Hemispheric Mean Energy Budgets and Cross-Equator Transport of Heat

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Area averages of surface energy budget constituents for either hemisphere are interesting because they exhibit strong annual cycles and can be coupled in ocean or atmosphere by cross-equator transports of mass and heat. It has been known for many years that the area-average of mean precipitation excess over evaporation is positive for the northern hamisphere, and negative by the same amount for the southern hemisphere, as required by the conditiom that world climate is in a steady state. In their re-evaluation of global hydrology, Baumgartner and Reichel (1973) re-determine this excess and obtain 72 mm/yr. As a fraction of northern hemispheric precipitation this excess amounts to 0.074, which corresponds to a hydrologic runoff ratio ($C^* = 0.074$) because it describes the discharge of water which crosses (within the world's ocean) the equator at the rate of 580,000 m^3/sec . Continuity requires a counterflow, that is an atmospheric "run-in" across the equator towards the north. Using representative meridional wind components and absolute humidities at the main isobaric surfaces for all geographic latitudes, Rasmusson (1972) was able to show that at the equator the average meridional transport of precipitable water is indeed northward and equivalent to 54 mm/yr evaporation excess over precipitation on the southern hemisphere. Rasmusson's atmospheric run-in ratio for the northern hemisphere is 0.056 which is consistent within the tolerable error limits of ± 15% with the hydrologic runoff ratio of 0.074.

The cross-equator advection of vapor and return flow of water establishes a coupling between the surface energy budgets of the two hemispheres. While the interchange of H_2O-substance occurs within a closed planetary system, radiation fluxes from and to space make the hemispheres an open system with regard to total energy. This does not exclude coupling between hemispheric fluxes of sensible heat by cross-equator transports in ocean or atmosphere. With regard to the ocean the only necessary restraint (for a steady-state world climate) is that the area-average of intake of sensible heat by the ocean on one hemisphere must equal the release on the opposite hemisphere.

Information on the hemispheric radiation balance south of the equator used to be rather incomplete. The situation has been improved since results of measurements from earth-orbiting satellites became available. An evaluation of such data by Raschke , VonderHaar, Bandeen,& Pasternak (1973) provided the annual hemispheric averages which are summarized in the first three lines of Table 1. Contrary to earlier speculations in the literature, the albedo measurements on the southern half of our planet came out slightly lower than on the northern half, which makes for even higher energy absorption than would follow from well-known astronomical effects of perihel and aphel.

Table 1 includes also independent appraisals of hemispheric mean parameters necessary to estimate surface energy budget terms. A variety of climatic factors appear to contribute towards raising surface net radiation of the southern above that of the northern hemisphere. It may suffice here to mention that these factors include independent estimates of precipitable water, turbidity

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For the southern hemisphere the Bowen ratio is controlled by its oceanic value known to be 0.16 or less. Establishing the range of possible B*-values for the southern hemisphere fixes not only the value of convective flux of sensible heat to the air, $\underline{Q}$(S.H.), but also (via the surface energy-budget equation) the value of conduction of sensible heat into the sea, $\underline{S}$ (S.H.). Then, the restraining condition $\underline{S}$ (S.H.) = $-\underline{S}$ (N.H.) is used whereupon, without any degree of freedom, the prescribed $\underline{R}$ (N.H.) - $\underline{E}$ (N.H.) determines $\underline{Q}$ (N.H.) and also the Bowen ratio. This B* (N.H.), in turn, can be compared with independent estimates for the northern hemisphere with its considerable land cover.

Clearly, the range of possible values indicated on Table 1 prohibits an unambiguous decision. It can only be suggested that the possible solution $\underline{S}$ (S.H.) = $\underline{S}$ (N.H.) = 0 is an unlikely borderline case, and that a more probable case is $\underline{S}$ (S.H.) = $-\underline{S}$ (N.H.) = 5 to 8 watts/m^2 . This corresponds to a transport of 300 to 500 $\cdot 10^{12}$ cal/sec across the equator from south to north.

The climatic significance of meridional heat transport by ocean currents is generally acknowledged. Previously, it was assumed to occur between low and high latitudes within each hemisphere. If indeed cross-equator transport of heat exists it may have climatic significance. A detailed investigation of full annual cycles of heat budget terms for both hemispheres simultaneously to clarify the coupling process appears well justified.

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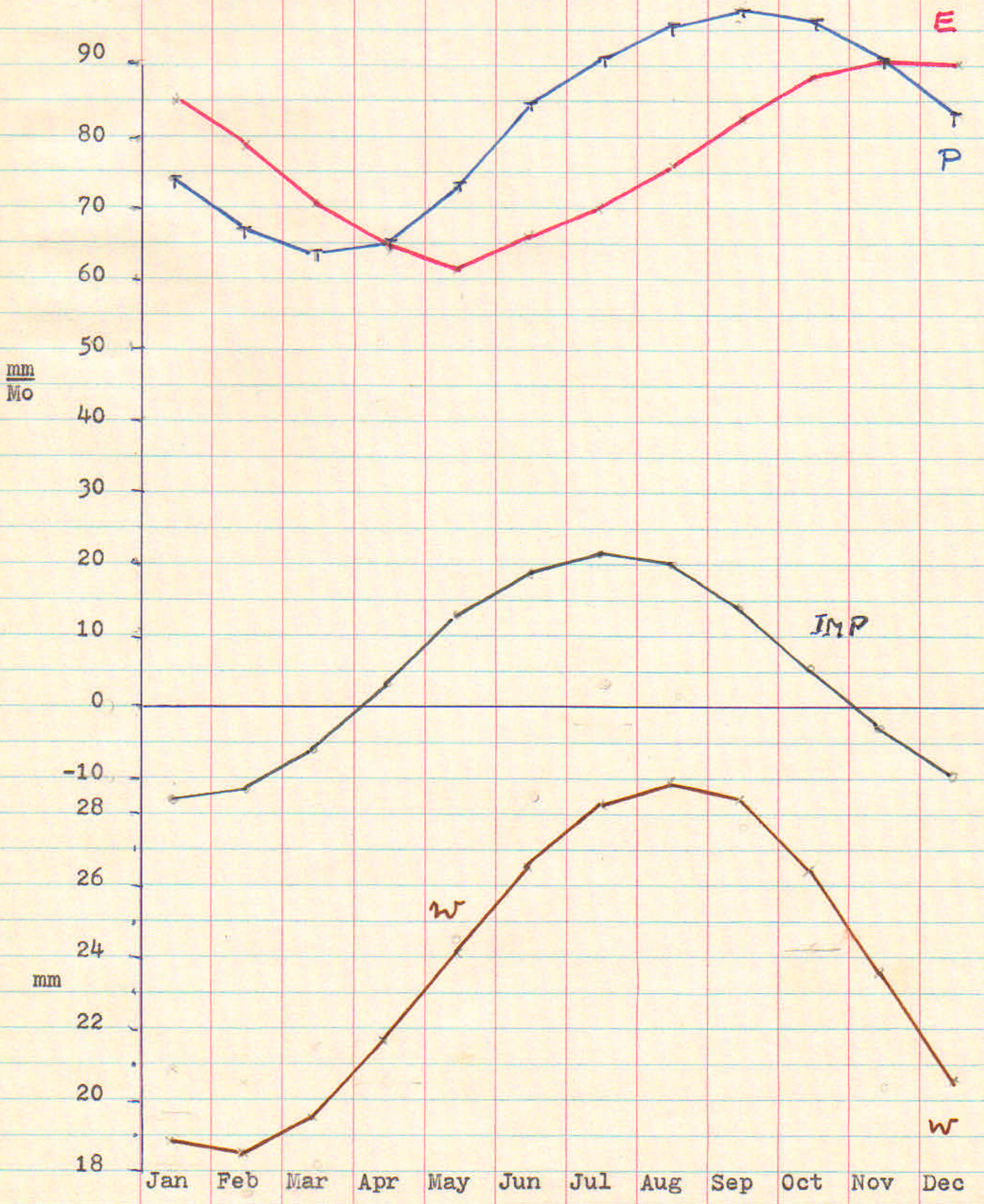
Table 1. Annual Means of Area-Averaged Energy Budget Terms for the Southern and the Northern Hemisphere.

A solar constant of 1.95 cal/cm^2 per min = 1360 watts/m^2 is assumed; all fluxes are given in watts/m^2 and all ratios as fractions; total hemispheric area = 255 $\cdot 10^{12}$ m^2; σ = Stefan-Boltzmann constant; e* = surface emissivity assumed to be 0.98.

Energy Budget Item	S.H.	N.H.
Shortwave Radiation Flux of Intercepted Extra-atmospheric Irradiance ($\underline{EI}$)	343	337
Effective Average Top-Albedo (a**)	.280	.287
Shortwave Radiation Flux Admitted (1-a**).$\underline{EI}$	247	240
Fraction of Atmospheric Absorption	.33 to .35	.34 to .36
Shortwave Radiation Flux of Ground-Absorption($\underline{SW}$)	165 to 161	158 to 154
Effective Surface Temperature (Average T, Kelvin)	285 to 287	287 to 289
Longwave Flux of Ground Emission ($e^* \sigma T^4$)	367 to 377	377 to 387
Effective Angstroem Ratio (A*)	.16 to .17	.17 to .18
Effective Flux of Ground Emission($\underline{LW} = A^* e^* \sigma T^4$)	59 to 64	64 to 70
Net Radiation at Ground Surface, ($\underline{R} = \underline{SW} - \underline{LW}$)	106 to 97	94 to 84
Runoff Ratio (C*)	(run-in)	.05 to .07
Convective Flux of Latent Heat to Air ($\underline{E}$)	82 to 84	71 to 73
Bowen Ratio (B*)	.10 to .16	.55 to .15
Convective Flux of Sensible Heat into the Atmosphere, ($\underline{Q} = B^* \underline{E}$)	8 to 13	39 to 11
Remainder Term of Surface-Energy Balance = Conductive Flux of Heat into Ocean, ($\underline{S} = \underline{R} - \underline{E} - \underline{Q}$) (Constrained by $\underline{S}$(S.H.) + $\underline{S}$(N.H.) = 0)	16 to 0	-16 to 0

NORTH-HEMISPHERE AVERAGES -Mean Annual Course of Atmospheric H_2O Budget Constituents (Evaporation, Precipitation, Cross-Equator Advection, Import) and total precipitable water in the air.

Source: Evapo-Climatonomy Run S-NH-114, 06/07/74



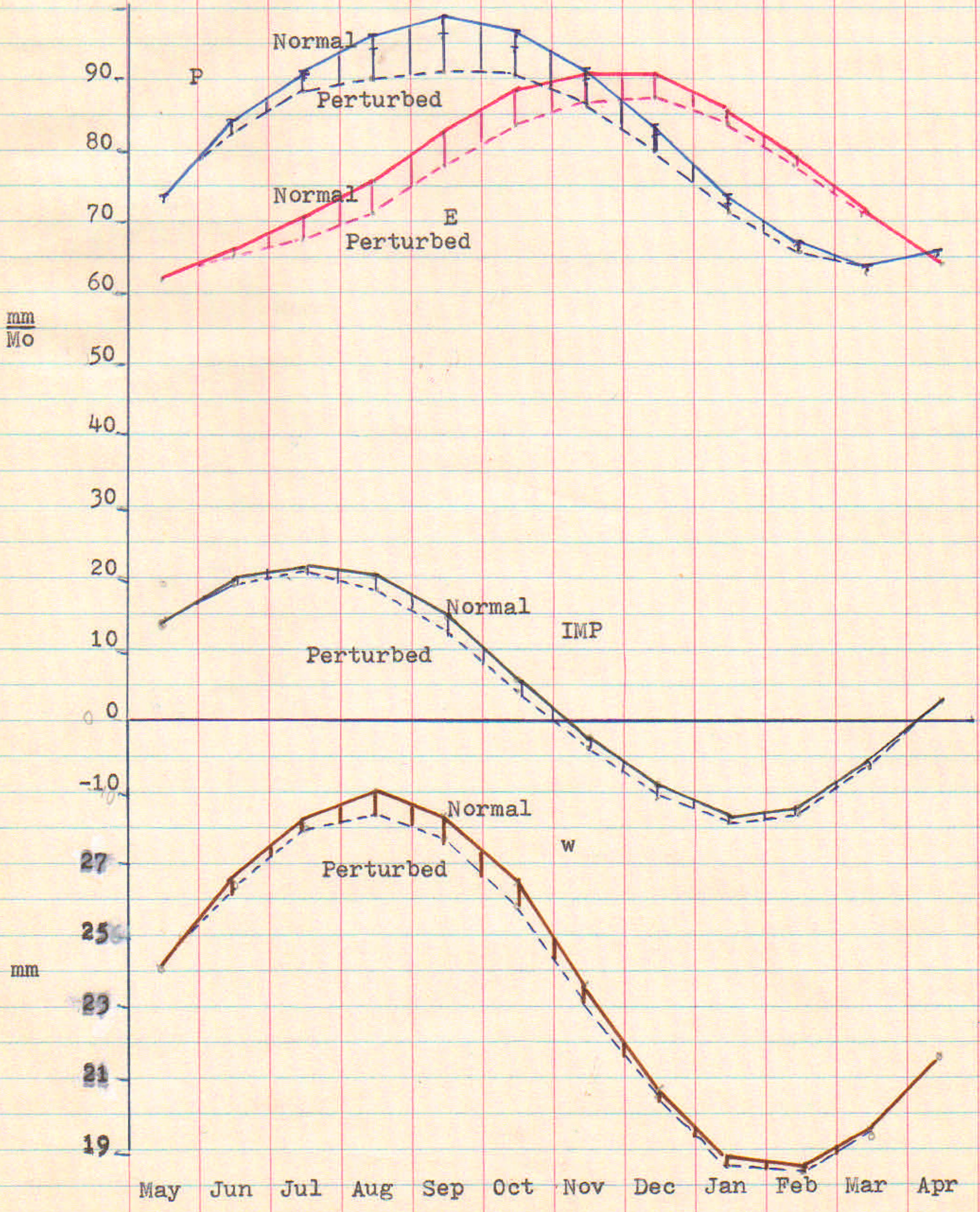
E: Result of Thermo-Climatonomy Run S-NH-114, 06/06/74

$P = p^* . (E + IMP) + m/t^*$; $p^* = 0.700 + 0.004(T_0 - T^{**})$; $T^{**4} = (EI - ES)/54.06$

$t^* = 2.5 - 0.040\ T_0$; $IMP = 1.705 . (T_{0,NH} - T_{0,SH})$

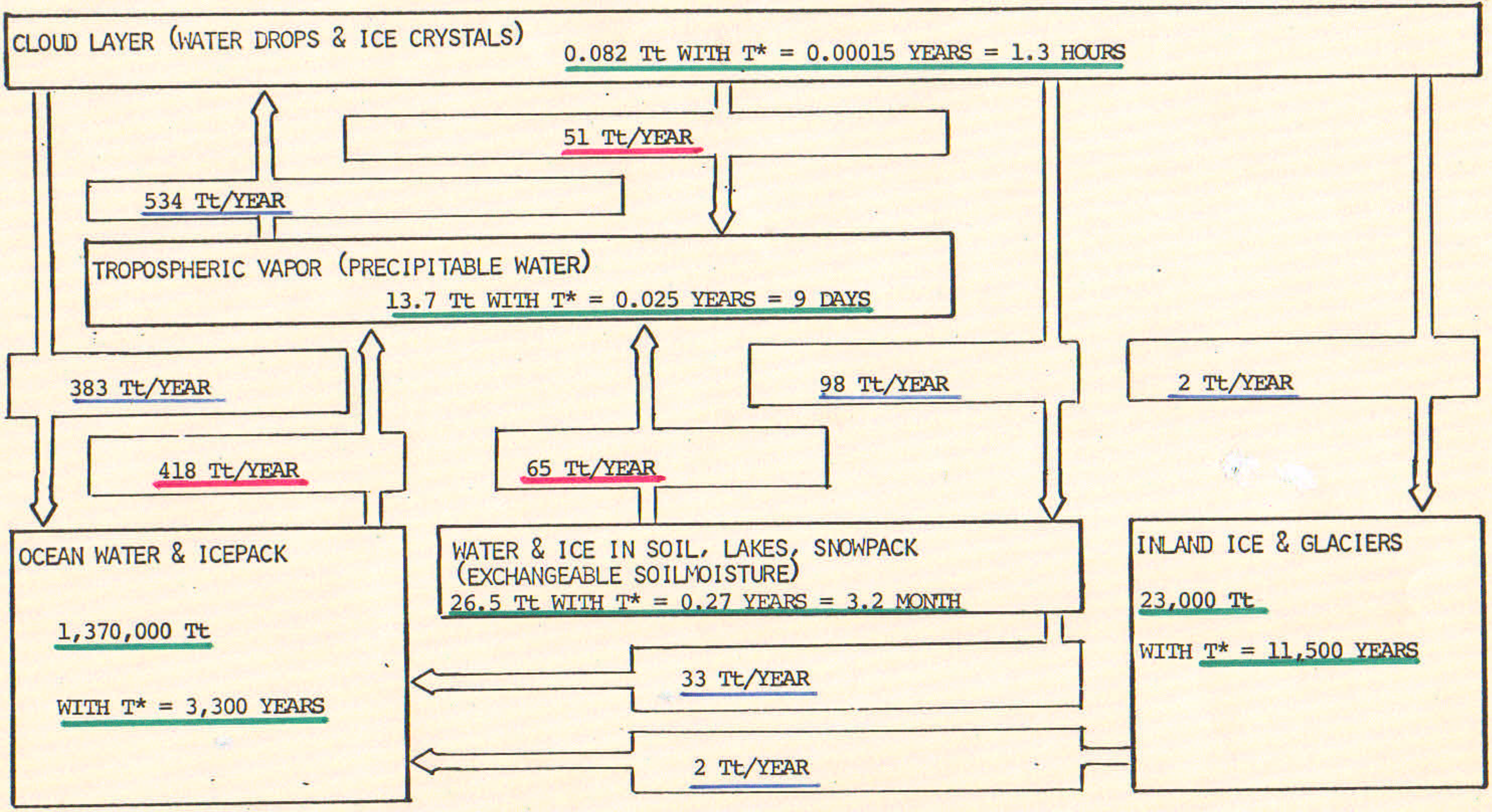
CLIMATONOMY EXPERIMENT, employing North-Hemispheric Averages of Atmospheric H_2O Budget Constituehts (E,P,&IMP) and Precipitable Water (w).

Groundlevel Normals of E,P,IMP,&w, in Comparison with 10-Month Period of Perturbation simulating Effects of the Katmai Event which began in June,1912; based on T_o-Perturbation and subsequent changes of p*, t*, and IMP.



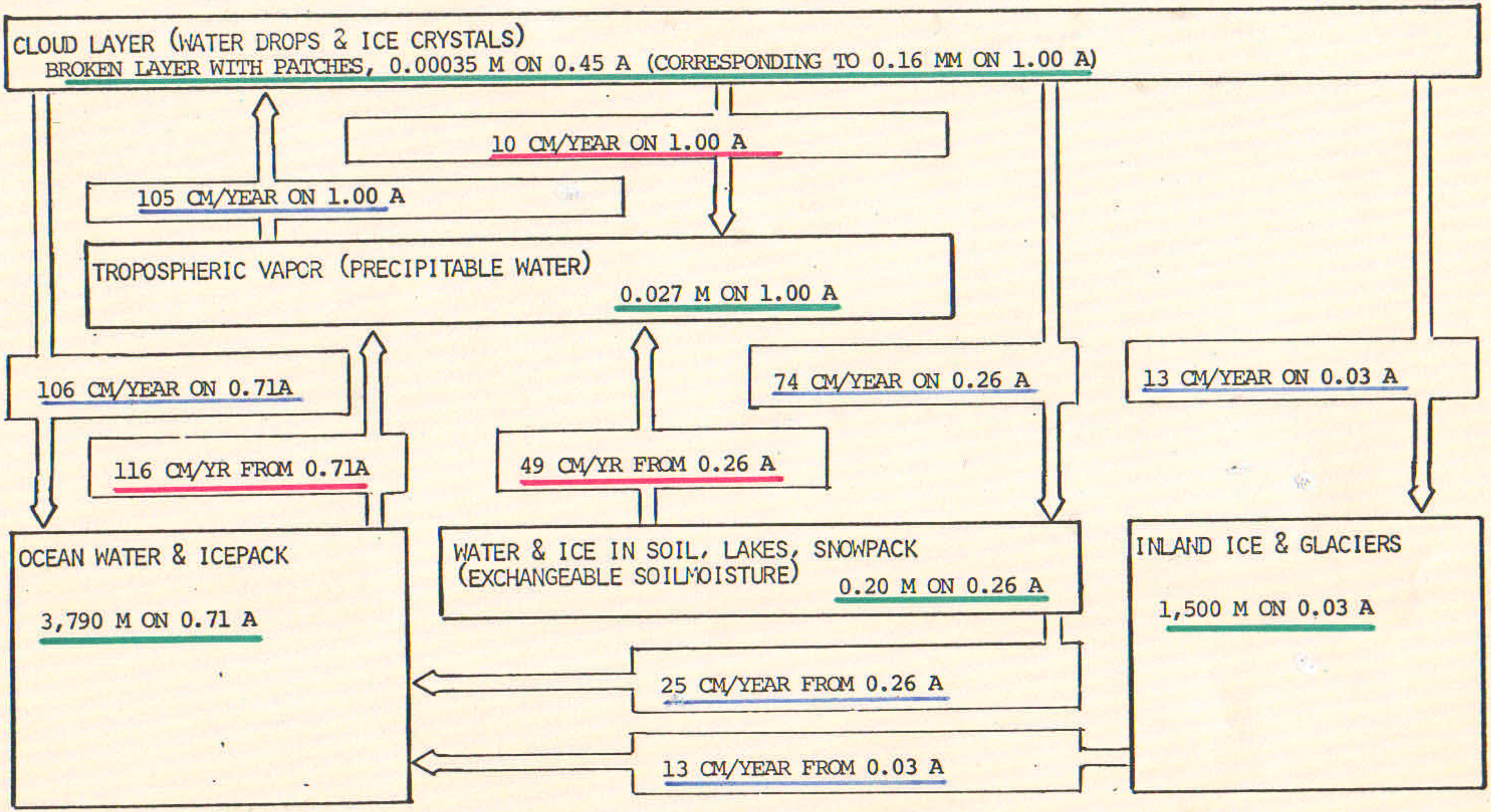
THE FIVE MAJOR RESERVOIRS OF THE HYDROLOGIC CYCLE

MASS OF H_2O IN RESERVOIRS (UNITS OF TERATONS, 1Tt = 10^{12} TONS)
ALSO RESIDENCE TIME T* BASED ON DEPLETION BY MAJOR PROCESS RATE (Tt/YEAR)



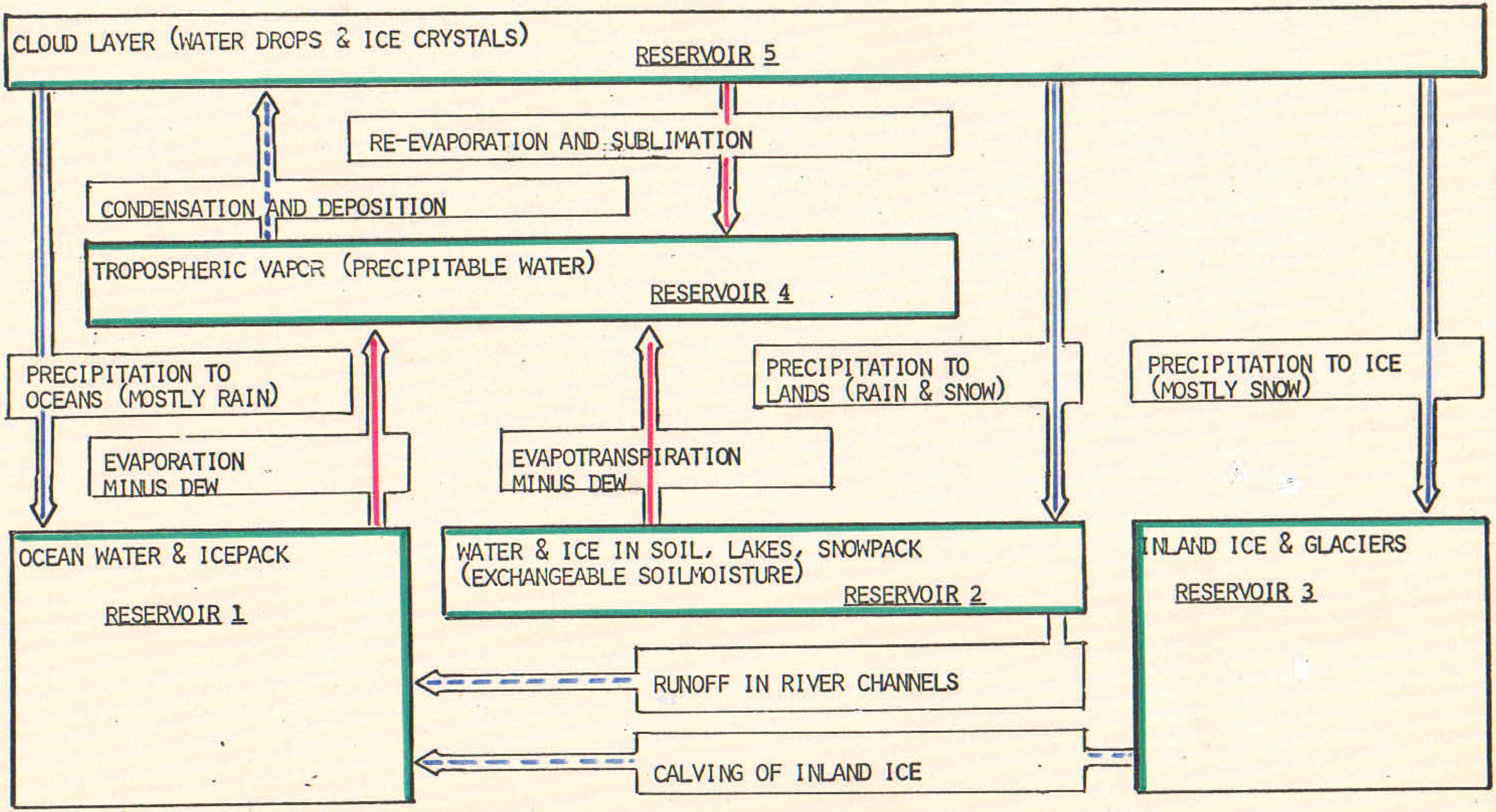
THE FIVE MAJOR RESERVOIRS OF THE HYDROLOGIC CYCLE

RESERVOIR DEPTH (M, WATER EQUIVALENT), RESERVOIR AREA (A, FRACTION OF $510 \cdot 10^{12} M^2$ = EARTH'S SURFACE AREA), AND INTERACTING PROCESS RATES (CM WATER/YEAR)

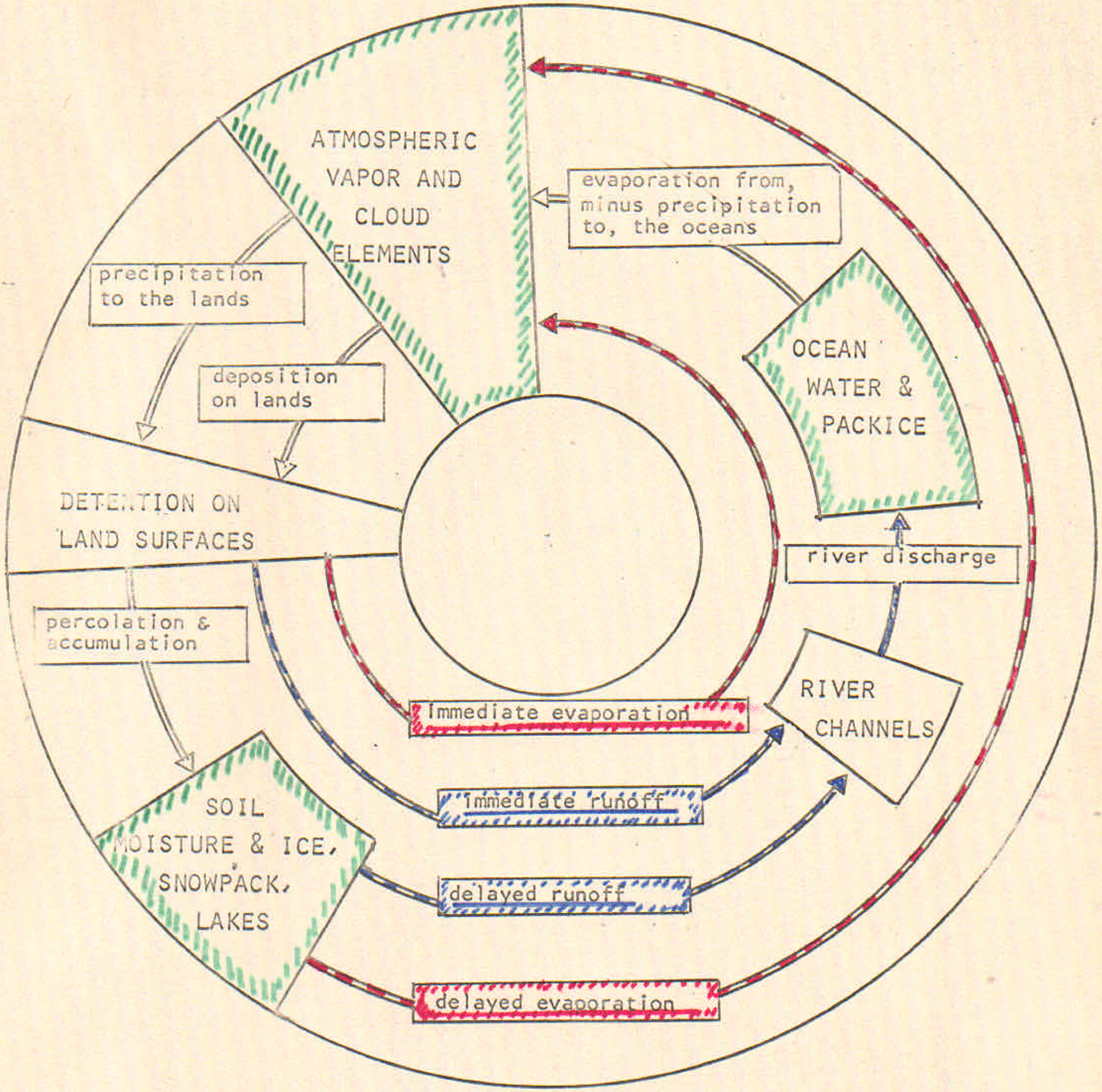


THE FIVE MAJOR RESERVOIRS OF THE HYDROLOGIC CYCLE

AND IDENTIFICATION OF MAJOR INTERACTING PROCESSES (MASS FLUXES AND TRANSPORTS)



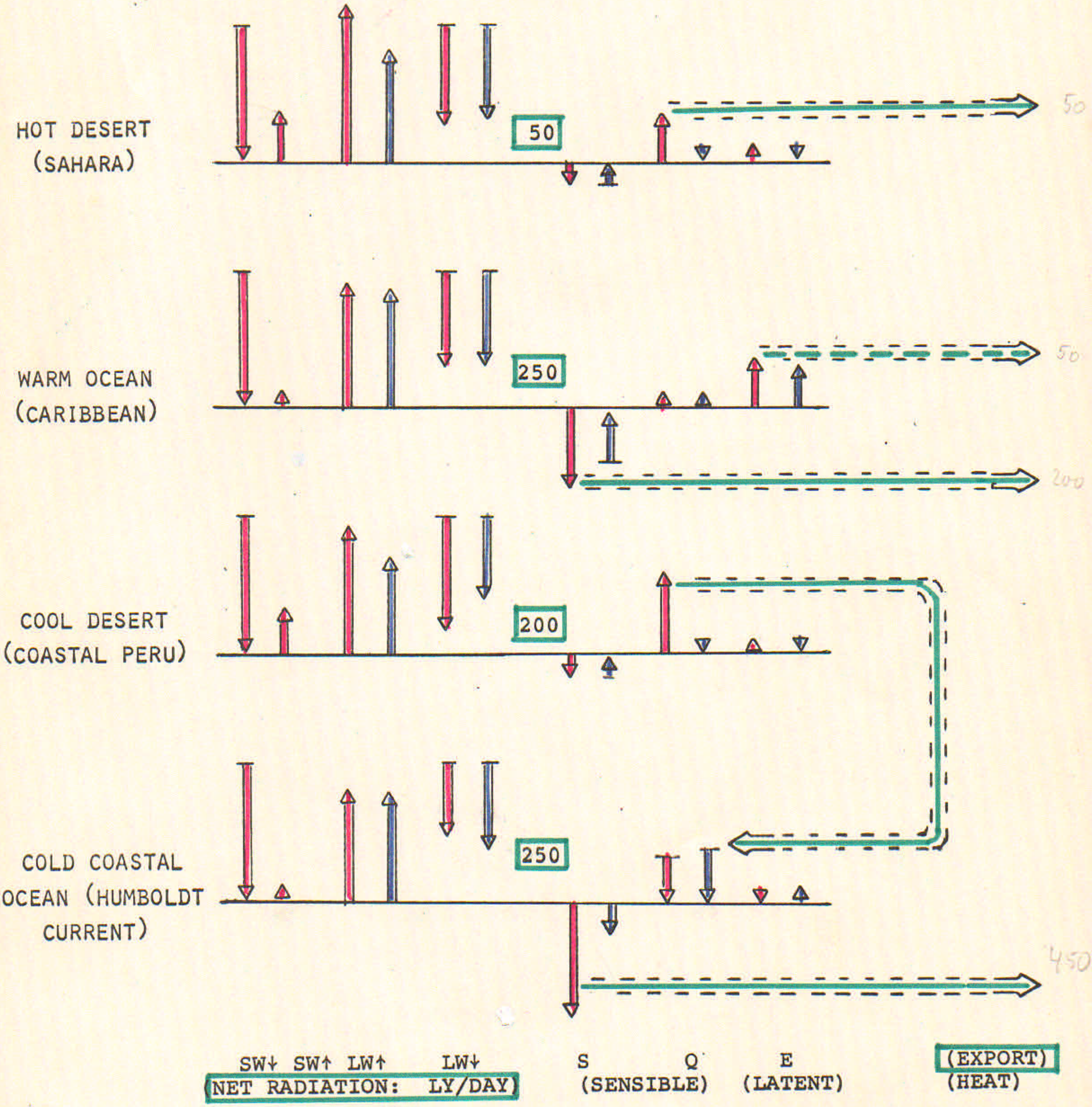
THE HYDROLOGIC CYCLE IN TERMS OF EVAPO-CLIMATONOMY



SECTORS REPRESENT STORAGE OR RESERVOIRS
arrows and rectangular boxes indicate processes

SURFACE ENERGY BUDGET STUDY FOR TROPICS AND SUBTROPICS

FOUR TYPES (DAY AND NIGHT SCHEMES) AND EXAMPLES OF REGIONAL CLIMATES



HEMISPHERIC-ANNUAL MEAN NET RADIATION, AND HEAT FLUX DENSITIES RESULTING FROM BALANCE REQUIREMENTS AT ATMOSPHERE-SUBMEDIUM INTERFACE

HEAT FLUX DENSITY (LY/DAY)	NORTH HEMISPH.	SOUTH HEMISPH.
Net Radiation, R	180.3	206.3
Latent Heat to Atmosphere, E	148.8	173.0
Sensible Heat to Atmosphere, Q	38.8	26.0
Sensible Heat to Submedium, S	-7.3	+7.3
CHARACTERISTIC RATIOS		
Bowen Ratio, B = Q/E	.261	.150
Evaporivity, $\underline{v}^*$ = E/F	.465	.514
CROSS-EQUATOR FLUX-EQUIV. (LY/DAY)		
Latent Heat in Atmosphere, 24.2	Importing	Exporting
Sensible Heat		
In Atmosphere, 12.8	Exporting	Importing
In Submedium (Oceans) 7.3	Importing	Exporting

HEMISPHERIC-ANNUAL MEAN RADIATION FLUXES AT ATMOSPHERE-SUBMEDIUM INTERFACE

RADIATION FLUX DENSITY (LY/DAY)	NORTH HEMISPH.	SOUTH HEMISPH.
SHORTWAVE RADIATION		
Received at Interface, SW↓	376.8	397.5
Rejected by Interface, SW↑	56.5	61.5
Absorbed, SW↓ - SW↑ = F	320.3	336.3
LONGWAVE RADIATION		
Emitted from Interface, LW↑	801.0	786.6
Counterradiated to Interface, LW↓	661.0	656.6
Effective Emission, LW↑ - LW↓	140.0	130.0
Net Radiation = SW↓ - SW↑ + LW↓ - LW↑ = R	180.3	206.3
CHARACTERISTIC RATIOS		
Surface Albedo, SW↑/SW↓,	.150	.154
Angstroem Ratio, (LW↑ - LW↓)/LW↑,	.175	.165

BALANCE EQUATIONS - PRIMITIVE EQUATIONS

Precipitable Water (w, in Atmospheric Column)

$$\boxed{\frac{\partial w}{\partial t} = E - P - A(\text{Advective Export})}$$

Exchangeable Soilmoisture (m, in Soil Column)

$$\boxed{\frac{\partial m}{\partial t} = P - E - N(\text{Runoff})}$$

EVAPO-CLIMATONOMY - METEOROLOGICAL VERIFICATION

Transformed Equation: $\frac{\partial w}{\partial \tau} = W - w$

Solution: $\boxed{w = w_o e^{-\tau} + e^{-\tau}\int_o^{\tau} e^{+\tau} W d\tau}$

Employing:

Dimensionless Independent Variable $\boxed{\tau = \int \frac{dt}{t^*}}$

and Parameters of:

$$\left.\begin{array}{ll}\text{Delay-Time:} & t^* = w/(P-P') \\ \text{Precipitivity:} & p^* = P'/(E-A)\end{array}\right\}\text{where } P' = \text{Part of P related to E-A}$$

Evaporivity: $v^* = E/F$ where F = Solar Forcing; Consequently:

Effective Solar Forcing: $\boxed{W = (E-A-P')\cdot t^* = (v^*F-A)\cdot(1-p^*)\cdot t^*}$

EVAPO-CLIMATONOMY - HYDROLOGICAL VERIFICATION

Transformed Equation: $\frac{\partial m}{\partial \tau} = M - m$

SOLUTION: $\boxed{m = m_o e^{-\tau} + e^{-\tau}\int_o^{\tau} e^{+\tau} M d\tau}$

Employing:

Dimensionless Independent Variable: $\boxed{\tau = \int \frac{dt}{t^*}}$

and Parameterization Based on Process Separation:

$N = N'(P) + N''(m)$; $E = E'(P,F) + E''(m,F)$

("Immediate" and "Delayed" Parts of Evaporation and Runoff, relating $E = E' + E''$ to Solar Forcing F)

Delay-Time Parameter: $t^* = m/(E''+N'')$

Effective Solar Forcing: $\boxed{M = (P - E' - N')\cdot t^*}$

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