A SYSTEMATIC APPROACH TO LOCAL OBJECTIVE FORECAST STUDIES

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SUMMARY

Problems in the design, preparation, and use of local objective forecasting studies ~~have been~~ were evaluated while specific local objective forecasting studies were being made. As a result, a systematic procedure that may be used as a guide in designing and preparing local objective forecasting studies was developed and tested in a number of seminar-workshop groups. The systematic procedure is outlined and discussed with illustrations from several local objective forecasting studies. The procedure consists of defining the local forecasting problem in terms consistent with observing and forecasting capabilities, resolving the variability of the forecast element into its cyclic (seasonal and diurnal) and "synoptic" components, and finally, reassembling the components into a forecast scheme that allows the forecaster to exercise his training as a meteorologist. ( )

I. INTRODUCTION

The more general problems of preparing local objective forecast studies were intensively considered while a number of local meteorological investigations were being made. The questions of the relative usefulness of objective aids to the forecaster versus a complete objective forecast system, the integration of objective techniques with standard forecasting training and skills, and the contribution of objective studies to the understanding of atmospheric processes were constantly reviewed throughout the work of each local study. Tentative answers to these questions were tested in a number of seminar-workshop groups formed of representatives from the forecasting staffs of U. S. Air Force weather detachments in Western Europe and England. The methods and procedures finally selected are presented in the form of a systematic approach to the preparation of local objective forecast studies.

The "systematic approach to the preparation of local objective forecast studies" as a standardized procedure will be designated SAPLOFS in the following paragraphs in order to distinguish it from specific local objective studies used as illustrations or in other contexts.

The outlined procedures contained in the SAPLOFS are analogous to standarized step by step methods employed in chemical analysis. The procedures of chemical analysis form a general method applicable to most chemical substances. In a like manner the SAPLOFS is applicable to a wide variety of local forecasting problems. Again, as in chemical analysis, the specific results obtained in each step guide the interpretation of the general instructions of the following step.

The work was performed while the writer was on active duty with the

Air Force, assigned to the Scientific Services Division of Headquarters, 2nd Weather Wing, and stationed with its Technical Support Branch at Rhein Main, Germany. Analysts and forecasters of the Technical Support Branch processed the data, prepared the charts and diagrams, and assisted with the analysis and interpretation of the results. The problem of forecasting the visibility at Rhein Main, Germany was used to investigate the over-all problems involved in the preparation of local objective forecast studies. Preliminary conclusions were evaluated and tested on studies of visibility at four other locations in Germany and England. Problems involving forecasts of surface winds, thunderstorms, and crosswind components were considered in evaluating the sufficiency of the derived procedure.

II. DEFINITION OF OBJECTIVE FORECAST STUDIES

The definition of objective weather forecasting studies given by Allen and Vernon (1951) in the Compendium of Meteorology is excellently suited to the concepts of this discussion. The essence of this definition is contained in their statement that, "the test of whether a system is objective is whether different meteorologists using the system independently arrive at the same forecast from a given set of maps and data." The meteorologist is allowed to use his training when standardized and based on established physical principles and observational fact. He is also permitted the use of analyzed maps and charts, even though some subjectivity enters into their preparation, as long as other meteorologists employing the same system use the same maps and charts.

For example, an operation may appear to require forecasts of visibility to the nearest 1/8 mile. The visibility observations at the site of the operation may, however, be accurate only to the nearest 1/4 mile due to directional variability, lack of check points or other reasons. Objective (or subjective for that matter) attempts to forecast to the nearest 1/8 mile cannot be expected to be satisfactory since they are based on and verified by observations less definitive than 1/8 mile.

III. CRITERIA FOR OBJECTIVE FORECAST STUDIES

Three criteria are applicable to all objective forecast studies:

1) The relationships tested should have a sound basis in physical reasoning.

2) The study should contribute to the forecaster's understanding and knowledge of the meteorological problem at hand.

3) The study should produce objective aids which allow the forecaster flexibility in time and, to some extent, in values of the forecast variable.

The first criterion guards against unprofitable results by eliminating unlikely possibilities. It also helps avoid the kind of results which look promising at first but fail to pass the tests of time and independent data. The second criterion gives the forecaster a feeling for the limitations of the results. It also gives him sufficient knowledge of the particular forecast problem to allow him to modify the objective results, when the conditions demand, without abandoning them in favor of purely subjective techniques. The third criterion gives the forecaster the flexibility with the objective study that will allow him to answer questions of modified operations posed during any period of the day. It will also permit the continued use of the same objective tools when operational criteria change, thus eliminating the need for a new study based on the new critical values of the changed operation.

A study of winter precipitation amounts at Washington, D. C., by R. R. Rapp (1949) affords an example of the application of these criteria to an objective forecast study. Rapp based his study on a theoretical expression for the rate of rainfall derived by Fulks (1935) and Holmboe, Forsythe and Gustin (1945). He proposed the theoretical expression as an hypothesis which he tested statistically with the meteorological data. Using the statistical results as a guide, he was able to modify the original expression for a better fit to the data. Rapp concluded that by employing the variables in the manner suggested by theory it is easier for the practicing forecaster, when using the method, to modify each individual case subjectively and to project the method further into the future.

IV. OUTLINE OF THE SYSTEMATIC APPROACH TO LOCAL OBJECTIVE FORECAST STUDIES (SAPLOFS)

The main steps in the suggested systematic procedures for the preparation of local objective forecast studies (SAPLOFS) are presented in this section in an abbreviated form. These steps will be discussed item by item and illustrated with examples in the subsequent section. The outline is presented at this point in order that the reader may orient himself for the discussions that follow and gain a feeling for the scope of the plan that is being suggested. The SAPLOFS may be briefly outlined as follows:

I. Define the meteorological problem.

II. Determine the realistic critical forecast limits.

III. Determine and remove the cyclic (seasonal and diurnal) variability from the data.

IV. Study the "synoptic" variability of the data for physically valid relationships with other "synoptic" parameters.

V. Organize the seasonal, diurnal and "synoptic" components into a systematic forecast method.

V. DISCUSSION OF SYSTEMATIC PROCEDURE FOR OBJECTIVE FORECASTING STUDIES

DEFINING THE METEOROLOGICAL PROBLEM

The meteorological problem should be defined as narrowly as possible, using the operational problem as a guide only. Frequently, if a literal translation of an operational problem into its meteorological counterpart is made the problem becomes physically unrealistic. For example, a particular operational problem may require forecasts of visibility less than 1/2 mile at a specified time. If an objective forecast study is prepared around this value and this time only, a new study probably would be required if operational demands suddenly change, as they frequently do. It is preferable to study the general problem of restricted visibility determining the forecast limits within the ability of the observer to distinguish separate ranges of visibility. Implied here also is the suggestion that the restriction to visibility is not specified at the outset. Distinction between haze and fog is difficult to specify objectively and more difficult to observe. Restrictions to visibility due to active precipitation can be separated from fog, haze and smoke since they occur as a result of different dynamic processes. The forecast limits, then, should not be specified until certain procedures, to be outlined in the following steps, have established the limit of accuracy of the meteorological variable in question.

It is desirable, also, to keep the time of forecast preparation and the forecast period flexible to avoid physically unrealistic time-lag relationships and to allow for future changes in operational criteria which would otherwise require a new study for each change in criteria or forecast period. Maximum benefit and minimum chance of unprofitable results are obtained by first studying the nature of the more general meteorological problem, then adapting the results to the specific operational problem.

DETERMINING THE CRITICAL FORECAST LIMITS

The practical interval of observational accuracy may be determined by plotting the frequency distribution of a random sample of observed and recorded values of the element to be forecast. One cannot expect an entirely smooth distribution; on the other hand, one should expect a more or less continuously varying distribution without large fluctuations in the frequency. When large frequency fluctuations occur as the observational values increase continuously, one can deduce that these are due to the observer's inability to distinguish between intermediate values. The explanations may not be obvious and are not necessary to the successful pursuit of the study. In the case of visibility it may be impossible for the observer, on occasion, to accurately specify the visibility by a single number. The visibility may be 1/4 mile in one quadrant, 1/2 mile in two quadrants and 3/4 mile in the fourth. If the observer reports 1/2 mile visibility, the visibility in two quadrants is different by 1/4 mile. Any of these visibilities could easily obtain at his observation point without significant change in any meteorological parameter. Other inaccurate visibility observations may be due to distances between check points, variability of light sources, the tendency for observers to prefer certain numbers and the operational importance of certain values. In any event, the fluctuations basically reflect the degree of uncertainty of the

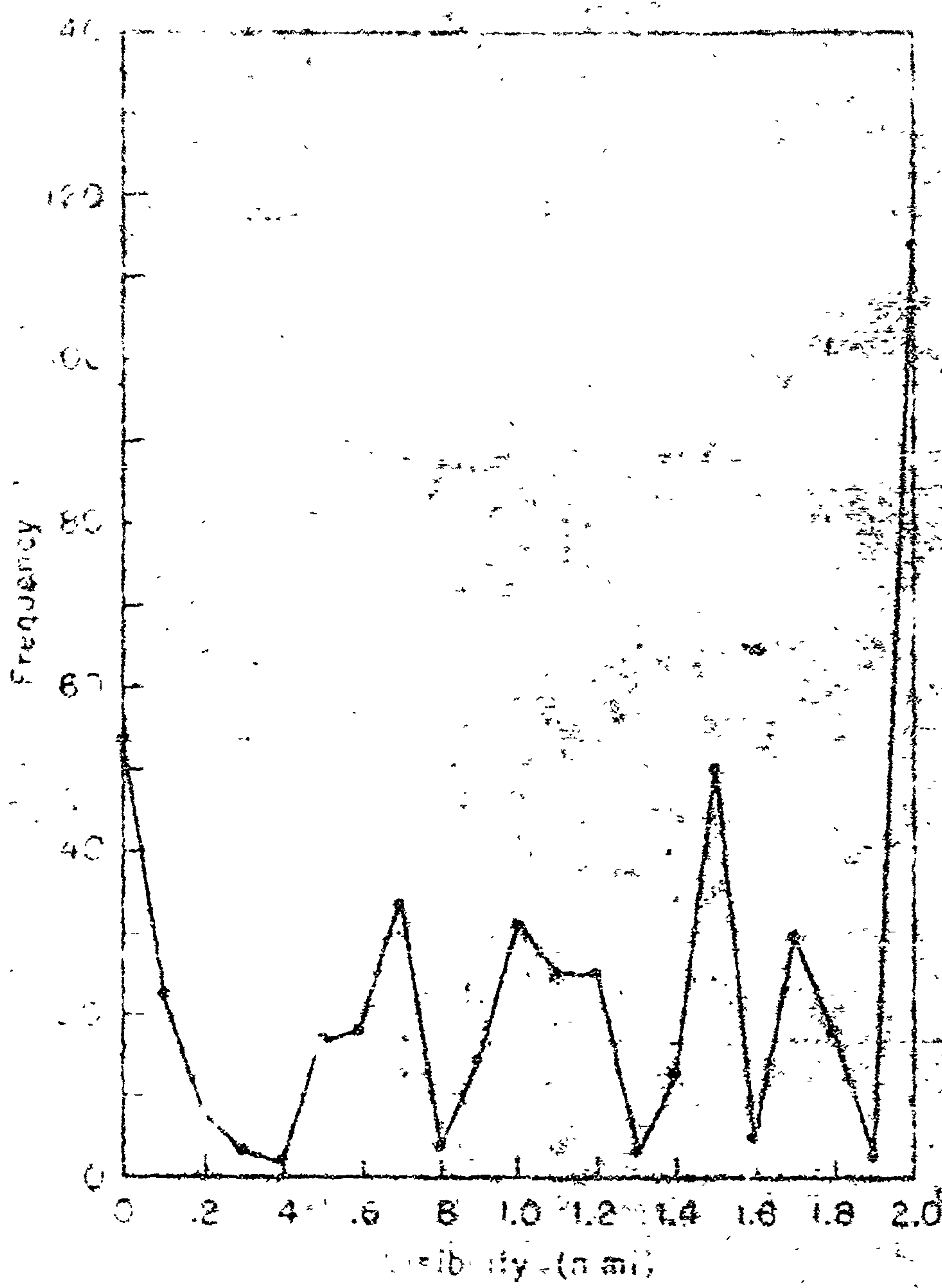

Figure 1

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observations and appear regularly in the recorded values of most meteorological elements. The critical forecast limits must be chosen with this inherent inaccuracy in mind. When steadily increasing values of the forecast element exhibit alternately these relative maxima and minima at short intervals as they do in Fig. 1, one may safely assume that the interval of observational accuracy is the interval between successive maxima. An observer certainly should be able to distinguish between zero visibility and 0.1 nautical mile. Beyond this, as far as Figure 1 is concerned, one can state with assurance that visibilities of 0.1, 0.2, and 0.3, can be distinguished from 0.5, 0.6, and 0.7, these from 0.9, 1.0, 1.1, and 1.2, etc. Conversely, one cannot defend the strong increase and decrease in the observed frequency of consecutive values on the basis of experience or physical reality. Consecutive values do not represent a true difference in visibility. Leaving out zero visibility a running mean of the frequencies for five 0.1 nautical mile intervals is required to produce a reasonably smooth curve from the data of Fig. 1. Thus one must conclude that the interval of observational accuracy in the visibility at Lakenheath is approximately 1/2 nautical mile and that a projected study of visibilities there should not attempt to forecast the visibility for intervals less than 1/2 nautical mile beyond 0.1 nautical mile visibility.

When a problem involves two forecast elements it is advantageous to determine to what extent one is a function of the other. Employing the previously determined intervals of observational accuracy and the operational criteria, the one variable is plotted against the other. If a strong functional relationship exists, only one of the two variables need be considered directly throughout the study. If the two elements are

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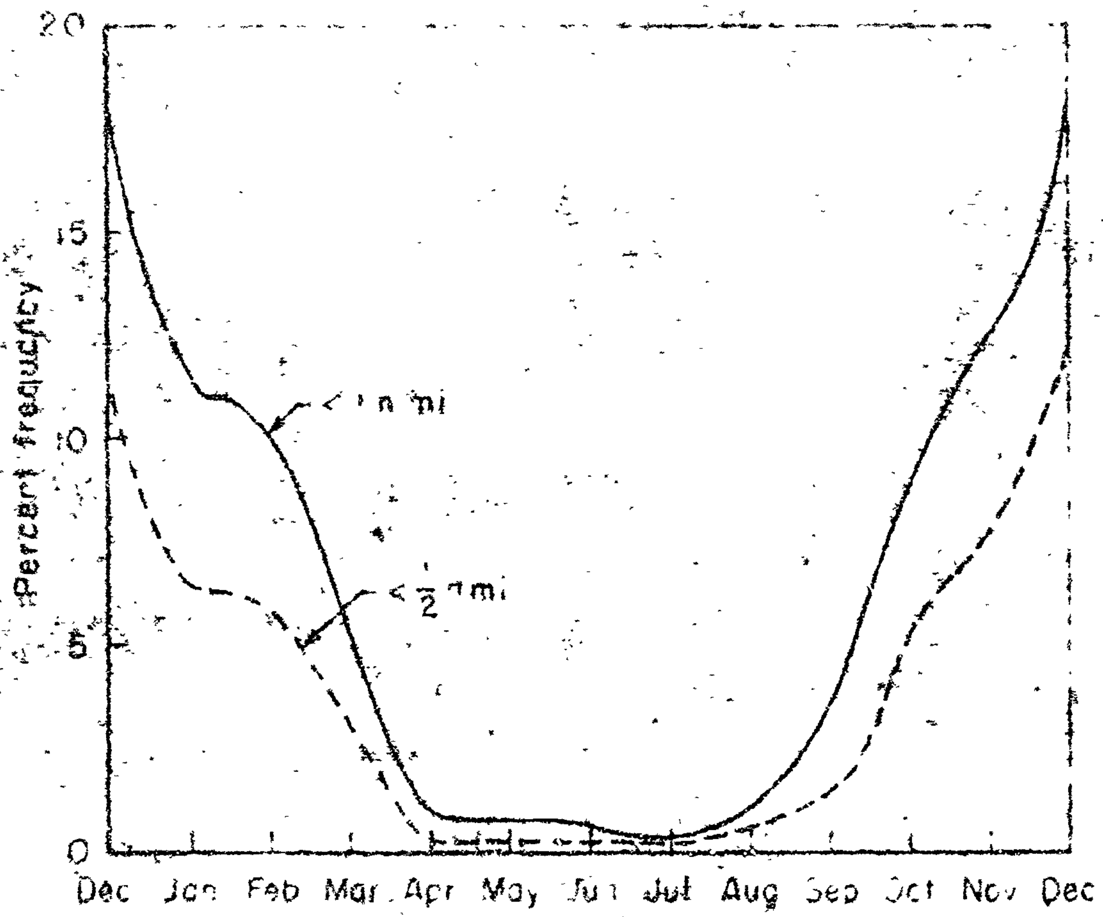
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Figure 2

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independent, they may be studied independently and combined only at the end when the forecast procedure is developed.

Often, in the light of operational criteria, one element will almost always cause critical conditions irrespective of the value of the other. An example is the range of ceiling and visibility at Rhein Main, Germany, where weather conditions below the minimum for safe aircraft operation are seldom due to ceiling alone, and one need investigate only the visibility in a study of critical conditions.

REMOVING THE SEASONAL AND DIURNAL VARIABILITY

The seasonal and diurnal variability should be determined and removed, if significant, before a study of predictors is begun. To determine the extent of seasonal and diurnal change, frequency distributions of the critical values, or the monthly and hourly averages, are plotted by month and by hour. Figure 2 is an example of the seasonal change in the per cent frequency of the critical visibilities less than 1 nautical mile and less than 1/2 nautical mile at Rhein Main, Germany. Figure 3 exhibits the diurnal temperature and visibility curves for Rhein Main, Germany, for December, the month of maximum frequency of critical weather. Employing these graphs, the year and day may be divided into intervals of small seasonal and diurnal change.

For the primary or pilot study, homogeneous data containing as much critical weather as possible is desired. For this purpose, the month of December would be chosen from Fig. 2. From the selected month or season with maximum frequency of critical weather one chooses two periods of the day; one containing the maximum frequency and the other the minimum frequency of critical weather. The maximum frequency of low visibilities

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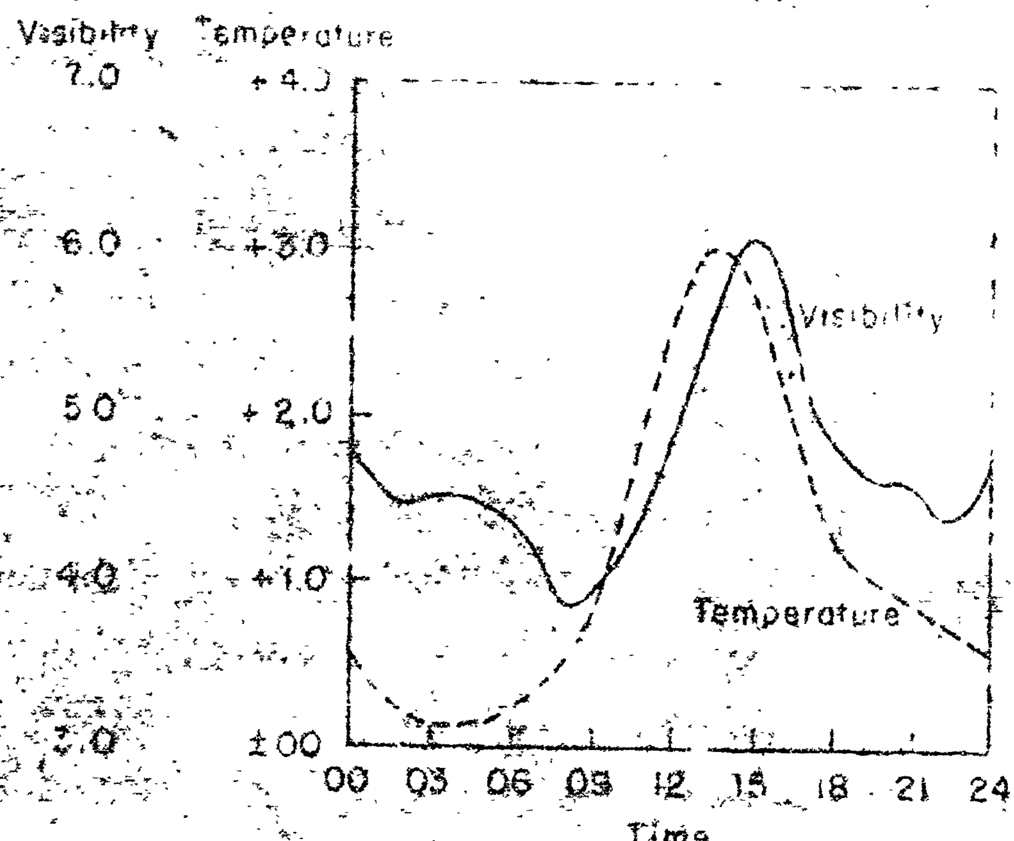
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Time
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Figure 3

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generally occurs at the same time as the minimum average visibility. Also the minimum frequency generally occurs with maximum average visibility. Thus from Fig. 3 one should choose the period from 06 to 09 hours for the maximum frequency of critical weather and 15 hours for the minimum frequency. These two periods represent the two extremes in visibility during the day and can serve as anchor points in a forecast scheme

STUDYING THE SYNOPTIC VARIABILITY OF HOMOGENEOUS DATA

The data to be studied now consists of a portion of the year containing a maximum frequency of critical weather and a minimum of seasonal variation. The period is confined to specified times of the day to eliminate diurnal fluctuations. We are now primarily interested in parameters which characterize different synoptic situations corresponding to different ranges of the weather element to be forecast. To maintain the desired flexibility in time and in order that the forecaster may exercise his judgment in the proper manner, the variables chosen for investigation should be forecastable by the usual standard objective, subjective, or numerical methods. The parameters to be investigated, then, should be derivable from the fields of pressure, temperature, and conservative moisture quantities.

Considerable attention to the selection of suitable forecastable parameters is justified before further work with the data is undertaken. The purpose of this step is to develop a physical concept of the mechanism producing the weather effects being investigated, and from this, to formulate a reasonable hypothesis to be tested with the data. This study and the selection of suitable parameters could well become the logical role of a central investigative unit. An example of how a central research unit can assist the local investigator occurred during the present work when pilot studies were prepared by a number of European localities. The local meso-scale surface pressure-gradient vector was found to be the most successful parameter (out of the score or so tested) for delineating winter visibilities at each of several locations in Germany, one in France, and two in England. Although refining parameters varied from place to place, the more successful were drawn from a quite small list, namely, contour curvature, thermal wind, and initial conditions involving present visibilities and previous precipitation or state of the ground. Thus a small number of parameters are provided for a meteorologically homogeneous region through the experience and investigations of a centralized investigation group. The overlapping efforts of a number of local investigators are thereby eliminated. Nothing precludes the selection of parameters by the local investigator, however the amount of effort required is usually considerable and cannot be minimized successfully in order to get on with the study.

After suitable parameters have been selected, they are tested with the data. Information gained from the previous steps and by a careful study of the physics of the problem should reduce the number of parameters necessary to test to three or four. An important consideration when attempting to measure a suitable parameter is that of the scale of the disturbance producing the weather effect. It is becoming increasingly evident that many weather elements are closely related to disturbances of a scale smaller than that appearing on the usual synoptic map. A more appropriate scale can frequently be determined by comparing contrasts in a series of carefully prepared local analyses associated with opposing values of the weather element. The comparison of synoptic analyses and other parameters associated with opposite extremes in the element to be forecast serve an excellent purpose in pointing up suitable parameters for use as independent or predictor quantities.

It is the essence of this procedure that simultaneous relationships be investigated first, since seasonal and diurnal fluctuations have been eliminated from the data. The integrated effect of a persistent situation producing a particular kind of weather is always a necessary and proper consideration. Previously observed values of the forecast element can be significant as initial conditions for a complete description or a relationship between variables. A case in point is the persistence of a low-lying inversion over an industrial area. The longer the inversion exists the greater the accumulation of pollutants and the worse the visibility becomes.

This more or less arbitrary breakdown of parameters into two types, forecastable and initial conditions, and the separation of the variability into seasonal, diurnal, and "synoptic" serves a useful purpose. It allows the local objective forecast study to be prepared in such a manner that the using forecaster can determine when and how he can adjust certain parameters, account for climatological changes in the forecast element, and evaluate the degree to which persistence enters into the forecast. In this way he can consistently improve on the "blind" use of objective charts and diagrams.

One might attempt a supplementary forecast study for objectively forecasting the independent or forecastable parameters, but the complexity and extent of the effort required to obtain prognostic charts by numerical weather prediction methods should be a warning that this probably cannot be achieved successfully in a simple manner. It is better, then, to concentrate on the use of numerically or subjectively prepared forecasts for longer periods and extrapolation for periods of 12 hours or less.

Following the testing of simultaneous relationships, time-lag dependence may be investigated separately or by working backward in time with parameters similar to those found to be suitable for expressing a simultaneous relationship. A significant drop in the correlation between independent and dependent variables clearly signifies that the most advantageous time lag has been exceeded. The emphasis placed on starting with simultaneous relationships stems from the observation that most correlations between meteorological data are maximum at zero time lag and decrease rapidly with time. If this is generally the case, successful objective forecast studies incorporating lag relationships directly may be reflecting, to a large extent, diurnal change in the forecast element or persistance of synoptic parameters. The knowledge of the best time dependency is, in itself, an aid to better forecasting. One can at least determine the most advantageous use of prognostic charts, extrapolation techniques, or direct lag relationships.

A technique which is time saving and helpful in analyzing meteorological data for simultaneous and lag relationships is the use of sufficiently large work sheets so that one can enter and identify values of the dependent variable for several different times on the same diagram. By entering the date of each observation, data which does not conform to the majority can be checked for errors and investigated for representativeness. Secondary parameters and initial conditions can be entered and their effect in modifying the basic relationship studied. Thus, at the same time a relationship is being checked by a scatter diagram, a forward look can be taken towards extending and improving the study. As many as five separate items of information, identified by a color code or by their location with

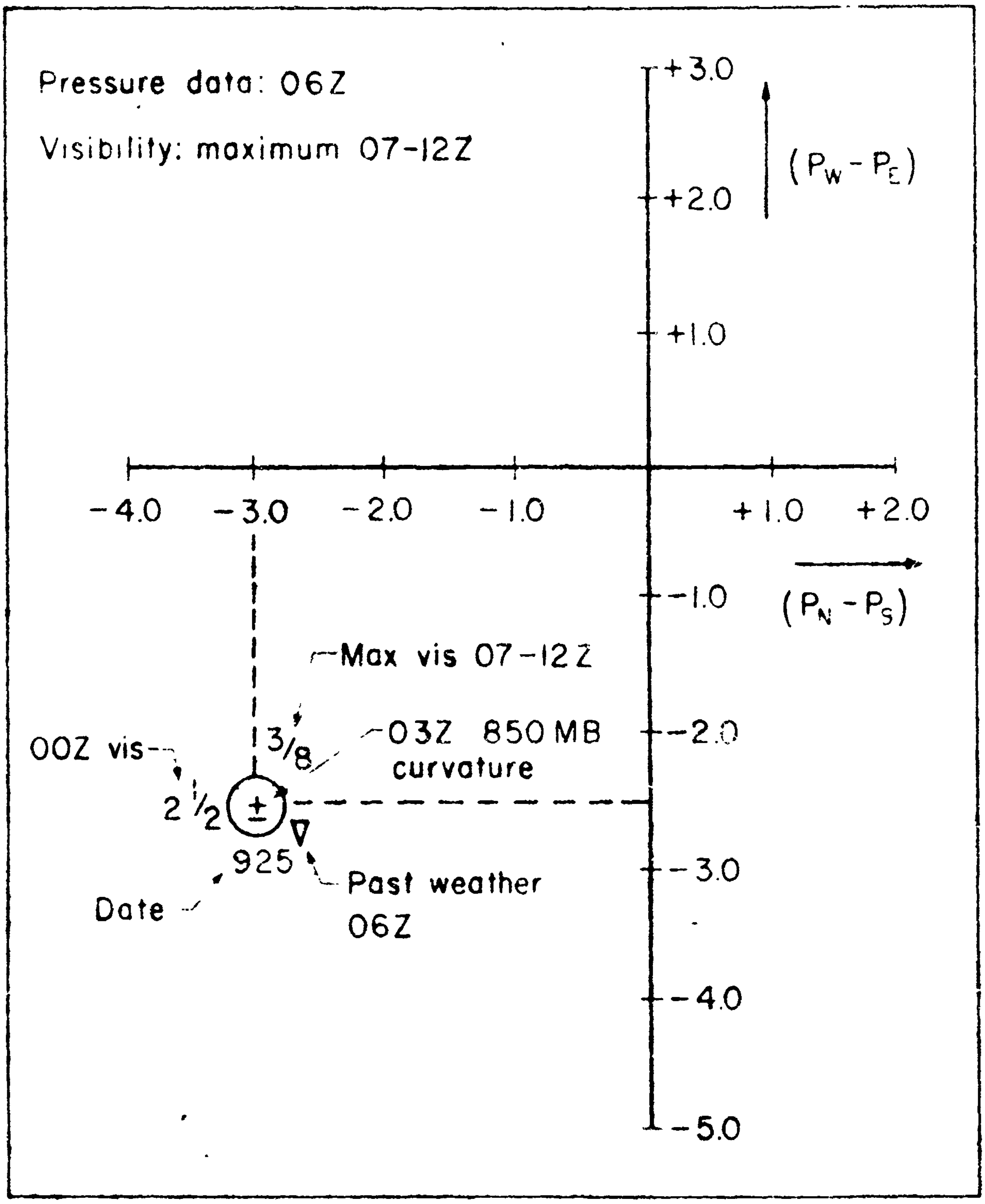
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Figure 4

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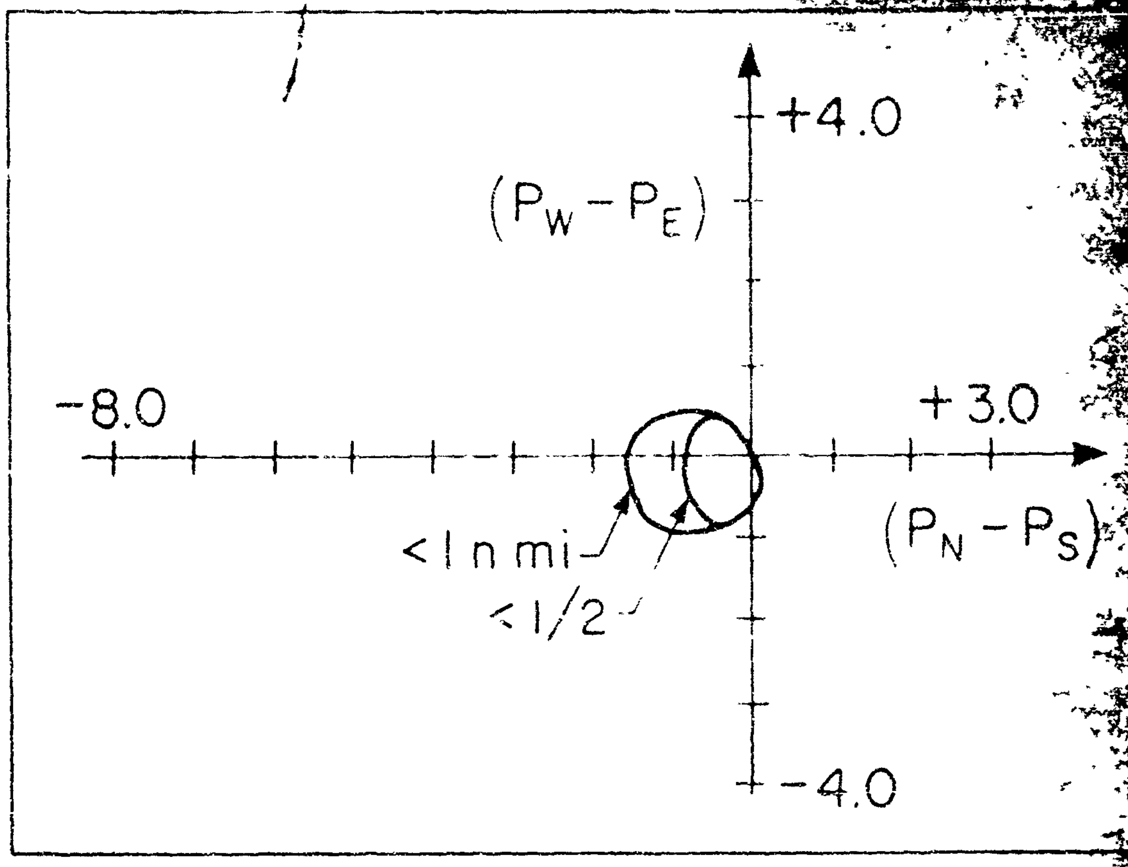

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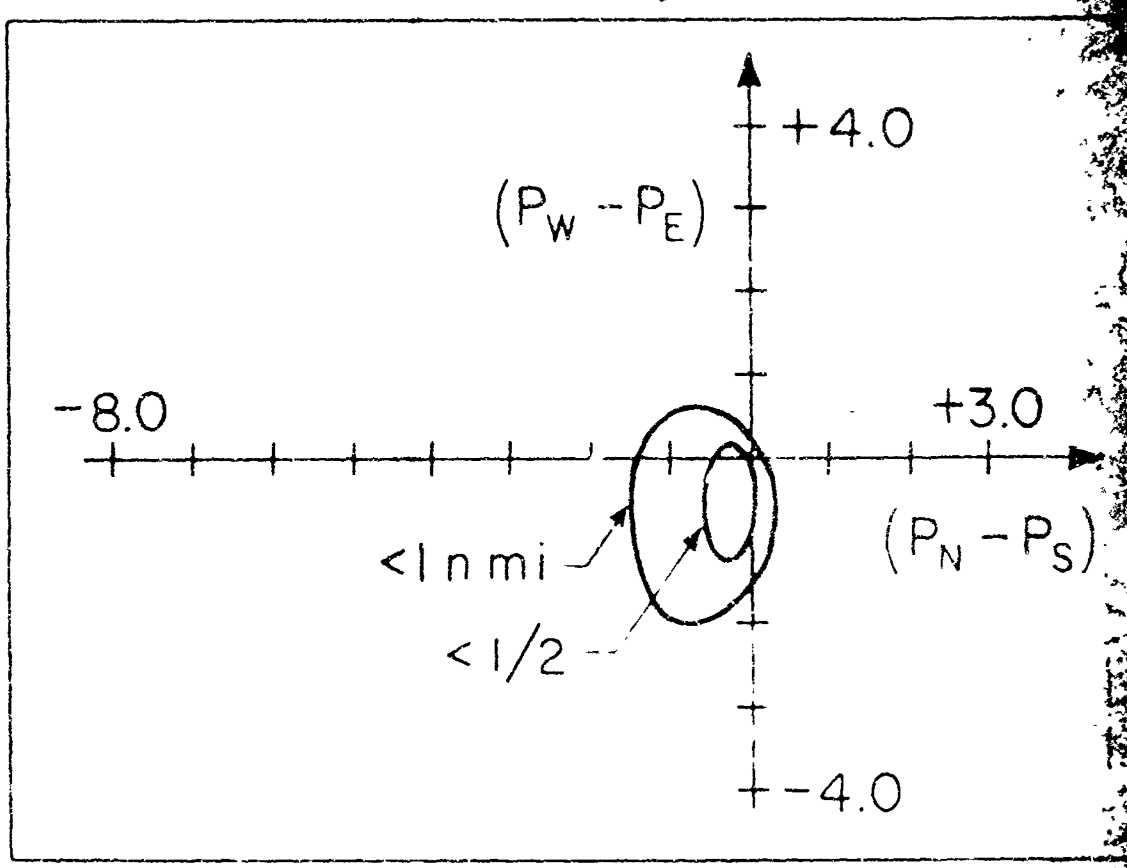

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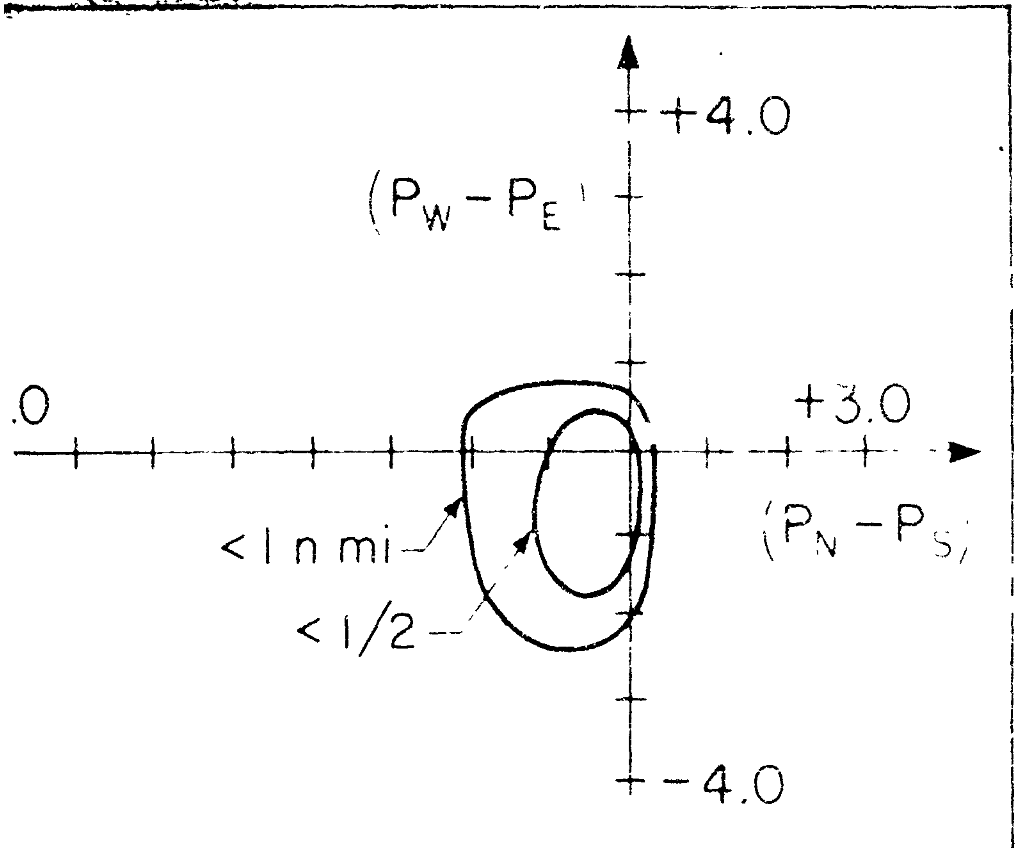

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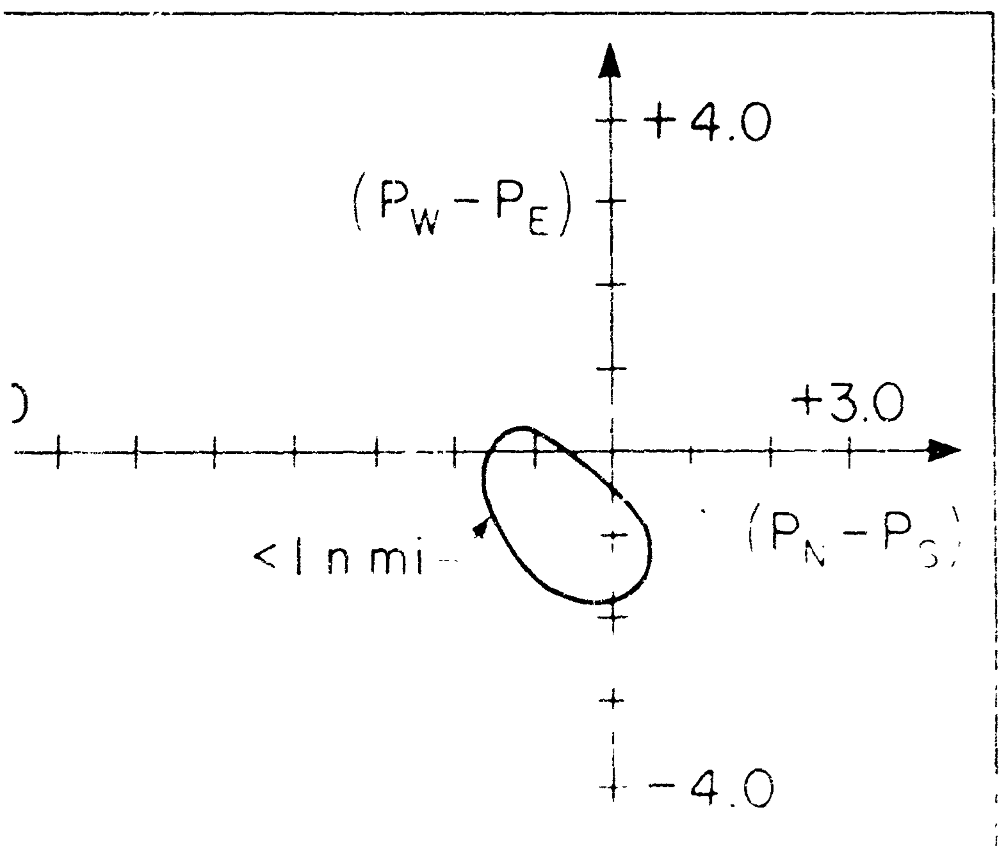

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reference to the position indicator, can be entered conveniently. The charts are analyzed much like a synoptic weather chart. Figure 4 shows the plotting model used in the preparation of the charts for the Rhein-Main visibility study. This plotting model was designed for the purpose of testing for a dependency of visibility on the north-south and east-west components of the local surface pressure gradient.

ORGANIZING SEASONAL, DIURNAL AND "SYNOPTIC" COMPONENTS INTO A SYSTEMATIC FORECAST METHOD

Once valid simultaneous or lag relationships of forecast parameters with the weather element are found for season and hour of maximum frequency of critical weather, other charts for other seasons and hours are prepared to cover periods of significant seasonal and diurnal change. Figure 5 is an example of a series of charts relating maximum visibilities for November through February at Rhein Main, Germany, during the 6 hour period 06Z to 12Z to the local 06Z pressure gradient. The charts span the period of worst visibilities at Rhein Main both seasonally and diurnally. The seasonal change in pressure-gradient versus visibility relationship is demonstrated in the changing size of the area of the charts enclosing visibilities less than one and less than 1/2 nautical mile. The length of the vertical and horizontal axes represents the spread of the west-east and north-south pressure gradient data. These charts, plus a second set spanning the period of best visibilities for the day and the diurnal visibility curves for each month, form a complete study of visibility at Rhein Main. Maximum and minimum visibilities over a 6 hour period were chosen as the forecast elements in order to obtain more representative parameters than the instantaneous visibility. Actual visibilities for any time during the period are obtained by combining information from the diurnal visibility curves and the forecasts of maximum and minimum visibility as given by the charts. The forecast period is extended by extrapolating the pressure gradient and 850 mb curvature or, when appropriate, by adding the diurnal change to the last visibility forecast by the charts.

An example of a systematic forecast procedure which might result from the suggested method is:

First: Forecast the value of the predictable parameters employed independent parameters on the synoptic variability charts for the "worst" and the "best" periods of the day.

Second: Obtain the corresponding predicted values of the forecast element for the "worst" and "best" periods from the charts.

Third: Employ the diurnal change charts to estimate the intermediate values or time of significant changes of the forecast element between the "worst" and "best" periods.

VI. CONCLUSIONS

Adherence to the systematized procedure (SAPLOFS) outlined does not guarantee completely successful objective studies. It will produce certain useful objective aids in the seasonal, diurnal and "synoptic" variability charts. It should maximize the probability of success in the search for predictor parameters by eliminating the confusion between seasonal, diurnal, and "synoptic" variability, and by adding to the forecaster's knowledge of the nature of the problem. By removing the chance of attempting a problem which requires greater accuracy than exists in the observations, it eliminates the possibility of attacking an unrealistic problem.

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TITLES FOR FIGURES

Figure 1. Frequency distribution of visibility values, Lakenheath, England.

Figure 2. Per cent frequency of criticical visibilities by month, Rhein Main, Germany.

Figure 3. Diurnal temperature and visibility for December at Rhein Main, Germany.

Figure 4. Sample plotting model for testing simultaneous and/or lag relationships.

Figure 5. Example of a series of charts relating the "synoptic" variability of the Rhein Main visibility to the surface pressure gradient and 850 mb curvature.