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METEOROLOGICAL OFFICE

FORECASTING TECHNIQUES BRANCH MEMORANDUM No. 8.

TESTS OF THUNDERSTORM FORECASTING METHODS

by

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PREFACE

Forecasting Techniques Branch Memorandum No. 7, "Forecasting techniques in use at Meteorological Office outstations", lists a large number of techniques - about 100 - in use by forecasters at outstations. Many of the techniques represent different methods of grappling with the same forecasting problem, and Memorandum No. 7 discusses the need for assessing the relative merits of such techniques in order that forecasters may have a rational basis for the selection of which technique to use on any particular occasion.

A number of forecasting techniques are at present being tested under operational conditions by outstation staff of the Meteorological Office. This memorandum is the first report on such tests and describes the results of tests of several methods of forecasting thunderstorms obtained by forecasters at stations under the control of S Met O., Manby.

The tests were carried out only over one summer and not all thunderstorm situations will be well represented, a fact which should be borne in mind when considering the results. Nevertheless, the results are illuminating and should enable forecasters to improve the service given to the user of the forecast by a careful choice of the method best suited to the synoptic situation and the user's requirements. This last point should be stressed since not all customers require the best all-round accuracy; some may prefer to receive a number of wrong forecasts of thunderstorms, say, in order not to miss being warned of those storms which do occur.

The report indicates, perhaps rather surprisingly, a weakness in forecasting thunderstorms when convection is augmented by the presence of a front or an isobaric trough. This indicates the need for further investigation and for care on the part of the forecaster confronted with such a synoptic situation. Hanssen's technique, included in the tests discussed in this report, gives good results when used in such a situation, despite the need for further development. Some details of this technique, which may not be widely known to forecasters in the British Isles, are given in an annex to this report.

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Tests of thunderstorm and hail forecasting methods

A report is given on tests of various forecasting methods for thunderstorms and hail which were carried out within the Manby Group of stations during the six months 1st April to 30th September, 1965.

1. Thunderstorm forecasting

1.1. Basis of testing

Forecasting techniques were allocated to stations such that, where possible, a station which was already using a method should be responsible for testing it.

The tests was arranged only for normal working days (i.e. usually Mondays to Fridays) during the six months, since many of the outstations were closed at weekends.

It was required that, at each station, the forecaster should use 0001/0600 GMT upper air data with the chosen technique, allow for effects of advection and surface heating as seemed appropriate, and record a simple Yes or No forecast for thunderstorms occurring in the Manby Group area in the period 1200-2359 GMT. The area concerned covers eastern and central England from the Scottish border down to near London.

The one exception to the procedure mentioned was that one of the methods, that due to Hanssen, is purely objective, and in that case no adjustments were made for advection or heating. This technique was not prepared to deal with all occasions, and had to be abandoned when a trough or ridge lay to the east of the area.

A record of whether thunderstorms actually occurred on each test day was kept at Manby, and subsequently used in marking outstation results. SFLOC reports were counted positive.

For the purpose of comparison, it was considered worthwhile including, with the results obtained for the various individual techniques, the results obtained by the Manby forecasters in the course of their ordinary forecasting practice. It was hoped that by this means, the results would show under what conditions general forecasting practice could be improved by use of newer techniques, and which techniques are best suited for use in different circumstances. In the tables giving the results of tests, these Manby forecasts are included under the heading "General practice". The question whether or not thunderstorms were forecast was decided by ascertaining whether or not this item had been included in the routine forecasts or aviation warnings issued by Manby up to 1200 GMT. These forecasts

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and warnings relate to the same area as that covered in the tests, and the "General practice" results are therefore fully comparable with those obtained in the tests. Aids which were available in the Forecast Room at Manby comprised charts of the Boyden and Similä instability indices, and the objective diagram of Hanssen. No allowance can be made for the extent to which any or all of these were used by forecasters. It may, however, be said that the separate techniques which were being tested at Manby were not dealt with by the forecasters responsible for the general forecasting, and every effort was made to test these techniques in an independent way.

1.2. Overall accuracy of thunderstorm forecasts

Table I shows the overall correctness of forecasts that thunderstorms would or would not occur. This includes the results for all days of the tests.

Table I

Overall accuracy of forecasts that thunderstorms would or would not occur

Method	Reference	Testing Station	No. of forecasts	No. correct	Percentage correct
General Practice	-	Manby	126	99	79
Rackliff	1	Syerston	119	91	76
Simila	2	Manby	125	90	72
Boyden	3	Topcliffe	123	87	71
Modified Jefferson	4	Strubby	124	87	70
Miller/ Starrett	5	Church Fenton	123	86	70
Hanssen	6	Manby	92*	64	70
Galway	7	Stradishall	124	81	65
Showalter	8	Leeming	124	80	65

* 33 abandoned cases, on 8 of which thunderstorms occurred

1.3. Accuracy of forecasts that thunderstorms would occur

Table II shows the correctness of forecasts that thunderstorms would occur.

Table II

Accuracy of forecasts that thunderstorms would occur

Method	No. of "Yes" forecasts	No. correct	Percentage
Rackliff	33	24	73
General Practice	47	33	70
Simila	37	24	65
Miller/Starrett	38	23	61
Hanssen *	48	29	60
Modified Jefferson	48	28	58
Boyden	57	33	58
Galway	58	30	52
Showalter	43	22	51

* see note under Table I

1.4. Accuracy of forecasts that thunderstorms would not occur

Table III shows the correctness of forecasts that thunderstorms would not occur.

Table III

Accuracy of forecasts that thunderstorms would not occur

Method	No. of "No" forecasts	No. correct	Percentage
General Practice	79	66	84
Boyden	66	54	82
Hanssen*	44	35	80
Rackliff	86	67	78
Modified Jefferson	76	59	78
Galway	66	51	77
Simila	88	66	75
Miller/Starrett	85	63	74
Showalter	81	58	72

* see note under Table I

1.5. Overall accuracy of forecasts on frontal or trough days

It is a matter of forecasting experience that thunderstorms are often more difficult to forecast on days when there is a front or isobaric trough over the area than they are on the straightforward convection days. The test results for these occasions were therefore analysed separately from the remainder.

Table IV gives the overall accuracy of forecasts on days when there was a front or trough over the area.

Table IV

Overall accuracy of forecasts that thunderstorms would or would not occur, on frontal or trough days

Method	No. of forecasts	No. correct	Percentage correct
Boyden	42	35	83
Hanssen	35*	26	74
General Practice	42	31	74
Modified Jefferson	42	31	74
Simila	42	30	71
Rackliff	41	29	71
Galway	42	27	64
Miller/Starrett	41	25	61
Showalter	42	23	55

* abandoned on 7 occasions, on 2 of which thunderstorms occurred

1.6. Accuracy of forecasts that thunderstorms would occur on frontal or trough days

Table V shows the accuracy of forecasts that thunderstorms would occur on these occasions.

Table V

Accuracy of forecasts that thunderstorms would occur on frontal or trough days

Method	No. of forecasts	No. correct	Percentage correct
Boyden	16	13	81
Rackliff	10	7	70
Simila	13	9	69
General Practice	16	11	69
Hanssen*	20	13	65
Modified Jefferson	20	13	65
Galway	20	11	55
Miller/Starrett	13	7	54
Showalter	16	7	44

* see note under Table IV

1.7. Accuracy of forecasts that thunderstorms would not occur on frontal or trough days

Table VI shows the accuracy of negative forecasts on these days.

Table VI

Accuracy of forecasts that thunderstorms would not occur on frontal or trough days

Method	No. of forecasts	No. correct	Percentage correct
Hanssen*	15	13	87
Boyden	26	22	85
Modified Jefferson	22	18	82
General Practice	26	20	77
Galway	22	16	73
Simila	29	21	72
Rackliff	31	22	71
Miller/Starrett	28	18	64
Showalter	26	16	62

* see note under Table IV

1.8. Extent to which actual thunderstorms were forecast

For some purposes, the extent to which actual thunderstorms are covered in forecasts may be more important than the accuracy of a forecast whether or not they will occur. Accordingly, the results were examined separately for days on which there were thunderstorms. These days were separated into those occasions of straightforward convection and those on which a front or trough was present.

Table VII shows the extent to which actual thunderstorms were correctly included on the convection days, and Table VIII the corresponding figures for the frontal or trough days.

Table VII

Inclusion in forecasts of thunderstorms which actually occurred - convection days

Method	No. of thunderstorm days	No. correctly forecast	Percentage correct
General Practice	29	22	76
Boyden	28	20	71
Hanssen*	23	16	70
Galway	28	19	68
Rackliff	27	17	63
Miller/Starrett	28	16	57
Modified Jefferson	28	15	54
Showalter	28	15	54
Simila	29	15	52

* this method was abandoned on 6 days of this type

Table VIII

Inclusion in forecasts of thunderstorms which actually occurred - frontal or trough days

Method	No. of thunderstorm days	No. correctly forecast	Percentage correct
Hanssen*	15	13	87
Boyden	17	13	76
Modified Jefferson	17	13	76
Galway	17	11	65
General Practice	17	11	65
Simila	17	9	53
Rackliff	16	7	44
Miller/Starrett	17	7	41
Showalter	17	7	41

* this method was abandoned on 2 days of this type

1.9. Thunderstorm gusts

The Miller/Starrett forecasting diagram includes a line separating those cases where thunderstorms are expected to produce gusts in excess of 30 kts.

The testing station recorded a separate forecast on each day of the test, stating whether or not these gusts were expected. A record of days on which actual thunderstorm gusts exceeding 30 kts were reported was kept at Manby.

In the event, a positive forecast was produced on only 3 days in the six months. Actual reports were logged on 4 days, none of which agreed with the forecasts.

2. Hail forecasting

Tests of hail forecasting by the method of Siskin (9) were carried out at Linton-on-Ouse and Oakington. The simple contingency table was used, a 50% probability of hail being counted positive.

The tests were arranged on a similar basis to those already described for thunderstorms. Each station kept separate records for forecasts based on cloud thickness forecast by the "parcel" and the "slice" methods. Records of actual hail days were kept by Manby, but these records themselves may be less accurate than those for thunderstorms, due to hail not occurring at reporting stations.

As in the thunderstorm tests, the Manby "General practice" forecast for hail has been included for purposes of comparison.

The overall correctness of forecasts that hail would or would not

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occur is shown in Tables IX and X.

Table IX

Accuracy of forecasts that hail would occur

Method	Station	No. of forecasts	No. correct	Percentage correct
General Practice	Manby	22	11	50
Parcel	Linton-on-Ouse	26	10	38
Parcel	Oakington	22	7	32
Slice	Linton-on-Ouse	6	1	17
Slice	Oakington	1	0	0

Table X

Accuracy of forecasts that hail would not occur

Method	Station	No. of forecasts	No. correct	Percentage correct
General Practice	Manby	102	99	97
Parcel	Linton-on-Ouse	94	90	96
Parcel	Oakington	99	92	93
Slice	Linton-on-Ouse	114	101	89
Slice	Oakington	119	105	88

The extent to which actual hail occasions were correctly forecast is shown in Table XI.

Table XI

Inclusion in forecasts of hail which actually occurred

Method	Station	No. of hail days	No. correctly forecast	Percentage correct
General Practice	Manby	14	11	79
Parcel	Linton-on-Ouse	14	10	71
Parcel	Oakington	14	7	50
Slice	Linton-on-Ouse	14	1	7
Slice	Oakington	14	0	0

3. Convective power diagram

Two stations not otherwise involved in the tests were asked to use data from the trial period to prepare convective power diagrams in the manner suggested by Tkachenko (10). Cranwell prepared a diagram for Lincolnshire, and Acklington one for Northumberland and Durham.

The Cranwell diagram suggested that a longer trial could produce a worth-while result. The number of cases is not yet sufficient to decide on this. At Acklington, no useful separation could be obtained between

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the different degrees of convection.

4. Time occupied in applying the techniques

The time taken in the daily routine application of a technique has a clear relation to its overall usefulness as a working tool. Forecasters engaged in the tests were asked to give an estimate of the average time taken daily in each case.

These estimates are given in Table XII.

Table XII

Average time taken to apply the techniques

Technique	Average time daily to apply technique (minutes)
Galway	5
Showalter	5
Miller/Starrett	5
Hanssen	5 - 10
Rackliff	10
Boyden	10 - 15
Modified Jefferson	10 - 20
Simila	60
Siskin	30 - 45

5. Discussion of results

The results in Tables I, II and III show that, taking all occasions together, the normal approach of the forecaster, which includes a subjective examination of tephigrams and other data, produces results which are better, though not very much better, than if he had concentrated on one of the techniques tested.

These results confirm that the more recently introduced instability index techniques give more helpful results than earlier methods from which they were derived. The Simila method gives useful results, but takes appreciably longer to apply (see Table XII) than other similar methods.

Perhaps the most significant results are those in Tables IV, V and VI, which show that on frontal or trough days some stations who concentrated on a particular technique produced better results than "general practice". The Boyden technique, which was designed to include use in the mobile type of situation, provided the most useful overall results on days of this type. The testing station (Topcliffe), where this technique had been in use since it was published in 1963, commented on its special usefulness in frontal or trough situations, and also mentioned that this method often allows quite small areas of thunderstorm activity to be defined and forecast.

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A further Topcliffe comment was that, in straightforward convection cases, the Boyden method tends to overestimate the thunderstorm probability, and on these occasions some other index is useful. Tables I and II confirm this impression and suggest that the Rackliff method is perhaps the most useful aid on these occasions. Table VII, however, shows that the Boyden method is still the most useful aid on convection days, if the object is to include in forecasts as many as possible of the thunderstorms which actually occur.

Table VIII is simply a rearrangement of some of the material already given in Table V, and the two tables should be regarded together. Thus, if the object is to include as many as possible actual thunderstorms, Table VIII shows that on frontal or trough days the Hanssen objective method gives the best results, but it includes some abandoned occasions, and Table V shows the extent to which "Yes" forecasts were wrong. Similarly, Table VIII shows that the Boyden and Modified Jefferson were equally useful in ensuring mention of storms when they occurred, on frontal or trough days, while Table V shows that the Boyden method contributed a higher proportion of successful "Yes" forecasts.

As regards thunderstorm forecasting, the tests seem to lead to the following conclusions:-

(i) On straightforward convection days, one of the several recently introduced instability index methods gives useful assistance to the forecaster. There is an indication of the Rackliff method being the most helpful.

(ii) On days when troughs or fronts are expected in the area, more weight should be given to the instability index, and on these occasions the Boyden index seems definitely the most helpful.

(iii) The Hanssen objective method already shows usefulness on frontal or trough days. This should be well worth further development, using British Isles data, and providing for use on all occasions.

As regards hail forecasting, the Siskin "slice" method seems consistently to under-estimate the cloud thickness, and fails to provide a basis for forecasting hail. Having regard to the time taken to apply this technique, it seems doubtful whether it could be used in daily routine.

6. Acknowledgements

Some forty forecasters have shared in the task of collecting data on which the tests described have been based, and in preparing the check sheets on which the tests were marked. Some were in the position of testing the technique which they already regarded as the most helpful, but many must have been well aware that the method they were testing was unlikely to prove the most effective of its kind. All have contributed to the results, and it is desired to express appreciation of the efforts of all concerned.

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5. Miller, R.C. and Starrett, L.G. Thunderstorms in Great Britain. Met. Mag., London, 91, 1962, p. 247.

6. Hanssen, A.W. An objective method for thunderstorm forecasts. De Bilt, K. Ned Met Inst Wetensch Rapp. 62-1, 1962.

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9. Siskin, N.S. The use of a slice method for forecasting convective cloudiness and precipitation. Leningrad GUEMS, Works of All-Union Scientific Meteorological Council, Vol III, Synoptic Met., Gidrometeorizdat, 1963.

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ANNEX

An objective method for thunderstorm forecasts by A.W. Hanssen
De Bilt, K. Ned.Met.Inst. Wetensch.Rapp. 62-1, 1962

This paper by A.W. Hanssen is the subject of Meteorological Abstract No. 178. The notes and diagrams below are sufficient to enable the method to be used by a forecaster in UK. Further information can be found in Meteorological Abstract No. 178 or better from the English translation of the original paper available from the Meteorological Office Library.

In the original paper the investigation of approximately 1000 cases enabled the data to be divided into categories of "Westerlies" and "Easterlies", but a scatter diagram for only the first category was reproduced. Consequently, without using data for the British Isles to construct the two scatter diagrams required, only "Westerly" cases can be considered.

The procedure is as follows.

1. Note the barometric pressure at 0001 GMT. Subtract 1000 to give pp for use with Fig.5.

2. Calculate the extreme latitude EL of an isopleth of the height of the 500 mb surface at 0001 according to the following rules.

(1) Follow the 500 mb height line through the station, against the wind, until the axis of a trough or ridge is reached. The latitude at which this occurs is called the extreme latitude EL.

(2) If the trough or ridge lies to the east of the station Hanssen's technique should be abandoned (since his published diagram is for westerly cases only).

(3) If the trough or ridge lies more than 15 degrees of longitude away from the station, then the latitude of the intersection of the isopleth through the station with the meridian 15 degrees west of the station is taken as EL.

(4) Axes of ridges or troughs which are 3 degrees of longitude or less from the station are ignored.

(5) If a point is reached more than 12 degrees of latitude North or South of the station then this value is taken as the extreme latitude.

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3. Use Fig. 5 to calculate the value of parameter X. The values of EL printed along the abscissa should be modified by adding algebraically to each number the value of station latitude minus De Bilt latitude.

4. Calculate the saturation deficits at 850 mb and 700 mb in gm/kgm. (Using the TØ gram saturation deficit is the value in gm/kgm of the pecked line through the dry bulb temperature minus the value of the pecked line through the dew point temperature.) Convert these into half-gm/m^3 using the tables provided and add them together to give D for use with Fig. 8.

5. Calculate the difference in decametres of 1000-700 mb thickness minus 700 - 500 mb thickness at the station to give $\Delta_{\Delta h}$ for use with Fig. 8.

6. With the values for D and $\Delta_{\Delta h}$ calculate parameter Y using Fig. 8.

7. Using the values of X and Y with the contingency table shown in Fig. 10, a thunderstorm forecast is produced. Blank squares in Fig. 10 imply a negative thunderstorm tendency, filled squares a positive one. The positive thunderstorm class was subdivided into three. Class V were those cases where a maximum of 5 reports of thunderstorms were received from the 10 reporting stations in the Netherlands used by Hanssen. Class ☈ were those cases where a minimum of 6 reports were received and class P were those cases which could not be fitted into either of the other classes. (Fig. 10 includes as positive forecasts all boxes for which the probability of thunderstorms exceeds the climatological averages - see third paragraph of comments by the abstractor of Forecasting Abstract No. 178. The two cases mentioned by the abstractor are omitted from the text of the paper, but are in fact included in diagrams Nos. 9 and 10.)

(Note: times shown on Figs. 9 and 10 are Central European Time.)

Conversion of Humidity Mixing Ratio
to Absolute Humidity

From the definitions in the Meteorological Glossary

Absolute Humidity $$d = \frac{216 \cdot 7e}{T} \text{ gm/m}^3 \qquad (1)$$

where e = vapour pressure in mb.
T = temperature in deg K.

and Humidity Mixing Ratio $$m = \frac{622e}{P - e} \text{ gm/kgm} \qquad (2)$$

where P = barometric pressure in mb.
e = vapour pressure in mb.

from (2) $$Pm - em = 622e$$

or $$e = \frac{Pm}{622 + m}$$

and substituting for e in (1)

$$d = \frac{216 \cdot 7}{T} \left(\frac{Pm}{622 + m} \right)$$

and, since m is much smaller than 622

$$d \simeq \frac{216 \cdot 7 \, P}{622 \, T} \cdot m$$

or, expressing d in half-grams per cubic metre (the unit used by Hanssen)

$$d \simeq \frac{\cdot 696 \, P}{T} \cdot m$$

The values of Hanssen's d ($\frac{1}{2}$ gm m^{-3}) for various values of m and T have been calculated for P = 850 mb and P = 700 mb from this final formula and are given in the following tables.

1. P = 850 mb

m	T deg C						
	-10	-5	0	+5	+10	+15	+20
0·5	1·1	1·1	1·1	1·1	1·0	1·0	1·0
1	2·2	2·2	2·2	2·1	2·1	2·1	2·0
2	4·5	4·4	4·3	4·3	4·2	4·1	4·0
3	6·7	6·6	6·5	6·4	6·3	6·2	6·0
4	9·0	8·8	8·7	8·5	8·4	8·2	8·1
6	13·5	13·2	13·0	12·8	12·5	12·3	12·1
8	18·0	17·6	17·3	17·0	16·7	16·4	16·1
10	22·5	22·0	21·6	21·3	20·9	20·5	20·2
12	27·0	26·5	26·0	25·5	25·1	24·6	24·2
14	31·4	30·9	30·3	29·8	29·2	28·7	28·2
16	36·0	35·3	34·7	34·0	33·4	32·8	32·3
18	40·4	39·7	39·0	38·3	37·6	36·9	36·3
20	44·9	44·1	43·3	42·5	41·8	41·0	40·3

2. P = 700 mb

m	T deg C						
	-15	-10	-5	0	+5	+10	+15
0·5	0·9	0·9	0·9	0·9	0·9	0·9	0·8
1	1·9	1·9	1·8	1·8	1·8	1·7	1·7
2	3·8	3·7	3·6	3·6	3·5	3·4	3·4
3	5·7	5·6	5·4	5·3	5·3	5·2	5·1
4	7·5	7·4	7·3	7·1	7·0	6·9	6·8
6	11·3	11·1	10·9	10·7	10·5	10·3	10·1
8	15·1	14·8	14·5	14·3	14·0	13·8	13·5
10	18·9	18·5	18·2	17·8	17·5	17·2	16·9
12	22·6	22·2	21·8	21·4	21·0	20·6	20·3
14	26·4	25·9	25·4	24·9	24·5	24·1	23·7
16	30·2	29·6	29·1	28·5	28·0	27·5	27·0
18	33·9	33·3	32·7	32·1	31·5	31·0	30·4
20	37·7	37·0	36·3	35·6	35·0	34·4	33·8

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X – diagram for troughs and ridges moving from the west

Probability classes of thunderstorms in the Netherlands depending on pressure and extreme latitude (west)

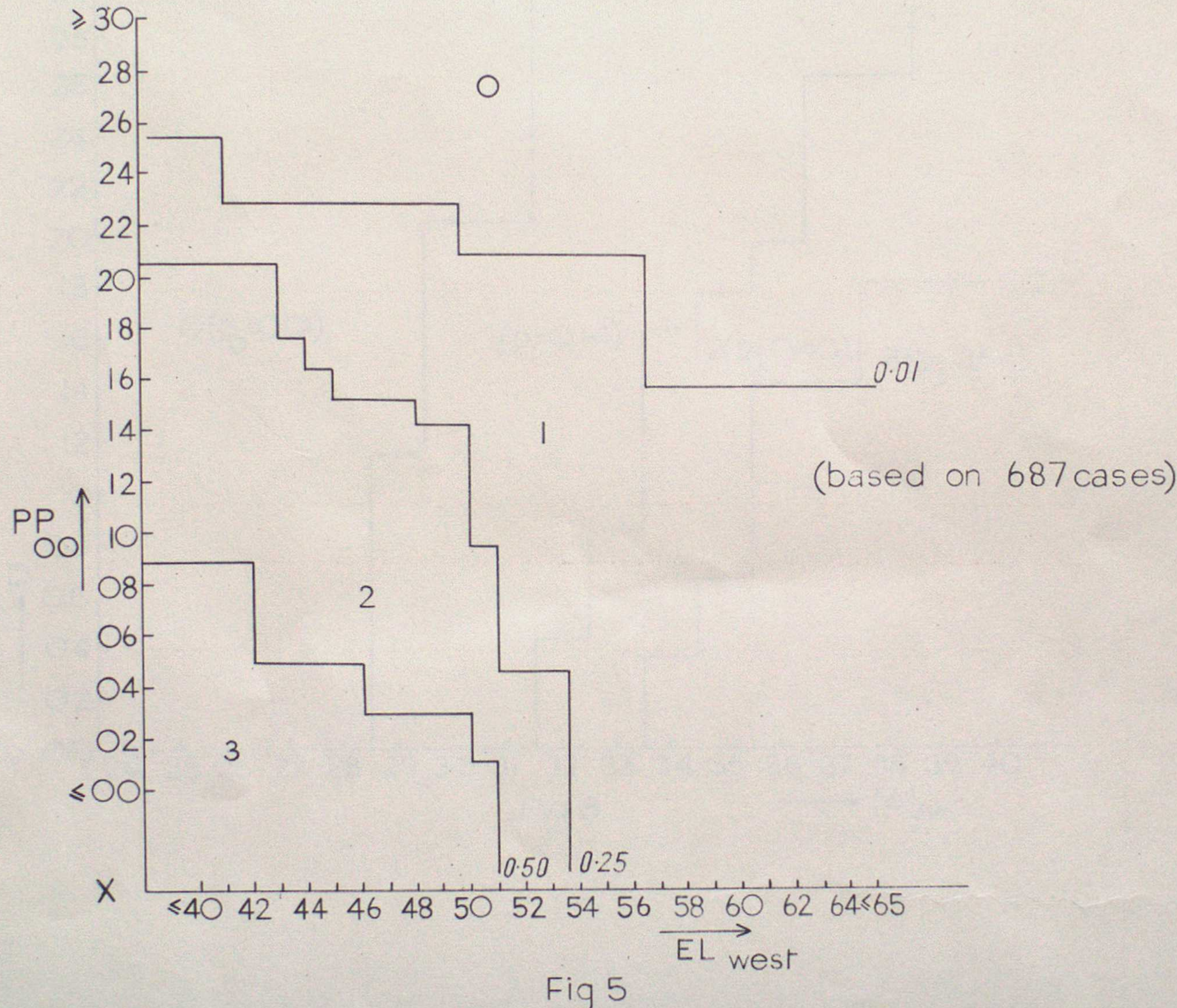

Fig 5

Y-diagram
Probability classes of thunderstorms in the Netherlands depending on thickness difference and moisture deficit (at 0000 G.M.T.)

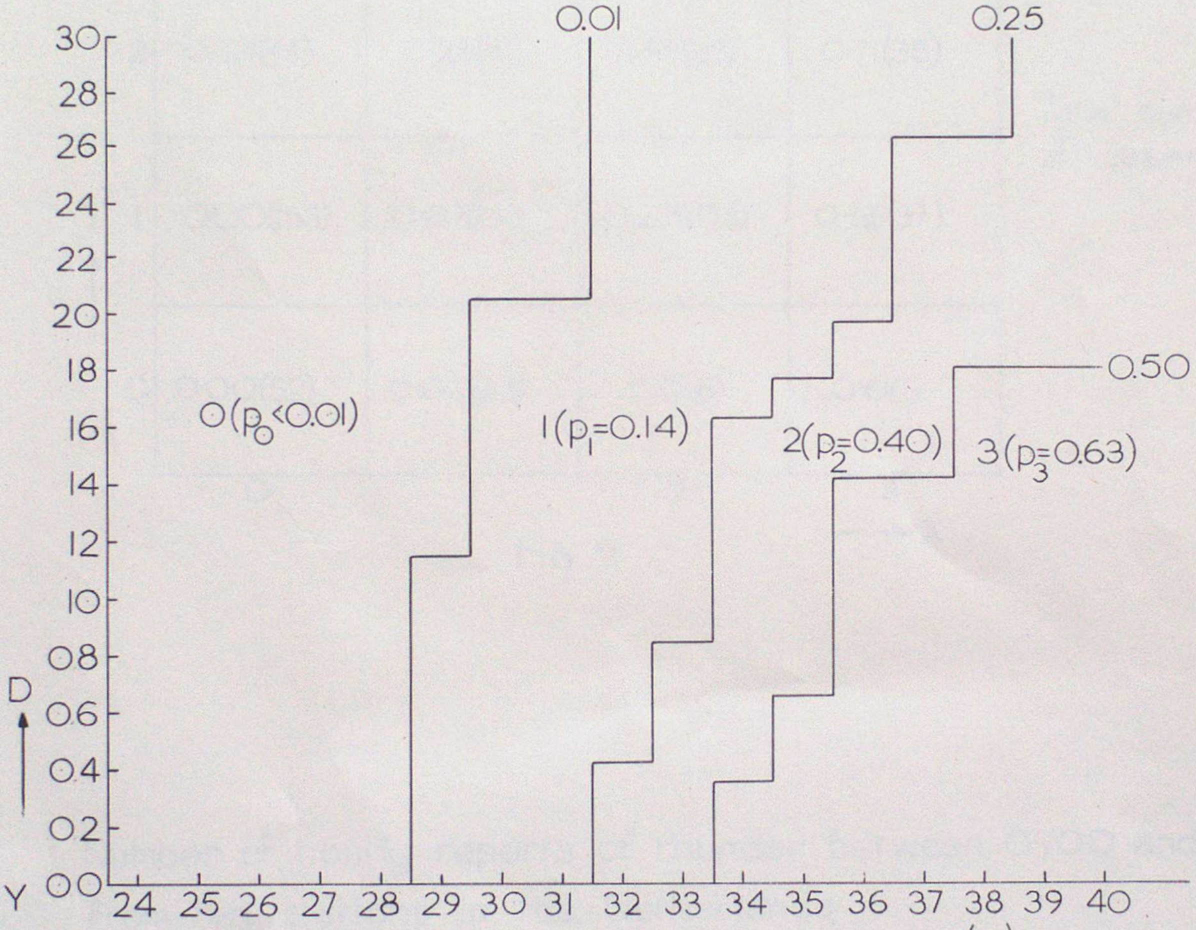

Fig 8

Probability of thunderstorms between 0700 and 2100 in the Netherlands from X and Y parameters

Y ↑ \ X →	0	1	2	3
3	0·0(5)	0·42(31)	0·65(71)	0·83(18)
2	0·04(44)	0·28(81)	0·55(133)	0·71(35)
1	0·00(153)	0·07(191)	0·29(103)	0·65(37)
0	0·00(52)	0·00(23)	0·0(8)	0·0(1)

Total number of cases = 986

Fig 9

Number of hourly reports of thunder between 0700 and 2100 from ten stations in the Netherlands

Y ↑ \ X →	0	1	2	3
3		V	P	↘
2		V	P	P
1			V	P
0				

Key

V ≤ 5 reports

↘ ≥ 6 reports

P number of reports unclassifiable

Fig 10