Climatic Presentations for Short-Range Forecasting Based on Event Occurrence and Reoccurrence Profiles[1]

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ABSTRACT

The climatology of persistency has been found to provide useful information to the short-range forecaster. This information can be obtained directly for any given station by computer-tracing initially observed events throughout the historical records for specified time intervals and tabulating the respective probability of their reoccurrence statistics. Several investigators have suggested ways of generating conditional probabilities of an event reoccurring without resorting to such extensive computer processing. Most of these approximation procedures incorporate the assumption that the conditional-unconditional relationships are independent of the initial forecast time, ceiling category, cloud type, and station location. Research conducted on cloud ceilings at Saint Louis University has shown that these assumptions break down during instances of rare events or when the forecast ceilings under consideration are below 1000 ft. Hence, data from 15 climatically non-homogeneous stations were processed to devise "universal" analytic functions which obviate them. The resulting empirical formulations permit the calculation of meaningful reoccurrence probabilities for stratified subsets of a station's data base.

The fundamental fact that the climatological statistics, for any one station when properly arranged, can separate certain informations which are geographically or topographically dependent, from others which are not, is discussed. A possible means of augmenting the information content of the climatic data base for any one location through the transferring of pertinent relationships contained in the data base of another is presented.

1. Introduction

This paper pertains to the problem of *forecasting and forecastability of sensible weather* as contrasted to the more commonplace study of atmospheric *predictability*. Confusion has arisen from the ambiguous use of the terms for several reasons. First, the word "weather" has different connotations to different people. To the dynamicist it refers to parameters such as winds, temperatures, heights, pressures, and their derivatives (since they can be formulated mathematically). To the synoptician it pertains to the associated weather events (such as precipitation amounts, ceiling heights, visibility restrictions, surface temperature extremes, and severe weather areas) which more directly affect man in the performance of his various activities. Needless to say, the forecasting of these two classes of events involves different considerations since one is modeled directly by the dynamic equations and the other is not. Second, the word "predictability" carries different meanings. The dynamicist considers it to be synonymous with the outer limit where numerical modeling efforts, based on the fundamental set of dynamic equations, show skill. The synoptician includes the areas where other techniques such as extrapolation, statistical correlation, persistency, or climatic trends show skill in his definition of the limits of predictability.

The purpose of this paper is to devise sensible-weather forecasting aids for the shorter-range time intervals using considerations based on persistency and climatology. The strengths of the techniques to be presented lie in their skill with respect to either simple persistency or climatology alone, and their applicability to any station without having to resort to lengthy computer processing.

2. Assessment of procedures for forecasting ceilings and visibilities in the 0–4 hr time frame

a. Extrapolation and dynamic modeling

One of the most important, yet perplexing, problems in forecasting is primarily that of timing, i.e., determining when a presently observed weather situation will improve or deteriorate and how much. The time duration of most continental U. S. flights is so short that a 0–4 hr forecast may be considered a "long-range" forecast by the aviation industry. To the meteorologist the 4-hr range is frequently too extended to warrant the use of prognostic tools based solely on the extrapolation of microscale features to include the weather event itself, and too short to use numerical prediction schemes based on observed input data which are synoptic with

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the sensible weather event being forecast. Furthermore, convective processes and energy exchanges influential in this time interval are frequently not resolved with the grid size of the current numerical models and are too short-lived to be extrapolated. In addition, these processes are highly dependent on thermal stratifications which are influenced by the lower boundary of the atmosphere. This influence varies with the time of day and season of the year in a manner complicated by scale couplings with the synoptic environment. These couplings are not fully understood or captured by the boundary layer parameterization of the models.

b. Persistency and statistical modeling

Persistency has been used in this time interval with some success both as a forecast aid and as a parameter for verifying other objective forecast procedures. It has been found to be sufficiently difficult to beat as a forecast within itself, when all classes of ceilings and/or visibilities are grouped together, that certain unwarranted generalities have been drawn with respect to its value in the short-range forecasting of the lower categories of these events.

Restivo and Hartfrant (1970–71) processed over a million hourly observations for seven terminals to demonstrate that a 1-hr "no change" forecast is indeed difficult to beat on a percent correct basis when *all* ceilings and all visibilities are grouped together. However, it was often found to be essentially worthless as a forecasting tool, even for this short-time interval, when the events were limited to low ceilings and restricted visibility categories.

A more useful proven aid to short-range forecasting than pure persistence is already at hand. It combines persistence and climatology to give the probability that a given event observed at a given time will be observed again (reoccur) after a specified interval of time. The Air Weather Service (AWS) has long recognized this superior aid and has computer-generated such conditional probabilities of event recurrences for numerous observed features and time ranges for a large number of locations throughout the world.

The main insurmountable problem encountered in computer-generating these tables is the limited size of the historical records. Significance is quickly lost as the data base is stratified into subsets in attempts to isolate specific types of weather event. McCabe (1968) estimates that at least ten years of hourly observations are needed per stratification. We have found that much longer periods of complete records are needed to acquire meaningful conditional probability statistics than to define the event frequencies (or unconditional probabilities).

To circumvent to some degree the restrictions imposed by data requirements in calculating conditional probabilities, climatologists have established statistical models to generate them directly from their unconditional counterparts. Pioneers in this area are Gringorten (1971), McAllister (1969) and McCabe (1968) who devised models based on the concept of a simple Markov process. Each of these respective models was verified against observed data at Saint Louis University for seven different ceiling categories and six visibility ones.

Generally speaking, the statistical models exhibited their least skills for the lower categories of these events. Each showed errors that varied in magnitude in response to changes in the local solar hour. The main thrust of our efforts, therefore, was to introduce the necessary flexibility into the modeling procedures to account for these effects.

3. Arraying the data base

Unfortunately, low ceilings and restricted visibilities represent critical operational forecasting problems that are often associated with "rare" events, in an overall statistical sense, due to the tendencies for good weather to predominate at most stations. This forces attention onto processed climatic information which is inherently less reliable than that available for the less critical problems. For example, the statistics for the most operationally significant cloud and ceiling categories for aviation forecasting found in the AWS conditional probability tables are frequently sufficiently biased by random occurrences to be misleading *when viewed apart from the time distributions of the weather elements*. Therefore, a first task was to devise smoothing schemes, based on hourly and monthly continuity considerations, to "clean" the data and render the derived statistics as meaningful as possible. The techniques devised to process the probability data and to array them in their most useful forms will be demonstrated with respect to a specific ceiling category and forecast time period, i.e., the probability that ceilings initially observed to be equal or less than 200 ft will be subsequently observed in that same category 2 hr later. This particular problem has obvious significance to operational forecasting and lies in the very time range where many meteorologists have been willing to concede to simple persistency the honor of providing the best available forecast tool.

The material being presented represents a selected fraction of the total research which has been conducted. Due to the nature of this selection, it is correct to infer that the results will tend to underestimate the potentialities of these techniques, were they to be applied to other categories or events which are less influenced by local effects.

4. Development and application of the techniques

Fig. 1 portrays the frequency of ceiling occurrences equal to or less than 200 ft at Vandenberg Air Force Base, Calif. It is based on 14 years of hourly surface data observations. Two points are to be noted in this illustration. First, the frequencies are highly variable with respect to time of day and season of the year.

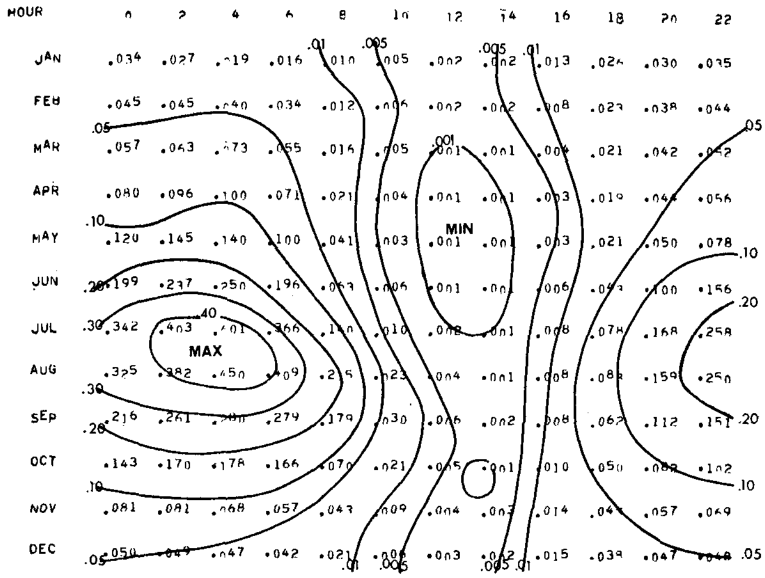

FIG. 1. Observed unconditional frequency of ceiling occurrences ⩽200 ft for Vandenberg AFB, Calif.

Second, the data arranged in this format are amenable to field analyses. Hence, values which do not fit a smoothed "first-guess" analysis within certain tolerances can be flagged for the human to evaluate. Furthermore, no one single bit of evidence is solely responsible for determining the statistical significance of the resulting isopleths! The employment of an analysis scheme which systematically progresses from the more reliable (higher frequency of occurrence) statistics toward the areas occupied by the less reliable ones was found to be fundamental to maintaining and assessing the significance of the analyses for the rarer frequencies of occurrences.

The data in Fig. 2 were computer-generated for Vandenberg AFB from the same original data base used to produce Fig. 1. They define the probability that an initially observed ceiling ⩽200 ft will also be observed 2 hr later. They were determined by computer tracing each initially observed event for 2 hr within the climatic records. The recurrence probabilities arranged in this format likewise conform to field analyses procedures. They are also found to be highly variable throughout

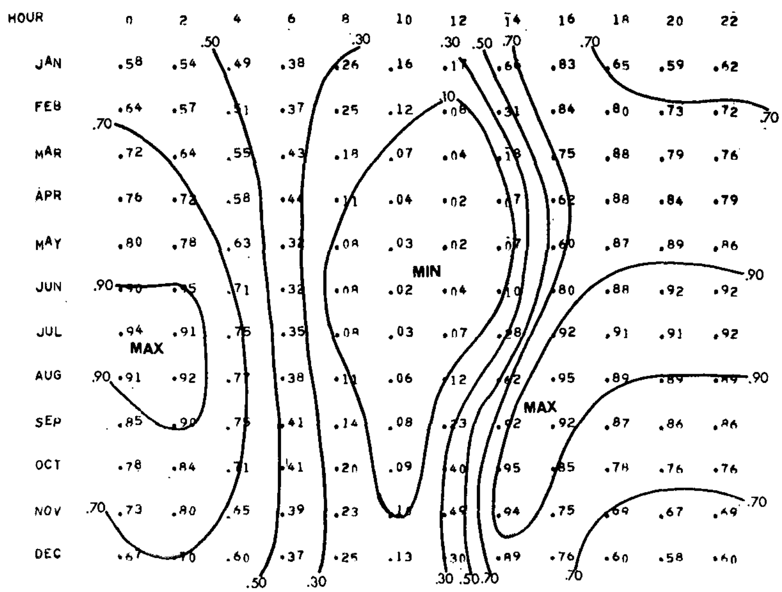

FIG. 2. Observed conditional 2-hr recurrence probabilities for ceilings ⩽200 ft for Vandenberg AFB, Calif.

the day and from one season to the next. Some diurnally variant relationships between the information shown in Figs. 1 and 2 will be illustrated by considering the frequency of occurrence values for 0400 in April, 0600 in May, and 2000 in June from Fig. 1. Each of these show a 10% value. However, the recurrence probabilities for these hours is found to vary considerably for each of these times (58%, 32% and 92%, respectively) in Fig. 2. In other words, a direct relationship between the chances of getting an event and the chances of its recurring 2 hr later does not appear to exist. A closer examination of Fig. 1 reveals that the 58% probability occurred when the 10% isopleth was near its ridge, the 32% when the diurnal frequency profile centered about the hour under consideration was on the decline, and the 95% when the profile was on the increase. Thus, the position of a frequency of occurrence value with respect to its neighbors seems to have some bearing on its "persistency." This is further illustrated in Fig. 3 where hourly frequency profiles from Figs. 1 and 2 have been extracted for the month of July.

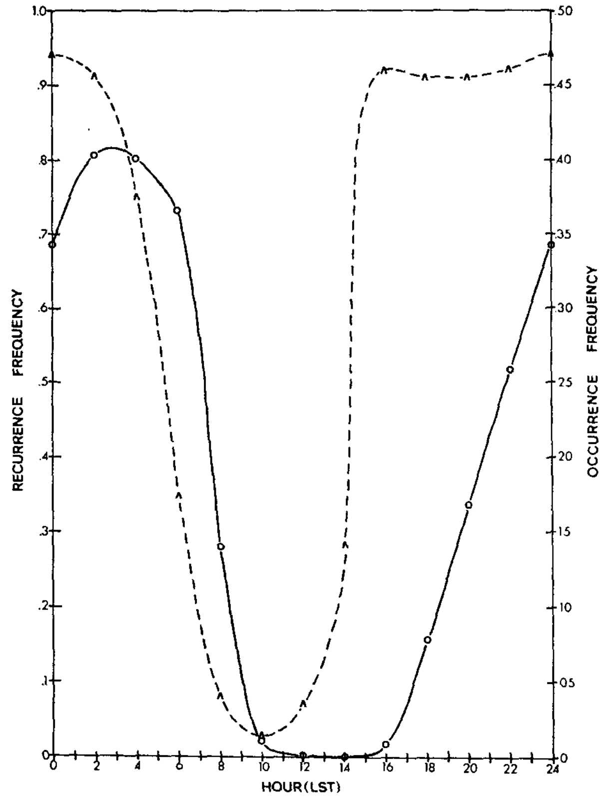

FIG. 3. Select occurrence (solid line) and recurrence (dashed line) profiles using the data of Figs. 1 and 2 for July.

Note, in particular, the period from 1600 to 2400 when the sun is either very low or set. Here the unconditional frequency of occurrence values represented by the solid line shows a nearly constant ascending slope while the 2-hr recurrence probabilities shown by the dashed line are quasi-invariant and in excess of 90% for that same time interval. For this part of the day the magnitude of the frequency of occurrence profile seems to be of lesser importance than its hourly slope in determining the persistency characteristics of an occurring event. During the period from 0600 to 1200 when the solar angle is ascending and the frequency of occurrence profile is descending toward its minimum, the 2-hr probability of recurrence profile is seen to be likewise descending. During this portion of the day the magnitude of the frequency of occurrence value at the final

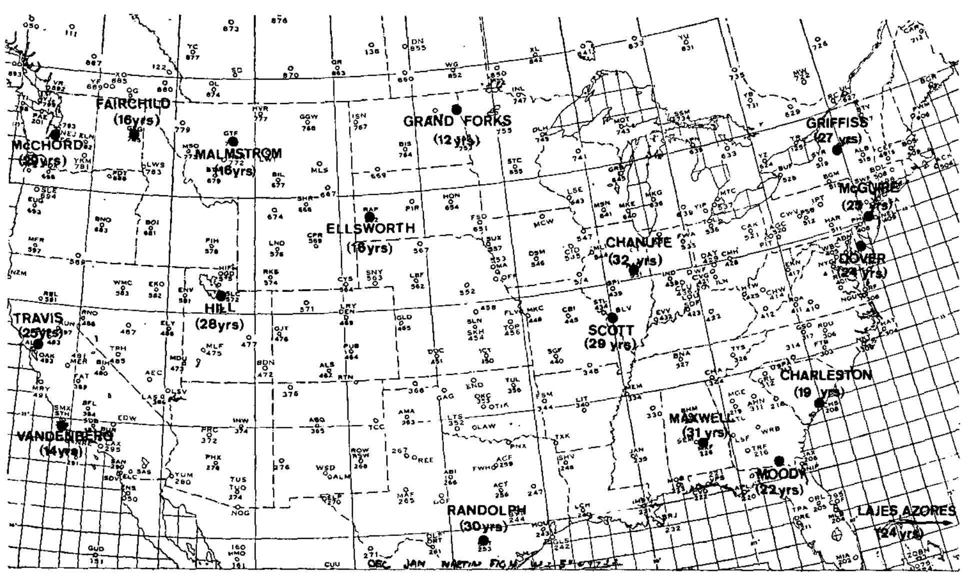

FIG. 4. Geographical location and length of records for the 15 stations comprising the singular data base (in excess of 340 years) used to deduce the empirical occurrence–recurrence relationships of this paper. The independent test stations are similarly shown.

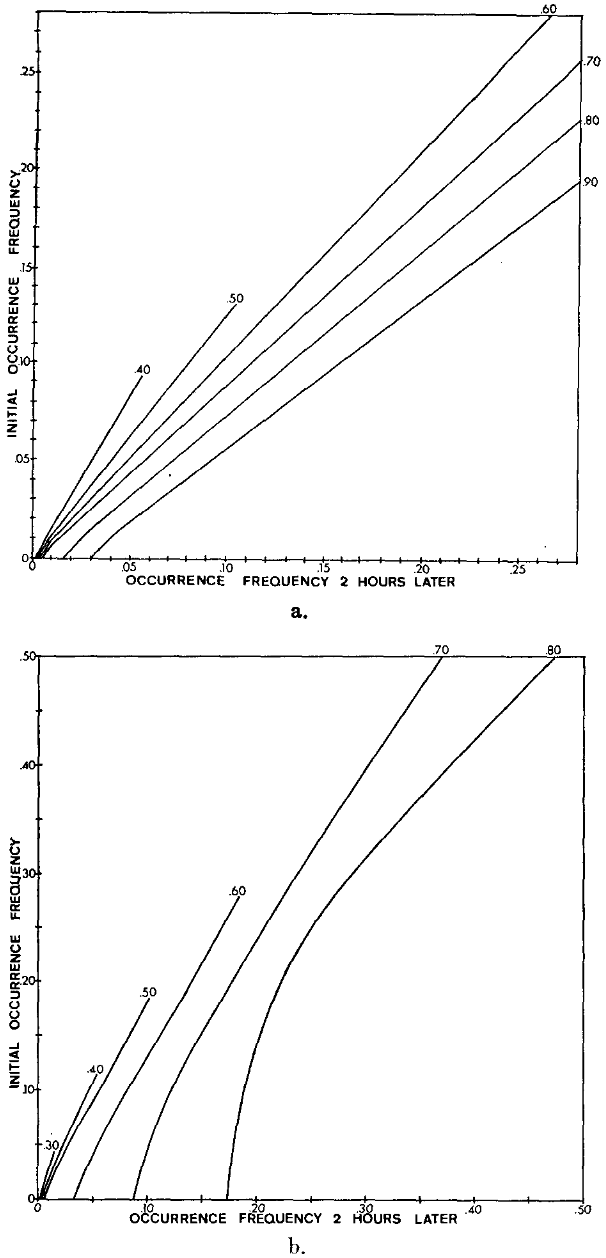

FIG. 5. Two-hour occurrence–recurrence relationships deduced from the 15-station data base during the evening hours (1700–2300 local time), a., and night hours (2300–0500), b., for summer (June–August).

hour takes on added significance as a persistency-evaluation criterion. Some implications contained in Fig. 3 also turn out to be very intriguing if viewed in the following light: which aspects of these curves are uniquely tied to the local station (Vandenberg) in this case, and which are not? Undeniably the slope and magnitude of the frequency of the event-occurrence profile fall into the former category. But how about the relationships between these respective slopes and magnitudes and the probability that the event, once it occurs, will subsequently reoccur after some specific elapsed time interval? Gringorten (1971), McAllister (1969) and McCabe (1968) say that these latter relationships are *not* crucially dependent on geography or topography. Each has presented rather conclusive evidence to substantiate his claims for certain parameters which are not as intimately associated with local time-variant couplings between the boundary layer and the free atmosphere as the ones currently under investigation.

If the aforementioned relationships between the frequency of occurrence and the probability of recurrence can be rendered independent of geography, rather obvious advantages are to be gained. For example, it should then be possible to combine the processed frequency of occurrence and recurrence data for numerous stations to establish a relatively "inexhaustable" single large data base to define relationships of increased significance for the "rare" categories of events over that possible were the data for only one station to be used. Such a data base has been established by using the hourly history data for 15 Air Force stations having long series of records. The number of stations used was strictly arbitrary. They were carefully selected with respect to location, however, in order to insure that the data used to form the combined data base represented a non-homogeneity of weather patterns and events. These stations (shown in Fig. 4) were Scott, Griffith, Chanute, Charleston, McChord, Ellsworth, Malmstrom, Grand Forks, Hill, McGuire, Moody, Vandenberg, Travis, Lajes and Randolph (all Air Force Bases). Processed occurrence and recurrence statistics were available for these stations from the Air Weather Services terminal forecast program. This fact also had a bearing on their selection.

The computer was programmed to produce scatter diagrams on which the event frequency at time (t_0) was the ordinate, the frequency at time (t_0+2) the abscissa, and the probabilities of the event recurrences from the 15-station data base were plotted at the respective intersections of these coordinate values. The array of data points was then subjected to isopleth of probability analyses. If the assumption of the geographic independency of these relationships is valid, the data should show little scatter about the smoothed isopleths.

The fact that certain restrictions needed to be placed upon the data to account for the diurnal and seasonal effects was discussed in conjunction with Fig. 3. This need was also pointed out previously by Sartor (1958) in his research of a similar problem for certain European stations. After considerable experimentation to incorporate these local time-variant effects in a most effective manner, while keeping the number of presentations manageable, it was found that a 16-fold partitioning of the data—four 6-hr periods per day for each season of the year—would define climatological relationships between event probability and event recurrence which were sufficiently independent of geography to permit the analysis of smoothed isopleths which fit the data

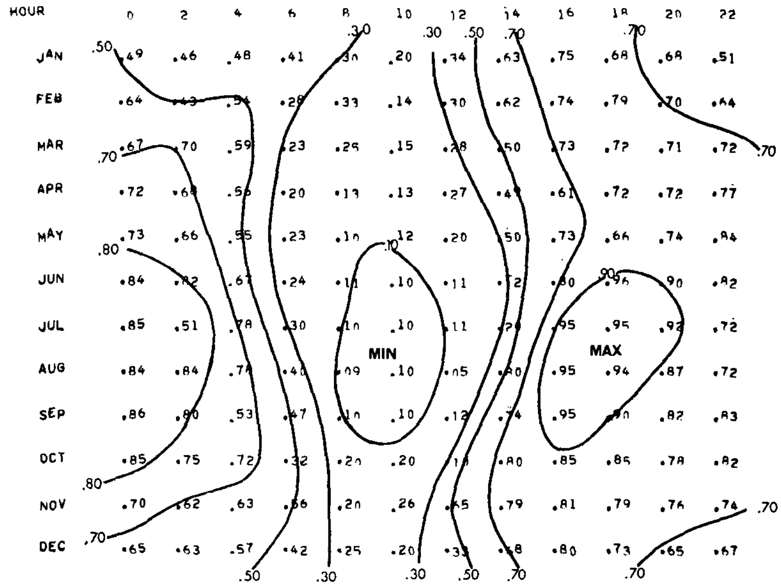

FIG. 6. Estimated 2-hr recurrence probabilities for ceilings $\leqslant$200 ft for Vandenberg AFB, Calif.

within the estimated reliability of the computer-generated conditional probability statistics. Two such graphs are shown in Fig. 5.

These charts were selected from the array of 16 which pertain to this particular category of cloud ceiling to illustrate that the evidences inferred from the Vandenberg data in Fig. 3 apply to the other stations as well. This fact is readily verified by comparing the respective slopes of the isopleths on Figs. 5a and 5b. Of particular significance to this discussion is the realization that Vandenberg's data constituted less than 7% of the total number of values used to define the isopleths in these latter two figures.

As previously mentioned, 16 such graphs were constructed for each ceiling category and each forecast time period. Thus, an array of graphs provides probabilities that cloud ceilings initially observed between 0–200, 200–500, 500–1000, 1000–3000, 3000–10,000, or >10,000 ft will reoccur in that interval or in a lower category at 2- and 4-hr later intervals. The probability for improving conditions is, of course, readily obtainable once one

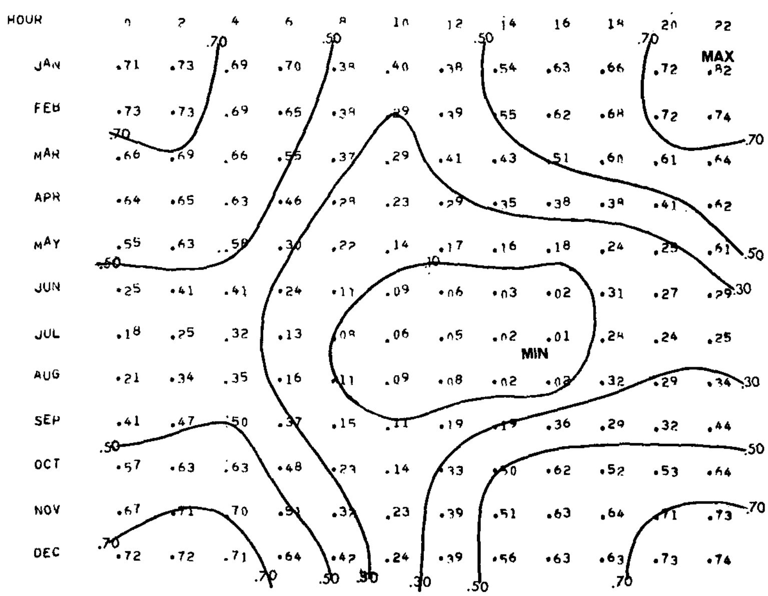

FIG. 7. Same as Fig. 6 except for Randolph AFB, Tex.

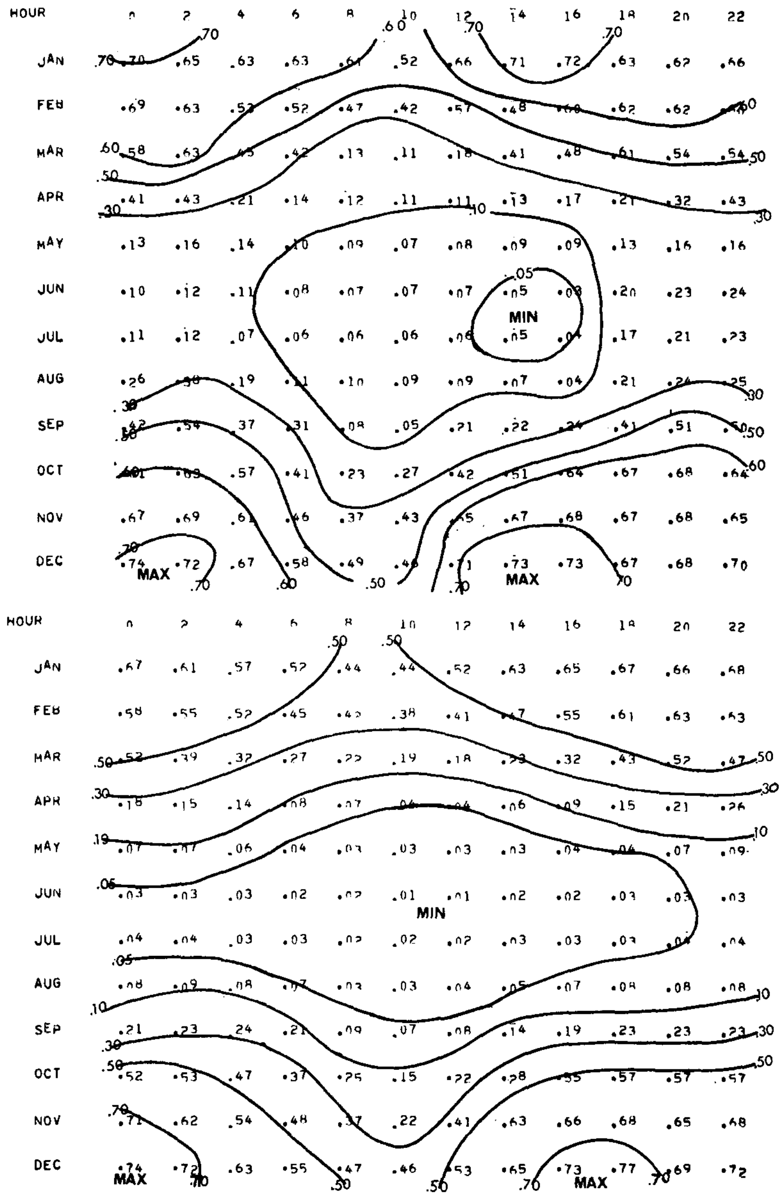

FIG. 8. Estimated (a., top) and observed (b., bottom) 2-hr recurrence probabilities for ceilings ⩽200 ft for Fairchild AFB, Wash.

knows the probability that an event will later be found in either the same category or any lower one.

The consistency of the graphs was tested against dependent data. This was done by using the frequency-of-occurrence statistics for each of the stations comprising the data base to estimate its respective recurrence probabilities. Figs. 6 and 7 provide such graphical estimates for two of the fifteen stations. Their observed counterparts are shown in Figs. 2 and 12, respectively. These two particular stations were selected from the array solely because they exhibited widely different diurnal and seasonal persistency characteristics in their low-ceiling statistics. The estimates in Figs. 6 and 7 were obtained by introducing the frequency of occurrence values in Figs. 1 and 11 into the 16 graphs discussed in conjunction with Fig. 5.

The appropriate data for three independent stations, Fairchild AFB, Wash., Dover AFB, Del., and Maxwell AFB, Ala., were used to further test the reliability of the graphs. Figs. 8a, 9a and 10a show the 2-hr recurrence probabilities estimated from the graphs using the observed frequency-of-occurrence data for each of the three respective stations. The recurrence statistics, provided by the AWS computer-tracing efforts, are shown in Figs. 8b, 9b and 10b. The data in each of these latter figures were subjected to the field analyses techniques mentioned earlier. Their relative skill with respect to simple persistency for almost every point on these

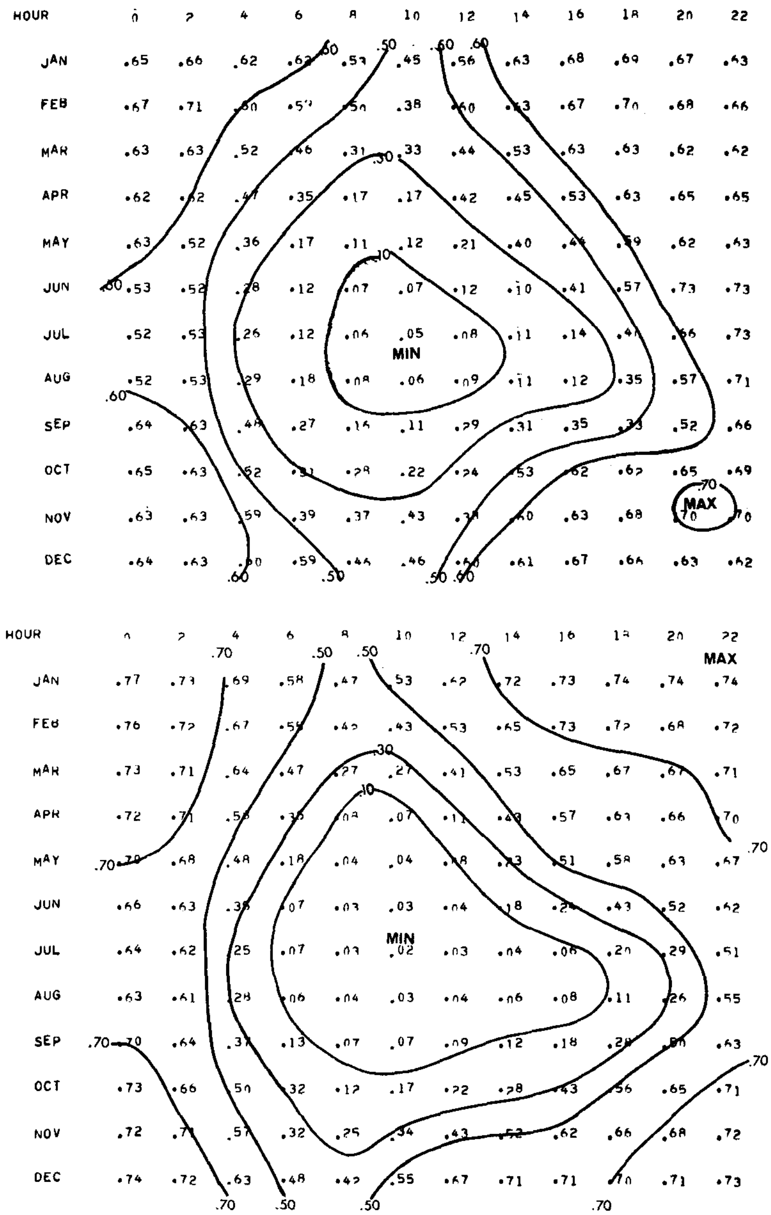

FIG. 9. Same as Fig. 8 except for Dover AFB, Del.

figures is rather obvious since persistency would call for probabilities of 100% throughout.

Similar comparisons on both dependent and independent data to those shown in this paper were made for a host of stations within the continental United States and Europe. In every instance the graphical estimated, and the computer-traced recurrence probabilities, showed agreements which would appear to rival both the climatic significance of the basic data and the practical limits of accuracy which can be realistically assigned to this type of climatic information in the forecasting routine. Verifications were also made using 45 wind-stratified subsets (three pairs for each of the fifteen aforementioned stations) to determine the applicability of the techniques in this regard as well. Such tests were made possible since the required computer-traced statistics were also provided for this verification by AWS.

Having verified the fact that the relationships uncovered in conjunction with the discussion of Fig. 5 also pertains to stratified subsets of the data, one is now in a position to quickly out-distance the computer-tracing methods for the following obvious reason. The amount of stratification permitted by any given data base for the latter method depends upon the climatic significance of a conditional probability, while the determining factor in the empirical approach is a less restrictive unconditional one. Herein lies the value of the

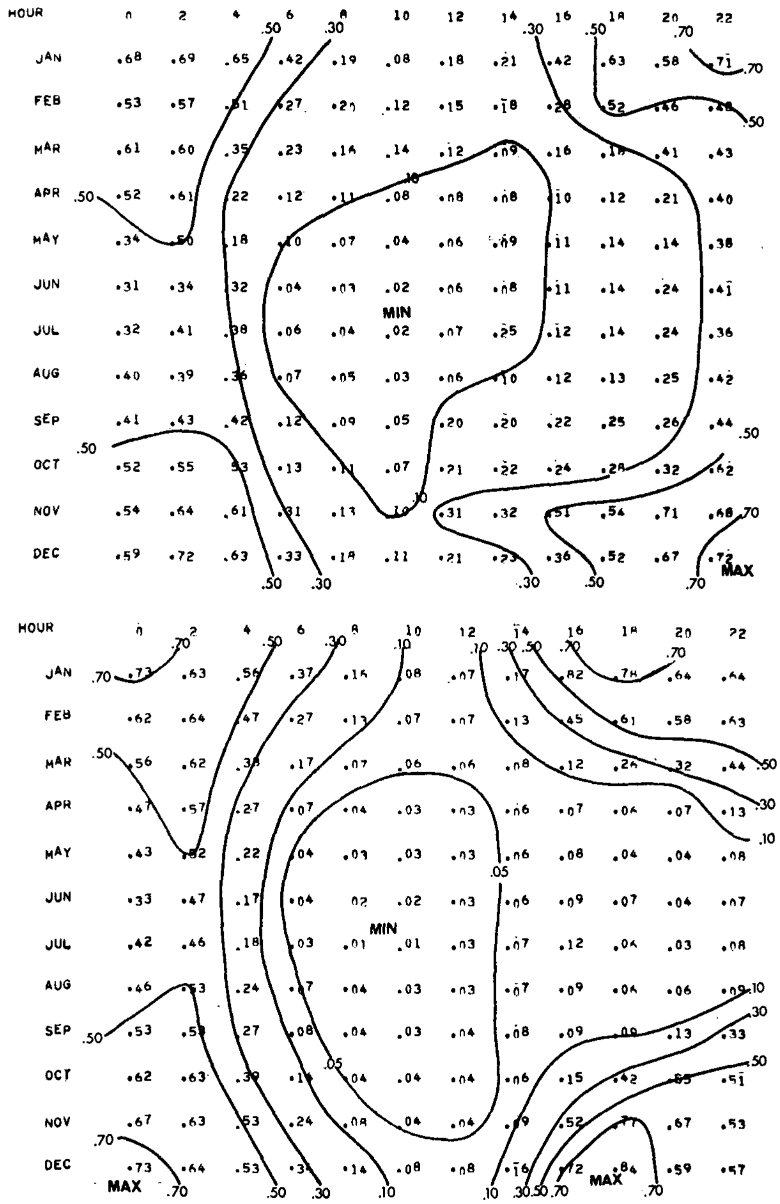

FIG. 10. Same as Fig. 8 except for Maxwell AFB, Ala.

research under discussion. The data base for any given station can be divided into "types," and the persistency characteristics of the sensible weather occurring within each of these types can be readily assessed without having to resort to lengthy computer processing or the incurrence of undue risks in the loss of climatic significance in the recurrence probabilities used to make these assessments.

5. Recommended applications to specific forecast problems

a. Discussion

The observed data presented in this paper have shown that the persistency characteristics of low ceilings exhibit marked diurnal and seasonal variations. Mention has also been made that this persistency is a function of the synotpic situation, as well, and that a partitioning of the station's data base into "weather types" provides an effective means of objectively incorporating each of these three determining factors into singular climatic presentations. The question to be answered is, which of the auxiliary informations available to the forecaster is most pertinent for defining these types. A number of potential candidates readily come to mind. Among these are winds, humidities and trajectories. Perhaps each forecaster has others which he may wish to add to the list. But when one considers the climatological availability of these parameters, the scales of

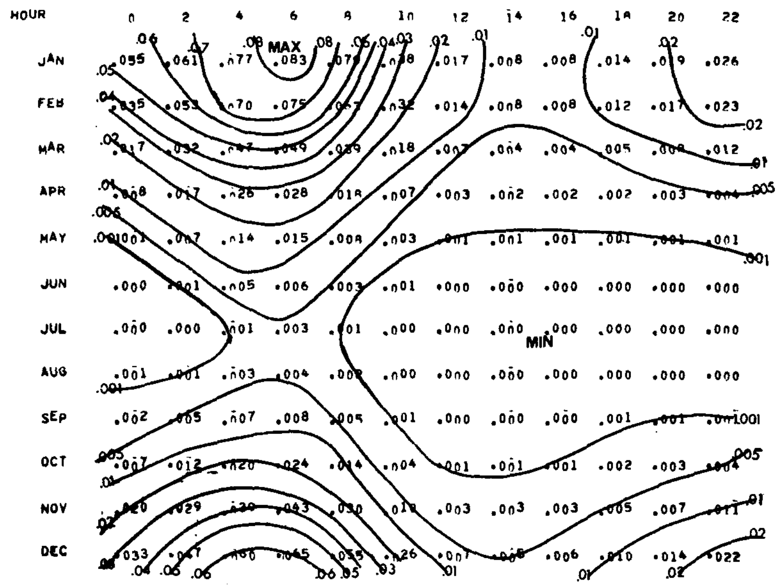

FIG. 11. Observed unconditional frequency of ceiling occurrences ≤200 ft for Randolph AFB, Tex.

motion they represent, the objectivity with which they can be categorized, and the skills with which they can be forecast within those respective categories, then the number of options becomes considerably reduced.

It is extremely dangerous, yet tempting, to select these stratifiers solely upon subjective synoptic recollections. It may be equally unwise to select them strictly on statistical evidences due to uncertainties concerning the climatic significance of the data during certain periods of the day and year. The particular screening method, to be discussed in the paragraphs to follow, is being recommended since its procedural steps embody concepts which readily submit their statistics to synoptic interpretations.

b. Selecting the stratifying agent

The hourly history data for Randolph AFB, Tex., will be used to illustrate how man and machine can work together to develop climatic aids which incorporate much of the auxiliary information which the forecaster has available to him at forecast time into a common objective package. This station has a 30-year data base and is strategically located, in a climatological

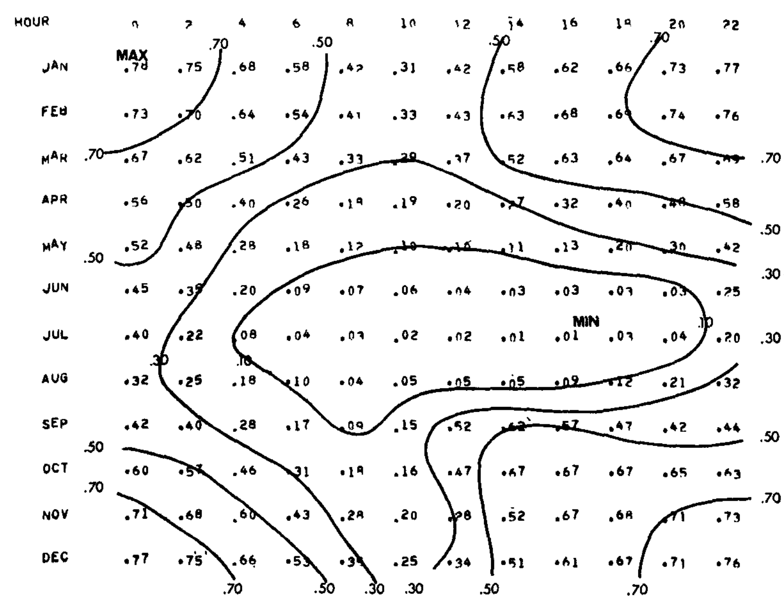

FIG. 12. Observed 2-hr recurrence probabilities for ceilings ≤200 ft for Randolph AFB, Tex.

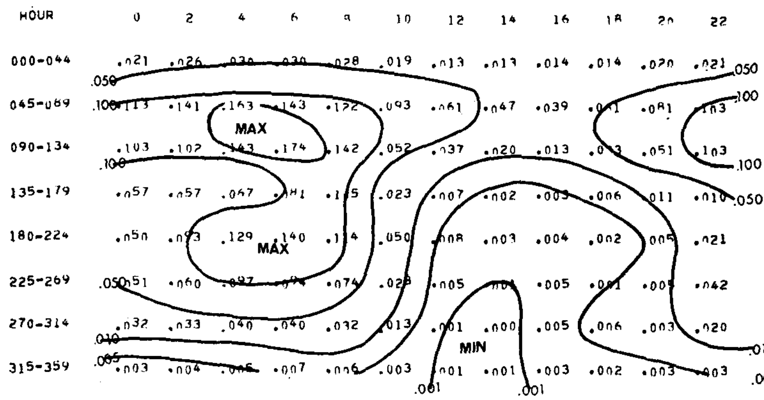

FIG. 13. Observed frequencies, for ceilings ⩽200 ft, occurring within given wind sectors, for Randolph AFB during the period December–March.

sense, so that the derived statistics can be assessed synoptically with some assurety.

The observed frequency of low ceiling occurrences and the observed 2-hr recurrence probabilities are shown in Figs. 11 and 12, respectively. The estimate of these recurrence probabilities, using the graphs illustrated in Fig. 5, has previously been shown in Fig. 7.

The computer was programmed to separate out those cases for the hourly history records for Randolph AFB when low ceilings were observed and produce wind roses for these occurrence cases. These wind-rose statistics indicated that some form of a wind direction parameter would, indeed, provide a useful stratifier for enhancing the probabilities of low ceiling occurrences in some cases and for minimizing them in others with respect to the information provided in Fig. 11. However, since the wind-rose statistics pertain to a "biased" sample, they do not necessarily tell the complete story. Hence it is desirable to return to the unstratified hourly history records for Randolph and conduct further experimentations. This time wind direction is permitted to assume the role of a stratifying agent with the frequency of low ceiling occurrences within each of these respective subsets providing the dependent probability of occurrence statistics.

In order to obtain a maximum of information from these experiments the hourly data for 4 months (December–March) were combined into a single season and subjected to the most extreme wind stratification that the data could conceivably be expected to support. The problems arising from overstratification were not considered as a limiting factor during this stage of the research since the field analyses procedures, previously discussed in this paper, provide a means of later assessing the reliability of the end product.

To our amazement, the overwhelming majority of these values could still be field-analyzed to produce isopleth patterns which readily submit to judicious meteorological interpretation (Fig. 13). Note that two frequency of occurrence centers are found near 0600 local time in Fig. 13 where only one was in evidence in Fig. 11. Also note that the wind-stratified data exhibit considerably greater values for these respective maxima. The increased information provided by Fig. 13, with respect to that given in Fig. 11, should not be overlooked as a climatic aid to assist in forecasting the onset of low ceilings. It essentially shows that the probability of subsequentially observing low ceilings is greatly enhanced if the numerical models can be relied upon to furnish wind forecasts within some 45° of accuracy.

The importance of forecasting the onset of ceilings in this height range adds to the significance of these increased occurrence probabilities. Similar experiments have shown that the probabilities of observing ceiling in other height ranges, such as the ones between 0 and 3000 ft, for example, can be increased to well over 75% for certain hours of the day through the objective consideration of pertinent informations of the type which are readily assessible to the forecaster in the form of numerically derived products.

Thus, the stratifying concepts which have advanced in this article offer a means of converting the numerical modeling products of winds and moisture into weather forecasts of ceilings and restricted visibilities for any time period within the range of these numerical skills. The role that the recurrence probabilities play in this expanded concept will be discussed in the next section.

c. *The persistency characteristics of ceilings occurring under different synoptic situations*

The graphs in Fig. 5 provide objective assessments of the persistency characteristics of an occurring event.

These pertain whether the event is occurring at the initial hour of the forecast or for any other subsequent hour for which other forecasting procedures, such as those discussed in Section 5b, exhibit skill in forecasting the onset of that event. The data of Fig. 13 were inserted into the winter-season graphs, discussed in conjunction with Fig. 5, to produce the recurrence estimates shown in Fig. 14. The significance of the recur-

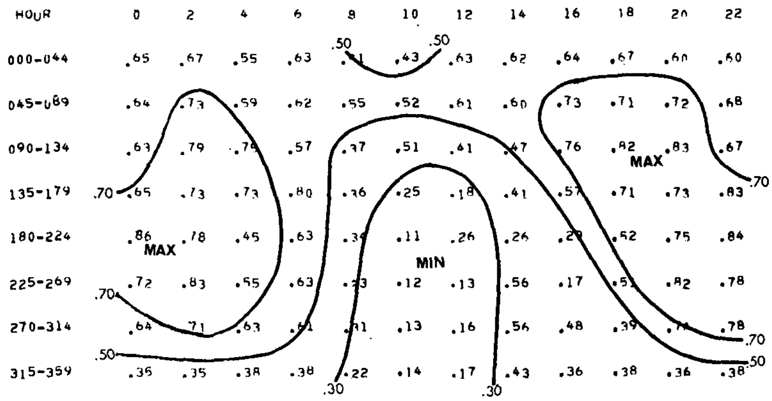

FIG. 14. Estimated probabilities that observed ceilings ⩽200 ft, presently occurring within a given wind sector, will reoccur 2 hr later for Randolph AFB during the period December–March.

rence estimation techniques now becomes more obvious.

If low ceilings are occurring, or are forecast to occur, in conjunction with easterly surface wind components, the chances of them persisting for longer than 2 hr during the daylight hours is a distinct possibility. However, if the wind component is westerly (or changes to that direction), the odds of their persisting beyond 1000–1200 local time are minimal.

A consideration of the geography at Randolph attests to the validity (in a qualitative sense) of the results shown in Figs. 13 and 14. One set of winds arise predominantly in conjunction with high pressure situations to the north and/or east of the station. The air parcel trajectories arriving at Randolph under these circumstances are usually from off the land. Such conditions are frequently characterized by synoptic-scale stabilities which dwarf or inhibit the local effects occurring at a given station. The other set of winds originate primarily from off the water. The low ceilings which develop during these regimes usually arise in response to a cooling of moisture-laden Gulf air as it is transported over the land surfaces during the nighttime hours. Its dissipation after sunrise is usually rather rapid.

6. Conclusion

Procedures for combining persistence and climatology have been discussed for the problem of forecasting low ceilings. Correlations were obtained between the climatic frequency that an event will occur and its persistency characteristic once it does occur. These were made possible by defining a "universal" data base which provides occurrence-recurrence relationships for the "rarer" categories of events which could not be devised by a direct search of the data records of any one station alone. The fact that the method obviates the need for lengthy computer processing adds to the significance of the research.

A procedure is recommended whereby the fruits of this research can be combined with the skills of numerical weather prediction to interpret the dynamically induced products in terms of probable ceiling developments and/or persistencies. The extension of these procedures and techniques to other weather elements and stratifying parameters is straightforward and recommended.

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