Question: Explain how one would go about computing the heat budget of the atmosphere and the ocean to show that the monsoon is a coupled atmosphere phenomenon

Answer: Based on Stephan Hastenrath [1993, 1979] and book (climate dynamics of the tropics)

Heat budget of the atmosphere-ocean

(1) $R_{N_{Top}} = Q_{va} + Q_{ta} + Q_{vo} + Q_{to}$

where $R_{N_{Top}}$: Net radiation at the top of the atmosphere

$Q_{va} + Q_{ta}$: divergence of the horizontal heat transport (v) and heat storage (t) by the atmosphere

$Q_{vo} + Q_{to}$: same as above but for ocean

Heat budget equation for the atmospheric portion of the column is obtained as follows. first an approximate form of the budget of potential energy plus sensible heat for the atmospheric column is described by:

(2) $\text{div}(gz + c_pT) + (gz + c_pT)_{ta}$
$= [R_{N_{Top}} - R_{N_{surf}}] + Q_s + LP$

$\text{div}(gz + c_pT)$: divergence of the vertically integrated transport of potential energy $(g(z))$ plus c_pT.

$(gz + c_pT)_{ta}$: atmospheric storage of these forms.

$R_{N_{top}} - R_{N_{sfc}}$: Net radiative cooling

Q_s: Sensible heat transfer at the ocean surface

LP: Latent heat released by the precipitation process [P is the precipitation rate, L is the latent heat of condensation)

Latent heat budget for the atmospheric column is:

(3) $div(Lq) + (Lq)_{ta} = Q_e - LP$

$div(Lq)$: divergence of the vertically integrated transport of latent heat (Lq)

$(Lq)_{ta}$: atmospheric storage of latent heat.

Q_e : Latent heat flux at the ocean surface

LP : P is Precipitation rate, L is latent heat of condensation.

we add (2) & (3)

$$Q_{va} = div(gz + c_pT) + div(Lq)$$

$$Q_{ta} = (gz + c_pT)_{ta} + (Lq)_{ta}$$

(4) $$\boxed{Q_{va} + Q_{ta} = (R_{N_{top}} - R_{sufc}) + Q_e + Q_s}$$

(4) is the heat budget of the atmospheric column.

The heat budget of the oceanic column is given by:

(5) $$\boxed{R_{N_{sfc}} = Q_e + Q_s + Q_{vo} + Q_{to}}$$

where R_{Nsfc} : Net radiation at the ocean surface; it is the sum of net shortwave radiation (SW_{Nsfc}) and the net long wave radiation ($LW_{N\text{-}sfc}$).

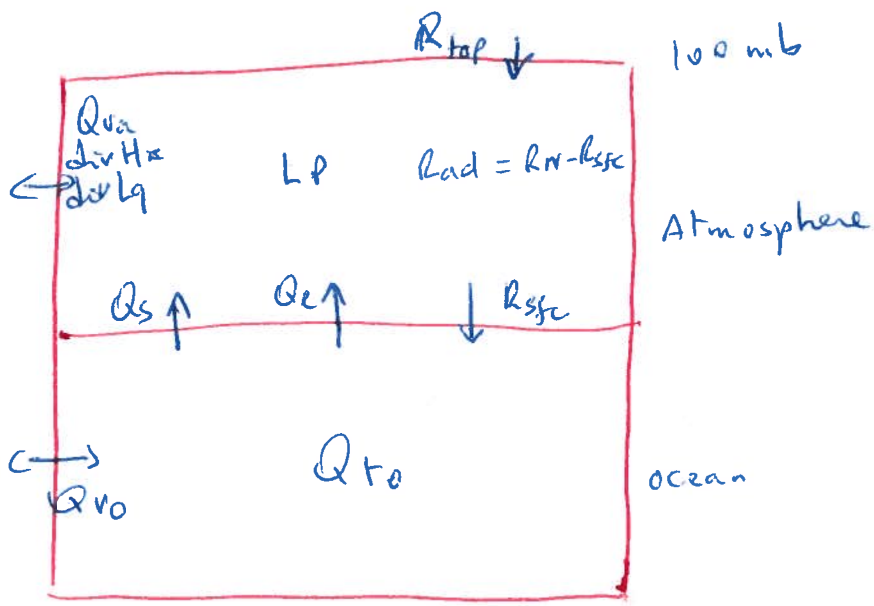
Q_e : Latent heat flux at the air-sea interface

Q_s : sensible heat

Q_{vo} : divergence of the horizontal heat transport

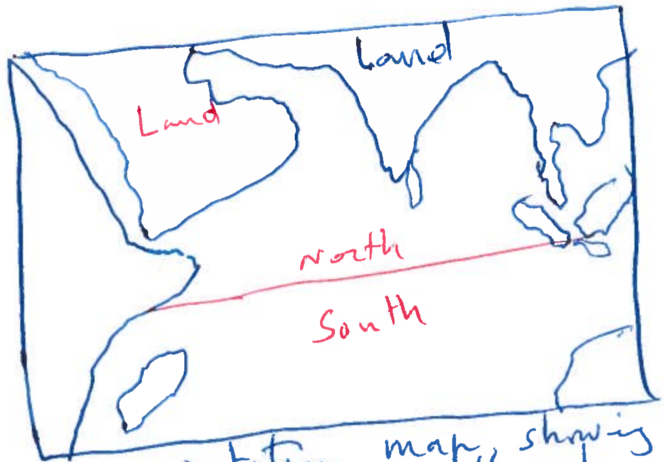
Q_{to} : heat storage.

where $H = gz + Lq$

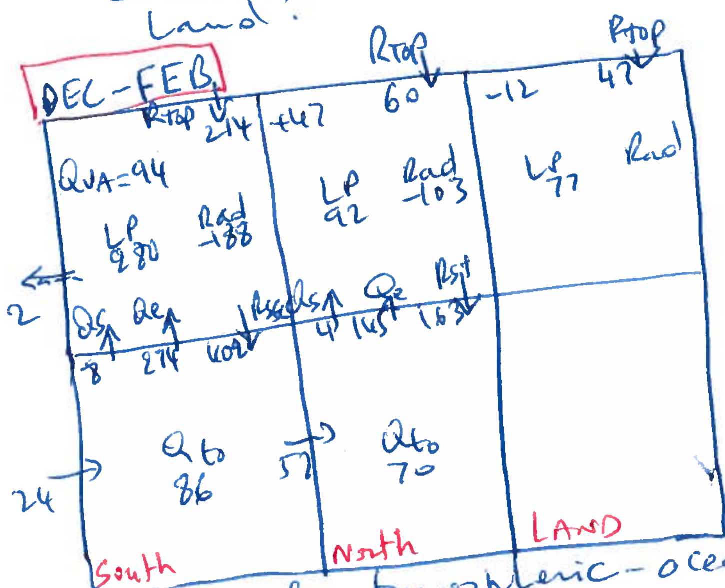


the atmospheric storage term are relatively small and are neglected Q_{ta} i.e. H_{ta}, Lq_{ta}.

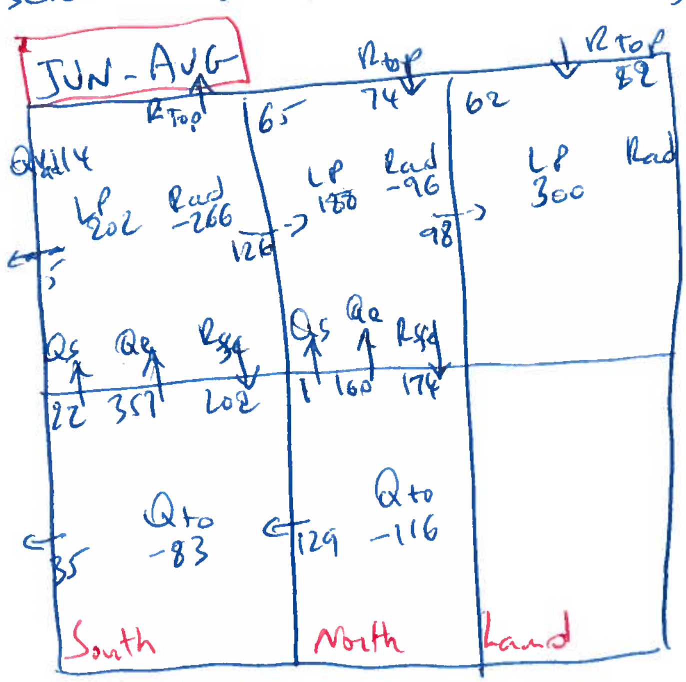
Estimation of the above terms are made using satellite measurement, net radiation, upper air analysis, surface ship observation, subsurface temperature, ECMWF reanalysis. the domain of interest where the budget calculations were performed are shown below



orientation map, showing domains South, North and Land.



Area integrated scheme of atmospheric-oceanic heat budget (10^{13} W) for domains Land, North, South.



From the budget heat terms, we notice [May-October] that the hydrospheric heat import from the northern portion of the basin and the local hydrospheric heat depletion make a substantial energetic contribution to maintaining the vigorous evaporation taking place from the wintertime Southern tropical indian ocean under the southeast trade winds. Also the heat carried southward across the equator by the oceanic water body is just about as large as the northward cross-equatorial transport of latent heat in the lower atmosphere, especially at the height of summer. Atmospheric export of geopotential energy and sensible heat and import of latent heat grow largest over the northern part of the indian sector, paralleling the development of vigorous ascending motion.

[August-October] the latent heat is carried northward across the equator by the lower tropospheric boundary layer monsoon flow and becomes instrumental in supplying the abundant precipitation and hence latent heat release over southern Asia and the northern indian ocean, where the moisture transport converges. The latent heat released by the precipitation in turn has an important role to play in the atmospheric portion of the monsoon.

During the boreal summer monsoon, the net radiative heat input at the top of the atmosphere is very small for the domain 0-30°S. The substantial southward directed oceanic heat transport characteristic of this season imports heat to the southern tropical Indian ocean. This together with the seasonal depletion of the total hydrospheric heat content, supports sensible heat losses from the southern tropical Indian Ocean which greatly exceed the net radiative supply. The atmospheric volume over the southern hemisphere waters export a large amount of latent heat throughout the northern summer half year; At the height of this semester's monsoon, the same atmospheric volume also imports geopotential energy and sensible heat. Such a pattern is consistent with atmospheric subsidence.

	$SWLW_{top}$	$SWLW_{sfc}$	LP	Q_e	Q_s	$(Q_v+Q_t)/_0$	Q_{to}
N winter monsoon season							
0-30°N	23	163	78	164	5	-6	0
0-30°S	286	396	261	272	7	117	130
N summer monsoon season							
0-30°N	148	192	124	169	-3	26	-90
0-30°S	-6	187	148	347	23	-183	-160

Hemispheric integrals of atmospheric and oceanic heat and moisture budget components (30-120°E)

	Q_{vo}	Q_{va}	$div(gz + c_pT)$	$(div\ Lq)_a$	$(div\ Lq)_a$
N winter monsoon					
0 - 30 N	-6	29	-57	86	-50
0 - 30 S	-3	169	158	11	0
N Summer monsoon					
0 - 30 N	116	122	77	45	100
0 - 30 S	-23	177	-22	199	180

Hemispheric integrals of atmospheric and oceanic heat and moisture budget component for the indian ocean and peripherals seas (30 - 120 E)