AFCRC-TN-58-645

AFCRC-TN-58-645 (I)

Technical Report

BEHAVIOUR OF ATMOSPHERIC ELECTRIC MAGNITUDES RECORDED SIMULTANEOUSLY AT SEVEN MOUNTAIN STATIONS BETWEEN 700 AND 3000 METRES ABOVE SEALEVEL

RESULTS OF ANALYSIS OF THE FINE AND THE DISTURBED WEATHER DATA, WITH SPECIAL ATTENTION BEING GIVEN TO PRECIPITATION AND ITS NITRATE AND NITRITE ION CONTENTS

REINHOLD REITER

171-p

VOLUME I

CONTRACT No. AF 61 (514) - 94

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TECHNICAL REPORT

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Reinhold Reiter

Volume I

July 1958

Contract No. AF 61 (514) - 949

The research reported in this document has been sponsored in part by the Geophysics Research Directorate of the Air Force Cambridge Research Center,
AIR RESEARCH AND DEVELOPMENT COMMAND, UNITED STATES AIR FORCE,
under Contract No. AF 61 (514) - 949 through the European Office, ARDC.

Contractors Adress: Dr. Reinhold Reiter, Farchant, Oberbayern, Germany

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Summary

By means of a station network built up in the Wetterstein Mountains (Northern Alps), continuous recordings of atmospheric electric elements were carried out during all seasons and weather conditions. The seven stations are situated at different altitudes between 700 and 3000 m above sealevel, their horizontal distances being relatively small.

The potential gradient was recorded at each of the stations, the air earth current of four of them. Besides, point discharge current, spherics, and the number of positive and negative small ions were recorded at one of the stations. The positive and negative conductivity of the air was measured through several hours at each station from time to time in fine weather. The nitrite and nitrate ion contents as well as the p_H value of each precipitation were determined; the samples were collected separately for each precipitation or, in the cases of longer precipitation, for several hours, and that at one of the valley stations, if possible simultaneously also at a neighbouring peak station. Meteorological observations were made at all the stationes. Fortunately two of the stations are housed at observatories of the German Weather Service, which are supplying us with their observation results and, if needed, records; at station Farchant, where are our "headquarters" and which commands a view of almost the whole station network, the meteorological observations include special observations on cloud development and precipitation types.

The obtained data and observations were evaluated extensively. The average diurnal variations of the atmospheric electric elements per month or season at the different stations in fine weather were used as a base for the study of bad weather phenomena. Since the stations are a sort of step-ladder through more than 2000 m of atmosphere, the network is especially fit for examining cloud and precipitation problems simultaneously at different altitudes. In the evalutation of the records, therefore, relations between meteorological and accompanying atmospheric electric phenomena were looked for and found out for instance with respect to space charges at sheet cloud boundaries, frequency of sign reversals of the atmospheric electric elements at different altitudes during unstable stratifications, sign and sign reversals in precipitation with the melting zone level being just within the station network, etc. Thunderstorm problems were approached by examining snow crystal friction and breaking and their electrical effects at the different stations during drifting snow, and further by gathering experience with respect to test thunderstorm

forecasts based on spherics recordings and to the correlation between thunderstorm occurrence and sun flares. The nitrate and nitrite contents of precipitation proved to be indicatory of atmospheric electric conditions at such altitudes, too, where there are no recording stations. Besides the eventual function of these contaminants in the process of cloud electrification is considered.

For all the meteorological and atmospheric electric situations dealt with single examples are described and illustrated by recording examples showing the records of the seven stations one above the other on one figure ("synoptic charts"). Beyond this, the results of the numerical and statistical analysis of the atmospheric electric recording curves are given in a great number of graphic representations.

Acknowledgements

The research reported in this document was made possible in part through support and sponsorship extended by the Geophysics Research Directorate of the Air Force Cambridge Research Center, ARDC, USAF, under Contract AF 61 (514)-949 through the European Office, ADRC.

Valuable assistance is due also to the German Weather Service (Deutscher Wetterdienst) and to several Mountain Railway Companies; we wish to express our gratitude to the following organizations and their numerous assistants:

Deutscher Wetterdienst:
- Wetteramt München (Direktor: Dr. R. ARENHOLD)
- Instrumentenamt Süd (Leader: Diplom-Ingenieur L. WÖLFLE)
- Bergwetterwarte Zugspitze (Leader: Diplom-Meteorologe H.WERNER, Diplom-Meteorologe H.HESS)
- Wetterstation Garmisch (Leader: Oberinspektor H.JURISCH)

Bayerische Zugspitzbahn Aktiengesellschaft (Direktor: Diplom-Ingenieur B. SCHMIDT)

Tiroler Zugspitzbahn Aktiengesellschaft (Direktor: Ingenieur W.PANKL)
Wankbahn Aktiengesellschaft (Techn.Leader: Diplomingenieur H.KIRSCHBAUER)

Furthermore we wish to express our thanks to the following firms:
Allgemeine Electrizitätsgesellschaft A.G. (AEG) Berlin-West
Calor-Emag A.G. Ratingen bei Düsseldorf
Hartmann und Braun A.G. Frankfurt / Main
Siemens und Halske A.G., München

We are indebted in many respects also to the following scientific institutes:
Max Planck Institut für Silikatforschung, Berlin-Dahlem (Dozent Dr. L.HOLZAPFEL)
Institut für Technische Elektronik der Technischen Hochschule München (Professor Dr. M.KNOLL)

The DEUTSCHE FORSCHUNGSGEMEINSCHAFT has made possible the numerical evaluation of the fine weather records by granting a subsidy (Sachbeihilfe).

- • -

The research was carried out in co-operation with Mrs. Mirjam REITER.

1. Introduction

In Technical Report AF 61 (514)-732-C we dealt with the first part of our studies an atmospheric electricity supported by the Geophysics Research Directorate of the US Air Force Cambridge Research Center, ARDC. This Report covered a period of two years, during which the station network was completed and measuring instruments were proved; furthermore, we endeavoured to obtain a preliminary insight into the manifold forms of atmospheric electric phenomena, the multiplicity of which appears clearly, if the connections with meteorological processes are considered. It was necessary, within these first two years, to obtain order and survey, to classify all the diverse single phenomena, and to arrange them according to types.

This classifying and finding out of types was carried out by means of "synoptic charts", which contain all the records and observations of one day from all the stations. A more or less large number of single instances were given to describe and establish the single types. However, already in the period covered by our first Technical Report, numerical evaluations of the single cases were started, which were intended to be followed by a statistical treatment of the data.

The scope, as to the methods, of the second investigation period, covering the two years 28 June 1956 till 27 June 1958 and described in this report, was

a) to continue the recording work and the observations as completely as possible, in order to increase the fundamental material;

b) to establish and apply statistical evaluation methods;

c) to carry out additional complementary investigations, in order to make up for some deficiencies and to complete the whole.

These points can be detailed as follows:

a) The station network, consisting of seven stations situated at different altitudes, and the instruments used as yet (see section 2 and 3) were kept on; additional atmospheric electric and meteorological recordings were started at station Farchant (see below point 3); see Table 1.

b) As a base for the statistical evaluations of the records we used, on the one hand, the synoptic charts; 310 such charts are in our archives till now; they were made for all days which, owing to their weather conditions, could throw light upon relationships not yet understood. On the other hand, every recording day was entered into a card index, which enables us to classify systematically the individual cases and to discriminate between the different types.

c) With regard to the measurements added under Contract AF 61 (514)-949, we have to mention the precipitation analyses for nitrate and nitrite ions and for the p_H - value. These analyses were carried out systematically and may complete the insight into the atmospheric electric processes, especially into those which take place during the formation of precipitation.

Besides, station Farchant was enlarged considerably by adding the continuous registration of air earth current, point discharge current, meteorological magnitudes (temperature, relative humidity, wind velocity) and of the number of positive and negative small ions (by means of an instrument lent from the Institut für Technische Elektronik der Technischen Hochschule München).

The <u>scientific objects</u> of the investigation carried out under Contract AF 61 (514)-949 are outlined by the following points:

a) behaviour of atmospheric electric magnitudes, studied simultaneously at different altitudes in the range 700 - 3000 m above sealevel, during all types of precipitation;
b) electric phenomena during drifting snow;
c) behaviour of atmospheric electric magnitudes below and near thunderclouds;
d) behaviour of atmospheric electric magnitudes during foehn;
e) atmospheric electric processes observed at mountain stations when immerging into or coming out of fog;
f) electric charges on sheet clouds;
g) values of electric conductivity of the air at different altitudes and their dependence on convection, wind direction, atmospheric radioactivity, etc.;
h) trial thunderstorm forecasts by means of spherics records;
i) influence of sun flares on the frequency of thunderstorms and spherics pulses
k) correlations between nitrate and nitrite concentration and p_H value in precipitation, and precipitation type, atmospheric unstability, and atmospheric electric processes.

For some of these studies it was necessary to know exactly the behaviour of the atmospheric electric magnitudes at the different levels in fine weather, i.e. the monthly and seasonal means of their diurnal variations recorded on fine weather days. Although this part of the numerical evaluations was not one of the main subjects of the work, we could not do without it; it was made possible through a subsidy of the DEUTSCHE FORSCHUNGSGEMEINSCHAFT. We wish to express our thanks for this essential help.

In the course of the two years covered by this Report, it became quite clear that our station network, being a step-ladder of seven stations situated at different altitudes, is specially appropriate for investigating the behaviour of atmospheric electric magnitudes during precipitation. Our synoptic method[+]), i.e. the uniform and simultaneous comparative evaluation of the synchronous records and observations of all the stations, proved to be suitable here and in some other respects. In this Report, therefore, the results obtained from the precipitation studies shall be described with more details than the others.

It is the purpose of this Report to give an insight, which is more profound now, into the atmospheric electric phonomena observed at different altitudes during different meteorological conditions and influences, great care being taken that the results should not only be demonstrated by <u>individual</u> cases, but expressed quantitatively after a statistical evaluation of <u>many</u> cases.

On the other hand, it could not be the purpose of this Report to develop and discuss theories for the correlations found, nor to give the existing literature. Some theoretical studies were already begun; we are intending to carry them through in the future, and also to collect further experience and to complete the picture by continuous recording and observations.

2. Recording Instruments

The instruments used are described in detail in Technical Report AF 61 (514)-732-C. The equipment, which till now proved to be suitable for the investigations carried out, was not changed essentially except the following:

a) At station Farchant, the number of positive and negative small ions has been recorded continuously since October 1957. The apparatus used for this purpose, als already mentioned, was lent by the Institut für Technische Elektronik der Technischen Hochschule München; it was developed and built by this institute according to the same principle as is applied in the recording instrument described by <u>Mühleisen und Creutzberg</u> (see <u>Mühleisen</u> (1957)).

b) At Farchant, also the registration of the point discharge current was added. A point at about 6 m above the ground, made of stainless steel (V4A), is used for this purpose. The point discharge current, passed through a simple amplifier, is recorded by an electronic potentiometer recorder (see below). For recording results we refer to section 14.

[+]) for more details on this method see Report AF 61 (514)-732-C

c) Since fall 1957, at Farchant the atmospheric electric data (potential gradient, air earth current, small ions both signs, point discharge current) have been recorded by means of an electronic potentiometer recorder (Siemens & Halske, Hartmann & Braun). We got this intrument as a loan of the firm Siemens & Halske. It is possible, with this twelve-channel dotted-line recorder, to record 12 different elements on the same sheet, the distance of the single points being 4 seconds, thus, if 12 different elements are recorded, 48 seconds for each element. This electronic potentiometer recorder proved to be very appropriate for our work. For recording examples see figure 1o3.

d) Since January 1957, we habe been able, through a grant of the Allgemeine Electricitätsgesellschaft (AEG) Berlin, to record continuously at Farchant wind velocity, zenith brightness, relative humidity, and temperature with one point recorder on one sheet. So the comparison of meteorological and atmospheric electric curves is made very easy.

3. The Station Network

The localities and the number of the stations for the atmospheric electric recordings have not been changed since our Technical Report AF 61 (514)-732-C; nevertheless, for the direct understanding of the statements and results presented in the following, it seems useful so give a short survey of the stations once more.

In table 1, names with abbrevations of the stations are given, further their altitudes above sea level, type and beginning of the respective recordings, and their geographical situations.

In table 2, we present the relative situations of the stations, i.e. their horizontal and vertical distances.

Fig. 1 is a simple map of the shape of the region and the situation of the stations. The highest mountain range, extending nearly in east-west direction, is called WETTERSTEINGEBIRGE (Wetterstein Mountains), the highest peak of which is the ZUGSPITZE. The Wetterstein Mountains as well as Garmisch and our "headquarters" Farchant are situated in the northern Alps.

Table 1

Station Network

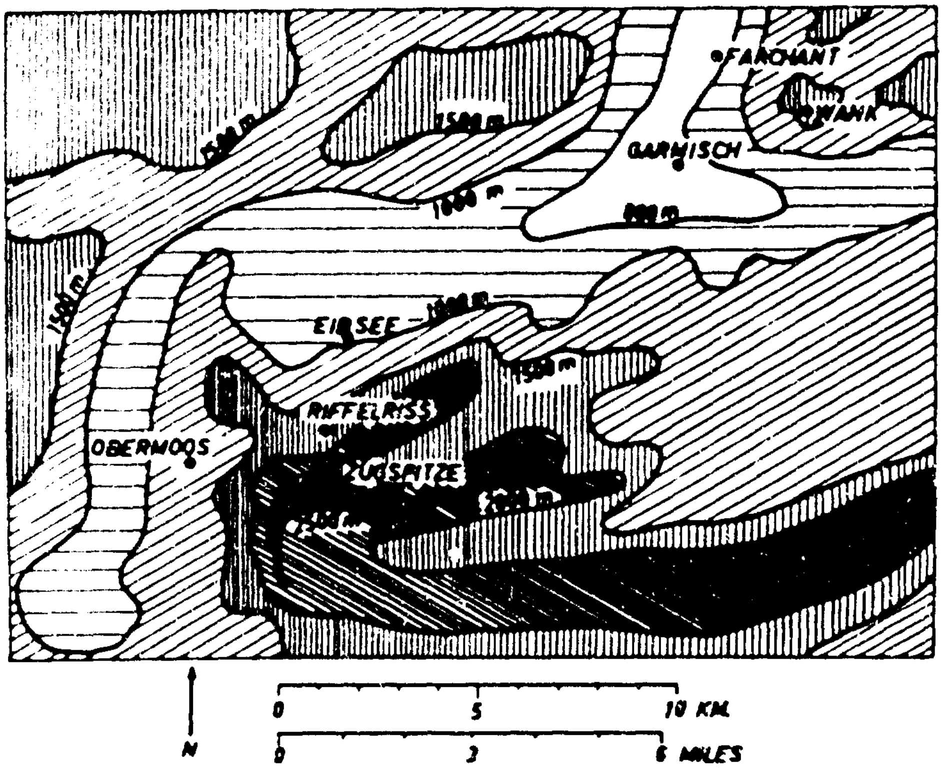
Station Name		Altitude above sea Level		Recordings		Situation
		feet	meters	Type	Beginning	
Zugspitze	(Z)	9730	2965	E i	Sept.52 Aug. 54	highest peak of the Wetterstein Mountains
Wank	(W)	5840	1780	E,i	July 55	flat mountain top
Riffelriss	(R)	5200	1585	E	March 54	steep slope
Obermoos	(O)	4100	1250	E	Aug. 54	lower end of steep slope
Eibsee	(E)	3298	1005	E	Oct. 55	valley terrace
Garmisch	(G)	2312	705	E i	May 55 Aug. 54	valley, in the village
Farchant	(F)	2216	675	E i J P n	Dec. 54 Apr. 55 Apr. 55 Febr.57 Oct. 57	valley, outside the village

E: potential gradient i: air earth current J: atmospherics P: point discharge current

n: small ions of both signs (number / cm^3)

Table 2

Name of the station	Difference in altitude between station and	horizontal distance from
	Zugspitze Peak (Z) Wank Peak (W)	
	feet	miles
Farchant	7514 (Z) 3624 (W)	9.08 (Z) 1.50 (W)
Garmisch	7418 (Z) 3528 (W)	7.52 (Z) 1.99 (W)
Eibsee	6432 (Z)	2.42 (Z)
Obermoos	5630 (Z)	2.06 (Z)
Riffelriss	4530 (Z)	0.93 (Z)
Wank	3890 (Z)	9.01 (Z)



Figur 1
The station network

4. The behaviour of atmospheric electric magnitudes, observed simultaneously at different altitudes, during precipitation

4.1. Behaviour of atmospheric electric magnitudes on typical days surveyed with the help of synoptic charts

Although we shall give a statistical evaluation of the results in section 4.2. and although in Technical Report AF 61 (514)-732-C a number of individual instances have been presented already, it seems not to be advisable, in this Technical Report, to omit such individual instances, whether with respect to precipitation nor to all the other problems; there are some reasons:

a) Further instructive examples have been collected these two years. They shall not be withheld from the reader.

b) Every statistical evaluation is based on simplifying and schematizing procedures applied when observed facts or curves are translated into significant numbers. With all carefulness it is within one's discretion to choose the means and methods. Therefore, we want the reader himself to have the opportunity, by means of the individual cases and original records, of checking if the elaborated and concentrated results, wich will be given later-on, represent the circumstances satisfactorily, if essential details are omitted, or if quite different viewpoints could be found with respect to the evaluation.

We have still to point to a fact, which must be always considered when looking at our records and their evaluations: in our equipment, the air earth current is always measured with aerials, the cross section of which is so small, that the precipitation charges falling down on the aerial have no significant influence on the recorded values. Thus, during precipitation, the precipitation current does not contribute to the measured current. This must be taken into acount, when our results are compared with those of other investigators (e.g. Chalmers (1956), who measures the total current including the precipitation current). In view of our method it is not surprising that, in our records obtained during precipitation, nearly always current and potential gradient show the same sign. It is not necessary, therefore, to view the behaviour of current und potential gradient separately in our evaluations of records which are obtained during precipitation.

4.1.1. Shower precipitation

To begin with, let us deal with some examples of light separated showers, represented by the figures 2 - 6. Seldom we find during shower precipitation

Notes to the Synoptic Charts

All curves are to be read from right to left. Time data are given in Central European Time (CET - MEZ). Distances of time marks : one hour.

E recorded potential gradient i recorded air earth current	heavy continuous lines
Monthly means of E and i calculated for each hour of fine weather days	light dashed lines
At the left margin in large circles: abbreviations of the stations (see tables 1 and 2 and figure 1)	e.g.: Ⓩ

Below the curves auf stations Z and F: cloud amount

⦶ 1/8; ◔ 2/8; ◔ 3/8; ◑ 4/8;
◕ 5/8; ◕ 6/8; ◍ 7/8; ● 8/8;

and species of the clouds abbreviated.

Type and duration of precipitations, fog, mist, etc. are entered in the respective records as follows:

● rain	✱ snow	✱ ● rain and snow mixed
, drizzle	△ graupel	▲ hail
▽ shower	⚡ thunderstorm	(⚡) distant thunderstorm
≡ fog	≡trb. drifting fog	∞ moderate mist
= strong mist		✛ drifting snow

Intensities: 0 = slight; 1 = moderate; 2 = strong

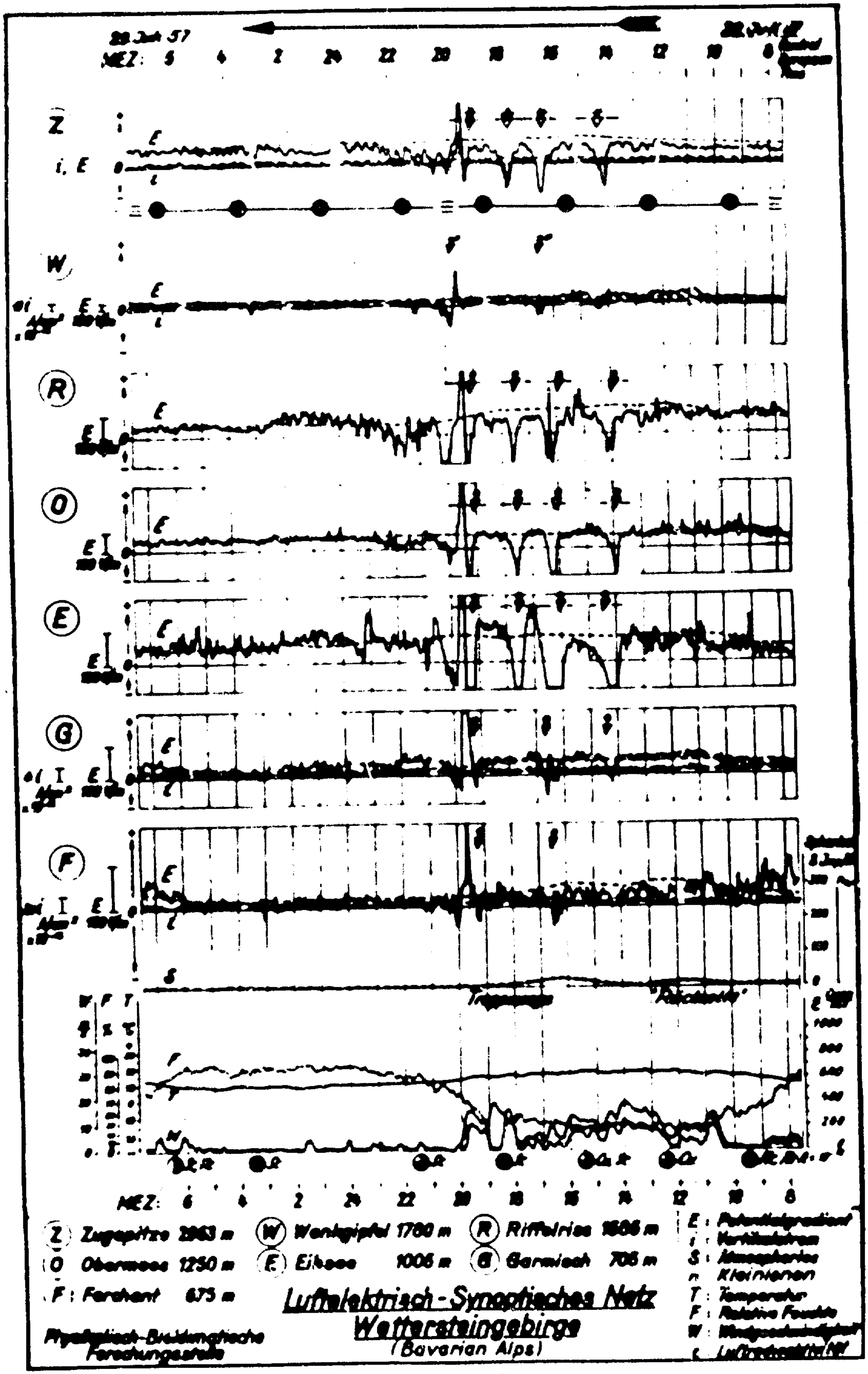


Figure 2

Light separated showers

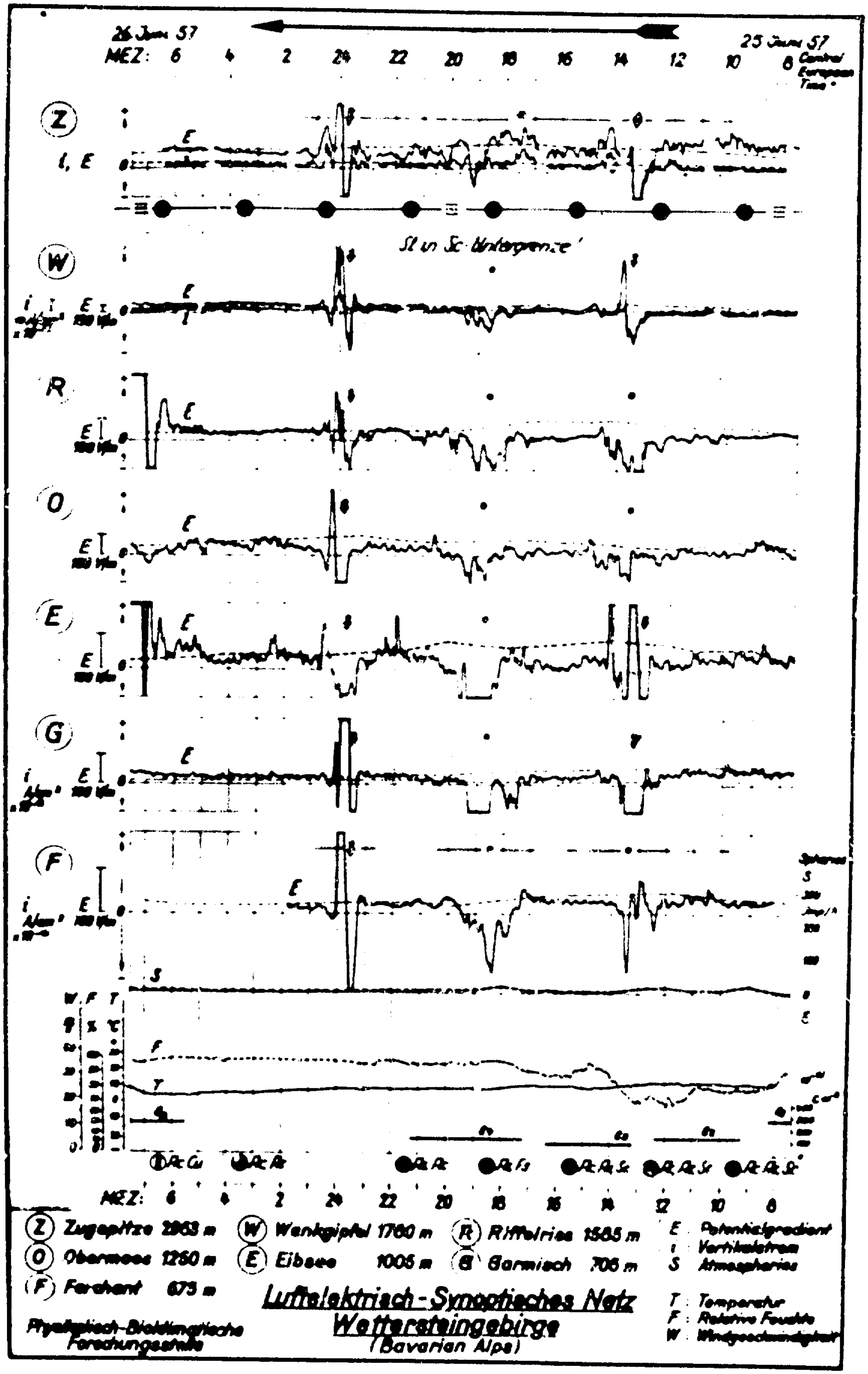


Figure 3

Light separated showers

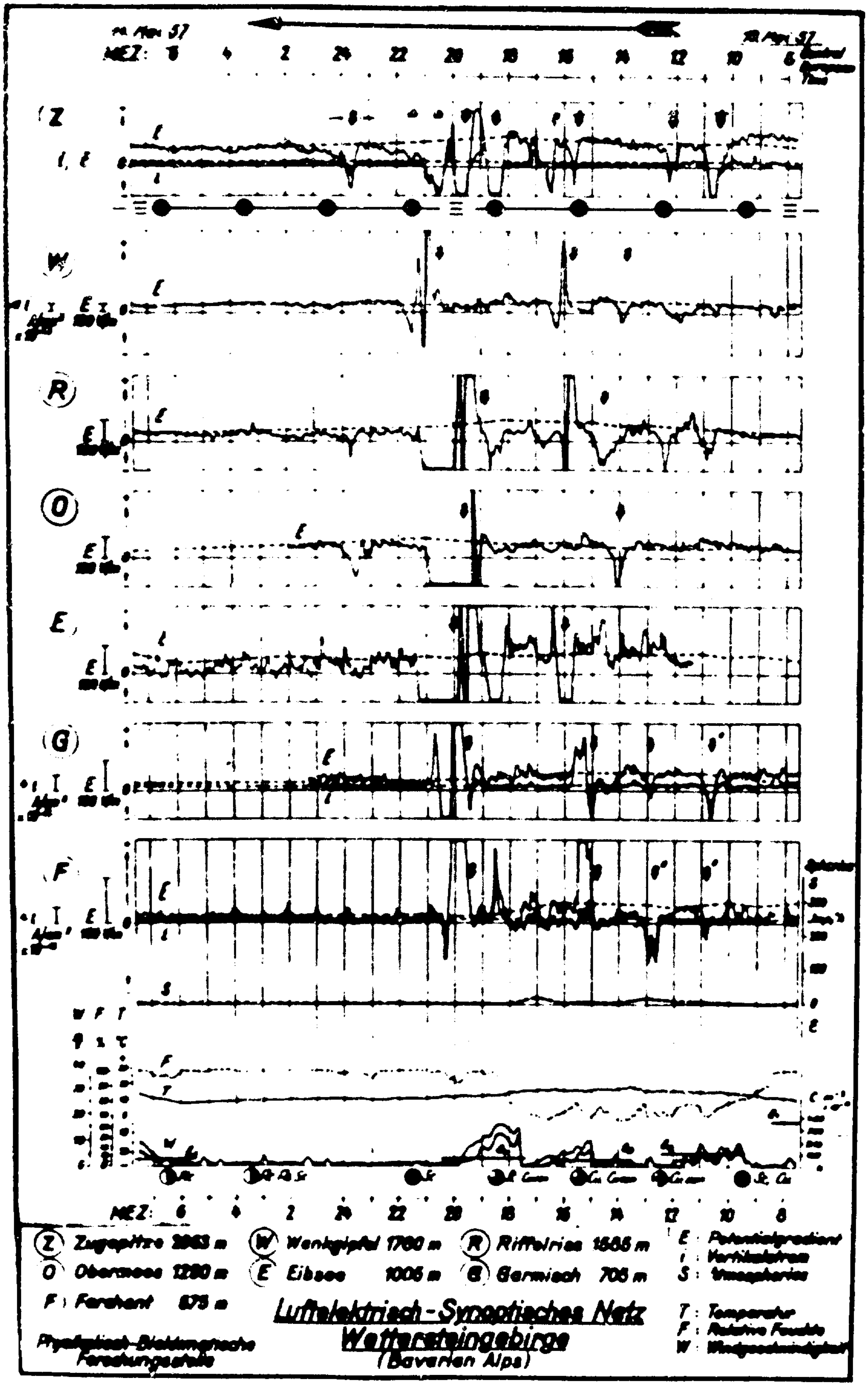


Figure 4

Light separated showers

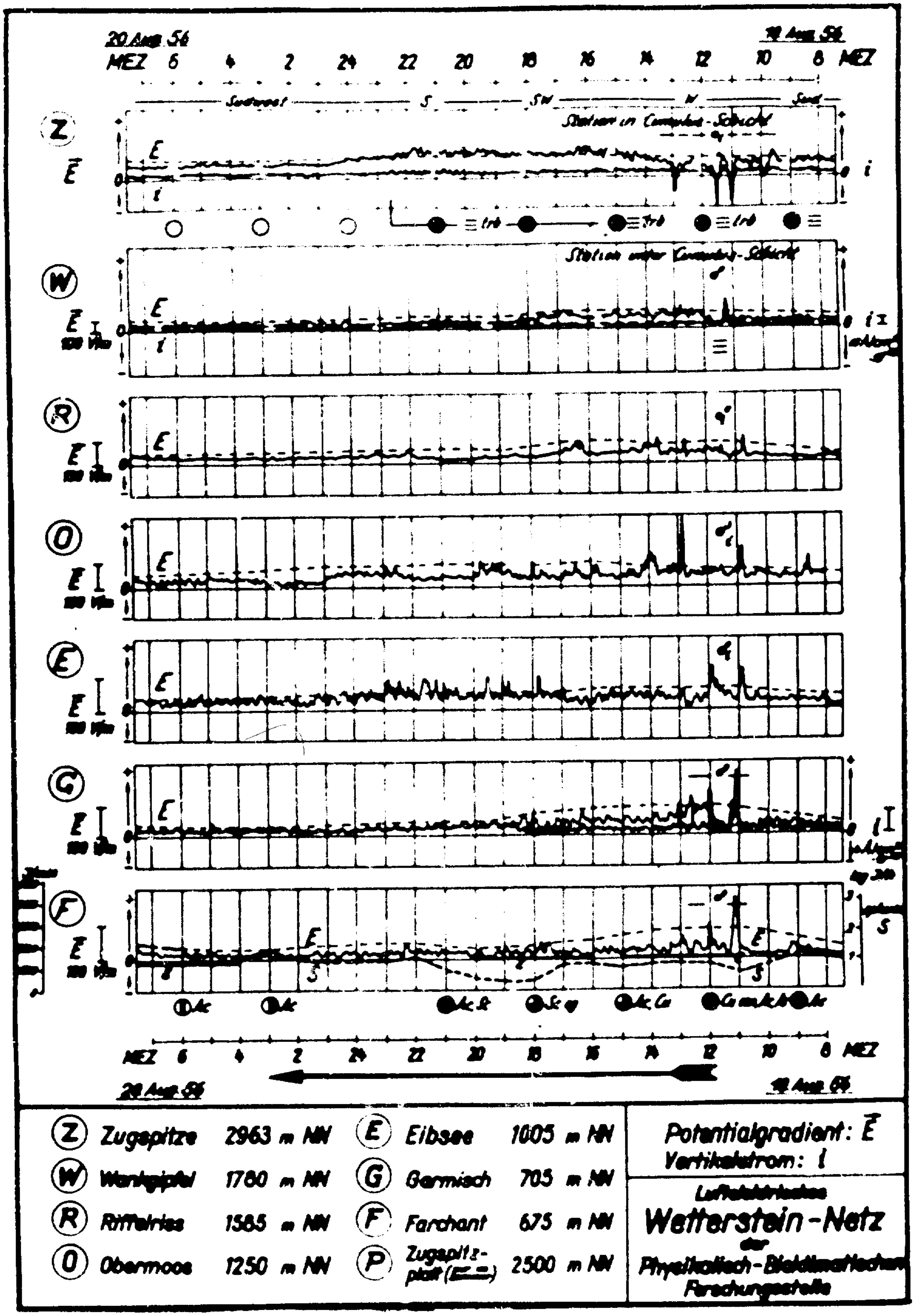


Figure 5

Light shower precipitation

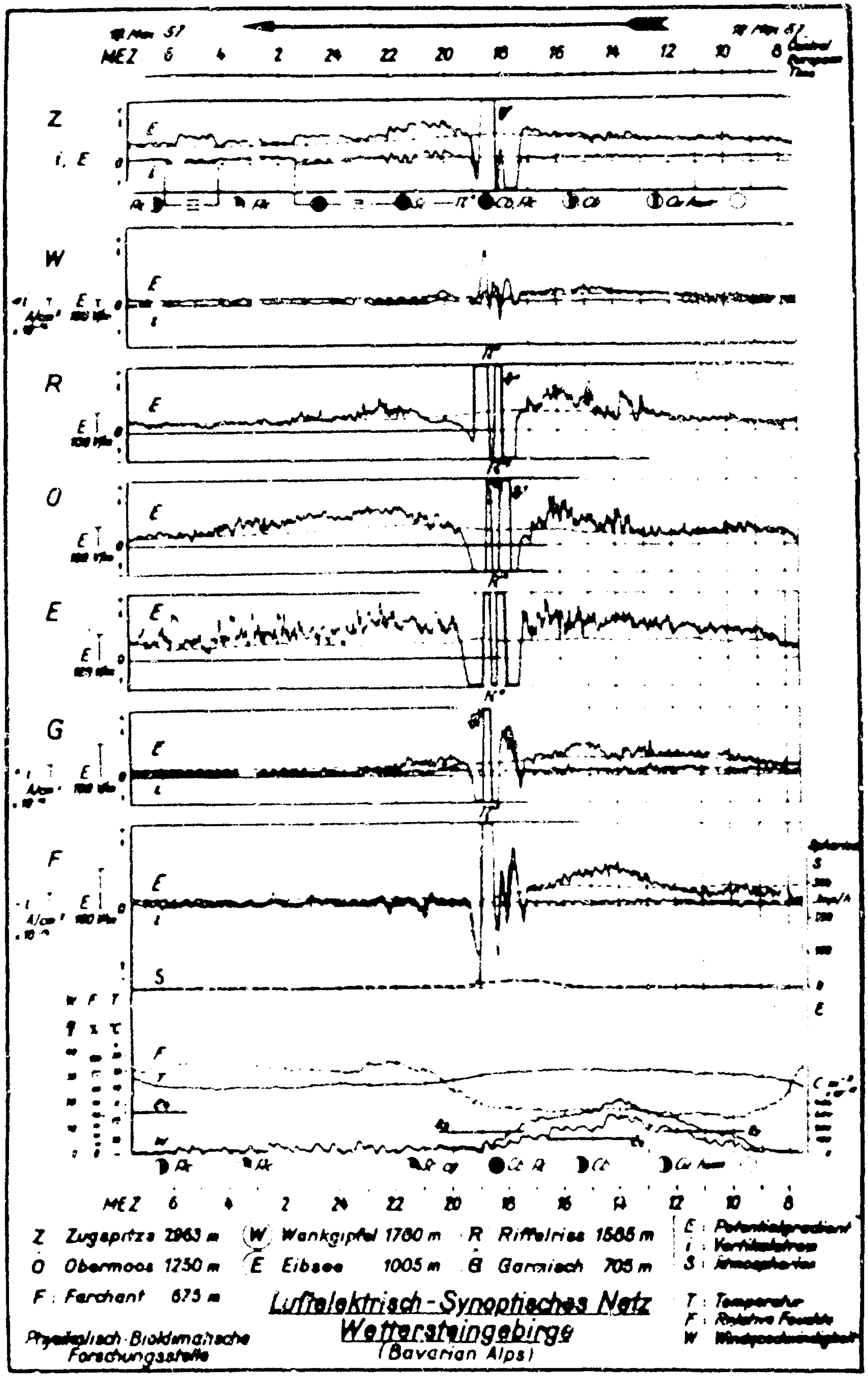


Figure 6

Light shower precipitation with thunderstorm the sign of the potential gradient to be predominantly the same at all levels (Figure 2). In much more cases the curve shapes of all levels differ from each other during the same shower (Figure 3, 12-14 h; Figure 4 and 6). Further, it is a fact that, during shower, the transition of the precipitations from the solid into the liquid state and vice versa has no influence on the shape of the recorded curve (Figures 2,3,4). Studying these and other examples, we notice that slight showers, especially at station Zugspitze, cause a negative potential gradient. At peak stations for instance, a predominantly negative foreign field[+]) is superimposed upon the fine weather potential gradient even then already, when the "mature stage" of a cumulus cloud is beginning. There are many observations (see below) which show that such a negative foreign field exists already before precipitation falling out of the cumulus cloud arrives at the station. However, we are not able to decide whether in these cases precipitation has been already formed in the cloud and is hovering because of anabatic winds, or whether there are great field strengths built up already before the formation of precipitation (Vonnegut and Moore (1958); Moore, Vonnegut and Botka (1958)) .

In Figure 5, we see an example of negative foreign fields recorded at station Zugspitze below Cumulus congestus clouds with the rain being very slight in each case of negative notch. Already these very slight "showers" exhibit the typical alteration of the curve shape with height: negative values during the rain at high levels, finally positive ones at low levels. Such sign reversals of the potential gradient, being quite unsystematical in general, are typical of light shower precipitations. By the way, they must not be confused with an other phenomenon, from which they differ essentially: with the sign reversals of the foreign field in non-showery precipitation , occurring when the physical state is changed (see sections 4.1.2, 4.2.3., 4.2.4.).

Light thundery showers do not differ essentially from light non-thundery showers (Figure 6 / Figure 4).

Heavy showers (Figure 7) differ from light showers only by greater positive and negative amplitudes of the foreign field. A correspondence of the course of the records at the different stations is only seldom observed during heavy showers.

[+]) "Foreign field" means that additional potential gradient which, caused by precipitation- or cloud-charges, is superimposed upon the potential gradient as it would be in fine weather

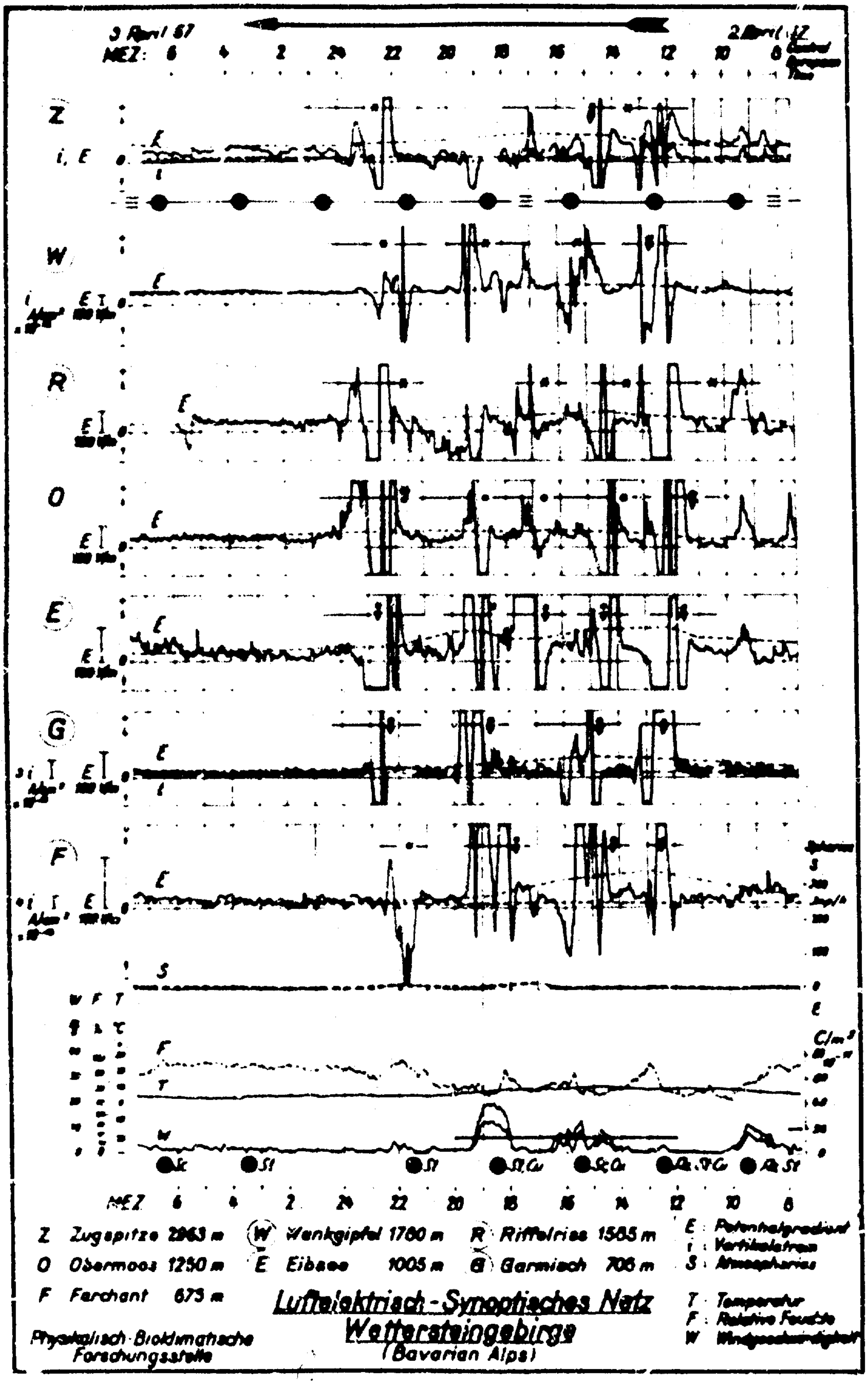


Figure 7

Heavy showers

The variations of the foreign field have especially great amplitudes and are very rapid and frequent during and after cold front passages (Figures 8 - 12), and, without cold front, also in the case of continuous great unstability of the atmosphere (Figure 13). Already from the individual examples presented we see that obviously the frequency of the sign reversals of the foreign field is the higher, the greater is the atmospheric lability.

Further it has been observed that, at high altitudes, the frequency of the sign reversals of the foreign field is somewhat less than at lower levels (see Figure 13 , which gives an extreme example).

In this section we have to mention a further phenomenon, which in the statistical evaluations becomes less manifest: if, by upslide motions, Altostratus is formed, which more and more becomes thicker and turns into Nimbostratus, the potential gradient at all stations is decreased during this process far below the fine weather value, a long while before precipitation comes down (Figure 11, 19 - 22 h). The first precipitation out of such a Altostratus or Nimbostratus cloud formed by upslide motion arrives at all stations in a negative potential gradient (Figure 11, 21 - 22 h; Figure 12, 15 h; Figure 13, 18.30). It makes no difference, what type of precipitation is falling, whether snow, or graupel, or rain etc.

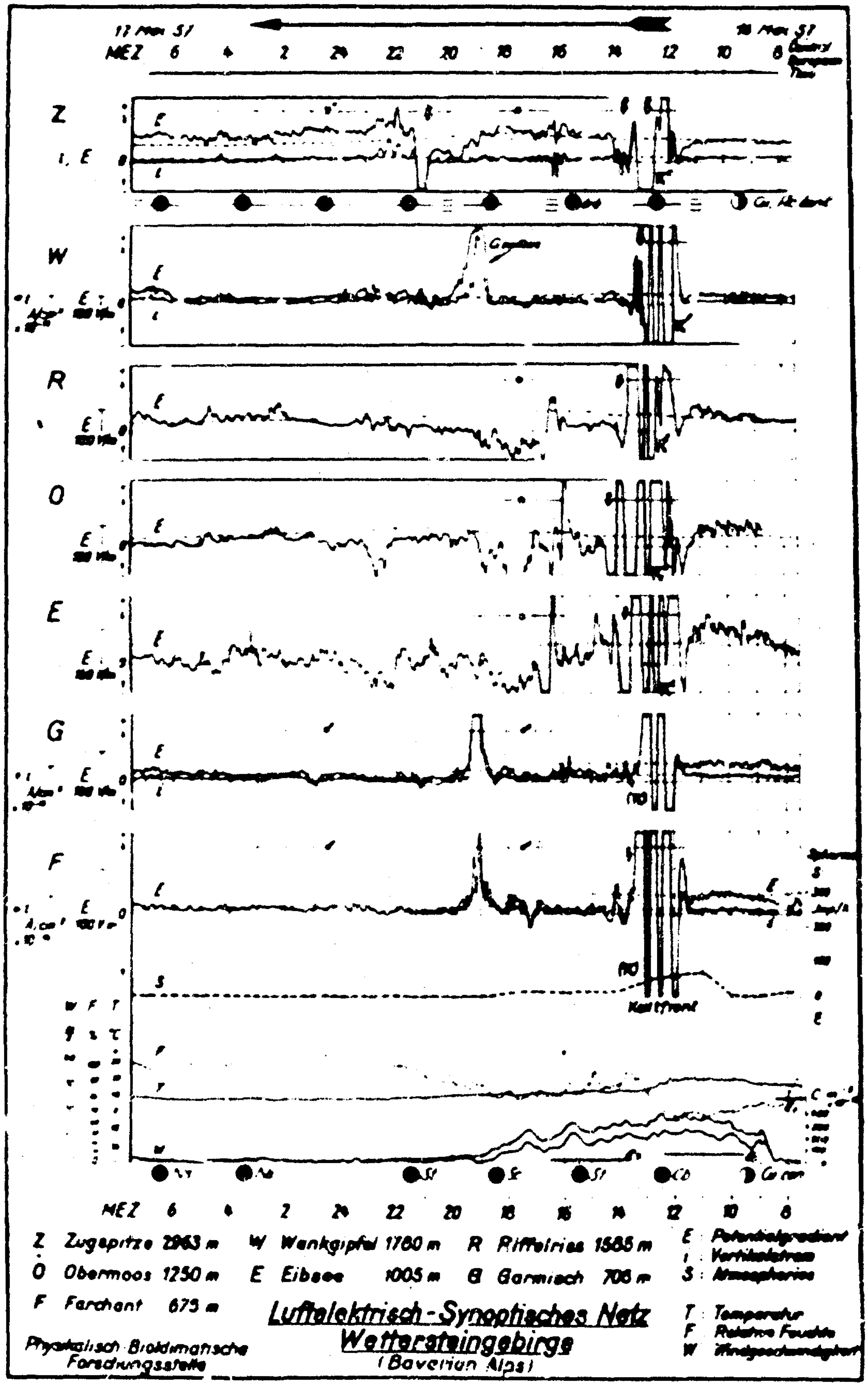


Figure 8

Cold Front

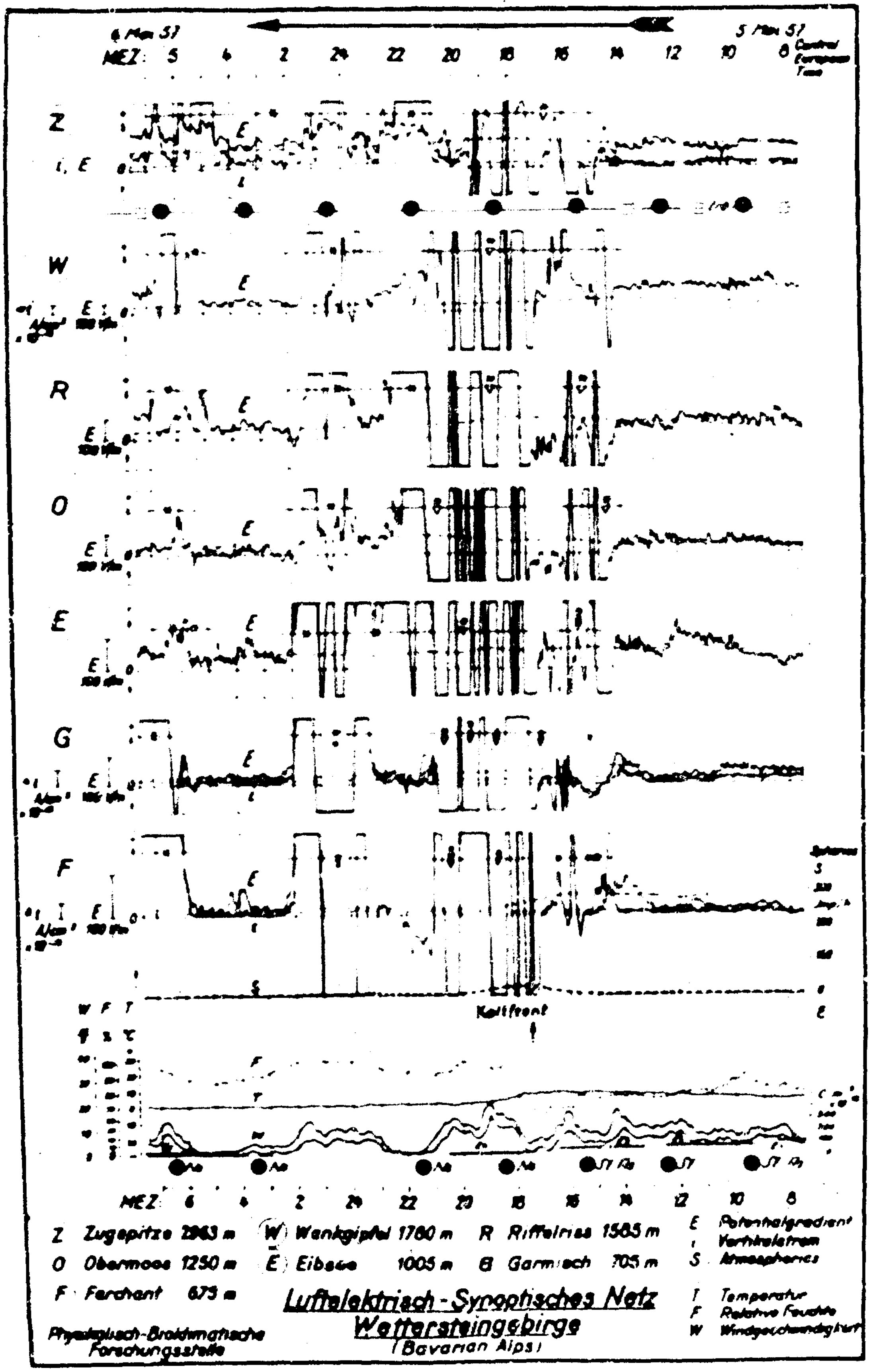


Figure 9

Cold front

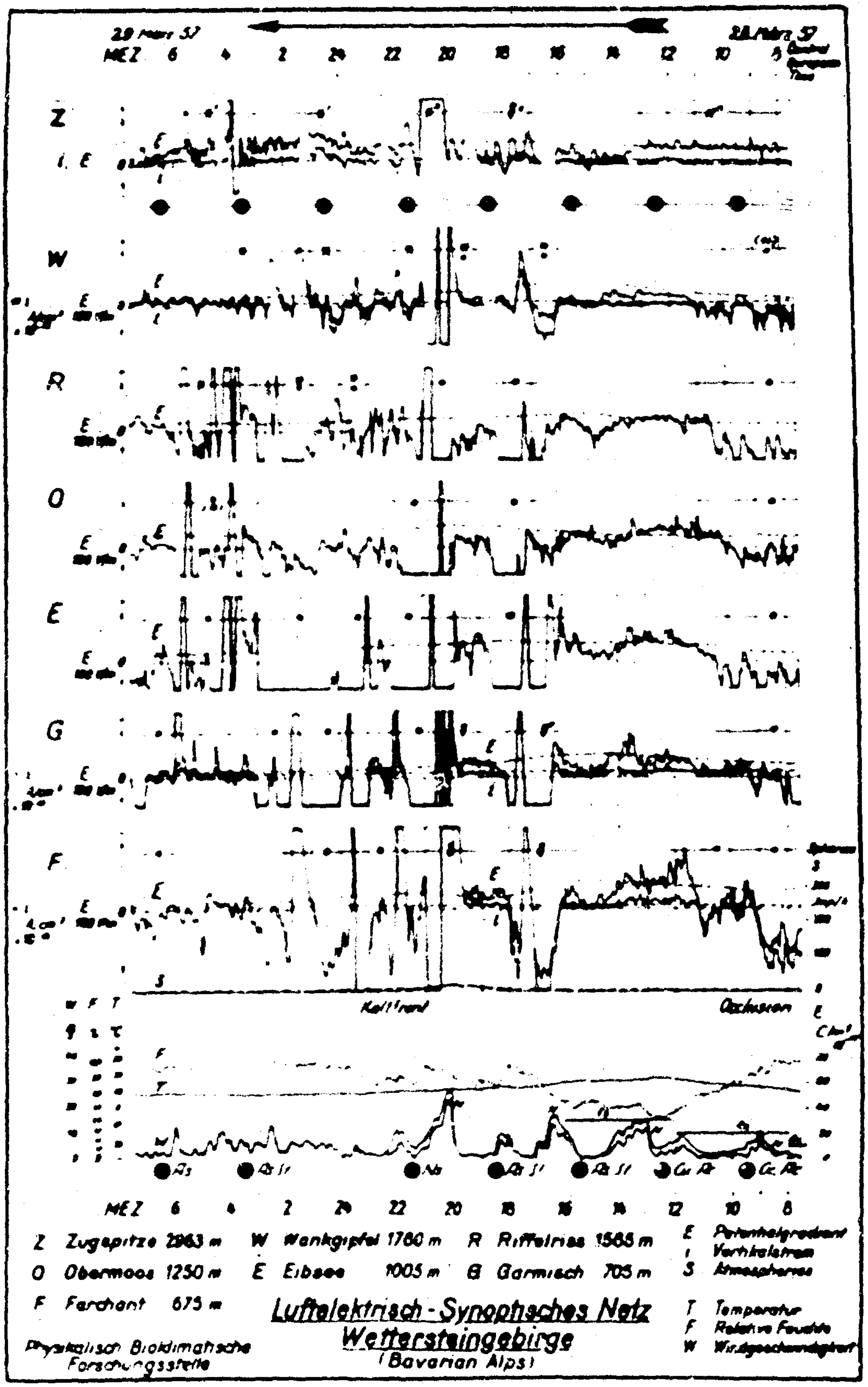


Figure 10

Cold front, occlusion

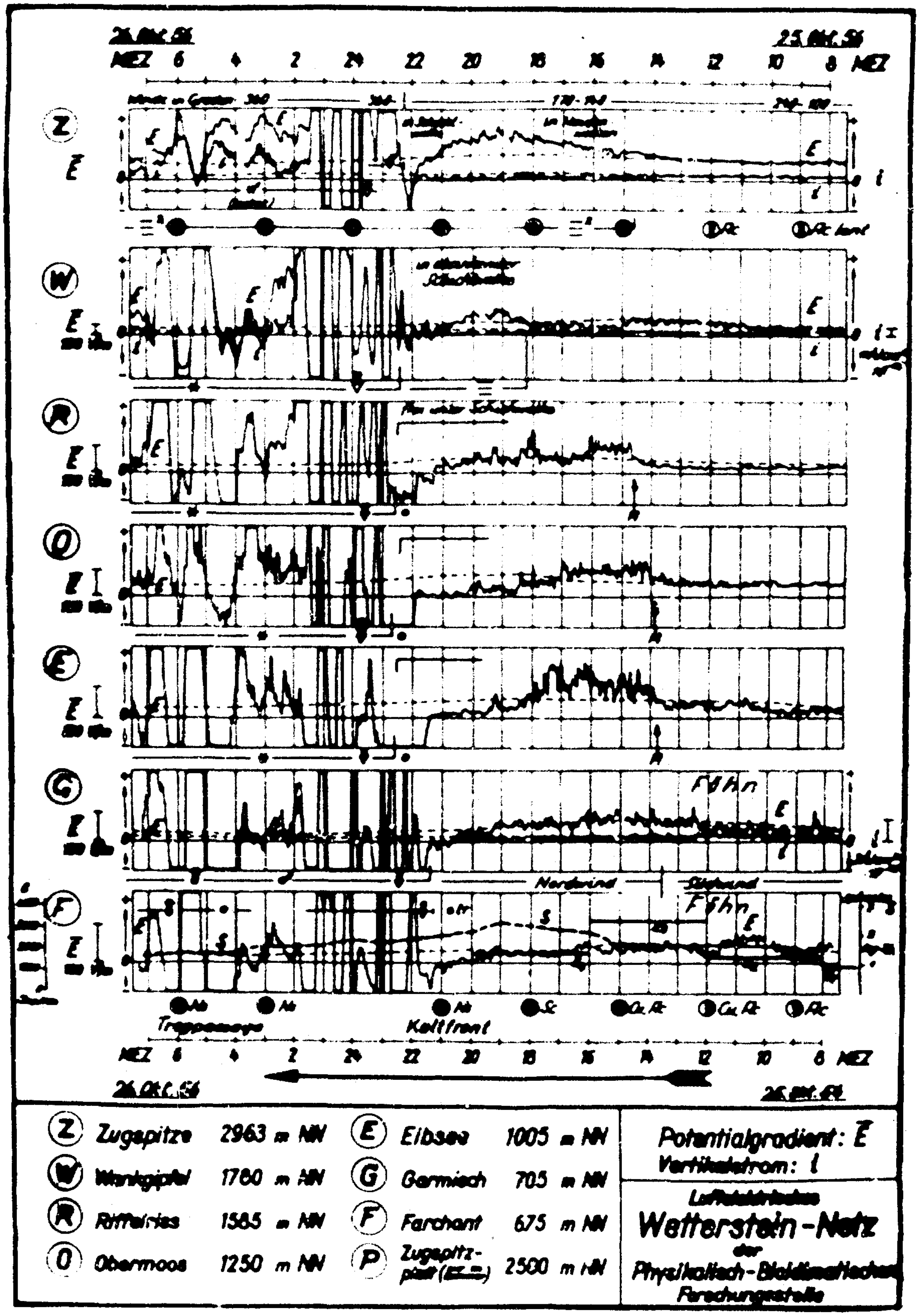


Figure 11

Cold front

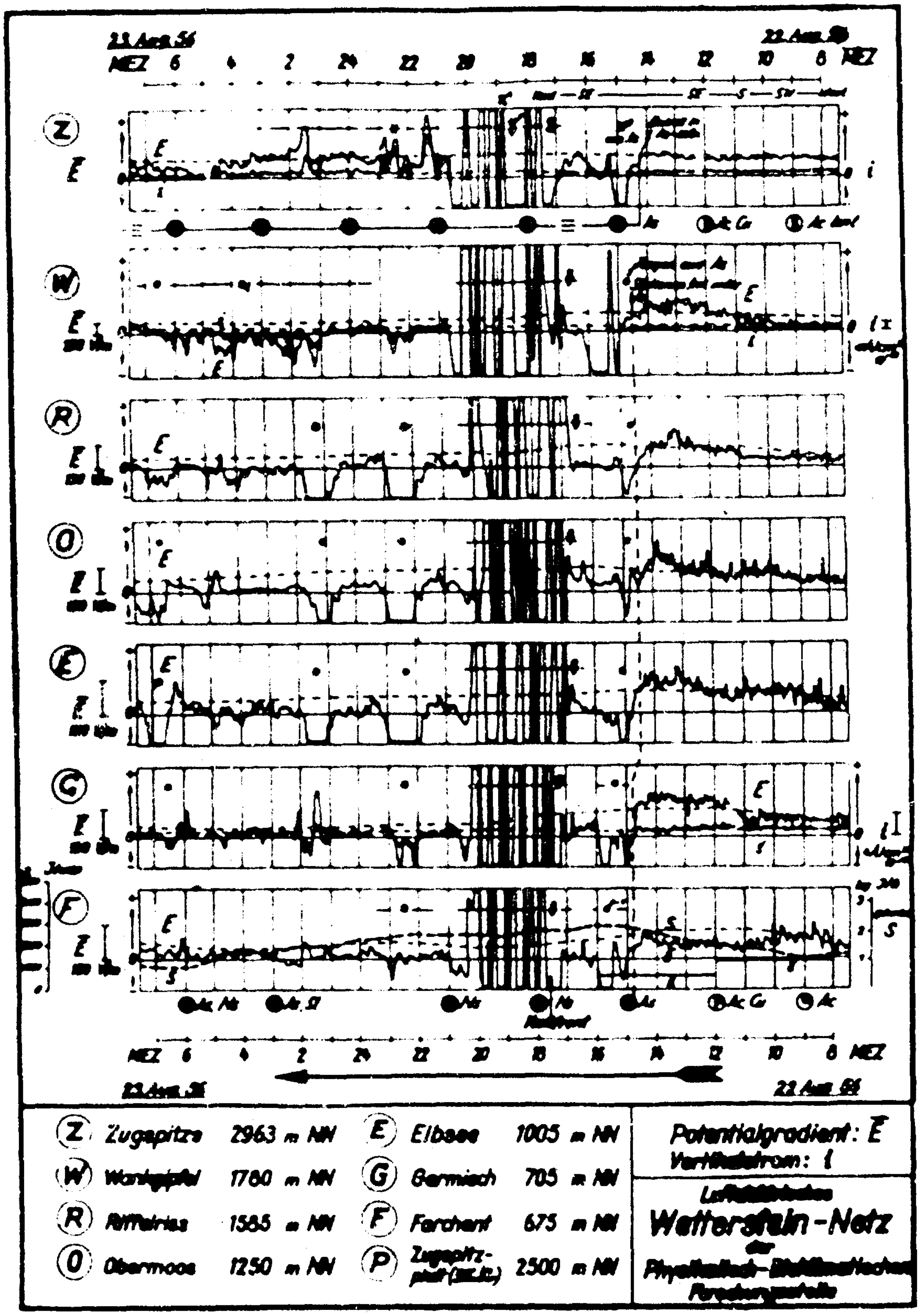


Figure 12

Cold front

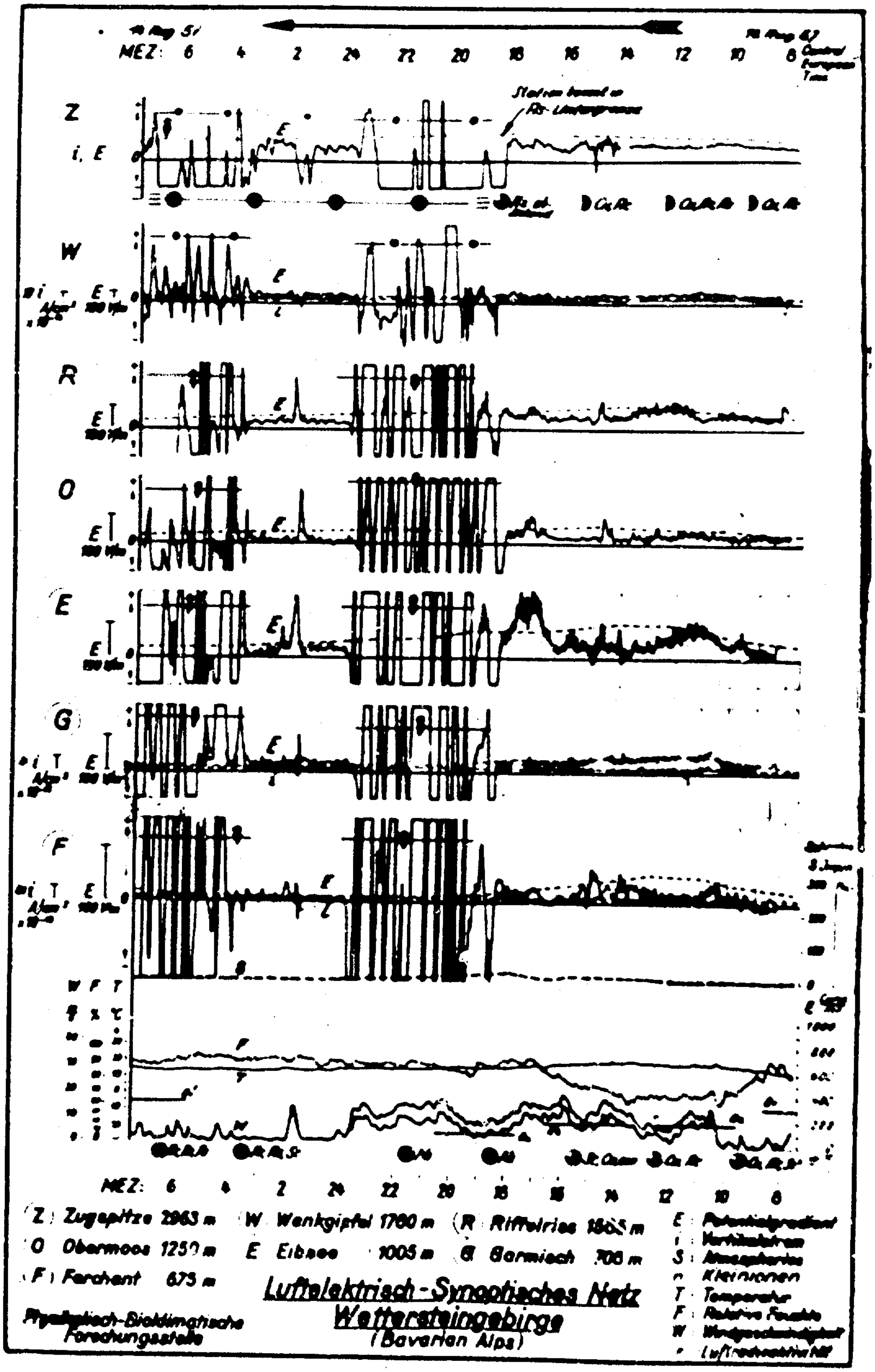


Figure 13

Strong atmospheric unstability

4.1.2. Non-showery precipitation

4.1.2.1. Light precipitation out of Altostratus or Nimbostratus

Let us begin with individual cases of light precipitation, first such out of Altostratus. Here the same is true as was said above about precipitation out of Altostratus (see here Figures 14 - 16). The potential gradient is predominantly negative, where precipitation out of Altostratus arrives at the station, whether it be rain or snow. There are also exceptions, of course (Figure 17): negative potential gradient at the lower levels in rain, but positive potential gradient in simultaneous snow falling out of Altostratus higher up. We point especially also to Figure 14: At 21.00 there were only single drops or trails of precipitation above the station. Nearly always, also in such cases only negative potential gradient is observed thus even when the precipitation doesn't touch upon the ground at the station, but is hovering about it.

During light non-showery precipitation out of Cumulus or Nimbostratus clouds we find predominantly positive foreign field at a station where snow is falling, and a negative one at a station where rain or wet snow is falling (Figures 18 - 20).

4.1.2.2. Heavy or continuous precipitation out of Nimbostratus

This last statement of section 4.1.2.1. is true also for heavy or continuous precipitation out of Nimbostratus. The case of rain at all the stations is demonstrated in Figure 21, the case of snow at alle the stations in Figure 22. In rain, negative foreign field is by far predominating; single thin positive points occurring are seldom. In snow, positive foreign field is predominating. With respect to snow, however, we have to make a complementary statement: it has been ascertained again and again, without exception, that the base of Nimbostratus carries negative charge, independent of whether snow is falling, or rain. In cases of no precipitation, therefore, the potential gradient is much lower below the Nimbostratus cloud than in fine weather, mostly between slightly positive and slightly negative. Where there is rain, the "negativity" is increased; where there is snow, the positive foreign field caused by the snow-fall is in competition at stations below the cloud base with the negative foreign field caused by the cloud base. This means, that the potential gradient mostly exceeds the fine wheather value during dense snow fall, but usually remains below the fine weather value during very slight

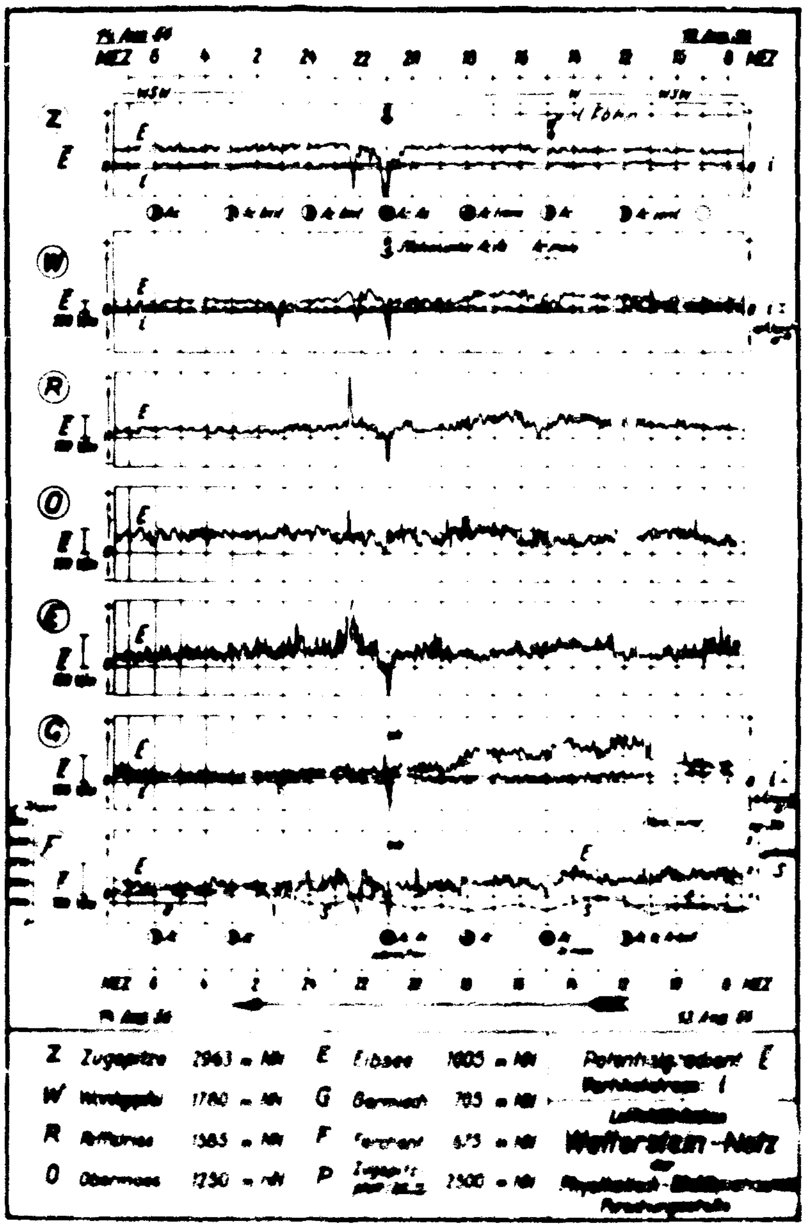


Figure 14

Warm front, slight precipitation out of an Altostratus

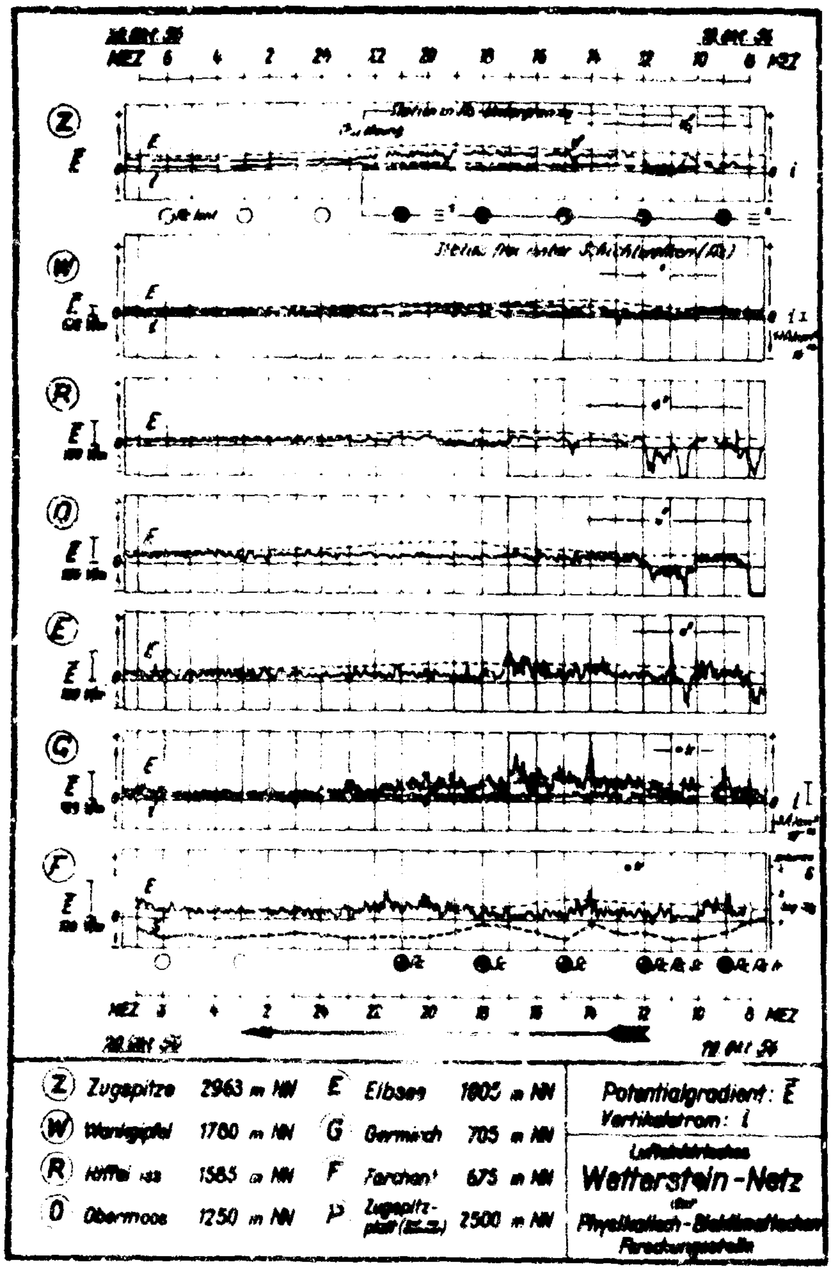


Figure 15

Precipitation out of Altostratus

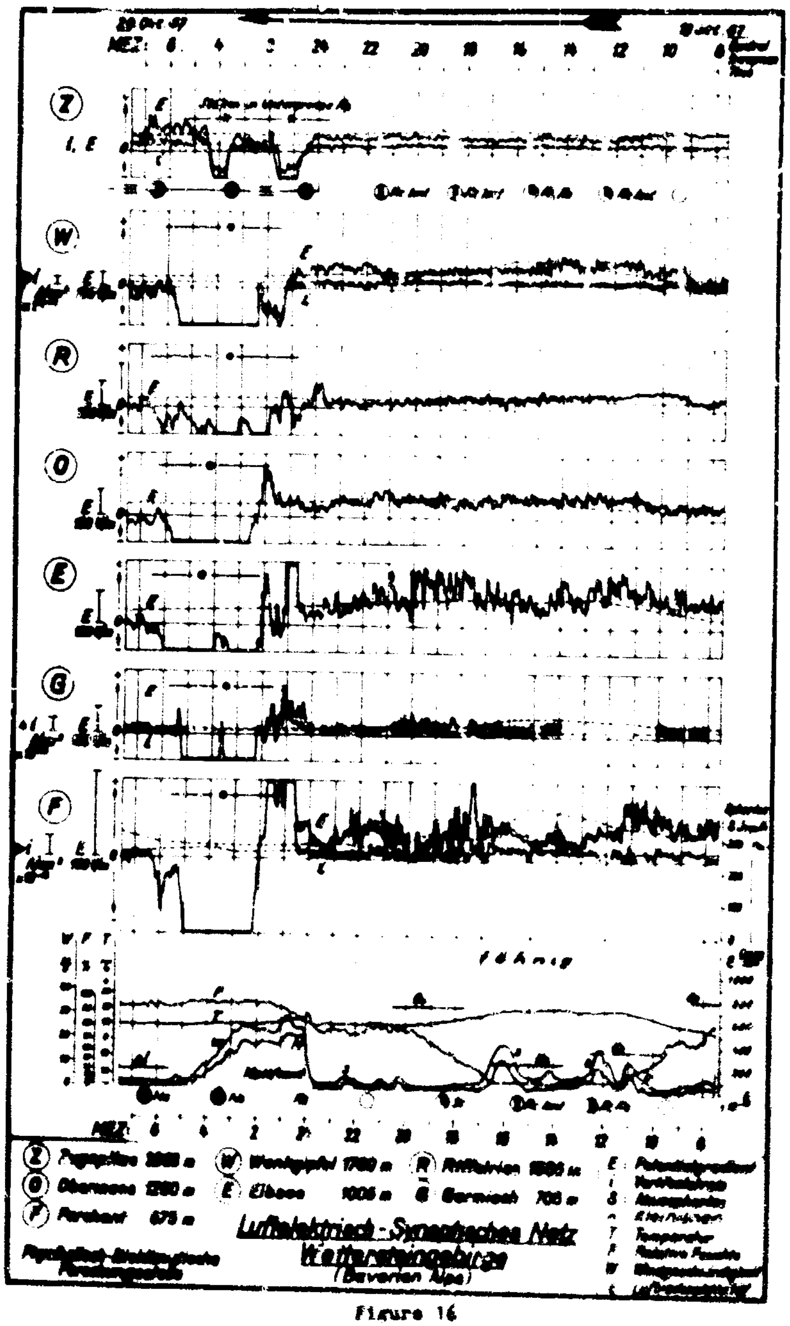


Figure 16

Precipitation out of Altostratus

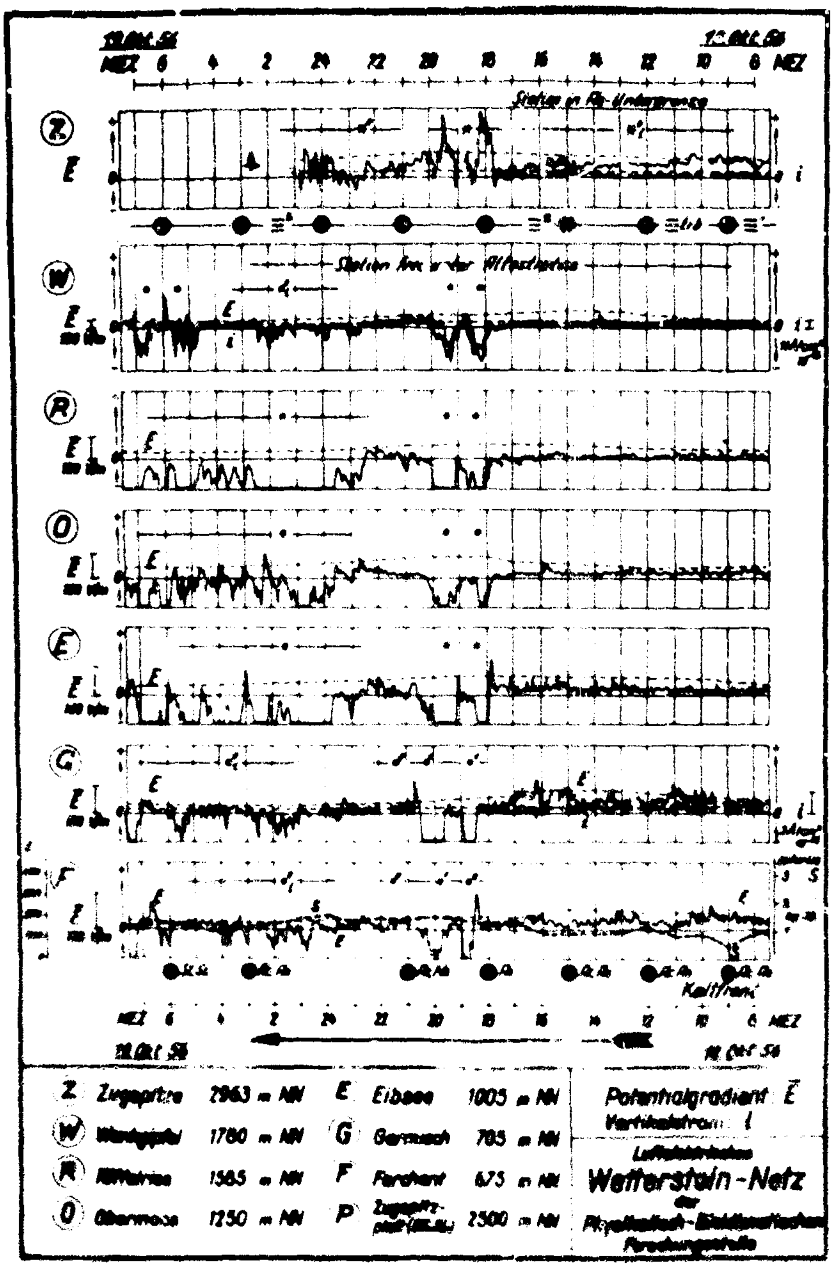


Figure 17

Precipitation out of Altostratus

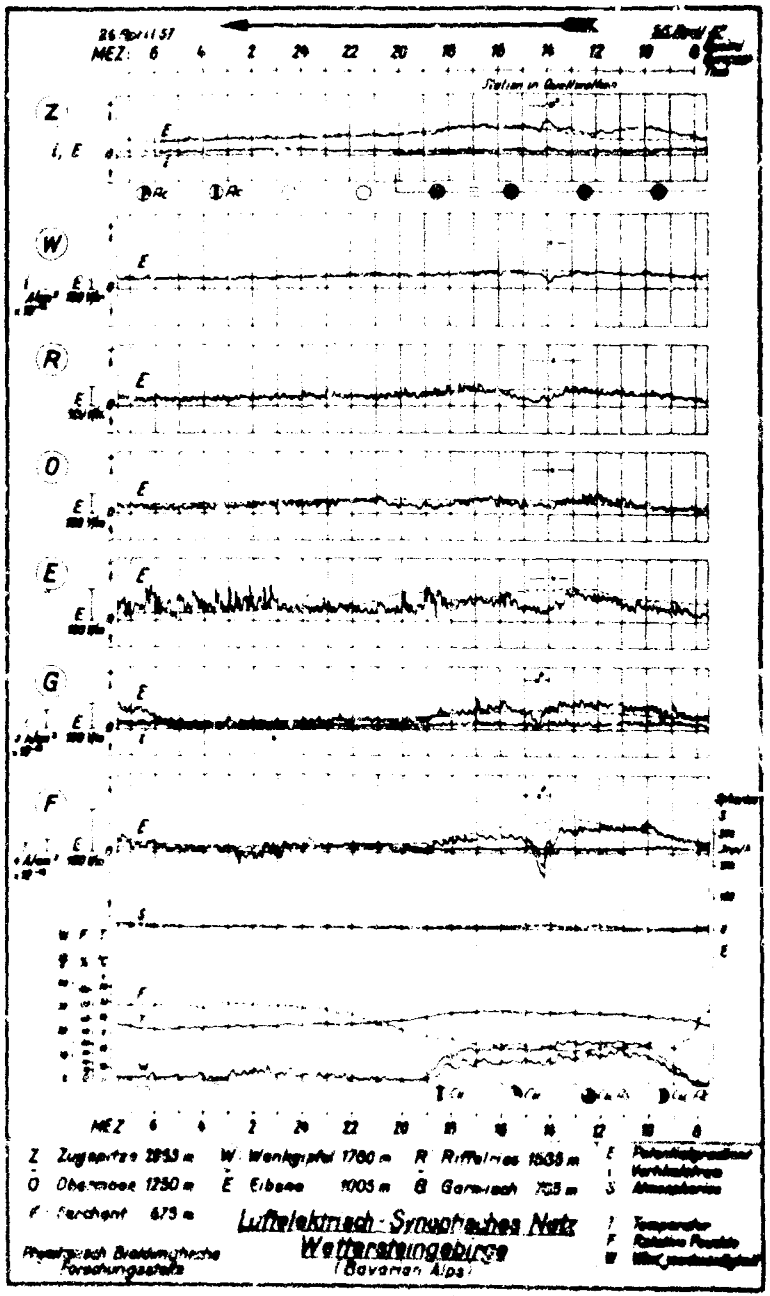


Figure 18

Slight precipitation out of a Cumulus

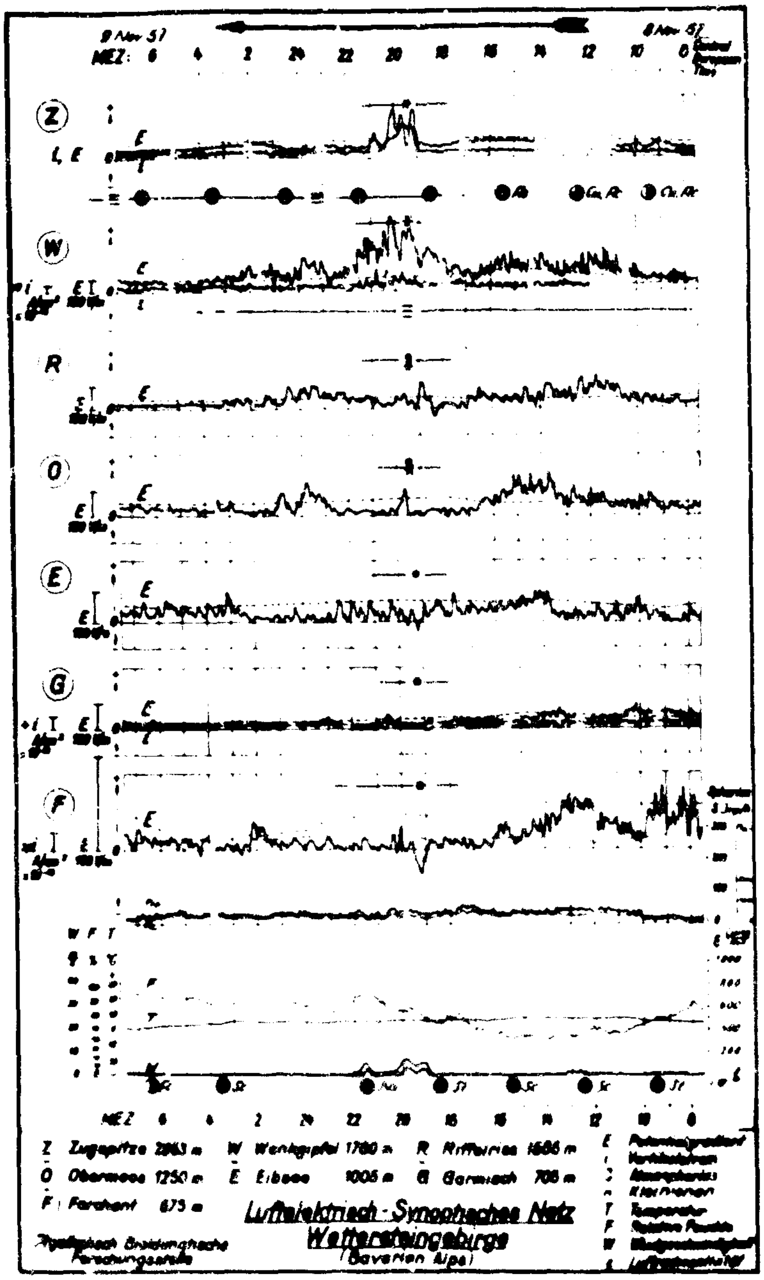


Figure 19

Slight precipitation out of Nimbostratus

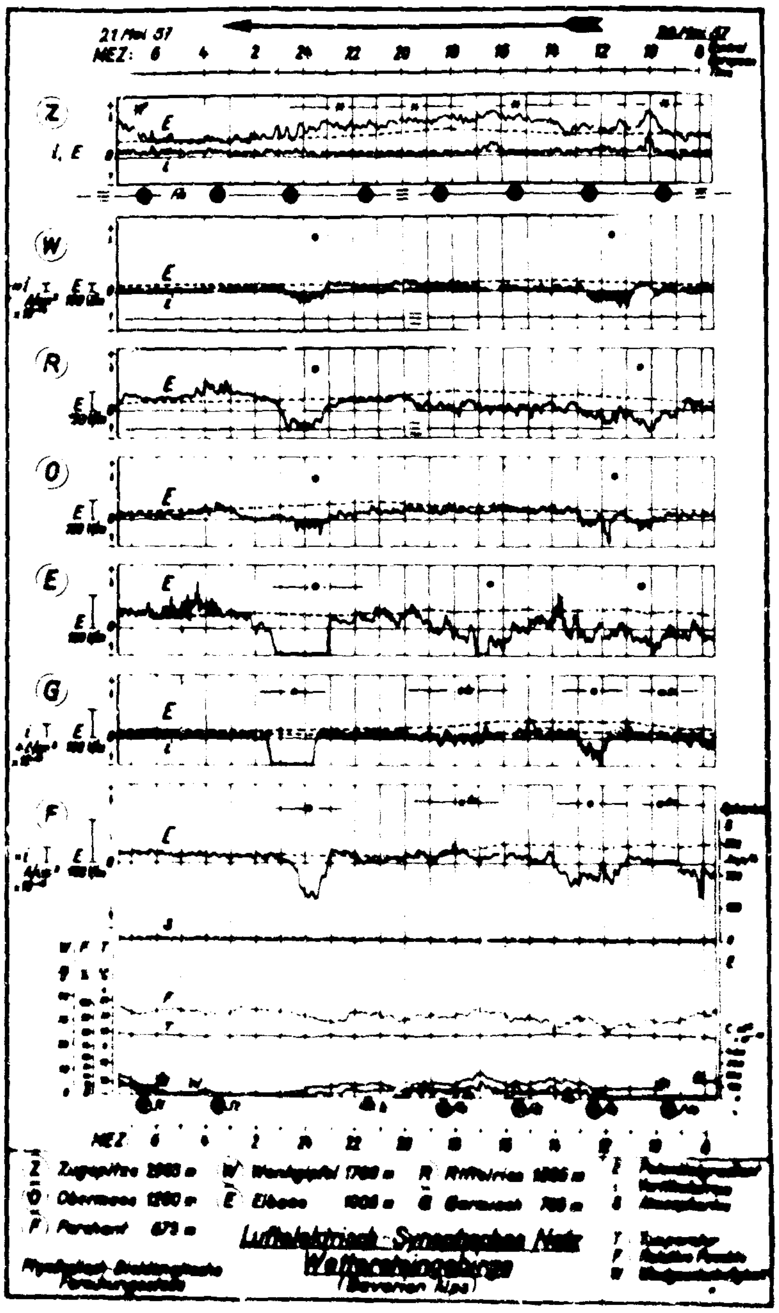


Figure 20

Slight precipitation out of Nimbostratus and Altostratus

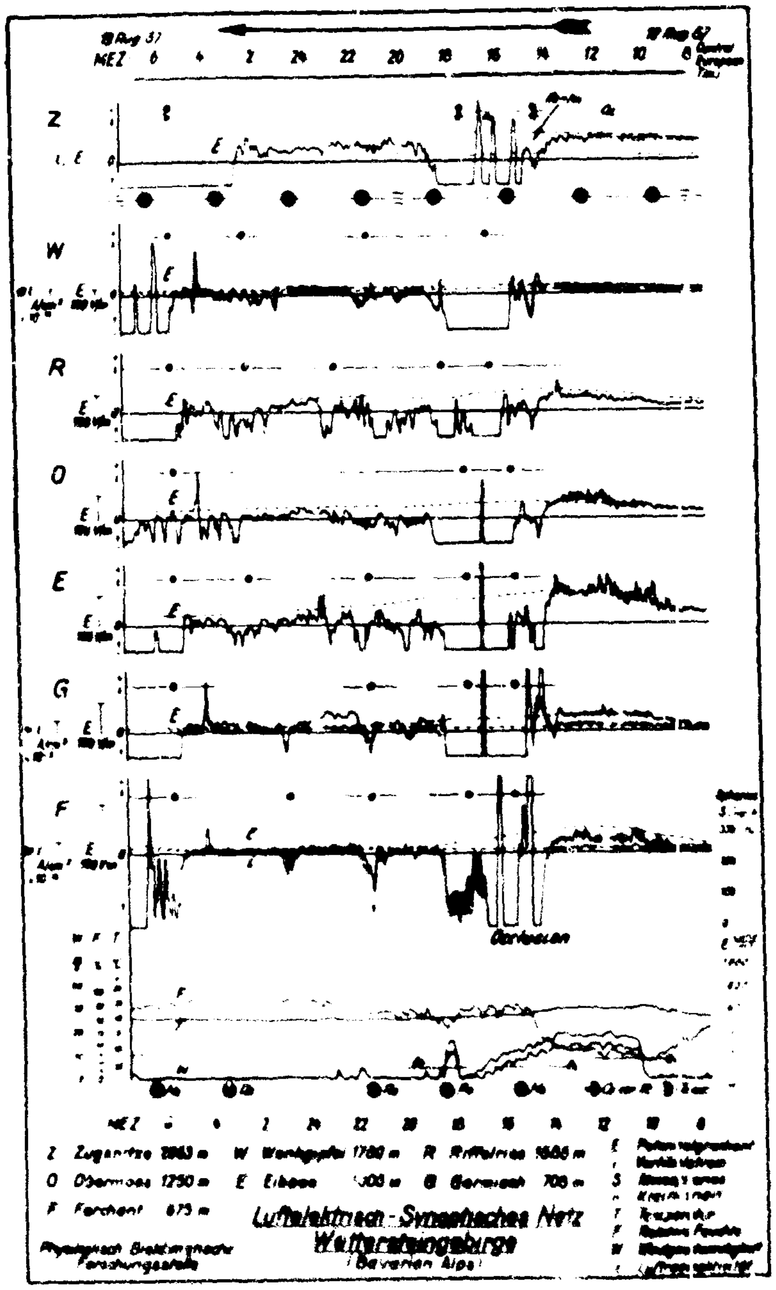


Figure 21

Precipitation out of Nimbo-
stratus
- only rain -

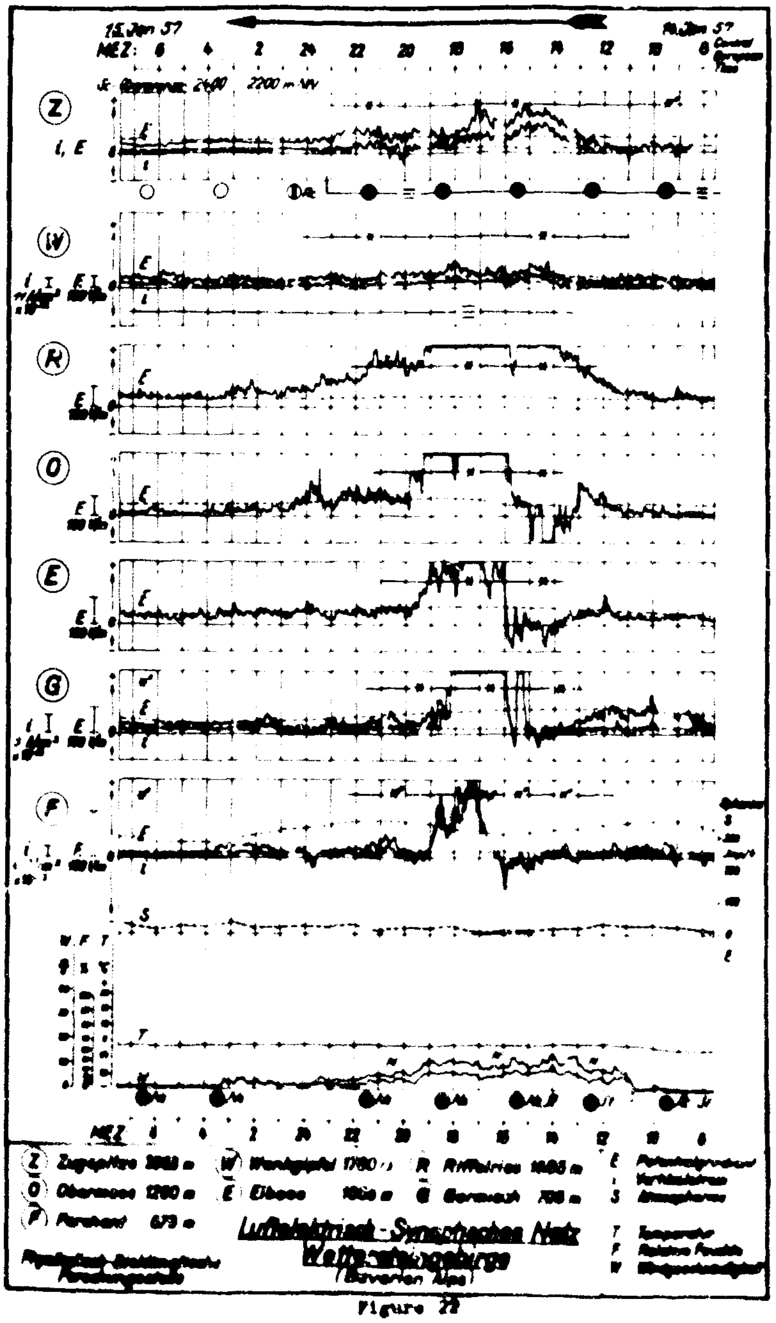


Figure 22

Precipitation out of Nimbostratus

- only snow -

snow-fall, as is clear in Figure 22 especially at stations Farchant and Garmisch.

If snow is falling only at part of the stations, higher up, while at the other stations, at lower atmospheric "floors", there is rain at the same time, then the foreign field is preponderantly positive at the stations with snow, but preponderantly negative at the lower stations where it is raining (Figures 23 - 27). This is independent of the height where the transition from snow into rain takes place, for instance whether (at higher levels) between Zugspitze and Wank, or (in the valley) between Eibsee and Farchant. It is independent also of whether part of the stations is within the cloud or not.

The conditions are the same, if the change from snow to rain, and vice versa, takes place not only with regard to space, but also, at one or more individual stations, with regard to time: as long as there is snow, the foreing field is prepondermantly positive, during rain, it es preponderantly negative (Figures 28 - 31).

4.1.2.3. Periodical variations of the foreign field during precipitations

In Figures 32 - 35 we see examples of a case found relatively seldom, namely that during quiet, uniform nonshowery precipitation there are sign reversals af the foreign field which are not connected with or not caused by a change in the physical state of the precipitation. These reversals of the sign of the foreign field are nearly rhythmical, alternating almost regularly. Reviewing synoptically the records of all the stations, we find two types:

a) the almost rhythmical, regular reversals of the sign of the foreign field are recorded at every station, partly even with a relatively good temporal coincidence existing from station to station (right hand side of Figure 32; Figure 33);

b) the reversals are recorded only at the valley stations and doesn't show any relationship with the records of the higher stations (right hand side of Figure 34; Figure 35).

4.1.2.4. Special cases

Finally, we have to mention some special cases, which occur only seldom, but nevertheless could be important in a future discussion of theoretical ideas.

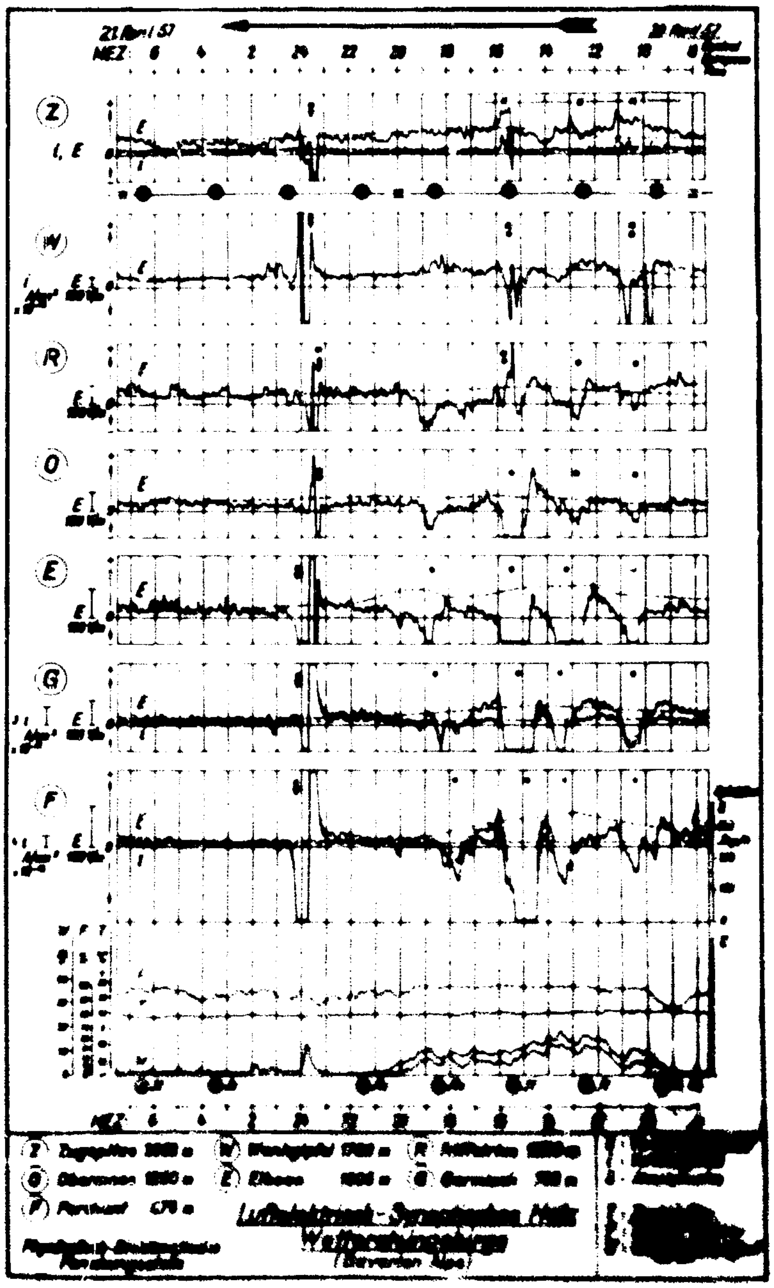


Figure 35
Zugspitze: snow; other stations: wet snow, rain

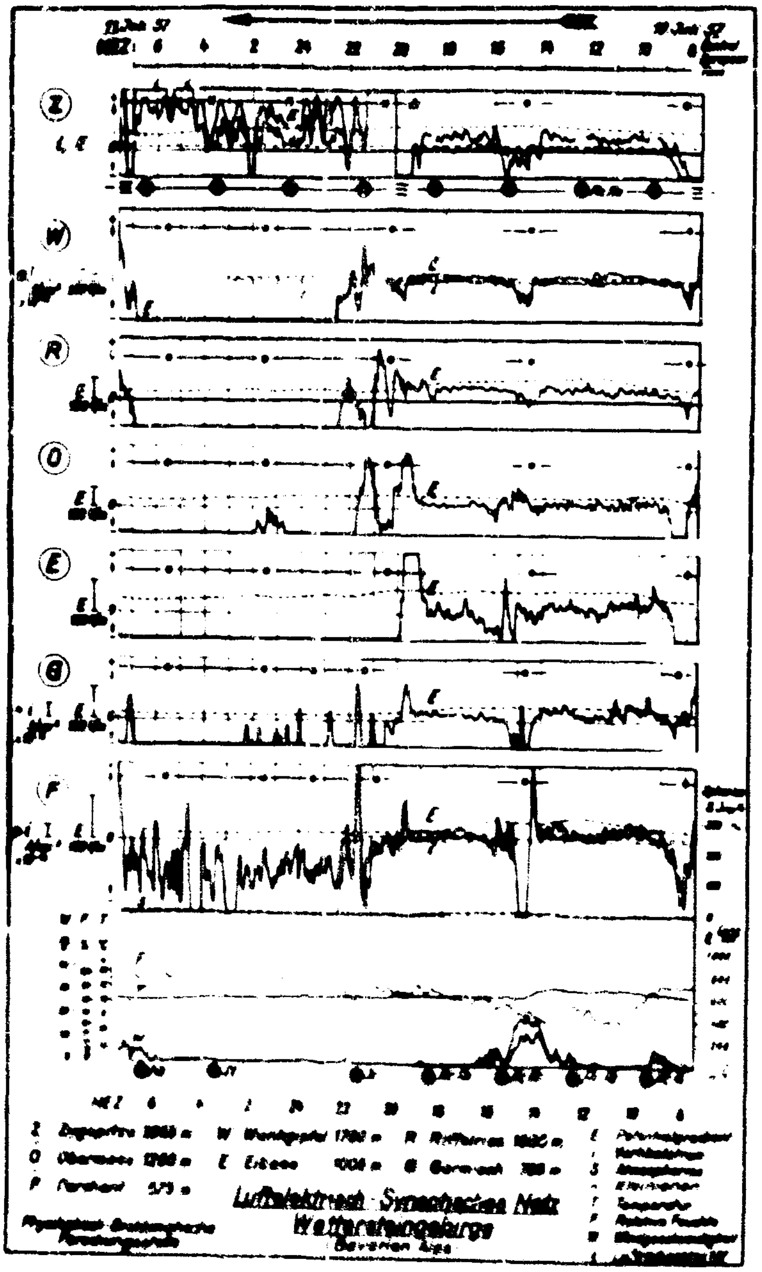


Figure 24

Zugspitze: snow; other stations: continuous rain at night

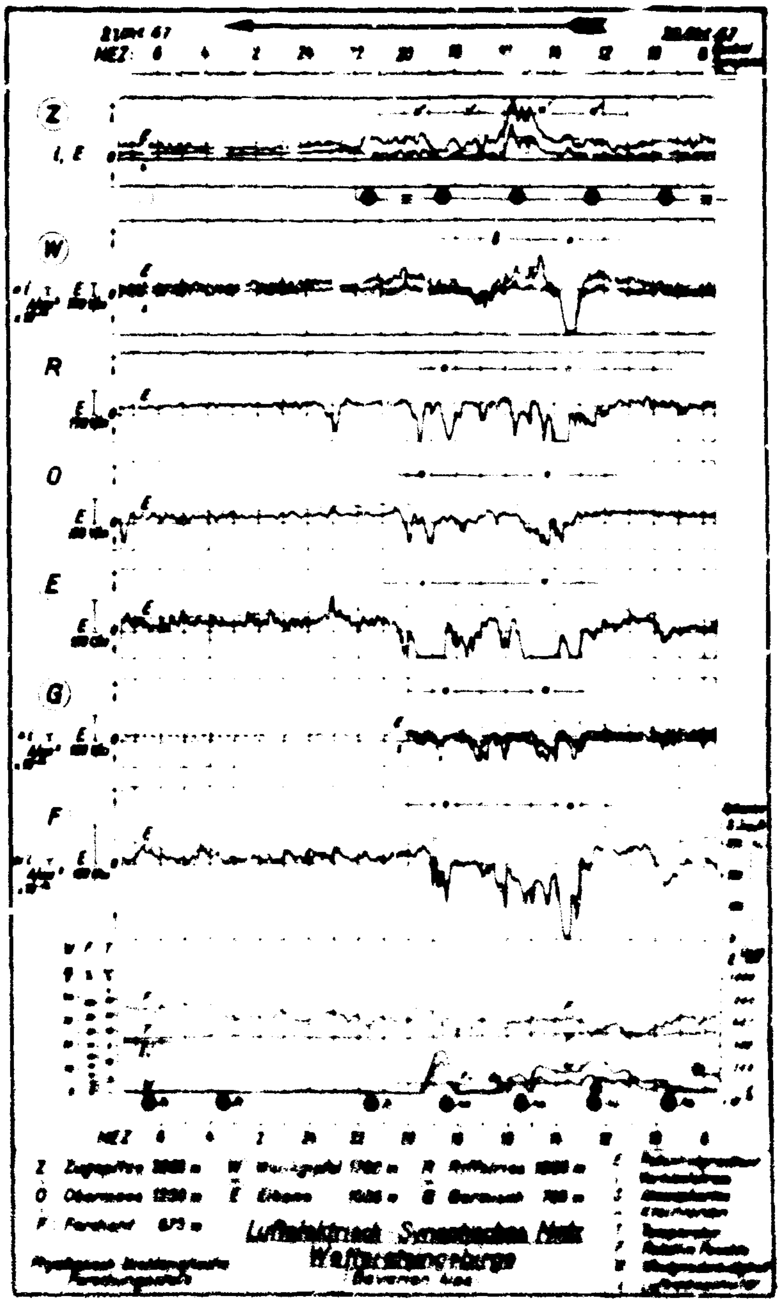


Figure 25

Zugspitze: snow; other stations: rain

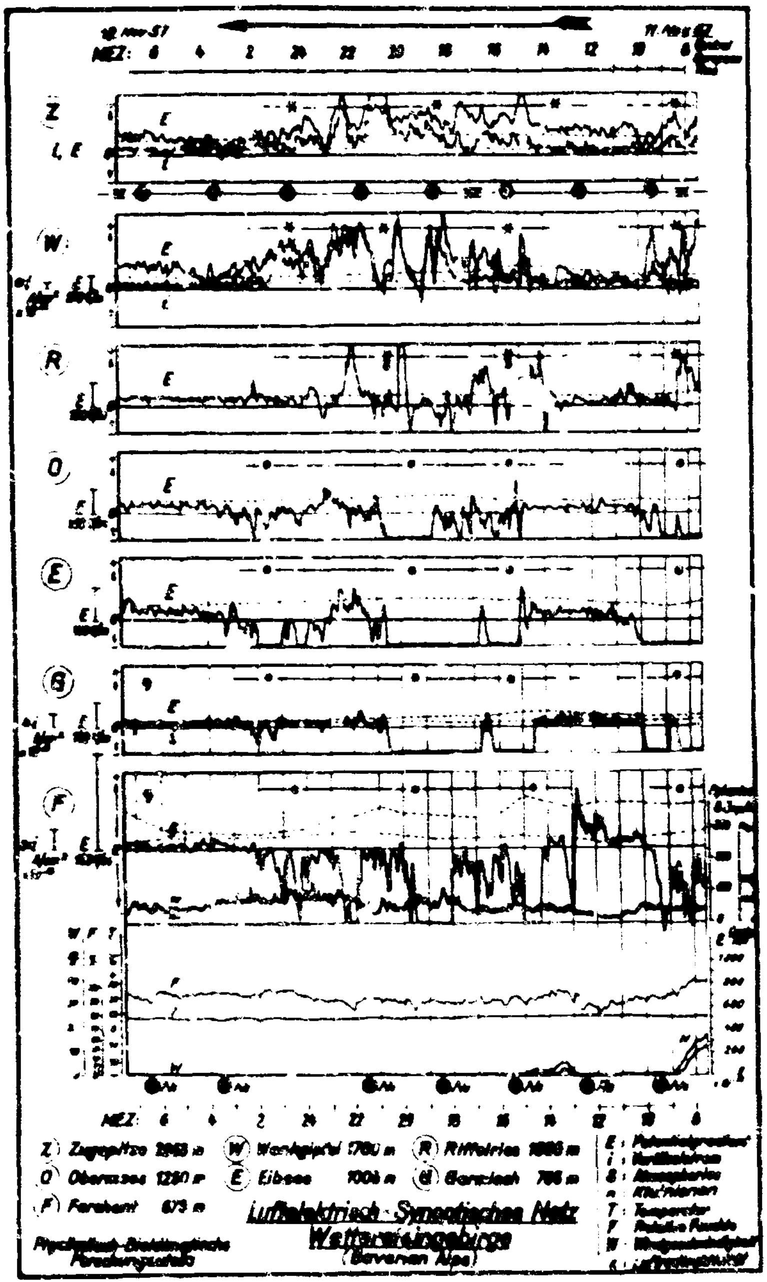


Figure 26

Zugspitze and Wank: snow; other stations wet snow or rain

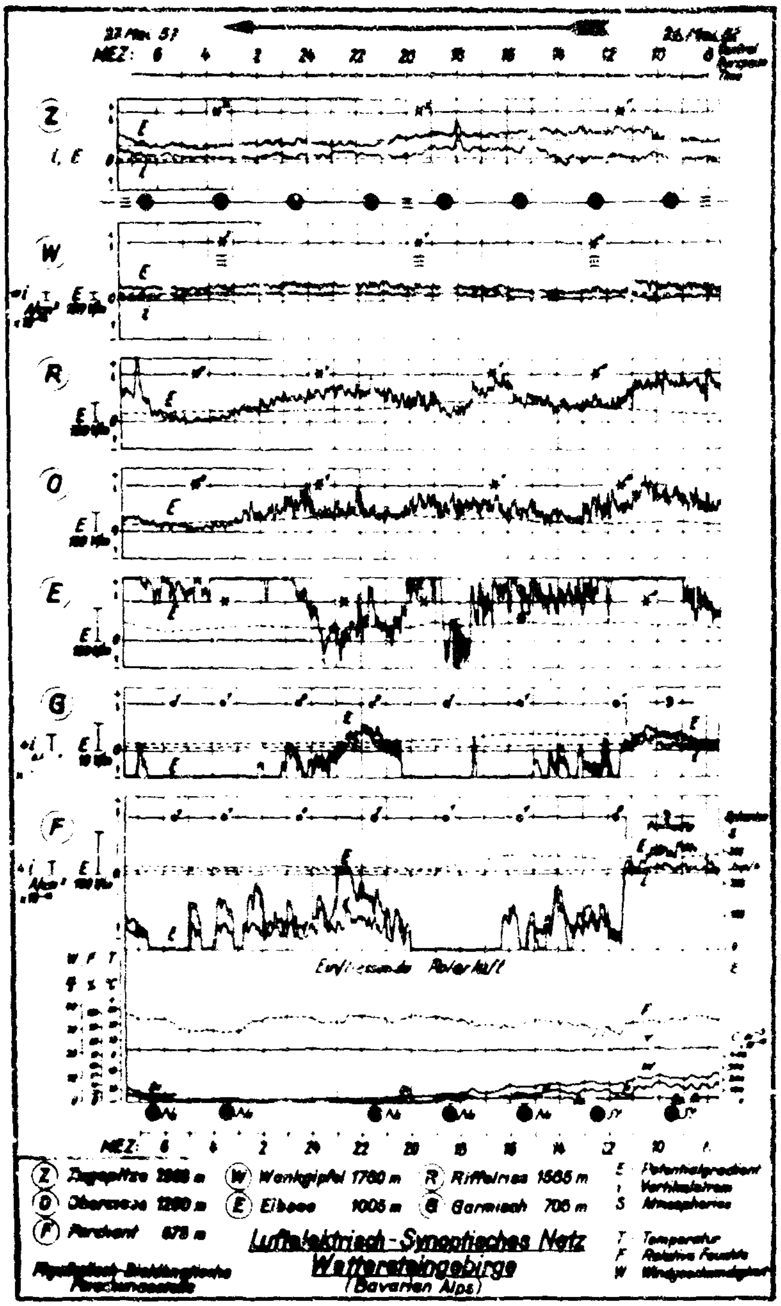


Figure 27

Garmison and Farchant rain; other stations: snow

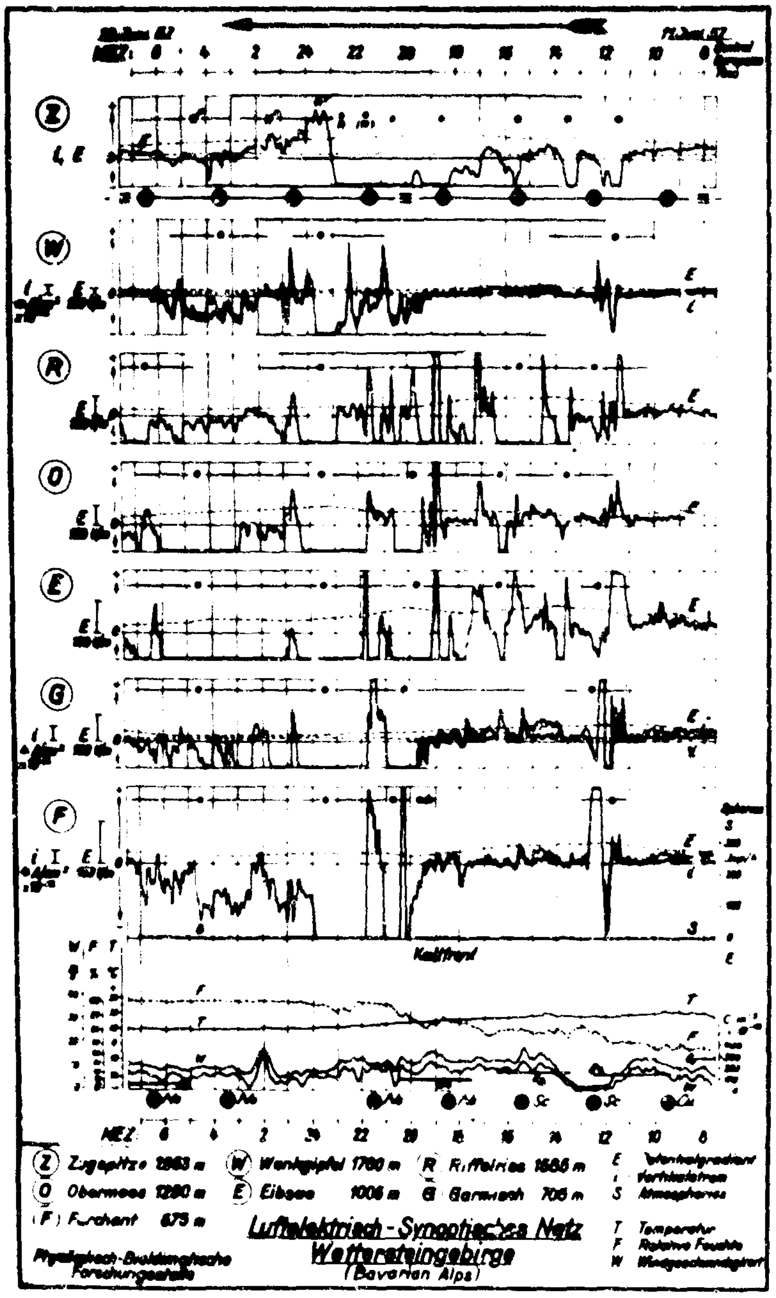


Figure 28

At station Zugspitze: rain is transformed into snow

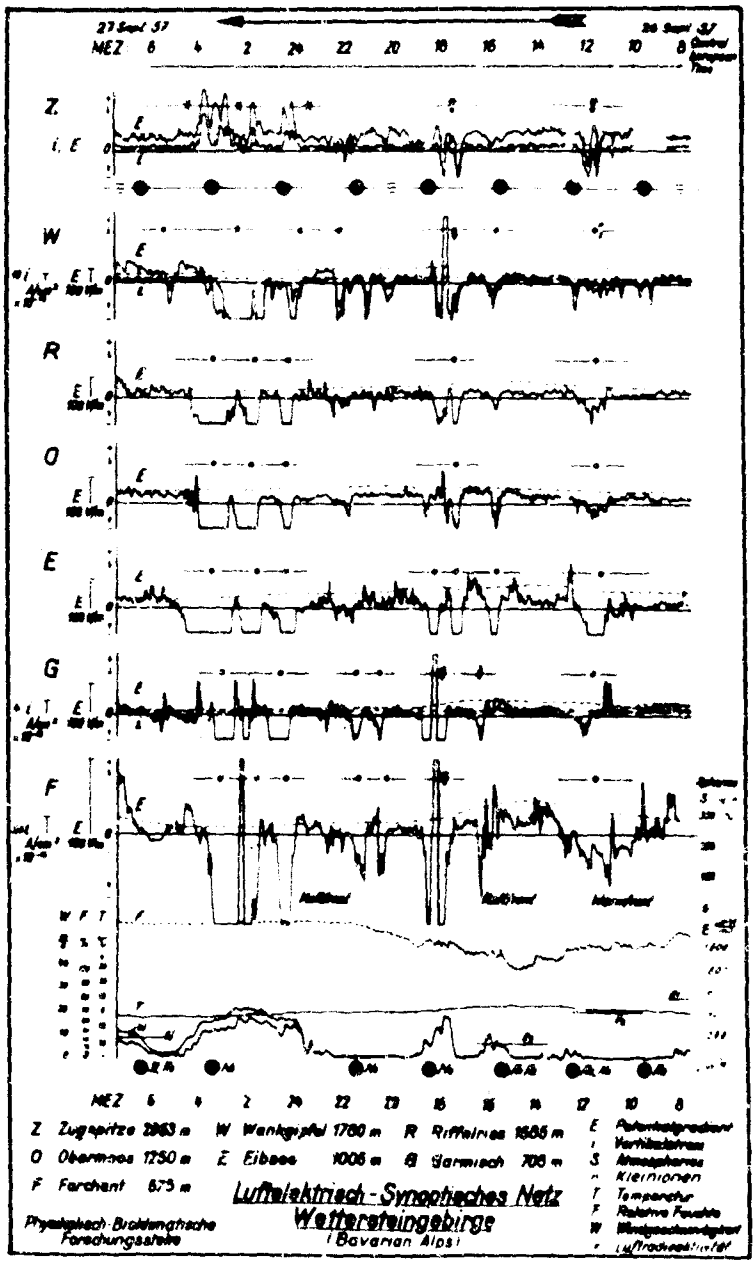


Figure 29

At station Zugspitze: wet snow is transformed into snow

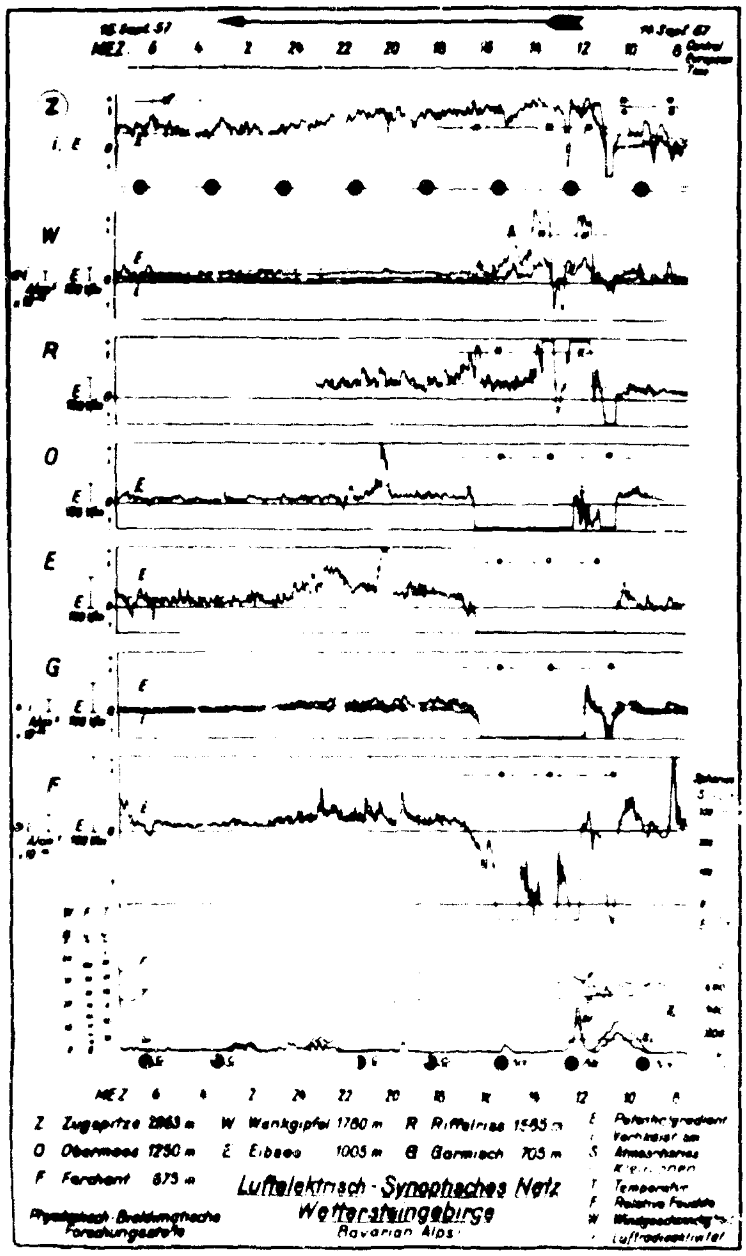


Figure 40

At station Zugspitze: wet snow is transformed into snow

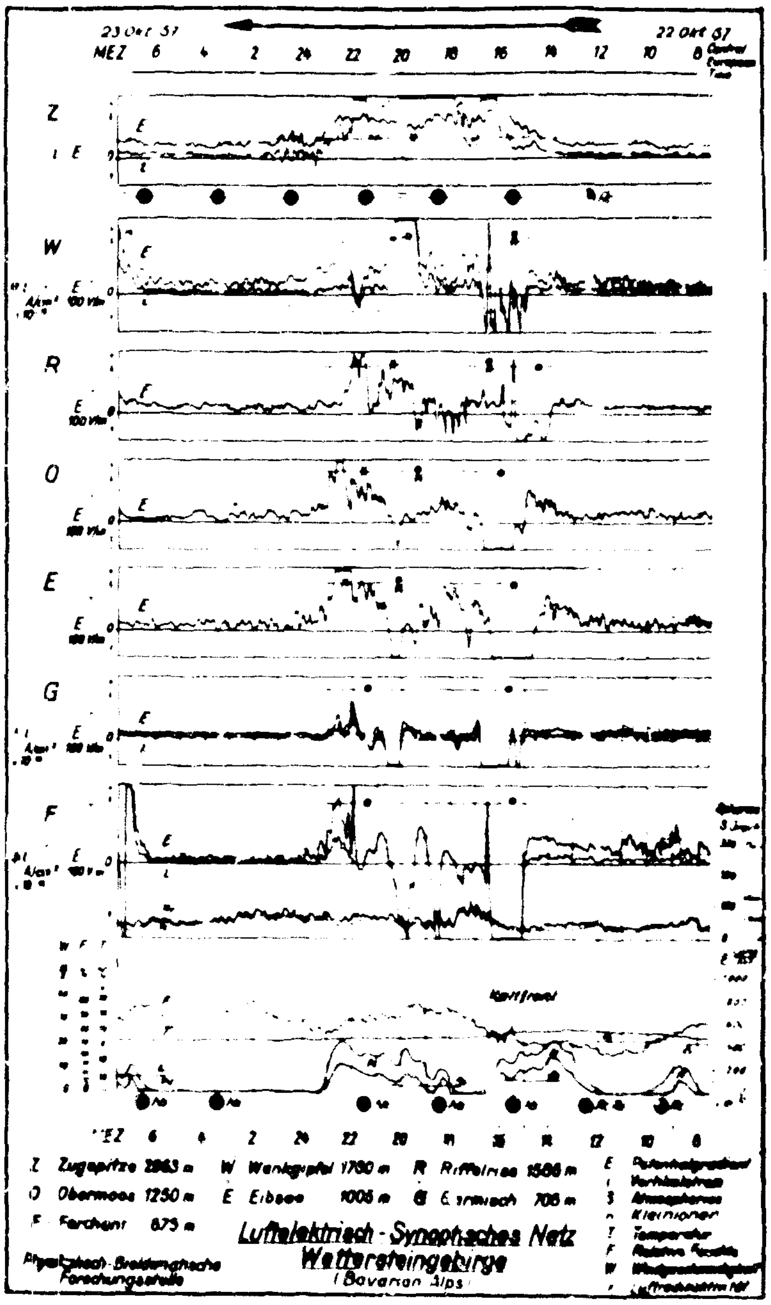


Figure 31

At stations Wank, Riffelriss, Obermoos, and Eibsee wet snow or rain is transformed into snow

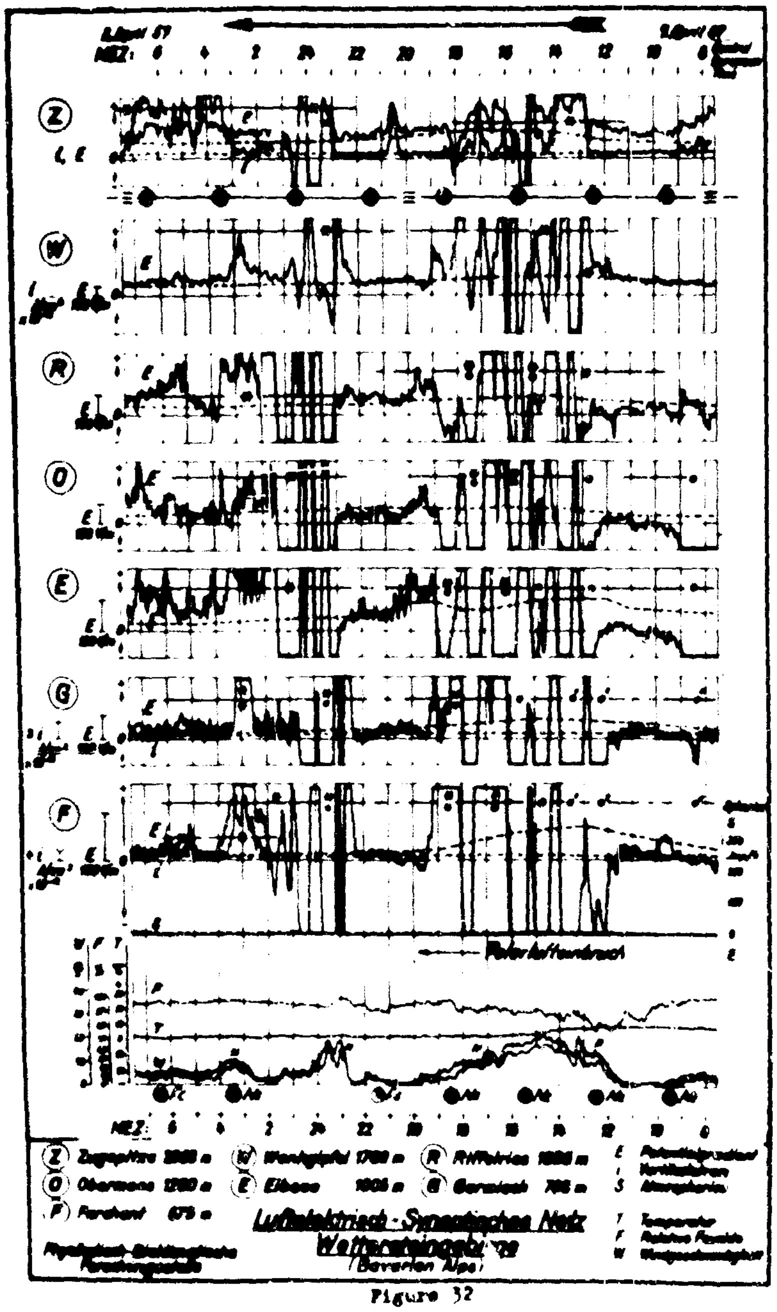


Figure 32

Regular sign reversals of the foreign field
at all stations Z - F

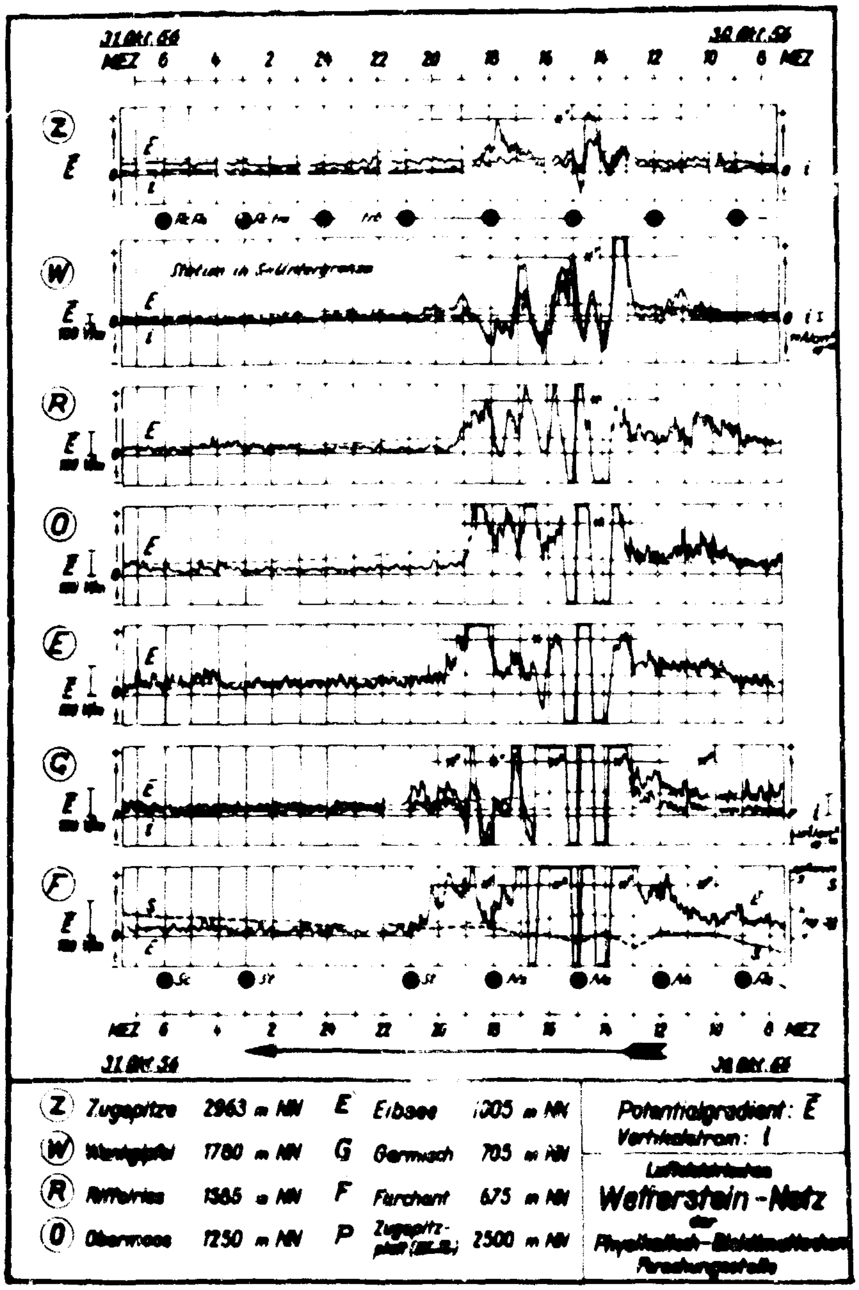


Figure 33

Regular sign reversals of the foreign field at all the stations, except at station Zugspitze

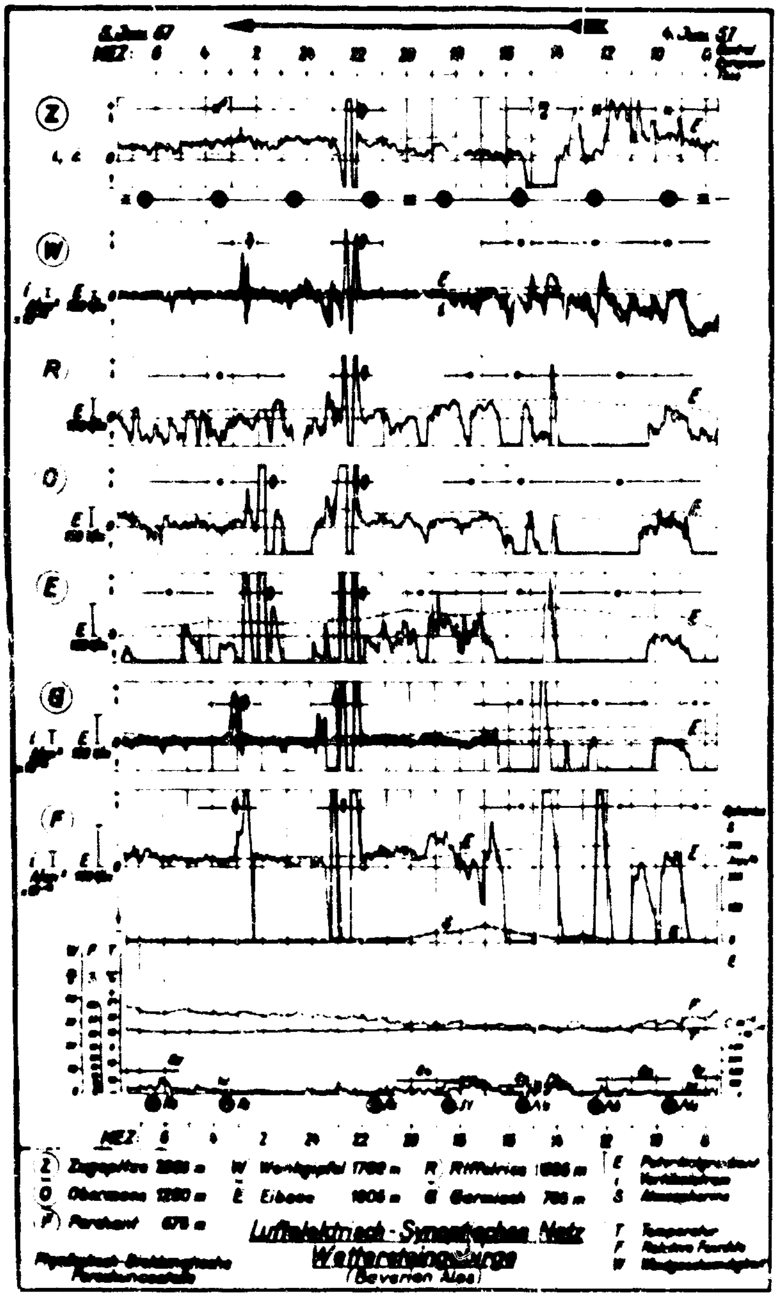


Figure 54

Right hand side: regular sign reversals of the foreign field only at valley station Farchant

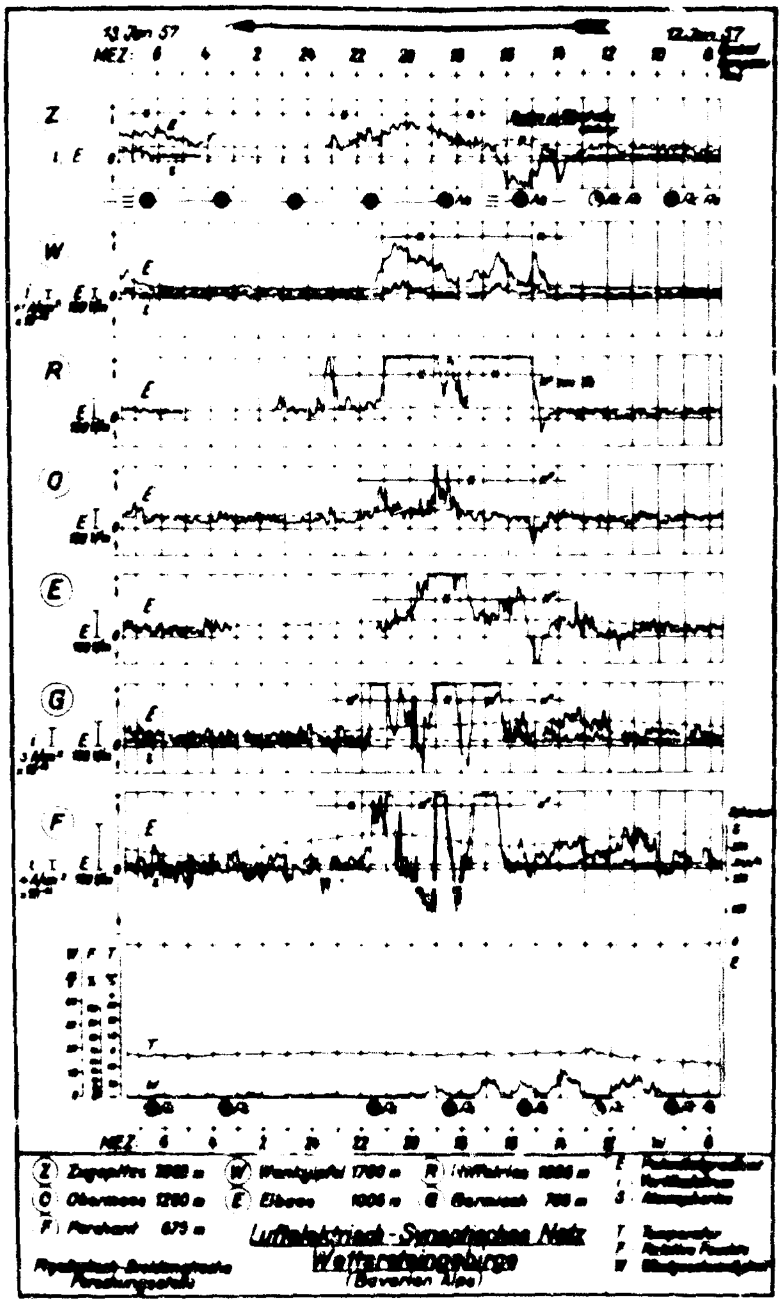


Figure 35

Regular sign reversals of the foreign field only at the valley stations Garmisch and Farchant

a) Occasionally, more or less rapid and frequent variations of the foreign field are found during uniform rain; often they take place especially within the area of negative values (Figure 36), seldom the curves have a tendency also to positive values (Figure 37). It is striking that this phenomenon is not limited to only one station, but that all the stations exhibit the same curve character, although the variations of the single stations mostly differ from each other in the frequency. Thus, in all these cases there must be a more than local cause.

b) Very seldom we find an inverse behaviour of the foreign field during non-showery precipitation, e.g. continuously negative values in snow-fall (althoug not out of Altostratus!) (Figure 38, stations Wank and Riffelriss), or positive values during rain, with negative values possible at the same time at other stations (Figure 39).

c) Very seldom it happens that the transition of rain into snow does not cause a reversal from the negative to the positive sign of the foreign field, and vice versa (provided conditions are non-showery and the cloud is not Altostratus). In Figure 40 we see that at the stations Riffelriss, Wank and Zugspitze positive foreign field exists during snow-fall, while at the lower stations Obermoos, Eibsee, Garmisch, and Farchant during rain and drizzle, high positive values are recorded, too, which remain after the following transition into snow.

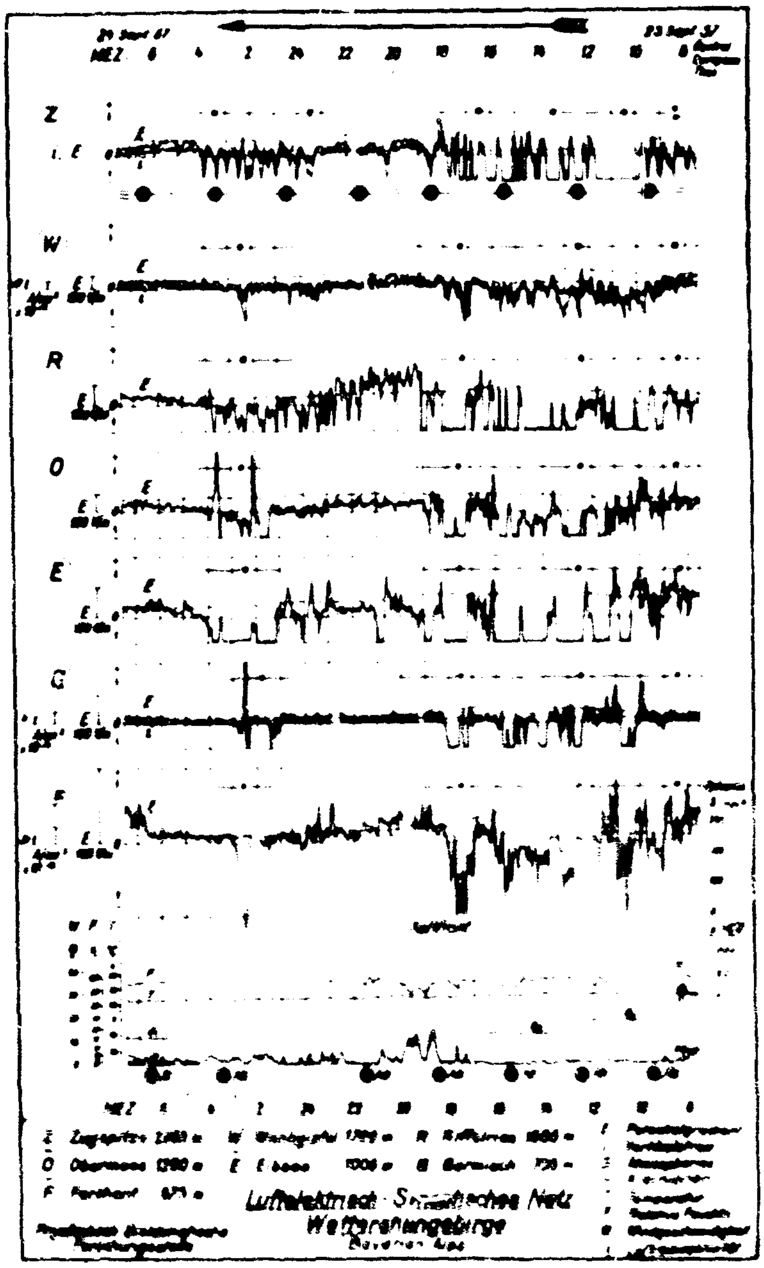


Figure 36

Rapid and frequent variations of the foreign field during uniform rain at all the stations

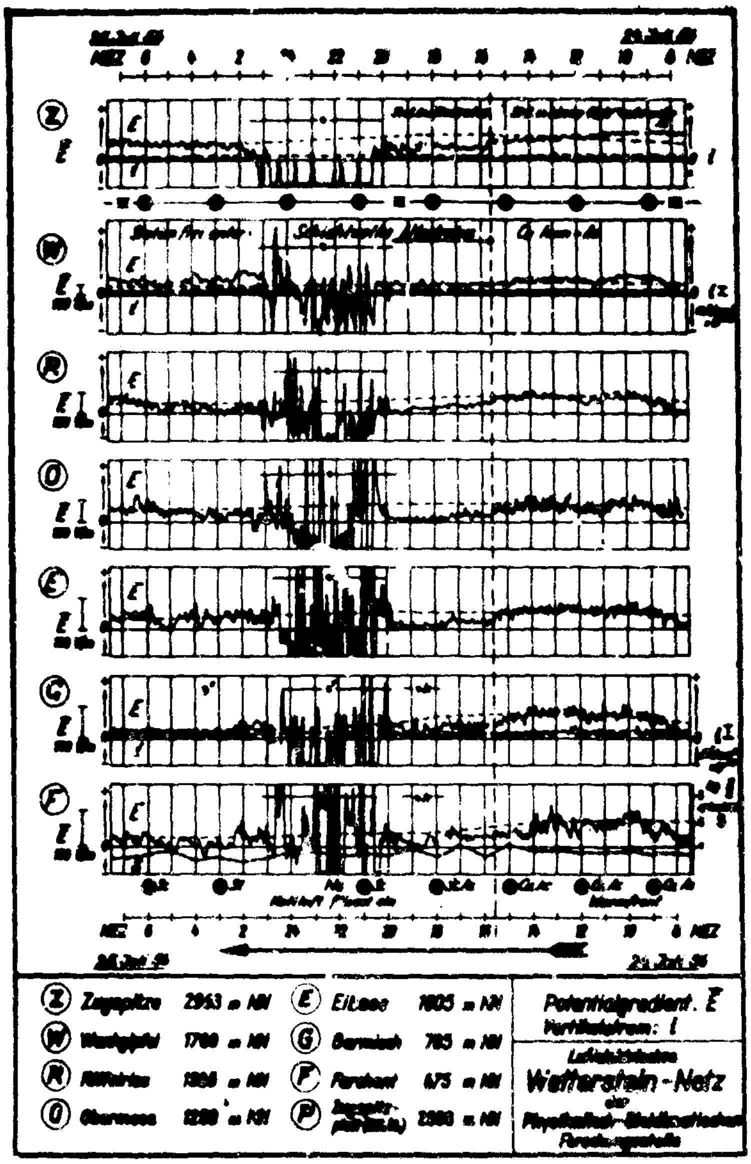


Figure 37

Rapid and frequent variations and positive points of the foreign field during uniform rain

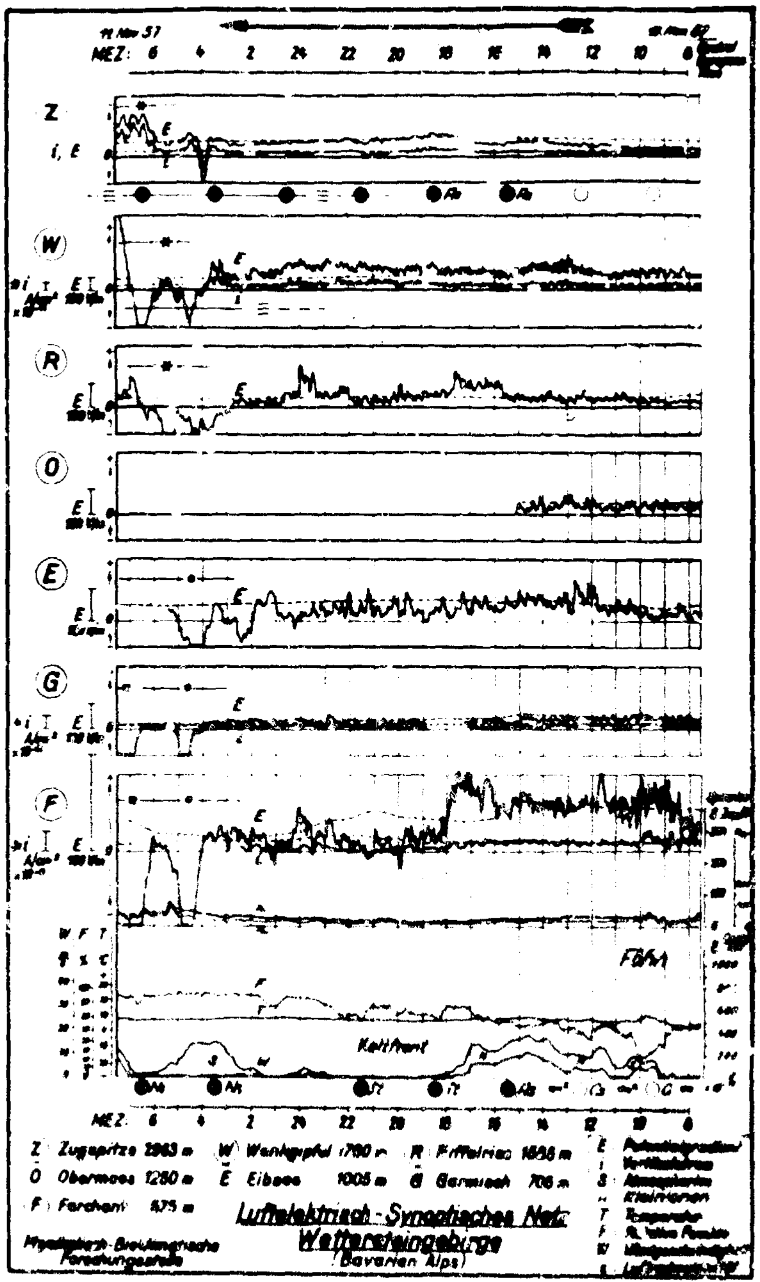


Figure 38

Negative foreign field during snow fall at Stations Wank and Riffelriss

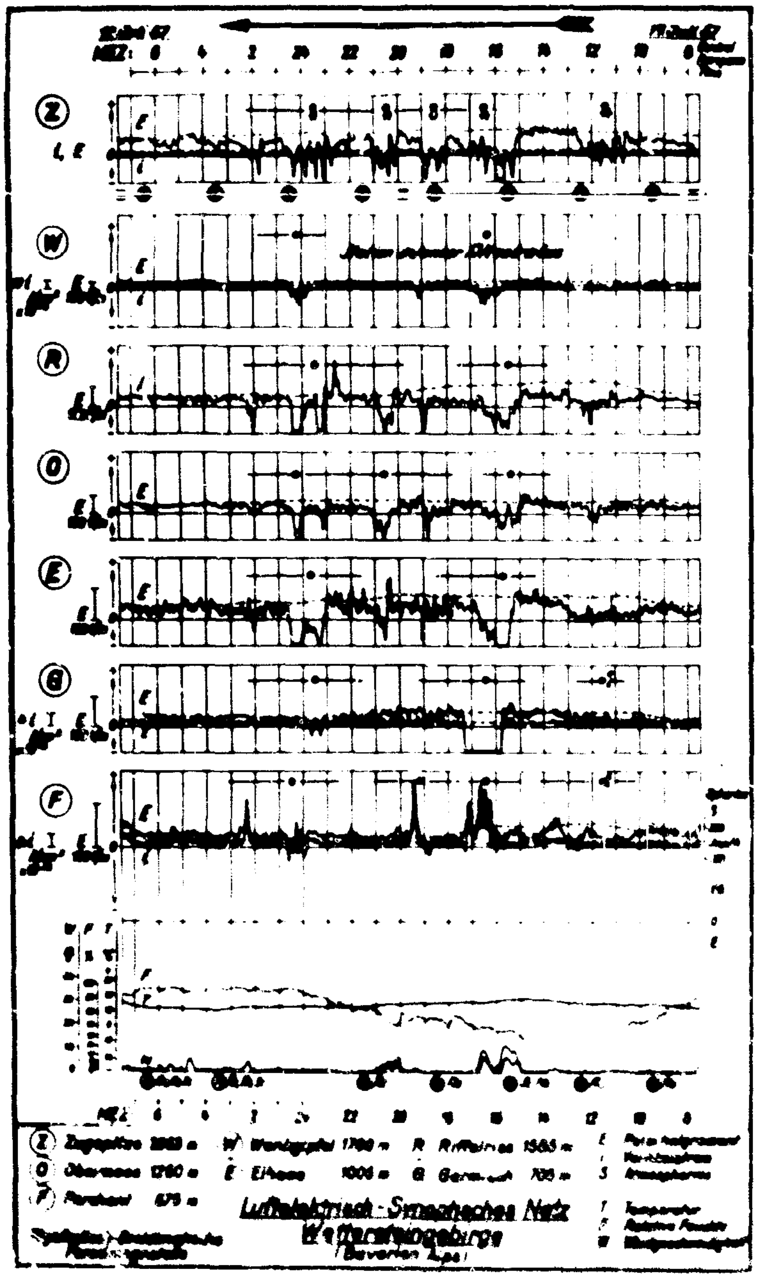


Figure 19

Positive foreign field during rain out of Alto-stratus, only at station Farchant

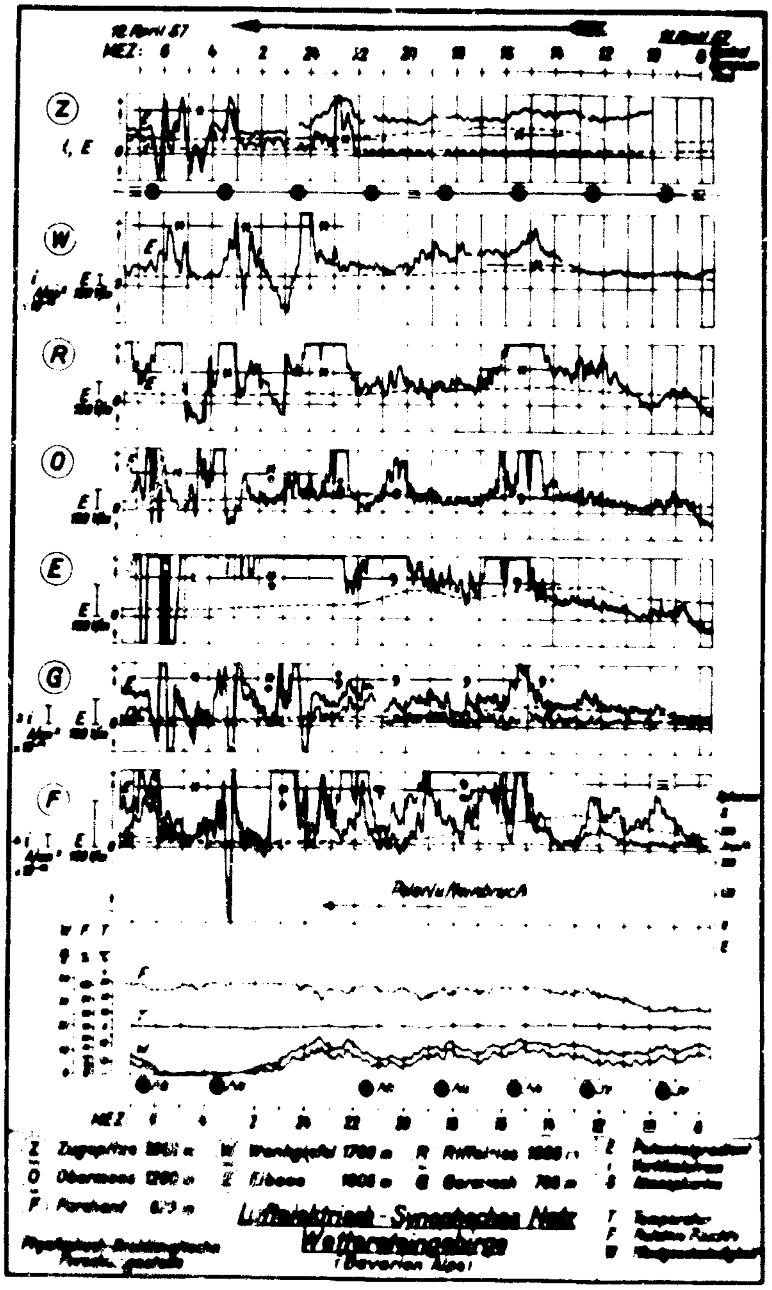


Figure 40

Positive foreign field during drizzle and rain at stations Ob moos, Eibsee, Garmisch and Farchant

Table 3

Cloud type	Precipitation type	Type and number of cases (observed 1955 + 1956 + 1957)
Nimbostratus; stable stratification	uniform snow	positive foreign field: 177 negative foreign field: 11 variations of for.field parallel at more than 2 stations: 18
	melting snow	foreign field shows sign reversals: 110 foreign field shows no sign reversals: 5
	uniform rain	positive foreign field: 10 negative foreign field: 165 variations of for.field parallel at more than 2 stations: 16
Altostratus or Altostratus being transformed into Nimbostratus (upslide clouds); stable stratification	uniform snow	positive foreign field: 3 negative foreign field: 53
	melting snow	foreign field shows sign reversals: 0 foreign field shows no sign reversals: 48
	uniform rain	positive foreign field: 7 negative foreign field: 57
	below trails of precipitation	positive foreign field: 2 negative foreign field: 15
Cumulus clouds; unstable stratification	rain showers or snow showers	chaotic course of for. field at all stations: 130 variations of for.field parallel at more than 2 stations: 46 variations of for.field antiparallel at more than 2 stations 4
	melting graupel	foreign field shows sign reversals 0 foreign field negative, no sign reversals 56
	light showers	only negative for.field at station Zugspitze: 25
Cumulus congestus	light shower during or after building up of the foreign field	positive foreign field: 33 negative foreign field: 2

4.2. Results of the statistical - synoptic evaluations

4.2.1. Survey on total numbers

In table 3 a survey is given, which was obtained by numbering the cases of the different types of potential gradient behaviour during the respective precipitation and cloud types. For this, our card index (see Intruduction) was used, which now comprises the years 1955, 1956, and 1957.

4.2.2. Snow showers and rain showers

For every station and every precipitation, i.e. for every coherent separate rain or snow period, we calculated by means of the "synoptic charts", during what percentage of the total precipitation duration there was positive foreign field. The total duration of such a precipitation period was considered 100%. Further, the numbers of sign reversals of the foreign field per hour were determined for the same precipitation periods. The fine weather value of the respective hour and month (see section 15) was the base for the calculation of these two magnitudes; the foreign field is assumed to be positive, where the potential gradient is above the light dashed line entered in the synoptic charts for each station and representing the average daily variation per month+) (see foot-note page 15). All our synoptic charts of the years 1955, 1956 and 1957, i.e. a total of 310 synoptic charts, were evaluated in this manner. Data obtained during an excursion to the Zugspitzplatt in 1955 (see Technical Report AF 61 (514)-732-C) were also included.

Then for each of the stations the arithmetic means of the magnitudes were calculated over all precipitation periods of the 3 years, i.e. over the number of recording hours entered at the right hand margin of the following figures. In the figures of section 4.2.2. and 4.2.3., the mean percentage shares of the precipitation duration, which have positive foreign field, always are designated by "% positive" and represented by black columns, while the mean numbers of the sign reversals of the foreign field per hour are designated by "changes p.h." and represented by white columns.

In Figure 41, the result for rain showers is given synoptically for all stations. The foreign field during rain shower is positive for 30 - 40 % of the precipitation duration, depending on the station. The number of its sign reversals per hour is between 2.2 and 3. The largest frequencies of sign reversals are found at the valley stations.

During snow-shower (Figure 42), the foreign field is positive in 40 - 50 % of the total precipitation duration, a percentage which is not considerably higher than the value found for rain shower. The number of the reversals per

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*) in fine weather

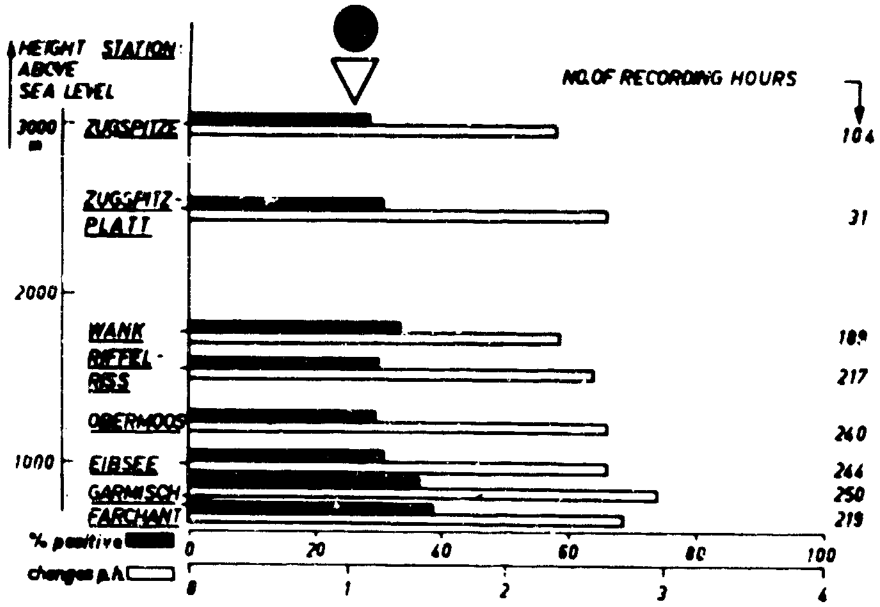

Figure 41

Foreign field and its sign reversals during rain shower

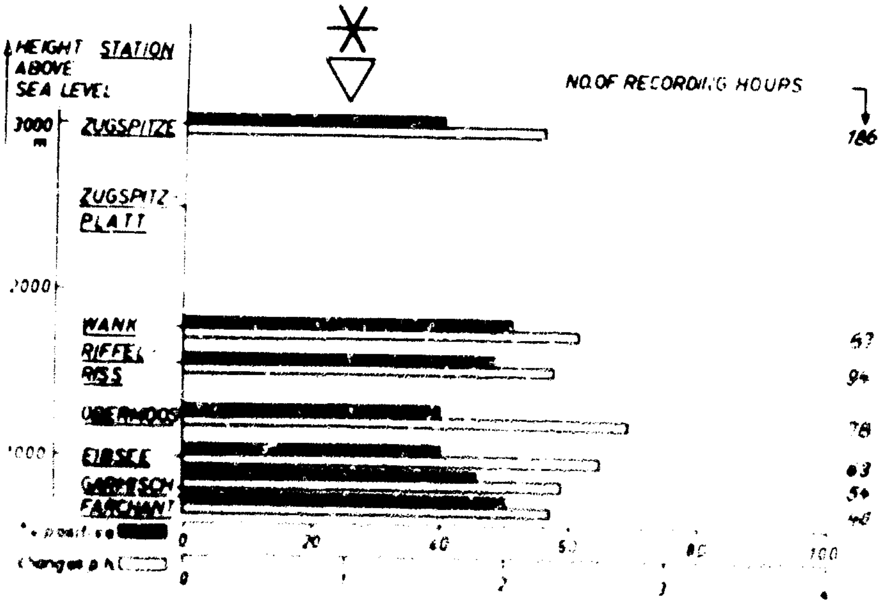

Figure 42
Foreign field and its sign reversals during snowshower

hour during snow shower is almost the same as during rain shower (2.2 - 2.7).

Neither in rain shower nor in snow shower an influence of the altitude of the station on the positive foreign field is found.

If we do not discriminate between the altitudes of the stations, but between three atmospheric "floors" chosen according to the physical state of the precipitation, thus

a) snow shower zone

b) melting zone, where the transition from solid to liquid state, or vice versa, takes place; here showery snow can be mixed with showery rain,

c) rain shower zone,

then we obtain Figure 43: the transition from the snow shower zone to the melting zone involves a light decrease of the positive foreign field percentage to a value which is the same as in the rain shower zone. The frequency of sign reversals is somewhat grater in the melting zone than in the two other zones.

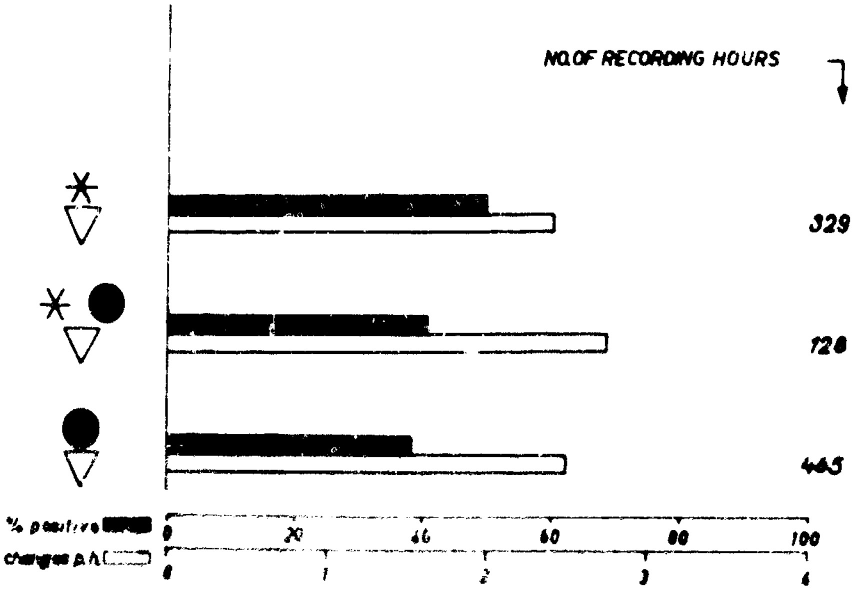

Figure 43

Foreign field and its sign reversals during shower in the three main precipitation zones

4.2.3. Non-showery precipitation; importance of the melting process

A quite different picture results from an analogous investigation of non-showery precipitations.

During uniform rain (Figure 44) the positive foreign field percentage is only 8 - 12 %, and the number of sign reversals of the foreign field per hour 0.7 - 1.2 . Thus, both magnitudes are smaller than in the case of rain shower.

During uniform snow (Figure 45) the range of the frequencies of sign reversals is about the same as during uniform rain, but the positive foreign field percentage is much higher than during uniform rain (80 - 90 %).

If we again discriminate between

a) zone of uniform snow

b) melting zone, where the transition from solid to liquid state, or vice versa, takes place; here snow can be mixed with rain,

c) zone of uniform rain,

then we obtain Figure 46. It differs fundamentally from Figure 43. In the case of non-showery precipitation+), the melting process, as is suggested by this Figure 46, is coupled with those processes which cause the sign reversal of the foreign field. If another zone were coupled with these processes, the black columns of the melting zone would be the same as for snow, or the same as for rain, and not in the middle of the sequence. We note further that the sign reversals are more frequent in the melting zone than in the snow and the rain zone. There is a simple reason for this: the transition from the rain "floor" to the snow "floor", or vice versa, involves <u>at least one</u> sign reversal, and these sign reversals always are added to the sign reversals occurring in the melting zone by other reasons. Beyond this, in the melting zone sign reversals are more probable, than in the two other zones, since ~~also~~ temporal changes of the physical state of the precipitation are relatively probable here. In the snow zone, sign reversals are more frequent than in the rain zone, but much less frequent than during showers.

+) Much more slightly already in the case of shower precipitation

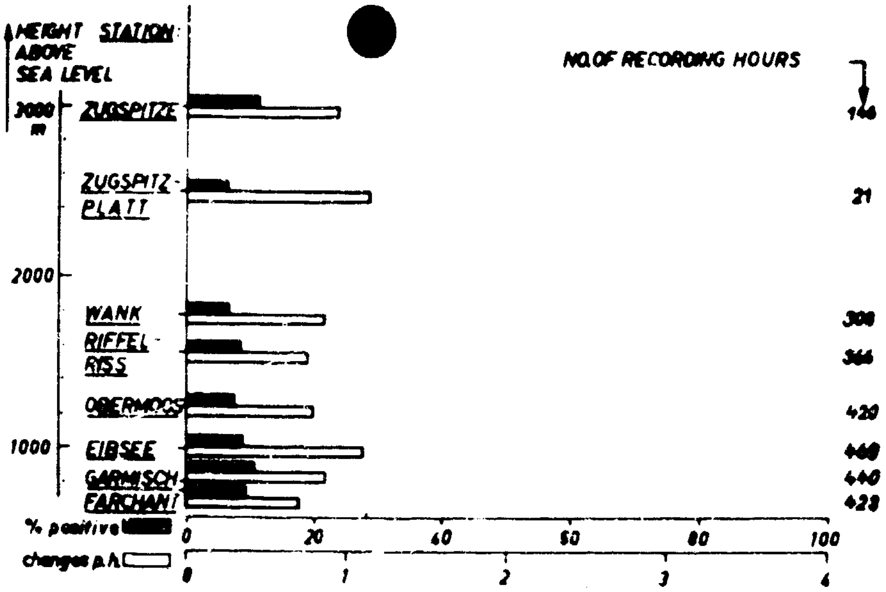

Figure 44

Foreign field and its sign reversals during non-showery rain

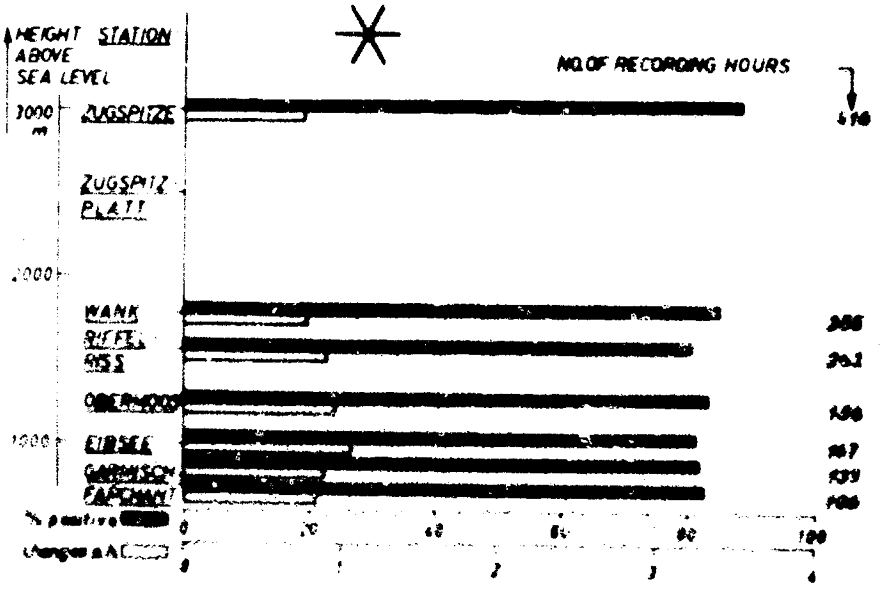

Figure 45

Foreign field and its sign reversals during non-showery snow

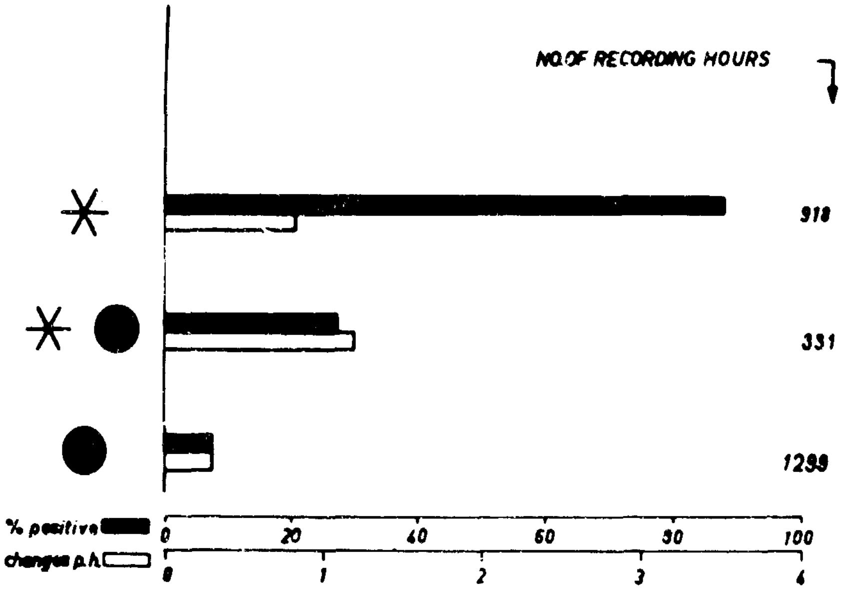

Figure 46
Foreign field and its sign reversals during non-showery precipitation in the three main precipitation zones

4.2.4. Strength and sign of the potential gradient at different altitudes during rain or snow

For each station, this analysis was carried out as follows (Figure 47):

a) For each hour of uniform snow (number of recording hours entered at the right hand margin of Figure 47 and marked with "✳"), we calculated, what percentage of the fine weather potential gradient (and conduction current) of this hour and the respective month (see section 15) the actual potential gradient E (conduction current i) is on the average, the respective fine weather value always being 100%. For instance: if, the actual conduction current equals the fine weather conduction current of the same hour, the percentage is +100; or: if it is twice the respective fine weather value, the percentage is +200; or: if it is zero, also the percentage is zero. The arithmetic mean of all the potential gradient (conduction current) percentages is entered in Figure 47 as black (white) column, and that for each station. All the seven values are far above +100 %. The potential gradient percentages decrease with increasing altitude (compare section 4.2.6.). About halt of the uniform snow cases could be evaluated systematically in this manner. The rest showed so high positive values, that the davitations surpassed the record sheet breadth; it hat to be omitted. Consequently we may assume, that actually the mean percentages are even higher.

b) The same calculation was made for uniform rain (number of recording hours entered at the left margin of Figure 47 and marked with "   "). These results give less information, since the range of "light rain" cannot be defined exactly. During strong uniform rain-falls, on the other hand, usually the breadth of the record sheet was surpassed, so these precipitation days had to be omitted. If all cases of uniform rain were included, the negative mean percentage, consequently, would be still more negative. The differences of the percentages from station to station, are here only small.

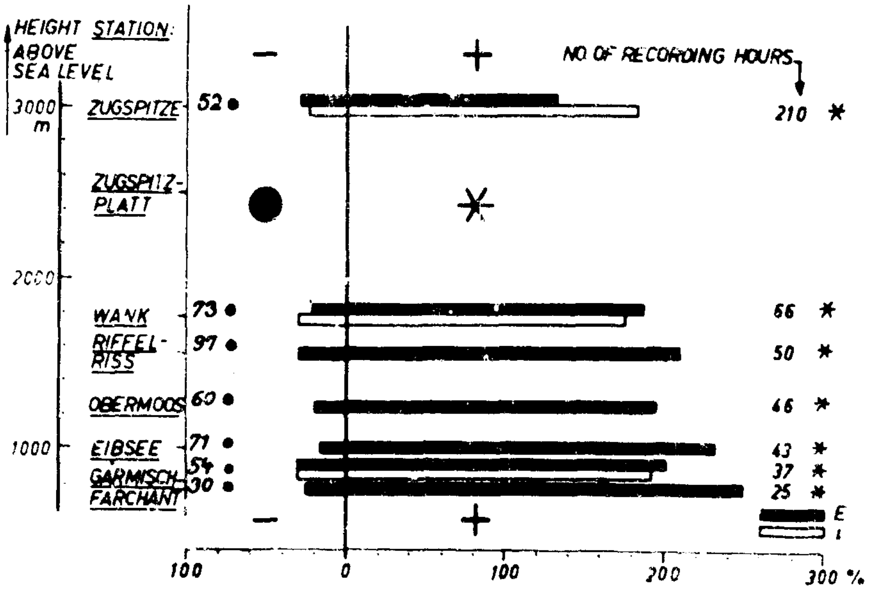

Figure 47

Strength and sign of the potential gradient at different altitudes during non-showery rain or snow

4.2.5. Strength and sign of the potential gradient below Altostratus with or without precipitation falling out of this

Here we recall, to begin with, that precipitation out of Altostratus is very slight. In Figure 48 and 49, for each station the mean strength of the potential gradient below Altostratus, in terms of percentages, is demonstrated, the fine weather potential gradient being 100 % (and represented by the vertical dashed lines). The calculation of the arithmetic means was made as described in section 4.2.4. The same analysis was carried out for the conduction current.

If there is snow-fall at station Zugspitze (Figure 48), the potential gradient (conduction current) nevertheless is lower than in fine weather. It is about the same as in the case of the station being below Altostratus without precipitation. However, where there is rain out of Altostratus (Figure 48), the values are clearly lower than in the case of the station being below Altostratus without rain (Figure 49). This investigation again shows that below Altostratus the potential gradient is lower than it would be in fine weather (see section 4.1.2.1.). Hence we may conclude that the base of the cloud sheet carries negative space charge.

If solid precipitation particles are falling through the Altostratus, cloud droplets, which doubtless carry negative charges, freeze upon the precipitation particles at the cloud base. This will prevent the positive values of the foreign field, which are usual in all the other cases of non-showery precipitation, appearing also in snow falling out of Altostratus. There can be several reasons, why this mechanism doesn't work in the case of Nimbostratus, the base of which also carries negative charge:

a) Altostratus mostly is only of small thickness. Consequently, the precipitation particles formed in it have still very small falling velocities, when they arrive at the cloud base. Thus,[+] they have relatively much time available there for picking up negative charges.

b) The Base of Altostratus, in contradistinction to that of Nimbostratus, is sharp and definite. So the negative space charge density there will be expecially high. Therefore relatively many negative charges of freezing-on cloud droplets are conveyed to the surface of the precipitation particles just in the last moments of their fall through the cloud, so that the compensation by positive cloud droplets freezing on the precipitation particles is small.

[+] in contradistinction to the conditions in Nimbostratus

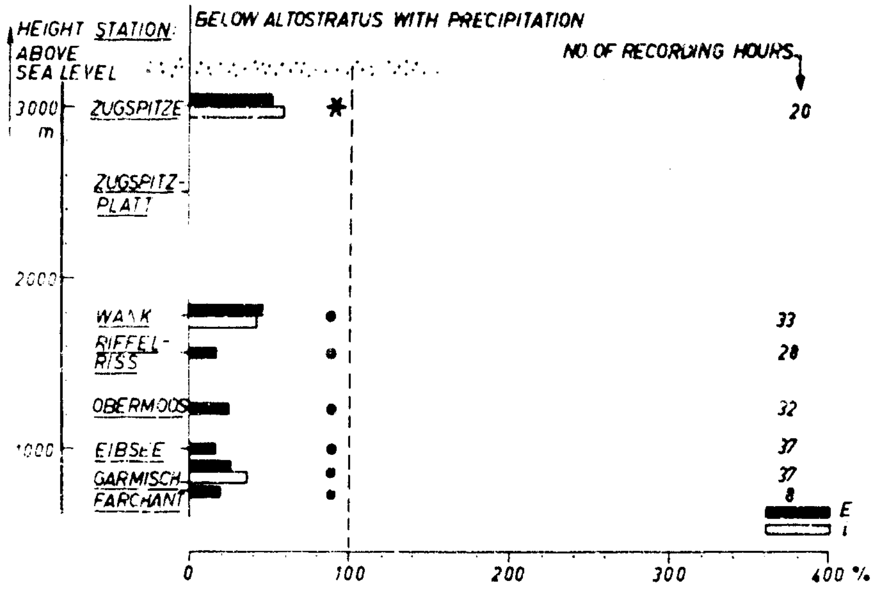

Figure 48

Strength and sign of the potential gradient below Altostratus with precipitation falling out of this

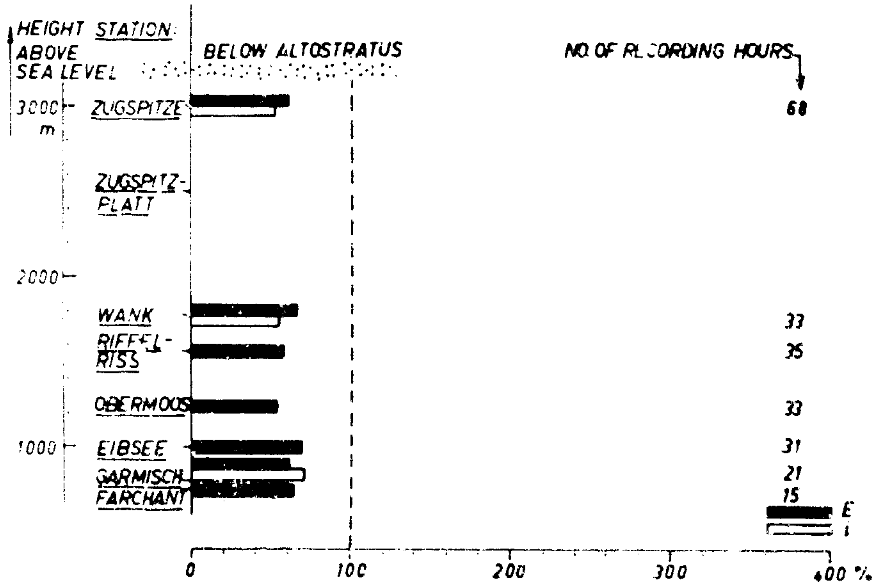

Figure 49

Strength and sign of the potential gradient below Altostratus without precipitation falling out of it

4.2.6. Influence of type and size of the snow crystals on the strength of the foreign field during snow-fall

Already in Technical Report AF 61 (514)-732-C we reported a preliminary investigation which showed that on the Zugspitze the foreign field in snowfall depends on size and crystal type. This result could now be confirmed with a much greater number of observations. Figure 50 gives, in terms of percentages, mean values obtained for station Zugspitze. The number of snow crystal observations+) are indicated on the top of each column. The 100 % level signifies the potential gradient as it would be, at the hour of the respective observation, in fine weather. The figure shows clearly that the potential gradient during snow fall is the greater, the greater is the diameter (i.e. extent in the largest dimension) of the snow crystals forming the snow fall (flakes are very seldom at station Zugspitze). Further, the potential gradient is higher in the case of flat (e.g. plate or star shaped) crystals than in the case of needle shaped crystals. Perhaps it is allowed to infer from these observations that the falling velocity of the precipitation particles is of importance, and so that the foreign field is the stronger, the smaller is the falling velocity of the precipitation particles. Besides, this view could be corroborated by Figure 47 (section 4.2.4.): in falling down, the single snow crystals, which

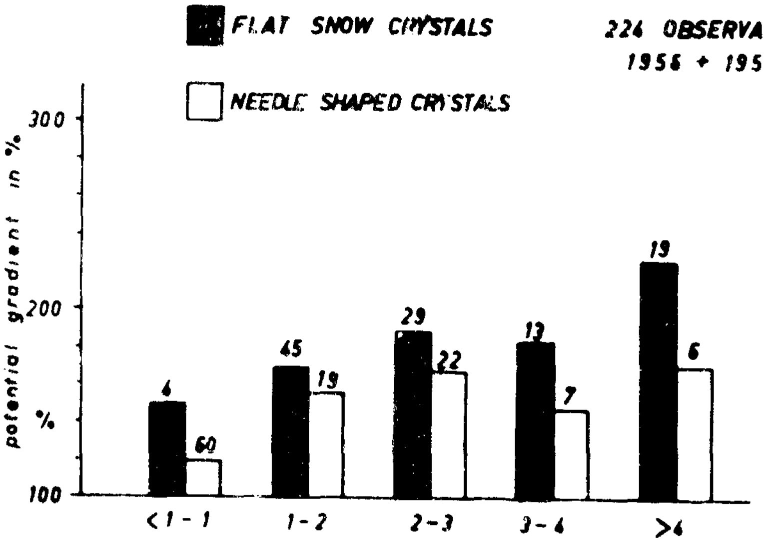

Figure 50

+)They were made by the observatory Zugspitze of the German Weather Service according to the directions of the UGGI.

are usual at station Zugspitze, more and more combine to form small flakes and at last, arriving in the valley, large flakes. The latter fall much more slowly than single crystals, and, indeed, the foreign field during snow fall is the stronger the more we go to lower levels.

4.2.7. Relation between lability degree of the stratification and frequency of the sign reversals of the foreign field during precipitation

Already by a comparison of Figure 43 with Figure 46 we see that there must be a corelation between the lability (=unstability) degree of the atmosphere during precipitation and the frequency of sign reversals of the foreign field. Beyond this, it was attempted to grasp this correlation quantitatively. For this purpose, we used the radio sonde ascent data of the Munich-Riem Airport. The temperature data were entered in the "STÜVE Diagram Paper" (observed lapse rate). The courses of the respective dry adiabatic and moist adiabatic were determined in the well known manner. Then the area between 500 mb level line, moist adiabatic, observed lapse rate, and 700 mb line was measured with planimeter. The value thus obtained in square centimetres is a relative value for the lability energy between 700 and 500 mb. When it is positive, the stratification is unstable. These evaluations were made for both radiosonde ascents of each day.

Here we have su insert that the radio sonde data are obtained in the free atmosphere, whereas in the region of our station network, i.e. at a distance of 100 km from Munich-Riem and in the mountains not far from the northern border of the Alps, the actual unstability can be somewhat different from the unstability existing in the free atmosphere above Munich. E.g. we have to consider that in many cases during slightly stable stratification of the free atmosphere there will be already unstable stratification in the mountains, since here the air in the lower atmosphere obtains additional energy by the insolation of sloping surfaces.

Figures 53 - 56 show the correlation which is obtained for each of the stations (Garmisch and Farchant being united to "valley"), if the frequency of the sign reversals of the foreign field during precipitation (all kinds) is plotted against the simultaneous relative value of the lability energy between 500 and 700 mb. The stratification above our station net, as mentioned above, is not exactly given by the radio sonde data of Munich-Riem, so we cannot expect the two magnitudes compared to show a very close connection. However, it is evident that the frequency of sign reversals increases with increasing

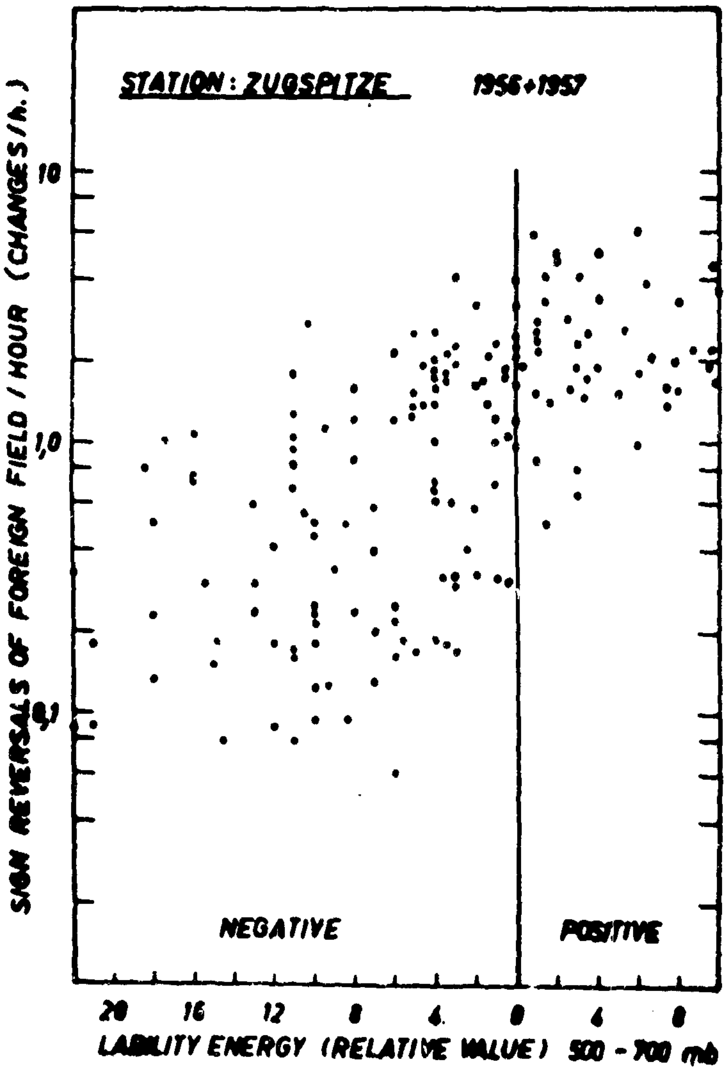

Figure 51

Lability energy between 500 and 700 mb v. sign reversals of the foreign field during precipitations;
Station Zugspitze

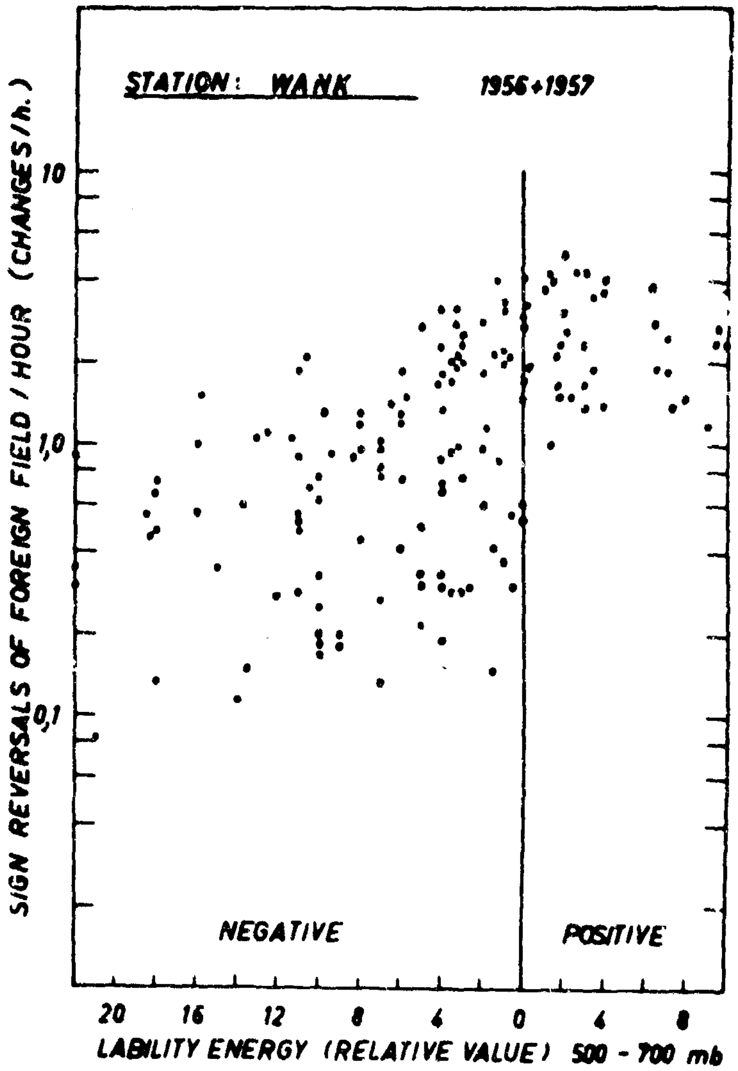

Figure 52

Lability energy between 500 and 700 mb v. sign reversals of the foreign field during precipitations; Station Wank

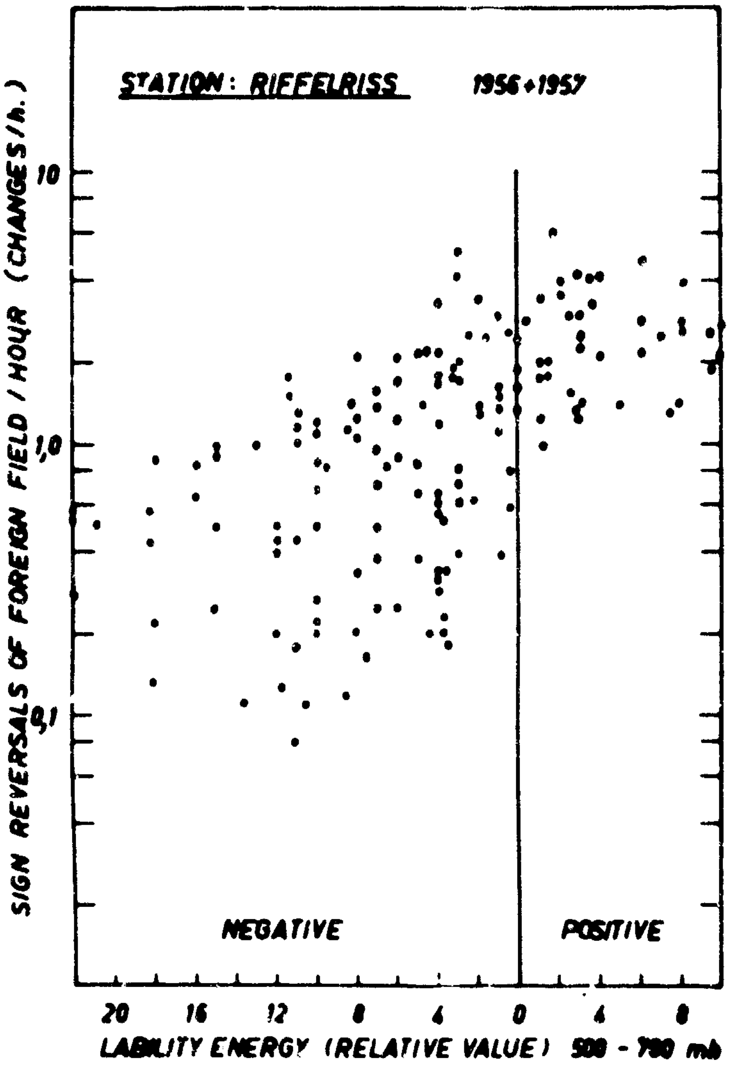

Figure 53

Lability energy between 500 and 700 mb v. sign reversals of the foreign field during precipitations;
Station Riffelriss

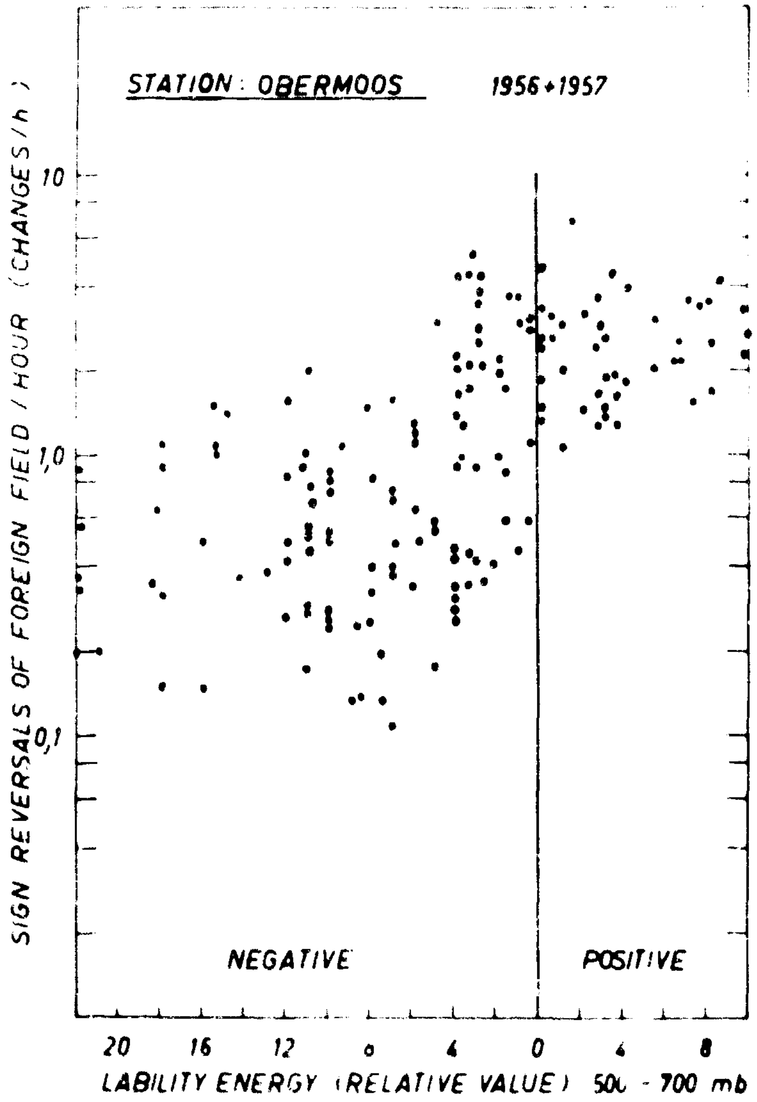

Figure 54

Lability energy between 500 and 700 mb v. sign reversals of the foreign field during precipitations;
Station Obermoos

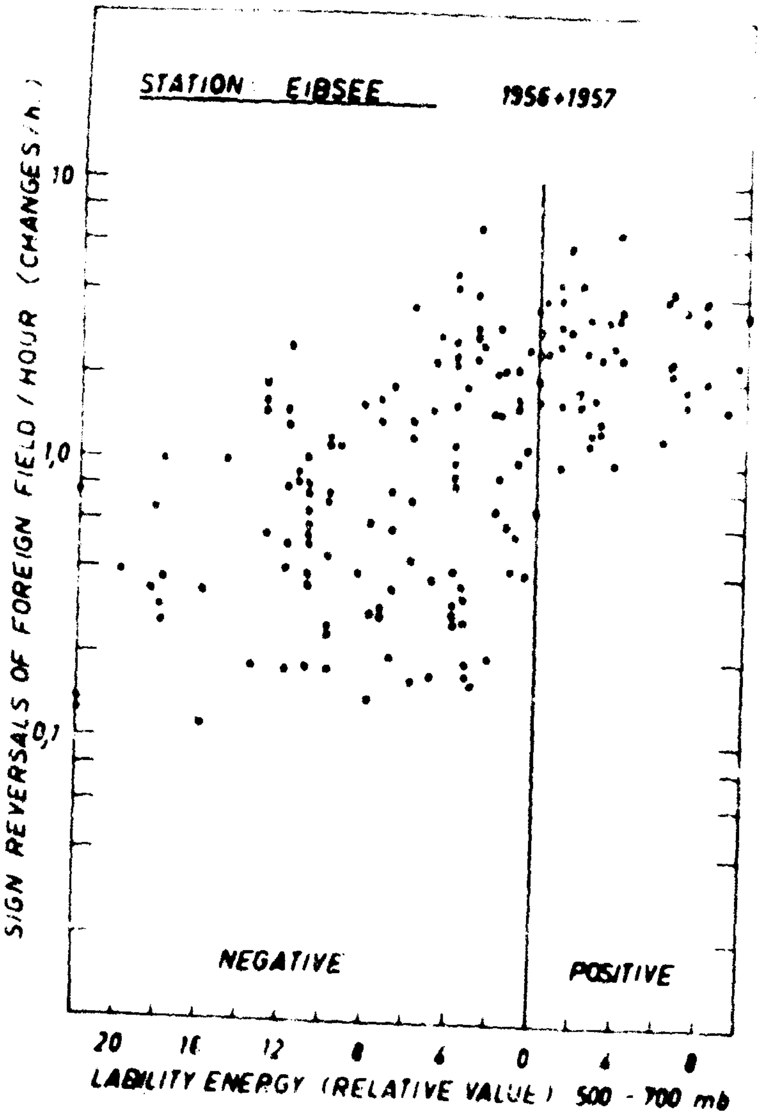

Figure 55

Lability energy between 500 and 700 mb vs. sign reversals of the foreign field during the [illegible]

Station Eibsee

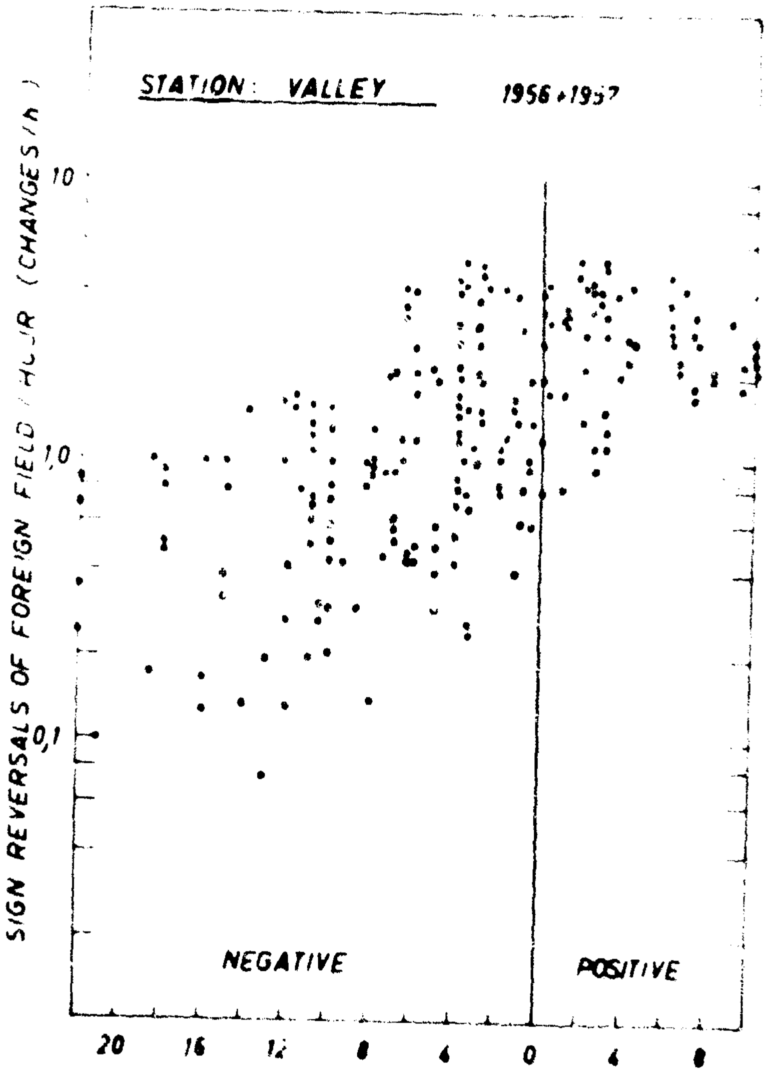

Figure 56

Lability energy between 500 and 700 mb v. sign reversals of the foreign field during precipitations; valley stations unstability. The differences from station to station are only slight and of no importance. The following can be gathered from the figures:

If the number of sign reversals per hour is more than 1, it is very probable that the stratification of the atmosphere is unstable between 700 and 500 mb, the fact being taken into account that a slight negative lability energy of the free atmosphere mostly signifies unstability above our region. If, on the other hand, the number of sign reversals per hour is less than 0.8, we may assume that, with high probability, the stratification is stable. Besides the possibility to apply this simple criterion in the meteorological practice, the investigation is of interest also for atmospheric electricity, because it yielded a sort of quantitative rule according to which the more or less chaotic sign reversals of the foreign field, occurring for instance especially during shower, actually are coupled with the degree of turbulence. This functional connection is independent of the orographic conditions and altitude of the station, thus it reflects facts of general importance.

As to the meteorological practice, the results could be used to find out, at a weather station which has no radio sonde and with the help of simple potential gradient recording, if the stratification conditions are changing in the course of a precipitation.

5. The behaviour of the foreign field during drifting snow.

Processes of snow and ice crystal friction, of charge separation by breaking of snow and ice crystals. etc., are of general interest for the explanation of thunderstorm electricity.

Since within our station net drifting snow is relatively frequent, which partly changes the electrical conditions in the neighbourhood of the stations considerably, a systematical evaluation of the records was carried out with respect to drifting snow.

The evaluation was based on the observation, that from the mountain ridges snow and ice crystals are whirled aloft many hundreds of metres. This causes particles of different sizes to be separated from each other by the wind. The large fragments soon fall back to the ground, to the neighbourhood of the place from where they hat been whirled up; the small fragments, according to circumstances, can wander along with the strong wind current many kilometres. In the evaluation, therefore, we had to consider above all the wind direction above the Wetterstein Mountains and the geographical situation of the stations. In Figure 57 a little map is added, which gives the main ridges of the Wetter-

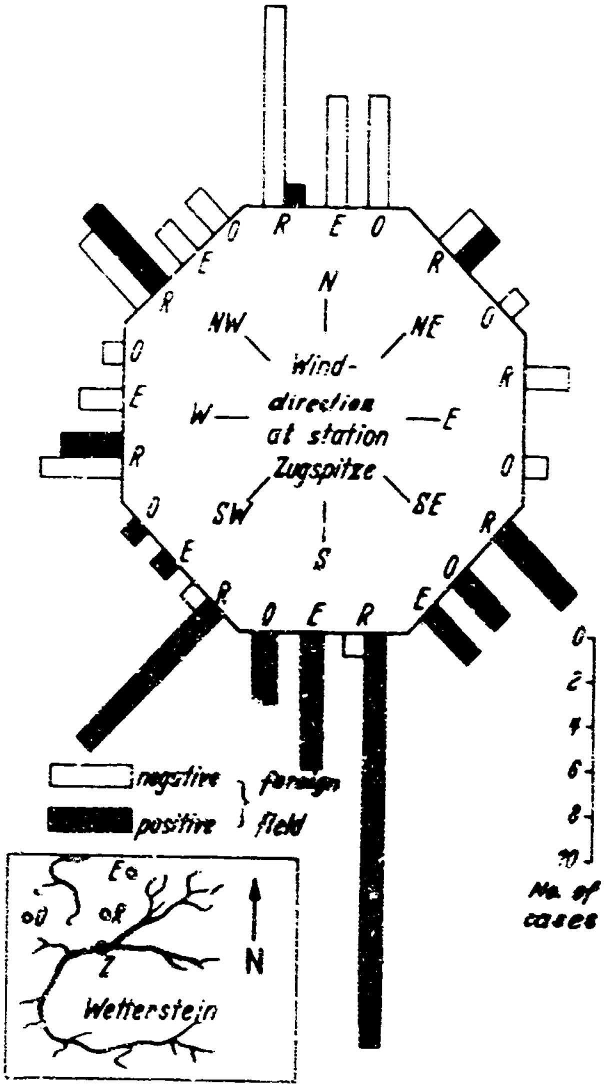

Figure 57
The behaviour of foreign field during
drifting snow whirled up from the
ridges of the Wetterstein
Mountains

stein Mountains, with station Zugspitze (Z). Especially from these ridges the snow is whirled up (compare Figure 1).

If the wind is coming from southern directions, the large fragments whirled up at the northern ridge shown in the small map of Figure 57 immediately fall back to the slope just north of this ridge, while actually clouds of the small fragments are carried away by the wind over stations Riffelriss (R), Eibsee (E), and sometimes also Obermoos (O).

If, on the other hand, the wind comes from northern directions, snow is whirled up near the stations, the large particles soon fall back in the neighbourhood of the place where they had been whirled up, and a certain separation of particles of different size takes place; but the small particles originating at E, O, or R cannot be carried over the wall formed by the ridge of the Zugspitze, and a seperation of the different kinds of those particles which are whirled up at station Z could only influence the atmospheric electric conditions at stations situated to the south of Z (which don't exist).

In Figure 57, all cases are included where

a) there was fine weather, and

b) drifting snow was observed at the mountain ridge, and

c) at one or more of the stations in question (E, or O, or R) the potential gradient had not the fine weather value.

The figure demonstrates that the foreign field at stations O, E, and R is positive during southern winds in nearly all cases, while during northern winds it mostly is negative. This means that the clouds of <u>tiny</u> particles flying over the stations predominantingly carry <u>positive</u> charges, and that, on the other hand, the <u>large</u> particles whirled up <u>near</u> the stations carry <u>negative</u> charges. The positive foreign fields caused by positive crystal clouds flying aloft with the south wind often could be observed even at stations Garmisch and Farchant, i.e. at a distance of at least 6.5 miles from the main ridge of the Wetterstein Mountains. Here the small crystals probably were already evaporated, leaving their positive charges on the nuclei of the air current. For record examples see section 7.

The result of this investigation, that, if ice crystals are broken, small splinters carry positive charges, and the larger residues negative charges, is in agreement with the laboratory experiments of <u>Kumm</u> (1951) and <u>Norinder and Siksna</u> (1955). It seems to be important for the theory of thunderstorms.

6. Sign of the potential gradient below and near thunderclouds

In Technical Report AF 61 (514)-732-C, we decuded from individual instances that below the base of thunderclouds the foreign field predominantly is negative, but that it is positive below a far extending Cirrus nothus. This statement is in agreement with the generally accepted view on the structure of thunderclouds.

Table 4, including all the thunderstorms of 3 years which occured at a high level station, gives an account of the behaviour of the foreign field as it was recorded at the respective station.

Table 4

Position of the station with regard to the cloud part	Type and number of cases (observed 1955 + 1956 + 1957)	
mountain station within or below the base of the Cumulonimbus	foreign field predominantly positive:	4
	foreign field predominantly negative:	31
mountain station below Cirrus nothus	foreign field predominantly positive:	27
	foreign field predominantly negative:	27
mountain station below Altocumulus cumulogenitus or mammatus	foreign field predominantly positive:	0
	foreign field predominantly negative:	16
mountain station within or below the base of the Cumulonimbus or below Cirrus nothus	chaotic course of foreign field:	44

We see, that in 44 cases the course of the foreign field was chaotic, so that it was impossible to discirminate the different parts of the thundercloud. Especially in heavy procipitation we often find a chaotic course of the foreign field in and below the thundercloud base and in the neighbourhood of the cloud. The records then are similar to those during showers.

In Figures 58 - 60 again individual cases are given. They demonstrate anew that predominantly a positive foreign field exists below Cirrus nothus, i.e. that this cloud part carries positive charges. From Figure 59, further, we learn that at the high level stations the negative sign of the foreign field is predominantly below the base of the thundercloud.

A statistical analysis of the cases obtained till now yielded the results condensed in Figures 61 and 62. The meaning of the columns is the same as described in section 4.2.2., only instead of precipitation periods we here have periods where the station is below the cloud part indicated at the top of the figure.

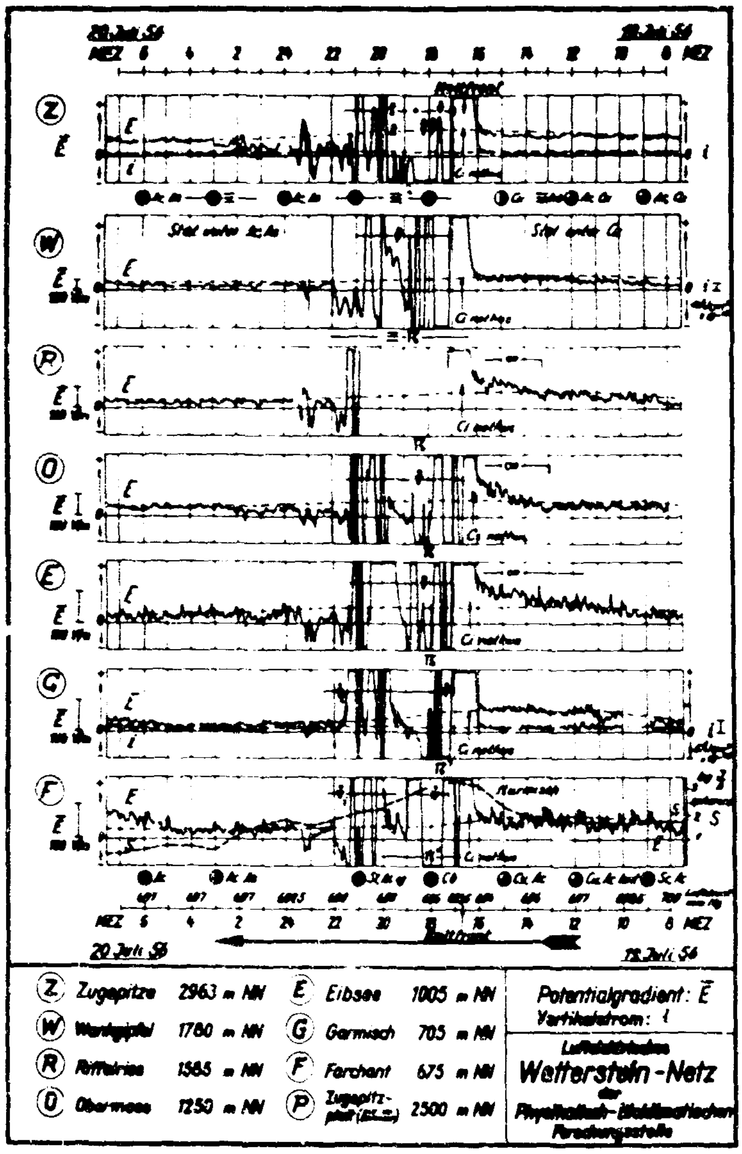

Figure 58

Positive foreign field below Cirrus nothus

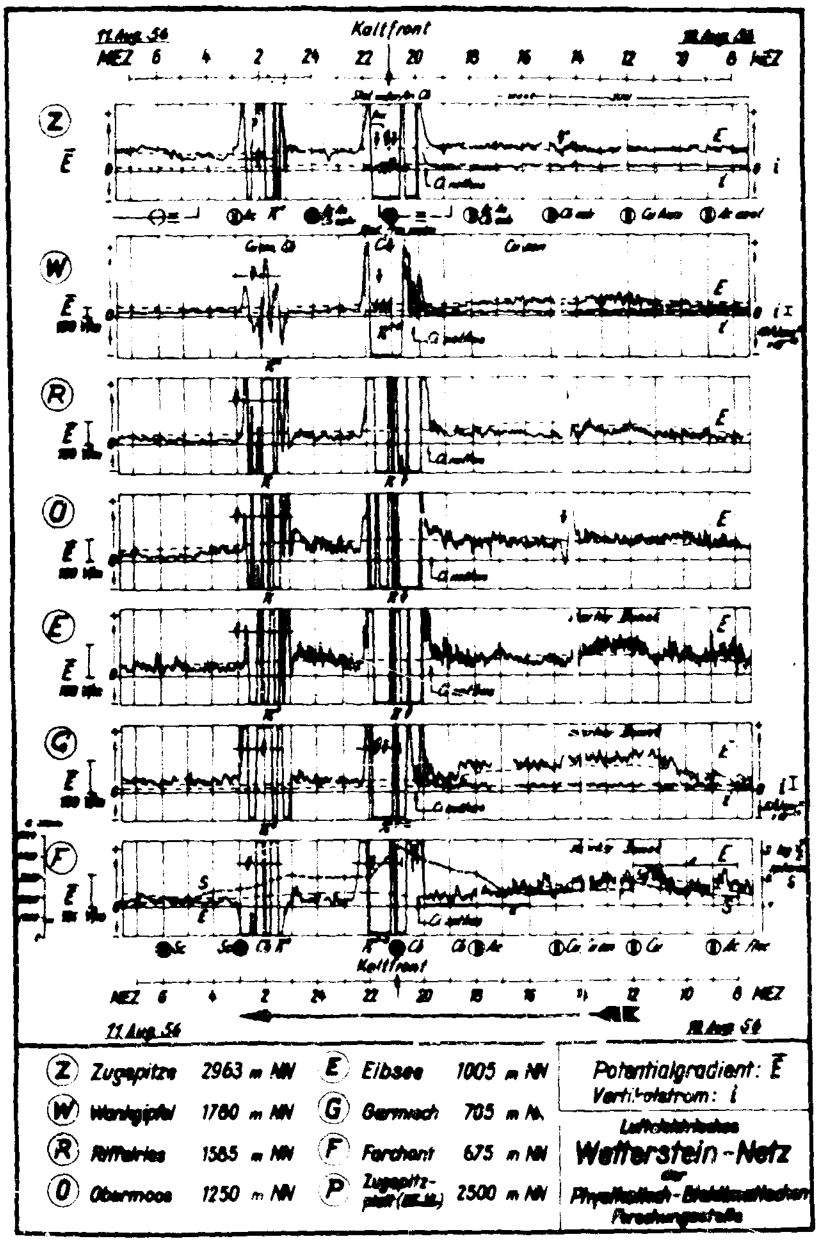

Figure 59

Positive foreign field below Cirrus nothus, and negative foreign field below Cumulonimbus base only at the peak stations Zugspitze and Wank

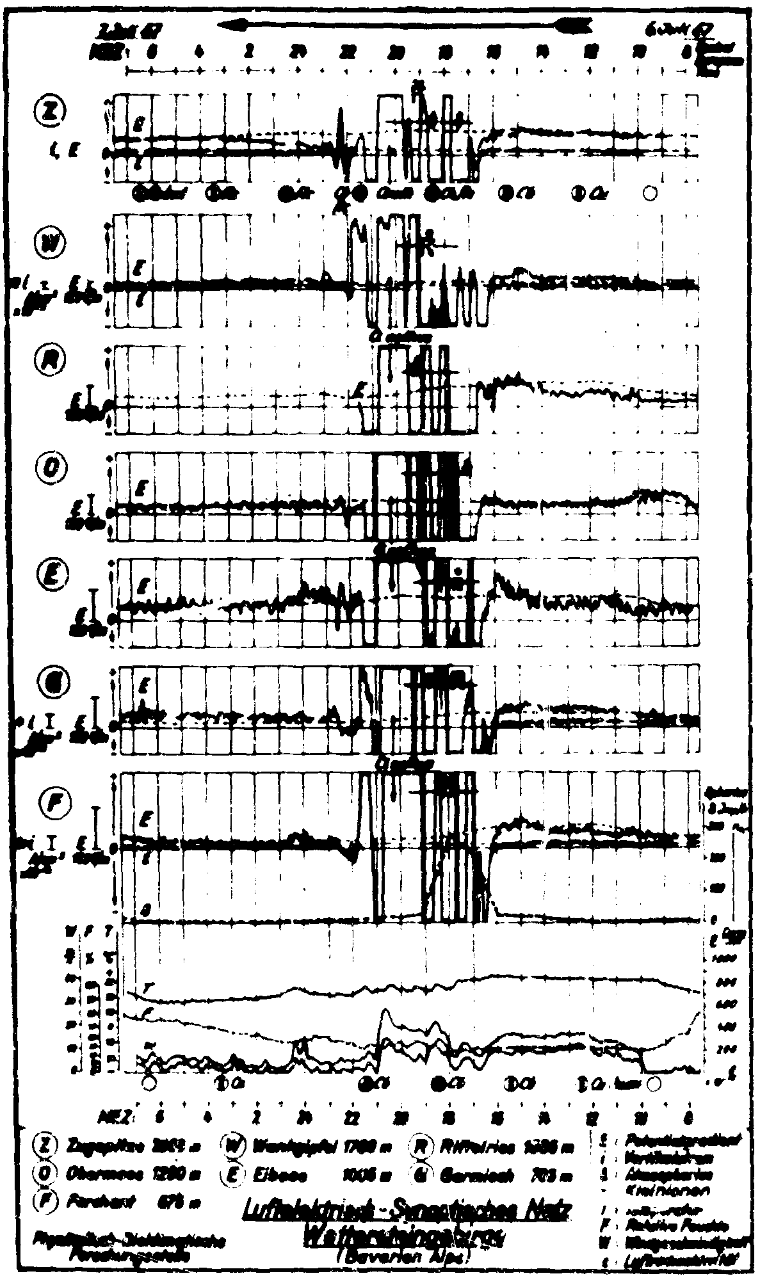

Figure 60

Positive foreign field below Cirrus nothus

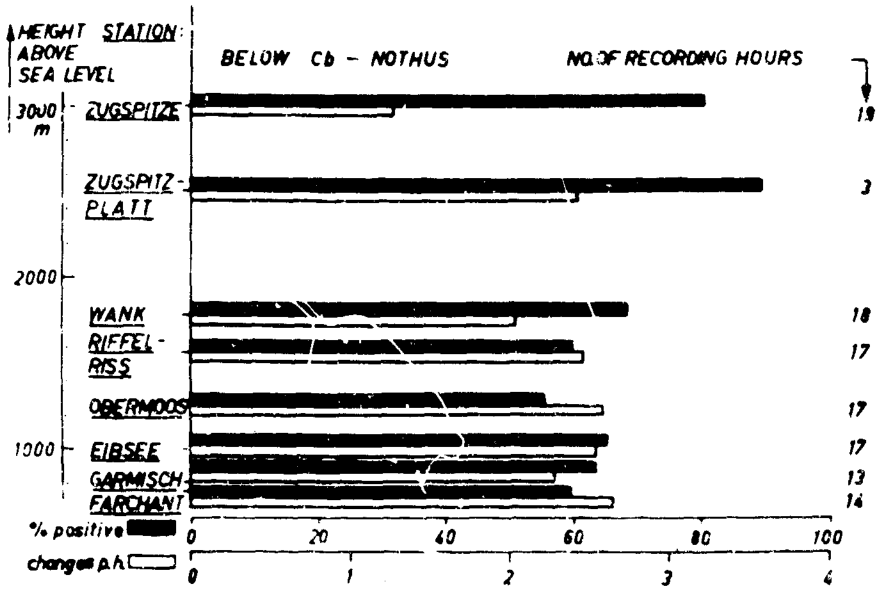

Figure 61
Foreign field and its sign reversals below Cirrus nothus

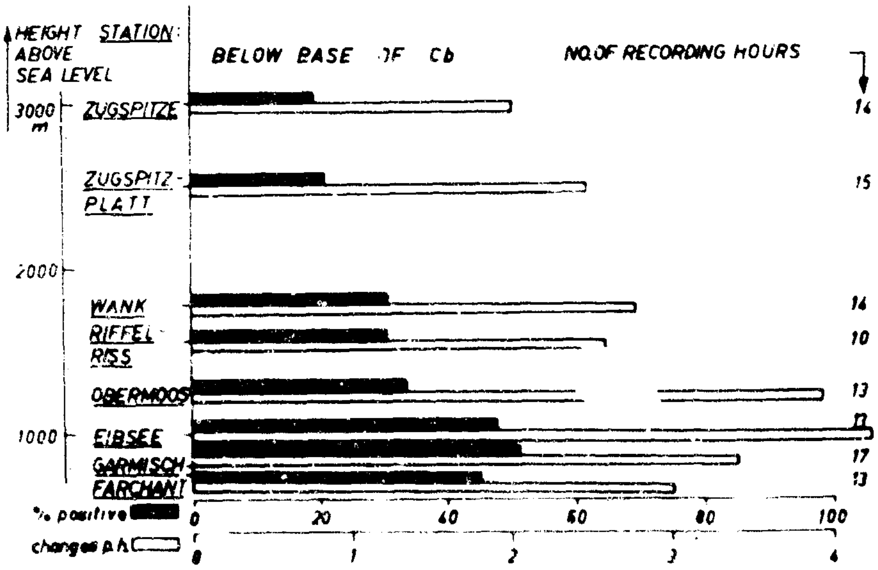

Figure 62
Foreign field and its sign reversals below Cumulonimbus base

At first let us look at the stations Zugspitze and Zugspitzplatt: below Cirrus nothus the foreign field is positive during about 80 - 90 % of the time, below the Cumulonimbus base it is positive during only 20% of the time. If we look at the other stations, the value is about 60 % below Cirrus nothus, and about 30 - 50 % below the Cumulonimbus base, the decrease and increase with height between the valley and 3000 m above sealevel the records are influenced in such a manner that, at the low level stations, it is no longer possible to draw reliably an inference from the record as to the actual cloud charge. Therefore records, wich one obtaines only at low levels, cannot yield any satisfactory results with respect to the investigation of the thundercloud structure. Further we learn from Figure 62 that the frequency of the sign reversals of the foreign field below a Cumulonimbus base is much greater at lower levels than at higher levels. From this we have again to infer that the low level records don't enable us to ascertain the temporal and, what is the consequence, the spatial charge conditions in the cloud. Thus electrical processes are occurring at the lower levels, which mask the true picture of the conditions in the Cumulonimbus cloud. Probably the processes in question are connected on the one hand with the precipitation, and on the other hand with space charges near the ground, which are caused by point discharge.

Summary and conclusions for sections 4, 5, and 6

During shower precipitation usually chaotic courses are recorded for the potential gradient and the conduction current, which practically runs parallel and always has the same sign as the simultaneous potential gradient. The character of the curves, which are obtained simultaneously during the same shower, only seldom is the same from station to station. The processes, therefore, by which the details of the curves are determined, must greatly differ from station to station and be of local importance only. Only seldom it is possible to draw conclusions from records obtained during shower as to the electric charge in the clouds.

However, during very light showers and especially under shower clouds passing over the stations without precipitation relatively often the character of the curves is the same at the different stations, i.e. at different altitudes. Hence we can conclude that it is the precipitation which during heavy shower so much disturbs the picture on the records.

At high level stations, always a slight foreign field of negative sign is observed at first, when the station is below a growing Cumulus congestus, and that before any precipitation is falling at the station itself. The latter fact suggests that this foreign field is caused by the negative space charge at the cloud base, which is being accumulated there in some way or other, while the cloud is becoming "mature". In this connection one remembers the ideas of Vonnegut (1953), who found that the electric fields in Cumulus clouds are built up already before any precipitation is formed. Vonnegut presumes that the point discharge on the earth's surface might be the source of the charges needed, forming ions which are brought into the respective cloud "floors" by downdrafts or updrafts. Comparing our records with this picture we find the following difficulties: the positive fine weather potential gradient existing at first is lowered below growing Cumulus congestus clouds by the negative charges accumulating at the cloud base. So point discharge more and more stops (until precipitation sets in), instead of supplying the cloud with more and more ions. Perhaps by increased observations it will be possible to explain this contradiction.

By the analysis of individual cases as well as by the statistical evaluation of the records carried out with respect to the behaviour of the potential gradient during shower it is demonstrated that no significant changes of the curve character are caused by changes of the physical state of the precipitation. During shower precipitation the frequency of the sign reversals of the foreign field is relatively great, it is the greater, the higher is the atmospheric unstability (e.g. during passage of active cold fronts).

In precipitation (showery and non-showery) out of upslide clouds, i.e. Altostratus wich is growing thicker, with the cloud base subsiding, and which then is developing into Nimbostratus, negative foreign field is recorded at all the stations below the cloud or in its base. This is independent of the physical state of the precipitation. It is likely that, because of the special conditions during precipitation out of clouds with small thickness, together with the cloud droplets many negative charges freeze upon the precipitation particles, since it is certain that, at the Altostratus base, there is high negative space charge and thus the cloud droplets carry many negative charges.

During non-showery precipitation (not coming out of Altostratus) there is a connection, almost like a law, between the sign of the foreign field and the physical state of the precipitation: the foreign field is negative in rain during more than 90 % of the precipitation duration, and it is positive in snow again during more than 90 % of the precipitation duration. The sign reversal of the foreign field exactly takes place in the zone where the precipitation is melting, and that independently of whether the transition from rain into snow or vice versa is only a spatial one or a temporal one, too, and at what altitude above the sealevel it takes place. The melting process thus must be coupled with that process which determines the sign of the foreign field during precipitation. Therefore it is important to give more attention to the melting zone.

The frequency of the sign reversals of the foreign field is very small during non-showery precipitation. It is less than one reversal per hour, and only in the melting zone, as is consequent, it is slightly higher.

During non-showery precipitation, and here relatively seldom, rhythmical, regularly alternating sign reversals of the foreign field are observed, which are not connected with changes of the physical state of the precipitation. Two groups of cases are found: the parallel and practically synchronous reversals occur a) at nearly <u>all</u> the stations, or b) only at the valley stations. The reversals are likely to be caused in group a) by fundamental cloud processes, and in group b) rather by local processes. With respect to group a), we may presume that a sign reversal of the precipitation charge taking place simultaneously at all levels is improbable; if, on the other hand, the sign reversals of the precipitation charge took place only once, at higher levels, the same reversal would be observed somewhat later at the lower stations, expecially in snow, which comes down slowly; but no such lag of the sign reversals could be observed from station to station. Thus, with regard to this problem, it is necessary to continue the observations.

It was observed that there is a clear influence of size and type of the snow crystals on the strength of the foreign field, both observed at the Zugspitze: the presence of such crystals as fall slowly more than others because of their size and shape is coupled with a higher foreign field. Further, during non-showery snow fall, the strength of the positive foreign field decreases with the altitude of the station. Since, the lower is the level, the more a formation of flakes takes place, that is a retardation of the fall, we consider that, possibly, the <u>falling velocity</u> of the precipitation particles is of some importance as to the strength of the foreign field. This would be confirmed by both aforementioned observations.

From this viewpoint, the sign reversal connected with the melting process of non-showery snow perhaps could be explained by the increase of the falling velocity also connected with the melting process. Theoretical studies on this subject being carried out just now, these problems will be discussed later on.

The connection between atmospheric unstability and frequency of the sign reversals of the foreign field during precipitation was examined carefully. The result of the examination is, that there is a functional connection between both magnitudes, so that the lability degree of the 500 - 700 mb level, which is of special meteorological importance with respect to the building up of Cumulus clouds, is indicated by and can be deduced from the sign reversal frequency. Besides, this functional connection is independent of the altitude and orographic situation of the station, where it is found.

The knowledge of this connection could also be of practical importance since it enables us to say, with the help of only primitive potential gradient recordings, but with satisfactory reliability, if the character of the atmospheric stratification is changing in the course of a precipitation. For instance, when after hours of rain with the foreign field being continuously negative, ferst sign reversals of the foreign field are recorded, then we know that the stratification became unstable or is just becoming unstable. This again means transition to squally weather with single showers and perhaps short clearing up periods. The possibility of such conclusions could be valuable, if one is interested in controlling the atmospheric lability degree also during the period between two radio-sonde ascents, e.g. on airports, where even slight changes in the weather situation are of importance. Also at places where radiosonde ascents are wanting, e.g. in countries with sparse population and at sea, the proposed supplementary potential gradient recordings could be of interest. With respect to ships, valuable improvements of the knowledge of the meteorological situation could be obtained by recording the potential gradient on board, since often the meteorological conditions above the oceans are not sufficiently known, or unexpected changes occur by spatial shifting of a perturbation or by the movement of the ship or by both. In this connection we wish to mention also the starting and landing operations on air-craft carriers.

Careful observations made during drifting snow showed that, without doubt, on the breaking of snow and ice crystals the resultant large fragments predominantly have negative charges, whereas the small, light splinters carry positive charges. These observations have been made in the open air, i.e. under natural, not under laboratory conditions. So they are perhaps of special interest, above all with regard to the problems of the electrification of shower and thunderstorm clouds by ice friction and ice breaking, for by laboratory conditions the course of what happens can be influenced in a manner which is often difficult to be surveyed.

Investigations on the sign of the foreign field below and in the neighbourhood of thunderclouds demonstrated that the Cumulonimbus base preponderantly carries negative charge, while the far extending Cirrus nothus carries positive charge. This is in agreement with the present views on this subject. Besides, as appeared during our studies, such statements can be made only with the help of high level records; at low level stations, the picture presented by the records is masked by local perturbations, and does not show any significant changes on a change of the cloud part present above the station (first thunderstorm cloud base, then Cirrus nothus, or vice versa).

7. Observations made during Foehn

Some preliminary observations on the behaviour of atmospheric electric magnitudes during "foehn" have been mentioned already in Technical Report AF 61 (514)-732-C. The foehn, being only a special phenomenon, restricted to mountains and their neighbourhood, e.g. the Rocky Mountains ("Chinook") and the Alps[+]), often has considerable influence on the atmospheric electric magnitudes. Therefore, in the following, we are handling particulars of the processes connected with this wind.

As has been stated already in the last Technical Report (AF 61 (514)-732-C) we have observed that there are two different types of atmospheric electric phenomena occurring during foehn:

a) At all stations, the curves of the potential gradient show values which are considerably lower than the fine weather values, and that also when the sky is nearly or completely cloudless. At the same time, the air earth current values are the same as in normal fine weather or slightly higher. In such cases we speak of "foshn type I".

b) During foehn of type II, the potential gradient is considerably higher than in normal fine weather and strongly disturbed and that at all stations exept the peak stations, where the described potential gradient behaviour is recorded only seldom.

In section 7.1. recording examples are given, for both types, together with some explanations based on our present experience on foehn phenomena.

7.1. The behaviour of atmospheric electric magnitudes at different altitudes during foehn

In Figure 63, a typical example of foehn type I is demonstrated. The potential gradient, especially in the valley, has a tendency to be lower

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[+]) Within the northern Alps, where is our station network, and in the adjoining plain, foehn is especially well pronounced and relatively frequent. It is here a dry and warm south wind: dry because of moist-adiabatic upslide motion in the southern Alps causing loss of water, warm because of dry-adiabatic downslide motion from the highest ridges of the Alps to the lower northern Alps and their valleys and to the northern plain.

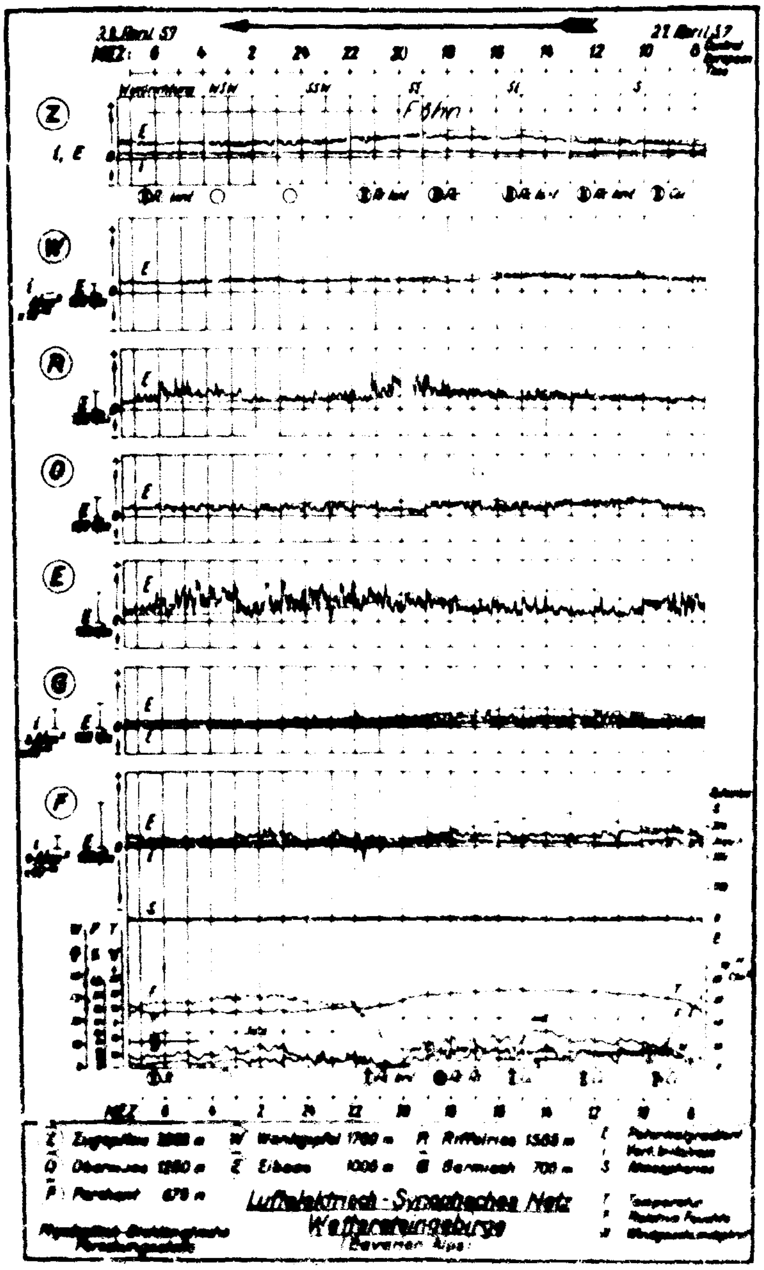

Figure [illegible]

Föhn - type I

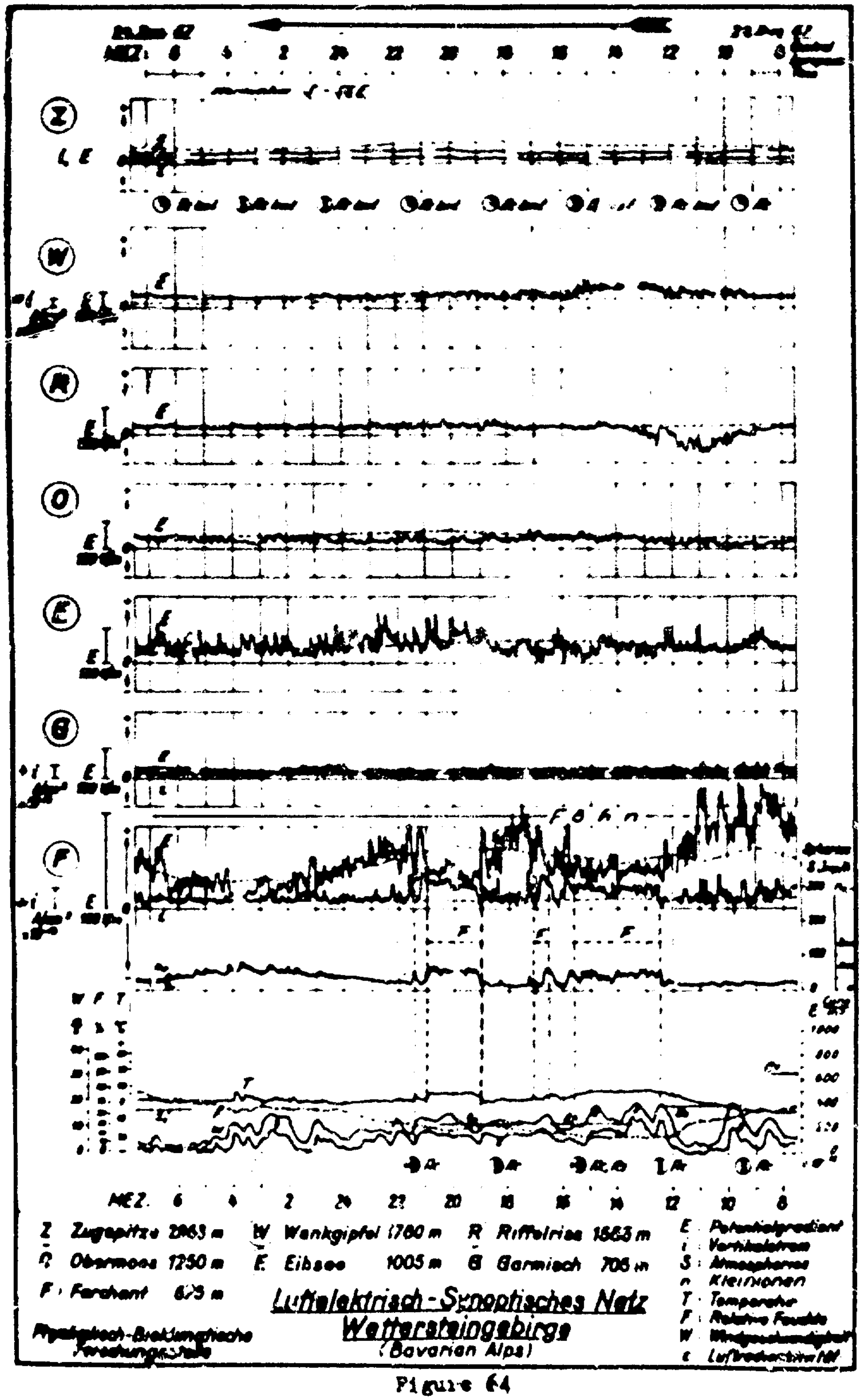

Figure 64

Foehn - type I

than the fine weather value. Southern winds are observed at high and low levels. In Figure 64 we have a good example for the effects of single foehn invasions (type I) into the valley. In each case of especially strong foehn invasion ("F" in the figure) the potential gradient is considerably lowered at station Farchant, whereas the air earth current is increased. Also at most of the other stations, especially at station Zugspitze, the foehn influence is very clear. Also the concentration of small ions responds sensitively to the foehn invasion, rising rapidly and thus showing a course similar to that of the temperature. Without doubt, this decrease of the potential gradient is caused by a strong increase of the number of small ions, in other words: of the atmospheric electric conductivity.

In section 7.2., we shall give more details on the reasons of the increase of the number of small ions, that is to say increase in conductivity observed in our region during southern wind directions over the Alps.

In Figures 65 and 66 we see typical examples of foehn type II. It is characteristic of foehn type II, that usually drifting snow is observed at the ridge of the Wetterstein Mountains at the same time. In section 5, we have already pointed to the fact, that during drifting snow in southern winds, positive foreign fields are observed at the stations situated north of the Wetterstein ridge. which are causes by the positive snow crystal clouds carried by the air currents above the stations. Now, the examples in Figures 65 and 66 demonstrate:

a) Negative foreign fields at station Zugspitze; they are caused by snow drifting to the station directly from the ground.

b) Strongly disturbed positive foreign fields, not connected with cloud or precipitation effects, at stations Wank, Riffelriss, Eibsee, Garmisch, and Farchant; they are caused by the separated small positive particles flying over these stations. During foehn type II, where the potential gradient is strongly increased, mostly the air earth current is increased, too; this is a sign of positive space charges above the stations. Unlike during foehn type I, there are no significant variations of the number of small ions near the ground, recorded at station Farchant.

In table 5 the frequency of both foehn types is given for the single months of the year. Type II, logically, doesn't occur during the summer months.

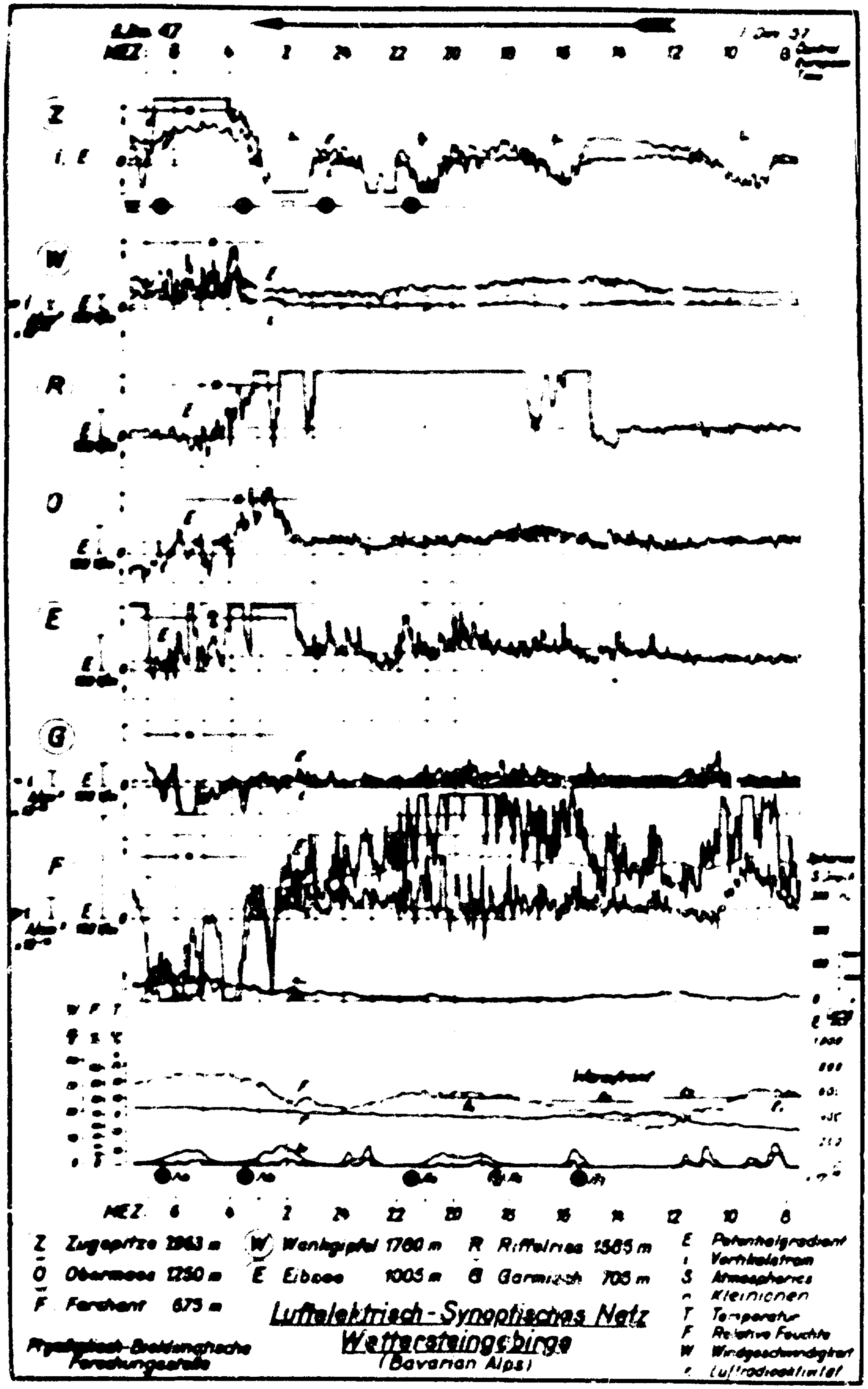

Figure 65

Foehn - type II

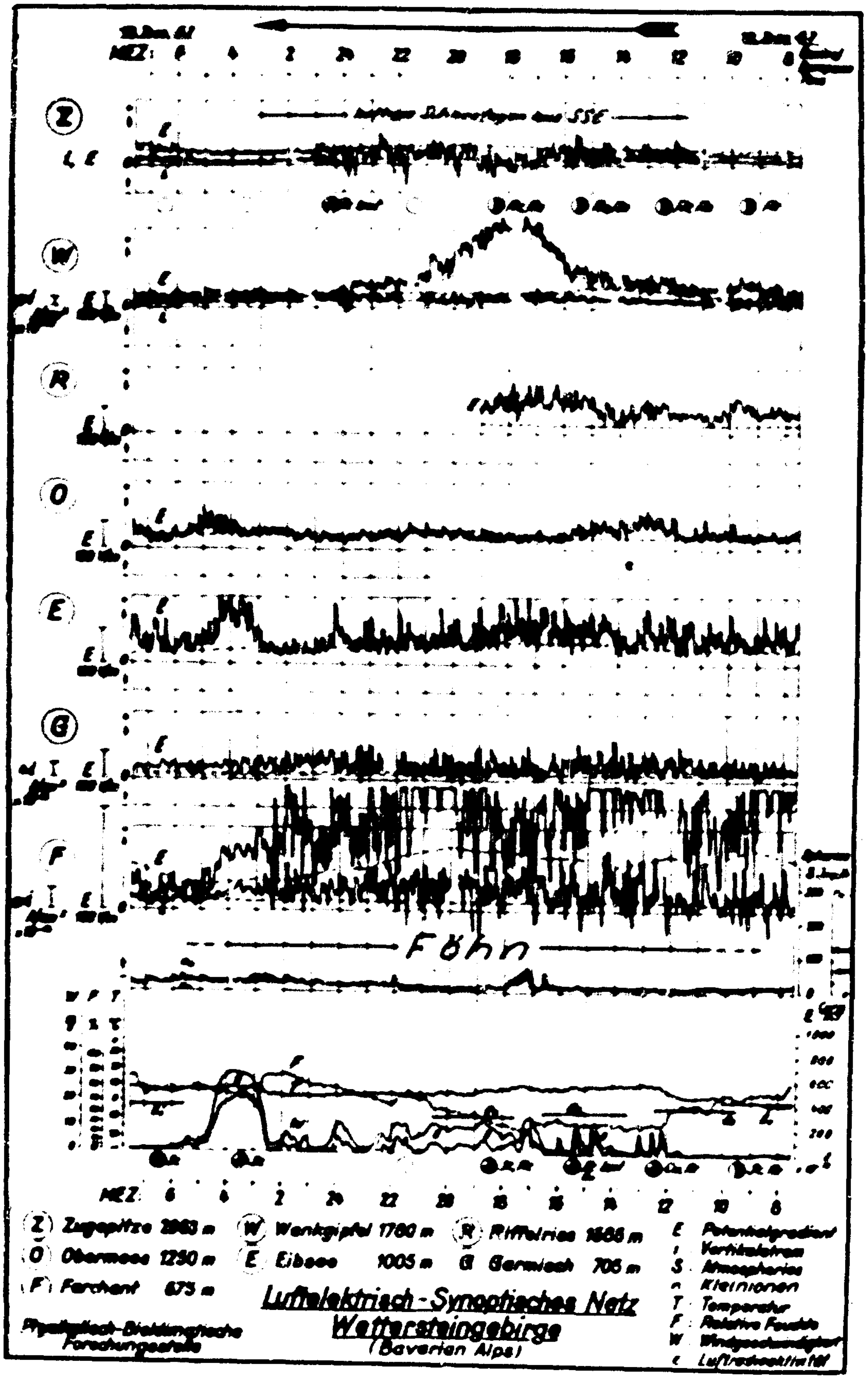

Figure 66

Foehn type II

Table 5

Foehn type	Total number of cases	Number of cases per month (1955 + 1956 + 1957)											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	28	2	1	3	2	2	1	3	1	4	3	5	1
II	33	9	4	2	1	1	0	0	0	0	2	4	10

7.2. Variations of the natural radioactivity in the air during southern winds over the Alps

During our second excursion to the Zugspitzplatt (1955), upon which we reported in Technical Report AF 61 (514)-732-C, it was found that the natural radioactivity in the air rises considerably at 2600 m above sealevel, if there are southern winds at the Zugspitze-Peak. We were able to show that this dependence on the wind direction has a geological reason (compare Figures 108 a and 108 b in Technical Report AF 61 (514)-732-C). Unlike the northern and southern Alps, the Central Alps, situated south of our station network, consist of rocks with relatively high uranium and thorium contents (acid igneous rocks).

Measurements of the natural radioactivity of the air carried through at Farchant in connection with another project have shown that there is a relation also between natural radioactivity of the air in the valley and wind direction aloft over the Alps. In Figure 67 we see, as a function of the direction of the wind over the Alps (which is not necessarily the same as in the valley!), the concentration[+]) of radon and its disintegration products in the valley air. In Figure 68, the same is shown for thoron and disintegration products. It is clear from the figures that the radioactivity af the valley air, especially that due to radon and disintegration products, is strongly increased in each season of the year, when there is southern wind over the Alps. Now, since the foehn traverses the Alps from south to north, these phenomena of increased radioactivity occur also during foehn. Thus, the increase of the number of small ions, i.e. of the conductivity, at high and low levels during foehn is caused by an increase of natural radioactive substances (see Figures 63 and 64).

The relations between wind direction over the Alps, natural radioactivity of the air, and behaviour of atmospheric electric elements shall be dealt with again in sections 10 and 11.

[+]) we made only relative measurements

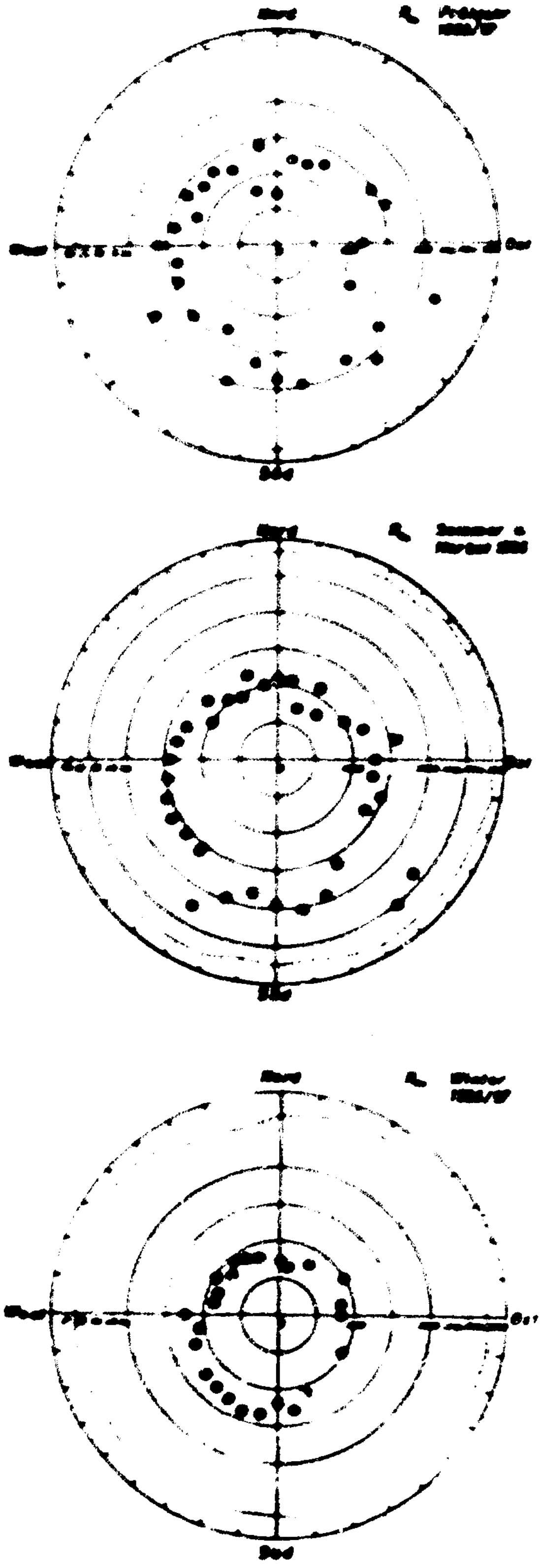

Figure 67 (Radon)

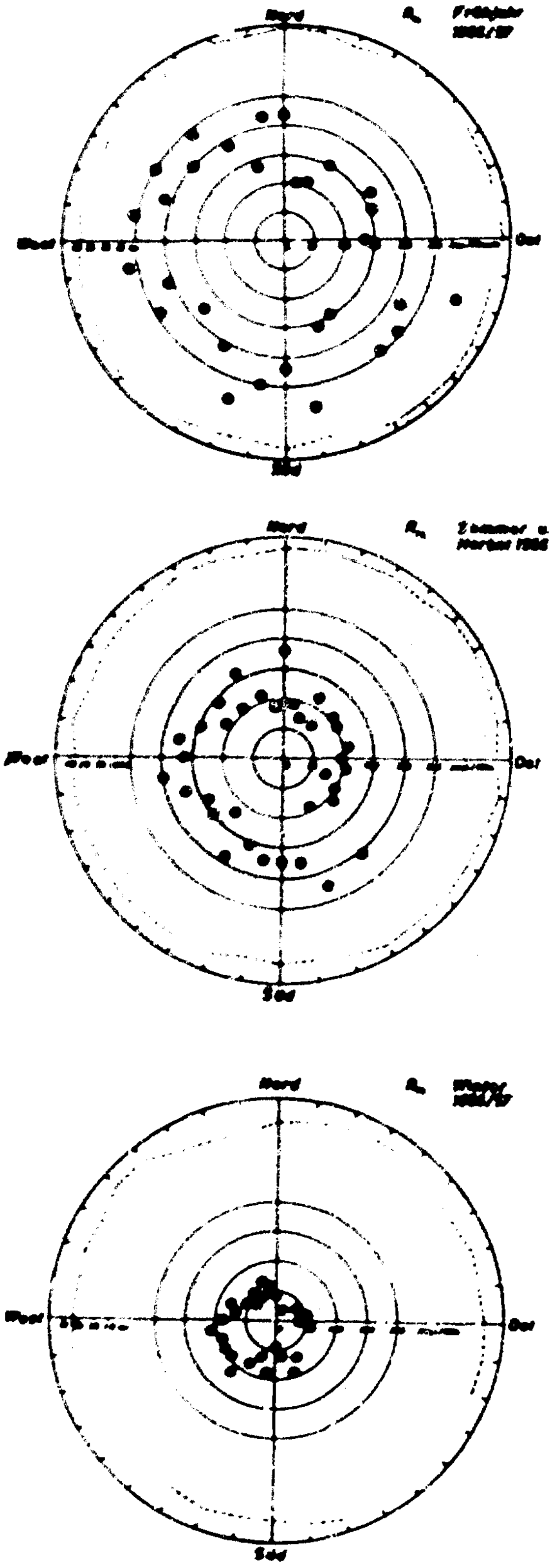

Figure 68 (Thoron)

Natural radioactivity of the valley air v. wind direction over the central Alps

8. Behaviour of atmospheric electric magnitudes at station Zugspitze, observed when this station enters into or comes out of fog.

Section 8 only deals with such cases where the cloud tops don't carry any significant space charges. Technical Report AF 61 (514)-732-C has concerned also the behaviour of the atmospheric electric magnitudes at station Zugspitze observed during inversion passages, in the presence of fog, when fog is on the point of enveloping the peak of the Zugspitze with the station, or this is just coming out of fog, etc. In the meantime, on an examination of all the records obtained till now, it appeared that now a definitive judgement is possible on the atmospheric electric phenomena occuring when station Zugspitze enters into or comes out of fog. This entering or coming out occurs especially, when

a) during upward or downward passages of inversions which are connected with fog, the cloud top, being situated in the inversion layer and being more or less sharp, is moving through the station level; see section 8.1.; or

b) station Zugspitze gets into the base of Altostratus or comes out of it; see 8.2.

With respect to those inversion passages which are not connected with fog effects at station Zugspitze, experience is not large enough till now, to make possible a definite judgement.

Before giving typical examples in section 8.1. and 8.2., we wish to present Figures 69 and 70, which clearly demonstrate that our recording equipment for potential gradient and air earth current is unaffected by wind effects, at station Zugspitze (were the records have been obtained) as well as at the other station, where exactly equal instruments and installations are operated. The curves of both figures were recorded during fair, cloudless weather. It is obvious that the curves E and i are smooth and not at all influenced by rapid variations of wind direction or wind velocity or by gusts. Therefore, it is not possible to explain the fog effects to be dealt with below by direct influence of variations of wind direction or velocity.

8.1. Individual examples of the phenomena occurring when station Zugspitze is at the top of cloud sheets in an inversion layer

The first group of examples, illustrated by three Figures (71 - 73), shows the behaviour of potential gradient E, air earth current i, relative humidity F, temperature T, wind direction, and wind velocity, recorded while station Zugspitze comes out of fog in the course of a downward inversion. Compared with the fine weather values, the potential gradient values are increased within the fog, while the average air earth current values are decreased; but both magni-

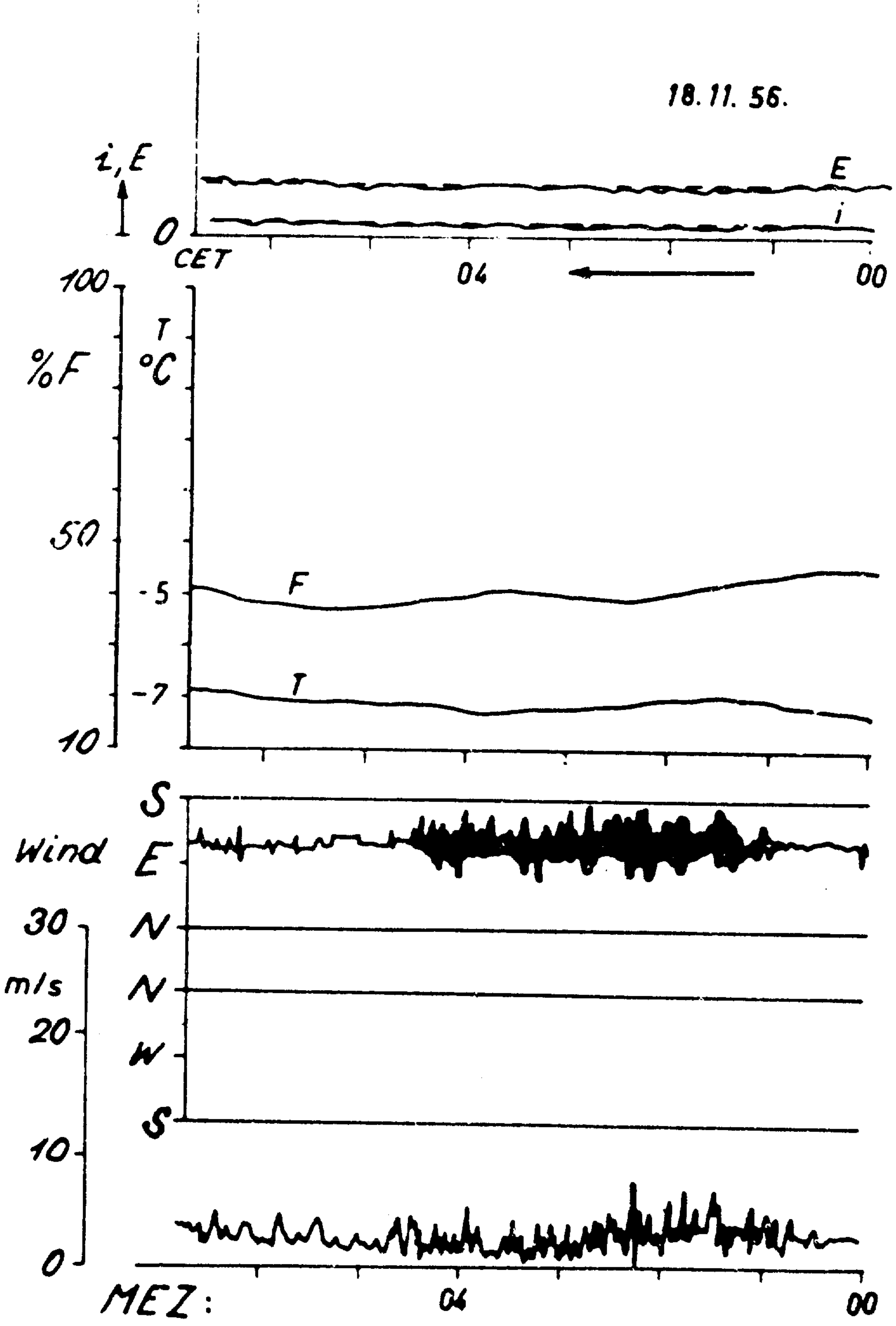

Figure 69
potential gradient and air earth
current are unaffected by pure
wind effects

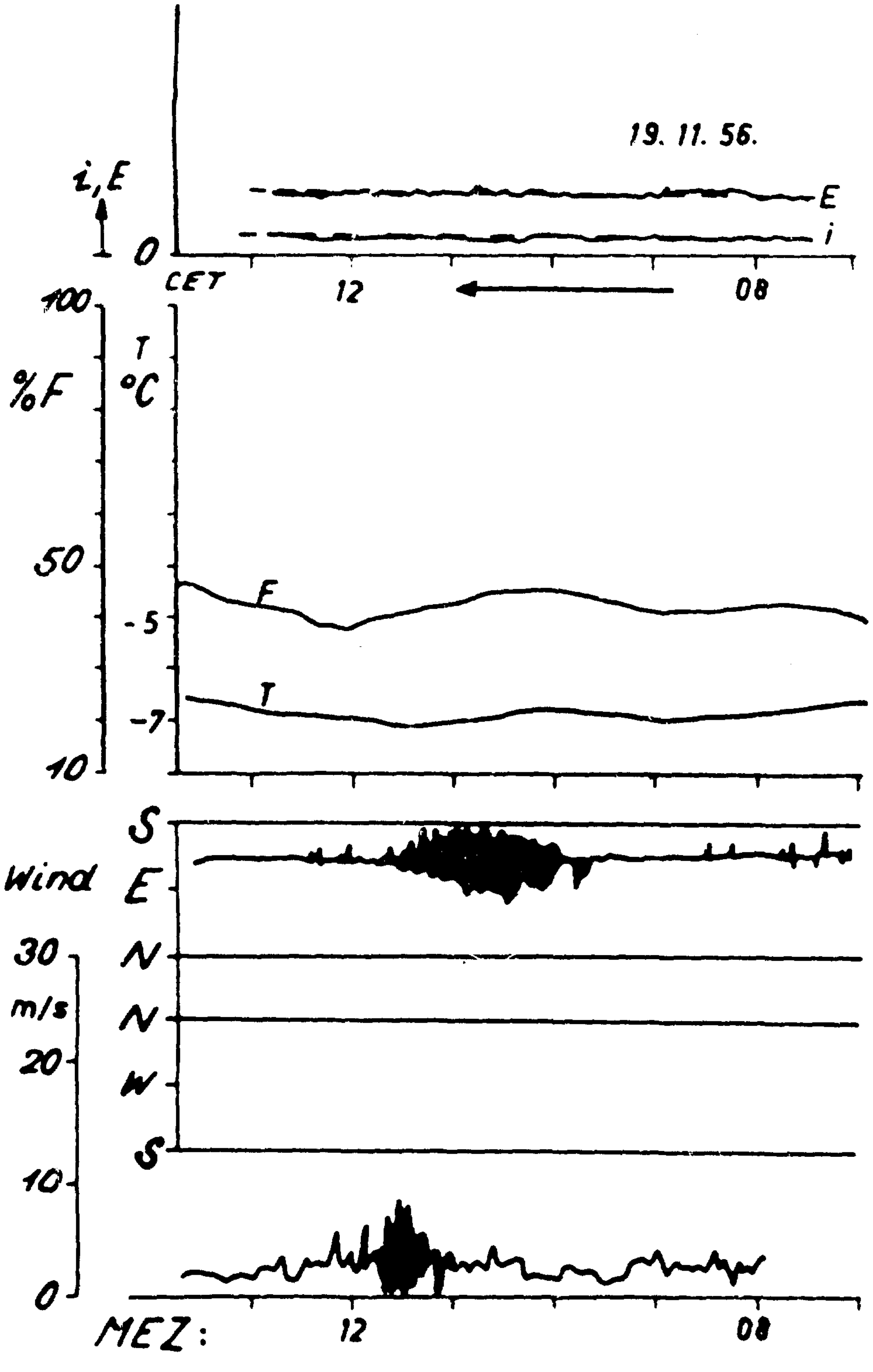

Figure 70

potential gradient and air earth current are unaffected by pure wind effects

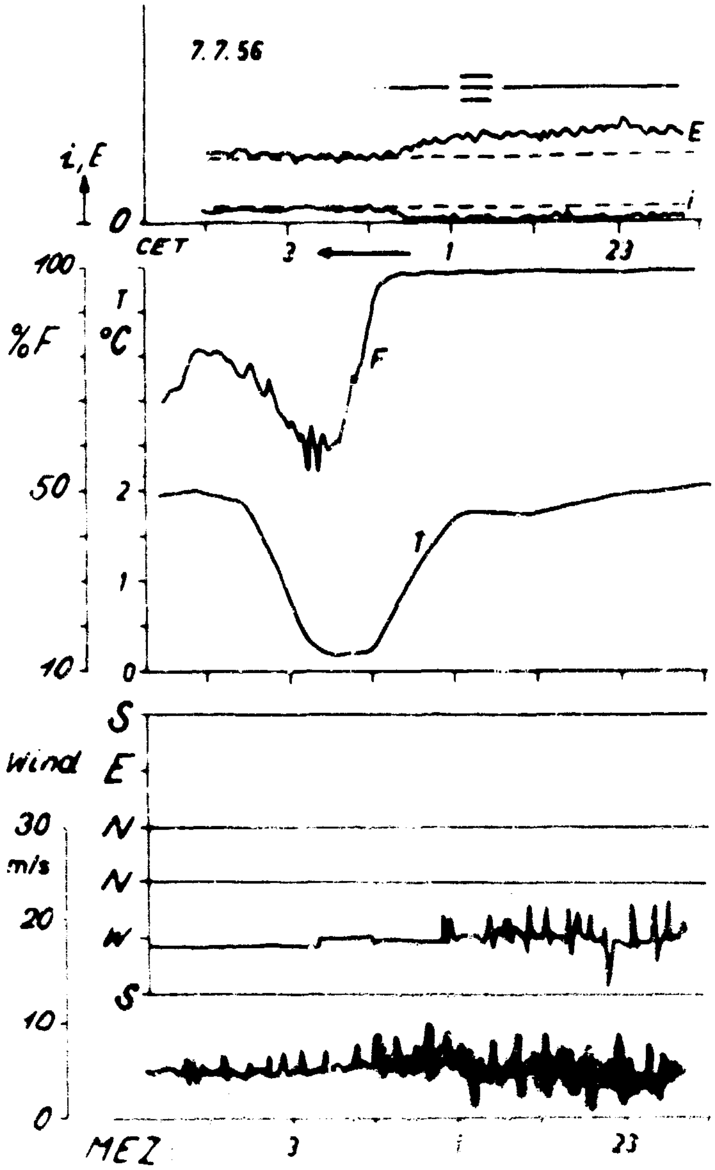

Figure [illegible]

Station [illegible]

Fog

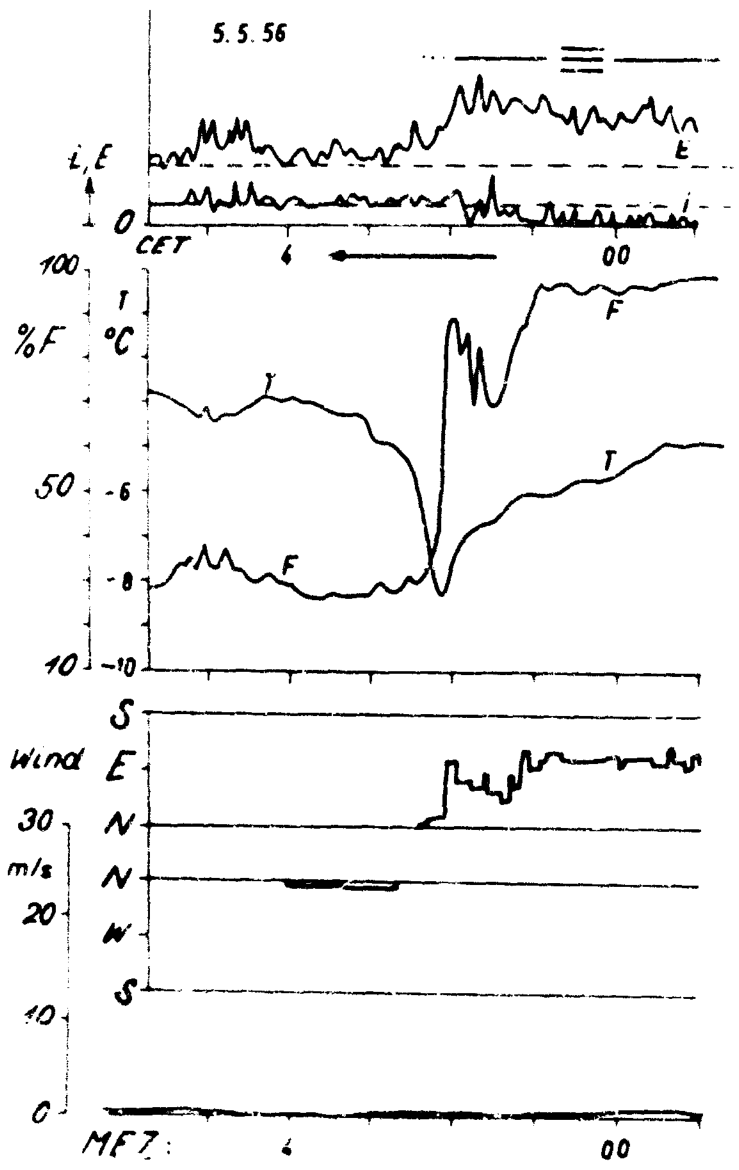

Figure 17

Station Zugspitze comes out of fog

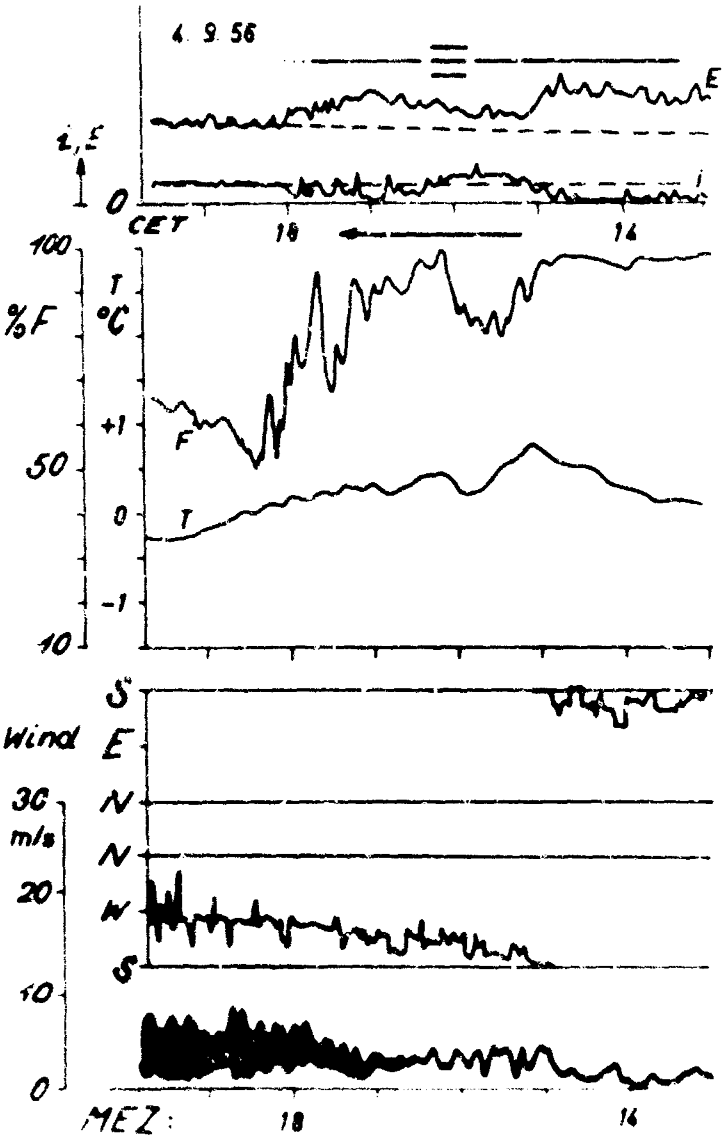

Figure 73

Station Zugspitze comes out of

fog

tudes conform to the fine weather curves, when station Zugspitze comes out of the fog. Relative humidity F and temperature T behave in a manner which is typical of passages of inversion-fog tops at peak stations. While coming out of the fog, the station usually records a change of the wind direction. Wind velocity and gustiness can decrease (Figure 71) or increase (Figure 73) in the course of the passage. However, these wind conditions have no connection with the behaviour of the atmospheric electric magnitudes.

In Figures 74 and 75 examples are given for the situation which is found when station Zugspitze enters into the fog in the course of an upward motion of an inversion. Again the potential gradient ~~the potential gradient~~ is increased in fog, while the air earth current is lowered. In Figure 76, showing short interrupted periods of fog, the variations are obvious, which arose, when station Zugspitze came into or out of fog.

A total of 95 fog effects of the type described in 8.1. have been observed during three years (1955, 1956, and 1957).

8.2. Individual examples of the phenomena occurring when station Zugspitze is at the base of Altostratus.

A behaviour quite different from that described in 8.1. is found for the atmospheric electric elements at station Zugspitze in cases where this station enters into or comes out of the base of an Altostratus. Examples are demonstrated in Figures 77, 78, and 79. As long as station Zugspitze is enveloped in an Altostratus base and therefore whithin fog, air earth current and potential gradient are strongly lowered, sometimes even negative. In three years (1955, 1956 and 1957) 45 such cases were observed, the atmospheric electric magnitudes behaving without exeption as described. Thus, without doubt, high negative space charges exist at the base of Altostratus clouds. The result of a statistical evaluation of such cases is demonstrated already in Figure 49.

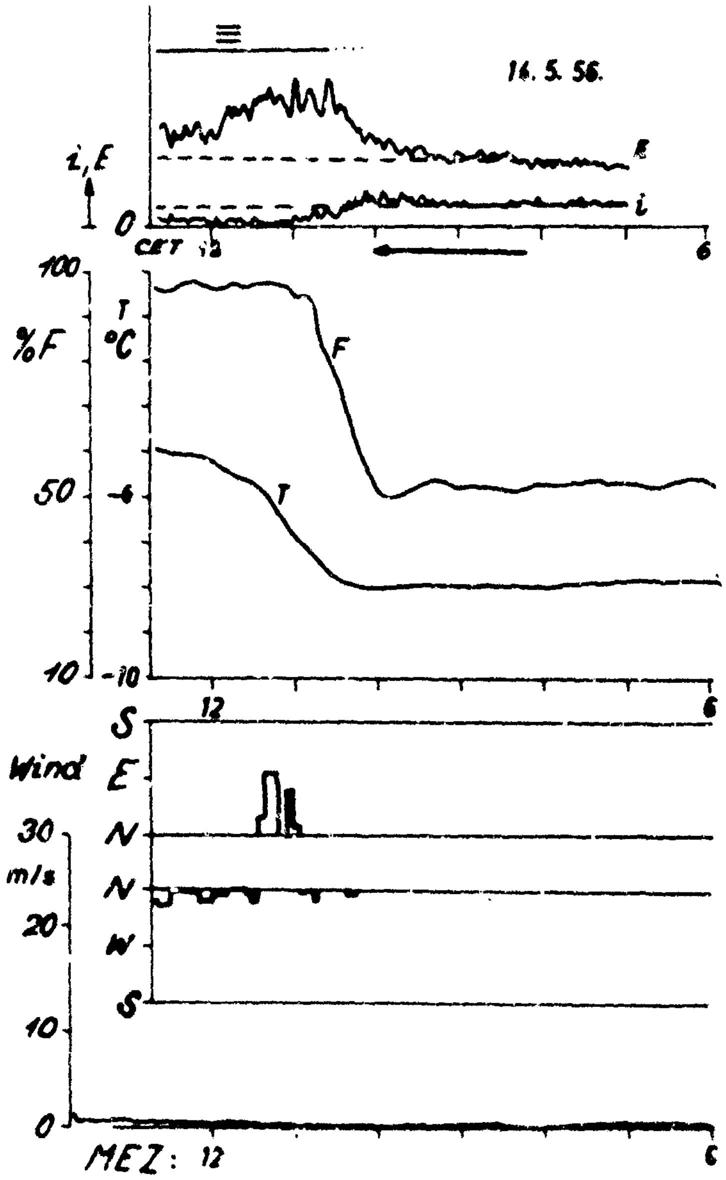

Figure 74

Station Zugspitze enters into

the fog

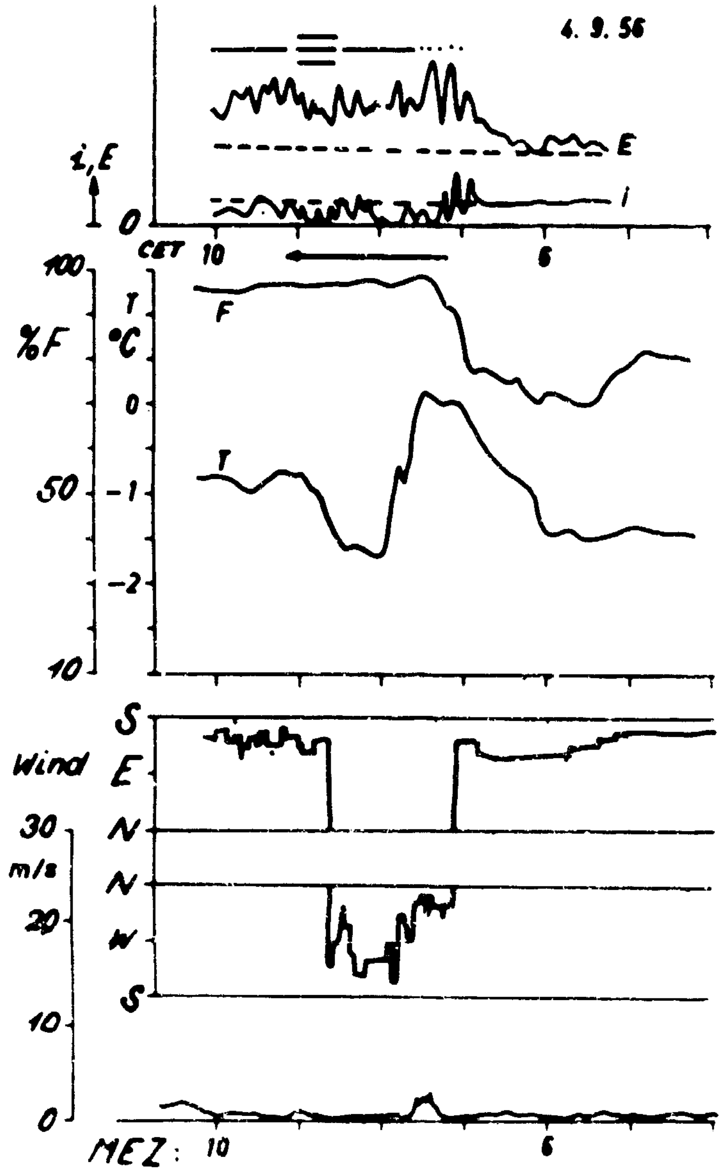

Figure 7[illegible]

Station Zugspitze enters into the fog

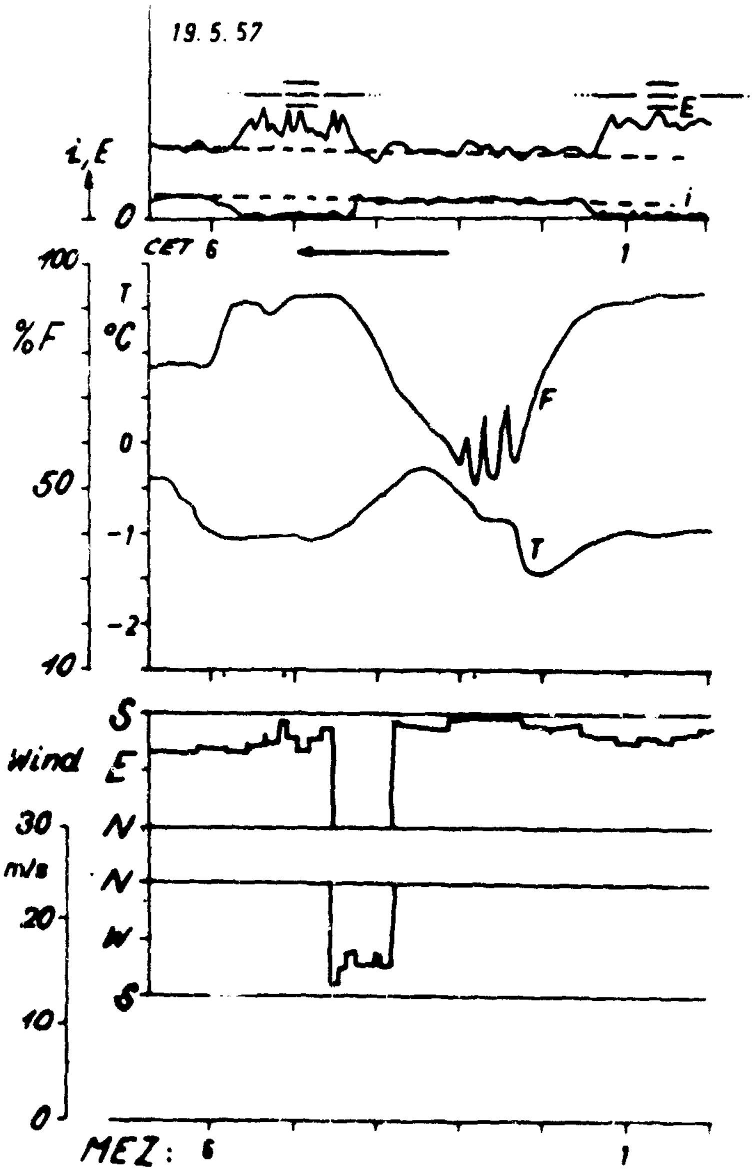

Figure 7b

Short interrupted periods of fog at station Zugspitze

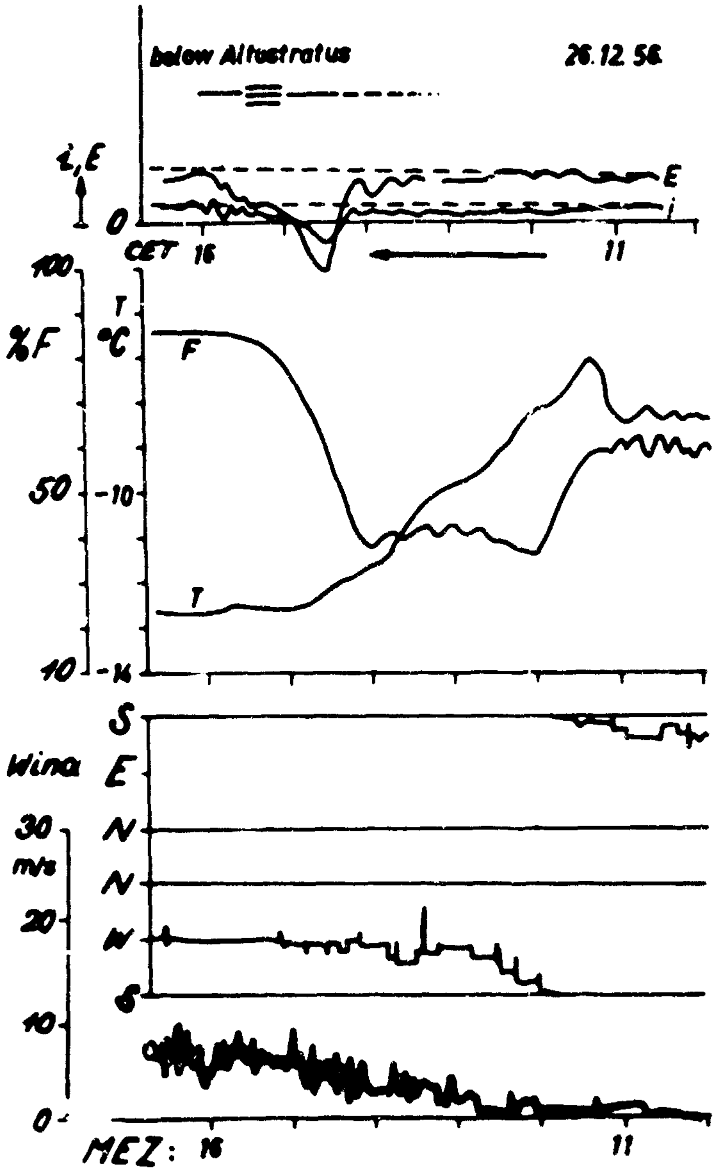

Figure 77

Station Zugspitze at the base of Altostratus (13-16.00 CET)

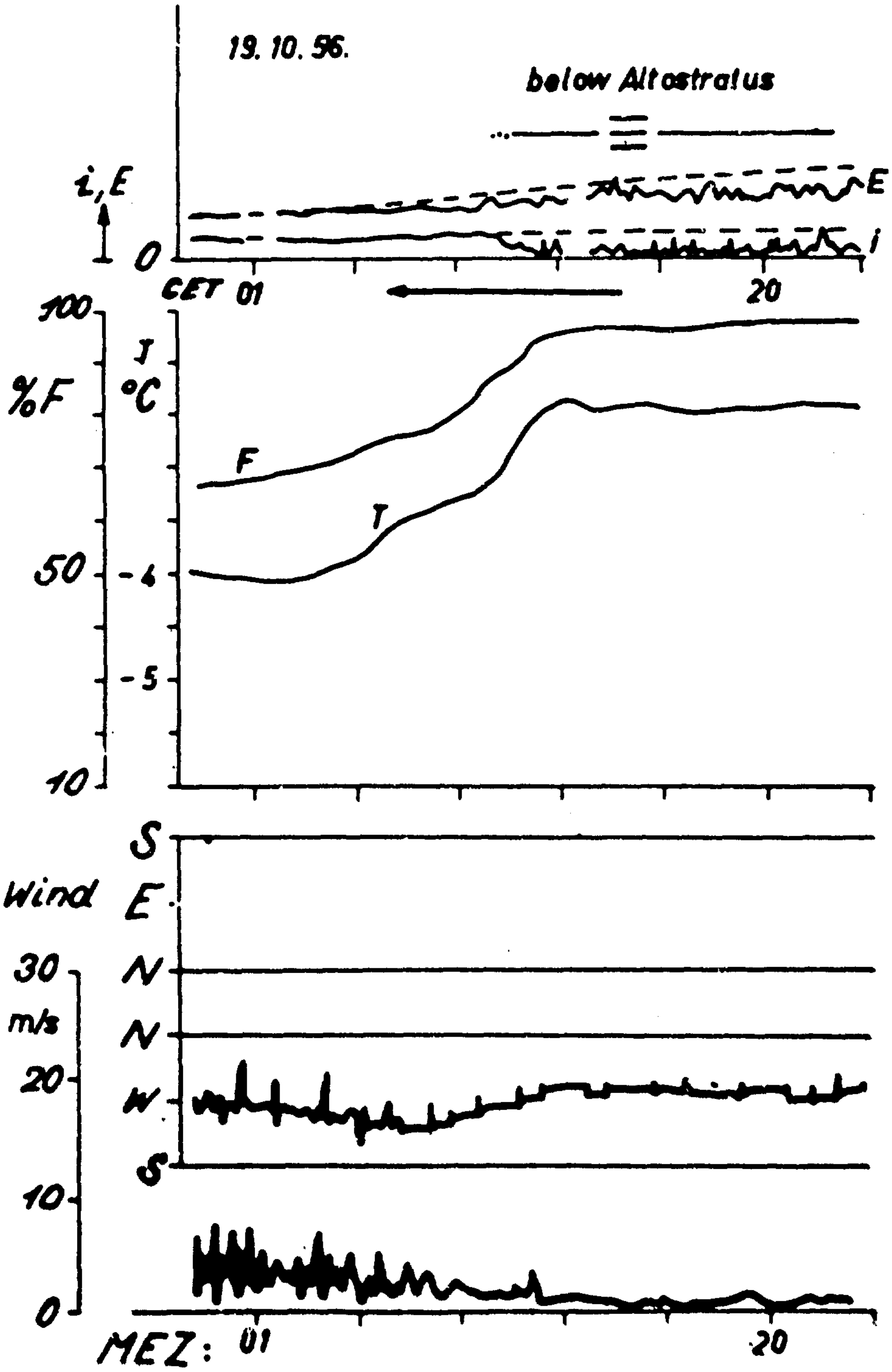

Figure 78
Station Zugspitze below Altostratus base

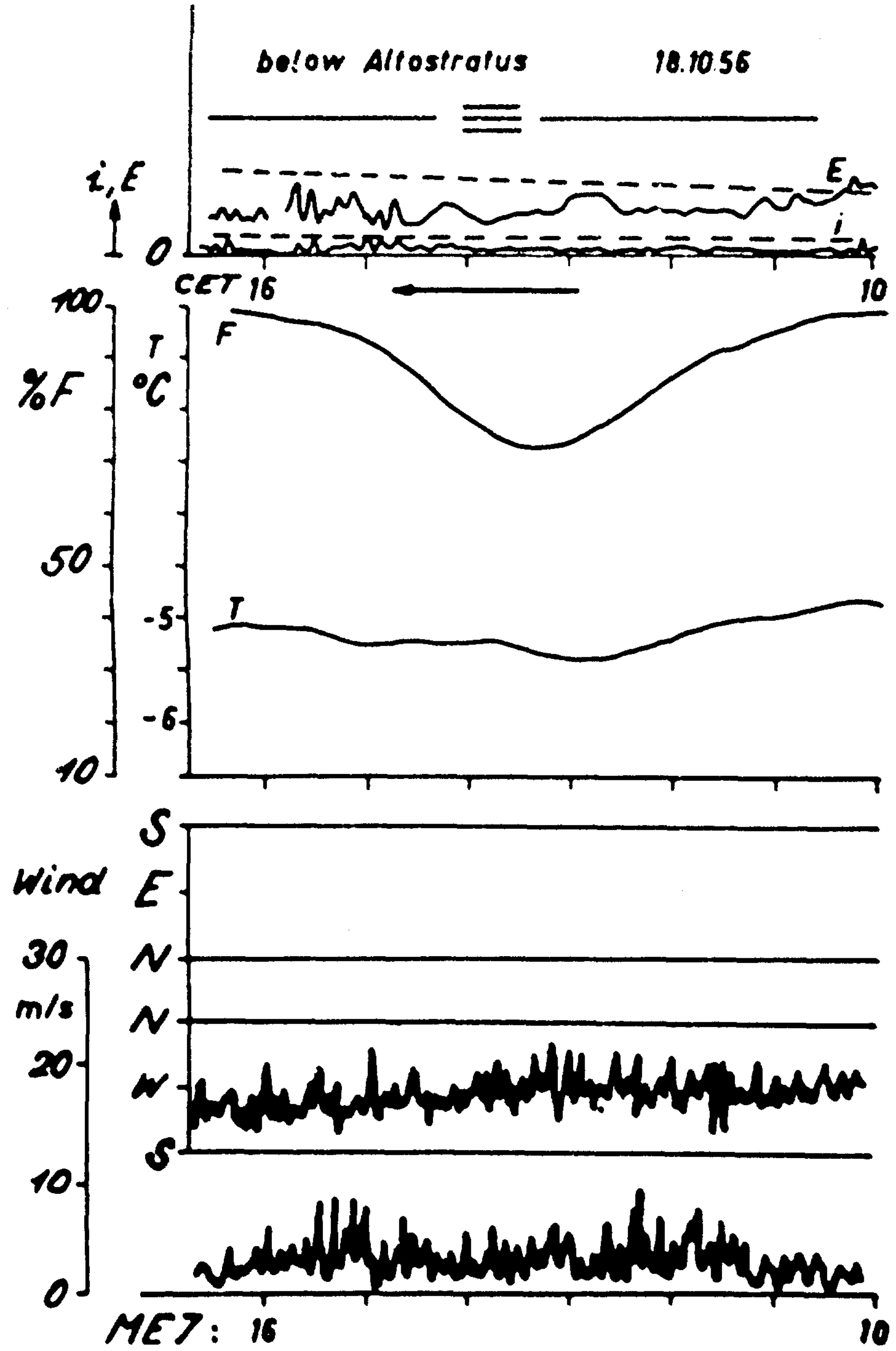

Figure 79

Station Zugspitze within Altostratus base

8.3. Statistical evaluation of the data obtained when station Zugspitze is at the top of cloud sheets in an inversion layer

From half hour to half hour, the area between potential gradient (E) or air earth current (i) curve and zero line was measured with planimeter. Then, for a number of typical cases, arithmetic means of the half hour areas were formed by synchronizing the area values with respect to the passage of the fog top (time "0" in the figures). In this way the mean courses of E and i, and i/E(= measure of conductivity) before and after the fog passage were obtained. This was carried out separately for downward passages (Figure 81) and upward passages (Figure 80). The average fine weather values of the respective recordings hours which were used, is set 100% in the percentage ordinate.

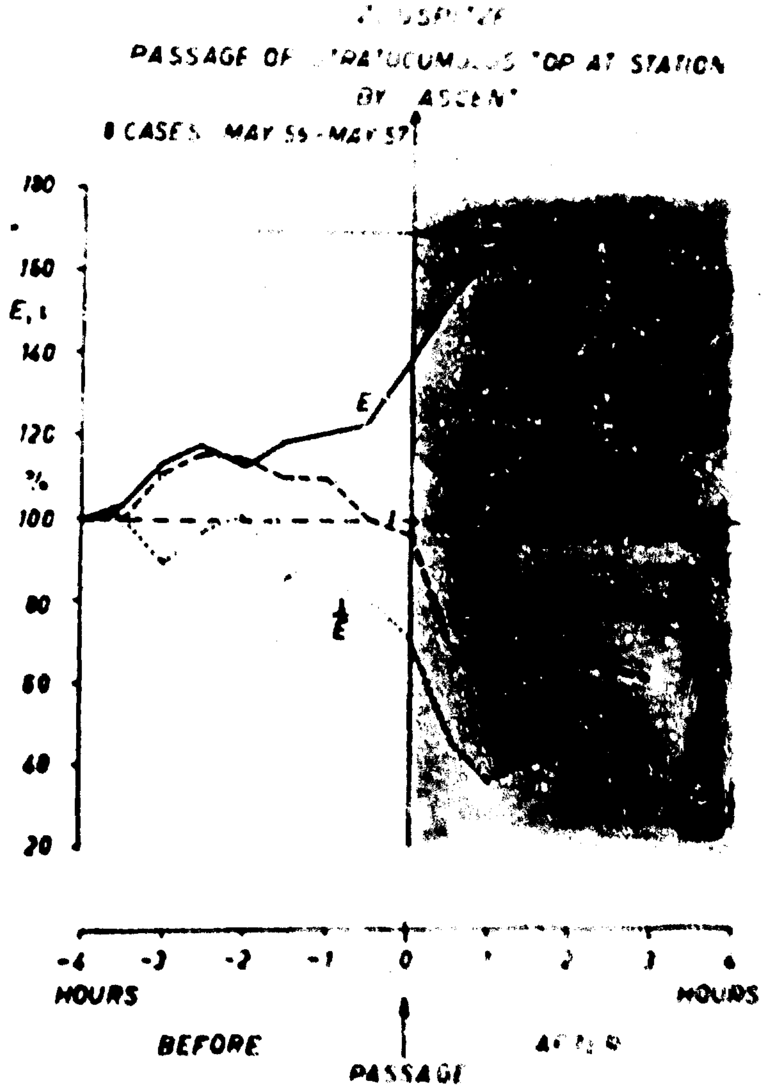

Figure 80

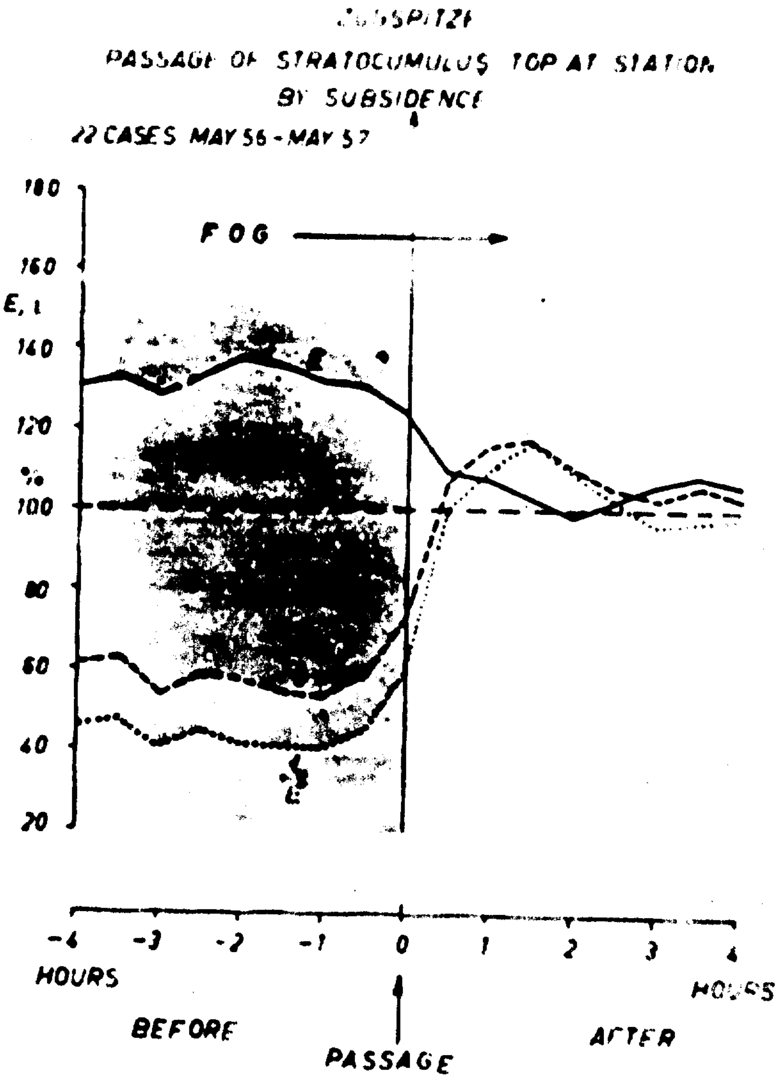

Figure 81

Comparing Figure 80 with Figure 81 we don't notice any significant difference between the case of coming fog (because of the ascending fog sheet enveloping the station) or leaving fog (because of emerging of the station from the subsiding fog sheet). In the fog the potential gradient is increased to 130 - 160 % of the fine weather value, the air earth current is decreased to about 60 % of the fine weather value. The conductivity is decreased to about 40 % of the fine weather value.

We said that there is no significant difference between the case of coming fog and that of leaving fog; however, we have to mention a secondary difference: in the case of ascending fog (Figure 80), the decrease of the conductivity (1/Z) takes place already 1 or 2 hours before the station enters into the fog, whereas the analogous process is not observed in the case of subsiding fog. The reason of this difference, as we assume, is, that a haze or mist layer exists above the ascending fog and is moved upwards together with it, so that the station gets into and through this layer, before the fog reaches the station.

A detailed theoretical treatment of these results is being performed.

9. Behaviour of potential gradient and air earth current at different altitudes in the presence of inversions, especially of such with sheet clouds, within the area of the station network

In the last Technical Report (AF 61 (514)-732-C) we mentioned also the behaviour of potential gradient and air earth current at the different stations of our station network during ascending or subsiding inversions. We presented some individual examples, which showed that frequently the inversion tops carry positive, and the bases negative space charges. However, only in cases where horizontal wind currents and, therefore, mixing processes are very slight, these space charges are concentrated to a definite, relatively thin layer at the respective altitude.

In Figure 82 an example is presented to demonstrate once more atmospheric electric conditions of this nature. At the stations Zugspitze, Wank, Riffelriss, and Obermoos there is normal fine weather. These stations are above a stratus layer, the top of which is at the level of station Eibsee , and record undisturbed curves conforming well to the fine weather value of October 1957. At station Eibsee, that is in the stratus top, the potential gradient is strongly increased, whereas below the stratus, at valley stations Garmisch and Farchant, air earth current and potential gradient are lower than the fine weather value and show relatively smooth curves.

In the period covered by the present report, separately for a number of typical inversion cases and for each of the stations the area between potential gradient or air earth current curve and zero line was measured with planimeter. So we obtained mean values of both magnitudes. These were reduced to percentages of the fine weather value (of the respective month and hour of day),

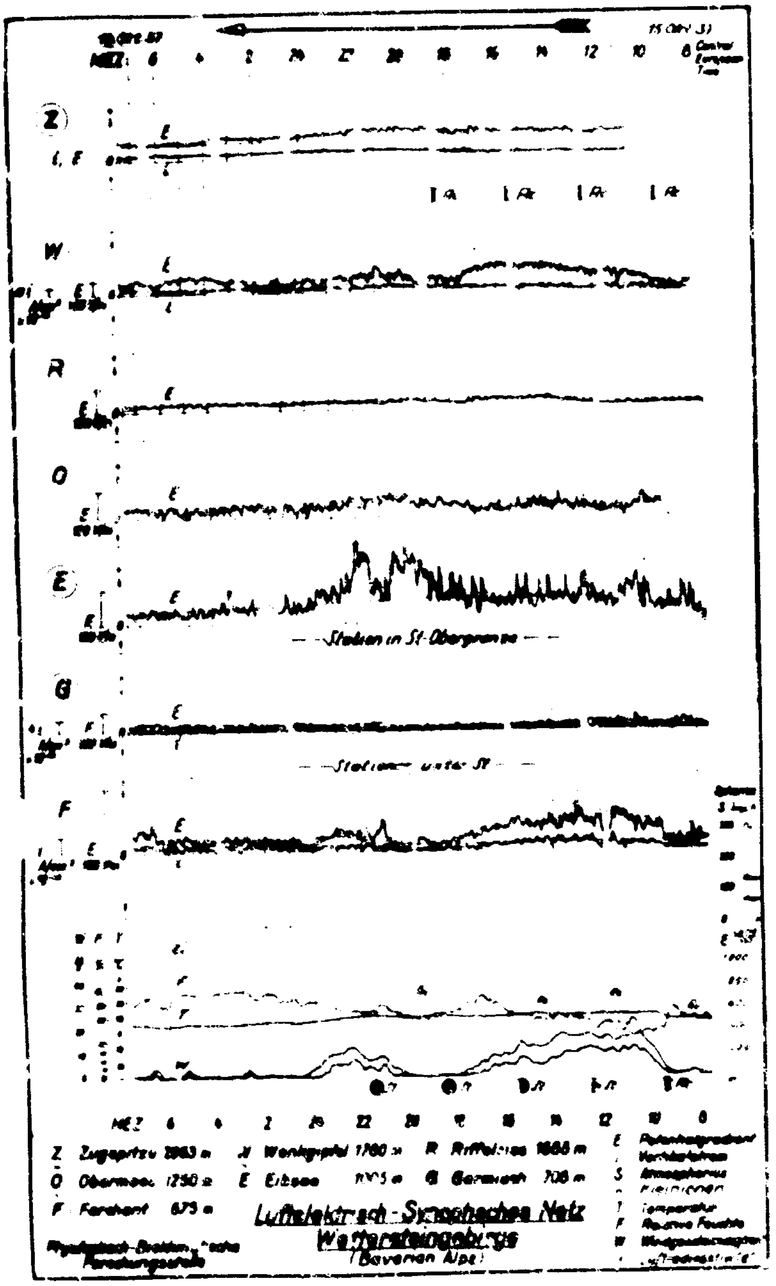

Figure 82

Top of stratus cloud at the level of station Eibsee which was put at 100 %. In Figures 83 - 87, these mean potential gradient and air earth current values of the stations are shown for different cases of inversions, i.e. inversions at different altitudes. Each such representation of one inversion case (Figure 83a - 87 a) is accompanied by a graph (Figures 83 b - 87 b) showing the appertaining radiosonde ascent results of Munich-Riem (T: Temperature; TT' difference actual temperature minus dew point temperature; both in degrees Celsius).

On looking over these figures we find, quite uniformly, practically normal fine weather values of potential gradient and air earth current everywhere above the inversion and/or the stratus. On the other hand, at stations being just in the top of the inversion and/or stratus, potential gradient and air earth current are strongly increased. The air earth current values are also increased (Figure 84a); that means that the increase of the potential gradient cannot be accounted for merely by the conductivity lowered at the station (compare section 8), but that positive space charges must cause an additional rise of the potential gradient. The potential gradient in the top of the inversion and/or stratus is 200 - 300 % of the fine weather value. Below the inversion and/or stratus the percentages are 50 - 80.

If, for each station, mean values are formed for periods when the respective station was in the top of an inversion and/or a stratus, we obtained Figure 88 from day time data and Figure 89 from night time data. It is obvious from the figures that during the night the increase of potential gradient and air earth current is much larger than in day time; the reason is simply that during the night there is less turbulence and higher space charge densities can accumulate at the boundaries of inversions and/or stratus layer

For each station, mean values were calculated also for periods when the respective station was below the inversion and/or stratus (Figures 90 and 91). Here the difference between day time and night results is only small. This can easily be accounted for by the wind current below the inversion and/or stratus being slight also in day time. At all the stations, when being below the inversions and/or stratus, the values of potential gradient and air earth current are about 60 % of the respective fine weather values.

Figure 92, lastly, gives the analogous mean potential gradient and air earth current values for each of the stations during periods when the station was not within the top nor within the base of a stratus, but in the midst of it. Here the potential gradient is always increased to 150 - 200 % of the respective fine weather value, whereas the air earth current is lowered to 60 - 80 %.

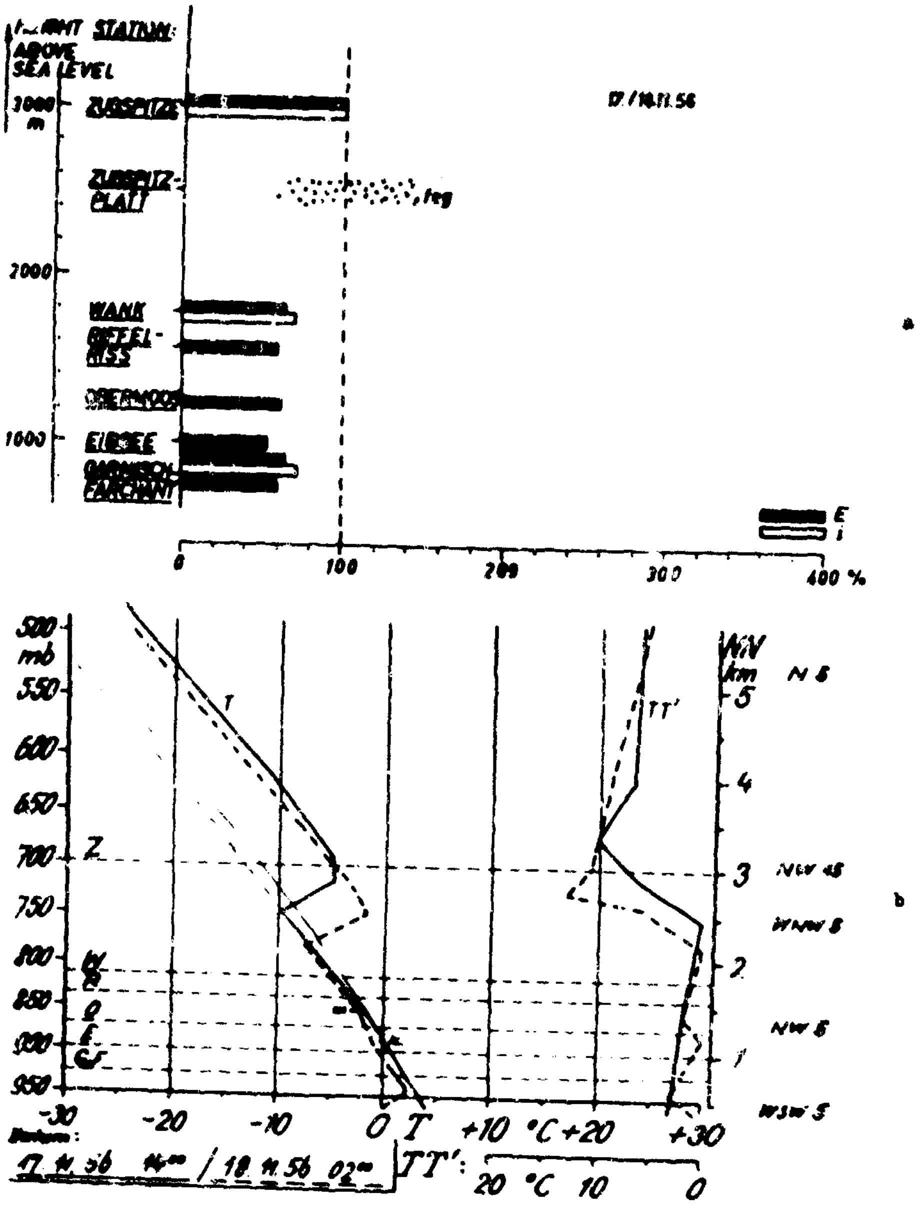

Figure 83 a and b

Stratus between the stations

Zugspitze and Wank

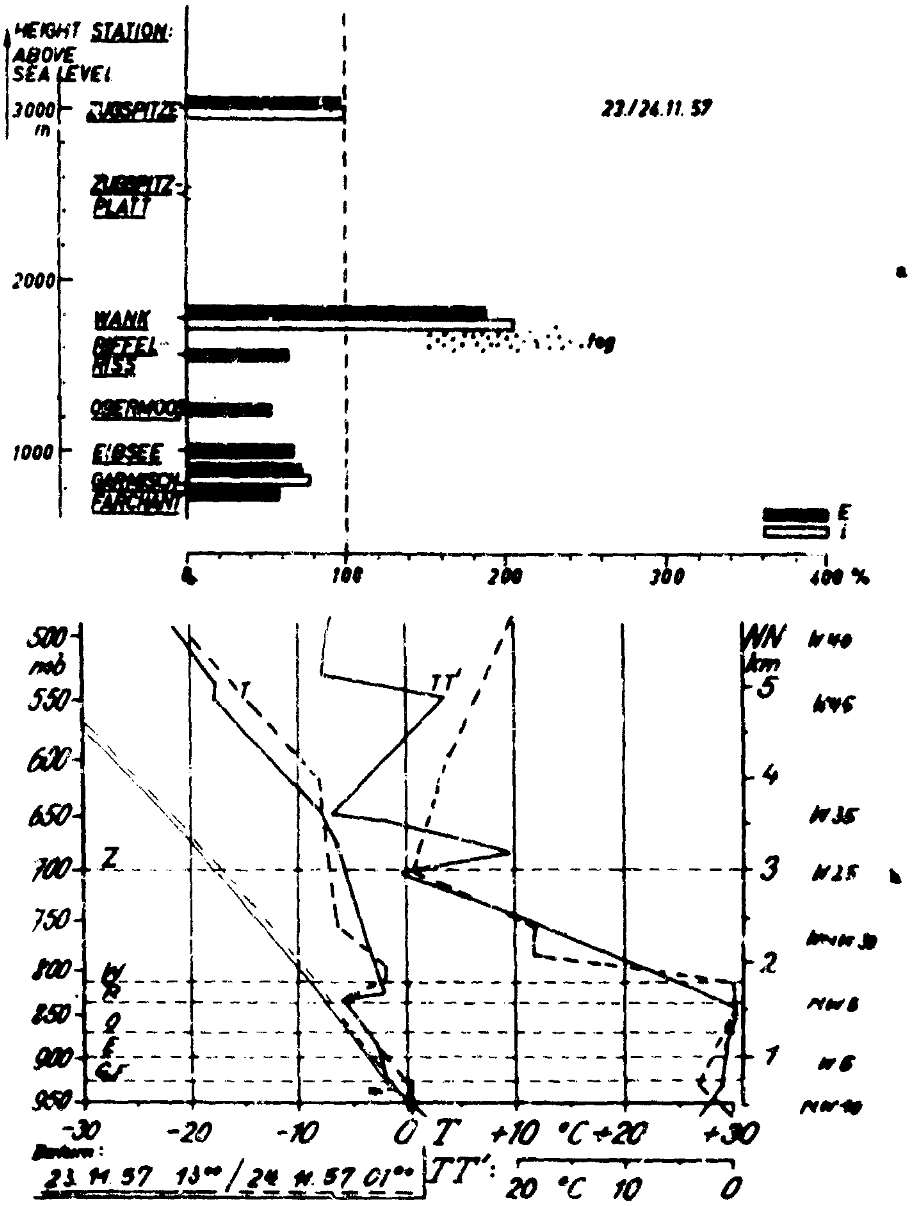

Figure 84 a and b

Station Wank just in the top of a stratus cloud

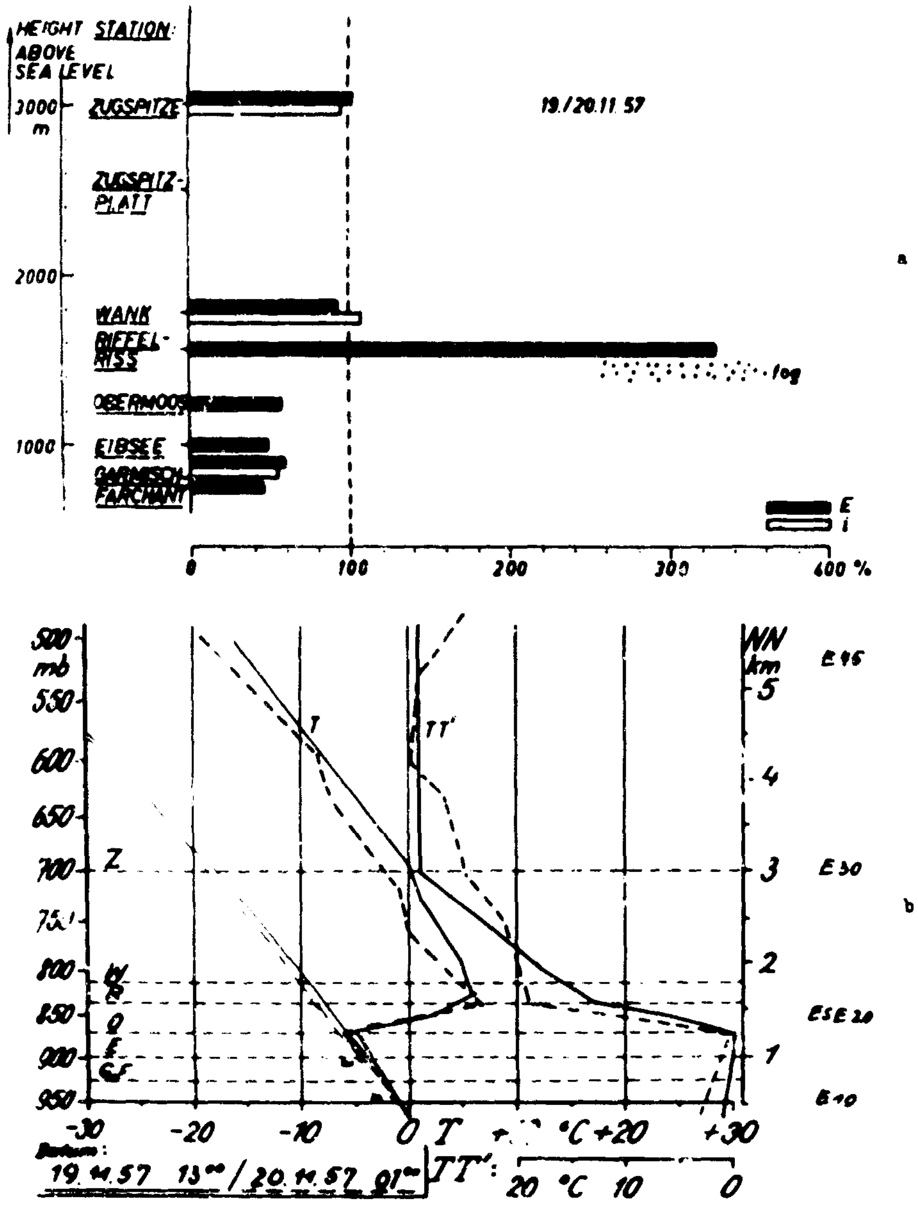

Figure 85 a and b

Station Riffelriss just in the top of a stratus cloud

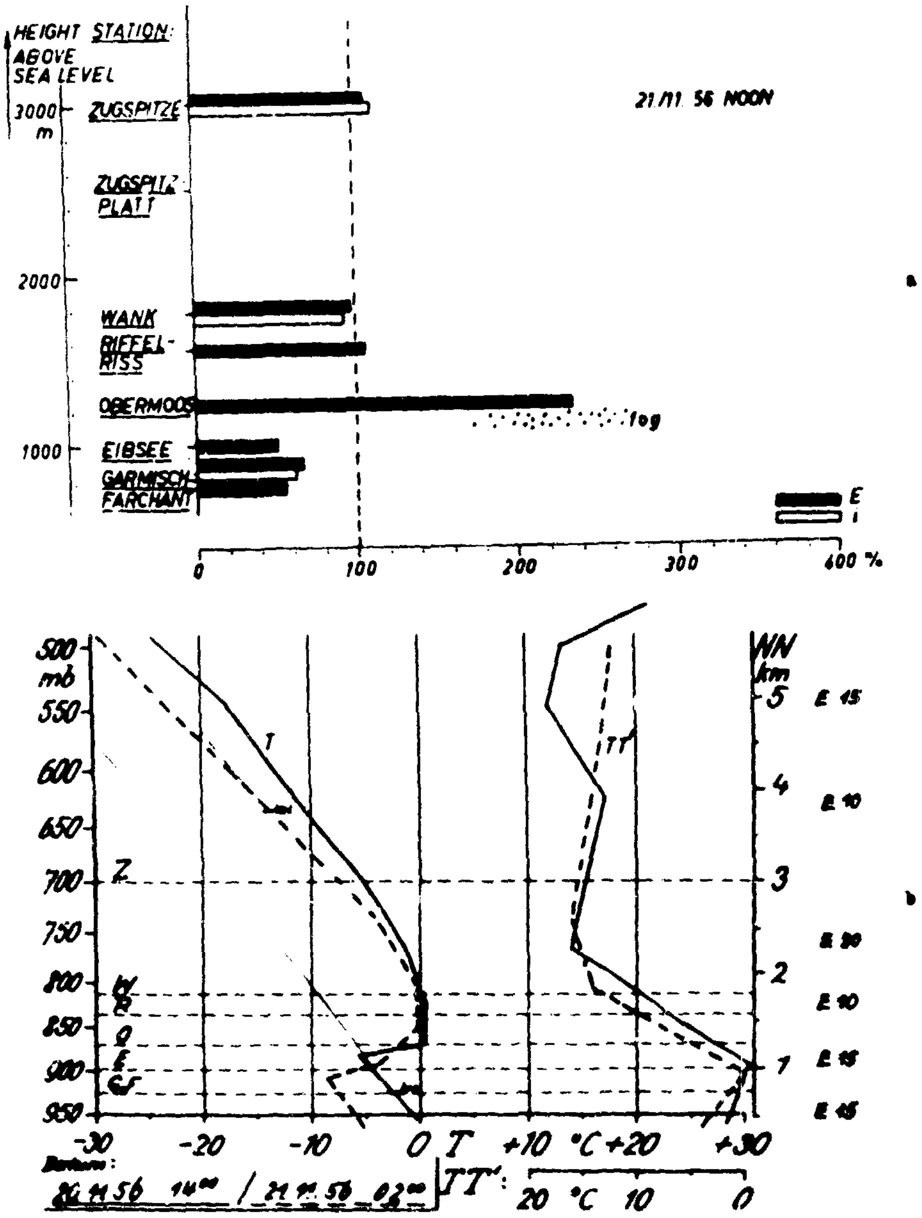

Figure 86 a and b

Station Obermoos just in the top of a stratus cloud

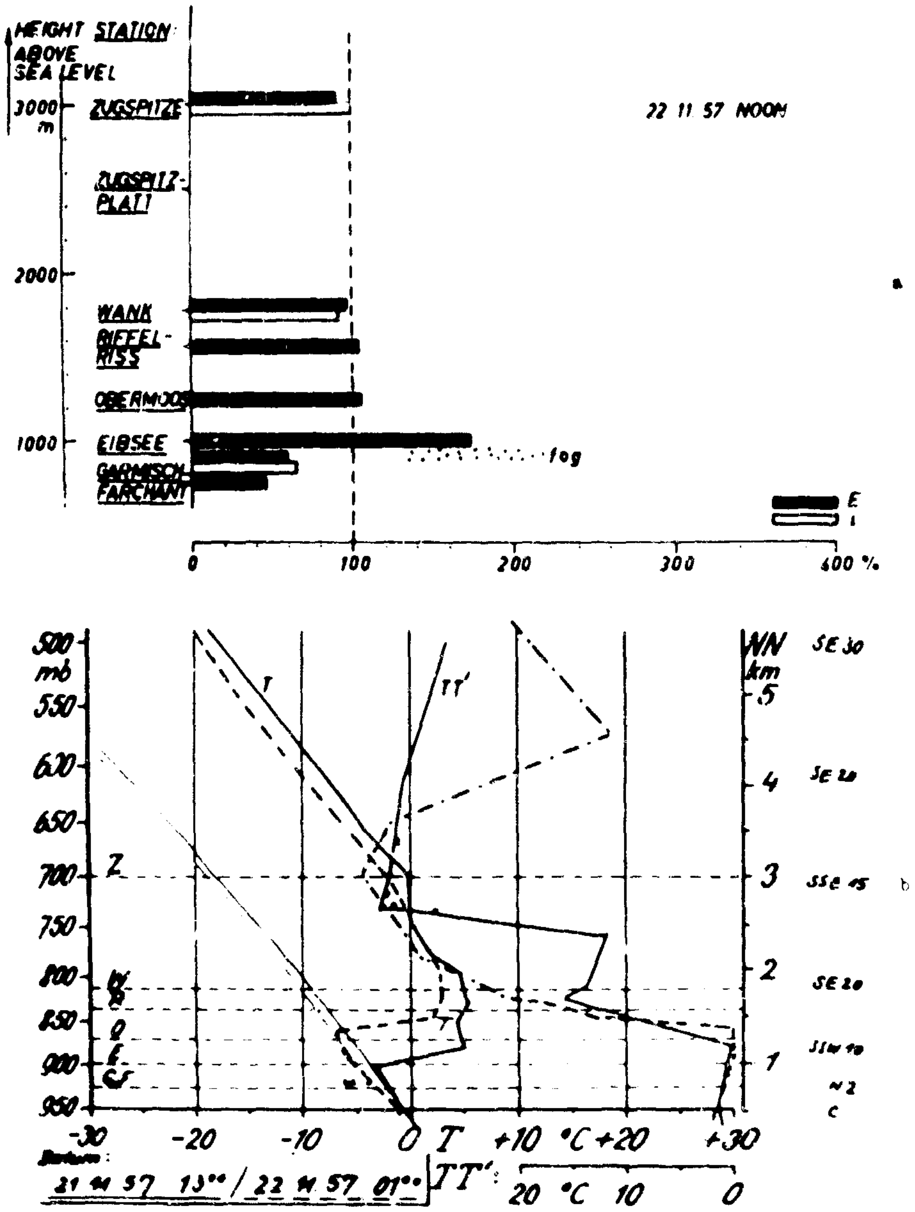

Figure 87 a and b

on Eibsee just in the top of a stratus cloud

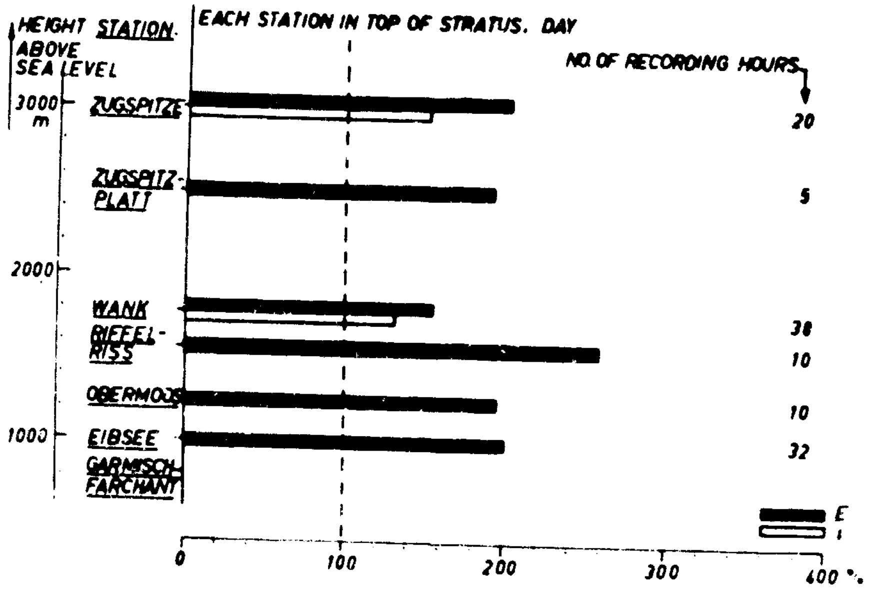

Figure 88

Each station in top of stratus, day

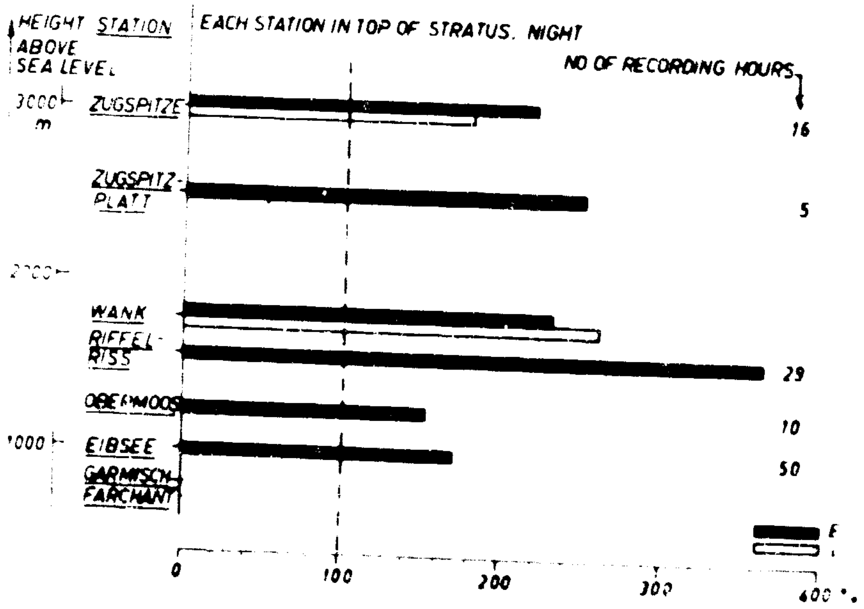

Figure 89

Each station in top of stratus, night

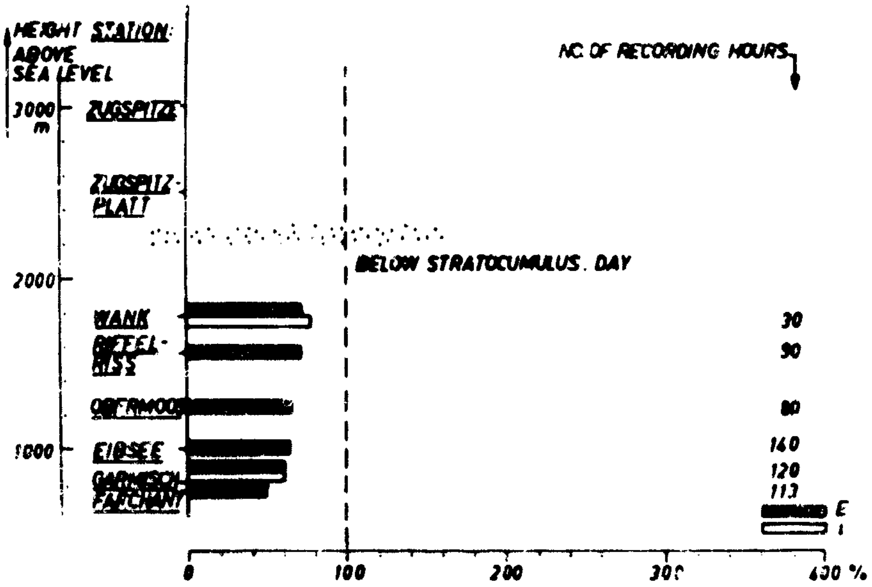

Figure 90
Stations Wank - Farchant below Stratocumulus base, day

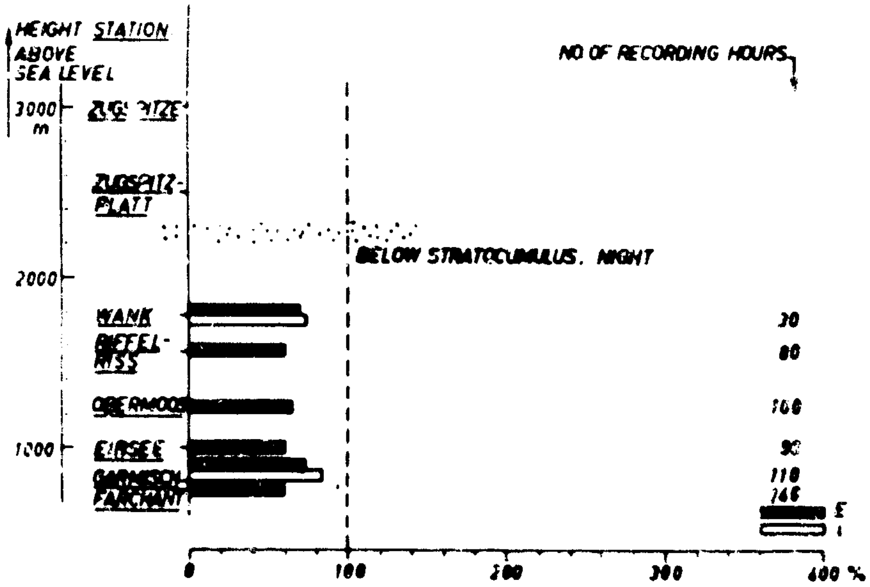

Figure 91
Stations Wank - Farchant below Stratocumulus base, night

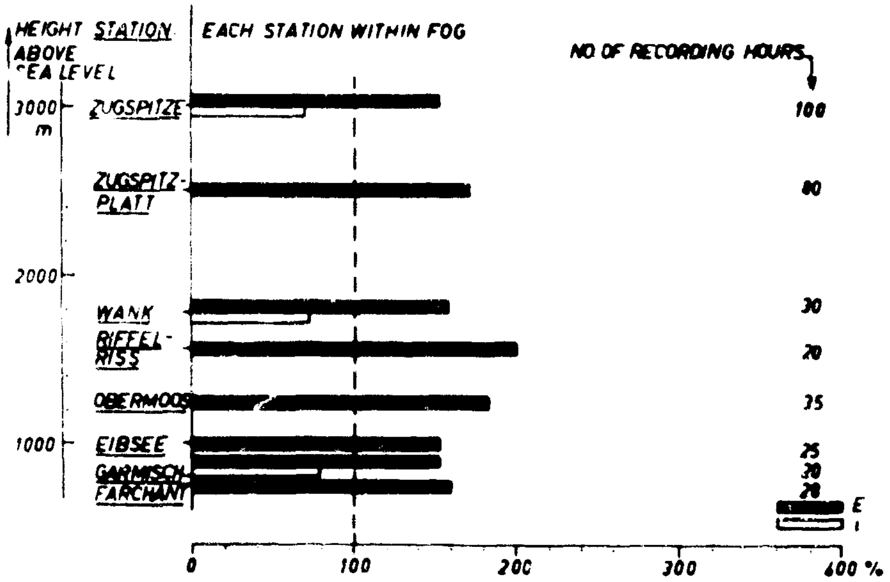

Figure 92
Each station within fog

On a comparison of Figure 92 with Figures 88 and 89 we notice that, within the stratus top, the potential gradient increments always are greater than in the midst of the thick fog. This fact, and the differente in the air earth current behaviour, again give evidence of the positive space charges existing in the stratus tops.

A theoretical investigation based upon these results is being performed. It shall be reported upon later.

Table 6, lastly, gives the total number of typical cases observed.

Table 6

Position of station relative to stratus cloud and/or inversion	Total number of cases in 3 years (1955 + 1956 + 1957)	
just within top of inversion and / or Stratus	positive foreign field:	46
	negative foreign field:	0
below base of inversion and / or Stratus	positive foreign field:	0
	negative foreign field:	137

10. Electric conductivity of the air between 700 and 3000 m above sea level; influence of convection and southern winds

From time to time, fine weather measurements of the positive and of the negative conductivity of the air were carried out at each station. The data obtained till spring 1956 have been summarized already in Technical Report AF 61 (514)-732-C. In an analogous table and graph the present report shall give information about all the data obtained till April 1958 (978 measurements were carried out for the positive conductivity and the same number of measurements for the negative conductivity).

Table 7 shows the mean values of all these data, no classification being made with respect to weather type etc

Figure 93 shows the same values, i.e. only the total conductivities, graphically as a function of the station level. They are classified as follows:

a) station within exchange layer, distinct vertical convection (dashed line);

b) all the measurements, e.g. also those obtained in cases of predominating advection (heavy continuous line);

c) only the data which were obtained during winds over the Alps from SE - SW (dashed and dotted line).

A comparison of the two left curves in Figure 93 will show that, by vertical exchange (a), the conductivity (λ) is increased at the valley level (Garmisch, Farchant), and lowered at higher levels. Within the exchange layer, the conduc-

Table 7

Station	n, Number of measurements 1955 +1956 +1957	Mean values of all conductivity measurements $Ohm^{-1}\ cm^{-1} \times 10^{-16}$			
		λ_+	λ_-	λ_Σ	λ_+ / λ_-
Zugspitze	284	4,25 (1,22 - 10,50)	3,55 (0,75 - 10,50)	7,80	1,20
Bark	129	2,54 (0,61 - 6,88)	2,23 (0,69 - 8,80)	4,78	1,15
Riffelriss	125	2,30 (0,50 - 6,20)	2,15 (0,44 - 5,65)	4,45	1,07
Obermoos	193	1,95 (0,63 - 4,50)	1,85 (0,57 - 3,0)	3,80	1,05
Eibsee	91	1,78 (0,34 - 4,60)	1,54 (0,35 - 3,90)	3,32	1,16
Garmisch + Farchant	152	1,22 (0,22 - 3,15)	1,13 (0,20 - 2,80)	2,35	1,07

λ_+ positive conductivity λ_- negative conductivity

λ_Σ total conductivity

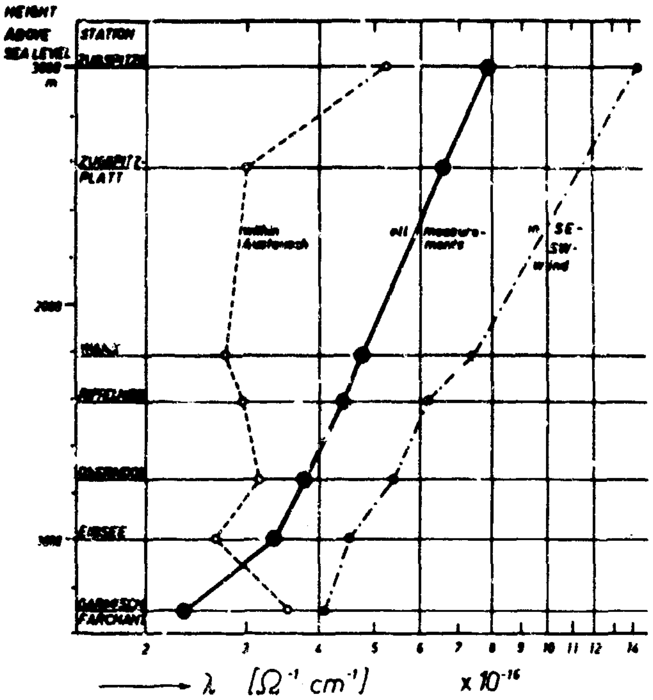

Figure 93
Electric conductivity of the air between 700 and 3000 m above sealevel; influence of convection ("Austausch") and of southern winds

tivity varies only little with height, which is in good agreement with the aircraft measurements of Sagalyn (1958).

The heavy continuous line, including all the measurements (b), is nearly an ideal logarithmic line. A logarithmic dependence on height is maintained, when the wind over the Alps is in the south (SE - SW) but in these cases the conductivity is strongly increased.

As cause of this conductivity increase, we must take into consideration the increase of the natural radioactivity of the air observed regularly during winds over the ridge of the Alps from SE - SW (see section 7.2.). These relations shall be discussed more extensively in the following section.

11. Influence of the natural radioactivity of the air on the atmospheric electric magnitudes at different levels

The connection between natural radioactivity of the air and atmospheric electric magnitudes was studied by using, on the one hand, the fine weather records of the seven stations as well as the appertaining evaluation results, and, on the other hand, the Farchant measurements of the natural radioactivity of the air, which were carried out several times a day+). Each filter was exposed four hours.

For each exposition period of four hours, we calculated the deviation of the individual observed four-hourly mean of the atmospheric electric magnitudes from the respective monthly fine weather mean of the same four hour-period. These deviations were expressed as percentages, the mentioned respective monthly fine weather means being put at 100 %. The calculation was carried out for the values of potential gradient and conductivity (computed from i/E). Then the mean values of these percentages were calculated for 5 degrees of simultaneous natural radioactivity of the air, and that for each station.

The result of this analysis is given in Figure 94, the data of which were obtained May - November 1956. The radioactivity values entered are those of the respective radon contents of the air. We notice that, during the presence of the average radioactivity of the air in our region, which is 180 - 270 x 10^{-12} Curie/m^3 radon, the deviations of the potential gradient are small, and their sign, i.e. whether the measured mean values are below or above the fine weather mean values, changes unsystematically with height. The conductivity is slightly lowered

If the natural radioactivity of the air is 90 - 180 x 10^{-12} Curie/m^3 radon, i.e. lower than the average, the potential gradient is increased, the conductivity decreases at all stations. If the natural radioactivity of the air is higher than 270 x 10^{-12} Curie/m^3 radon, i.e. higher than the average of our region, all the potential gradient values are lower, the conductivity values higher than the fine weather value of the respective station and that the more, the greater is the radioactivity. During extreme values of natural radioactivity, this being higher than 540 x 10^{-12} Curie/m^3 radon, the potential gradient is lowered by about 20 %, while the conductivity is about 20 % higher than in fine weather. The differences from station to station are not very striking nor systematic. However, from the figure it would appear that the influence of the natural radioactivity is smaller at station Zugspitze than at the other stations.

+) by means of a filter air sampler

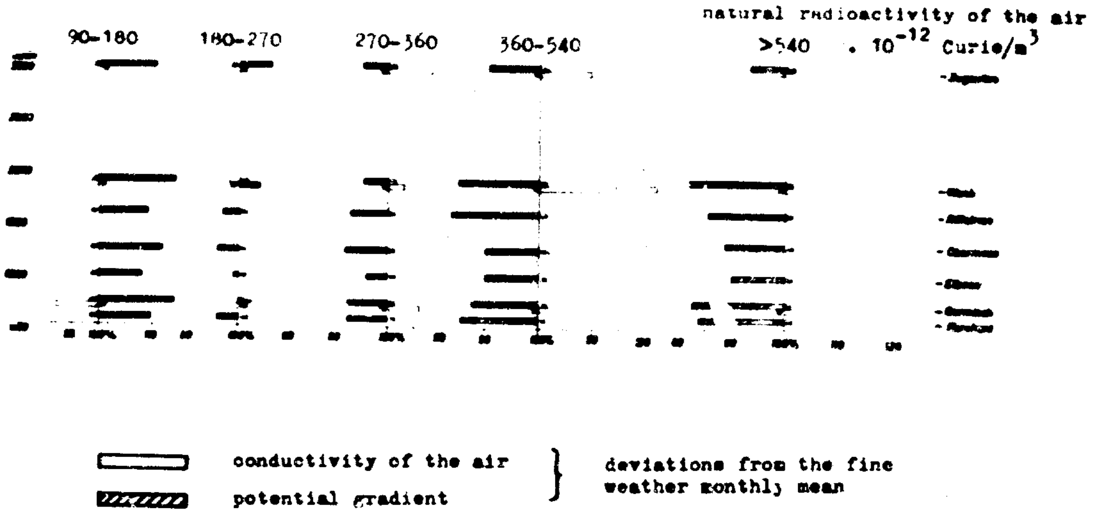

Figure 94

Influence of the natural radioactivity (concentration of radon in the air) of the air on the potential gradient and the conductivity (computed from 1/E)

For some years, investigators have been discussing the influence*)of nuclear fission products on the atmospheric electric elements (see **Harris** (1954, 1955), **Koenigsfeld** (1958), **Pierce** (1958), **Reiter** (1958)). Since continuous records of several years are at our disposal, and that for all the stations, it was interesting to examine the monthly means of the potential gradient with respect to this problem. The curves in Figure 95 represent the fine weather monthly means (P) of the potential gradient at the different stations. At Zugspitze, Wank, Riffelriss, Obermoos, and Eibsee, we don't notice any systematical going down of the curves during the last years. At Garmisch there is a very slight, and at Farchant a distinct lowering. However, since as is known, the fission products are present not only in the low level air, but also higher up, from where they are coming down, their influence, if noticeable, would be noticed also at the higher stations; but here, no such influence is suggested by the figure. If the course of the monthly means of the natural radioactivity in the air (R_n = radon concentration in the air, unit: 10^{-12} Curie/m^3) and that of the monthly means of the fission products contained in the air (R_k ; unit: 10^{-12} Curie/m^3), both measured at station Farchant, are compared with the potential gradient curves, an approximately anti-parallel course will

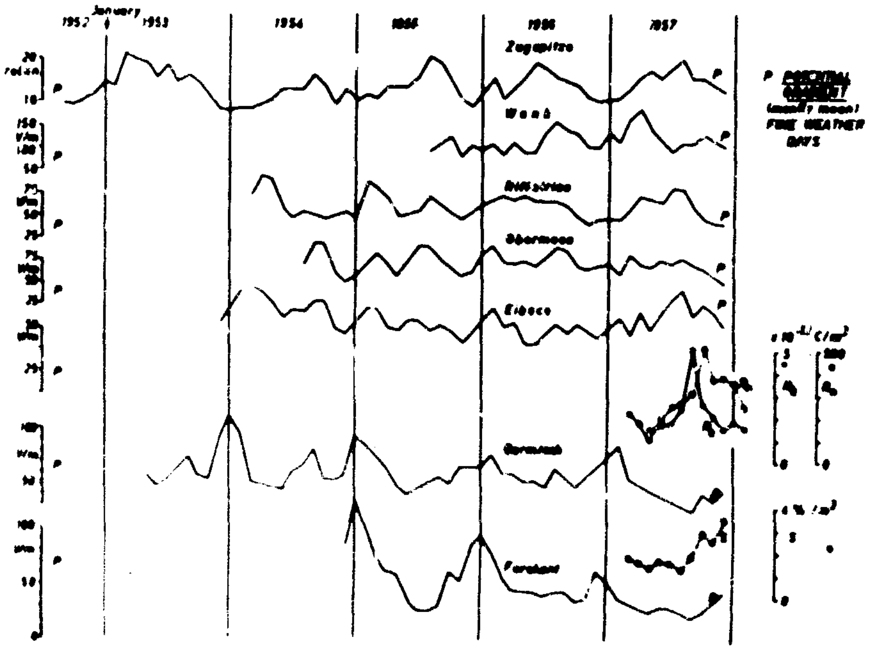

Figure 95

Fine weather monthly means of the potential gradient (P) for each station.

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*)Especially an eventual decrease of the potential gradient has been considered

be noticed for Garmisch and Farchant, but also a partial parallelism for stations Eibsee, Obermoos, Riffelriss, and Zugspitze. The course of the concentration of fission products in the air with time, therefore, doesn't help us to account for the potential gradient course.

Curve "S" in Figure 95 represents the aerosol concentration of the air at station Farchant, and that in relative units. It is rather parallel to the potential gradient curves of Garmisch and Farchant. This parallelism is due to a real causal connection, since, the more aerosol particles are in the air, the lower is the conductivity of the air, and the higher the potential gradient (compare Technical Report AF 61 (514)-732-C). At the higher stations Eibsee, Riffelriss, etc., the annual variations of the aerosol contents of the air are not the same as at the valley stations Garmisch and Farchant; therefore it is quite consequent that the "S" - curve, measured at Farchant, is not parallel to the potential gradient curve of these higher stations, a fact which, on the other hand, is not inconsistent with a causal connection between "S"-curve and potential gradient at the *valley* level.

With respect to the annual variations of the potential gradient, the curves obtained in the valley *must* be antiparallel to those obtained at the higher stations, since the highest air pollution of the valley air is observed in winter, the season during which the purest air of the whole year is found at higher levels.

To sum up the results given in this section: there is a considerable influence of the *natural* radioactivity of the air on the behaviour of the atmospheric electric magnitudes, but the present concentrations of nuclear fission products in the air don't influence the behaviour of the atmospheric electric magnitudes between 700 and 3000 m above the sealevel (for more details see *Reiter* (1958)).

12. Thunderstorm forecasts with spherics recordings

On 149 days of summer 1956 (5 months, June - October) and on 147 days of Summer 1957 (6 months, April - September) test forecasts were carried out concerning the thunderstorm frequency to be expected within the Alpine area during the 20 hours following the forecast. The forecast was made always at 09.00 CET in 1956 and at 08.30 CET in 1957, and that in 1956 by means of the spherics recorded between 07.00 and 09.00 CET, in 1957 by means of the spherics recorded between 06.00 and 08.30 CET. The purpose of this work was to ascertain reliability and geographical range of such forecasts.

The highest sensitivity of the receiver used was in the band 5 - 20 kc.

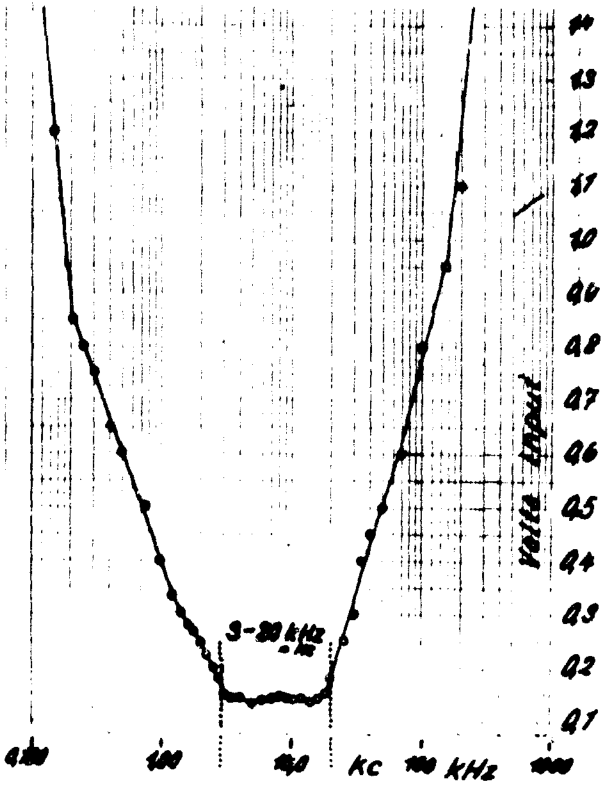

Figure 96

Sensitivity of the amplifier v. frequency of the electromagnetic waves received

In Figure 96 the minimum voltage, necessary at the amplifier input to make respond amplifier and counter, is plotted against the frequency of the electromagnetic waves received. The sensitivity threshold of the receiver was set so high that only relatively strong pulses were counted, i.e. pulses with relatively high amplitudes.

In making the thunderstorm forecasts, three degrees of the number of pulses recorded within the two hours preceding the forecast were distinguished (see below). According to these degrees, three sorts of forecasts were given as follows:

P 0: No thunderstorms to be expected. This forecast was given in 1956 on 88 days, in 1957 on 85 days.

P 1: Only a small number of thunderstorms to be expected. This forecast was given in 1956 on 28 days, in 1957 on 38 days.

P 2: A great number of thunderstorms to be expected. This forecast was given in 1956 on 33 days, in 1957 on 24 days.

In Figure 97, curve 0 (dotted) gives the average diurnal variation (hourly means) of the number of pulses per hour on the 85 days on summer 1957, when forecast P 0 was given in the morning. Curve 1 (dashed) of the figure gives the same for the 38 days in summer 1957, when forecast P 1 was given, and curve 2 gives it for the 24 days of summer 1957, when forecast P 2 was given in the morning. "P" is the time when the forecast was made. It is evident from the figure, that there is a connection between the number of pulses per hour in the morning and their tendency (whether is is increasing or decreasing) on the one hand, and the behaviour of the sperics in the course of the same day on the other hand.

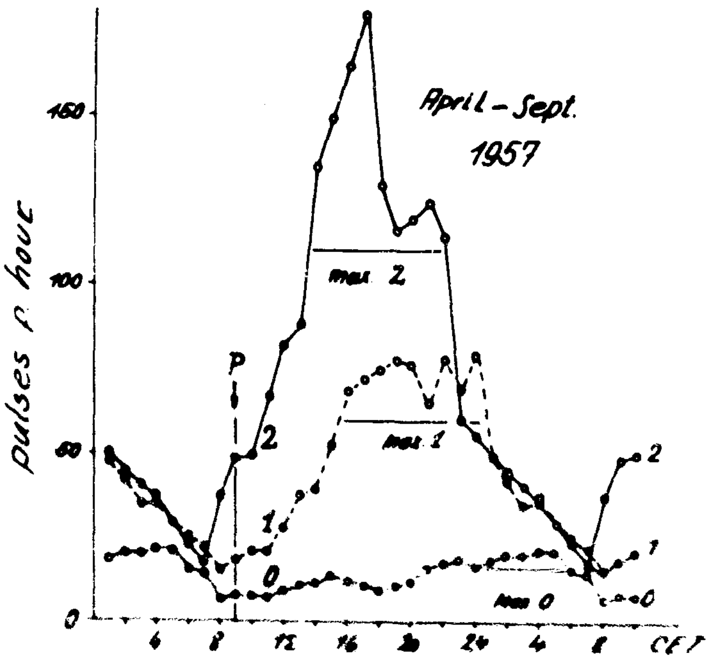

Figure 97
Average diurnal variation of the spherics pulses on P 0, P 1, and P 2 days

When, in the morning, the sperics pulses are above a certain threshold, and from this threshold, an inference can be drawn as to the height of the following maximum. When, in the morning, their number per hour is very low (see Figure 97), a strong rise is not probable on the same day.

The analogous curves of summer 1936 are given in Figure 98. A comparison of Figure 97 with Figure 98 shows a practically complete agreement; thus we can say that the results demonstrated in Figures 97 and 98 are of general value and independent of the weather development varying from sommer to summer.

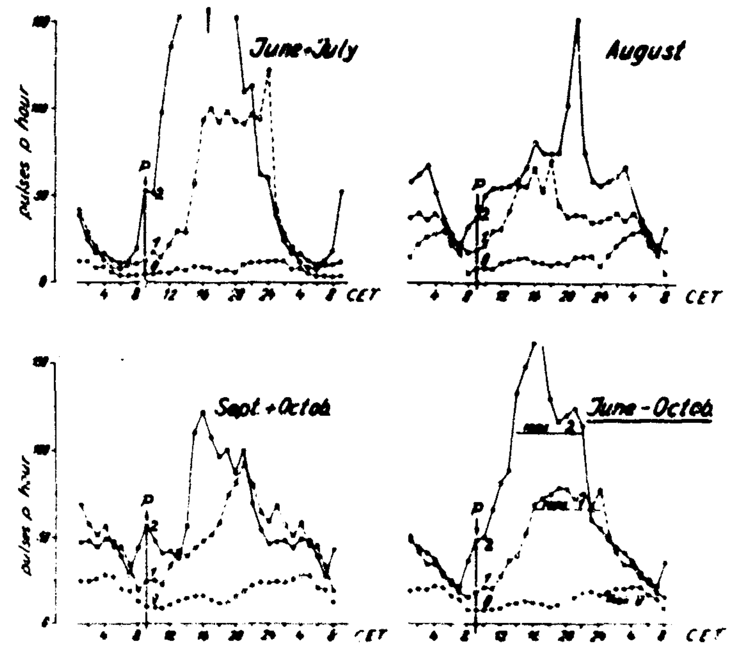

Figure 96

Average diurnal variation of the spherics pulses at P 0, P 1, and P 2 days
1 9 3 6

Now it had to be examined how these results agree with the actual distribution and frequency of thunderstorms on the forecast days whithin a certain geographical area, and the percentage of right forecasts had to be ascertained. For this purpose, all the thunderstorms observed by 43 meteorological stations in the Alpine area of Germany, Austria, Switherland, and Italy were extracted from the teleprint reports of the respective Weather Bureaus, and that for the 149 plus 147 forecast days. About 120,000 teleprint reports were used. The geographical distribution of these meteorological stations is given in Figure 99.

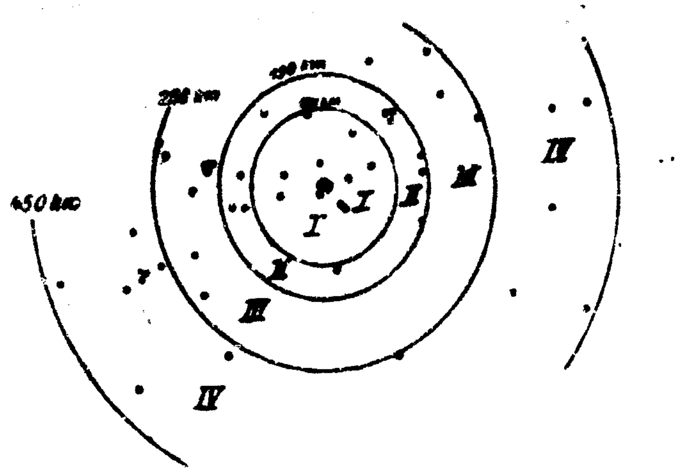

Figure 99
The geographical distribution of the 45
meteorological stations in the
Alpine area

In this figure, we see the whole Alpine area divided into 4 zones by concentric circles of 100, 150, 250, and 450 km radius, zone I being a circular surface, zones II, III, and IV being annuli. Station Farchant, where the spherics are recorded, is the centre; zone I is nearest to Farchant, zone IV has the greatest distance. Each of the zones contains approximately an equal share of the 45 meteorological stations situated within or near the Alps, and all the 45 stations are situated within the area of the 4 zones. The investigation had to be restriced to the Alps and their neighbourhood, because this area must be regarded as a unity with respect to the thunderstorm formation.

It was ascertained how many thunderstorms were observed (by the meteorological stations in the respective zone) per forecast type(P 0, P 1, P 2), zone (I,II,III,IV) and interval reported upon. This was carried out for

a) the reports given every third hour (Figure 100): reporting hours: 00, 03, 06, 09, 12, 15, 18, and 21 GMT; observations used: thunderstorms, audible thunder, sheet lightnings at night.

b) the reports given every sixth hour (Figure 101): reporting hours: 00, 06, 12, 18 GMT; observations used: thunderstorms within the 6 hours preceding the reporting hour.

In Figure 100, the results of both 1956 (white columns) and 1957 (black columns) are demonstrated. Ordinates of each horizontal line: the average frequency of a thunderstorm observation per station and interval reported upon. It is obvious that, for zones I and II, the observed thunderstorm frequency actually corresponds with the forecast degree.

In case of P 0, the probability per station of the occurrence of thunderstorms between 19 and 22 CET (maximum of the thunderstorm frequency) is only 0.02 in zone I. In the case of P 2, the probability per station of the occurrence of thunderstorms is about 0.2, that is to say ten times the value of P 0,

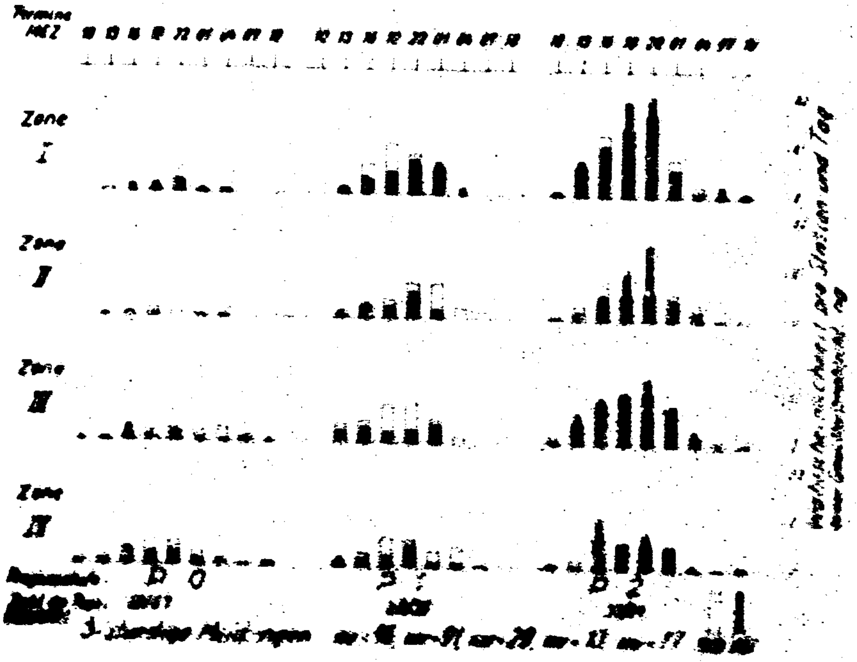

Figure 100

in the same zone and during the same hour. 0.2 signifies that an average of about two stations of zone I out of ten observed thunderstorms between 19 and 22 CET in cases where forecast P 2 had been given. In view of the fact that also for the other three-hour periods thunderstorms were reported, we are allowed to say that in the case of P 2 a great number of thunderstorms occurred in zone I (and also in zone II).

Comparing this with the results for zone IV, we find here the differences between the forcast degrees to be relatively small. Consequently, the forecast can be considered to cover, round about the recording place of the spherics, at least an area of 150 km (93 miles) radius.

A similar result is found, if the reports given every sixth hour are considered (Figure 101). The differences, in the thunderstorm frequencies, between P 0, P 1, and P 2 are very clear in zones I and II, only slight in zone III, and almost imperceptible in zone IV.

Figure 101

In case P 0 and zone I, the thunderstorm probability per station is 0.05 between 19 and 01 CET (maximum of thunderstorm activity), This means that, on the average, thunderstorms are observed within the six hours before 01 CET only by one station out of 20. In case P 1 and zone I, the thunderstorm probability per station for the same hours is 0.25, i.e.: 5 stations out of 20 must report thunderstorms. In case P 2 and zone I, the thunderstorm probability per station for the same hours is 0.5 , i.e.: 10stations out 20 must report thunderstorms observed between 19 and 01 CET. The conditions P 0: No thunderstorms to be expected, P 1: Only a small number of thunderstorms to be expected, and P 2: A great number of thunderstorms to be expected are fulfilled satisfactorily for zone I and still for zone II, the results of the two years being in very good agreement. Figure 101 shows that the geographical range of the forecasts is about 150 km (93 miles).

In calcutaling the success probabilities of the thunderstorm forecasts of 1956 and 1957, these being based only on the recorded sperics, the "tendency of persistence" was always taken into account. Only the first two days of persistent periods with or without thunderstorms were used, the rest was rejected. If the rest were included, the resulting percentage of right forecasts would be too high.

In summer 1957, the following result was obtained with regard to the percentage of right thunderstorm forecasts:

Number of right forecasts:	110	=	85 %
Number of wrong forecasts:	19	=	15 %
sum:	129	=	100 %

Forecasts were made on 147 days; 18 of these days were rejected because of tendency of persistence (see above). The maximum percentage of forecasts which could be right only by chance is 65 % (in the case of 129 forecasts). Consequently, a share of 85 % right forecasts is beyond chance. In 1956, 78 % of the forecasts were successes.

Conclusions of section 12

From the number of spherics observed in the morning it is possible to infer satisfactorily the thunderstorm frequency of the same day till about 2 hours after midnight for an area of about 93 miles radius round the station recording the spherics. This experience can be of practical importance in those regions where the network of meteorological stations is not dense enough, and where no radiosonde ascents are carried out. Here it may be possible to improve the reliability of thunderstorm forecasts by the relatively simple recording of spherics. Beyond this, since the spherics of the frequency received by our set generally are indicative of atmospheric lability, this sort of recording is a suitable complement to the use of potential gradient records mentioned in section 4.

13. Correlations between thunderstorm frequency, spherics and sun flares (Figure 102)

We are regularly receiving the daily maps of the sun, edited by the FRAUNHOFER INSTITUT, Freiburg im Breisgau, Germany (Director: K.O.Kiepenheuer). They include also informations on start and end, position on the sun, and importance of flares.

It has been investigated, if the frequencies of thunderstorms and, consequently, of spherics are altered beyond the variations which could be caused by chance during flares and in their temporal neighbourhood. The investigation was carried out for summer 1957 (in 1956, flares occured too seldom).

The study was based on

a) the days on which flares were observed

b) all the thunderstorms, reported per day by the above mentioned 43 Alpine stations (which also were used for the studies dealt with in section 12);

c) the numbers of spherics pulses of each day, always devided by 24; or the logarithmus of these daily means per hour.

In selection the flare days, we looked at

a) the importance of the respective flares

b) their position on the sun relative to the central meridian

c) their position on the sun relative to the equator.

The distinctions made with respect to this b) and c) (see tops of Figure 102) are significant, because the particle clusters ejected by the flares, as is known, don't strike upon the earth unless the eruption has taken place in the neighbourhood of the central meridian and equator of the sun.

By restriction according to a), b), and c), three groups of flare-days were obtained; for each group, the mean course of

A) spherics (logarithmus of daily means per hour)

B) thunderstorms reported per station and day

on the three days preceding the selected flare-days (-3, -2, -1), on these flare-days (0), and on the four days following the selected flare-days (+1,

+2, +3, +4) were determined (synchronization method) and entered in Figure 102.

At the top in Figure 102, the respective position and importance of flares and the number of selected flare-days (n) of summer 1957 is indicated for each group. The upper curves demonstrate the average behaviour of the spherics, the lower curves the average variations of the thunderstorm frequency before, on, and after each sort of flare days. We notice from the Figure 102 that, on the average, the frequency both of thunderstorms and spherics is increased after flares. The maximum is reached 1 or 2 or 3 days after the eruption. It is indicated by this observation that thunderstormes can be induced by the particle clouds, which are ejected by the flares, and which, as is known, cover the distance sun-earth within 1 - 2 days. The portions of the curves surpassing the variations caused by chance have a black filling - out. For calculating

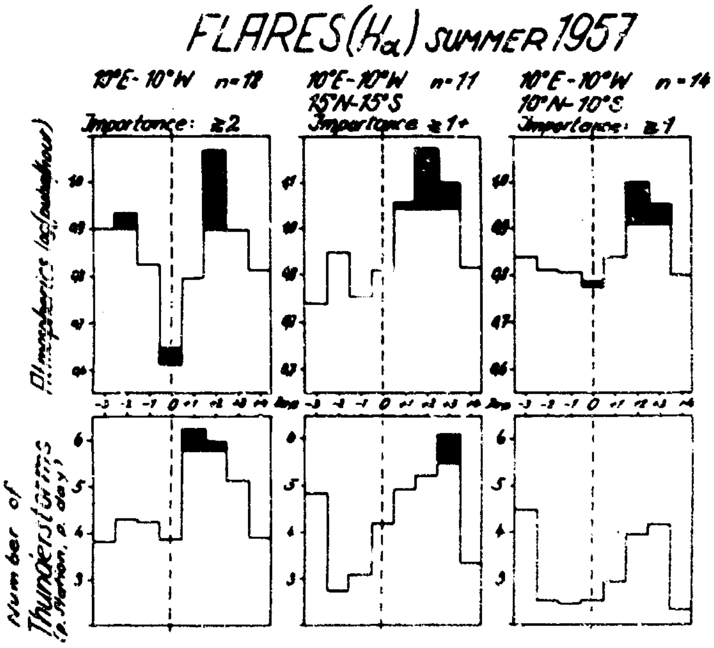

Figure 102

Number of spherics and thunderstorms before, on, and after flare days. Abscissae: time relative to flare-day (0). Ordinate of upper three graphs: mean value of logarithms of hourly sums of spherics pulses per day. Ordinate of lower three graphs: mean value of numbers of thunderstorms reported per meteorological station and day.

the range of chance dispersion we used a common method: the standard deviations σ from the arithmetic mean of the values forming the curves of Figure 102 were calculated. Whenever a mean of thunderstorm numbers per station and day or of spherics logarithms (as defined above), obtained by synchronisation, had a deviation from the arithmetic mean of the values forming the respective curve of not more than three times the standard deviation, it was assumed to be possibly determined by chance. Deviations by more than three times the standard deviation from the arithmic mean of the values forming the respective curve in Figure 102 were considered to have a cause beyond chance.

It must still be mentioned that there is no contradiction between the maximum of spherics being after the flare and the other well known observation that the spherics generally increase simultaneously with the flare and that for a relatively short duration only.

The latter observation is based on highly sensitive recordings of spherics, waves being received which have covered great distances; in this case, the ionospheric propagation conditions are of importance, which, for long waves, are improved during and immediately after flares.

On the other hand, the spherics received at station Farchant have a relatively near provenance; they indicate the variations of the thunderstorm frequency for 150 - 200 km round Farchant (see section 12), the ionospheric conditions for wave propagation being of practically no influence.

Thus, as essential we may state, that the thunderstorm freuqency increases 1 - 2 days after flares of relatively high importance.

14. Relations between the contents of nitrate and nitrite ions in precipitations and simultaneous atmospheric electric processes +)

14.1. Introduction

It is more than a hundred years since investigators began to determine the contents of nitrate ions or the sum of nitrate and nitrite ions in precipitations. Since that time, a great number of papers have dealt with analyses of nitrate (NO_3') and nitrite (NO_2') in precipitation. On the average, about 1.5 mg NO_3' and about 0.05 mg NO_2' were found per litre of precipitation. The values vary considerably depending on time, place, kind of precipitation, etc. (compare Gmelin).

The main sources for the nitrogen-oxygen compounds determined in precipitation will be summarised in section 14.4., where we shall see that atmospheric electric processes are possible causes for NO_3' and NO_2' in precipitation. As has been shown by preliminary trials (Reiter (1955) and Technical Report AF 61 - (514) - 732 - C), it is worth while in atmospheric electric investigations to determine the nitrogen-oxygen compounds in precipitation continuously, especially if after several precipitation hours or less the collecting vessels are always changed and the nature of the precipitation - whether showery or not, physical state, etc. - is taken into account. The objective of such studies, generally, is to find out what conclusions, if any may be drawn from the contents of NO_3' and NO_2' in the respective precipitation as to the elotrical processes in the atmosphere. Provided that clear relations can be derived, it might be possible, in the future, to complete the knowledge of atmospheric electric situations by the knowledge of the nitrate and nitrite contents in the simultaneous precipitation (or dew or rime), and that also for those levels where continuous recording of atmospheric electric elements is difficult.

The use of precipitation alalyses in this sense presupposes a knowlegde of the proportion of the nitrogen-oxygen compounds in the precipitation which actually comes from higher atmospheric layers, and which from near the ground (compare Mukherjee (1955)). It is necessary to study, to what extent additional nitrogen-oxygen compounds are absorbed by the precipitation particles during their fall through the layer near the ground. Nitrogen oxide and dioxide can

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+) See paper presented by Reinhold Reiter and Mirjam Reiter at the Second Conference on Atmospheric Electricity, Wentworth by-the-Sea, Portsmouth, N.H., USA, May 20-23, 1958. Pergamon Press, New York be formed near the ground principally

a) by chemical, technical, and industrial processes[+])

b) by point discharges at trees, houses, etc., in increased atmospheric electric fields,

and certainly are absorbed by the precipitation particles in detectable quantities during the last phase of their falling down (compare section 14.4.).

This study, therefore, mainly deals with the question of additional absorption of nitrogen-oxygen compounds by precipitation in the lower atmosphere up to about 1000 m above the ground. The method was:

a) comparison of NO_3' and NO_2' contents in precipitation collected in the valley at 675 m above sealevel with that in samples of the same precipitation collected simultaneously on a neighbouring flat mountain top of 1780 m above sealevel, the type of precipitation being taken into account (rain, snow, shower, thunderstorm etc.);

b) comparison of the NO_3' and NO_2' contents in precipitation collected in the valley at 675 m abavoe sealevel with that in artificial dew or rime condensed at the same place; this artificial condensate has to be regarded as indicative of the chemical properties of the air near the ground;

c) investigation of the influence of point discharge near the ground in the valley, at 675 m above sealevel, on the NO_3' and NO_2' contents of presipitation and of artificial dew or rime collected at the same place.

After a rough estimate of the influence of the lowest kilometre of the atmosphere was obtained, we looked for the existence of relations between the NO_3' and NO_2' contents of the precipitation and the lability degree of the atmospheric stratification as well as certain atmospheric electric phenomena. A final derivation, however, of fundamental relations between atmospheric electric processes and concentration of nitrogen-oxygen compounds in precipitation will be possible, if at all, only on the base of further data, which are being collected.

14.2. Experimental method

14.2.1. Point discharge current

The point discharge current was recorded at station Farchant as described in section 2. It yielded a relative measure for the ionization of the air caused by discharge from adjacent points of houses, trees, etc. The steel point was

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[+]) Our station network, where the investigation was carried out, is far away from industries and other significant sources of air pollution.

at the same height, on the average, as the surrounding houses and trees.

As an example, Figure 103 shows a portion of a record obtained during slight (02 CET) and heavy (20 CET) snow fall. The following curves are included: Potential gradient (E), air earth current (i), point discharge current (P), number of positive and negative small ions per cm^3 at 1.5 m above the ground (n_+, n_-). We see that the number of small ions of both polarities rises considerably whenever the point discharge current exceeds a certain threshold, and this occurs whenever the potential gradient exceeds a value of 1000 - 1500 V/m (both sign). In our equipment, the number of ions rose appreciably only if the point discharge current reached five times its fine weather values. In the following, we shall use the expression "increased point discharge current" only in such cases where this threshold value is exceeded.

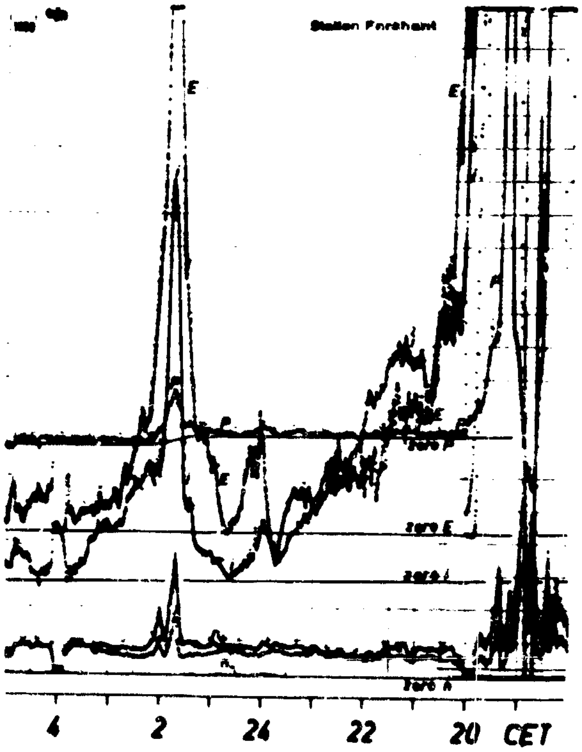

Figure 103

Example of behaviour of potential gradient (E), air earth current (i), point discharge current (P), and number of small ions (n_+, n_-) at station Farchant. Dense snow fall before 20 CET, slight snow fall 02.00 CET. Recorded with electronic potentiometer recorder (Siemens und Halske, Hartmann und Braun)

14.2.2. Collection of precipitation and dew or rime. Method of chemical analysis

Precipitation was collected at Farchant, part of it simultaneously at Farchant and on the Wank peak. Polyethylene-bottles and -funnels, carefully cleaned before each exposure, were used for this purpose. During long continued precipitation, the collecting vessels were always replaced after several hours at the most, especially in cases where the type of precipitation did not remain the same (transition of non-showery into showery or thunderstorm precipitation; transition of rain into snow, etc.).

Thanks to a collaboration with the Max Planck Institut für Silikatforschung it was possible to carry out nitrate and nitrite analyses also of artificial dew or rime. Most of the atmospheric moisture was condensed, as dew or rime, on cooling fins placed in an out-door apparatur sucking about 200 m^3/hr of air through the fins. Dew and rime were analyzed in the same way as was the precipitation.

All the NO_3' and NO_2' analyses were made as soon as possible, in general at once or before the second day after the collectingat the latest. The p_H values were measured with the ionometric method, and that usually immediately after the samples had been obtained.

Nitrate and nitrite were determined colorimetrically with the help of the Griess-Ilosvay Reagent, which is a mixture of sulfanilic acid, alpha naphthylamine, and acetic acid. With this mixture nitrite ions react to yield a red azo dye. For the nitrate determination, part of the water to be analyzed was allowed to run through an acid cadmium reductor, reducing nitrate to nitrite+), and then the Griess-Ilosvay Reagent added. The colors obtained were compared with the colors of fresh mixtures of the reagent with a number of nitrite and reduced nitrate solutions of different but known concentrations, by steps and visually for the nitrite (hence the discontinuous ordinate values in the figures), with a photometer for nitrate. The results are all given in mg NO_3' or NO_2' per litre. The sensitivity was 0.02 mg/litre for NO_3' (limits of error about ±5 %), and 0.002 mg/litre for NO_2' (limits of error in cases of such low concentration about ±15 %). When the NO_2' concentration was found to be certainly less than 0.002 mg/litre, it was noted down as 0.000 or, when using logarithmic coordiantes in figures, as 0.001.

+ The method was developed together with K.Potal and shall be published elsewhere.

14.3. Results

14.3.1. Influence of a difference in altitude of about 1100 m (3600 feet) on NO_3' and NO_2' in precipitation

In Figure 104, the NO_3' and NO_2' concentrations in precipitation samples collected on the Wank peak are plotted against those samples collected simultaneously at the valley station Farchant. It is evident from this figure that there is a systematic relation between the Wank and the simultaneous Farchant precipitation as far as the NO_3' contents are concerned. Predominantly they are higher in the valley than at the peak station. For the NO_2' contents, however, no equivalent relation exists, as is seen on the right hand side of Figure 104.

This means that:

a) On the average, at least 50 % of the NO_3' contents in the precipitation originates in altitudes at least 1000 m above the valley station. Due to influences from near the ground the NO_3' contents vary systematically, i.e. increase by a factor which is nearly the same for all weather conditions.

b) The NO_2' contents of the precipitation are strongly varied, and that unsystematically, by influences from near the ground. Only a small share of the NO_2' contents found in the valley precipitation originates with certainty in altitudes more than 1000 m above the ground (compare table 10).

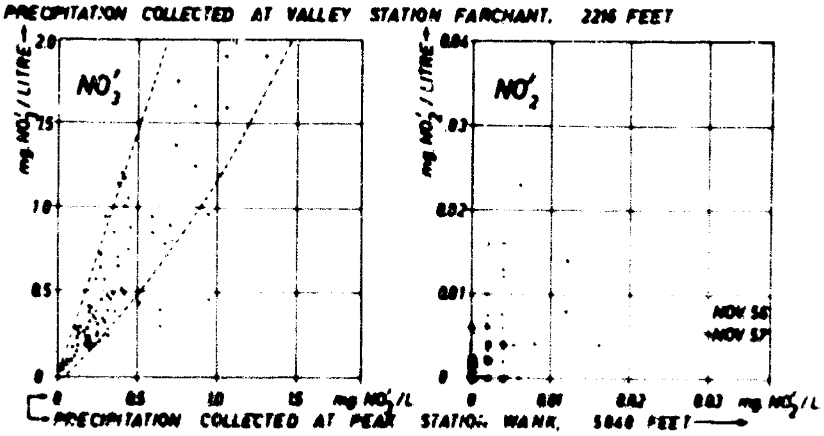

Figure 104

Comparison of precipitation collected at valley station Farchant with that collected at peak station Wank

14.3.2. Comparison of NO_3' and NO_2' in precipitation with contents in dew or rime, both collected in the valley

A comparison of NO_3' and NO_2' contents in precipitation on the one hand, and in artificial dew or rime, which is collected simultaneously, on the other hand, shows how the concentration of nitrogen-oxygen compounds in the precipitation particles increases during their fall through the layer near the ground, since the chemical properties of the latter are indicated by dew and rime. In Figure 105, the case of non-showery and non-thunderstorm precipitations is given; we see that the NO_3' concentrations in dew (rime) do not correlate with and are smaller (factor about 2 - 10) than the NO_3' concentrations in simultaneous precipitation. With respect to NO_2', a clear correlation between dew (rime) and precipitation concentration is demonstrated by the figure. The NO_2' contents in dew (rime), furthermore, is about twice that of precipitations.

We may conclude that:

a) The influence of the nitrogen-oxygen compounds in the layer near the ground (indicated by nitrate in the artificial condensate) on the NO_3' contents of the precipitations is small;

b) with increasing nitrogen-oxygen compounds in the layer near the ground (indicated by nitrite in the artificial condensate), the NO_2' contents of the precipitation increase too.

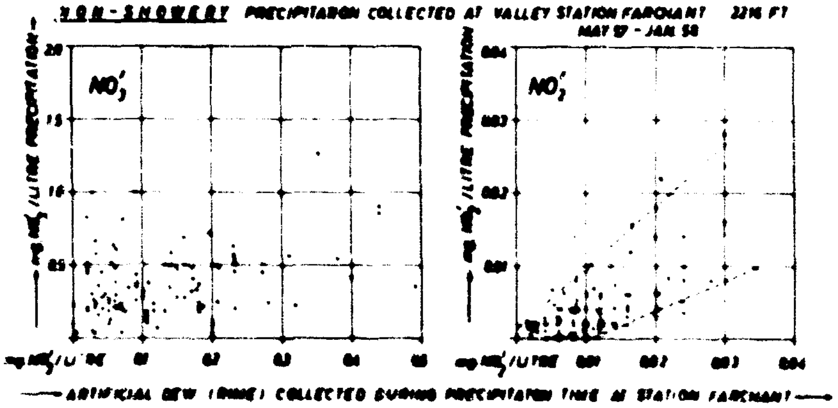

Figure 105

Comparison of precipitations with artificial condensate, both collected simultaneously at valley station Farchant. Non - showery precipitation

Regarding only the conditions during shower and thunderstorm precipitation (Figure 106) we find the ratios of NO_3' in precipitation to NO_3' in dew or rime and (less clearly) NO_2' in precipitation to NO_2' in dew or rime on the average to be shifted, compared with non-showery conditions, in favour of the contents in the precipitation. This suggests that the increase, compared with non-showery conditions, of nitrate and nitrite in the shower and thunderstorm precipitations is caused predominantly by an absorption of nitrogen oxides at <u>higher</u> levels.

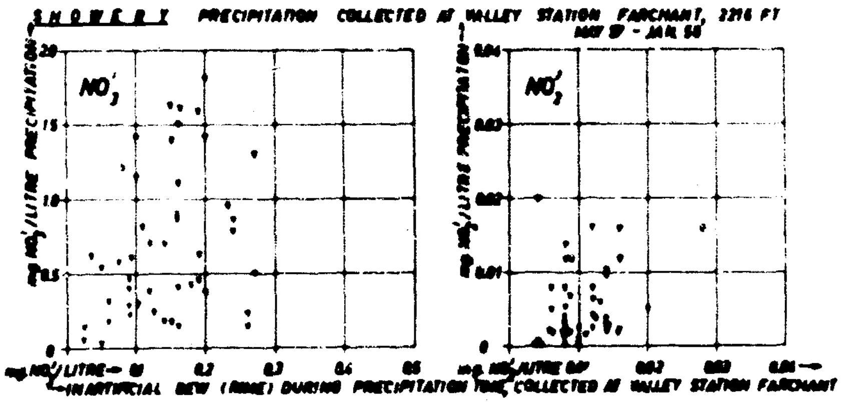

Figure 106

Comparison of precipitation with artificial condensate, both collected simultaneously at valley station Farchant. Shower precipitation.

<u>14.3.3. Influence of point discharge near the ground on the NO_3'- and NO_2' contents in precipitations and artificial dew or rime, both collected in the valley</u>

It may be supposed that detectable amounts of NO and NO_2 are formed near the ground at times when the point discharge near the numerous points on the earth's surface (on plants, houses, etc.) increases (see section 14.2.1.). The duration of increased point discharge current as a percentage of the precipitation duration was chosen as a relative measure in the evaluations.

As is illustrated in Figure 107, there is no influence of the duration of increased point discharge current on the NO_3', but a definite one on the NO_2' contents of precipitation. If the concentration is more than 0.01 mg NO_2'/litre,

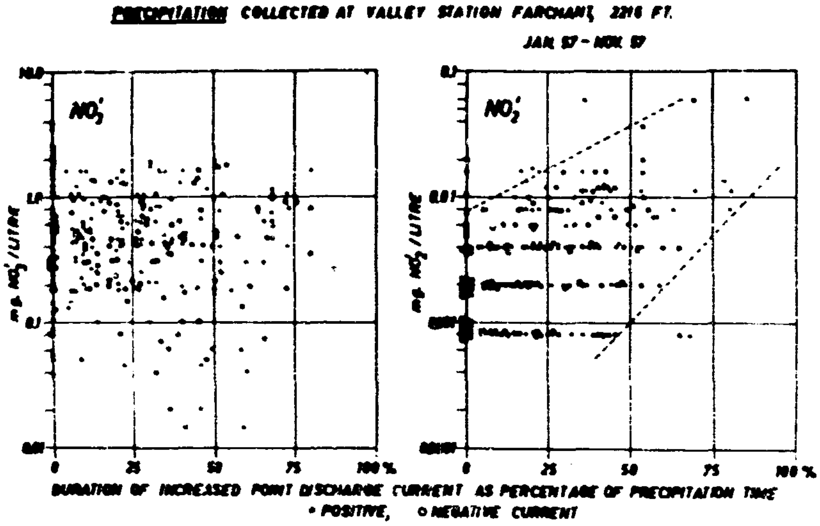

Figure 107

Influence of point discharge on nitrate and nitrite contents in precipitation

the point discharge current is increased during about 25 - 50 % of the precipitation time; if it is less than 0.002 mg NO_2/litre, the point discharge current is increased, on the average, during less than 25 % of the precipitation time.

Corresponding results were obtained from the NO_3' and NO_2' analyses of the

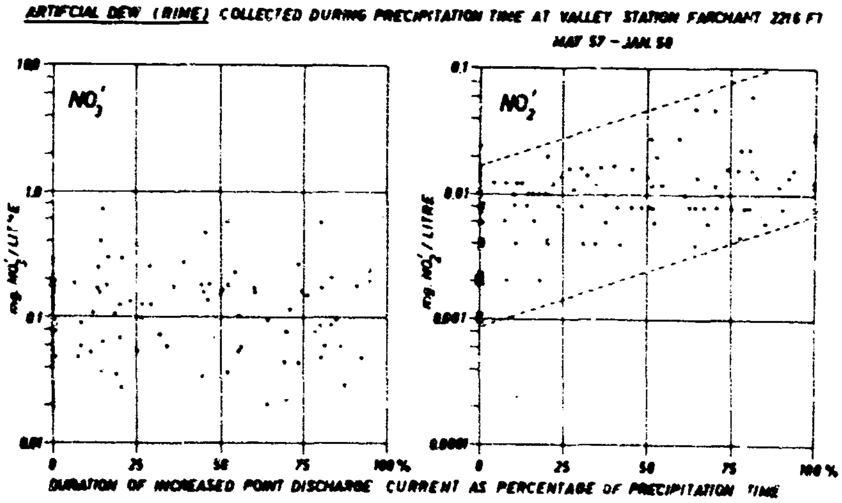

Figure 108

Influence of point discharge on nitrate and nitrite content of artificial condensate artificial condensate (Figure 108): the NO_3' concentration is not influenced by the duration of increased point discharge current, but the NO_2' concentration clearly rises with rising percentages.

This study demonstrated: during extended periods of increased point discharge near the ground, detectable amounts of nitrogen oxides are formed. They cause the NO_2' concentration to rise in the artificial condensate (but are not large enough to influence noticeably the NO_3' values, which are so much higher). Also in precipitations, they influence only the NO_2' but not the NO_3' contents, which is in agreement with section 14.3.2.

14.3.4. Influence of the lability energy in the 700 - 500 mb layer on the NO_3' and NO_2' contents of precipitation collected in the valley

In section 14.3.2. it was found, that in shower and thunderstorm precipitation there is more NO_3' than in the non-showery type. It appeared interesting, therefore, to examine if a correlation exists between the atmospheric lability degree and the NO_3' and NO_2' contents in precipitations. Relative values of the lability energy between 700 and 500 mb, which layer proved to be the most important for our studies and therefore was used in the evaluations, were obtained as described in section 4.2.7.

The results of this examination are given in Figures 109 (rain) and 110

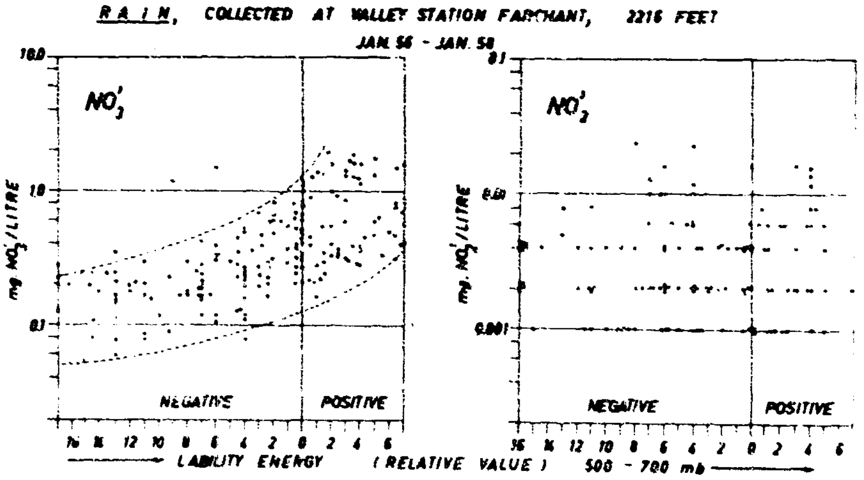

Figure 109

Correlation between lability energy of the 700 - 500 mb layer and nitrite or nitrate content in rain (snow). Neither in rain nor in snow does the NO_2' concentration exhibit any obvious correlation with the lability energy, but the NO_3' concentration does, both in rain and in snow.

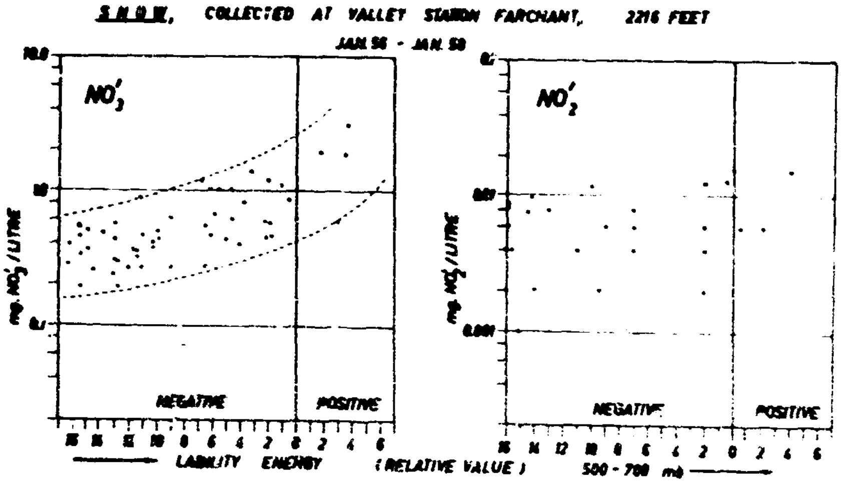

Figure 110
Correlation between lability energy of the 700 - 500 mb layer and nitrite or nitrate content in snow

In the case of negative lability energy, the NO_3' concentration in rain is below 1.0 mg/litre, sometimes even below 0.1 mg/litre. In the case of positive lability energy, the range is 2.0 - 0.2 mg/litre. All the NO_3' concentrations found during high lability energy are higher than those found during extreme negative lability energy. The results for snow are analogous, but the NO_3' values are higher than in rain.

Thus we can state: the NO_3' content of precipitations is clearly increased with rising lability energy of the atmospheric layer between 700 and 500 mb, while the NO_2' contents do not shew any correlation with it. This is true for rain and for snow.

14.3.5. Influence of the frequency of sign reversals of the foreign field on the NO_3' and NO_2' contents of precipitations collected in the valley

Synoptic atmospheric electric investigations have demonstrated that during precipitation a correlation exists between the frequency of the sign reversals of the foreign field and the simultaneous lability energy in the 700 - 500 mb layer (compare section 4.2.7.).

In this connection an investigation seemed appropriate concerning the correlation between frequency of sign reversals of the foreign field and NO_3' or NO_2' contents in precipitation. The study was based on the mean frequency of sign reversals per hour computed from the potential gradient records at the low level stations Farchant, Garmisch and Eibsee. The result is given in Figure 111. The NO_2' contents show no correlation, but a rather close connection appears between NO_3' contents and frequency of sign reversals of the foreign field. For instance, the NO_3' concentration in the case of 3 reversals /hr is ten times the concentration found in the case of 0.5 reversals/hr.

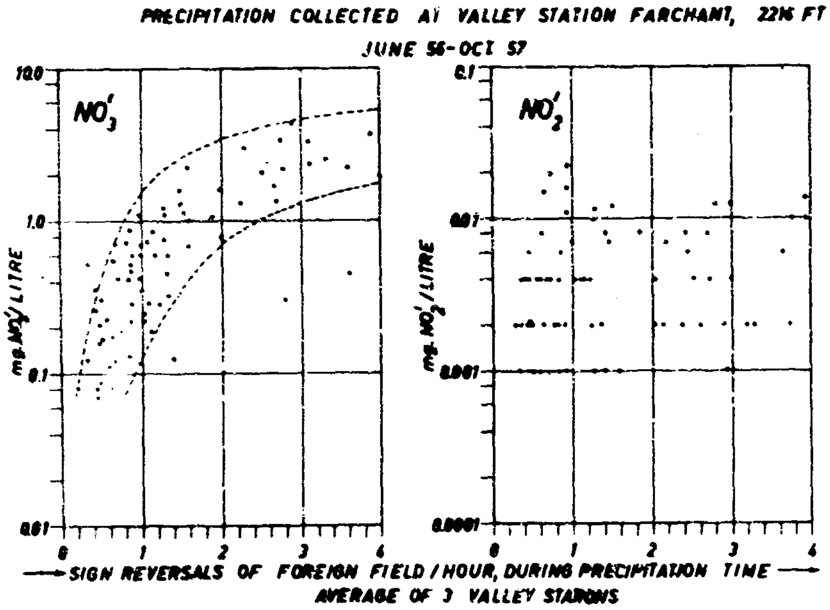

Figure 111

Correlation between the frequency of sign reversals of the potential gradient and nitrate or nitrite contents in precipitation

We may conclude, that the NO_3' content of precipitation is closely connected with such atmospheric electric processes as are important also for the sudden and frequent sign reversals of the foreign field. This possibly means, on the other hand, that the NO_3' content in precipitation may be regarded as sensitive indicator for important electric processes, occurring during the formation of precipitation and of shower and thunderstorm charges. Such a supposition would be confirmed by the facts reported in sections 14.3.1. and 14.3.5., namely that only a low percentage of the NO_3' content of precipitation is affected by influences from near the ground. According to 14.3.1., the NO_3' content of precipitation during the fall through the lowest 1000 m, is increased not more than by the factor 2, and not at all by the factor 10 or 20, which on the other hand, can accompany increasing sign reversals. Since the NO_2' concentrations are indicatory of processes near the ground, as our data suggest, it is reasonable that they do not show any correlation with the frequency of sign reversals of the foreign field.

14.3.6. Tabular survey of results

In Table 8 the results of analyses are summarized which were obtained for the precipitation samples collected at Farchant, and in Table 9 we have the analogous Wank values. The date are given separately for each type of precipitation. In Table 10, the proportions Wank-value to Farchant-value are presented. The tables demonstrate, that more nitrate and nitrite is in shower precipitation and, excepted Wank values for nitrite, in snow, than in uniform rain. The thunderstorm values, again excepted Wank values for nitrite, are situated about at the middle of the sequence. Especially high nitrate values are found in hail and in rain of very large drops occurring at the beginning of some shower rainfalls, but here we have few data and this result, therefore, is rather uncertain.
The proportions concentration NO_3' to concentration NO_2' differ greatly from each other. The proportion is most shifted in the direction of NO_3'

a) on Wank peak during thunderstorm

b) in the valley (Farchant) during snow shower (rain of very large drops and graupel omitted).

The average values NO_3' concentration / NO_2' concentration are 105 at the valley station Farchant and 185 at the peak station Wank, in agreement with Table 10. This may signify that most of the nitrogen-oxygen compounds are oxidized, while the precipitation is falling down to the Wank, and that new nitrite is absorbed, while it is falling from the Wank level down to the valley.

Table 8

NO_2' / Litre in precipitation collected at valley station Farchant

	snow showers	rain showers	steady rain	steady snow	thunderstorm rain	rain, large drops	graupel	all precipitation
mean value	0.0095	0.0054	0.0036	0.0086	0.0067	0.0050	0.012	0.0054
maximum	0.040	0.063	0.040	0.024	0.063	0.012	0.012	-
minimum	0.000	0.000	0.000	0.000	0.000	0.002	0.012	-
number of analyses	20	93	136	35	26	8	1	319

NO_3' / Litre in precipitation collected at valley station Farchant

	snow showers	rain showers	steady rain	steady snow	thunderstorm rain	rain large drops	graupel	all precipitation
mean value	1.199	0.641	0.300	0.626	0.732	1.694	1.60	0.5673
maximum	2.00	3.45	1.10	1.30	2.20	3.50	1.60	-
minimum	0.38	0.04	0.00	0.08	0.12	1.05	1.60	-
number of analyses	20	94	135	35	27	8	1	320
$\frac{\text{conc. } NO_3'}{\text{conc. } NO_2'}$	126	119	83	73	109	339	133	105

Table 9

NO_2' / Litre in precipitation collected at peak station Wank

	snow showers	rain showers	steady rain	steady snow	thunderstorm rain	rain, large drops	all precipitation
mean value	0.0040	0.0028	0.0019	0.0016	0.0012	—	0.0020
maximum	0.006	0.012	0.008	0.004	0.004	—	—
minimum	0.002	0.000	0.000	0.000	0.000	—	—
number of analyses	3	15	27	20	5	—	70

NO_3' / Litre in precipitation collected at peak station Wank

	snow showers	rain showers	steady rain	steady snow	thunderstorm rain	rain, large drops	all precipitation
mean value	0.533	0.550	0.268	0.339	0.346	—	0.375
maximum	0.72	1.30	1.10	0.90	0.70	—	—
minimum	0.43	0.03	0.02	0.06	0.06	—	—
number of analyses	3	19	27	21	5	—	75
$\frac{\text{conc. } NO_3'}{\text{conc. } NO_2'}$	133	196	141	212	288	—	185

Table 10

Ratio: $$\frac{NO_2' \text{ / Litre in predipitation collected at peak station Wank}}{NO_2' \text{ / Litre in precipitation collected at valley station Farchant}}$$

snow showers	rain showers	steady rain	steady snow	thunderstorm rain	all precipitation
0.421	0.519	0.528	0.186	0.179	0.196

Ratio: $$\frac{NO_3' \text{ / Litre in precipitation collected at peak station Wank}}{NO_3' \text{ / Litre in precipitation collected at valley station Farchant}}$$

snow showers	rain showers	steady rain	steady snow	thunderstorm rain	all precipitation
0.445	0.858	0.893	0.542	0.473	0.662

Table 11

p_H values in precipitation collected at valley station Farchant

	snow showers	rain showers	steady rain	steady snow	thunderstorm rain	all precipitation
mean value	5.73	6.27	6.10	6.13	6.37	6.14
maximum	7.20	7.02	7.20	6.40	7.30	--
minimum	3.72	5.52	4.40	5.14	5.60	--
number of measurements	8	35	66	14	11	134

As is shown in Table 10, the NO_3' contents of the Wank precipitations, on the average is 66 % of that determined in the valley. The analogous percentage for NO_2' is only 20 %.

By these tables, the statements derived in sections 14.3.1. - 14.3.3. from the figures are confirmed.

In Table 11, the results of the p_H measurements are summarised. Here, too, the different kinds of precipitation are separated. The values in rain shower, thunderstorm rain, even rain, and snow are nearly the same. The differences are assumed to be casual ones. Only the low p_H values in snow showers are rather striking. Since the highest NO_3' values also are found in showery snow, it is imaginable that the low p_H is caused by the existence of free acid (HNO_3) (compare McCabe (1957): nitrogen oxides are catalysts for the oxidation of SO_2 and responsible in part for acidity in rain and fog.).

14.4. View points on the origin of nitrate and nitrite in precipitations

14.4.1. Sources of atmospheric nitrogen oxide (NO) and nitrogen dioxide (NO_2)

In section 14.5., we shall discuss the experimental results given above. Before this, it seems suitable to state the most important sources which exist for NO and NO_2 (or N_2O_4, which is in equilibrium with NO_2) in those atmospheric layers where precipitation is found. In this connection we may recall the fact that NO easily combines with atmospheric oxygen by the exothermic reaction:

$$2\ NO + O_2 \rightleftharpoons 2\ NO_2 \qquad (1)$$

At 200° C, this equilibrium still lies far over to the right side; at 650° C, however, all NO_2 molecules decompose to NO and O_2.

a) NO is a highly endothermic compound. One of the ways of formation is that by the action of electrical discharges upon air:

$$N_2 + O_2 \rightleftharpoons 2\ NO \qquad (2)$$

A reaction mechanism starting from the ionisation of the nitrogen molecule:

$$N_2 \rightarrow N_2^+ + e \qquad (3)$$

has been suggested by a number of authors (Henry (1930), Wansbrough-Jones (1930), and others); it seems plausible, because NO formation just sets in at a voltage corresponding to the ionisation energy of N_2 according to (3), i.e. at about 17 eV. The NO formation is accelerated at about 23 eV, where dissociation into the atoms N^+ and N takes place. Since 17 eV are easily reached in all kinds of atmospheric discharges, also in silent discharges, we are perhaps allowed to say that the occurrence or at least a high value of NO or NO_2 is an indicator of ion production in the air. This is true even if ionization reactions, such as (3), are not the only mode of formation of NO or NO_2.

Although the amount of NO being in equilibrium with air is only 5 % by volume at 3000° C and 1 % by volume at 2000° C, such percentages are possible also at lower temperatures, if the NO, once formed, is cooled very quickly to temperatures of slow equilibrium establishment, where it is metastable.

Reynolds (1923, 1930) found that the proportion of NO_2 in the atmosphere never did increase during thundery weather. This is not inconsistent with the above statements and with the experimental results presented in section 14.3., since Reynolds made analyses of air, and not of the thunderstorm precipitation, which absorbs the NO_2 existent in the air (see below 14.4.2.). Mukherjee (1955) states that electric spark discharges in the atmosphere are not primarily responsible for formation of nitrates in rain, although they may have some effect in the lower atmosphere. This statement must not be considered inconsistent with the data of section 14.3., which show a certain nitrate level in all kinds of precipitation (compare section 14.5.).

As is well known, ozone (O_3) also is formed by electrical discharges.

b) Industrial and technical origin: NO_2 may be regarded as the most prevalent of the oxides of nitrogen in air pollution and smog; it is liberated in many chemical processes, by internal combustion engines, overhead transmission lines, during welding operations, etc. Many papers deal with the relatively high concentration of NO and other nitrogen oxides in the air of Los Angeles and other towns (see survey given by Miller (1954)).

NO_2 of this origin, of course, is formed near the ground; according to the meteorolocical conditions it is transported in horizontal and vertical direction. It has to be mentioned that for an area of about 30 miles radius round Farquart there are now towns nor industrial works.

14.4.2. Reactions of nitrogen oxide and nitrogen dioxide with water

The processes occurring when NO or NO_2 or mixtures of these oxides react with water are very complex, and depend on many factors such as quantity and kind of cations present, presence of ozone, concentrations of NO or NO_2, physical state of the water, temperature, available time, etc.

One possible reaction is:

$$NO + NO_2 + H_2O \rightleftharpoons 2\ HNO_2 \qquad (4)$$

In cases where we may assume that there is sufficient time (several minutes), that most of the NO, if present, be oxidised to NO_2, the main reaction leading to nitric and nitrous acids and nitrates and nitrites in precipitation will be:

$$2\ NO_2 + 2\ OH^- \rightleftharpoons NO_2^- + NO_3^- + H_2O \ (5)$$

Nitrous acid decomposes easily by the endothermic reaction

$$3\ HNO_2 \rightleftharpoons HNO_3 + 2\ NO + H_2O \qquad (6)$$

This decomposition is promoted by rising temperature and by all the circumstances which favour elimination of the NO (reactions, again yielding HNO_2, according to (1), (4), (5), and (6)). Solutions of nitrites are more stable than those of nitrous acid, their stability depends on the cation, p_H, concentration, temperature, etc. Free HNO_2 of very low concentration is said to decompose not so easily as do less dilute solutions; on the other hand, the formation of nitrates is promoted in the presence of ozone.

14.5. Discussion and conclusions

The data obtained suggest that no detectable share of the nitrate contents in precipitation and artificial condensate is caused by point discharge at the earth's surface (section 14.3.3.; Figures 107 and 108). Most of the nitrite contents in the valley precipitation, it is true, is formed near the ground (section 14.3.6., table 10), and that at least partly by the influence of point discharge (section 14.3.3., Figure 107). But the average nitrite amount in precipitation caused by lasting point discharge is only about 0.01 mg/litre (Figure 107), and, owing to relatively low temperature, little available time, etc., not much more nitrate can be formed by the same process (see section 14.4.). Since the average NO_3' contents in precipitations collected in the valley is found to be about 0.5 mg/litre, and even more for showers and thunderstorms (table 8), the nitrate added near the ground by point discharge, therefore, is within the limits of error and can be neglected (Figure 107). On the other hand, the NO_3' contents in the valley precipitation rise by the factor 5 - 10 (14.3.4.; Figures 109 and 110), when stable stratification is changed into unstable one in the 700 - 500 mb layer. Accordingly the NO_3' contents in precipitations are essentially increased with the transition from non-showery to shower or thunderstorm precipitation (section 14.3.2., 14.3.6.; Figures 105 and 106; tables 8 and 9 (valley and mountain top). An especially clear increase of the nitrate contents in the precipitation is observed, when the frequency of sign reversals of the field is increased (section 14.3.5.; Figure 111). A certain NO_3' amount, however, is found also in steady precipitation, in the valley and on the Wank peak, caused perhaps by electrical processes occurring also in nimbo-stratus clouds; this amount is not likely to be caused by industrial or similar processes, for we could observe that in the course of long continued strong steady precipitation its nitrate contents is not diminished.

From these facts it is evident that those 60 - 70 % of the valley precipitation nitrate contents which are found already on the Wank top and thus originate at altitudes at 1000 m higher than the valley station (section 14.3.1.; Figure 104; table 10) essentially are formed not on the Wank's surface, but higher up, and that also the nitrate increment observed during showers and thunderstorms is due to electrical processes in the free atmosphere. The comparison of tables 8 and 9 shows furthermore that the proportion NO_3'/NO_2' always is higher at the Wank than at Farchant. This, too, may indicate that the origin of the nitrogen-oxygen compounds in the precipitation must be at altitudes high above the Wank, so that there is enough time for the NO_2' to be oxidized.

Therefore, if it is allowed to assume that formation of nitrogen oxides or nitrates is connected with ionization processes in the atmosphere, then we may, with all reserve, conclude from our data, that during all kinds of precipitation many more ions are formed in the cloud level, e.g. at more than 1000 m above the ground, than near the ground by point discharges. Anyway, the field strengths occurring in the cloud level must be supposed to be higher than those near the ground.

As far as the artificial condensate is concerned, its nitrate concentration is not appreciably influenced by point discharge near the ground, unlike its nitrite concentration (Figure 108). The reasons may be the same as suggested above for the case of precipitation. The nitrate content in the condensate is not influenced by whether simultaneous precipitation is showery or not (Figures 105 and 106), since the condensate represents the chemical properties of the atmosphere near the ground, where it is collected.

As to thunderstorms, it is surprising that the highest nitrate and nitrite concentrations are determined not in thunderstorms, but in showers, especially snow showers (Tables 8 and 9). We cannot explain this fact as yet. Besides we learn from table 8 and 9 that an especially high proportion NO_3'/NO_2' is observed in thunderstorm rain collected on the Wank peak.

The following objection could be raised to the assertion, that the nitrate increase found during unstable conditions is due to electrical discharges in the free atmosphere at higher altitudes: during strong turbulence the vertical exchange of the air is considerable, so that nitrogen oxides from near the ground are transported higher up than during stable conditons. These gases then can be absorbed by precipitation much more thoroughly than in cases where the precipitations meet them only in a relatively thin layer above the ground. This objection, however, is decidedly refuted by the fact, that in precipitations lasting several hours and even days no tendency of the nitrate contents to decrease could be observed (see above). On the contrary, the nitrate concentration rises during lasting precipitation as soon as steady precipitation changes into showery or thunderstorm precipitation, The NO_2' contents of the precipitation, on the other hand, which always are indicatory of chemical processes near the ground, were observed to be diminished in the course of long precipitation periods.

Workman and Reynolds (1950) point to the phenomenon that, with certain contaminants in freezing water, potential differences of as much as 250 V arise between the solid and liquid phases. According to Reynolds (1955) contaminations of 10^{-4} mole NaCl per 1000 g ice are sufficient to produce effects on the frictional charging (compare Reynolds et al. (1955a, 1955b)). In this connection it might be of interest that the maximum concentrations of NO_3', which we found in solid (liquid) precipitation, are 2 (3.5) mg/litre, i.e. 3 (5) x 10^{-5} mole/litre (Table 8), thus of nearly the same order of magnitude. If also nitrate contaminants should be important in the process of cloud electrification and charge separation, they could, caused by discharges, again cause discharges and thus an avalanchelike accumulation of electricity, when showers or thunderstorms are built up.

The matter is complicated and the conclusions are presented for discussion more than for acceptance. The results are to be confirmed and refined by more observations and data. In particular, the relations between nitrogen-oxygen compounds in precipitation and atmospheric electric processes have to be studied more thoroughly, since it seems certain that the nitrate contents of precipitation must be taken into consideration as indicatory of processes occurring in the cloud level.

5. Mean diurnal variations of the atmospheric electric magnitudes per month or season at each station during fine weather

As already mentioned in section 1., the fine weather[+] hourly means of potential gradient and air earth current were determined for each month and season and for each of the stations. They will serve to make possible comparisons with the data of other investigators obtained in other geographical regions and climates. In the course of our work they were needed as a base, deviations from which were characteristic of and due to bad weather and just the main subject of our studies; thus the fine weather means were a sort of by-products. They are being published in volume II, part A, of the present Report, where we shall find for each station:

1) The mean diurnal variations (average hourly means) of potential gradient and air earth current for each individual month of the years 1955, 1956, and 1957.
   The diurnal variation curves of the single stations are arranged for each month on one separate page, one above the other according to the altitude above sealevel. Opposite to each such plate there is a table giving numerically the same data as are used in the plates and additionally the total monthly mean for each station as well as the number of fine weather days. Each table and each plate contains a key to the signs used.

2) The mean diurnal variations (average hourly means) of potential gradient and air earth current for each individual meteorological season[++] from fall 1954 till winter 1957/58.
   The arrangement on the plates and the accompanying tables are analogous to those mentioned under 1.

3) The mean diurnal variations (average hourly means) of potential gradient and air earth current for the four meteorological seasons[++], the seasonal mean values for each hour of day being formed of the data of <u>all</u> the respective seasons from fall 1954 - winter 1957/58.
   The arrangement on the plates and the accompanying tables are analogous to those mentioned under 1.

[+] By "fine weather" we understand a weather situation where: a) it is cloudless, or there is only Cumulus with not more than half of the sky overcast and/or Cirrus and b) the respective station is not within fog and c) there is no precipitation, consequently.

[++] "Meteorological seasons": winter = December, January and February,
spring = March, April, and May; etc.

The recording and evaluation work is still being continued for a time, and further data shall be obtained. Therefore the results given in volume II, part A, will not yet be discussed definitively here. However, we wish to state the following:

The variation of the atmospheric electric elements on fine weather days are strongly influenced by the orographical position of the station. At the high level stations Wank and (especially) Zugspitze the influenze of "Austausch" becomes evident, if we compare the potential gradient curves with the air earth current curves: when nuclei are carried up to the station level by convection, the potential gradient is increased, while the air earth current is lowered. Therefore, in the seasons with strong exchange, not even at Wank and Zugspitze the maxima of potential gradient and air earth current coinside with the oceanic or arctic maxima, which are worldwide and found in fine weather at the same Greenwich Mean Time everywhere. On the other hand, at station Zugspitze the maxima are synchronous with the worldwide oceanic or arctic maxima during most of the winter months. Thus, only in winter and at altitudes of at least 2500 m above the sealevel, the global maxima, which are independent of the local time, can be observed over the continent of Central Europe. At 1800 m above sealevel, as is shown by the Wank results, both maxima are influenced by the exchange even often in winter.

Sunrise and sunset effects[+]) are especially clear at the valley stations: the potential gradient here decreases about at sunset time, immediately after sunrise it increases. Consequently, at the valley stations the daily day-time maxima are higher and broader in summer than in winter. Mean diurnal variations of the potential gradient in fine weather with two maxima per twenty-four hours occur seldom.

At the slope stations Eibsee, Obermoos, and Riffelriss, the fine weather curves are less easy to be understood; they are strongly influenced by inversion levels and orographic upward or downward winds preponderating in the respective month.

+) These effects will be analyzed in detail in the course of the further work

16. Comparison of the fine weather behaviour of the atmospheric electric magnitudes with water vapour pressure, ΔRF-value, and potential equivalent temperature

According to section 15., the presence or absence of exchange, its range, strength etc., are of considerable importance for the monthly or seasonal mean diurnal variations of the atmospheric electric magnitudes in fine weather. Therefore we studied the correlations between fine weather potential gradient and air earth current on the one hand, and simultaneous water vapor pressure, "convection indicator" ΔRF, and potential equivalent temperature on the other hand. This will be dealt with in the present and last section, though not yet definitively, as the measuring data are still being increased. It is the purpose of this investigation to find out, which of the three mentioned meteorological magnitudes correlates the best with the deviations of the atmospheric electric magnitudes caused by the vertical exchange. The three meteorological magnitudes were calculated from the records of temperature and relative humidity obtained at our station Farchant and at the observatories of the German Weather Service Garmisch and Zugspitze (where our atmospheric electric intruments are housed); to speak more exactly: we calculated them from the hourly mean values of these records, which we determined planimetrically. The methods of calculating water vapour pressure and potential equivalent temperature, the latter by using the respective values of atmospheric pressure, may be presumed to be well known. The method of calculating the ΔRF values will be found in volume II, Part B. It has been described already in Technical Report AF 61 (514)-732-C (p. 72 foll.), where first results with this magnitude have been reported upon.

Volume II, Part B of the present Report gives the results of the evaluation, which are obtained till now; it gives for the stations Zugspitze, Garmisch and Farchant and for each individual season of the years examined the mean diurnal variations (average hourly means) of

a) water vapor pressure (e)
b) ΔRF value
c) potential equivalent temperature (Tp)
d) potential gradient (E) (as in part A 2 of volume II)
e) air earth current (i) (as in part A 2 of volume II)

in fine weather, and that again in graphs and tables.

First let us look at the curves of station Zugspitze: we notice that the typical behaviour of potential gradient (E) and air earth current (i), which is caused by exchange in the afternoon, only occurs in seasons when at the same hours of day, Tp and Δ RF show very high maxima (consider scales of ordinates!). Usually also the water vapor pressure shows a simultaneous maximum, but not always; so it would appear that it is less suitable for examining exchange problems than the other two meteorological magnitudes considered. In winter, when potential gradient and air earth current at station Zugspitze show the curves typical of records also of arctic or oceanic stations, there is no pronounced maximum in the diurnal curves of Tp and Δ RF: not even during insolation the station is reached by air masses from the layer near the ground.

In Garmisch, pronounced maxima of RF and Tp were found in all seasons. The Maxima of e, if existent, are only slight. The depression of the Δ RF curve found within the maximum in spring and in summer, sometimes also in fall, but never in winter, must be regarded as a typical criterion of the exchange being just at its culmination and carrying up and away from the valley part of the humidity and of the nuclei. The correlations between the meteorological magnitudes on the one hand, and the atmospheric electric magnitudes on the other hand are not easily to be surveyed. For the present we can state:

During the above mentioned depression in the maximum of the Δ RF curve, both air earth current and potential gradient are lowered, the potential gradient remaining much higher than the diurnal mean value of the respective season (this = 100 %), while the air earth current goes below its diurnal mean value. The Tp curves always are strikingly parallel to the potential gradient curves.

The curves of station Farchant, because of local influences, can not easily be accounted for as yet.

The correlations mentioned in section 16 are intended more to be presented than to be analyzed. A profounder analysis, including further data which are being collected, will be given later on.

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