Tellus (1978), *30*, 252–259

Three-dimensional wind structure around convective elements over a tropical island

By C. I. ASPLIDEN, R. S. HIPSKIND, J. B. SABINE and P. VALKENAAR, *Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, U.S.A.*
and R. L. DESOUZA, *Department of Earth Sciences, Millersville State College, Millersville, Pennsylvania, U.S.A.*

(Manuscript received February 11; in final form July 5, 1977)

ABSTRACT

During the summer of 1973 a pilot balloon experiment was undertaken on the island of Barbados. One of the objectives was to obtain measurements of the flow fields around cumulus clouds during undisturbed conditions. The main results were: less than 1% of the balloons entered the base of clouds; no balloon was observed to enter the sides of the clouds; the clouds moved on the average of 2 m s^{-1} slower than the surrounding air when positive vertical shear existed; balloons accelerated over the clouds on the cloud's upwind side instead of entering or circumscribing them; when in close proximity of the clouds balloons on either side of the clouds moved laterally, not into them, but into the overriding current on the upwind side; up- and downdrafts associated with the clouds were of the order of 1–3 m s^{-1}; and circulation around a horizontal axis through the cloud and perpendicular to the general flow may support the existence of a cumulus cloud street parallel to the flow for hours.

1. Introduction

The windfield in the lowest 1 km of the tropical troposphere has always been of great concern to the meteorologist. In this layer convergent windfields must exist in order to transport heat, mainly latent, from the surface upwards to produce clouds. Detailed measurements of the windfield in this layer, however, are not carried out on a regular basis. Routine rawinsondes provide the major part of such information. Yet this instrument is not suitable for low-level measurements since such ascents are subject to considerable uncertainty even during controlled research experiments. Recently, elaborate tethered balloon systems have been designed to obtain details of the kinematic and thermodynamic properties of the subcloud and lower cloud layers (Ropelewski, 1975; Echternacht and Garstang, 1976). These electronic packages are expensive and require much attention and cumbersome calibrations. Much improvement of these systems is still desired to increase their reliability. A cheap and well-proven method to obtain low-level winds is the pilot balloon. Its greatest disadvantage is that it is limited to operation during fair weather conditions, when the cloud amount is small. The pibal is very suitable for studying the windfields around small trade cumuli in the tropics, since releases can be carried out with fairly high space and time resolution at a minimal cost. Such a program was conducted on the island of Barbados during the summer of 1973.

2. Data

Nearly 4000 pilot balloons were released from various sites on the southeastern corner of the island (Fig. 1). The 10 g balloons were tracked with recording theodolites using both single and double theodolite methods. The balloons were filled with helium until they just fit into a pre-measured metal loop to give an ascent rate of 120 m min^{-1}. In this way the balloons would have the same diameter at release and also they could be checked for roundness, which is a very important controlling

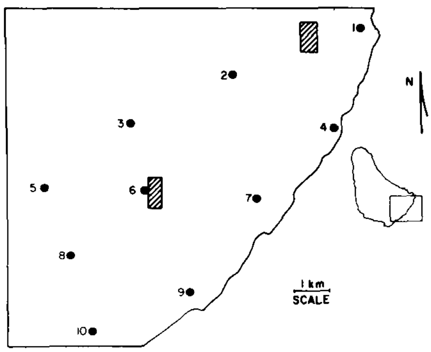

Fig. 1. Pilot balloon station network on the south-eastern corner of Barbados during the summer of 1973. High density time series ascents were executed in the hatched areas. Station 10 is Seawell airport from where rawinsondes were released.

factor of the ascent rate (Ludlam, 1953). Several empirical formulas for calculating the ascent rate for use with the single method are found in the literature (Berry et al., 1945; Meteorological Office, London, 1944). The following one has been used here:

$$V = \frac{qL^{1/2}}{(L + W)^{1/3}}$$

where V = ascent rate in m s^{-1}, q = constant = 1.40, L = free lift in g, W = mass of balloon in g.

The azimuth and elevation angles were mechanically recorded every 30 s on paper tapes. The azimuth angle was read to the nearest 0.1 degree, and the elevation angle to the nearest 0.05 degree.

It has been assumed throughout this study that the balloons with their very small inertia react to the motion of the air they are rising through to such a degree that no serious errors are introduced into the measurements.

The winds were computed in both raw and smoothed form. Smoothing was done by utilizing a weighted (1, 2, 1) moving average of order three. This procedure filters out high frequency fluctuations that are both real and erroneous.

Initially control operations were carried out, to raise the skill of the observers and to ensure the proper functioning and operation of instruments and balloon filling. Five theodolites at either end of a north–south baseline (almost 600 m and normal to the average wind direction) were set up. Using the double theodolite method twenty-five wind profiles were obtained for each balloon release. Computer facilities on the island permitted wind calculations following each day's operation. In this way, errors and problems could be located and the training program was continued until the errors were reduced to an acceptable minimum, i.e. the profiles for each ascent were virtually all the same.

The hatched areas in Fig. 1 indicate where intensive time series measurements were taken. During the acquisition of these data series ten theodolites were used, either in pairs, five at each end of a baseline (double method) or singly at the same site (single method). Both methods have their limitations. If the double method was used balloons could be released every 2 min to reach a maximum height of about 1000 m, or every 4 min to reach about 2000 m (in both cases allowing some time for balloon filling, log keeping, etc.). When the single method was employed balloons could be released twice as often to reach the corresponding heights with the sacrifice of some accuracy in the measurements. The data presented here are mostly of a 1-min interval (single method) although double-method measurements have been used where needed for the interpretation of some results.

During these series the balloon trajectories were not only observed from the release point, but also from the side and from a site down stream. Such visual observations often helped to clarify the balloon path in relation to the clouds. Very detailed logs were kept during the experiment giving information about every ascent, cloud and weather conditions, and any other relevant facts.

Supporting data included four rawinsonde ascents at 08, 12, 16 and 20 LT from Seawell airport (station ten in the array, Fig. 1). A rainfall network with approximately 200 fence post raingages and 10 recording gages was established within the network. The non-recording gages were read twice a day when conditions so warranted.

The weather conditions during the days on which the data were taken were typically undisturbed mode 1 or 2 conditions (Aspliden, 1976).

3. Results

Only those results which are directly associated with the flow fields around trade cumuli will be discussed in this paper. Wind measurements covering other parts of the project have been reported on elsewhere (Aspliden et al., 1976).

In Table 1 are given typical sample sizes, ascent rates and standard deviations for double theodolite soundings taken around small cumuli. In front of an approaching cumulus downdrafts are encountered; after its passage there are on the average updrafts, while between these extremes the mean ascent rate is about the same as the assumed. The standard deviation is large. This is to be expected as the balloons were purposely launched so that their paths would intersect the three-dimensional flow associated with the cumulus elements.

Table 1. *Mean ascent rates of double theodolite soundings taken between July 11–18, 1973*

	In front of clouds	Between* clouds	Behind clouds
Number of ascents	24	28	29
Mean ascent rate (over 30 s)	48.2	59.8	69.4
Standard deviation	20.3	8.0	17.5

* Interpreted as not being under direct influence of clouds.

The strength of the smoothed up- and downdrafts is of the order of 1–3 m s^{-1}, Table 2. Peak values in the raw data exceeded occasionally 4 m s^{-1} (measured over 30 s). The time during which the balloons were affected by the up- and downcurrents associated with the small trade cumulus was in general less than 1 min.

Table 2. *Smoothed vertical velocities calculated from double theodolite ascents. Vertical component calculated for each 30 s interval for 40 ascents*

	Sample size	Mean (m s^{-1})	Standard deviations (m s^{-1})
Positive values	175	+2.52	0.53
Negative values	150	−2.50	0.52
Total	325	+2.05	–

Number of values > 3 m s^{-1}: 36.
Maximum "updraft" velocity: 3.18 m s^{-1}.
Maximum "downdraft" velocity: −3.48 m s^{-1}.

Ascents at a release interval of 1 min (using the single method) were made from the hatched areas in Fig. 1, during a few days when a small but seemingly organized cumulus population was present for several hours of the day. Most of these time series contained at least one hundred ascents. Several interesting observations were made during such flights:

(1) Less than 1% of the balloons entered the base of cumulus clouds. Less than 30 balloons of nearly 4000 released during the project are known to have penetrated the cloud base.
(2) Not a single balloon was observed to enter the sides of the cumuli.
(3) The cumuli moved slower than the current in which they were embedded. The difference in the majority of cases was 1.5–2 m s^{-1}. On all the undisturbed days during which balloons were released, the horizontal wind exhibited a positive shear with height in the subcloud and cloud layer. This is verified in Fig. 2 which illustrates the mean wind profiles in this layer as obtained from rawin and pilot balloon observations during three days (July 25–27).

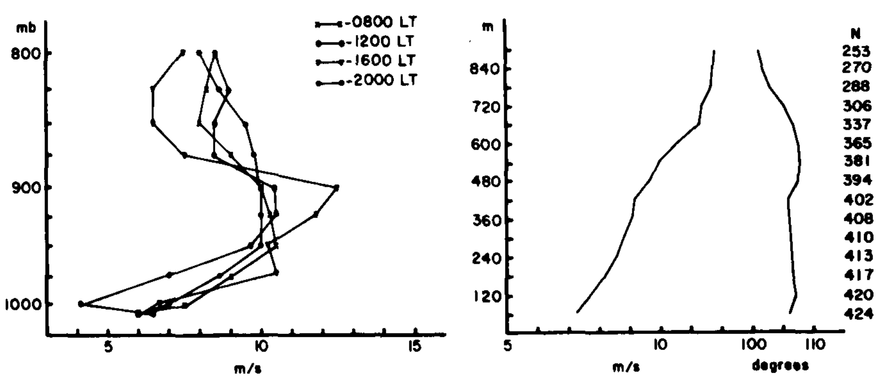

Fig. 2. Mean windspeed profiles as measured by rawinsonde (left) and mean windspeed and direction profiles as measured by pilot balloons on July 25–27 1973. N = number of measurements at each level.

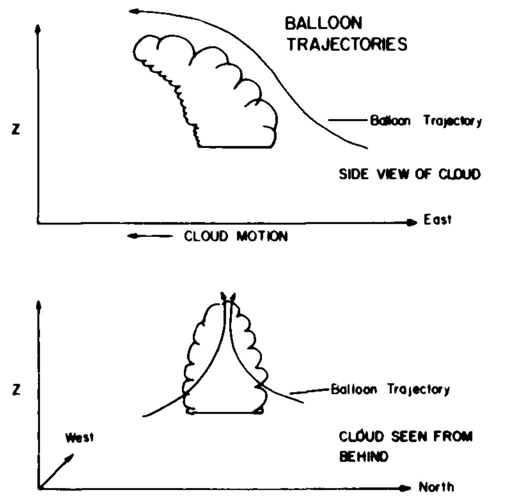

Fig. 3. Balloon trajectories in the vicinity of cumulus clouds.

The shear was also very well evidenced by the clouds, which always sloped markedly downwind with height.

(4) Trajectories of balloons, which were released after the passage of clouds and in their down stream paths, went over the upwind side of the clouds, into what appeared to be an accelerating current (Fig. 3).

(5) Balloons which were released after the passage of clouds but to either side of their paths down stream, were observed to move in toward the cloud and to enter the accelerating current outside of the cloud on its upwind side (Fig. 3).

(6) Wind speed and direction exhibited a systematic pattern of oscillations in the subcloud layer extending through the lower cloud layer. The oscillation was most pronounced during morning hours at about 400 m above ground (cloud base was at 600–700 m); the period varied from 10–15 min; the speed ranged from 8–15 m s^{-1} and the direction fluctuated between 100–110 degrees. A typical time series, for July 25, displaying such oscillations is presented in Fig. 4. Time series containing more than one hundred consecutive ascents each were exposed to spectral analysis. Although the samples are rather small for such a treatment, the obtained results, 0.08 cycles min^{-1} or a period of 12.5 min, agree with our visual inspection of the time series.

4. Discussion

The observation that very few balloons entered the cumulus clouds through the base is not new. Although it is difficult to find publications with explicit reference to such events, it seems to be generally accepted by meteorologists in the tropics. Charnock et al. (1956) reports that ... "the balloons rarely, if ever, disappeared into the Anegada cumulus." Nearly four hundred ascents were made during the experiment. There are a few incidents reported in the literature when balloons were either accidentally caught in a cloud (Levine et al., 1973; Barnes, 1970) or deliberate attempts were made to get balloons into clouds (Booker et al., 1966). A cumulus humilis or small trade cumulus has a life span of not more than 15–20 min (Malkus, 1950). Its growing period is about one-third of that. The growing is not continuous but occurs in stages. Bubbles of latent heat are fed, not from the surface, but from the upper subcloud layer into the cloud. BLIS (Boundary Layer Instrumentation System) data taken during the GATE show that maritime cumulus clouds have shallow roots (Emmitt, 1975). The observed resultant balloon trajectory is the sum of the free lift ascent velocity of the balloon, the horizontal air motion and vertical air motion. Net upward balloon motion occurs for vertical air motion > -2 m s^{-1}, while the horizontal balloon velocity is assumed to be that of the air and is in most cases 1–2 m s^{-1} greater than that of the cloud. Therefore the more vertical the resultant balloon trajectory is, the greater is the chance that the balloon may enter the cloud. It follows that the favorable area of the cloud base for the balloon to enter is only a fraction of the total cloud base and the entering should preferably take place during that fraction of the cloud's life when upward motion exists there. Outside the updraft area and during the whole decaying period the cloud is primarily associated with downward motion. Considering these space and time constraints it is therefore not surprising that cumuli bases are so inhospitable to balloons.

Similarly, no balloons were seen to enter the walls of the clouds. On the downwind side of the cloud downward motion must be the rule judging from the fragmented structure that is observed here throughout the life of the cloud. On the upwind side wind currents override the cloud (discussed in the next section). Therefore, it is very unlikely for an

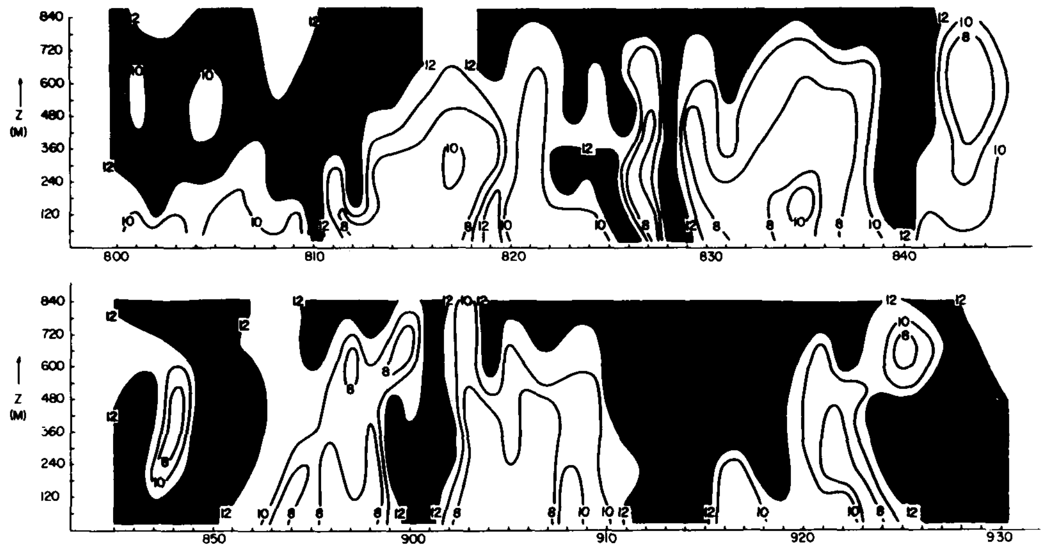

Fig. 4. Oscillations of windspeed as measured at the 400 m level on the morning of July 25 1973. The horizontal axis indicates local time in min. Windspeeds greater than 12 m s^{-1} are shaded.

ascending balloon in the subcloud layer to enter a cloud either from the front or from behind. However, one would have thought it should be feasible for balloons to become entrained into the cloud from the sides. Since this was not observed to take place, it is assumed that the balloons either did not come close enough to become part of the entrainment, or the detrainment shedding protected the cloud from intrusion during such occasions. As entrainment occurs in response to the updrafts, its existence both with regard to space and time must be limited in a similar way to that of the updrafts.

The observations of balloon trajectories overriding cumulus clouds as well as balloons being forced into the overriding current from the sides of the cloud are spectacular. The questions that first come to mind are of course "why don't the balloons go horizontally around the clouds?" and "why doesn't the overriding current condense?" Melkus (1949, 1952a and 1952b) determined that cumulus clouds embedded in a positive shear move slower than the environmental air. She found that the horizontal velocity difference between clouds and environmental air is mainly dependent on the shear while the effect of mass-momentum entrainment is only minor. Our results of 1.5–2 m s^{-1} velocity difference for shallow cumulus substantiate those of hers which were "on the order of 2 m s^{-1}".

The cloud moves in a torque field with a horizontal axis perpendicular to the general wind flow. This torque is set up partly by the shear and partly by the up- and downdrafts associated (thermodynamically induced) with the cloud itself. Riehl (1954) discussed these conditions from the viewpoint of vorticity considerations. The change of vorticity around the axis may be written as:

$$\frac{d\eta}{dt} = -\eta \, \mathrm{div}$$

where

$$\eta = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}$$

and

$$\mathrm{div} = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z}$$

and other terms are neglected; u and w represent the flow field just outside of visible cloud. If it is assumed that initially mass-balance exists (div = 0) and that the vorticity in the environment is conserved, it follows that

$$\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \frac{\partial U}{\partial z}$$

where U is the horizontal wind component in the environment in the direction parallel to wind (x-component, easterlies are positive). In the low levels of a normal tropical atmosphere $\partial U/\partial z > 0$. In the immediate vicinity of the cloud itself, $\partial u/\partial z$ is also > 0. Observations indicate that on the upwind side $\partial u/\partial z > \partial U/\partial z$ and on the downwind side $\partial u/\partial z < \partial U/\partial z$. In agreement with these results, it follows that $\partial w/\partial x > 0$ on the upwind side and $\partial w/\partial x < 0$ on the downwind side. Visual observations confirm this. Billowing appearance and sharp contours are characteristic of the upwind side of the cloud. There is no indication of any mixing with outside air. On the downwind side the cloud is ill-defined and fragmented. Here cloud matter can actually be seen to dissolve. Cloud drops which emerge and evaporate in the surrounding air, cool the air and consequently the air becomes negatively buoyant. This is confirmed by measured downward motion in this region. These downdrafts are frequently larger than 2 m s^{-1} as the balloons entering here are actually descending. The flow around the cumulus is not as simple as described by the abbreviated two-dimensional vorticity equation. Mass-balance is only achieved by importation of air from the sides as shown in Fig. 3. Also the circulation set up by the cloud and the shear must affect the immediate environmental air both on the upwind and the downwind sides of the cloud. Balloon trajectories confirm that upward motion exists on the upwind side and downward motion on the downwind side of the cloud.

The observation that air is moving over the clouds without condensing is informative. In Table 3 low-level temperatures and humidities are given as measured by radiosonde at Seawell at 11 LT, July 25, one of the days on which balloons were observed to ride over the clouds. If the overriding current consisted of air from below the cloudbase with $q \geqslant 16.2$ g kg^{-1} condensation would occur somewhere between cloudbase and 1200 m (lower cloud tops). It is to be expected, however, that some air would be entrained into the current from the sides as well as from upstream. Since the clouds frequently occurred in a cloud street parallel with the flow, each cloud ejects droplets into the air, which evaporate and increase the air's humidity content. This added humidity would be of the order of 1 g kg^{-1}, since the liquid water content of small cumulus is about 1 g m^{-3} (Malkus, 1954). Despite these modifying processes, there are still no traces of condensation observed at the cloud tops (1200–1500 m). One may conclude, therefore, that the air in the overriding current must be primarily of above cloudbase origin.

Table 3. *Temperature (T) and specific humidity (q) at 11 LT, July 25 1973, at Seawell*

Height (m)	Observed T (°C)	Observed q (g kg^{-1})	Saturated q (g kg^{-1})
1200, cloud tops (1200–1500)	19.6	11.4	16.2
600, cloudbase (600–750)	22.1	16.2	18.0
Surface	29.6	17.0	26.5

During 7 days, July 25–31 1973, several 1 min interval time series with a hundred or more consecutive ascents were run. Part of such a series is shown in Fig. 4. The shaded areas indicate wind speeds greater than 12 m s^{-1}. There is a regular pattern of high and low wind speeds. The high speeds are noted to occur on the downwind side of the cumulus and the low speeds on its upwind side. From the double theodolite soundings taken around cumulus it is known that on the upwind side updraft currents exist and downdrafts on the downwind side as well as above average horizontal wind speeds. However, a downdraft will cause a decrease in the elevation angle which will correspond to a fictitious increase in the horizontal speed, when using the single theodolite method with an assumed ascent rate. The reverse is true for an updraft. In these time series, therefore, the high wind speeds which were measured on the downwind side, most likely represent both downward motion as well as an increase in the horizontal speed. Unfortunately no double theodolite readings were taken during these series. Therefore these contributing factors to the resultant horizontal wind speed cannot be specified separately.

Similarly to the observed variations in wind speed small changes in the wind direction were also noted. On the morning of July 25 the measured wind directions were on the average of 5–10 degrees more northerly on the downward side of the clouds than on their upwind side. However, these small but noticeable changes were on each occasion consistent with the change of wind direction with height. For example, if the winds backed with height then the wind directions downwind of the clouds also were more northerly than those on their upwind side. These changes of the wind speed and direction in the upper subcloud and lower cloud layers on the downwind side of the clouds indicate that the downdrafts transferred momentum from higher levels.

Based on the various observations discussed above and especially those taken during the 1 min time series a schematic model of the wind flow associated with a cumulus cloud street moving in a wind field with positive vertical shear and parallel with the flow, can be assembled. Such a model is presented in Fig. 5.

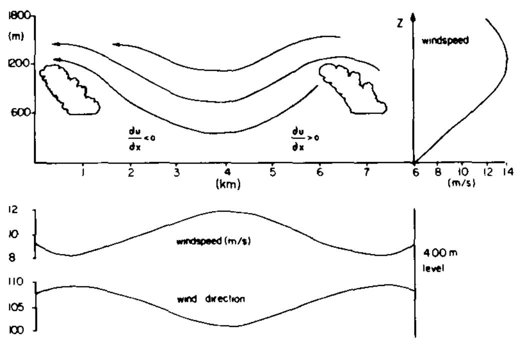

Fig. 5. Schematic model of the wind flow associated with a cumulus cloud street parallel with the flow with positive vertical shear during undisturbed conditions.

The suggested alternating divergence–convergence field is a direct result of the vertical wind shear and the up- and downdrafts associated with the cumuli. Once a cumulus is formed a cloud row would develop and have a tendency to maintain itself provided the initial meso and synoptic scale conditions are not altered. Also the individual clouds would propagate downstream and their otherwise relatively short life span would be prolonged considerably. Sixteen-millimeter time lapse films of such cloud streets are available from the pre-BOMEX experiment of 1968. During a 15-day spell in September 1968, a street of such clouds was visible over the ocean a few kilometers south of Barbados from morning to late evening. These films show that each cloud within the row sustained itself while within observational range, i.e. for more than 1 hour.

It is very likely that the cloud street found over the island on several days during the 1973 experiment was only a part of an array of cloud streets over the region (Malkus, 1963). Our network was not designed to make such measurements of the overall island cloud distributions.

5. Concluding remarks

A number of interesting wind measurements made around small tropical cumulus clouds during undisturbed conditions have been presented and discussed. It is evident from these observations that the factor that to a great extent determines the flow conditions around these convective elements is the vertical shear of the horizontal wind. Without the shear a rotation around a horizontal axis perpendicular to the general flow would be unlikely. Nor would the up- and downdraft regions in the environment of the immediate vicinity of the clouds be so well distinguished. These up- and downflows in the environment govern to a large extent the entrainment–detrainment of the clouds. The vertical shear is also the mechanism responsible for the development of a particular kind of cloud streets parallel to the flow. However, the family of cumuli consists of a large and diversified hierarchy of clouds. It is therefore very likely that the associated flow fields are as diversified as the clouds themselves. Depending on the environmental conditions individual cloud rotation may be established around vertical and horizontal axes or both, so that a multitude of different wind regimes could result. However, nature is rather selective, so that even if dozens of combinations are theoretically possible very few would indeed be probable and realistic. It should therefore be possible to specify the dominant environmental conditions so that the resulting flow conditions around cumulus clouds could be determined in each case. Not only would such a classification of conditions be an aid in forecasting, e.g. rotational severe storms, but it would also be of interest to cloud experimentalists and researchers, e.g. in the field of cloud seeding.

6. Acknowledgements

The authors wish to thank the Royal Swedish Air Force for making fifteen recording theodolites available during the field project. They also would like to acknowledge the assistance given them by Mr G. Rudder, Director of the Caribbean Meteorological Institute, and the Government of Barbados. The work was supported by the National Science Foundation under grant GA36321 and by the Global Atmospheric Research Program, National Science Foundation, and the U.S. GATE Project Office, National Oceanic and Atmospheric Administration, under grant ATM74-21701-A02.

REFERENCES

Aspliden, C. I. 1976. A classification of the structure of the tropical atmosphere and related energy fluxes. *J. Appl. Meteor. 15*, 692–697.

Aspliden, C. I., Lynn, A., DeSouza, R. and Rudder, G. 1976. Diurnal and semi-diurnal low level wind changes over a tropical island. (Accepted by *Boundary-Layer Meteor.*)

Barnes, S. L. 1970. Some aspects of a severe, right-moving thunderstorm deduced from meso-network rawinsonde observations. *J. Atmos. Sci. 27*, 634–648.

Berry, F. A., Bollay, E. and Beers, N. R. 1945. *Handbook of meteorology*. New York: McGraw-Hill Book Company.

Booker, R. D., Cooper, L. W. and Auer, A. H. 1966. A new system for severe storm studies. Final Rept. Grant CWB-11274 to the National Severe Storms Laboratory.

Charnock, H., Francis, J. R. D. and Sheppard, P. A. 1956. An investigation of the wind structure in the trades: Anegada 1953. *Phil. Trans. R. Soc. Ser. A, 249*, 179–234.

Echternacht, K. L. and Garstang, M. 1976. Changes in the structure of the tropical subcloud layer from the undisturbed to disturbed states. *Mon. Wea. Rev. 104*, 407–417.

Emmitt, G. D. 1975. Momentum redistribution by enhanced mixing over heated islands. Ph.D. dissertation, University of Virginia, Department of Environmental Sciences, Charlottesville, Virginia.

Levine, J., Garstang, M. and LaSeur, N. E. 1973. A measurement of the velocity field of a cumulus cloud. *J. Appl. Meteor. 12*, 841–846.

Ludlam, F. H. 1953. The rate of rise of pilot balloons. *Meteor. Mag. 82*, 306.

Malkus, J. 1949. Effects of wind shear on some aspects of convection. *Trans. Amer. Geophys. Union 30*, 19–25.

Malkus, J. S. 1950. The birth and death of a cumulus. *Weatherwise 3*, 4.

Malkus, J S. 1952a. The slopes of cumulus clouds in relation to external wind shear. *Quart. Jour. Roy. Meteor. Soc. 78*, 530–542.

Malkus, J. S. 1952b. Recent advances in the study of convective clouds and their interaction with the environment. *Tellus 4*, 71–87.

Malkus, J. S. 1954. Some results of a trade-cumulus cloud investigation. *J. Meteor. 11*, 220–237.

Malkus, J. S. 1963. Tropical convection: Progress and outlook. Symposium on Tropical Meteorology, Rotorua, New Zealand, 3, 247–277.

Meteorological Office, United Kingdom, 1944. *Wind calculations from pilot balloon measurements*. London, U.K.

Riehl, H. 1954. *Tropical meteorology*. New York: McGraw-Hill Book Company.

Ropelewski, C. F. 1975. BOMEX wind spectra derived from the boundary layer instrument package. CEDDA, NOAA Tech. Memo. EDS BOMAP-17, Washington, D.C.

ТРЕХМЕРНАЯ СТРУКТУРА ВЕТРА В ОКРЕСТНОСТИ КОНВЕКТИВНЫХ ЭЛЕМЕНТОВ НАД ТРОПИЧЕСКИМ ОСТРОВОМ

В течение лета 1973 г. на острове Ьарбадос был предпринят шаропилотный эксперимент. Одной из целей было получение полей скорости в окрестностях конвективных облаков при невозмущенных условиях. Основными результатами были следующие: в основание облаков проникло меньше 1% шаров; ни один из шаров не проник через боковую стенку облаков; облака двигались в среднем на 2 м/с медленнее окружающего воздуха, когда ноблюдался положительный вертикальный градиент скорости ветра; шары ускорялись над облаками на их наветренной стороне, вместо того, чтобы проникать в них или огибать их; в тесной близости от облаков с их обеих сторон шары двигались в сторону от облаков, а не к ним, в поток, огибающий сверху облако с наветренной стороны; подъмы и опускания воздуха, связанные с облаками, были порядка 1–3 м/с; циркуляция вокруг горизонтальной оси, проходящей через облако, и перпендикулярной направлению общего потока может поддерживать в течение многих часов существование гряд конвективных облаков, параллельных потоку.