Lecture 2:
Structure and Composition of the Atmosphere and Ocean

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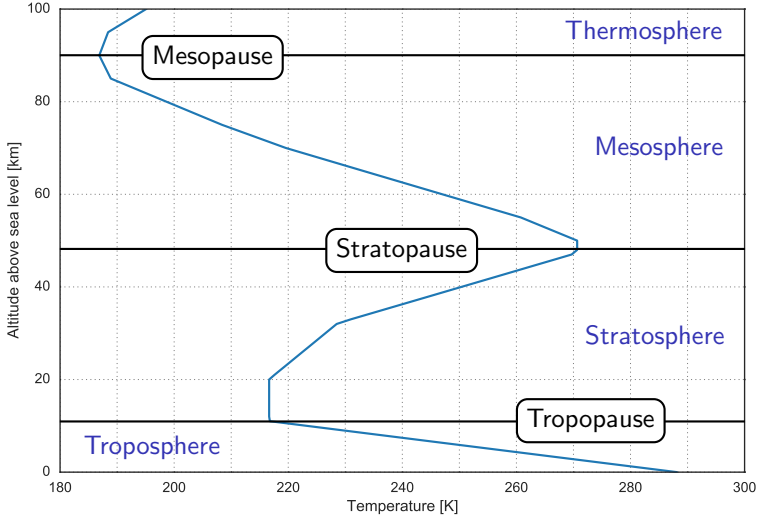
The atmosphere
- Temperature structure
- Major constituents
- Greenhouse gases

Equation of state and hydrostatic balance
- The atmospheric equation of state
- Hydrostatic balance

The ocean
- Composition
- Equation of state
- Vertical structure



data from 1976 US Standard Atmosphere

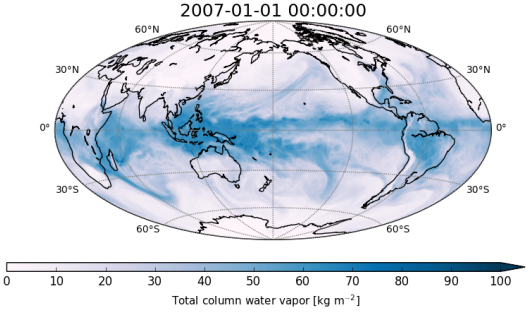
The Lapse Rate

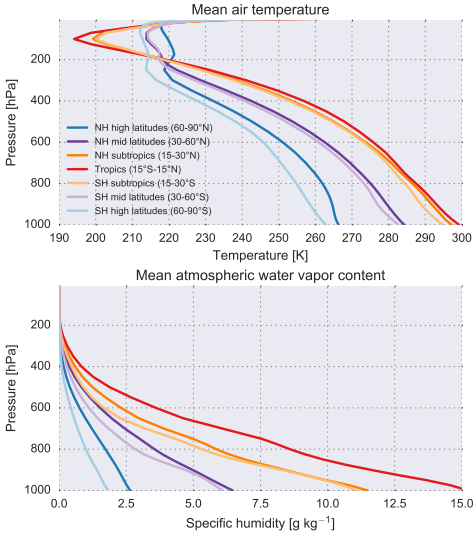
$$\Gamma = -\frac{dT}{dz}$$

Gas	Percent by volume
Nitrogen (N_2)	78.08%
Oxygen (O_2)	20.95%
Argon (Ar)	0.93%
Water Vapor (H_2O)	0.00001–4.0%
Carbon Dioxide (CO_2)	0.039%
Neon (Ne)	0.0015%
Helium (He)	0.0005%
Methane (CH_4)	0.00018%
Ozone (O_3)	0.000003–0.001%
Krypton (Kr)	0.0001%

Water Vapor

- a chemically active greenhouse gas
- critical for energy transport
- temperature determines upper limit

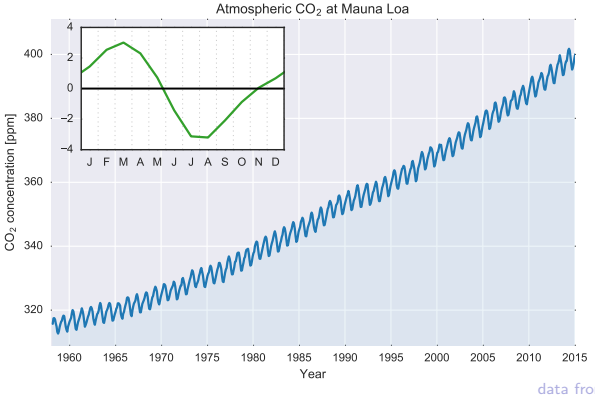




data from CFSR

Carbon Dioxide

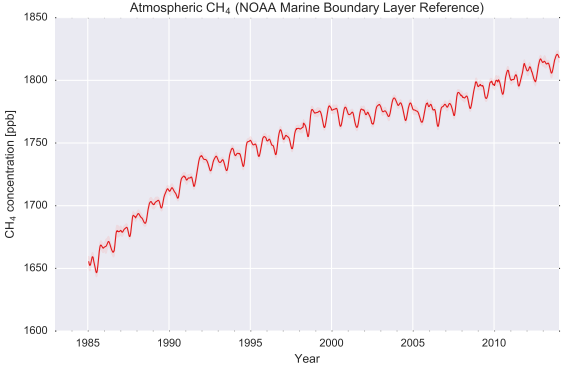
- another important greenhouse gas
- primary source of carbon for photosynthesis
- affects ocean acidity
- well mixed



data from NOAA ESRL

Methane

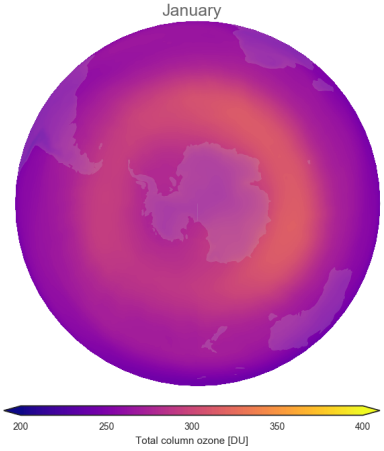
- also a greenhouse gas
- natural and anthropogenic sources
- important source of water vapor in the stratosphere



data from NOAA ESRL

Ozone

- absorber of both solar and infrared radiation
- chemically active
- important for life, but harmful to health

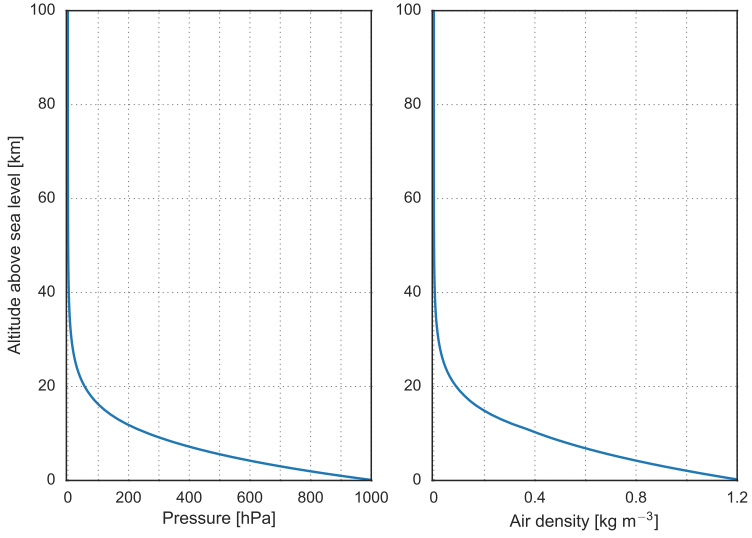


data from OMI

Atmospheric equation of state

$$p = \rho R_d T$$

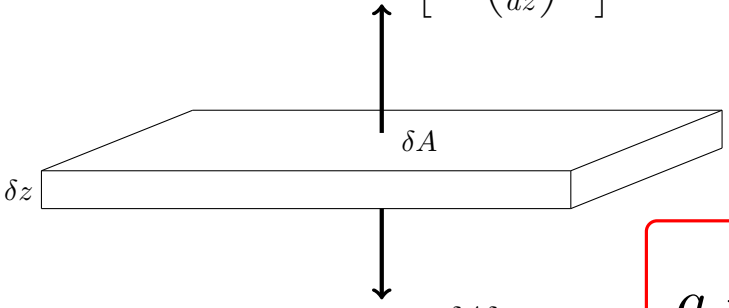
Assumptions:
- motion of air molecules is random
- individual molecules interact rarely
- air is dry: no water vapor



data from 1976 US Standard Atmosphere

Hydrostatic balance

pressure gradient force: $\left[p - \left(\frac{dp}{dz}\right)\delta z\right]\delta A - p\delta A = -\left(\frac{dp}{dz}\right)\delta z\delta A$



$$g = -\left(\frac{1}{\rho}\frac{dp}{dz}\right)$$

Applying hydrostatic balance

hydrostatic balance $g = -\frac{1}{\rho}\frac{dp}{dz}$

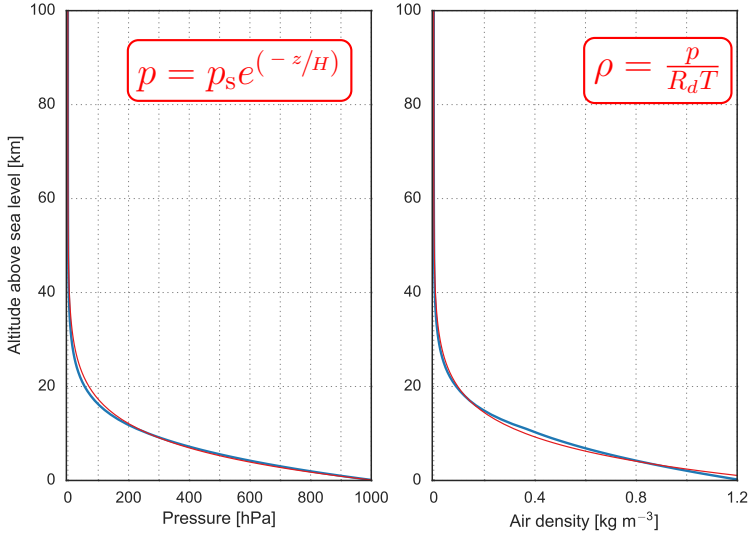
equation of state $\rho = \frac{p}{R_d T}$

$$\longrightarrow \quad \frac{dp}{p} = -\frac{dz}{H}, \; H = \frac{R_d T}{g}$$

scale height

If temperature is constant with height, then so is H:

$$p = p_s e^{(-z/H)}$$



data from 1976 US Standard Atmosphere

Applying hydrostatic balance

hydrostatic balance $g = -\frac{1}{\rho}\frac{dp}{dz}$

mass of a layer $m = \rho dz$

$$\Rightarrow \quad m = \frac{dp}{g}$$

The pressure at the top of the atmosphere is zero, so the mass per unit area is:

$$M = \frac{p_{\mathrm{srf}} - p_{\mathrm{toa}}}{g} = \frac{p_{\mathrm{srf}} - 0}{g} = \frac{p_{\mathrm{srf}}}{g}$$

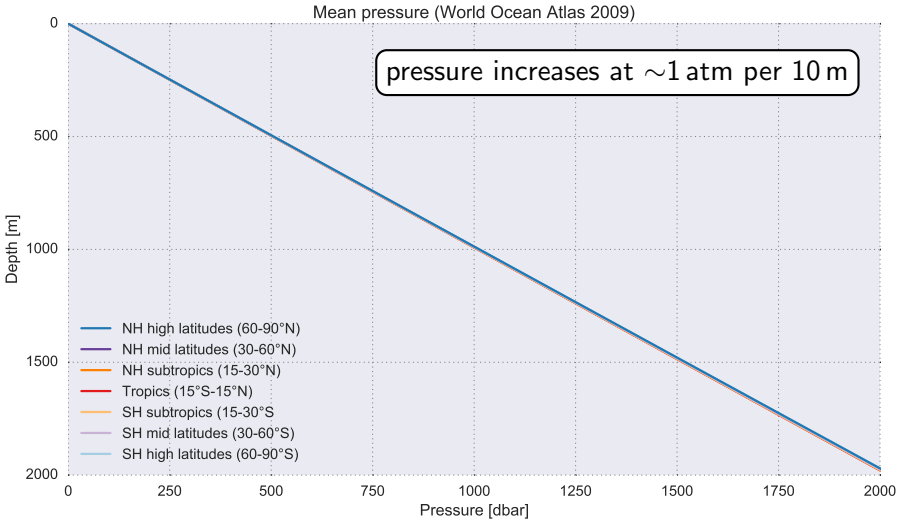
constituent ion	mass mixing ratio in seawater [g kg^{-1}]	percentage of global salt
Chloride (Cl^-)	19.215	54.96%
Sodium (Na^+)	10.685	30.58%
Sulphate (SO_4^{2-})	2.693	7.70%
Magnesium (Mg^{2+})	1.287	3.69%
Calcium (Ca^{2+})	0.410	1.17%
Potassium (K^+)	0.396	1.13%
Bicarbonate (HCO_3^-)	0.142	0.41%
Bromide (Br^-)	0.067	0.19%
Boric acid (H_3BO_3)	0.026	0.07%

Equation of state for seawater

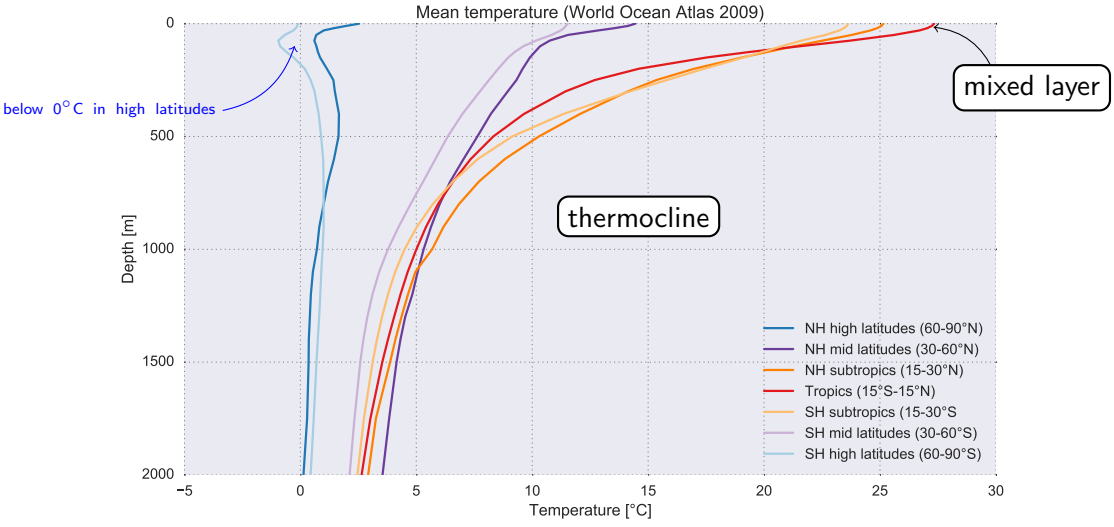
- pressure
- temperature
- density
- salinity

No general theory for liquids

Must be determined by fitting a function to measurements



data from WOA2009



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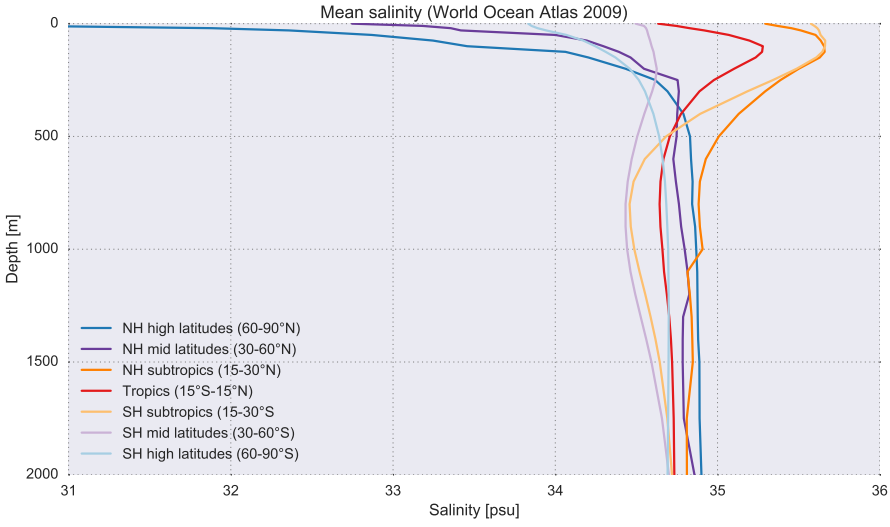


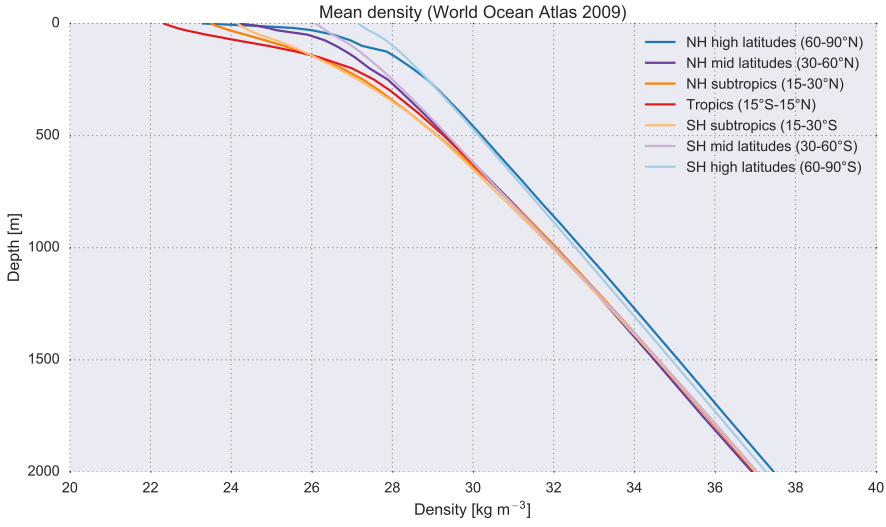
data from WOA2009

Density of seawater

- pressure
- temperature
- salinity

generally report density relative to density of pure water:

$$\sigma(T, p, S) = \rho(T, p, S) - 1000\mathrm{kg\,m^{-3}}$$



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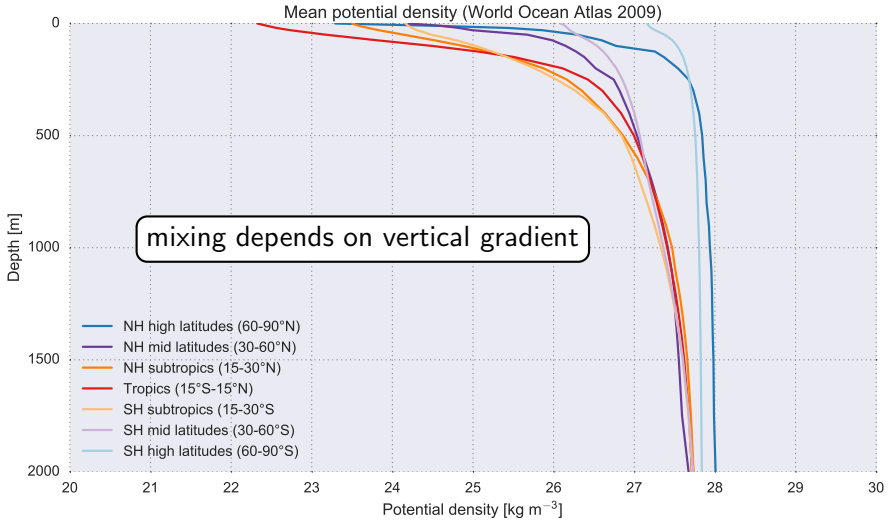

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