# Mean cloud distributions over tropical oceans

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ABSTRACT

The paper suggests that mean cloud distributions over tropical coeans as revealed by satellites may be intimately related to distributions of mean ocean surface temperature. From a qualitative consideration of the atmosphere's response to the underlying ocean surface temperature through energy exchanges, formation of clouds in a moving airmass over cold and warm oceans is discussed and illustrated with specific examples from the Indian ocean. It is shown that when warm air moves over a cold ocean, there is little or no formation of clouds. In the case of cold air moving over a warm ocean, there is gradual transformation of clouds from stratified to cellular type and development of cloud cells and cloud groups in the warmer parts of the ocean. Randomly distributed large cloud masses or ensembles known as cloud clusters appear to form over warm equatorial oceans. The intertropical convergence zone which is located in the region of maximum ocean surface temperature appears to be characterised by a band of cloud clusters. Occasionally, two separate cloud bands may be seen in near-equatorial waters, one in each hemisphere. Formation of two prominent cloud bands in the southern hemisphere is discussed. Finally, an examination of the mean rainfall distribution over tropical oceans suggests that it may be related to distribution of mean ocean surface temperature in much the same way as the mean cloud distribution.

## 1. Introduction

Bjerknes (1966, 1969) has recently demonstrated that equatorial anomalies of ocean surface temperature in the Pacific caused by variation in the strength of the Peruvian current affects the intensity of the atmospheric Hadley circulation of the northern hemisphere and through it the circulation features of higher latitudes. Namias (1969) has sought to discover a systematic correlation between long-period anomalies of ocean surface temperature and fluctuations of the general circulation of the atmosphere in middle and high latitudes. Recently, Saha (1970*a*) has indicated a possibility that zonal anomalies of sea surface temperature in equatorial Indian ocean may produce a marked effect upon the intensity of the monsoon circulation and rainfall distribution over India. In two subsequent papers, Saha (1970*b*, *c*) has suggested that equatorial anomalies of the ocean temperature in the major oceans may be largely responsible for observed longitudinal asymmetry in the location and seasonal oscillation of the intertropical convergence zone as well as formation of a double intertropical convergence zone. In the present paper, it is proposed to study mean cloud distributions over tropical oceans as revealed by satellites in relation to distributions of mean ocean surface temperature. A possible correlation between the distributions of mean ocean surface temperature and mean annual rainfall is also examined.

## 2. Distribution of mean ocean surface temperature

Fig. 1 shows the distribution of mean surface temperatures (Sverdrup et al., 1942) and principal cold ocean currents in tropical oceans during February and August. The cold ocean currents are the Peruvian current south of the equator and the Californian current north of the equator in the Pacific ocean and the Benguela current south of the equator and the Canaries current north of the equator in the Atlantic ocean during both February and August and the cold Somali current in the Indian ocean during August. The contribution of the ocean currents to the observed distribution of ocean surface temperature is qualitatively evident from Fig. 1. Upwelling along the coast of Peru and the equatorward moving cold Peruvian current maintain an almost permanent regime of cold equatorial waters from near Galapagos island (00°54′ S, 89°37′ W) to almost Canton island (2°48′ S, 171°43′ W.)

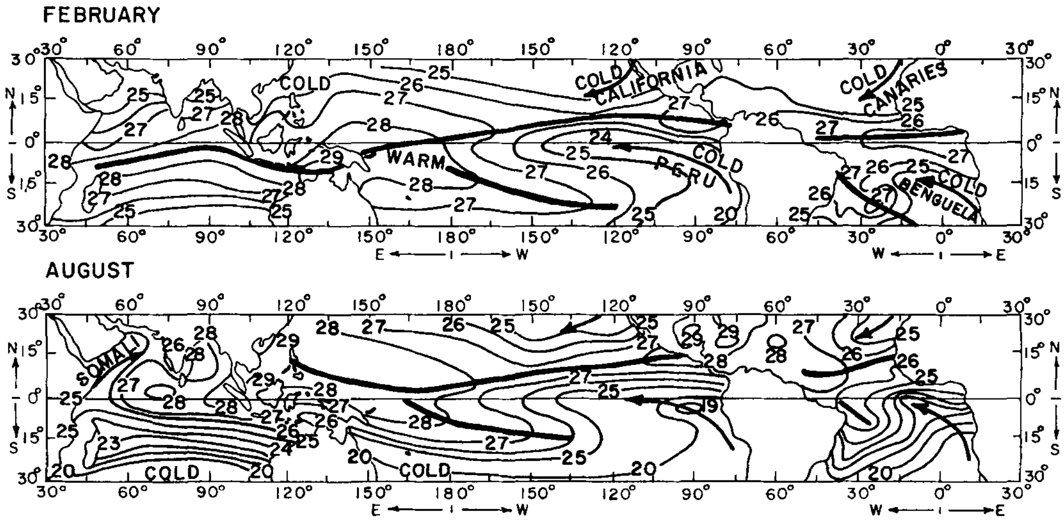



*Fig. 1.* Distribution of mean ocean surface temperature in tropical oceans. Thin continuous lines are isotherms (°C). Thick continuous lines areridges of high ocean surface temperature. Thick lines with arrow-heads show direction of cold ocean currents.

Between this wedge of cold equatorial waters and the cold waters of the south Pacific ocean, there appears a well-marked temperature ridge extending from near Solomon islands (longitude about 160° E) eastsoutheastward into south Pacific. The temperature ridge between the Peruvian current and the Californian current in the eastern Pacific lies north of the equator throughout the year but in the western Pacific it lies north of the equator during August and south of the equator during February. In the Indian ocean, the temperature ridge lies a few degrees south of the equator during February, whereas it practically disappears during August. However, during the southwest monsoon, upwelling along the Somali coast and the cold Somali current in the extreme western Indian ocean maintains a strong zonal temperature anomaly with cold water in the western Indian ocean (West of about 60° E) and warm water in eastern Indian ocean (Saha, 1970*a*).

In the Atlantic, two temperature ridges appear during February one north of the equator, but very close to it, between the Benguela current and the cold Canaries current and the other in extreme southwestern Atlantic between the Benguela current and the cold waters of the southern Atlantic. During August, the temperature ridge north of the equator persists but that in southwestern Atlantic weakens and remains confined near the coast of Brazil. The seasonal movement of the ocean currents and temperature ridges is evident from Fig. 1.

## 3. Ocean-atmosphere itneraction

Physical processes that may lead to cloud formation over an ocean must be very complex indeed, involving as they do, a two-way interaction between the ocean surface and the atmosphere. A crude but somewhat realistic picture of these processes may, however, be obtained from a qualitative and simplified consideration of heat and water vapour exchanges with the ocean surface. Normally, when an airmass after flowing over a cold surface enters a warm ocean, there is likely to be upward flux of both sensible heat and water vapour across the ocean-atmosphere interface according to the well-known flux-gradient relationships (Priestley, 1959),

$$H = -\varrho C_p K_H \left( \frac{\partial \bar{T}}{\partial z} + \Gamma \right)$$

$$H = -\varrho K_w \frac{\partial \bar{q}}{\partial z}$$

where $H$, $E$ denote respectively the vertical fluxes of sensible heat and water vapour, $\varrho$ is density of air, $C_p$ is specific heat of air at constant pressure, $\bar{T}$ and $\bar{q}$ are respectively time-mean temperature and specific humidity of air, $K_H$, $K_w$ are respectively the eddy diffusivities of heat and water vapour, $\Gamma$ is dry-adiabatic lapse rate of temperature, and $Z$ is vertical co-ordinate positive upward.

Evaporation and non-adiabatic warming of the lower boundary as the airmass moves over the warm ocean and updrift due to boundary-layer frictional convergence may cause, through turbulent mixing, a rapid modification of the airmass into a warm and humid atmosphere, the depth of the moist layer above the ocean surface increasing downstream. At some stage, condensation may begin with formation of clouds, each cloud cell releasing its latent heat of condensation into the atmosphere. This condensation heating together with surface heating may lead to a gradual fall of barometric pressure which in its turn may cause increased frictional convergence and upward motion and development of the cloud cells over the warm ocean. The importance of both ocean surface heating and condensation heating in the development of tropical atmospheric circulation systems has recently been demonstrated by Charney & Eliassen (1964) for hurricanes and by Pike (1968) and by Manabe, Holloway & Stone (1970) in the case of the intertropical convergence zone, using numerical models. The above processes are likely to be reversed when a warm airmass flows over a cold ocean. Rapid loss of sensible heat to the cold ocean may occur across the lower boundary with the depth of the cooled layer above the ocean surface increasing downstream. Taylor (1915) who first investigated this problem showed that the height $Z$ to which the effect of surface cooling will proceed after a time $t$ may be given approximately by the relation $Z = 2\sqrt{Kt}$, where $K$ is the co-efficient of eddy diffusion. The net effect of the surface cooling may thus be vertical stabilisation of the airmass and general lack of updraft. In fact, cooling may produce a general rise in barometric pressure, slow subsidence, and divergence of air. The net result of these processes may be a general lack of cloudiness over a cold ocean when a warm airmass moves over it. Both the processes mentioned above may, however, be considerably influenced by the presence of convergence or divergence in the moving airmass. Rapid cloud growth should occur when a system with

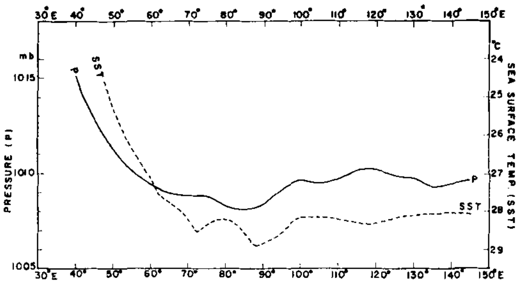



*Fig. 2.* Equatorial distribution of sea surface temperature (*SST*) and barometric pressure (*P*) in Indian ocean and parts of Western Pacific during July, 1964. Values of SST east of 97.5° E refer to 2.5° S latitude.

convergence of air such as a developing pressure trough or front enters or lies over a warm ocean. Cloud growth is likely to be retarded or subdued when a system with divergence lies or moves over a cold ocean. Intermediate cloud growth may be expected when a system with convergence moves over a cold ocean or a system with divergence moves over a warm ocean.

The validity of the above analysis of ocean–atmosphere interaction may be qualitatively demonstrated with reference to conditions in equatorial Indian ocean (Saha, 1970*a*). Fig. 2 shows equatorial distribution of mean sea surface temperature and mean sea level barometric pressure over the Indian ocean and neighbouring Western Pacific during July, 1964. It shows the equatorial eastern Indian ocean which is warmer having a lower surface barometric pressure than equatorial western Indian ocean which is colder. Fig. 3*a–d* show the distribution of mean air temperature and humidity mixing ratio at surface, 850, 700 and 500 mb, respectively, over equatorial Indian ocean during July 1964. It is qualitatively evident that ocean–atmosphere interaction has modified the temperature and humidity structure of the overlying atmosphere upto at least 500 mb.

## 4. Observed cloud distributions over cold and warm oceans

In a study of trade wind cloud formation over Western Caribbean, Malkus (1957) relates the presence and development of trade cumulus cloud groups to regions in the ocean which

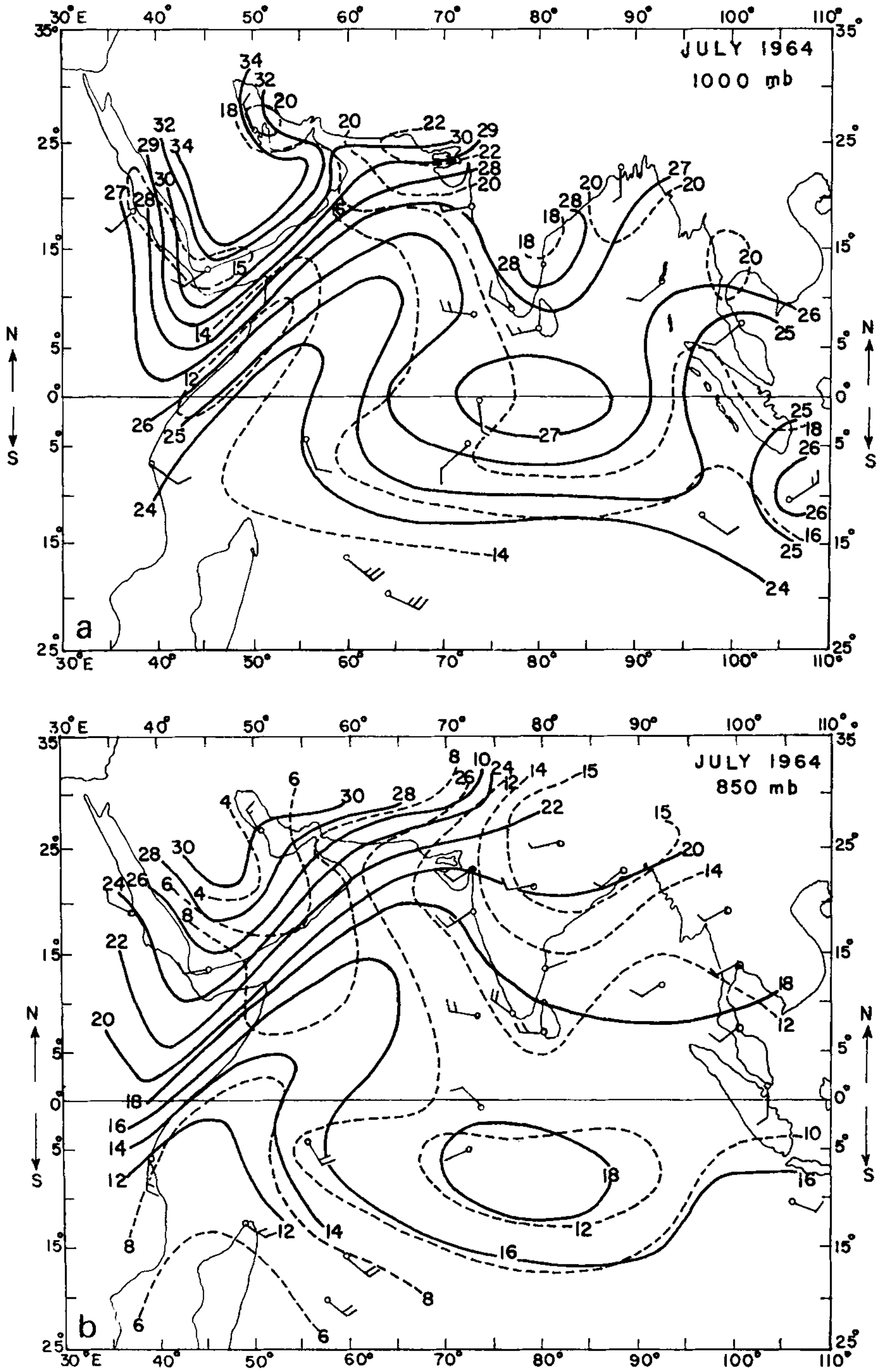
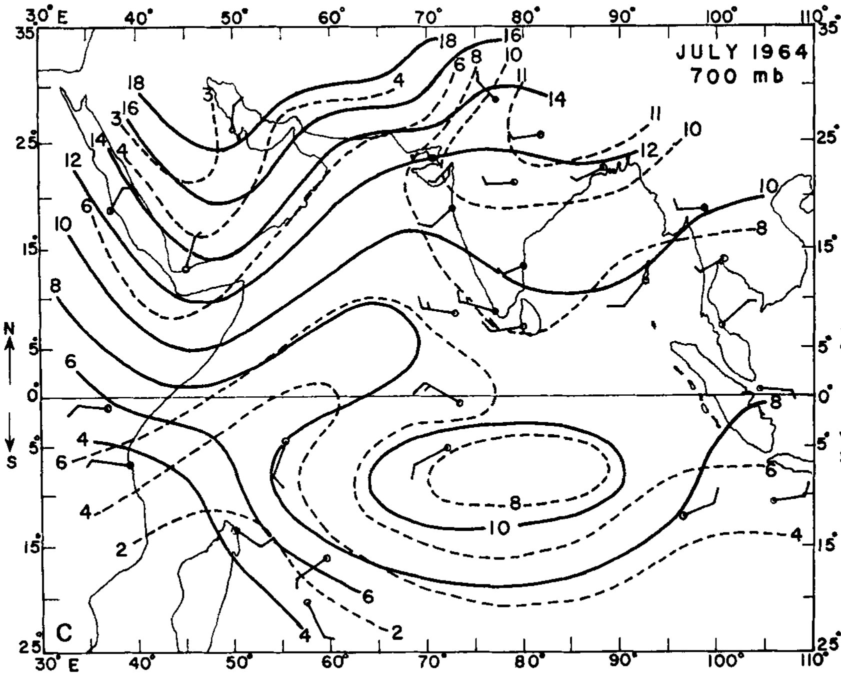



*Fig. 3.* Distribution of air temperature (°C) and humidity mixing-ration (g/kg) over equatorial and northern Indian ocean during July, 1964 at (*a*) 1 000 mb, (*b*) 850 mb, (*c*) 700 mb, and (*d*) 500 mb. Continuous lines represent isotherms and dashed lines isohygries.


JULY 1964
700 mb
c
30° E
40°
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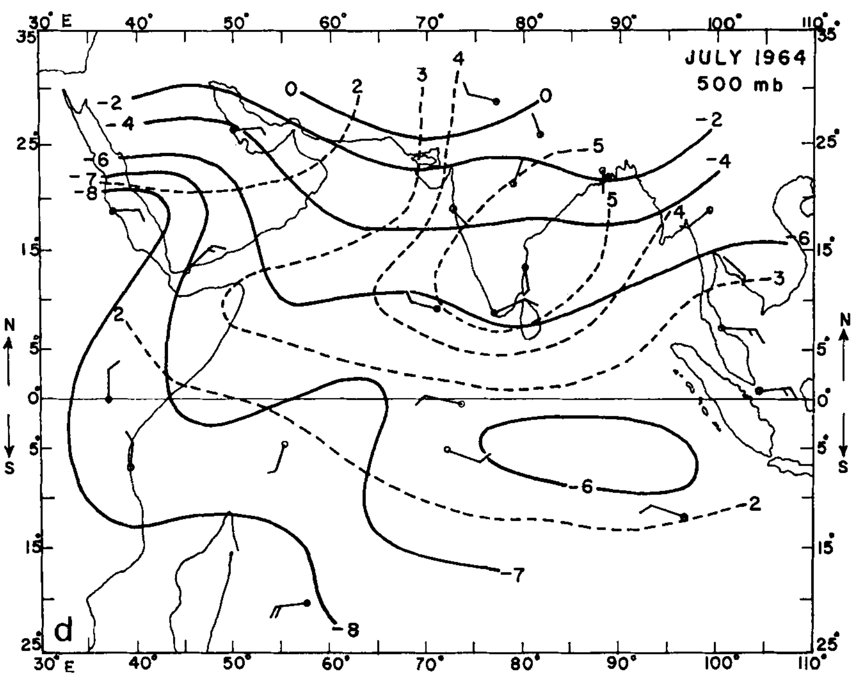
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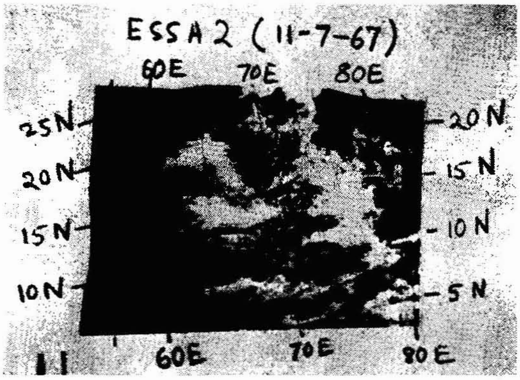


*Fig. 4.* Typical cloud pattern over the Arabian seadurig northernn summer as viewed by ESSA-2 satellite on 11 July, 1967 (orbit no. 6311).

are slightly warmer than the surroundings. Krueger & Fritz (1961) who studied the satellite-observed distribution of cellular clouds in the areas of north Atlantic and north Pacific anticyclones with relevant meteorological data find that in the region of formation of these clouds, ocean temperatures were on an average about 3°C higher than the air temperatures with the smallest difference on the western downwind side and the greatest on the eastern upwind side. Hubert (1966) who made a detailed study of meso-scale cellular cloud formations in the ocean finds that there are two types of cellular clouds, namely open cells which are invariably found when the ocean temperature is higher than the air temperature and closed cells which are occasionally found when the ocean temperature is actually colder than the air temperature. Hubert shows that closed type cells which may have updraft at the center and downdraft in the surrounding areas are quite commonly found in the regions near the Canaries and off the California coast where the ocean temperatures are cold compared with other ocean temperatures. During the last few years, polar-orbiting satellites have made daily passes over the Indian ocean and revealed the cloud patterns relating to different circulation systems. Fig. 4 shows an ESSA-2 satellite view of typical cloud patterns over the Arabian sea on 11 July 1967 during the southwest monsoon season. It shows the sea area west of about 60° E which is generally colder than the air practically free of clouds. East of this longitude, stratified clouds first appear which

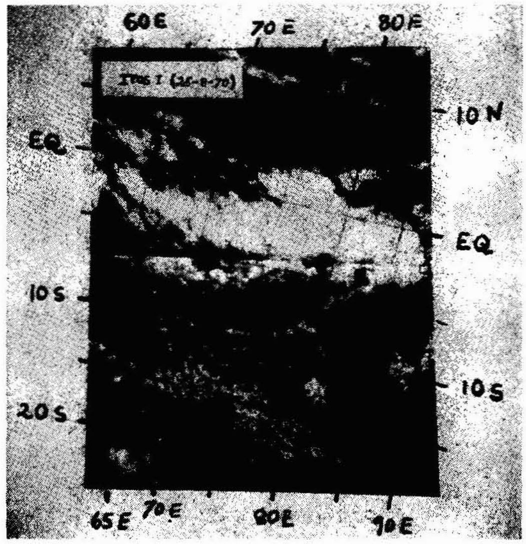


*Fig. 5.* Cellular cloud patterns in the south-east trade wind region of south Indian ocean as viewed by ITOS-1 satellite on 25 August, 1970 (orbit nos. 2676, 2677).

soon give way to cellular clouds of closed cell type. Cloud cells appear to grow rapidly as the airmass moves over the warmer waters in eastern Arabian sea. It is not quite clear from the photograph whether the transformation from closed cell type to open cell type takes place as the airmass moves on to warmer sea, although such transformation could be clearly seen on many other occasions, e.g. on 18 and 21 Aug. 1966. Individual cloud cells as well as cloud groups, however, appear to develop rapidly over the warm eastern Arabian


*Fig. 6.* An ESSA-8 photograph of a typical cloud cluster in equatorial Indian ocean on 11 September, 1970 (orbit nos. 7965, 7966).

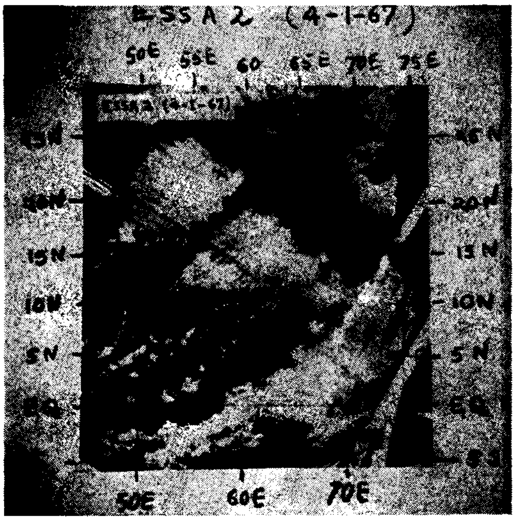


*Fig. 7.* An ESSA-2 satellite view of typical cloud patterns over Arabian sea during northern winter on 4 January, 1967 (orbit no. 3927).

sea. Fig. 5 shows an ITOS-I satellite photograph of cellular cloud patterns on 25 Aug. 1970 in southeast trade winds of the southern Indian ocean as they approach the warm equator. Small cloud cells which form over cold ocean in the field of the subtropical anticyclone grow rapidly as the trades move on to warm equatorial sea. Near the equator, cloud cells develop both individually and in groups and appear to form masses usually known as clusters. Fig. 6 shows satellite photograph of a typical cloud cluster over the equator during the southwest monsoon season. The circulation pattern over the Indian ocean is reversed during the northern winter. In the Arabian sea, in particular, cold northeast trade winds blow at first over cold waters of north Arabian sea but subsequently over warmer waters of south Arabian sea. Fig. 7 shows an ESSA-2 satellite view of typical cloud patterns over the Arabian sea on 4 January 1967 during the northern winter. It shows northern Arabian sea practically clear of clouds. Cellular clouds appear to form and develop progressively over south Arabian sea where the ocean surface is warmer than the air.

In recent years, a number of workers (e.g. Winston & Taylor, 1967; Taylor & Winston, 1968; Sadler, 1969; Kornfield & Hasler, 1969; Winston, 1969; Oliver & Anderson, 1969; Anderson et al., 1969) have studied the mean cloud distributions over tropical oceans, utilising data furnished by either polar-orbiting or geostationary satellites or both. Most of these workers give the average cloudiness in different parts of the tropics. Fig. 8 shows the distribu-

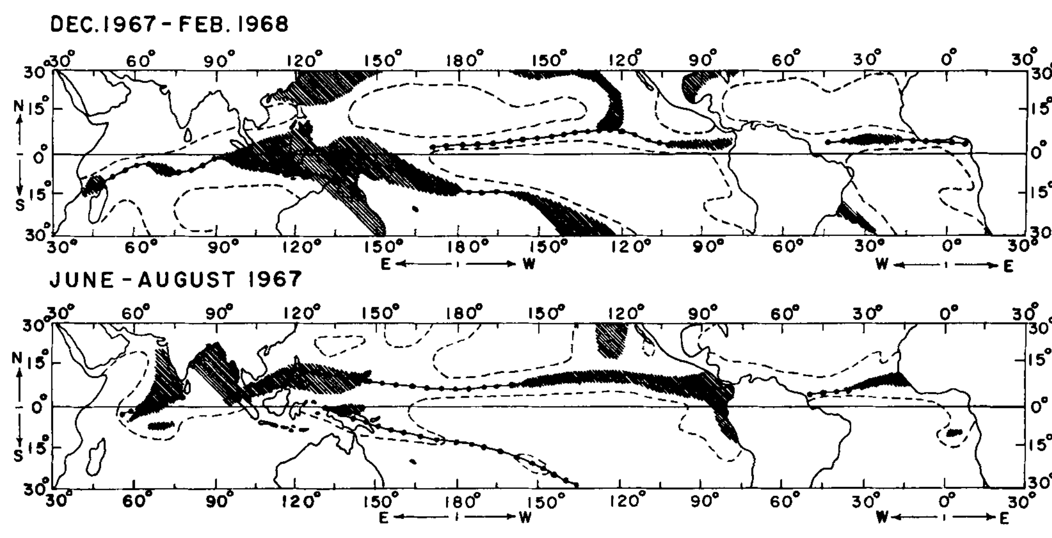


*Fig. 8.* Distribution of brightness from ESSA-3 and 5 digitized pictures for periods Dec. 1967 – Feb. 1968 and Jun.–Aug., 1967. The dashed lines enclose areas of minimum brightness, while hatched areas show regions of maximum brightness. The heavy dotted lines indicate the major axes of maximum brightness (or cloudiness). (After Hubert, Krueger, and Winston, 1969.)

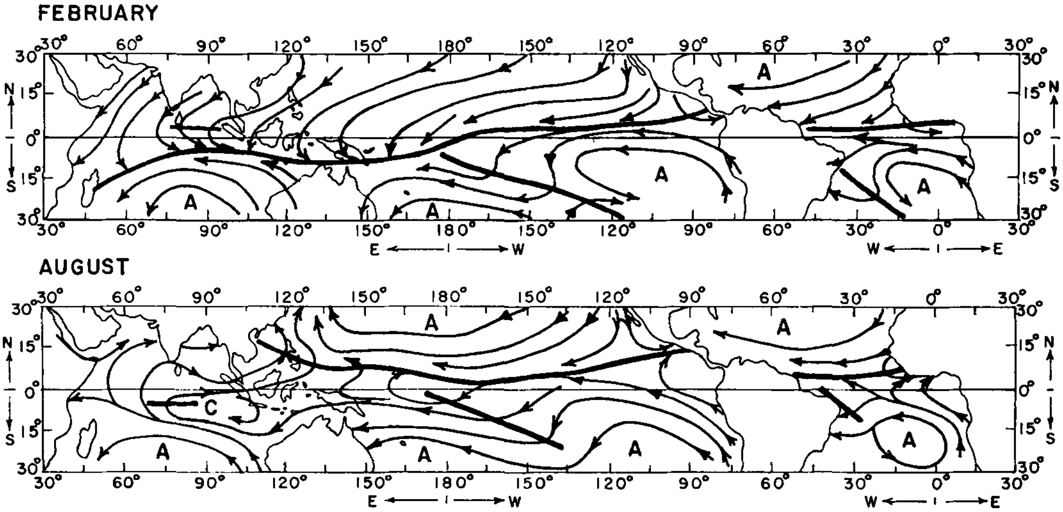


*Fig. 9.* Schematic diagram showing horizontal air flow patterns near ocean surface during February and August, C-cyclonic, A-anticyclonic. Thin continuous lines with arrow-heads show flow lines. Thick continuous lines show zones of convergence.

tion of brightness from ESSA 3 and 5 digitized pictures, averaged for periods December 1967 – February 1968 and June–August 1967, as presented by Hubert, Krueger & Winston (1969). A comparative study of Figs. 1 and 8, though Fig. 8 presents average seasonal cloudiness during one year only, appears to show that the zones of maximum brightness (cloudiness) are located over the warmest parts of the oceans. During both the seasons, there is minimum cloudiness over equatorial eastern Pacific and equatorial eastern Atlantic oceans which remain cold practically throughout the year. Areas of subtropical anticyclones in both the oceans show minimum cloudiness. In the Indian ocean, region of maximum cloudiness lies south of the equator during northern winter and north of the equator but east of longitude about 60° E during the northern summer. Two prominent zones of maximum cloudiness appear in the southern hemisphere during Dec.–Feb., one in extreme western Atlantic ocean and the other in central south Pacific ocean. During June–August, the cloud zone in the Pacific becomes weak, while that in the Atlantic practically disappears. Besides the above, extensive stratus cloud off the west coasts of American and African continents where the cold ocean currents maintain very low surface temperatures has been reported (Sadler, 1969). Stratus or thick haze is also observed over cold western Arabian sea during both the monsoon seasons.

## 5. Cloud clusters and bands

As already mentioned, cloud formations over warm equatorial oceans tend to be of large cluster type. The dimensions of individual clusters may vary considerably. The cloud cluster shown in Fig. 6 covers about one million square kilometers of ocean surface. This may be taken as an average size, since clusters of much larger and smaller sizes have been observed. Over equatorial eastern Indian ocean and equatorial western Pacific, cloud clusters appear to be randomly distributed except in convergence zones where they tend to be organised in bands. Fig. 9 which is a sketch of the mean sea level air circulations over the tropical belt shows the mean positions of the intertropical convergence zone and the convergence zones of the southern hemisphere during February and August. Generally, cyclonic circulations and convergence zones appear over warm oceans and anticyclonic circulations and divergent flow over cold subtropical oceans. An examination of Figs. 1 and 9 appears to show that the intertropical convergence zone appears in almost the same

Table 1. *Number of days of occurrence of double cloud bands in equatoriel Indian oceen during July 1966 through Sept. 1970*

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | a | a | a | a | a | a | 23 | 15 | 12 | 12 | 8 | 15 |
| 1967 | 4 | 6 | 4 | 4 | 3 | 3 | 3 | 6 | 4 | 2 | 0 | 3 |
| 1968 | 4 | 4 | 8 | 5 | 3 | 7 | 5 | 8 | 12 | 9 | 14 | 14 |
| 1969 | 3 | 3 | 1 | 0 | 6 | 4 | 6 | 7 | 7 | 2 | 3 | 1 |
| 1970 | 5 | 11 | 6 | 2 | 3 | 11 | 4 | 4 | 5 | — | — | — |

[a] APT pictures not available.

location as the near-equatorial ridge of ocean surface temperature. This is certaintly as it should be, for convergence zones are the regions of ascending air motion and hence conversion of latent heat of water vapour into sensible heat energy by way of condensation. Riehl & Malkus (1958) have emphasised the role of the equatorial trough zone or the intertropical convergence zone in the heat balance of the tropical atmosphere and pointed out that although the tropics as a whole serves as a heat source for the general circulation of the atmosphere, it is mainly through the equaorial trough zone that both sensible and latent heat energy is transmitted upward for eventual transfer to higher latitudes. Cloud distributions are thus visible manifestations of this important process of energy transfer and Figs. 8 and 9 would seem to imply that bulk of this transfer takes place through the ITCZ. Occasionally, two separate cloud bands apparently associated with formation of double ITCZs, may be seen over limited regions of the tropical belt, one on each side of the equator, though the existence of these bands may not be reflected in the average seasonal pictures. Hubert, Krueger & Winston (loc. cit.) who computed seasonally-averaged cloud distribution during 1967–68 over the tropical belt conclude, *inter alia* that the Indian ocean does not exhibit any double tropical cloud zones. Daily APT photographs relating to Indian ocean, however, appear to reveal a different situation. Table 1 presents the number of days of occurrence of double cloud bands in the Indian ocean during period July, 1966 through September, 1970, as revealed by satellites. It is evident that double cloud bands which no doubt are to be associated with double intertropical convergence zones are of fairly frequent occurrence in the Indian ocean, although Table 1 shows that there were at least two months during the 51 month period when no double ITCZs were observed. One may also note from Table 1 that the number of days of occurrence of double cloud bands during period July through September, 1966 which was a drought year in India is much greater than that during corresponding periods in other years which were all good monsoon years, i.e. they had normal or more than normal amounts of rainfall. The life period of a double cloud band appears highly variable with an average at about 5 to 6 days, and extremes at 1 and 12 days. Fig. 10 shows satellite photographs of two typical double cloud bands in the Indian ocean, one an ITOS-1 photograph on 11 June, 1970 during the SW monsoon and the other an ESSA-8 photograph on 19 December, 1968 during the NE monsoon season.

The occurrence of a double cloud band in equatorial eastern Pacific ocean during northern late winter and spring season has been reported by a numer of workers (see, for example, Kornfield & Hasler, 1967). Table 2 shows the number of days of occurrence of double cloud bands in equatorial Pacific ocean during February, 1967 through March, 1969.

A conspicuous difference between the two oceans appears to be that whereas in the Pacific a double cloud band may be observed during northern later winter and spring only, it may be observed in the Indian ocean at any time of the year.

In a numerical study of the interaction between the ocean and the atmosphere using a time-dependent two-dimensional primitive-equation model of a zonally-symmetric atmosphere, Pike (1968, 1970) shows that the ITCZ structure over the ocean is determined mainly by the surface temperature profile, the major

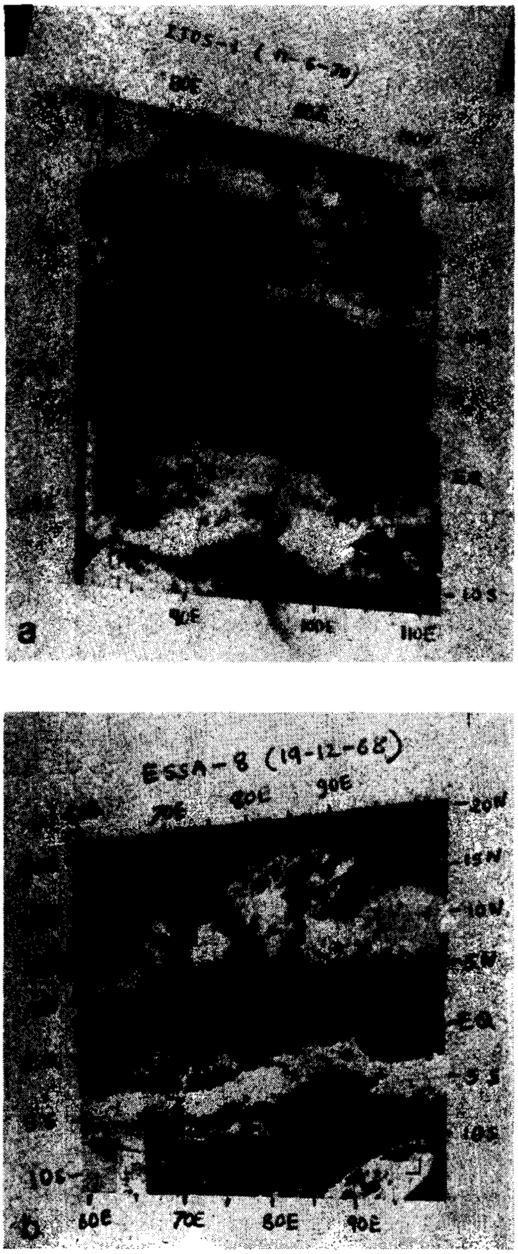


*Fig. 10.* A satellite view of two typical double cloud bands in the Indian ocean, one (*a*) an ITOS-1 photograph on 11 June, 1970, (orbit nos. 1738, 1739), and the other (*b*) an ESSA-8 photograph on 19 December, 1968 (orbit nos. 0043, 0044).

updrafts being located, on the average at the latitudes of maximum temperature. With hemispherically symmetric conditions at the surface and in the subtropical atmosphere, a single equatorial convergence zone appears to be the equilibrium state unless there is a marked surface temperature minimum there when the ITCZ forms several degrees of latitude away from the equator. It may be double with a branch in each hemisphere or it may become single if one of its branches reaches sufficient strength to suppress the other by flank subsidence. Pike's finding that the ITCZ forms at the latitude of maximum ocean surface temperature is, indeed, most interesting in the context of the present study. However, his model being two-dimensional cannot possibly take account of the marked zonal asymmetry that exists in equatorial ocean surface temperature (Fig. 1) and that may have important bearing on the formation of double ITCZs (Saha, 1970*c*). It is interesting to note that Manabe, Holloway & Stone (1970) who carried out numerical experiments, with a global general circulation model conclude that a continuous supply of energy from the warm sea surface is necessary for the location and intensity of the intertropical convergence zone as well as for development of tropical cyclones which may form in it.

## 6. Southern hemispheric cloud bands

As shown in Fig. 8 and amply confirmed by recent ATS photographs, two prominent and extensive cloud bands appear in the southern hemisphere, one in central Pacific and the other in western Atlantic, both originating near the equator and extending deep into southern latitudes in a NW–SE orientation. The cloud bands are prominent during February and fade out considerably during August. In fact, during August the band in southwest Atlantic appears to be confined near the coast of Brazil only. One may ask: what is the origin of these huge cloud bands forming in the southern oceans. Riehl (1954) is of the view that a belt of heavy rainfall in south central Pacific (which more or less coincides with the position of the cloud band shown in Fig. 8) can be connected with a large trough and convergence line emanating from the polar zone and extending northwest towards the equatorial trough. From Figs. 1 and 8 it may be seen that the cloud bands in both the Pacific and the Atlantic oceans appear in more or less the same positions as the re-

Table 2. *Number of days of occurence of double cloud bands in cquatorial Eastern Pacific*

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1967 | 0 | 4 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1968 | 0 | 0 | 6 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1969 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

spective ridges of ocean surface temperature. One may, therefore, speculate that these bands may be generated in troughs or convergence zones that may form over warm waters which may be drawn into higher latitudes by the anticlockwise circulations of the subtropical anticyclones. During February the equatorial belt is warmest and there may be maximum penetration of warm equatorial waters into higher latitudes with the result that the bands may be very prominent and extensive. During August, when the equatorial ocean temperature ridge line moves well north of the equator and the cold ocean currents of the southern oceans reach their northernmost positions, there may be lesser penetration of warm water into the southern hemisphere with consequent disappearance or weakening of the convergence zones and hence the cloud bands. Satellite pictures appear to show tht the above convergence zones of the southern oceans interact frequently with eastward-moving polar fronts that appear to extend from the south polar zone into the tropics. The interaction, however, appears to be rather complex.

## 7. Mean rainfall distributions

It may seem relevant here to comment briefly on distributions of mean annual rainfall over tropical oceans in relation to mean ocean surface temperature. Although clouds are essential for rainfall, mere presence of clouds may give no indication of the distribution of rain. However, Sadler (1969) who compared 2-year average cloud distribution as revealed by satellites with normal rainfall distribution over equatorial and southern Africa during February, 1965–1966, found a surprisingly close correlation between the two. Also, Pike (1968) in his numerical study has shown that a rainfall peak appears over equatorial ocean when it is warm and a rainfall minimum when it is cold. The cold oceans of the subtropical belts are generally dry. Almost desert conditions prevail in equatorial eastern Pacific where Peru currents maintain an almost permanent regime of cold surface water and in equatorial Atlantic where the Benguela current keeps a minimum surface temperature. In equatorial Indian ocean, the region west of about 60° E including the Arabian sea which is affected by the cold somali current is practically dry. The equatorial belt comprising eastern Indian ocean and western Pacific ocean is the wettest region of the tropical oceans (Riehl, 1954). In south Pacific and south Atlantic oceans, the locations of cloud bands associated with the ridge of ocean surface temperature discussed in the preceding section appear to be marked by high precipitation (Riehl, 1954). In short, the distributions of mean annual rainfall appear to be related to mean ocean surface temperature in much the same way as mean cloud distribution.

## 8. Summary and conclusion

It has been suggested that mean cloud distributions over tropical oceans may be largely related to distributions of mean ocean surface temperature. Stratified as well as cellular types of clouds which form over cold oceans seldom appear to grow vertically. On the other hand, cellular clouds that form over warm oceans appear to grow to large heights. Large groups for ensembles of developed cellular clouds known as cloud clusters appear to be characteristic features of warm equatorial oceans. Cloud clusters which are usually randomly distributed appear to organise themselves in bands along the intertropical convergence zone and other convergence zones which form over the warmest parts of the oceans. Evidence is produced of formation of double cloud bands in the Indian ocean and the Pacific ocean. Two prominent cloud bands which appear in southern oceans appear to be associated with ridges of ocean surface temperature in the respective regions. An examination of the distribution of mean annual rainfall suggests that it may be related to mean ocean surface temperature in much the same way as mean cloud distribution.

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## СРЕДНИЕ РАСПРЕДЕЛЕНИЯ ОБЛАКОВ НАД ОКЕАНАМИ В ТРОПИКАХ

Результаты статьи показывают, что средние распределения облаков над океанами в тропиках, полученные с помощью спутников, могут быть тесно связаны с распределениями средней температуры поверхности океана. Исходя из качественного рассмотрения реакции атмосферы на температуру поверхности океана путём процессов обмена энергией обсуждается образование облаков в воздушных массах, движущихся над холодными и теплыми частями океана. В качестве иллюстрации приводятся специальные примеры для Индийского океана. Показывается, что когда теплый воздух движется над холодным океаном, то образуется мало облаков или они совсем не образуются. В случае движения холодного воздуха над теплым океаном происходит постепенное преобразование облаков из слоистых в кучевые и развитие ячеек и групп облаков над более теплыми частями океана. Случайно распределенные большие облачные массы или ансамбли облаков, известные как «кластеры», представляются образующимися над теплыми океанами в экваториальных областях. Зона междутропической конвергенции, находящаяся в области максимальных температур поверхности океана, характеризуется полосой облачных кластеров. Иногда можно видеть две отдельных полосы облаков в приэкваториальной области, по одной в каждом полушарии. Обсуждается образование двух четко выраженных полос облаков в южном полушарии. Наконец, исследование средних распределений осадков над тропическими океанами показывает, что оно может быть связано с распределением средней температуры поверхности океана во многом аналогичным образом, как и среднее распределение облаков.