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Studies on Evaporation from the North Indian Ocean

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Evaporation from the surface of the North Indian Ocean is estimated following the aerodynamic approach. The influence of the southwest monsoon and the northeast monsoon is significant giving rise to maximum evaporation from the sea surface due to strong wind field and high saturation deficit respectively. An annual maximum evaporation of > 160 cm is observed in the southern regions. Due to the advancement of the southwest monsoon evaporation maximum in the Arabian Sea is reached earlier by 1 month than in the Bay of Bengal while the reverse is the case during the northeast monsoon.

Evaporation from any surface including oceanic may be determined from the vertical distribution of moisture in the air and the intensity of turbulent mixing. The heat balance method is one among the others used in the determination of evaporation from the water bodies.

Basing on the theoretical work of Sverdrup[1] and Montogomery[2], Jacobs[3] has employed the following formula

$$E = 0.143(e_o - e_z)\,u_z$$

where E is evaporation measured in mm/day, e vapour pressure in mbs, o and z sea surface and height above sea level respectively and u_z wind speed in mm/sec.

From published marine climatic data he was able to calculate Q_E by the relationship of $Q_E = L_E$, where L is the latent heat of evaporation of water. Budyko[4] after slight amendment of Jacob's formula expressed it as

$$E = 0.134(e_o - e_z)\,u_z$$

Both have used a constant K which varied slightly.

Using the published climatic charts of the Indian Ocean and the values of radiation surplus given by Schmidt[5], Venkataswaran[6] computed evaporation rates in different seasons from each 5° square over the Indian Ocean between lat. 20°N-40°S. Privett[7] computed monthly values of the rate of evaporation from each 5° square of the North Indian Ocean using a modified form of Jacob's formula and climatic data supplied by the Meteorological Office, London.

Colon[8] has studied the energy balance components of the Arabian Sea during August-September (southwest monsoon). He has obtained rather large rates of heat flux by evaporation from the west-central portions of the Arabian Sea. Bunker[9] has studied the interaction of summer monsoon air with the Arabian Sea. He has estimated the evaporation rates of 0.7 cm/day in the western section and 0.4 cm/day in the eastern section.

Pisharoty[10] has estimated a mean evaporation value of 0.28 cm/day from studies of evaporation from the Arabian Sea and the Indian southwest monsoon. He has concluded that the evaporation value appears to be significantly less than the evaporation calculated by the flux computations, when precipitation over the sea area as well as the flux upward through the 450 mb lid are considered.

Materials and Methods

The meteorological data used in this investigation are supplied by the marine section, Indian Meteorological Department, Poona. About 10 yr data of various marine meteorological parameters have been used in this work. The data include dry and wet bulb temperatures of the sea surface, temperature of the sea surface, wind speed and the cloudiness for various synoptic hours.

In this study, the regional investigation extends longitudinally from 55° to 100°E and latitudinally north of the equator. The entire region is divided into 2 degree square grids. For obtaining the climatological average values of various parameters for 1 month the following procedure is used.

The data are available for different synoptic hours over the entire region. The data of a particular synoptic hour is taken in a 2° square area during different days of a month and the average value of that parameter is obtained for that synoptic hour. Similarly for other synoptic hours the average value is obtained during that month. Then the monthly average value of the parameter is obtained from the average values of different synoptic hours. Similarly the monthly average values of various parameters are obtained for all 2° square areas of the entire region.

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Using transfer formulae for heat and moisture, it is estimated that an error of about 7% may be obtained due to averaging of data for over a long period[11]. But the use of mean values for the constant and of climatological data in the transfer formulae is satisfactory within the purposes for which such a long period calculation are generally made.

Taking the useful forms of the exchange formulae and assuming the similarity between momentum, heat and water vapour transfer in the lower boundary layer, the authors used the following equation for estimating the evaporation from the North Indian Ocean:

$$Q_E = L_E = \rho L C_D (q_o - q_a) U_a$$

where C_D is drag coefficient, L latent heat of vapourisation, ρ density of air, $(q_o - q_a)$ specific humidity gradient, U_a the wind speed, and o and a sea surface and anemometer height respectively.
The authors have taken the value of C_D as 1.4×10^{-3} for a mean wind speed of 15 knots from the graph given by Deacon *et al*[12]. Humidity gradient is replaced by vapour pressure gradient in millibars and wind speed in knots, then the following equation is obtained:

$$E = 4.73 \times 10^{-3} (e_o - e_a)\, U_a \text{ cm/day}$$

Using the above equation the evaporation from the sea surface is estimated for all the 12 months.

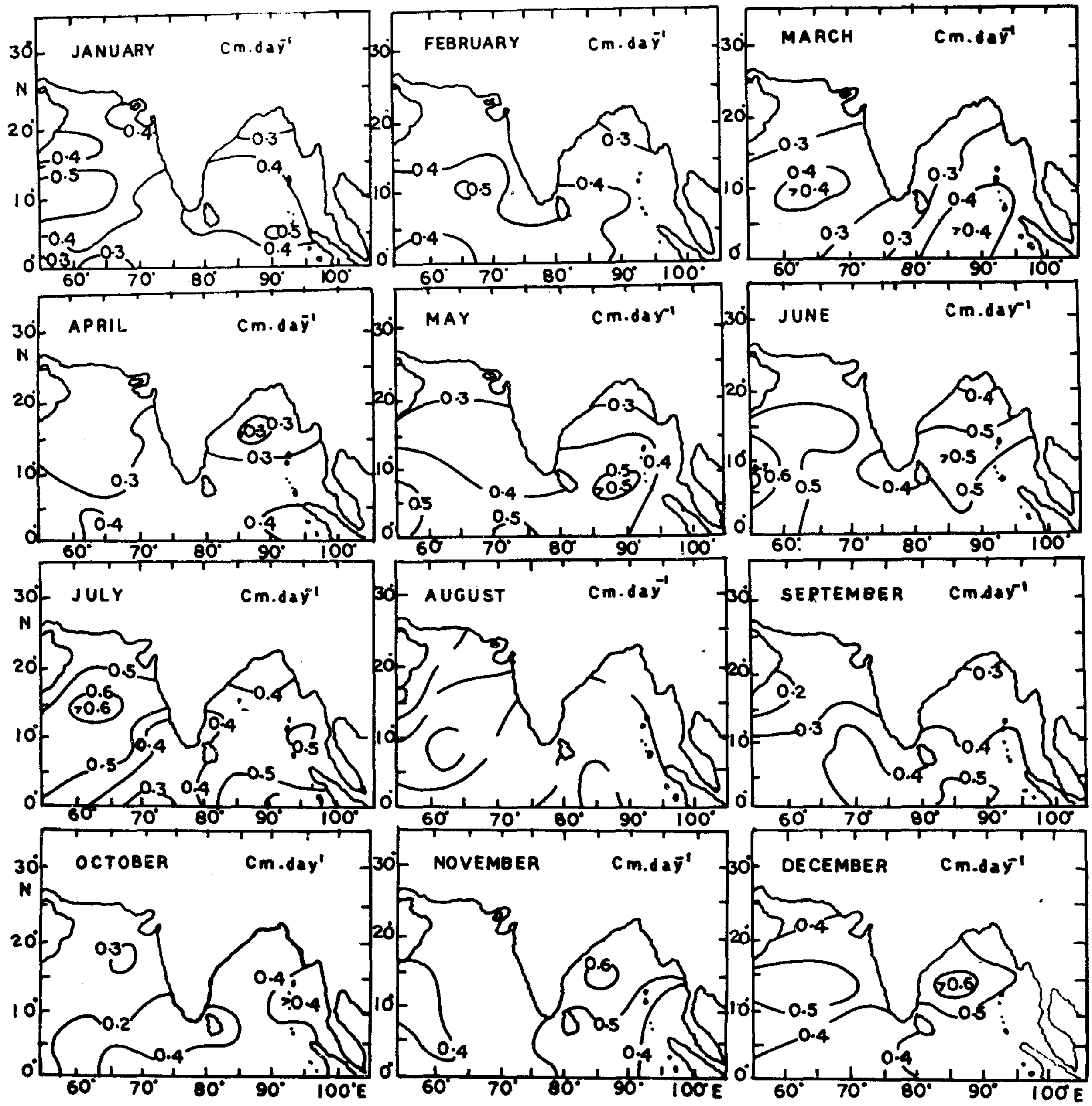

Fig. 1—Distribution of evaporation from the sea surface during different months

Results and Discussion

During January and February the northeast monsoon is very active with cold wind blowing over a relatively warm water. Eventhough cold winds of northeast monsoon will be blowing over the sea surface in the north, the evaporation is minimum due to calm winds whereas in the south due to high winds associated with frequent disturbances in the sea the evaporation is more (Fig. 1).

In March, the northeast monsoon has little influence and a general decrease in evaporation from the sea surface (Fig. 1). During April northeast monsoon is completely absent over the entire region and a further decrease of evaporation is observed all over the region.

During May to September the southwest monsoon is active over the North Indian Ocean. In May the monsoon is active over the equatorial region and the wind field is generally strengthened over the region. Under these conditions the evaporation is increased markedly from that of the previous month excluding northern parts with minimum evaporation of < 0.3 cm/day. During June and July a further increase of evaporation is observed with a maximum of 0.6 cm/day in the southern region of the Bay of Bengal. During August and September, a general decrease in evaporation is noticed. The maximum evaporation region is shifted to the southern region alongwith the retreat of southwest monsoon.

In October there is no significant change in the rate of evaporation from the Arabian Sea (Fig. 1). But in the Bay of Bengal the northern region is having dry winds from northeast and consequently the evaporation is increased in the north.

The northeast monsoon with cold and dry winds is active over the entire region during November and December (Fig. 1). Under this influence a significant increase in the evaporation over the entire region is observed with a maximum of 0.6 cm/day in November over the Central Bay of Bengal around 85°E. In December further increase in the evaporation is observed from the Arabian Sea with a maximum of 0.6/day over the central region and in the Bay of Bengal the same picture of the previous month is maintained.

Distribution of Annual evaporation is shown in Fig. 2. On the whole the evaporation is maximum in the southern regions of the Arabian Sea and the Bay of Bengal. Maximum evaporation of > 160 cm is observed in the western section of the Arabian Sea and in the southern Bay of Bengal.

Fig. 3 shows the annual variation of evaporation from the ocean surface for 2 stations each in the

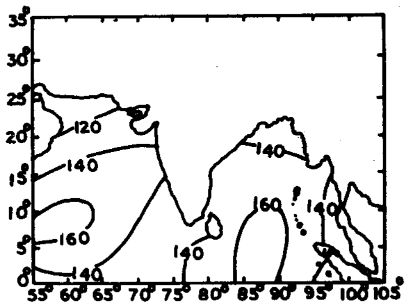

Fig. 2—Distribution of annual evaporation

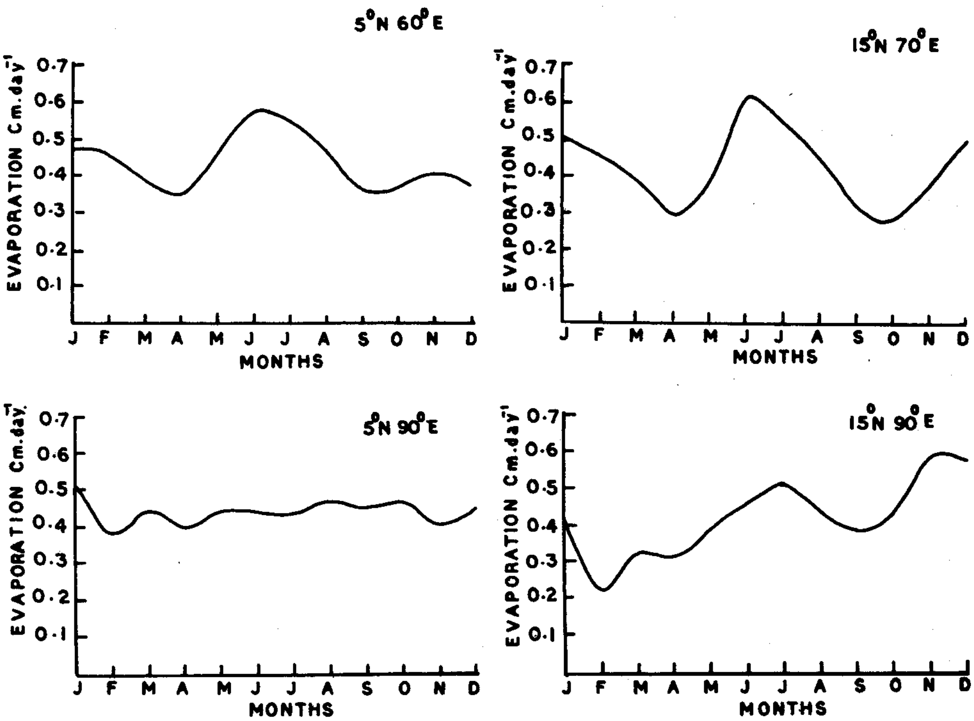

Fig. 3—Annual distribution of evaporation at 4 different stations

Arabian Sea (5°N, 60°E and 15°N, 70°E) and the Bay of Bengal (5°N, 90°E and 15°N, 90°E).

In the equatorial region the station in the Arabian Sea is showing pronounced maximum evaporation in June with secondary maximum in January. Minimum evaporation values are observed in April and September relating to premonsoon and postmonsoon periods. However, the equatorial station in the Bay of Bengal is showing a different picture. Practically the distribution of evaporation is almost uniform throughout the year with slightly increased values in January which corresponds to winter monsoon (northeast).

St 15°N 70°E is showing maximum evaporation in June and secondary maximum in December with double minima during April and October. However, st 15°N 90°E is showing the maximum evaporation in November (northeast monsoon) with a secondary maximum in July. During southwest monsoon, the evaporation maximum in the Arabian Sea is occuring 1 month earlier than in the Bay of Bengal. But in the case of northeast monsoon, the Bay of Bengal station is showing pronounced maximum and is observed one month earlier than in the case of Arabian Sea.

During the premonsoon period (hot season) of March and April the evaporation is small reaching minimum in April over most parts of the region. During this period, weak wind field prevails over the region with small vapour pressure gradients accounting for low values of evaporation.

With the progress of the southwest monsoon over the region the evaporation increases in May from the equatorial region and reaches maximum in June and July over the entire region with the advancement of the monsoon flow. In the late summer due to retreat of the monsoon there is a gradual decrease in evaporation over most parts of the region and this decrease is phenomenal in the northwest region of the Arabian Sea due to pronounced upwelling off the coast of Arabia near lat. 20°N.

Evaporation in this region reaches a maximum once again during the northeast monsoon (winter season) period due to the advection of the cold and dry trade wind airmasses and is connected with a considerable increase in saturation deficit. The evaporation reaches maximum in December over the entire region. Due to decrease in the activity of winter monsoon a gradual decrease in the evaporation is observed from February.

In the southern Bay of Bengal and western section of the Arabian Sea annual maximum evaporation of 160 cm is observed.

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