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EMPIRICAL RESULTS ON THE GEOMETRY OF CIRRUS BANDS AS RELATED TO METEOROLOGICAL CONDITIONS

- Part I: Text -

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für Meteorologie der
TECHNISCHEN HOCHSCHULE DARMSTADT

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Technical Report No. 1
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under
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CONTENTS

C O N T E N T S

of part II: F I G U R E S

The report summarizes the results obtained within ten years of photogrammetric cloud studies mainly devoted to cirrus bands.

Foreword

As a technical report, this script restricts mainly to the empirical facts with less emphasis on interpretation. In view of the variety of cloud forms and conditions under which they may form, the twelve cases reported here do not permit to draw conclusions of general validity beyond doubt; they may contribute, however, to the probability of assumptions and to the clarification of the problems and ways to solve them. For an appropriate way of describing the results and for practical reasons the 180 figures of this report were separated from the text.

The precision photo theodolites used for taking the stereo photos were designed and built in 1953 by ASKANIA/Berlin on the initiative of H. KOSCHMIEDER; they were sole paid by the SENATOR FÜR WIRTSCHAFT UND KREDIT of Berlin from funds of the European Recovery Program (ERP). Since 1954 the taking of stereo pairs, gathering experience in all of the special work of cloud photogrammetry and subsequent research work have been financed by the DEUTSCHE FORSCHUNGS-GEMEINSCHAFT (DFG). Also the stereocomparator, by which the coordinates are measured is of DFG property. Mr. J. REUSS who has worked on DFG funds until then has been employed since January 1, 1962 by the FLUGWISSENSCHAFTLICHE FORSCHUNGSANSTALT e.V.München (FFM) as leader of the cloud photogrammetry group.

An expansion of the research program on cirrus was introduced by the present contract made by the EUROPEAN

OFFICE OF AEROSPACE RESEARCH of the U.S. AIR FORCE CAMBRIDGE RESEARCH LABORATORIES and professor H. KOSCHMIEDER, effective May 1, 1962.

Our gratitude is due to the contract monitor, Mr. J.H. CONOVER, for the problems he explained and the suggestions he made in many discussions and by both his personal notes and his publications.

Thanks are also due to Messrs. B. HELLING and H.WIRTZ for their cooperation in taking and evaluating the single and stereo photograph sequences, as well as to Miss M. LUCZKA for the reproduction of the many figures and Mr. R. MEISSNER for the design and contouring of the synoptic maps, cross sections etc. Most of the Indian-ink drawings were made by our Turkish student assistants.

Dr. K.KEIL of the DEUTSCHER WETTERDIENST, central office has kindly placed at our disposal the synoptic data used in this report.

Beside the support given to this research with a share in funds of approximately one third by the FFM, by two thirds the research reported in this document has been sponsored by the U.S. AIR FORCE CAMBRIDGE RESEARCH LABORATORIES through the EUROPEAN OFFICE, AEROSPACE RESEARCH, UNITED STATES AIR FORCE .

Darmstadt, April 1963
Germany

The authors

Abstract

Prior to individual case studies of cirrus, the behaviour of wird in the upper troposphere is explored.

Based on routine weather service data, the deviation of mean vertical wind shear direction from the wind direction turns out to be small only at great wind velocities, whilst it may have any value at small velocities (at least at moderate latitudes). The mean deviation angle $\bar{\alpha}$ thus behaves statistically analogue to, and in connection with results of cloud photogrammetry explains to a great extent, the results obtained by CLAYTON (1896) upon the analysis of 1396 observations of the orientation of banded and streaky cirrus as compared to their respective direction of motion. From these and recent results found by CONOVER (1959), KÜTTNER (1959), J.S. MALKUS and RIEHL (1962) et al and PLANK (1959), a working hypothesis is deduced. For a preliminary test of it, six series of stereo photos and six sequences of single photos are analysed with respect to their respective weather situation. The analysis concentrates on the following cirrus features (as far as available): height, location, orientation, cloud and cell spacing, structure as compared to the corresponding wind velocity, vertical and horizontal shear, vertical gradients of wind shear, isotach cross sections normal to the 300 mb wind, as well as isotherms, contours and isotachs of the 300 mb level, and the horizontal distribution of cloud cover. The gradients of potential temperature as well as stability and gravity

wave criteria will follow in the final report. Among all the synoptic featur s, the mean direction of the isotherms seems to correlate best to the respective direction of bands (or more general: elongation) of cirrus at the same level.

Due to the great number of variables involved in the problem and due to the limited accuracy and "grid density" of the available data, the present number of cases under study is not yet sufficient to establish relations beyond doubt. This can be expected only from additional cases and studies to be published in a final report.

A. Meteorological Introduction

From the many variables of atmospheric dynamics, in this chapter those will be treated which have foremost bearing on cloud orientation and structure: direction and magnitude of wind, vertical and horizontal wind shear and probably, the gradients at least of the former.

1) Statistical relation of the deviation of band orientation from their motion direction, versus their motion velocity

In 1896 CLAYTON (1) upon 1396 observations of cirrus bands over the Boston area, covering the time from 1889 till 1894, made the following statements (cited from KUTTNER, 1959):

*"... at all velocities the majority of bands lies in the general direction of their motion and but few at right angles to it; but the proportion of the bands which move in the direction of their length increases rapidly with the velocity .... nearly 80 % of the rapidly moving bands (more than

100 knots) varied less than 23° from the direction of motion". He also concluded that cirrus bands have the greatest mean velocity when moving longitudinally, and the least when extending at right angles to their direction of motion.«

The last remark may be interpreted to mean, that at small velocities the bands may orient in any direction with respect to their motion direction [1], whereas the preceding statement means that the band orientation deviates only by small angles at great velocities.

2) Statistical relation of the deviation of the mean wind shear direction from the wind direction, versus wind velocity

The deviation of the mean vertical wind shear, between the 200 - 300 and the 300 - 400 mb levels, from the 300 mb wind will be defined by the acute angles α_1 and α_2 , respectively, according to Fig. 1. The mean deviation or drift angle is defined as

$$\bar{\alpha} = \frac{1}{2} (|\alpha_1| + |\alpha_2|) \qquad (1)$$

For a first experiment, 174 dates were chosen from the weather maps, of which the data of routine aerologic ascents were used; the concept and methods and results have been described (REUSS, 1963). An improved method used here considers also the amounts of wind shear; it is as follows: from the data of aerologic ascents of one station (i.e. Stuttgart and/or Emden) $\bar{\alpha}$ is calculated (from graphical charts of the kind of Fig. 1) for a number of days which

1) Some waves might also be among what CLAYTON called bands.

is great enough for statistical evaluation. Fig. 2 depicts 330 values of $\overline{\alpha}$ versus the corresponding value of the velocity u at the 300 mb level. The diameters of the full circles are proportional to the mean amount $\overline{s} = \frac{1}{2} (|s_1| + |s_2|)$ of the mean vertical wind shear amounts s_1 (between the 400 and 300 mb level) and s_2 (between the 300 and 200 mb level; for scale of $\overline{s}$, see upper right of Fig. 2). A correlation of u versus $\overline{s}$ is shown in Fig. 3.

The method still bears the following disadvantages : The values α and s (and u) are not precisely known since (1) the wind data are relatively inaccurate as to both direction and velocity (REITER, 1961); (2) wind data are too sparse as to allow for the systematic use of levels closer to 300 mb for the determination of neighboured vertical shear (which would allow for a different, more detailed definition and determination of $\overline{\alpha}$); (3) if the wind maximum lies within 400 to 200 mb, the case of Fig. 4 will not be the rule (wind directions were arbitrarily chosen as 260°, 270° and 280° for 400, 300 and 200 mb, respectively); instead, in the general case, maxima or minima will occur neither at 300 nor at 400 mb, as shown in Fig. 5. If, in addition to equ. (1) on p. 5 we define $\overline{\alpha}'$ as the mean angle of deviation of vertical wind from the direction of the maximum wind, and $\overline{s}'$ as the mean amount of the shear vectors neighboured to the maximum wind it becomes evident that $\overline{\alpha} \geq \overline{\alpha}'$ and $\overline{s} \leq \overline{s}'$. This means that, even at greater velocities, $\overline{\alpha}$ may reach or even exceed 45°; this has to be kept in mind in judging Fig. 2 and the figures 7 to 9.

While Fig. 2 shows the absolute frequency, Fig. 7 contains the relative frequency, normalized so that the sum of the (hatched) areas in the horizontal lines of 5 m/sec intervals is the same for each. The hatched area of each square (5 m/sec and 10° interval) is proportional to the number of points in that area. Fig 8 contains the distribution of relative frequency which would probably result if the difficulties described above would not exist and if a much greater number of ($\overline{\alpha}$, u)-points would have been evaluated.

Furthermore, wind measurements of all days within long periods of fair weather and such of bad weather have been evaluated by the same principle. A marked period of fair weather (in Europe) was the summer 1959. The relative frequencies of the 95 ($\bar{\alpha}$,u)-points of the noon terms of all days from Juli 1 till September 30 1959 are depicted in Fig. 8 ; an evaluation correspondingly made for the 85 days of the bad weather period lasting from July 8 till September 30 1957 is depicted in Fig. 9 . The main difference between Fig. 8 and Fig. 9 is that the variation of $\bar{\alpha}$ (i.e. toward 90^0) is greater and greater velocities are encountered in Fig. 8 than in Fig. 9 . Additional evaluations of this kind from other periods seem to indicate that the weather situation is responsible for this difference.

The statistical relations depicted here will as a rule represent vertical wind shear which - especially for great values of $\bar{\alpha}$ - does not comply with the conditions of the KÜTTNER wind profile. It is, however, suspected that - though in rare cases only - the KÜTTNER wind profile $\partial^2 u / \partial z^2 = -1.10^{-5}\ m^{-1} sec^{-1}$ may be organized across the wind (i.e. u would here represent the direction of vertical shear only, not the direction of the wind; this question will also be discussed in the working hypothesis, chapter A, 5 , and under case V). The mean behaviour of vertical wind shear may also be true for that of horizontal wind shear. This is of importance as far as the horizontal wind shear affects cloud formation and orientation. The role of the horizontal shear gradient will be treated at a later date.

3) <u>Definitions of cloud characteristics :</u>

With the exceptions explained below, Fig. 10 represents the general case of the geometrical features of a cloud (H. KOSCH-MIEDER, 1963). It contains the directions of 1) the clouds' motion and of 2) its elongation (orientation); the difference of 1) and 2) is called the drift angle in Fig. 10.
Fig. 10 also contains the direction of 3) streaks and of 4) the isophases of waves. The cells and "wings", however, which constitute typical bands as described below, could not be in cluded in the drawing.

Concerning Fig. 10, the following explanations have to be added : It is conceived for a cirrus of limited thickness, within which wind shear, temperature gradient ect. do not considerably alter. For this reason the denotation "streaks" does not apply to "Fallstreifen" which are too far below the mother cloud and may be exposed to vertical shear much different in direction and value.

With this restriction, the following statements can be made :

a) the streaks cross the (isophases of the) waves always at right angles;
b) the streaks and the cloud orientation in most cases coincide as to their direction.

Depending on wheather the waves in case a) or the streaks in case b) are more marked, the clouds will be called <u>wave trains</u> or cirrus streaks, respectively.
Bands will be called those cirrus clouds which can be understood in analogy to cumulus streets. In the case of cirrus, they seem to bear cells along their (nearly straight) axis, from which streaks originate which diverge to both sides of the axis (as has first been measured by CONOVER 1959; see there Figs. 285, 286 and 289; in this report, case I (2 March 1957) represents a typical example).

<u>Nomenclature :</u> K = KÜTTNER value $\overline{\delta^2 u/\delta z^2}$; $K_o = -1.10^{-5} m^{-1} sec^{-1}$.

4) <u>A brief account on the present state of knowledge</u>

For the systematic exploration of the relations between cloud bands and the accompanying aerological state, essential contributions in recent years were made by J.H. CONOVER (1959), J.KÜTTNER (1959), J.S. MALKUS and H. RIEHL et al (1962), and V.G. PLANK (1960).

KÜTTNER (1959) has found from both empirical data and theoretical research that well organized cumulus streets occur only when

1) the wind profile obeys the condition

$$\overline{\partial^2 u / \partial z^2} = -1 \cdot 10^{-5} m^{-1} sec^{-1}, \quad ^{1)} \qquad (2)$$

whereby it is apparently presumed that

2) the direction of wind does not change considerably with height.

Following a proposal made by CLEM (1955), KÜTTNER (1959) and CONOVER (1959) have assumed that cirrus bands are analogue to cumulus streets as to both behaviour and the aerological state.

At two cases of cirrus band occurence CONOVER has corroborated the value of eqn. (2) as to sign and order of magnitude, while in three cases of positive shear gradient no bands occured. In the former two cases and in cases I, III, VI and VII, described here, cirrus bands approximately parallel the wind. However, already PLANK in a first short account on his extensive research work indicates that the orientation even of

1) $\overline{\partial^2 u / \partial z^2}$ is the average value of $\partial^2 u / \partial z^2$ within the wind profile considered.

cumulus streets in some cases deviates by considerable angles from their direction of motion; (the research done by J.S.MALKUS and H.RIEHL et al (1961) yields about the same result for cumulus growing into the middle troposphere; in case of great deviations of the orientation from wind direction, they are called "normal mode" by the authors). For cumulus streets, especially, these results seem to be remarkable; because it is likely to assume that in the lower quarter of the troposphere the direction of shear would with a higher probability parallel the wind than in the upper troposphere.

From these and other facts, shown by the results described here, bands are assumed to behave according to the following

4) Working hypothesis:

a) The orientation at least of long bands and streaks is always parallel to the isotherms at their (p=const.)-level (REUSS, 1963).

b) Cirrus streaks may occur and orient parallel to vertical wind shear which does not obey the KÜTTNER wind profile (e.g. cases X and XI).

c) If wind is defined to mean the wind vector relative to a ground-fixed coordinate system, while relative wind is defined to mean the wind relative to a coordinate system moving with the wind adjacent below, the following statement can be made:

It is possible that the KÜTTNER profile of the relative wind, and consequently cirrus bands, orient across the wind. This may be the case when, in an area of considerable extent, isotherms of considerable horizontal gradient cross the wind. Because of the condition that the relative wind within its profile should both 1) satisfy eqn. (2)

and 2) not change very much in direction, this case will rarely occur (a typical example seems to be case V). The case by far more likely to occur is that of the K"TTNER wind profile being approximately parallel to the wind.

d) The probability that cirrus streaks and bands orient parallel to the wind is higher at great (than at small) velocities (Figs. 2,7; REUSS 1963). Bands, in turn, are more likely than cirrus streaks to parallel the wind.

B. General explanations of the figures:

A short formal explanation of what the figures contain is given at the respective figures of case I; it applies also to the figures of cases II through XII, since they are of the same category in principle (except for the photographs).

The following remarks will be necessary for better understanding of the figures which pertain to the meteorological conditions; the figure numbers refer to those of case I (March 2, 1957):

Fig. 5: At the numbers which denote the 300 mb-isotherm temperatures, the "minus" has been omitted since it is evident that only negative temperatures may occur at this level. The minus has only been set in front of the dimension -C° at upper right of this figure.

The scale of this map of Europe, which due to the type of projection is a mean scale, is 1 : 50 000 000 (see lower left). The tiny dot near the crossing of 50 N and 10 E marks the position of Darmstadt, where the clouds of ten of cases described in here were photographed (cases I to VI, and IX to XII). The position of the dot is a different one only for cases VII and VIII, the clouds of which were photographed at Kniebis/Black Forest (Schwarzwald).

The rectangle, drawn in thick lines, marks the position of the map shown in Figs. 11.

Fig. 6: The contours are denoted in units of 10 meters.[1] The dash-stippled straight line marks the position of the cross sections shown in Fig. 8. Although the portions depicted in the cross section are smaller, this dash-stippled line has been drawn from one edge of the frame to the other, so that eventual reconstruction of its position could be easier. In the cross section of Fig. 8, the measured winds of those stations are depicted, which lie within 150 km to both sides of the dash-stippled line.

Fig. 7: Due to some major discrepancies of the wind measurements at different stations, the isotachs - especially in the region of eastern stations - in some of the cases are possibly not very precise. The path of the Jet Stream has therefore not in each case been drawn.

Fig. 8: The position of the cross sections depicted here is dash-stippled in Fig. 6 (see the explanation thereof in this chapter). The cross sections are very exaggerated as to height. Since they are constructed in a position-height coordinate system, the millibar-levels do not portray horizontally. The levels depicted in each case are those of 850, 700, 500, 300, 200, 150, and 100 mb. In the scale of height, 1 cm ≙ 1.16 km; in the scale of horizontal distances, 1 cm ≙ 580 km. The numbers (or letters) denote the aerologic station.

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[1] geopotential meters

listed on page 17. The straight vertical line within the frame of the cross section marks the position of Darmstadt, without additional denotation. In the cross sections which depict dashed isotachs, the Low is at the left, the High at the right side.

If the succession of hours is "2.00, 14.00, 2.00", the first two hours are those of the same day, while the third is of the following day.

Fig. 9: The cloud cover is denoted in units of 1/8 (8 ≙ 100 %). Since the total cloud cover is be-ing reported, cloud types (as e.g. cirrus, altocumulus) could only be distinguished if merely one of these occurred (for further explanation see upper right).

Fig. 10: In the denotation of the time, e.g. 12^h is identical to 12.00 Z. The numbers at the upper brink which increase from right to left have the dimension km[1] of altitude.

At the lower brink, scales of the temperature t, the potential temperature ϑ and the velocity v of the wind profile were drawn. The continuous (steady) lines running from the lower right to the upper left are the altitude-pressure lines; the contankerous lines running from the lower right to the upper left represent the pressure-temperature lines. The thick lines depict the wind profiles; the numbers at their marked points

1) geopotential kilometers

denote the wind direction in units of 10° (angle degrees; e.g. 27 means "wind from W").
The scale of pressure is denoted on the outer right.
The relative humidity is depicted at the outer left.

Fig. 11: The figures of this kind were conceived to show the field of vertical shear vector directions. The original drawing, as a rule, showed the 400, 300, 250, and 200 mb-wind vectors. In the order of succession of these levels, the shear vector directions were drawn in thick dashed lines, from one level to the upper next in the succession just mentioned.
The wind vectors, except for the 300 mb-wind, were later omitted in the figures reproduced here.
As far as these plottings of mean shear vector directions obey the rule of 400, 300, 250, 200 mb-order of succession (see upper right), the millibars were not written next to the points; only in the case of exceptions, the millibars were written next to the points marked by arrows, which denote the shear vector directions.

The individual meteorological contents of the figures were conceived as to require a minimum of comment in the text. A few of their details, as e.g. the potential temperatures in Fig. 10, were not yet entirely evaluated. These and the wind profiles will be evaluated as to stability and gravity wave criteria, when more comparable data of cloud photogrammetry and of the accompanying meteorological conditions will be available.

List of aerologic stations and their numbers
concerning the wind cross sections :

01 415	Sola	
01 492	Oslo	
02 084	Göteborg	
03 005	Lerwick	
03 026	Stornoway	
03 160	Edinburgh	
03 772	London	
06 180	Kopenhagen	
06 260	de Bilt	
06 610	Payerne	
06 705	Genf	
07 110	Brest	
07 151	Paris	
07 180	Nancy	
07 280	Dijon	
07 335	Poitiers	
07 510	Bordeaux	
07 760	Ajaccio	
10 035	Schleswig	Sw
10 203	Emden	E
10 338	Hannover	Ha
10 382	Berlin	B
10 633	Wiesbaden	Wi
10 639	Darmstadt	Da
10 737	Stuttgart	St
10 803	Freiburg	
10 866	München-Riem	Mü
11 036	Wien	
12 375	Warsaw	
12 425	Breslau	
12 840	Budapest	
13 274	Belgrade	
13 334	Split	
16 080	Milan	
16 235	Rome	
16 560	Cagliari	
16 596	Malta	

Bi	Bitburg
Bru	Brüssel
Erl	Erlangen
GY	Great Yarmouth
Jut	Jütland
Kö	Köln
Mar	Marseille

I. 2 March 1957

Photogrammetry: Stereo photographs were taken in Griesheim (some 5 km west of Darmstadt) along a base 1.79 km in length.

Cirrus clouds moved across the previously cloudless sky of the test area, approaching from the North at 11:30. From 11:43 on, photographs were taken first by the northern camera at 11:43, 11:48, 11:50 and 11:55. Fig. 1 shows the photograph taken at 11:55, Fig.2 its situation map, both affixed with cloud point marks for identification. The depicted band in the foreground had later been stereo photographed (see below).

The mean distance of the cells shown in the map from one another appears less in the front than in the rear portion of the band. This is at least partly due to a foreshortening effect, to better recognizability and larger scale of the cloud parts in the foreground than in the rear were only the biggest and brightest cells are readily visible.

The orientation of the band is about 10°-190° in the foreground (down to point ②), and after point ② changes to about 0°-180°. The motion vector is constant at 184°, 34 m/sec; the average altitude of the cloud parts is 10.1 km. An evaluation of the sequence of single photos shows that the tips of the "wings" drift laterally away from the band axis at approximately 1.0 m/sec; the same result has been found in evaluating the stereo photographs. A change in the altitude of the "wing tips" could not be clearly established.

Stereo photographs were taken along an axis directed toward zenith at one-minute intervals beginning at 12:06 and proceeding until 12:28. Fig. 3 depicts the photograph taken at 12:27. The topography map and cross sections thereof are shown in Fig. 4. Whereas the photograph depicts the cirrus clouds "as viewed from below", the situation map is the horizontal projection as seen from above. This means that the sides are reversed image-like. See the marked points A, B, C, D and E (which apply only to Figs. 3 and 4!) for identification. The positions of the two cross sections have been dash-stippled in the map; the points which constitute the cross sections were projected at right angles to them; the results are the vertical sections in Fig. 4, left (scale of height = scale of situation map; the reference level - dashed line- is 10 km above sea level). The "wing tips" of this band are only some 0.25 km above the axis of the band; hence, the cross sections are relatively flat by comparison with Fig. 1, III.

Meteorological state of the upper troposphere: this cirrus band lies within the zone of entrance of the Jet Stream and is located at its right side (Figs. 7,8). The band is approximately parallel to the core of the Jet Stream as are the lines of equal cloud cover, which is almost entirely cirrus (Fig.9). The Jet Stream obeys the rule that in the zone of entrance it crosses the contours toward lower altitudes (Figs. 4, 6, 7, 11).

Since, in the present case, the wind flows approximately parallel to the isotherms, it is less striking than in other cases where the latter are parallel to the cirrus bands (Figs. 4, 5). This will be important, however, in cases IV, V, VIII and XI, where the isotherms cross the contours at about the same angles as do the bands.

The KÜTTNER shear gradient at 14:00 hours at Wiesbaden is $K = -0.4 \times 10^{-5}\ m^{-1}\ sec^{-1}$; its absolute value may have been a little higher between 11:30 and 12:30, when the bands described herein were photographed.

The surface isobars (Fig. 12) show a reversed wind direction near the surface of the test area (compare Fig. 10, below). For the surface istotherms, see Fig. 13).

II. 23 September 1957

Photogrammetry: Stereo pairs were taken in Darmstadt at different time intervals from 10:00 till 16:00 from a base 0,93 km in length with the taking axes alternately directed toward NNW, zenit and SSE.

This sequence has only for a small part been evaluated, since the base length has proved to be too short for detailed measurements, while also the high cirrus were interrupted by lower clouds of the alto and cumulus kinds.

At 10:00, a chaotic sky prevailed: Cu med et con with condensation levels at about 1.0 km of altitude; an altocumulus layer at an altitude of about 3.2 km, with a sharp edge directed WNW-ESE, which is approximately equal to its direction of motion; in the rear, bands of cirrus were indicated.

At about 11:30, the sky was the clearest of this day (as is corroborated by Figs. 6); hence, the fast moving cirrus depicted in Fig. 1 could be traced by a few identical points; most of the results of this evaluation can be taken from the lower part of Fig. 1. However, the altitude of the transverse cirrus streaks, one point of which is denoted by B, could not be determined with satisfying accuracy; the altitude is probably between 11.5 and 12.2 km as determined by different methods.

Chaotic and more dense cirrus and lower clouds turned up soon after, prevailing until about 15:00; at about 16:00 no cirrus but only cumulus clouds occured.

Meteorological state of the troposphere : The chaotic sky is mainly caused by the dynamic instability in connection with a relatively great humidity in the lower half of the troposphere (Figs. 7,8). The dynamic instability, in turn, is caused by the Jet Stream core overhead which, at the time the pictures were taken, had a velocity of about 66 m/sec. At times which differ from this by only half an hour, only about 55 m/sec were measured by radiosondes at stations close to Darmstadt (Figs. 4,5,7,8). Although there is a difference between rawin and photogrammetric measurements even as to the direction of motion (Figs. 1,9), the deviation of the motion vector of cirrus B from that of A (Fig. 1, upper rigt of plan) corresponds to the deviation of the Bitburg winds (Figs. 7,9) at 250 and 300 mb, from each other.

From the experience hitherto gained it is greatly probable that the long streaks (one point of which is denoted by B, Fig. 1) are parts of a broad band which is oriented across the streaks approximately at a right angle, thus being approximately parallel to the motion vector. A decision about this question is hardly possible yet since the 200 mb isotherms as drawn from the small number of stations with wind measurements at that level would not be reliable.

The generally dense cloud cover (Fig. 6) does not show remarkable features except for a slight orientation of the minimum cloud cover in the general flow direction. The general wind direction is close to the direction of the contours and isotherms at 300 mb (Figs. 2,3)

The orientation of the streaks in the background of the photograph (Fig. 1, lower right), which may be Fallstreifen (fall streaks), deviates from the wind vector at 300 mb b[illegible] y some 10°.

III. 5 October 1962

Photogrammetry: Stereophotographs were taken in Darmstadt along a base 1.73 km in length.

The cirrus cloud formation described in the following was first sighted at about 9:00 hours; the sequence was taken by both cameras at one minute intervals, from 9:25 until 9:45 . Fig. 1 depicts the band at 9:27. The evaluation of the stereo photographs completed to date covers only the first seven stereo pairs (those from 9:25 until 9:31) and yields both the topography and two sections across the axis of the cloud (Fig. 2), the latter of which shows that the "wings" (i.e. the streaks pointing laterally away from the axis) have a considerable upward slope on both sides of the axis. Moreover, the "wing tips" tend to drift away from the axis at about 1.0 m/sec. The mean motion vector 290°, 18,5 m/sec almost coincides with the bands orientation which is 102° - 282°.

Besides the band, Fig. 2 contains the position and altitude of some points of the neighbouring altocumulus layer. It should be noted that the level of this layer lies between the levels of the axis and the "wing tips".

Further evaluation of this sequence is being undertaken and will be reported in the final report. The possibility of this band originating in the way described by LUDLAM and SCORER (1957; see Fig. 79, page 71) cannot be excluded.

<u>Meteorological state of the upper troposphere :</u> There are only minor differences in the 300 mb temperature distribution at 12:00 (Fig. 3). The isotherms seem to parallel the band. The band lies to the right of the core of the - rather local - Jet Stream (Figs. 4, 5, 6), and approximately parallel to the lines of equal cloud cover (Fig. 7).

The proximity of the altocumulus layer to the band seems to indicate that the latter is not exposed to great vertical shear. It therefor appears questionable wheather the KÜTTNER wind profile could have caused this band; especially since its value was only $-0,2.10^{-5}$ $m^{-1}sec^{-1}$ at 12:00 in Stuttgart (Fig.8). It hence appears to be probable that the band originated in the way described by LUDLAM and SCORER (1957).

IV. 6 November 1962

Photogrammetry: Stereo photographs were taken in Darmstadt along a base 1.73 km in length. The cirrus clouds described here were photographed at 1-minute intervals from 14:14 until 14:24. They had a triple-deckered formation in which each of the three layers were separate from the next by about 1.0 km each: cirrus streak I (points A, B) is at an altitude of about 7.0 km, cirrus streaks II (points C, D, E, F) at about 8.0 km and the cirrocumulus (point G) at about 9.0 km above the sea level. Their motion vectors and the mean shear vectors between them can be seen in Fig. 1. The streaks I and II are approximately parallel to the shear vector $\overrightarrow{\text{I II}}$; the cirrocumulus layer, on the other hand, does not seem to be exposed to considerable shear. The mean shear vector $\overrightarrow{\text{II III}}$ here is apparently not a satisfactory approximation of the real path of the vertical shear vector.

Meteorological state of the upper troposphere: although cirrus streaks I and II are perhaps a transition state between what might be classified as cirrus streaks and what might still be called random masses, their orientation are still approximately parallel to the 300 mb-isotherms - which are not very marked (Fig. 2). The 300 mb synoptic conditions here roughly compare with those of cases V, VIII and IX. In these cases, the location of the clouds are not far from a 300 mb high ridge; their orientation as well as the mean orientation of the 300 mb-isotherms cross the respective winds and contours at about the same angles (Figs. 1, 2, 3; the neighborhood of a high ridge in such cases has been stated earlier by REUSS, 1963). These cirrus clouds in this case occur to the left of the 250 mb-wind maximum; at the cirrus level itself, however, there is no marked wind maximum (Fig. 5). The lines of equal cloud cover, especially those at 15:00, also cross the mean wind (Fig. 6). The wind profile at 12:00 bears no remarkable features (Fig. 7). The shear vectors at 12:00 apparently do not yet cross the wind (Fig. 8) at angles great enough to account for the orientation of the streaks: The former do not seem to be representative for the conditions at 14:00 hours over Darmstadt.

V. 7 November 1962

Photogrammetry: a few single photographs were taken between 8:22 and 8:30 in Ober-Ramstadt (Figs. 1, 2, 3); stereo pairs were taken in Darmstadt at 1 minute intervals from 10:57 till 11:15 from a base 1.73 km in length with the taking axis tilted by 45° toward E.

The orientation of the bands photographed at about 8:30 was approximately 150° - 330°; it crosses the motion vector at 60°. Both the stereo measurement of the bands taken at about 11:00 and the wind vector at 12:00 in Stuttgart (from which the altitude of the bands may to a certain extent be determined independently) were taken as a basis for calculating the altitude of these bands. The results in both cases is about 8.0 km above sea level = 7.8 km above the ground; their motion vector is 210 °, 28 m/sec. Fig. 2 shows those bands which have been rectified in Fig. 4; Fig. 3 depicts a sequence of two photographs. At about 10:30 a great field of not very bright bands was sighted. The left stereo picture taken at 10:58 is identical to Fig. 6.
In the meantime, at 11:05, the panorama was taken (Fig. 5).

> The evaluation of these stereo pairs proved to be extremely difficult
> (1) due to the great distance of the bands and
> (2) because they lie almost parallel to the x'-axis in the pictures. As described by REUSS (1963), this causes great relative mean errors in the horizontal parallax $p_{x'}$. Additional measurements using different methods were necessary in order to attain the required accuracy.

The mean altitude of the system of points A, B, C, D, P and F was found to be 8.1 ± 0.3 km above sea level; its motion vector 230°, 23 m/sec; That of the points G, H, I, L, M and N is some 9.6 ± 0.4 km above sea level, moving 220°,25 ± 3 m/sec; their orientations can be read from the situation maps. In calculating the height of clouds, the effects of the earth' curvature and of refraction have been taken into acount. Finally, the tiny cloud Z, which vanished only a few minutes after its birth, is at 9.0 ± 0.1 km, moving 225°, 28 m/sec.

It is interesting to note that despite their relatively great motion velocity the bands cross their direction of motion at an angle of about 65°.

Meteorological state of the upper troposphere: Among the isopleths of the 300 mb-level the isotherms are the most striking (Fig. 7). This is one of the rare cases in which the isotherms along a length of some 1000 km cross the contours at almost right angles (Fig. 8). It is evident from figures 6 and 7 that the bands are nearly parallel to the mean direction of the isotherms at the same level and in the same region. The isotachs in Fig. 10, at least those measured at Darmstadt, agree well with those in Fig. 9; they compare less satisfactorily to the motion velocity of these cirrus clouds at about 11:00 (Fig. 6). The cloud cover (Fig. 11) at 12:00 is a minimum in the vicinity of Darmstadt. This minimum coincides with the temperature minimum (Fig. 7); whereas at greater temperature gradients (north and south of Darmstadt) the cloud cover has much greater value. The aerologic ascent of Stuttgart shows that above 250 mb the stability sharply increases. The bands may have been caused by a KÜTTNER wind profile which lies transverse to the wind but parallel to the isotherms (or bands). The shear gradient, therefore, should not be measured at the profile in Fig. 12, which is approximately parallel to the mean wind; but rather from a profile which has been drawn parallel to the isotherms - approximately ESE-WNW in this case. The construction of this profile has been based on the mean winds of 400, 300, 250 and 200 mbs, respectively. (These mean winds are the average of the winds at Cologne (Kö), Stuttgart (St) and Hannover (Ha) at 12:00 - see Fig. 12; they were plotted at the right of Fig. 13, northeast of Darmstadt,(Da)). Of this profile, a mean KÜTTNER value $K = -0,7 \cdot 10^{-5}\ m^{-1}\ sec^{-1}$ results; near 300 mb it is approximately K_0.

VI. 1 March 1963

Stereo pairs were taken in Darmstadt at different time intervals from 10:42 until 13:49 from a base 1,73 km in length. Fig. 1 depicts the position of the band which is some 10 km behind its front position.

The evaluation and discussion of this very typical band which was some 300 km long, was originally planned for the final report. Owing to its similarity with the bands of case I, as to shape, upper troposphere conditions and the date of occurence, however, a short account of it is included in this report. The mean altitude of this band is about 9,2 km above the sea level; the differences in height within the cloud do not exceed 0,3 km; both of these values compare with the values in case I. Similar bands were observed south of the photographed band. They were recorded on some single photographs. Their exact position has not yet been determined. The motion vector of the band is 80°, 17 m/sec; its orientation is 70° - 250°. The wind profiles at Cologne (Kö, Fig.2) and Stuttgart (Fig.3) seem to indicate that the KÜTTNER shear gradient near 300 mb has a positive value.

VII. 31 August 1956

Photogrammetry: the three panoramas in Fig. 1 were taken in Kniebis/Black Forest (Kn); in the diary of H. KOSCHMIEDER they are entitled: "cirrus-row photographed in Kniebis, Reservoir". The evaluation of the photographs was difficult since the data of the outer orientation could only be partially or inaccurately obtained. This cirrus band seems especially interesting since the constituent parts of the characteristic "wing-like" formation are clearly visible (see point A in Fig. 1). Determination of the motion vectors of points at the ends of the "wings" and of points along the axis of the band (or cell centers) shows that 1) the direction of motion of the band practically coincides with its longitudinal orientation and that the tips of the "wings" diverge from the axis (or cells) with a speed of approximately 2 m/sec,- basically in agreement with the results of CONOVER (1959) and with cases I and III. The position of the cirrus band is represented schematically by its axis in the situation plan of Fig. 1 (points A and B). Since the motion velocity calculated does not differ greatly from the wind velocity at 300 mb at 14:00 h, this latter, as an average of the aerological values obtained from ascents at Bitburg, Wiesbaden and Munich, was entered into the situation plan.

Meteorological state of the upper troposphere: in this case the direction of the isotherms coincides with the wind direction and orientation of the band (Fig. 1, 2a,b - only the data from the night ascent were available). The mean value of the wind profile at Bitburg (Fig. 8) and Wiesbaden (Fig. 7) approximates

the KÜTTNER value K, of the shear gradient. The photographically recorded cirrus band is approximately centrally located between two marked wind maxima. These two Jet Streams are separated from one another by about 700 km - measured perpendicular to the wind direction (Fig. 5).
At about the time the photograph was taken in Kniebis (Kn) (the hours given in Fig. 1 are CET), a "street" of minimum cloud cover was passing overhead, lying approximately parallel to the wind direction. (Compare Fig. 6 with Fig. 10 and the situation plan of Fig. 1).

VIII 2 September 1956

Photogrammetry: The three panoramas in Fig. 1 were taken in Kniebis/Black Forest (Kn); in the diary of H.KOSCHMIEDER, they are entitled "Movement of the band perpendicularly to its longitudinal orientation; rapid movement from the south". Evaluation of the photographs was difficult since the data of the outer orientation could only be partially or inaccurately obtained. This cirrus appears especially noteworthy in that it shows the characteristic form of a band although its direction of motion is almost perpendicular to its longitudinal orientation (Fig. 1, situation plan). Owing to the difficulties alluded to above it was not possible to determine whether the slightly formed "wings" of the band (Fig. 1) diverge towards the sides. The position of the cirrus bands is represented schematically by its axis in the situation plan of Fig. 1 (points A and B). Since the motion velocity which was calculated differed only slightly from the wind velocity at 300 mb at 14:00 h, the motion velocity drawn into the situation plan was set equal to the aerologically measured wind velocities.

Meteorological state of the upper troposphere: the cirrus band lies in an area of relatively small horizontal temperature gradients (Fig. 2). The path of the isotherms does not permit any clear comparison with the orientation of the cirrus. It is located in that region of the Jet Stream in which the wind velocity in the direction of the wind decreases, so that the wind crosses the contours toward higher pressures (Fig. 4, 5, 7, 8). Hence, near the location where the photograph was made, the wind velocity steadily increased (Fig. 6); while at the same time, the 300 mb Low north of Spain moved northward at about 7 m/sec. Following the general frequency distribution, the cirrus occurs to the right of the Jet Stream (Fig. 6); with increasing wind velocity the lines of equal cloud cover orient parallel to the wind. That the cirrus band does not orient in the direction of the wind, may be caused by its location in the region of a High ridge (Fig. 4; comp. REUSS 1963).

IX. 19 June 1962

Photogrammetry: The recording of this cirrus began with a panorama at 6:56 (Fig. 1) and was followed by a sequence of five photographs taken at 4-minute intervals. The cloud moves along a path of 250° at about 6 - 7 m/sec at a height of about 7 - 8 km (Estimate of the weather station "Bismarckturm": 7.2 km above the ground = 7.5 km above sea level). The longest of the wave trains is oriented in a north - south direction and hence, parallel to the ridge (that is, the west slope) of the "Odenwald" forest (Fig. 1, points A and B, and Fig. 11 on page 8). This lends support to the supposition that this wave train, as well as the others, were caused by the "Odenwald" forest. The mean wave length, measured in the W - E direction is about 3 km. The length of the smaller shear waves, in the north - south direction, is about 0,45 km.

Meteorological state of the upper troposphere: In this case, the isotherms at 12:00 show no definite general trend. (Fig 2); thus, a comparison with the longitudinal orientation of the relatively short band is not strictly permissible. In view of the above hypothesis (Odenwald), such a comparison is superfluous. The shear waves are oriented approximately in a west - east direction. This can most likely be explained by the apparently locally limited orientation of the vertical <u>shear vector</u>, which in Stuttgart at 6:00 lay between 400 and 300 mb with a value of $3,3 \cdot 10^{-3} sec^{-1}$ in a north - south direction (Fig 8, left).

The wave trains are again situated to the <u>right of the wind maximum</u> (Fig 5). Their appearance starts an increase in the cloud cover (Fig.6). The steady increase of the wind velocity with altitude as a prerequisite for the formation of lee waves (according to the theory presented by SCORER, 1949) is not clearly illustrated by the wind profiles (Fig. 7). Apparently, these are not representative, for the time and place in question, with sufficient accuracy.

X. 12 September 1962

Photogrammetry: Large streaks of high altocumulus were observed from 7:30 on. Photography began at 8:16. The most striking is that both the front and the rear of the streaks (Fig. 2, upper left and right) are quasi stationary, whereas individual cloud points move along the streak direction with considerable speed (Fig. 1). The determination of the clouds' altitude by a procedure described by REUSS (1962) yields 7,8 km above sea level; the estimate made by the observatory Bismarckturm is 7,5 km above ground = 7,8 km above s.l.; the motion vector results as 260°, 37 m/sec. The length of the streaks is about 60 km.

Meteorological state of the upper troposphere: the most remarkable feature of the meteorological state is the steady increase of wind velocity with height without change in wind direction in the upper troposphere (Fig. 8). It is evident without calculation that this wind profile meets the condition that the SCORER parameter l^2 decreases with altitude. This cloud, therefore, is a long wave cloud; since there is no (or only small) change in wind direction, the wind shear is of about the same (Fig. 9), so that the streaks, too, are approximately oriented in that direction (Fig. 2). Finally also, this direction is that of the mean paths of the isotherms (Fig. 3). The streaks occur at the right side and at approximately the same level of the Jet Stream (Fig. 6), but near the zone of exit (Fig. 5). The cloud cover irregularly increases from south (0) to north (8) of Fig. 7.

For a synoptic comparison to the surface isobars, see Fig. 10.

XI. 25 September 1962

Photogrammetry: These cirrus clouds were first sighted at 10:30, and thereafter, a sequence of photographs was taken at 1-minute intervals between 10:42 and 11:09 (Fig. 2 shows only every fifth picture). In the meantime, a panorama of the eastern and of the western celestial hemispheres were made. Both are shown along with the situation map in Fig. 1.

Apparently, the cirrus bands photographed are at different levels. This is indicated, on the one hand, by the slight differences existing between the direction of motion and orientation (Fig. 2, situation map), and from a comparison of the height as calculated from the wind vector and estimated by the weather station "Bismarckturm" on the other. The altitude of the cirrus probably lies between 6.5 and 8.5 km above sea level. The inability to determine the value more accurately is not a great drawback, since those directions which are to be compared with the longitudinal orientation, i.e. the direction of the vertical wind shear (Fig. 9, Stuttgart) and, at any rate, the mean path of the isotherms, vary only slightly at these altitudes (see below). The velocity of motion of the cirrus clouds, in the direction of motion, as shown in the situation map, is aproximately 7 m/sec. In the cirrus streaks of the sequence in Fig. 1, a growth (as at point E) as well as a drying (as at point D) can be observed.

<u>Meteorological state of the upper troposphere:</u> The photographed clouds lie in the region of a southwest wind of a 300 mb High ridge (Fig. 4). A comparison with the situation map of Fig. 2 shows the movement to be in the direction along the contours. Their orientation, however, is approximately parallel to the 40°-isotherm. In this case, the High ridge causes nearly a 180° change in the direction of the air flow (Fig. 4,6). The cloud cover still lies to the right of the flow direction of the Jet Stream (Fig. 6,7,2). In the region of the High ridge, surrounded by the air stream, the air is essentially calm throughout the troposphere (Fig. 8). The vertical wind shear, however, between 500 and 300 mb has a mean value of $2.5 \cdot 10^{-3}$ sec^{-1} (Fig. 9, Stuttgart), which is rather high. Since its mean direction runs parallel to the longitudinal orientation of the cirrus streaks, it is surely the direct cause of their formation. (In view of the above working hypothesis, the KÜTTNER wind profile is not necessary to explain the origin of cirrus streaks). For a synoptic comparison to the surface isobars, see Fig. 10.

XII. 19 November 1962

Photogrammetry: Photographic sequences of these cirrus were taken at 2-minute intervals from 13:15 until 14:57. These cirrus may neither be called bands nor streaks. They are rather composed of layers (at about the same level), the edges of which lie approximately parallel to the motion vector (Fig. 1 shows only a small portion). The observatory Bismarckturm estimated their altitude at approximately 7.0 km above the ground = 7.3 km above sea level. From these values and the values which rectification yields, their velocity of motion must be 20 m/sec, which is in agreement with the wind measurements at 12:00 (Fig. 5, middle, and Fig. 7).

Meteorological state of the upper troposphere: the edges of the cirrus layer are approximately parallel to the 55°-isotherm (just north of Darmstadt). These cirrus are located to the left of the core of the jet stream. Between the cirrus and the jet core there is a zone of high horizontal shear, (Fig. 4, 5, 8). These cirrus occured in a zone of minimum cloud cover, (Fig. 6).

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