CHAPTER-2

GLOBAL ENERGY

&

WATER CYCLE

GLOBAL ENERGY CYCLE

N
Pakistan
YAHOO! Travel
TURKMENISTAN
UZB.
TAJIK.
CHINA
Gilgit
35°
Kābol
(Kabul)
Islamabad
Peshawar
Rawalpindi
AFGHANISTAN
IRAN
Sialkot
Gujranwala
Faisalabad
Lahore
PAKISTAN
Kot
Addu
Multan
Quetta
30°
INDIA
Bahawalpur
New
Delhi
Jacobabad
Kandhkot
Sukkur
Turbat
UAE
Gwadar
Hyderabad
25°
Karachi
0 100 200 mi
0 100 200 km
Masqaţ
(Muscat)
Arabian Sea
OMAN
60°
65°
70°
75°
©maps.com

The Global Energy Cycle

Primary Source of energy for the Planet

Solar Radiation → Short wave Radiation

Radiation having wave lengths between 0.3 μm – 3 μm.

Primary Sink of energy

Long wave Radiation → Terrestrial Radiation →

Infrared radiation

Radiation having wave lengths between 3 μm – 100 μm.

Over long term basis

Short wave radiation = Long Wave Radiation

Radiant energies are absorbed, emitted, scattered or reflected

ANNUAL MEAN GLOBAL ENERGY BALANCE

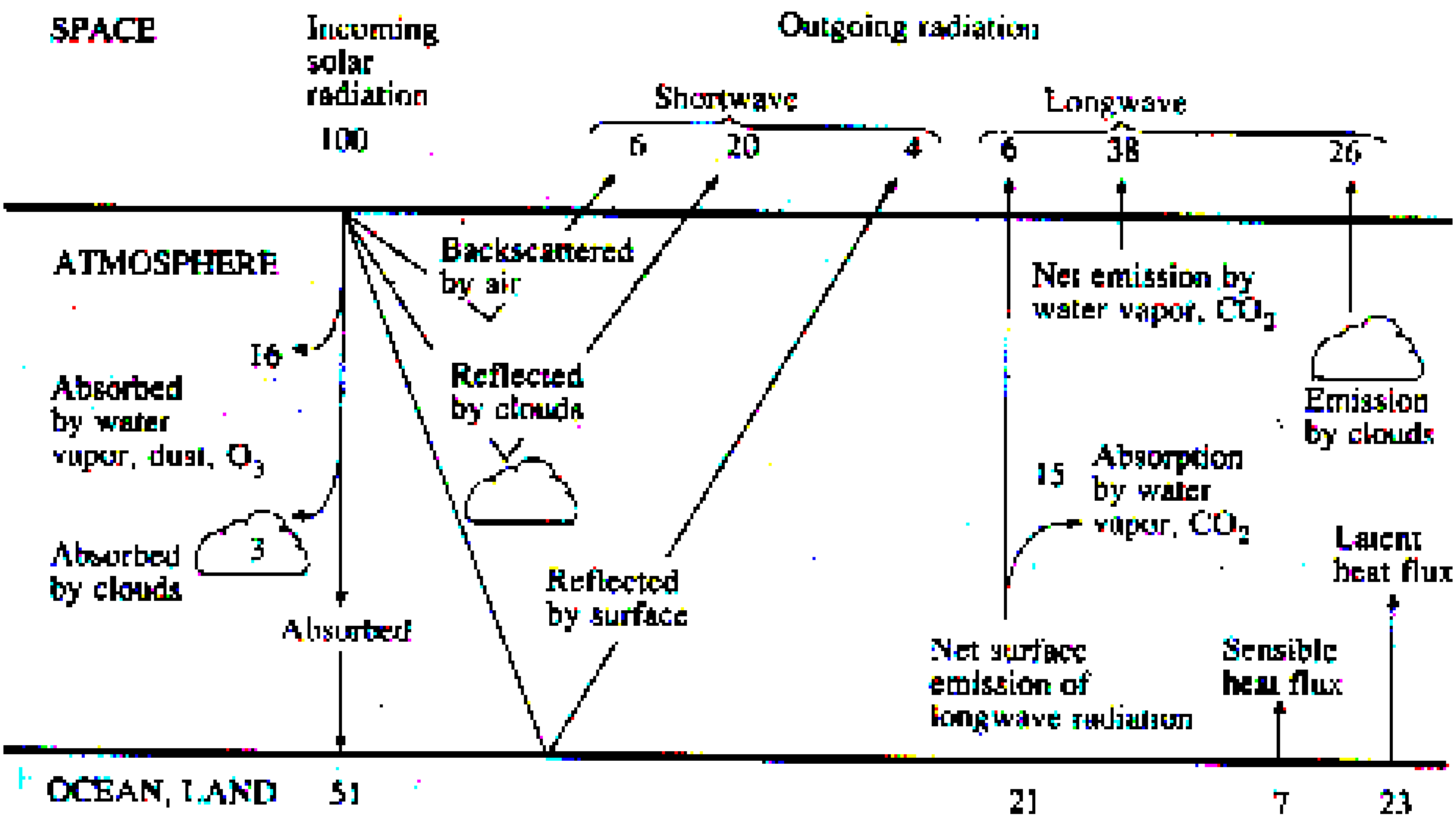


FIGURE 2.8.4

Radiation and heat balance in the atmosphere and at the earth's surface. (*Source:* "Understanding Climatic Change," p. 18, National Academy of Sciences, Washington, D.C., 1975. Used with permission.)

Albedo

Ratio between reflected radiation and incoming solar radiation.

$$\alpha = \frac{Reflected\ Radiation}{Incoming\ Solar\ Radiation} = \frac{Outgoing\ Radiation}{shortwave\ Radiation}$$

Albedo is a function of

(i) Direction of Solar Beam
(ii) Portion of diffused Radiation
(iii) Land surface conditions

S.No.	Land-use type	α
1	Open Water Surface	0.08
2	Bare Soil	0.1-0.35
3	Snow & Ice	0.2-0.8 (new)
4	Grassland, Agriculture	0.23

- Oceans are the main source to absorb solar energy and control wind directions on the globe.
- Mean Albedo of the Planet is 0.30

Latent Heat Flux

Amount of heat absorbed / released by a unit mass of substance without change in temperature while passing from liquid to vapor state.

Net energy transferred from the surface to the atmosphere associated with the change in water phases. (On global basis, 23 units).

Sensible Heat Flux

Portion of radiant energy input to the earth surface (not used for evaporation) which warms the atmosphere in contact with the ground and then moves upward. (Globally, 7 units)

In absence of these two, the mean earth surface temperature would have been 50° K hotter.

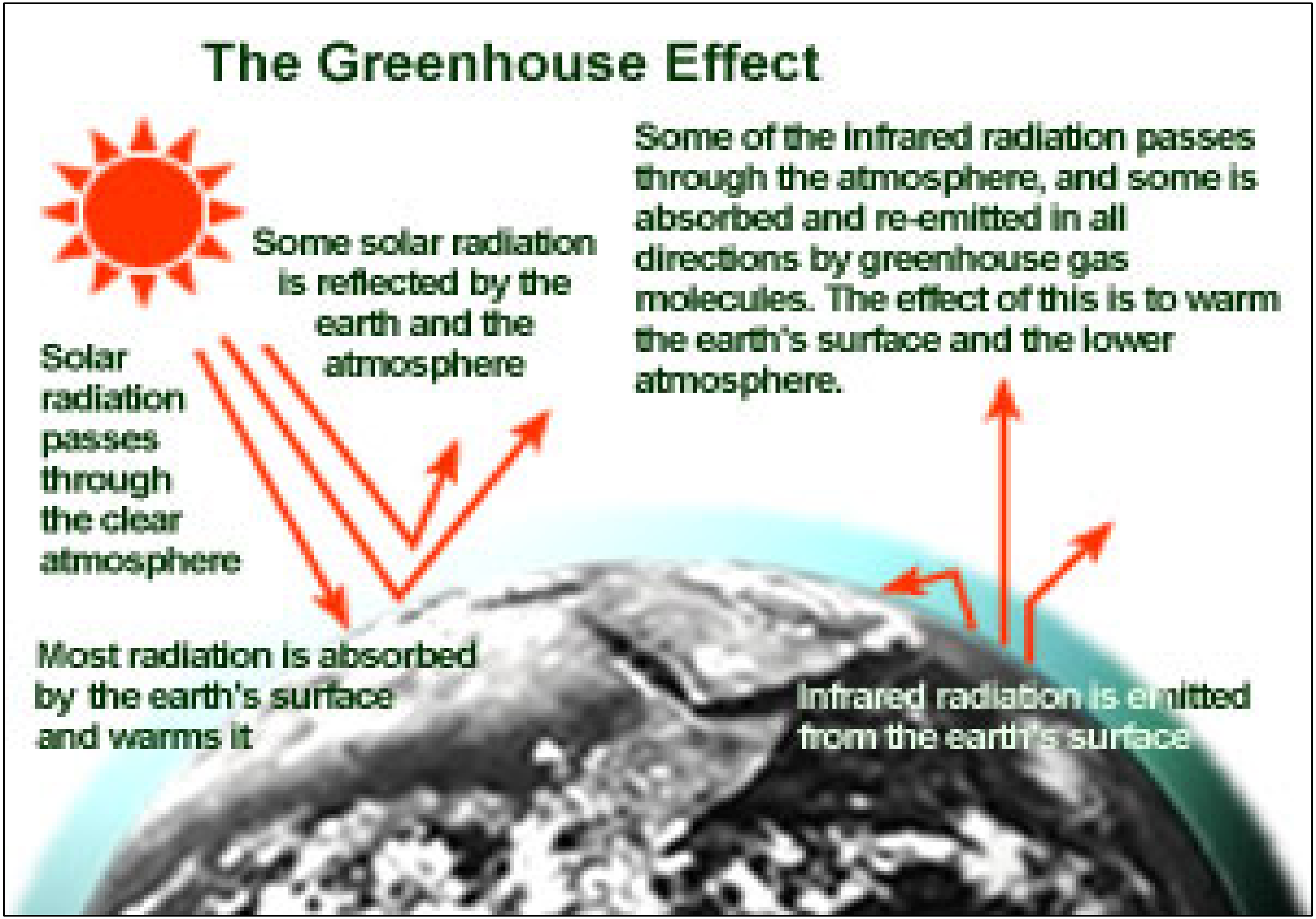
Green House Effect

Long wave radiation emitted by the surface is absorbed in atmosphere and some of its part re-emits back to the surface which increases the mean surface temperature and is known as green house effect.

Otherwise, the mean surface temperature would have been 33° K (60° F) colder.

Current life on Earth could not be sustained without the natural greenhouse effect.

Green House Effect



Green House Gases

Any Gas That Absorbs Infra-red Radiation in the Atmosphere.

- Greenhouse Gases Include Water Vapor
- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Halogenated Fluorocarbons (HCFCs)
- Ozone (O_3)
- Perfluorinated Carbons (PFCs)
- Hydrofluorocarbons (HFCs).

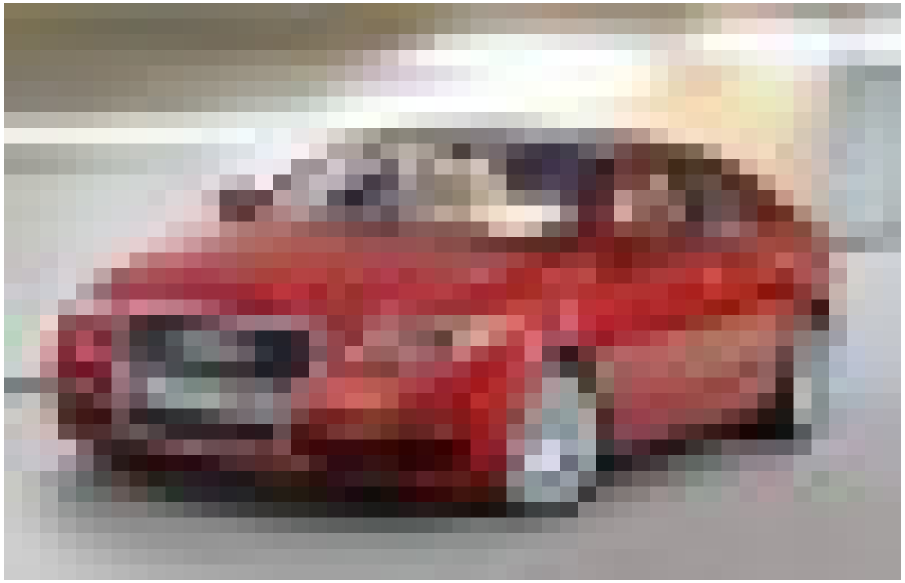
Are we increasing their amounts?

If Yes, we are calling to GLOBAL WARMING

Localized Green House Cases

Plantation in winter

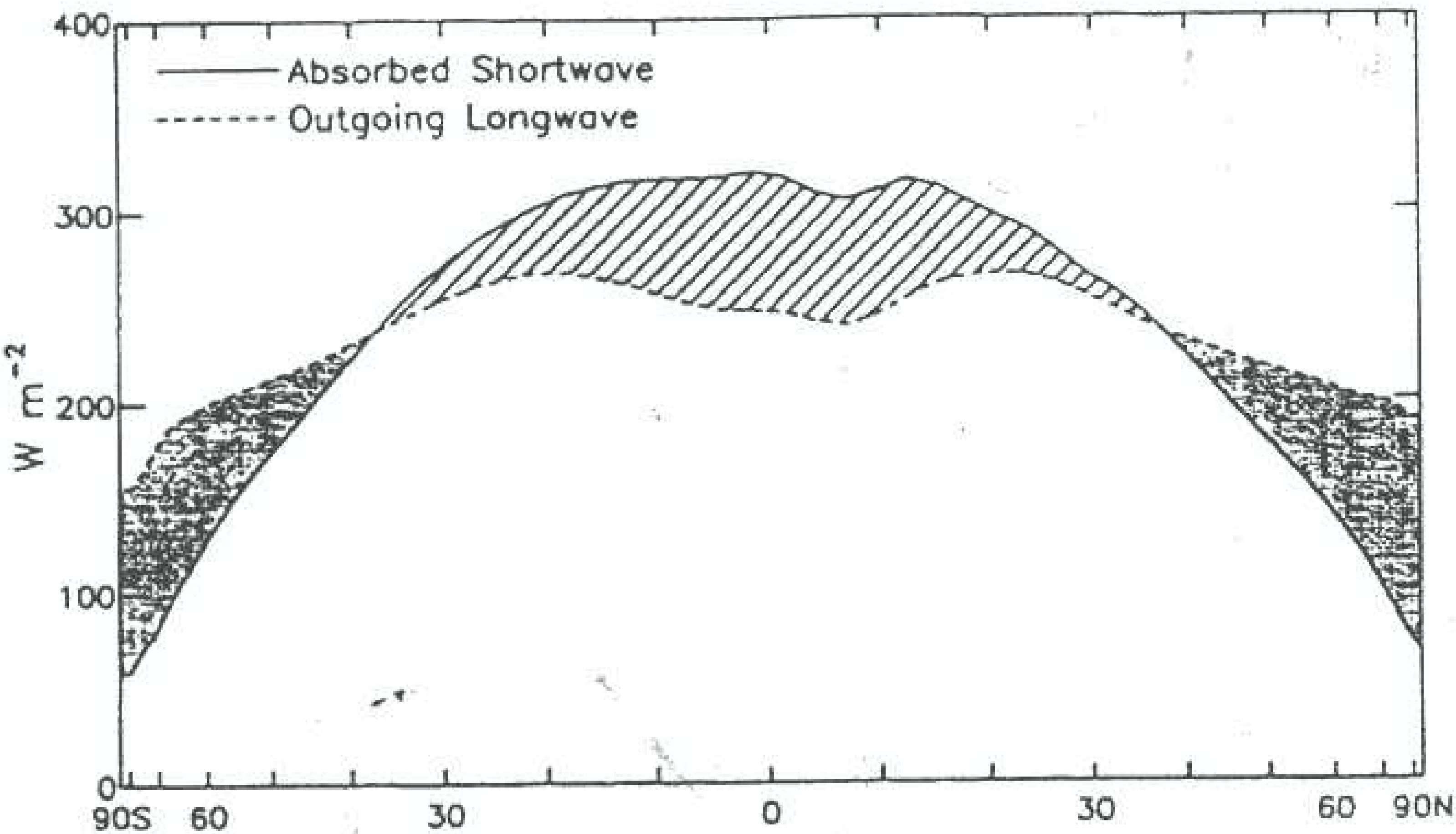
Parking of cars in summer under solar radiation



Global Energy Balance

- Out of 100 units radiation incident at the top of atmosphere, 30 units are reflected and scattered back to space by clouds, cloud free air and surface.
- At surface it can be transformed into other forms of energies.
- To balance the absorbed solar radiation, combination of longwave radiation, sensible and latent heat fluxes are returned.
- Long wave radiation emitted by surface is absorbed in atmosphere by clouds, water vapor or other trace gases.
- More than half of the Planetory Albedo is due to clouds.
- Most of the infrared radiation emitted by atmosphere is due to water vapor.

ZONALLY AVERAGED ANNUAL MEAN TOP OF THE ATMOSPHERE RADIATION



Flow of Energy in Climate

- Solar energy reaching to the top of atmosphere varies sharply with

  (i) earth shape

  (ii) Orbital characteristics (near equator app. = 2 x near poles)

- Snow has large Albedo values
- Outgoing radiation is a function of

  (i) Temperature

  (ii) latitude (less dependent)

- At low latitudes absorbed radiation is more than emitted radiation & vice versa for high altitudes.
- To achieve balance in each region, atmosphere and oceans transport energy from tropics towards poles.

Planet Fluid Energies

1) **Internal Energy** = $I = C_v \, T$

2) **Potential Energy** = $\phi = g \, Z$

3) **Kinetic Energy** = $k = \frac{1}{2}\left(u^2 + v^2 + w^2\right)$

4) **Latent Energy** = $L = l \, q$ (liquid to vapor)

where	C_v	= Specific heat at constant volume
	T	= Temperature
	g	= Acceleration due to gravity
	Z	= Potential height
	u	= Zonal wind
	v	= Meridional wind
	w	= Vertical velocity
	l	= latent heat of vaporization
	q	= Specific Humidity

Energy Balance Equation

$$\frac{\partial}{\partial t}\left(C_p\ T + l\ q + k\right) + \nabla\left(S + l\ q + k\right)\ v + \frac{\partial}{\partial p}\left(S + l\ q + k\right)w = Q$$

C_p = Specific heat at constant pressure (heat to raise 1°K temp for 1gm mass)

p = Pressure

$S = C_p T + \phi$ = Dry static energy

Q = Adiabatic heating (due to radiative,sensible and latent frictional process)

$h = S + lq$ = moist static energy

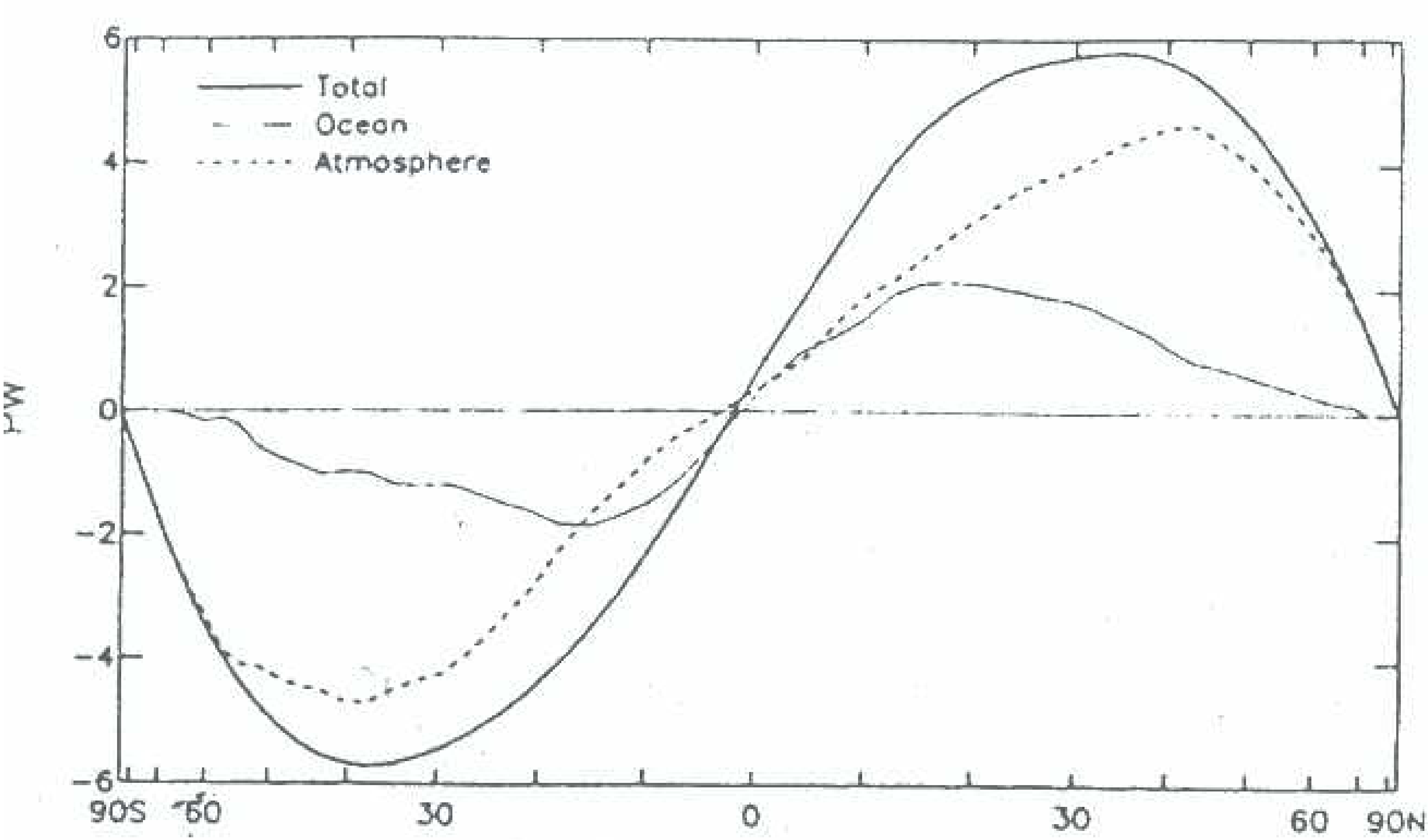
As K.E. of atmosphere >> (potential energy =0)

$$\frac{1}{g}\int \frac{\partial}{\partial t}\left(C_p T + l\ q\right)\ dp + \frac{1}{g}\int \nabla\ h\ v\ dp = F_T - F_B$$

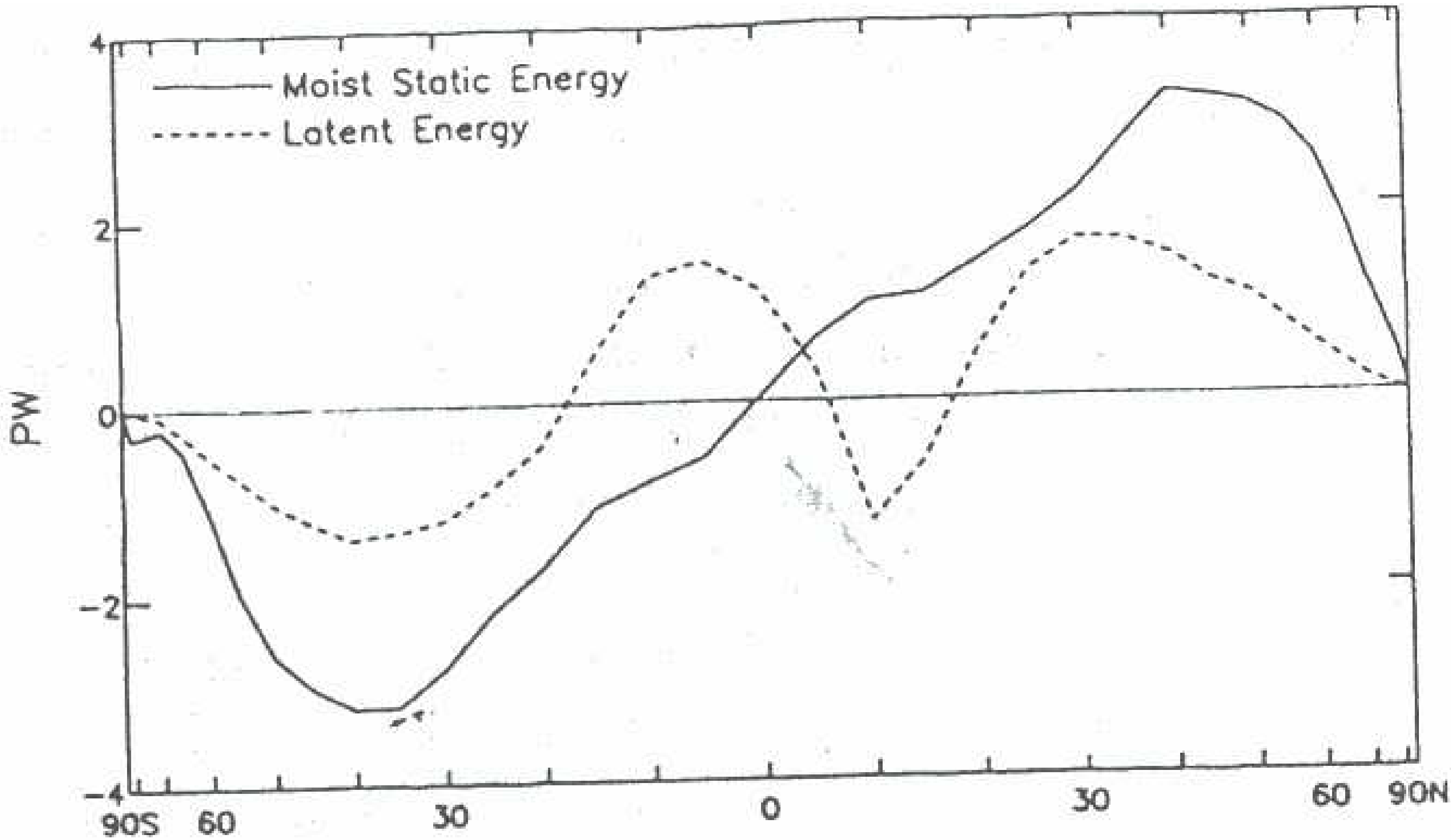
F_T = Net downward fluxes of energy at top of atmosphere

F_B = Net downward fluxes of energy at bottom of atmosphere

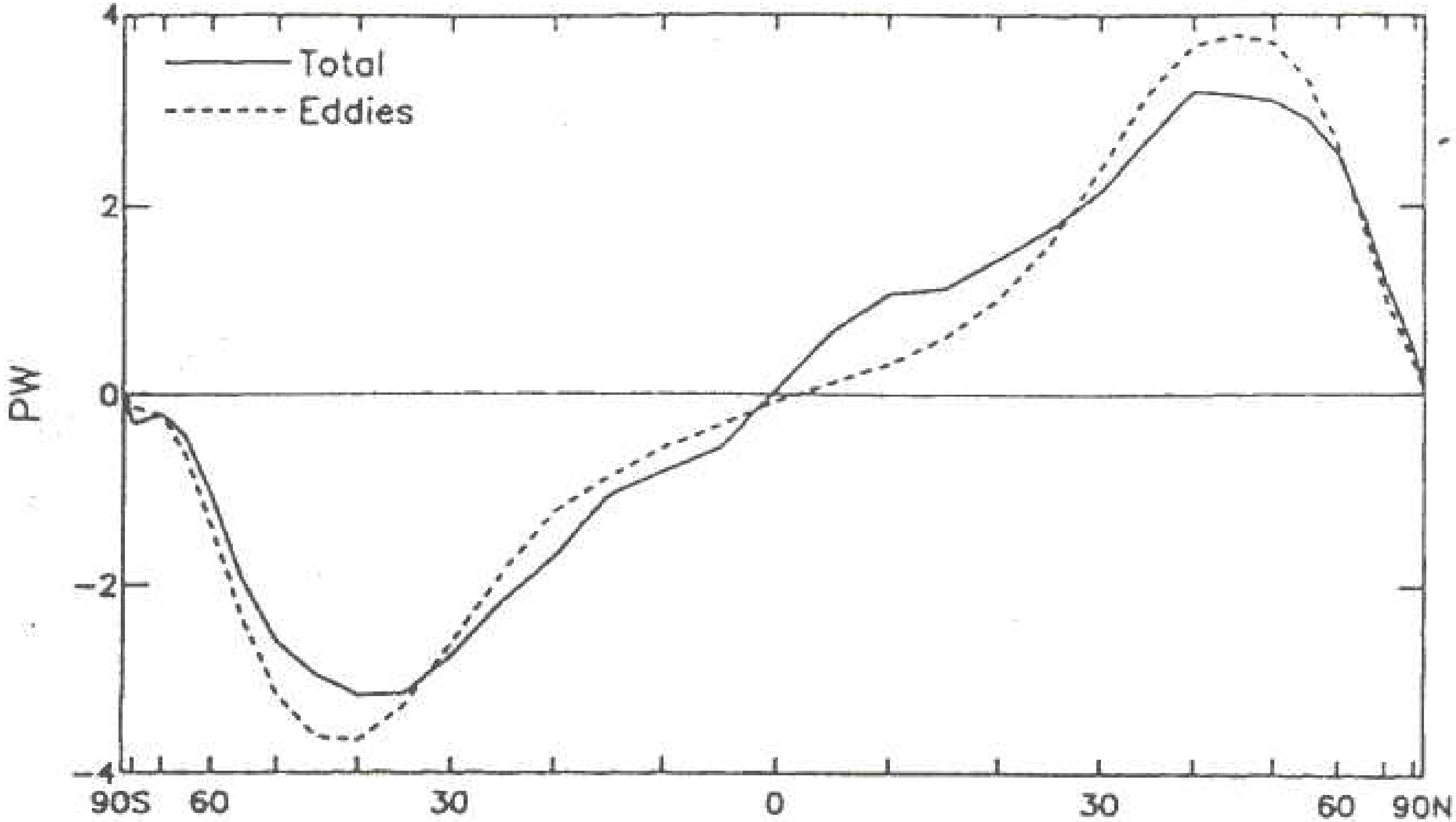
ANNUAL MEAN TOTAL NORTH-WARD TRANSPORT OF MOIST STATIC ENERGY PLUS KINETIC ENERGY



ANNUAL MEAN TOTAL NORTH-WARD TRANSPORT OF MOIST STATIC ENERGY BY THE ATMOSPHERE



ANNUAL MEAN TOTAL NORTH-WARD TRANSPORT OF MOIST STATIC ENERGY

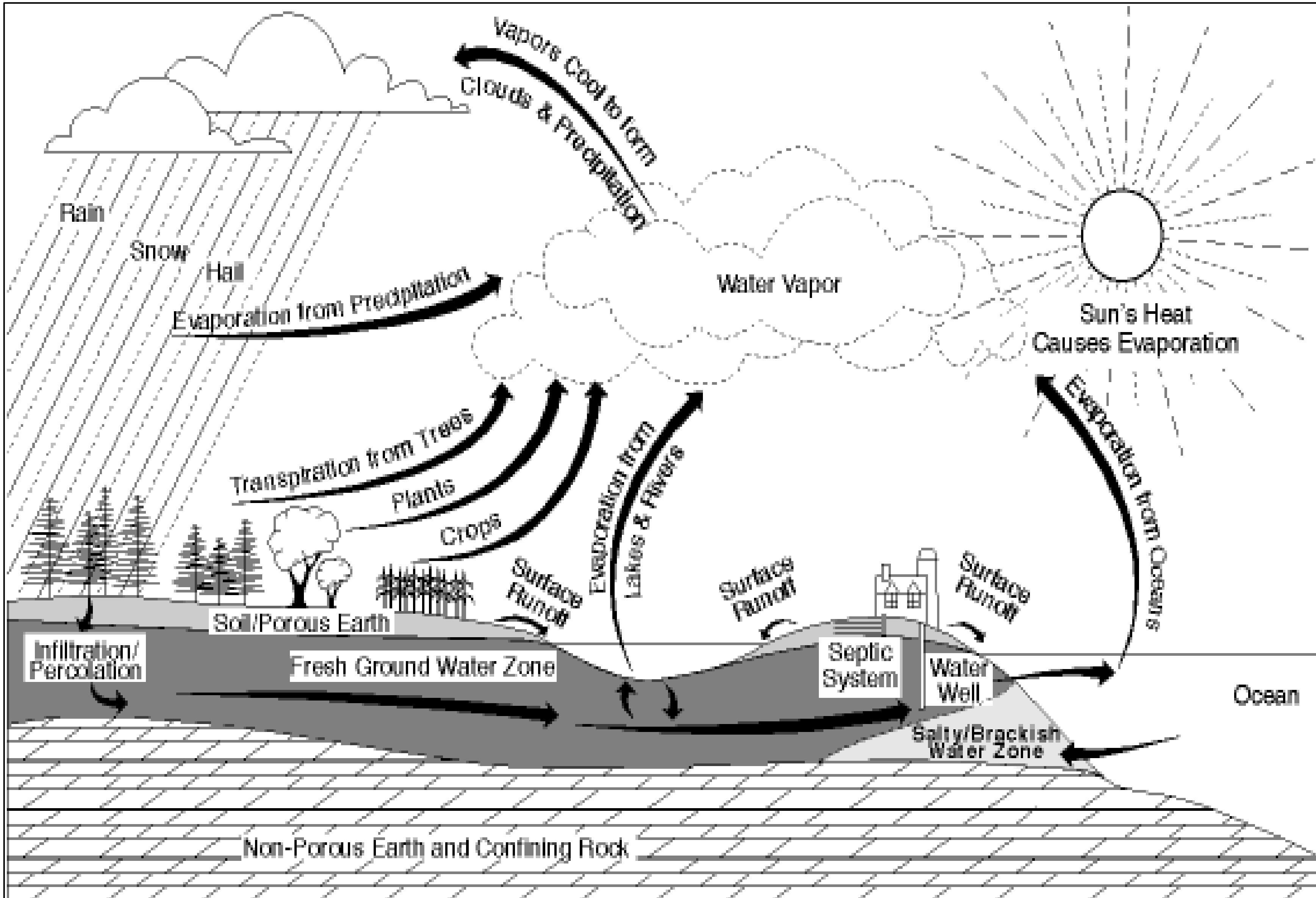


Conclusions

- Atmosphere and oceans play important role in effecting the pole-ward transport of energy.
- Major role is of atmosphere
- Winds are agent to transport energies at higher altitudes.
- Due to rising of warmer air and sinking of colder air lowers the C.G. of the atmosphere (reduce potential energy and increase kinetic energy).
- Oceans release heat to atmosphere during winter that accumulates in summer.
- Increase in green house gases invites Global Warming.

GLOBAL WATER CYCLE

GLOBAL WATER CYCLE



GLOBAL WATER CYCLE

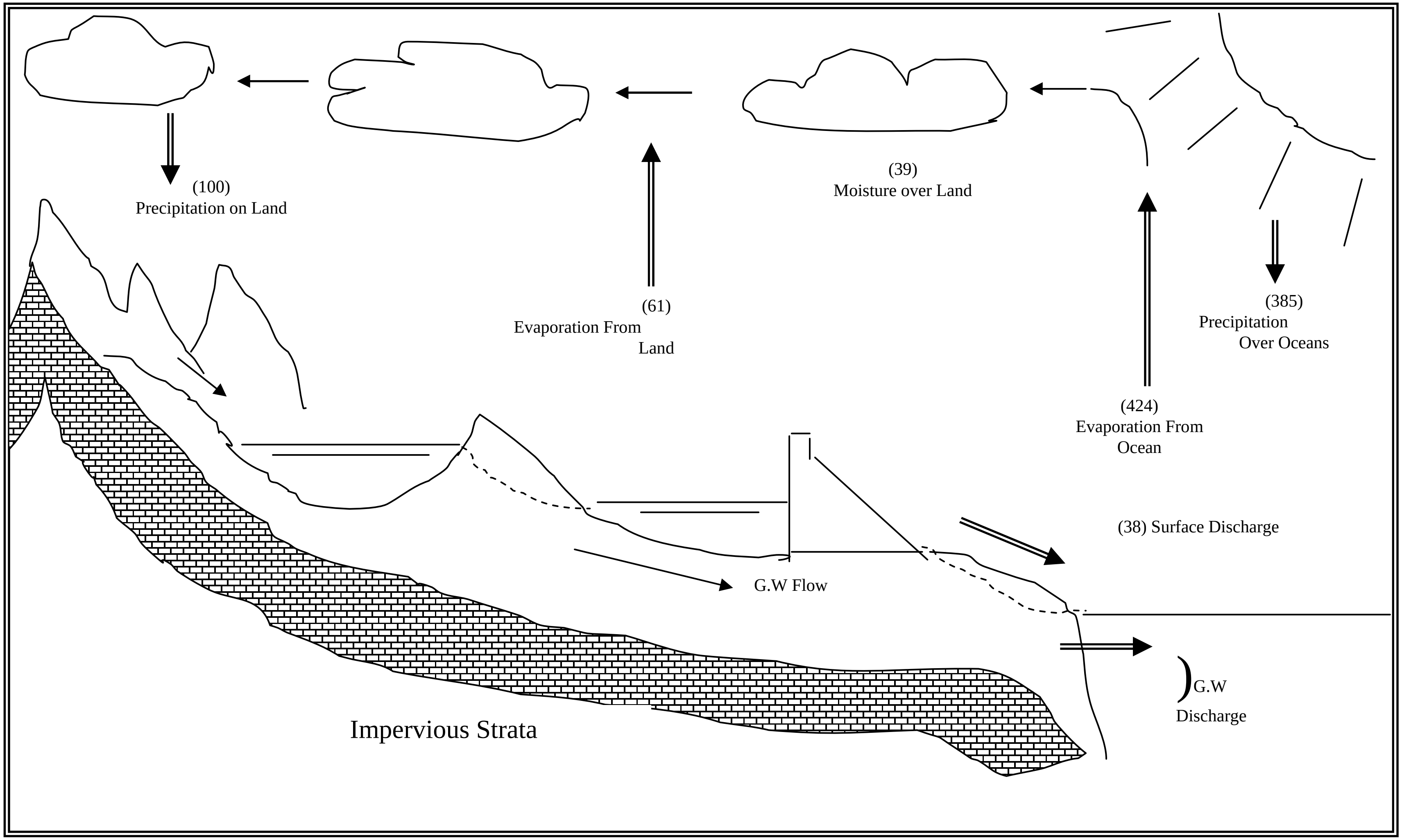


Fig.-1 The Hydrologic Cycle with annual volumes of Flow given in units relative to the annual precipitation on the land surface of the earth (119 000 Km^3/year).

GLOBAL WATER CYCLE

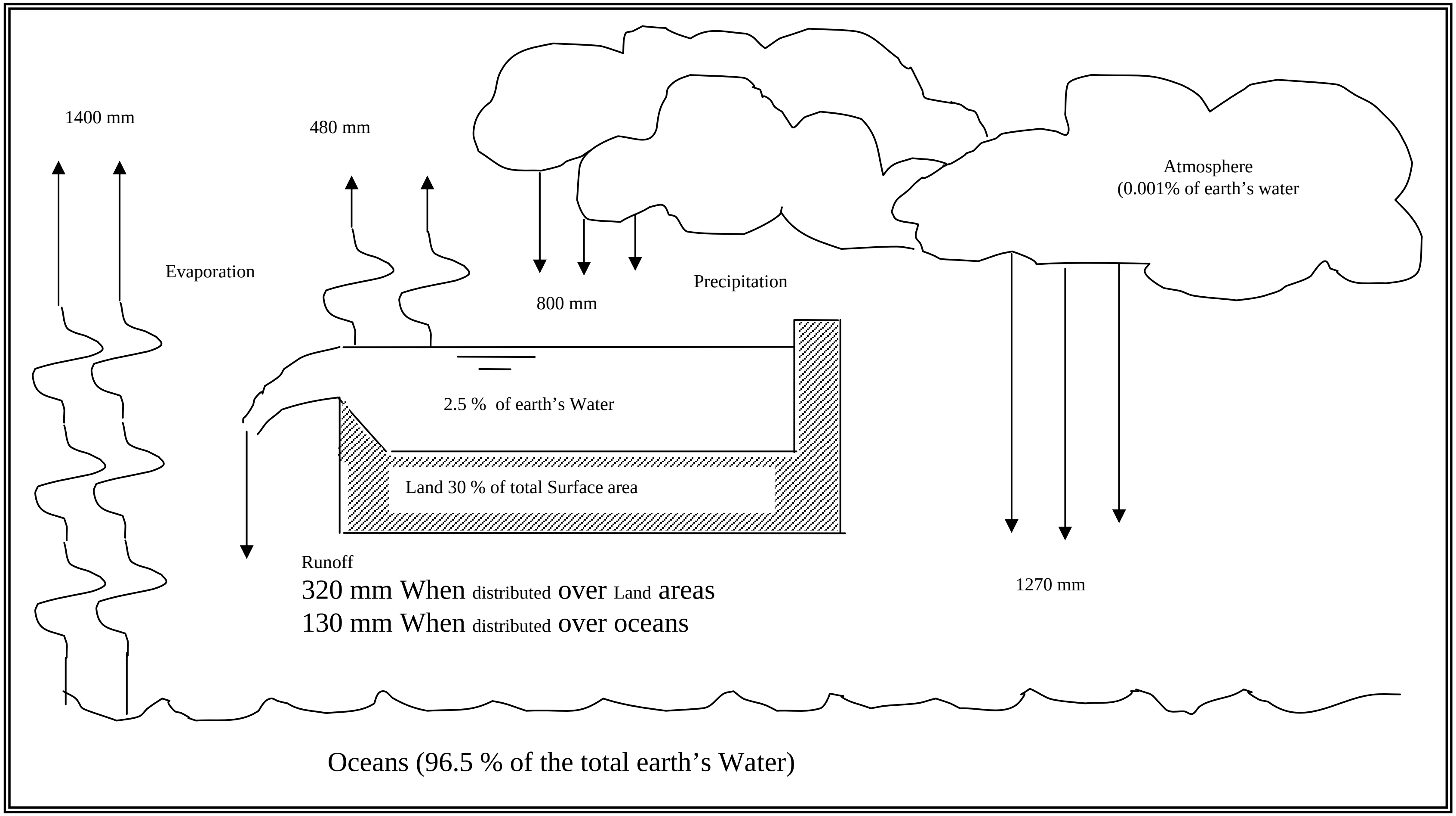


Fig.-2 Annual quantities of World Water Balance

Table-1 Global water estimates given by Korzun (1978)

S. #	Form of Water	Covering Area (km^3)	Total Volume (km^3)	Mean depth (m)	Share (%)
1	World ocean	361300 000	1338 000 000	3700	96.539
2	Glaciers and permanent snow cover	16 227 500	24 064 100	1463	1.736
3	Ground water	134 800 000	23 400 000	174	1.688
4	Ground Ice in zones of permafrost strata	21 000 000	300 000	14	0.0216
5	Water in lakes	2058 700	176 400	85.7	0.0127
6	Soil moisture	82 000 000	16 500	0.2	0.0012
7	Atmospheric water	510 000 000	12 900	0.025	0.0009
8	Marsh Water	2 682 600	11 470	4.28	0.0008
9	Water in rivers	148 800 000	2120	0.014	0.0002
10	Biological water	510 000 000	1120	0.002	0.0001
	Total water reserves	510 000 000	1 385 984 610	2718	100.00

Table-2 Global Water estimates UNESCO, 1978.

S.#	Item	Area, 10^6 (km^2)	Volume (km^3)	Percent of Total Water	Percent of Fresh Water
1	Oceans	361.3	1 338 000 000	96.5	
2	Ground Water:				
	Fresh	134.8	10 530 000	0.76	30.1
	Saline	134.8	12 870 000	0.93	
3	Soil Moisture	82.0	16 500	0.0012	0.05
4	Polar Ice	16.0	24 023 500	1.7	68.6
5	Other Ice and Snow	0.3	340 600	0.025	1.0
6	Lakes:				
	Fresh	1.2	91 000	0.007	0.26
	Saline	0.8	85 400	0.006	
7	Marshes	2.7	11 470	0.0008	0.03
8	Rivers	148.8	2 120	0.0002	0.006
9	Biological Water	510.0	1 120	0.0001	0.003
10	Atmospheric Water	510.0	12 900	0.001	0.04
	Total Water	510.0	1 385 984 610	100	
	Fresh Water	148.8	35 029 210	2.5	100

Global Water Balance given by UNESCO

S.#	Item	Units	Ocean	Land
	Area	Km^2	361 300 000	148 800 000
1	Precipitation	Km^3/yr	458 000	119 000
2	Evaporation	Km^3/yr	505 000	72 000
3	Runoff to Ocean			
	Rivers	Km^3/yr	-	44 700
	Ground Water	Km^3/yr	-	2200
	Total Runoff	Km^3/yr	-	47 000

Estimated earth Water inventory by E.M.Wilson

S.#	Location	Volume (10^3 Km^3)	Percentage total Water
1	Fresh Water in Lakes	125	0.0090
2	Rivers	1.25	0.00009
3	Soil Moisture	65	0.0048
4	Ground Water	8 250	0.606
5	Saline Lakes and inland seas	105	0.008
6	Atmosphere	13	0.001
7	Polar Ice caps, Glaciers and Snow	29200	2.1
8	Seas and Oceans	1 320 000	97.25
	Total	1 360 000	100.0

Global Water Balance (through internet)

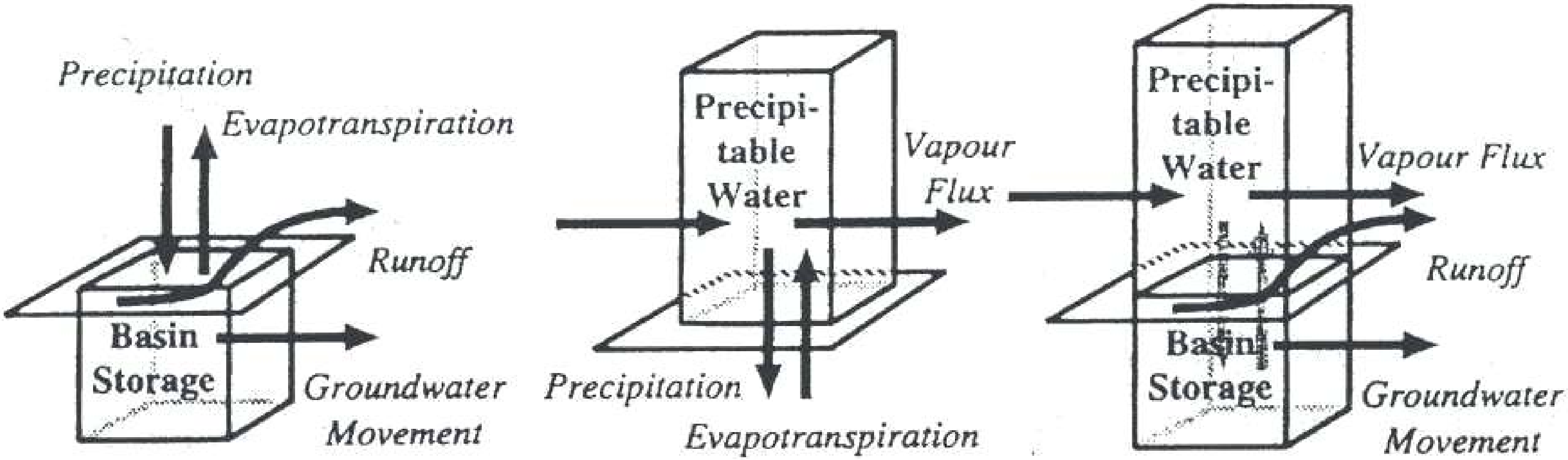
. (http://www.ecs.umass.edu/cee/reckhow/courses/370/370l4/sld008.htm)

S.#	Water Source	Mass (Kg)	Volume (Km^3)*
1	Oceans	$13\ 700 \times 10^{17}$	1370 000 000
2	Ground Water	$3\ 200 \times 10^{17}$	320 000 000
3	Water Locked in ice	165×10^{17}	16 500 000
4	Water in lakes, rivers	0.34×10^{17}	34 000
5	Water in atmosphere	0.105×10^{17}	10 500
6	Total yearly stream discharge	0.32×10^{17}	32 000

Role of Hydrologic Cycle in the Climate System

- Atmospheric Water (influences heat budget)
- Liquid Water (PPT. Changes the surface salinity over the ocean)
- Snow (High albedos, so surface temperature doesn't rise)
- Evaporation (Latent heat of vaporization)
- Transpiration (Vegetation changes the surface albedo)
- Soil Moisture (Changes the surface albedo)
- Ground Water (Long-term climatological changes)
- Runoff (Returns water to oceans)
- Ocean (Carries huge amounts of energy and water)

Water Balances



(a) Water balance in the basin

(b) Water balance in the atmosphere

(c) Combined water balance

Water Balances

(1) Water Balance at the land surface

$$\frac{\partial S}{\partial t} = -\nabla_H \overrightarrow{R_o} - \nabla_H \overrightarrow{R_u} + (P - E) \quad (1)$$

$$\boxed{\frac{\partial S}{\partial t} = -\nabla_H \overrightarrow{R_o} + (P - E)} \quad (2)$$

$$\frac{\partial S}{\partial t} + \nabla_H \overrightarrow{R_o} = (P - E) \quad (2A)$$

(2) Water Balance in Atmosphere

$$\frac{\partial W}{\partial t} + \frac{\partial W_C}{\partial t} = -\nabla_H \vec{Q} - \nabla_H \overrightarrow{Q_C} + (E - P) \quad (3)$$

$$\boxed{\frac{\partial W}{\partial t} = -\nabla_H \vec{Q} - (P - E)} \quad (4)$$

$$(P - E) = -\frac{\partial W}{\partial t} - \nabla_H \vec{Q} \quad (4A)$$

where

$\overrightarrow{R_o}$ = Surface runoff

$\overrightarrow{R_u}$ = Ground water movement

S = Water storage within area

∇_H = Horizontal divergence

$$\nabla \vec{a} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

W = Precipitable water (water vap)

W_C = Col storage of liq & solid water

$\vec{Q}$ = 2-dimensional water vapor flux

$\vec{Q}_C$ = 2-dimensional water vapor flux in liquid & solid phases

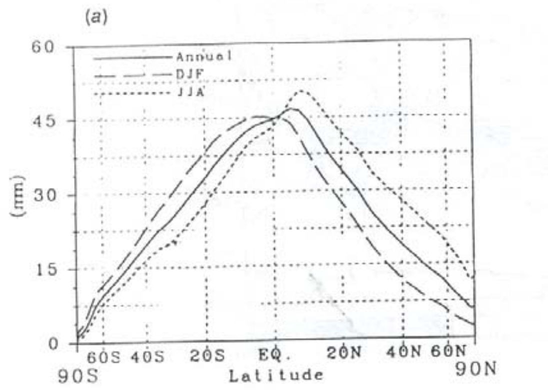
(3) Combined Watershed-River basin Water Balance

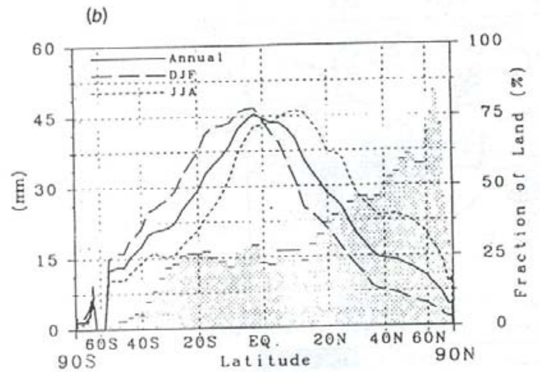
(2A)=(4A)

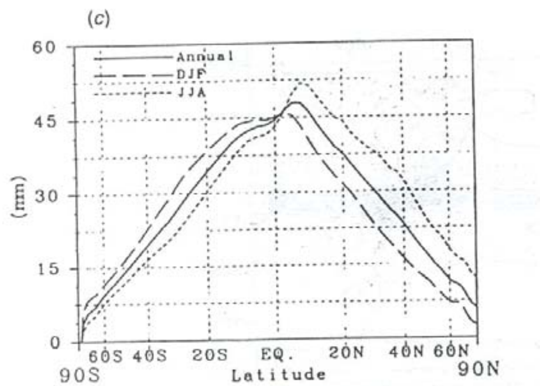
$$\boxed{\frac{\partial S}{\partial t} + \nabla_H \overrightarrow{R_o} = (P - E) = -\frac{\partial W}{\partial t} - \nabla_H \vec{Q}} \quad (5)$$

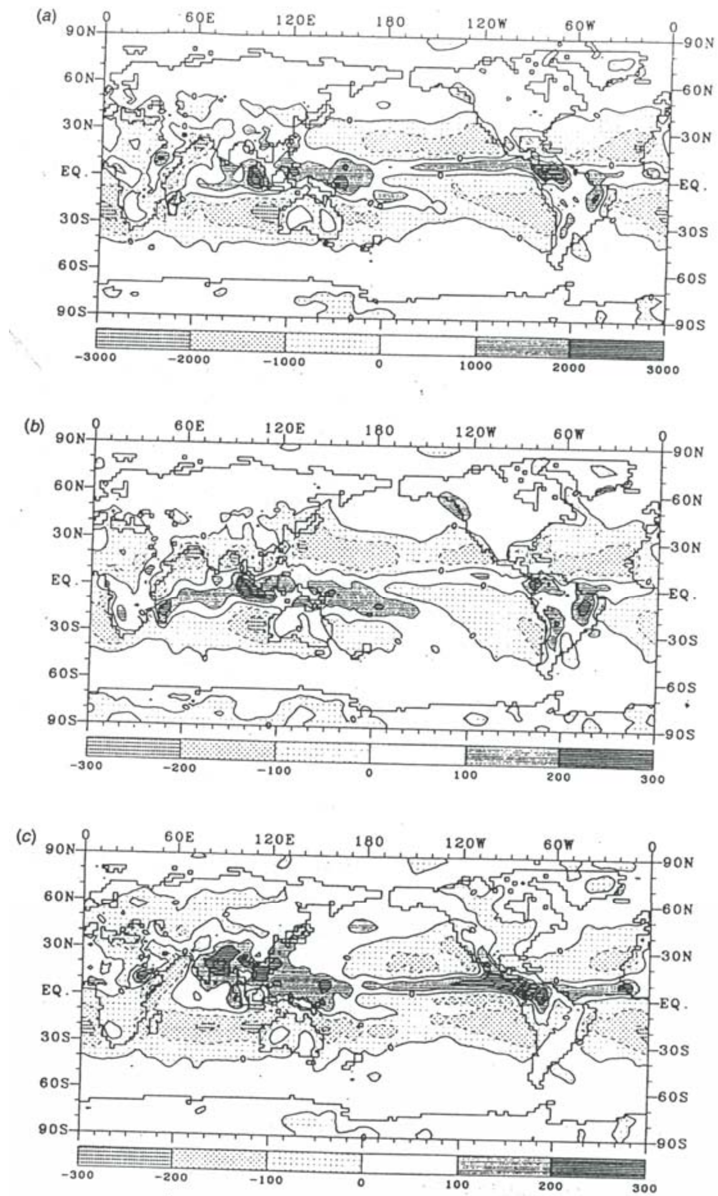
MERIDIONAL DISTRIBUTION OF PRECIPITATION

- (a) Over land & sea
- (b) Mean over land only
- (c) Mean over sea only



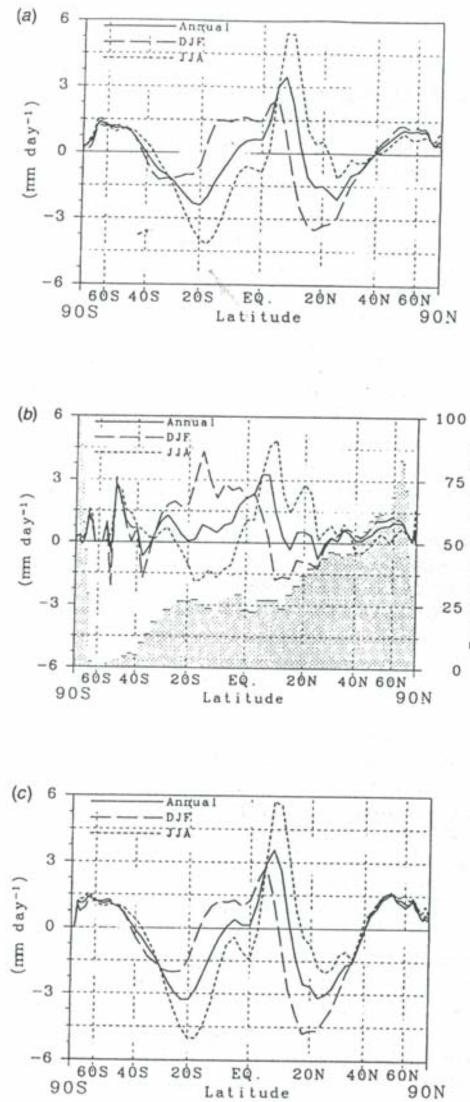


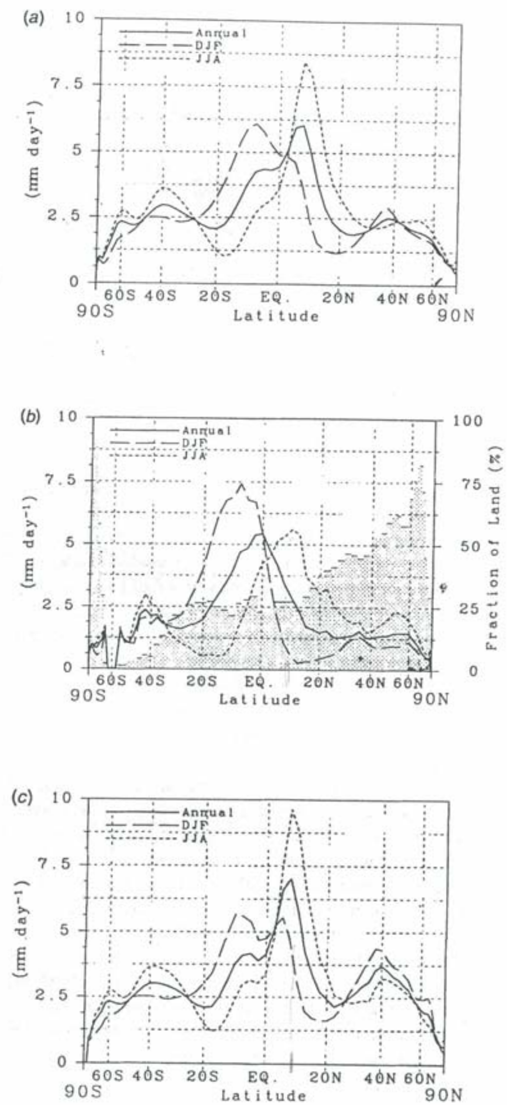



(a)
0
60E
120E
180
120W
60W
90N
60N
30N
EQ.
30S
60S
90S
-3000
-2000
-1000
0
1000
2000
3000
(b)
-300
-200
-100
0
100
200
300
(c)
-300
-200
-100
0
100
200
300

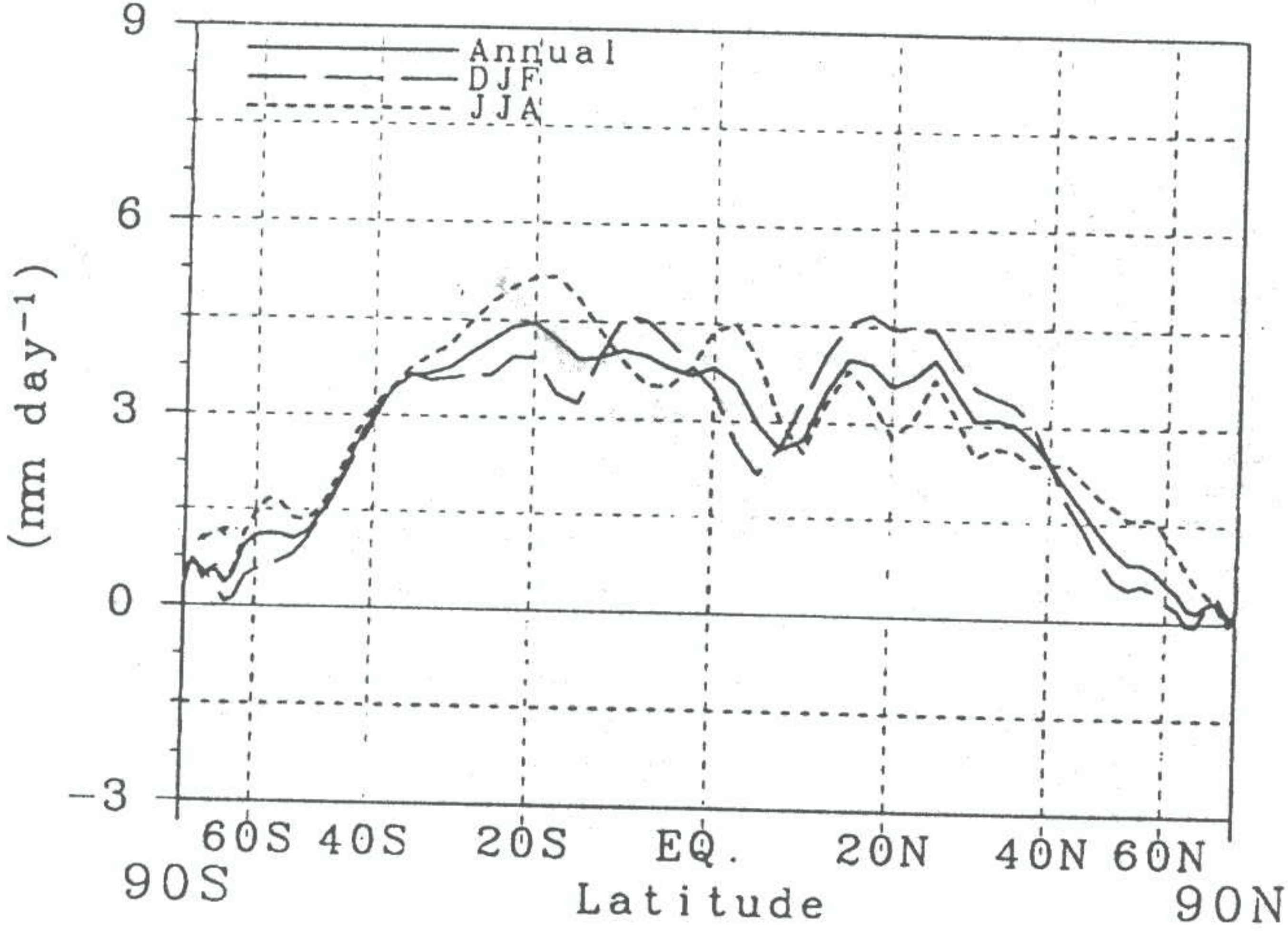
Vertical integrated horizontal vapor flux

Distribution of Zonal mean PPT.





DISTRIBUTION OF ZONAL MEAN EVAPOTRANSPIRATION



DISTRIBUTION OF ZONAL MEAN ANNUAL RUNOFF

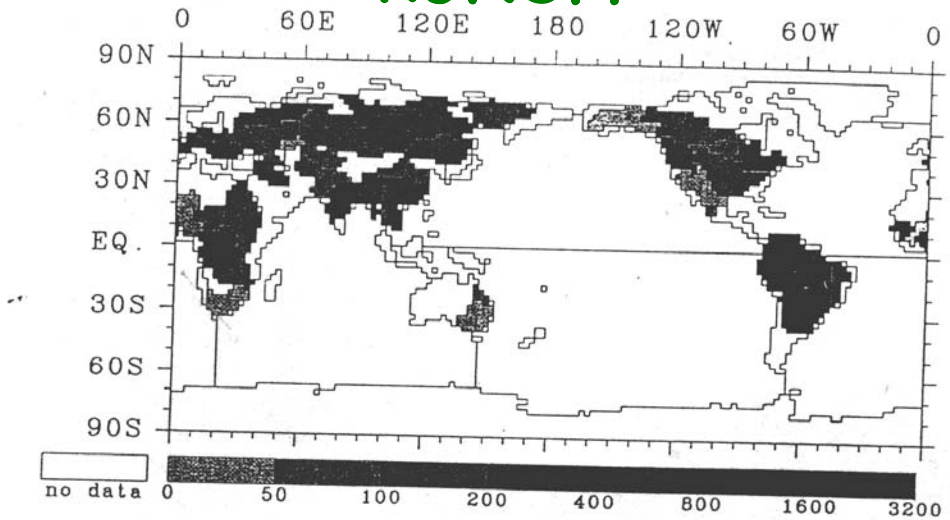
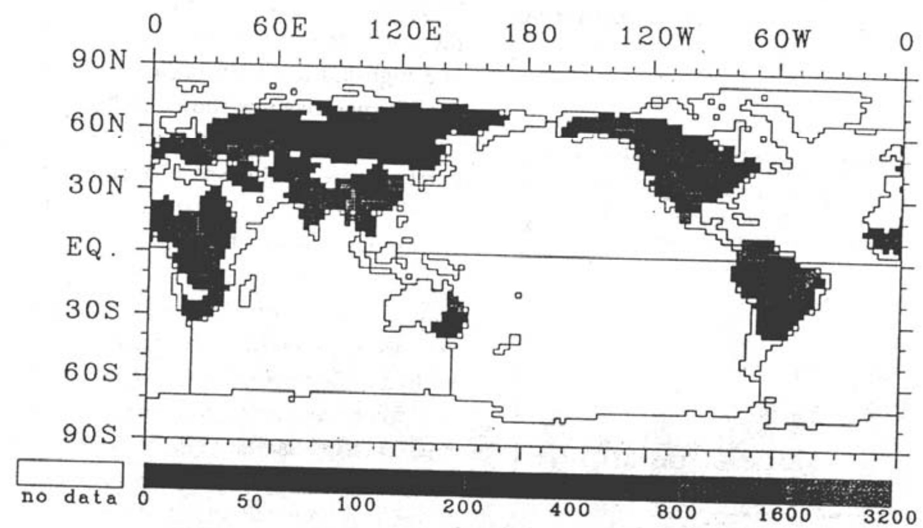
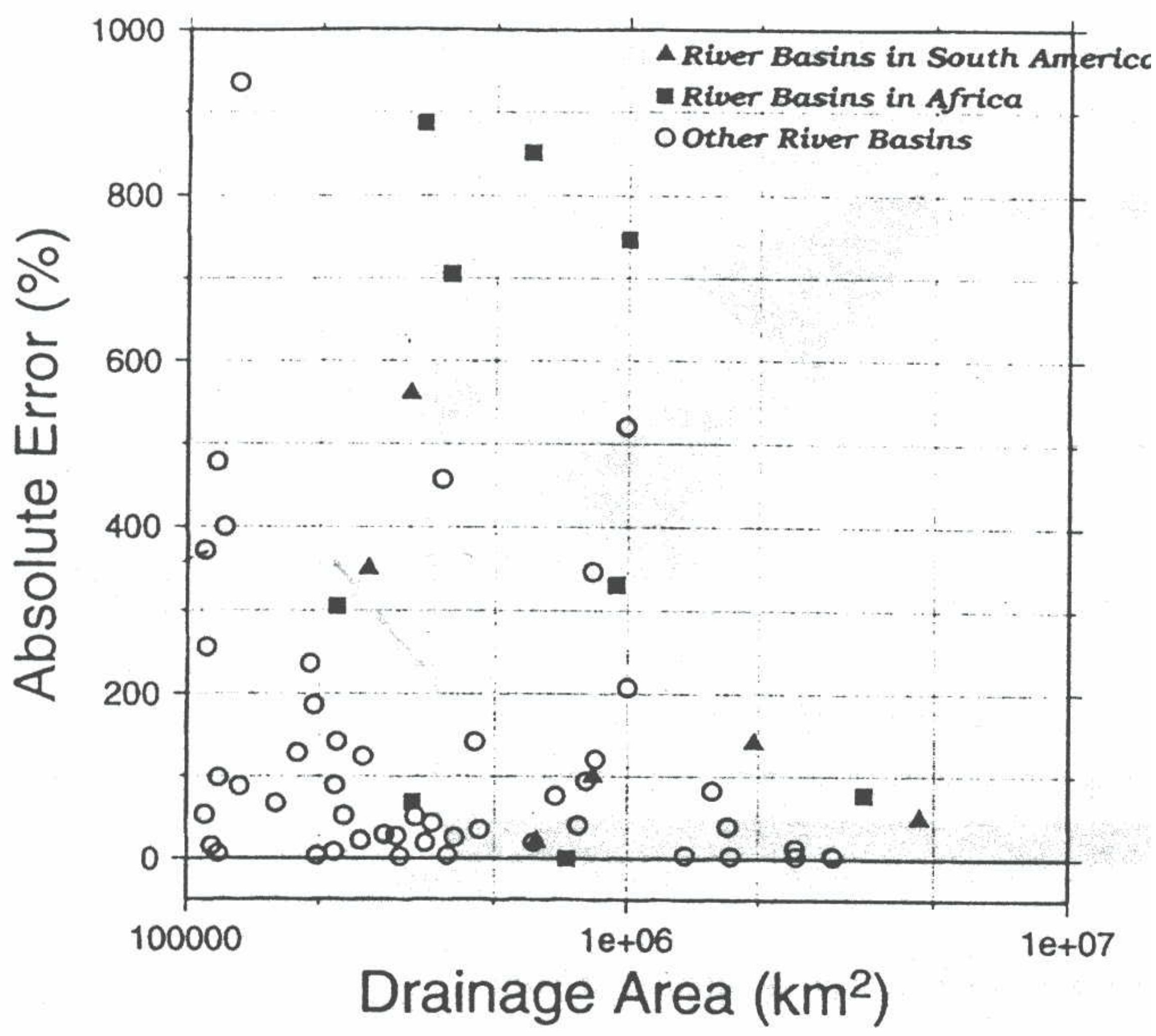


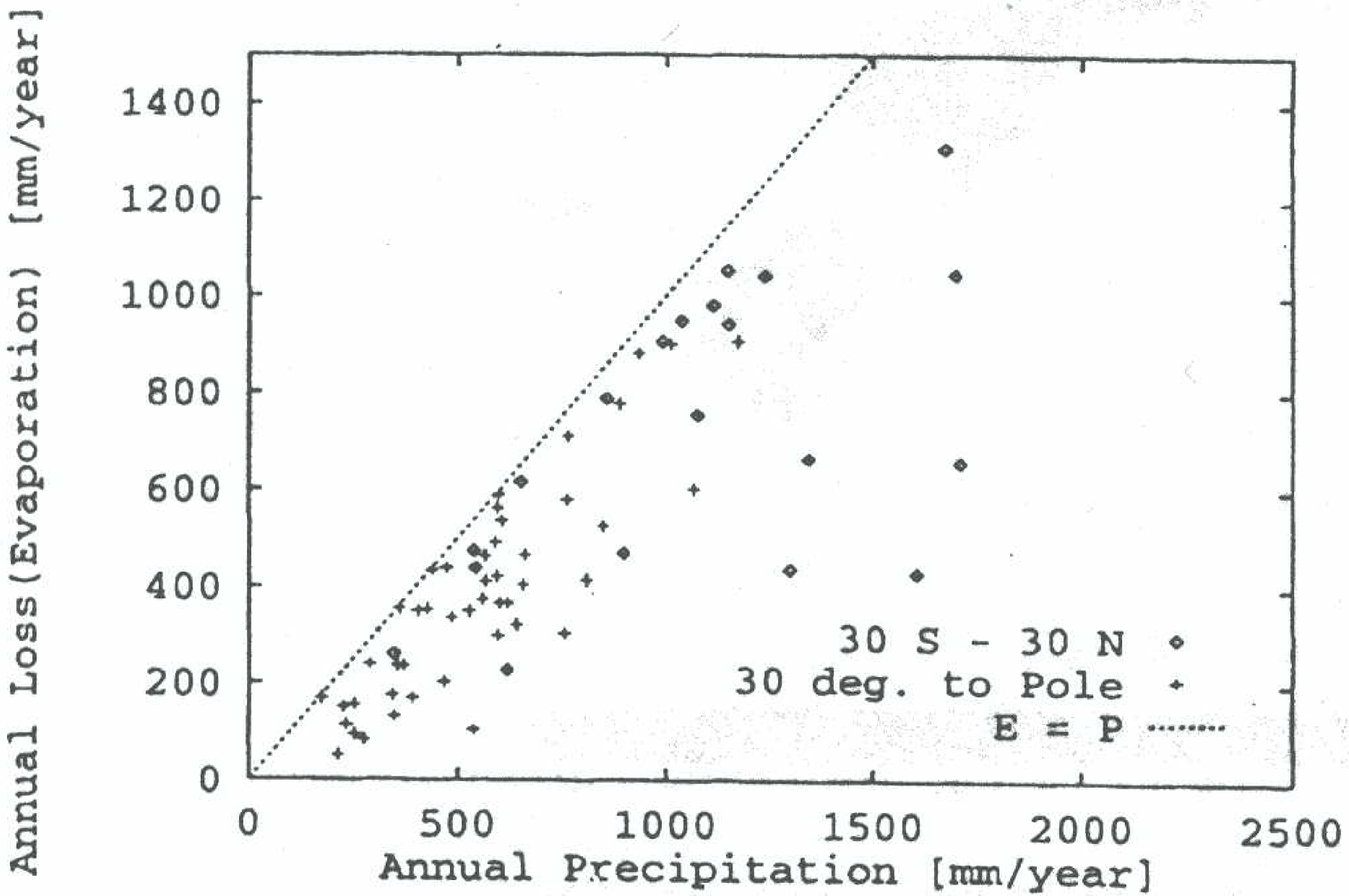
Figure 1.14. Annual runoff $\vec{R}_o$ (mm yr^{-1}) of major rivers. Climatic mean is calculated from GRDC data.



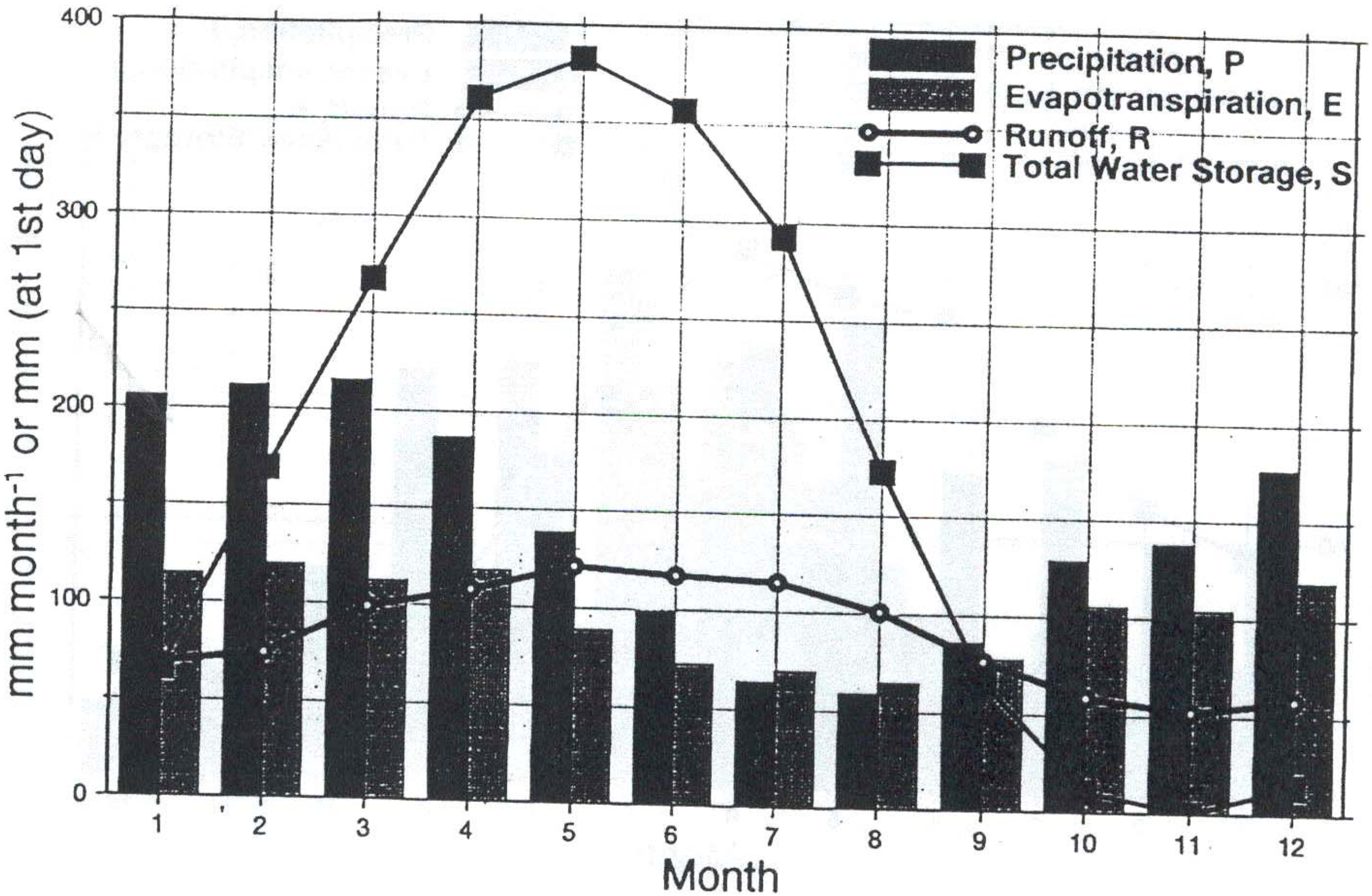
Absolute error of annual water vapor flux



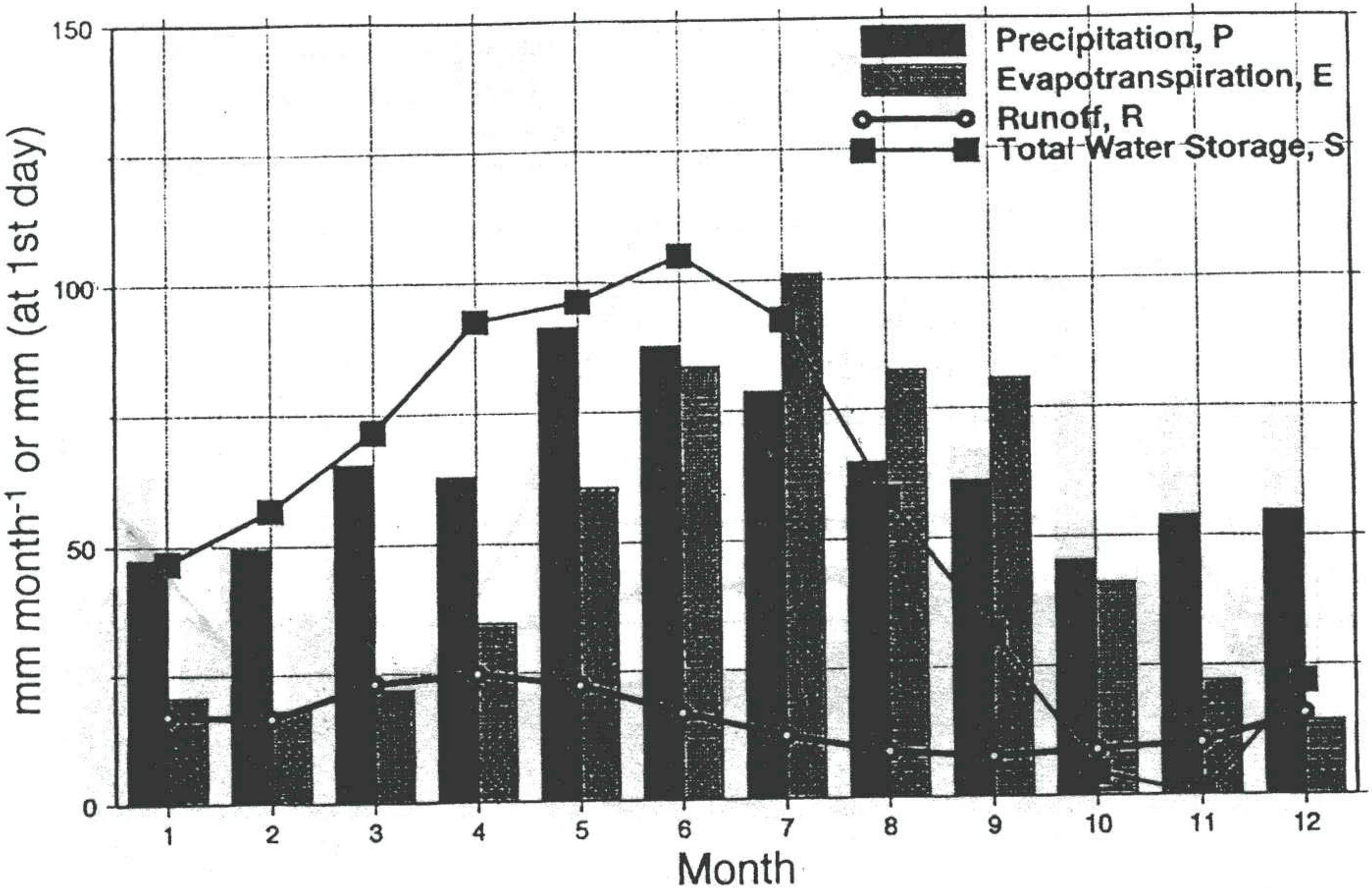
MEAN WATER BALANCE OF MAJOR RIVER BASINS



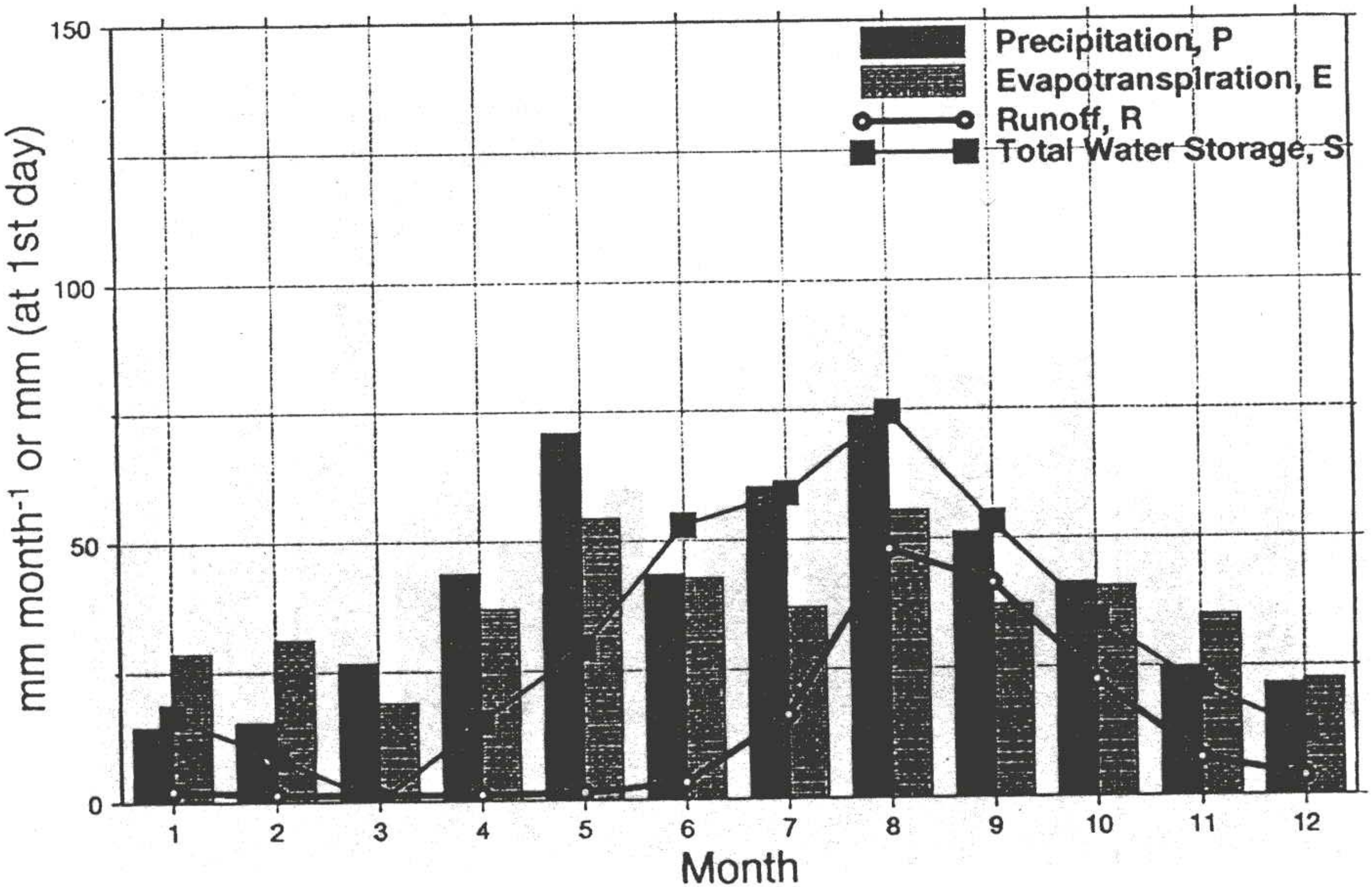
WATER BALANCE OF AMAZON RIVER BASIN



WATER BALANCE OF MISSISSIPI RIVER BASIN



WATER BALANCE OF NILE RIVER BASIN



ANNUAL FRESH WATER TRANSPORT BY ATMOSPHERE, OCEAN & RIVERS (LAND)