Friday 6 October 2017, Class #17

Concepts for Today

- Wind/current climo
- Hydrological Cycle
- Do you suffer from Kalimeraphobia?

Review

•

Hydrological Cycle - Why important?

- **Reading References: Chapter 5 Hartmann, Cook: 33-40 & Chapter 9**
- **Heat engine of the climate, because transporting moisture around is equivalent to transporting heat. Why?**
- **Water is important to life, need precipitation to grow crops and feed humanity**
- **As climate warms the forecast is that the hydrological cycle will get stronger, more vigorous (past climate evidence of this and consensus is building that this is happening)**
- **Chemical weathering depends on water, Biological processes depends on water**
- **Clouds are formed from water and are key for planetary albedo (62 of total 102 W/m^2 is from clouds for solar reflection)**
- **Evaporation accounts for half the surface cooling (80 of 161 W/m^2 surface heat out)**
- **Other reasons????**

Climatological Annual Fluxes of Water

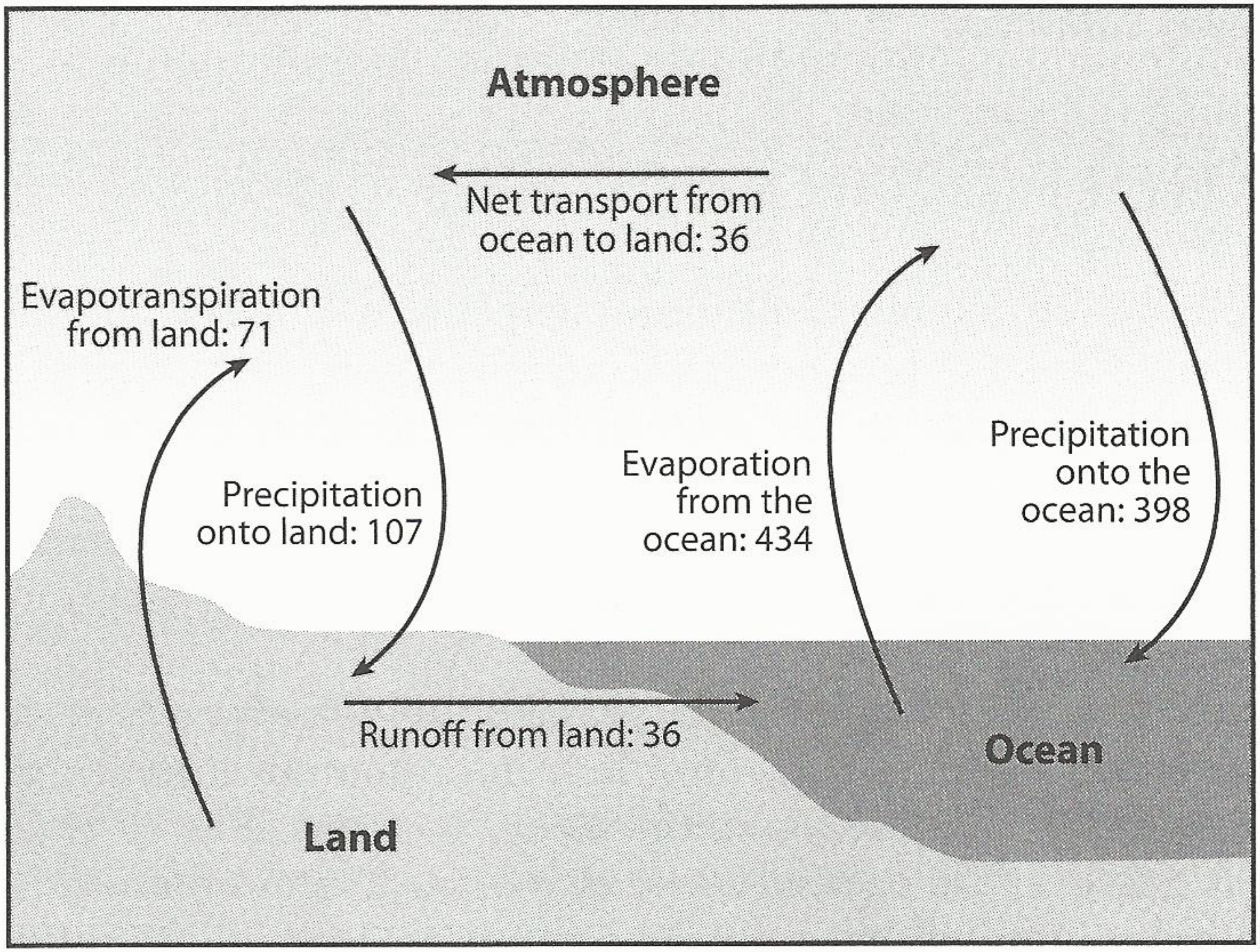


Figure 2.24 Estimated climatological fluxes (in 10^{15} kg/yr) of water in the climate system.

Peta-kg or Exagrams per year

[Cook, 2012]

Seasonal cycle of surface winds

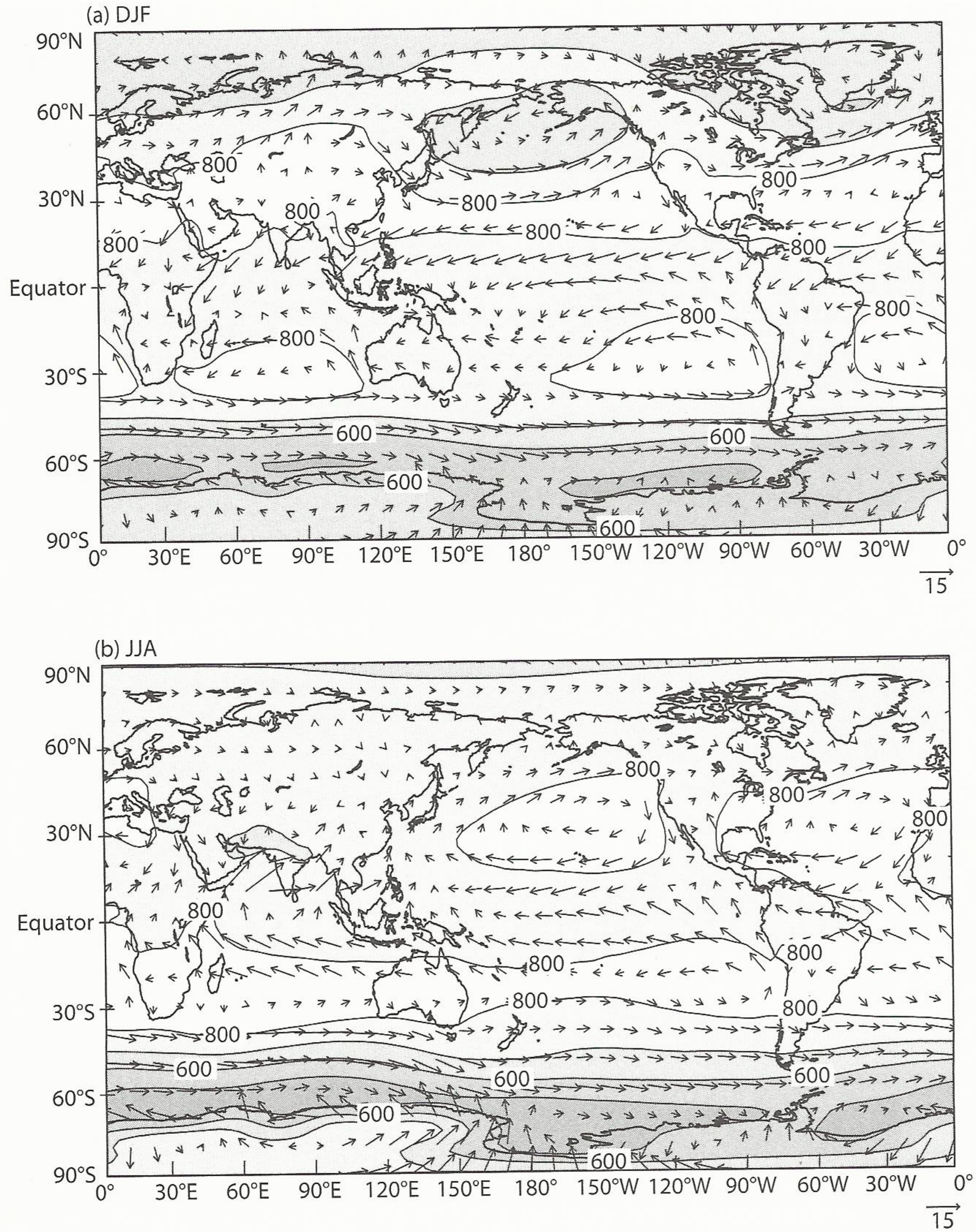
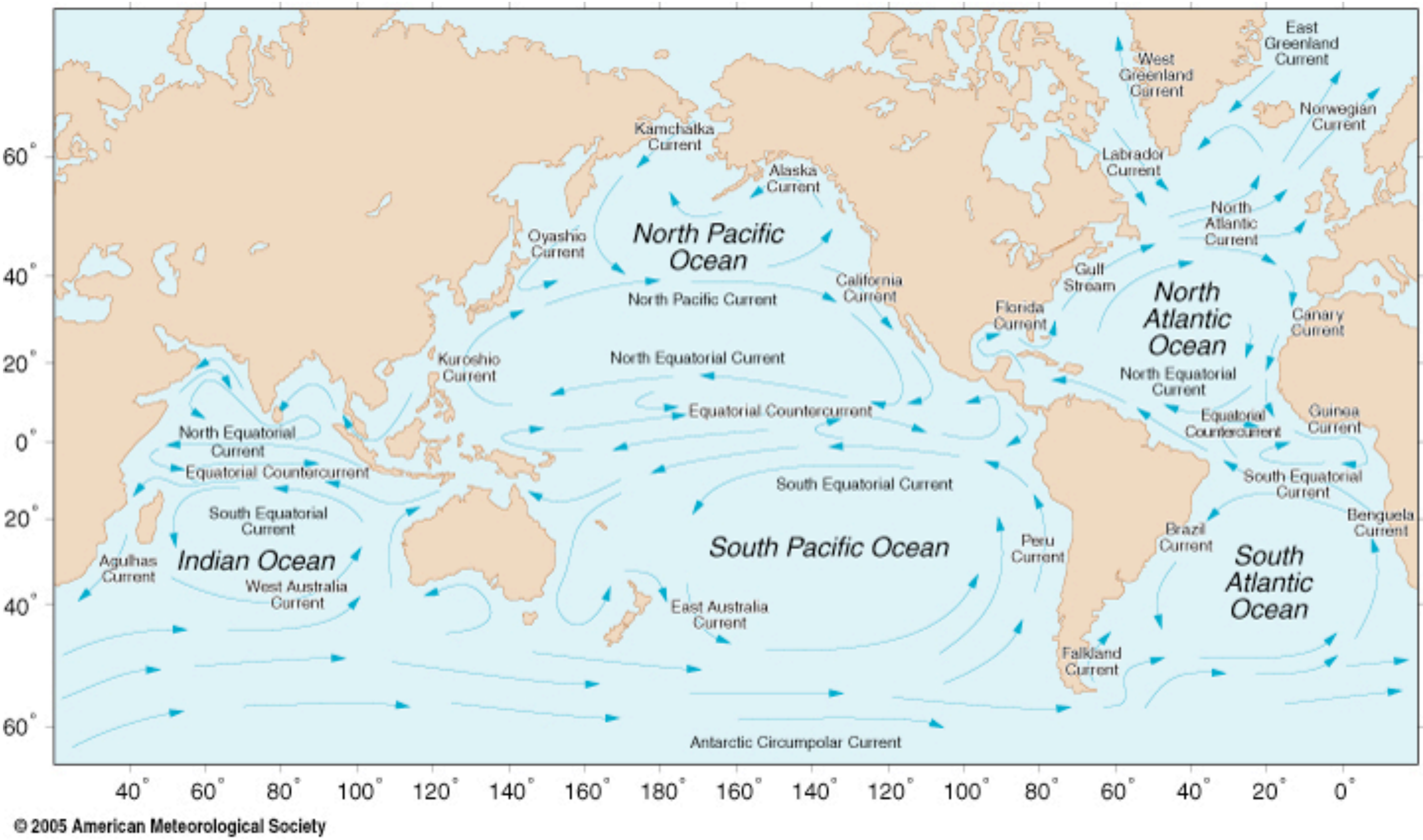


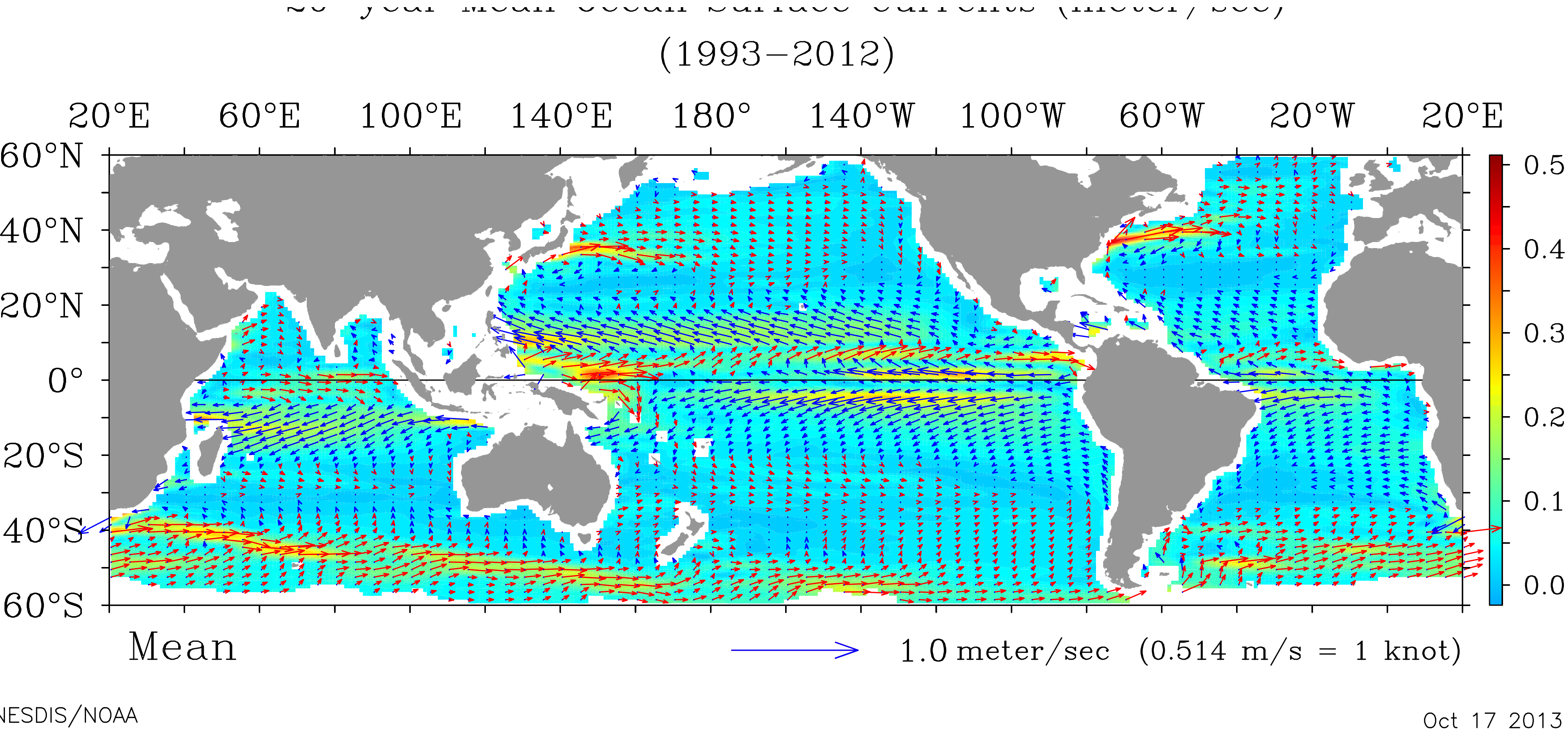
Figure 2.13 Lower-troposphere (900 hPa) winds and geopotential height contours for (a) December-January-February (DJF) and (b) June-July-August (JJA). The vector scales indicated in the lower right are in m/s.

Climatological Surface currents



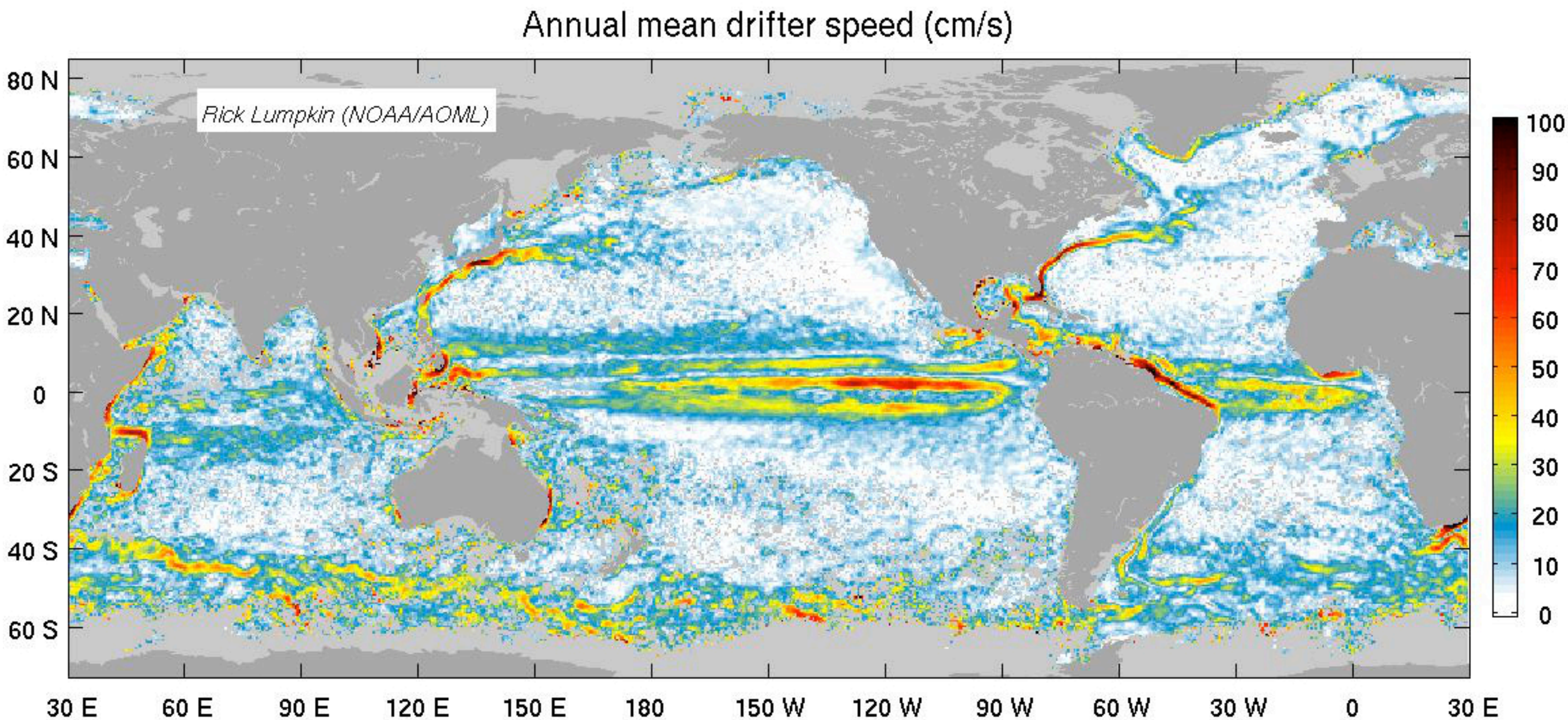
http://oceanmotion.org/images/surface_current_map.jpg

Satellite Derived Surface currents



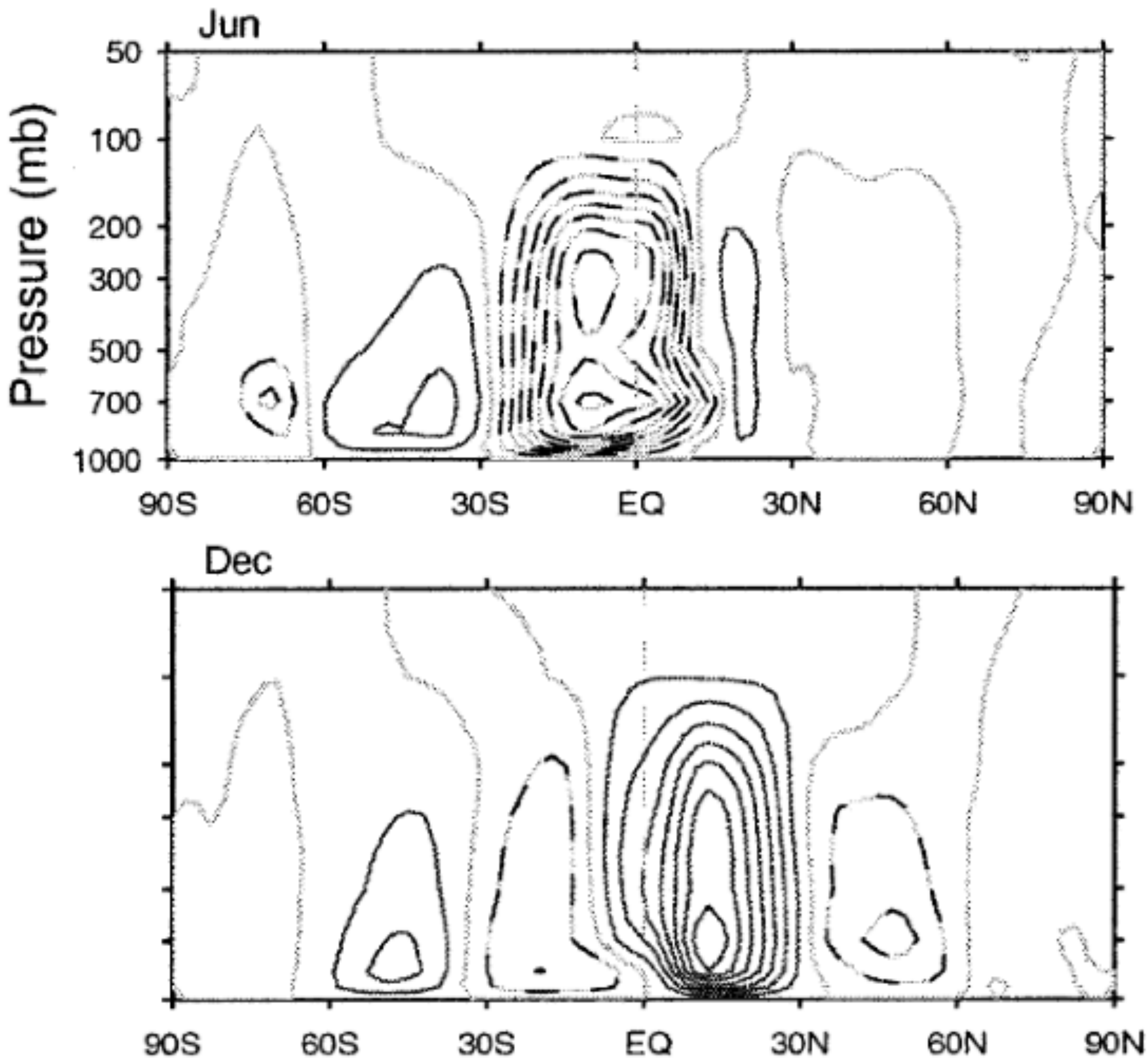
http://www.oscar.noaa.gov/datadisplay/oscar_latlon.php?pagetype=nonjava

Surface current speed based on drifters



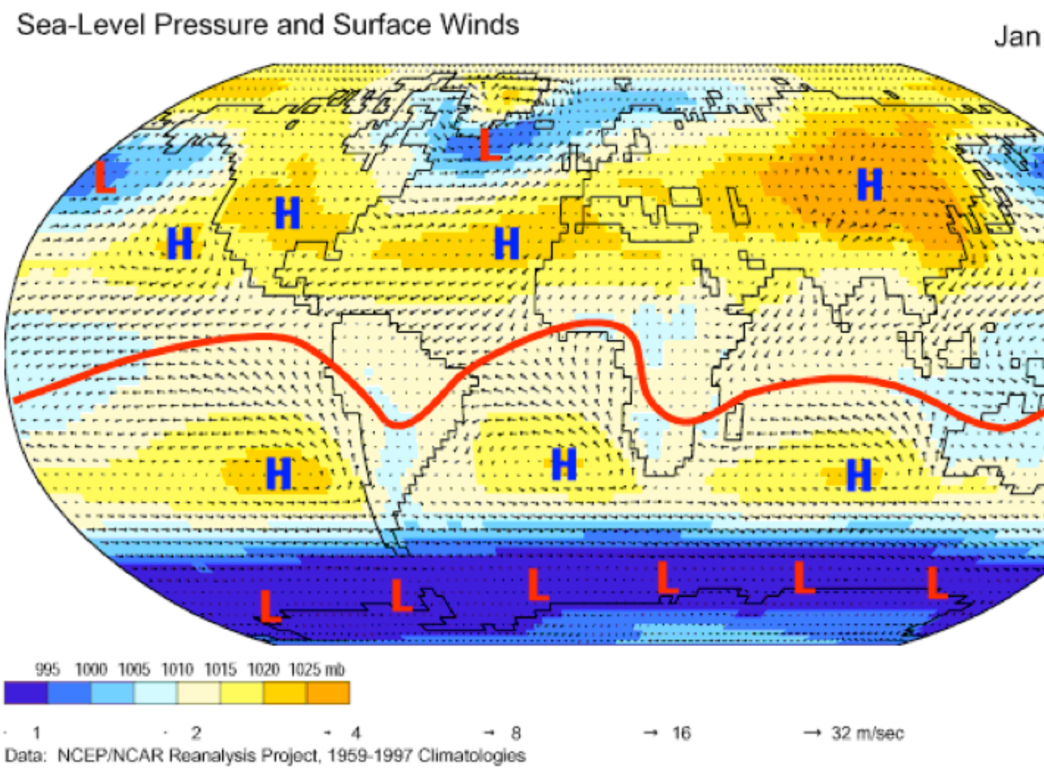
http://www.aoml.noaa.gov/phod/dac/drifter_climatology.html

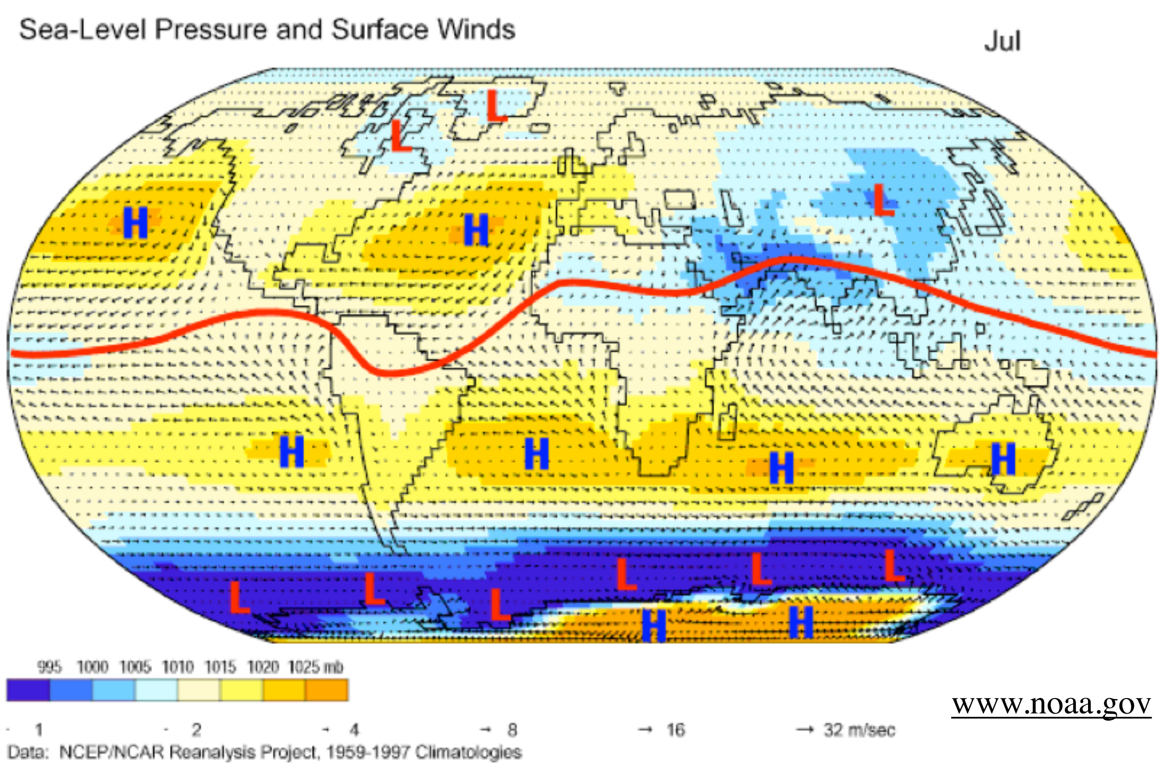
Hadley Circulation Seasonality



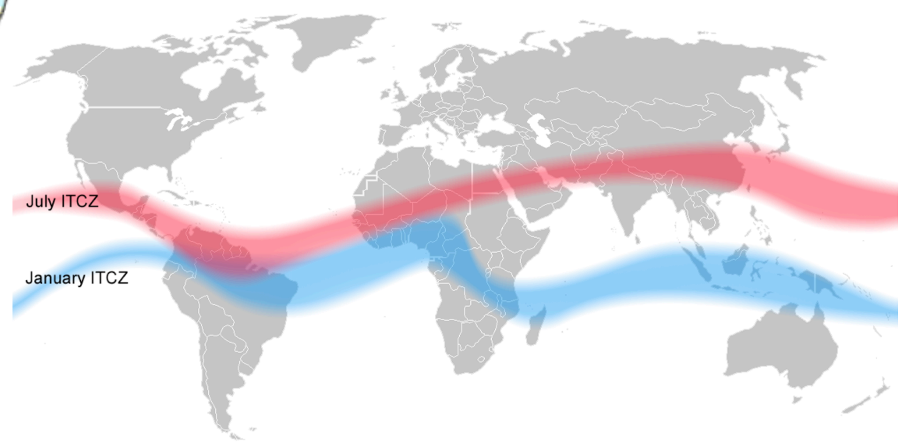
Seasonal changes in the Hadley Cell

Position of the ITCZ with Season





www.noaa.gov



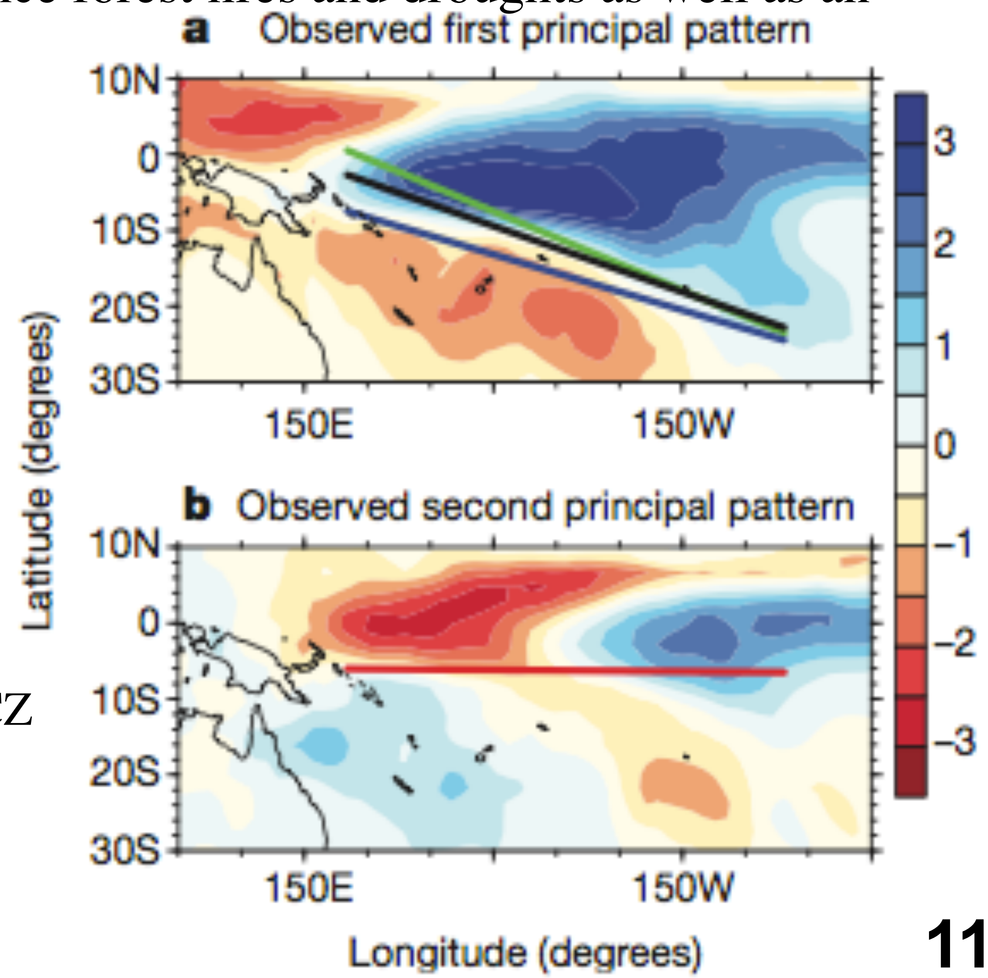
en.wikipedia.org

South Pacific Convergence Zone (SPCZ)

“The SPCZ plays an important part in global circulation and is a major feature of the Southern Hemisphere’s climate. Its location largely controls rainfall, ocean circulation and tropical cyclogenesis patterns in the South Pacific. **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.** As the SPCZ moves northward during El Niño events, countries located within the climatological SPCZ position experience forest fires and droughts as well as an increased probability of tropical cyclone hits.”

Cai et al. 2012 Nature

ENSO position, zonal SPCZ



Process of Precipitation

- Air parcels become supersaturated (usually associated with ascent of parcels) with water vapor
- Condensation and droplet formation occur
- Precipitation are the droplets that reach the surface without re-evaporating
- Ascent of air parcels occurs from
  - Forced movement over mountains
  - Synoptic systems
  - Convective systems

Zonally averaged precipitation

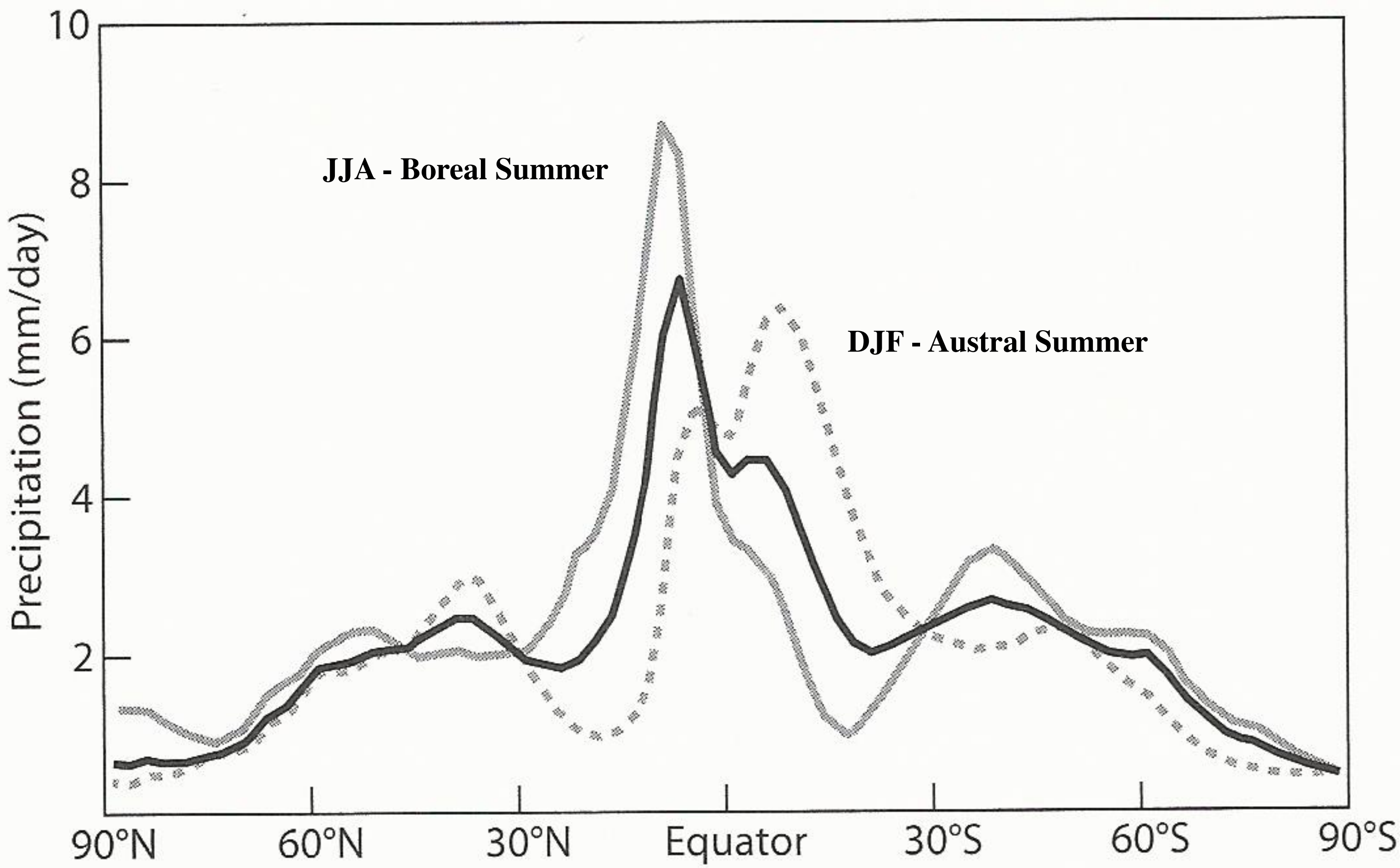


Figure 2.25 Zonally averaged precipitation climatology in mm/day for the annual mean (black line), December-January-February (DJF) mean (dotted line), and June-July-August (JJA) mean (gray line).

Large Seasonal difference due to Hadley Cell shifts

[Cook, 2012]

Global Precipitation Climatology, Annual Values
CPC data 1979-2011, 5 satellites with rain gauges

CI 2 mm/day

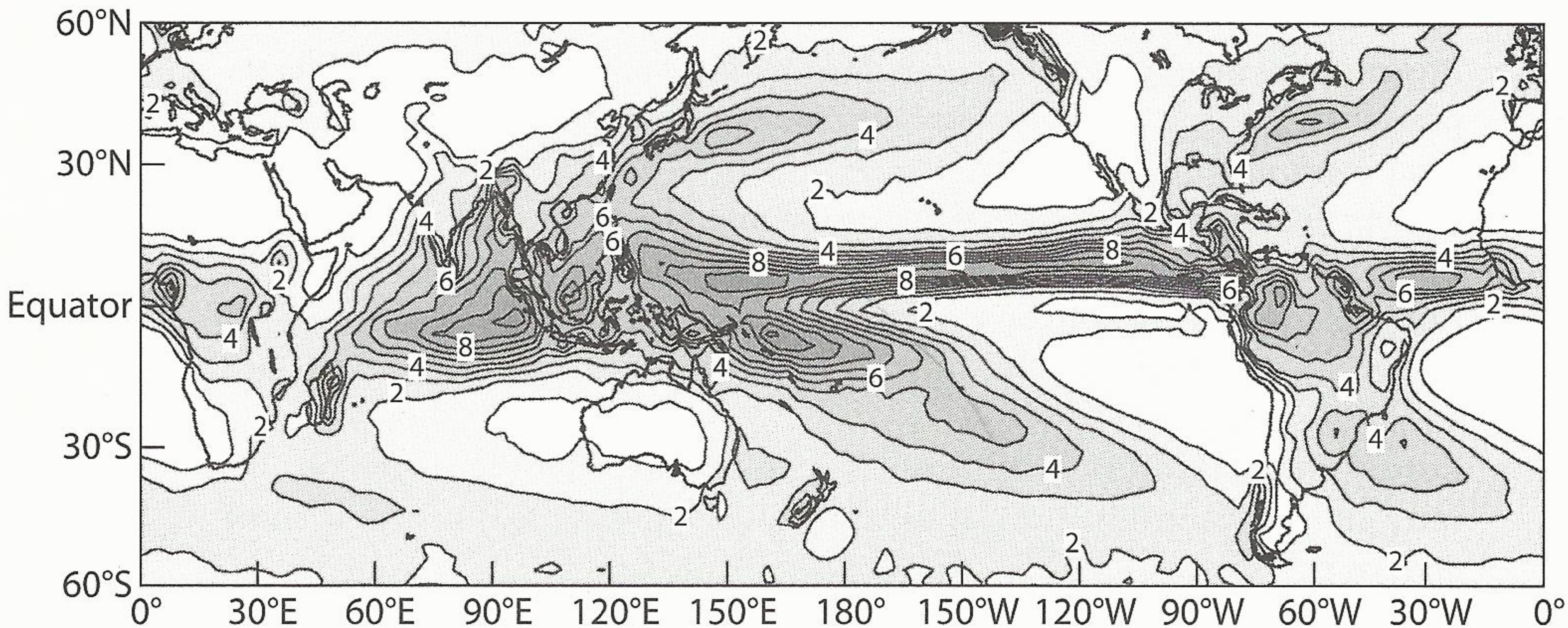
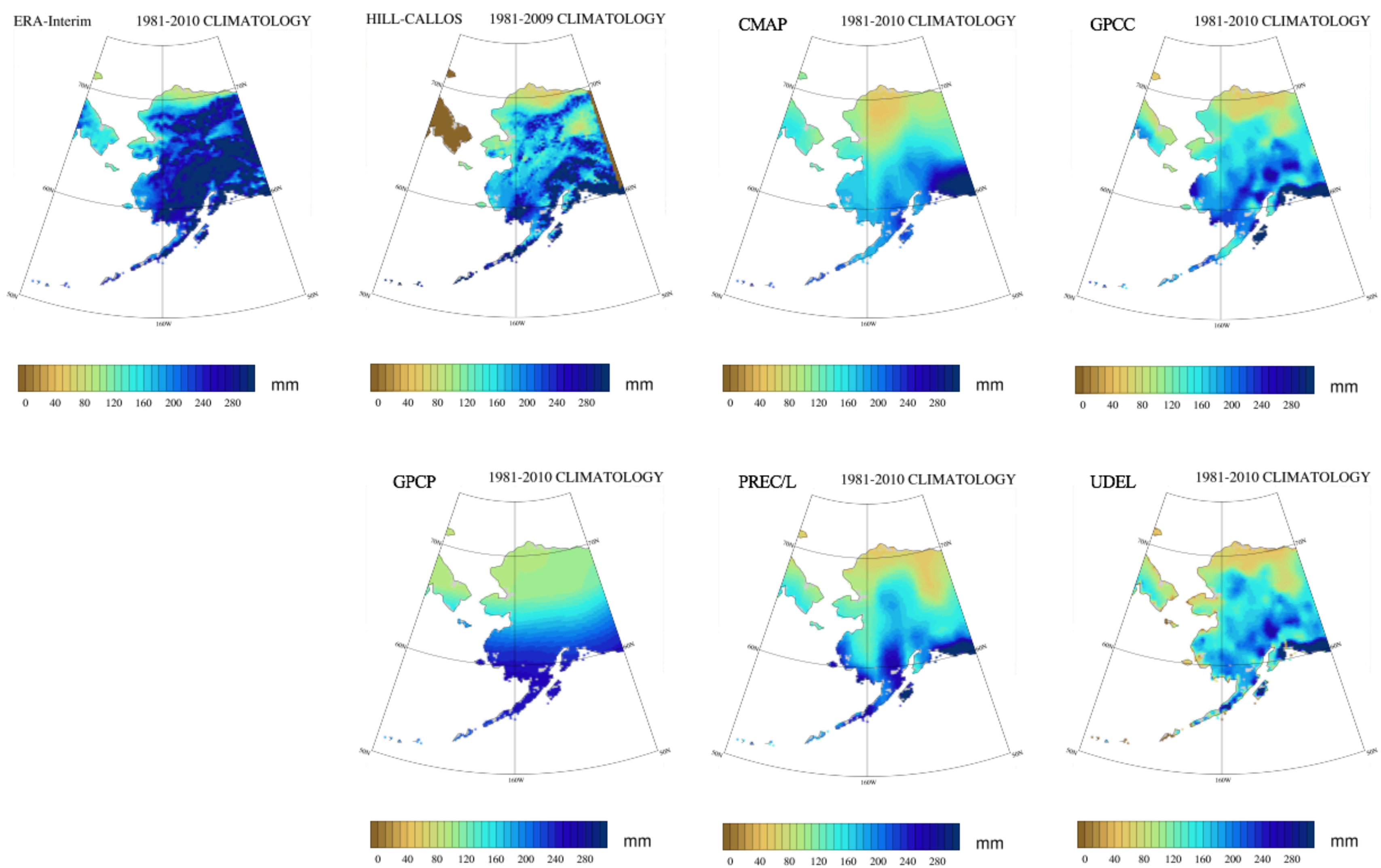


Figure 2.26 Annual mean precipitation climatology. Contour interval is 2 mm/day.

[Cook, 2012]

Precipitation is highly varied in time so hard to observe! Long records in India, China & Europe. satellite measured gives global but issues

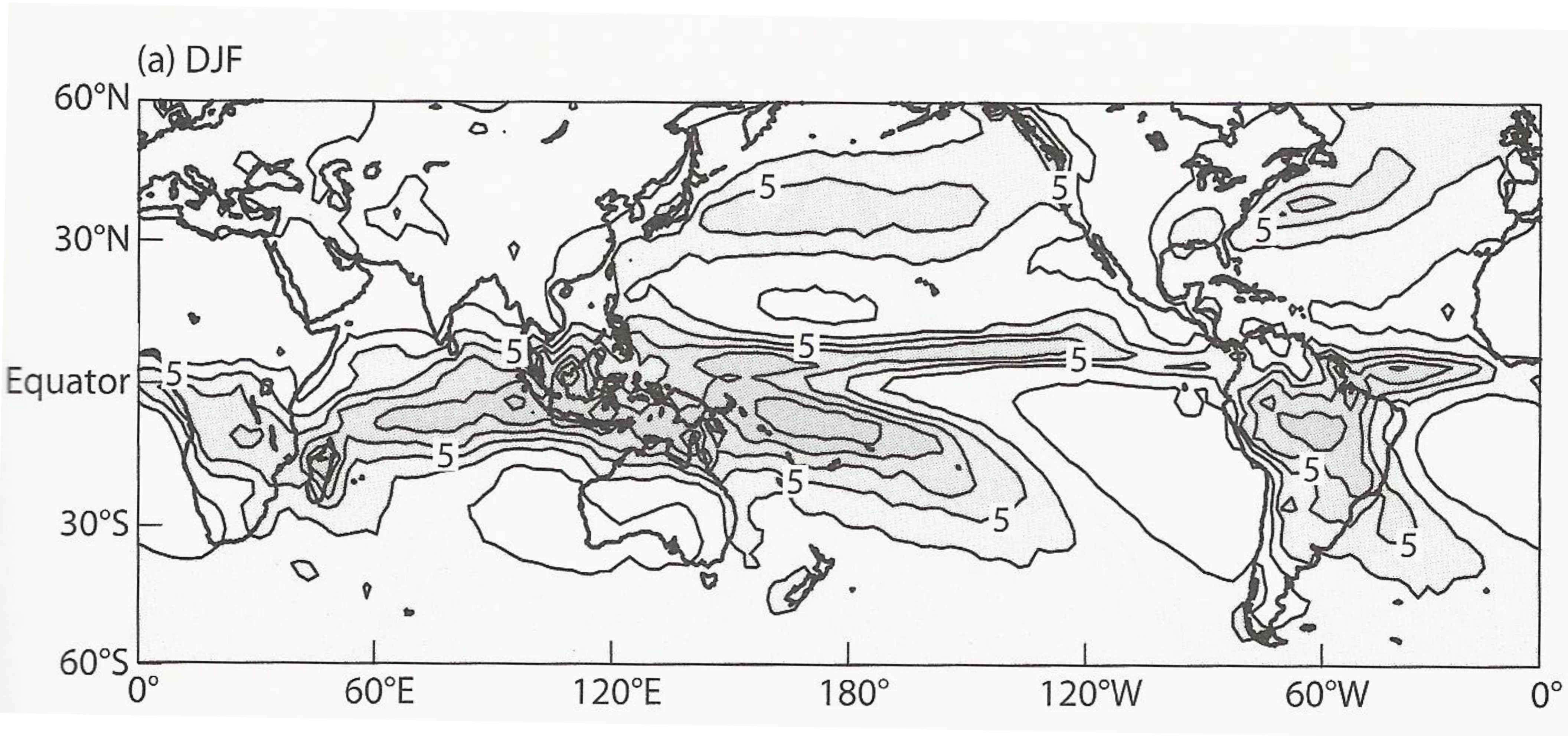
Precipitation Climatology, June-August total 1980-2009, 7 different sources for Alaska



What is the truth?

[Amy Hendricks, UAF grad student]

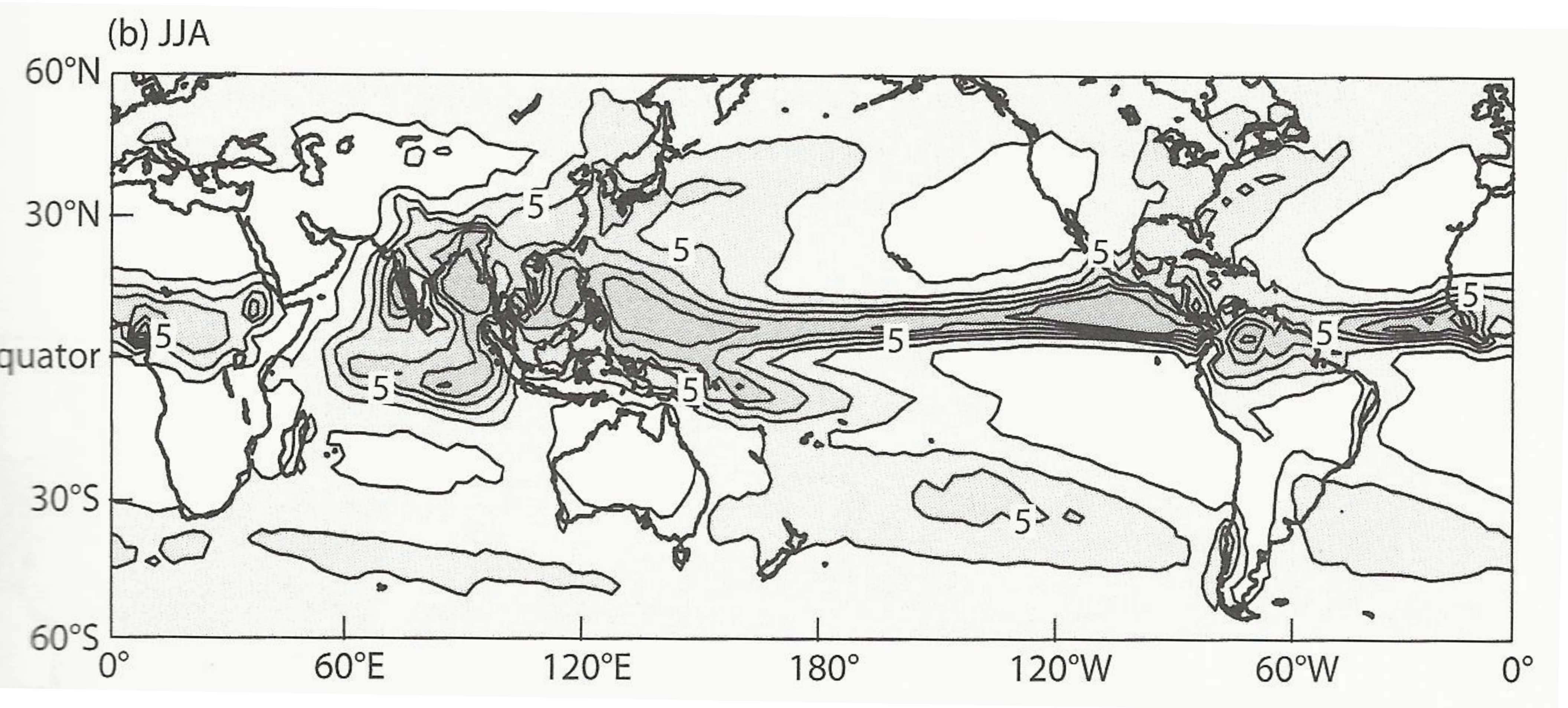
Global Precipitation Climatology
Boreal Winter



CI 2 mm/day

[Cook, 2012]

Global Precipitation Climatology
Boreal Summer



CI 2 mm/day

[Cook, 2012]

Zonal Mean Evaporation Rates

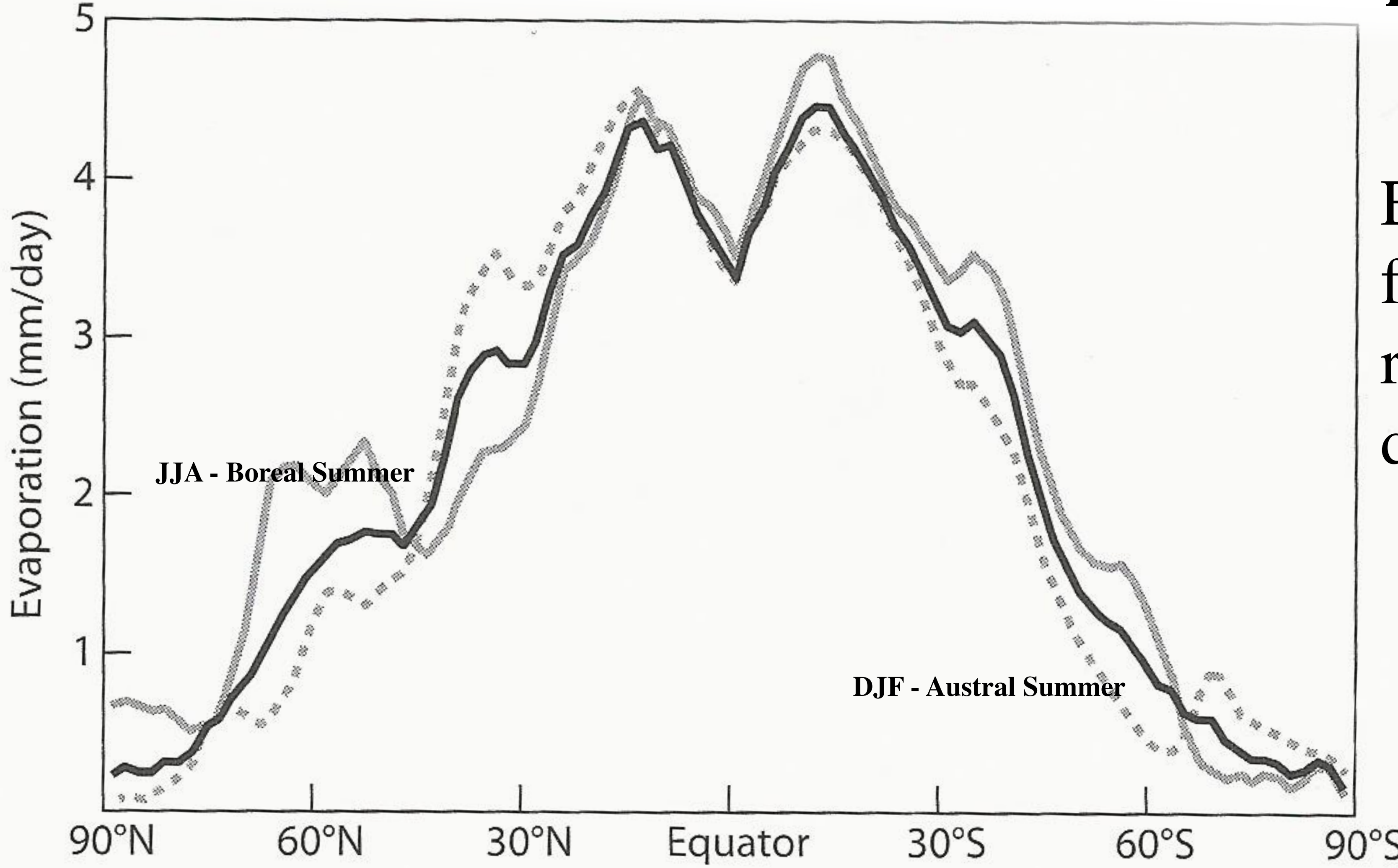


Figure 2.28 Zonally averaged evaporation climatology in mm/day for the annual mean (black line), December-January-February mean (dotted line), and June-July-August mean (gray line).

mm/day

Estimated from reanalysis data

[Cook, 2012]

Annual Mean Evaporation

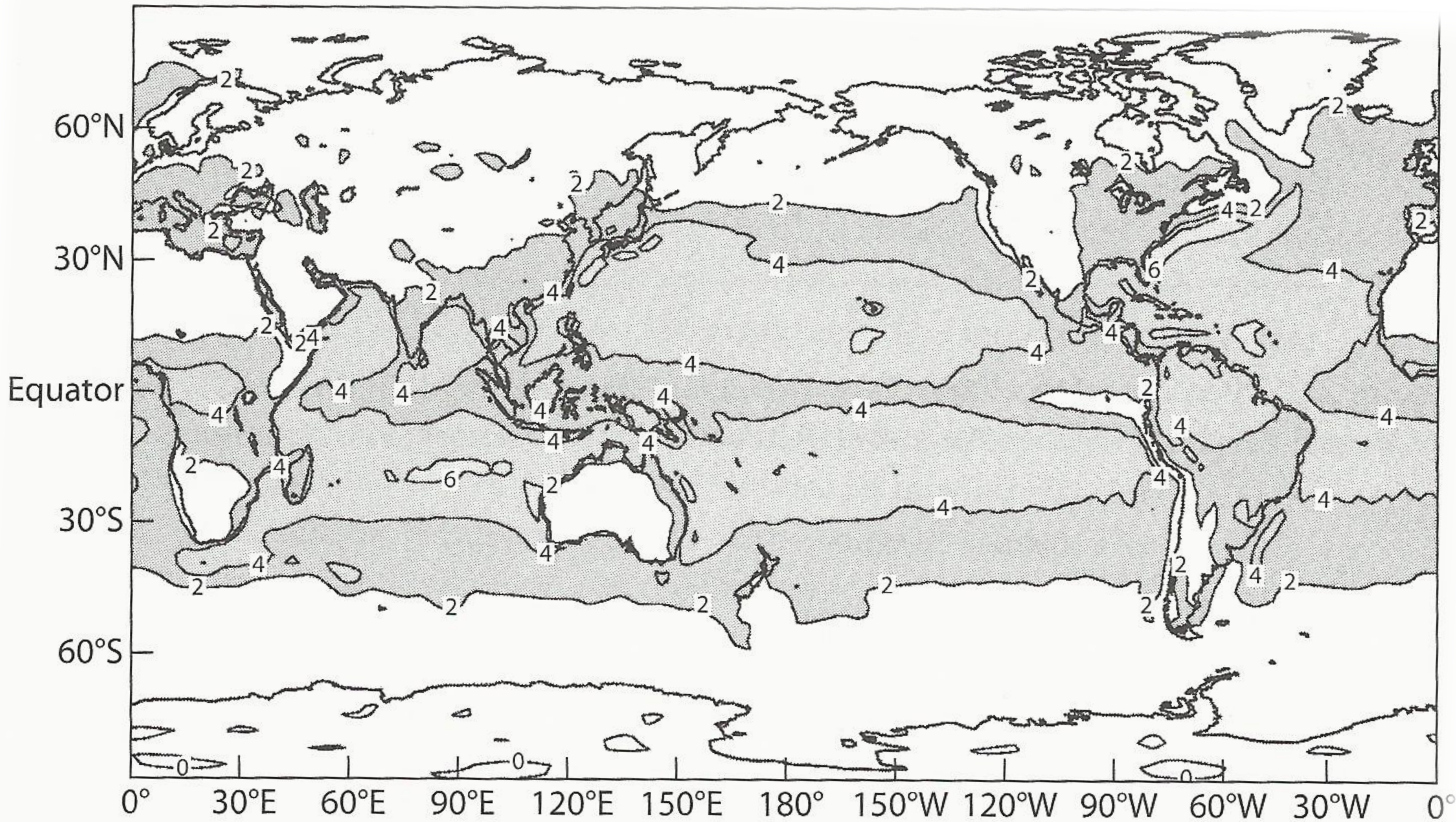


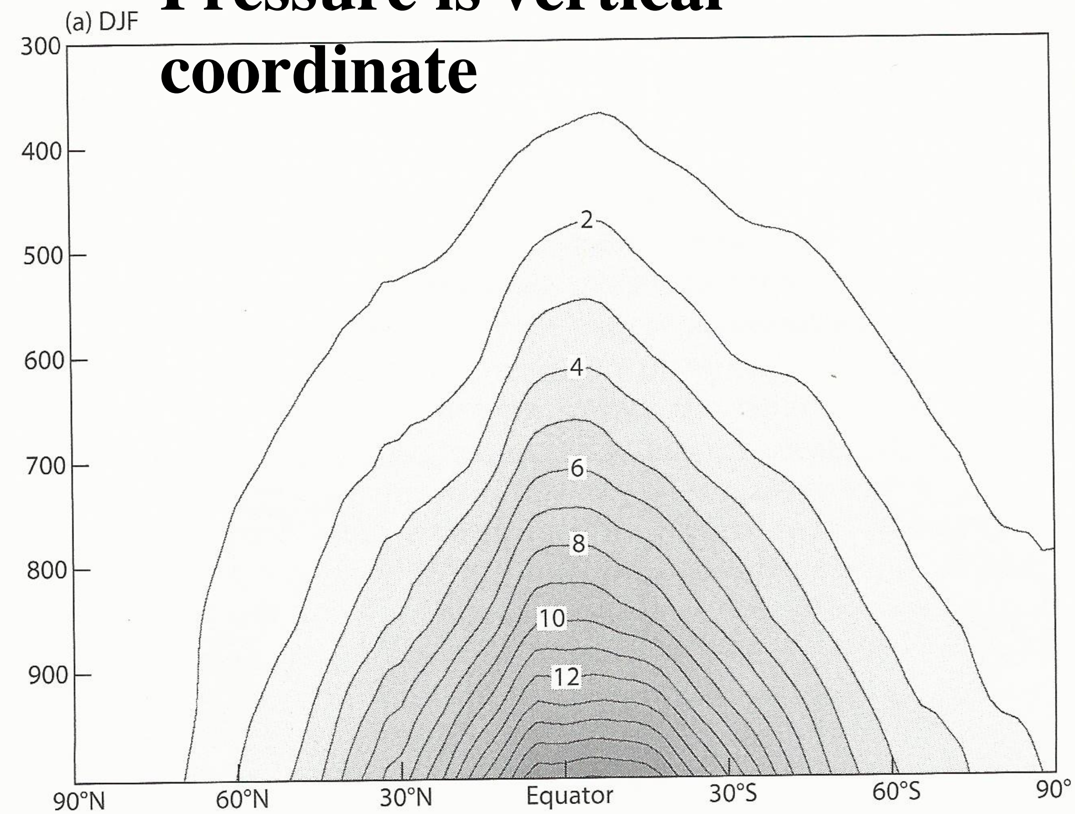
Figure 2.29 Annual mean evaporation climatology as represented in the NCEP/NCAR reanalysis. Contour intervals are 2 mm/day.

CI 2 mm/day

[Cook, 2012]

Specific humidity- zonal view

Pressure is vertical coordinate



CI 2 grams (water)/kg(air)

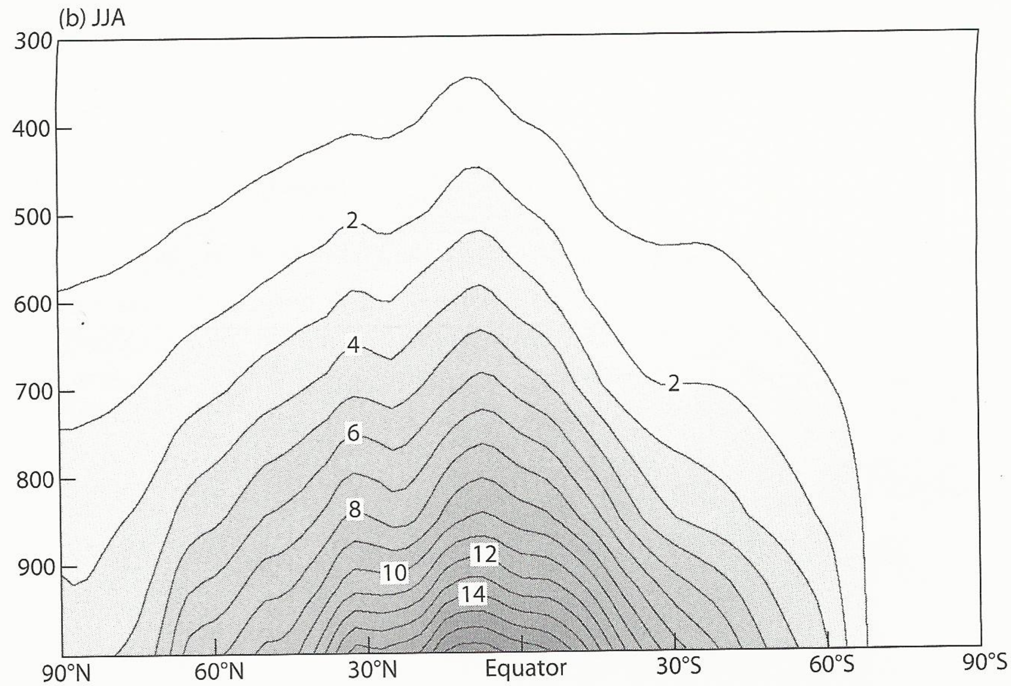


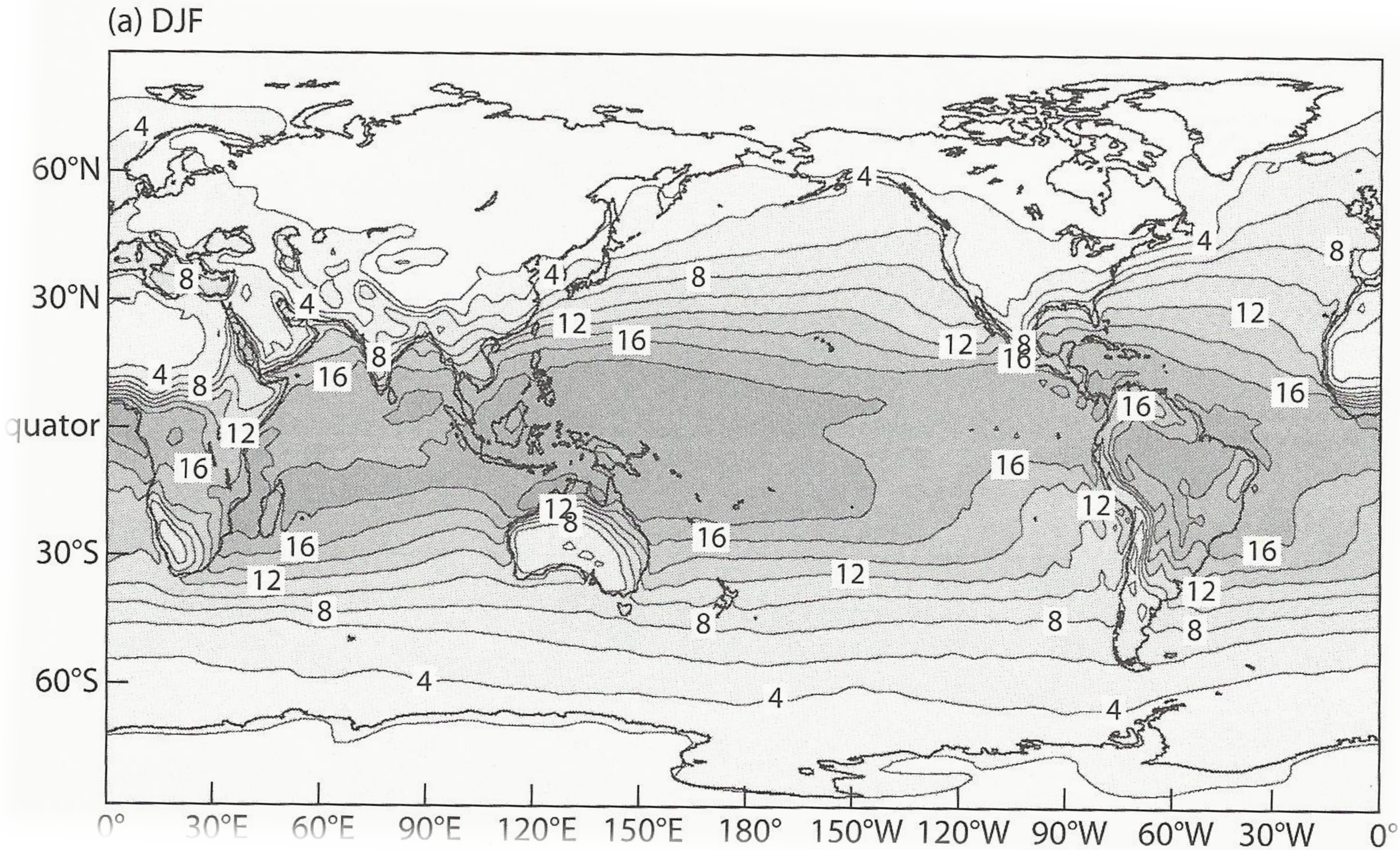
Figure 2.30 Zonal mean specific humidity climatology for (a) December-January-February (DJF) and (b) June-July-August (JJA). Units are 10^{-3} kg_{H_2O}/kg_{air}.

Estimated from reanalysis data

- **Specific Humidity** is the mass of water vapor to that of dry air plus vapor (total air mass)

[Cook, 2012]

Specific Humidity Climatology DJF



CI 2 grams $_{(water)}$/kg$_{(air)}$

[Cook, 2012]

Specific Humidity Climatology JJA

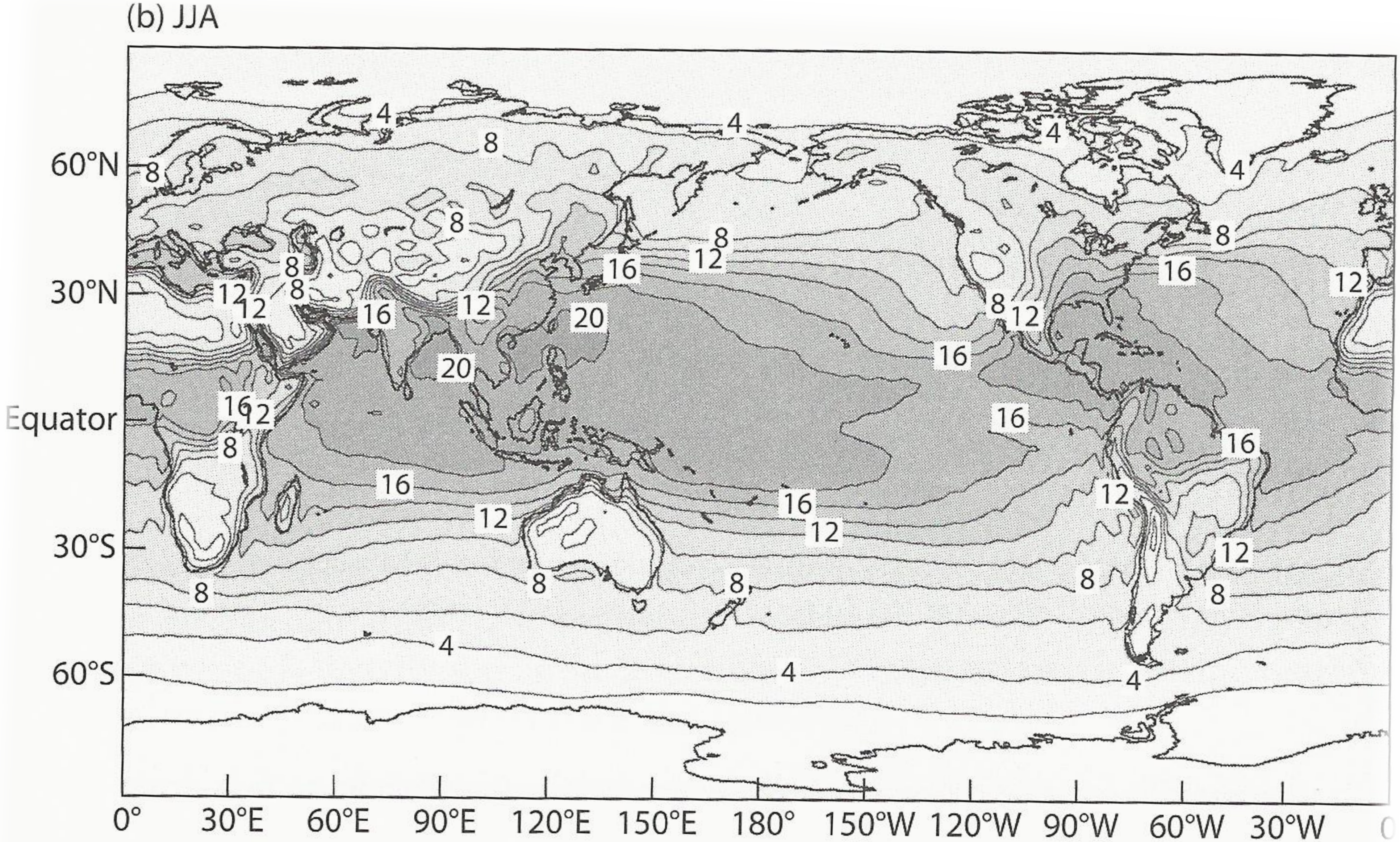


Figure 2.31 Geographical distribution of specific humidity at 900 hPa for (a) December-January-February (DJF) and (b) June-July-August (JJA). Units are 10^{-3} kg_{H_2O}/kg_{air}.

CI 2 grams $_{(water)}$/kg$_{(air)}$

[Cook, 2012]

Hydrological Cycle Processes

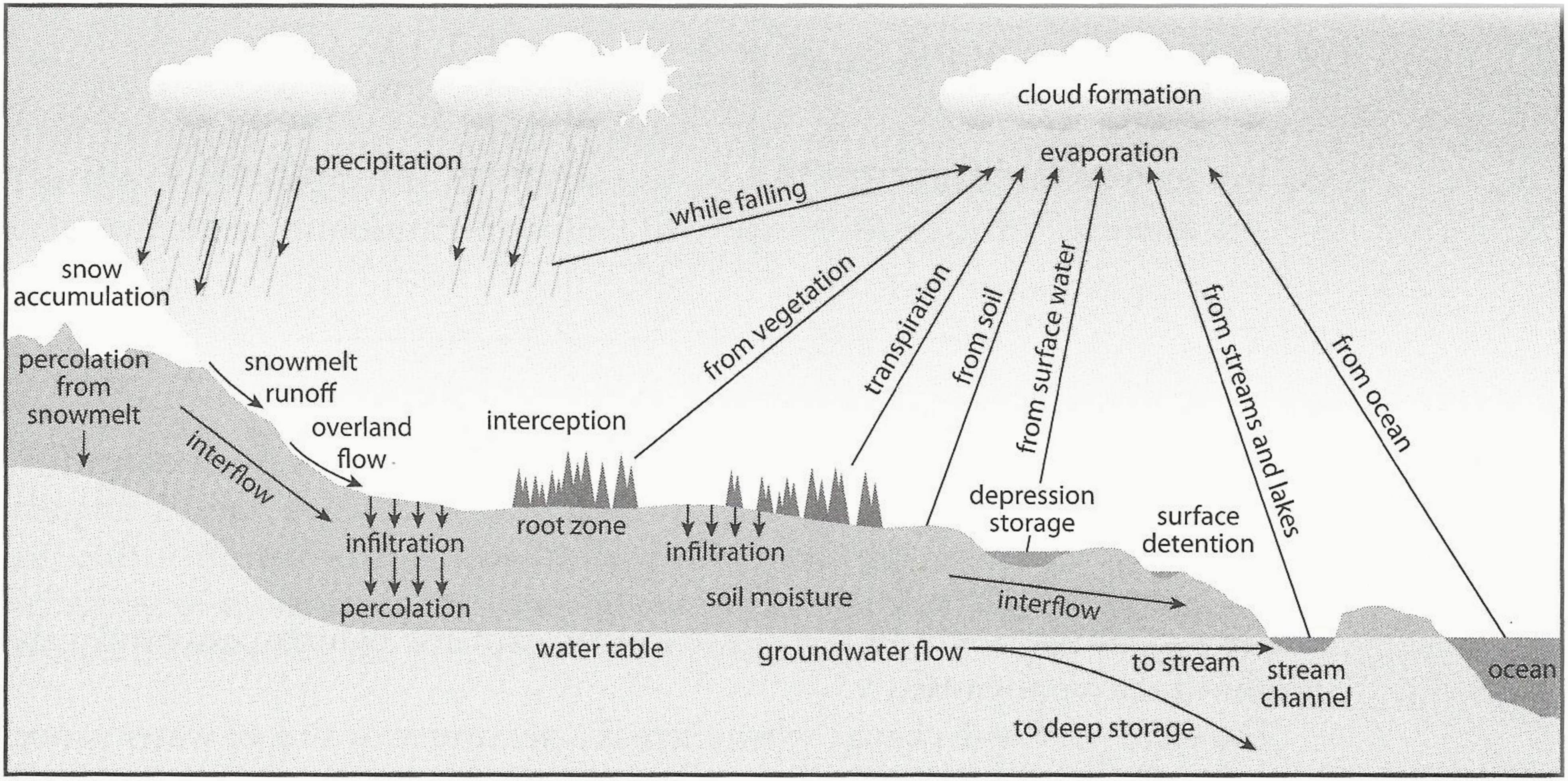


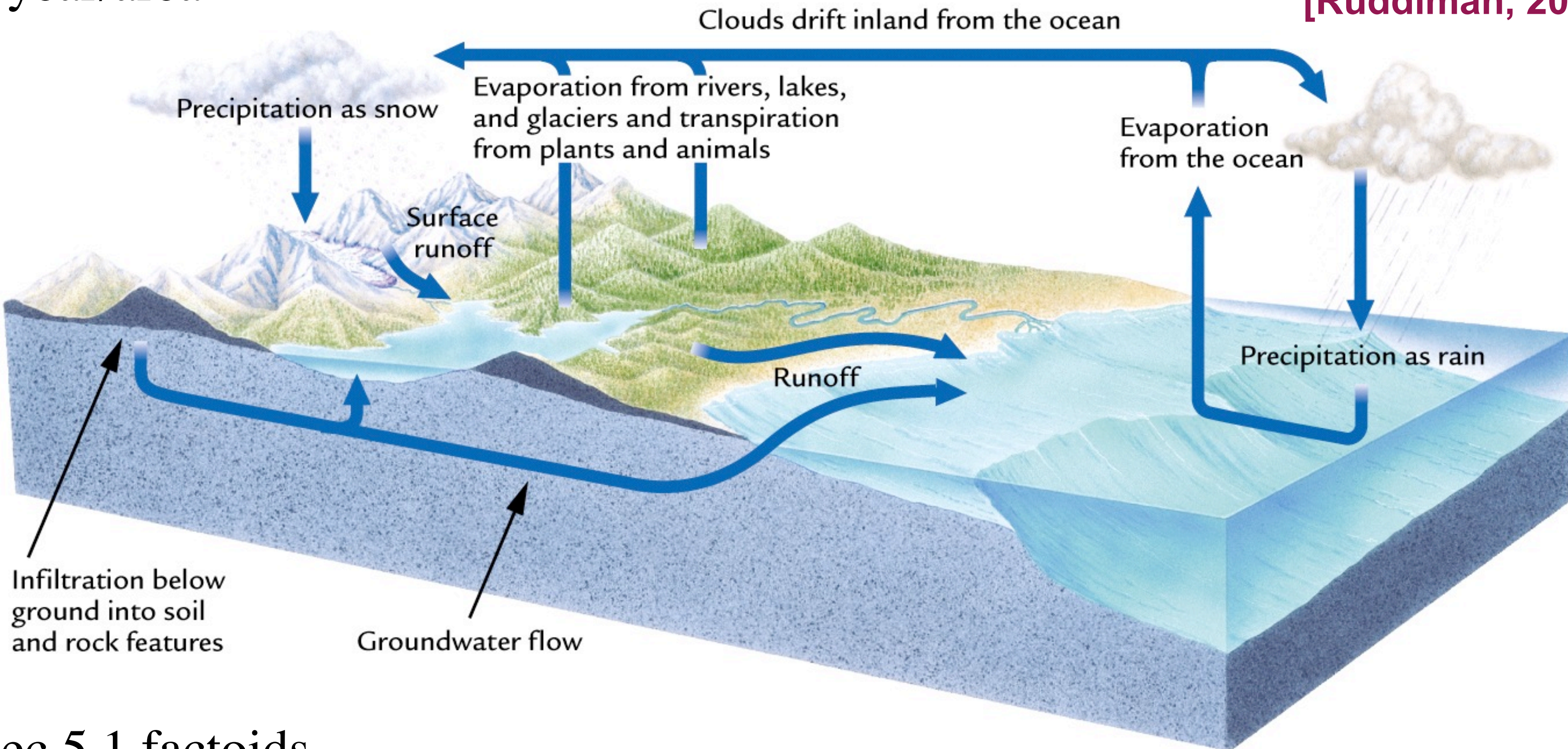
Figure 9.1 Schematic representation of exchanges and processes important for the hydrological cycle. From http://rst.gsfc.nasa.gov/Sect16/Sect16_4.html/.

[Cook, 2012]

The Hydrological Cycle: Numbers

cm/year/area

[Ruddiman, 2001]



Sec 5.1 factoids

- **30% land precip is water evaporated from ocean,**
- **1m globally is moved through hydrological cycle in a year**
- **1m water requires 80 W m^{-2} to evaporate**
- **Small amount of water in atmosphere: 2.5 cm if all condensed, so 1m/2.5 cm = 40 times a year or every 9 days, residence time estimate!**

Renewal Times - Note these are estimates!

Table 1. Periods of water resources renewal on the Earth Water of Hydrosphere

Period of renewal (TURNOVER TIME, RESIDENCE TIME)

- World Ocean 2500 years
- Ground water 1400 years **(10,000 or more at depth)**
- Polar ice 9700 years
- Mountain glaciers 1600 years
- Ground ice of the permafrost zone 10000 years
- Lakes 17 years
- Bogs 5 years
- Soil Moisture 1 year **(days)**
- Channel network 16 days (Rivers)
- Atmospheric moisture **8 days**
- Biological water several hours

http://webworld.unesco.org/water/ihp/db/shiklomanov/summary/html/summary.html

Distribution of Global Water

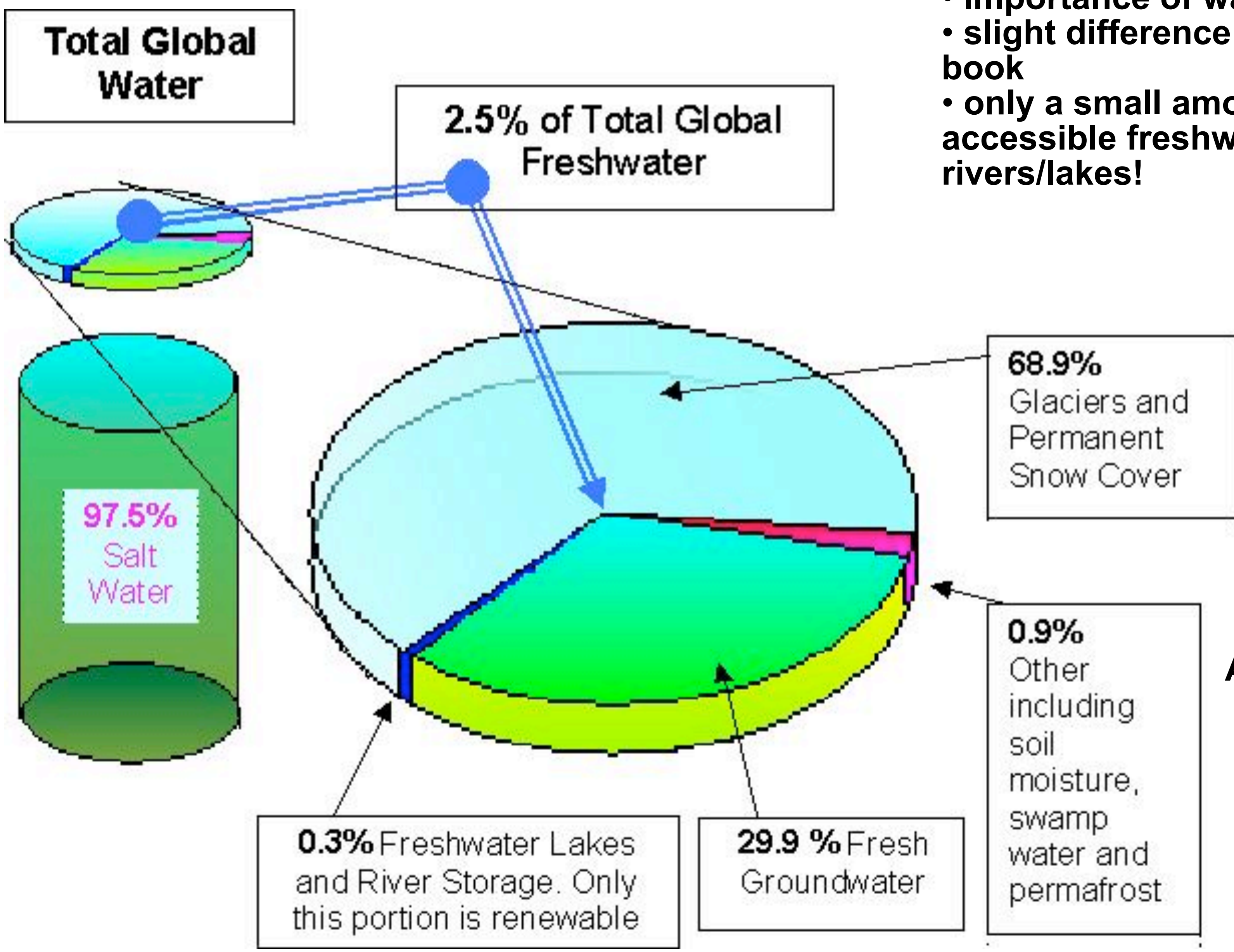
Table 2.1 Distribution of water in the climate system

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]

Where is the fresh water?



- Importance of water
- slight difference from book
- only a small amount is in accessible freshwater rivers/lakes!

ATMOS

http://webworld.unesco.org/water/ihp/db/shiklomanov/summary/html/summary.html

Moisture Budget Diagram

[Hastenrath, 1991]

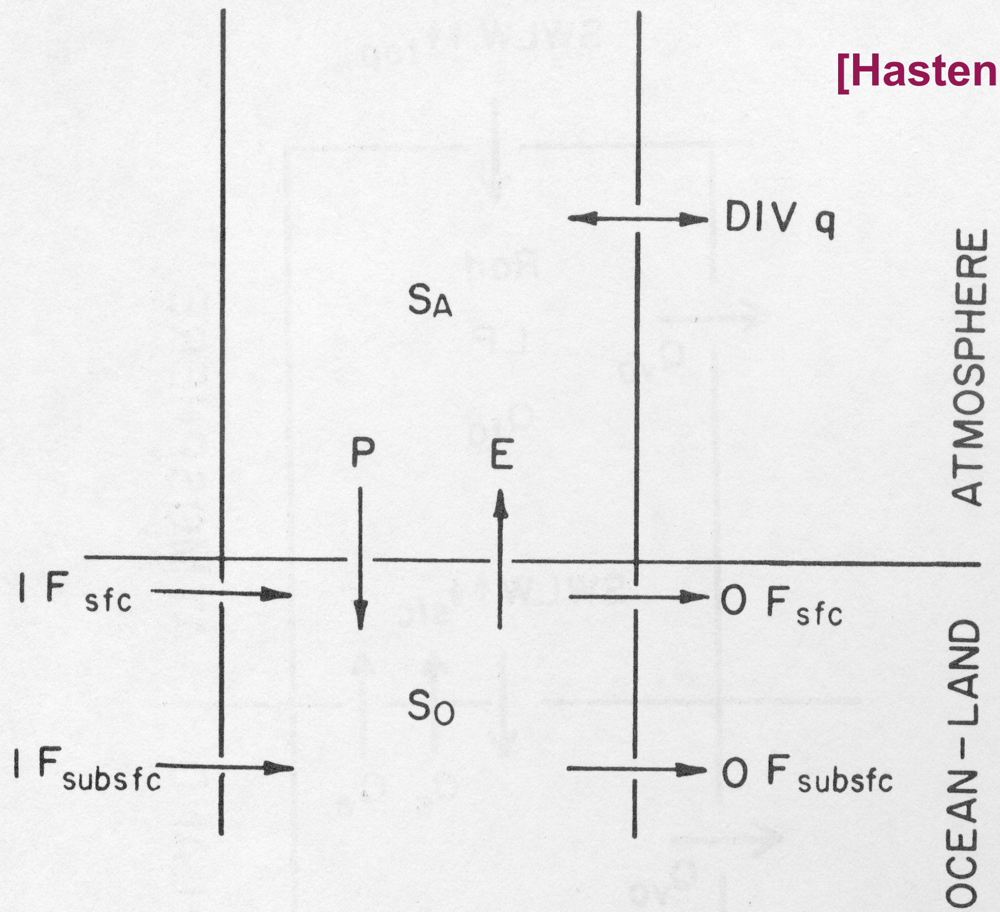


Fig. 5.1:2. Water budget scheme for the atmosphere-lithosphere-hydrosphere system. P denotes precipitation, E evaporation from land or water surfaces, div q divergence of the total vertically integrated water vapor flux in the atmosphere, q_t rate of change of precipitable water, and S_O storage in the 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

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

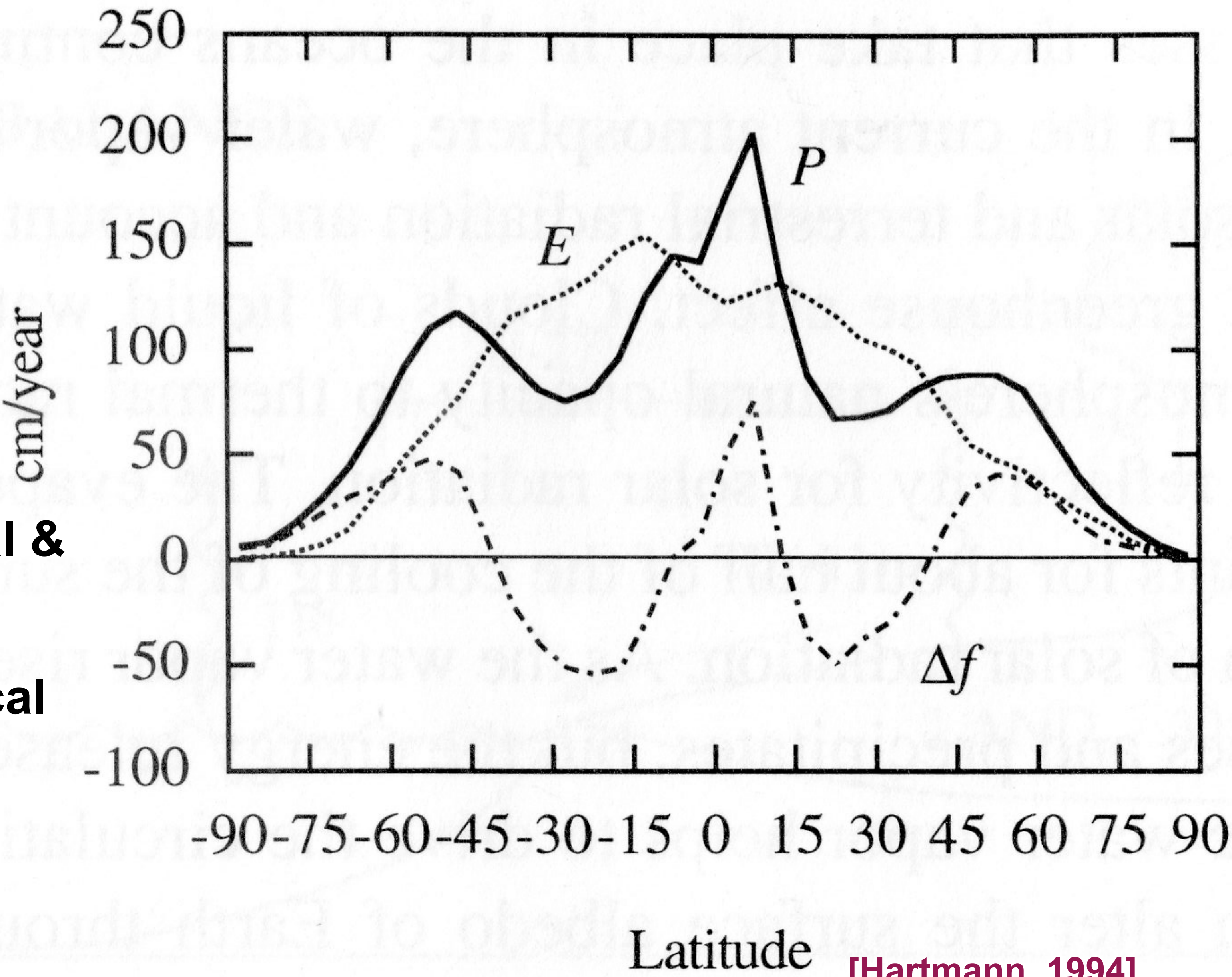
- Divergence is the rate at which F, flux, exits some space, and quantifies how much the density within the space of some quantity changes.

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

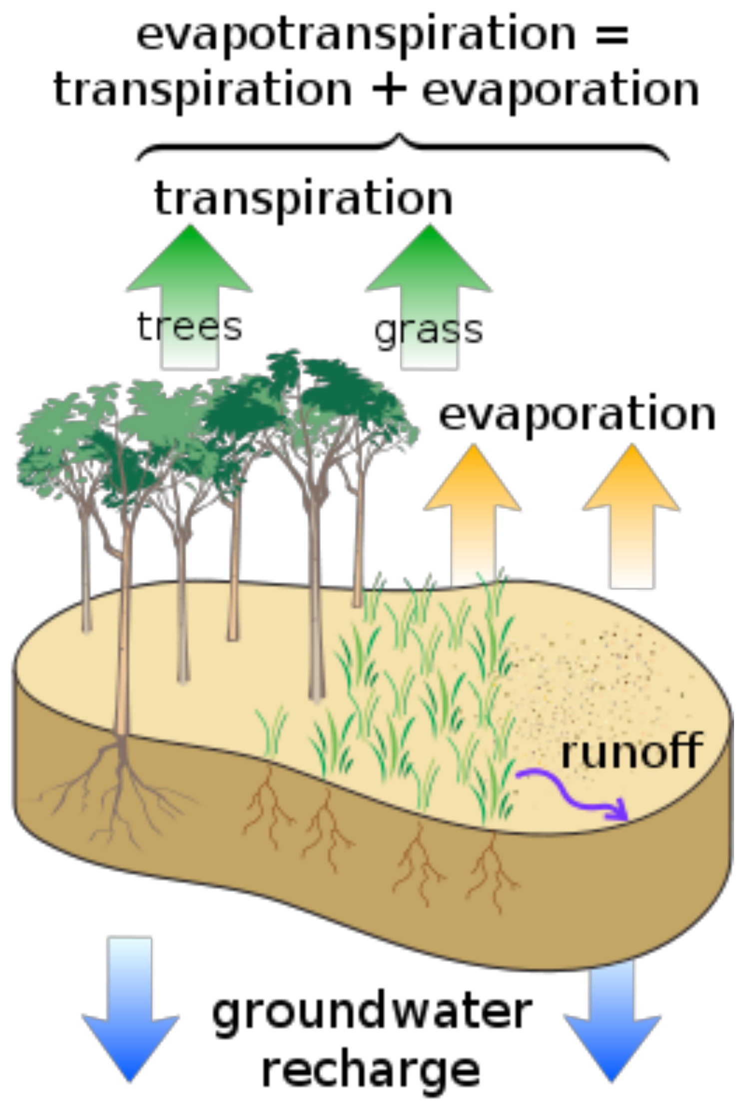
- P: Equatorial & Midlatitude Peaks
- E: Subtropical Peaks
- P-E



[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

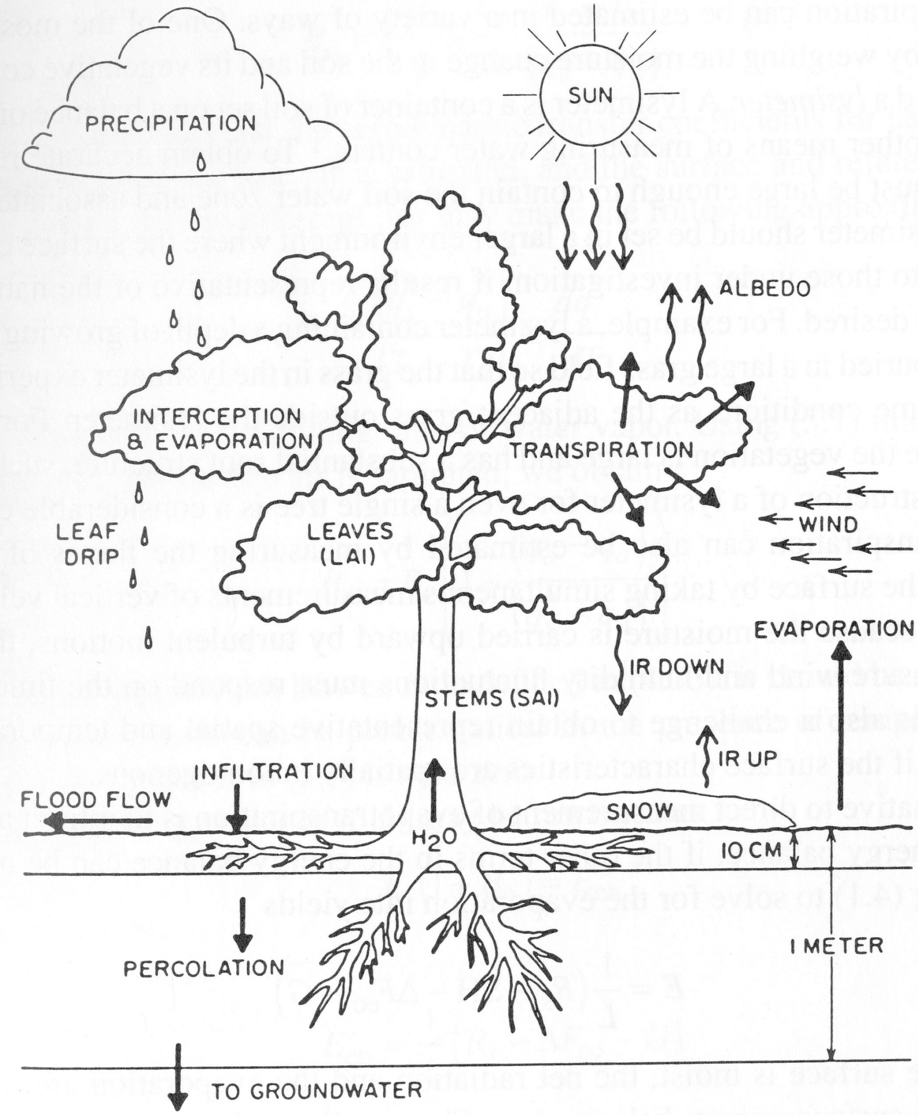


Fig. 5.5 Diagram showing the effects of the vegetation canopy on the water and energy fluxes. [From Dickinson (1984). © American Geophysical Union.]

[Hartmann, 1994]

Measure Evapotranspiration

- Weigh moisture change with a *lysimeter*

N. Mölders

- Micro-meteorology measurements, w & q

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

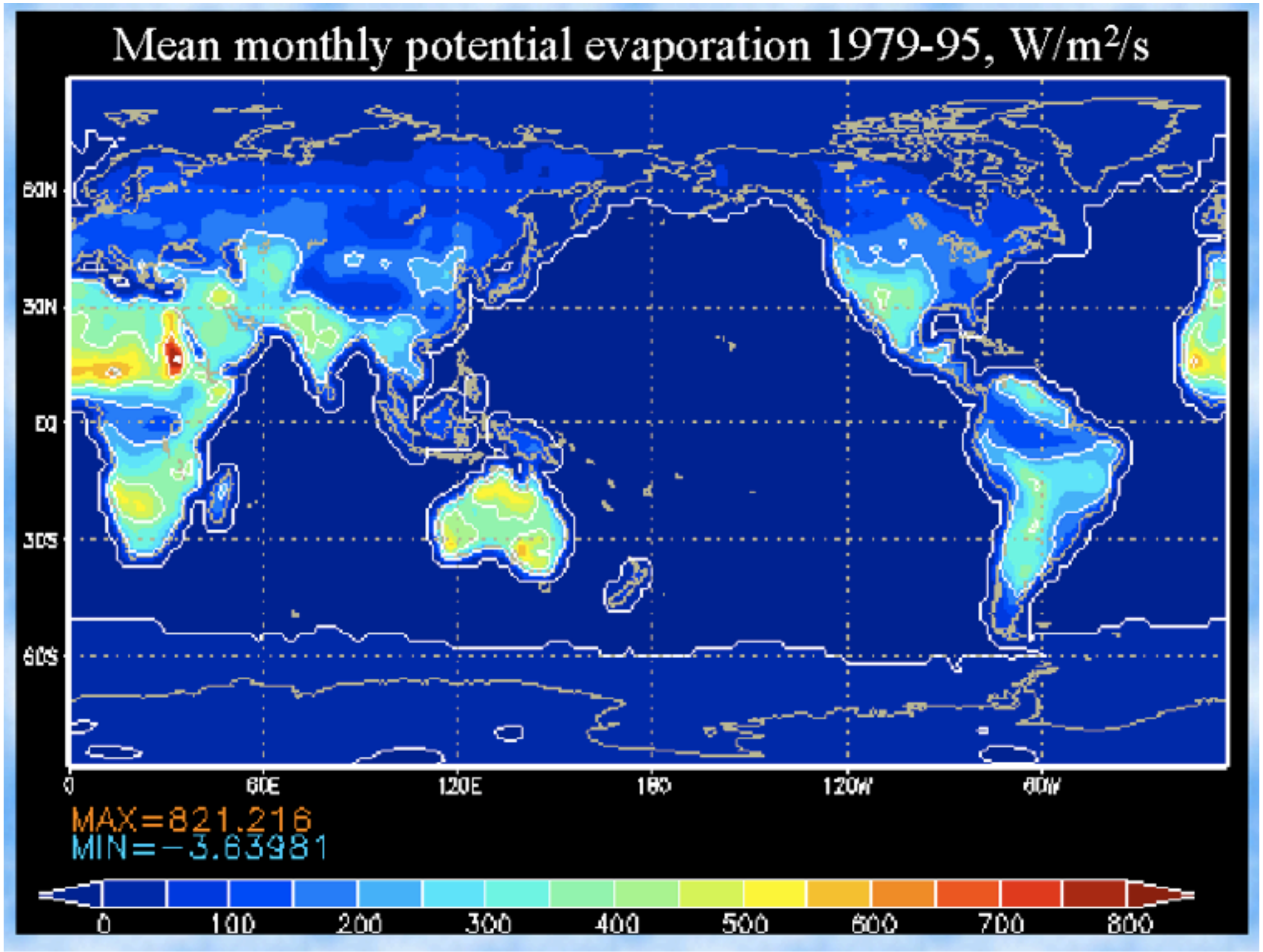
$$E = \frac{\left(R_s - SH - \Delta F_{eo} - G\right)}{L}$$

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

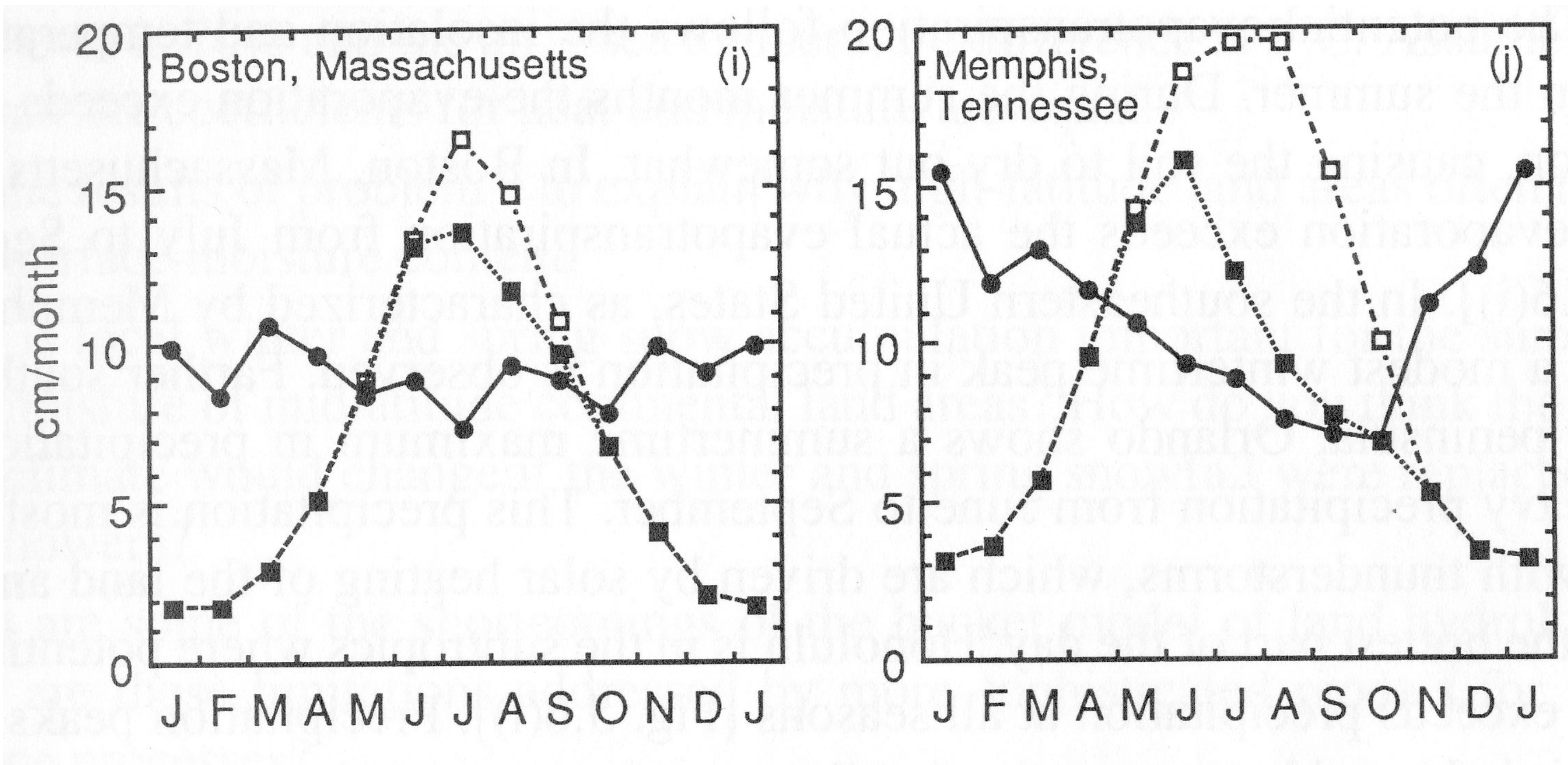


http://ag.arizona.edu/~lmilich/pe.html

Water Balance - Annual Cycle

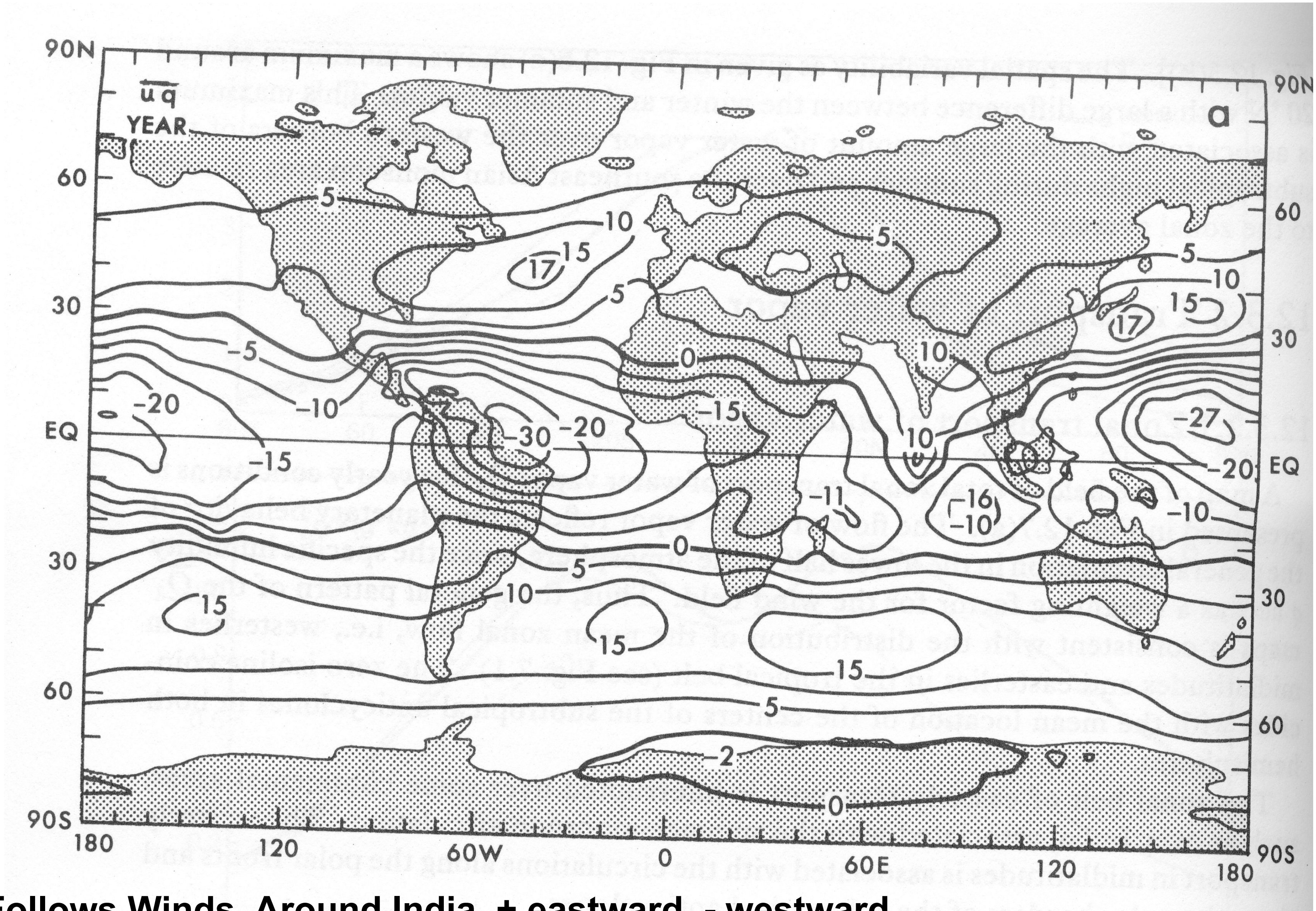
- Precip varies little in Boston over year and PE follows solar insolation.
- Memphis (southern US) winter precip peak, PE follows insolation also

● 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

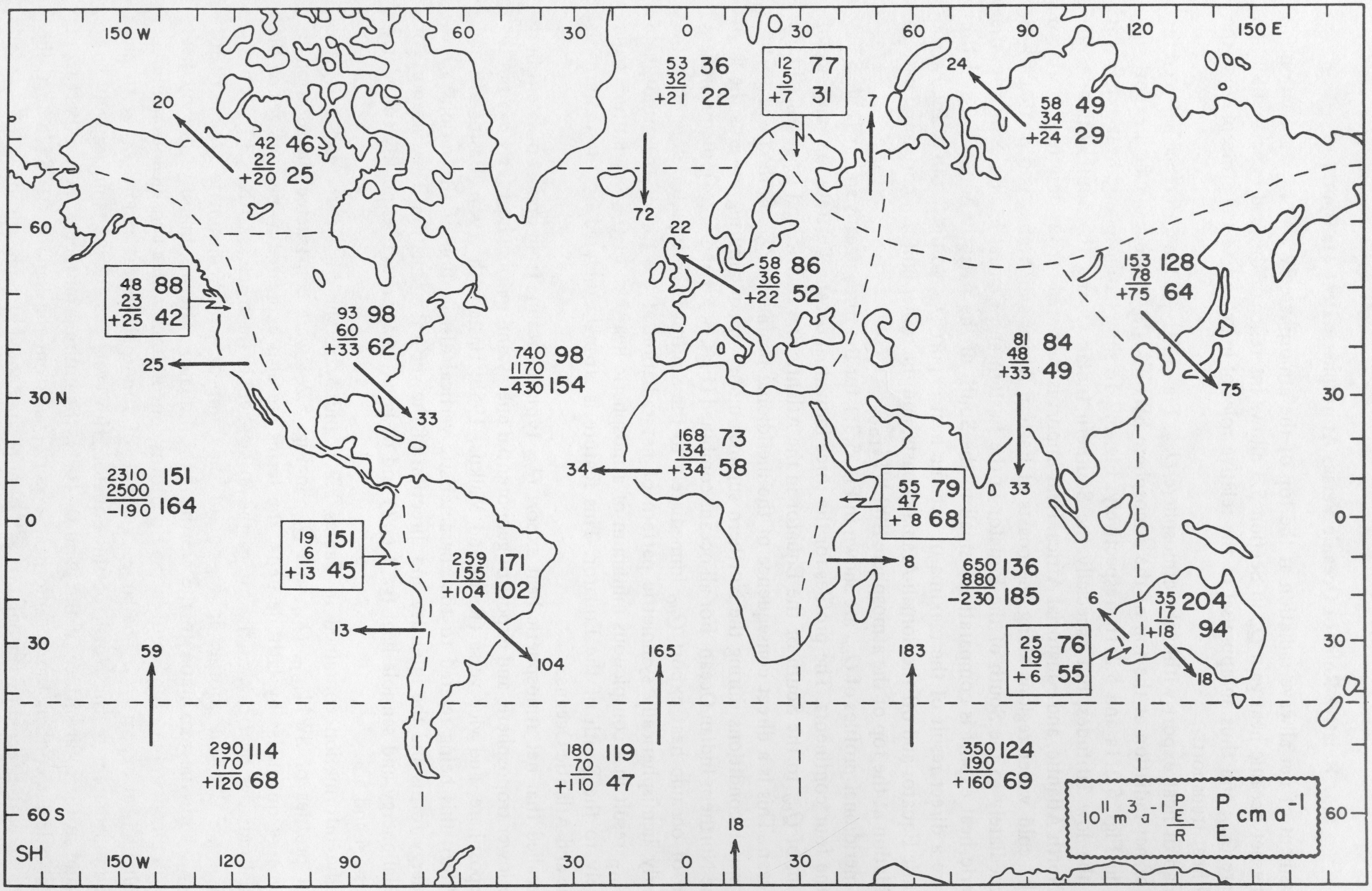


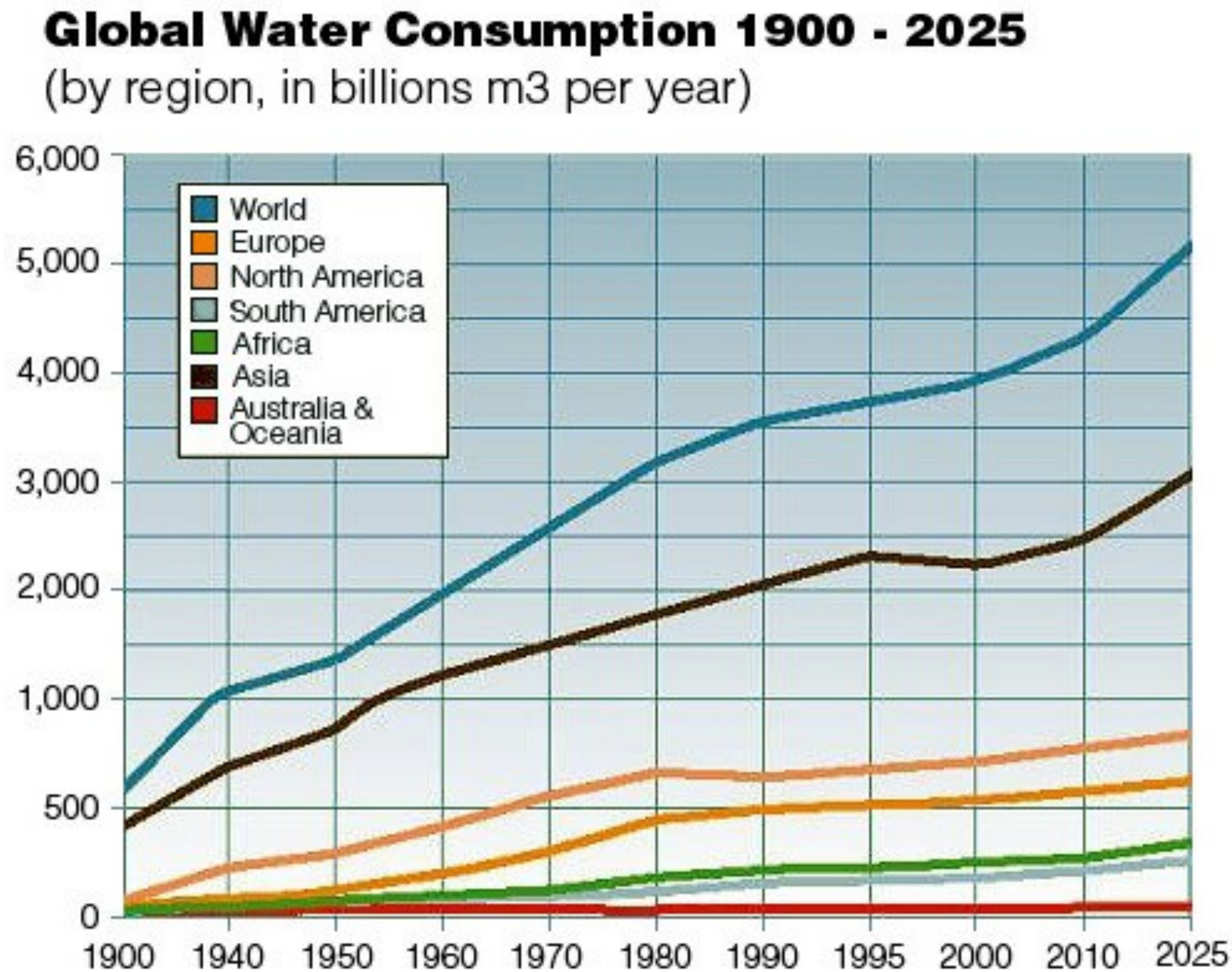
Fig. 5.5:2. Schematic map of the water budget of continents and oceans. Broken lines delineate continental drainage basins and sectors of the ocean. The large numbers in boxes denote precipitation, P (top) and evaporation E (bottom) in cm a^{-1}. The small numbers signify, from top to bottom, P, E, and 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 and What Next?

- Key Ideas for Today
  - What is a reanalysis data set?
  - What drives and is forced by the SPCZ?
  - Annual cycle of the ITCZ
  - Global precipitation patterns and their seasonal cycle
  - 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?