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METEOROLOGICAL OFFICE

FORECASTING TECHNIQUES MEMORANDUM

Nº 15

WORK ON PROBLEMS  
IN LOCAL FORECASTING

by

W.D.S. McCaffery

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AUGUST 1967

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by

W.D.S. McCaffery

## 1. Introduction

In July 1958 a small unit was formed at Meteorological Office Headquarters as the 'Techniques' part of a new Assistant Directorate for Techniques and Training. Charged specifically with looking into the problems of local forecasting, and working closely in co-operation with many forecasters at Meteorological Office outstations, this unit has maintained its present form for some years now. In December 1964 it was regrouped to form part of a new Forecasting Techniques Branch (the other part of the branch dealt with numerical forecasting methods) and in November 1966, following a major reorganisation, the complete unit found itself once more grouped with the Meteorological Office Training School under the control of the Assistant Director, Publications and Training, and short-titled Met O 18c.

The present composition of Met O 18c is: one scientist (PSO), three members of the experimental officer class and two scientific assistants. The number of outstation forecasters actively co-operating in work on local forecasting problems, in addition to their routine work, is difficult to determine since projects may be undertaken by one forecaster, two or more working as a team or, in some cases all the 40 to 60 forecasters under the control of a Senior or a Chief Meteorological Officer. Some attempt is made in this paper to indicate the volume of work being done on local forecasting problems both in Met O 18c and by outstation staff.

It is perhaps not out of place to mention here that in seeking solutions to forecast problems the approach is much more empirical than theoretical. The forecaster customarily uses a number of rules and techniques, not only in local forecasting (micro- or meso-scale) but also on synoptic or planetary scales, which are only partially based on a sound theoretical understanding and which owe a good deal to empiricism. He tends to use theory to suggest profitable lines of investigation to be pursued empirically, rather than to formulate possible solutions which can then be tested by experiment.

It should also be pointed out that much of what is done is not necessarily original work, but consists of adapting to a particular station or circumstance methods which were originally evolved for another station or set of circumstances. For this reason the effort made in improving the forecast service provided is not reflected in the number of articles on local forecasting techniques published in, say, the Meteorological Magazine. The Weather Information Book maintained at each forecast office provides a record of forecasting methods evolved for a particular station or area as well as containing summaries of the local characteristics of a variety of synoptic situations. This latter record provides the basis for an analogue system of forecasting.

Finally it should be remembered that work on forecasting problems by outstation forecasters is carried on under considerable difficulties and that staff postings often mean that work proceeds slowly and may not reach a stage suitable for formal publication even though useful results may have been obtained.

## 2. Historical review

Co-ordinated work on local forecasting problems started in 1958 with an analysis of replies by Chief and Senior Meteorological Officers to an earlier request by the Director of Services for statements of local forecasting problems important to stations under their control. The analyses suggested that problems could be classified as being either mainly topographical or non-topographical; the two resulting lists are given as Appendices A and B. The lists were not regarded as a complete statement of local forecasting problems because of the omission of local aspects of fog and of other problems regarded as not very promising subjects for study with the limited effort available.

/ Circulation



Circulation of the two lists was followed by a meeting attended by a number of Headquarters staff and Senior Meteorological Officers. Largely as a result of this meeting outstation forecasting problems were regrouped into lists of synoptic problems and statistical problems. It was envisaged that synoptic problems would be tackled locally by staff of the station concerned, with advice and co-ordination from Headquarters. Statistical problems were to be tackled jointly, maximum use being made at Headquarters of machine methods. The aim was to encourage research at outstations with forecasters being able to discuss their problems before becoming too deeply involved in their investigation. Advice from other Headquarters branches of the Meteorological Office would be available. Thus better planned and more comprehensive investigations should result, time and labour would be saved, with overlapping of activities avoided and results from different workers more easily compared or combined.

In addition, because of the increasing volume of climatological data becoming available on punched cards, a Standard Statistical Programme was evolved to produce analysis of such data by various times of day and by season and in various ranges of visibility, height of cloud base, humidity and of wind speed and direction. As well as providing useful climatological summaries to be used as background knowledge in local forecasting it was hoped that much of the information obtained would prove of direct use in solving some local forecasting problems. In the event the analyses produced have been of more use in providing convenient summaries of local weather characteristics, usually in diagrammatic form, and in facilitating the comparison between stations of such characteristics, than in leading immediately to the formulation of objective forecasting techniques.

For convenience, some items were included in the programme to cover WMO requirements for statistical climatological summaries in an agreed form for international airports. The programme has been amended from time to time in the light of experience and the current version is given at Appendix C. Some results from the Standard Programme analysis of cloud and visibility according to wind speed and direction and to time of day and of year have been given by Atkins<sup>1</sup>.

A computer programme has now been written which will not only produce the basic tabulations previously obtainable by punched card methods, but will then go on to produce analyses, previously done by hand, enabling information to be presented to the forecaster in a digestible form. The programme is extremely flexible, and any desired ranges of up to four parameters can be specified at the beginning of each run of the programme. The programme will thus not only produce statistical analyses in an agreed standard form, but can also be used to make special analyses to the requirements of individual stations.

At further meetings attended by Headquarters staff and by invited staff from outstations, problems were assessed as to their suitability for investigation, priorities decided, new problems introduced into the programme from time to time and, later, work on some problems stopped when it was seen that worthwhile results were not forthcoming. Original work of sufficient general interest has been written up and published from time to time in the Meteorological Magazine, though, as has already been said, probably the bulk of the results from this work is contained locally in station records.

More recently a method of fostering interest in outstation investigations and of providing a means for circulating results of some interest but not, for one reason or another, suitable for formal publication, has been found in the issue of branch memoranda, written either by staff in the Headquarters unit or by outstation staff. Fourteen memoranda† have so far been produced, three dealing with objective analysis and forecasting, work no longer the concern of the branch, the remaining eleven being either reviews of aspects of forecasting methods and techniques or reports on investigations carried out.

/ An

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† Listed on inside of back cover



An important review of forecasting methods and techniques in use by forecasters at home and overseas was undertaken in 1963, when staff at all forecasting offices were asked to consider how they carried out their normal forecasting tasks and to list the techniques used. Some guidance as to what was required was given in the form of a questionnaire. Many extremely detailed and informative replies were obtained and analysed. A report was prepared by McCaffery and Harrower<sup>2</sup> giving details of techniques in use and discussing implications contained in outstation replies. Appendices D and E are taken from the report. The first of these lists techniques in use at outstations in the United Kingdom and indicates on a seven-point scale a "value of usefulness" given by stations using particular techniques. Appendix E lists suggestions by outstations for further research on forecasting problems (not necessarily "local") or development of forecasting techniques.

From Appendix D it is clear that for many of the more usual forecasts a number of techniques exist. The report also makes it clear that different techniques are used to make similar types of forecast, not only at different stations, but also often by individual forecasters at the same station. Many things may influence a forecaster in his choice of a techniques. His past training and experience are obviously important, and so also are the time and facilities available to him, but a major disadvantage in making a sound and reasoned choice is the almost complete lack of adequately controlled comparative tests of techniques carried out under conditions of normal outstation routine. Consequently outstation forecasters have been asked to co-operate in conducting comparative tests of techniques and some results have already been published (Saunders<sup>3,4</sup>). A number of other results are now being considered for publication, while still more results, in the form of interim reports, have been circulated between stations or individual forecasters conducting similar tests. Some details are given below. An interesting side effect, which has been commented on by officers-in-charge of stations where this work has been carried on, is the increase in interest shown by staff, not only in the particular test, but also in related aspects of their work, and this in turn has led to some improvement in forecast success.

In the present era of rapid advances in numerical forecasting methods it yet remains true that a detailed forecast of local weather, tailor-make to suit the requirements of an individual must be finally prepared and presented by a forecaster in close touch with his client. Dangerous though it is to prophesy, this situation seems likely to persist for some time, if only because we have not yet either the information or the knowledge to forecast numerically all aspects of the weather on a meso- or micro-scale. This the human forecaster attempts to do using a synthesis of basic physics and meteorological experience grafted on to an extrapolation of trends in current weather, gleaned from a variety of incoming information available to him. The final presentation of a forecast, complete with all the details of weather required by the recipient, is complementary to the initial assessment of the broad-scale development. Work on local forecasting problems is thus a highly necessary part of any attempt to improve a forecasting service to meet the needs of a wide variety of user interests. Current trends in numerical forecasting methods present both an opportunity and a challenge; an opportunity for forecasters to concentrate on careful and detailed analysis and forecasting of local weather, and a challenge to improve the techniques necessary for doing this to match improvements in forecasting larger-scale developments brought about by the introduction of numerical methods.

The remainder of this paper is essentially a catalogue of work in progress or which has recently been concluded. The work is grouped into sections on data processing, visibility, cloud, wind, temperature, miscellaneous investigations, tests of forecasting techniques, and publications. No attempt has been made to indicate clearly the separate contributions to a project made by headquarters and outstation staff, though for the most part the work has been done by the latter. For the sake of completeness a few items are included which are entirely the work of outstation staff.



### 3. Status of work on problems in local forecasting

#### a. Data processing

Tabulations according to items on the Standard Statistical Programme have been produced for the following number of stations:

Item

1	(visibility) .....	22
2	(cloud base) .....	28
3	(combined cloud base and visibility) .....	18
4	(sea-level pressure) .....	2
5	(wind speed and direction) .....	52
7	(five-day temperature means) .....	6
8	(clear skies in relation to wind speed and direction) .....	1
9	(surface and 900 mb wind relationship) .....	4

Summaries and analyses made from these tabulations are noted in the sections below on visibility, cloud and wind. Non-standard tabulations have been made to assist with a number of investigations and these are noted in the relevant sections below.

#### b. Visibility

##### (1) Analyses of visibility

Summaries from Standard Programme tabulations of visibility have been worked up in Headquarters for 24 stations. Four stations have prepared their own summaries of the basic tabulations, while nine other stations have prepared summaries using other available data. Most of the summaries are in diagrammatic form for quick and easy reference. Diagrams mostly show ranges of visibility, notably below 2200 yards, by time of day and year. Analyses by half-year relate visibility to wind speed and direction and to humidity.

##### (2) Visibility at Kinloss

An article by Ross<sup>5</sup> on visibility in precipitation at Kinloss has been published in the Meteorological Magazine. For the same type and intensity of precipitation visibilities at Kinloss were found to be generally less than at Ocean Weather Ships and more in accord with results previously given for Manchester, despite the difference in smoke pollution at Kinloss and Manchester.

##### (3) Secular changes in visibility

Results of a pilot investigation at Headquarters into visibility at Manchester Airport appear to confirm the impression of forecasters there that the incidence of poor visibility has been decreasing during recent years on account of the implementation of the Clean Air Act. The effects of the Clean Air Act have also been investigated at Bawtry and Finningley, where analyses by sectors of wind direction has been carried out. The results are broadly in accord with the varying degrees of implementation of the Clean Air Act in the different sectors. An article has been written and is being considered for publication.

##### (4) Visibility forecasting at London (Gatwick) Airport

At Gatwick a regression equation for determining the fog point (temperature at which fog is expected to form) has been determined in the form published by Craddock and Pritchard<sup>6</sup>. This work is the first



adaptation to a local area of a method originally devised to give a general indication over a large part of England and is part of a larger investigation into the determination of night minimum temperatures. Results using the local formula differ only slightly from the results using the more general equation.

(5) Visibility at Shawbury

Diagrams have been prepared at Shawbury using 15 years' data to show the local and diurnal variations in the frequency there of visibility less than 2200, 1100, and 220 yd and also variations in the frequency of shallow fogs. Special visibility tabulations and some derived summaries have been provided for subsequent work on relationships with surface wind speed and direction and relative humidity.

(6) Visibility at Birmingham Airport

Following a pilot study made at Headquarters an investigation into the characteristics of visibility at Birmingham Airport is being carried out there. The aim is to represent the different diurnal trends in visibility associated with heavily polluted air and with air which is relatively free from pollution. Hourly data for 16 years have been extracted to make an analysis in sufficient detail. Preliminary results, as expected, show that at most times of the day, and especially in winter during late afternoon and early evening, light winds from the extensive adjacent smoke source (to west and north-west) are more likely to be accompanied by poor visibility than are light winds from other directions. In the early hours of the morning during winter, however, poor visibility is rather less likely with winds from the smoky sector than from other directions.

(7) Fog at high-level stations

Investigations have been made into the problem of forecasting radiation fog at stations above the general level of the surrounding countryside. An account of some of the work has been published by Sparks<sup>7</sup>. Case histories are being accumulated to provide material for synoptic studies.

At Headquarters meso-scale maps have been drawn of the spread of fog in the upper-Thames basin on two nights in December 1944, using a fairly close network of war-time reporting stations. Although synoptic conditions were broadly similar on both occasions, on one night fog formed first in the valley and spread upwards, while on the other fog was first reported from the higher stations and later extended downwards to the valley bottom.

(8) Time of clearance of fog

An investigation into Kennington's<sup>8</sup> method of forecasting the time of clearance of fog has been carried out at a number of stations in Bomber Command. Three articles<sup>9,10,11</sup> have been published describing developments of the technique and adaptations for local application. These included improved methods for estimating the depth of fog, and empirical methods for allowing for effects of topography with varying wind directions.

(9) Fog in estuaries

At the instigation of the London Weather Centre a very close network of observing stations has been set up in the area of the Thames under the control of the Port of London Authority. Observations plotted on a large-scale chart are currently used in routine forecasting, but data and charts are being accumulated for possible future investigations.

/ A



A similar project for Southampton Water is in hand. It is thought that the forecasting of fog over the water is akin to the forecasting of fog over the nearby land, and that association with fog in the English Channel is likely to be rare.

(10) Advection fog

An investigation is being made at West Raynham into the advection of fog and low stratus. Occurrences are being classified, as they occur, into various synoptic types, e.g. drifting fogs from the Fens, frontal fogs, very low cloud from the North Sea. Common features within the various classes are being sought.

(11) Fog and low cloud associated with surface discontinuities

Cases are being studied in Headquarters when local fog or low stratus cloud appear to be associated with shallow low-level discontinuities between cold, dry air, and less cold, moist air. Such discontinuities appear to result from contrasting surface influences (e.g. sea and land) during the very recent history of the air. One meso-synoptic model has been developed and found useful in forecasting the very local occurrence of fog and low stratus over parts of East Anglia during northerlies in winter. The detailed profiles of temperature and dew point given by the Cardington Baltham have been found valuable. Profiles of this sort from other places (which may become available from the instrumentation of high masts) are needed to assist in developing other local meso-scale synoptic models as an aid in understanding the processes of their formation and development.

(12) Effect of Lough Neagh on fog and stratus at Aldergrove

Interim reports have been received on the progress of this investigation which seeks to discover inter-relationships between the occurrence of fog and low stratus cloud at Aldergrove and, among other things, water temperatures from Lough Neagh. The investigation so far has yielded information on the pattern of change in water temperature following sudden and fairly large changes in air temperatures, as occur, for instance, following the passage of a well-marked cold front. Radiation fogs have been mostly studied so far and there is some indication that on radiation nights steam-fog formed by mixing round the shores of the lough may be important. In seeking an understanding of the role played by Lough Neagh in the occurrence of fog and low cloud at Aldergrove a very helpful background of climatological detail has been built up.

(13) Thick fog in South Yorkshire

A report has been written at Bawtry on an investigation into the occurrence of thick fogs in South Yorkshire. A notable feature is that many thick fogs are associated with a drift of surface air from the southeast. Comments and suggestions for further work have been sent from Headquarters together with statistics which appear relevant to the problem. In this study use was made of observations of all types, including those made by Automobile Association Patrols (Autobs) and from fire stations (Fisobs) in an attempt to build up an adequate picture of fog distribution.

(14) Visibility characteristics at a coastal and an inland station

A paper by Smith<sup>12</sup> comparing annual and diurnal trends of visibility at Strubby, near the coast, with those at Syerston has been published. Frequencies of fog and thick fog are found to be much lower at Strubby than at Syerston particularly during winter. With light westerly winds the Lincolnshire Wolds may form a natural barrier to the spread of fog eastwards from more fog-prone areas.

/ (15)



(15) Fog and katabatic winds

At Edinburgh (Turnhouse) Airport pilot-balloon ascents are being made after radiation nights in an attempt to detect any katabatic drift which might help to account for the observed infrequency of fog. Only a very few cases have so far been accumulated.

(16) Objective forecasting of visibility

Work has nearly been completed on prediction diagrams for London (Heathrow) Airport enabling 3-hour and 6-hour forecasts from each synoptic hour for the winter half-year (October to March). An article by Miss Jack<sup>13</sup> describes some of the work done and gives the results of tests of five diagrams when used operationally. Seventeen diagrams were tested during the winter 1966-67; the objective forecast using the diagram and a specially prepared subjective forecast were compared with the visibility reported at the appropriate time. Eleven of the diagrams gave objective forecasts which, overall, were slightly better than the subjective ones; the remaining six diagrams gave forecasts which were not quite as good as the subjective forecasts. The diagrams are thus useful, at least as a first step in preparing the forecast, and particularly to new and inexperienced staff. Up to now this work has been done using a Ferranti Mercury computer (Meteor). It is now being programmed to run on Comet. Diagrams for other major airports will be produced after all necessary diagrams for Heathrow are made available.

c. Cloud

(1) Analyses of cloud

Summaries from Standard Programme tabulations of cloud have been worked up in Headquarters for 25 stations. Analyses prepared at the station have been received in Headquarters from nine stations while useful comments and suggestions on the tabulation of data and the presentation of derived statistics have been received from several other stations. Histograms and polar diagrams show heights of cloud base below 1000 ft in relation to season, and surface wind speed and direction. For some stations, the data have been arranged to illustrate specific local topographic effects on height of cloud base, e.g. upslope motion, or winds off the sea.

(2) Cloud at Leuchars

An article by Alexander<sup>14</sup> on the relationship between easterly winds and low cloud at Leuchars has been published. Parameters considered include surface and 900 mb wind directions, lapse rate, dew-point depression, excess of dew point over sea temperature, and synoptic type. The results go some way towards the formulation of an objective technique for forecasting low stratus at Leuchars.

(3) Cloud at London (Heathrow) Airport

An article by Atkins<sup>15</sup> on very low cloud at Heathrow during the winter half-year has been published. The likelihood of very low cloud was shown to vary considerably according to the direction of the geostrophic wind even when this is as light as 7-14 knots. Cloud bases below 300 ft were found to be extremely rare with geostrophic winds of 25 kt or more unless snow is falling, or warm moist air is moving over a very cold surface.

(4) Cloud at Ronaldsway

An analysis has been received from Ronaldsway relating cloud height with surface wind and time of year. An interesting feature shown is a strong seasonal variation, very low cloud being particularly frequent in spring. This variation is a much weaker feature at Valley, to the south, and almost absent at St. Mawgan, still further south.



(5) Cloud at Cottesmore

At Cottesmore the incidence of low stratus is being related to the direction of the surface wind. The work has made only slight progress on account of staff shortages and changes.

(6) Clearance of cloud in warm sectors

Little useful result has yet been obtained from an investigation at Lindholme and Bawtry into the clearance in wide warm sectors of low cloud to the east of the Pennines. Complications due, for example, to the presence of old weak fronts within the warm sector, have prevented any simple relationships emerging, and the statistical investigation has now been abandoned. It is hoped to examine future cases synoptically.

(7) Clearance of stratus by day-time heating

Work on this problem is being done at Headquarters Bomber Command, following similar lines to those of Kennington<sup>8</sup> on clearance of fog. A difficulty is that adequate measurements of cloud thickness are not usually available.

d. Wind

(1) Wind roses

Standard Programme tabulations of wind frequency have now been made for about 50 stations and worked up to show seasonal and annual distributions of directions and speeds. The tabulations can also be used to show diurnal variations. Annual wind-roses, all speeds taken together, have been plotted in their correct position on a large-scale map as an aid in assessing local variation in wind characteristics due to topographical effects. A limited number of these wind roses are shown in Figure 1 which is reproduced from references 16 and 17. Even with this limited distribution there is clear evidence of orographic effects. The mean pressure distribution over the British Isles implies a maximum frequency of southwesterly winds, but the maximum wind frequency at individual stations may vary through a wide range of directions. For example its occurrence from 270° at Rhoose (near Cardiff), 240° at Filton (near Bristol), 210° at Pershore (near Evesham), and 180° with a secondary maximum from 300-330° at Liverpool is very suggestive of air-flow round the Welsh mountains. At other stations the importance of local mountain and valley wind systems is indicated.

(2) Sea breezes

Investigations of various aspects of sea breezes are being carried out at several stations. The results obtained so far have been incorporated into a Forecasting Techniques Branch Memorandum<sup>18</sup>. A computer programme has been written to calculate the vector mean wind for each hour during the day when a sea breeze developed. Some preliminary results have been obtained for Kinloss where a record of sea-breeze days has been kept since 1958. The hourly variation of monthly vector mean winds, when printed out as a hodograph, is an ellipse of low eccentricity for all months from April to September. The sea-breeze regime at Kinloss has been compared with that at Wick and at Dyce and all three are found to be different. At Kinloss the sea breeze - land breeze cycle results in a fairly steady veer of wind during the 24 hours. At Wick the wind backs instead of veering, while at Dyce the sea breeze is more constant in direction with a more-or-less reciprocal land breeze at night.

(3) Surface winds related to upper winds

Results of work in Headquarters on the relationship between winds at the surface and at 900 mb are summarized in a Forecasting Techniques Branch Memorandum.<sup>17</sup> The work has more recently been revised and

/ published



published as a Scientific Paper.<sup>18</sup> The results suggest a possible forecasting technique, particularly for forecasting winds over the sea, or over land without marked orographic features. In fact, the National Institute of Oceanography is planning to use the results to derive, from Comet 1000 mb and 850 mb charts, surface winds at a grid of points over the Atlantic in connection with wave prediction.

A preliminary report on an investigation into the relationship between the surface wind at Leuchars and the 900 m wind at Shanwell has been written. An analysis in ten-degree steps of upper wind direction is being done since, because of the local topography, slight changes in upper wind direction can result in large changes in surface wind direction. The importance of effects of lapse rate have been demonstrated and some tests of forecasters' ability to forecast lapse rates have been carried out. With a broad classification of lapse rates into stable or unstable (less than or greater than the saturated adiabatic lapse rate) forecasters achieved 91% correct forecasts of unstable lapse rates and 84% correct forecasts of stable lapse rates. When four lapse rate classifications were used, based on the dry and saturated adiabatic lapse rates and an isothermal lapse rate, results varied between 76% and 31% correct forecasts of the various types.

(4) Evaluation of geostrophic winds

Geostrophic winds for London (Heathrow) Airport for each synoptic hour for the months October to March for years 1949 to 1963 have been evaluated by a technique due to Freeman<sup>19</sup>. Pressure data, necessary for the calculation of geostrophic winds, have been extracted for about 25 stations in south-east England for seven of the eight synoptic hours during thirteen summer half-years. Geostrophic winds have been evaluated primarily because of their value as a parameter in objective predictions of visibility, but they have also proved useful in other investigations, e.g. that carried out by Atkins<sup>15</sup>, who related height of cloud base at Heathrow to geostrophic wind. Relationships between geostrophic winds and other parameters are useful to forecasters since forecasts of geostrophic winds can be obtained by numerical methods.

At Watnall geostrophic winds have been measured for each synoptic hour over a period of five years up to April 1967. These measurements are expected to be useful in other investigations.

(5) Forecasting surface winds in the Largs/Cumbraes area

An investigation has been carried out at Glasgow Weather Centre into the occurrence of unusually strong surface winds in the Largs/Cumbraes area of the Firth of Clyde. The most important sector of geostrophic wind direction has been found and some tentative forecasting rules have been derived based on the pressure difference between Prestwick and Glasgow Airport. Suggestions for further work have been made including the possible use of several other forecasting parameters. Using a specially prepared nomogram, a list of dates has been compiled when the geostrophic wind direction over Scotland was in the sector considered suitable for the development of the strong winds, so that other parameters can be examined against the occurrence or non-occurrence of strong winds in the area.

(6) Low-level turbulence

Headquarters Bomber Command are investigating cases of low-level turbulence and reports are being examined as they are received from Bomber Command pilots in an attempt to detect significant common features. An account of three cases of severe turbulence encountered by Bomber Command aircraft has been published by Cashmore.<sup>20</sup> An earlier paper by Gray and Stewart<sup>21</sup> described occurrences of low-level turbulence in north-east England.

/ (7)



(7) Winds near the tropopause

An article on how errors in forecasting wind direction and wind speed affect forecasts of equivalent headwinds and flight times has been published by Howkins and Chuter.<sup>22</sup> Work on winds near the tropopause has since been transferred elsewhere because of its close connection with numerically computed upper wind charts.

(8) Meso-analysis of a squall line

Staff at Upavon carried out a detailed synoptic analysis of a squall line which developed over the Midlands and moved towards the English Channel. Following comments and suggestions from Headquarters an article by McNair and Barthram<sup>23</sup> has been published.

(9) Katabatic winds

A series of pilot-balloon ascents have been made at Kinloss on occasions when the winds were considered to be katabatic. The results show an unexpected depth of katabatic wind, often around 1000 ft. An explanation of the katabatic wind at Kinloss in terms of large-scale horizontal eddy effects is favoured, but the small number of observing stations in the area makes this hypothesis difficult to test.

(10) Checks of forecasts of upper winds

The vector error distribution of 3258 18-hour and 24-hour forecasts of spot-winds at 200 and 300 mb has been examined at Bomber Command. The forecasts were made during a period of one year for various points over and around the British Isles. The mean vector error for all cases amounted to 25 kt and the standard vector error was 30 kt, 50% of errors being under 25 kt and 70% under 30 kt. Comparisons were also made between routine forecasts by forecasters at Bomber Command and forecasts obtained numerically from Comet. Results were slightly in favour of the numerical forecasts. An article on the distribution of vector errors derived from tests of routine upper wind forecasts is being prepared for publication.

e. Temperature

(1) Night cooling - forecasting techniques in use at outstations

A summary of work done at many outstations in evolving techniques for forecasting cooling at specific places, or adapting published techniques for local application has been issued to all forecasting outstations as a Forecasting Techniques Branch Memorandum.<sup>24</sup> Some of the more important work is indicated briefly below.

(2) Night cooling at London (Heathrow) Airport

Mr. I.G. MacKenzie, a vacation student working temporarily in Headquarters, made a preliminary study of minimum temperatures on radiation nights at Heathrow. Regression equations were derived relating the minimum temperature to temperature and dew point during the preceding afternoon. He also studied some effects of wind direction in an attempt to discover any tendency for temperature to be higher on nights with winds from London than on other night, other factors being unchanged. The evidence suggests a very slight tendency for this during winter. When winds were from the north-west during summer, minimum temperatures also tended to be slightly higher than would be expected from the data of the preceding afternoon. There was little change in the accuracy of the forecast minimum temperatures when 1200 GMT data were used instead of 1500 GMT. Following this pilot study further, more detailed work is being planned by C Met O, Heathrow.



(3) Night cooling at London (Gatwick) Airport

An equation for predicting the local night minimum temperature has been calculated by the method of Craddock and Pritchard.<sup>6</sup> Since Gatwick is subject to particularly low temperatures on radiation nights the differences between this equation and that of Craddock and Pritchard (based on combined data for a number of inland stations) are of interest. For small amounts of cloud overnight and a weak pressure gradient the minimum predicted by the equation for Gatwick can often be 3 deg C and occasionally as much as 5 deg C lower than that predicted by the more general equation. This difference between minima for Gatwick and those more generally observed is in accord with experience. In the course of this work it was found that when fog formed during the night the minimum temperature at Gatwick was significantly lower than forecast by the local equation if gradient winds were in the range 13-25 kt but not with winds in the range 0-12 kt. An article on this work is being considered for publication.

(4) Night cooling at Abingdon

Local constants have been determined for Abingdon for use in forecasting night minimum temperatures by the method developed by Boyden<sup>25</sup> for Kew. The results from forecasts made using these constants in Boyden's equation are being compared with results obtained by other methods.

(5) Night cooling at West Raynham

Local cooling curves have been prepared at West Raynham and classified according to season, cloud amount during the night, surface wind speed, and whether the wind is off the sea or off the land. It has been suggested that the technique be developed by taking some account of humidity if possible.

(6) Temperature variations on radiation nights

A series of profiles of surface temperatures across valleys in Kent on nights with clear skies and little wind has been compiled at London Weather Centre and an article describing results has been accepted for publication. Similar work is being done in the Shawbury area.

(7) Bomber Command investigation into night cooling

Comprehensive nomograms for winter and summer months of the year have been prepared for use at each Bomber Command station. The nomograms enable a cooling curve to be constructed, allowance being made for cloud amount, wind speed, times of sunrise and sunset, and also the presence or absence of an inversion below 900 mb. Some work is also being done on the depression of the grass minimum temperature below the screen minimum. Reports on this work have been prepared and an article describing the main features has been submitted for publication.

(8) Temperature differences between London Weather Centre and London (Heathrow) Airport

A report has been prepared at London Weather Centre on the differences between daily extreme temperatures recorded there and at Heathrow. (The analysis is on similar lines to temperature comparisons made by Marshall.)<sup>26</sup> The minimum temperature at Kingsway is almost invariably higher than the corresponding minimum temperature at Heathrow, the difference varying during the two years studied between +13 deg F and -4 deg F, the mean difference being approximately +3 deg F. The differences in maximum temperatures vary between +8 deg F and -7 deg F with a tendency for maximum temperatures at Kingsway to be higher

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during the winter half-year and lower during the summer half-year. Some suggestions have been sent from Headquarters for extending the analysis: the differences might be grouped according to surface wind and cloud amount; synoptic situations might be examined on occasions of exceptional temperature difference.

(9) Afternoon temperatures at high moorland stations

This investigation into the temperature regime at high moorland stations attempts to relate maximum temperatures to temperatures at similar levels in the free atmosphere as reported by radiosonde ascents. A considerable amount of data has been collected at Glasgow Weather Centre and interim reports have been commented on at Headquarters. A final report is now being considered for publication. At noon at Lowther Hill and at Great Dun Fell temperatures on sunny days were, on average, 2.6 and 2.2 deg C higher respectively than noon temperatures on appropriate radiosonde ascents; maximum temperatures were 5.2 and 4.0 deg C higher than the noon radiosonde ascents temperatures.

(10) Night cooling - effect of fog formation

An investigation is being carried out at Wattisham to study the cooling which takes place in high radiation conditions after the formation of fog. For 124 cases occurring over a five-year period the average drop in temperature after the formation of fog was 2.4 deg C with a standard deviation of 1.6 deg C. The investigation is being extended to consider cases of thin fog (sky visible) and thick fog (sky obscured) separately, and also to classify occasions of fog by the number of night hours remaining after fog formation rather than by months as was done originally.

This investigation was started because of some results noticed at Birmingham Airport of the effect of snow-covered ground on minimum temperature. On five radiation nights, when the ground was snow-covered, it was found that the minimum temperature was within two or three degrees of the fog point. Since fog formed on all five occasions it is not certain whether the relationship between the minimum temperature and the fog point was due to snow cover or fog.

f. Miscellaneous Investigations

(1) Fine structure of the lowest atmospheric layers

For a trial period of five months, selected outstations were supplied with extra details of the temperature and humidity structure of the lowest 3000 ft of the atmosphere computed from the radiosonde Cintel record. In addition an examination was made in Met 0 18c of the original Cintel records of radiosonde ascents on several occasions when it was thought that the extra detail from the Cintel record might be useful in the preparation of cloud and visibility forecasts. The results, which have had a limited circulation in a Forecasting Techniques Branch Memorandum,<sup>27</sup> indicated that useful information was lost only infrequently from a coded report of a radiosonde ascent.

To augment data available from radiosonde ascents, observations from instruments mounted on two tall television masts will be disseminated by teleprinter, probably hourly. One mast is at Lichfield near Birmingham, the other at Belmont, on the Lincolnshire Wolds, 11 miles west-south-west of Manby. Observations are expected to become available late in 1967.

In connection with the project to mount instruments on television masts two studies have been completed in Headquarters. In the first a comparison was made between data from Baltham ascents and radiosonde ascents on days when it was expected that more frequent and more



detailed information at low levels would be useful. The results of the study supported the case being made for the advantages to be gained from having observations from instruments mounted at several levels on tall masts. The second study was to find the probable length of time a wet-bulb muslin and wick could be left unchanged on instruments on towers without introducing serious errors into the readings. A number of out-stations co-operated in this work which is described in detail in a Forecasting Techniques Memorandum.<sup>28</sup> A brief report has been published by McCaffery.<sup>29</sup>

(2) Forecasting large pressure falls

A method of forecasting large pressure falls (a rate equivalent to 4 mb or more in three hours) has been devised by J.M. Nicholls, who has adapted Petterssen's kinematic rules to advect isallobars. The technique has been tested at Bawtry and Pitreavie. A final report has been prepared and submitted for publication. The technique gives an advantage of one hour over extrapolation from two positions of a minus 4 mb/h isallobar.

(3) Observations from differently exposed urban sites

A comparison has been made at Southampton Weather Centre between observations of rainfall and temperature made on the roof of the centre and observations made at a nearby site with a more orthodox exposure. The rainfall records suggested significant differences between the sites, but it is not possible to say whether this arose because of site differences or because of real differences in rainfall. The temperature comparison was more useful indicating that fairly systematic differences occurred, the maximum temperature on the roof site being about 1 deg C lower and minima about 1 deg C higher than at the ground-level site. A report is being revised for submission for publication.

(4) Checks on accuracy of forecasts

Stations in Bomber Command are carrying out a comprehensive test of the accuracy of forecasts issued for Bomber Command operations. The criteria of accuracy have been decided in relation to the requirements of pilots and operations controllers. The techniques used by forecasters in arriving at their forecasts are not being examined in this exercise. Among the aims of the experiment is to test the accuracy of both long-period forecasts (12 to 24 hours), and short-period forecast (up to three hours), issued by a central office for an outstation against forecasts issued by staff at the outstation.

A series of tests of the accuracy of routine TAFS (terminal aerodrome forecasts) is being carried out at Bawtry. Particular attention has been paid to the marking system used in verifying the forecasts and the possibility of the forecaster 'playing the system' has been considered. According to the marks scored forecasts are classified as: correct (10), satisfactory (7-9), dubious (4-6), misleading (1-3) and wrong (0). The marking system is applied to individual parameters (wind, cloud, and visibility) as well as to the complete TAF. Preliminary results indicate the uneven success achieved in forecasting the various elements at four different aerodromes. They also show that at different aerodromes the elements which are difficult to forecast satisfactorily are different, and they indicate which techniques are in need of improvement at particular aerodromes. Misleading forecasts can be analysed, for instance, according to time of day, season and synoptic situation; individual synoptic situations in which wrong forecasts were made can be studied in the hope of specifying difficulties and improving techniques.

At Glasgow Weather Centre tests have been made over one year of how well various parameters used in forecasting night minimum temperatures can themselves be forecast. The percentages of correct forecasts (made

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at 1000 GMT) are given below, a correct forecast being taken as one that satisfied the criterion given in brackets:

Afternoon maximum temperature:	70% (not in error by more than 1 deg C)
Average dew point overnight:	66% (not in error by more than 1 deg C)
Average amount of cloud overnight:	54% (not in error by more than 1 okta)
Average wind force overnight:	77% (not in error by more than 1 force on Beaufort scale)

#### (5) Forecasting heavy falls of rain

Investigations are being carried out at Preston of occurrences of heavy falls of rain over the Lake District and over the catchment area of the River Dee. A number of occurrences in the Lake District have been examined synoptically and some tentative forecasting rules formulated. These relate to parameters such as depression tracks, and distance and depth of depression centres, stability and moisture content in approaching systems and the stage of development. A similar approach is being used in the study of heavy falls over North Wales and the Dee catchment area.

### 4. Tests of forecasting techniques

#### a. Background to tests of forecasting techniques

Replies from outstations to a Headquarters questionnaire on methods and techniques used in forecasting have been analysed and discussed in a Forecasting Techniques Branch Memorandum.<sup>2</sup> A wide variety of techniques are in current use, but little information is available to assist forecasters in deciding on the relative merits of various techniques or whether, in particular circumstances, one technique may not be better than another. Accordingly tests of a number of forecasting techniques have been or are being made by volunteers at outstations. Reports have been received from several workers and, where necessary, circulated to others working on the same or a related technique. Comments and suggestions for further work have been made to a number of volunteers and assistance has been given with the supply of necessary information and some data processing. Further details of the tests are given below.

#### b. Tests of instability indices and other methods of forecasting convection and thunder

The group of stations under the control of the Senior Meteorological Officer, RAF Manby, carried out tests of a number of methods of forecasting thunder during 1965, and further tests were made on a limited selection of methods during 1966. The results give some guidance on choice of methods, and pinpoint a weakness in the accuracy of forecasts of thunder in advance of frontal and non-frontal troughs (a weakness which was mostly eliminated during 1966). They also indicate the role of objective methods of forecasting thunder as being a "first guess" at the final answer decided on by the forecaster after considering further relevant details. Full reports on these tests are available in memoranda by Saunders;<sup>30,31</sup> brief reports have also been published in the Meteorological Magazine (Saunders<sup>3,4</sup>).

Tests of instability indices have also been made by forecasters at Watnall and Uxbridge and reports have been circulated.

A method due to Tkachenko<sup>32</sup> of forecasting the amount of cumulus development during the day is being adapted and tested at several stations. Preliminary reports have been received from Abingdon, Colerne, Cranwell, Ronaldsway and St. Mawgan. The method requires that for each station or area a forecasting diagram be constructed by plotting convection according to a three or four point scale on a scatter diagram. The diagram has for ordinate the mean relative humidity (or mean dew-point depression) in the convective layer as indicated by an appropriate radiosonde ascent, and for

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abscissa the logarithm of the "Convective Power" P. This is defined by Tkachenko as:

$$P = cZ_{cv} \overline{\Delta T}$$

where

c = mean wind in the layer 500 to 1500m

$Z_{cv}$  = the height to which convection will extend (taken to be the equilibrium level according to the parcel method)

$\overline{\Delta T}$  = the mean temperature difference between the ascending parcel and its environment averaged over the depth of the cloud.

An example of such a diagram, determined from one year's data for Abingdon, and tested over a second year, is given in Figure 2. The diagram is based on 63 occasions, and for those occasions gave a total percentage of correct forecasts of 84 and a skill score (Heidke<sup>33</sup>) of 0.50. The skill score (S) is given by:

$$S = \frac{\text{number correct} - \text{number correct by chance}}{\text{total number} - \text{number correct by chance}}$$

When tested on 39 cases of independent data results obtained were:

Overall percentage of correct forecasts = 79

skill score = 0.67

After preliminary failure, a more successful Tkachenko diagram was constructed at Ronaldsway by assessing convection according to the sea surface temperature instead of according to the maximum temperature over land. At Cranwell wind shear was used as ordinate instead of mean relative humidity and appeared to give satisfactory results; this diagram is now being tested on independent data. At four other stations where this method was tried little or no success was achieved. Three of the four are coastal stations and the fourth is much influenced by orographic effects of the Welsh mountains, the Cotswolds and the Bristol Channel. It seems likely that, at these stations, wind direction is a parameter which cannot be ignored.

#### c. Tests of techniques for forecasting night cooling

Tests of a technique due to Schmidt<sup>34</sup> for forecasting night minimum temperatures, using data available during the previous morning, are being carried out at a number of stations. Reports received suggest an accuracy can be achieved not very different from that obtained when using mid-afternoon data. The experiment at Heathrow is being written up for submission to the Meteorological Magazine.

Various objective techniques for forecasting night cooling are being compared at stations under the control of the Chief Meteorological Officer, Headquarters Bomber Command, and the Senior Meteorological Officer, Manby. Two articles have been received and are being considered for publication. No one method emerges as being clearly superior to all others in all circumstances. The technique due to McKenzie,<sup>35</sup> originally developed from data for Dyce, is very simple and easy to use and gives good results if the necessary local constants have been determined. Saunders' technique<sup>36</sup> gives rather better results when locally derived curves and constants are used, but these are less easily produced than the constants required by the McKenzie technique. Both the Saunders and the McKenzie methods require a knowledge of the afternoon maximum temperature and dew point as well as requiring a forecast of the overnight average wind strength and cloud amount. The McKenzie technique also requires a forecast of the mean dew point overnight. If forecasts of night minimum temperatures are required before the time of maximum temperature, other methods may be preferable. Glasgow Weather Centre have done some work on this aspect, but more work is required.

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At Mount Batten a test has been carried out of forecasts of night minimum temperatures for places in southwest England by means of a nomogram described by Barthram.<sup>37</sup> For these places (two coastal and one inland) separate analyses were made which showed similar features, about half of the forecast values in each case being within 1 deg C of the actual minimum temperature and about threequarters within 2 deg C. At coastal stations, occasions with winds off the sea were considered separately, sea temperatures being used instead of maximum temperatures over land.

A general conclusion which may be drawn from the results of all tests so far carried out is that there is not a great deal of difference in the results from different techniques, root mean square errors being usually about 1.5 to 2 deg C for tests carried out operationally. Lower errors are of course obtained if observed values of all necessary parameters are used. With Saunders' method, when necessary graphs and constants are derived from local data, and when observed values of all parameters are used, the root mean square error is reduced to just under 1 deg C.

d. Tests of snow predictors

4. Following a series of tests carried out at stations in the Manby group between January 1965 and March 1966, Gloucester and Glasgow Weather Centre, as well as the Manby group of stations, have arranged to carry out further tests based on an interim report from Manby. Little further work has yet been done because of the absence of snow during the winter 1966-67.

The tests carried out under operational conditions at eleven stations of the Manby group were of three techniques for determining the form - rain, sleet or snow - of wintry precipitation. The three techniques were each single-parameter forecasts based on work by Boyden<sup>38</sup> and Lumb.<sup>39</sup> The three parameters were:

- a) height of the dry-bulb freezing level
- b) adjusted 1000-850 mb thickness (adjusted for mean-sea-level pressure and height of station)
- c) height of the wet-bulb freezing level.

One object of the tests was to ascertain the results obtained in forecasting operationally for aerodromes remote from radiosonde stations. For these stations patterns of 1000-850 mb thickness lines and contours of the zero isotherm were advected by a suitable wind field to give forecast values of necessary parameters. The results, therefore, while indicating the degree of success achieved with the final forecast, do not distinguish between failures of the techniques themselves and failures to forecast correctly the values of the parameters. Occasions were separated into showery and non-showery types of precipitation, but no classification according to intensity of precipitation was attempted in this first exercise.

In all, 1025 forecasts were tested, cases being included only if they fell within certain cut-off limits suggested in the article by Boyden; this ensured the exclusion of cases when there was virtually no chance of a forecast of rain, or of snow, being wrong. Each forecast was for the station making it and was marked against the subsequent record at the station. The results are given in Table 1. Leaving out the small number of cases of equal probability forecasts (sleet), the percentage accuracy of forecasts of snow and forecasts of rain (postagreement) is given in Table 2.

Table 2 indicates, that for the cases considered, if snow is forecast there is little to choose between the methods; the height of the dry-bulb freezing level gives the best result for showers and the thickness method is better in non-showery cases. If the forecast is rain, however, the height of the wet-bulb freezing level method is markedly more accurate than the other methods for non-showery precipitation. For rain showers the wet-bulb method is slightly better than the dry-bulb freezing level method.

/ Table



Table 1. Results of tests of snow predictors

Method	Type of cases	<u>Forecast snow</u>			<u>Forecast sleet</u>			<u>Forecast rain</u>		
		<u>Observed</u>			<u>Observed</u>			<u>Observed</u>		
		Snow	Sleet	Rain	Snow	Sleet	Rain	Snow	Sleet	Rain
Dry-bulb	Non-showery	86*	11	7	2	1	-	18	9	38
Freezing level	Showery	130	6	4	4	2	-	25	11	45
Method	All cases	216	17	11	6	3	-	43	20	83
Adjusted	Non-showery	75	4	3	2	1	1	28	11	52
1000-850 mb thickness	Showery	147	13	15	4	-	1	9	9	43
Method	All cases	222	17	18	6	1	2	37	20	95
Wet-bulb	Non-showery	63	4	7	-	-	-	1	2	18
Freezing level	Showery	69	10	8	-	2	2	1	5	16
Method	All cases	132	14	15	-	2	2	2	7	34

\* numbers of occasions

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Table 2. Percentage accuracy of forecasts of snow and forecasts of rain

Method	Type of cases	<u>Forecast snow</u>			<u>Forecast rain</u>		
		Number of cases	Number correct	Percent correct	Number of cases	Number correct	Percent correct
Dry-bulb	Non-showery	104	86	83	65	38	58
Freezing level	Showery	140	130	93	81	45	56
Method	All cases	244	216	89	146	83	57
Adjusted	Non-showery	82	75	91	91	52	57
1000-850 mb thickness	Showery	175	147	84	61	43	70
Method	All cases	257	222	86	152	95	63
Wet-bulb	Non-showery	74	63	85	21	18	86
Freezing level	Showery	87	96	79	22	16	73
Method	All cases	161	132	82	43	34	79



Table 3 gives an assessment of the methods based on the overall percentage of correct forecasts and on the Heidke skill score. The figures are based on 3 x 3 contingency tables (forecast and observed occurrences of rain, sleet and snow) except for the last set of three results which are based on 2 x 2 tables. In these last results a prediction of sleet is taken as a forecast of snow or of rain as is suggested somewhat vaguely by the results in Table 1. The results can be analysed further using the data in Table 1 to determine the degree of success achieved in predicting the occurrence of an event (prefiguration), an important aspect in a warning system. The two aspects, probability that an event will be predicted (prefiguration) and probability that a forecast of an event will verify (postagreement), though separately important to different users of forecasts, cannot always be considered in isolation since, for instance, a high degree of prefiguration may be obtained at the expense of too many forecasts which do not verify.

The account given above of work carried on by the Manby group of stations is based on data given in an interim report by W.E. Saunders.

As well as the work described above, forecasters at Aldergrove have considered combinations of parameters as snowfall predictors. A preliminary report indicates that a scatter diagram with pressure at the freezing level against temperature at 850 mb gives useful results.

At Manchester Weather Centre a method, due to Mineeva<sup>40</sup>, of forecasting the form of wintry precipitation has been tested. This method, which is based on the 1000-850 mb thickness (unadjusted; c.f. Boyden's use of an adjusted thickness) gave results only slightly better than those obtained in the Manby test of predictors, although the former used actual values of parameters after the event while the latter used forecast values.

e. Penetration of rain into a blocking anticyclone

A technique, due to McElmurry,<sup>41</sup> for forecasting the eastward penetration of frontal rain into a blocking anticyclone over the British Isles is being tried, as cases arise, by staff in the Manby group of stations and at Liverpool and Birmingham Airport. So far there have been too few cases for any assessment to be made.

5. Publications

a. Aerodrome Weather Diagrams and Characteristics

Forty-five entries have now been included in this loose-leaf publication which is intended to supersede an earlier publication Airfield Weather Diagrams. Data for a number of other stations are being worked up at Headquarters. Proposals have been made, and are now being considered by outstation staff, for a standard presentation of statistical analyses to support the entries for individual stations. Arrangements are in hand to include entries for naval air stations.

b. A Century of London Weather<sup>42</sup>

This publication has been entirely rewritten by a former S Met O, London Weather Centre (Mr. J.H. Brazell) and should be available this year under the title London Weather.

c. The Weather Map<sup>43</sup>

This publication has been superseded by a somewhat more advanced book written by Mr. P.G. Wickham at the Training School. Under a new title it will become a companion volume to A Course in Elementary Meteorology.<sup>44</sup> Publication is expected in 1968.

d. Handbook of Weather Forecasting<sup>45</sup>

Parts of this book were written as early as 1957, and those sections dealing with aspects of meteorology which are advancing, at times rapidly,



Table 3. General measure of success of tests of snow predictors

Method	Type of case	Overall percent correct	Skill score
Height of dry-bulb freezing level	Non-showery	73	•48
Adjusted 1000-850 mb thickness		72	•50
Height of wet-bulb freezing level		85	•65
Height of dry-bulb freezing level	Showery	78	•55
Adjusted 1000-850 mb thickness		79	•53
Height of wet-bulb freezing level		77	•51
Height of dry-bulb freezing level	All cases	76	•52
Adjusted 1000-850 mb thickness		76	•53
Height of wet-bulb freezing level		81	•57
Dry-bulb (sleet = snow) *	All cases	81	•57
Thickness (sleet = snow) *		81	•58
Wet-bulb (sleet = rain) *		85	•64

\* A prediction of sleet taken as a forecast of snow or of rain as indicated in results in Table 1 - see text.



are likely to need revision in the near future. Accordingly a scheme has been organised by means of which many sections of the handbook are being kept under review by volunteers from Meteorological Office staff who have undertaken to keep abreast of advances in knowledge or of forecast practice relevant to the section in which they have a particular interest. Revised drafts of sections will be called for when considered necessary. A total of 34 volunteers, 22 of them from outstations, are registered at Headquarters, and between them keep under review between one-half and two-thirds of the material in the handbook.

e. Forecasters' Reference Book

This book, which is an expanded and improved version of the Pocketbook for Forecasters,<sup>46</sup> was first drafted by a former C Met O, Headquarters Fighter Command (Dr. J. Pepper). Drafts were examined and commented on by a number of outstation staff, who also put forward a number of ideas on form and content. A revised draft is now being examined and put into final form by a panel of Headquarters staff. The book is likely to be available in 1968 and will contain forecasting rules, methods and techniques stated as briefly as possible and collected into appropriate chapters. Any tables, nomograms, diagrams or other information needed to enable the techniques to be used will be included together with any cautionary notes. Where possible some indication will be given of the effectiveness of techniques, and comprehensive references will enable background information to be readily obtained when desired. To facilitate use an adequate list of contents and an index will be included.

6. Future plans

Much work remains to be done on projects already in existence, and outstation staff are encouraged to bring their efforts to a successful conclusion with publication of items of general usefulness or interest, while at the same time projects which do not seem likely to bring useful results for the effort expended are abandoned. New problems are thrown up from time to time as commitments change or it may be possible to look at old problems anew if fresh data or techniques become available.

Data from instruments mounted at various levels on two television masts 1000 ft or more in height will be available, probably from late 1967. Measurements of wind speed and direction, temperature and humidity will be made at up to six levels (wind measurements at only two of these) and the data, which will be recorded at the foot of the mast, will also be available at any time by interrogation from nearby meteorological offices. The two masts are at Lichfield near Birmingham and at Belmont on the Lincolnshire Wolds. Thus data will be available for places, heights and times from which data have not been available before and should be extremely useful in studies of low cloud and perhaps fog. For considerable areas round the masts the data can be used with existing techniques as information more appropriate in time and place than that available from the present network of radiosondes. Additionally the existence of such data, continuously available, makes possible studies of the formation and dispersal of fog and very low cloud which could lead to improvements in forecasting techniques.

Two new instruments which are now available are the cloud-base recorder and the photo-electric visibility meter (transmissometer). Proposals have already been made for several investigations into the variation of cloud height using the former instrument. The continuous record available from the latter will make possible a detailed analysis of the variation of visibility with time. Two or three of these instruments at a large airport will enable studies of spatial variations in fog to be made.

Another possibility for the future arises from current advances in telemetering and the production in quantity of automatic weather stations. By careful siting of automatic stations or of sensors for measuring, perhaps, only one parameter, local synoptic studies can be facilitated which were not previously possible because of the absence of data.

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Appendix A

Outstation forecasting problems related to effects of topography

1. EFFECTS ON CLOUD

1.1. Thorney Island

'The sheltering effect of the Isle of Wight on cloud formation'

1.2. Middleton St. George

'The effect of the Pennines on precipitation and cloud associated with a front moving eastwards over the country. There is some evidence that under these circumstances standing waves are produced.'

1.3. Plymouth

'The variation of cloud base with wind direction is very marked in many places in S.W. England. The most useful aid to detailed forecasting is to have in existence statistics showing the variation of cloud height with wind direction and speed. This had already been carried out with regard to Exeter Airport, and similar work is in hand at Chivenor.'

1.4. Linton

'Sheltering effects of Pennines with winds 220-340°; cloud mainly broken and above 1000 feet. Sheltering effects of Yorkshire Moors and Wolds against N. Sea stratus.'

1.5. Leeming

'Sheltering effects of Pennines and Yorkshire Moors in winds 230-260°, 300-350°, 070-100°, keeping cloud base normally above 1000 feet.'

1.6. London Airport

'There seems plenty of qualitative evidence for the sheltering effect of both the Chilterns and the N. Downs, and also for the complete lack of shelter in Easterlies. These 'feelings' can only be checked by a statistical investigation. If this were done, according to wind direction and speed, time of day and month of year, it would throw some light on the shelter effect, and also on the advection of low stratus from the North Sea in Easterlies.'

1.7. Turnhouse

'Effect of high ground on cloud base.'

1.8. Kinloss

'Effect of shelter on cloud.'

1.9. Ballykelly

'The absence of very low cloud due to the sheltering of surrounding hills.'

1.10. Defford

'The main problem is to decide how the high ground to the west of the area (especially over Wales) will affect the structure of fronts and clouds'.

1.11. Driffield

'Break-up of cloud after passage over the Pennines and Yorkshire Wolds'.

1.12. Benson (see 3.1.)

2. EFFECTS ON SURFACE WIND

2.1. Benson

'All surface winds are subject to a certain amount of deflection due to the proximity of the Chiltern Ridge which lies NE-SW just off the SE edge of the airfield. This effect seems most marked with gradient winds from a northerly point; a veer of some 30/40 degrees is fairly consistent. Similarly a southwesterly airstream tends to back towards south.'

/ 2.2.



- 2.2. Hullavington  
'With wind directions between 250 and 280 degrees the Bristol Channel funnelling effect produces strong surface winds.'
- 2.3. Syerston  
'Local topography has a great effect on both the direction and the speed of the surface wind. With a gradient between S.W. and N.W. the surface wind is often about 60 to 100 per cent of the gradient wind.'
- 2.4. Ternhill  
'Accurate forecasting of the winds in the lower layers is a major problem at this station because of the important effect produced by the Welsh and East Midlands hills and mountains. Fronts approaching from between 320° and 340° give appreciably worse weather than fronts from between 210° and 300°. In an unstable northwesterly airstream the exact track of the airstream is most important because it influences the frequency with which showers penetrate the Cheshire Gap. A small fluctuation in the direction of the airstream may have a great effect on the shower frequency.'
- 2.5. Shawbury  
'Topography plays a most important part in the weather experienced at this station, therefore one of the major problems is accurate forecasting of the wind in the lower layers. The rugged surrounding countryside makes this very difficult at times. Accurate forecasts of visibility, cloud and temperature are frequently dependent on accurate forecasts of wind and on making the correct allowance for any wind effects such as Fohn or Katabatic. For instance, with westerly winds the Fohn effect usually results in a fairly high cloud base or no cloud at all, but with winds from about 250° low cloud and precipitation may pass through the 'Dovey' gap. Thus a small change in wind may result in a change from overcast conditions with drizzle and poor visibility to fine weather with little or no cloud.'
- 2.6. Hawarden  
'Forecasting surface wind speed and direction with certain pressure gradients. The 'Cheshire Gap' appears to have a controlling effect under certain conditions.'
- 2.7. Leuchars  
Turnhouse  
Donibristle  
'Conditions favourable for strong surface wind due to funnelling.'
- 2.8. Dyce  
'Unusually strong SSW surface winds.'
- 2.9. Kinloss  
'Effect of shelter on surface wind.'
- 2.10. Rhoose  
'The difficulty of forecasting the surface wind speed in easterly or northeasterly airstream. The funnel effects between the Somerset and Devon hills to the south and the Welsh hills to the north would appear to have a fairly constant effect, yet it has been noted at Rhoose that on two successive days with no apparent change in the general situation the wind speed on the first day will be 5-8 kts and on the second day 15 kts.'
- 2.11. Leeming  
'Effect of Wensleydale Valley and Yorkshire Moors on wind speed.'
- 2.12. Heathrow  
'The derivation of a general relationship between surface wind and gradient wind for various wind directions would enable the effects of the surrounding hills and valleys to be determined.'



3. EFFECTS ON TEMPERATURE AND HUMIDITY

3.1. Benson

'The Welsh hills exercise a marked drying effect on air reaching Benson from a WNW direction.'

4. EFFECTS ON PRECIPITATION

4.1. Middleton St. George

As 1.2. above.

4.2. Preston

'What are the conditions which give rise to prolonged or unexpectedly large amounts of precipitation in different parts of the Lake District and Pennines? The problem here is partly to recognise the occasions when they occur. Due to scarcity of regular observations it is not unusual for the morning newspapers to give the first intimation of, say, a heavy snowfall.'

4.3. Leuchars

'Effect of shelter on shower frequency.'



Appendix B

Outstation forecasting problems, mainly non-topographical

1. CLOUD

- 1.1. Manby and Strubby  
'North Sea stratus'
- 1.2. Wyton  
'Effect of sea breeze on North Sea stratus'
- 1.3. Valley  
'Break-up of stratus in 'wide warm sector''
- 1.4. Bawtry  
'Clearance of stratus in a 'fairly wide warm sector''  
'North Sea stratus'
- 1.5. Mildenhall  
'North Sea stratus'
- 1.6. Aldergrove and Nutts Corner  
Re-formation of low stratus after post cold front clearance'
- 1.7. West Raynham  
'North Sea stratus'
- 1.8. N. Luffenham  
'North Sea stratus'
- 1.9. Waterbeach  
'Height of base of low stratus with various wind directions'
- 1.10. Horsham St. Faith  
'North Sea stratus'
- 1.11. Prestwick  
'Extension of existing work on low stratus'
- 1.12. Hurn  
'Height of low cloud base with various wind directions'
- 1.13. Bovingdon  
'Height of low cloud base with various conditions of wind and stability'

2. VISIBILITY

- 2.1. Manby and Strubby  
'Sea fog inland'
- 2.2. Thorney Island  
'Effect of land breeze on fog formation'
- 2.3. Ballykelly  
'Encroachment of sea fog with sea breeze'
- 2.4. Watnall  
'Effect of winter ground surfaces on fog formation and dispersal'  
(snow cover, frost, etc.)
- 2.5. Acklington  
'Sea fog inland'
- 2.6. Hurn  
'Encroachment of sea fog with sea breeze'



3. SURFACE WIND

- 3.1. Woolsington  
'Conditions for abnormally strong westerly winds'
- 3.2. Aldergrove  
'Conditions for abnormally strong SE'ly winds'
- 3.3. Prestwick  
'Extension of existing tables of surface/gradient wind relations'
- 3.4. London Airport  
'Topographical effects on surface/gradient wind relations'
- 3.5. Bovingdon  
'Surface/gradient wind relations'

4. TEMPERATURE AND HUMIDITY

- 4.1. Pitreavie  
'Persistence of cold surface air in Forth valley when milder air has arrived elsewhere'
- 4.2. Mildenhall  
'Extent inland of diminution in frost risk due to recent sea track of air'
- 4.3. Uxbridge  
'Diurnal variation of temperature as affected by cloud cover and fog'
- 4.4. London Airport  
'Average monthly diurnal temperature curves'
- 4.5. Hurn  
'Cooling characteristics (in relation to fog and frost)'

5. PRECIPITATION

- 5.1. Preston  
'Abnormal diurnal variation of shower frequency on and near coast'
- 5.2. Speke  
'Abnormal diurnal variation of shower frequency'
- 5.3. Bawtry  
'Snow showers from N or NE'
- 5.4. Pitreavie  
'Intensity on fronts at east coast stations vis-a-vis west coast stations'  
  
'Conditions for heavy rain in Spey valley'
- 5.5. Mildenhall  
'Occurrence, (usually in winter), of rain or snow on NW coast of Norfolk, late at night or early morning in Northerly airstream which is unstable over sea but not over cold land'
- 5.6. Aston Down and Colerne  
'Abnormal diurnal variation of shower frequency'
- 5.7. Pembrey  
'Abnormal diurnal variation of shower frequency'

/ 5.8.



- 5.8. Leeming  
'Sheltering by Pennines and Yorkshire Moors'
- 5.9. Uxbridge  
'Amounts and types of snow (dry powdery, large wet flakes, etc.)'
- 5.10. Prestwick  
'Extension of existing work on snow'
- 5.11. London Airport  
'Amounts of snow in particular synoptic situations'



Appendix C

Standing Programme for Statistical Treatment of Climatological Data  
(Incorporating amendments made by the Met O 8 Statistical Working Group on 7/11/63)

1. Visibility

- (a) For each month separately (irrespective of year)  
For each hour  
Frequencies of visibilities in each of the following ranges  
(tens of metres)  
000-019, 020-039, 040-099, 100-199, 200 or more
- (b) For April-September combined and for October-March combined  
(irrespective of year)  
For each visibility range given in 1(a) separately  
For each wind direction in the 30° ranges  
00 (Calms), 35-01, 02-04 ..... 32-34  
Frequencies of wind speed in the ranges  
0, 1-3, 4-6, 7-10, 11-14, 15-19, 20 or more knots  
Frequencies of relative humidity in the ranges  
0-79, 80-89, 90-96, 97-100

2. Cloud Base

For each of the seasons (irrespective of year)  
Spring (March to May), Summer (June to August)  
Autumn (September to November), Winter (December to February)  
For each of the following ranges of the height of the lowest layer of  
cloud of  $\frac{5}{8}$  or more or vertical visibility (in hundreds of feet)  
separately  
00-02, 03-05, 06-09, 10 or above, unlimited i.e. no cloud layer of  $\frac{5}{8}$   
or more.  
For each wind speed in the following ranges (in knots)  
0, 1-3, 4-6, 7-10, 11-14, 15-19, 20-29, 30-39, et. seq.  
Frequencies of wind direction in the 30° ranges  
00 (Calms), 35-01, 02-04, ..... 32-34

3.\* Combined Cloud Base and Visibility Summary

For each month separately (irrespective of year)  
For each of the 8 synoptic hours separately  
Frequency tabulations in ranges:  
visibility, (tens of yards) 000-004, 005-010, 011-021, 022-032,  
033-043, 044-054, 055-065, 066-076, 077-087, 088-098,  
099-109, 110-129, 130-169, 170-219, 220-329, 330-439,  
(miles) 3, 4, 5, 6, 7-12, 13-24, 25 or more.  
cloud base,  $\frac{5}{8}$  or more, (hundreds of feet) 0, 1, 2, 3, 4, 5, 6-7,  
8-9, 10-11, 12-14, 15-19, 20-29, 30-39, 40-49, 50-59,  
60-69, 70-79, 80-119, 120-199, 200-299, 300 or more.

4. Sea Level Pressure

This item has now been deleted from the Standard Programme.

5.\* Wind Speed and Direction

For each month separately (irrespective of year)  
For each of the 8 synoptic hours separately

/ For

\* Includes Met O 9 requirement based on WMO Technical Regulations.



For each 30° range of direction (02-04, 05-07 ..... 35-01)  
Frequency of spot winds in the ranges

0, 1-3, 4-6, 7-10, 11-16, 17-21, 22-27, 28-33, 34-40, 41-47, 48-55,  
56-63, more than 63 kt.

6. Cooling Curves

This item has to be re-formulated and may be programmed for COMET.

7. Five-day Temperature Means

For each five-day period starting Jan. 1st-5th et. seq. (omitting Feb. 29th)  
Five-day mean maximum and minimum temperatures, extremes, and upper and lower  
ten-percentiles.

8. Analysis of Clear Skies in relation to Wind Speed and Direction

For each month separately (irrespective of year)

For occasions when the total cloud was 0 or  $\frac{1}{8}$

(a) Frequency of wind directions in 10° ranges

(b) Frequency of wind speeds in the following ranges

0, 1-3, 4-6, 7-10, 11-14, 15-19, 20-29, 30-39 et. seq.

9. Comparison of Surface Wind with Wind at 900 mb

For this item, tapes containing the basic data will be supplied by MOPCI  
to Met 0 8. The data will then be processed by Met 0 8, using the computer.

Tapes required from MOPCI:

For each month (irrespective of year) three tapes are required for a  
day hour and three for a night hour. The three classes of tape are:

(i) To contain 900 mb winds for the specified radiosonde  
station, punched;

dddSpSpffffCRLF

The tape for day will be for the 1400 GMT ascent  
till 1.4.57, then for the 1100 GMT ascent.

(ii) To contain surface temperature, 900 mb height and  
900 mb temperature from the specified radiosonde  
station, punched:

T<sub>0</sub>T<sub>0</sub>T<sub>0</sub>SpSpH<sub>9</sub>H<sub>9</sub>H<sub>9</sub>H<sub>9</sub>SpSpT<sub>9</sub>T<sub>9</sub>T<sub>9</sub>CRLF

The hours for the day and night tapes will be as in (i)

(iii) To contain surface winds from the specified surface  
station, punched:

ddSpSpffCRLF

The surface wind should be that for the available  
observation nearest to the time of the radiosonde ascent.  
(For some surface stations, cards are available for only  
3-hourly observations.)

Observations punched at the same position on each of the three  
tapes must refer to the same time. Characters for missing data  
should be punched as "9". On tapes of class (i), calm should be  
punched as:

099SpSp000CRLF

Heights may be in metres or tens of feet, and temperatures in  
°C + 100 or °F + 200. The number of observations on each tape  
should be noted.



Technique is in use, very helpful.

Technique is in use, but not found satisfactory.

Technique is in use, but limited applicability.

Technique tried and found wanting; not now used. ✓

[illegible]



# Appendix E

## Suggestions for research and development

<u>KEY</u>	Category A	Development requested
	Category B	Development strongly supported
	Category C	Development very strongly supported

Technique	Number of stations supporting category		
	A	B	C
<u>PREPARATION OF FORECAST CHARTS</u>			
Movement and development of features at surface and aloft	2	1	
Development and movement of non-frontal troughs and polar lows	2		
Acceleration and deceleration of fronts over British Isles	1		
Speed of warm fronts over cold land in winter	1		
"Helmholtz-Cranwell" method for movement of fronts	1		
Short-term limited-area forecast charts - early issue	2	1	1
Analysis of "A" and "C" areas on thickness charts	1		
Thickness change with developing highs and lows	1		
Charts of vertical motion	1		
Vorticity charts	3	1	
Relationship between 300 mb patterns and weather	1		
<u>TEMPERATURE</u>			
Forecasting night minimum temperatures over snow	4		
Modification of air passing from sea to land	2		
Warming and cooling of air passing over the sea	1		
Corrections to above for wind speed and depth of turbulence	1		
Temperature and humidity fine structure in lowest 1000 ft	1	1	
Extension to other places of Belasco's work at Kew	1		
Inland penetration of thaws (warm air advection over snow)	1		
Formula for Chill Factor for public-service forecasts	1		
Meso-scale turbulence - effects on temperature	1		
<u>VISIBILITY</u>			
Fog dispersal using network of low-level soundings	4		
Probability statistics of fog formation	1		
Variation of visibility in fog	2		
Fog clearance during evening or night	1		
Onset and clearance of sea-fog	1		
Meso-scale turbulence - effects on fog	1		
<u>CLOUD</u>			
Stratus dispersal using network of low-level soundings	4		
Meso-scale turbulence - effects on stratus	1		
Relationship between cloud layers and the tephigram plot	3		
Structure and amount of turbulence-cloud (Sc)	11	1	
Formation and dispersal of turbulence-cloud (Sc)	11	1	
Variation of cumulus tops with time	2		
Frontal cloud structure	1		
Amount of instability cloud	1		
Interpretation of satellite pictures	1		
Onset and clearance of stratus	7		
Height of base of stratus	7		
<u>PRECIPITATION</u>			
Frontal rain and the 300-100 mb thickness pattern	1		
Frontal rain - amount in given area	4	1	1
Objective methods for amount, duration and type	1		
Statistical investigation of orographic shelter from rain	1		
Deceleration of frontal rain approaching a blocking anticyclone	1		
Use of radar information	1	2	
Formation of thunderstorms and hail	1		
Instability indices for whole year	2		
Thunderstorms - Simila's method	1		

P.T.O.



Suggestions for research and development (contd.)

KEY    Category A    Development requested  
           Category B    Development strongly supported  
           Category C    Development very strongly supported

Technique	Number of stations supporting category		
	A	B	C
<u>PRECIPITATION (contd.)</u>			
Thunderstorms - Skeib's method	1		
Thunderstorms and hail - Miller and Starrett's method	1		
Early morning showers in coastal areas	1		
Rates of subsidence - effects on showers	1		
Conditions under which falling snow may be expected to lie	1		
Determination of height of snow line - snow over high ground	2		
Relationship between thickness values and snowfall	1		
<u>WIND AND TURBULENCE</u>			
Vertical extent of frictional turbulence over hilly regions		1	
Turbulence near jet-streams - Harrison and George's method	1		
Clear air turbulence in relation to jet-streams	4		
Relationship between winds and topography	1		
Relationship between surface and gradient winds	1		
Sea breezes at specific localities	4		
Short-term, limited-area, upper wind forecasts	3		1
Streamline and isotach charts	1		
<u>LOCAL WEATHER</u>			
Meso- and micro-scale effects of topography of British Isles		1	
Statistics as an aid in local forecasting	2	1	
Objective methods at small stations, e.g. similar to George's	5		
Urban "heat-island" effects	1		
Pollution sources and Clean Air Act	1		
Shower frequency distribution	1		
<u>MEDIUM-RANGE FORECASTING</u>			
Use of 10-day mean-thickness charts	1		
Lowndes' techniques for other parts of Britain	2		
Duration of settled and unsettled spells in various regions	1		
Climatology of thickness patterns and associated weather	1		
<u>SUBTROPICAL AND TROPICAL</u>			
Position, intensity, movement of subtropical jet-stream	1		
Meridional extension in low latitudes	2		
Study of upper-flow patterns in the Eastern Mediterranean	2		
Heavy rainfall at Gibraltar	1		
Wind through Straits of Gibraltar - pressure difference method	1		
Statistics of rainfall according to time of day	1		
Equivalent headwinds - regression equation method	1		
Alternatives to frontal analysis south of 40°N.	1		
Modification to cloud structure on crossing large land masses	1		
Changes in upper easterlies during summer at Bahrain	1		
Movement of semi-permanent trough in Persian Gulf	1		
Wind structure of Inter-tropical Convergence Zone	1		



Scale: 1cm = 10 %  
Percentage of calms  
beneath roses





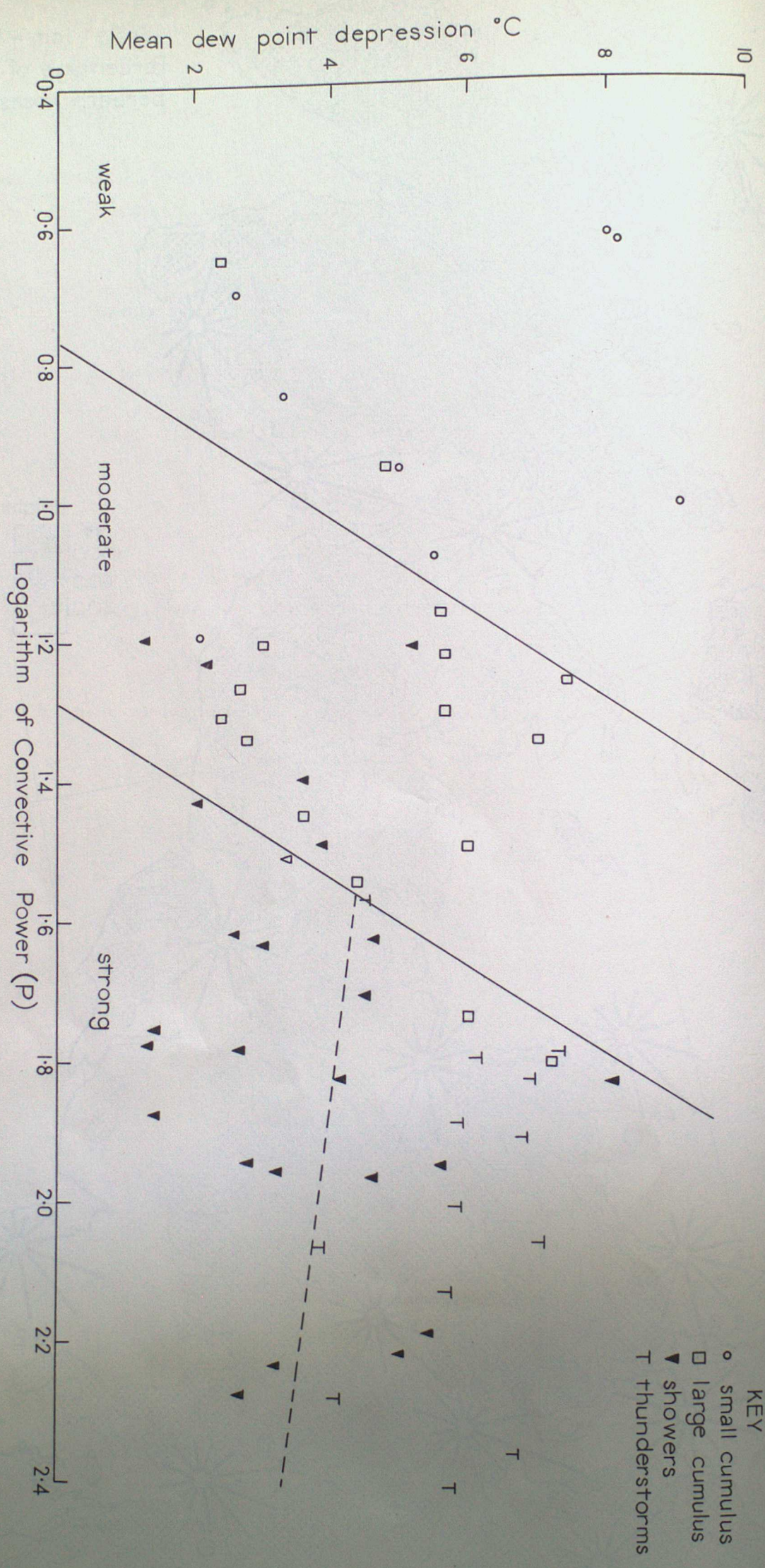


Fig 2. Tkachenko diagram for Abingdon



## FORECASTING TECHNIQUES MEMORANDA

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