The Hydrologic Cycle

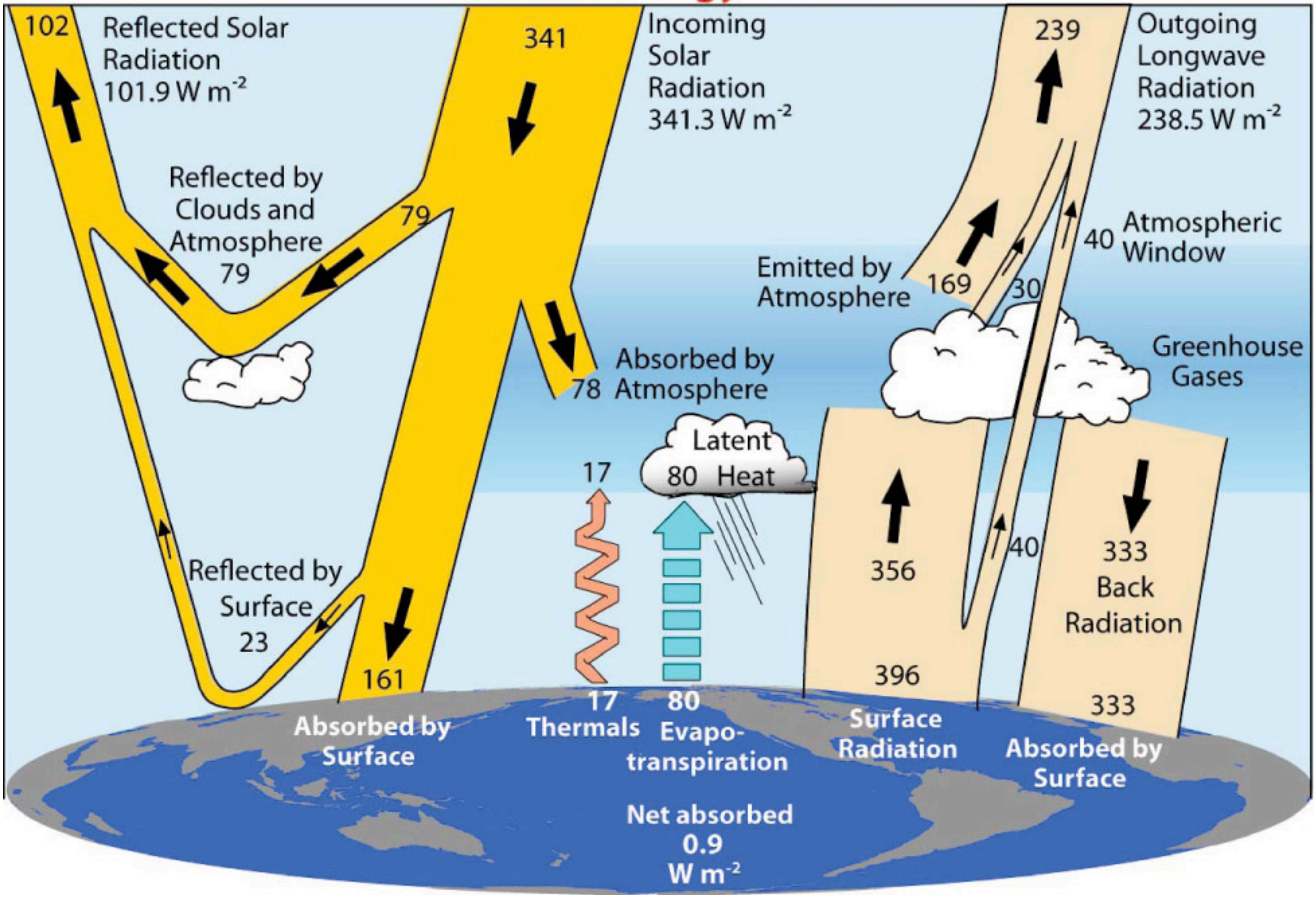
October 7, 2010

Why do we care about the hydrologic cycle?

The amount of water that flows through the hydrologic cycle each year is equal to about a 1 m depth of water averaged over the Earth's surface. This requires an average energy input of 80 W m^{-2} per year.

The average column water content of the atmosphere (sometimes called precipitable water), is about 2.5 cm. Since 100 cm evaporates (and precipitates) each year, the atmospheric water is replaced about 40 times per year, giving an average residence time of 9 days. Since evaporation is really a net flux of water, the actual residence time of an individual molecule is about 3 days.

Global Energy Flows W m⁻²



Updated version of Kiehl and Trenberth (1997)

The atmosphere contains a relatively small amount of water.

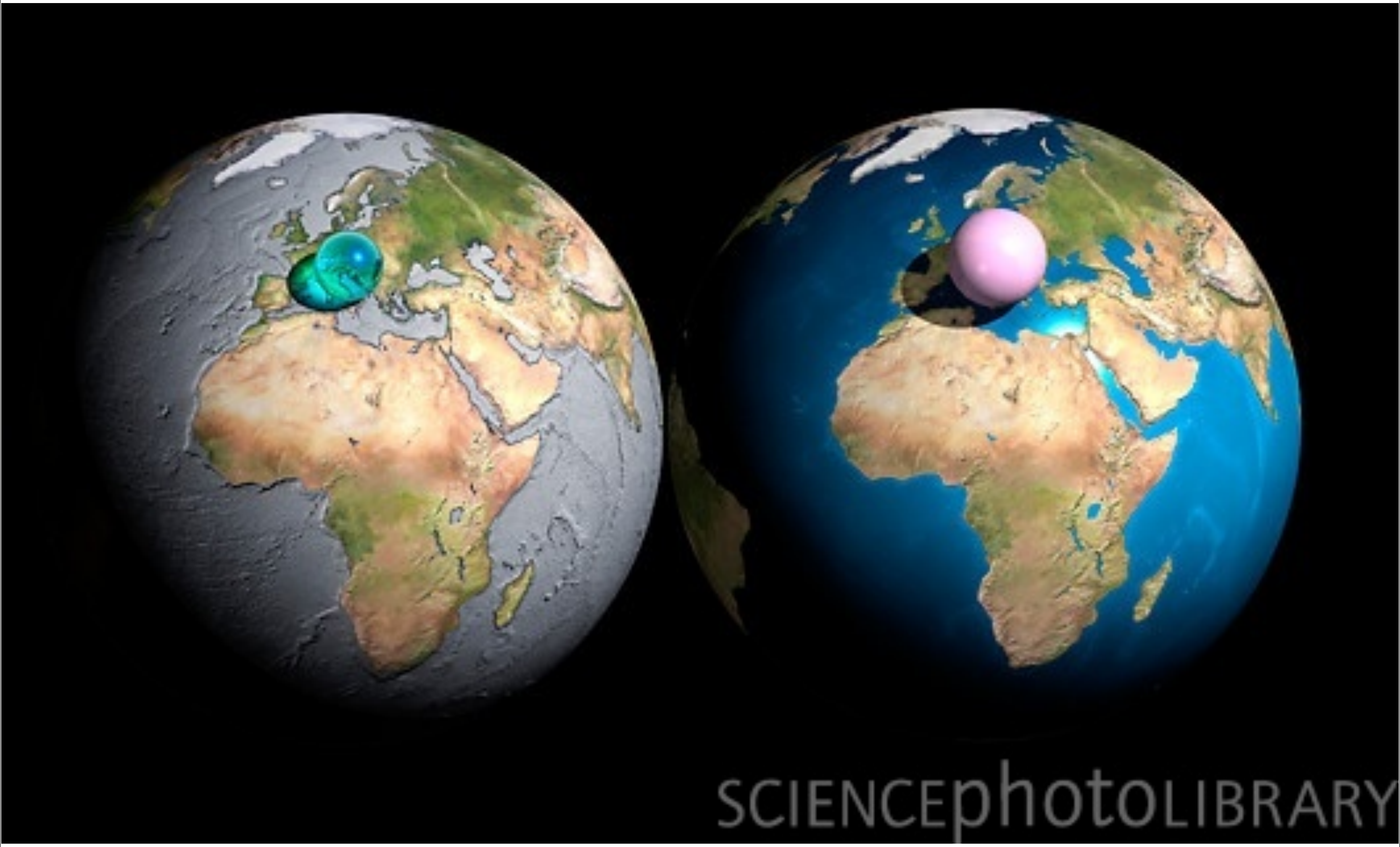
Table 5.1

Water Volumes of Earth

Category	Volume (10^6 km^3)	Percent
Oceans	1348.0	97.39
Polar ice caps, icebergs, glaciers	227.8	2.010
Groundwater, soil moisture	8.062	0.580[a]
Lakes and rivers	0.225	0.020
Atmosphere	0.013	0.001
Total water amount	1384.0	100.0
Freshwater	36.00	2.60
Freshwater reservoirs as a percent of total freshwater		
Polar ice caps, icebergs, glaciers		77.2
Groundwater to 800-m depth		9.8[a]
Groundwater 800–4000-m depth		12.3[a]
Soil moisture		0.17[a]
Lakes (freshwater)		0.35
Rivers		0.003
Hydrated earth minerals		0.001
Plants, animals, humans		0.003
Atmosphere		0.040
Sum		100.000

[From Baumgartner and Reichel (1975).]

[a]Numbers uncertain.


SCIENCEphotoLIBRARY

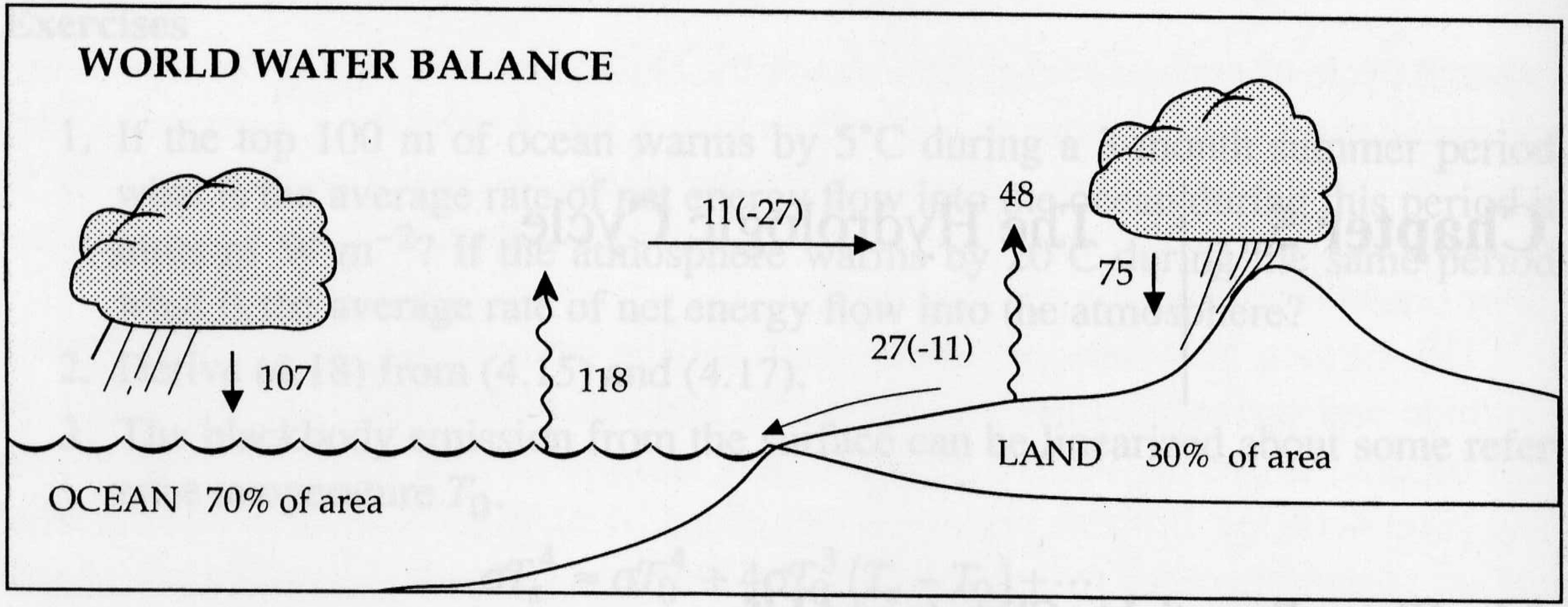
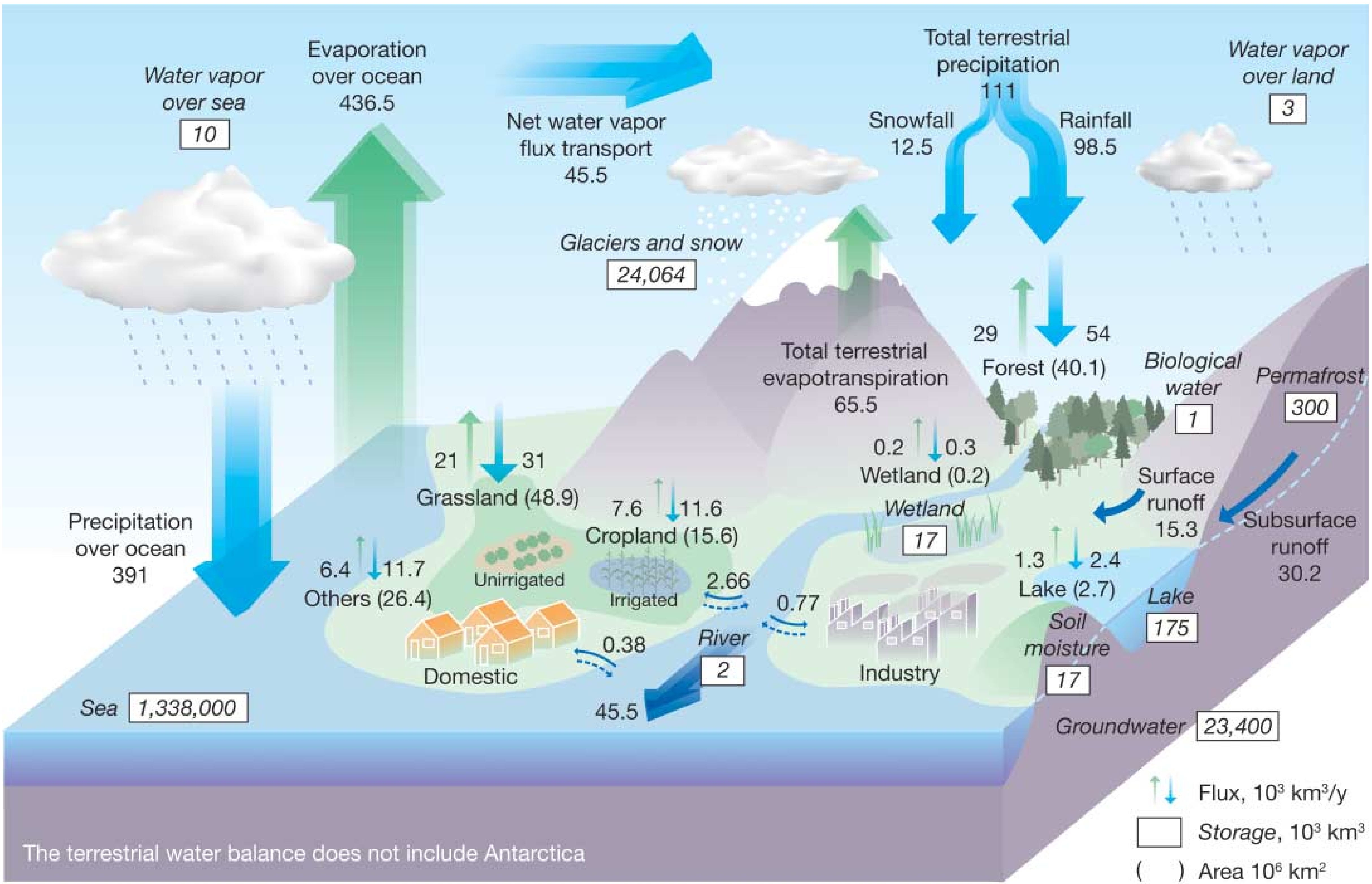


Fig. 5.1 Schematic diagram showing the basic fluxes of water in the global hydrologic cycle. Units are centimeters per year spread over the area of the land or ocean. Since the areas of land and ocean are different, the land–ocean water exchanges by atmospheric transport and river runoff have different values depending on the reference area, as indicated by the parentheses. The smaller values are those referenced to the larger oceanic area.

Oki and Kanae (2006), Figure 1



The Water **Balance**

For the surface:

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

- g_w: storage at and below the surface
- P: precipitation (rain and snow)
- D: dew and frost
- E: evapotranspiration
- Δf: runoff

The Water **Balance**

For the surface (averaged over a long time):

$$0 = P - E - \Delta f$$

precipitation (rain and snow) → P

evapotranspiration → E

runoff → Δf

Over a long period of time, the storage is small, and dew/frost can be incorporated into the precipitation term.

The Water **Balance**

For the atmosphere:

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

storage term

precipitation
(rain and snow)

dew and frost

evapotranspiration

horizontal
export of water
(mostly vapor)

Total Water Balance

(adding the two previous balance equations)

$$g_a + g_{wa} = - \Delta f - \Delta f_a$$

Total Water Balance

Averaging over a long period of time, the storage term disappears:

$$\Delta f = \Delta f_a$$

The moisture convergence in the atmosphere over a region is equal to the runoff.

Latitudinal Distribution

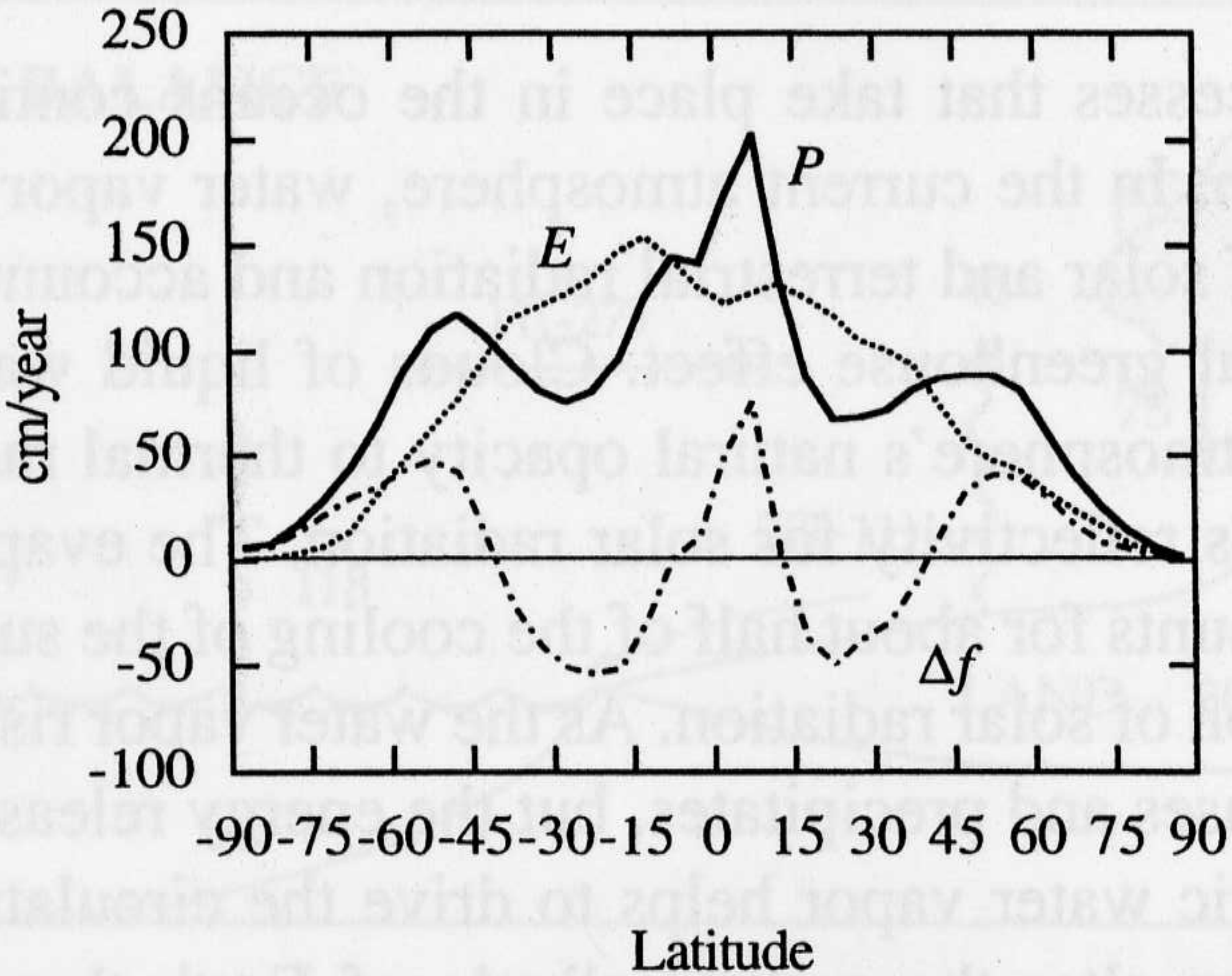


Fig. 5.2 Latitudinal distribution of the surface hydrologic balance, showing evaporation *E*, precipitation *P*, and runoff Δ*f*. [Data from Baumgartner and Reichel (1975).]

Table 5.2

Water Balance of the Continents and Oceans (in mm/year)

Region	E	P	Δf	$\Delta f / P$
Land				
Europe	375	657	282	0.43
Asia	420	696	276	0.40
Africa	582	696	114	0.16
Australia	534	803	269	0.33
North America	403	645	242	0.37
South America	946	1564	618	0.39
Antarctica	28	169	141	0.83
All land	480	746	266	0.36
Ocean				
Arctic Ocean	53	97	44	0.45
Atlantic Ocean	1133	761	−372	−0.49
Indian Ocean	1294	1043	−251	−0.24
Pacific Ocean	1202	1292	90	0.07
All ocean	1176	1066	−110	−0.10
Globe	973	973	0	

[From Baumgartner and Reichel (1975).]

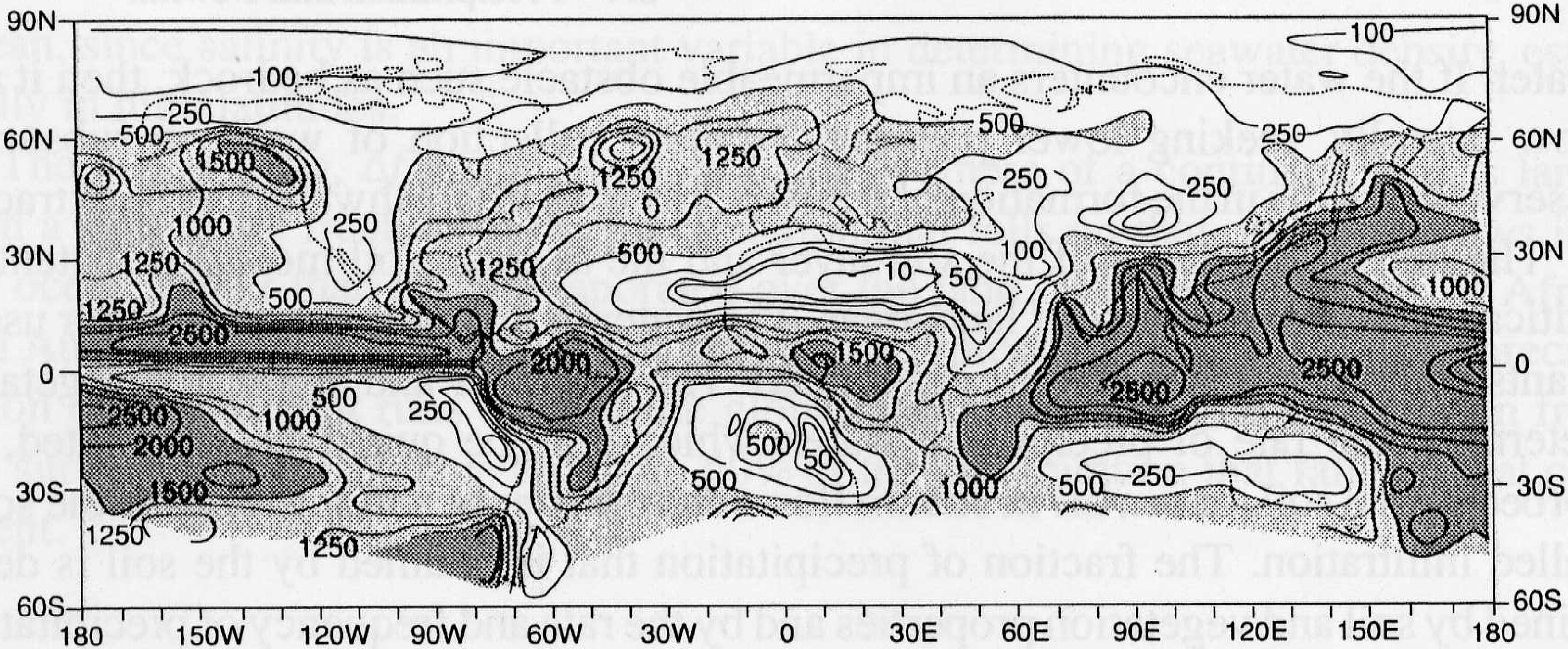


Fig. 5.4 Geographic distribution of annual mean precipitation in mm. [After Shea (1986). Reprinted with permission from the National Center of Atmospheric Research.]

Surface Water Storage

- Snow
- Soil Moisture
- Ground water

Evapotranspiration

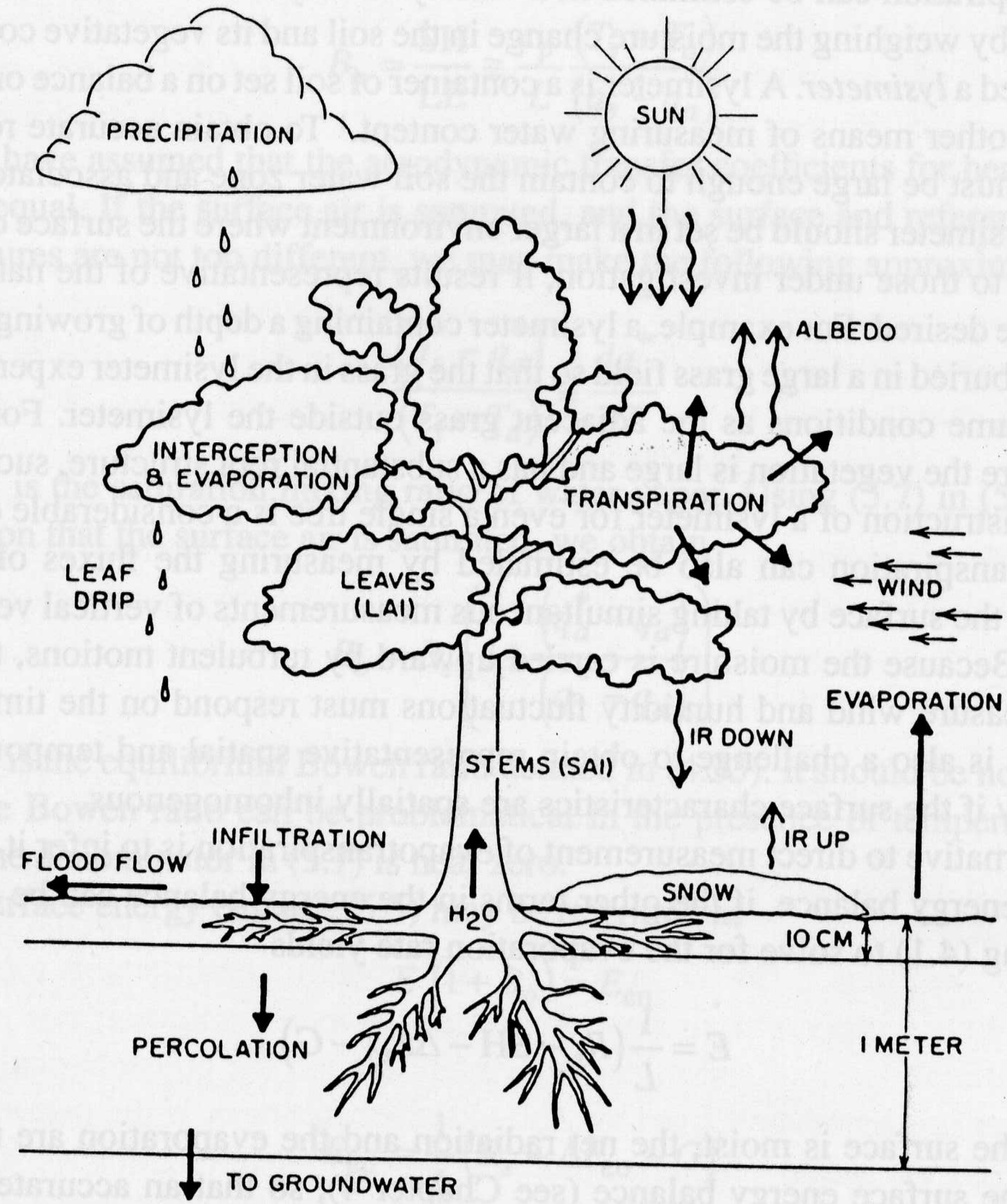


Fig. 5.5 Diagram showing the effects of the vegetation canopy on the water and energy fluxes. [From Dickinson (1984). © American Geophysical Union.]

Measuring Evapotranspiration

- Lysimeter (pot with soil and vegetation on a scale or balance)
- Inference

Evaporation rate from a wet surface (potential evaporation) can be inferred from the Penman equation:

$$E = \frac{1}{(1+B_e)} E_{en} + \frac{B_e}{(1+B_e)} E_{air}$$

Evaporation rate necessary to balance the energy supply to the surface by radiation, horizontal flux below the surface, and storage (equation 5.10)

Equilibrium Bowen ratio (sensible heat flux over latent heat flux) (equations 5.6 and 5.8)

Evaporating capacity of the air (equation 5.13)

Advantages of the Penman equation

- Can be measured with observations at only one atmospheric level
- Shows the relative roles of radiative input (first term) and atmospheric demand (second term)
- Can precisely calculate potential evaporation if you have both surface and atmospheric observations

Evaluate this statement:

Under climate change due to anthropogenic greenhouse gases, we will experience more floods and more droughts.

paraphrase of Kevin Trenberth

How and why do we measure soil moisture?