SESSION IX

GENERAL STUDIES OF MONSOONS

CHAIRMAN : DR. T. MURAKAMI

Hawaii University, USA

Indian J. Met. Hydrol. Geophys. (1978), 29, 1 & 2, 435-440

551.553.21 : 551.507.321.3 : 551.3 : 551.552(267)

Lagrangian study of the low-level flow field over the Indian Ocean during the summer monsoon

DANIEL CADET, PAUL OLORY-TOGBE and GILLES SOMMERIA

Laboratorire de Meteorologie Dynamique, Ecole Polytechnique
Palaiseau Cedex, France

ABSTRACT. A new tool has been developed for Lagrangian study of the Planetary Boundary Layer over long distances. During the summer of 1975, 45 low-level superpressure balloons were launched from the Seychelles Islands for flights within the tropical boundary layer over the Indian Ocean. The balloons were located by the Nimbus-6 satellite which also relayed pressure measurements made aboard the balloons. The experiment provided very adequate Lagrangian trajectories up to 10 days, which have shown the different regimes of the monsoon. The main results are summarized. They clearly prove the large range of possibilities offered by low-level balloons to map air currents and complement other types of meteorological data, especially in sparse coverage areas.

The Laboratoire de Meteorologie Dynamique plans a new and larger experiment for the MONEX period in 1979. A brief account of its scientific and experimental objectives is given.

1. Introduction

The following paper gives an account of experiments led by the Laboratoire de Meteorologie Dynamique over the tropical Indian Ocean with the use of constant density low-level balloons.

The advantages of superpressure balloons to complement conventional meteorological data have been demonstrated by the GHOST (Lally *et al.* 1966) and EOLE (Morel and Bandeen 1973) experiments. Launched from a few selected sites they fly at approximately constant density levels, acting as pseudo-Lagrangian tracers of air parcels and as meteorological platforms; the localization and data relay is best obtained through a satellite equipment. This technique is well adapted for the study of large scale air flow patterns over vast poorly surveyed oceanic areas: although it was primarily developed for high level flights, the need to extend its capabilities to the planetary boundary layer was felt, especially for tropical studies (Sommeria and Cadet 1974).

Preliminary experiments were performed in 1973 and 1974 (Cadet *et al.* 1975) to achieve the degree of reliability needed for low-level flights of sufficient length. The main one took place during the 1975 northern summer (Cadet and Ovarlez 1976): between June 26 and August 6, 45 balloons were launched from the Seychelles Islands (4·7°S, 55·5°E) to explore the low-level flow over the Indian Ocean. Trajectories over periods of up to 10 days were obtained mostly in the southwesterly flow over the Arabian Sea and shed a new light on some of the problems related to the Indian monsoon. A larger and improved experiment of this kind is again planned in connection with the MONEX GARP subprogram for the 1979 summer. After a presentation of the main experimental characteristics and results of the 1975 campaign, our objectives for 1979 will be stressed.

2. Experimental aspects of the 1975 experiment

The experimental objectives aimed at obtaining reliable platforms able to fly as low as 500 metres over tropical oceans for more than a week. Besides the satellite localization, the only meteorological variable to be measured was the ambient pressure at flight level, recorded every hour.

The test flights performed in 1973 showed that the most important difficulties faced by balloons at low altitudes over tropical areas are first, the heavy rain showers which overload the envelope and force it down to the sea and, second, the loss of buoyancy during the night provoked by condensation of dew on the balloon skin. The first problem was solved in 1974 with a new entirely enclosed disposition of the equipment inside the balloon and the second one by covering its upper hemisphere with a thin aluminized mylar cap.

The balloons were 2-metre diameter spheres made of mylar film. The electronic equipment, except for the antenna and pressure transducer, was placed inside the envelope as shown in Fig. 1. A white plastic container attached to both poles of the balloon housed the power supply (lithium cells) and the transmitter-oscillator. The antenna, the barometric capsule (an aneroïd capsule with capacite coupling) and associated electronics were fastened to the upper pole of the balloon with an appropriate protection against water for the pressure transducer. This design was meant to survive waves and rain buffeting, and allowed the balloon to recover its nominal buoyancy after drying out. The upper hemisphere of some balloons was covered by a thin aluminized mylar cap for radiative control of the envelope temperature in order to prevent a deposition of dew during the night.

The platforms were located by the Random Access Measurement System (RAMS) on the Nimbus-6 satellite, positions being generally obtained every 12 hours. Every minute, each balloon transmitted for one second a 401·2 MHz signal including 340 ms of unmodulated continuous wave and a 64 bit message including 32 bits of meteorological data. Subcommutation allowed transmitting 4×32 bits of information in 4 successive emissions. During the sequences of emission, the balloon telemetered the instantaneous as well as the last 12 recordings of the ambient pressure taken at a one-hour interval. The spacecraft passed in view of the tropical areas where the experiment was taking place every 12 hours for a maximum of 2 or 3 orbits in a row (the orbit period was 2 hours). When the messages from a balloon were received on two successive orbits, the average velocity over two hours was available as well as the position. The uncertainty was of the order of 5 km for the position and 1·5 m sec^{-1} for the velocity. When the messages from the emitting platforms were received on a single orbit of the satellite only its position was available.

The balloons were released during three launching periods. In the first period, from 26 June until 5 July, launchings were at a rate of one balloon per day. During the second one, 11 July until 24 July and the third period, 28 July until 6 August, two launchings were performed almost every day.

3. Main results of the 1975 experiment

The mean lifetime of the balloons was 4 days with a maximum of 9 days for 4 of them, providing very adequate trajectories. This result can be regarded as mediocre but it has to be reminded that the environment for low-level superpressure balloons in tropical areas is severe : thus it was noticed that for many balloons their last locations were near intense convective areas.

Flight levels were planned at 1000 or 500 metres above the ocean, however the actual levels were found to be rather variable. The main feature of this variability is the diurnal oscillation within the very moist tropical boundary layer (Fig. 2). Some balloons were found to fall to the sea surface recovering their flight levels after drying out. Due to this oscillation, it is somewhat questionable to qualify the balloons of "quasi-Lagrangian tracers". One is led to admit that the wind shear is small within the sub-cloud layer in trade wind regimes and that a balloon provides an average mixed layer trajectory when its nominal level is planned for 500 metres and its actual level oscillates between sea level and 500 metres. Of course any period of time spent at sea level should not be taken into account.

Examples of trajectories will now be presented. During the first launching period (Fig. 3), they clearly illustrate a gradual change in direction of the air flow over the western part of the Indian Ocean. At the beginning, the air crossing the equator near 55°E reaches the western coast of India and brings rain. Afterwards, probably due to the existence of intense convection over the western Arabian Sea, the direction veers to west-northwest and one balloon engages the East African low-level jet (Findlater 1969). Figs. 4(a) and 4(b) illustrate the trajectories obtained at the beginning of the second launching period. They indicate a great steadiness in direction and speed of the low-level winds. They show that during that period, the air crossing the equator to the east

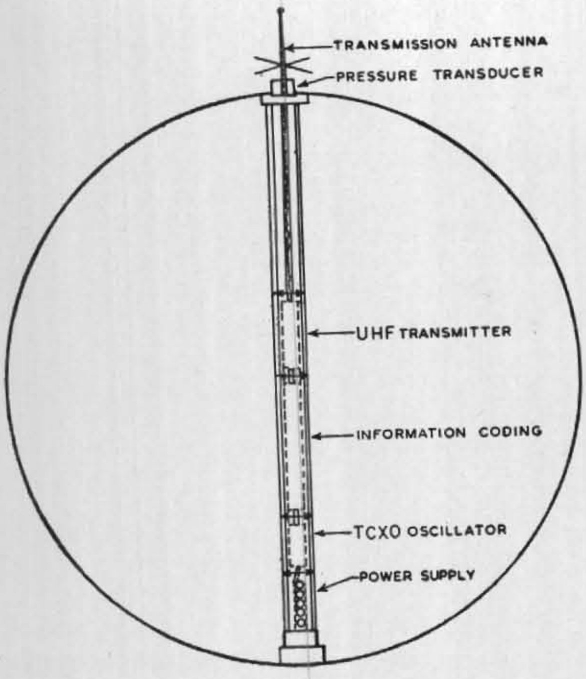

Fig. 1. Internal balloon payload and envelope

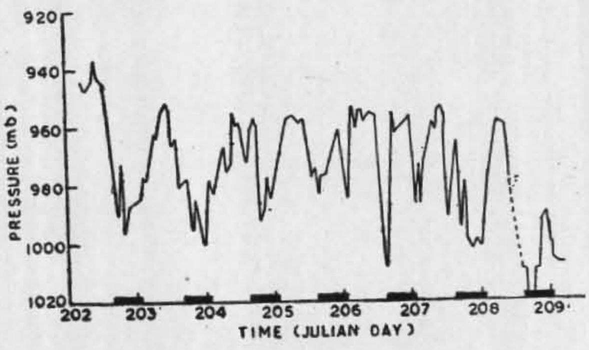

Fig. 2. Pressure-height *versus* time graph. Flight 1117. Expected flight level, 955 mb. The diurnal oscillation is easily noted. Dates are in Julian days. The black marks on the time scale correspond to local night

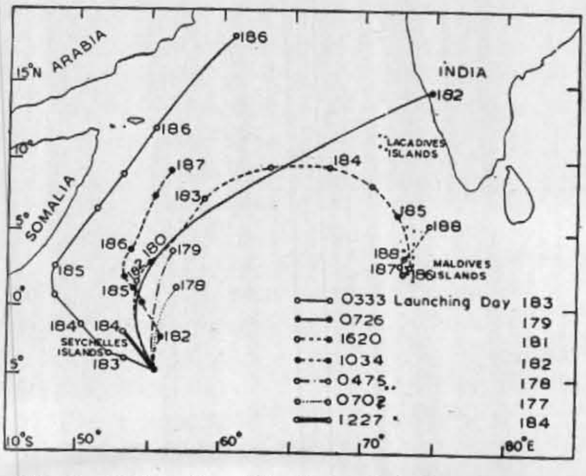

Fig. 3. Trajectories of the first period : 26 June-5 July (D 177-186). The numbers correspond to the 1975 Julian days

of 55°E flows eastwards along the southern Indian coast to join the Bay of Bengal branch of the monsoon. Thus the air striking the western coast of India must cross the equator to the west of 55°E. At the end of the second launching period (Fig. 4c), except for the first flight which is similar to the previous ones, the monsoonal flow reverses. The last balloons are drawn towards Madagascar. This is due to the passing over of a westward-moving tropical disturbance propagating over the southern Indian Ocean (Cadet and Olory-Togbé 1976a). During the third period, the trajectories resume the classical circulation (Fig. 5). However a change in the air flow occurs : the direction of the first trajectories are north-northwest and the last ones have initially a northeast direction. This

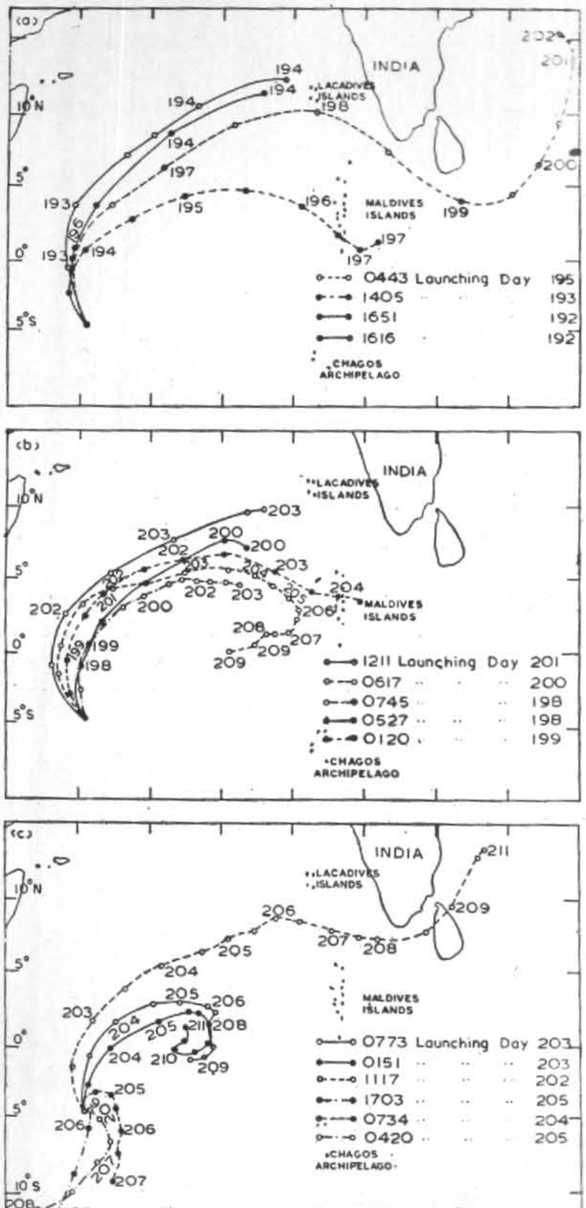

Fig. 4(a). Trajectories of the second period (first part) : 11 July-14 July (D 192-D 195)

Fig. 4(b). Trajectories of the second period (second part) : 15 July-20 July (D 196-D 201)

Fig. 4(c). Trajectories of the second period (third part) : 21 July-24 July (D 202-D 205)

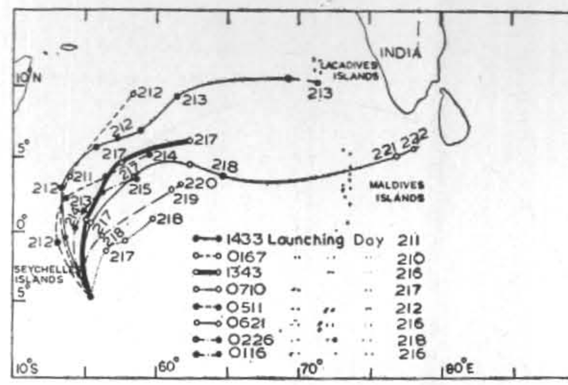

Fig. 5. Trajectories of the third period : 28 July-6 August (D 209-D 218)

seems to be related to the occurrence of an eastward-moving disturbance over northern equatorial Indian Ocean.

The trajectories by themselves provide important pieces of information but it is useful in any case to combine them with other data. An analysis of the fields of some parameters as the wind intensity and direction, sea surface temperature etc is now under way at LMD and will be presented by Cadet and Olory-Togbé (1976 b). The analysis is based on conventional data available over the Indian Ocean during the same period and which are compared to the trajectories. This comes in addition to the compilation of cloudiness data from the NOAA-4 satellite visible photographs.

Up to now two general ideas can be stressed in relation to the summer monsoon circulation: the first one is the evidence of a quasi-permanent large scale atmospheric flow from the southern hemisphere (southwest part of the Indian Ocean) all the way to both western and eastern coast of India. Typically the air reaching the western coast crosses the equator west of 55°E and goes through the East African low-level jet. The air crossing the equator in the vicinity or eastwards from 55°E is deflected towards the east in the northern hemisphere and meets the Bay of Bengal branch of the monsoon. This goes along with Findlater's (1969) findings showing the division of the Arabian Sea branch of the monsoon into two separate currents. The northern current affects the western coast of India north of 15°N and the southern current breaks away near 10°N over the Arabian Sea and flows eastward along the southern Malabar coast.

The second main idea is the importance of northern and southern hemisphere tropical disturbances which trigger the fluctuations of each element of the monsoon flow. The disturbances are clearly observed on the satellite nephanalyses and in our case move eastwards in the northern hemisphere and westwards in the southern hemisphere. Their passing over thoroughly affects the balloon trajectories and the best example of that is the reversal of the flow near the Seychelles islands at the end of July 1975. These changes are linked to wind and pressure changes all along the monsoon flow which ultimately affect the rainfall over India.

4. Plans for a participation in MONEX

The results of the 1975 campaign encourage the planning of an improved and larger experiment which would take place during MONEX in summer 1979.

The first objective is to obtain a sufficient number of cross-equatorial trajectories in the monsoon flow for a given period of time. One or two flight levels should be chosen as low as possible in order to yield data representative of the mixed layer over the ocean but high enough for a fair life expectancy of the balloons. Trajectories provide wind data in the absence of other observations and can be studied as it has been shown below. It is however desirable to launch simultaneously from two sites in order to get an extensive coverage of a given area. This allows also divergence and vorticity studies from triads of tracers. The Seychelles Islands will probably be kept as the first launching site and a second one will be chosen in a more meridional position which would permit longer trajectories. It seems desirable to avoid that too many balloons engage the low-level jet over the western Arabian Sea because of the risk involved in passing over the orographic features of East Africa. The possible use of a ship as a second launching platform is also studied.

The second scientific objective of the experiment is to obtain better understanding of the dynamics of the planetary boundary layer on large horizontal scales. Constant-level trajectories present the advantage of averaging the horizontal velocity over periods of a few hours and estimates of the mean "friction" over the ocean can be derived with the use of the horizontal wind equation :

$$\frac{d\bar{V}}{dt} + f\bar{k} \times \bar{V} + \frac{1}{\rho}\,\overline{\nabla p}\,\left[\overline{w}\,\frac{\partial \bar{V}}{\partial Z} + \right. \left. + \frac{\partial}{\partial z}(\overline{w' v'})\right] = 0$$

where d/dt is the Lagrangian horizontal derivative and $\bar{V}$ is the average horizontal wind vector. The first two terms are directly given by the balloon trajectory and the term in brackets can be computed as a residual if the large scale pressure gradient is measured by the ship network with sufficient accuracy. The pressure gradient at flight level is then computed with the knowledge of the balloon height from its pressure measurement. No geometric altitude measurement is scheduled for this experiment. When the vertical wind shear can be neglected or estimated, it is possible to deduce a value for the mean vertical gradient of the momentum flux. This evaluation, especially if made at more than one level, can be used in the parameterization of the tropical boundary layer.

A third objective would be a Lagrangian thermodynamic study along the trajectories with the help of temperature, moisture and possibly radiative budget sensors aboard the balloons. The technical feasibility of adding these devices is presently studied. The data, along with schematic one-dimensional model for the tropical boundary layer, would allow estimates of the rates of evaporation and heating from the ocean surface in various regions along the monsoon flow; it would help understanding the relationship between the rainfall over India and the other features of the monsoon circulation.

REFERENCES

Cadet, D., Ovarlez, H. and Ovarlez, J. 1975 *J. appl. Met.*, **14**, pp. 1478-1484.

Cadet, D. and Ovarlez, H. 1976 *Quart. J. R. met. Soc.*, **102**, pp. 805-816.

Cadet, D. and Olory-Togbe, P. 1976a The propagation of tropical disturbances over the Indian Ocean during the summer monsoon. Submitted to *Mon. Weath. Rev.*

1976b Low-level air flow circulation over the Arabian Sea during the summer monsoon as deduced from satellite-tracked superpressure balloons. Part II : Analysis of the flow field. To be submitted to *Quart. J. R. met. Soc.*

REFERENCES (contd)

Findlater, J.	1969	*Quart. J. R. met. Soc.*, **95** pp. 362-380.
Lally, V.E., Lichfield, E. W. and Solot, S. B.	1966	*WMO Bull.*, **15**, pp. 124-128.
Morel, P. and Bandeen, W.	1973	*Bull. Amer. met. Soc.*, **54**, pp. 624-640.
Sommeria, G. and Cadet, D.	1974	Constant-level balloon flights in the boundary layer : Pre-GATE tests and plans for GATE, Int. Trop. Met. Meeting, Nairobi, Amer. met. Soc., **2**, pp. 79-83.