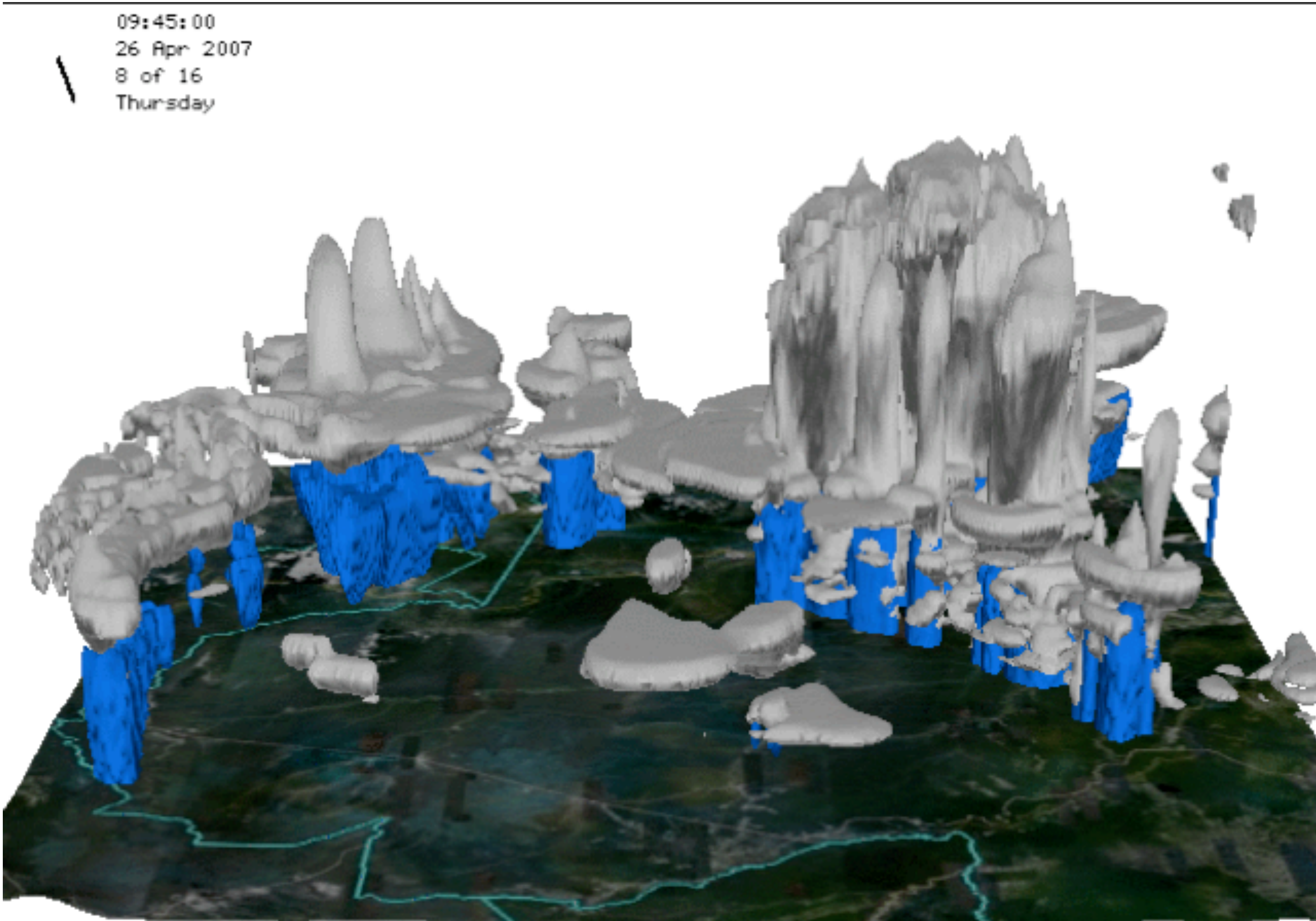



Trenberth et al. 2009

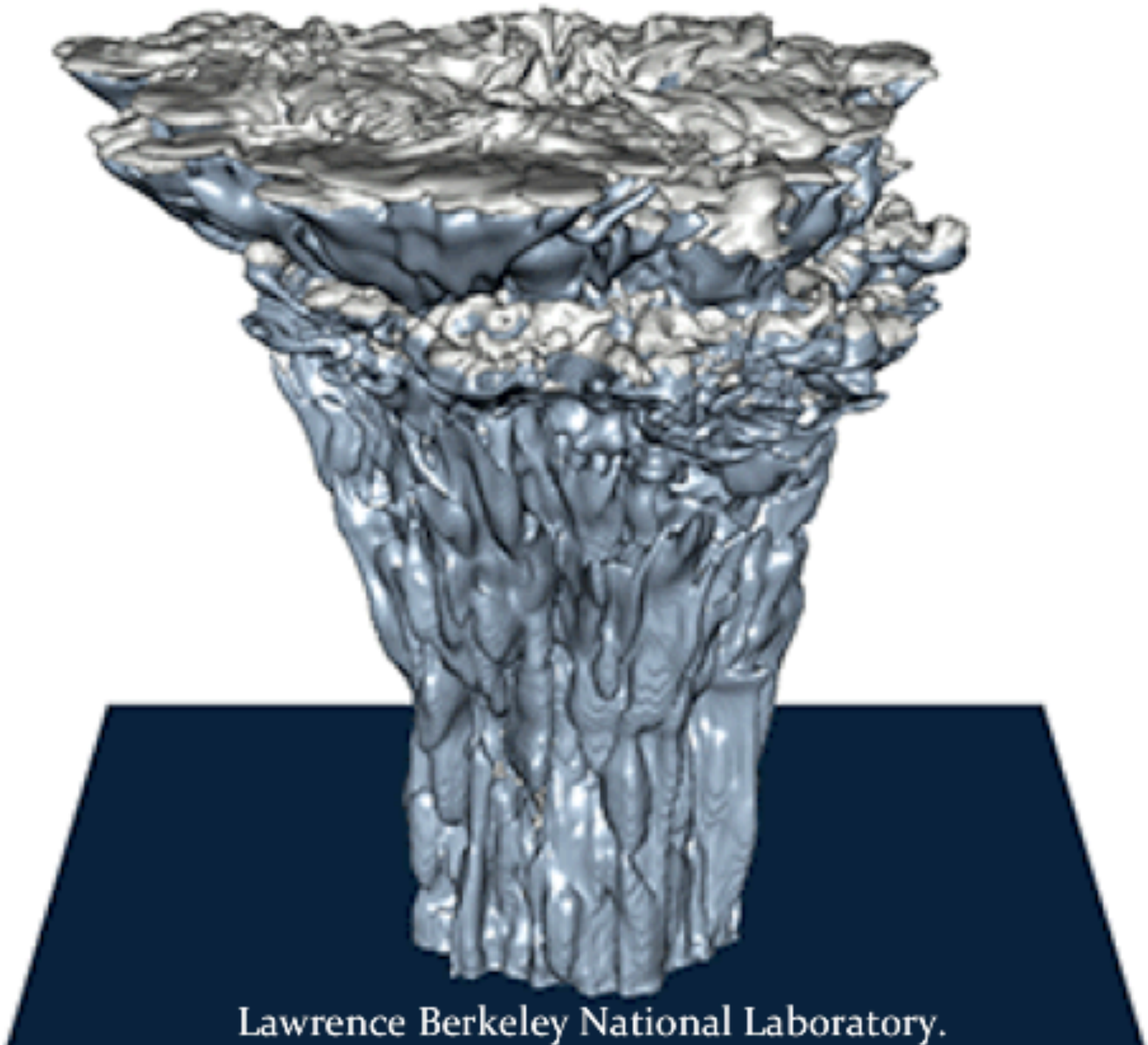
# Heat Exchange

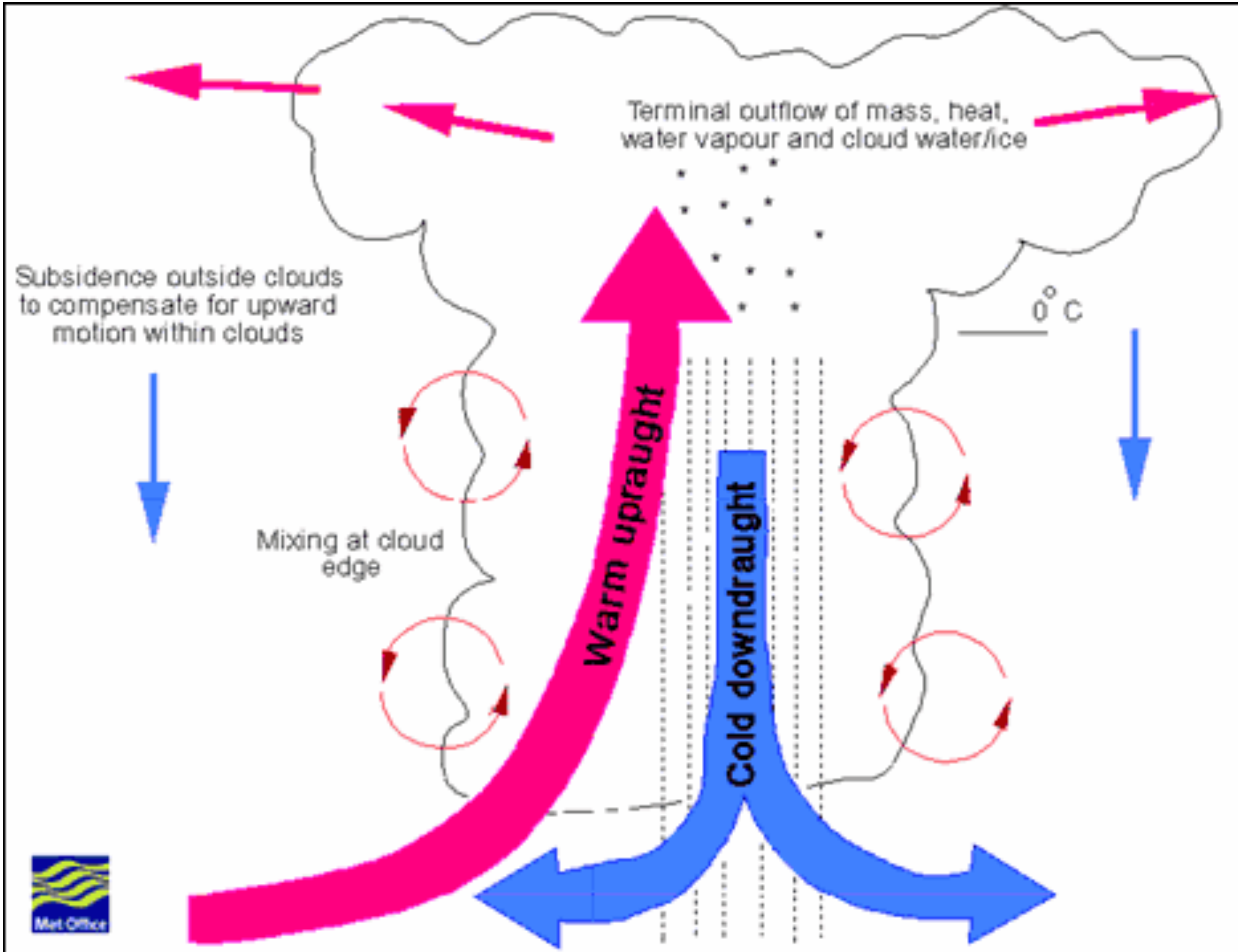





CPTEC - INPE


Lawrence Berkeley National Laboratory.


Terminal outflow of mass, heat, water vapour and cloud water/ice
Subsidence outside clouds to compensate for upward motion within clouds
0° C
Warm upraught
Cold downdraught
Mixing at cloud edge
Met Office

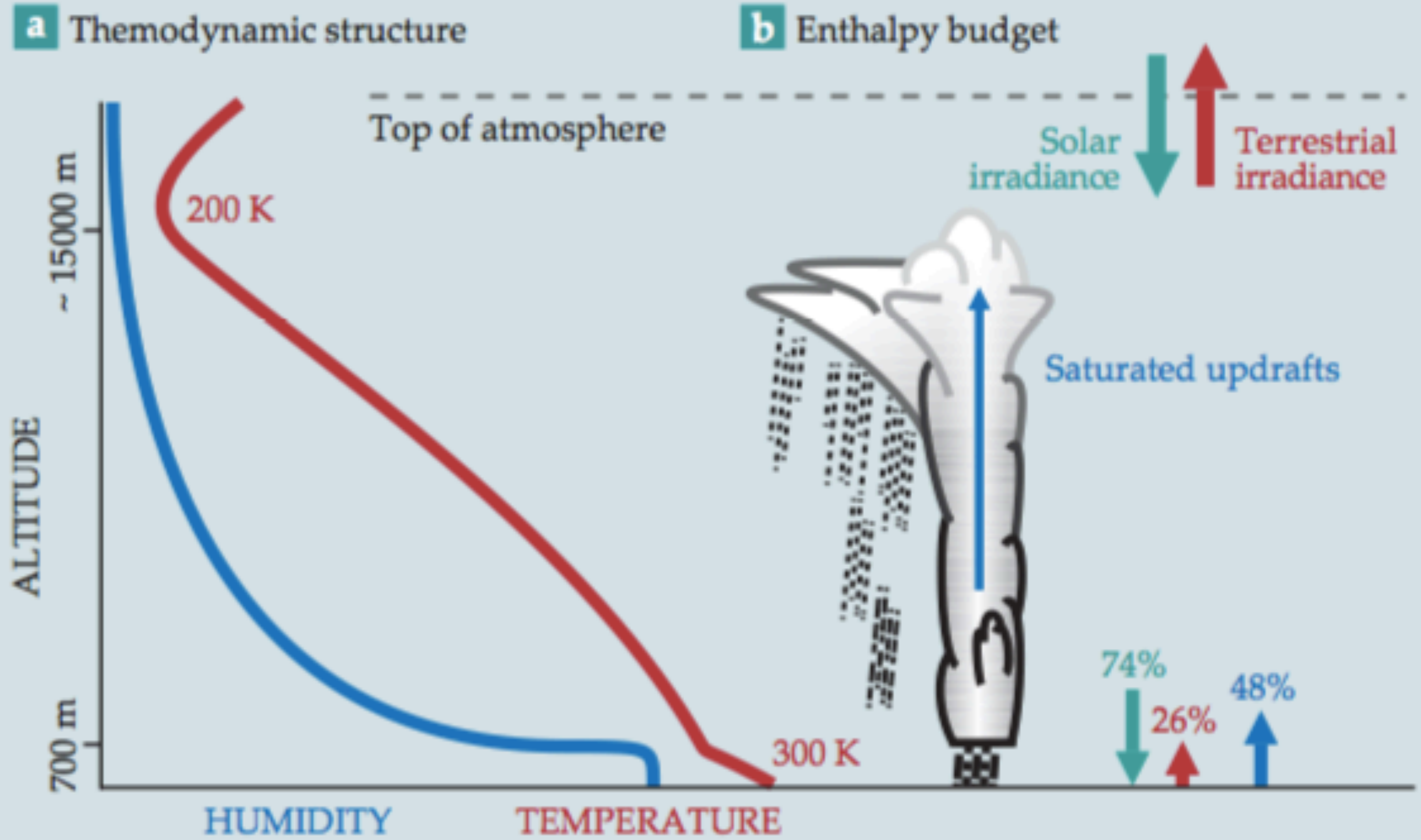
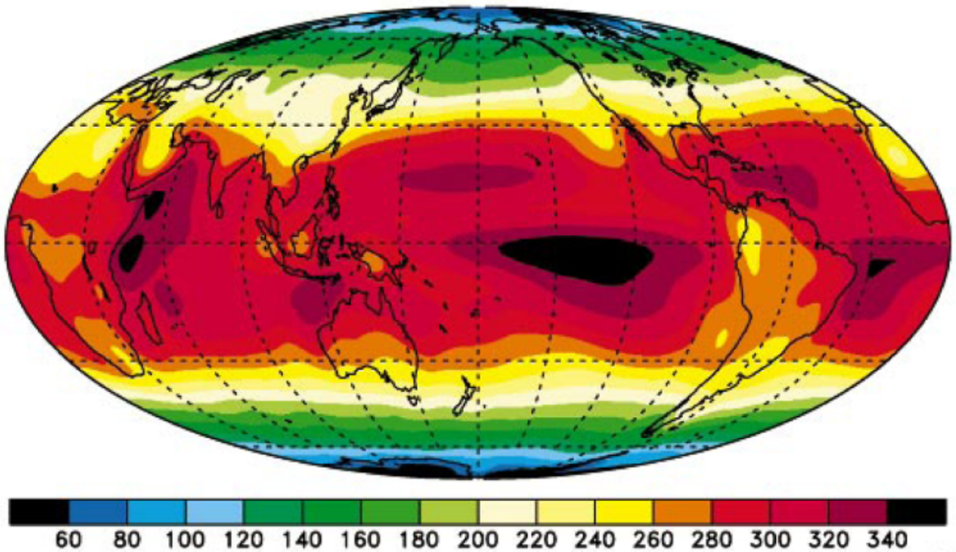


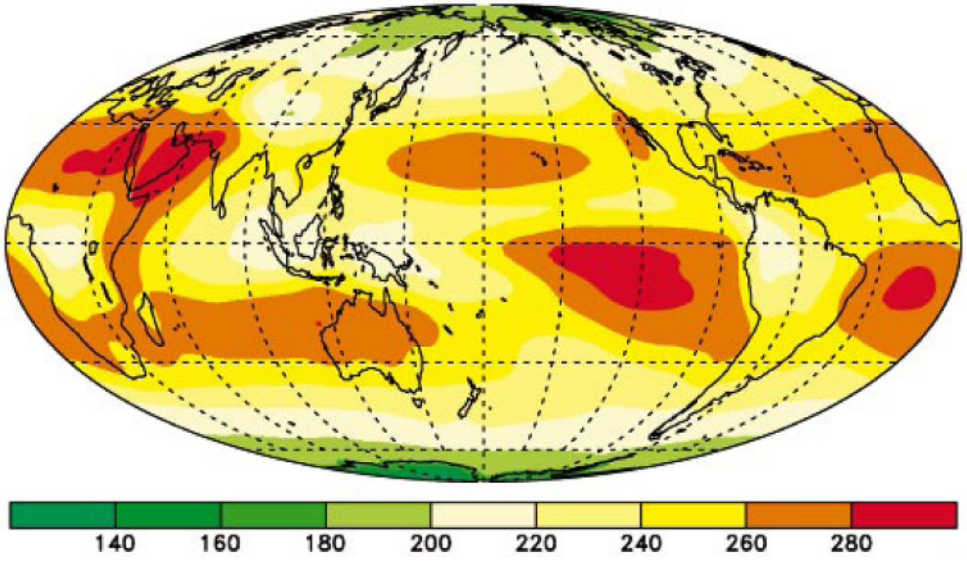

**Figure 3. The thermodynamic structure and enthalpy budget** of the atmosphere. **(a)** The atmosphere's temperature (red) and its absolute humidity (blue) are closely coupled. **(b)** At the top of the atmosphere solar and terrestrial irradiances balance one another. According to calculations, most (74%) of the incoming solar irradiance reaches the surface, but the net terrestrial irradiance at the surface is only a small fraction (26%) of its value at the top of the atmosphere. The radiative deficit (48%) is balanced by surface turbulent fluxes of enthalpy, arising mostly from evaporation, that transport warm water vapor from the surface to the troposphere, where it cools and condenses.

Stevens & Bony, Physics Today 2013

# Distribution on the Earth

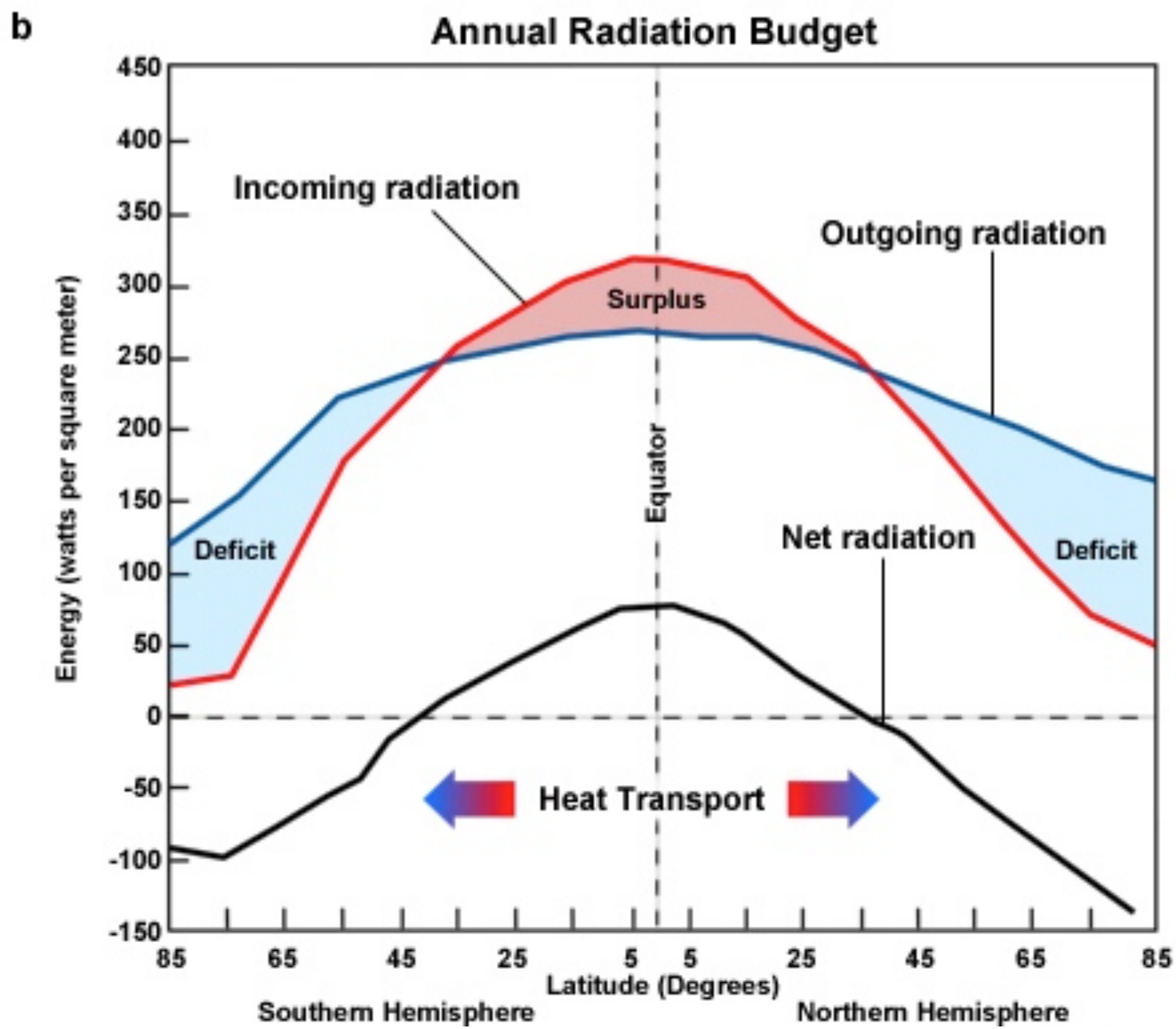



Annual mean solar radiation
budget at top (W/m2)

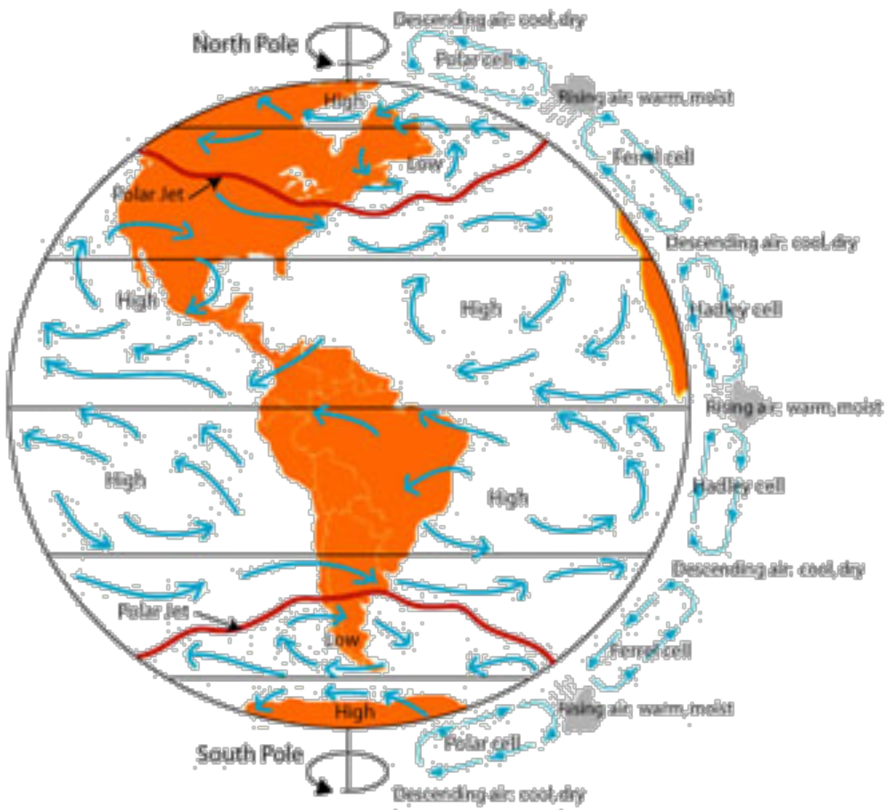


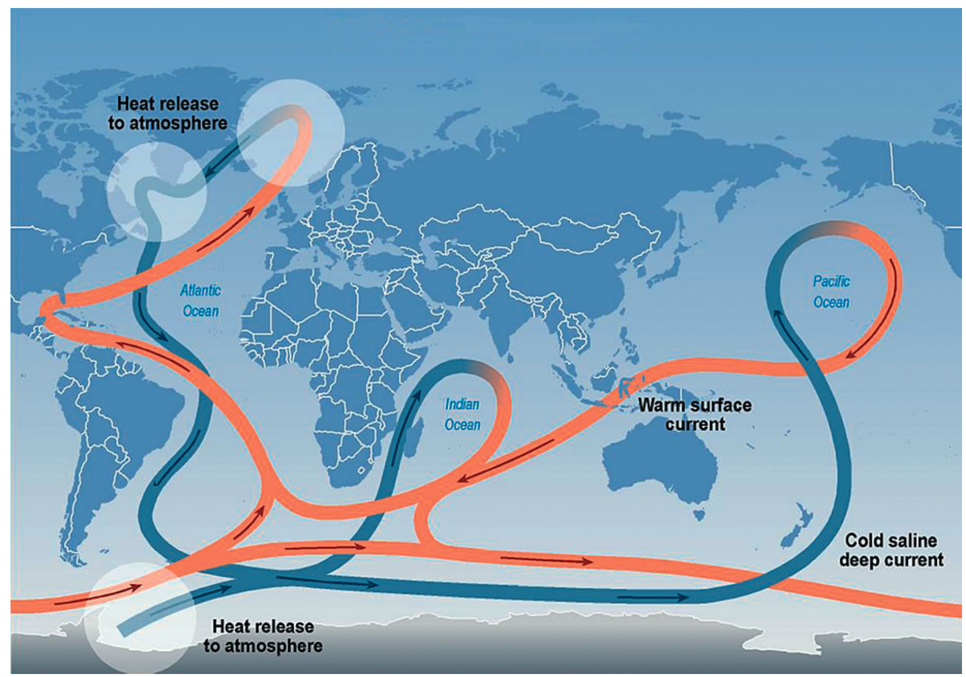

Annual mean outgoing long
wave radiation at top (W/m2)

Trenberth and Stepaniak, J. Clim. (2003)

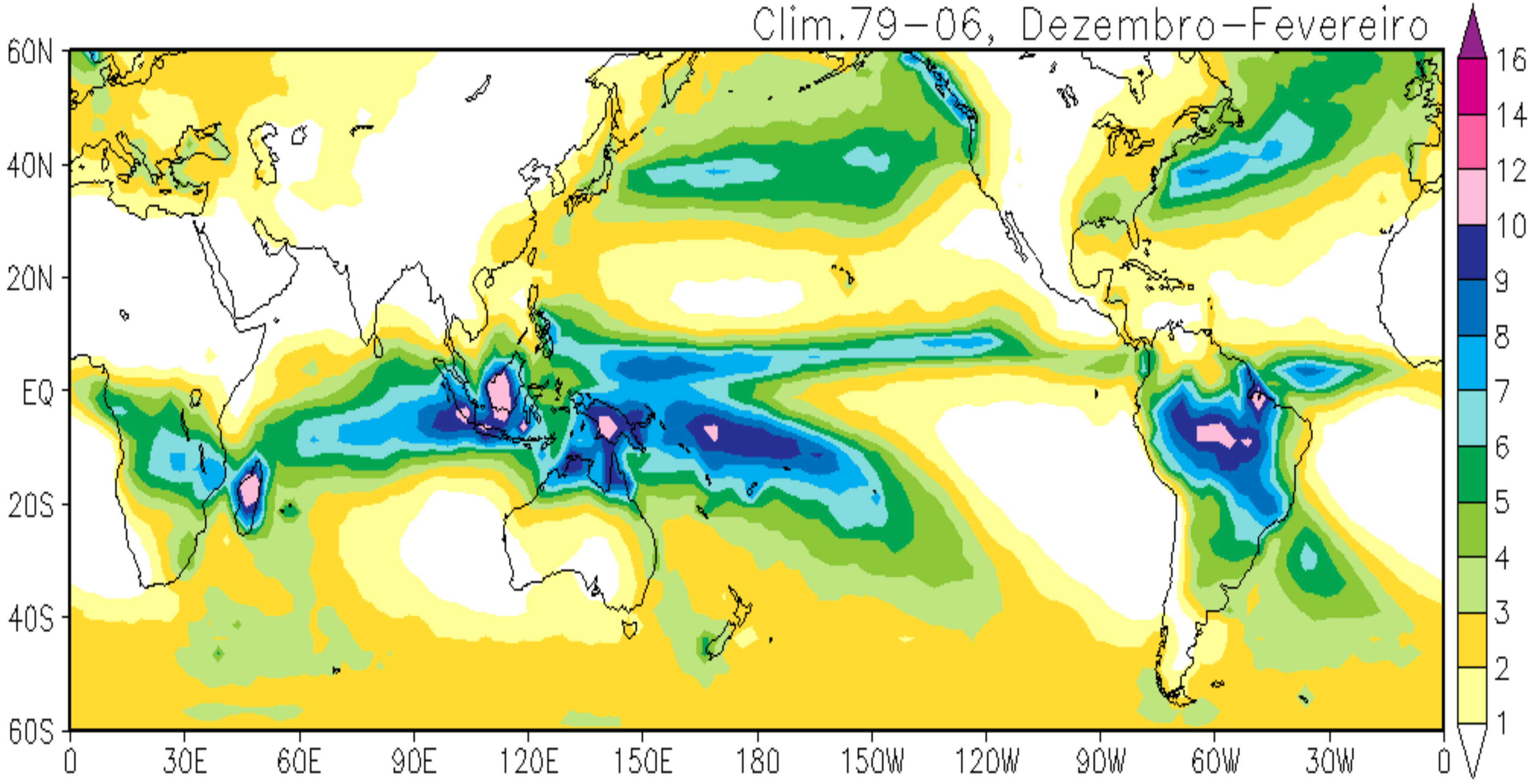

b
Annual Radiation Budget
Incoming radiation
Outgoing radiation
Surplus
Deficit
Deficit
Equator
Net radiation
Heat Transport
Energy (watts per square meter)
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
85
65
45
25
5
5
25
45
65
85
Latitude (Degrees)
Southern Hemisphere
Northern Hemisphere

# Atmospheric and Oceanic circulation

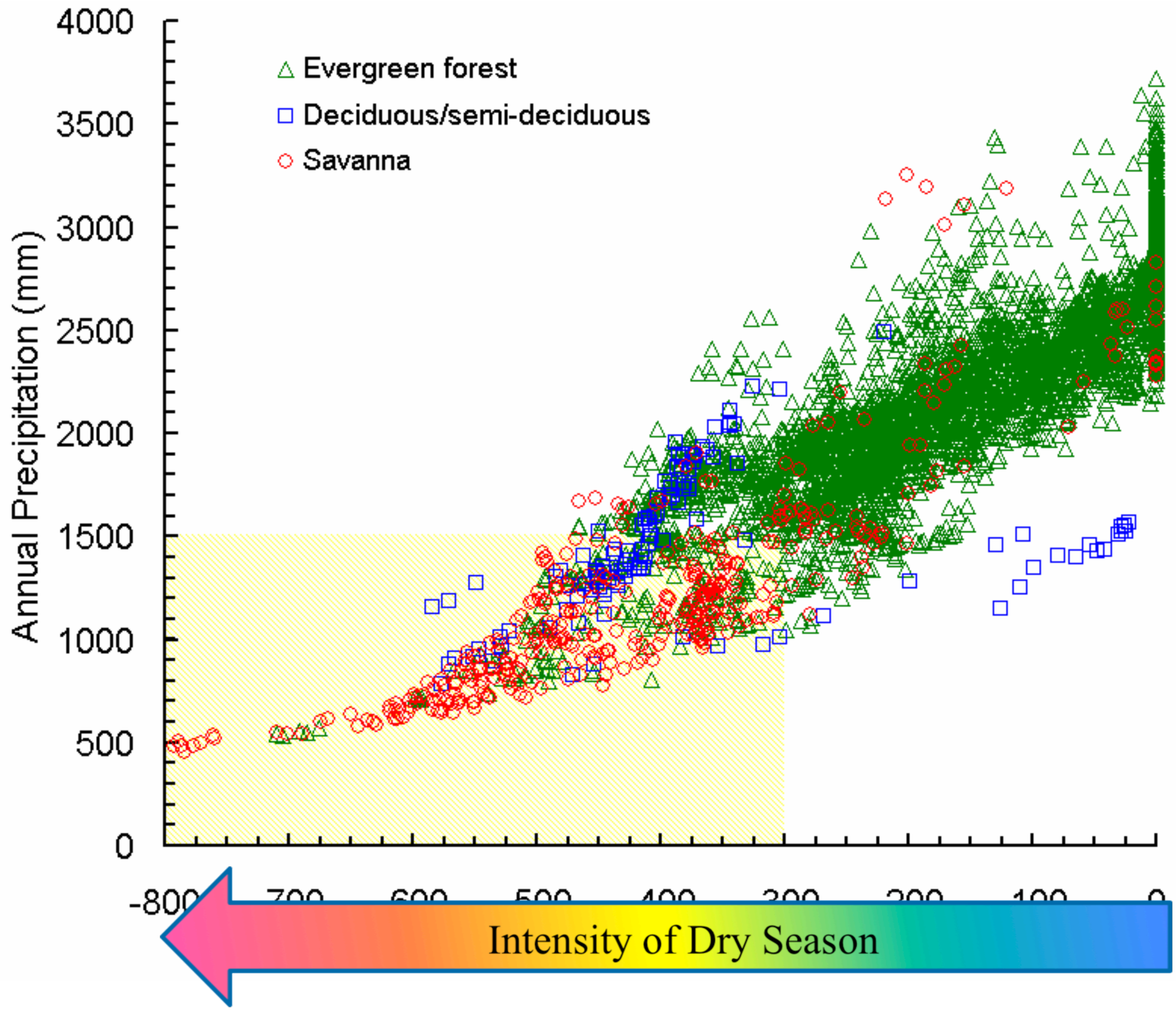


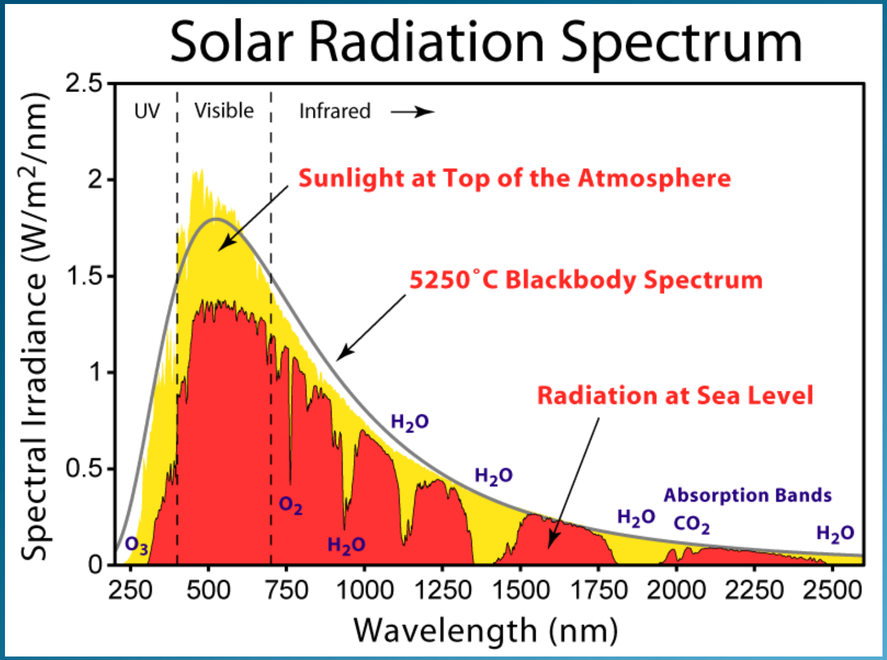
# Global Precipitation



# A Rainfall Biogeography of Amazonia




Source: Malhi *et al.*, **Exploring the likelihood and mechanism of a climate-change induced dieback of the Amazon rainforest,** *Proceedings of the National Academy of Sciences*, 2010





# Thanks!

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www.fap.if.usp.br/~hbarbosa