

## HEAT BUDGET OF THE OCEAN

V. Ramesh Babu  
National Institute of Oceanography,  
Dona Paula, Goa

### Introduction:

I divide the lecture in three parts consisting of (1) basic concepts of processes involved in the heat budget of the ocean, (2) estimation of various heat fluxes, and (3) a case study to describe the heat budget parameters of the Caribbea Sea.

Most of the energy required for setting up atmospheric motions is largely received through boundary processes whereas the direct heating due to the radiation transfer through the atmosphere is considered very small. Since about 3/4th of globe is covered with oceans, the importance of oceanic heat budget comes into picture in the context of energy resources study of the atmosphere. The exchange of heat by a volume of water body with its surroundings is broadly divided into two types - one taking part at its air-sea boundary and the other (interior) taking part within the water column. Sometimes, the transfer of heat energy involves the transfer of matter also. Fig. 1 shows schematic picture of processes involved in the heat budget of the ocean.

### Heat budget equation:

Under steady state conditions, the mean annual heat balance for the world ocean as a whole is achieved by equating fluxes of heat gain against those of heat loss.

$$Q_i + Q_x + Q_y = Q_b + Q_s + Q_c \quad (1)$$

where  $Q_i$  = Global radiation absorbed in the ocean.

$Q_b$  = Effective back radiation.

$Q_x$  = Heat gained due to friction.

$Q_y$  = Heat gained from biological, chemical and radioactive decay processes.

$Q_z$  = Heat gained from the earth's interior.

$Q_s$  = Heat loss through conduction (sometimes, it is taken as gain when surface air is warmer than sea surface).

$Q_c$  = Heat loss through evaporation (rarely, it is considered as gain when condensation takes place over sea surface).

The three terms ( $Q_x$ ,  $Q_y$  &  $Q_z$ ) are generally assumed unimportant as their contributions in the overall heat budget of the world ocean are insignificant compared to the orders of other terms. The heat budget for the world ocean on annual basis is thus reduced simply as following:

$$Q_i - Q_b = Q_s + Q_e \quad (2)$$

However, for a particular region of world ocean on seasonal basis, additional terms of heat storage ( $S$ ), oceanic heat flux divergence ( $Q_v$ ) are to be considered. The heat budget equation then becomes:

$$Q_i - Q_b = Q_s + Q_e + S + Q_v \quad (3)$$

#### Individual flux terms:

- $Q_i$  The incoming global radiation reaches sea surface in both direct and diffuse forms. It depends on sun's altitude (season and even time of the day), geographical latitude, cloudiness and turbidity of the atmosphere. Various empirical formulae are available in literature to estimate  $Q_i$ . Even direct observations of  $Q_i$  by radiation measuring instruments (pyranometers) have been made occasionally during special scientific expeditions.
- $Q_b$  The effective back radiation is actually the difference between upward long-wave radiation from the sea surface and downward long-wave radiation re-radiated from the atmosphere. Normally empirical formulae are used to obtain  $Q_b$  after considering absolute sea surface temperature, vapour pressure over sea surface and cloudiness.
- $Q_s$  Heat transfer through conduction, takes place either from the ocean to the atmosphere or vice-versa depending upon the direction of sea-air temperature gradient. The transfer of  $Q_s$  from the sea to atmosphere directly affects the lower atmosphere in setting up convective processes and thereby the warmer air masses rise up and cooler air masses advect into the area near the surface. Reverse process occurs in the case of heat transfer from the air to sea like at Newfoundland coast.
- $Q_e$  It is very important heat gain term as far as atmosphere is concerned. Nearly 50% of heat received through radiative transfers is utilised for evaporation. The gain to the atmosphere acts as source of energy for setting up atmospheric motions whereas the loss to the ocean determines the salinity field of the upper ocean. The reverse process, i.e. condensation takes place when warm air advects over cold oceanic areas causing sea fogs.
- $S$  The heat storage term is determined from the annual cycle of thermal structure of the upper ocean where seasonal effects are normally felt. The depth at which the annual range vanishes has to be obtained first before attempting computation of heat storage flux. In general, the seasonal variability is limited within upper 500 m of the water column. The oceanic heat content increases normally during summer and decreases during winter and thereby the storage rate becomes zero during each tran-

sitional season.

Qv The estimation of oceanic heat flux divergence requires knowledge on ocean currents and vertical motions (upwelling or downwelling). However, the contribution of vertical motions are generally considered negligible as compared to those of horizontal motions. Information on mean temperatures of water column within the depth range of consideration at each boundary of the water body together with flow field is pre-requisite for computation of mean Qv.

Estimation of various heat fluxes:

Estimations of Qs and Qe terms are described in detail as we usually adopt empirical formulae for the estimation of other Qi and Qb terms of heat balance. For world-wide synoptic applications as well as for the studies on behaviour of general atmospheric circulation, bulk parameterization of Qs and Qe needs knowledge of variables like  $\Delta T$  (mean difference between surface air and sea surface temperatures),  $\Delta q$  (mean difference between specific humidity of the surface air and saturated specific humidity at sea surface temperatures) and wind speed. The following are corresponding parameterization formulae for transports of Qs and Qe:

$$Q_s = \rho C_p C_s W \Delta T \quad (4)$$

$$Q_e = \rho L C_e W \Delta q \quad (5)$$

where Cs and Ce are the transport coefficients;  $\rho$  is air density; Cp is the specific heat at constant pressure and W is the wind speed and L is the latent heat of vaporisation. The transport coefficients are considered as constants for matter of convenience. However, in reality they change with wind speed. They also depend upon stability of lower atmosphere.

Evaporation distribution over global ocean shows occurrence of two minima - a primary one at high latitudes of each hemisphere and the secondary one near the equator owing to cold airmasses and super saturation conditions respectively. The total surface heat loss (Qs + Qe) is, in general, higher over western sides than over eastern sides of northern Atlantic Ocean. During winter, combined flux (Qs + Qe) reaches maximum due to higher  $\Delta T$  and wind force regimes.

On shorter time scales, the net heat transport across ocean surface results in change in the heat content. The heat storage (S) in the layer under influence of seasonal cycle is given in integral form

$$S = C_w \rho_w \int_V \frac{\partial T}{\partial t} dv \quad (6)$$

where Cw and Pw are specific heat and density of water respectively; T is the average temperature of water column under consideration; t is time and v is the volume of the water column. For individual water bodies, heat flux divergence (Qv) has to be considered to achieve the steady state conditions. Otherwise, the areas with positive (negative) surface heat balance go on continuously increasing (decreasing) with temperature. The heat flux divergence (Qv) due to currents is obtained from following equation

$$Q_v = \text{Div } C_w \int_{A_i} M_i T_i dA_i \quad (7)$$

where 'i' denotes number of each boundary of water body under consideration.  $M_i$  and  $T_i$  represent the horizontal mass flow and temperature across lateral area element  $dA_i$  of 'i'th boundary respectively. The convergence of heat due to ocean currents takes place when cooler watermass exists out and warmer watermass comes in. On the other hand, divergence of advective heat flux is possible when warmer watermass exists out and cooler watermass comes in.

#### Case study of Caribbean Sea's heat budget:

Salient features of the Caribbean Sea heat budget study as adopted from Colon (1960), are highlighted in Table 1, in order to gain some insight into energy resources of the area which may be of special interest to the participants of CORE programme, since Caribbean Sea is considered as one of the energy active zones for the generation of Atlantic hurricanes. Further, this region acts as feeder zone to the Gulf Stream. Large-scale oceanic surface heat input ( $Q_e + Q_s$ ), helps in creating low pressures in the lower atmosphere and thereby in maintaining downstream pressure gradient for the trade winds to persist.

#### Detailed works for further reading:

- Malkus, J.S. 1962. Large-scale interactions in The Sea (Ed. M.N. Hill), John Wiley & Sons, Inc., New York, Vol. 1, 188-285 pp.
- Dietrich, G.; K. Kalle; W. Krauss and G. Sielder. 1980. Energy and water budgets of world ocean in General Oceanography: An Introduction. John Wiley & Sons, New York, 158-202 pp.
- Colon, J. 1960. On the heat balance of the troposphere and water body of the Caribbean Sea. National Hurricane Research Project. Rep. No. 41, U.S. Dept. of Commerce, Washington, D.C., 65 pp.



TABLE - 1

Heat budget of the Caribbean Sea (K Cal/cm<sup>2</sup>/month)  
(After Colon, 1960)

Parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Shortwave radiation absorbed at sea surface (Q) <sup>i</sup>	11.9	13.2	14.3	14.9	14.8	13.9	13.4	13.3	13.1	12.3	11.5	11.1
Effective back radiation (Q) <sup>b</sup>	5.2	5.2	5.0	4.8	4.6	4.4	4.4	4.2	4.3	4.3	4.5	4.8
Radiation balance (Q - Q) <sup>i b</sup>	6.7	8.0	9.3	10.1	10.2	9.5	9.0	9.1	8.8	8.0	7.0	6.3
Oceanic heat flux divergence (Q) <sup>v</sup>	0.2	-0.2	-0.2	0	+0.3	+0.4	+0.5	+0.8	+0.5	-0.2	-0.3	-0.4
Heat storage rate (S)	-3.0	-0.3	1.8	2.4	1.9	1.2	1.7	2.4	1.2	-1.7	-3.7	-4.2
Q + Q <sub>e s</sub>	9.9	8.5	7.7	7.7	8.0	7.9	6.8	5.9	7.1	9.9	11.0	10.9