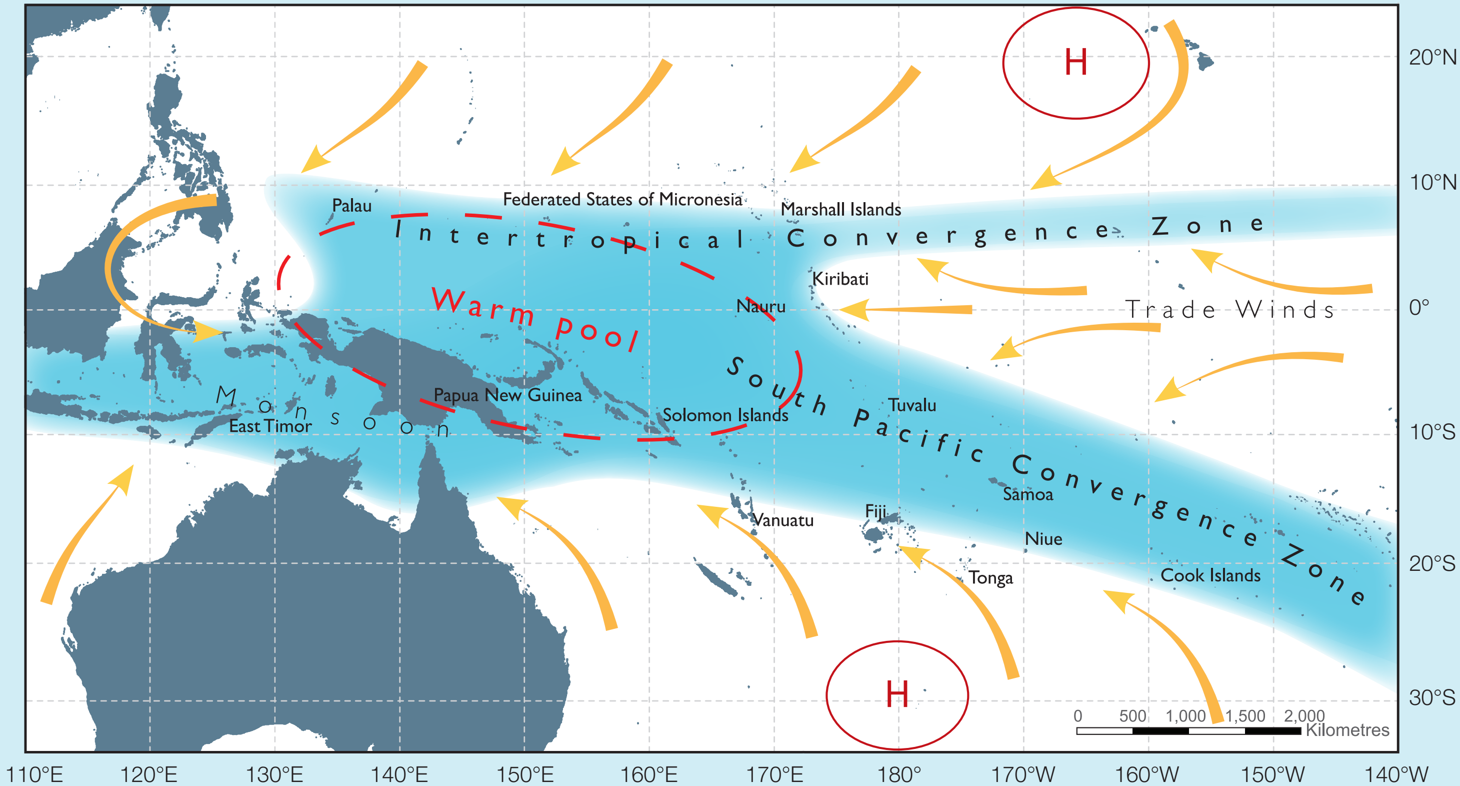
Monday 23 October 2017, Class #22

Concepts for Today

- SPCZ question
- Hydrological Cycle (finish up evaporation)
- Atmospheric Dynamics

South Pacific Convergence Zone (SPCZ)



The average positions of the climate features in November to April. The yellow arrows show near-surface winds, the blue shading represents the bands of rainfall (convergence zones with relatively low pressure), and the red dashed oval indicates the West Pacific Warm Pool. H represents the typical positions of moving high pressure systems.

- **SPCZ is part of ITCZ, Impacted by El Nino when it moves north and east, During La nina it moves south and west.**
- **The western, more equatorial portion of the SPCZ rainfall band is largely controlled by sea surface temperature (SST), whereas its eastern portion is also influenced by extra-tropical circulation and the subtropical dry zone of the southeastern Pacific.**

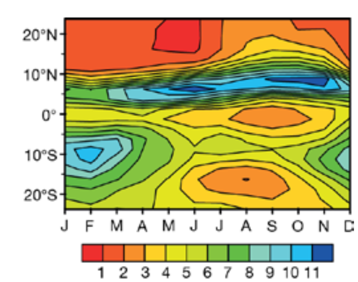


Figure 2.7: Variation of average rainfall with month (horizontal axis) and latitude (vertical axis) averaged over longitude band 155°E–140°W in mm per day. Data from the Climate Prediction Center Merged Analysis of Precipitation dataset for years 1979–1999. The regions of strong rainfall (blue/green) to the south and north of the equator indicate positions of the SPCZ and ITCZ respectively.

Sea Surface Temperature and Salinity in SPCZ

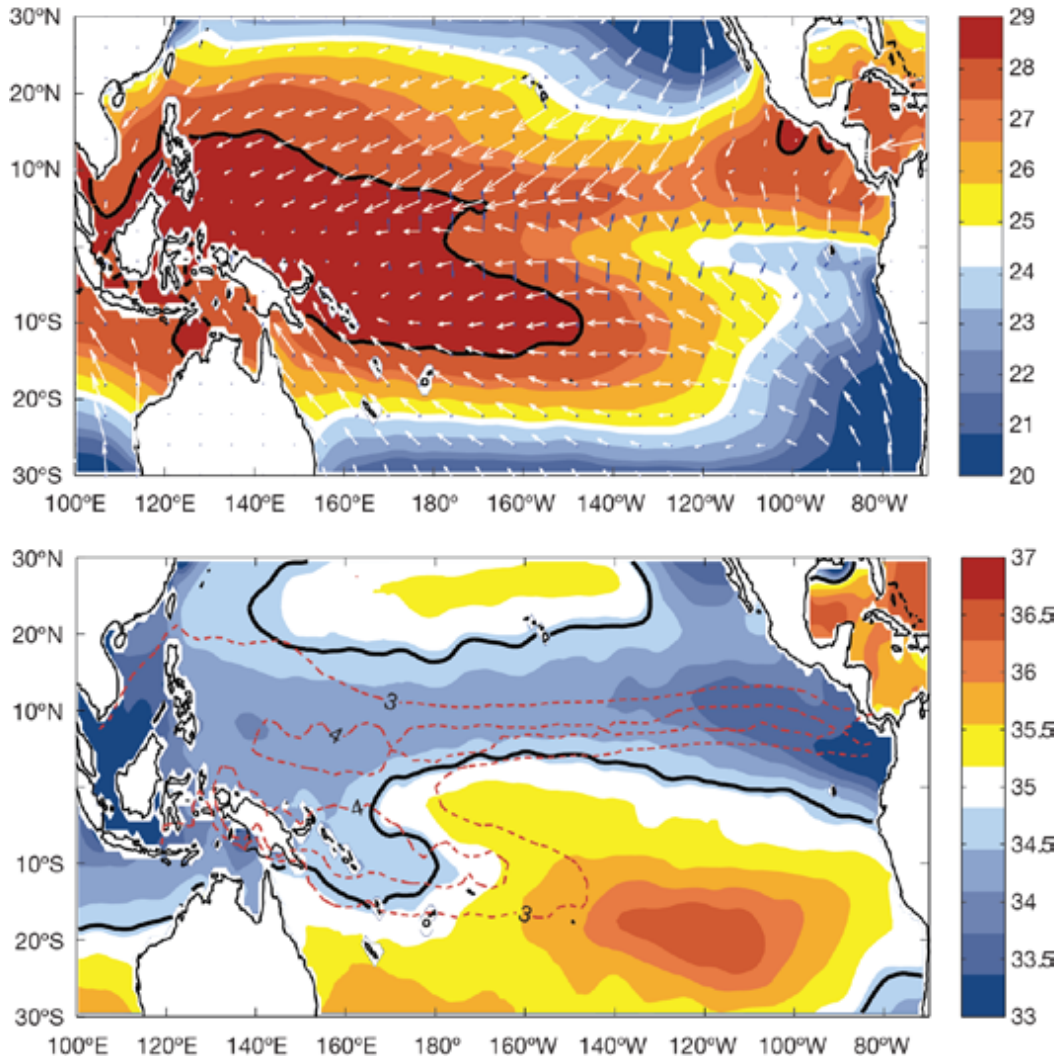


Figure 2.11: Long-term annual-average sea-surface temperature (°C) (top) and sea-surface salinity (parts per thousand, ppt) (bottom) from the World Ocean Atlas 2005 Database. Thick black lines show the 28.5°C and 34.8 ppt contours, commonly used for the boundary of the Warm Pool. Also shown on the upper panel are the Quikcat wind stress vectors (white arrows) and surface Ekman currents (blue arrows, computed from windstress). Precipitation minus evaporation from ERA-40 reanalysis is shown on the lower panel (mm per day, red dashed contours). See text for explanations of these terms and Tables 2.2 and 2.3 for data sources.

Distribution of Global Water

Table 2.1 Distribution of water in the climate system

Location	Percentage of global water	Volume of water (km^3)	Mass of water (kg)
Oceans	97%	1.37×10^{10}	1.37×10^{22}
Ice (glaciers, sea ice)	2%	2.9×10^{8}	2.9×10^{20}
Groundwater	0.7%	9.5×10^{7}	9.5×10^{19}
Lakes	1×10^{-2}	1.25×10^{6}	1.25×10^{18}
Soils	5×10^{-3}	6.5×10^{5}	6.5×10^{17}
Atmosphere	1×10^{-3}	1.3×10^{5}	1.3×10^{17}
Rivers and streams	1×10^{-4}	1.7×10^{4}	1.7×10^{16}
Biosphere	4×10^{-5}	6×10^{3}	6×10^{15}

The amount of water in atmosphere, soils and biosphere is soooo small yet it is so important to climate processes.

[Cook, 2012]

Moisture Budget Diagram

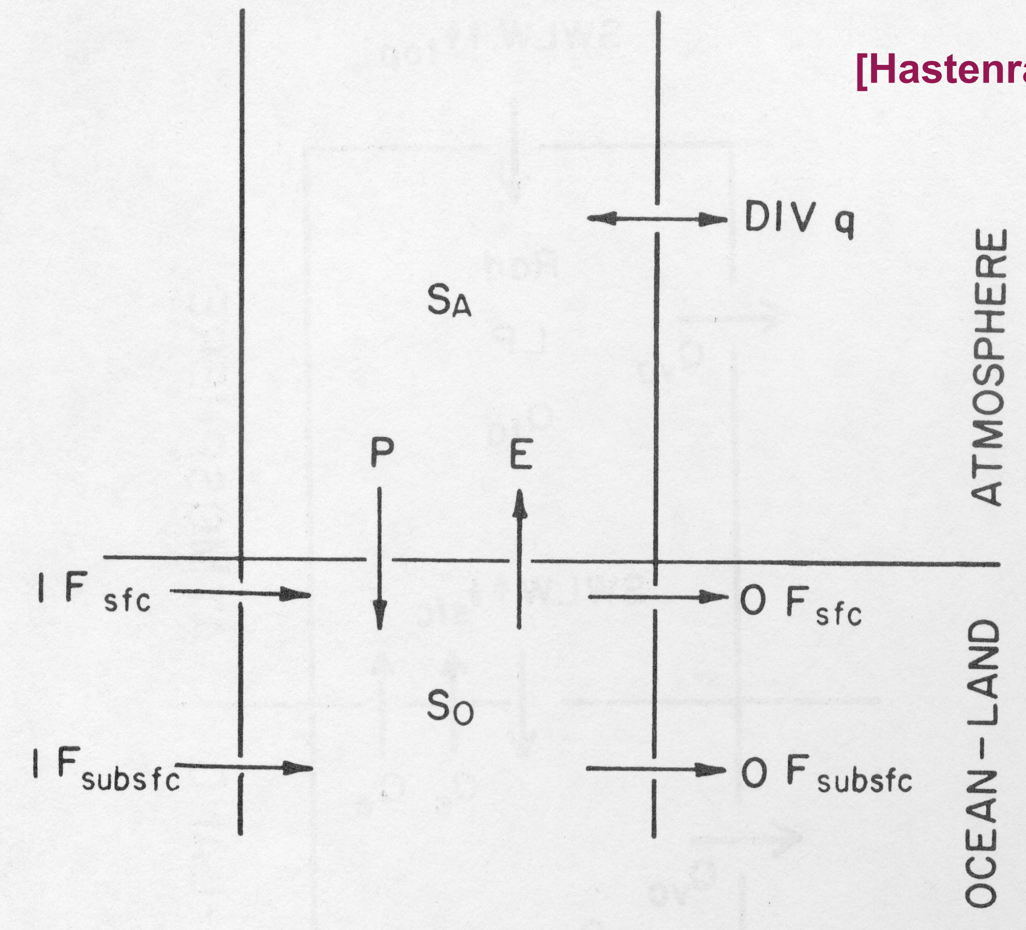


Fig. 5.1:2. Water budget scheme for the atmosphere-lithosphere-hydrosphere system. P denotes precipitation, E evaporation from land or water surfaces, div q divergence of the total vertically integrated water vapor flux in the atmosphere, q_t rate of change of precipitable water, and S_O storage in the lithosphere-hydrosphere. The terms IF_{sfc}, OF_{sfc}, IF_{subsfc}, OF_{subsfc} signify, respectively, surface inflow and outflow, and subsurface inflow and outflow.

The Water Budget

- **Surface Balance, long-term**

storage dewfall

$$g_w = S_o = P + D - E - \Delta f$$

precip evap runoff

$$\Delta f = P - E$$

- **Atmospheric Balance, PDE opposite sign**

$$g_{wa} = S_A = -(P + D - E) - \Delta f_a$$

storage in air horizontal export in atmos

Divergence - Aside

- Divergence of some quantity F

$$\vec{\nabla} \bullet \vec{F} = \frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z}$$

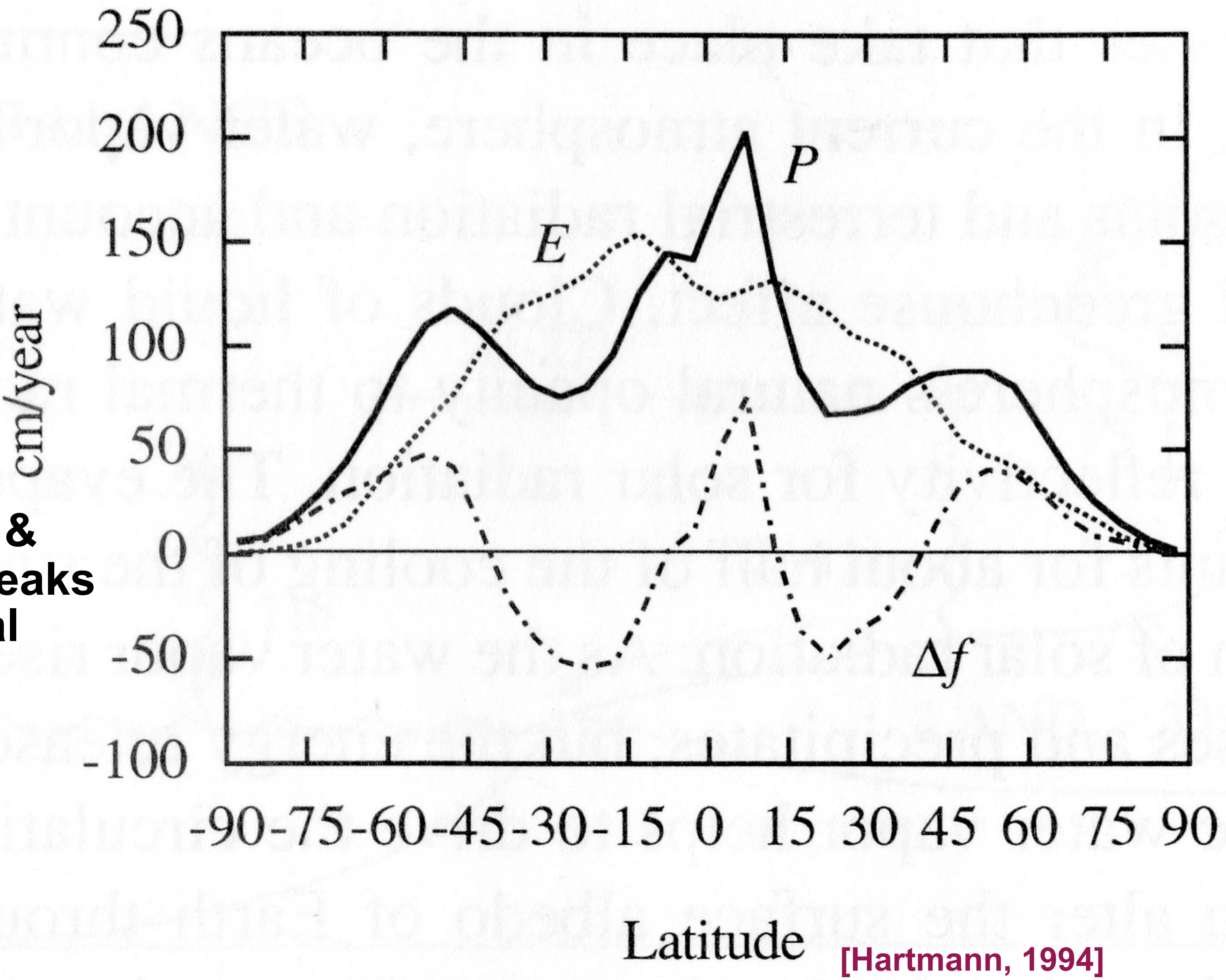
- Divergence is the rate at which F, flux, exits some space, and quantifies how much the density within the space of some quantity changes.

$$\vec{\nabla} \bullet \left(r\vec{U} \right) = -\frac{\partial r}{\partial t}$$ **Continuity Equation**

Gauss's Theorem: the sum of all sources minus the sum of all sinks gives the net flow out of a region. Volume integral of divergence of a quantity = net amount crossing surface

Evaporation, Precipitation, & Runoff (P-E)

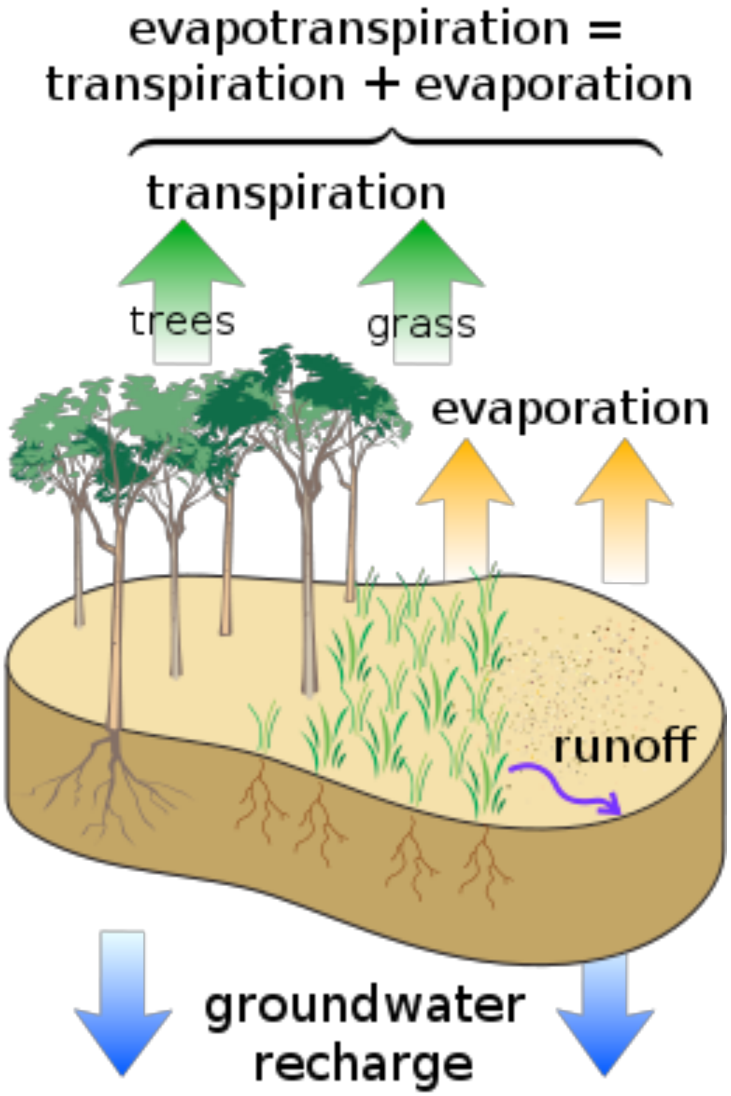
- P: Equatorial & Midlatitude Peaks
- E: Subtropical Peaks
- P-E



[Hartmann, 1994]

Evaporation and Transpiration

- ***Evapotranspiration*** **- water going from surface to atmosphere, transforming from liquid to gas phase, but passes from soil through plant stomata to the atmosphere. *Sublimation* may also be included in this term.**



http://en.wikipedia.org/wiki/Evapotranspiration

Land Surface Influences Surface Heat and Water Fluxes

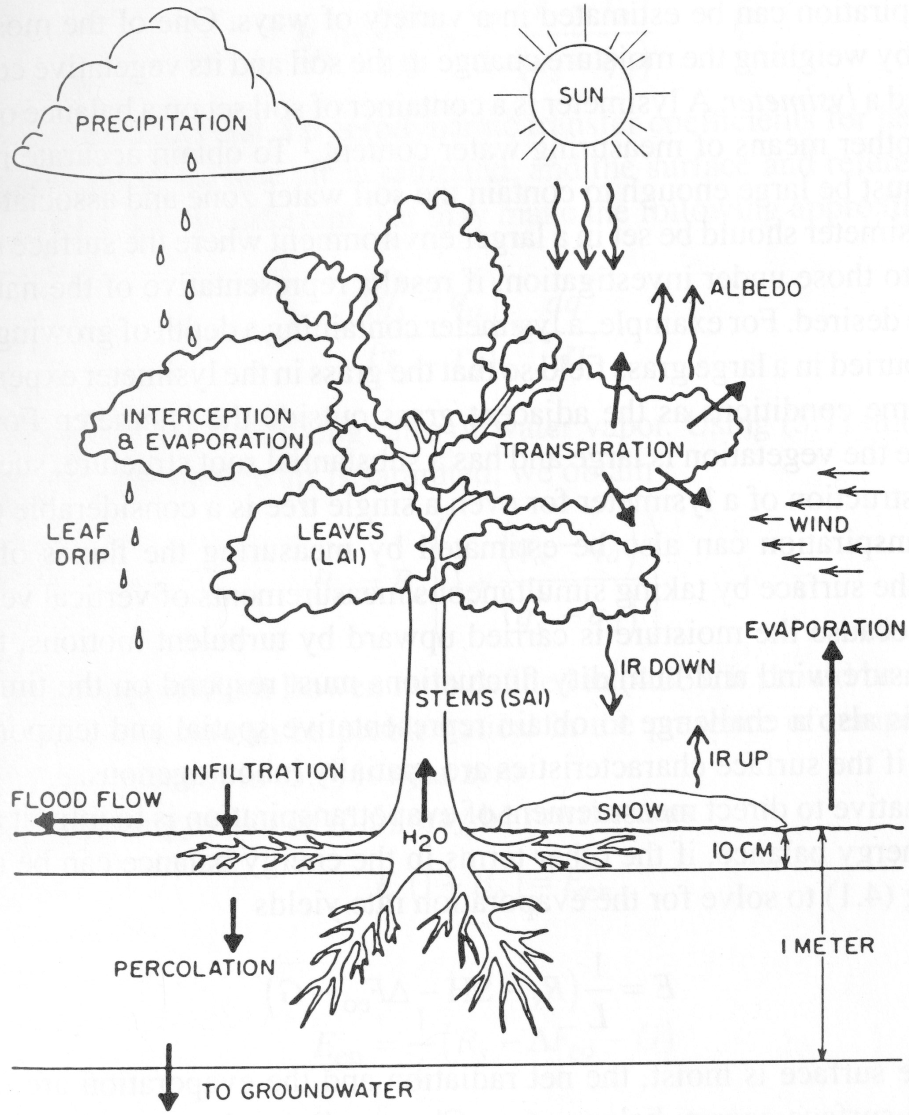


Fig. 5.5 Diagram showing the effects of the vegetation canopy on the water and energy fluxes. [From Dickinson (1984). © American Geophysical Union.]

[Hartmann, 1994]

Measure Evapotranspiration

- Weigh moisture change with a *lysimeter*

- Micro-meteorology measurements, w & q

N. Mölders

- Alternate method is to infer as a residual in the energy balance

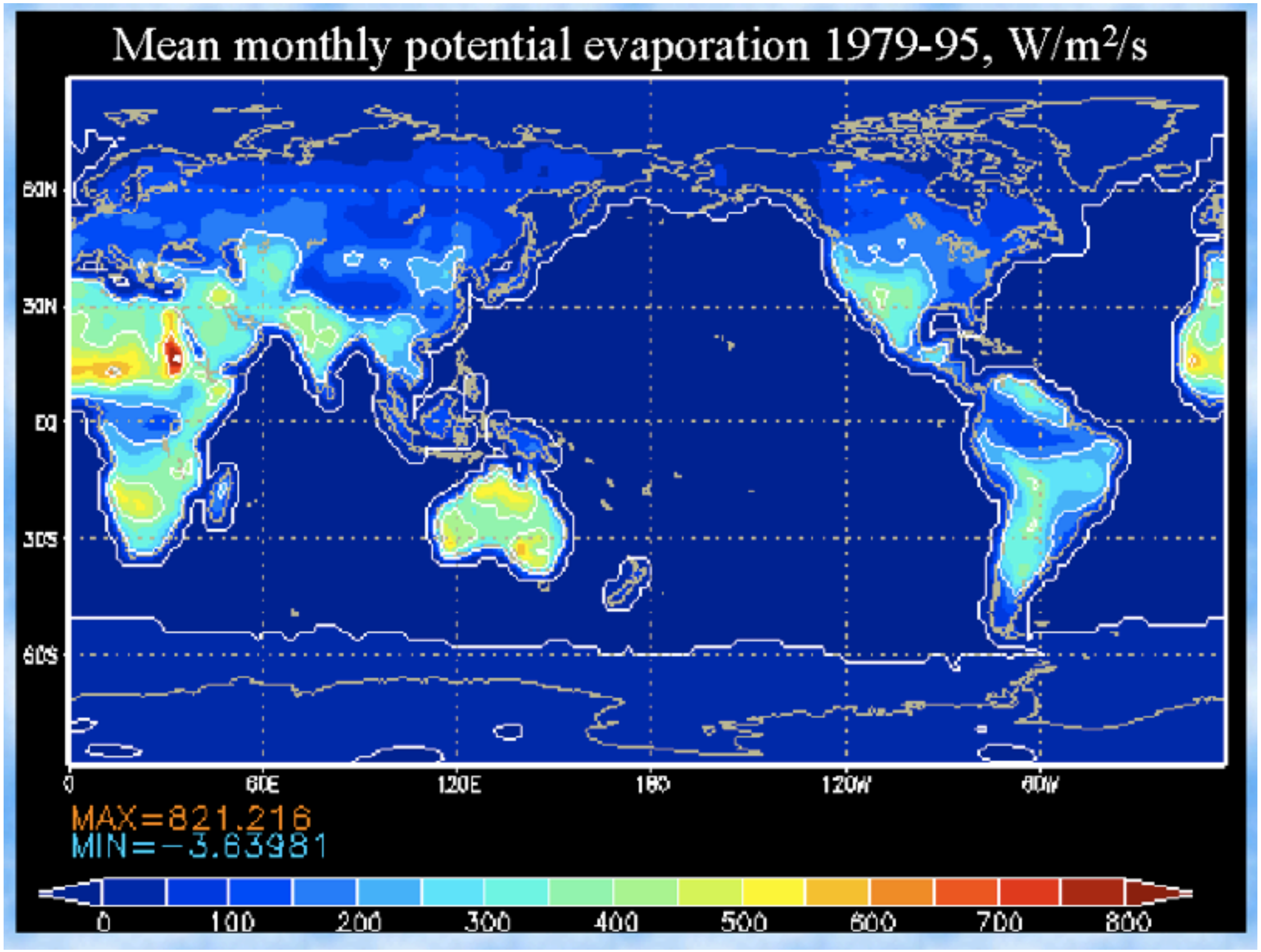
$$E = \frac{(R_s - SH - \Delta F_{eo} - G)}{L}$$

Poorly observed quantity

Potential Evapotranspiration

- **Amount of water that can be lost from a saturated (wet) surface is called potential evapotranspiration.**
- **Usually PE larger than E, since soil may not be saturated or plants are not transpiring at maximum rate.**
- **Calculate using Penman's Equation or other theoretical or empirical techniques.**

1) Constraints on Evaporation
-water supply
-energy for evaporation
-surface air conditions

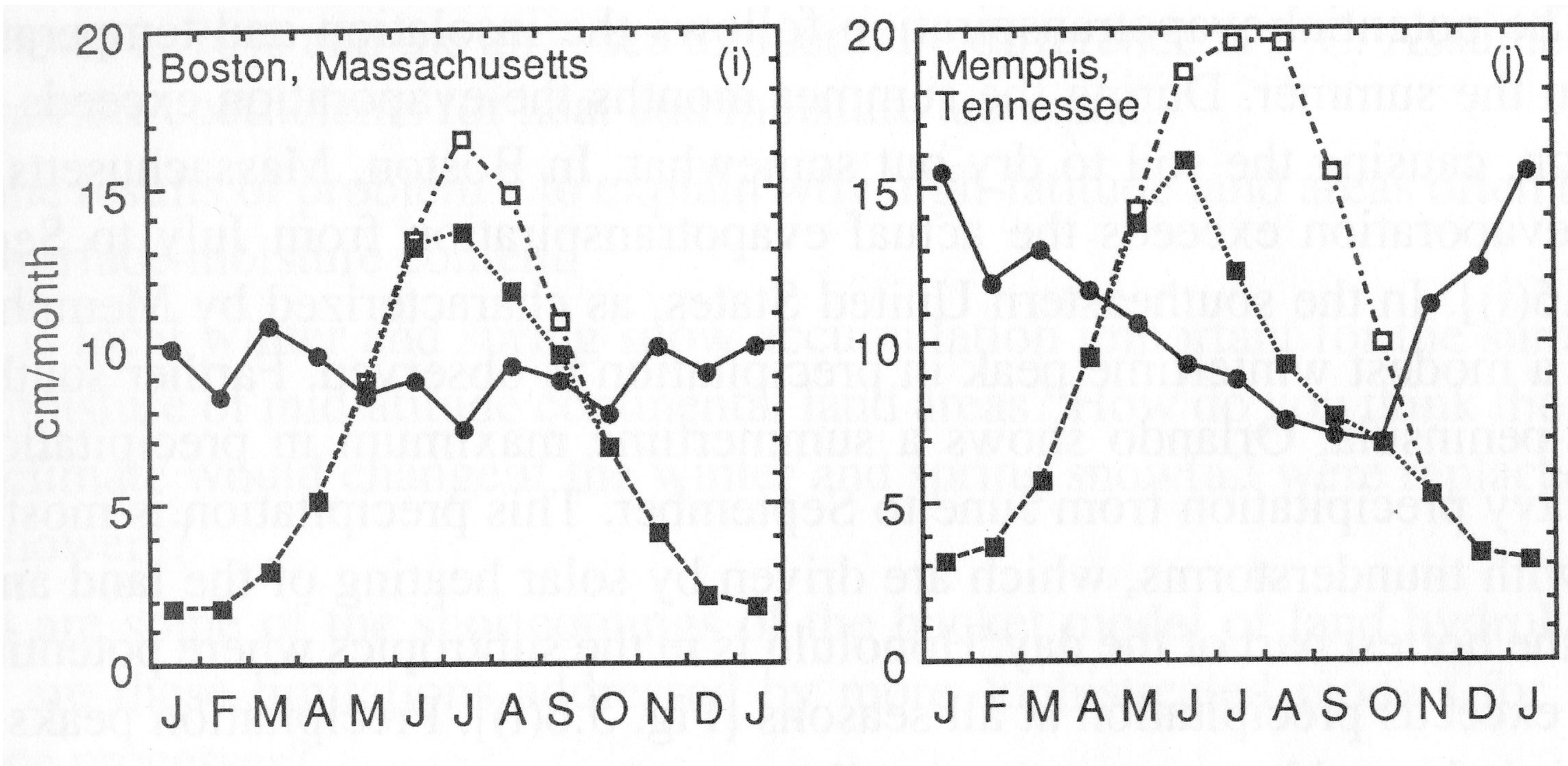


http://ag.arizona.edu/~lmilich/pe.html

Water Balance - Annual Cycle

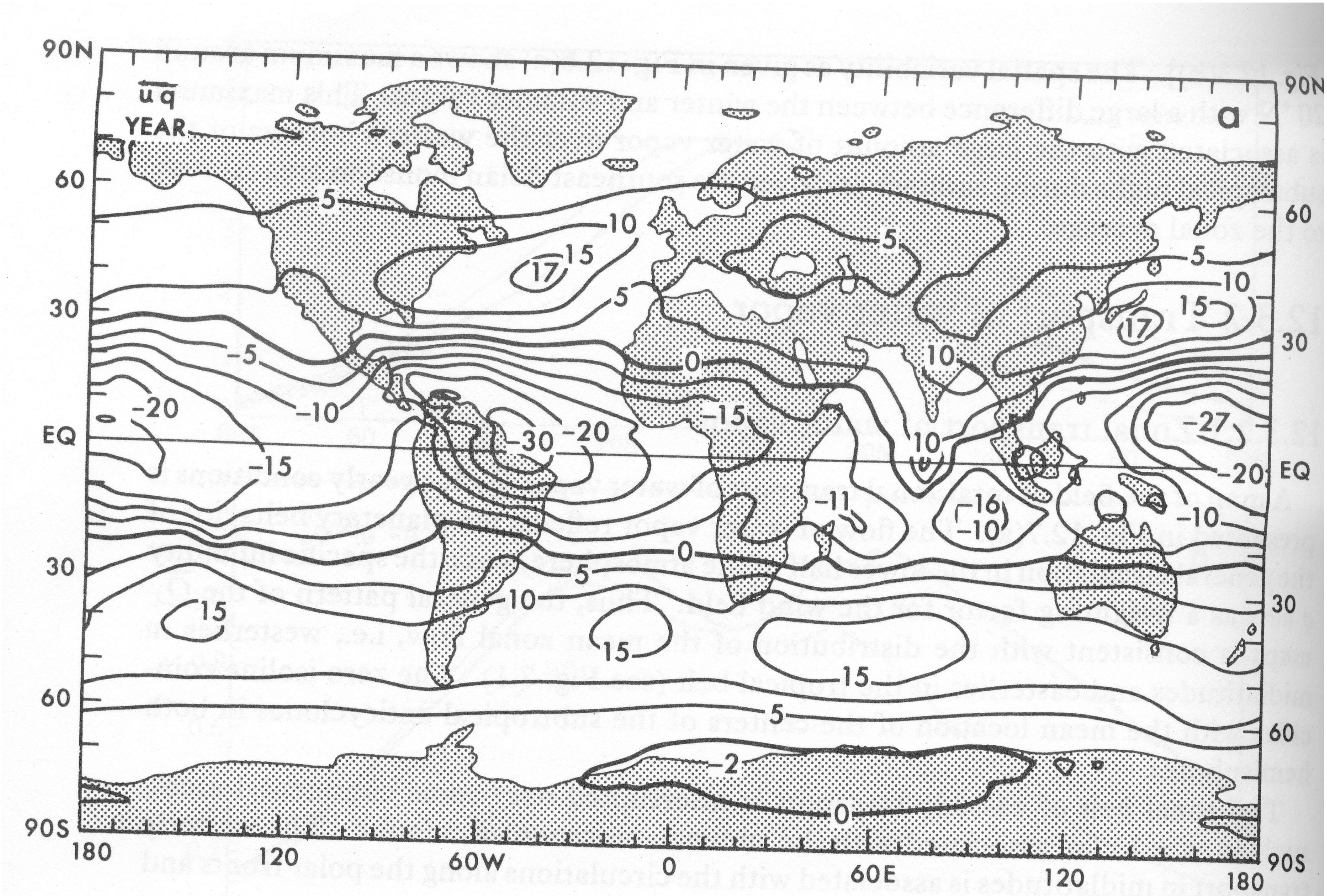
- **Precip varies little in Boston over year and PE follows solar insolation.**
- **Memphis (southern US) winter precip peak, PE follows insolation also**

● P ■ E □ PE cm/month



[Fig 5.6, Hartmann, 1994]

Zonal Water Vapor (vertically integrated) transport by all Motions



Follows Winds, Around India, + eastward, - westward

[Peixoto & Oort, 1992]

Water Budget: Oceans and Continents

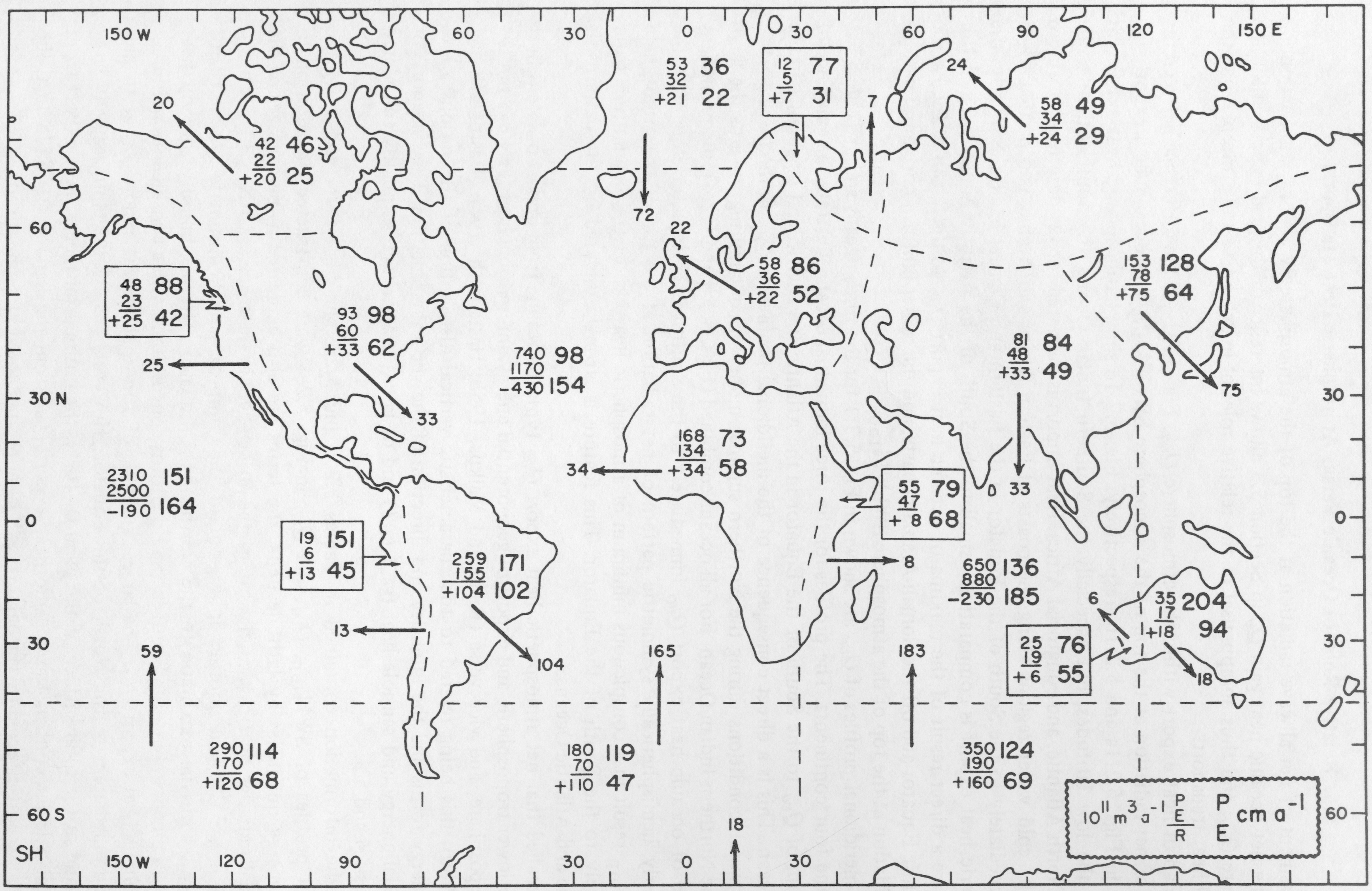


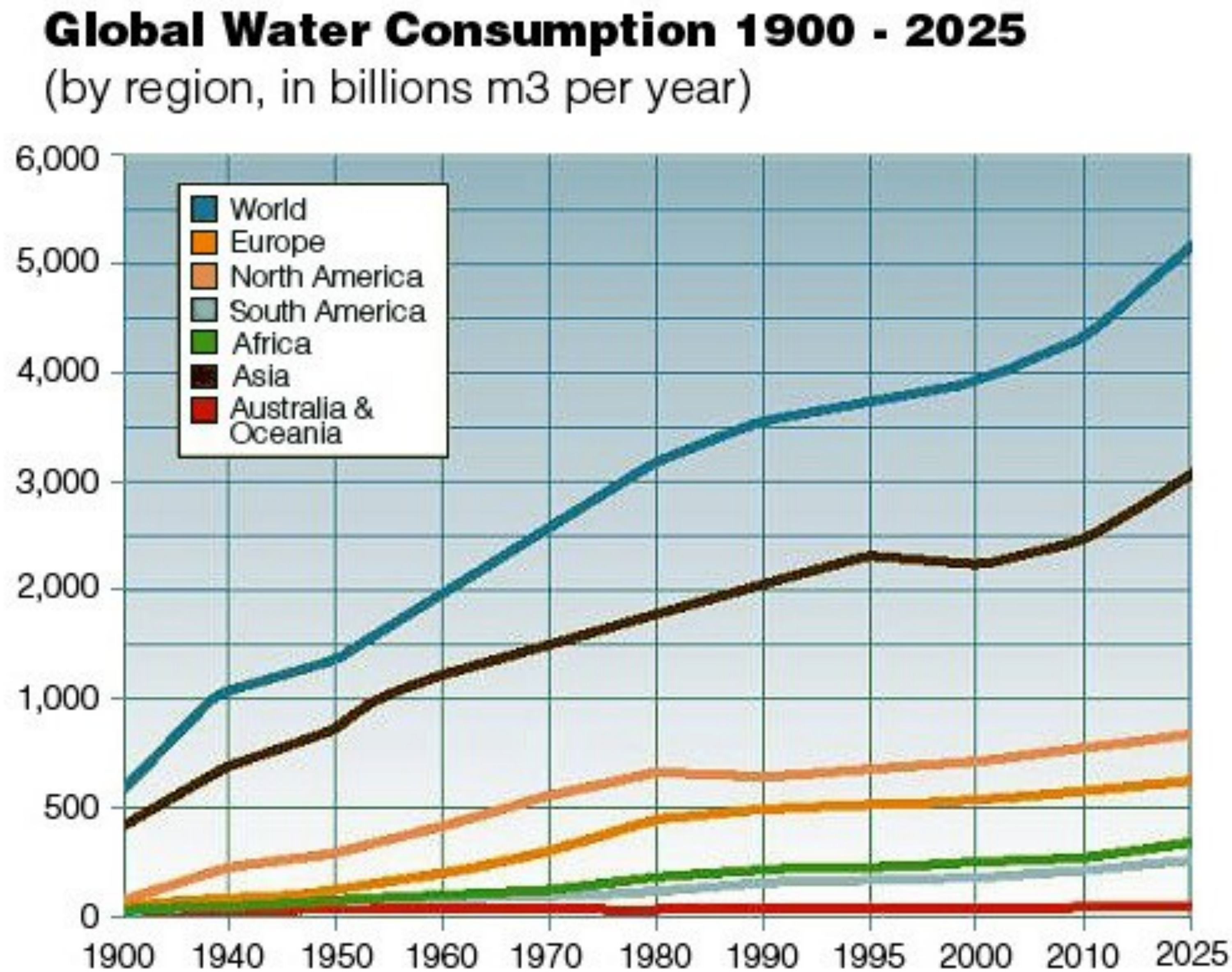
Fig. 5.5:2. Schematic map of the water budget of continents and oceans. Broken lines delineate continental drainage basins and sectors of the ocean. The large numbers in boxes denote precipitation, P (top) and evaporation E (bottom) in cm a^{-1}. The small numbers signify, from top to bottom, P, E, and $P–E$, in 10^{11} m^3 a^{-1}. Arrows indicate continental discharge and net water exchange between segments of the ocean, with the same units. Source: UNESCO (1978).

- Explain plot
- ATL, IND, PAC net export
- ART, ANT net gain

[Hastenrath, 1991]

Compare with Hartmann Table 5.2

Next war over water??

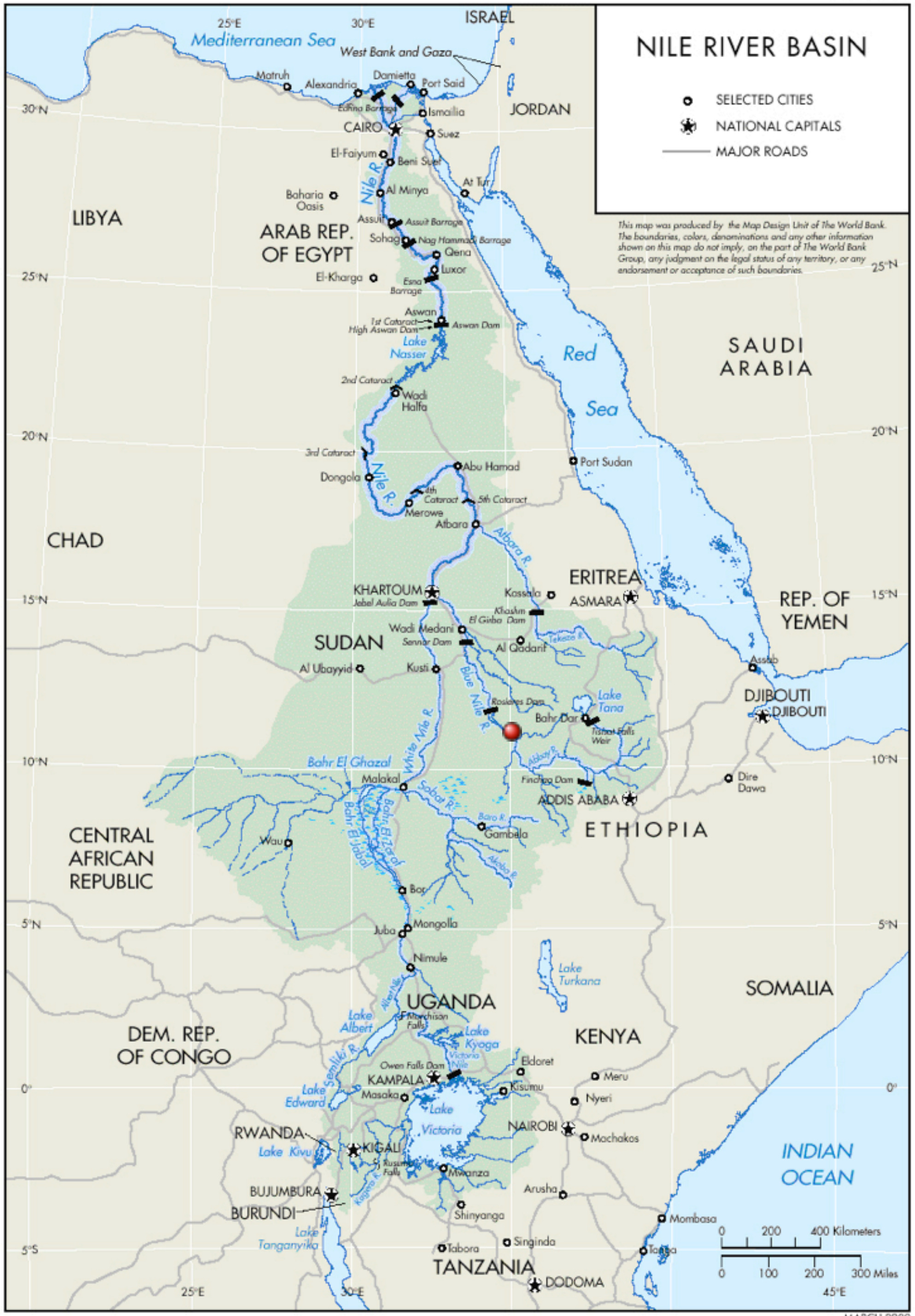


Goldman Sachs describes it as “the petroleum of the next century”.

Newsweek 2015: http://www.newsweek.com/2015/05/01/world-will-soon-be-war-over-water-324328.html

worldwaterexchange.com

Ethiopia's Planned Renaissance Dam on the Nile



6000 MW hydroelectric plant

Nile River Cooperative Framework deal, challenging the colonial-era treaty that guarantees Egypt "natural and historic rights" over the Nile waters

World » Africa

Ethiopia and Egypt face off over billion-dollar Nile dam project

October 16, 2013 Updated: October 16, 2013 23:27:00

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Summary of Hydrology

- **Key Ideas for Today**
  - **Global evaporation cycle**
  - **Measuring evaporation and soil moisture**
  - **P-E, P-E budgets, P-E zonal mean pattern**
  - **Freshwater in the earth system**
  - **Evapotranspiration**
  - **Potential Evapotranspiration**
  - **Water stress leading to unrest?**

Global Atmospheric Winds

http://www.youtube.com/watch?v=qh011eAYjAA

Global Ocean Currents

http://www.youtube.com/watch?v=xusdWPuWAoU

Newton's First Law

- ΣF=ma, sum up all the forces
- What forces come into play in the atmosphere?
  - Coriolis
  - Pressure Gradient Force
  - Friction

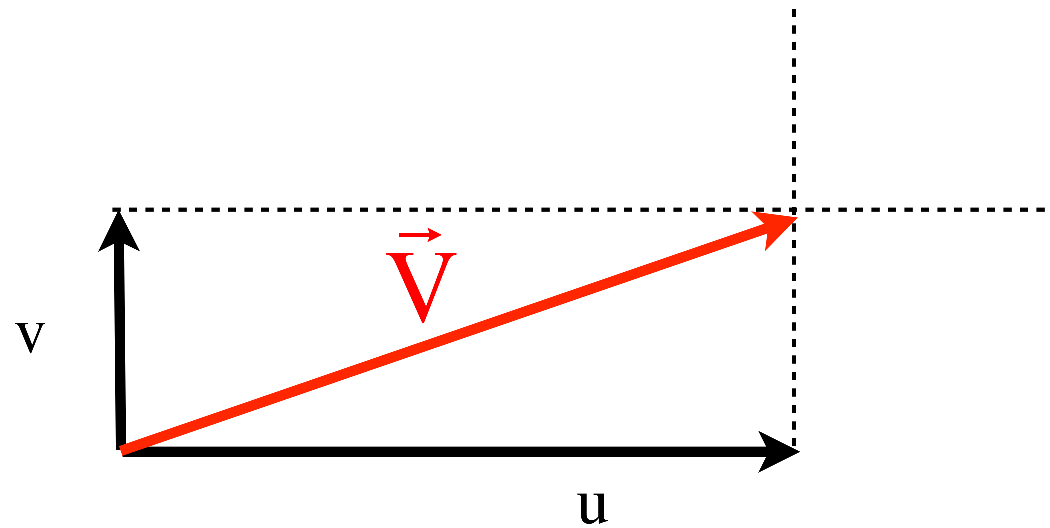
$$\sum \vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt}$$

units

kg m/s^2

Vector Aside

- **A quantity that has *magnitude* and *direction* (example: wind)**



$$\vec{V} = u\vec{i} + v\vec{j}$$

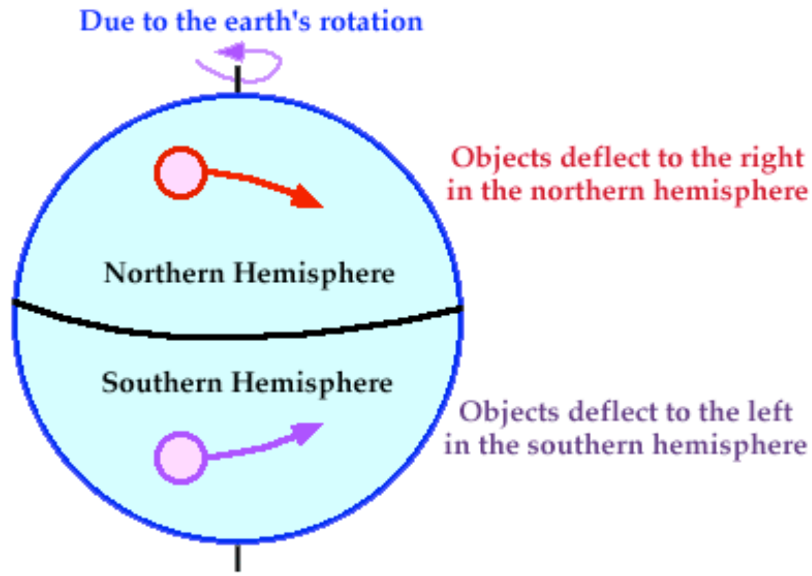
Coriolis Force

http://www.classzone.com/books/earth_science/terc/content/visualizations/es1904/es1904page01.cfm

- **Because the earth is turning this fake force has to be included in the sum of forces. Newton's laws only apply in an inertial reference frame (not rotating).**
- **To the right in the northern hemisphere and to the left in the southern hemisphere.**
- **Earth spins counterclockwise if you are looking down on the north pole (opposite if you are looking down on to the south pole.**

What is the Coriolis ‘force’?

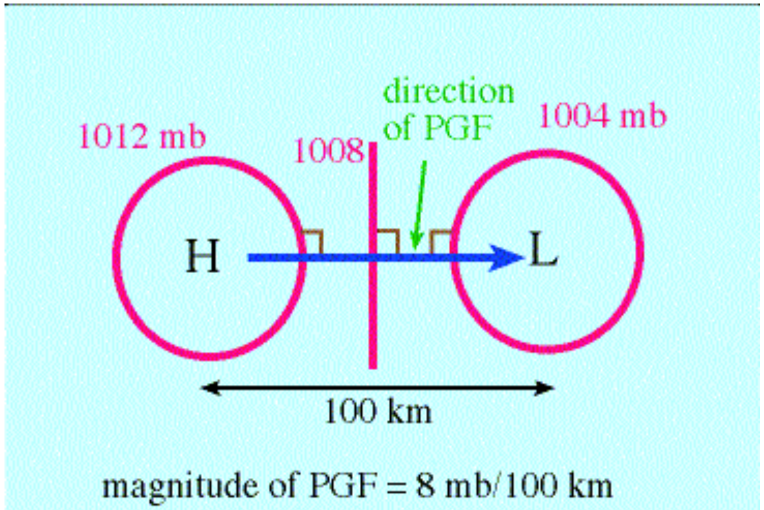
Once air has been set in motion by the pressure gradient force, it undergoes an apparent deflection from its path, as seen by an observer on the earth. This apparent deflection is called the "Coriolis force" and is a result of the earth's rotation.



$$Coriolis = fv\vec{i} - fu\vec{j}$$

f is the Coriolis parameter, a function of latitude

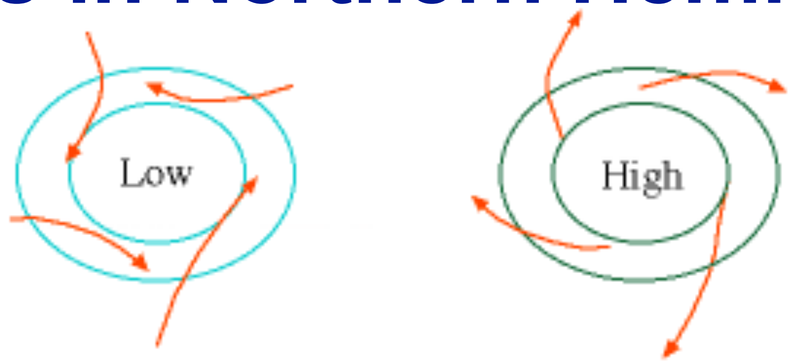
Pressure Gradient Force



http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/pgf.html

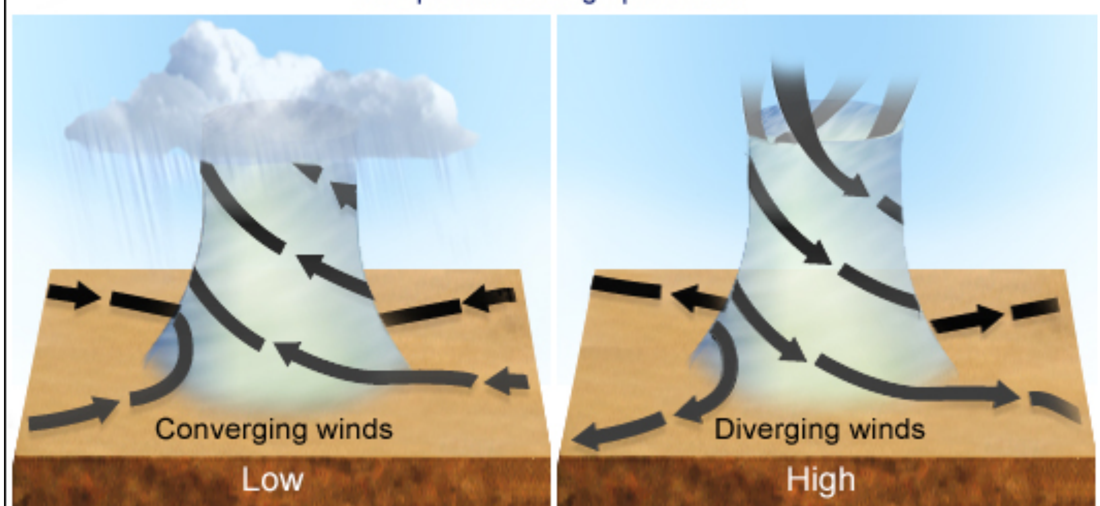
- **Pressure gradients occur when there are differences in pressure. What leads to pressure differences?**
- **The direction of the pressure gradient force is from high to low.**
- **Differential heating leads to pressure difference that forces winds.**
- **Think of a high pressure as a hill of atmospheric mass that wants to even out so moves downhill.**

Circulation around high and low pressure centers in Northern Hemisphere



Air flows *into* a low-pressure region but the coriolis effect creates a spiralling pattern. Air spirals *out of* a high-pressure in the opposite direction.

Low pressure v high pressure



In a low pressure system, air is dragged in and forced upwards where it cools and forms clouds. In a high pressure system, dense air is forced downwards and spreads out over the surface of the Earth.

- **Flow is opposite in the southern hemisphere around highs and lows.**