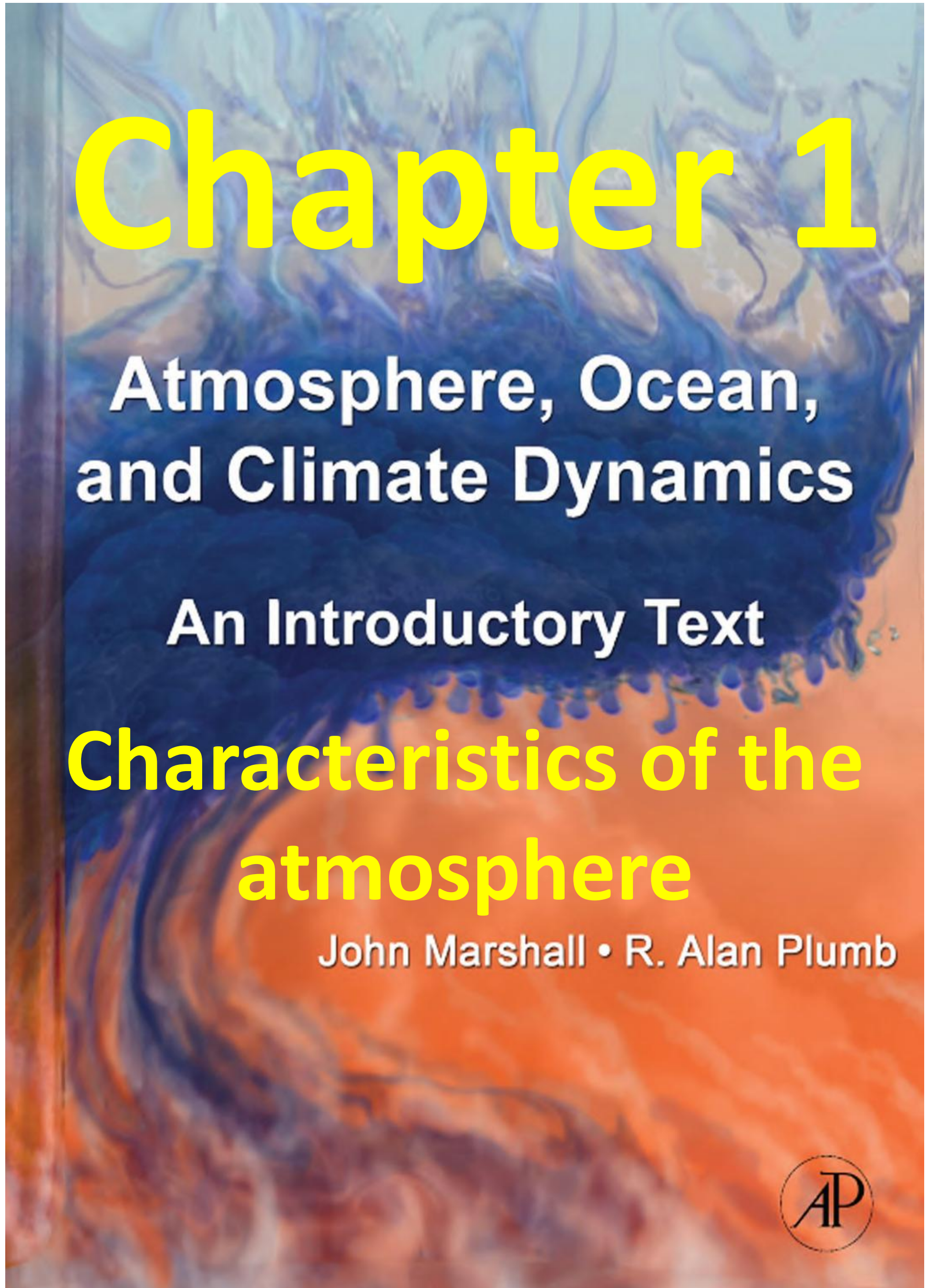
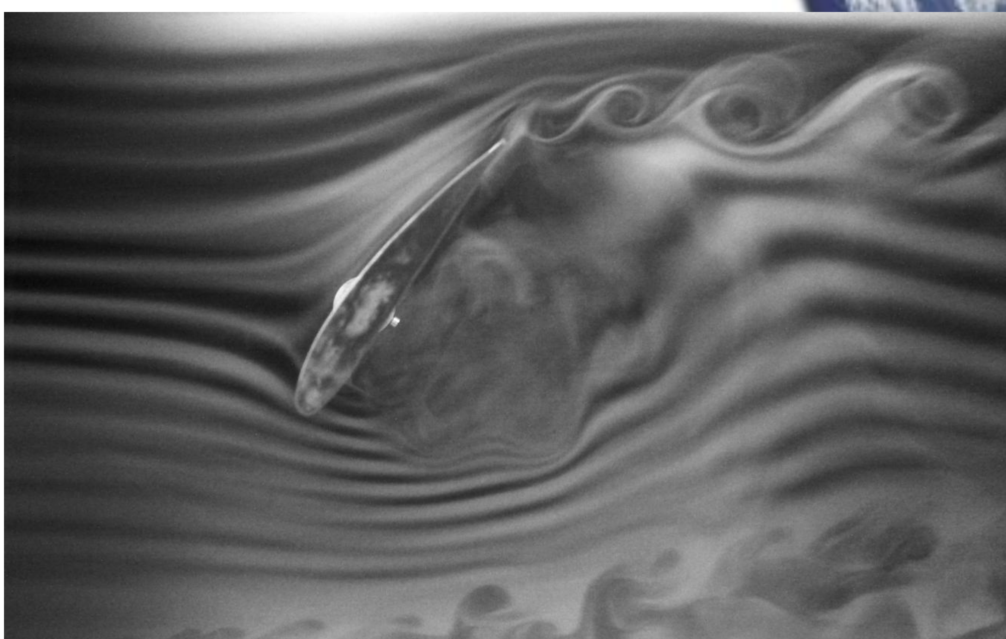
Chapter 1



Characteristics of the atmosphere



Characteristics of the atmosphere and ocean

- Thin film of fluid, under influence of
  - Gravity
  - Earth’s rotation
  - Differential solar heating
- Horizontal forces due to differential heating
  - Not only friction and velocity shear
- Geophysical Fluid Dynamics

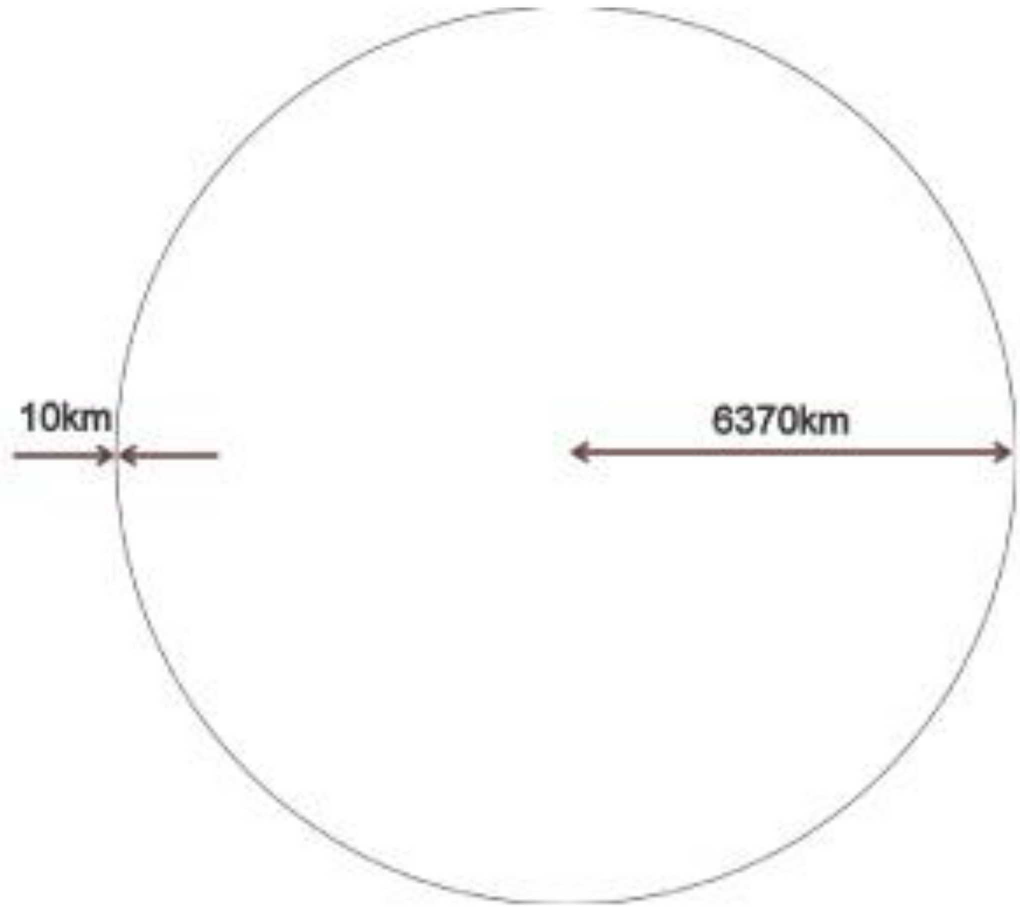


Figure 1.1: The thinness (to scale) of a shell of 10 km thickness on the Earth of radius 6370 km.

TABLE 1.1. Some parameters of Earth.		
Earth's rotation rate	Ω	$7.27 \times 10^{-5} s^{-1}$
Surface gravity	g	$9.81\ ms^{-2}$
Earth's mean radius	a	6.37×10^{6} m
Surface area of Earth	$4\pi a^2$	$5.09 \times 10^{14}\ m^2$
Area of Earth's disc	πa^2	$1.27 \times 10^{14}\ m^2$

TABLE 1.1. Some parameters of Earth.

Tangentialhastighet ved Ekvator v_T

Omkrets: 40×10^6 m

$v_T = 40 \times 10^6 /24 = 463$ m/s (1670 km/h)

Characteristics of the atmosphere

- Density decreases ~exponentially with altitude
- Falling by a factor *e* every ~7km
- ~80% of the mass below 10km

Characteristics of the atmosphere

- Temperature changes with altitude
  - Decreases in the troposphere
    - Adiabatic expansion
  - Increases in the stratosphere
    - Absorption of UV radiation by ozone

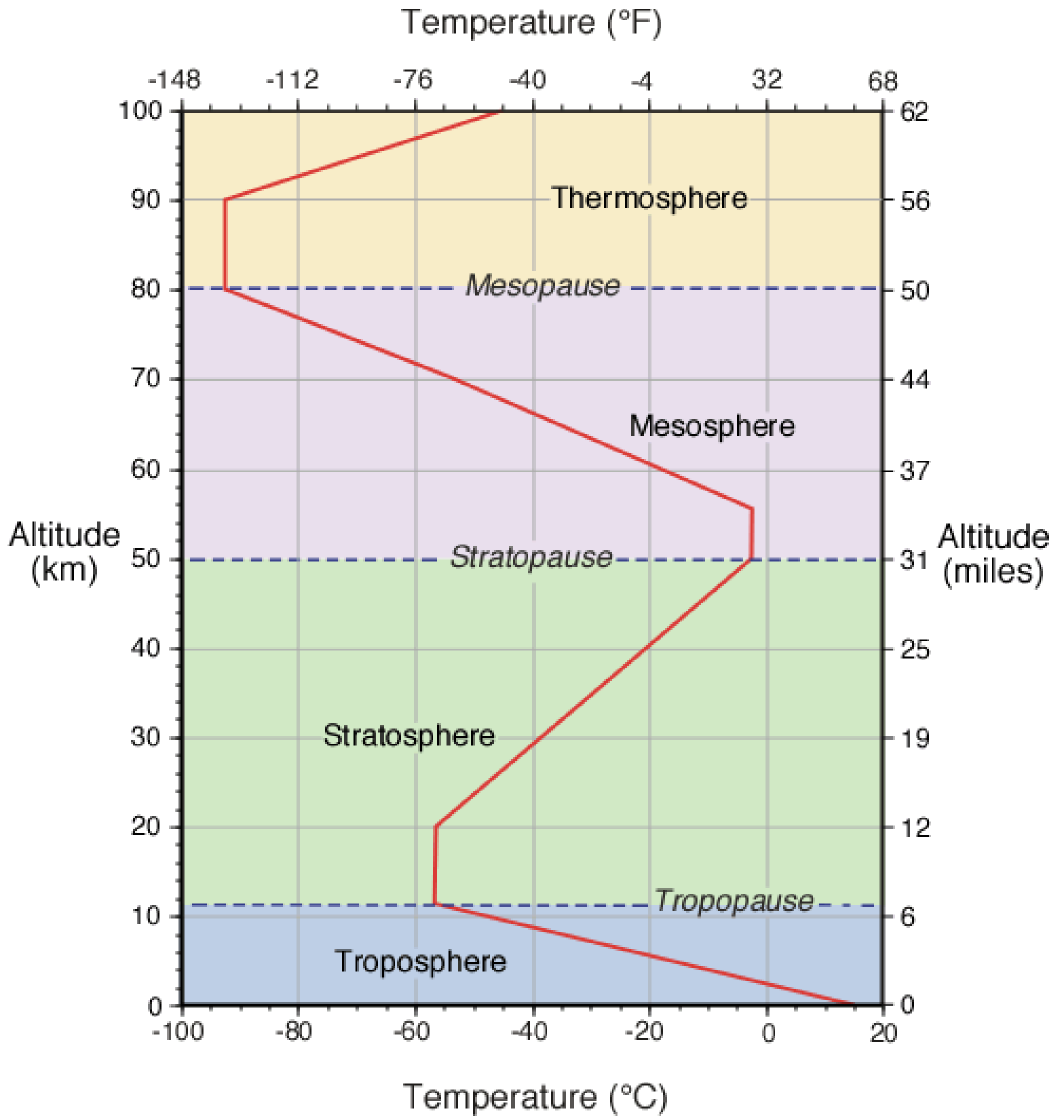


Fig. 1.2 The main zones of the atmosphere defined according to the temperature profile of the standard atmosphere profile at 15°N for annual-mean conditions. [Data from U.S. Standard Atmosphere Supplements (1966).]

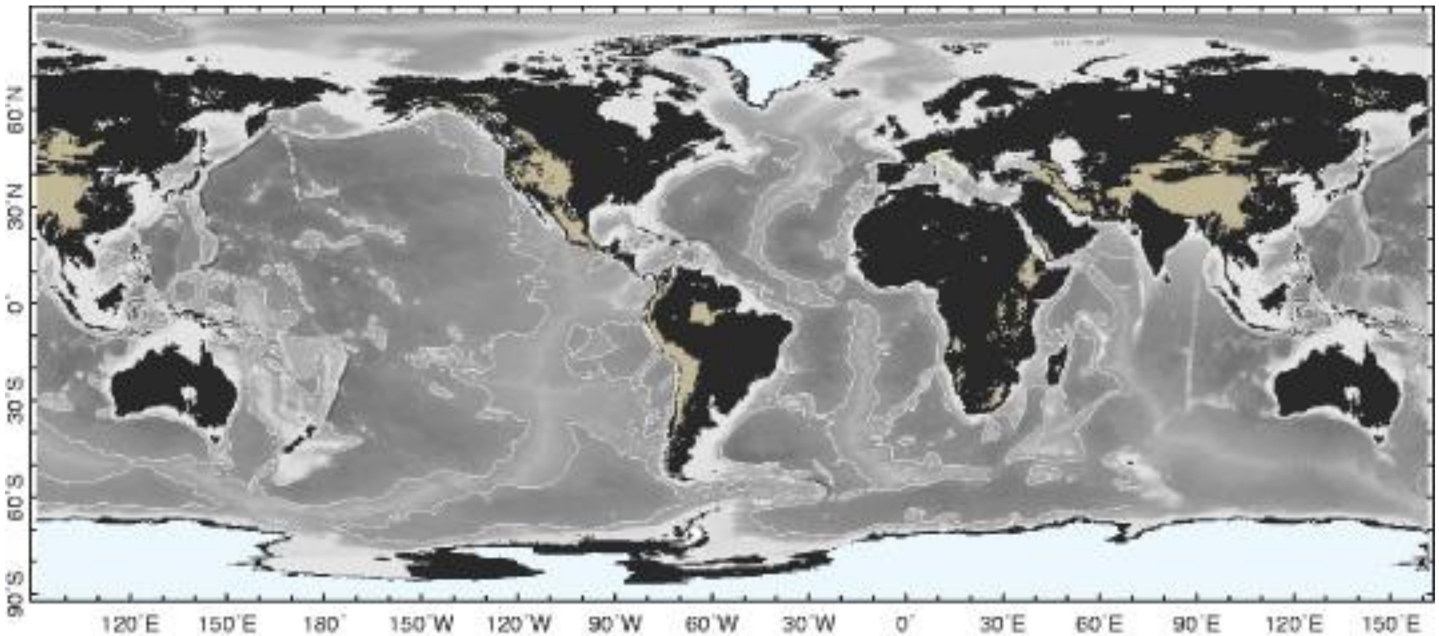


Figure 9.1: World relief showing elevations over land and ocean depth. White areas over the continents mark the presence of ice at altitudes that exceed 2 km. The mean depth of the ocean is 3.7 km, but depths sometimes exceed 6 km. The thin white line meandering around the ocean basins marks a depth of 4 km.

- Land covers ~30% of the globe
- NH covers ~70% of total
- Thermal contrasts + topography

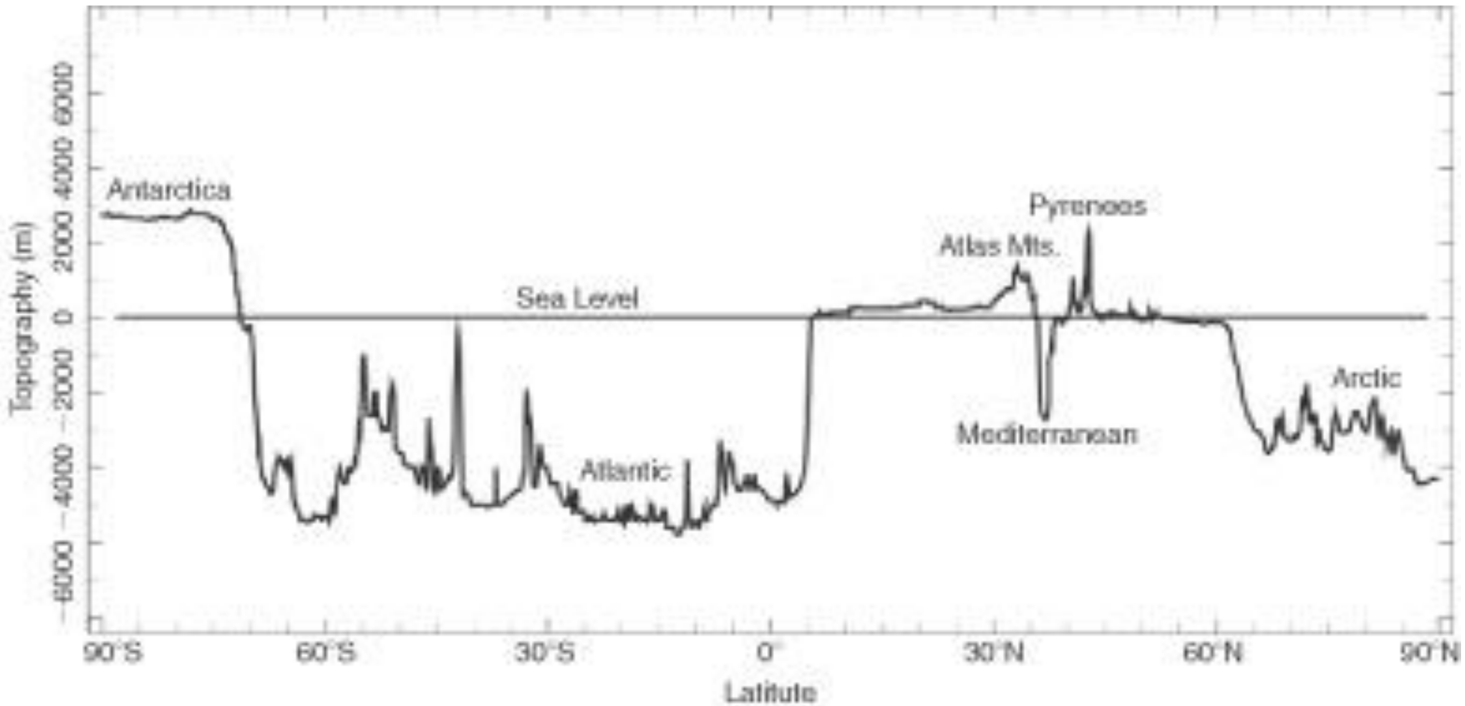


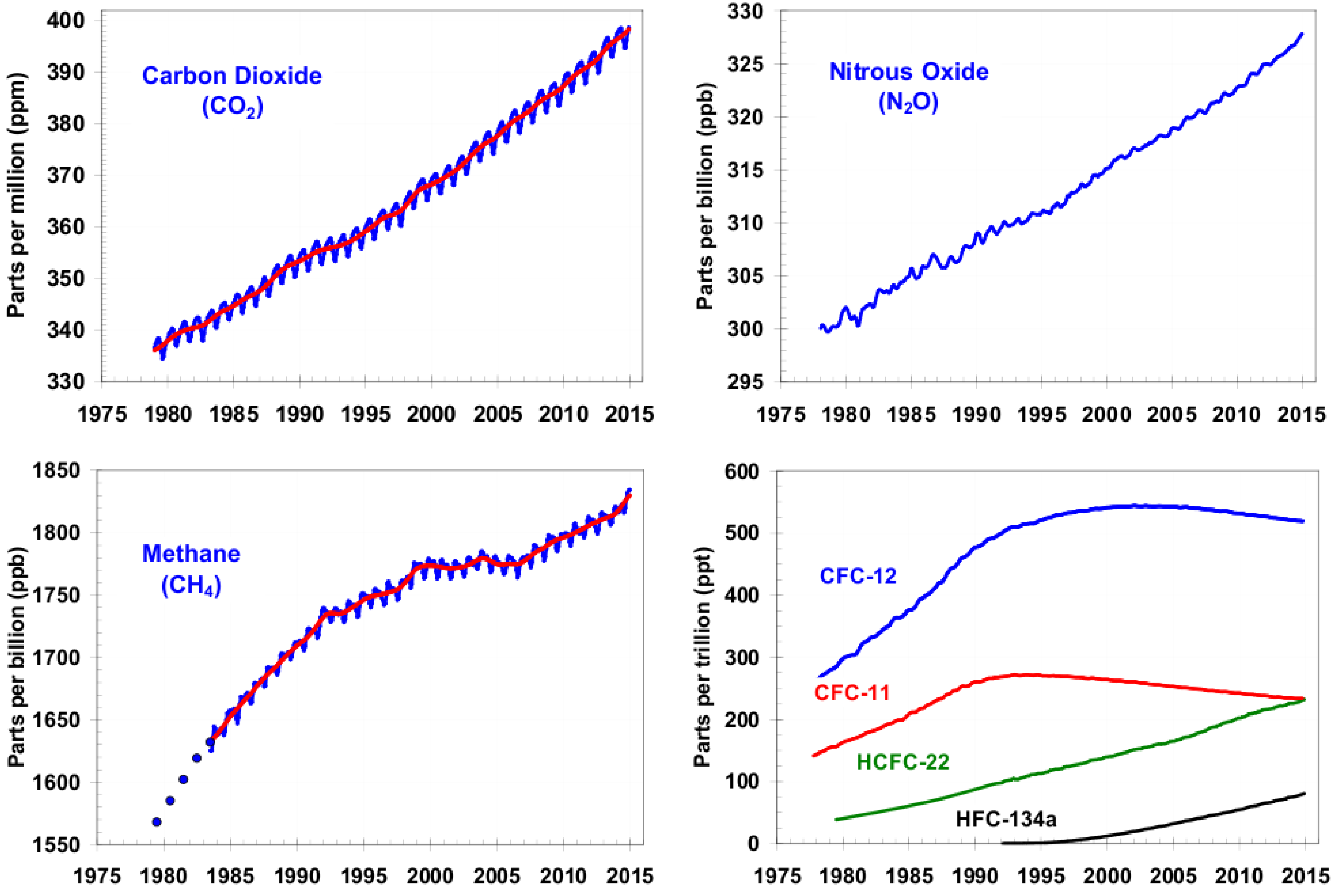
Figure 1.2: A north-south section of topography relative to sea level(in meters) along the Greenwich meridian (0° longitude) cutting through Fig. 9.1. Antarctica is over 2 km high, whereas the Arctic Ocean and the south Atlantic basin are about 5 km deep. Note how smooth the relief of the land is compared to that of the ocean floor.

TABLE 1.2. The most important atmospheric constituents. The chlorofluorocarbons (CFCs) CCl_2F_2 and CCl_3F are also known as CFC12 and CFC11, respectively. [N.B. (ppm, ppb, ppt) = parts per (million, billion, trillion)] The concentrations of some constituents are increasing systematically because of human activity. For example, the CO_2 concentration of 380 ppm was measured in 2004 (see Fig. 1.3); CFCs are now decreasing in concentration following restrictions on their production.

Chemical species	Molecular weight (g mol^{-1})	Proportion by volume	Chemical species	Molecular weight	Proportion by volume
N_2	28.01	78%	O_3	48.00	~500 ppb
O_2	32.00	21%	N_2O	44.01	310 ppb
Ar	39.95	0.93%	CO	28.01	120 ppb
H_2O (vapor)	18.02	~0.5%	NH_3	17.03	~100 ppb
CO_2	44.01	380 ppm	NO_2	46.00	~1 ppb
Ne	20.18	19 ppm	CCl_2F_2	120.91	480 ppt
He	4.00	5.2 ppm	CCl_3F	137.37	280 ppt
CH_4	16.04	1.7 ppm	SO_2	64.06	~200 ppt
Kr	83.8	1.1 ppm	H_2S	34.08	~200 ppt
H_2	2.02	~500 ppb	AIR	28.97	

TABLE 1.2. The most important atmospheric constituents. The chlorofluorocarbons (CFCs) CCl_2F_2 and CCl_3F are also known as CFC-12 and CFC-11, respectively. [N.B. (ppm, ppb, ppt) = parts per (million, billion, trillion)] The concentrations of some constituents are increasing systematically because of human activity. For example, the CO_2 concentration of 380 ppm was measured in 2004 (see Fig. 1.3); CFCs are now decreasing in concentration following restrictions on their production.

Recent changes in CO_2,N_2O, CFCs and CH_4



http://www.esrl.noaa.gov/gmd/aggi/

Characteristics of the atmosphere

TABLE 1.3. Some atmospheric numbers.		
Atmospheric mass	Ma	5.26×10^{18} kg
Global mean surface pressure	Ps	1.013×10^{5} Pa
Global mean surface temperature	Ts	288 K
Global mean surface density	ρs	1.235 kg m^{-3}

TABLE 1.3. Some atmospheric numbers.

- A column of air with the surface density and ~7-8km thick will excert a pressure equivalent to 1 atmosphere

TABLE 1.3. Some atmospheric numbers.		
Atmospheric mass	*Ma*	5.26×10^{18} kg
Global mean surface pressure	*Ps*	1.013×10^{5} Pa
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TABLE 1.3. Some atmospheric numbers.

Masse av luft i en kolonne (B) med areal $1m^2$

B= $M_a/A = 5.26x10^{18}/5.09x10^{14} \approx 10^4$ kg/m^2

Characteristics of the atmosphere

- Below ~80km
  - The mean free path short and molecular collisions frequent
  - The atmosphere can be regarded as
    - a continuum fluid
    - in local thermodynamic equilibrium (LTE)
  - Composition not influenced by weight of gas molecules

Dry air

If in LTE, the atmosphere accurately obeys the perfect gas law,[1] then

$$p = \rho \frac{R_g}{m_a} T = \rho R T, \qquad (1\text{-}1)$$

where p is pressure, ρ, density, T, absolute temperature (measured in Kelvin), R_g, the universal gas constant

$$R_g = 8.3143\,\mathrm{J\,K^{-1}mol^{-1}},$$

the gas constant for dry air

$$R = \frac{R_g}{m_a} = 287\,\mathrm{J\,kg^{-1}K^{-1}},$$

and the mean molecular weight of dry air (see Table 1.2, last entry), $m_a = 28.97$ $(\times 10^{-3}\,\mathrm{kg\,mol^{-1}})$.

p: Trykk (hPa) 1 Pa = 1 N/m^2
ρ : Tetthet (kg/m^3)
T: Temperatur (K)
V: Volum (m^3)
m_a: Molekylvekt (kg/mol)
Mol: 6.023×10^{23} molekyler

Tilstandslikning for ideal gass

$pV = nR_gT$

n: Antall mol gass
R_g: Universell gasskonstant
$R_g = 8.31 \times 10^3$ J/(K molekyl)

$\rho = n \cdot m_a/V \rightarrow \rho/m_a = n/V$

Dry air

$$p = \rho \frac{R_g}{m_a} T = \rho R T, \qquad (1\text{-}1)$$

- State variables: *p*, *ρ*, *T*
- Necessary to know only two of them

STP: Standard Pressure and Temperature (p=1013 hPa, T=273K)

TABLE 1.4. Properties of dry air at STP.		
Specific heat at constant pressure	c_p	1005 J kg^{-1} K^{-1}
Specific heat at constant volume	c_v	718 J kg^{-1} K^{-1}
Ratio of specific heats	γ	1.40
Density at 273K, 1013mbar	ρ_0	1.293 kg m^{-3}
Viscosity at STP	μ	1.73×10^{-5} kg m^{-1} s^{-1}
Kinematic viscosity at STP	$v = \frac{\mu}{\rho_0}$	1.34×10^{-5} m^2 s^{-1}
Thermal conductivity at STP	K	2.40×10^{-2} W m^{-2} K^{-1}
Gas constant for dry air	R	287.05 J kg^{-1} K^{-1}

TABLE 1.4. Properties of dry air at STP.

- Air is compressible (as opposed to liquids)

Moist air

$$e = \rho_v R_v T; \qquad (1\text{-}2)$$

$$p_d = \rho_d R_d T, \qquad (1\text{-}3)$$

where e is the partial pressure of water vapor, p_d is the partial pressure of dry air, R_v is the gas constant for water vapor, and R_d is the gas constant for dry air. By Dalton's law of partial pressures, the pressure of the mixture, p, is given by:

$$p = p_d + e.$$

In practice, because the amount of water vapor in the air is so small (see Table 1.2), we can assume that $p_d >> e$, and so $p \simeq p_d$.

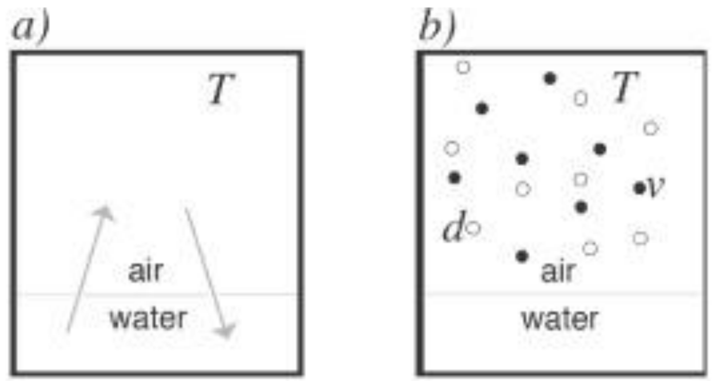

Figure 1.4: Air over water in a box at temperature *T*. At equilibrium the rate of evaporation equals the rate of condensation. The air is saturated with water vapor, and the pressure exerted by the vapor is e_s, the saturated vapor pressure. On the right we show the mixture comprising dry '*d*' and vapor '*v*' components.

Moist air

$$e_s = Ae^{\beta T} \tag{1-4}$$

where $A = 6.11$ hPa and $\beta = 0.067°\mathrm{C}^{-1}$ are constants and T is in °C, a simplified statement of the Clausius-Clapeyron relationship. The saturated vapor pressure

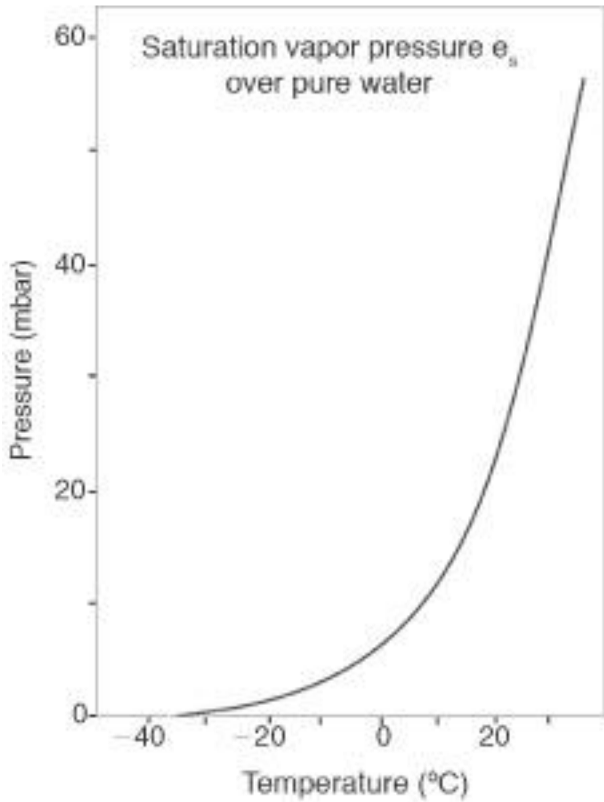

Figure 1.5: Saturation vapor pressure e_s (in mbar) as a function of T in °C (solid curve).

(From Wallace & Hobbs, (2006).)

Hvorfor fortsetter kurven forbi T=0°C?

Moist air

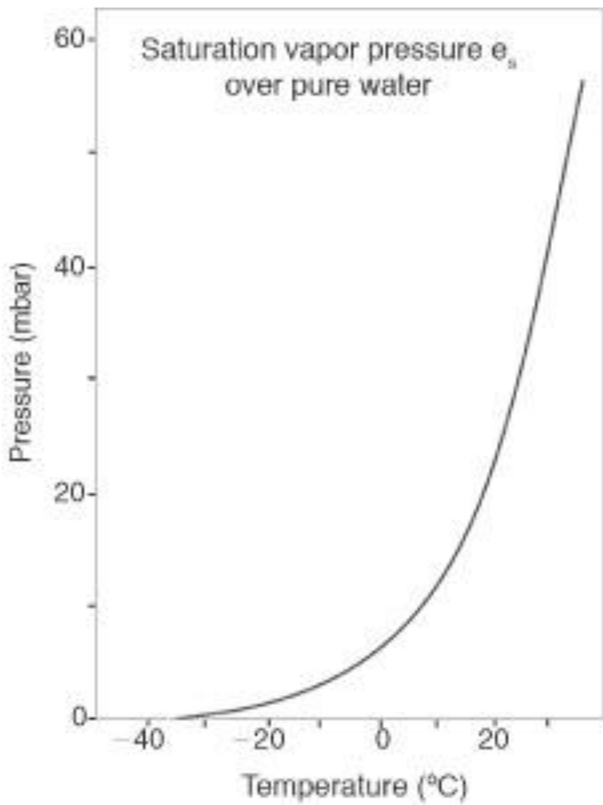

Figure 1.5: Saturation vapor pressure e_s (in mbar) as a function of *T* in °C (solid curve).

(From Wallace & Hobbs, (2006).)

- Moisture content decays rapidly with height
- The tropics more moist than polar regions
- Clouds form and precipitation occurs when moist air becomes saturated
  - Rising air (clouds)
  - Radiative cooling (fog)

Figure 1.7: Dawn mist rising from Basin Brook Reservoir, White Mountain National Forest, July 25, 2004.

(Photograph: Russell Windman.)

Figure 1.8: A photograph of the sound barrier being broken by a US Navy jet as it crosses the Pacific Ocean at the speed of sound just 75 feet above the ocean. Condensation of water is caused by the rapid expansion and subsequent adiabatic cooling of air parcels induced by the shock (expansion/compression) waves caused by the plane outrunning the sound waves in front of it. Photograph was taken by John Gay from the top of an aircraft carrier. The photo won First Prize in the science and technology division of the World Press Photo 2000 contest.