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CROSS-EQUATORIAL JET STREAMS AT LOW LEVEL OVER KENYA

By J. FINDLATER

Summary.—Mean monthly winds up to 10,000 ft for an equatorial station in East Africa have been calculated. Considerable differences are noted from comparable values for Nairobi. High-energy flow, in the form of low-level jet streams, has been observed during the period of the south monsoon, and the associated vertical shears have attained remarkable values.

Introduction.—Since 1963, reports have been received from aircraft operating at low levels over the North Eastern Province of Kenya that, on occasions, winds in the height band 4000–7000 ft above MSL have been very strong and on at least two occasions aircraft flying at 80–100 kt have been unable to make much headway against them. The area is sparsely populated and most of the international air traffic flying over north-east Kenya does so at heights in excess of 10,000 ft ; that these winds have received scant attention has been because of the lack of low-level air traffic, the relative infrequency of really extreme winds, and the fact that the only regular series of pilot-balloon soundings in the area, at Garissa, commenced as late as 1962. In a private communication, however, Mr J. E. B. Raybould has stated that the existence of these strong winds was suspected in the years 1944–46. Since that period occasional reports of strong wind have been received by the East African Meteorological Department.

Sufficient pilot-balloon data have now been accumulated to enable an analysis to be carried out and this paper furnishes mean monthly winds up to 10,000 ft above MSL for one observing station in the area, and discusses some of the extreme winds which have been measured. These extreme winds, with one exception, were all from a southerly point and occasionally reached peak speeds of 90–100 kt well below the 10,000-ft level.

The monsoon pattern.—The area to which this paper refers lies astride the equator and on the western edge of the great monsoon system which may be considered as starting with the south-east trade winds of the southern Indian Ocean. These winds (see Figure 1) curve through Madagascar and the Comores Islands as south-easterlies to become southerlies over the coastal strip of East Africa and the adjacent sea areas in the vicinity of the equator. North of the equator the winds curve to south-south-westerlies at Mandera

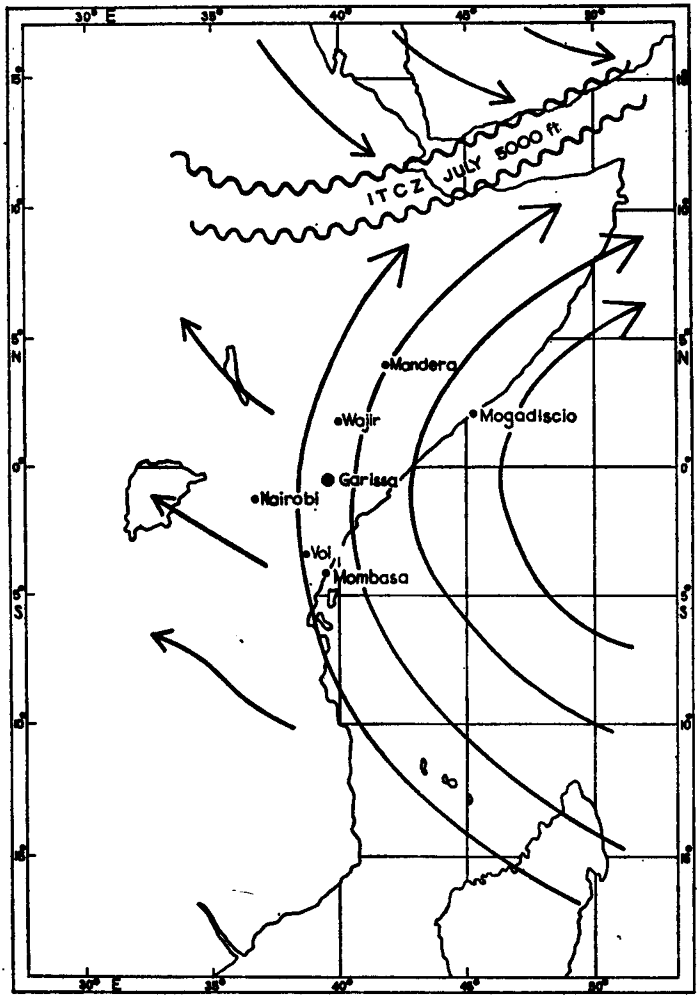


FIGURE 1 — LOCATION OF STATIONS AND GENERAL PATTERN OF STREAMLINES AT 5000 FT IN JULY

and to south-westerlies over the northern parts of Somalia. Thence the winds travel across the northern Indian Ocean as the south-west monsoon. This monsoon, which blows from about May to September, is barely traceable on the higher ground of East Africa, as shown by Ramsey's analysis of winds at Nairobi.[1] Nevertheless the southerlies blow over the flat low-lying areas of Tanzania, Kenya and Somalia east of longitude 38°E with considerable force. South of the equator this wind is known as the south-east monsoon and north of the equator as the south-west monsoon. Since the mean direction at the equator is from almost due south all further references in this paper to results for Garissa will be to the south monsoon. References to the south-east and south-west monsoons will be to the monsoon at some distance from the equator, southwards and northwards respectively.

From December to February or March the north-east monsoon from Arabia blows over Kenya and the adjacent areas of the Indian Ocean, but wind speeds are generally light.

Patterns of average streamlines for July, at the 5000-ft level, are shown in Figure 1 and stations to which reference is made in the text are shown also.

Data used.—Pilot-balloon ascents have been made since January 1962 at Garissa whose position, latitude 00°29′S longitude 39°38′E, lies in the flat semi-desert area of the North Eastern Province of Kenya. The altitude of the station is 420 ft above MSL.

A total of 614 soundings were available and only winds up to 10,000 ft were considered since the aim of the investigation was directed towards winds which might prove hazardous to aircraft operating at low level. Data were carefully scrutinized to omit winds whose accuracy was in doubt, and after these restrictions had been made 4758 individual winds remained for analysis. Many of the soundings did not reach the 10,000-ft level because of cloud or strong winds.

The extreme speeds recorded on some of the ascents are such that their validity might be questionable. Possible errors might be due to :

(i) Leaking balloons
(ii) Lee-wave effects or convection
(iii) Incorrect computation.

Causes (i) and (ii) could result in incorrect high wind speeds when the assumed constant rate-of-ascent technique is used. However, it is noteworthy that many of the cases of high wind speed at Garissa have been confirmed by aircraft flying in the area, by high winds being recorded on the same day at Voi, Mombasa, Mogadiscio or Mandera, and by the Garissa balloon being lost in the distance at low heights. Also, the terrain is flat and is unsuitable for the generation of lee waves. Convection currents could result in either high or low wind speeds being recorded, but very wide and sustained down-draughts of the magnitude necessary to produce really high speeds from the computation are unlikely. No aircraft reports are known of lee waves in the area, and convection patterns at low level tend to be so narrow that interference from them, over a period of a few minutes, would most likely be self-cancelling. A few cases of incorrect computation have been noticed and where possible these have been corrected. When it has not been possible to correct computational errors the winds have been neglected.

In view of the foregoing it is considered that the winds which have been used in the analysis are reasonably accurate within the limitations of the constant rate-of-ascent technique.

Upper winds at Garissa have been measured at many daylight hours of the day but in the analysis they were grouped into morning and afternoon ascents only. Morning ascents were those between dawn and 0900 GMT, and afternoon ascents thereafter. Local time in the area is three hours in advance of GMT.

Analysis and discussion.—

Monthly mean winds.—For each 1000-ft level up to 10,000 ft, with the exception of the 9000-ft level for which no winds were calculated, monthly mean winds have been computed separately for morning and afternoon.

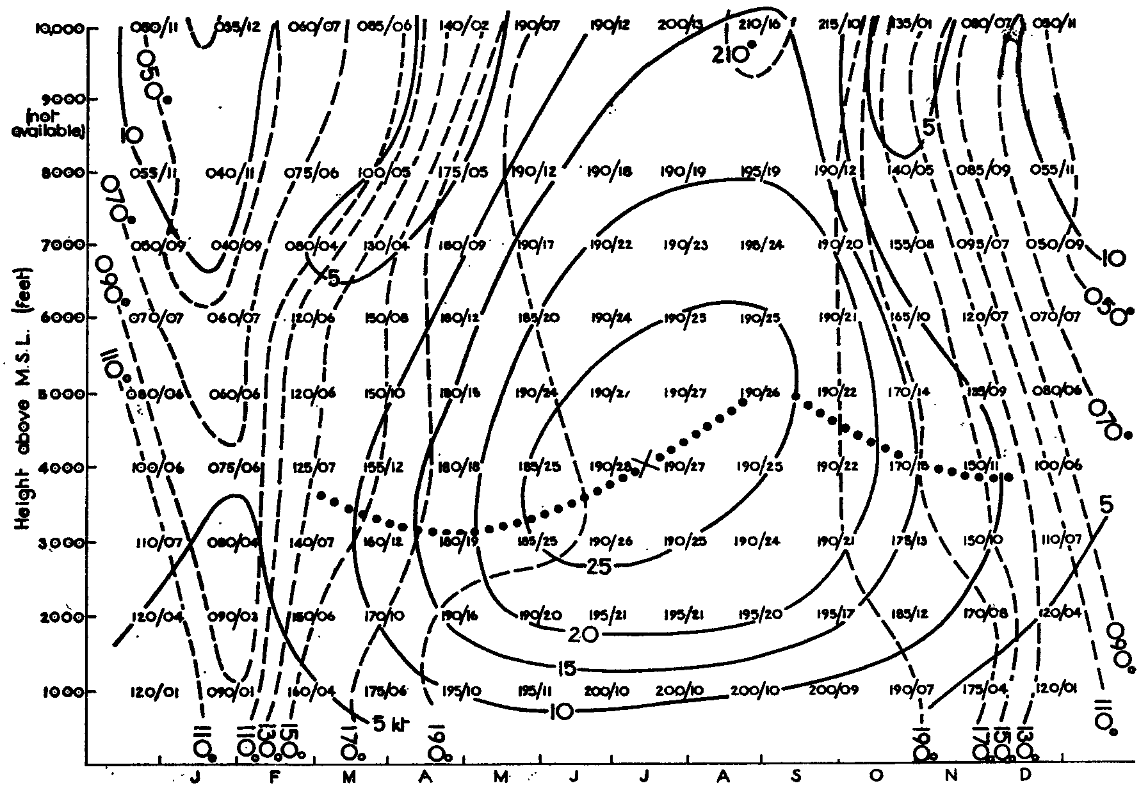


FIGURE 2—MEAN MONTHLY UPPER WINDS AT GARISSA, KENYA FOR 1962 TO 1964 INCLUSIVE

Means have been computed using one month overlapping (see text) and results are ascribed to the first day of each month.

– – – Isogons ; ——— Isotachs ; . . . . . . Level of maximum wind ; X=Core of south monsoon.

Several of the mean values showed irregularities in speed which might have been due to the inclusion of extreme values in some classes where the total number of soundings was few. To obtain an overall view of the monsoon pattern at Garissa, morning and afternoon soundings were combined and means computed using an overlap of one month, the results being ascribed to the first day of each month, e.g., January and February averages were combined and the resulting mean value was ascribed to 1 February. These results are shown in Figure 2.

Several features of interest are apparent in Figure 2. The south monsoon and the north-east monsoon are clearly defined, and are separated by winds of less than 10 kt associated with closely packed isogons. The south monsoon is dominant at low levels from March to November, reaching peak mean speeds in June, July and August and attaining its greatest depth, somewhat more than 10,000 ft, in August and September. Peak speeds generally occurred between 3000 ft and 4000 ft during the first half of the monsoon, and between 4000 ft and 5000 ft during the second half. In the whole of the south monsoon period the mean wind direction is nearly constant from 190°.

The north-east monsoon is mainly an upper feature and it barely reaches down to the 1000-ft level in January and February, and mean speeds are only about 10 kt even at 10,000 ft. Ramsey, in his analysis of upper winds at Nairobi (Dagoretti) (01°18′S 36°45′E, height 5900 ft), noted that the north-east monsoon extended over a longer period at 10,000 ft than at lower levels. Only from July to September was the north-east monsoon absent at 10,000 ft at Nairobi. Results for Garissa broadly confirm this finding, but the persistence of the north-east monsoon is less marked than at Nairobi. At Garissa it is evident at 10,000 ft into April, about a month after it has disappeared from lower levels, and it reappears at 10,000 ft in November.

In the case of the south monsoon the patterns for Nairobi and Garissa are quite different. Ramsey noted that, for the 10,000-ft level at 0000 GMT, little trace of the south monsoon could be found, but at 1200 GMT it could just be discerned in the months from June to September inclusive. At Garissa however, the dominance of the south monsoon is in striking contrast to the pattern for Nairobi. Monthly mean winds at 5000 ft and 10,000 ft at Garissa are plotted on a polar diagram in Figure 3(*a*) to illustrate these effects, and from Ramsey's published data a similar diagram, Figure 3(*b*), has been prepared for winds at 10,000 ft at Nairobi, showing also the diurnal changes at that level. Comparison of the two diagrams reveals the marked changes between the two stations. It is evident that the south monsoon blows over the flat low-lying eastern part of Kenya with considerable force, yet it hardly affects the highland areas a little further to the west. On the other hand, the north-east monsoon which is just discernible at low levels at Garissa is well in evidence at Nairobi.

Extreme speeds — south monsoon.—The mean speed of the core of the south monsoon for the period investigated was about 28 kt (Figure 2), but frequently speeds rose to over 40 kt and on a number of occasions reached speeds of 60–100 kt at surprisingly low levels. An analysis of all core speeds in excess of 40 kt has been made and related to the height of the core. The results, as shown in Table I, reveal that of the 101 cases where core speeds were $\geqslant 40$ kt, most occurred at or below 7000 ft. It would seem that there are two favoured levels for very high core speeds, 4000 ft and 7000 ft, and at

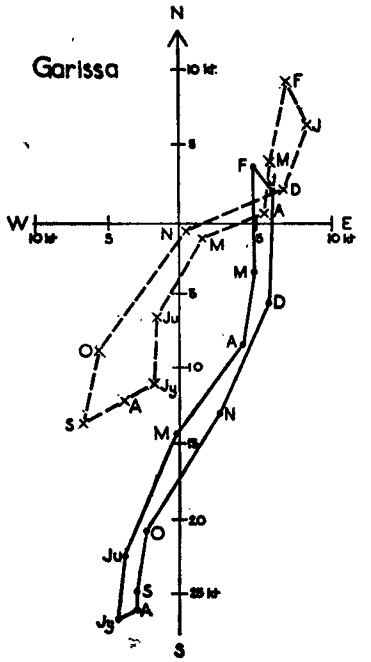


FIGURE 3(*a*) — MONTHLY MEAN WINDS AT 5000 FT AND 10,000 FT ABOVE MSL AT GARISSA, KENYA FOR 1962 TO 1964 INCLUSIVE

•——• = 5000 ft; x — — x = 10,000 ft.

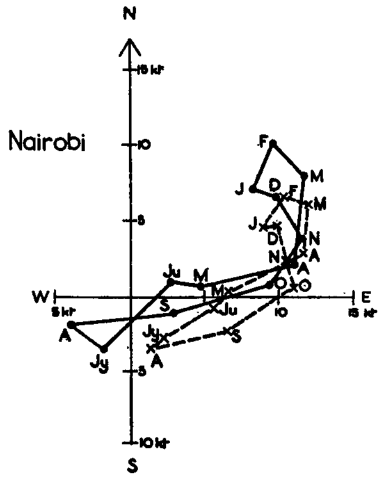


FIGURE 3(*b*) — MONTHLY MEAN WINDS AT 10,000 FT ABOVE MSL AT NAIROBI, KENYA (FROM DATA GIVEN BY RAMSEY[1] FOR 1959–63)

•——• = 10,000 ft; x — — x = 10,000 ft.
0000 GMT 1200 GMT

both of these levels wind speeds of over 90 kt have occurred. From Figure 2 it has already been noted that the mean level of maximum speed lies between 3000 ft and 5000 ft, but the really high-speed cases occur most often at 4000 ft or 7000 ft.

TABLE I—OCCURRENCES OF CORE SPEEDS RELATED TO HEIGHT OF CORE
(Based on 101 cases during the south monsoon at Garissa in the years 1962–64 inclusive, where core speed ≥ 40 kt.)

Height of core of maximum wind above MSL (ft)	40–49	50–59	60–69	70–79	80–89	90–99	≥100	All speeds
			number of occasions					
10,000	4	2	1					7
9000			winds not computed for this level					
8000	5	1		1				7
7000	5	3	4			2		14
6000	6	3	2	1				12
5000	13	5						18
4000	12	5	3		1	1		22
3000	14	3	2					19
2000	1	1						2
1000								0
All heights	60	23	12	2	1	3	0	101

The highest wind speed which has been measured in the south monsoon at Garissa during the period of the analysis is 150°/98 kt which was recorded on the afternoon of 5 April 1963 at 7000 ft. The highest speed recorded at 4000 ft was 190°/91 kt on the morning of 26 May 1963.

The high wind speeds, when they do occur, do so in very shallow layers in similar fashion to that of jet streams at high level. To illustrate the variation of wind with height, 18 cases where the wind speed at Garissa was ⩾60 kt are plotted in Figure 4 to compare the profile of speed above and below the level of maximum wind. All of these cases occurred during the south monsoon, and the average direction of the 18 cases was 183°. The profiles show some remarkable shear values ; the maximum value of shear recorded above the core was 71 kt/1000 ft and the maximum below the core was 46 kt/1000 ft. On a number of occasions a secondary core occurred 2000 ft to 3000 ft below the main core.

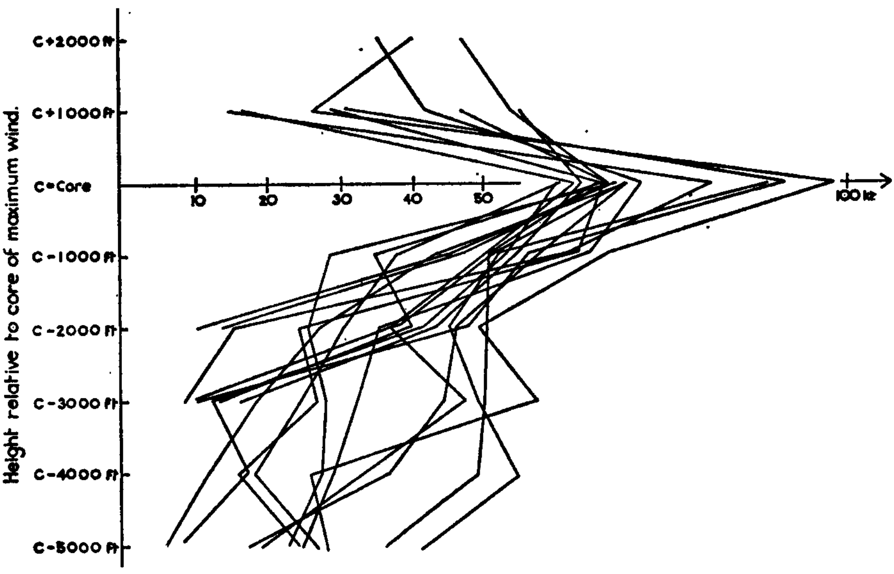


FIGURE 4—PROFILES OF SPEED FOR 18 CASES WHERE CORE SPEED ⩾ 60 KT

Ascents on which speeds of 60 kt or more were recorded are considered as having reached the core of the stream even though the true maximum speed may not have been recorded.

Riehl,[2] in a comprehensive study of jet streams at high level, refers to a case of high-level shear of 20 kt/1000 ft as 'extraordinary' but he adds that it is as yet uncertain how large vertical shears can become. The shears reported from Garissa are remarkable, and the only other shears of this magnitude to which reference can be found are those reported by Crossley.[3] Pilots of aircraft who have met the extreme winds over Kenya have reported that by changing altitude by 2000 ft or 3000 ft, either upwards or downwards, they found that their observed wind speed was reduced by half or more.

Turbulence near the layers of fast-moving air has been reported as being of the 'cobblestone' or high-frequency judder type although the aircraft have been flying at speeds of about 100 kt.

Cloud in the area during the occurrence of high wind speeds is usually in the form of morning stratocumulus which lifts and breaks during the day to become cumulus fractus in the region of strong shear below the level of maximum wind. A few cases of cloudless skies have been noted also.

A profile of mean speeds, based on the eighteen cases where core speeds were ⩾60 kt in the south monsoon, is shown in Figure 5. Average values of vertical shear are 38 kt/1000 ft above the core and 21 kt/1000 ft below, and the general form of the average (and individual) profile is similar to that noted by Riehl.[2] He states that :

(i) Vertical shear and maximum wind are often correlated ; the stronger the jet stream, the stronger the vertical shear above and below the core.

(ii) Vertical shear just above the core of a jet stream is usually greater than that just below the core.

(iii) Most jet streams show little change of direction with height.

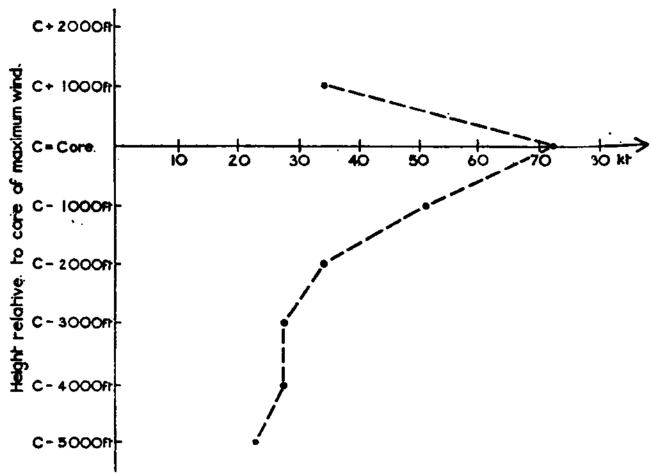


FIGURE 5—MEAN PROFILE OF SPEED ABOVE AND BELOW CORE

(Based on 18 cases where core speed ⩾60 kt.) Average shear above core = 38 kt/1000 ft. Average shear below core = 21 kt/1000 ft. *Note :* few soundings reached more than 1000 ft above the core.

The Garissa profiles in Figures 4 and 5 show that they conform to the characteristics (i) and (ii) above and an inspection of the individual soundings confirms that characteristic (iii) is satisfied also.

Extreme speeds — north-east monsoon.—During the north-east monsoon upper wind speeds are generally much lighter than in the south monsoon. Only one case was recorded at Garissa where the speed of a north-easterly wind exceeded 40 kt below 10,000 ft. This occurred on 30 January 1964 when the wind at 5000 ft was 040°/65 kt. Since no other occurrence of high speed in the north-east monsoon has been observed, the solitary case has been omitted from the analyses of Table I, Figures 4 and 5, and the foregoing discussion. In the private communication referred to earlier, however, Raybould has commented that on a few occasions high speeds in the north-east monsoon were noted over Kenya and Uganda in the period 1944–46, but these were recorded in highland areas where the topography could generate pronounced lee waves or cause the airflow to be channelled.

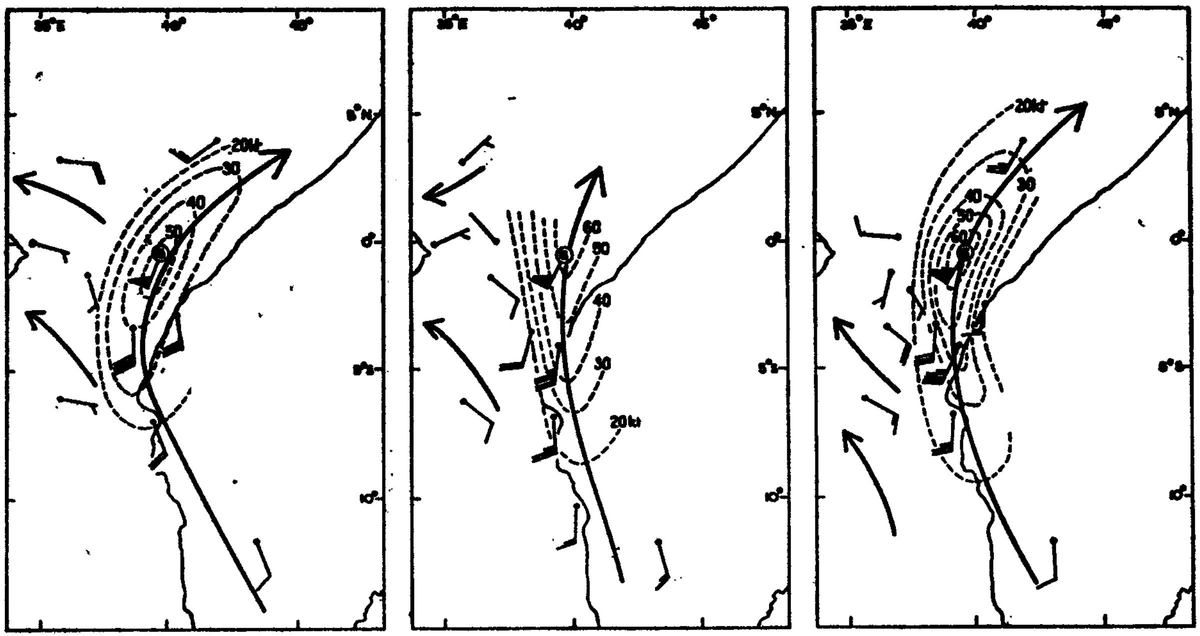
Extreme speeds — Persistence.—In the south monsoon speeds of 60 kt or more do not appear to exist at Garissa for very lengthy periods. On most occasions the time period over which high speeds occur at any one level at Garissa is about 12 to 48 hours.

Extreme speeds — Horizontal extent.—From the foregoing paragraph it is apparent that the core of highest speed varies in height and is associated with very strong vertical shears. Reports indicate also that the core moves horizontally to a limited extent along the general pattern of streamlines but since this analysis was restricted to Kenya it is not at present known if the core of high speed is restricted to an area near the equator or if it moves into Kenya from the south and passes through the country. There is also a suggestion from pilots' reports that the core may be found to the east of Garissa on some occasions. Although the network of upper wind reporting stations is not dense, it is known that the strong southerlies do not affect Nairobi. It is evident also that when extreme winds ($\geqslant$50 kt) occur at Garissa, high speeds ($\simeq$40 kt) are sometimes, but not always, reported from Mombasa, Mandera or Mogadiscio on the same day. Thus it is clear that strong lateral shears exist and in the case of the section from Nairobi to Garissa it is known that the shears are often concentrated along the edge of the high ground at about 38°E. In the mean, lateral shears at 7000 ft between Nairobi and Garissa in July are about 20 kt/150 n. miles but this value must be more than trebled when very high speeds are recorded at Garissa. Eastwards from Garissa values of lateral shear appear to be considerably less than those to the west.

Charts have been plotted for the 5000-ft level and several cases have been selected to show the horizontal extent of the high-speed flow. These cases, illustrated in Figures 6(*a*)–(*f*), were chosen because a sufficient number of pilot-balloon reports were available to permit isotachs to be drawn with reasonable confidence, but it does not follow that 5000 ft was the level of maximum wind in each case. For example, a wind speed at 5000 ft (=850 mb) of 65 kt at Garissa is shown in Figure 6(*c*) but this value is not included in Table I because the core lay at a higher level in this case.

It will be noted that the six examples illustrated all show high-speed flow from a south-south-westerly direction although it has been pointed out previously that the average direction of the high winds at Garissa is from almost due south. The reason for the bias is that when winds are from south or south-south-east the onshore winds at the coast produce low cloud which restricts the number of balloons reaching the 5000-ft level, thus precluding accurate isotach analysis.

With regard to the maximum speeds recorded at Garissa, the velocity and shear profiles which have been discussed, the horizontal dimensions of the high-speed flow evident in Figures 6(*a*)–(*f*), and the associated lateral shears, there is a marked similarity between the flow described here and the well-documented high-level jet streams. The World Meteorological Organization definition of a jet stream[4] relates specifically to streams in the upper



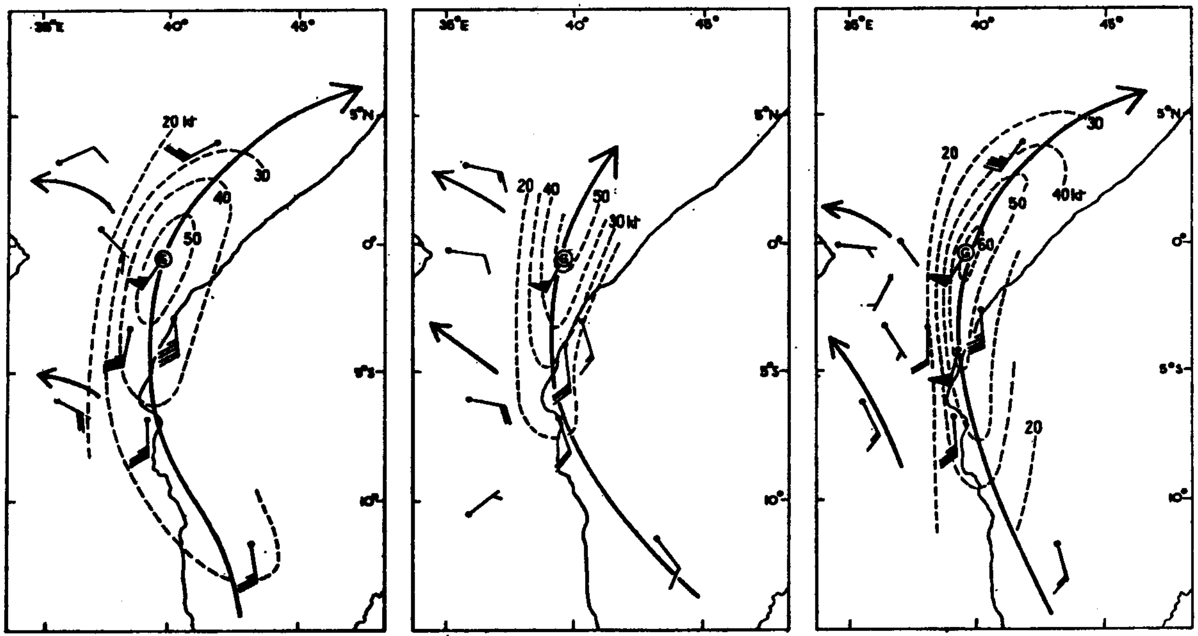
(*a*) 5000 ft, 0600 GMT
16 May 1964

(*b*) 5000 ft, 0600 GMT
29 June 1964

(*c*) 5000 ft, 0600 GMT
27 June 1964

G= Garissa ; - - - - Isotachs at 10-kt intervals ; Major streamlines and the axis of the maximum wind speed are denoted by long arrows ; Minor streamlines are denoted by shorter arrows.

FIGURE 6—EXAMPLES OF LOW-LEVEL JET STREAMS OVER KENYA



(*d*) 5000 ft, 0600 GMT
7 July 1964

(*e*) 5000 ft, 0600 GMT
13 July 1964

(*f*) 5000 ft, 0600 GMT
9 July 1964

G= Garissa ; - - - - Isotachs at 10-kt intervals ; Major streamlines and the axis of the maximum wind speed are denoted by long arrows ; Minor streamlines are denoted by shorter arrows. (The wind speed at Mandera in (*f*) was 35 kt not 45 kt.)

FIGURE 6—*continued*

troposphere, or stratosphere, but the high-speed flow over eastern Kenya exhibits so much similarity with high-level jet streams that it would seem appropriate to refer to the phenomena described in this paper as low-level jet streams. The periodic strengthening of the south monsoon may produce considerable effects downstream also.

Diurnal variations.—Pilot-balloon ascents from Garissa have been grouped according to whether they were made during the morning or afternoon, but all ascents were made during daylight and it is unlikely that any satisfactory deductions regarding the diurnal variation can be made therefrom. Ideally, winds measured just before dawn should be compared with measurements made about the time of maximum heating, but in the case of the Garissa data many morning ascents may have been made as late as 0800 GMT (=1100 local time) when surface heating near the equator is powerful and turbulent mixing is likely to extend above 3000 ft.

An inspection of the data, and some trial analyses, have indicated that at present there are insufficient data to attempt a study of diurnal changes at low level. Nevertheless it is of interest to note that very high wind speeds (>90 kt) have been recorded during both morning and afternoon.

Cause.—It is not clear how the accelerations of the south monsoon are initiated but it is likely that some part is played by the confluence of the streamlines towards the equator as the airflow curves from south-easterly to south-westerly, especially when the flow is partly restricted by high ground west of 38°E. The basic cause of the accelerations, however, may lie much further afield than in East Africa.

Conclusions.—The monthly mean values of wind up to 10,000 ft which have been calculated reveal some interesting features of the monsoon patterns, especially when compared with the analysis for Nairobi. A notable feature is the dominance of the south monsoon over the flat eastern areas of Kenya and the comparative lack of an effective north-east monsoon in the area at surface levels.

The south monsoon is at times concentrated into a high-energy flow at low levels which shows many of the features normally associated with high-level jet streams, except that the vertical shears reach much higher values. These jet streams with speeds over 60 kt at low levels are of great importance to aircraft operations in the area.

Acknowledgements.—The writer is grateful to the Director of the East African Meteorological Department for making the Garissa pilot-balloon data readily available, and to Professor A. F. Jenkinson and Dr H. T. Mörth for helpful discussions during the course of the analysis. Thanks are also due to several members of the Meteorological Office staff at Eastleigh for assistance in the transcription and checking of the data.

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METEOROLOGY AND GLIDING — 1966

By P. G. WICKHAM

In spite of or perhaps, because of, the unsettled weather of the summer, the gliding movement called on the Meteorological Office for considerable numbers of weather forecasts during 1966. Apart from some routine forecasts prepared for certain of the bigger gliding clubs, and a large number of non-routine inquiries from individual pilots, special forecast facilities have again been provided for the more important gliding competitions. At the National Championships, held at Lasham (Hampshire) in May, a temporary forecast office was set up. This was manned by a staff of two forecasters and an assistant, with a Channel 1 teleprinter on the site providing the normal working data. At most of the Regional Competitions, held at five different sites during the summer, no official forecasting service was laid on. However, at four of these meetings, individual forecasters, working in their own time and drawing their working data from nearby meteorological offices, provided a forecast service which was very greatly appreciated by the organizers of the competitions.

Cross-country competition flying by gliders depends very largely on the plentiful occurrence of thermals and, quite simply, thermals occur where there is sunshine. A day with no sunshine is generally a day with no flying at a gliding competition, and such days were rather common this year, as the following table shows.

TABLE I—GLIDING COMPETITIONS IN ENGLAND IN 1966

Location	Period	Length of competition	Number of contest flying days
Bicester (Oxon.)	8 – 17 April	10 days	1 day
Long Mynd (Salop)	8 – 11 April	4 days	1 day
Lasham (Hants.)	21 – 30 May	10 days	5 days
Nympsfield (Glos.)	18 – 26 June	9 days	5 days
Camphill (Derbyshire)	2 – 10 July	9 days	5 days
Dunstable (Beds.)	30 July – 7 August	9 days	3 days
Bicester (Oxon.)	20 – 29 August	10 days	8 days

In all gliding competitions the pilots are set a specific task to fly each day. The task may be a race, in which points are awarded for the glider's speed over a set course, or it may be a distance task, in which speed is not rewarded but points are gained simply for the distance flown. The overall success of a competition depends very much on the right task being set each day, and the meteorological advice given to the task-setters each morning is crucial in this.

High on the list of his special considerations comes the forecaster's assessment of the likely convection activity throughout the day. As well as predicting the height to which convection will penetrate, and the time that usable thermals will start and finish, the forecaster must try to assess the possibility of any meso-scale patterns in the organization of the convection. Systems of cloud-streets ; patterns produced by lee-wave effects ; convergence lines and sea-breeze cloud formations — any of these may form important irregularities in the basic field of convection and should be forecast. To overestimate the general vigour of the convection may lead to an impossible task being set, while an underestimate can be wasteful if the most is not made of a really good day. This year has been a rather stormy one, with strong winds and rapidly changing conditions much in evidence. All too frequently it has been a delicate matter to decide in advance whether or not a short period of soarable sunny weather will last long enough to allow a fleet of some 30–40 gliders to be launched on a task that is equally fair to all competitors. Since there may be a difference of something like one and a half hours in the times at which the first and last gliders are launched, it is necessary to have some four hours of fairly uniform conditions if every pilot is to have an equally fair chance. A further difficulty in strong wind conditions is that gliders tend to be blown rather quickly either towards a coast-line, or towards some controlled air-space. With such conditions it has often been necessary this year to set tasks involving some very stiff cross-wind flying in order both to clear the forbidden Control Zones and also to avoid having all the aircraft landing early in the day on the same stretch of coast-line. The latter situation would contribute nothing at all to the result of the competition and would probably involve all the pilots and their aircraft in a long and tedious journey home which would be doubly frustrating and pointless.

On the other side of the ledger, a forecaster gets in return for his forecast each day the aggregate experience of many deeply interested and observant pilots who, with varying skill and success, have spent the day sampling the behaviour of the atmosphere in the area to which they have been sent. There is invariably much that can be learnt from this. Sometimes a particular meso-scale feature may have been encountered and described, but more often there is a valuable general impression of the weather and its variations in relation to the topography. The scale of interest is usually smaller than that which can be studied on a normal synoptic chart, but it is nevertheless one that is extremely important for detailed local weather forecasting.

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AN EXAMPLE OF FORECASTING RAINFALL IN CYPRUS BY USING THE 300 MB JET STREAM IN CONJUNCTION WITH A 700 MB ANALYSIS

By R. M. MORRIS

Introduction.—The dynamical significance of the 300 mb jet stream has received a fair amount of attention in meteorological literature, and one of the most comprehensive and up-to-date treatments has been given by Riehl.[1] In particular, the fast moving and fairly short (1000 nautical miles) jet streams can have considerable significance. If moisture is available there will be an area of cloud and perhaps precipitation in the well-known area of ascent in the 'left-exit' region of a jet stream. On the other hand, areas lying to the warm side of the jet core are often characterized by very dry and stable air indicating marked descent in the middle troposphere. The prominence of this dry zone associated with both warm and cold fronts has been described by Sawyer,[2] Freeman,[3] Miles[4] and Boyden.[5]

In the eastern Mediterranean the synoptic analyst often has considerable difficulty in explaining weather in terms of the conventional frontal-analysis technique. This is because the three-dimensional structure of the troposphere shows considerable asymmetry and often changes markedly over short periods of time (24 hours) compared with north-west Europe and the North

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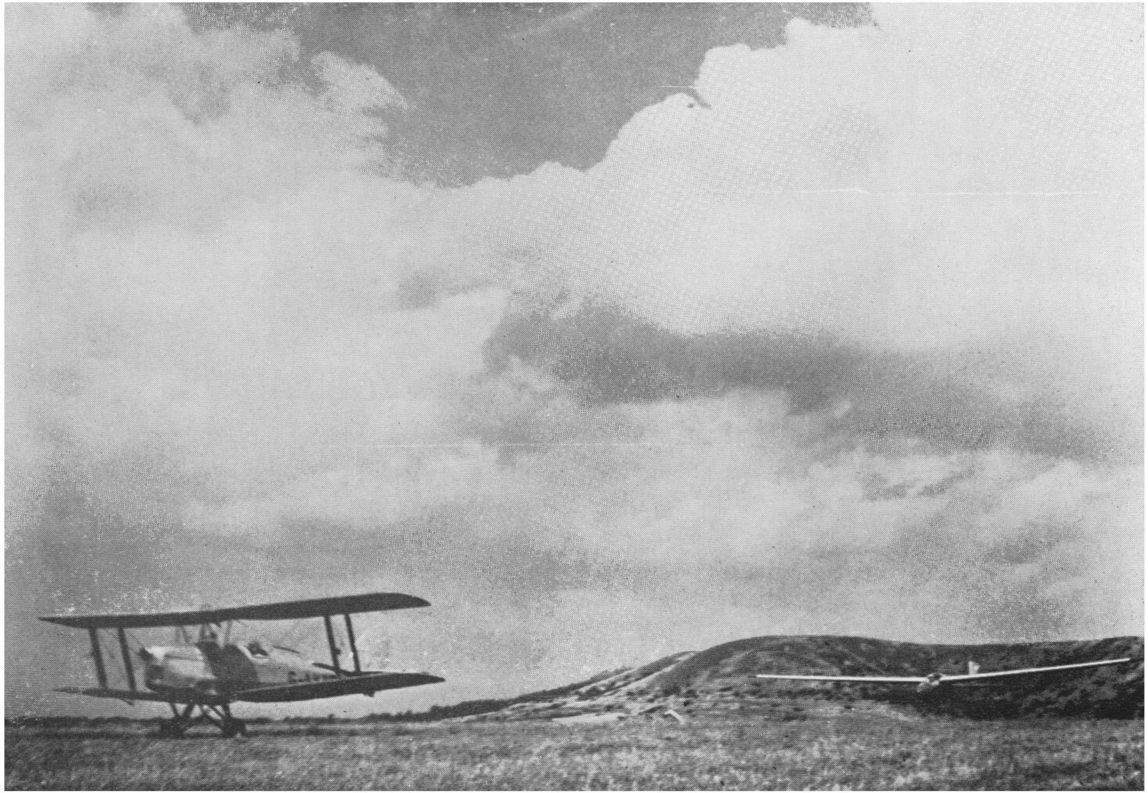

Photograph by P. G. Wickham

PLATE I—LAUNCHING A GLIDER AT THE LONDON GLIDING CLUB, DUNSTABLE

A picture taken during the Regional Gliding Competition held at Dunstable in early August. In most competitions the gliders are towed up to a height of 2000 feet before being released. In the background is the edge of the Dunstable Downs.

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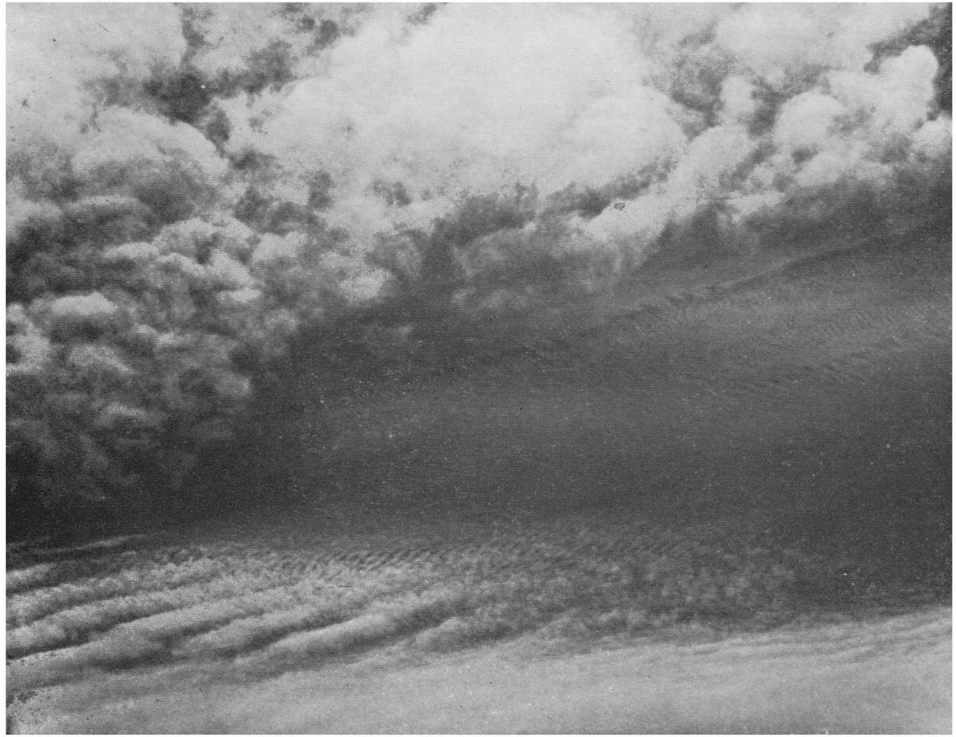

Photograph by A. H. P. Jarrett

PLATE II—UPPER CLOUD STRIATIONS

The photograph was taken at London (Heathrow) Airport looking south-south-east at 1115 GMT 7 September 1966. It shows dense cirrocumulus at about 30,000 feet, cross-striated in complex mode, and at about 15,000 feet altocumulus with billows in two directions. Strato-cumulus is seen at the top of the picture. Many variations in the upper cloud structure were seen on the same day.

Atlantic. Whilst the mean-sea-level chart represents an essential basis upon which the forecaster can analyse the weather, it seems desirable to produce on one chart the salient three-dimensional features of the troposphere which cannot be deduced from the mean-sea-level chart. This type of analysis is similar to one of the type outlined by Sawyer,[6] and makes use basically of the 700 mb chart to describe the state of the lower middle troposphere (see Figure 1). The contours of the 700 mb height are smooth and indicate the direction of advection of cloud in the middle troposphere. Isotherms depict the areas of warm and cold air, and isopleths of dew-point depression depict dry and moist zones. A note of caution is required since on a single occasion the dew-point depression at exactly 700 mb may not be representative of a complete layer; furthermore a small dew-point depression may be a consequence rather than a cause of a rain-producing process. The 300 mb jet core is added to this chart with approximate speeds indicated at various points along its length. Undoubtedly the paucity and unreliability of data in the Mediterranean impose limitations upon the accuracy of jet-stream analysis. Nevertheless the principal object of this type of analysis is to locate the approximate position of the jet core together with its entrance and exit regions rather than to locate precise isotachs. The various regions of jet streams can generally be located with some confidence. A final addition to the 700 mb chart is the area of precipitation taken from the mean-sea-level chart.

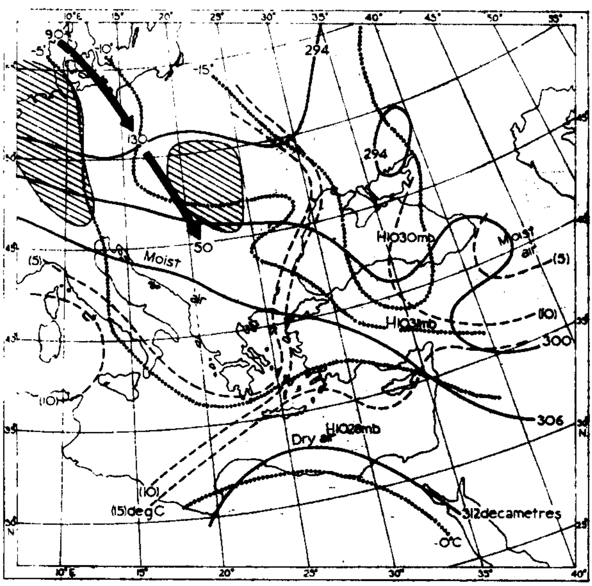

FIGURE 1—SYNOPTIC ANALYSIS 0000 GMT 18 DECEMBER 1965

——— 700 mb contours; - - - - 700 mb dew-point depression; . . . . . . 700 mb temperature.

Bold arrows and associated figures denote jet streams at 300 mb and their speed in knots. Precipitation areas are shaded.

This note deals with an occasion on which this type of analysis was used to illustrate rapid development in the middle troposphere occurring in association with a 300 mb jet stream which veered steadily and extended southwards.

Analysis at 0000 GMT 18 December 1965.—Figure 1 shows the analysis represented on the 700 mb chart for 0000 GMT on 18 December 1965 at Episkopi Main Meteorological Office. The 700 mb contours showed a light to moderate west to north-west flow across south-east Europe and Turkey. There was also an extensive area of moist air across the Balkans with a sharp boundary. A strong narrow 300 mb jet core was advancing south-east across Poland. Note the area of precipitation at the left exit of this jet. The warm air advection at the northern end of the jet core was stronger than advection in the south, mainly as a result of the stronger gradient in the lower layers. The indication was, therefore, that the jet would veer steadily with time.

Analysis at 1200 GMT 18 December 1965.—At 1200 GMT (Figure 2) the veering winds over Italy and backing winds across Turkey at 700 mb suggested a weak trough somewhere near the Aegean Sea but otherwise there was little change. The advancing jet had reached 25°E, indicating a speed of about 25 kt in the north and about 14 kt in the south, and had veered about 45 degrees. A careful estimation indicated that the jet had extended south along its axis at about 25 kt. The moist area had moved south of east to the Crimea with outbreaks of rain and snow. Note also the appearance of some

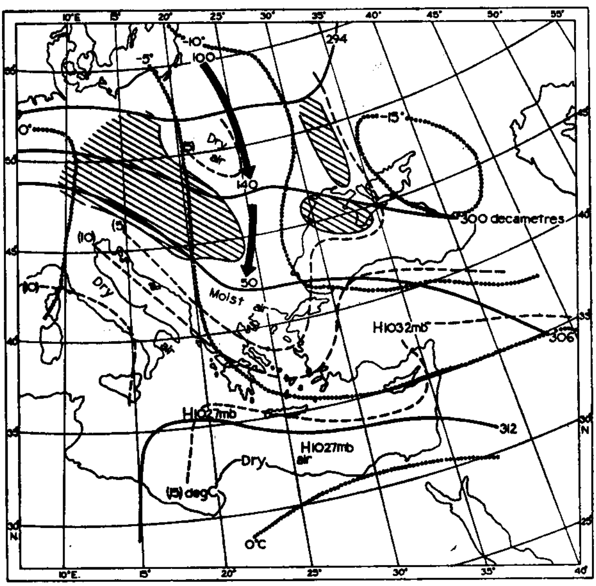

FIGURE 2—SYNOPTIC ANALYSIS 1200 GMT 18 DECEMBER 1965

——— 700 mb contours ; - - - - 700 mb dew-point depression ;
...... 700 mb temperature.

Bold arrows and associated figures denote jet streams at 300 mb and their speed in knots. Precipitation areas are shaded.

dry air just to the warm side of the jet stream. As at 0000 GMT, the warm advection in the lower layers was stronger in the north than in the south suggesting that the jet should continue to veer as it extended south.

Analysis at 0000 GMT 19 December 1965.—At 0000 GMT (Figure 3) a rise of contour height across the Adriatic and a fall over central Turkey at 700 mb, indicated a general veer in the flow although the 0000 GMT 700 mb wind at Izmir (38° 20′N, 27° 13′E) was westerly thus emphasizing that the precipitation in west Turkey, with moderate and heavy outbreaks of rain and snow, was largely developmental and not the result of advection.

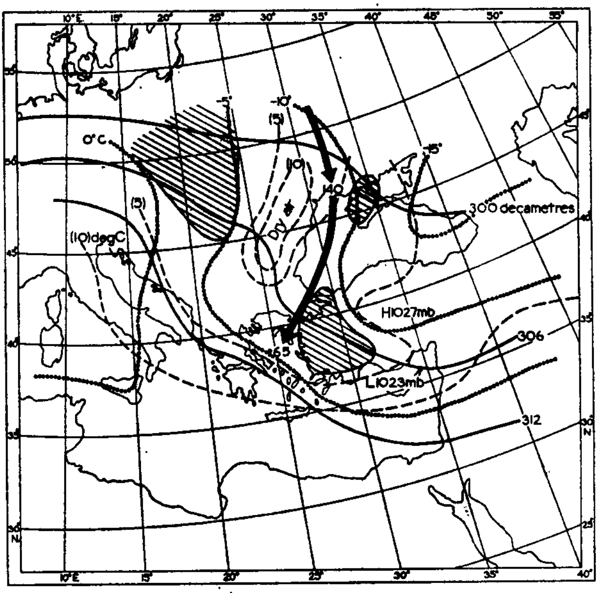

FIGURE 3—SYNOPTIC ANALYSIS 0000 GMT 19 DECEMBER 1965

——— 700 mb contours ; - - - - 700 mb dew-point depression ; ...... 700 mb temperature.

Bold arrows and associated figures denote jet streams at 300 mb and their speed in knots. Precipitation areas are shaded.

The 300 mb jet core had continued to veer and could be located down the western Black Sea into the north Aegean Sea. Note the location of the precipitation relative to this jet core and furthermore note the long narrow tongue of dry subsided air on the warm side of the jet core. The precipitation area subsequently moved across Cyprus where the average rainfall, for the period 0600 GMT 19th to 1800 GMT 19th at five meteorological stations in Cyprus (Paphos, Episkopi, Akrotiri, Nicosia and Ayios Nicolaos), was 12·5 mm.

Surface analysis.—It is worthy of mention that during this period the Black Sea, central and eastern Mediterranean were under the influence of a broad ridge of high pressure, everywhere in excess of 1024 mb, and the only indication of development in the middle and upper troposphere was the formation of a small depression of 1022 mb over eastern Bulgaria which subsequently moved south towards Egypt.

Conclusions.—The technique of using a combined 700 mb – 300 mb analysis showed quite clearly a sequence of rapid development illustrating how a 300 mb jet stream, veering and extending along its axis across fairly moist air in the lower and middle troposphere, can produce copious rainfall associated with the left exit of the jet, irrespective of the value of mean-sea-level pressure.

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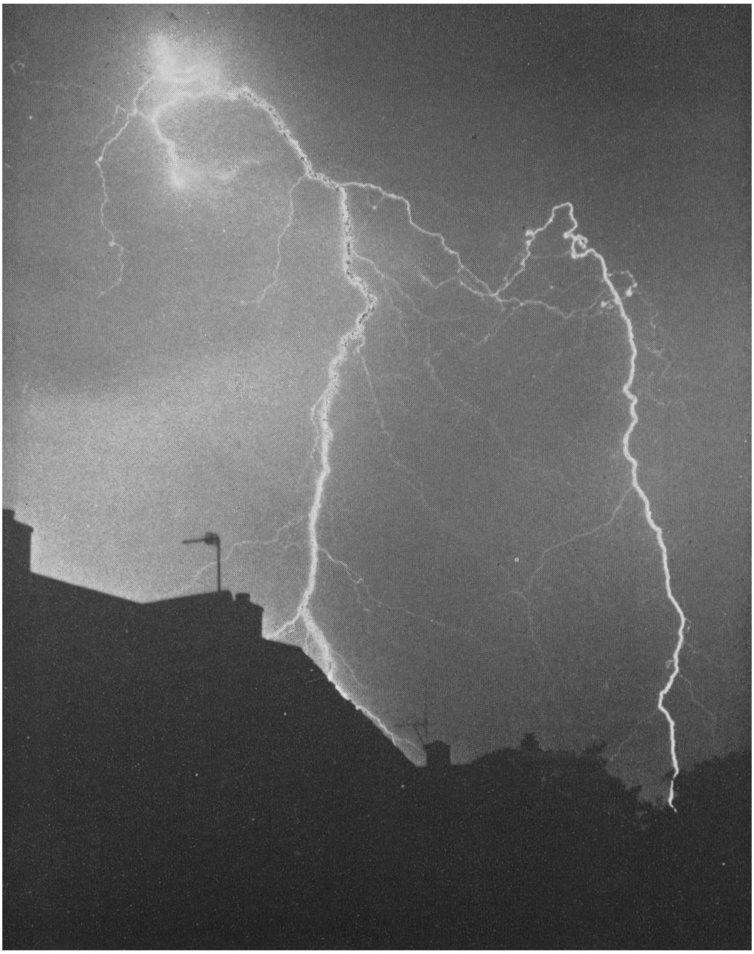
INERTIAL NAVIGATION AND GUST MEASUREMENT FROM METEOROLOGICAL RESEARCH FLIGHT AIRCRAFT

By I. ROSS

Summary.—Equipment originally designed for inertial navigation purposes has been adapted to meteorological research, in particular to the measurement of gusts in regions of the atmosphere and in situations where the aircraft is the best experimental vehicle.

Introduction.—Vertical air movements are of great importance in the atmosphere, from the large-scale slow uplift at a front to the relatively small-scale but more vigorous updraughts in cumulus cloud. Methods based on the equations of motion and thermodynamics can be applied to estimate vertical motions over lateral dimensions of the order of 200 miles but for the measurements of updraughts in clouds and clear air these methods are not practicable and measurements from aircraft seem to offer the best approach. Such measurements have been made with varying degrees of success by the Meteorological Research Flight (see for example Zobel[1]) but recent developments in equipment for inertial navigation have greatly increased the possible accuracy for a given length of run.

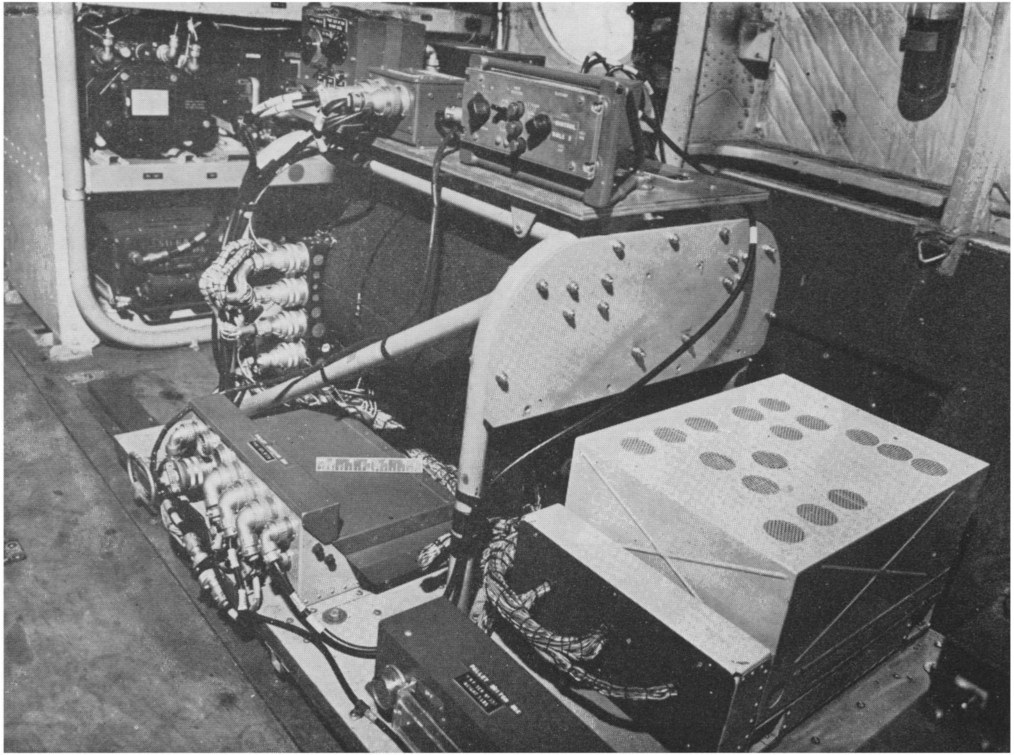
Among the first attempts to measure vertical gust velocities from aircraft was the installation of an accelerometer fixed rigidly to the airframe. From the dimensions, weight and other characteristics of the aircraft some estimate could be made of the magnitude of the gust from the acceleration experienced. The pitching, rolling and yawing motions which all aircraft perform even in non-gusty conditions (and also any pilot-induced motions) were neglected at first in this approach and an improvement came with the stabilization of the accelerometer against these motions by means of aircraft gyroscopes. A further refinement involved the addition of small wind vanes on a nose probe, and this equipment obviated the calculation of a particular aircraft's response to a gust but necessitated the accurate measurement of pitch and roll angles and aircraft vertical velocity in order to relate the gusts — measured relative to the aircraft by the wind vanes — to the earth. Aircraft gyroscopes



Photograph by P. C. Mitchell

PLATE III—CONTORTED PATH OF A LIGHTNING FLASH

During a storm near Borough Green, Kent, on the evening of 10 June 1966 an electricity sub-station was struck by lightning. The district was plunged into darkness and the BBC VHF transmitter at Wrotham Hill was temporarily off the air.



Photograph by courtesy of Royal Aircraft Establishment

PLATE IV—THE STABLE PLATFORM IN THE METEOROLOGICAL RESEARCH FLIGHT HASTINGS AIRCRAFT

The gyroscopes and accelerometers together with some ancillary electronics are contained in the large cylinder in the centre of the photograph. The cylinder is fixed in the tubular steel frame which in turn is fixed rigidly to the floor of the aircraft. The other boxes in the picture contain power, control, output, switching and testing units (see page 373).

such as the Artificial Horizon were used in this measurement of pitch and roll. A so-called Stable Platform, developed for the TSR2 aircraft for inertial navigation purposes, uses much higher quality gyroscopes than normal aircraft equipment and by virtue of this, allows reliable observations to be made over longer periods than previously. Equipment associated with the Stable Platform provides a complete picture of the attitude (i.e. of the pitch, roll and yaw) of the aircraft and also, by integration of three mutually perpendicular components of acceleration, the velocity components and, by further integration, the distance flown.

By geometry the equation relating the vertical gust to the attitude, vertical velocity and airspeed of the aircraft and the deflexion of the wind vanes is :

$$w = U\,(\tan\alpha\,\cos r - \tan\beta \sin r - \tan\theta)\cos\theta + V_z + L(\mathrm{d}\theta/\mathrm{d}t) \quad \ldots (1)$$

where : w = vertical gust

U = airspeed

θ = pitch angle

r = roll angle

α = angular deflexion of a horizontal wind vane

β = deflexion of vertical wind vane

(α and β are relative to axes fixed in the aircraft.)

V_z = aircraft vertical velocity

L = distance between Stable Platform and wind vanes.

Similar equations can be written for the lateral and longitudinal gusts :

$$v = U[\,(\tan\alpha\sin r + \tan\beta\cos r)\cos\varphi - (\cos\theta + \tan\alpha\cos r\sin\theta - \tan\beta\sin r\sin\theta)\sin\varphi\,] + V_{LAT} + L(\mathrm{d}\varphi/\mathrm{d}t) \ldots (2)$$

$$u = U\,[\,(\cos\theta + \tan\alpha\cos r\sin\theta - \tan\beta\sin r\sin\theta)\cos\varphi + (\tan\alpha\sin r + \tan\beta\cos r)\sin\varphi\,] + V_{LONG} \quad \ldots (3)$$

where : φ = yaw angle, i.e. deviation from the mean heading over the run

V_{LAT} = lateral velocity of aircraft (i.e. across the direction of the mean heading)

V_{LONG} = longitudinal velocity of the aircraft (i.e. along the direction of the mean heading).

A computer is necessary to handle the equations because of the large number of observations available in any flight record.

Inertial navigation.—The heart of an inertial navigation system is a platform which carries accelerometers maintained in fixed directions by gyroscopes. It is well known that a spinning gyroscope maintains the direction of its angular momentum vector in space. Three gyroscopes aligned along mutually perpendicular directions are therefore sufficient to provide a Cartesian reference system fixed in space. The rate of rotation of the earth, which is constant, can be allowed for automatically so that the reference system rotates with the earth. An accelerometer measures acceleration along a particular direction — its sensitive axis. The most accurate type of accelerometer is the force-balance type where the acceleration is measured by the electromagnetic force required to rebalance a pivoted coil against an input acceleration. The output of the force-balance accelerometer is a voltage proportional to the input acceleration. The acceleration integrated with respect to time gives velocity along the direction of the sensitive axis of the accelerometer and a double integration gives distance travelled in that direction.

For our purposes the constant directional properties of gyroscopes are used to maintain three accelerometers in directions fixed with respect to the earth, i.e. in the north–south, the east–west and the local vertical direction. Because of slight imbalances and because of friction in the bearings a practical gyroscope tends to drift from its initial direction. This drift, although it may be small as 0·01° per hour in modern gyroscopes, must be corrected if information obtained from the accelerometer is not to be in error after some hours of operation. The accelerometers themselves can be used to supply this correction in the following manner :

Consider the Stable Platform as a horizontal table on which three accelerometers are mounted with their sensitive axes along three mutually perpendicular directions, two horizontal and one vertical. When the table is quite level and not accelerating horizontally the vertical accelerometer gives an output corresponding to the acceleration due to gravity (one g at the earth's surface) and the two horizontal accelerometers experience no acceleration along their sensitive axes. If the table becomes tilted slightly for some reason, say gyroscope drift, then the horizontal accelerometers experience a small acceleration due to the component of the earth's gravity along their sensitive axes. The integrated outputs from the accelerometers (which are error velocities) can be amplified and fed to erection motors which rotate the table about a horizontal axis in the direction necessary to level it, that is until both accelerometers give no output (see Figure 1(a)). Such a table will in fact tend to oscillate about the horizontal with a period dependent on the characteristics of the feedback loop ; the platform can be regarded as a pendulum.

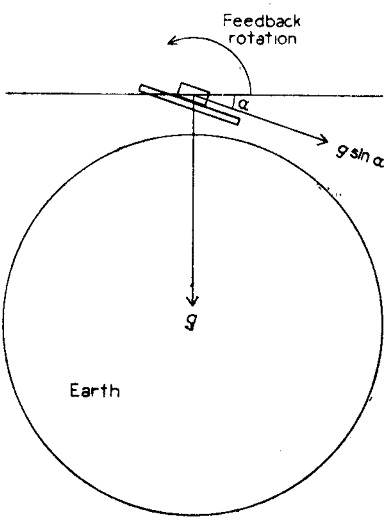


FIGURE 1(a)—PLATFORM TILTED WITH RESPECT TO THE LOCAL VERTICAL

The apparent velocity is fed back to rotate the table. Rotation takes place when the vehicle is actually accelerating and travelling around the earth.

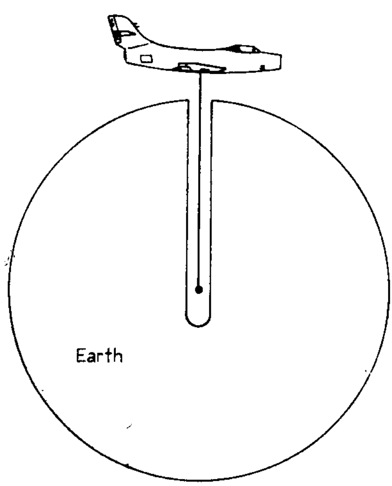


FIGURE 1(b) — THE PENDULUM STRING ALWAYS REMAINS VERTICAL AS THE AIRCRAFT FLIES AROUND THE EARTH

It can be seen that with this arrangement a horizontal acceleration of the vehicle supporting the platform will be sensed by the accelerometers, with a resulting rotation of the table. Analogously, the string of a pendulum mounted on an accelerating vehicle will become inclined to the vertical at an angle proportional to the acceleration. However, if the pendulum bob were at the centre of the earth, the string would always remain along the local vertical no matter what horizontal acceleration were applied at the top of the string (see Figure 1(*b*)). The natural period of such a simple pendulum is easily shown to be 84.4 minutes. Now if the period of oscillation of the Stable Platform is made to be 84.4 minutes by adjustment of the feedback loop, any accelerations of the platform in the horizontal do not affect the horizontal alignment of the table — accelerations give rise to a rotation of the platform which exactly matches the rotation of the accelerating vehicle about the earth. The 84.4-minute 'tuning' is called Schuler tuning after Schuler who first formulated the theory in 1923; the oscillation is termed the Schuler oscillation.

It has been shown that the platform is automatically compensated to keep pace with the rotating earth and with any movement of the supporting vehicle about the earth and that, although it is a pendulous system, accelerations do not affect its alignment with the horizontal. Compensations must also be made for the Coriolis force, for height above the earth's surface, for variations of g from place to place and for the centripetal force resulting from the travel at constant altitude around the curved surface of the earth. These corrections are often very small but are nevertheless necessary to maintain accurate alignment of the platform with the local horizontal. The corrections can be automatically computed and fed back from the various output stages of the platform which in effect 'knows' its position and velocity at any time given the co-ordinates of the starting point.

The platform performs a Schuler oscillation both while in flight and stationary. A typical amplitude of this oscillation is of the order 10 minutes of arc in present stable platforms and the oscillation, as can be expected, gives rise to errors, more especially in the values of horizontal acceleration (and therefore velocity and distance travelled). Although the vertical accelerometer is not affected to the same extent by the Schuler oscillation it normally senses one g and this acceleration has to be backed off electrically. The backing off cannot be done perfectly and therefore the vertical acceleration, velocity and distance outputs show a drift from the true values.

In an operational inertial navigation system the errors arising from the Schuler oscillation and from the vertical drift can be allowed for by 'mixing' with independent sources of information. For example the horizontal velocity can be compared with the velocity as measured by Doppler radar. Over periods greater than about 10 minutes the Doppler is more accurate than the inertial system; for short periods the platform outputs can be used to measure the variations in speed which the Doppler cannot measure accurately.

The Meteorological Research Flight Stable Platform.—The Meteorological Research Flight Hastings has recently been fitted with a Stable Platform FSP100, developed by Ferranti Ltd and the Inertial Navigation Division of the Instruments and Electrical Engineering Department, Royal Aircraft Establishment, Farnborough (see Plate IV). It is hoped to complete shortly a similar installation on the Canberra. The Meteorological Research Flight installation does not make use of automatic mixing but it is possible to correct the Schuler oscillation error in the horizontal velocity outputs by taking readings of the Doppler velocity while recording the platform outputs. Combination of the two can be made on the ground after the flight. The drift in the vertical velocity is fairly linear and is therefore allowed for by finding the best-fit straight line to the velocity output. The drift must not be allowed to proceed too far as the platform could then 'think' it was many miles from the surface of the earth with corresponding effects on the various corrective feedbacks. This requirement places a limitation on the period for which the vertical velocity can be allowed to drift, which is about 10 minutes with the FSP100 ; after 10 minutes the drift must be zeroed, a process which takes a few minutes. When Doppler mixing is used there is no such limitation on the computation of the horizontal velocities but the effect on the vertical velocity of the absence of mixing (e.g. by comparison with an altimeter) means that the Meteorological Research Flight Stable Platform can be used only to measure *changes* in vertical velocity from a given point and not the absolute values. In computation of gust velocities the velocity at the starting point is at first assumed to be zero and the gusts through the sampling run are related to this arbitrary zero. A good estimate of the absolute values can be made later, for if the aircraft does not change height appreciably over the run it is safe to say that the aircraft's mean vertical velocity is about zero.

The platform outputs together with the wind-vane deflexions are recorded by a photographic galvanometer recorder. The deviations of the various parameters from their values at the starting point are read off from the record at fixed time intervals. The data are punched on tape suitable for processing by computer to solve the equations at each time step. The airspeed U used in the equations is a mean value over the run because the gusts themselves affect the static vent of the pitot-static system and make the instantaneous accurate measurement of airspeed impossible. Examination of equations (1), (2) and (3) shows that although U is large compared with the vertical and lateral gusts, errors in U give rise to only small errors in them. Errors in U do however cause considerable errors in the longitudinal gusts.

Some idea of the accuracy of vertical velocity measurement may be obtained by asking the pilot to manœuvre the aircraft in pitching and rolling motions in non-turbulent air, say above an inversion. The computation of the equations in this case should give the vertical velocity as zero. From this type of experiment it can be deduced that the error in vertical gust velocity arising from instrumental and trace reading errors is about ± 1ft/s. Considering that the Hastings cruises at about 300 ft/s this order of accuracy is remarkably high.

Some results.—Some measurements of vertical gusts in shallow cumulus over southern England on 29 March 1966 are shown in Figure 2. The aircraft flown was the Hastings which then had a single wind vane mounted horizontally on a boom at the side of the fuselage. This arrangement is unsatisfactory because airflow around the fuselage affects the wind vane and because no provision is made for the measurement of β (see equations) for which a second, vertical wind vane is required. However, the term $\tan\beta \sin r$

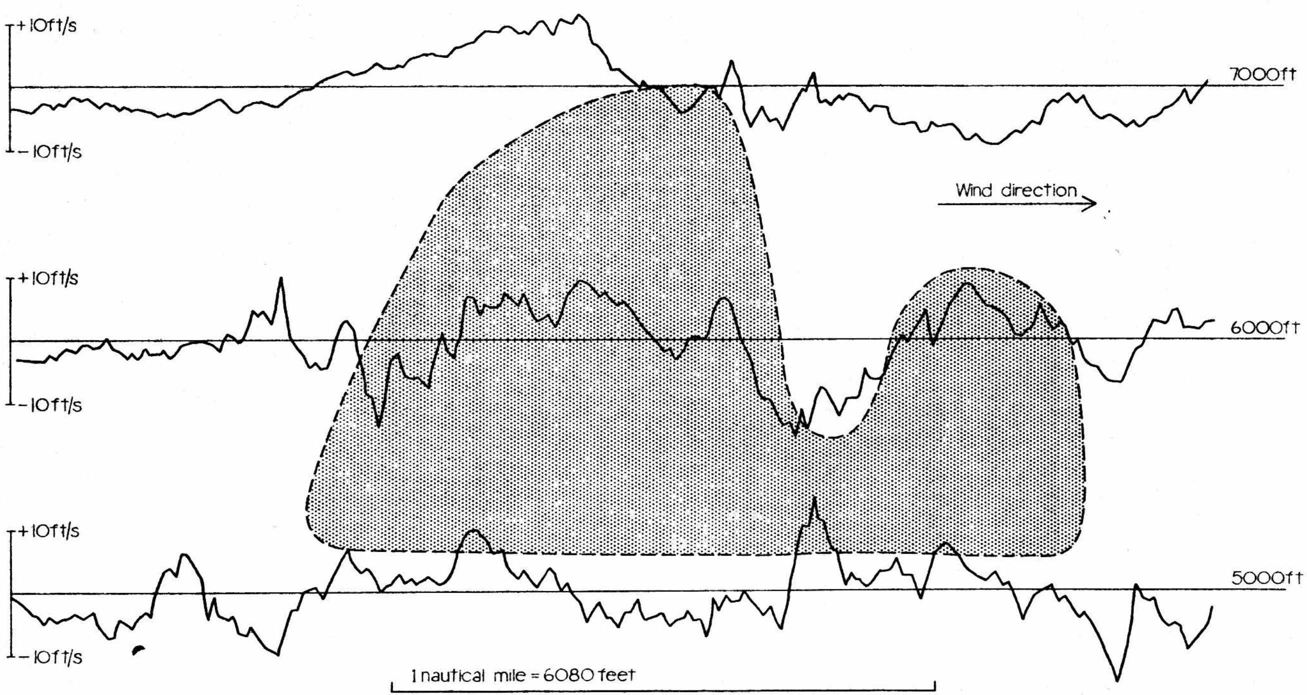


FIGURE 2—VERTICAL GUSTS IN SHALLOW CUMULUS OVER SOUTHERN ENGLAND ON 29 MARCH 1966

The shading shows the approximate extent of the cloud.

in equation (1) is in general much smaller than the term $\tan\alpha\cos r$, and the neglect of this term does not cause a large error in the vertical gust measurement. The Hastings aircraft is to be fitted with a nose probe similar to that of the Canberra which allows measurement of both α and β.

The cloud was penetrated near the top and about the middle and just below the base. Each run, made straight and level either upwind or downwind, was carefully timed, as were the turns and descents between runs, in order to relate, if possible, the gusts at each level. The cloud was about 2000 ft deep, top 7000 ft, base 5100 ft. The regions of cloudy air are marked on the graph of vertical velocity measurements. The updraughts in the cloud itself with downdraughts at the edges are well marked as is the decrease of turbulence towards the top of the cloud where there was a well-marked inversion.

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THE FIRST INTERNATIONAL SYMPOSIUM ON METHODS IN AGROCLIMATOLOGY, READING, 20–30 JULY 1966

The Symposium was organized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) with the understandable interest and co-operation of the Food and Agriculture Organization (FAO) and the World Meteorological Organization (WMO). Its formal purpose was 'to review critically the current progress of methods of measurement, analysis and presentation in agroclimatic studies and the practical uses to which they can be put.'

One can hope to convey the substance but not the savour of the opening speaker's remarks. Dr Austin Bourke, having established the relation between agrometeorology and agroclimatology took as a definition that 'the task of the agrometeorologist is to apply every relevant meteorological skill to helping the farmer to make the most efficient use of his physical environment, with the prime aim of improving agricultural production — both in quality and quantity.' The key question was the practical utility of agroclimatic classification and its application to overall agricultural strategy. After underlining some of the difficulties of handling meteorological and biological data, and of establishing relationships between the two, Dr Bourke indicated some of the hazards that may occur when models of behaviour are formulated. The only valid test of any agrometeorological rule was 'Does it give practical results?' A procedure that worked with an efficiency of 80 per cent would be a reasonably good one in the agricultural world.

After these general remarks, the papers became more specific. Professor Budyko, speaking on solar radiation and its use by plants, showed how purely meteorological data could be developed into an agroclimatic index. The intensity and amount of solar radiation reaching the earth's surface may either be measured directly, or the components of the radiation régime derived by computation from observations of basic meteorological elements. One of the results of the International Geophysical Year, for example, was to show that mean monthly and annual values of total radiation may be derived with an error not exceeding a few per cent.

Dr Rijtema showed that agreement is possible between observed and derived values of transpiration and emphasized the possibility of transferring empirically derived crop parameters from one climatic region to another. He briefly mentioned some of the early empirical methods of calculating evapotranspiration, for example those based on monthly mean temperature, but soon moved on to methods taking fuller account of the meteorological processes involved, as well as to factors relating to the plant and the physical condition of the soil.

After the review by Dr Rijtema, Dr Slatyer was able to focus attention on the problems of using soil water balance data for agroclimatic purposes in regions where meteorological observing stations are few and record only one or two elements.

Agroclimatic models using soil water balance data are usually set up on the basis of a water budget in which precipitation (or irrigation) minus run-off (or plus run-on) is added to the soil water store, which is then depleted by deep drainage and evapotranspiration. Because of inaccuracies in measuring or assessing the individual items of the soil water budget, the method is restricted to regions of relatively high potential evapotranspiration rates and characteristically intermittent rainfall. It was demonstrated by reference to models developed for the Alice Springs area of central Australia.

A typical result might be, in regions where both summer and winter rainfall are alone inadequate to carry a crop through, the recommendation of a summer fallow, followed by a winter crop which could realize a harvest by drawing on the soil water reserves established in the summer. Soil water balance estimates, in addition to providing an index of regional climate, have found a use in the calculation of irrigation need, the estimation of drought hazard, and in studies of the leaching of soils and of water-table levels.

Dr Waggoner's paper was in its way a very compendium of examples of ways of manipulating meteorological data and the limiting agrometeorological factors — of passing from primary observation to derived data and back again — of examples of the utility of a limited run of observations already available, and of the diminishing marginal utility of additional observations as the run increases.

Whilst on the subject of data manipulation, this is perhaps a convenient point to draw attention to the paper by Dr Sharon. In agroclimatology and particularly in microclimatology, observations may be taken over limited periods and conclusions drawn from a small number of observations only. Dr Sharon was interested in the size of sample necessary to achieve a predetermined degree of reliability. The procedure was illustrated by examination of the number of observations necessary to determine the frost liability of a site.

Dr Waggoner kept before us the need to concentrate on the weather phenomena most relevant to a given problem, or the kind of parameter to be written into the 'decision matrix'. A decision matrix is a contingency table in which the resultant profit is tabulated under the various combinations of two variables, one being the relative probability of alternative weather or climatic features and the other being alternative farming systems or actions.

Dr MacQuigg gave examples relevant to the agrometeorological field, both for decisions made over periods of time which rule out the use of weather trends and for decisions which can incorporate the use of a medium-range forecast. An example of the latter type was in the choice of a planting date for cotton ; but he was able to show that weather information does not have to be perfect to be of use and an interesting by-product was that it is possible to place an economic value on forecasts whose accuracy ranges from 50 per cent to 100 per cent in the example.

After this general review and examples of the application of observed and derived meteorological data to the establishment of crop/climate relationships, the specialists were permitted to have their field day — for there are obviously considerations other than the purely meteorological environment to be taken into account when attempting to assess the agricultural potential of an area. The total environment includes factors such as soil fertility (its maintenance or restoration), insects and other pests, plant disease, etc.

Whilst others present may have been hoping for ways of identifying climatic trends and for means of 'getting in on them at the bottom and out at the top,' the meteorologists present were perhaps resigned to the conclusions of Professor Sutcliffe. There are difficulties in establishing scientifically based relations for fluctuations and trends in climate and we have to fall back on a statistical approach to future events on the broader time scale. This view was not entirely accepted and Dr Penman pointed out that, when faced with a system of many variables, a standard approach was to look first for the more conservative elements and to take them outside the problem. In this country, the climatic factors deciding between arable and grassland farming were rainfall and evaporation. When considering possible shifts in the pattern of farming here over the next 20 years, rainfall would be the determining factor since potential evaporation might be expected to remain reasonably constant. We should probably find though that the farmers would have adapted to a changed rainfall régime before the climatologists had agreed that there was a trend.

These papers were followed by others which offered the basis for some action. The population dynamics of pests and the foci of plant disease are influenced by much the same meteorological elements as the plants themselves, reacting to temperature, moisture, light and wind. An understanding of the part these factors play at the various stages of the life cycle of the pest opens the way to the possibility of prediction from meteorological data and of control.

The recent report of a WMO Working Group on shelter left Dr van Eimern free to concentrate on outstanding problems, for example the estimation of wind danger in hilly areas, and the need for reports to be compiled in such a way that the results of different investigations can be compared. The point was made by several speakers that despite a suitable macroclimate, local climatic conditions need to be studied in deciding the suitability of small areas for agriculture, particularly with regard to frost liability.

Professor Mahadevan spoke on the relation between climatic factors and animal production, though his main interest was in the adaptation (through selective breeding for heat tolerance) of high-yielding temperate-zone animals to the tropics.

The methods employed in the recent FAO/UNESCO/WMO surveys were presented by Mr Cochemé and Dr Wallén. The surveys had been of the arid and semi-arid areas of the Levant and of that part of West Africa south of the Sahara. With the emphasis on water availability as a crop-limiting factor, much attention naturally centred on rainfall and evapotranspiration.

The meeting closed without formal resolutions or formal recommendations for future work, but there was an attempt to obtain some consensus of opinion on the problems to be tackled over the next few years and the data that would help. On the latter point, there was a definite requirement for radiation networks, for a convenient assemblage of instruments for topoclimatological studies and there was little doubt that lysimeters of the sunken-pan type were to be preferred. Future progress is dependent upon money and, in summarizing or looking ahead, speakers were at pains to demonstrate their interest in profit or economic gain.

C. V. SMITH

551.5(04):551.501.8

NOTES AND NEWS

Lecture by Professor David Atlas

Meteorologists are familiar with the use of radar as a powerful tool in the study of cloud physics, and Professor Atlas of Chicago University has been a leading figure in this field since it began 20 years ago. In recent years, however, Professor Atlas's interest has shifted to the use of radar to probe the properties of the *cloudless* atmosphere, and his recent work in this field formed the subject of his lecture at the Meteorological Office, Bracknell, on 15 September 1966.

Since the earliest days of radar, workers have reported signals from an apparently cloudless atmosphere which have been called 'clear-air returns' or 'angels'. These angels were generally ascribed either to birds and insects, or to local inhomogeneities in the refractive index of the atmosphere caused mainly by fluctuations in water-vapour concentration. However, little systematic effort to identify the origin of angels was made until fairly recently when the advent of more powerful and sophisticated equipment began to attract radar meteorologists to this field.

The most comprehensive attack on the study of angels to date has recently been made by Professor Atlas using three powerful radars operating at wavelengths of 3·2, 10·7 and 71·5 cm and installed at Wallops Island, Virginia. This combination of different wavelengths and great power has led to an analysis which Professor Atlas described with great enthusiasm.

He distinguished between two basic angel types : discrete echoes which appear to emanate from a point in space and are called 'point' or 'dot' angels ; and diffuse echoes of some horizontal extent appearing as bands or cells on PPI (Plan Position Indicator) or RHI (Range-Height Indicator) displays.

Dot angels may be produced either by birds and insects, or by partial specular reflection from the concave (downwards) regions of smooth, undulating laminar layers.

Atlas claimed the two causes could be distinguished by the wavelength dependence of the signal intensity. Birds and insects scatter radiation roughly isotropically with an intensity roughly proportional to λ^{-4} (Rayleigh's Law) and thus appear strongest on the 3·2-cm radar, whereas partial reflections have a wavelength dependence which is weak and may be slightly positive, and so appear strongest at 71.5 cm.

The use of insects as wind tracers has already been exploited by several workers — notably Lhermitte who studied the structure of the nocturnal low-level jet over Oklahoma — while the motions of the insects relative to their local wind (i.e. their airspeed) can also be studied, and this may be of interest to entomologists. Professor Atlas predicted that radar could well replace the radiosonde as a wind-finder over the next 10 years!

Diffuse angels may appear in various forms. The best known are thin horizontal layers which have been shown by Saxton and Lane of the Radio and Space Research Station, Slough, to correlate perfectly with stable layers in the lower troposphere containing sharp refractivity gradients.

Professor Atlas also reports these low-level layers as a common feature but, at Wallops Island this summer, a faint layer was observed at the tropopause on six occasions, which led Professor Atlas to suggest (from theoretical considerations) that clear-air turbulence should be detectable from *forward*-scattered beams with equipment of moderate power since forward-scattered intensities would be 100 to 10,000 times the back-scattered intensities detected with the powerful Wallops Island equipment.

These ideas gave rise to a good deal of discussion. It was pointed out that the scales of turbulence detected by radar were one or two orders of magnitude less than those detected by aircraft, and implied an assumption regarding flux of energy down the spectral scale of turbulence. It was also by no means clear that turbulence experienced by an aircraft would always be detectable by radar particularly if it was in the form of wave motion of hundreds of metres wavelength. Objections to the identification of 'refractivity turbulence' with mechanical turbulence were also made: the former could occur without the latter (e.g. moist patches left by evaporating cloud in non-turbulent air) and vice versa (e.g. the tendency for turbulence to mix out any gradients of water-vapour concentration).

Professor Atlas agreed, but suggested that refractivity turbulence and mechanical turbulence will generally occur close enough in space and time for practical purposes.

The other features of interest were the detection of diffuse echoes from sea-breeze fronts and thermal convection cells. Mr Lane of the Radio and Space Research Station was present, and described his observations at Wallops Island in collaboration with Professor Atlas where he flew a radio refractometer suspended 80 feet below a helicopter through thermals over the sea, and was able to identify the turbulent shells of thermal cells with the regions of diffuse echoes shown by the radar complex. Thus it is clear that this represents a powerful technique for studying low-level convection, although one of the members of the audience claimed it showed nothing he would not have expected 'by looking out of his bedroom window'. This is perhaps rather unfair, since unexpected features might well appear on closer inspection and this work should be especially relevant to recent work on low-level convection.

The discussion was brought to a close at 5 p.m. and Professor Atlas was thanked by the Director-General for his stimulating and exciting talk.

W. T. ROACH

REVIEW

Weather prediction by numerical process, by L. F. Richardson. 9¼ in × 6½ in, pp. xvi+236, *illus.*, Constable & Co. Ltd, 10 Orange Street, London, WC2, 1966. Price : $2.00.

This book by L. F. Richardson is one of the outstanding scientific books of his era. The scientific content of the book, however, is now mainly of a historical nature, despite the publisher's claim that this is one of the best textbooks on dynamical meteorology ever written, and I do not recommend that this book should be used as a classroom text. Nevertheless, this book is of considerable interest to all active workers in the field, and Dover Publications are to be congratulated on their decision to reprint it.

Richardson sets out a systematic method of computing the future state of the atmosphere given its initial condition, and computes six-hour changes in fundamental parameters such as pressure, wind and temperature. Unfortunately, his one example produced pressure changes more than an order of magnitude too large, and he attributed this to errors in evaluating the horizontal divergence from the wind field. The subject then lay dormant until the advent of modern electronic computing machinery when methods of numerical weather prediction which did not depend upon evaluating the horizontal divergence were developed by Charney, Phillips and others. Recently, it has been shown by Hinkleman and others that the basic equations used by Richardson can be used to predict weather changes, provided certain precautions are taken. It is essential that there should be no spuriously large divergences implied by the initial wind field, and it is necessary that the time-step should be of the order of a few minutes in order to stop the amplification of sound and fast-moving gravity waves, rather than the six hours used by Richardson.

Thus it is true to say that whilst all workers in numerical weather prediction should read this book, it is unlikely that anyone can make very much useful progress in this field without studying much more up-to-date textbooks and research papers.

F. BUSHBY

LETTERS TO THE EDITOR

551.509.317:551.509.56

Instability index

A recent article by Saunders[1] describing tests of thunderstorm forecasting techniques states that the time taken to apply the modified Jefferson index[2] (T_{mJ}) was 10–20 minutes using 0000 GMT upper air data and allowing for the effects of advection and surface heating as seem appropriate.

The figure of 10–20 minutes could certainly be substantially reduced by using the procedures now adopted at Episkopi.

(i) The formula for the index has been slightly modified by adopting a wet-bulb potential temperature at 850 mb, θ_{w850}, instead of at 900 mb. Thus when T_{500} is the air temperature (°C) at 500 mb and T_{d700} is the dew-point depression in degC at 700 mb the formula reads

$$T_{mJ} = 1{\cdot}6\ \theta_{w850} - T_{500} - \tfrac{1}{2}T_{d700} - 8$$

and can be calculated from readings at the standard pressure levels reported in the upper air message.

The modification makes little difference to the index itself and may in fact be an advantage in the Mediterranean area. I think it would have little if any adverse effect if it were used in the United Kingdom area.

(ii) A table has been constructed to give θ_{w850} to the nearest half-degree Celsius from dry-bulb and dew-point readings. The table on page 94 of *Meteorological Magazine*, Volume 92, 1963, can be used to give T_J from θ_{w850} and T_{500}. The table on page 314 of *Meteorological Magazine*, Volume 92, 1963, gives the further correction to T_J to obtain T_{mJ} from T_{d700}. All tables can be laid under perspex on the plotting bench.

(iii) Using these tables T_{mJ} can be evaluated in not more than 30 seconds per station direct from the upper air message. At Episkopi such evaluations are carried out and a chart of the index plotted station by station.

By using all ascents received for the area of the map and not merely those for which tephigrams are plotted, an additional upper air chart is produced to stand alongside the normal contour charts for standard levels but showing the spatial distribution of instability. While not replacing the usual study and analysis of the plotted ascents available it does form a very useful additional aid to analysis.

Episkopi, Cyprus. G. J. JEFFERSON

[It is learned that a test is being made in the United Kingdom of the Jefferson index using θ_{w850}. Ed. M. M.]

REFERENCES

1. SAUNDERS, W. E.; Tests of thunderstorm forecasting techniques. *Met. Mag., London*, **95**, 1966, p. 204.
2. JEFFERSON, G. J.; A further development of the instability index. *Met. Mag., London*, **92**, 1963, p. 313.

551.557.5:551.576.11:77

Upper cloud striations

On 7 September 1966 an inactive warm front was moving slowly north-east over south-west England and the Channel area. The photograph (Plate II) shows cloud to the south-south-east of London (Heathrow) Airport at 1115 GMT. At 1200 GMT the maximum wind at Crawley, Sussex was 250°/90 knots at about 40,000 ft but the core of the jet stream lay over northern England. Although the clouds shown were in association with a frontal system and some distance from the core of the jet stream the complexity of their structure is typical of the structure of clouds near a jet stream.*

19 Ensign Way, Stanwell, Staines, Middlesex.

A. H. P. JARRETT

* JEFFERSON, G. J. Photographs of jet-stream clouds. *Met. Mag., London*, **93**, 1964, p. 91.

OFFICIAL PUBLICATIONS

SCIENTIFIC PAPERS

No. 23—*Surface and 900 mb wind relationships*, by J. Findlater, T. N. S. Harrower, M.A., B.Sc., G. A. Howkins, M.B.E., B.Sc. and H. L. Wright, M.A.

The paper presents an analysis of surface and 900 mb wind relationships made during a search for an objective method of forecasting the surface wind from the geostrophic wind. A basis was obtained for a forecasting technique for surface wind over sea areas but little progress was made for land areas.

Nearly 17,000 observation pairs for two locations over the sea and two over the land were used to make a comprehensive analysis and results are presented in some detail because of their interest in relation to general questions of turbulence. Particular attention is paid to the influence of lapse rate in the lower layers.

No. 24—*An atmospheric diffusion slide-rule*, by C. E. Wallington, M.Sc.

The paper describes a slide-rule that can be used to calculate concentrations and dosages in clouds of aerosols being transported and diffused by atmospheric wind and turbulence.

The slide-rule includes scales for incorporating into the calculations several methods of assessing depths and widths of diffusing clouds, but the relative merits of the methods are not discussed in detail ; the main purpose of the paper is to present the slide-rule as a calculating aid.

The slide-rule is not intended for laymen to the subject of atmospheric diffusion ; it is more for those who have at least a little understanding of the theoretical background. For such users the slide-rule provides a means of predicting or assessing experimental diffusion observations ; it facilitates comparison of various methods of diffusion calculations and it enables a user to compile tables or graphs suitable for use by laymen.

No. 25—*The relation between Beaufort force wind speed and wave height*, by R. Frost, B.A.

In this paper it is shown that the present internationally agreed wind-speed and wave-height equivalents of the Beaufort numbers are incompatible with the wind/wave relationships obtained by oceanographers, and a new set of wind equivalents is proposed. With winds measured in metres per second at the internationally agreed height of 10 metres above the surface, the wind-speed equivalents (W) of the Beaufort numbers (B) are shown to be for all practical purposes independent of the atmospheric stability and to be given by

(i) $W = 1{\cdot}38\, B^{7/6}$ over the open oceans,

and (ii) $W = AB^{14/9}$ over coastal waters,

where A varies with the fetch. (In particular, with a fetch of approximately 35 kilometres this formula yields the present international equivalents.)

It is hoped that the paper will prove of value not only to meteorologists and oceanographers but also to the increasing number of other scientists and engineers who need to have a knowledge of sea state conditions.

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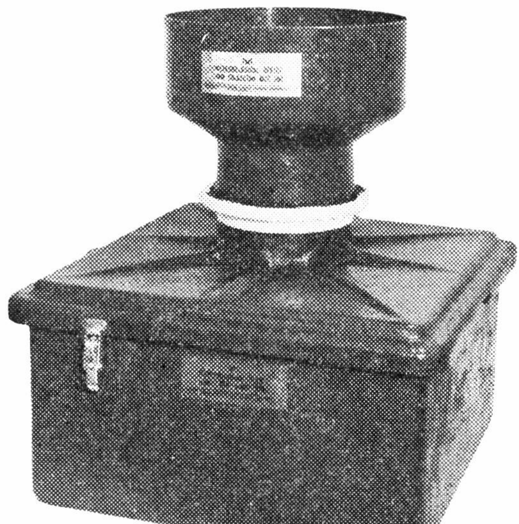

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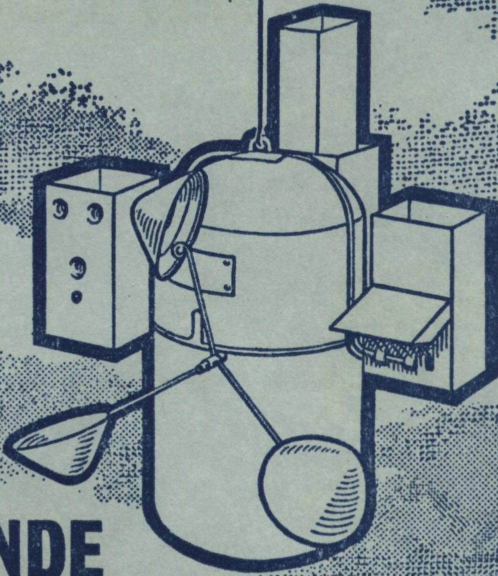

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