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Methods of Presenting Climatological Information for use in Planning and Supporting Weather Sensitive Operations

by

Donald E. Martin, Louis J. Hull
and Edwin Chin

Saint Louis University
Department of Earth and Atmospheric Sciences
St. Louis, Missouri 63103

Contract No. F19628-70-C-0247
Project No. 8624
Task No. 862402
Work Unit No. 86240201

FINAL REPORT

Period Covered: 1 April 1970 through 30 June 1973
30 June 1973

Contract Monitor: Irving I. Gringorten
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Approved for public release; distribution unlimited.

Prepared for

Air Force Cambridge Research Laboratories
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ABSTRACT

This research considers the devising of climatic presentations for usage in preparing 2- and 4-hour forecasts of low ceilings and restricted visibilities and the providing of integrated-wind information within the drop-zone layer in support of paradrop operations.

A hierarchy of empirical relationships for estimating the recurrence probabilities under a number of contingencies are made possible through the use of statistical modelling techniques which act to conserve the data base. These are: 1) a model for generating recurrence probabilities which considers only the latest observed ceiling category, 2) one which incorporates surface wind information, 3) another which includes moisture considerations and 4) one which introduces observed moisture and wind information diagnostically without having to assume the persistency of these variables, or otherwise forecast their behavior, throughout the forecast interval.

Climatic presentations for estimating integrated winds within the drop-zone layer, from a knowledge of the winds at flight level, are discussed apart from those which pertain when surface winds are similarly available.

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PERSONNEL

The following members of the Department of Earth and Atmospheric Sciences were engaged in the research program at various stages. Professor Donald Martin was the principal investigator. Assistant Professor Edwin Chin was the co-investigator. Professor Chin expended most of his efforts in the paradrop area.

Dr. Segrid Steinhauser was a post-doctorate research scientist and principal assistant to Dr. Chin. Other professors to be included are Drs. Y. J. Lin and G. V. Rao who participated for short intervals as their expertise was needed.

Major Jerome Wacker and Captain Richard Nieman completed their Masters theses in the research area which devised climatic aids for the forecasting of low ceilings.

Mr. Louis Hull acted as a research scientist in the areas pertaining to low ceiling and restricted visibility forecasting. He was Professor Martin's principal graduate assistant throughout the entire period.

Paul Hwang, Jack Fishman, and William Raymond were graduate students who participated as computer programers. Mary Helen Hanlon and Larry Heitkemper acted in the same capacity on a full-time basis.

Miss Lydia Wu and Messrs. Dan Bloom and Gary Alessi, graduate students, worked part time in the data processing phases of the project.

A number of undergraduate students were employed intermittently on the project. They were Laura Buchman, Susan Gluck, Susan Kayar, Marge Humphrey, William Klint Randy Kalish, Thomas Lachajczyk, Robert McLeod, Ken Lapenta, Pin-Tse Chang, William Bolhofer, Robert Bunting, Elliot Mulberg, Richard Stodt, Arthur Donahue, Walter Drag, Zeng-Ba Tsai, Curt Holderbach, Claude Penny, and Patrick Burke.

Special credit is given to Mrs. Frances Brummell who served as secretary throughout the entire course of the research.

I. INTRODUCTION

Early in the program the AFCRL-AWS-SLU team completed the first task of the contract– to investigate the critical problem areas to be researched and establish criteria and priorities for attacking them. Two specific areas were outlined: 1) Devising climatic presentations for operational Air Weather Service (AWS) usage in preparing 2- and 4- hour forecasts of low ceilings and restricted visibilities, and 2) designing climatic information to support paradrop operations under conditions when only the winds at flight and ground levels are known.

The ground rules for research developments were also established at that time. First priority was to be given to the undertaking of feasibility studies to establish the relative merit of each proposed attack. Once feasibility was established, solutions were to be sought which offer possibilities of generalized applicability throughout the diverse areas of AWS interests. The final products were to be presented in formats acceptable to the operational AWS forecaster. All the problems were to be considered from a climatological point of view, i.e., the contract calls for providing climatic information to assist the forecaster—not designing it to eliminate him. The research efforts for the two aforementioned areas will be presented separately in this report.

The problem of forecasting low ceilings is not new to meteorology. In fact, the literature abounds with reports of partial successes and failures by others who have attempted to solve the problem. Hence, our first task was to review these studies in order to circumvent as many "false starts" as possible during the course of our research. It is perhaps trivial to state that the problem would have been solved long before if ready solutions existed. However, this stark realization is important from the outset in order to avoid discouragements later. Consequently, the research was oriented toward the devising of climatic presentations to be used as forecast aids rather than the seeking of forecast entities which, in all probability, are beyond our abilities to produce for a number of reasons. Foremost among these is simply the fact that the data records are not sufficiently refined to contain many of the short term meteorological fluctuations which affect the ceiling conditions over this time period. The data problem is particularly significant for low ceiling heights due to the added complications imposed by the local geography and topography of the earth's surface. For example, on occasions low ceilings are produced by local effects and on the others by quasi-stationary weather systems which cover wide areas of the map. Low ceilings may also occur in conjunction with well-defined migratory features. Thus, at times the best procedures for forecasting ceiling changes may be extrapolative or advective in character while on others the best tools to use may be simple persistency or its climatology.

AWS has devised persistence probability tables (PPT) which are particularly applicable under stagnant weather regimes. We chose to build upon this expertise and use their processed data bases for devising and testing improved applications of this basic concept.

Since climatology is but one approach to the problem of forecasting ceilings, the forecaster is encouraged to use its guidance along with that provided by a synthesis of the other materials at his disposal. The relative weighing of these forecast informations is a judgment factor which he is best suited to make since it depends upon the meteorological conditions under which a particular ceiling is occurring and their past histories of movement and association. Our research aim is to incorporate objectively the more common parameters which affect ceiling persistency so that the problem becomes primarily one of deciding when to use climatology rather than how to use it.

Most researchers who have attacked this problem have relied heavily on statistical techniques to uncover forecast relationships of note. We chose to do likewise and solicit the aid of the computer to diagnose the physical significance of these relationships. In particular, we hope to incorporate objective considerations based upon time of day, season of the year, wind speed and direction, and humidity conditions into the climatic recurrence statistics.

A most important consideration which must be made at the outset is how best to display these statistical relationships. If the approach is to involve a mix between the data processing attributes of the computer and the interpretative abilities of man, these displays must necessarily be kept sufficiently simple to permit an effective interplay. Many of the failures in the past have resulted from inabilities to recognize that man has this role to play. Either by direct design, or because the statistical methods being employed rapidly became too involved for man to mentally interpret, the forecaster has been handed categorical forecasts produced by a combination of regression terms which he is asked to either accept or reject, in total, with little guidance on when to do either. To avoid this pitfall, we chose to use simple diagrammatic techniques which pictorially portray various non-linear combinations of meteorological parameters under synoptic conditions which are most commonly found in the natural atmosphere.

Having decided on the problem to attack and the statistical approaches to use, we turned our attention to the most formidable problem yet to be resolved. How can the problem of ceiling persistency best be resolved in view of the restrictions that a limited data base imposes upon it? In attempting to answer this question, we have systematically progressed through four complexities of statistical modelling. These are: 1) a model for generating recurrence probabilities which considers no meteorological input other than a knowledge of the observed ceiling category at the time of forecast, 2) a model which incorporates the latest observed surface wind information, 3) a version which includes moisture considerations (the latest observed temperature dew-point spread), and 4) a revised concept which incorporates moisture and wind information diagnostically without requiring that any prognostic information whatsoever be supplied.

II. GENERATING RECURRENCE PROBABILITIES BY A MODEL WHICH CONSIDERS NO METEOROLOGICAL INPUT AT THE TIME OF FORECAST

Probabilities that given ceiling events will recur at later times can be obtained by various means. Those used as a standard for comparisons and for model developments in this research were provided by AWS. They were computer-generated by that establishment in its Asheville, North Carolina facility by simply tracing each event throughout the hourly records. These were made available to us for a number of ceiling categories and stations located throughout the world. They provide a direct evaluation of persistency without resorting to any assumptions whatsoever. They are as reliable as the data records will provide by "brute-force" computer processings. Therefore, if sufficient data were available to insure statistical significance to the results, and, if computer processing time did not constitute a restraining influence, there would be no need to resort to the modelling procedures as we are about to outline. A fundamental problem arises. Sufficient data are not available anywhere, for any station, to incorporate objectively the many meteorological considerations which the forecaster is presently attempting to do subjectively in his assessments of the persistency qualities of a given observed event.

The model offers a means of circumventing some of those processing steps which rapidly consume the data base by relying on certain other well-founded statistical relationships. McCabe (1968) estimates that it requires ten times as much data to produce reliable conditional probabilities that an event will reoccur as it does to determine their unconditional frequency of occurring in the first place. Hence, the specific step which we hope to circumvent involves the necessity of computer tracing the subsequent behavior of each given observed event. Only by conserving data in this way are we able to have enough left to incorporate consideration of the embedding synoptic environment in which a given ceiling is being observed into our recurrence probability statistics. Three specific models were found in the literature which had a direct bearing on our problem. They were provided by McCabe (1968), McAllister (1969), and Gringorten (1971). We chose to evaluate the latter two prior to embarking on the developing of models of our own. These two respective evaluations appear to be a relatively simple matter. Each uses a pair of unconditional frequency of ceiling occurrence climatologies (one for t_o and the other for $t_o + 2$ in the case of a 2-hour forecast) as input parameters to generate conditional climatologies of recurrence probabilities. Thus, both the necessary input and output values for these evaluations are contained in the AWS computer-generated data. However, there is one big problem. The raw statistics provided by AWS are not consistently reliable for the simple reason that during certain times of the day and months of the year an insufficient number of low-ceiling occurrences were observed to provide a reliable set of recurrence statistics by the direct computer-tracing approach. Also, ceilings are often rendered fictitiously discontinuous (by the very definition of a ceiling) since wild fluctuations in ceiling heights are reported whenever the accumulated cloud coverate oscillates between broken and scattered. Fortunately many of these effects can be minimized by subjecting the climatic representations, which are derived from these individual data reports, to hour-to-hour and month-to-month time continuity constraints. The need for some such procedure for "cleaning-up" the data, without destroying its information content, becomes increasingly apparent whenever one shrinks the original data base by stratifying it into "homogeneous" subsets of meteorological occurrences. The validity of using some such continuity constraints was confirmed by the data themselves whenever the probability statistics were derived from sufficiently large samples to dwarf the errors arising from the aforementioned more random considerations. Invariably we found that the more frequent the occurrence the better the data fit the climatic time-continuity constraints. The format of Figure 1 was designed to enhance and maintain the integrity of the data as a representative climatology by these considerations.

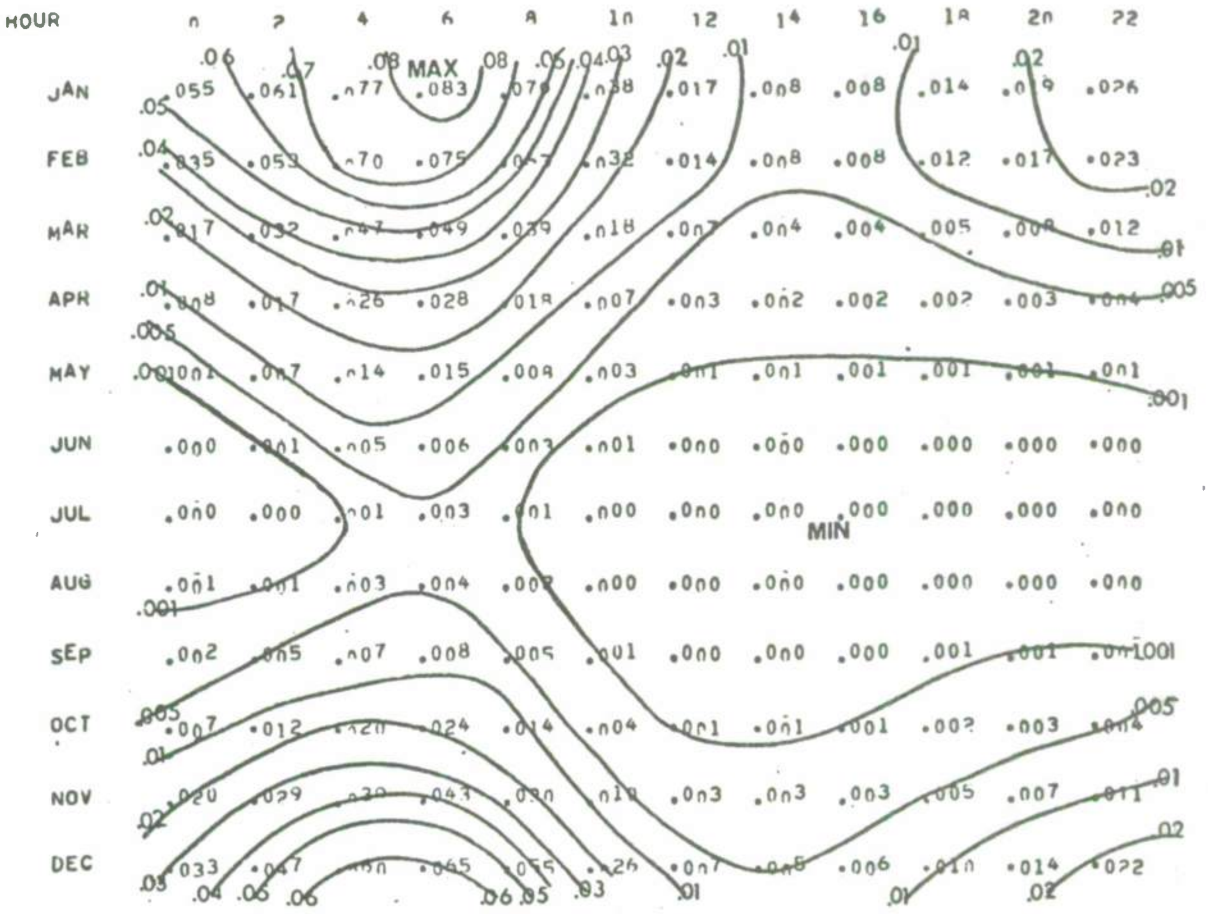


Fig. 1. Observed unconditional frequency of ceiling occurrences equal to or less than 200 feet for Randolph AFB, Texas.

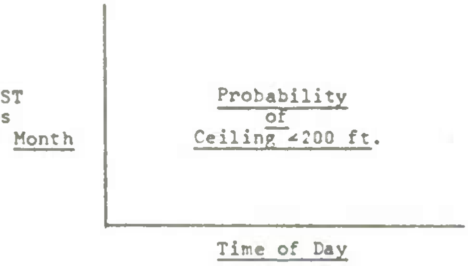
Values aligned in the format of Figure 1 which do not conform to a smoothed isoline of frequency of occurrence probabilities are immediately isolated for man's interpretation by providing him a means of viewing the misfits against the backdrop of a "continuous" field of meteorological information. The field analysis of a station's climatic records for a given set of occurrence frequencies can be best performed by systematic progressions from the more reliable (highest frequency of occurrence) statistics toward those areas occupied by the more suspect ones. Meteorologists are particularly adept in employing such procedures since most of the analyses they have been trained to make involve mixes of reliable and unreliable data over dense and sparse coverages. The isoline of probability analyses can either be made subjectively or objectively. After considerable experimentations an objective 3 x 3 smoothing matrix (see Figure 2) was found to give values at the respective grid points which fit those produced by our best subjective analysts within accepted tolerances. The data in Figure 1 has already been smoothed in the above manner.

Fig. 2. The objective 2-dimensional
smoothing operator

Restriction: The statistics for any event must change smoothly and continuously across the 2-dimensional field used to present the data.

EXAMPLE:

Actual Data June 12 LST
699 Total Observations
17 Ceilings <200 Feet
Probability of
Occurrence = .024



To smooth data for any month and time (eg. June 12 LST) the 8 surrounding data sets are

	11 LST	12 LST	13 LST
May	862 (20) .023 1	862 (13) .015 A	862 (14) .013 1
June	699 (17) .024 B	699 (17) .024 A.B	700 (11) .016 B
July	860 (24) .028 1	858 (16) .019 A	859 (14) .016 1

A and B are weighting factors
A = 2 for data each hour
B = 3 by month or dew-point spread
B = 3 if dew-point spread replaces month on vertical axis

SMOOTHED UNCONDITIONAL PROBABILITY =

$$\left[\begin{array}{l} (1)(862)(.023) + (2)(862)(.015) + (1)(.862)(.013) \\ + (3)(699)(.024) + (6)(699)(.024) + (3)(.700)(.016) \\ + (1)(860)(.028) + (2)(858)(.019) + (1)(.850)(.016) \end{array}\right]$$

$$\div \left[\begin{array}{l} (1)(862) + 2(862) + (1)862) + (3)(699) + (6)(699) + (3)(700) \\ + (1)(860) + (2)(858) + (1)(859) \end{array}\right]$$

$$= .0204$$

Note in Figure 1 that the frequencies of low ceiling occurrences are highly dependent on the local hour-of-the day and the season-of-the year and that the time of maximum and minimum occurrences are readily perceived. Particularly noteworthy is the fact that the frequency of ceiling occurrences is not predicated on any forecast input or observed knowledge. Hence, these statistics are presented in a compact format that should be particularly helpful to any forecaster who assumes duties in an area for the first time. He is immediately and straightforwardly introduced to the times and conditions when he is most likely to encounter a specific forecast problem at that location.

Just as the "observed" unconditional frequencies of occurrences were found to change smoothly and continuously across the 2-dimensional display of Figure 1 so did the respective "observed" conditional probabilities which we extracted from the persistence probability tables of AWS (see Figure 3). This display discloses at a glance the hours and months when persistency does and does not offer the best statistically probable forecast.

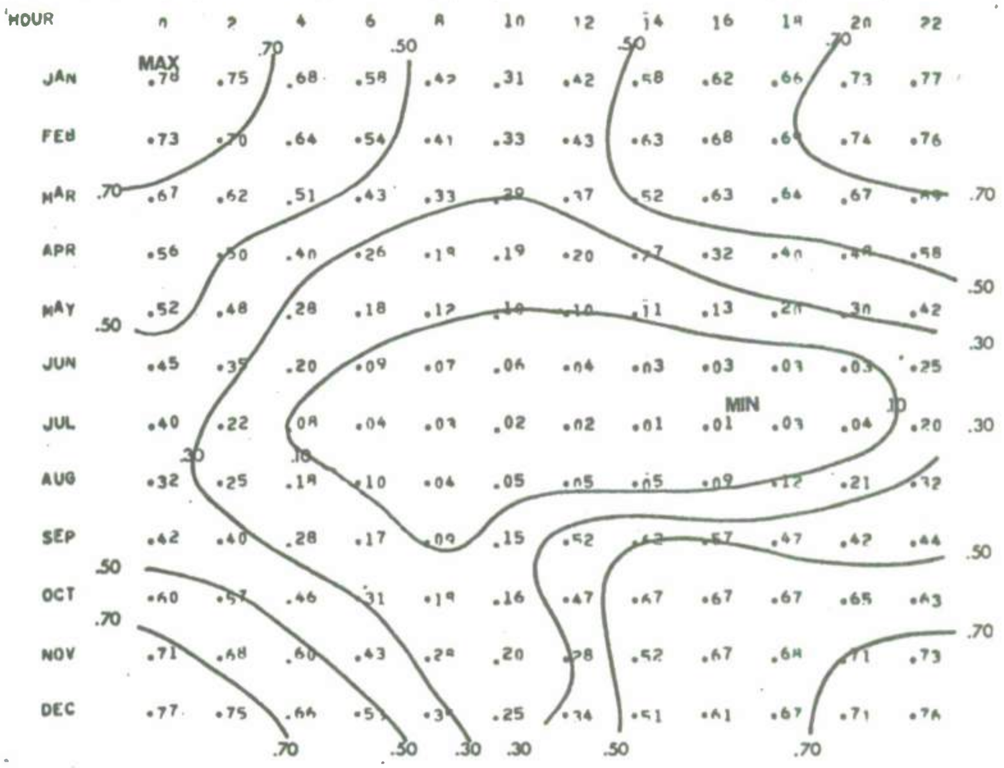


Fig. 3. Observed 2-hour recurrence probabilities for ceilings equal to or less than 200 feet for Randolph AFB, Texas.

Formats, such as those shown in Figures 1 and 3, represent an important spin-off of this research. We recommend them for AWS consideration as a better means of presenting reliable climatic information than the ones now in being.

The information contained in Figures 1 and 3 readily provides a sufficient set of reliable statistics for verifying the techniques of McAllister and Gringorten. McAllister (1969) investigated the recurrence probabilities of cirrus clouds and found that "A sensitivity analysis shows results that are essentially independent of particular data source with regard to geographic location, climatic regime, or season of the year insofar as parameter determination and concomitant accuracy of estimation are concerned. Extensions to broader classes of meteorological phenomena are also indicated." His findings are particularly intriguing since they meet one of our aforementioned objectives—to orient the research towards those solutions which offer the possibility of generalized application throughout the areas of Air Weather Service's interests. An evaluation of McAllister's model was undertaken by Captain Richard Nieman, (1971), a graduate student at Saint Louis University. A brief discussion of his research follows:

> "The empirical recurrence formula proposed by McAllister was used to estimate unconditional probabilities of various ceiling categories for three stations located in Texas. These stations lie in an area far removed and climatically different from the area that McAllister used to derive the formula. The parameter values given by McAllister and those derived from the Texas data were tested, in turn, to determine the reliability of the estimated conditional probabilities of recurrence under various time, area and ceiling groupings. The results indicate reliability for the formula's estimates under conditions of large unconditional probabilities. The method breaks down when the unconditional probabilities are small. Since an exponentially decreasing function is involved, the greatest errors in the estimates occur in the shorter forecast periods. Hence, the usefulness of the formula is dependent on the frequency of the weather phenomena under consideration and the time period of the forecast.
>
> Since the frequency and persistency of weather phenomena are dependent on factors such as season,

> time of day, and topography in combination with dynamic and thermodynamic processes, some type of data stratification would appear necessary to obtain 'unconditional climatologies' which are less biased toward those categories which are highly recurrent."

Nieman's conclusions that the accuracy of McAllister's model is dependent on the magnitude of the unconditional probabilities were also verified by Gringorten (1971). These investigations show that McAllister's model is not directly applicable to our problem since low ceilings and restricted visibilities occur rather infrequently at most stations during certain hours of the days and months of the year. Nieman's comments on stratification were further amplified by Major Jerome Wacker (1971), a contemporary graduate student conducting research on a allied aspect of the problem. Wacker showed that the occurrence statistics for low ceilings at Randolph AFB, Texas were highly dependent on the wind direction. He concluded that data stratification effectively "provides information as to which parameters need to be forecast, and in what detail, for any particular station or problem area where a solution exists within the available climatic records."

A model set forth by Gringorten (1971) was also evaluated using the aforementioned computer-traced statistics of AWS. His model used the same forms of input data to generate conditional probabilities as those employed by McAllister. Gringorten takes advantage of the Markov chain assumption and the U. S. Bureau of Standard's bivariate-normal tables to produce the desired result. The unknown variable in this approach is the hour-to-hour correlation of the normalized frequency of ceiling occurrences. Its value is assumed in his model to be 0.95. Although he found the hour-to-hour correlation to be relatively invariant for the elements which he tested, Gringorten recognized the need for it "to be surveyed and mapped as a function of element, geography and possibility time of year"

Data of the type presented in Figures 1 and 3 are sufficient to calculate the hour-to-hour correlation value explicitly and evaluate its constancy. The process merely involved the input of the known 2-hour conditional probability values for ceilings less than 200 feet provided by AWS into Gringorten's formula. Such calculations based on the data of Randolph AFB, Texas are shown in Figure 4.

	HOUR (LST)											
	0	2	4	6	8	10	12	14	16	18	20	22
JAN	.975	.964	.959	.949	.964	.917	.975	.964	.933	.949	.959	.938
FEB	.927	.938	.938	.933	.954	.938	.975	.970	.959	.954	.964	.959
MAR	.922	.906	.900	.900	.922	.949	.975	.949	.959	.949	.959	.954
APR	.900	.889	.872	.843	.860	.900	.866	.889	.889	.917	.927	.927
MAY	.883	.883	.825	.825	.825	.848	.794	.819	.819	.860	.900	.922
JUN	.883	.849	.800	.748	.860	.768	.686	.762	.735	.632	.775	.860
JUL	.900	.806	.648	.608	.700	.640	.632	.663	.678	.656	.837	.906
AUG	.866	.819	.768	.800	.775	.860	.806	.800	.825	.825	.906	.894
SEP	.889	.894	.843	.831	.883	.911	.980	.985	.938	.933	.933	.917
OCT	.911	.917	.894	.894	.917	.964	.959	.964	.954	.964	.964	.943
NOV	.954	.943	.933	.927	.959	.927	.894	.938	.959	.959	.959	.949
DEC	.959	.959	.943	.933	.927	.969	.927	.933	.938	.954	.959	.964

Fig. 4. Hour to hour correlation values (ρ) for ceilings less than 200 ft. at Randolph AFB, Texas. Calculate from Figures 1 and 3 and bivariate normal statistics.

Here the values are found to be hourly and seasonally variable. The question arises, Since McCabe (1968), McAllister (1969) and Gringorten (1971) found certain relationships between unconditional and conditional probabilities which were relatively independent of geographic location for the parameters and categories which they tested, "Why should low ceilings constitute an exception?" The answer appears to lie in the nonhomogeneity of conditions which can produce low ceilings compared to those less readily affected by the radiational transfer process occurring near the atmospheric lower boundary. Thus, the correlation may, in fact, be quite constant for each type of ceiling-producing cloud. Since fog and stratus (the main cause of low ceilings) are highly dependent on the local solar hour, steps were taken to partition the data according to the local time of day.

To determine the optimum partitioning, we decided to assume that a generalized solution to the problem of determining conditional probabilities statistically (once their unconditional counterparts were derived observationally) does, in fact, exist providing the hourly and monthly variability of cloud types are constrained. An "inexhaustible" data base was devised for testing the array of options open to us for finding that solution by arbitrarily selecting and combining the hourly station records of fifteen AWS widely separated locations (see Figure 5). The respective smoothed unconditional frequency of occurrence and their 2-hour recurrence probabilities for every hour-of-the-day and month-of-the hear were extracted for each particular station. A common diagram was then produced using this set of statistics for each of the stations assuming

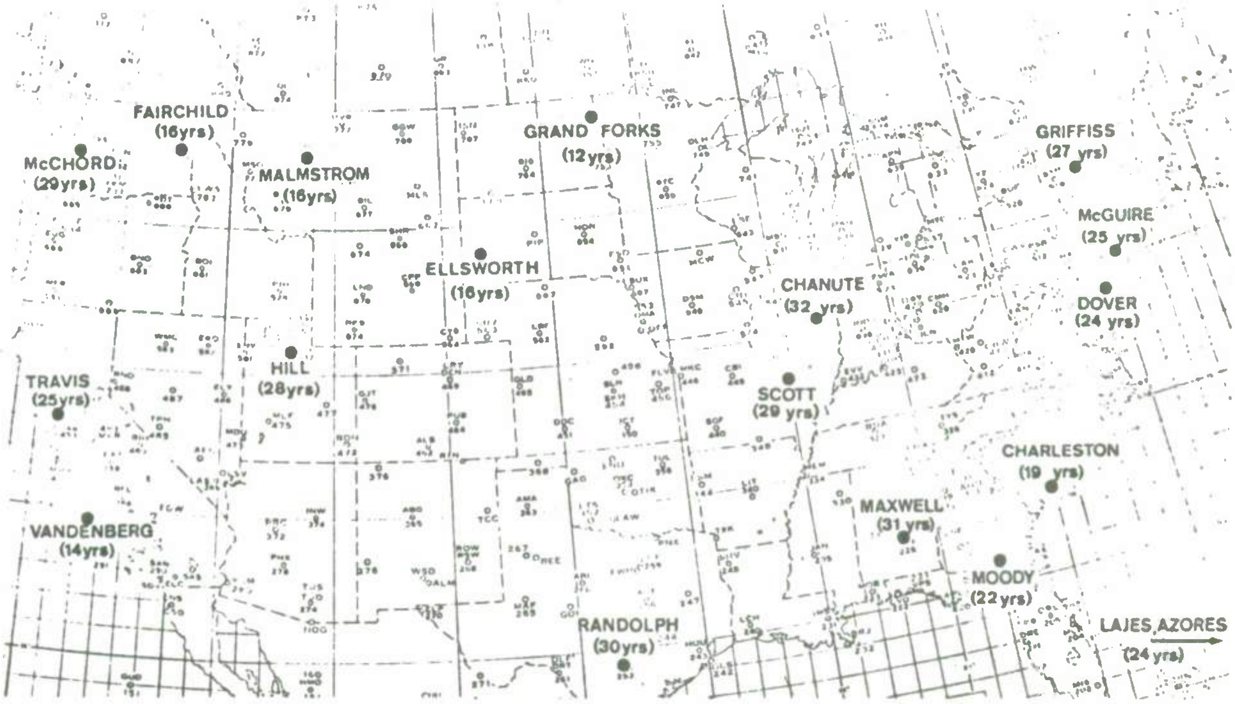


Fig. 5. Geographical location and length of records for the fifteen stations comprising the singular data base (in excess of 340 years) used to deduce the empirical occurrence-recurrence relationships of this report. The independent test stations are similarly shown.

each hour-of-the-day constituted an initial forecast hour (t_o). The unconditional frequencies of low ceiling occurrences at forecast time, t_o, were represented on the ordinate. The corresponding unconditional values 2 hours later define the abscissa. The respective 2-hour recurrence probabilities were plotted at the coordinate intersection of these two values. Since all these informations were derived from observed values, their plotted array represents a host of observed ceiling occurrences and recurrences under widely variant topographic and geographic conditions. As expected, when all possible times of the day and months of the year were included in the plotted array, an analysis of the recurrence statistics was difficult to complete under required tolerances. However, as more-and-more constraints were imposed, such that only those select portions of each station's data base which pertains to certain solar times and seasons were plotted on the common graph, the variance in the recurrence data about the analyzed value became progressively reduced. Essentially these results confirm our original assumption that when the ceiling-producing clouds are rendered near homogeneous through considerations based upon the time of day and season of the year, the concepts of universality as advanced by Gringorten essentially pertain for the low ceiling category as well. Hence, if two or more stations exhibit identical profiles of unconditional probabilities within any segment of the time partitioned subset, the extent to which they were topographically or geographically induced becomes essentially irrelevant for our purposes. Thus, a station's records contains at least two types of pertinent information to the problem at hand. Locally dependent geographical and topographical factors work to identify which respective coordinate intersections apply to each particular station. The recurrence statistic at each given intersection does not require a knowledge of which stations meet the particular magnitude-and-slope criteria for their frequency of occurrence values which are demanded by that specific coordinate intersection.

After considerable experimentation, it was found that a 16-fold partitioning of the data (four 6-hour periods per day for each season of the year) defined relationships between event occurrence frequencies and their recurrence probabilities which were sufficiently independent of geography and topography that these features need not be identified more specifically. Two such graphs are shown in Figures 6a and 6b. The diurnal difference in these relationships is seen by comparing the isopleth slopes between the two graphs. Complete sets of 2- and

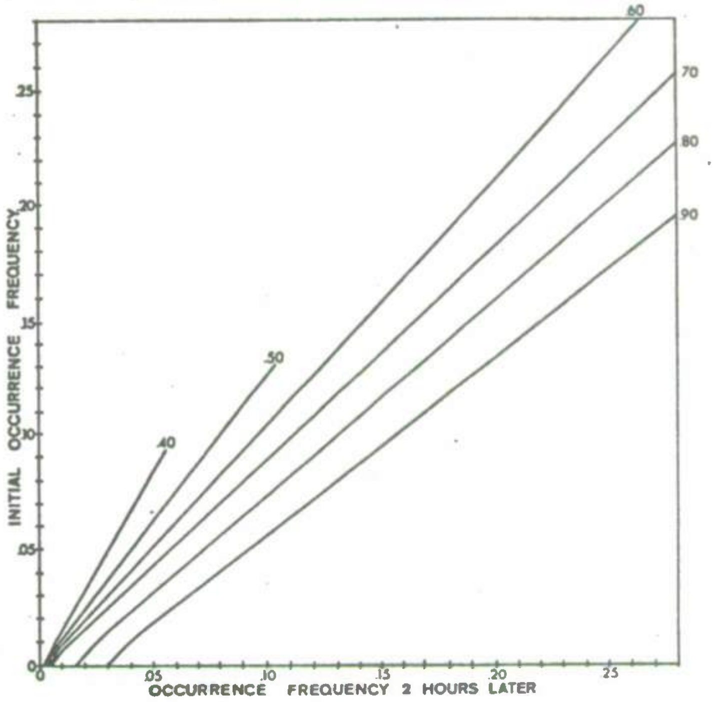


Fig. 6a. 2-hour occurrence-recurrence relationships deduced from the 15-station data base during the evening hours (1700-2300L) for Summer (June-August).

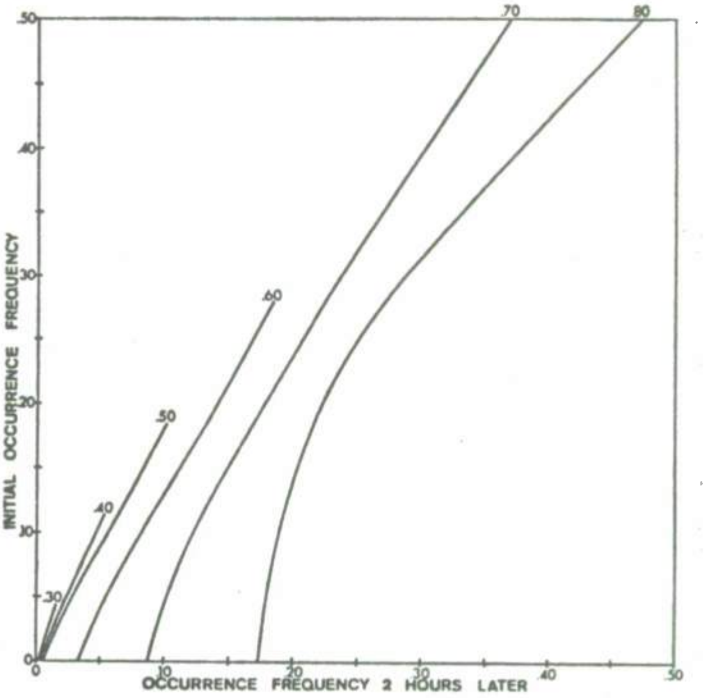
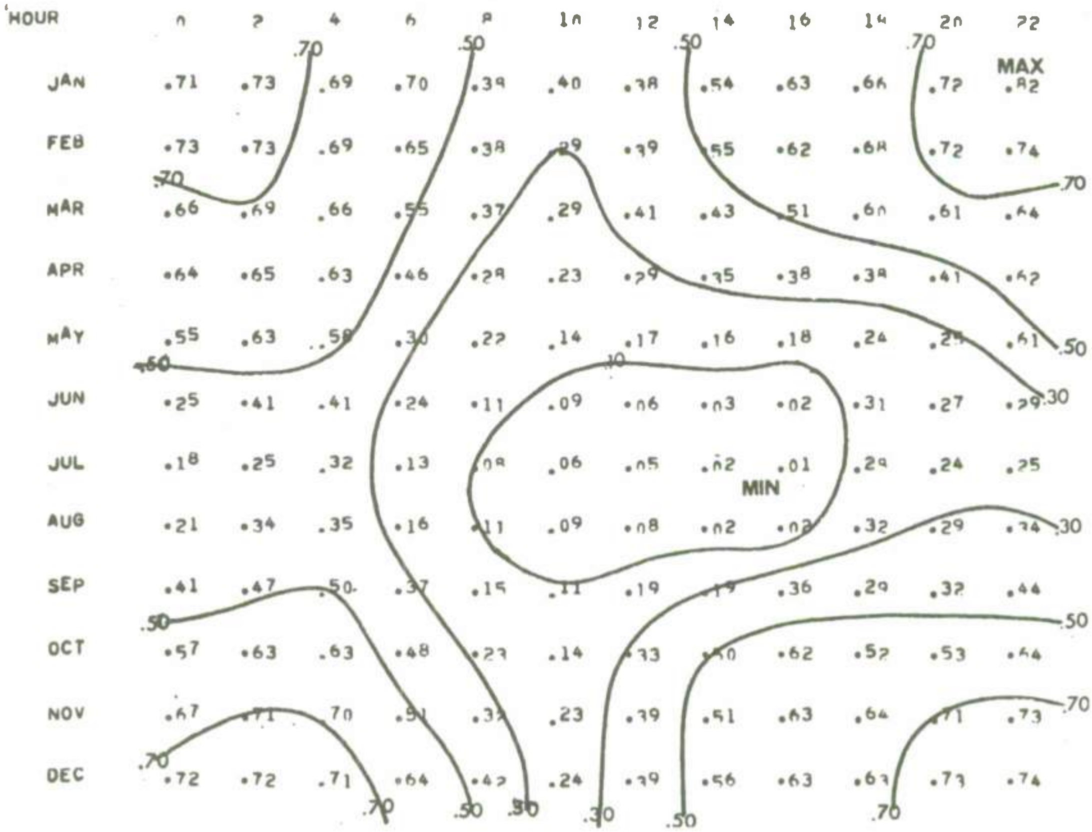


Fig. 6b. 2-hour occurrence-recurrence relationships deduced from the 15-station data base during the night hours (2330-0500L) for Summer (June-August).

4-hour ceilings and 2-hour visibility graphs are available in a Saint Louis University publication, Hull (1973). They represent another by-product of our continuing research efforts. Essentially, they provide a means of generating conditional probabilities for those stations having weather records of too short a time duration to permit their determination by direct computer tracing.

The accuracy of the graphical relationships was tested against dependent and independent data. The dependent-data verifications were accomplished by simply using the graphs and the frequency-of-occurrence data to reconstitute the 2-hour recurrence arrays for <u>each</u> of the 15 stations in formats such as that shown in Figure 3. These were then compared against the AWS generated and objectively smoothed recurrence probabilities for each individual station, category and time period. These comparisons readily verify the fact that the techniques developed did, in fact, apply to <u>each</u> individual station as well as to the majority. Figures 7 and 8 show the graphically reproduced arrays for



HOUR	0	2	4	6	8	10	12	14	16	18	20	22
JAN	.71	.73	.69	.70	.39	.40	.38	.54	.63	.66	.72	.82
FEB	.73	.73	.69	.65	.38	.29	.39	.55	.62	.68	.72	.74
MAR	.66	.69	.66	.55	.37	.29	.41	.43	.51	.60	.61	.64
APR	.64	.65	.63	.46	.28	.23	.29	.35	.38	.39	.41	.62
MAY	.55	.63	.58	.30	.22	.14	.17	.16	.18	.24	.29	.61
JUN	.25	.41	.41	.24	.11	.09	.06	.03	.02	.31	.27	.29
JUL	.18	.25	.32	.13	.08	.06	.05	.02	.01	.29	.24	.25
AUG	.21	.34	.35	.16	.11	.09	.08	.02	.02	.32	.29	.34
SEP	.41	.47	.50	.37	.15	.11	.19	.19	.36	.29	.32	.44
OCT	.57	.63	.63	.48	.23	.14	.33	.50	.62	.52	.53	.64
NOV	.67	.71	.70	.51	.32	.23	.39	.51	.63	.64	.71	.73
DEC	.72	.72	.71	.64	.42	.24	.39	.56	.63	.63	.73	.74

Fig. 7. Estimated 2-hour recurrence probabilities for ceilings equal to or less than 200 feet for Randolph AFB, Texas.

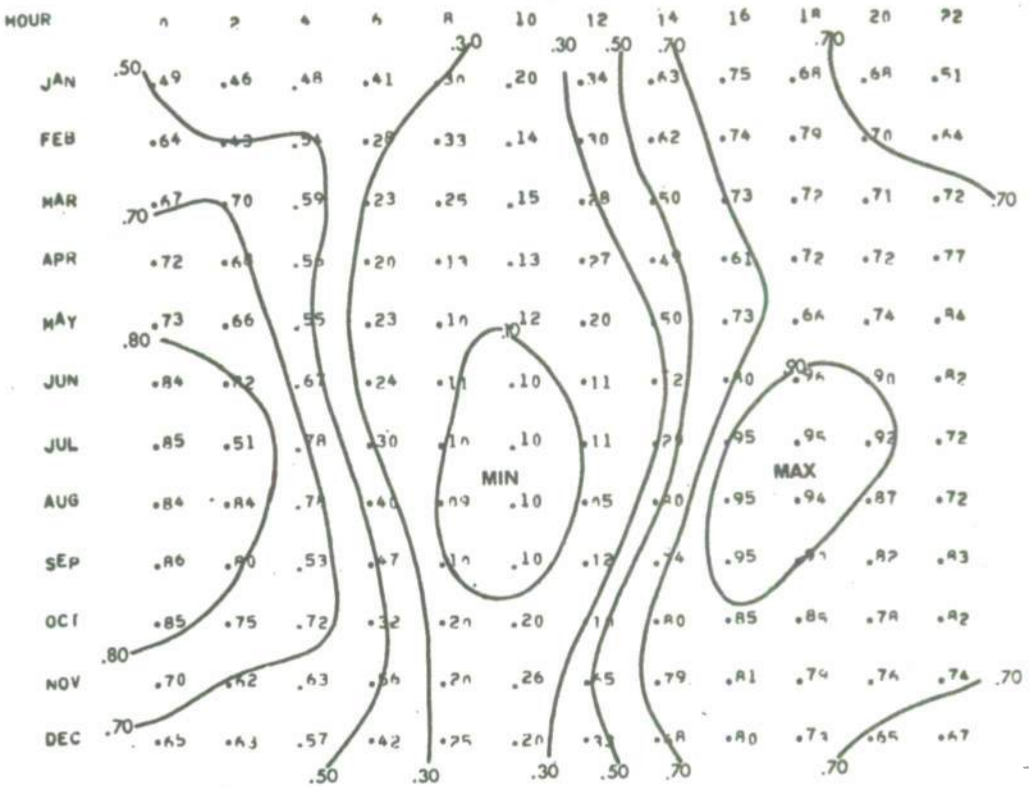


Fig. 8. Estimated 2-hour recurrence probabilities for ceilings equal to or less than 200 feet for Vandenberg AFB, California.

two of the fifteen stations. Their observed counterparts are shown in Figures 3 and 9, respectively. These two

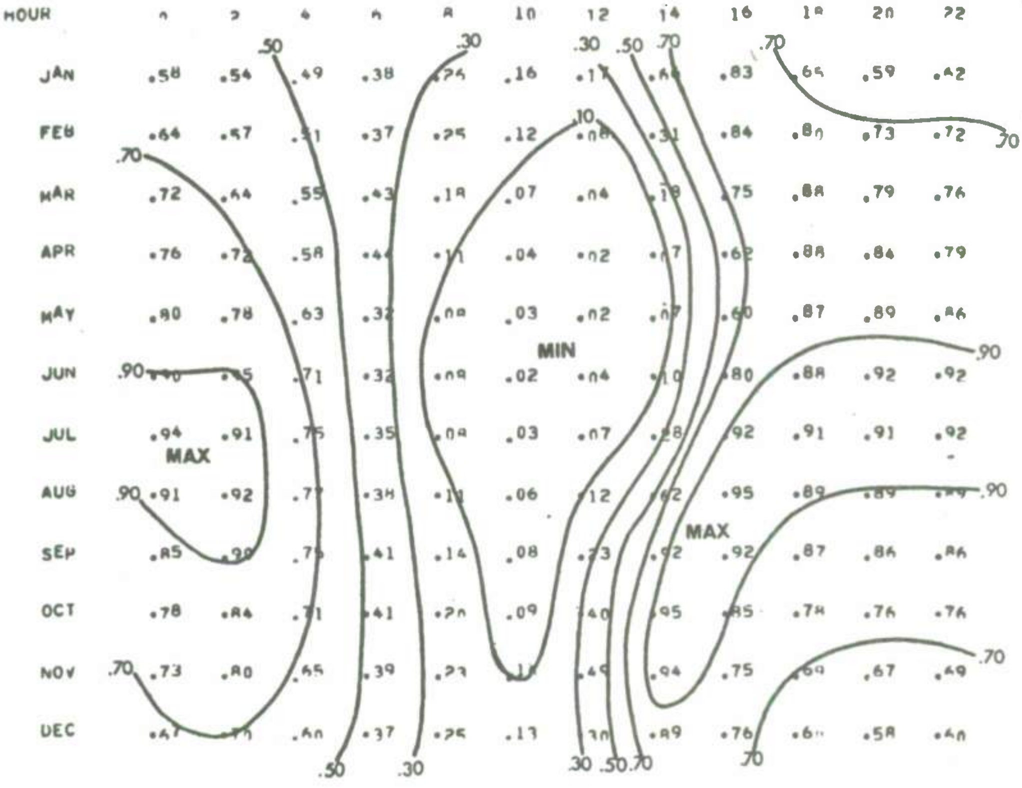


Fig. 9. Observed conditional 2-hour recurrence probabilities for ceilings equal to or less than 200 feet for Vandenberg AFB, California.

particular stations were selected for presentation solely because their climatologies respond quite differently to hourly and seasonal effects.

Test results using independent data are shown for Wiesbaden, Germany, Otis Air Force Base, Massachusetts and March Air Force Base, California in Figures 10, 11 and 12.

THE 2-HR RECONSTRUCTED CONDITIONAL PROBABILITY OF CEILINGS<200' RECURRING

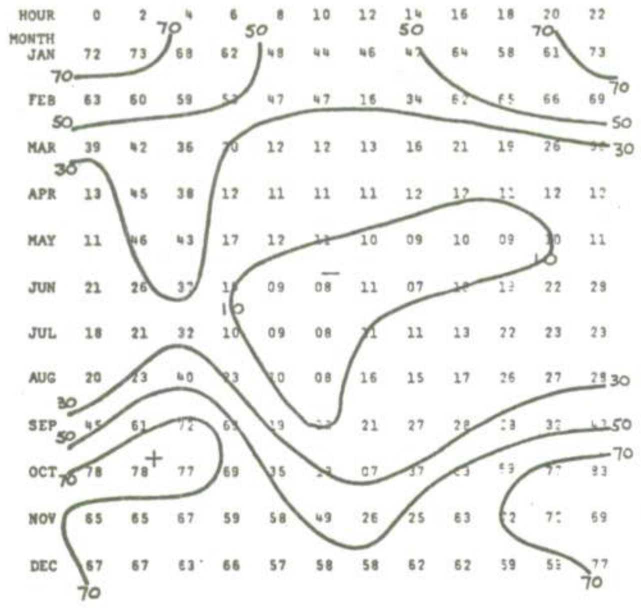


Fig. 10. Wiesbaden, Germany.

THE 2-HR RECONSTRUCTED CONDITIONAL PROBABILITY OF CEILINGS<200' RECURRING

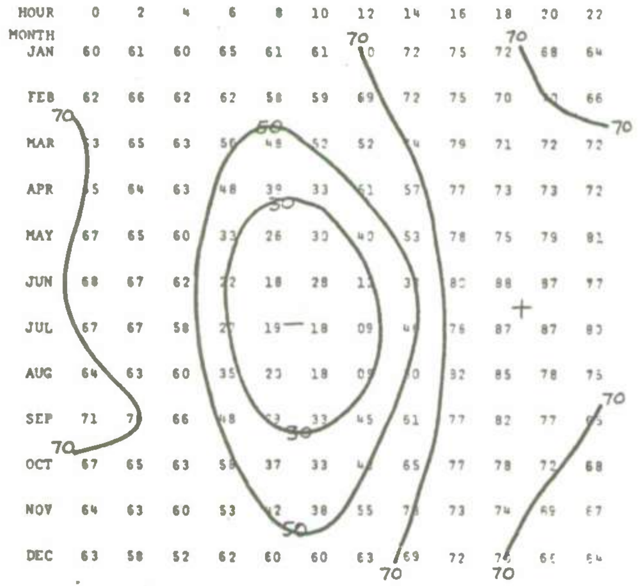
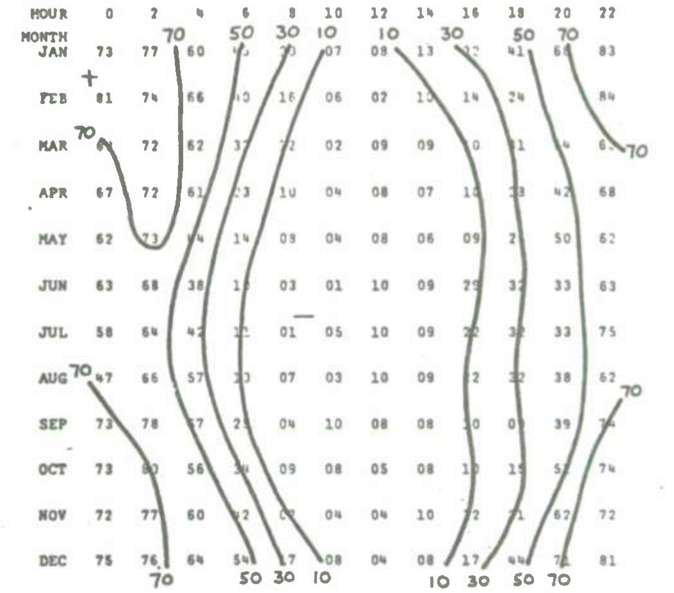


Fig. 11. Otis AFB, Mass.

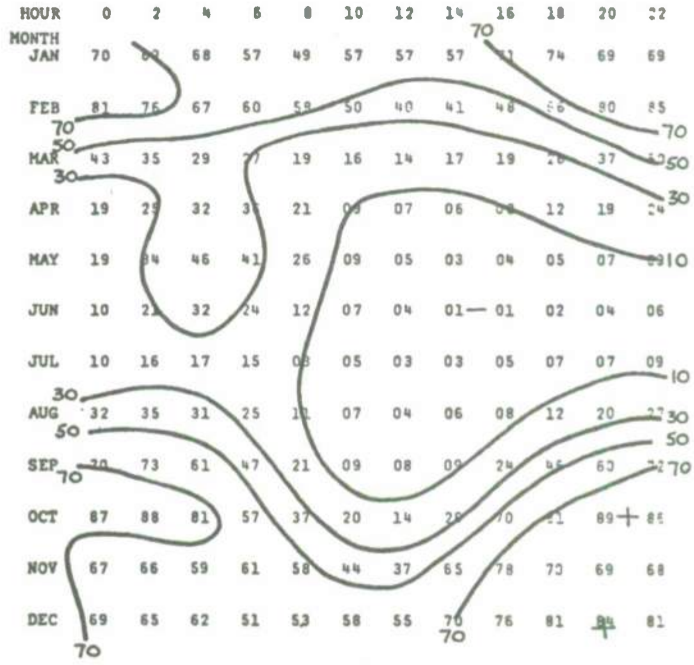


THE 2-HR RECONSTRUCTED CONDITIONAL PROBABILITY OF CEILINGS<200' RECURRING

HOUR / MONTH	0	2	4	6	8	10	12	14	16	18	20	22
JAN	73	77	60	45	20	07	08	13	32	41	68	83
FEB	81	74	66	40	16	06	02	13	14	24	[illegible]	84
MAR	[illegible]	72	62	37	22	02	09	09	10	31	44	[illegible]
APR	67	72	61	23	10	04	08	07	10	33	42	68
MAY	62	73	44	14	03	04	08	06	09	[illegible]	50	62
JUN	63	68	38	15	03	01	10	09	29	32	33	63
JUL	58	64	42	12	01	05	10	09	22	32	33	75
AUG	47	66	57	30	07	03	10	09	12	32	38	62
SEP	73	78	57	25	04	10	08	08	10	[illegible]	39	74
OCT	73	80	56	34	09	08	05	08	10	15	52	74
NOV	72	77	60	42	[illegible]	04	04	10	12	21	62	72
DEC	75	76	64	54	17	08	04	08	17	44	71	81

Fig. 12. March AFB, Calif.

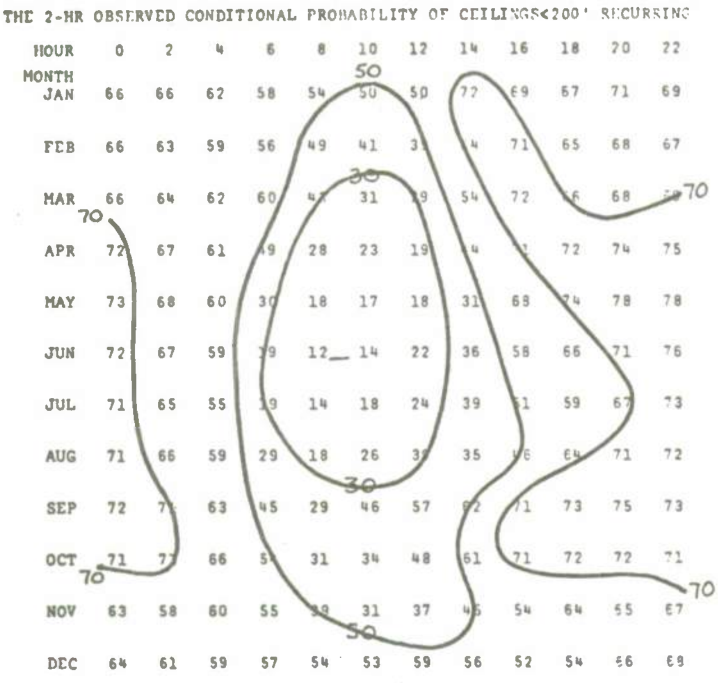
Again, the estimated 2-hour recurrence probabilities were obtained by introducing observed frequency-of-occurrence pairs for each of the three respective stations into the appropriate graphs. The recurrence statistics, provided by the AWS computer-tracing efforts, against which these graphical estimates are to be compared, are shown in Figures 13, 14 and 15.



THE 2-HR OBSERVED CONDITIONAL PROBABILITY OF CEILINGS< 200' RECURRING

HOUR / MONTH	0	2	4	6	8	10	12	14	16	18	20	22
JAN	70	69	68	57	49	57	57	57	71	74	69	69
FEB	81	76	67	60	58	50	40	41	48	66	80	85
MAR	43	35	29	27	19	16	14	17	19	20	37	42
APR	19	25	32	35	21	09	07	06	08	12	19	24
MAY	19	34	46	41	26	09	05	03	04	05	07	09
JUN	10	21	32	24	12	07	04	01	01	02	04	06
JUL	10	16	17	15	08	05	03	03	05	07	07	09
AUG	32	35	31	25	11	07	04	06	08	12	20	27
SEP	70	73	61	47	21	09	08	09	24	46	63	72
OCT	87	88	81	57	37	20	14	29	70	71	89	85
NOV	67	66	59	61	58	44	37	65	78	73	69	68
DEC	69	65	62	51	53	58	55	70	76	81	84	81

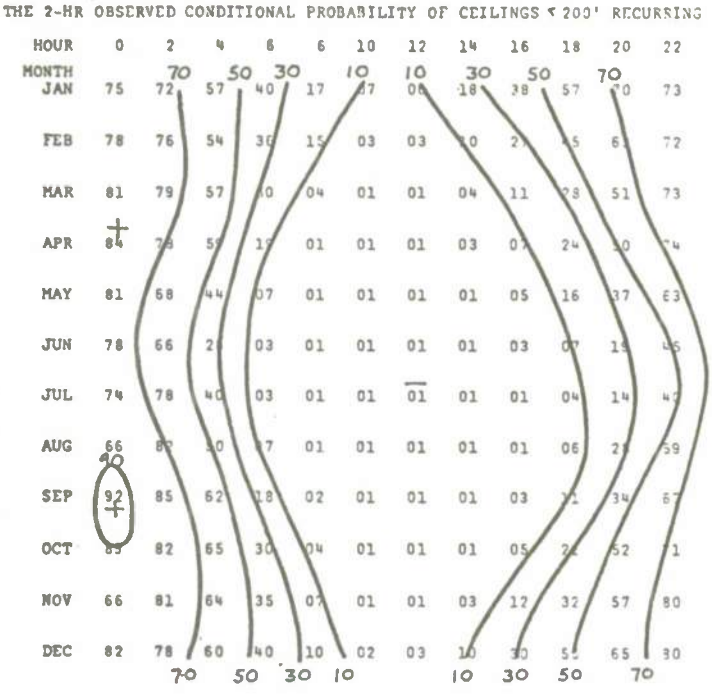
Fig. 13. Wiesbaden, Germany



THE 2-HR OBSERVED CONDITIONAL PROBABILITY OF CEILINGS<200' RECURRING

HOUR MONTH	0	2	4	6	8	10	12	14	16	18	20	22
JAN	66	66	62	58	54	50	50	72	69	67	71	69
FEB	66	63	59	56	49	41	31	[illegible]	71	65	68	67
MAR	66	64	62	60	47	31	[illegible]	54	72	[illegible]	68	[illegible]
APR	72	67	61	49	28	23	19	[illegible]	[illegible]	72	74	75
MAY	73	68	60	30	18	17	18	31	69	74	78	78
JUN	72	67	59	[illegible]	12	14	22	36	58	66	71	76
JUL	71	65	55	[illegible]	14	18	24	39	51	59	67	73
AUG	71	66	59	29	18	26	39	35	46	64	71	72
SEP	72	[illegible]	63	45	29	46	57	62	71	73	75	73
OCT	71	73	66	54	31	34	48	61	71	72	72	71
NOV	63	58	60	55	39	31	37	45	54	64	55	67
DEC	64	61	59	57	54	53	59	56	52	54	56	69

Fig. 14. Otis AFB, Mass.



THE 2-HR OBSERVED CONDITIONAL PROBABILITY OF CEILINGS < 200' RECURRING

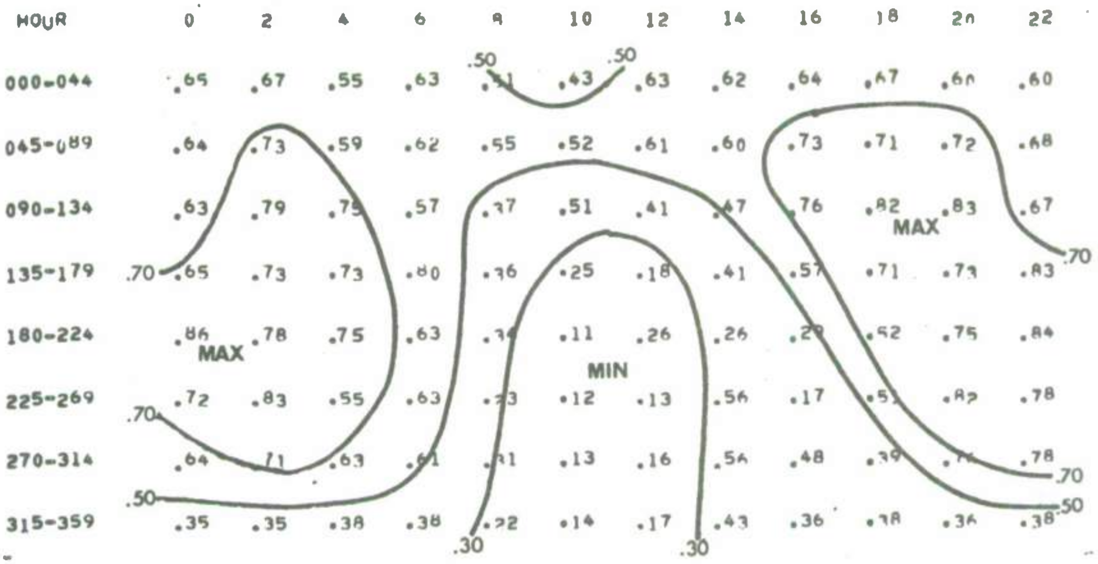
HOUR MONTH	0	2	4	6	6	10	12	14	16	18	20	22
JAN	75	72	57	40	17	07	08	18	38	57	70	73
FEB	78	76	54	36	15	03	03	10	27	45	[illegible]	72
MAR	81	79	57	[illegible]	04	01	01	04	11	28	51	73
APR	84	78	59	19	01	01	01	03	07	24	[illegible]	74
MAY	81	68	44	07	01	01	01	01	05	16	37	63
JUN	78	66	[illegible]	03	01	01	01	01	03	07	19	45
JUL	74	78	40	03	01	01	$\overline{01}$	01	01	04	14	[illegible]
AUG	66	[illegible]	[illegible]	[illegible]	01	01	01	01	01	06	[illegible]	59
SEP	92	85	62	18	02	01	01	01	03	[illegible]	34	67
OCT	[illegible]	82	65	30	04	01	01	01	05	[illegible]	52	71
NOV	66	81	64	35	07	01	01	03	12	32	57	80
DEC	82	78	60	40	10	02	03	10	30	[illegible]	65	80

Fig. 15. March AFB. Calif.

The same general methodology as that presented above for the 0-2 hour time period also was found to pertain for the 4-hour time frame. Likewise, it proved valid when visibilities, rather than ceilings, represented the parameters being investigated. These graphical relationships are similarly contained in the aforementioned Saint Louis University publication.

III. A REVISED MODEL WHICH INCORPORATES THE LATEST OBSERVED WIND INFORMATION

The fact that the persistency of a ceiling event is dependent on the wind regime occurring in association with it is shown in Figure 16 where the recurrence data for Randolph AFB, Texas are presented as a mere example.



HOUR	0	2	4	6	8	10	12	14	16	18	20	22
000-044	.65	.67	.55	.63	.51	.43	.63	.62	.64	.67	.60	.60
045-089	.64	.73	.59	.62	.55	.52	.61	.60	.73	.71	.72	.68
090-134	.63	.79	.75	.57	.37	.51	.41	.47	.76	.82	.83	.67
135-179	.65	.73	.73	.80	.36	.25	.18	.41	.57	.71	.73	.83
180-224	.86	.78	.75	.63	.34	.11	.26	.26	.29	.52	.75	.84
225-269	.72	.83	.55	.63	.33	.12	.13	.56	.17	.51	.82	.78
270-314	.64	.71	.63	.61	.31	.13	.16	.56	.48	.39	[illegible]	.78
315-359	.35	.35	.38	.38	.22	.14	.17	.43	.36	.38	.36	.38

Fig. 16. Estimated probabilities that observed ceilings equal to or less than 200 feet, presently occurring within a given wind sector, will reoccur 2 hours later for Randolph AFB during the period December through March.

It is readily evident from these data that the problem is not one of whether or not wind information should be incorporated into the persistency evaluations but rather one of how to effect it without compromising the general-applicability attributes of the modelled products. Two other pertinent questions also arise. How severely can a given station's data base be partitioned and still be expected to produce climatically significant conditional probabilities? Secondly, do the empirical relationships which we have found still pertain when stratified subsets of a station's data base are considered? Neither of these questions afford an obvious answer. The number of years of historical data required to establish climatic significance for the computed results depends upon the percentage frequency that an event occurs and the variance in its persistency qualities. Often both of these are enhanced by dividing the data into subsets. Thus, the question of the number of years needed to establish climatic significance for a given type is not a simple multiple of that needed for the unstratified data base. This point becomes particularly evident when moisture considerations are invoked as the stratifying agent. Since certain humidity values preclude the formation of clouds, and others almost guarantee it, this type of stratification drastically alters the frequency of occurrence statistics. With respect to the question as to whether or not the empirical relations given by the graphs apply to stratified subsets, the answer is "yes" providing the stratifying agent itself persists. This conclusion was determined by introducing the 3-wind sector stratified "unconditional" probabilities contained in the AWS statistics into the graphs of Section II and comparing the estimated recurrence probability values against their computer-traced counterparts.

Certain problems also arise in using these graphs on the stratified subsets which are not found when unstratified climatologies are considered. The problem is simply one of determining which wind sector to use for obtaining the wind-stratified frequency of occurrence statistic for the hour $t_o + 2$. This obviously requires a 2-hour forecast of the winds and an assumption that a changing wind direction does not represent a sufficiently significant change in "physics" to destroy the Markov-chain-type relationships in the data. Since low ceilings frequently occur or persist in association with weak winds and dissipate when the winds accelerate, particularly in the early morning hours, the graphs were found to be biased towards persistency. Herein lies the most formidable obstacle we have faced in devising a statistical model which brings additional meteorological knowledge to bear upon the persistency of an event. The approach we are using demands that the same knowledge be available for $t_o + 2$ as that used to stratify the data at t_o. Thus, care must be taken that one forecast problem is not simply being substituted for another. The statistics for Randolph and Scott AFB shown in Figure 17 emphasize this problem.

Station	No. of Cases	Persistence	All Winds (Graph)	All Winds (Book)	3 Wind Sector Stratification (Graph)	3 Wind Sector Stratification (Book)
Randolph (1949-1952)	446	65	73	73	75	73
Scott (1960-1963)	110	56	57	56	63	69

Fig. 17. 2-hour forecast verification for cases when the ceiling initially ranged between 0 and 199 feet (winter season).

Verification statistics for ceilings and winds were extracted from the observed records for each station whenever the time-marched initial time, t_o, showed ceilings less than 200 feet to be occurring. The appropriate 3 wind-stratified frequency of occurrence statistics for determining the ordinate position on the graphs were then extracted from presentations such as those given in Figure 1. Two sets of abscissa values were also selected. One neglected wind information throughout the two hour time period. The other was based on a knowledge of the wind initially and two hours later. Whenever the estimated conditional probabilities for $t_o + 2$ were 50% or greater, a persistent forecast was rendered. The persistency of low ceilings during the 3 year winter period for both stations is greater than 50% for the 2 hour period (Figure 17, Col. 2). Columns 3 and 4 show the percentage of correct forecasts under all wind conditions, while columns 5 and 6 show the results when wind stratifications were invoked. Note that the graphs of Section II faithfully provided verification statistics comparable to those given by the AWS computer-traced product for both locations when wind information was not considered, i.e., when the model discussed in Section II was used. Also note that the estimated conditional probabilities verified better for the wind-stratified data for Randolph than they did when wind information was not considered. The data for Scott showed different results. Here wind stratification proved less effective due to the simple fact that low ceilings at this mid-continent location are more critically affected by a more variable wind climatology.

Next the emphasis was shifted from one of low ceilings persisting to that of low ceilings forming rapidly from a much improved height category, i.e., the rapidly deteriorating weather. The records of Randolph AFB were carefully screened to separate out those cases when rapid ceiling deteriorations occurred and the data were processed through the appropriate graphs. Some case studies are shown in Figures 18 and 19.

(when neither latest observed dew-point depressions or winds.were considered).

Local Hour	D.O.	F (10,000>)	E (3000-9999)	D (1000-2999)	C (500-999)	B (200-499)	A (0-199)	Observed Ceiling
23	6	63	11	13	6	4	2	F
0	5	62	10	13	7	6	4	F
1	3	61	9	13	6	6	4	F
2	2	60	9	14	7	6	6	F
3	2	67	9	14	7	5	6	F
4	0	56	10	16	7	6	7	A

(when only the observed wind was considered).

Local Hour	D.D	F (10,000>)	E (3000-9999)	D (1000-2993)	C (500-999)	B (200-499)	A (0-199)	Observed Ceiling
23	6	63	11	12	6	5	3	F
0	5	62	11	12	5	5	4	F
1	3	62	11	12	5	5	4	F
2	2	61	10	13	6	6	5	F
3	2	59	11	13	8	5	6	F
4.	0	56	11	14	6	6	6	A

(when only the observed dew-point depression was coneidered).

Local Hour	D.D.	F (10,000>)	E (3000-9999)	D (1000-2669)	C (500 699)	B (200-499)	A (0-196)	Observed Ceiling
23	6	62	15	22	4	3	2	F
0	6	66	10	26	6	3	2	F
1	3	36	8	22	17	10	3	F
2	2	30	6	16	24	16	10	F
3	2	30	6	19	20	18	12	F
4	0	15	3	6	8	12	60	A

Fig. 16. "Unconditional" probability of event occurrencee at Randolph AFB on December 23, 1951.

(when neither latest observed dew-point depressions or winds were considered).

Local Hour	D.D	F (10,000>)	E (3000-9999)	D (1000-2999)	C (500 999)	B (200-499)	A (0-199)	Observed Ceiling
13	0	57	13	18	7	4	1	A
14	0	59	13	17	7	3	1	A
15	3	62	13	15	6	3	1	F
16	5	64	14	13	5	3	1	F
17	2	66	13	13	4	3	1	F
18	1	65	12	13	5	4	1	B
19	0	65	11	13	5	4	2	A

(when only the observed wind was considered).

Local Hour	D.D.	F (10,000>)	E (3000-9999)	D (1000-2999)	C (500-999)	B (200-499)	A (0-199)	Observed Ceiling
13	0	78	4	13	4	1	0	A
14	0	54	14	15	9	5	1	A
15	3	58	15	14	8	5	1	F
16	5	65	18	14	2	0	0	F
17	2	88	4	6	2	0	0	B
18	1	61	13	14	6	5	2	B
19	0	61	12	14	6	5	2	A

(when only the observed dew-point depression was considered).

	D.D.	F (10,000>)	E (3000-9999)	D (1000-2999)	C (500-999)	B (200-499	A (0-199)	Observed Ceiling
13	0	1	1	4	16	40	38	A
14	0	1	1	4	18	40	36	A
15	3	1	7	25	47	22	4	F
16	5	4	10	58	17	3	2	F
17	2	3	4	18	32	38	9	B
18	1	2	3	12	22	43	18	B
19	0	3	2	12	8	35	43	A

Fig. 19. "Unconditional" probability of event occurrences at Randolph AFB on January 14, 1949.

Note that neither the wind stratified climatic statistic, nor those devoid of such considerations produced conditional probabilities for any category other than "F" remotely approaching the 50% criterion which we arbitrarily set for determining that a new forecast be rendered. Hence, climatic considerations based on wind fields alone appear to offer little encouragement to the problem of forecasting rapid deteriorations. The limited data does, however, suggest that considerations based upon moisture fields (note that the temperature dew-point spread indicates increasing humidities long before the ceiling is found to lower or form) may deserve a better fate. This point was independently supported by each of the AWS teams which attempted to use our products on a trial basis. It represents another topic which will be presented later in the report.

Before proceeding to that discussion, however, it should be noted that the wind-stratified statistics provide much useful information apart from that of statistically deducing recurrence probabilities.

Presentations such as that shown in Figure 20 quickly alert the forecaster to those ceiling forecast problems at his location which are the most strongly wind related. Of particular significance, these statistics are not predicated on a knowledge of the observed ceiling conditions at forecast time. They, therefore, apply equally well to tomorrow's weather, for example, as they do for today's. Hence, they can be used in conjunction with the numerical models for any time period by simply asking that model to supply a gross estimate of the wind direction when the speeds exceed a certain limit. We used 4 mph as that criterion in our own study. For example, if the 24-hour fine mesh upper air and surface progs show a low-level wind out of the east at 0600 LST, the forecaster's odds that ceilings ≤199 feet will form are given by Figure 20 to be 0.157. The probability

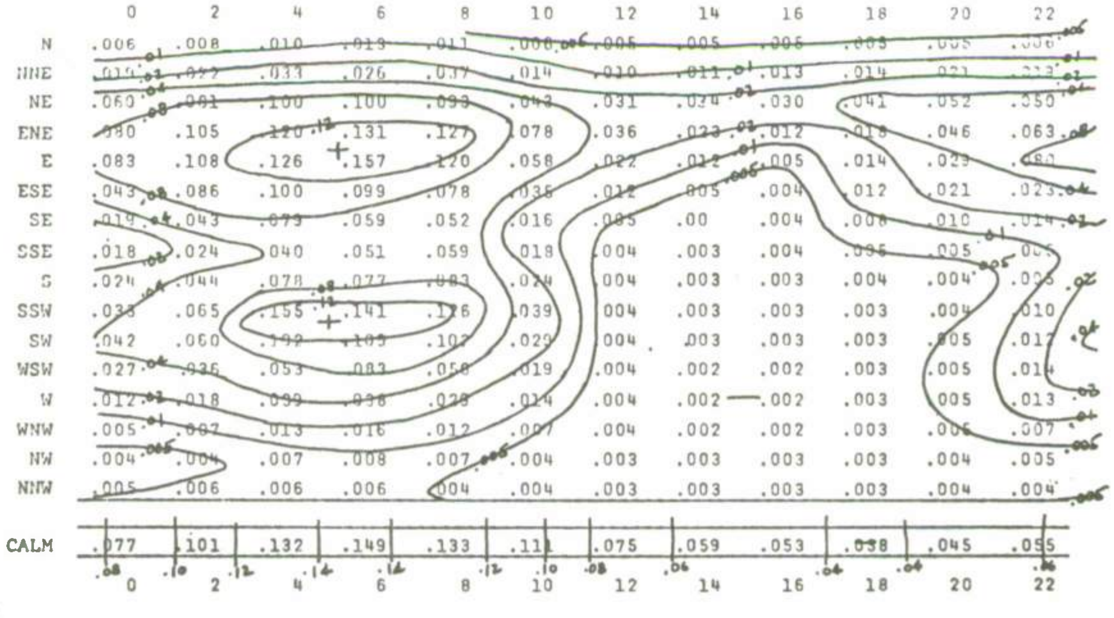


Fig. 20. Observed frequencies for ceilings equal to or less than 200 feet, occurring within given wind sectors, for Randolph AFB during the period December through March.

two hours later, providing the wind is forecast to persist, is found to be 0.120. The 2-hour persistency probabilities for this forecast ceiling condition starting at 0600 can be computed from the graphs to be about 0.59 (59%)(see Figure 16.

Such applications of the wind-stratified technique should only be attempted when the wind direction can be assumed to persist. The reason being that a shifting wind often infers a discontinuity in the physical processes that maintain low ceilings. For this reason we turned our attention to additional stratifying agents of a more continuous nature than that of winds alone. These will be described in the section to follow.

IV. A REVISION TO INCLUDE MOISTURE CONSIDERATIONS (TEMPERATURE DEW-POINT SPREADS)

Some problems arising in conjunction with the modeling of wind-stratified data to provide recurrence probabilities were discussed above. Others arise from the fact that winds are not physically related to ceilings but essentially enter the picture by providing the mechanisms which amass those parameters that are critical to ceiling informations. Moisture, on the other hand, plays a more direct role since it is a fundamental ingredient in cloud-droplet formation processes.

For this reason humidity parameters (we used the temperature dew-point spread) appear to be superior to winds as a stratifying agent since an imposed humidity constraint more effectively serves to reduce the variances in the occurrence and recurrence statistics. This offers the very fundamental advantage that climatically significant statistics can be realized from a smaller period of records. Another advantage is that certain problems arising with the rarely occurring ceiling event can be effectively recast to that of a rarely occurring <u>continuous</u> moisture parameter. This also has its benefits by permitting a maximum of information to be extracted from a minimum of data. To illustrate these points, an inspection of the historical records readily shows that ceilings $\leq$ 199 feet occur rather infrequently for most stations. Hence, the statistics are often computed on too small a data sample for them to stabilize due, in part, to the variability of the recurrence statistics. Note, for example, in Figure 1 during the daylight hours of the winter season unconditional frequencies are found to be as low as .008. Figure 21 shows this same statistic to be much higher when ceiling occurrences are "conditioned" on the

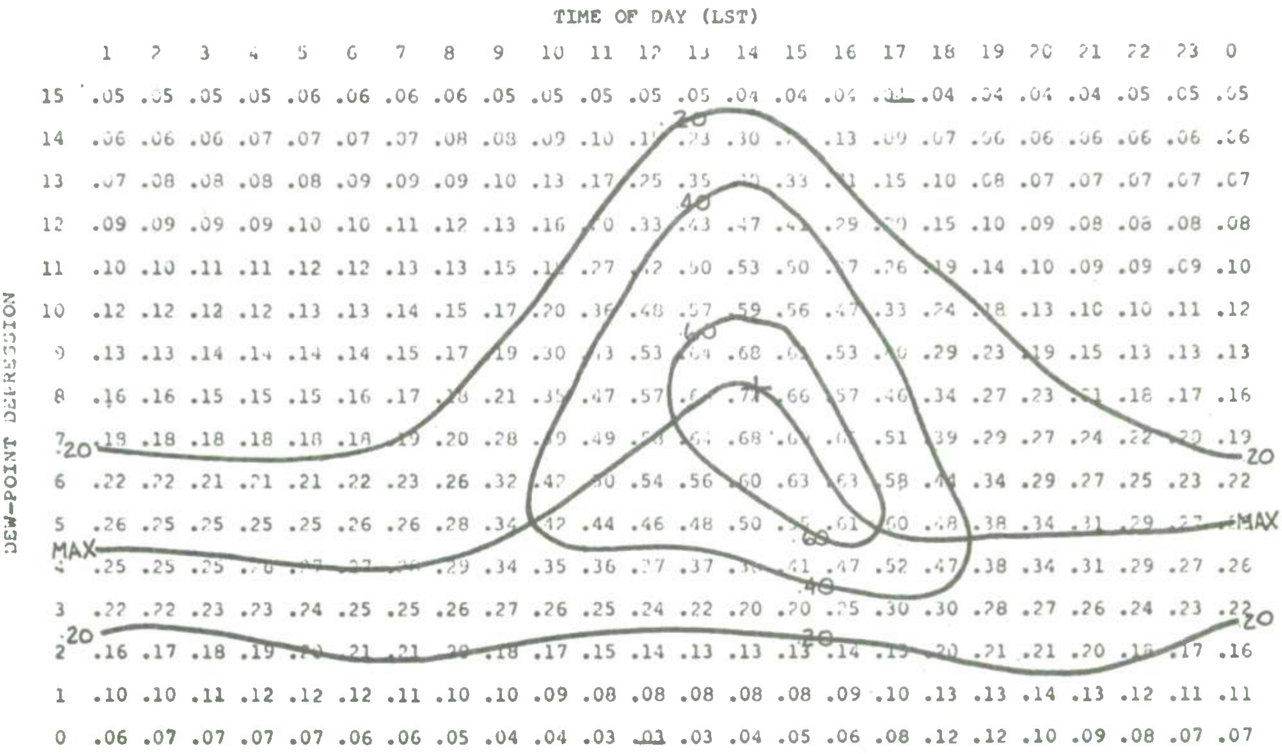
Dew Point Spread (°F)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	0	0	0	0	1	1	0	0	1	2	2	0	0	0	0	0	0	2	0	0	1	0	0	0	0
4	1	1	0	0	1	2	2	2	1	0	0	0	0	0	1	0	0	0	1	0	1	1	0	1	1
3	1	1	3	2	3	4	4	3	3	3	2	4	3	3	1	0	0	1	1	2	2	3	2	1	1
2	9	9	6	7	7	6	8	8	10	10	9	10	16	6	9	5	5	13	11	8	12	8	9	10	9
1	19	28	25	22	25	23	28	23	28	29	22	23	22	22	14	12	18	14	17	29	15	23	25	18	19
0	51	49	55	57	64	62	58	55	59	57	50	36	39	43	36	37	32	46	47	43	45	48	46	49	51

Local Time of Day

Fig. 21. Probability (percent) of Cloud A as a function of dew point (all winds) at Randolph AFB, Texas in the winter season.

associated temperature dew-point spread. The argument is not one that by some wizardry a rare occurring event now becomes a highly occurrent one. Rather, the criterion for determining the rarity is shifted to the occurrence of a temperature dew-point spread. Although these spreads rarely occur, the statistics associated with them can better be inferred by bringing the entire data records to bear upon the problem as discussed in conjunction with Figure 1. The moisture parameter affords other distinct advantages which soon become clearly evident. For example, each specific ceiling category can be represented by some median height value within that category. At this cloud base height the humidities are automatically pegged as being near 100%, otherwise a ceiling would not exist. This knowledge of height and humidity, together with that of moisture values at the surface, establishes a linear approximation to the moisture lapse rate between the ground and the ceiling base. This information provides a crude "typing" of the ceiling-producing clouds. Primarily it serves to delineate the low-level fog cases from the remainder of the sample. The fact that fog has different persistency characteristics than other types of ceiling-producing phenomena is common knowledge.

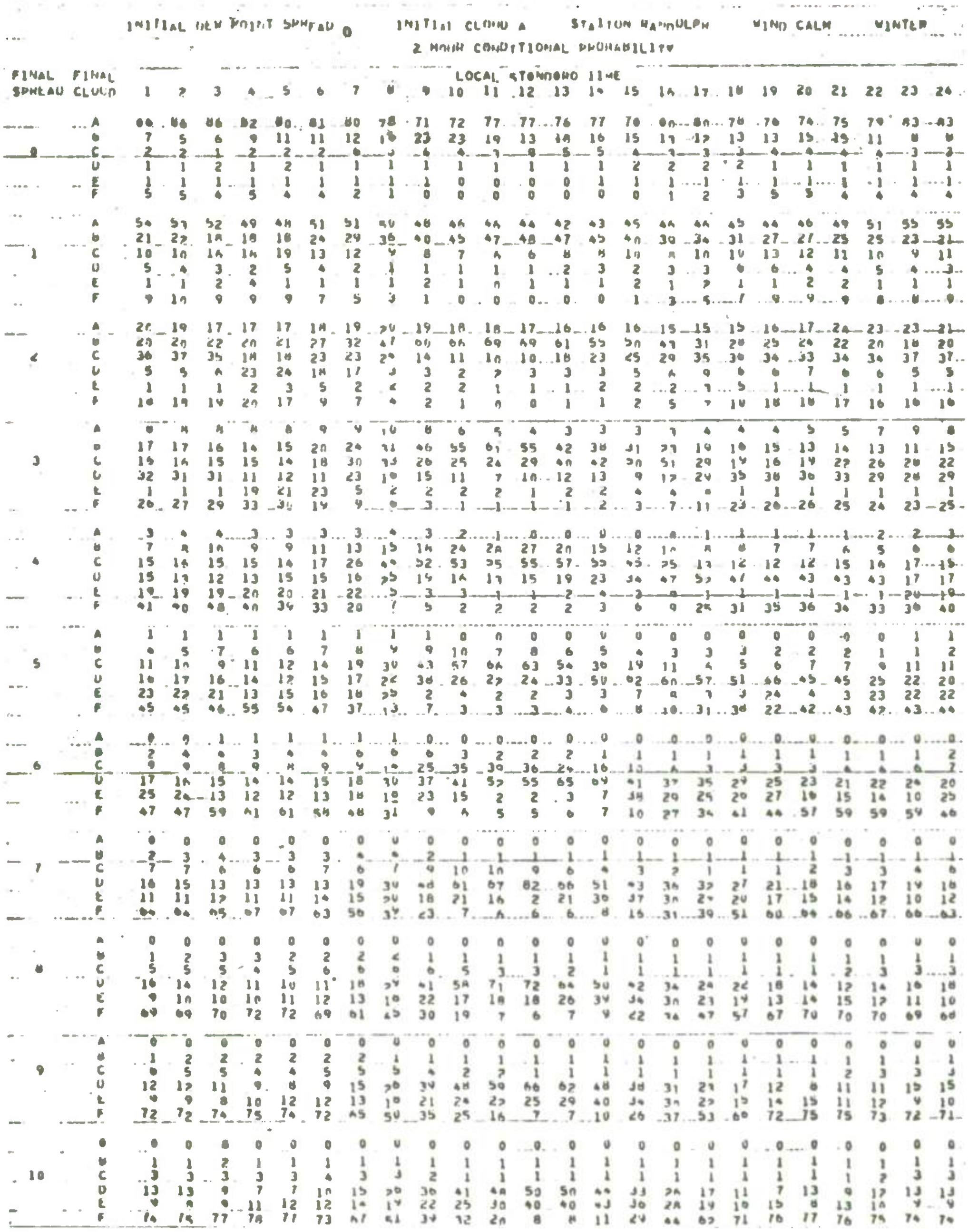
Displays such as those shown in Figure 22 were produced for each ceiling category. Note how the frequency of ceiling occurrences vary diurnally with surface



DEW-POINT DEPRESSION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
15	.05	.05	.05	.05	.06	.06	.06	.06	.05	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.04	.05	.05	.05
14	.06	.06	.06	.07	.07	.07	.07	.08	.08	.09	.10	[illegible]	.23	.30	[illegible]	.13	.09	.07	.06	.06	.06	.06	.06	.06
13	.07	.08	.08	.08	.08	.09	.09	.09	.10	.13	.17	.25	.35	[illegible]	.33	[illegible]	.15	.10	.08	.07	.07	.07	.07	.07
12	.09	.09	.09	.09	.10	.10	.11	.12	.13	.16	[illegible]	.33	.43	.47	[illegible]	.29	[illegible]	.15	.10	.09	.08	.08	.08	.08
11	.10	.10	.11	.11	.12	.12	.13	.13	.15	[illegible]	.27	[illegible]	.50	.53	.50	[illegible]	.26	.19	.14	.10	.09	.09	.09	.10
10	.12	.12	.12	.12	.13	.13	.14	.15	.17	.20	.36	.48	.57	.59	.56	.47	.33	.24	.18	.13	.10	.10	.11	.12
9	.13	.13	.14	.14	.14	.14	.15	.17	.19	.30	.43	.53	.64	.68	[illegible]	.53	.40	.29	.23	.19	.15	.13	.13	.13
8	.16	.16	.15	.15	.15	.16	.17	.18	.21	.35	.47	.57	[illegible]	[illegible]	.66	.57	.46	.34	.27	.23	.21	.18	.17	.16
7	.19	.18	.18	.18	.18	.18	.19	.20	.28	[illegible]	.49	[illegible]	.64	.68	[illegible]	[illegible]	.51	.39	.29	.27	.24	.22	.20	.19
6	.22	.22	.21	.21	.21	.22	.23	.26	.32	.42	.50	.54	.56	.60	.63	.63	.58	.44	.34	.29	.27	.25	.23	.22
5	.26	.25	.25	.25	.25	.26	.26	.28	.34	.42	.44	.46	.48	.50	[illegible]	.61	.60	.48	.38	.34	.31	.29	[illegible]	[illegible]
4	.25	.25	.25	[illegible]	[illegible]	[illegible]	[illegible]	.29	.34	.35	.36	.37	.37	[illegible]	.41	.47	.52	.47	.38	.34	.31	.29	.27	.26
3	.22	.22	.23	.23	.24	.25	.25	.26	.27	.26	.25	.24	.22	.20	.20	.25	.30	.30	.28	.27	.26	.24	.23	.22
2	.16	.17	.18	.19	.20	.21	.21	.20	.18	.17	.15	.14	.13	.13	.13	.14	[illegible]	.20	.21	.21	.20	.18	.17	.16
1	.10	.10	.11	.12	.12	.12	.11	.10	.10	.09	.08	.08	.08	.08	.08	.09	.10	.13	.13	.14	.13	.12	.11	.11
0	.06	.07	.07	.07	.07	.06	.06	.05	.04	.04	.03	.03	.03	.04	.05	.06	.08	.12	.12	.10	.09	.08	.07	.07

Fig. 22. Ceiling frequencies of clouds 1,000 to<3,000 feet as a function of dew-point depression and time of day for Randolph AFB (winter).

humidities. Although similar variations are evident for other ceiling categories as well, this particular illustration was chosen since these ceilings lie in the upper reaches of the atmosphere's lower boundary layer and have the option of rising above it or deteriorating more deeply into it. The diurnal relationships between ceilings and given temperature dew-point spreads presumably reflect diurnal changes in low-level thermal stratifications associated with the local solar hour. Thus another bit of pertinent information, having a bearing on ceiling persistency appears to be implicitly incorporated into the model. Moisture stratified subsets of the data for a number of stations were processed to produce similar relationships to those shown in Fig. 6a and 6b between moisture stratified occurrence values and the recurrence probabilities that a ceiling occurring under these conditions will recur two hours later. Matrices of information were extracted from each of these respective graphs and placed on punch cards and magnetic tape to facilitate the calculation of recurrence probability statistics for any given station and ceiling event (see Figure 23).



INITIAL DEW POINT SPREAD 0 INITIAL CLOUD A STATION RANDOLPH WIND CALM WINTER

2 HOUR CONDITIONAL PROBABILITY

FINAL SPREAD	FINAL CLOUD	LOCAL STANDARD TIME 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	A	84	86	86	82	80	81	80	78	71	72	77	77	76	77	78	80	80	78	76	74	75	79	83	83
	B	7	5	6	9	11	11	12	16	23	23	19	13	18	16	15	13	12	13	13	15	15	11	8	8
0	C	2	2	1	2	2	2	4	3	4	4	3	8	5	5	4	3	3	3	4	4	4	4	3	3
	D	1	1	2	1	2	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1	1
	E	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
	F	5	5	4	5	4	4	2	1	0	0	0	0	0	0	0	1	2	3	5	5	4	4	4	4
	A	54	53	52	49	48	51	51	50	48	46	46	44	42	43	45	46	46	45	44	46	49	51	55	55
	B	21	22	18	18	18	24	29	36	40	45	47	48	47	45	40	38	34	31	27	27	25	25	23	21
1	C	10	10	16	18	19	13	12	9	8	7	6	6	8	8	10	9	10	10	13	12	11	10	9	11
	D	5	4	3	2	5	4	2	1	1	1	1	1	2	3	2	3	3	6	6	4	4	5	4	3
	E	1	1	2	4	1	1	1	1	2	1	0	1	1	1	2	1	2	1	1	2	2	1	1	1
	F	9	10	9	9	9	7	5	3	1	0	0	0	0	0	1	3	5	7	9	9	9	8	8	9
	A	24	19	17	17	17	18	19	20	19	18	18	17	16	16	16	15	15	15	16	17	20	23	23	21
	B	20	20	22	20	21	27	32	47	60	66	69	69	61	55	50	43	31	28	25	24	22	20	18	20
2	C	36	37	35	18	18	23	23	24	14	11	10	10	18	23	25	29	35	36	34	33	34	34	37	37
	D	5	5	6	23	24	18	17	3	3	2	2	3	3	3	5	6	9	6	6	7	6	6	5	5
	E	1	1	1	2	3	5	2	2	2	2	1	1	1	2	2	2	3	5	1	1	1	1	1	1
	F	14	18	19	20	17	9	7	4	2	1	0	0	1	1	2	5	7	10	18	18	17	16	16	16
	A	8	8	8	8	8	9	9	10	8	6	5	4	3	3	3	3	4	4	4	5	5	7	9	8
	B	17	17	16	14	15	20	24	31	46	55	61	55	42	38	31	23	19	18	15	13	14	13	11	15
3	C	15	16	15	15	14	18	30	33	26	25	24	29	40	42	30	51	29	19	16	19	22	26	28	22
	D	32	31	31	11	12	11	23	18	15	11	7	10	12	13	9	12	29	35	38	36	33	29	28	29
	E	1	1	1	19	21	23	5	2	2	2	2	1	2	2	4	4	8	1	1	1	1	1	1	1
	F	26	27	29	33	30	19	9	6	3	1	1	1	1	2	3	7	11	23	26	26	25	24	23	25
	A	3	4	4	3	3	3	3	4	3	2	1	0	0	0	0	0	1	1	1	1	1	2	2	3
	B	7	8	10	9	9	11	13	15	18	24	28	27	20	15	12	10	8	8	7	7	6	5	6	6
4	C	15	14	15	15	14	17	26	44	52	53	55	55	57	55	45	25	13	12	12	12	15	16	17	15
	D	15	13	12	13	15	15	16	25	19	16	13	15	19	23	34	47	52	47	44	43	43	43	17	17
	E	19	19	19	20	20	21	22	5	3	3	1	1	2	4	3	8	1	1	1	1	1	1	20	19
	F	41	40	40	40	39	33	20	7	5	2	2	2	2	3	6	9	25	31	35	36	34	33	38	40
	A	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	B	4	5	7	6	6	7	8	9	9	10	7	8	6	5	4	3	3	3	2	2	2	1	1	2
5	C	11	10	9	11	12	14	19	30	43	57	66	63	54	30	19	11	4	5	6	7	7	8	11	11
	D	16	17	16	14	12	15	17	22	38	26	22	24	33	50	62	60	57	51	46	45	45	25	22	20
	E	23	22	21	13	15	16	18	25	2	4	2	2	3	3	7	9	3	3	24	4	3	23	22	22
	F	45	45	46	55	54	47	37	13	7	3	3	3	4	8	8	18	31	38	22	42	43	42	43	44
	A	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	2	4	4	3	4	4	6	6	6	3	2	2	2	1	1	1	1	1	1	1	1	1	1	2
6	C	9	9	8	9	8	9	9	14	25	35	39	36	24	16	13	6	3	3	3	3	4	4	6	7
	D	17	16	15	14	14	15	18	30	37	41	52	55	65	69	41	37	35	29	25	23	21	22	24	20
	E	25	24	13	12	12	13	18	18	23	15	2	2	3	7	38	29	25	26	27	18	15	14	10	25
	F	47	47	59	61	61	58	48	31	9	6	5	5	6	7	10	27	34	41	44	57	59	59	59	46
	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	2	3	4	3	3	3	4	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	C	7	7	6	6	6	7	6	7	9	10	10	9	6	4	3	2	1	1	1	2	3	3	4	6
	D	16	15	13	13	13	13	19	34	48	61	67	82	66	51	43	36	32	27	21	18	16	17	19	16
	E	11	11	12	11	11	14	15	20	18	21	16	2	21	36	37	30	27	20	17	15	14	12	10	12
	F	64	64	65	67	67	63	56	35	23	7	6	6	6	8	16	31	39	51	60	64	66	67	66	63
	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	1	2	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	C	5	5	5	4	5	6	6	6	6	5	3	3	2	1	1	1	1	1	1	1	2	3	3	3
	D	16	14	12	11	10	11	18	29	41	58	71	72	64	50	42	34	24	22	18	14	12	14	16	18
	E	9	10	10	10	11	12	13	18	22	17	18	18	26	39	34	30	21	19	13	14	15	12	11	10
	F	69	69	70	72	72	69	61	45	30	19	7	6	7	9	22	34	47	57	67	70	70	70	69	68
	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	C	6	5	5	4	4	5	5	5	4	2	2	1	1	1	1	1	1	1	1	1	2	3	3	3
	D	12	12	11	9	8	9	15	26	39	48	59	66	62	48	38	31	23	17	12	8	11	11	15	15
	E	9	9	8	10	12	12	13	18	21	24	22	25	29	40	34	30	22	15	14	15	11	12	9	10
	F	72	72	74	75	74	72	65	50	35	25	16	7	7	10	26	37	53	66	72	75	75	73	72	71
	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	C	3	3	3	3	3	4	3	3	2	1	1	1	1	1	1	1	1	1	1	1	1	2	3	3
	D	13	13	9	7	7	10	15	26	36	41	48	50	50	44	33	26	17	11	7	13	9	12	13	13
	E	9	8	9	11	12	12	14	19	22	25	30	40	40	43	36	28	19	16	15	8	13	10	9	9
	F	74	75	77	78	77	73	67	51	39	32	20	8	8	11	29	44	62	71	76	77	76	75	74	74

Fig. 23 Computer produced 2-hour conditional probabilities using dew-point spread and wind stratified "universal" relationships for Randolph AFB, initial spread 0, for initial ceilings less than 200 feet. (Note: the letters "A,B,C,D,E,F" refer to cloud categories used by AWS. The definitions, in order, are "ceilings 0 to <200 feet, 200 to <500 feet, 500 to <1000 feet, 1000 to <3000 feet, 3000 to <10000 feet, and ceilings at or above 10000 feet or no ceiling.")

A major obstacle common to that found in Section III remains with us, however. How is one to determine the dew-point spread two hours hence? This is a fundamental requirement of the technique. Two possible solutions came to mind. One was to provide the forecaster a climatology of dew-point spread changes. This climatology was obtained by searching the historical records and noting how similar initial moisture conditions subsequently evolved in the next two hours. This approach was quickly shown to be limited (both in our evaluations and those of the field stations) simply because of data restrictions. The reason for this is rather obvious. The purpose of modelling, in the first place, was to conserve the data base. We were able to do this by isolating certain relationships which permitted the consideration of a multi-station data base. Dew-point spread changes do not lend themselves to such considerations since the local influences which determine their changes cannot be separated out from the rest of the sample by simply relying on generalized statistical relationships. Hence, we are caught in the dilemma of being able to employ sophisticated methods to build a reliable model which we are then forced to run with unreliable data. Another possibility is to have the forecaster provide the required dew-point information by employing other techniques and materials available to him. These are primarily the extrapolation of immediately past trends and the use of advective principles and deductive informations from the latest available 12-hour prognostic products. Ideally, this procedure automatically combines the best of climatology with the best forecast information available to produce a happy marriage of the two. Hence, we set forth to test our procedures in the operational routines. It was our hope that the forecaster could weigh the scanty climatic evidence provided by us for the dew-point spread changes along with the other informations available to him to provide the required dew-point forecast for $t_o + 2$. Four Air Weather Service stations were selected: Norton AFB, California, Offutt AFB, Nebraska, Andrews AFB, Maryland and Warner Robbins AFB, Georgia. Each station was provided statistics such as those shown in Figure 24a and b to test its operational routine. A digest of their reaction to the technique is: A knowledge of the moisture fields and the persistency of an existing ceiling appears to be useful (in post-mortem) but, unless better guidance can be provided for supplying the dew-point spread two hours hence, it has limited operational value.

It is perhaps also fair to state that the forecasters tended to view the materials being presented more as

INITIAL DEW POINT SPREAD 0   INITIAL CLOUD A   STATION ANDREWS   WIND CALM   WINTER

2 HOUR CONDITIONAL PROBABILITY

FINAL	FINAL	LOCAL STANDARD TIME																							
SPREAD	CLOUD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	A	76	77	76	75	73	71	69	65	62	63	60	59	60	64	70	73	74	76	76	76	77	75	74	75
	B	14	17	13	14	15	18	21	24	29	29	32	33	32	28	23	20	18	16	16	15	14	16	17	16
	C	4	4	5	5	5	5	4	4	5	4	4	4	4	4	3	3	4	4	3	4	3	3	3	3
	D	1	1	1	1	1	1	1	1	1	3	3	3	3	3	2	1	1	1	1	1	2	1	1	1
	E	2	2	2	1	1	1	2	2	2	1	1	1	1	1	1	2	2	1	2	1	1	2	2	2
	F	3	3	3	4	4	4	3	2	1	0	0	0	0	0	1	1	1	2	2	3	3	3	3	3
1	A	49	49	49	49	50	49	45	43	40	41	44	44	46	50	57	56	54	56	54	52	51	49	48	48
	B	30	24	24	29	24	31	37	44	48	48	45	46	44	39	32	30	31	30	30	31	30	30	29	30
	C	2	3	4	4	3	4	3	1	3	3	2	2	2	3	3	3	1	2	2	1	3	3	4	4
	D	10	10	9	9	9	8	8	7	5	5	5	5	5	5	5	5	6	5	7	8	7	9	10	9
	E	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1	1	2	3	2	3	3	3	3	3
	F	6	6	6	6	6	5	4	3	2	1	1	1	1	1	2	3	4	4	5	5	6	6	6	6
2	A	32	33	33	33	33	34	34	33	33	35	33	31	32	33	36	34	29	26	23	22	22	23	25	29
	B	22	24	25	24	24	31	33	39	44	46	47	49	50	49	46	46	44	41	38	34	32	29	24	22
	C	15	13	12	13	13	8	9	11	8	6	8	8	8	7	5	5	2	5	9	14	17	18	20	19
	D	1	1	1	1	1	1	1	10	8	9	8	8	6	7	7	7	16	17	1	1	1	1	1	1
	E	22	21	21	21	19	19	17	3	4	2	2	2	2	2	3	3	2	3	21	21	19	21	22	21
	F	8	8	8	8	8	7	6	4	3	2	2	2	2	2	3	5	7	8	8	8	9	8	8	8
3	A	18	22	26	27	28	29	29	24	25	23	19	19	22	23	21	15	10	9	8	8	10	13	15	16
	B	18	15	13	13	14	19	25	33	43	48	51	53	52	50	48	50	41	35	29	27	22	18	16	17
	C	16	14	13	11	12	14	14	14	14	14	16	14	12	12	13	7	10	10	13	12	15	16	20	17
	D	1	1	1	1	1	1	1	1	11	8	8	8	7	7	1	1	1	25	1	2	2	2	1	1
	E	29	29	28	30	29	26	22	17	3	4	4	3	4	4	11	20	23	11	34	33	31	31	28	32
	F	18	19	19	18	16	11	9	6	4	3	2	3	3	4	6	7	9	10	15	18	20	18	20	17
4	A	8	10	11	13	14	15	15	15	10	7	6	9	10	11	9	7	6	5	4	4	4	5	7	8
	B	18	11	11	10	10	12	18	31	46	52	40	45	43	37	35	32	25	19	19	16	14	12	10	10
	C	12	9	7	9	8	10	16	26	16	18	24	26	28	24	25	23	17	13	10	11	12	12	11	11
	D	9	9	9	7	5	4	1	1	1	14	12	11	1	3	2	1	1	8	9	8	8	9	11	11
	E	27	26	27	27	31	32	35	25	21	5	5	5	13	19	22	28	43	30	33	33	32	31	28	26
	F	34	35	35	35	32	27	15	8	6	4	4	4	5	6	7	9	11	25	25	28	30	31	33	34
5	A	2	3	3	3	3	3	3	3	2	2	2	2	3	4	4	4	3	2	2	2	2	2	2	2
	B	7	7	7	7	8	9	11	19	33	37	35	30	22	22	25	22	18	15	10	7	5	4	4	5
	C	4	4	4	4	3	6	12	20	23	28	34	39	42	35	28	20	4	7	6	6	5	6	5	6
	D	13	11	11	10	11	11	9	5	2	2	1	1	3	7	5	5	13	12	14	13	15	15	13	12
	E	31	31	36	37	38	36	42	41	32	26	22	22	24	25	29	40	37	32	34	35	35	34	35	34
	F	43	44	39	39	37	35	23	12	8	5	6	6	6	7	9	9	21	32	34	37	38	39	41	41

INITIAL DEW POINT SPREAD 0   INITIAL CLOUD A   STATION ANDREWS   WIND NON-CALM   WINTER

2 HOUR CONDITIONAL PROBABILITY

FINAL	FINAL	LOCAL STANDARD TIME																							
SPREAD	CLOUD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	A	63	64	66	62	61	59	53	47	48	52	55	56	60	63	57	56	65	71	75	75	76	72	68	65
	B	28	26	27	29	30	32	38	45	46	41	38	37	33	30	36	37	29	22	18	17	17	18	23	25
	C	3	4	3	3	3	4	4	4	4	3	3	4	4	4	4	4	3	4	3	3	4	4	3	4
	D	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2
	E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
	F	3	3	3	3	3	2	2	1	1	0	0	0	0	0	0	0	1	1	1	2	2	3	3	3
1	A	37	38	39	38	38	38	36	32	28	29	33	42	43	43	40	38	47	55	58	53	48	45	38	38
	B	48	46	46	47	47	48	50	55	60	50	57	48	47	47	49	50	42	33	29	32	35	36	43	44
	C	4	3	3	3	3	4	5	5	5	6	6	6	6	5	5	5	3	4	4	5	5	4	4	4
	D	6	6	6	6	6	5	5	5	4	3	3	3	2	3	3	4	5	5	5	6	7	7	8	7
	E	3	3	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	2	3	2
	F	4	4	4	5	5	4	3	2	1	1	0	0	1	1	1	2	2	2	3	3	4	4	4	5
2	A	27	28	29	26	24	22	21	20	21	24	23	21	19	17	13	11	14	20	22	22	24	26	25	25
	B	41	44	44	48	50	54	58	62	63	61	62	64	64	67	71	72	68	61	52	42	36	36	41	44
	C	14	11	10	9	10	10	8	7	7	7	9	8	10	8	7	5	7	7	12	20	22	19	15	12
	D	1	1	1	1	1	1	7	7	6	5	5	4	4	5	5	7	5	6	7	8	10	11	1	1
	E	11	10	9	9	8	7	2	2	1	2	1	2	2	1	2	2	3	2	3	4	3	2	12	12
	F	6	6	7	7	7	6	4	2	2	1	1	1	1	2	2	3	3	4	4	4	5	6	6	6
3	A	18	16	16	14	13	12	12	12	14	14	12	13	13	13	10	7	8	7	7	8	9	15	15	14
	B	31	36	41	41	44	51	55	61	62	65	67	66	62	64	64	63	64	64	51	39	29	26	29	31
	C	21	20	17	19	20	17	16	13	12	11	12	12	15	12	14	16	14	14	22	28	33	31	25	22
	D	1	1	1	1	1	1	1	1	1	1	6	6	7	7	6	8	7	8	11	15	14	1	1	1
	E	21	19	17	17	14	12	10	9	9	7	1	1	1	2	3	2	2	2	3	4	6	18	19	22
	F	8	8	8	8	8	7	6	4	2	2	2	2	2	2	3	4	5	5	6	6	7	11	11	8
4	A	6	5	5	5	5	5	5	5	5	6	7	7	8	8	6	5	5	5	4	4	4	5	6	6
	B	15	19	20	24	33	38	48	54	63	66	63	63	61	60	58	52	53	44	29	26	24	18	17	14
	C	32	30	33	31	25	28	24	23	17	15	17	18	19	18	21	25	25	31	40	35	33	32	26	28
	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3
	E	27	27	28	25	24	19	15	11	10	9	9	8	8	9	9	11	10	13	19	22	24	24	29	30
	F	19	19	13	14	12	9	7	6	4	3	3	3	3	4	5	6	6	6	7	12	14	18	19	19
5	A	3	4	4	4	4	3	3	3	3	3	4	4	5	5	3	3	3	3	3	3	3	3	3	3
	B	11	11	10	8	16	25	32	42	43	49	49	49	47	45	38	36	27	24	14	8	5	7	9	9
	C	20	17	18	19	21	28	31	30	35	32	32	32	33	33	38	40	44	44	39	28	24	22	22	21
	D	10	11	12	14	7	1	1	1	2	2	2	2	1	2	4	7	6	5	5	13	15	14	10	11
	E	28	29	29	28	28	30	24	17	11	9	9	9	10	10	11	14	12	13	30	30	32	29	31	30
	F	28	26	27	27	24	13	9	7	6	5	4	4	4	5	6	6	8	11	9	18	23	25	25	26

Fig. 24a. 2-hour conditional probabilities for initial ceilings less than 200 feet (produced as in figure 23) submitted to field testing at Andrews AFB, Maryland.

INITIAL DEW POINT SPREAD 0 ANDREWS WINTER CLOUD CEILING CATEGORY A

TIME	WIND CATEGORY								
	NNW-N	NNE-NE	ENE-E	ESE-SE	SSE-S	SSW-SW	WSW-W	WNW-NW	0-4MPH
1	32 0	40 0	6 0	10 0	28 0	38 0	10 .3	8 0	212 0
2	28 0	48 0	8 .5	8 0	18 0	20 0	4 1.0	12 0	210 0
3	24 0	42 0	14 0	8 0	18 0	10 .8	2 1.0	16 0	214 0
4	28 0	30 0	16 0	8 0	22 0	18 .7	0	8 0	236 0
5	24 .3	22 0	18 0	8 0	28 0	22 .4	4 .5	4 0	238 0
6	20 0	22 .3	24 0	8 0	28 0	18 0	8 .5	8 0	222 0
7	22 0	22 .8	26 0	10 2.0	24 0	16 0	6 1.0	6 0	208 0
8	24 0	14 0	16 0	14 0	26 0	16 .7	4 5.0	8 0	174 .0
9	22 0	6 0	4 1.0	12 0	22 .8	12 2.0	4 3.5	10 .5	130 .2
10	14 0	4 2.0	0	4 1.0	12 0	4 3.5	4 2.0	6 1.0	96 .4
11	12 0	4 1.0	0	2 0	6 0	0	4 1.0	6 1.0	64 .2
12	14 0	6 0	0	4 0	6 0	0	6 0	8 .5	40 0
13	6 0	12 0	2 1.0	2 0	10 0	0	8 0	8 1.0	36 0
14	2 2.0	16 0	6 1.0	0	8 0	0	8 2.0	6 3.0	42 0
15	6 2.0	12 0	8 0	0	6 0	0	8 .5	6 1.0	36 0
16	6 0	6 0	8 0	0	12 0	0	8 .5	8 .5	38 0
17	8 0	4 0	8 0	2 0	18 0	4 0	6 0	4 .5	60 0
18	16 0	10 0	10 0	6 0	18 0	12 0	2 0	0	84 0
19	18 0	20 0	14 0	10 .3	20 0	14 0	4 .5	4 0	108 0
20	18 0	32 0	16 0	16 0	28 0	12 0	10 .8	10 0	128 0
21	26 0	44 0	14 0	24 0	34 0	18 0	14 .3	10 0	148 0
22	34 0	42 0	16 0	28 0	36 0	24 0	18 0	10 .3	174 0
23	36 0	32 0	22 0	24 0	34 0	26 0	22 0	10 0	194 0
24	36 0	30 0	16 0	16 .2	34 0	36 0	20 0	8 0	204 0

Fig. 24b. Climatological 2-hour dew-point spread changes (lower value) and their number of occurrences submitted to field testing as a forecasting aid at Andrews AFB, Maryland.

complete solutions than as climatic aids. Although the field evaluations provided less causes for optimism than we had hoped, they were far from being negative. In fact, we were much encouraged by their dedication, frankness and perception. This experience merely highlighted the necessity for us to rework our technique to circumvent a common weakness of the science- in the short-range forecasting problem, little information except persistence and its climatology can be relied upon in making a forecast. Therefore, before one can incorporate diagnostic informations at t_o, he must circumvent the need for a forecast input of these same criteria at $t_o + 2$. This we have proceeded to do. Our means of doing it will be discussed in the section to follow.

V. A MODEL WHICH INCORPORATES DIAGNOSTIC WIND AND MOISTURE INFORMATIONS AT t_o WITHOUT REQUIRING THAT THEY BE PROVIDED PROGNOSTICALLY AT $t_o + 2$

One of the more thought provoking statements forthcoming from the field evaluation was supplied by Captain Strater of the Andrew's evaluation team. He questioned at length the wisdom of total reliance on dew-point spread changes to carry the meteorological history of ceiling changes. His comment was much deeper than that of questioning the accuracy of the temperature dew-point values as they are presently measured. He particularly emphasized a fact that we had overlooked. The round-off errors introduced in reporting temperatures and dew points in whole degrees automatically provided "errors "of the same magnitude as those found in the climatic dew-point statistics. This realization has caused us to rework the problem by deviating from the basic concept underlying all of our previous models as well as those of McCabe, McAllister and Gringorten's in a very fundamental respect. No longer can we compare the unconditional frequency of occurrence value at one hour to that of a subsequent one if we want to take full advantage of the observed diagnostic informations available at t_o. Instead we must demand that the frequency of occurrence values for the subsequent hour under consideration (in this case $t_o + 2$) be conditioned on the same observed moisture and wind considerations as those which were used for the initial hour. This implies a double conditioning process. The original "unconditional" probabilities at $t_o + 2$ now become conditioned on the existence of some meteorological parameter at t_o. On those occasions when ceilings in a given category are also being observed, these occurrence statistics are then used to determine the conditional probability that the event will subsequently recur at $t_o + 2$.

The procedure is as follows: The unconditional frequency of ceiling category occurrences for each initial hour, t_o, is computed exactly as before when moisture and wind stratification procedures were invoked. However, the two hour later frequency of occurrence statistics are based only on that fraction of its climatic records which had previously met the requirements imposed at t_o except for the existence of a particular ceiling. The "unconditional" probabilities as they are now being computed can be greater than those which were previously considered for that hour. This fact presumably has little bearing on whether or not empirical relationships, with the same universal tendencies as that found when the "purer" statistical approach, exist. Since this supposition demands proof, we are proceeding to accumulate it. Preliminary evidence to support this assumption is shown in Figure 25.

INITIAL CLOUD A STATION RANDOLPH WIND CALM WINTER

2HR CONDITIONAL PROBABILITY

INIT. SPREAD	FINAL CLOUD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		LOCAL STANDARD TIME																							
	A	83	83	83	77	74	69	59	43	30	30	36	46	51	58	67	88	92	85	76	72	73	78	82	83
	B	5	5	4	7	9	13	20	31	42	44	46	38	36	31	26	9	5	10	16	18	15	11	8	6
0	C	4	4	5	7	8	9	10	14	16	17	10	8	6	5	3	1	1	1	1	2	3	3	2	3
	D	0	0	1	2	2	2	4	6	6	4	5	6	5	4	3	1	0	2	3	4	2	1	1	1
	E	3	3	2	3	3	3	3	2	2	2	1	0	1	1	0	0	1	1	3	2	3	2	2	2
	F	5	5	5	4	4	4	4	4	4	3	2	2	1	1	1	1	1	1	1	2	4	5	5	5
	A	81	80	78	75	73	69	58	46	33	31	33	37	44	61	72	83	91	84	79	75	74	77	78	80
	B	6	7	7	10	12	14	23	33	45	48	49	47	45	30	21	10	4	9	10	13	13	10	9	8
1	C	4	4	6	5	4	6	7	9	10	12	10	9	5	4	3	2	1	.0	3	4	4	4	4	4
	D	3	1	2	3	4	4	5	6	6	4	5	5	4	3	3	3	2	5	4	4	2	2	2	1
	E	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	F	5	7	6	6	6	6	6	4	5	4	2	1	1	1	0	1	1	1	3	3	6	6	6	6
	A	70	71	71	70	63	59	56	47	41	39	40	41	43	48	60	70	74	65	60	63	67	68	69	70
	B	14	13	13	15	21	24	26	35	40	43	43	43	43	40	29	21	18	24	27	23	19	17	15	14
2	C	7	7	7	6	9	10	11	11	10	10	10	10	8	7	6	4	2	4	5	6	6	7	8	8
	D	3	3	3	3	1	1	1	2	5	5	4	3	4	3	3	3	4	5	5	4	3	3	2	2
	E	2	2	2	2	2	2	2	2	1	1	1	2	1	1	1	1	1	0	0	1	1	1	2	2
	F	4	4	4	4	4	4	4	3	3	2	2	1	1	1	1	1	1	2	3	3	4	4	4	4
	A	55	57	57	57	55	52	48	43	36	33	37	38	33	31	40	49	49	48	49	50	51	53	54	55
	B	27	25	25	25	27	30	33	37	42	45	43	44	49	52	44	36	36	36	34	33	31	29	28	27
3	C	11	11	11	11	11	11	12	12	14	15	12	10	11	10	9	8	8	9	10	10	11	11	11	11
	D	0	0	0	0	0	0	0	2	3	3	5	5	4	4	4	4	4	3	2	1	1	1	1	1
	E	3	3	3	3	3	3	3	2	2	2	1	1	2	2	2	2	2	2	2	3	2	2	2	2
	F	4	4	4	4	4	4	4	4	3	2	2	2	1	1	1	1	1	2	3	3	4	4	4	4
	A	44	47	48	49	49	47	43	32	18	20	21	22	19	18	19	30	39	39	40	40	41	43	44	46
	B	34	31	31	31	30	31	34	42	54	50	50	50	55	59	59	48	39	38	37	38	37	35	34	32
4	C	13	13	12	11	13	13	14	17	19	22	21	21	19	16	15	15	14	15	14	13	13	13	13	13
	D	1	1	1	1	0	1	1	1	2	2	4	3	3	3	3	3	4	3	1	1	1	1	1	1
	E	3	3	3	3	4	4	4	4	3	3	2	2	3	3	3	3	2	2	4	4	4	3	3	3
	F	5	5	5	5	4	4	4	4	4	3	2	2	1	1	1	1	2	3	4	4	4	5	5	5
	A	30	31	31	33	38	31	22	18	15	16	16	16	16	15	16	18	21	21	21	21	21	21	22	23
	B	47	40	41	40	37	44	50	52	51	45	37	38	50	56	57	55	51	50	50	50	50	51	49	48
5	C	17	17	17	16	14	13	16	17	21	26	35	34	23	19	17	17	18	16	12	12	12	12	14	15
	D	2	2	1	1	1	2	2	4	4	5	6	6	5	5	5	5	5	7	9	8	8	6	5	4
	E	1	1	1	1	1	1	1	4	5	4	3	3	3	3	3	3	3	5	4	4	4	1	1	1
	F	3	9	9	9	9	9	9	9	4	4	3	2	3	2	2	2	2	1	4	5	5	9	9	9

Fig. 25. 2-hour statistically reconstructed conditional probabilities based on a "conditioned" unconditional probability at $t_o + 2$ and does not need a dew-point spread forecast. The example is for Randolph AFB, Texas under calm winds.

The fundamental advantage to the technique is, of course, the elimination of a requirement to forecast the dew-point spread. However, the model previously discussed in Section IV can still offer an option to the forecaster to enter such information should he feel confident in doing so. The main differences between the models of Section IV and V are that one requires an explicit dew-point change forecast and the other treats this parameter implicitly. Since the observed information all comes from the same data base, Figure 23 and Figure 25 should be compatible providing the "effective" dew-point spread changes were, in fact, known for insertion into Figure 23. Hence, a comparison of the respective modelling results provides a means of inferring the effective climatic dew-point spread changes.

We plan to proceed in this direction in the months to come and prepare climatic presentations for reintroduction to the field by the onset of the 1973-1974 winter season. Our plans are to provide the climatic forecast as a standard and let the field forecaster trend his other relevant materials as he may or may not wish to do. There is little doubt in our minds but that the ultimate procedure lies in some such man-climatology mix. The primary contribution of the model in this section then is to establish the best that climatology alone has to offer without requiring a forecast input and present it in a form that man can provide modifications to as he deems fit without entirely abandoning the worth of climatology. In fact, the better the man can provide inputs into the model the more relevant the climatic information becomes to the specifics of the problem at hand. The need for this mix will loom increasingly important for the forecasting of rapidly deteriorating ceiling conditions since climatology alone would not appear to suffice.

We have not abandoned our obligation to devise climatic information to help man enter these forecast inputs. Our preliminary investigations, on how best to forecast the moisture parameter, show that the problem needs to be treated in two parts. The temperature component of the combination conforms quite closely to the types of climatic considerations we have discussed in this report since it is strongly affected by solar insolations. The dew-point change component, on the other hand, is somewhat less dependent upon these effects. Here past weather, its trends, and its advection from local source regions appear to play a much more predominant role than the diurnal climatological amplitude fluctuations of the dew-point curves. Attempts at forecasting the dew point independently from the temperature should automatically lead us directly into one of the main goals of the proposed carry-on research— the incorporation of synoptic considerations common to given regions into models which generate recurrence probabilities for specific point locations within that complex.

A more detailed discussion of much of the material in this report is contained in an article published in the Journal of Applied Meteorology (Martin, 1972).

VI. DESIGNING CLIMATIC INFORMATION TO SUPPORT PARADROP OPERATIONS

This research is based upon the following assumptions: 1) Paradrops are released at heights approximating 1,000 feet and fall freely through the air for some 150 feet before the chute opens, 2) The position of the aircraft is accurately known, 3) The flight level wind direction and wind speed are known for the release point, and 4) The surface conditions are available either through remote sensing devices or from radio contacts with a ground base observer. The meteorological problem is to determine the integrated wind for that portion of the trajectory when the chute is open. A guiding criteria is for the wind information to be sufficiently accurate that it leads to some high percentage, say 95%, of the troops landing within a prescribed circular drop zone.

The vertical structure of the atmospheric layer of interest covers all of the so-called constant flux layer (some 50' above the ground) and portions of the Ekman layer (a theoretical layer which extends from the top of the constant flux layer to the lower extremities of free atmosphere).

Theoretical treatments of the lower layer often carry the assumptions that the earth's topography is relatively level and quasi-homogeneous and that the mean pressure gradient is invariant with height. These conditions signify plane-parallel motions and a constant-wind direction within the surface layer. The additional assumption of quasi-steady state conditions restricts the surface layer to one of constant mean vertical momentum and heat fluxes. According to the Monin-Obukhov similarity theory (1954), the wind speed, u, and temperature, T, profiles in this layer can be expressed by the dimensionless universal functions f_u and f_T:

$$\bar{u}(z_2) - \bar{u}(z_1) = \frac{u_*}{k}\left[f_u\left(\frac{z_2}{L}\right) - f_u\left(\frac{z_1}{L}\right)\right]$$

$$\bar{T}(z_2) - \bar{T}(z_1) = T_*\left[f_T\left(\frac{z_2}{L}\right) - f_T\left(\frac{z_1}{L}\right)\right]$$

where z_1, z_2 are arbitrary levels, k is the von Karman's constant, u_* is the frictional velocity, T_* and L are the characteristic temperature and length scales defined as

$$T_* = -\frac{q}{ku_*C_p\rho_o} \quad , \quad L = -\frac{u^3_*}{k\left(\frac{g}{T_o}\right)\left(\frac{q}{C_p\rho_o}\right)}$$

Here q is the vertical turbulent heat flux. ρ_o and T_o are "standard values" of air density and temperature in the surface layer. C_p is the specific heat for dry air at constant pressure and g is the gravitational acceleration.

Relatively few investigations have been made on the wind characteristics for the Ekman layer. The best known model is due to Taylor (1916) which is based on the assumption of steady motion, no advection, neutral stability, no thermal wind, and constant eddy-viscosity coefficients.

A widely accepted empirical relationship which relates the wind speeds at different heights is the so-called power law,

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2}\right)^p .$$

This law states that the wind speeds at different levels can be fitted by a straight line with a slope of 1/p on a log-log diagram. Unfortunately the exponent, p, varies with stability conditions and geography (Davenport, 1960), and the theoretical wind spirals below 3,000 feet often display little or no resemblance to the observed evidences (Blackadar, 1960).

Our approach to the problem of estimating the integrated wind for the paradrop problem at hand was to determine statistical relationships between the integrated wind and various combinations of flight level and surface wind informations. These statistics were then used to provide estimates of the integrated wind through the layer intervening between the two levels.

Two data sets were obtained from instrumented towers. One of these was Cedar Hill, Texas, and the other was in Oklahoma City, Oklahoma. The Cedar Hill Tower is located approximately 20 miles SSW of Dallas, Texas, at an elevation of 850 feet above sea level. The terrain elevation decreases by about 300 feet over a distance of 3 to 5 miles to the west and north of the site. The topography is essentially flat to the south and east (see Gerhardt et al, 1962).

The instrumentation consists of Bendix-Friez Aerovanes (± 3° in direction) and copper-constantan thermocouples ($|\text{error}| < 1^{\circ}F$) located at 12 levels: 30, 70, 150, 300, 450, 600, 750, 900, 1,050, 1,200, 1,300 and 1,420 feet. These sensors are mounted on booms extending 12 feet from the tower structure. A continuous record of digital recorded 10 minute-averaged wind and temperature observations on magnetic tape for December, 1960 to December, 1962 was used in this study.

The Oklahoma City data were taken on the instrumented WKY-TV tower. The terrain about this site is gently rolling with an average height of 1,148 feet above sea level. A Bendix Aerovan wind sensor and thermistor (± 1°C) were used to take the observations. The instruments are mounted at six levels: 146, 296, 581, 874, 1,166 and 1,458 feet. A surface station 250 feet away provided concomitant wind data averaged over a period of five minutes every hour on the hour at the 23-foot level. The wind data from this tower which was used in our study extends from May, 1966 to May, 1967. The temperature registrations were somewhat of lesser duration extending from December, 1966 to May, 1967. For further details with respect to the data and its accuracy see Carter, 1970.

The procedure which we used for calculating the integrated winds from observed data is as follows. The u and v components of the integrated wind were obtained as a weighted average of the u and v components of the observed winds at each of the reporting levels. For example, the observed wind at 600 feet was assumed to be representative of the 525 to 675 foot layer. The weighting factor for this wind is 150 feet. Since the thickness of the given layer is a function of the spacing between the instrumented levels, the weighting factors vary throughout the vertical.

The winds at the 6-foot level were found by extrapolating downward from the adjacent highest level using the power law

$$\frac{u_6}{u} = \left(\frac{z_6}{z}\right)^p .$$

Singer et al (1970) estimated the exponent p to have a value of 0.2. We used his value since the relatively small height increments through which these extrapolations were made did not appear to warrant the introduction of diurnally or seasonally varying exponents.

Some diurnal and seasonal characteristics of the integrated wind speeds at each of the contributing levels in the Cedar Hill data are found in figures 26 through 29.

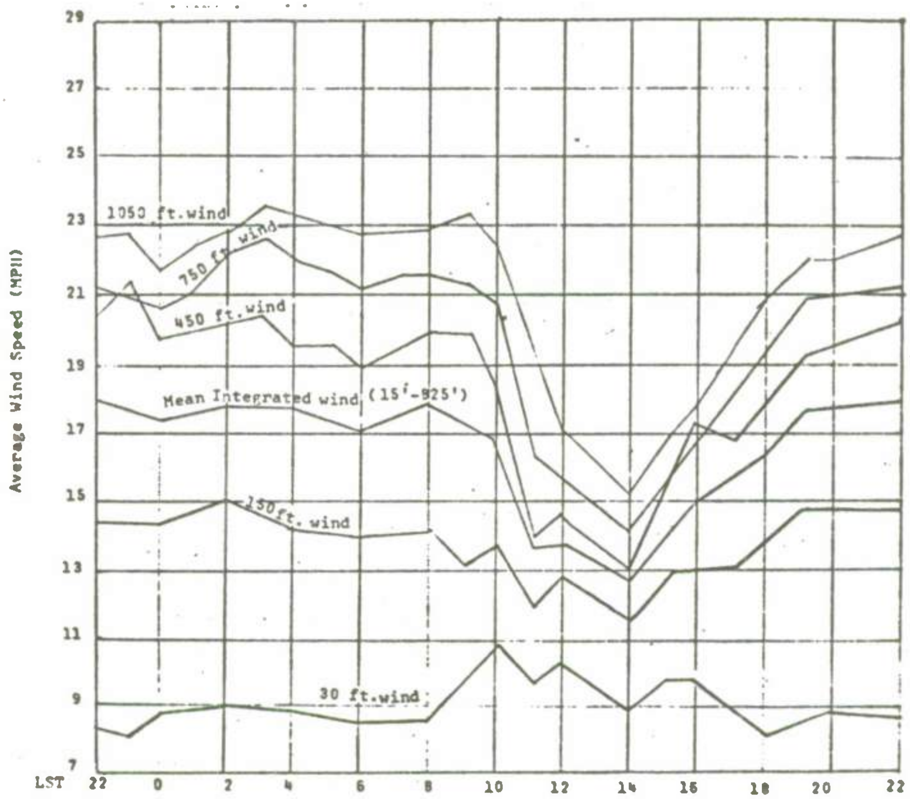


Fig. 26. Mean wind speed distributions at various levels for Cedar Hill during January.

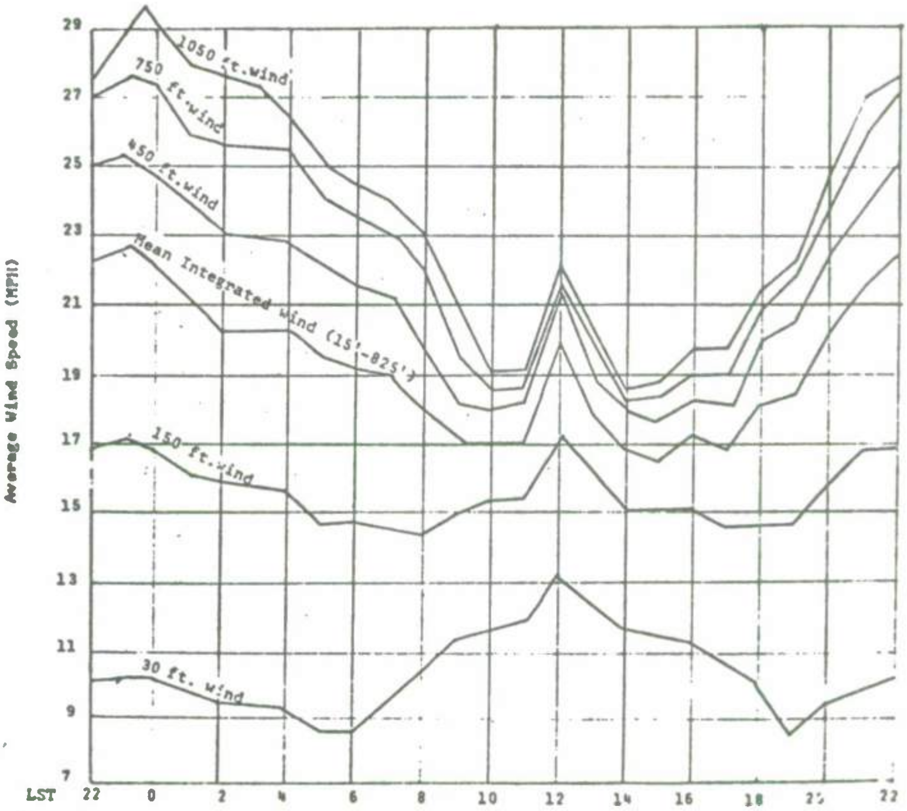


Fig. 27. Mean wind speed distributions at various levels for Cedar Hill during April.

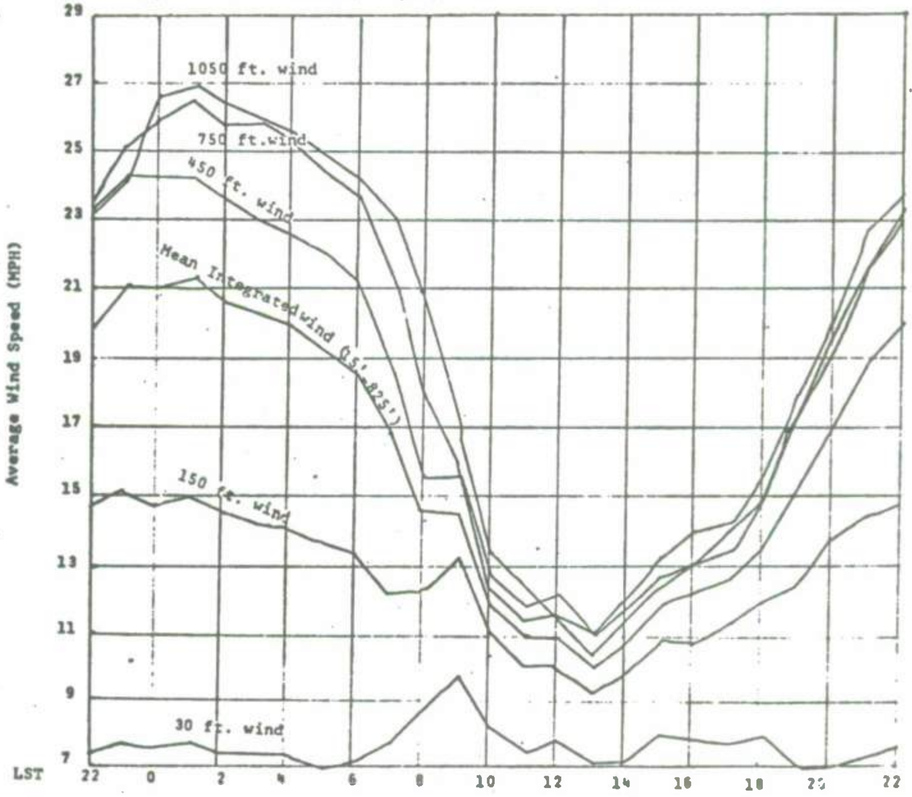


Fig. 28. Mean wind speed distributions at various levels for Cedar Hill during July.

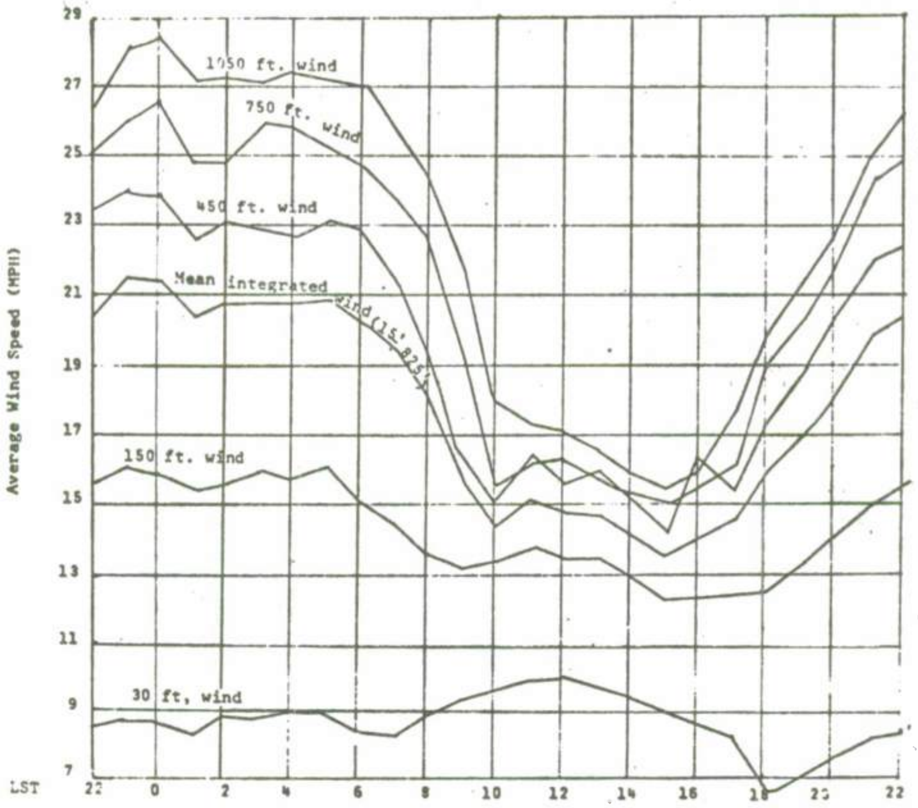


Fig. 29. Mean wind speed distributions at various levels for Cedar Hill during October.

The averaged winds for each level were computed from the data of that 10-minute time interval which ended 1 minute before the hour. The data in these figures show the integrated wind to correlate closely to a mid-layer wind and that this wind is not an algebraic average between the flight level and surface winds. Note that the respective wind profiles at levels above 450 feet show more homogeneity among each other than do the winds at levels below these heights and that the integrated wind profile exhibits its best phase and amplitude relationship with the higher grouping. The inference is rather apparent. The most single pertinent piece of meteorological information which could be entered into the parachute-trajectory equations would be a wind observation midway between the paradrop release point and the ground. Thus, it is recommended that such a pass be taken whenever it is feasible to do so. When and if such procedures are prohibitive, the most valuable information is the flight-level wind at the release point.

The techniques that we shall discuss apply only when the first alternative (mid-level observation) is not feasible. Should such mid-level observations be available, we recommend that the empirical methods which we have devised for estimating the integrated wind be supplanted by them.

Many of our attempts either proved fruitless or became too involved for eventual operational application. They will not be included since our objective is to seek positive results without becoming overly involved in tidying up our failures for historical purposes. Hence, when any particular line of attack showed overwhelming evidence of not being able to meet certain criteria it was immediately discontinued irrespective of the efforts we had spent upon it. These criteria are: Will a continuance of the approach produce a better climatic product than those already at hand, and will the end results be sufficiently straightforward and readily attainable that they can be applied within the constraints imposed by real-time operations?

The simplest approach we have found which meets these aforementioned criteria relies solely on the latest observed wind at flight level. It is presented in Figures 30 through 37 for the months of January and July. These were obtained by partitioning the Cedar Hill winds for each month at the assumed flight level of 1,050 feet into increments of 5 mph speed and 45° direction.

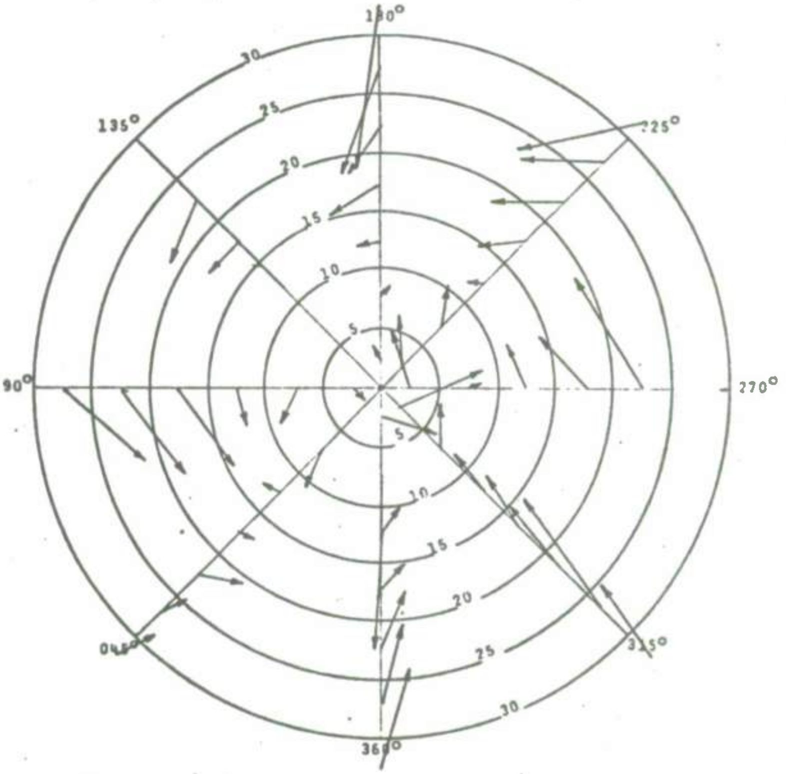


Fig. 30. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 2100-0259 during January.

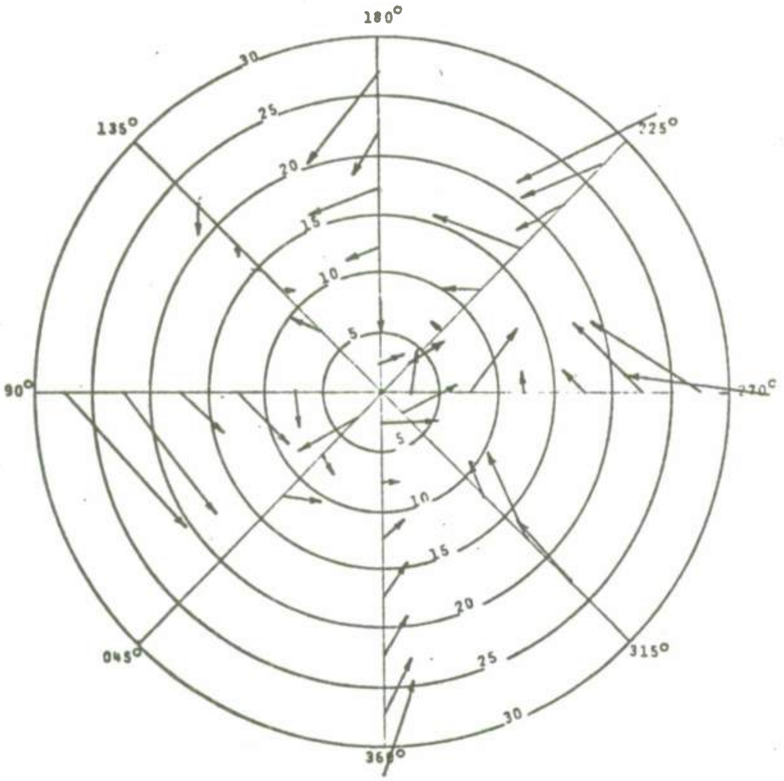


Fig. 31. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 0300-0859 during January.

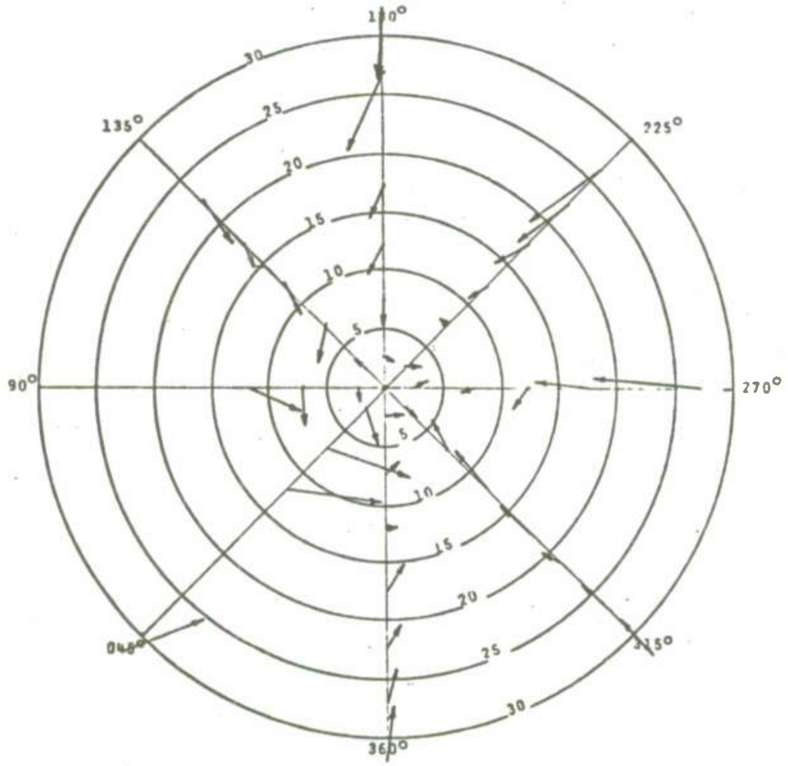


Fig. 32. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 0900-1459 during January.

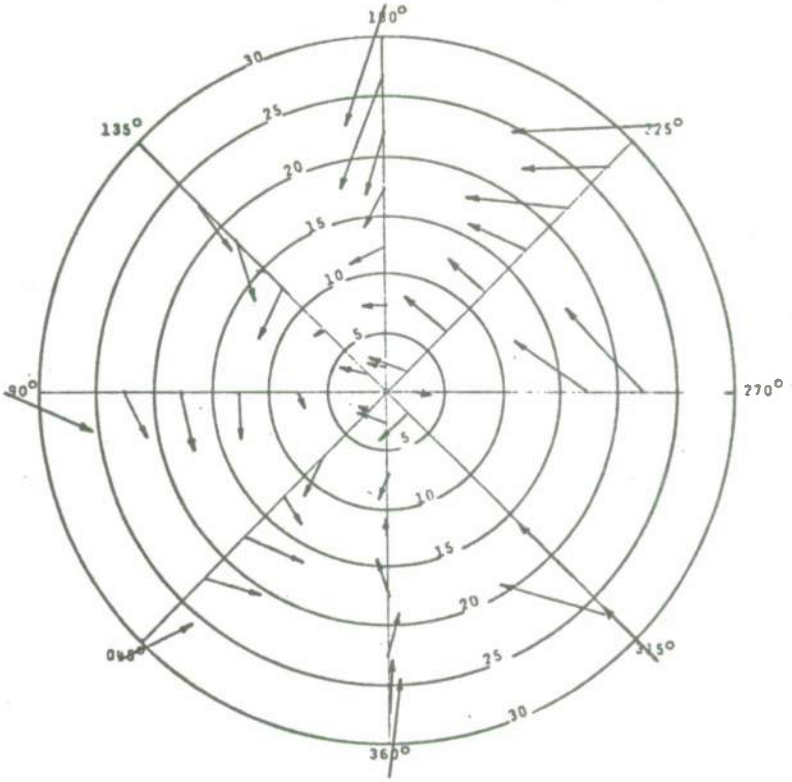


Fig. 33. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 1500-2059 during January.

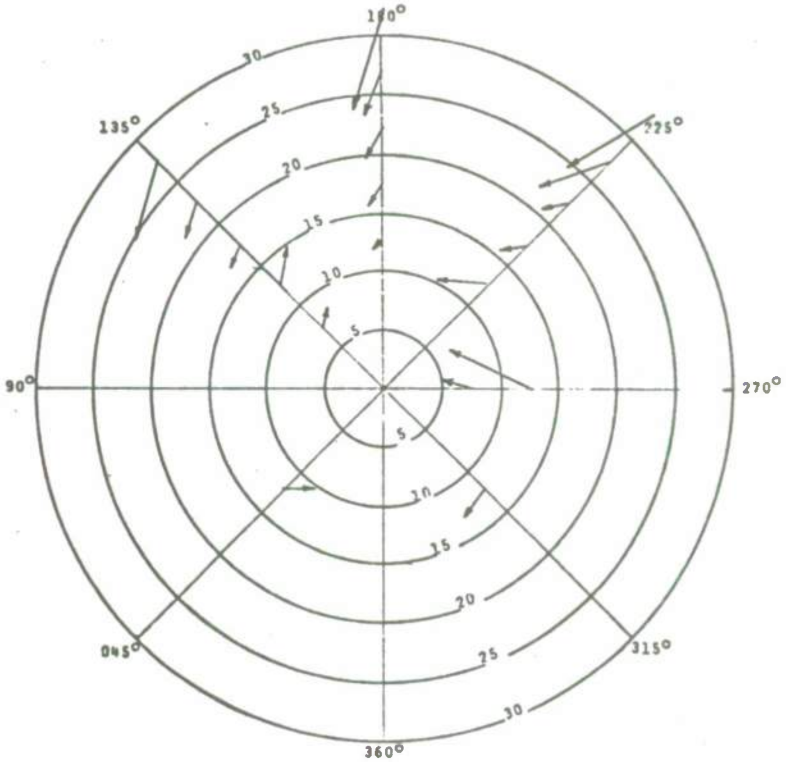


Fig. 34. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 2100-0259 during July.

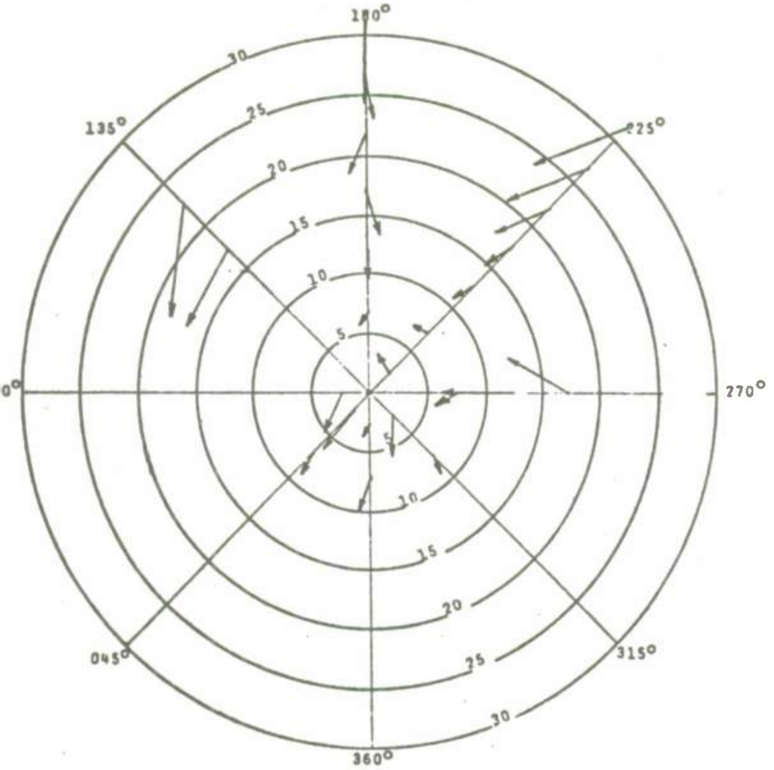


Fig. 35. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 0300-0859 during July.

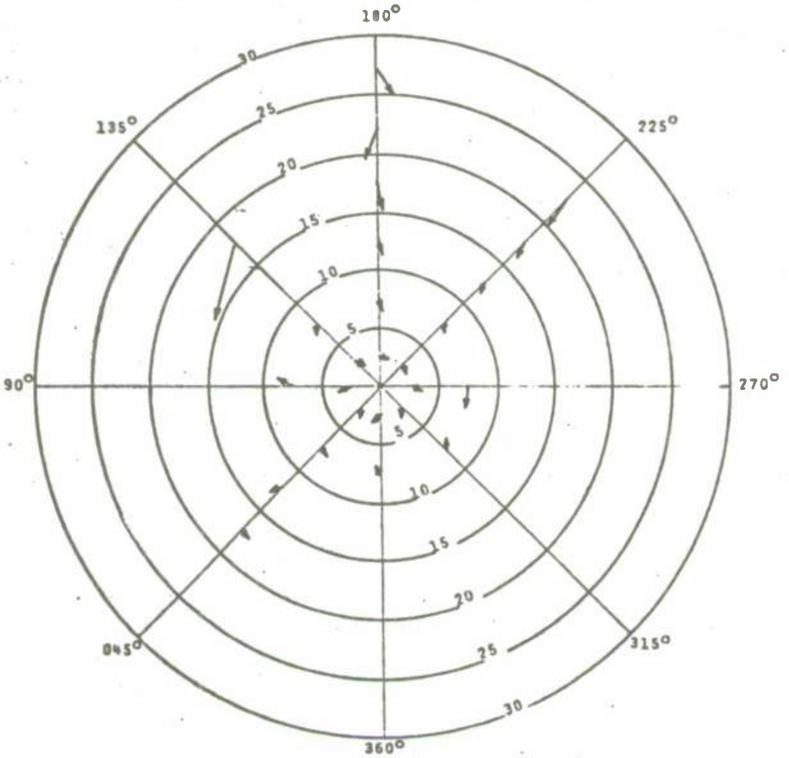


Fig. 36. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 0900-1459 during July.

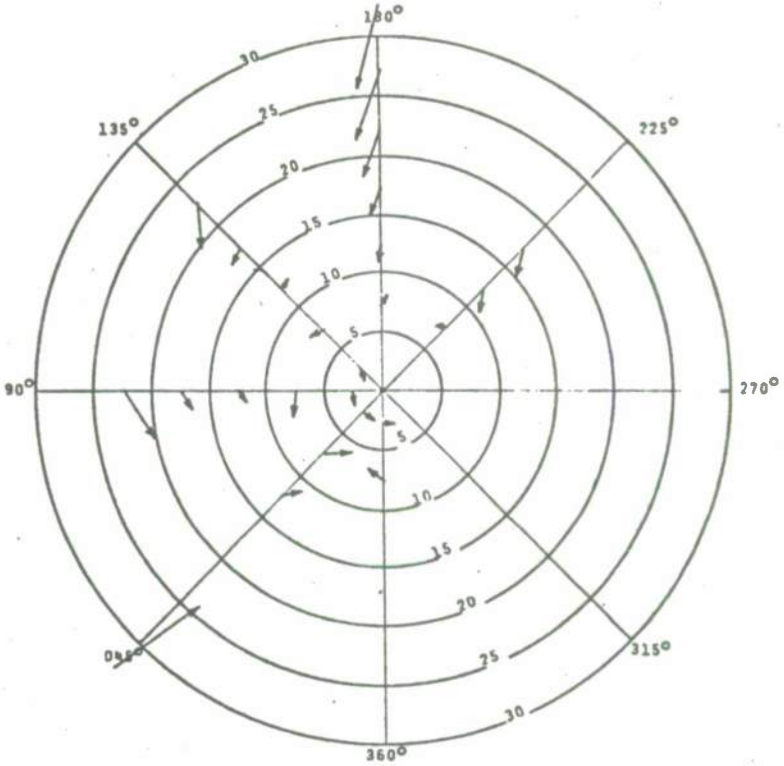


Fig. 37. Deviation vectors for calculating the integrated wind at Cedar Hill, Texas for 1500-2059 during July.

The observations at each respective lower level were individually processed to obtain the integrated wind which pertained to each respective flight level wind observation. These integrated winds were then vector-averaged to obtain a mean for the particular subset that it represents. These presentations permit a graphical estimation of the integrated wind from a knowledge of the flight level wind. For example, assume that the observed flight level wind at 0630 local solar time in January was 225° at 22.5 mph. The integrated wind is found by drawing a vector from the center of the display to the head of the arrow eminating from the 225° and 22.5 mph location. A value of some 220° and 18 mph is readily attained. Identical procedures applied to other wind direction for the 22.5 mph wind speed value produces integrated winds of relatively the same magnitude (18 mph). However, the directional relationships between the upper level and integrated winds are found to be somewhat more dependent on the initial wind direction. Referring to Figure 26, a value slightly greater than 17 mph is given. Thus, the displays in Figs. 30 through 37 add another important dimension (initial wind direction) to that given by Figures 26 through 29.

The reliability of the "deviation vectors" on these graphs is obviously a function of the sample size.

In our research we discarded all data points having less than 5 cases for constituting the average. For example, the wind at Cedar Hill has a predominantly southerly component during July. The rarely occurring northerly components account for the general blank area about the 360° sector.

We recommend this simple climatic presentation for operational implementation whenever the winds at flight level constitute the only meteorological input into the parachute-trajectory computation.

The best approaches which we found to apply when the 6-foot wind direction and speed were also known of the integrated wind will be presented at this time. The first one to be discussed involves regression equations of the form

$$v_I = a_o + a_1 v_6 + a_2 v_{1050}$$

where v_6 and v_{1050} are the wind speeds at 6 feet and flight level respectively, the v_I is the integrated wind for that portion of the intervening layer where the chute is assumed to be open (825-15'). The respective equations for Cedar Hill are shown in Figure 38. Here for convenience, the standard errors of estimate are labeled as root mean square errors (RMSE). They are found to be the smallest during the time period 09-15 for all seasons since this interval is conducive to a maximum of vertical coupling and momentum exchange between the two levels.

An alternate means for estimating the integrated wind from a knowledge of those at flight level and the ground is shown in Figures 39 through 42. The main advantages of this technique over the regression equation approach are the relaxation of some of the linearity constraints and a presentation of the relationships as a field variable more conducive to pictorial assessments. To illustrate this point select isolines from each of these four figures were transposed onto one graph (see Figure 43). Here it is seen that the specific combinations of flight level and surface winds which produce estimated integrated winds on the order of 5 mph are relatively invariant throughout the day for this location and month. A similar statement would pertain to higher values equal to or greater than 25 mph. The fact that the intermediate values (as represented by the 15 mph isolines) show the most variance immediately serves to alert the user to those cases when a climatic approach to the problem is the least likely to give acceptable results.

	Local Standard Time			
	03-09	09-15	15-21	21-03
January				
a_o	2.069	-0.886	1.047	2.903
a_1	0.682	1.061	0.735	0.644
a_2	0.512	0.422	0.556	0.500
$\bar{v}_6$	4.603	5.845	4.663	4.639
$\bar{v}_{1050}$	17.807	15.110	14.799	18.144
$\bar{v}_I$	14.324	11.696	12.709	14.963
RMSE (v_I)	2.280	1.508	1.804	2.494
April				
a_o	1.854	-0.274	1.497	1.256
a_1	1.275	0.968	0.546	1.303
a_2	0.388	0.486	0.601	0.445
$\bar{v}_6$	5.295	8.627	7.192	5.283
$\bar{v}_{1050}$	19.126	19.499	20.086	19.575
$\bar{v}_I$	16.037	17.562	17.511	16.859
RMSE (v_I)	3.445	1.158	1.757	3.038
July				
a_o	0.607	-0.137	1.050	3.263
a_1	0.669	0.666	0.518	1.807
a_2	0.576	0.642	0.634	0.310
$\bar{v}_6$	5.332	6.200	5.810	5.016
$\bar{v}_{1050}$	22.360	13.600	17.970	24.518
$\bar{v}_I$	17.398	12.724	15.448	19.932
RMSE(v_I)	2.752	0.842	1.287	2.033
October				
a_o	4.356	-0.673	0.980	1.751
a_1	0.399	1.161	0.510	0.982
a_2	0.507	0.420	0.633	0.533
$\bar{v}_6$	5.470	7.325	5.676	5.081
$\bar{v}_{1050}$	23.278	17.907	19.300	22.440
v_I	18.360	15.362	16.101	18.707
RMSE (v_I)	2.919	1.228	1.641	2.785

Fig. 38. Dependent test of regression equation
$v_I = a_o + a_1 v_6 + a_2 v_{1050}$

Fig. 39. Integrated Wind Speed (15-825 Ft.) in MPH
Cedar Hill (October 2100-0259)

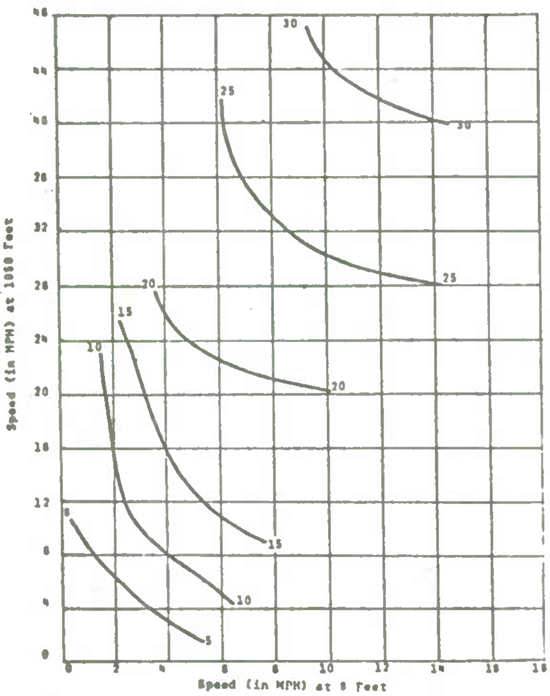


Fig. 40. Integrated Wind Speed (15-825 Ft.) in MPH
Cedar Hill (October 0300 - 0859)

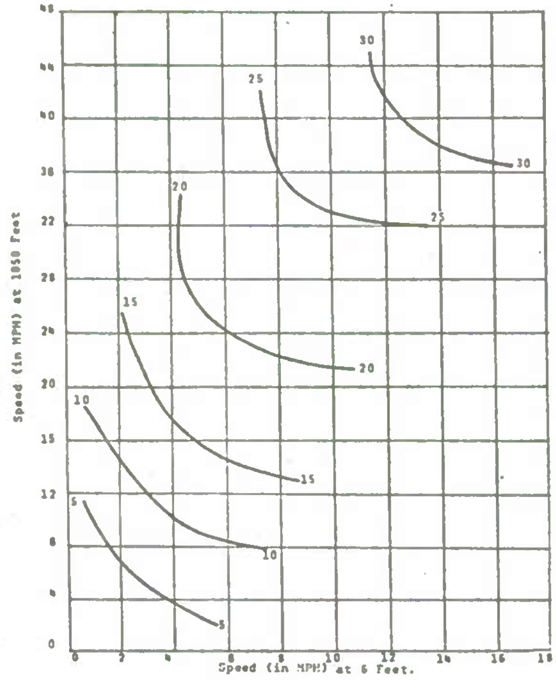


Fig. 41. Integrated Wind Speed (13-822 Ft.) in MPH
Cedar Hill (October 0800-1428)

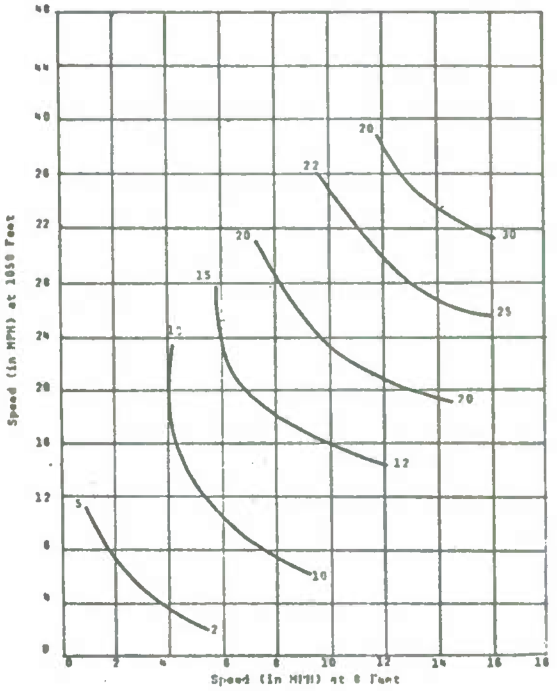


Fig. 42. Integrated Wind Speed (12-822 Ft.) in MPH
Cedar Hill (October 1200 - 2050)

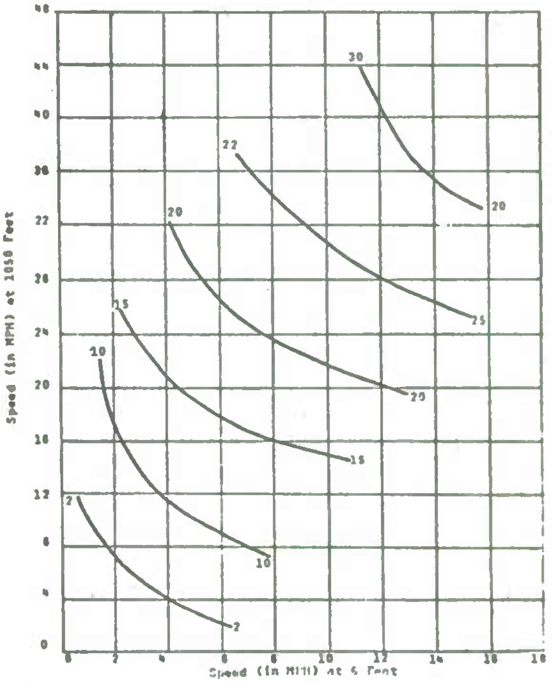
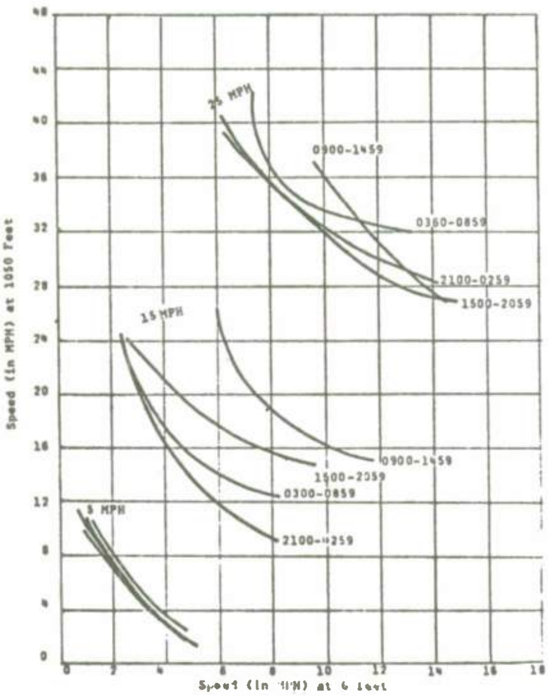


Fig. 43. Integrated Wind Speed (15-825 Ft.) in MPH Cedar Hill (October) for Various 6-Hourly Time Periods



In the final analysis, the value of each of the aforementioned climatic aids is dependent upon the "universality" of the relationships which they contain since it is highly unlikely that separate dependent data displays will ever become available for every conceivable release point throughout the world. Thus, it is necessary that these aids be tested on independent data to determine the nature and extent of the given relationships. We applied the regression coefficients which were derived from the Cedar Hill Tower data to the flight level and surface wind data of Oklahoma City to produce an estimated integrated wind, $\hat{v}_I$. The results are shown in Figure 44. RMSE, the standard error of estimate, pertains when the data for Oklahoma was independent to the regression coefficients. The term RMSE* pertains when the data from Oklahoma City were used to derive another set of coefficients (not shown) to obtain a dependent estimate of the integrated wind v_I. The term RMSE/v_I

	Local Standard Time			
	03-06	09-15	15-21	21-03
January				
a_o	2.066	-0.556	1.047	2.903
a_1	0.582	1.061	0.735	0.644
a_2	0.512	0.442	0.655	0.600
$\bar{v}_s$	4.371	5.714	6.272	4.061
$\bar{v}_{1050}$	15.393	14.955	16.777	17.476
$\bar{v}_I$	16.050	11.659	14.170	14.553
$\hat{\bar{v}}_I$	14.465	12.555	14.991	14.255
RMSE	3.065	2.095	2 172	2.243
RMSE/$\bar{v}_I$	0.161	0.180	0.150	0.153
RMSE*	2.615	1.515	1.574	2.136
April				
a_o	1.654	-0.274	1.497	1.256
a_1	1.275	0.655	0.545	1.303
a_2	0.356	0.456	0.601	0.445
$\bar{v}_s$	5.544	10.128	5.075	6.033
$\bar{v}_{1050}$	24.434	19.928	19.360	22.490
$\bar{v}_I$	15.522	15.035	15.979	17.335
$\hat{\bar{v}}_I$	20.074	19.225	17.555	17.632
RMSE	4.105	1.935	1.550	3.246
RMSE/$\bar{v}_I$	0.220	0.107	0.097	0.187
RMSE*	2.410	1.316	1.626	1.551
July				
a_o	0.607	-0.137	1.059	3.263
a_1	0.559	0.665	0.515	1.507
a_2	0.676	0.642	0.534	0.310
$\bar{v}_s$	2.409	3.272	3.255	2.195
$\bar{v}_{1050}$	11.643	5.159	7.526	12.425
$\bar{v}_I$	6.313	5.633	6.927	6.123
$\hat{\bar{v}}_I$	6.924	6.995	7.714	11.054
RMSE	1.291	0.635	0.951	2.362
RMSE/$\bar{v}_I$	0.155	0.113	0.139	0.259
RMSE*	1.053	0.455	0.555	0.672
October				
a_o	4.356	-0.573	0.950	1.761
a_1	0.399	1.151	0.510	0.982
a_2	0.507	0.420	0.633	0.533
$\bar{v}_s$	3.647	4.553	4.026	3.387
$\bar{v}_{1050}$	14.271	9.495	11.051	14.311
$\bar{v}_I$	10.555	8.184	9.125	10.945
$\hat{\bar{v}}_I$	13.059	6.955	10.042	12.706
RMSE	2.540	1.306	1.266	2.506
RMSE/$\bar{v}_I$	0.234	0.156	0.136	0.229
RMSE*	1.191	0.742	0.551	1.155

Fig. 44. Independent and dependent tests of the regression equation $v_I = a_o + a_1 v_s + a_2 v_{1050}$

tends to normalize the independent data error according to the magnitude of the integrated wind. It is logical that the RMSE for independent data would exceed the RMSE* of the dependent set. Nevertheless, in many cases, particularly for the 09-15 and 15-21 time periods for each season, the comparative magnitudes of the two terms are similar.

Presently the integrated winds are calculated operationally by averaging the surface and flight level wind (see AWS special study, 1971). Figure 45 compares the standard errors of estimates for the aforementioned independent data verification for the Cedar Hill regression coefficients on the Oklahoma City data versus that which would have been attained had the simple averaging scheme been employed in its stead. These statistics indicate that the regression technique is relatively more reliable during the hours of 09-2100 for all seasons. Hence, if paradrop operations are confined to these hours, the technique we have devised offers possible improvements over the operational procedures currently in existence during those times when active mixing processes are in being. The fact that

	Local Standard Time			
	03-09	09-15	15-21	21-03
January				
a.	4.145	2.886	3.624	3.783
b.	3.068	2.095	2.122	2.243
April				
a.	2.987	3.586	3.409	3.189
b.	4.105	1.935	1.650	3.248
July				
a.	1.133	1.089	1.380	1.339
b.	1.291	0.638	0.961	2.362
October				
a.	1.983	1.596	1.900	2.076
b.	2.540	1.306	1.266	2.509

Note: "a." represents RMSE due to V_I estimation using $V_I = 1/2\ (V_6 + V_{1050})$

"b." represents RMSE due to V_I estimation when the regression coefficients developed for the Cedar Hill Tower data were used to make integrated wind estimates on the data base for Oklahoma City.

Fig. 45. Comparison of standard errors of estimates in obtaining V_I, Oklahoma City Tower.

the "nighttime" hours verify somewhat poorer on the independent data set than the daytime hours suggests that stability considerations be introduced more directly into the method. This parameter was, indeed, found to provide a decided improvement in the accuracy of estimation when the observed temperature profile throughout the layer was known. However, a linear representation of the profile, found by simply considering the temperatures at flight level and the surface, did not suffice. Hence, the presentations were altered to better incorporate the diurnal stability trends implicitly by increasing the diurnal resolution. The need for this is clearly seen from an examination of the statistics presented in Figure 46.

Hour	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Number of Data	257	273	286	278	235	260	245	250	233	297	302	289
a_o	3.0	3.4	3.3	2.0	1.4	-0.3	-1.0	-0.5	0.2	1.4	3.0	3.1
a_1	0.54	0.53	0.53	0.50	0.41	0.27	0.31	0.46	0.46	0.40	0.45	0.47
a_2	0.48	0.41	0.47	0.74	0.98	1.30	1.30	0.98	0.98	1.22	0.83	0.68
RMS	2.21	2.26	1.99	2.47	2.66	1.13	0.99	0.89	1.75	2.64	2.17	2.26
Mean of v_{1050}	20.1	20.2	19.2	17.2	16.3	13.3	11.6	11.2	13.9	17.0	18.3	19.4
Std. dev. of v_{1050}	7.6	8.0	8.2	7.4	8.4	8.9	8.6	8.5	7.9	8.1	8.0	7.3
Mean of v_6	6.3	5.8	5.8	5.3	6.2	6.0	5.4	5.2	5.2	4.8	4.9	5.2
Std. dev. of v_6	2.5	2.6	2.5	2.6	3.4	3.7	3.9	3.7	3.0	2.1	2.1	2.3
Mean of v_I	16.9	16.5	16.3	14.7	14.1	11.1	9.7	9.7	11.8	14.1	15.3	15.7
Std. dev. of v_I	5.4	5.4	5.5	5.6	6.7	6.9	7.6	7.5	6.5	5.9	5.5	5.0

Fig. 46. Regression coefficients for Cedar Hill during January using the equation $v_I = a_o + a_1 v_{1050} + a_2 v_6$

The diurnal variation of a_2 is found to be more than 300% and that of a_1 some 200%. The a_1 coefficient shows a uniform diurnal bias with a minimum near mid-day similar to that evidenced by the integrated wind profile (see Figures 26 through 29). The a_2 coefficient on the other hand shows a lesser diurnal regularity. Thus, a six-hourly stratification of the data might be warranted in the derivation of a regression equation if upper level winds alone were to be considered. However, this time interval is much too long for partitioning the data when surface wind considerations are also introduced. Since hourly or bi-hourly stratifications would be rather unwieldy and unreliable, due to a shrinking of the data base, we propose that other means than the regression equation be sought for introducing the surface wind information into the integrated wind estimates. Some of these possibilities are in the checking-out stage.

Attempts were also made to devise schemes for estimating the flight wind at a given point location from a knowledge of the observed winds at nearby locations. Rawin data from Fort Worth, Oklahoma City, Little Rock, Shreveport, Lake Charles, San Antonio, Midland and Amarillo were used in various combinations to estimate the 1,300 foot winds for Cedar Hill. For example, one experiment considered the data of all eight stations, another only that of a few, etc. The best set of correlation statistics were found when only wind information for the geographically most proximate station, Fort Worth, was considered. A 21-day test during January showed this regression equation to be y = x - 2 where y is the 1,100 foot wind at Forth Worth and x is the 1,300 foot wind at Cedar Hill. The RMSE of this estimation was less than 4 mph.

If the wind distribution is assumed to be circular normal, then the u and v components are independently distributed and the standard deviation of wind speed is related to the variance of the components by

$$\sigma = \left(\sigma_u^2 + \sigma_v^2 \right)^{\frac{1}{2}} .$$

The formula

$$P = \frac{1}{2\pi} \frac{2}{\sigma^2} \int_0^{\delta r} \int_0^{2\pi} \exp \left[- \left(\frac{\delta r}{\sigma} \right)^2 \right] (\delta r) \, d\theta \, d(\delta r)$$

describes the circle of radius δr that contains the tip of the wind vector with probability, P.

Figure 47 represents the climatic mean wind vector for v_{1050} (at Cedar Hill for 09-15 October) that has a speed range 10-15 mph and a direction range 157.5°-202.5°.

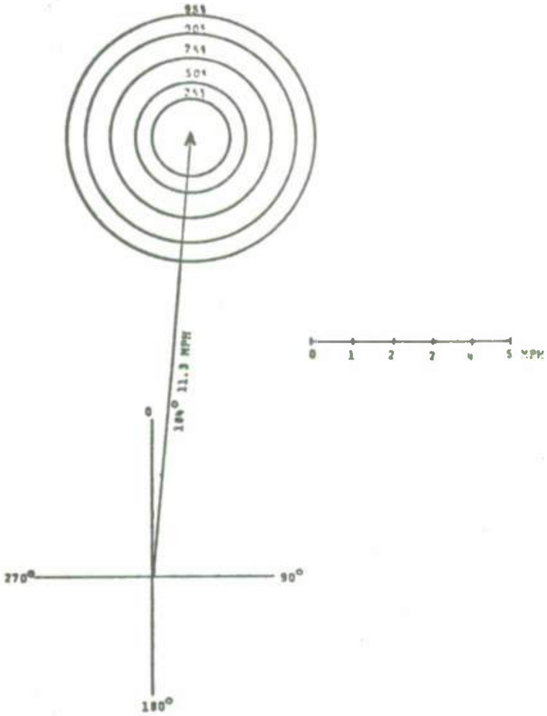


Fig. 47. Probability distribution of the 1050 foot wind (based upon 222 cases) for Cedar Hill during the hours 0900-1500 in October when that wind was observed between 157.5 and 202.5 degrees with speeds between 10-15 mph. The climatic mean wind vector and "probability circles" are shown.

A mean vector wind of 184°, 11.3 mph was found from a sample of 222 cases. The number on the circles denote the percentage probability that the tip of the wind vector would fall on or within that circle.

Another important consideration in this work involves the time variability of the wind information. For example, if V_1 and V_2 denote two random variables for an initial time and a subsequent time respectively, their interdependence may be determined from their covariance tensor

$$\overline{V_{1i}' \, V_{2j}'}.$$

Here i and j represent the components of the vectors and the prime denotes the deviation from the sample mean. The problem is to best estimate V_2 from a given V_1. By assuming the regression is linear and applying the least square criterion, this best estimate is expressed as the scalar $\hat{V}_{21} = B_{ij} V_{ij}$ providing the autogression tensor B_{ij} satisfies the requirement that $\overline{(V_{2i} - B_{ij} V_{ij})^2}$ is a minimum.

The elements of B_{ij} are obtained by setting the derivative of this expression with respect to B_{ij} equal to zero. The first element of the autogression tensor is found to be

$$B_{11} = \frac{\overline{(u_2' u_1')}\,\overline{(v_1')^2} - \overline{(u_2' v_1')}\,\overline{(u_1' v_1')}}{\overline{(u_1')^2}\,\overline{(v_1')^2} - \overline{(u_1' v_1')}^2}$$

Other elements are similarly derived.

The curves in Figures 48 and 49 were derived from two years of wind data at Cedar Hill. Ten minute averages of u's and v's were used. The standard error of estimate (for convenience labeled as RMSE), the mean phase error and the mean relative errors in establishing subsequent wind speeds at 1050 km from a knowledge of the initial ones, at 0100 and 1300 in January are presented as a

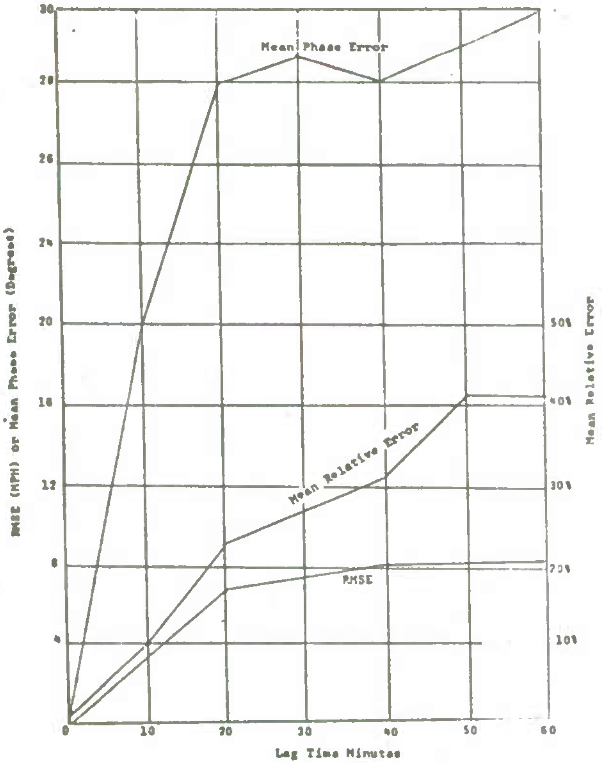


Fig. 48. Autoregression for 1050 foot winds at Cedar Hill, Texas with initial time 0100 LST during January.

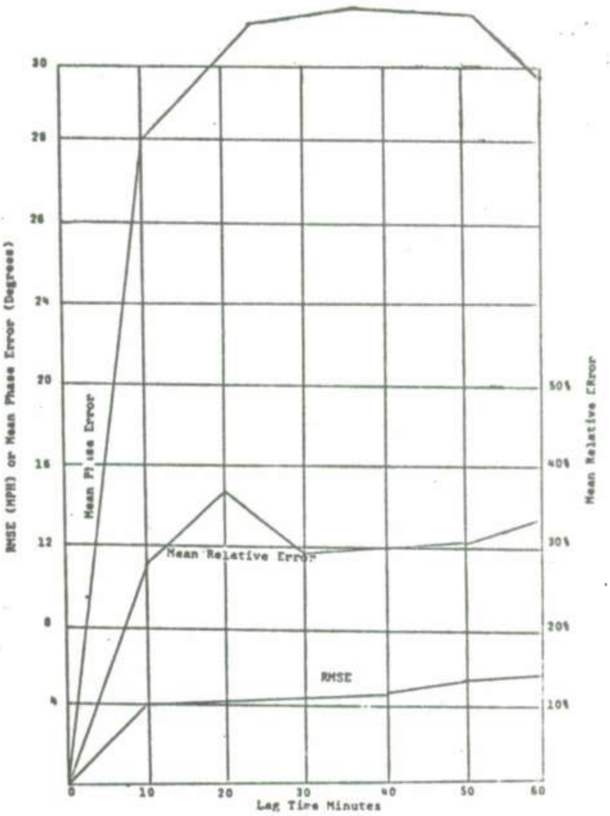


Fig. 49. Autoregression of 1050 foot winds at Cedar Hill, Texas with initial time 1100 LST during January.

function of lag time. Here the mean phase error (MPE) is defined as the average of the absolute directional differences between the observed wind and the estimated winds for a particular lag time. The mean relative error is the average ratio of the errors in speed estimations to the observed wind speed. Each set of errors is seen to grow most rapidly during the first 10 to 20 minutes after observation.

Figures 50 and 51 show a similar set of statistics for the integrated wind. This wind is seen to exhibit a somewhat better set of statistics (errorwise) than the flight level wind. These illustrations simply confirm the fact that the accuracy of wind information over the drop zone perishes rapidly with time. Every attempt should be made, therefore, to confine the time difference between observation- and release-time to less than 30 minutes.

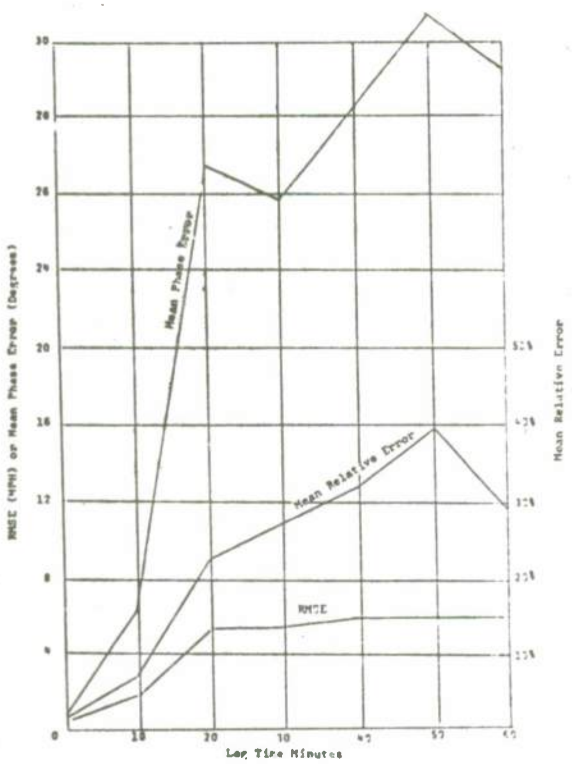


Fig. 60 Autoregression for integrated winds at Cedar Hill, Texas with initial time 0100 LST during January.

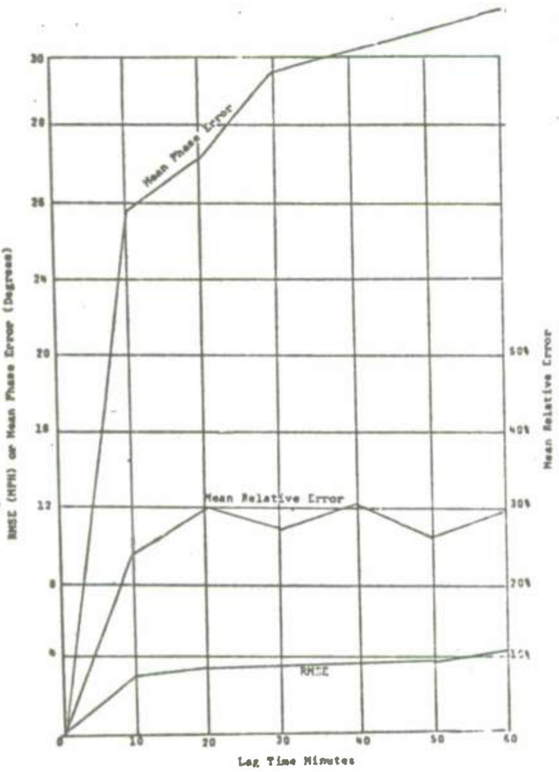


Fig. 61. Autoregression for integrated winds at Cedar Hill, Texas with initial time 1300 LST during January.

The directional deviation, d, is defined as the angular difference between the flight level wind and the integrated wind. A positive (negative) deviation indicates that the flight level wind veers (backs) from the integrated. If the idealized Ekman-Taylor spiral representation were to pertain for the wind distribution between the flight level and the ground, then "d" would be a positive value. Our empirical results indicate that a first approximation to the integrated wind direction would be a direction of 10° less than the observed flight level wind. A pictoral assessment of those initial wind directions which give integrated winds that deviate most from this average is provided by the arrows in Figures 30 through 37. A statistical breakdown of the directional deviations which lie between -5 and +25° for different hours and seasons for the Oklahoma and Cedar Hill data is given in Figure 52.

VII. SUMMARY AND CONCLUSIONS

This research has demonstrated that improved climatic aids can be provided for the forecasting of low ceilings and restricted visibilities. It was found that the conditional probabilities, which are currently being provided to the field forecaster, are misleading for the less frequently occurring events. This difficulty can be partially overcome by subjecting these probabilities to the hour-and-month continuity considerations discussed in this report. This study also shows that conditional probabilities, of comparable quality to those currently being produced by computer-tracing methods, can be provided by empirical formulations on a much smaller data base than presently needed.

The persistency of a cloud ceiling is a function of the wind and moisture conditions occurring in association with it. Methods for introducing these considerations into the recurrence statistics were demonstrated for various degrees of modelling sophistications.

The integrated winds, characteristic of a drop-zone layer, were studied as functions of the flight level, the surface wind, and various diurnal stability processes. Several different empirical methods were presented for estimating the integrated winds.

Our future efforts will adapt these procedures to the 4-hour time period and apply them to the prediction of visibility as well.

Each of the 2- and 4-hour methodologies will be tested in a two fold manner. One will use the entire data records of several independent stations as a verfication. The other will introduce the new sets of universal graphs into the field to determine their operational acceptability.

Hour (LST)		January	April	July	October
21-03	CHT (1)	82.7	84.0	87.1	84.3
	(2)	90.3	88.3	90.1	87.9
	OKC (1)	83.0	85.5	93.2	88.4
	(2)	86.8	90.1	96.3	93.9
03-09	CHT (1)	83.7	82.5	82.1	76.1
	(2)	91.1	83.2	89.9	81.6
	OKC (1)	68.2	84.0	75.4	68.9
	(2)	82.4	90.5	88.7	81.1
09-15	CHT (1)	81.7	74.1	74.7	73.8
	(2)	86.8	78.6	85.7	79.7
	OKC (1)	73.0	80.9	81.6	92.9
	(2)	87.2	84.4	84.7	95.6
15-21	CHT (1)	80.7	78.3	84.2	79.8
	(2)	88.7	83.4	90.6	84.4
	OKC (1)	75.8	82.7	87.1	97.5
	(2)	82.2	89.6	87.8	99.2

Note: (a) Range of integration for V_I: CHT (1) 15-825 ft., CHT (2) 15-1125 ft., OKC (1) 11.5-874 ft., OKC (2) 11.5- 1166 ft.

Fig. 52 The percentage of directional deviations (d) which lie between -5° and +25° for different hours and seasons for the Oklahoma (OKC) and the Cedar Hill (CHT) data.

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13. ABSTRACT

This research considers the devising of climatic presentations for usage in preparing 2- and 4-hour forecasts of low ceilings and restricted visibilities and the providing of integrated-wind information within the drop-zone layer in support of paradrop operations.

A hierarchy of empirical relationships for estimating the recurrence probabilities under a number of contingencies are made possible through the use of statistical modelling techniques which act to conserve the data base. These are: 1) a model for generating recurrence probabilities which considers only the latest observed ceiling category, 2) one which incorporates surface wind information, 3) another which includes moisture considerations and 4) one which introduces observed moisture and wind information diagnostically without having to assume the persistency of these variables, or otherwise forecast their behavior, throughout the forecast interval.

Climatic presentations for estimating integrated winds within the drop-zone layer, from a knowledge of the winds at flight level, are discussed apart from those which pertain when surface winds are similarly available.

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