Mausam, (1985), **36**, 2, 151-158

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The monsoon experiment*

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(*Received 3 February 1981*)

सार — इस आलेख में 1979 के मानसून प्रयोग (मोनेक्स) के प्रेक्षण कार्यक्रम का वर्णन किया गया है। यह कार्यक्रम अन्तर्राष्ट्रीय वैज्ञानिक संघ (आई० सी०एस०यू०) तथा विश्व मौसम संगठन के तत्वाधान में प्रथम गार्प भूमण्डलीय अनुप्रयोग (एफ०जी०जी०ई०) का एक उप-कार्यक्रम था।

इस प्रयोग की सफलता में कई देशों ने योगदान दिया। इस प्रयोग में सोवियत रूस के पांच अनुसंधान पोतों तथा संयुक्त राज्य अमेरिका के तीन अनुसंधान वायुयानों ने भाग लिया, जब कि फ्रांस ने एक जहाज तथा एक स्थिर स्तर गुब्बारा कार्यक्रम द्वारा योगदान दिया। भारत ने चार जलयान और एक वायुयान उपलब्ध कराए। भारत देश के ऊपर प्रेक्षण कार्यक्रम तेज कर दिया गया।

अन्तरिक्ष स्थित मंचों में से एक भूस्थिर उपग्रह जिसे सं०रा०अ०-गोज हिन्द महासागर में प्रक्षेपित किया था, को मोनेक्स क्षेत्र के लिये विशेष रुप से स्थानान्तरित किया गया था। जापान द्वारा प्रक्षेपित एक अन्य भूस्थिर उपग्रह ने मोनेक्स क्षेत्र के पूर्वी क्षेत्र के मेघ चित्र उपलब्ध करवाए।

इस शोध पत्र में 1979 के मानसून के कुछ उन प्रमुख लक्षणों का वर्णन किया गया है जो इस प्रयोग में प्रेक्षित किए गए। भारतीय वायुयान ने तीव्र तापमान प्रवणता रिकार्ड की और जी०ओ०ई०एस० मेघ सदिशों ने मानसून के आरंभ होने के विषय में मूल्यवान आंकड़े उपलब्ध करवाए।

अन्त में, इस शोध पत्र में एक साधारण पूर्वग समीकरण मॉडल द्वारा नैदानिक अध्ययनों का वर्णन किया गया है। यह मॉडल जिन मानसून लक्षणों की हू-बहू नकल उतार सका उनका भी वर्णन किया गया है। साथ ही मानसून के अन्य पहलुओं के अध्ययन में इसके विस्तार की भी चर्चा की गई है।

ABSTRACT. The paper describes the observation programme of the Monsoon Experiment (MONEX) of 1979. This experiment was a sub-programme of the First GARP Global Experiment (FGGE) under the aegis of the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO).

A number of countries contributed to the success of the experiment. Five research ships from the USSR and three research aircraft from the USA took part, while France contributed a ship and a constant level balloon programme. India contributed four ships and one aircraft. The observation programme over the country was intensified.

Of the space based platforms, a geostationary satellite launched by the USA-GOES Indian Ocean was specially moved to cover the MONEX region. Another geostationary satellite launched by Japan provided cloud imageries for the eastern sector of the MONEX region.

The paper describes some of the prominent features of the monsoon of 1979, which were observed by this experiment. Strong temperature gradients were recorded by the Indian aircraft, and the GOES cloud vectors provided valuable data on the onset of the monsoon.

Finally, the paper describes diagnostic studies with a simple primitive equation model. Those monsoon features, which the model was able to simulate, are described, and its extension to the study of other facets of the monsoon is discussed.

1. Introduction

A Global Atmospheric Research Programme (GARP) was organised by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) in 1967. Under this programme a Global Weather Experiment was conducted for one full year beginning on 1 December, 1978. This is one of the biggest ever international experiments — on a global scale — for observing the earth's atmosphere.

Some idea of the dimensions of this experiment may be had from the fact that during May of 1979 as many as 52 research ships were deployed over the tropical oceans between the latitudes 10 deg. N and

*Paper presented in the symposium "Indo-French school on recent advances in Computer Techniques in Meteorology, Biomechanics and applied systems" held at I.I.T., New Delhi, February 1980.

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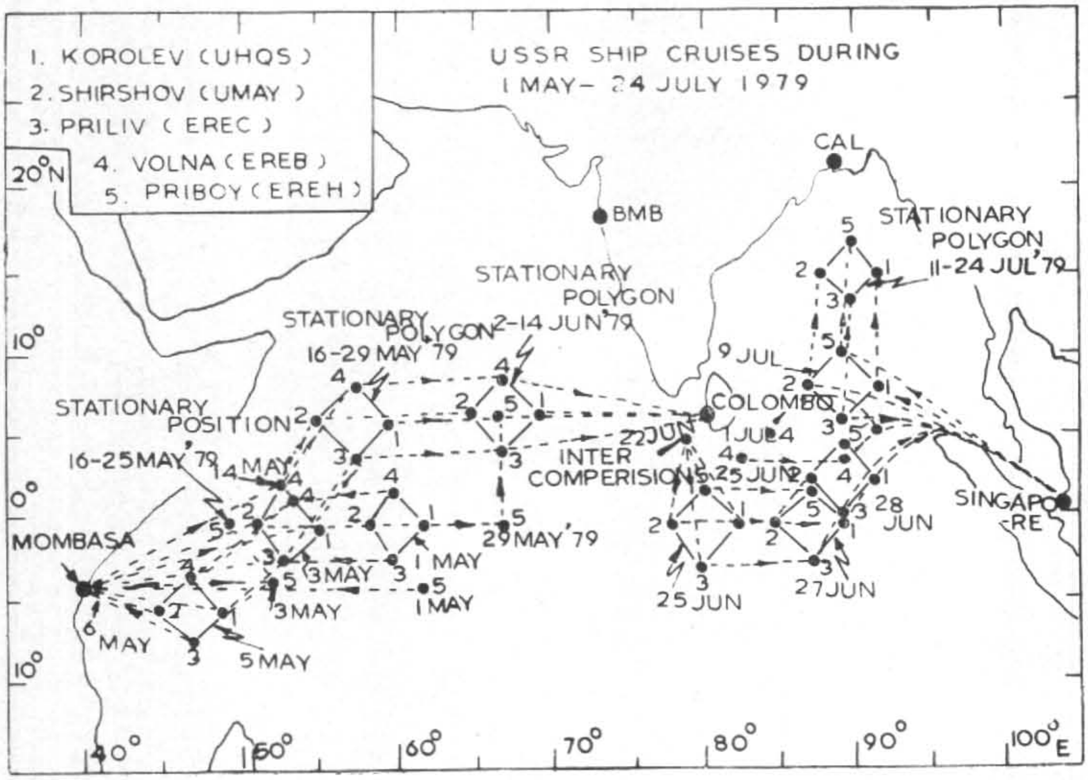

Fig. 1. USSR ship cruises

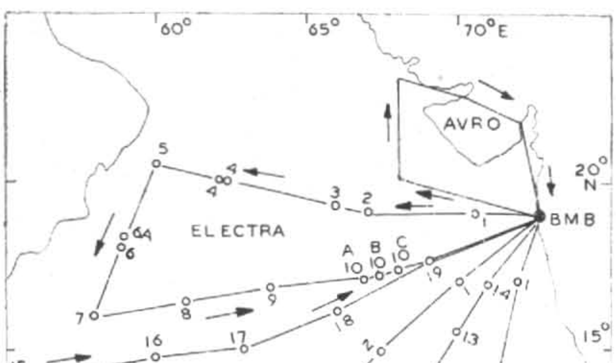

Fig. 2. Flight tracks of US and Indian aircraft missions on 27 June 1979

10 deg. S, while 104 aircraft missions were successfully completed over different parts of the Pacific, the Atlantic and the Indian Oceans during the same period.

Of considerable interest to India is a sub-programme of the Global Weather Experiment. This is the Monsoon Experiment, popularly known as MONEX. Its purpose was to study the contribution of the monsoon, in different parts of the world, to the earth's atmosphere.

There are two main monsoon systems. The winter and northern monsoon is a consequence of north-easterly winds blowing over the oceans, and the westward passage of disturbances to the south of the equator. The winter rains over the southern half of the Indian Peninsula are associated with the winter monsoon. But, by far the more extensive system is the summer monsoon, when southwesterly winds flow over the Indian Ocean and seasonal rains extend over India and many countries in Southeast Asia. The duration of the summer monsoon is roughly a hundred-day period, beginning with the end of May each year.

The monsoon is also observed over Africa, especially its western and central parts. There appears to be only one monsoon over Africa, and this is associated with the northern summer.

2. MONEX management centres

In view of its seasonal character, the Monsoon Experiment (MONEX) was divided into the following three parts :

(*i*) Winter MONEX from 1 December 1978 to 5 March 1979 : Which covered the eastern Indian Ocean and the Western Pacific Ocean along with the land areas of Malaysia and Indonesia.

(*ii*) Summer MONEX from 1 May 1979 to 31 August 1979 : This covered the eastern coast of Africa, the Arabian Sea, the Bay of Bengal and the adjacent land areas. It also extended over the Indian Ocean from 10 deg. N to 10 deg. S.

(*iii*) West African Monsoon, or WAMEX, over the western and central parts of Africa for the duration of the northern summer.

International MONEX Management Centres were set up in Kuala Lumpur and in New Delhi to supervise the winter and summer components, respectively, of the Monsoon Experiment. A large number of scientists from different countries visited and worked at these Centres to plan the experiment. A similar centre was set up in West Africa for WAMEX. To maximize the data output, plans were drawn up for the transmission, storage and retrieval of data. The data have been divided into the following three categories :

(a) *Level I* — raw primary data, such as the original record of different sensors,

(b) *Level II* — meteorological variables, such as wind speed and direction from raw data,

(c) *Level III* — processed data in the form of charts and weather maps.

Some of the data will be processed on real time, while other will be processed later. The Level III data are expected to become available two years after the termination of the experiment, but a good part of the Level II data will become available six months after the field phase of the experiment. Indian scientists at the International MONEX Management Centre in New Delhi have drawn up computer programmes for real time checks on the consistency and accuracy of incoming data.

3. Observation platforms

3.1. *Surface based platforms*

Among the surface based platforms, the major contributions for Summer MONEX were the following :

(a) five research ships from the USSR

(b) three civilian research aircraft from the USA

(c) four research ships and one aircraft from India

(d) one research ship from France.

The five research ships from the USSR moved into the Bay of Bengal after completing the Arabian Sea phase of the experiment. They cruised in the form of a moving polygon, with a spacing of approximately 400 km between adjacent ships. This is illustrated in Fig. 1.

Valuable data were obtained by the flight missions of three civilian research aircraft from the USA. Of particular interest were data on the radiation balance of the earth-atmosphere system. They measured both the incoming radiation from the sun and the radiation emitted by the earth's surface. The latter was, in turn, modified by overlying clouds and aerosols in the atmosphere. The reflectivity of the soil was another important variable, which was measured from the air. The US aircraft were equipped with dropwindsondes. These instruments were fitted with meteorological sensors and a tiny parachute. The sensors transmitted their data directly to the aircraft as they descended with the parachute. Fortysix scientific missions were flown by US aircraft for the Arabian Sea phase of MONEX with a similar number for Bay of Bengal part of the experiment.

The Indian ships were equipped, for the first time, to measure upper winds. This was achieved with the help of balloon-borne Omegasondes. It used a system based on the intersection of radio beams, on very low frequencies, to monitor the track of a balloon which in turn, provided a measure of the speed and direction of the wind. One of the ships ran into very disturbed sea. It was stationed fairly near to a cyclone which later struck the coast of Andhra Pradesh. Observations were recorded with much difficulty.

Flights by an Indian aircraft, belonging to the National Remote Sensing Agency, for monsoon studies represent a creditable achievement which augurs well for the future. This aircraft recorded the following parameters in analog form :

(*i*) Total air temperature

(*ii*) Static and dynamic pressure

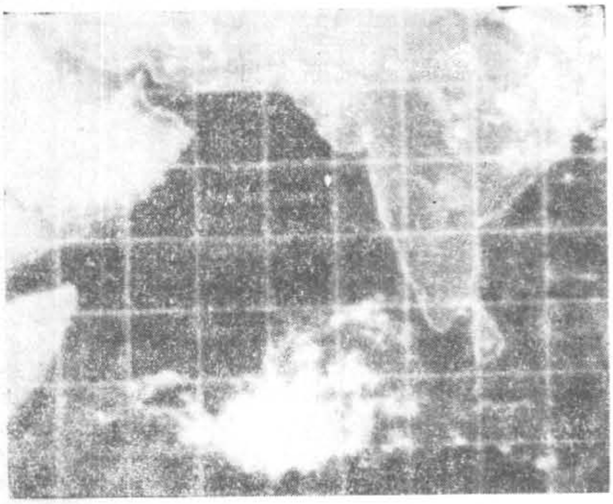

Fig. 3. Satellite picture received on 16 May 1979

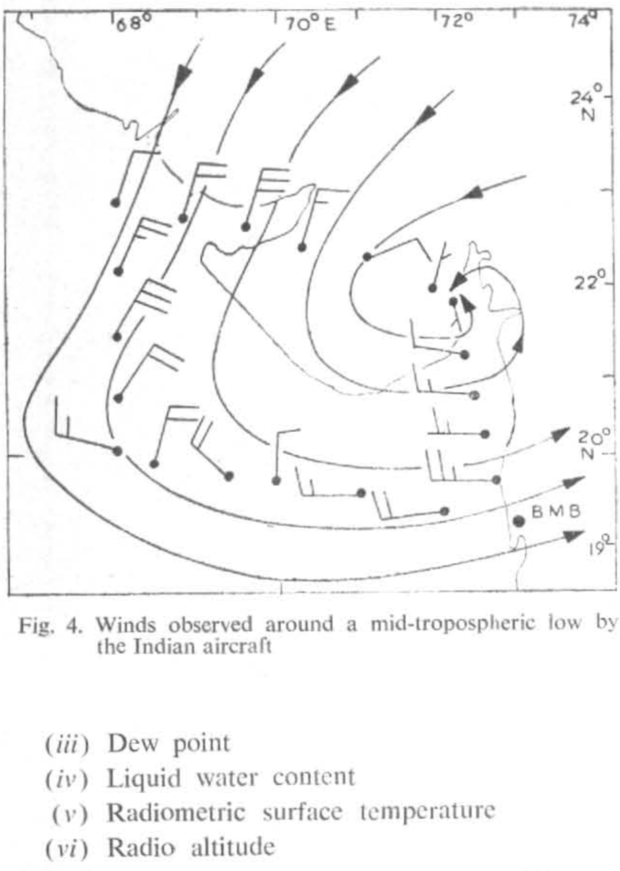

Fig. 4. Winds observed around a mid-tropospheric low by the Indian aircraft

(*iii*) Dew point

(*iv*) Liquid water content

(*v*) Radiometric surface temperature

(*vi*) Radio altitude

Some of the data were obtained under conditions of turbulent and disturbed weather, associated with depressions and tropical cyclones. These observations owe a good deal to the skill and courage of the aircraft crew. Typical flight tracks of all the aircraft (US and Indian) taking part in MONEX over the Arabian Sea are shown in Fig. 2.

France contributed a ship to track the path followed by the monsoon air with the help of balloons that flew at a constant altitude. These balloons were designed to reveal the trajectory of the air as it approached the Indian coastline during the southwest monsoon.

The observation programme of the India Meteorological Department was considerably increased and intensified to meet the MONEX requirements. A number of additional stations were set up to measure upper winds, along with a network of 8 stations for measuring solar and terrestrial radiation profiles with balloon-borne equipment.

A boundary layer programme for measuring meteorological elements near the earth's surface was designed, jointly, by the Indian Institute of Science, Bangalore and the US MONEX Project. This programme achieved a series of extremely interesting observations of the flux of momentum, sensible heat and water vapour at Digha, a coastal station near Contai in West Bengal. These observations were made with a 10 m mast and they represent, probably for the first time, measurements of the flux of atmospheric variables close to the earth's surface under Indian conditions. A very sensitive Lymen-alpha Hydrometer was used to measure water vapour fluxes.

There were two other programmes which considerably enhanced the overall importance of MONEX. The first was designed to investigate the lower stratosphere with the help of rockets launched from (*i*) Thumba, (*ii*) Sriharikota, and (*iii*) Balasore, with a frequency of approximately one per week. This was organised by the Indian Space Research Organisation (ISRO). The importance of this programmes arises from the fact that it will enable us to assess, probably for the first time, the response of the stratosphere to the lower tropospheric monsoon circulation in a co-ordinated manner. One of the rocket stations was located near the equator; consequently, this programme could be valuable for studies on the propagation of the equatorial waves in the lower stratosphere. It is expected to continue this programme with further expansion in the near future.

The second programme was concerned with oceanography. Vertical profiles of ocean currents and other oceanographic elements were measured by all ships taking part in this experiment. These data, apart from being of interest to oceanographers, will also interest meteorologist, because they will provide the input for ocean-atmosphere coupled models.

3.2. *Space platforms*

One of the attractive features of MONEX was the response it generated from many countries. Several countries agreed to intensify their national observational programmes during the operational phase of MONEX and to communicate their data to the International MONEX Management Centre in Delhi.

Weather satellites are now capable of measuring an impressive array of meteorological elements. Television cameras fitted on these satellites observe the structure of clouds beneath them and transmit them, automatically, to a ground station located on the earth. This is referred to as an Automatic Picture Transmission (APT) system, and the receiving point on the earth is an APT station. A network of eight APT stations was set up in India during MONEX.

Weather satellites are of two broad types : (a) those which orbit round the earth from pole to pole, and (b) those which rotate round the earth with the same speed as that of the earth round its own axis. The latter are geostationary satellites, because they appear to be stationary with respect to the earth. The geostationary satellites have the advantage of being able to monitor, continuously, any part of the earth's surface round the clock.

A beginning towards reception of data from the geostationary satellites was made during MONEX. A geostationary satellite — GOES INDIAN OCEAN — was specially moved to a location on the equator at 60 deg. E to cover the MONEX region. Clouds and cloud clusters observed by GOES were beamed towards Bombay by another geostationary satellite, METEOSAT, which was launched earlier by the European Space Agency. Cloud imagery from GOES were first received at Lannion in southern France, and thence transmitted to METEOSAT for onward communication to Bombay. Ground reception facilities were set up at Bombay for this purpose. One of the pictures received at Bombay during the early phase of the monsoon is shown in Fig. 3. The clarify of the Indian land mass is remarkable. Facilities were also provided at Dacca in Bangladesh for receiving cloud images from another geostationary satellite launched by Japan. Collaboration between India and Bangladesh thus provided us with satellite coverage for both the western and the eastern sectors of the MONEX region.

4. Scientific objectives

MONEX was an exercise at one-time data collection. The greatest value of this experiment lies in the expectation that it would reveal those features of the monsoon, which we need to monitor every year for anticipating its performance. The prolonged drought in the current monsoon has once again emphasized the importance of long range prediction of monsoon rainfall. There are three facets on which we require immediate improvement in our prediction capability. They are :

(*i*) an indication of the likely dates of onset and withdrawal of the monsoon over different parts of the country,

(*ii*) a forecast of the total quantum of monsoon rainfall during the hundred-day period from beginning of June to mid-September,

(*iii*) likely periods of either heavy or lean rainfall leading to floods or droughts during the monsoon season.

There are several important crops in our country, which are grown in areas that depend critically on rainfall. Paddy is an example, because the main rice producing regions are rainfall dependent; consequently, an indication of the monsoon features, which we have enumerated above, are important for the periods just prior to sowing, transplantation and finally, the harvest.

There are fairly well identified lines on which research could immediately commence after the MONEX data become available. One of them is concerned with the earth-atmosphere radiation balance. There is a delicate balance between the total energy which we receive by way of solar radiation and the radiation that is lost to space from the gaseous envelope that surrounds the earth.

Recent satellite data reveal, for example, that the excess or deficiency of incoming solar radiation over the amount which the atmosphere loses to space is only of the order of 50 watts per square metre. Regions of excess in radiation show wide variations from year to year. It is possible that the performance of the monsoon is linked to this pattern of radiation balance over the MONEX region. The MONEX data could be utilised to study this linkage.

It is a fairly well-known fact that the atmosphere is a highly turbulent medium in which a number of waves on different scales of motion are hurtling round the earth. How do these waves interact with each other to generate the weather producing systems, such as the monsoon depressions and the tropical cyclones ? The accurate wind data, coupled with information on the thermal structure of the atmosphere, would help meteorologists in India to understand these physical processes. The data collected by the Indian research aircraft have shown that the monsoon depressions in the north Bay of Bengal are often generated in region of strong thermal contrast. Hitherto, it was widely believed that these depressions were merely cyclonic vortices emitted in regions of weak or no thermal contrast, but recent aircraft data suggest a temperature gradient of 6-8 deg. C over a distance 500 km. The interaction between the thermal and wind fields raises several interesting possibilities, which have a bearing on the genesis of the monsoon depressions.

Short term changes in the monsoon rainfall are mainly the result of : (*i*) depressions in the Bay of Bengal, (*ii*) mid-tropospheric low pressure system over Gujarat, and (*iii*) the north-south movement of an elongated low pressure zone over the Gangetic zone, known as the monsoon trough. By way of an illustration, we indicate the winds that were observed around a mid-tropospheric low by the Indian aircraft during one of its flight (Fig. 4). We could not have acquired such data over a small region by conventional means. The MONEX data will help us to identify these systems with much greater accuracy.

There is an increasing realisation that in addition to features of regional interest, such as the depressions and vortices of small dimensions, the monsoon is a much large phenomenon which makes a big impact on the global circulation of the atmosphere. Observations are beginning to emerge which suggest that a lean monsoon over India is often balanced by abundant rainfall in some other parts of the world or *vice-versa.* Hitherto, we had envisaged the global circulation of the atmosphere in terms of Hadley or anti-Hadley cells. These cells were either driven by an

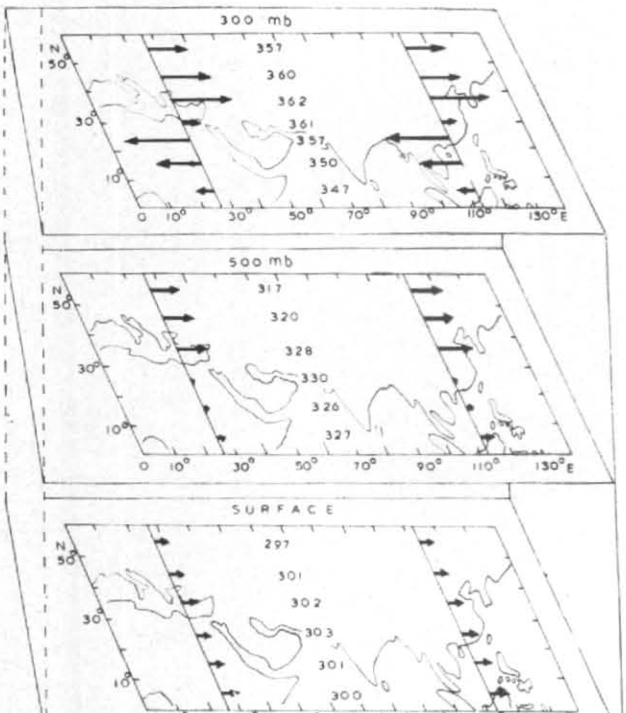

Fig. 5. Initial state with meridional and vertical shear. Arrows indicate wind directions and figures represent temperatures

excess of radiation near the equator, or at mid-latitudes by the rotation of the earth. It has been conjectured that there exist large-scale circulations of another type, oriented in an east-west direction which are perpendicular to the Hadley and anti-Hadley cells. The dynamics of these cells is still obscure because the data for this purpose were not available, but there is the interesting possibility that by monitoring the intensity of these atmospheric circulations (east-west cells) in other parts of the world we could anticipate the performance of the monsoon over India. Further details of the experiment and its scientific objectives, are available in planning reports of the experiment [WMO 1978; WMO 1979 (a) and (b)].

5. Numerical modelling

One way of investigating the behaviour of the monsoon modelling experiments. Numerical experiments are designed to simulate the monsoon in all its facets by a mathematical model. If we begin with an initial state, albeit hypothetical, we could, with the help of an electronic computer, identify those features of the atmosphere which help to generate the monsoon. The model could help us to ascertain, in quantitative terms, what would be the response of the monsoon if some of these features, such as the input of solar radiation, was either increased or decreased.

5.1. *The governing equations*

The basic equations of a numerical model are: (*i*) the equations of motion, (*ii*) the equation of continuity, (*iii*) an equation of state and (*iv*) the first law of thermodynamics. The equations of motion represent Newton's second law of motion for an atmosphere rotating with the earth, while the equation of continuity represents the conservation of mass. The acceleration of a moving parcel of air is related to body forces by the equations of motion. The main body forces are generated by gradients of pressure and friction. The equation of state provides a relation between the three scaler variables of the atmosphere, namely, the pressure p, density ρ and temperature T, while the first law of thermodynamics relates changes in the entropy of air with non-adiabatic (known as "diabatic" in meteorology) sources of heat.

The principal diabatic sources of heat are related to the heat balance of the earth-atmosphere system, and the physics of condensation in the atmosphere. The latent heat released during a change in phase from vapour to liquid water is an important source of diabatic heat in the atmosphere.

We will not describe the derivation of the basic equations in more detail because this is available in several texts. A review article by Phillips (1963) provides a complete account of the derivation, and the simplifications which are normally made in deriving the governing equations. These simplifications are based on a scale analysis of the motion which we wish the model to reproduce. For the purpose of a monsoon model, with which we have had some experience in India, a convenient system of governing equations is :

$$u_t+(uu_x+vu_y+\dot{\sigma}u_\sigma)-fv=-\varphi_x-c_p\theta\pi_x+\mu\nabla^2u \quad (1)$$

$$v_t+(uv_x+vv_y+\dot{\sigma}v_\sigma)+fu=-\varphi_y-c_p\theta\pi_y+\mu\nabla^2v \quad (2)$$

$$\varphi_\sigma+c_p\theta\pi_\sigma=0 \quad (3)$$

$$\theta_t+(u\theta_x+v\theta_y)+\dot{\sigma}\theta_\sigma=\dot{Q} \quad (4)$$

$$p_{\sigma_t}+(up_\sigma)_x+(vp_\sigma)_y+(\dot{\sigma}p_\sigma)_\sigma=0 \quad (5)$$

In the above system x and y are horizontal cartesian coordinates pointing eastwards and northwards; t is time; u, v are the x and y components of velocity; f is the coriolis parameter; c_p is the specific heat of air at constant pressue and θ is the potential temperature. φ stands for the geopotential, and $\dot{Q}$ is the rate of diabatic heating per unit mass of air. μ is a diffusion coefficient (10^5 m^2 sec^{-1}). The suffix notation is used to denote partial derivatives. We also define

$$\pi=(p/1000)^k \quad (6)$$

$$\sigma=(p-200)/(p_s-200) \quad (7)$$

where $k=R/c_p$ and p_s is the surface pressure. On differentiating (5), we find

$$p_\sigma\dot{\sigma}_\sigma+p_\sigma(u_{\sigma_x}+v_{\sigma_y})+u_\sigma p_{\sigma_x}+v_\sigma p_{\sigma_y}=0 \quad (8)$$

Along the lateral walls of the limited area model, the

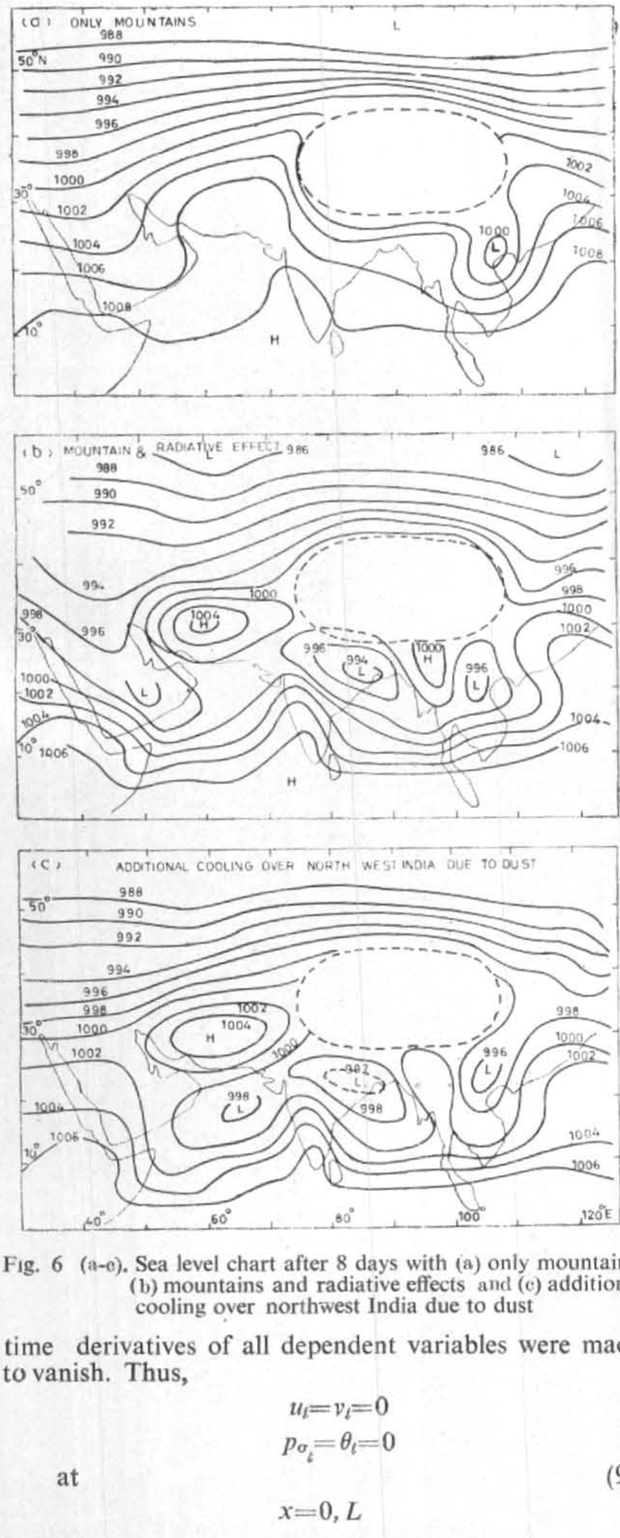

Fig. 6 (a-c). Sea level chart after 8 days with (a) only mountains, (b) mountains and radiative effects and (c) additional cooling over northwest India due to dust

time derivatives of all dependent variables were made to vanish. Thus,

$$u_t = v_t = 0$$

$$p_{\sigma_t} = \theta_t = 0$$

$$\text{at} \qquad x = 0, L \qquad y = 0, L \tag{9}$$

The above system of equations and the computational procedure for monsoon studies has been described by Das and Bedi (1977), and it will not be repeated here. The computation scheme replaces partial derivatives with finite difference in both space and time There are other models, which are currently used in other parts of the world. Some of them have been

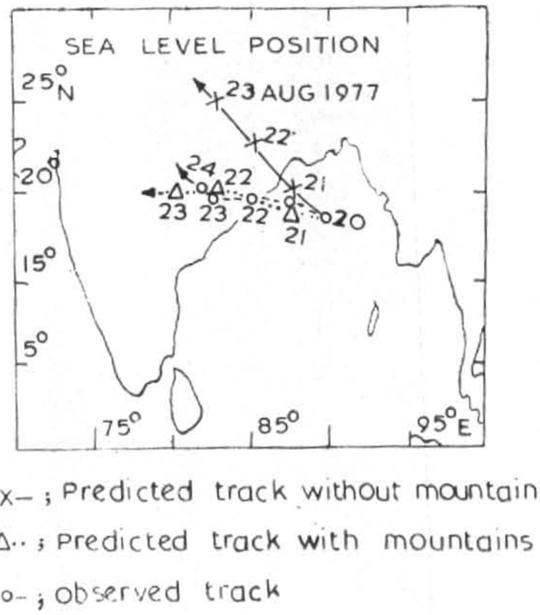

Fig. 7. Observed and predicted depression tracks. Full line indicates predicted track without mountains, dotted line with triangles indicates predicted track with mountains. Dotted line with circles indicates the observed track

used for monsoon studies. In this context, we mention a model by Krishnamurti *et al.* (1973) for the tropics. A modified version of this model was developed by Singh and Saha (1976). Multilevel models have been also constructed by the U. K. Meteorological Office for research and operational use (Corby *et al.* 1977; Saker 1975). Their utility for monsoon studies was described by Shaw (1978).

5.2. *Results of modelling experiments in India*

We shall discuss below a few results, which have been obtained with the model described in 4.1 :

Fig. 5 depicts an idealised initial state. It has westerlies at the surface but, at 500 mb, the westerlies weaken south of 30 deg. N. At 300 mb the tropospheric westerlies are replaced by easterlies to the south of 30 deg. N. This corresponds, approximately, to the monsoon circulation which has a transition at 500 mb between lower westerlies and upper easterlies. The easterlies aloft are generated by an anticyclonic circulation over the monsoon regime. The vertical and meridional wind shears in Fig. 1 were carefully adjusted so that the initial state was not dynamically unstable. It may be noted, however, that there was an anticyclonic wind shear in the initial state along 30 deg. N.

Fig. 6 (a) indicates the result of integrating the model up to 8 days with mountain forcing. The dotted area indicates the idealised Himalayas which were introduced into the model. The figure shows that no monsoon trough was generated as the result of forcing by mountains. The Western Ghats and the Burmese mountains were also included in the model, although they have not been explicitly shown in the figure. It was interesting to observe the anticyclonic curvature of isobars as the wind traversed the Western Ghats.

The deep lee trough to the east of the Himalayas was another important feature.

In Fig. 6 (b) the result of 8 days integration is shown with the additional inclusion of radiative forcing. It was interesting to note in the figure that the model was able to reproduce the monsoon trough. This suggests that the formation of the monsoon trough is not merely a mechanical effect caused by the alignment of mountains. Radiative imbalances play an important part in its formation. The model, however, generates a well-marked anticyclone over Iraq and Iran. This was unrealistic. The reason for this are now being investigated. In Fig. 6 (c) we again illustrate 8 days integration, but with the addition of a heavy dust load over north-west India. We see that the model succeed in giving a more realistic picture of the monsoon trough, but the unrealistic anticyclone over the middle east still remains in a weakened form.

During the Indo-Soviet expedition of 1977 the four USSR ships, aligned in the form of polygon, were able to provide useful data on a monsoon depression in the Bay of Bengal on 20 August 1977. We used the model to predict the movement of this depression with and without mountains. The track without mountains was very far to the northwest. This is shown by a full line in Fig. 7. On the other hand, when mountains were included (dotted line with triangle) the computed track was in fairly good agreement with the observed path of depression (dotted line with circles). While these experiments are in a preliminary stage, they illustrate the fact that many of the well-known features of monsoon could be reproduced with the help of simple three-dimensional primitive equation models.

6. Summary and conclusions

We have presented an account of the operational phase of monsoon experiment. The data management phase of the experiment is in progress. At the end of this phase, we should have processed the data and compiled them in a convenient form for the scientific community. Preliminary research, with the data have been started by scientists in India and abroad. As the final data set becomes available, a large increase in monsoon research is likely. It is not too much to expect that as a result of MONEX, our understanding of various aspects of monsoon will improve in the near future. The MONEX data will, we hope, enable us to ultimately improve our capability to predict the behaviour of the monsoon. This experiment represents a significant step toward helping the rural sector of India through better information on the changes in weather.

The numerical model which we have discussed above is in a preliminary stage. Precipitation physics, cumulus convection and air-sea interaction processes, which are important for the tropics, have not yet been incorporated. But it is encouraging to note that it is possible to simulate a number of interesting features of the Indian monsoon by simple models. It seems reasonable to expect better results in future by extending the capability of these models. We have, for example, partly succeeded in simulating the monsoon trough, but the models have not yet been able to throw much light on why the trough moves periodically north and south of its normal location. A similar situation prevails on the question of the formation of monsoon depressions. The models so far have not been able to simulate the formation of a depression starting from an initial stage, but there has been some success in predicting the course of a depression after it has formed. There are other areas where further modelling work is needed; the formation of the Inter-tropical Convergence Zone (ITCZ) is an example of such a field. It is not yet clear whether the ITCZ merely loses its identity with the advance of the monsoon, and a secondary low pressure area forms over India, or whether the ITCZ gradually moves northwards across Arabia.

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