AN ESTIMATION OF HEAT CHANGES IN THE BAY OF BENGAL OFF VISAKHAPATNAM*

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INTRODUCTION

HEAT changes in the upper layers of the sea result from a number of factors which might be conveniently divided into two groups. They are (1) the energy transfer processes and (2) the advective processes. Over limited areas and time intervals the heat budget of the oceans has been studied previously by a number of scientists and thus the factors that change the temperature are fairly well known and are listed in detail by Severdrup *et al.* (1942) and LaFond (1954).

In earlier studies energy changes in a column of seawater were examined in specific regions over time intervals of about one week. In one of such studies Jung and Gilcrest (1955) have discussed various processes that could profitably be included in the evaluations of heat changes in a water column, They used a relationship of the type

$$A_T = A_S + A_B + A_E + A_D + A_P$$

where the respective A's during the time interval considered, stand for the total heat change in the water column, the heating of the column due to the effective solar radiation, the loss of heat by the long wave back radiation from the sea surface to the atmosphere and space, the loss of heat due to evaporation of water from the surface of the column, heat change due to the stress of the wind over the sea surface and the unexplained residual amount of heat change not covered by the processes listed.

In the following, a similar study for a column of seawater in the Bay of Bengal off Visakhapatnam has been attempted. Because of the limited nature of the meteorological data available, A_E and A_D could not be evaluated. But from a calculation of Bowen ratio the relative importance of evaporation as compared to the convection of sensible heat to the atmosphere could be inferred. Thus in the present case the energy balance equation would be

$$A_T = A_S + A_B + A_P$$

where A_P now includes A_E and A_D also.

* This paper was read at the Symposium on Oceanography of the Bay of Bengal held at Waltair, on 5th May 1956.

Data and Computations

The thermal and meteorological data used in this investigation are taken from the Andhra University Oceanographic Cruises made during the year 1952–53. For an evaluation of A_T daily bathythermographic data at any single station would be necessary. But, for want of such data, one has to confine attention to those observations made in a line perpendicular to the coast off Visakhapatnam during different times of the year. Since observations were made rather unevenly both in time and space, only an estimation of the total heat change could be made.

For the computation of A_T the following is the procedure. Detailed vertical sections of temperature in a N-W to S-E direction have been constructed for each of the dates listed in Table I. Only those observations which lie on the same straight line are considered for this purpose and from successive sections and also from the plot of station locations, points having the same geographic position are judged. These are our assumed stations which are fixed in space at which the thermal data could be interpolated during each time interval. Though this is the general procedure adopted, actual data are used as far as possible.

The depth of water column considered at each of these stations is either up to bottom or up to a maximum depth of 400 ft. and the area of cross-section of the column is 1 $cm.^2$ The total heat change during any time interval can be obtained by planimetering the area between the temperature-depth curves plotted on the same paper. Thus an estimate of the A_T at different stations during different intervals of time, could be obtained. This is given in Table I.

The average seasonal change in effective solar radiation and the effective back radiation from the ocean surface are calculated as suggested by Jung and Gilcrest (1955). *Smithsonian Meteorological Tables* (1939) are consulted for the solar radiation data. These data are verified with Brunt (1939) and both give estimates which agree reasonably well.

Components of Heat Change

A_T—The total heat change.—The total heat change during three different periods has been estimated and expressed as Ft – deg. F. per day and is presented in Table I.

Except at stations V and VI, during September 1952, A_T is calculated up to the sea bottom. Though there is a net loss of heat in the layer of the water considered during the entire period there are a number of reversals

TABLE I

Heat changes in the Bay of Bengal off Visakhapatnam (A's expressed as Ft—deg. F. per day)

Station Number	Period	Position: Latitude N	Position: Longitude E	Depth (ft.)	A_T	A_S	A_B	A_{SB}	A_P
I	21st October to 29th October 1952	17° 37·0′	83° 21·6′	170	−13·3	25·4	−14·9	10·5	−23·8
II	,,	17° 33·3′	83° 24·9′	190	−33·6	25·4	−15·0	10·4	−44·0
III	,,	17° 29·4′	83° 28·2′	250	−43·3	25·5	−15·0	10·5	−53·8
IV	,,	17° 25·3′	83° 31·5′	320	− 2·8	25·5	−15·1	10·4	−13·2
V	,,	17° 21·5′	83° 34·7′	300	−15·5	25·5	−15·1	10·4	−25·9
VI	,,	17° 17·6′	83° 37·9′	440	− 7·2	26·1	−15·1	11·0	−18·2
VII	19th February to 4th March 1953	17° 39·7′	83° 19·6′	120	−17·9	26·3	−14·4	11·9	−29·8
VIII	,,	17° 36·4′	83° 23·3′	180	−27·5	26·9	−14·9	12·0	−39·5
IX	,,	17° 33·9′	83° 26·1′	200	−17·1	27·0	−15·0	12·0	−29·1
X	,,	17° 28·5′	83° 29·7′	300	− 6·1	27·1	−15·0	12·1	−18·2
XI	,,	17° 26·3′	83° 33·5′	400	30·7	27·1	−14·7	12·4	18·3
XII	4th March to 17th April 1953	17° 39·5′	83° 19·6′	100	− 3·7	28·7	−14·1	14·6	−18·3
XIII	,,	17° 35·6′	83° 22·8′	180	− 6·7	28·7	−14·2	14·5	−21·2
XIV	,,	17° 31·1′	83° 26·7′	180	− 6·3	28·7	−14·3	14·4	−20·7

in the heat change throughout the line of stations except at station II. It has been shown elsewhere by the author (1955) that this station falls in a region where the inshore sinking almost stops. There are slight positive gradients in the surface layers. Because of seasonal cooling and sinking the surface layers lose some heat whereas the same is either preserved or transferred to a sub-surface level and is maintained. The actual estimations and levels of reversals are given in Table II. In this table the bracketed figures indicate the level of transition where no heat change is observed and the figures with signs are A's expressed as Ft – deg. F. per day, the signs *plus* and *minus*, indicating the gain and loss of heat respectively. As

TABLE II

Total heat change in the water column in different layers

Station Number	Values of A_T
I	– 15·0; (100) + 1·7
II	– 33·6
III	– 14·4; (75) + 3·9; (160) – 32·8
IV	– 10·5; (80) + 7·7; (150) – 6·1; (210) + 6·1; (285) – 0·5; (300) + 0·5
V	– 17·2; (95) + 3·3; (150) – 4·4; (210) – 4·4; (255) – 1·6
VI	– 16·7; (90) + 25·0; (260) – 15·5
VII	– 17·9
VIII	– 27·5
IX	– 17·1
X	+ 3·2; (170) – 11·4; (270) + 2·1
XI	+ 3·4; (135) – 2·0; (170) + 29·3
XII	+ 2·2; (15) – 3·9
XIII	+ 4·2; (60) – 10·9
XIV	+ 4·9; (80) – 11·2

sinking comes to an end towards October much mixing takes place in the vertical and hence there are a number of reversals during this period.

During the period, February to March, there is considerable cooling from surface down to the bottom up to about 10 miles off Visakhapatnam. Beyond this distance there is slight heating at the surface and on the whole the column loses heat. The north equatorial current of the Indian Ocean brings in warm water along this coast during this part of the year and the currents are towards N-E (Ramasastry and Balaramamurty, 1957). Due to the proximity of land and dilution from rivers very near the coast, in spite of the warm surface current, the sea surface loses heat on the whole and hence at stations VII to IX there is a continuous loss of heat from surface to the bottom. This might be partly due to the onset of upwelling very near the coast hence the mixing processes might be of some importance. But however about 20 miles from the coast there is net gain of heat (station XI). All this is achieved below the thermocline depth. Here the offshore current is in the opposite direction to the inshore one.

During March to April, with the onset of summer much heat is gained in the surface layers. But very near the bottom however heat is lost resulting in a net loss of heat in the column. It is during this period an isothermal water mass over the continental shelf was found. The characteristics of the continental shelf water are discussed elsewhere by the author (1955) wherein it is shown that there is mixing near the bottom of such a nature that the vertical temperature gradients are completely eliminated. But, because of the mixing towards the end of the period there is a net loss of heat. By analogy with the previous season, it may be inferred that there might be net gain of heat beyond about 15 to 20 miles from the coast.

A_S—*Heat gain due to effective solar radiation.*—Since the latitude variation of the stations is very small the effective solar radiation, after allowing for an average *albedo* of 42%, is almost uniform at different stations in each period and gradually increases towards summer.

A_B—*Back radiation.*—The long wave back radiation from the sea surface results in cooling of water and the amount of cooling so produced is very nearly uniform in each of the periods considered. There is only an indication that amount of heat loss by this process increases with increasing distance from the coast and this in agreement with the humidity of the atmosphere. During October the loss of heat is about 60% of the net solar radiation received while in the other two periods the corresponding figures are 55% and 50%. This is evident since A_S increases with approaching summer and A_B decreases with increasing humidity of the atmosphere.

A_{SB} is the sum of A_S and A_B and gives an idea of the net amount of heat gained in the water column. Comparing this with A_T, it is seen that there should be a greater loss of heat to the column of water in order to produce the observed net loss of heat A_T. These values are listed under A_P. In order to get the amount of cooling required for A_T there should be other processes which are more effective than those considered above. It is suggested (Jung and Gilcrest, 1955) that the change in heat content of water column due to evaporation and to the dynamic effect should comprise a major part of the net variation. Both these effects could not be studied. But an evaluation of Bowen ratio shows that 1% of the total loss due to evaporation is returning to the sea as transfer of sensible heat from the atmosphere to the sea. Except during the period of north equatorial current, heat is not brought into the region by currents. Hence the net loss of heat, required for balance, should be mainly due to evaporation and partly due to the dynamic effect of the wind. Because of upwelling and sinking, processes of vertical mixing should also be considered.

Conclusions

During the entire period of investigation there is a net loss of heat in the Bay of Bengal off Visakhapatnam. The net loss is more during winter than in summer.

As is found by Jung and Gilcrest solar radiation and back radiation play a minor part in the heat budget of the sea.

At least for regions of upwelling and sinking, vertical mixing should be considered as one of the factors which bring in heat changes in the water column.

Bowen ratio is very small and is negative.

At some stations there are sub-surface regions where heat is stored up in each of the periods.

Summary

An estimate of heat changes in the Bay of Bengal off Visakhapatnam during three different periods, *viz.*, 21st October 1952 to 29th October 1952, 19th February to 4th March 1953, and 4th March to 17th April 1953 is made from the data of Oceanographic Cruises of the Andhra University, following the method of Jung and Gilcrest (1955). During the entire period there is a continuous loss of heat from the bay and maximum loss of beat occurs at about 10 to 15 miles from the coast. Evaporation, advection and vertical turbulent mixing are supposed to play an important role in the heat

changes of the sea off Visakhapatnam during the period under investigation. For want of data the individual effect of these processes could not be studied.

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