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THE OCEAN AND THE ATMOSPHERE*

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INTRODUCTION

MARINE meteorology is essentially concerned with the interaction between the oceans and the atmosphere and the atmospheric phenomena resulting from this interaction. The ocean and the atmosphere are two fluid media in physical contact at their interface which covers about three-quarters of the surface area of the globe. Both the fluid media are in turbulent motion in which many mutually interacting scales of motion co-exist. Exchange of heat, momentum, water, gases, salt particles, etc. takes place at the interface. These exchanges are basic for maintaining the circulations of the ocean and the atmosphere.

The oceanic waves are generated by the force which wind exerts on the water surface. The waves act as a brake on the wind and abstract momentum from it. This drag of the ocean on the wind is responsible for generating and maintaining the oceanic circulations. At the same time the atmosphere derives its water vapour from the oceans. When the vapour condenses and falls as rain the latent heat of condensation if imparted to the atmosphere, often at places far away from the place of intake of the moisture. The atmosphere derives the large bulk of its heat supply in this manner. Pressure gradients set up by differential heating give rise to the atmospheric wind systems. This shows the close links between the ocean and the atmosphere. By and large, the atmosphere supplies momentum to the ocean while the ocean supplies heat to the atmosphere.

As a consequence of the earth's rotation, large-scale motion of the ocean and the atmosphere tend to be nearly '*geostrophic*', the motion being at right angles to the pressure gradient. Since kinetic energy can be generated only by 'ageostrophic' motion, the geostrophic flow results in the storage of potential energy in the form of air-and water-mass density contrasts ; this energy is released far away in space and time from the location of input.

HEAT SOURCES AND SINKS

Short wave radiation from the Sun provides the energy for all motions of the ocean and the atmosphere. The atmosphere is largely transparent to this radiation so that most of it penetrates to the earth's surface where it is absorbed by the earth and the oceans and increases their surface temperature. The atmosphere derives its heat energy at the air-sea and air-earth interfaces. Nearly 80% of this is in the form of water vapour at the air-sea interface. More than half of this is derived from the tropical oceans.

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Averaged over the entire globe and for a sufficiently long interval of time it is believed that there is balance between the short-wave radiation absorbed from the Sun by the earth-atmosphere system and the energy returned to space from the earth and the atmosphere in the form of long-wave radiation. Most of this radiation is from the water vapour in the upper layers of the atmosphere and to a first approximation it is independent of latitude. On the other hand the energy received from the Sun is much larger in the tropics than at the higher latitudes. The overall radiation balance (energy received minus energy lost) of the earth-atmosphere system is positive approximately between latitudes ±40° and negative polewards. The circulations of the oceans and the atmosphere convey energy from the regions of positive balance (tropics) to those of negative balance (higher latitudes). The free atmosphere is a heat sink and would cool at the rate of about 1° to 2°C per day if the heat supply from the bottom is cut off.

The tropical oceanic areas are the important regions of heat input to the atmosphere. Most of the input takes place in the so-called equatorial trough zone—a belt of about 10° latitude on either side of the thermal equator. It is an area of intense convective activity and extensive clouding. It can be prominently seen on satellite cloud photographs. Inside the tall cumulo-nimbus clouds that develop in the equatorial trough zone, heat is transported upwards from where it is carried polewards.

GARP Tropical Experiment

The tropics from 30°N to 30°S cover half the surface area of the globe. More than 70% of this area is oceanic. This is the most important part of the global atmosphere so far as the energy input for driving the atmospheric circulations is concerned. The physical processes occurring at the air-sea interface in the tropics and in the tropical atmosphere have been receiving increasing attention in recent years. The meteorological satellite as an observational tool has provided a great break-through in this regard. The satellite photographs reveal certain types of organisations in the cumulus clouds over the tropical oceans and land areas. Individual convective cells have dimensions of the order of 1 to 10 km. The cells tend to arrange themselves in lines or rings with dimensions of 10 to 100 km. A group of such lines or rings constitute a cloud cluster which has a typical dimension ranging from 100 to 1000 km. Clusters appear to be embedded in wave disturbances whose characteristic wavelengths range from 2000 to 10,000 km. The GARP tropical experiment proposed to be undertaken in the tropical Atlantic will make a thorough study of the physical processes leading to the development of these cloud organisations and the interaction between the different scales noticed in them.

The South-west Monsoon

The meteorology of the Indian Ocean and the adjoining seas and land areas is dominated by the monsoon circulation for which there is no parallel elsewhere in the world. The development of this circulation results from the peculiar configuration of land and sea over this part of the globe. Unlike the Atlantic and the Pacific, the Indian Ocean is bounded in the north by the large continental masses of Africa and Asia. The differential heating of sea and land during the summer months initiates a series of atmospheric processes leading to the onset of the south-west monsoon early in June.

The south-west monsoon circulation is best developed in the month of July. It begins to weaken by September and changes over to the winter circulation in the course of October. The south-west monsoon brings rain to India and other countries of south-east Asia. The economy of these countries is primarily agricultural and is heavily dependent on the monsoon rains.

There are large variations in rainfall over different parts of the region during the south-west monsoon. The activity of the monsoon undergoes fluctuations not only from year to year but also within the monsoon season. The causes responsible for these fluctuations are not well understood. It appears probable that short-term and long-term fluctuations in the oceanic temperatures may have a decisive influence on the activity of the monsoon rains.

It is well known that extensive upwelling of cold water takes place off the Somalia Coast during the south-west monsoon months. This upwelling results from the Ekman layer flow which sweeps the surface water away from the coast towards the east. As a consequence of this upwelling of cold water, the lower layers of the atmosphere are cooled and steep pressure gradients are built up over the west Arabian Sea off the Somalia Coast leading to very strong winds in the low levels. During the IIOE period extensive studies were made over the Arabian Sea by research aircraft of the US Weather Bureau. Vertical profiles of temperature and humidity were also determined with dropsondes. The studies revealed the existence of a strong low-level thermal wind jet off the coast of Somalia. Speeds of 50 knots were found at a height of 1 km. The existence of such strong winds was noticed over several parts of the Arabian Sea south of 15°N. The results of these studies have been discussed by Bunker (1965). As a result of the upwelling and the Ekman layer flow, the western parts of the Arabian Sea are colder than the eastern parts. Mr. P. V. Joseph has drawn attention to the occasional appearance of low level jets over the southern parts of the Indian peninsula during the SW monsoon months. It is possible that these may be associated with the upwelling along and off the west coast of India.

Recently Findlater (1969, 1970) has found that cross-equatorial jet streams at low levels occur over Kenya during the south-west monsoon months. He has also attempted to establish a link between the fluctuations in the intensity of this jet stream and the rainfall over north India.

The existence of large scale disturbances in the equatorial atmosphere has been very well brought out by the cloud distributions observed in the satellite pictures. It has been also found that there are preferred areas of cloud development over the sea. Much interest centres round such studies in the context of the GARP experiments to understand the behaviour of the tropical atmosphere.

Several decades ago in tryping to foreshadow the south-west monsoon rainfall over India, Sir Gilbert Walker found significant correlations between the monsoon rainfall and antecedent meteorological conditions at distant places such as south America, south Rhodesia, Djakarta and Port Drawin. Recently interest in atmospheric teleconnections has been revived by the work of Bjerknes (1969) who found association between ocean temperature anomalies in the equatorial Pacific and the so-called 'Southern Oscillations' of Walker, according to which positive pressure anomaly at Djakarta is associated with negative pressure anomaly at the southern stations in South America such as Buenos Aires, Santiago and Cardoba. From a study of the maps of world precipitation and precipitation anomaly distribution it has been recently found (Tsuchiya, 1970) that there is an inverse association between the precipitation in the so-called equatorial Pacific dry zone which extends from the Peru Coast to beyond the 180° meridian along the equator and the rainfall in the India-Indonesian region. It has also been found that variations of the mid-latitude westerlies of the Southern Hemisphere play an important role in weakening or strengthening of the Walker Circulation through the variations of the sea surface temperature under the south-east trades.

Satellite mapping of oceanic surface temperatures open out a new field for studies of this type in the Indian Ocean area.

Storms and Depressions

Storms and depressions occur in the Indian Seas during the period April to December. In the south Indian Ocean they occur off Madagascar and off the west coast of Australia, the frequency being a maximum during January, February and March. Much new information relating to storms and depressions in the Indian Ocean and the adjacent seas has come from the satellite photographs in recent years and the satellite has now become an invaluable tool for locating and tracking tropical storms and depressions.

Conclusion

The survey that I have tried to present is rather sketchy and incomplete in several respects. Nevertheless, I hope it provides a background for the papers that will be presented and discussed shortly.

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DISCUSSION

K. R. SAHA : You have referred to Bunker's explanation of the low level Somali jet as a thermal wind. Since thermal wind in the area is from a north-easterly direction, it would appear that the description of the Somali jet as a thermal wind may not be correct.

R. ANANTHAKRISHNAN : The Somalia Coast runs approximately SW-NE ; the effect of upwelling off this coast is to cause a temperature gradient in the perpendicular direction over the sea area and the overlying air of the atmosphere. With such a situation, the thermal wind in the lower layers of the atmosphere over the West Arabian Sea off the Somalia Coast will be in a south-westerly direction.

N. S. BHASKARA RAO : How can the westerly jet (low level) reported by P. V. Joseph cause upwelling of the west coast.

R. ANANTHAKRISHNAN : I have not examined this matter. It occurred to me after listening to Dr. Panikkar's talk last evening that there might be a possible association as we find off the Somalia Coast. The matter needs further study.

A. NOBLE : What is the relation between the wind and rainfall during monsoon period ? What is the common causative cause behind this ? Can the amount of rainfall expected in a season be predicted earlier by studying the wind ? Such informations would possibly help in the prediction of certain fishery along our coasts.

R. ANANTHAKRISHNAN: The relation between wind and rainfall is not very simple and direct. Rainfall is associated with situations of low level convergence in the wind field which favours vertical motion of air. Rainfall occurs when there is sufficient supply of moisture at the lower levels under such situations. Low level convergence can arise from several causes. It is not practicable to predict the total rainfall in a season by studying the antecedent wind field. Seasonal forecasts of monsoon rainfall which is being done by the India Meteorological Department are based on statistical methods employing a number of parameters most of which relate to areas outside Indian region.

P. K. VIJAYARAJAN : Please explain the discrepancy between the onset of south-west monsoon in May and the rain in June in Arabian Sea.

R. ANANTHAKRISHNAN : I do not clearly understand this question. Over Kerala as well as over Bengal and Assam the monsoon rains are preceded by pre-monsoon thunderstorms in April and May. It becomes difficult, therefore, to decide the date of onset of the monsoon from the rainfall curves alone. The word 'Monsoon' is used with two different meanings by the India Meteorological Department. Over the sea area it relates to wind while overland it relates to rainfall.