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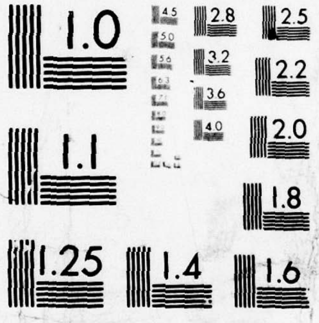

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WEATHER INFORMATION AND TACTICAL ARMY ACTIVITIES

PART 1: Assessment of the Operational Utility of Mesoscale Weather Forecasting Improvements for Army Forces

John Metzko
Henry Hidalgo

June 1979

Prepared for
Office of the Under Secretary of Defense for Research and Enginering

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The objective of this paper is to assess the operational utility of the most optimistic, but reasonable, improvement in reliability of mesoscale weather forecasts projected for Army forces in the mid-1980s. Data from recent forecast verification programs are the source for the reliability of current mesoscale weather forecasts. An understanding of the impact of weather forecasts on Army operations is developed by a series of workshop-type discussions with a broad cross section of Army officers. (over)

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The main finding is that for a projected 1985 improvement in mesoscale weather forecasting reliability there does not appear to be a corresponding improvement in the utility of mesoscale ~~weather~~ forecasts for tactical planners.

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400 Army-Navy Drive, Arlington, Virginia 22202

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PREFACE

The task for which this Part 1 report is written was initially intended to evaluate potential mesoscale weather forecasting systems for support of Army tactical operations in the mid-1980s. The task was to be accomplished in two phases, the first of which had the following major objective: evaluate the gain in operational utility of the most optimistic, but reasonable, improvement that might be expected in the precision (i.e., accuracy or reliability) of mesoscale weather forecasts by 1985. The second phase was to consider systems with lower levels of prediction precision as well as acquisition and support costs of alternative systems.

However, following the Phase 1 effort, whose major findings made cost-capability tradeoffs among alternative mesoscale weather forecasting systems appear unimportant, the Phase 2 effort was redirected toward (1) a broader assessment of the effects of weather information on Army activities and (2) a reexamination of the Phase 1 findings, which several interested people found somewhat surprising.

The Phase 2 effort is described in the Part 2 report, entitled "Opportunities for Increasing Army Effectiveness Through Improvements in Weather Information Systems," which includes discussion of the reexamination of Phase 1 findings.

FOREWORD

This report describes the Phase 1 effort to evaluate the gain in utility of an improved mesoscale (i.e., small spatial and short temporal scales) weather prediction capability to support Army tactical operations in the mid-1980s.

The report is presented in briefing form. The introductory material, analyses, findings, and conclusions are contained in a series of exhibits to allow a reader to quickly assimilate the essence of the entire report or any of its parts. For the more careful reader, supporting details, important observations, and pertinent discussions are provided with the appropriate exhibits; appendices contain additional information and supporting material. The subject of each section (group of related exhibits) of the report is indicated in the table of contents.

EXECUTIVE SUMMARY

The main objective of this study effort is to assess the operational utility of the most optimistic, but reasonable, improvement in reliability of mesoscale weather forecasts projected for the mid-1980s for Army ground and aviation forces in the European theater. Data from recent (1975-1977) tests on the verification of weather forecasts by the National Weather Service and the Air Weather Service are used to estimate the reliability of current mesoscale weather forecasts.

The study effort, based on well-accepted assumptions that weather and weather forecasting affect tactical operations, is directed specially toward answering the following question: Can Army forces be utilized more effectively or efficiently in day-to-day operations given an optimistic projected improvement in weather information used as inputs for tactical planning?

The data-gathering investigation of Army operations involved many workshop-type discussions with a broad cross section of Army officers with varied experience, education, training, and rank at the schools of most Army branches (Exhibit 20). The discussions concerned detailed descriptions of operational situations and information inputs relative to factors considered in tactical decisions (in those situations) and with the effects that various levels of weather information reliability would have in decision-making processes.

The major findings are (1) the mutual supporting nature of the missions and objectives of lower command levels (platoon, company, and battalion) limit their flexibility to react to weather forecasts, and (2) for higher command levels (division and corps), at which battlefield planning is primarily done, the projected reliability of 1985 mesoscale weather forecasts appears to be insufficiently better than the reliability of current forecasts to make weather predictions a more decisive planning factor (Exhibits 26 and 27).

Thus, it is concluded that an optimistic mesoscale weather forecasting capability projected for 1985 offers no advantages for Army tactical operations (Exhibit 28).

CONTENTS

I. INTRODUCTION

EXHIBIT 1: MESOSCALE WEATHER FORECASTING (MWF) TASK, PHASE 1, OBJECTIVES

1. IDENTIFY PARAMETERS USEFUL IN DESCRIBING WEATHER PREDICTION PRECISION
2. DETERMINE HIGHEST PRECISION MWF SYSTEM THAT APPEARS TECHNICALLY FEASIBLE FOR THE MID-1980s
3. IDENTIFY RELATIONSHIPS BETWEEN WEATHER FORECASTING PRECISION AND TACTICAL OPERATIONAL CAPABILITY, AND, IF POSSIBLE, DEVELOP SOME MEASURABLE INDICATORS

EXHIBIT 1

The objectives indicated are those for the MWF Task, Phase 1. A copy of the task order, which describes a two-phase study, is contained in Appendix A. Considerations of less capable MWF systems and their costs are deferred until Phase 2, which would be undertaken if the most capable MWF system that might be available in the mid-1980s would appear to offer potential improvements for Army tactical operations.

EXHIBIT 2: SCOPE OF STUDY

- EUROPE - 1985
- GROUND-BASED FORCES - INFANTRY, ARMOR, ARTILLERY
- ARMY AVIATION FORCES
- ALL COMMAND ECHELONS UP THROUGH CORPS
- WEATHER INFORMATION AS INPUTS FOR PLANNING NOT AS COMBAT INFORMATION (I.E., NOT FOR REAL-TIME USE FOR WEAPON SYSTEM OPERATIONS)
- ASSUMPTIONS
  1. WEATHER AFFECTS TACTICAL OPERATIONS
  2. WEATHER FORECASTING AFFECTS TACTICAL OPERATIONS
  3. BETTER WEATHER FORECASTING WILL NOT CHANGE FORCE STRUCTURE
- ISSUES
  1. WILL IMPROVEMENTS IN WEATHER FORECASTING IMPROVE TACTICAL CAPABILITY IN DAY-TO-DAY OPERATIONS?
  2. CAN AVAILABLE FORCES BE UTILIZED MORE EFFECTIVELY OR EFFICIENTLY WITH PROJECTED IMPROVEMENTS IN WEATHER FORECASTING?

EXHIBIT 2

The study effort focuses on Army forces, ground-based and aviation, in a European scenario. Consideration is not given to USAF or USN forces.

This study is concerned with the predictive value of weather information to operational planners at all command echelons from platoon through corps, and not for its real-time use for operating weapon systems (e.g., crosswind for the tank gunner or upper winds for the artillery man). It is recognized that weather information for use in current combat may be as important, or more important, than its use for weather forecasts.

Anyone even modestly familiar with recent wars--World War II, Korea, Vietnam--can identify numerous examples of the impact of weather on tactical operations. Examples of the influence of weather forecasting on tactical operations also exist but are less numerous. One example in the Korean War is the timing of Red Chinese and North Korean major attacks in front of oncoming Arctic cold fronts, forcing United Nations Command (UNC) counterattacks to be conducted facing high winds, snow storms, and extremely cold temperatures after frontal passage. Another example, also in the Korean War, is the habitual North Korean timing of ground assaults in periods of poor flying weather to negate UNC air superiority. In the Vietnam War, North Vietnamese forces also often took advantage of low ceiling and poor visibility to initiate ground attacks (examples are taken from Ref. 1). Similarly, the German Army Ardennes offensive in December 1944 was timed to coincide with a period of poor flying weather because of Allied air superiority.

While the Normandy invasion in June 1944 is a memorable example of the influence of weather forecasting on operational planning, this study is not concerned with the impact of weather forecasting on such epic events but on the possible utility of weather forecasting for day-to-day tactical planning and operations.

It is assumed that all-weather and limited-weather systems (e.g., radar and infrared sensors and weapons) are developed and procured for U.S. forces without considering specifics of times and places at which they will be used. These capabilities are acquired because of (1) the reasonable likelihood of encountering poor weather conditions in future combat situations, (2) the added capability these systems provide even in good weather situations, and (3) the certainty that such systems provide enhanced nighttime capability. Thus, it is assumed that the Army force structure will not be affected by potential improvements in weather forecasting capability.

EXHIBIT 3: STUDY APPROACH

1. IDENTIFY PRIMARY ENVIRONMENTAL PARAMETERS AND PARAMETERS WHICH DESCRIBE USEFULNESS OF WEATHER FORECASTS TO OPERATIONAL COMMANDERS

2. ESTIMATE VALUES EXPECTED FOR THOSE PARAMETERS BY 1985, GIVEN THE MOST PRECISE MWF SYSTEM

3. DETERMINE FROM DISCUSSIONS WITH A BROAD CROSS SECTION OF ARMY OFFICERS IN SEVERAL BRANCHES (INFANTRY, ARTILLERY, ARMOR, AVIATION, ETC.) THE POTENTIAL INCREASED OPERATIONAL UTILITY ACCRUING FROM THE 1977-TO-1985 WEATHER FORECASTING IMPROVEMENT

EXHIBIT 3

The first step in the study effort is to identify parameters associated with weather forecasting and the utility of weather forecasting information from an operational commander's perspective.

The next step is to characterize the precision of the weather forecasting information in quantitative terms both for 1977 and for 1985 through discussion with technical personnel of the meteorological community (agencies of the Federal government and some key universities) involved in research, development, testing, and evaluation of weather forecasting systems.

With the weather forecasting products characterized quantitatively, discussions with a large number of Army officers with varied backgrounds and experiences are the basis for identifying specific potential tactical advantages from the most optimistic projected 1977-to-1985 improvement in weather forecasting and for developing measurable indicators of those advantages.

Since operational situations are so diverse and involve so many variables and factors apparent only to those who have been involved in actual and simulated combat environments, identification of operational improvements that might accrue from the projected MWF capability were sought from lengthy group discussions with a large number of Army officers with wide-ranging backgrounds at several Army schools and commands. Appendix B is a copy of an ODDR&E letter sent to the Army War College seeking assistance for this study. Similar letters were sent to, and discussions were held at, the U.S. Army

Training and Doctrine Command, Intelligence Center, Aviation Center, Armor School, Engineer School, Infantry School, Field Artillery School, and Combined Arms Combat Development Activity.

Thus, the study approach is to characterize quantitatively the MWF capability for 1977 and the best expected for 1985, and then to obtain subjective data from operator-users on the operational utility of the optimistic projected MWF improvement.

II. IMPORTANT STUDY ELEMENTS: DEFINITIONS AND IDENTIFICATIONS

EXHIBIT 4: DEFINITION OF MESOSCALE WEATHER FORECASTING (MWF)

- MWF IS PREDICTING THE OCCURRENCE OF SUB-SYNOPTIC SCALE EVENTS FOR A LOCAL AREA
- MWF IN THIS STUDY IS AN INTERMEDIATE-SCALE (BETWEEN MACRO- AND MICROSCALE) FORECASTING PROCESS WHICH IS CONCERNED WITH ATMOSPHERIC DYNAMICS HAVING A SPACE SCALE OF 1-200 KM AND A TIME SCALE OF LESS THAN 24 HOURS AND WHICH IS CONCERNED WITH THE EFFECTS OF ELEMENTS, SUCH AS TERRAIN AND CUMULUS CONVECTION, WHICH ARE NOT IMPORTANT TO LARGER SCALE METEOROLOGY
- MWF METHODS ARE OF THREE TYPES: PERSISTENCE, LOCAL (SUBJECTIVE), AND GUIDANCE (OBJECTIVE)

METEOROLOGICAL SCALES (APPROXIMATE)

TYPE SCALE	SPATIAL SCALE, KM	TEMPORAL SCALE, HR	FORECASTING TECHNIQUE
MACROSCALE	> 2000	> 24	NUMERICAL WEATHER PREDICTION (NWP)
MESOSCALE (COARSE MESH)	200-2000	24	MESOSCALE NWP
MESOSCALE (FINE MESH)[a]	1-200	< 24	PERSISTENCE, LOCAL (MAN), GUIDANCE
MICROSCALE	< 1	1	PERSISTENCE, LOCAL

[a] OF PRIMARY CONCERN IN THIS STUDY. SPATIAL SCALE BOUNDARY BETWEEN MESOSCALE (FINE MESH) AND MICROSCALE IS ASSUMED TO BE 1 KM. MESOSCALE (FINE MESH) FORECASTING TECHNIQUES ARE DESCRIBED IN DISCUSSION ACCOMPANYING EXHIBIT 15.

EXHIBIT 4

A variety of definitions appear in the meteorological community for space and time scales for atmospheric processes (see Refs. 2, 3, 4, and 5, which are not consistent in some scaling details).

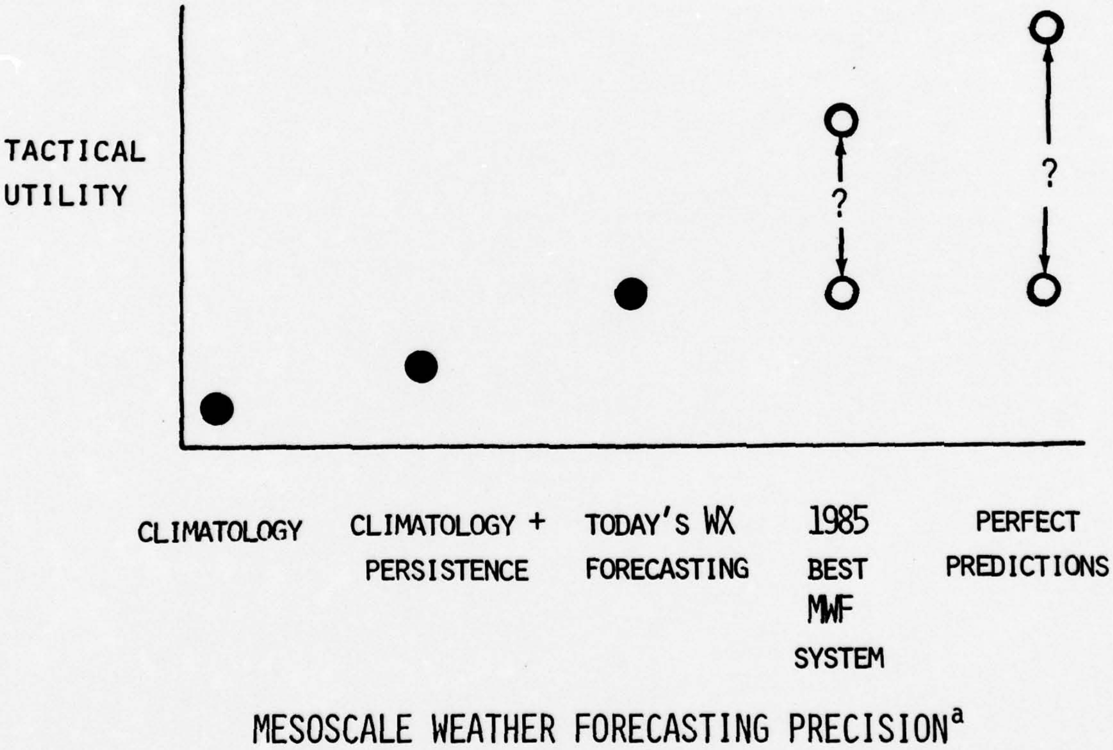
Two conceptual bases are used for defining "mesoscale": (1) weather event dimensioning and (2) weather event predictability. Spatial and temporal scales are utilized under each concept with different meanings but with similar ranges of values. Under the dimensioning basis, spatial and temporal scales mean the spatial size and lifespan, respectively, of the weather event; under the predictability basis, spatial and temporal scales mean the spatial size of the area and length of time, respectively, in which a weather event is predicted to occur. The contexts in which spatial and temporal scales are considered in this report will indicate that the predictability basis is usually implied.

"Mesoscale" defines all intermediate scales between macroscale, whose lower space limit is about 2000 km, and microscale, whose upper space limit is 1 km (Ref. 2). For this study "mesoscale" is considered to involve a fine-mesh space scale of 1 to 200 km.

While the mesometeorological community considers time scales whose upper limits are 6-12 hours, consideration is given in this study to weather forecasting precision extended over a longer period. It appears most useful for discussions with Army operator-users of weather forecast information to consider the continuum of weather forecasting precison over longer periods but with emphasis on the mesoscale time period (before forecasting precision has deteriorated to uninteresting levels).

Appendix C contains a more complete discussion of mesometeorology. Appendix D contains descriptions of the forecasting techniques indicated in Exhibit 4.

EXHIBIT 5: UTILITY OF MESOSCALE WEATHER FORECASTING



[a] PRECISION = SPATIAL AND TEMPORAL ACCURACY OF PREDICTED WX COMPARED TO OBSERVED WX OF THE FORECAST PERIOD

EXHIBIT 5

Theoretically, the utility of combat forces and combat support forces in tactical operations is a function of, among other things, the capability of the supporting weather forecasting system. If tactical planning were based on a minimum of weather information, say, climatology,[a] one would expect some incremental utility over the utility when not even an almanac is available. If, in addition to climatology, tactical planning could also factor in persistence (weather during the next time period will be the same as currently observed or the pattern of weather during the next period will be the same as the weather pattern over the present period--e.g., day-to-day fog formation in the San Francisco area), utility should be even better. And if today's numerical and statistical weather forecasting techniques are also used to provide weather information, tactical utility might be better yet.

While it appears conceptually reasonable that combat forces and combat support forces might be utilized more effectively or efficiently as weather forecasting precision is increased, quantifying the relationship between tactical utility and weather forecasting precision is difficult because of the numerous ways in which tactical utility can be manifested and because several elements are needed to describe weather forecasting precision (viz., time, space, and weather parameter). Indeed, even scaling the five rank-ordered levels of weather

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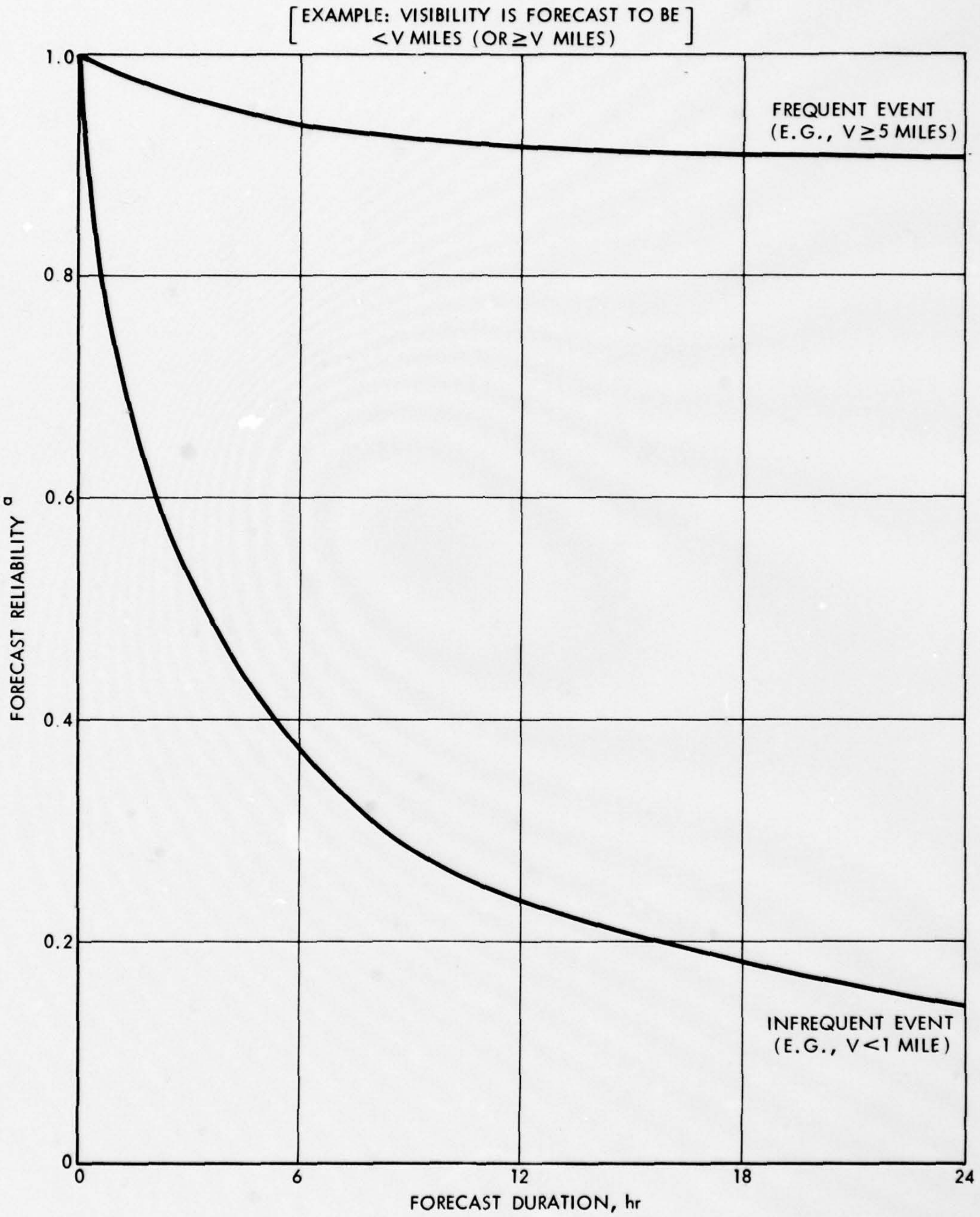
[a] Average local weather conditions for a period of time (as provided, for example, by an almanac).

forecasting precision shown in Exhibit 5 is itself difficult (quite likely the differences in capabilities are not equal as indicated). A comparison of mesoscale weather forecasting precision for 1977 and for 1985 is developed in the following section.

The objective of Phase 1 of this task is to determine the incremental tactical utility that can be expected, given the best MWF capability that might be achieved by 1985. Since there appears to be no viable way for quantifying the relationship of utility and weather forecasting capability, without oversimplications such as indicated in comments related to Exhibit 8, the improvement in utility will be estimated by subjective operator-user data collected at various Army schools and commands.

Since a weather forecasting system which would produce perfect predictions cannot now be defined, nor its cost estimated, consideration is not given to such a hypothetical capability.

EXHIBIT 6: CHARACTERIZATION OF WEATHER FORECASTING PRECISION



$$^{a}\text{RELIABILITY} = \frac{\text{NO. OF EVENTS IN WHICH A SPECIFIED WX STATE IS FORECAST AND OBSERVED}}{\text{NO. OF EVENTS IN WHICH A SPECIFIED WX STATE IS OBSERVED}}$$

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EXHIBIT 6

Forecast reliability is defined from the standpoint of the operator-user who wants to know the "batting average" (i.e., cumulative average accuracy) of the forecaster or forecasting system based upon past predictions as an indicator of confidence he should place in current predictions. Quite reasonably, he would be expected to equate the batting average with the probability that a currently forecast weather event will actually occur.

The example shown uses 1977 data (see Exhibit 16) from the National Weather Service to illustrate the characterization of weather forecasting precision: forecast reliability as a function of (1) time after the forecast is issued and (2) frequency of the weather event. Forecast reliability very shortly after forecast issuance (i.e., forecast duration equals zero) is based on assumptions indicated in Exhibit 12.

The process for determining accuracy of a weather forecast by comparing the predicted weather with the observed weather of the forecast period is called forecast verification, whose principal purposes are the testing of forecasting skills and methods. As will be shown in the next section (Exhibits 14 and 15), verification data indicate a high correlation between forecast reliability and frequency of the weather event of concern.

EXHIBIT 7: WEATHER PARAMETERS OF PRIMARY CONCERN TO UTILIZATION OF WEAPON SYSTEMS IN TACTICAL OPERATIONS

FOR	PARAMETER
TARGET ACQUISITION AND WEAPON DELIVERY	VISIBILITY CEILING
MOBILITY	PRECIPITATION (AMOUNT AND RATE)[a]

[a] IN CONJUNCTION WITH OTHER FACTORS--SUCH AS SOIL TYPE AND CONDITION, SURFACE RELIEF, DRAINAGE, VEGETATION, ETC.--PRECIPITATION DETERMINES TRAFFICABILITY, A MORE COMPLETE INDEX OF GROUND MOBILITY.

EXHIBIT 7

The Army Training and Doctrine Command has identified 50 environmental parameters of interest to various Army users of weather information (Ref. 6). In view of the time and manpower constraints of this study effort, only those environmental parameters of primary concern to the utilization of weapon systems in tactical operations are considered.

Selection of visibility, ceiling, and precipitation as the primary weather parameters[a] was endorsed by several Army officers whose advice was sought. Because of their consideration by several Army branches, surface winds are also considered in this study.

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[a] Alternatively described as "environmental" or "weather manifestation" parameters.

EXHIBIT 8: BAD WEATHER (WX) FOR TACTICAL OPERATIONS

DEFINITION: WX WHICH LIMITS PERFORMANCE OF EQUIPMENT AND PERSONNEL TO LESS THAN LIMITS IMPOSED BY
(1) INHERENT PHYSICAL CHARACTERISTICS OR
(2) TERRAIN CONSTRAINTS

EXAMPLES: LOW VISIBILITY, LOW CEILINGS, HEAVY RAIN, HIGH WINDS

SIGNIFICANCE: POTENTIAL PAYOFF FROM RELIABLE FORECASTING APPEARS HIGHER FOR BAD WX; EQUIPMENT AND PERSONNEL CAN BE DEPLOYED--ALL ELSE BEING EQUAL--SO THE FULL POTENTIAL OF THEIR PERFORMANCE ENVELOPES CAN BE UTILIZED

EXHIBIT 8

Tactical deployments of weapons are assumed to be made normally without regard to weather forecasts (although one can conceive of consideration of climatology possibly influencing decisions on weapon system deployment to a theater). The normal deployment may "waste" potential effectiveness of some weapon systems during periods in which weather, rather than inherent physical characteristics or terrain constraints, limits their performance. Theoretically, at least, redeployment of weapon systems (ATWs, for example) to areas where their full performance envelopes can be utilized would provide a number of weapon-hour-km[a] of potential additional effectiveness at the new locations. The viability of such a concept remains to be evaluated with Army personnel.

If forces, or force elements, are to be utilized more effectively or efficiently, it appears such improved utilization must reasonably take advantage of periods of "bad" weather, where "bad" is defined differently for different weapon systems. For example, bad weather for several antitank weapons (ATWs) and tank guns is 1, 2, or 3 km corresponding to the maximum effective range of the specific type weapon. Bad weather for helicopter operations might be ceiling/visibility less than 500 ft/2 miles in hilly terrain or less than 200 ft/1 mile in flat terrain.

---

[a] (No. of ATWs redeployed) x (No. of hours each is temporarily redeployed) x (Maximum effective range of ATW minus visibility at original location).

EXHIBIT 9: WEATHER FORECAST PARAMETERS

- FORECAST RELIABILITY (DEFINED IN EXHIBIT 6)
  FOR VARIOUS VISIBILITY, CEILING, PRECIPITATION
  EVENTS OR STATES

- SPATIAL RESOLUTION, KM x KM
  GEOGRAPHICAL SPACE WITHIN WHICH WEATHER EVENTS
  CAN BE FORECAST

- FORECAST DURATION, HR
  TIME FOR WHICH RELIABILITY IS HIGH ENOUGH
  TO MAKE PREDICTIONS POTENTIALLY USEFUL

- PLANNING-PREPARATION TIME, HR
  TIME DURING WHICH OPERATIONAL PLANS ARE FORMULATED AND FORCES PREPARED FOR ACTION

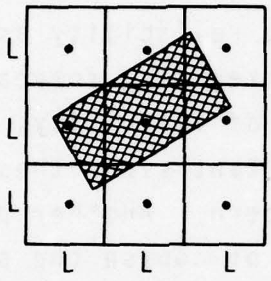
EXHIBIT 9

Exhibit 9 identifies the parameters considered most useful in characterizing weather forecast precision and in utilizing weather forecasts. First, reliability as previously defined is used as a parameter characterizing forecast precision. And obviously the reliabilities of visibility, ceiling, and precipitation forecasts are important since these are the weather parameters of primary concern. Another parameter characterizing forecast precision is of course the spatial resolution, or space scale, within which weather events can be forecast.

Connected to reliability of forecast is forecast duration, the time for which forecasts can be made with sufficient reliability to be useful to the planner. And related to forecast duration is the planning-preparation time required by tactical operators to take advantage of the weather forecasts. Planning typically involves details of force firepower employment and logistical support; preparation may involve moving personnel and equipment, additional maintenance periods to improve equipment availability, and building up supply stocks.

EXHIBIT 10: ANOTHER FORM OF FORECAST UNRELIABILITY

INCOMPATIBILITY OF AREA FORECASTING AND POINT OBSERVATIONS CAN CAUSE LARGE DIFFERENCES IN WEATHER FORECAST-OBSERVATION AGREEMENTS (AND THUS RELIABILITY) DEPENDING ON (1) WEATHER EVENT OF INTEREST, (2) TERRAIN FACTORS, AND (3) SCORING METHOD ADOPTED FOR MAKING FORECAST-OBSERVATION AGREEMENT DECISIONS.



EXPECTED TERRAIN INFLUENCE	WEATHER EVENT	RELIABILITY [a]
MINOR	PRECIPITATION > 1 INCH	
	FORECAST IN 9 L^2 UNITS	
	OBSERVED IN 7 L^2 UNITS	7/9 (FRACTIONAL COVERAGE SCORING)
	OBSERVED AT 2 STANDARD POINTS	2/9 (STANDARD POINT SCORING)
MAJOR	VISIBILITY < 1 KM	
	FORECAST IN 7 L^2 UNITS	
	OBSERVED IN 7 L^2 UNITS	7/7

$$^{a}\text{RELIABILITY} = \frac{\text{NO. OF EVENTS IN WHICH SPECIFIED WEATHER STATE IS FORECAST AND OBSERVED}}{\text{NO. OF EVENTS IN WHICH SPECIFIED WEATHER STATE IS OBSERVED}}$$

WHERE "EVENT" MEANS WEATHER STATE IN AN L x L GRID UNIT.

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EXHIBIT 10

The form adopted for expressing weather forecasting precision, viz.,

$$\text{Reliability (R)} = \frac{\left(\begin{array}{c}\text{No. of events in which a specified weather} \\ \text{state is forecast and is observed}\end{array}\right)}{\left(\begin{array}{c}\text{No. of events in which a specified} \\ \text{weather state is observed}\end{array}\right)}$$

introduces an identifiable, measurable degree of unreliability (i.e., 1.0-R) from the perspective of a tactical commander. However, in verification of weather forecasts, i.e., comparing the forecast weather (F) with the observed weather (O) of the forecast period, another form of unreliability--not so identifiable nor measurable--may be introduced. This forecast unreliability is due to errors incidental to scoring agreement (or nonagreement) between F and O. As an example, suppose precipitation is predicted in an area 3L x 3L containing 9 mesoscale grid units as part of a fine-mesh modeling system. If precipitation is observed for the period of the forecast to cover the cross-hatched portion of the 3L x 3L area in Exhibit 10, agreement between F and O may be very good if the scoring standard is the observance of precipitation in any part of each L x L mesoscale grid units. If the scoring standard for determining agreement between F and O is the observance of precipitation at the center of each L x L grid unit, forecast reliability may appear to be quite poor. Thus, scoring methods for determining F-O agreement may distort forecast reliability because of inconsistency between mesoscale <u>area</u> forecasting and <u>point</u> observations; since spatial resolution of the weather forecast is at the L x L level, forecast reliability (no matter how good) may not convey predictability of fractional coverage (amount and location) of an L x L area by a weather event.

However, there also appear to be circumstances, involving particular weather events and terrain effects not important to large-scale meteorology, in which the above defect in scoring methods for determining F-O agreement is not a factor. For example, suppose the cross-hatched area in Exhibit 10 represents a valley surrounded by hills in the 3L x 3L area. If the weather event of interest is fog (and consequent low visibility which might be of interest to a tactical commander), a mesoscale weather forecast might well be able to predict morning fog in specific portions of the grid units over which the sky is clear, the relative humidity at sunset is high, and the wind is light, because these conditions, already conducive for the formation of radiation fog, are also reinforced by heavy colder air flowing down from surrounding hills at night.

Thus, a hidden degree of uncertainty may be incidental to the reliability of the mesoscale weather forecast, depending on the combination of particular weather event and terrain.

III. VALUES OF WEATHER FORECASTING PARAMETERS

EXHIBIT 11: ESTIMATES OF VALUES FOR SPATIAL RESOLUTION AND DURATION OF WEATHER FORECASTS

TYPE SCALE	SPATIAL RESOLUTION, KM		FORECAST DURATION, HR	
	1977	1985	1977	1985
MACROSCALE[a]	200	200	24-48	24-48
MESOSCALE (COARSE MESH)	-	35	-	24
MESOSCALE (FINE MESH)	4	4	12	12
MICROSCALE	< 1	< 1	1	1

[a] VALUES GIVEN FOR LIMITED AREA FINE MESH MODEL

EXHIBIT 11

Values for spatial resolution and forecast duration parameters are estimated on the basis of discussions with personnel involved in weather forecasting R&D at the National Oceanographic and Atmospheric Administration (NOAA)[a] and the Drexel University.[b]

The improvement in spatial resolution by 1985 is the projected result of development of a "regional scale" numerical weather prediction model with a grid mesh size of about 35 km.[c] At the lower end of the mesospatial scale, fine-mesh modeling by model output statistics (MOS) is expected to provide about the same spatial resolution of weather events as MOS provides today, i.e., 4 x 4 km^2. The impact of the regional scale, or coarse mesh mesoscale, capability is expected in the form of additional input data for the fine-mesh mesoscale model, thus enhancing the reliability of MOS predictions. Optimistic projections of the consequent improvements are shown in Exhibit 15.

While the period of most expected usefulness of coarse mesh mesoscale weather prediction should remain in 1985 on the order of 24 hours beyond the time of latest observation, finer mesh mesoscale predictions are expected to be useful for periods up to about 12 hours.[c]

The fine-mesh mesoscale forecasts of interest in this study are conditional forecasts in that they are based on the assumption that larger scale forecasts (i.e., macroscale in 1977 and macroscale plus coarse mesh mesoscale in 1985) are accurate.

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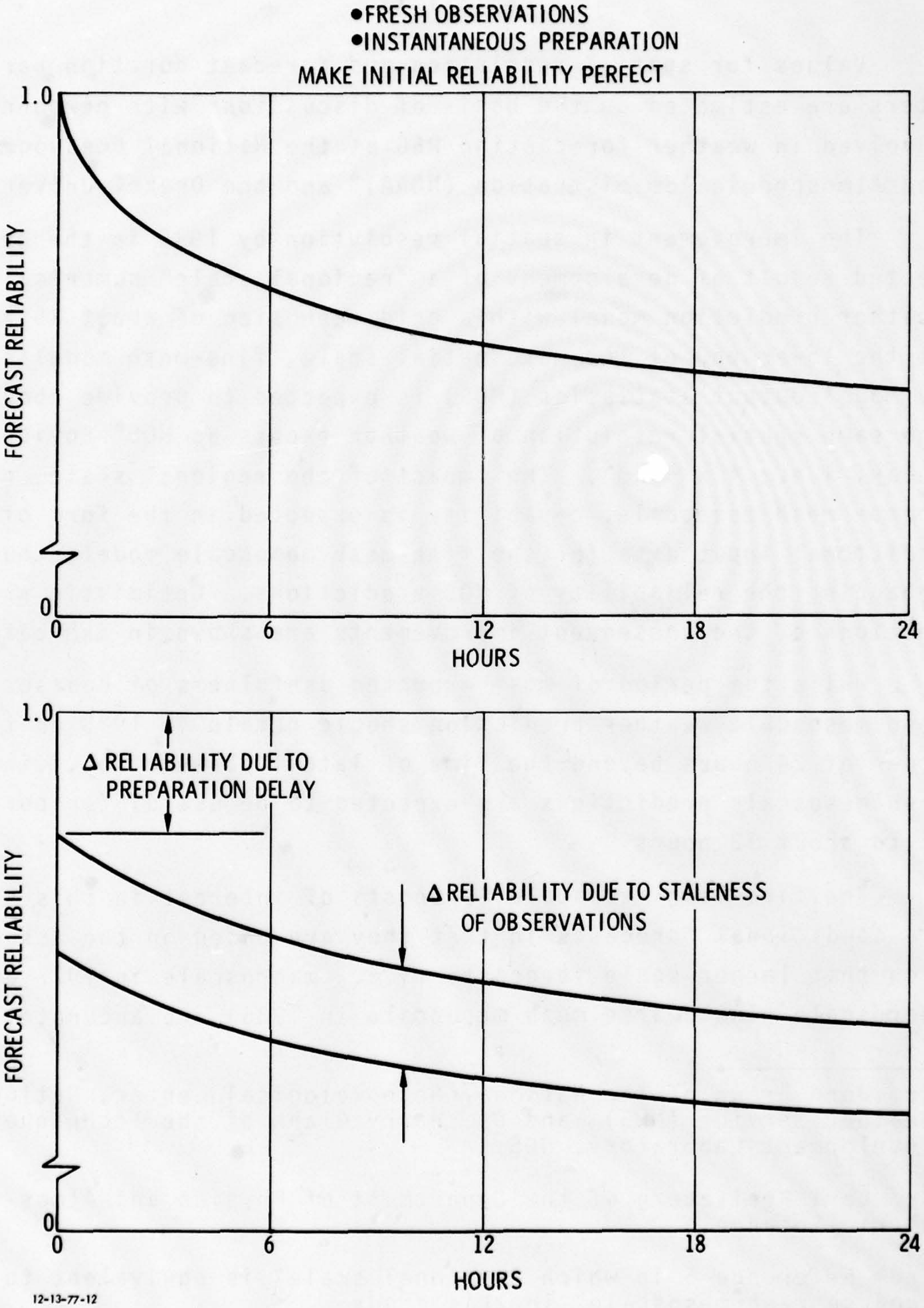
[a] Dr. John Brown of the National Meteorological Center, National Weather Service (NWS), and Dr. Harry Glahn of the Techniques Development Laboratory, NWS.

[b] Dr. Carl Kreitzberg of the Department of Physics and Atmospheric Science.

[c] From Reference 5 in which "regional scale" is equivalent to "coarse mesh mesoscale" in this study.

EXHIBIT 12: SOME ASSUMPTIONS IN ESTIMATING RELIABILITY OF WEATHER FORECASTS



12-13-77-12

EXHIBIT 12

Forecast verification data indicate that verification (comparing predicted weather of a forecast period with the observed weather of that period) is usually made 3, 6, 12, and 24 hours after issuance of the forecast. While typical "guidance" forecast preparation time is about one hour and observation data on which the forecast is based are typically two hours old when forecast preparation is begun,[a] variations in preparation times and in freshness of the observation data bases are expected but unknown. And while preparation time and age of data base are typically even less (than one hour and two hours, respectively) for "local" forecasts, "persistence" forecasts are, of course, perfect "now-casts."

Therefore, it is assumed that fresh observations and instantaneous preparation make the forecasts perfectly reliable at issuance, as indicated in the top sketch and, thus, the axis of the abscissas represents time elapsed since forecast issuance.

Descriptions of the three mesoscale weather forecasting techniques are included in discussion accompanying Exhibit 15.

The axes of the ordinate in Exhibit 12 are not scaled and the sketches are simply notional illustrations.

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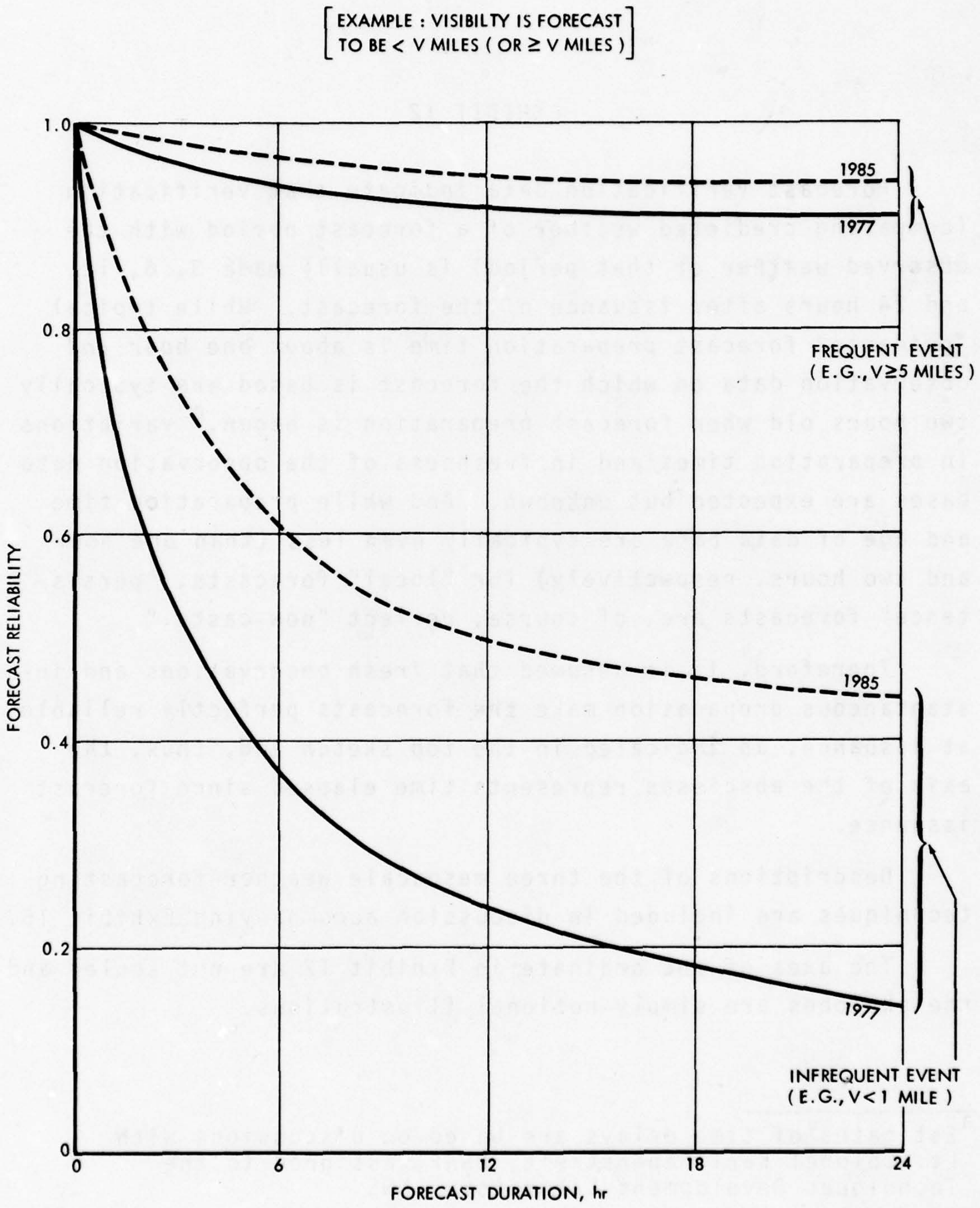
[a] Estimates of time delays are based on discussions with Lt. Colonel Karl Hebenstreit, USAF, assigned to the Techniques Development Laboratory, NWS.

EXHIBIT 13: PROJECTING RELIABILITY OF FORECASTS



1-16-78-6

EXHIBIT 13

With the example introduced in Exhibit 6 and with forecast reliability data shown later (see Exhibit 16), this exhibit illustrates the method of projecting forecast reliability for 1985. While background details follow, 1985 projections are based directly on: (1) predictions of various weather events nine hours from issuance being as reliable as 1977 predictions of similar events three hours from issuance, (2) perfect reliability at forecast issuance, and (3) an arbitrary curve through those two points and with a slightly slower rate of decay then exhibited by the verification data for 1977.

Methodology currently used by the National Weather Service (NWS) and the USAF Air Weather Service (AWS) to validate weather forecasts is described in Appendix E. The basis for projecting forecast reliability for 1985 is described in Appendix F.

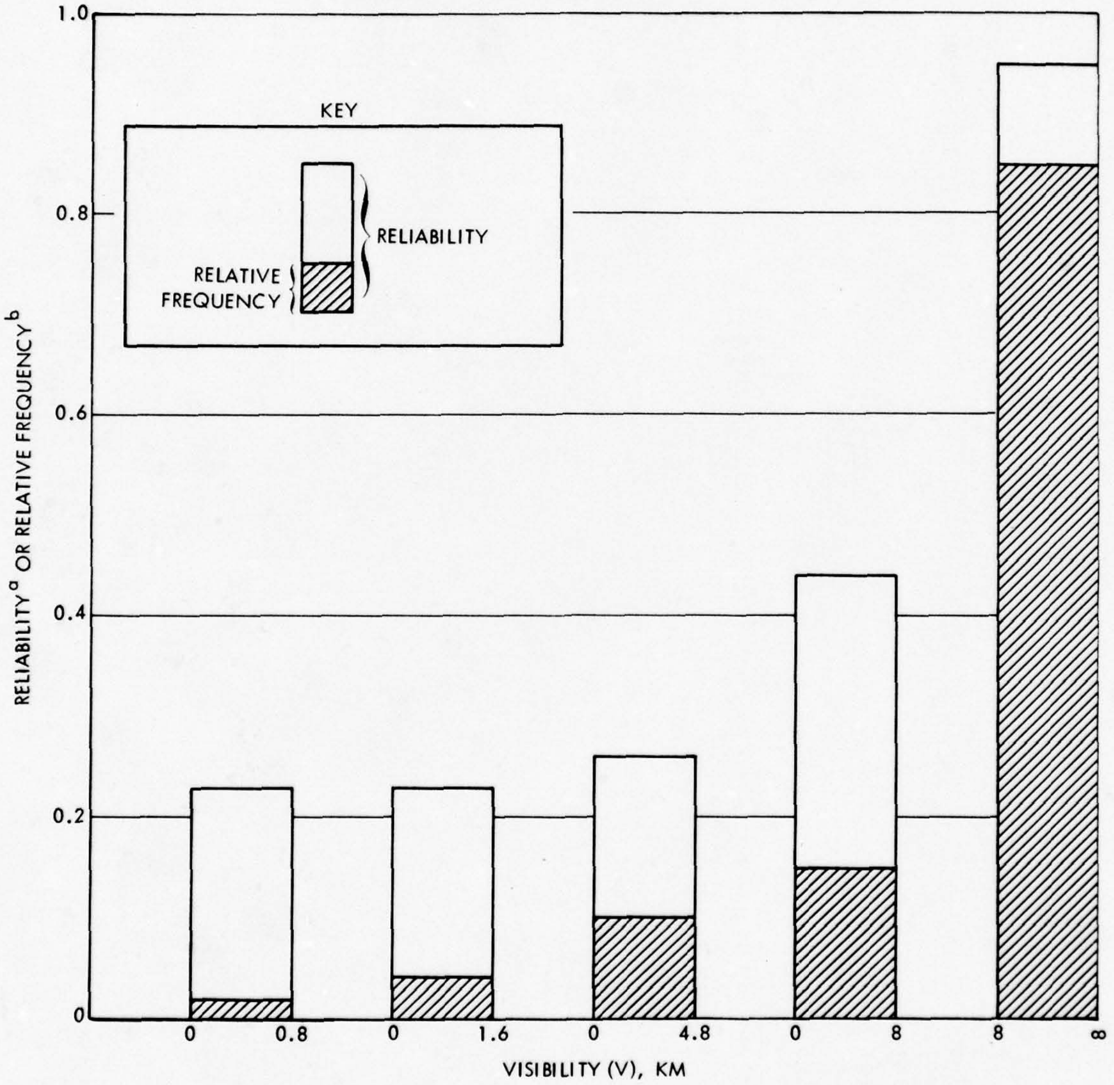
Statistical summaries of NWS verification of operational forecasts at many stations in the U.S. during the fall-winter period of 1975-76 are used as a basis for estimating 1977 forecast reliability. Similar AWS statistical summaries of forecast verification at European stations during the same seasons a year later are also considered. These statistical summaries, contained in Appendix G, are the distillation of recent independent efforts of the NWS and the AWS to evaluate their forecasting skills and methods.

Projections for 1985 are based on assuming that past improvements (over nearly the last three decades) of synoptic forecasting (using numerical weather prediction models) over persistence forecasting of a relatively easy-to-predict parameter, the height of the 500-mbar pressure level (see Appendix F) is an indicator of the near-term (next decade) improvements in forecasting more difficult (relatively) parameters, such as visibility, ceiling, and precipitation (see last section of Appendix E). Thus, the 1985 projections are based on optimistic assumptions of future improvements in mesoscale weather forecasting.

The high correlation between forecast reliability and weather event frequency is developed and discussed in Exhibits 14 and 15.

EXHIBIT 14: HISTOGRAM FOR FORECAST RELIABILITY AND FREQUENCY DATA

(EXAMPLE: 6-HOUR LOCAL FORECAST OF VISIBILITY IN FIVE DISCRETE CATEGORIES)



[a] OF CATEGORICAL FORECAST OF VISIBILITY (E.G., $0<V<0.8$)

[b] OF ALL VISIBILITY OBSERVATIONS

1-26-78-2

Exhibit 14

The histogram is based on test data from the Techniques Development Laboratory, NWS, and contained in Appendix G. The data, resulting from NWS efforts to verify local forecasts,[a] show that low forecast reliability is typically associated with relatively infrequent events and that high reliability is typically associated with events which are relatively frequent. A frequency distribution of the observations is given in the following tabulation.

Visibility (V), km	<0.8	<1.6	<4.8	<8	≥8	Total
No. of Observations	260	508	1477	2352	12970	15322
Fraction of Total	0.02	0.04	0.10	0.15	0.85	1.00

While the data indicate that low forecast reliabilities correspond to low visibilities and high reliabilities to good visibilities, that correlation exists because only a small fraction of the NWS observations (at 92 stations throughout the contiguous U.S. during October 1975 to March 1976) indicated the existence of low visibilities (i.e., low enough to be classified as "bad" weather as defined and discussed in Exhibit 8). In certain locales and in certain periods of the year, one can expect frequent occurrences of bad weather and, therefore, low correlation between forecast reliability and goodness of visibility. To illustrate, while good visibility (say, ≥ 8 km) is

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[a] It is assumed that the distribution of the approximately 15,000 observations in the verification testing is similar to the distribution of all weather event occurrences, i.e., the observations represent a large random sample from the universe of occurrences.

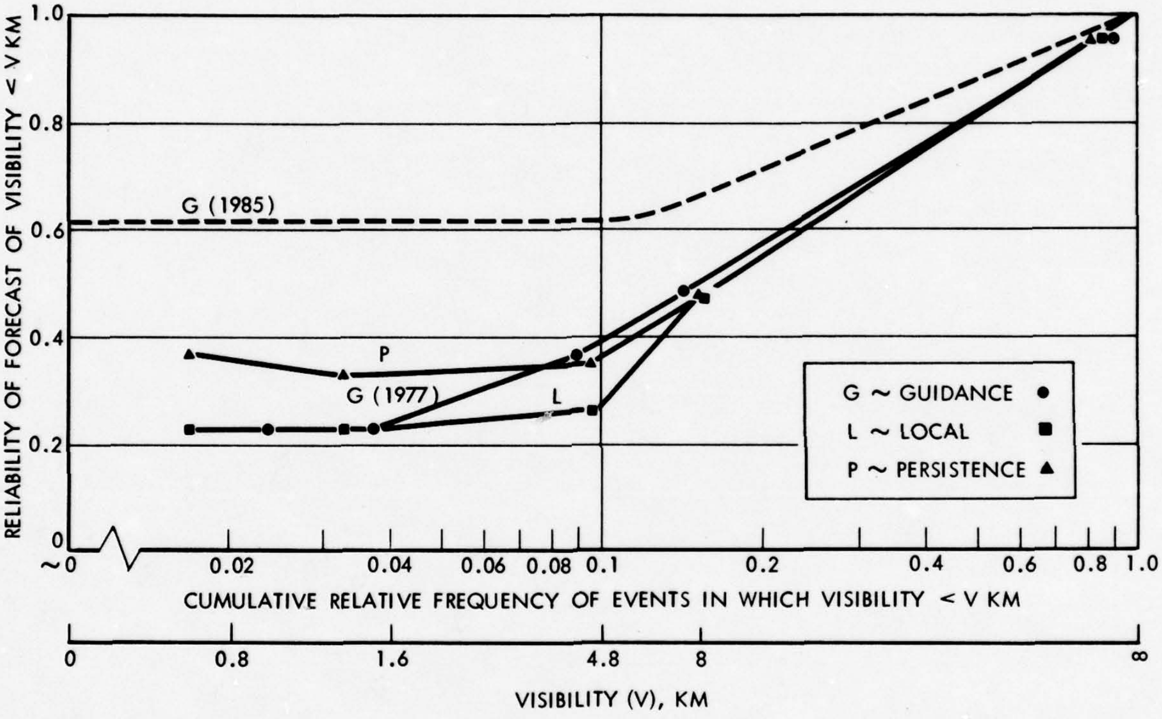
usually an appropriate forecast for White Sands, New Mexico, where such a weather event is nearly an everyday occurrence, low visibility due to morning fog in the fall and winter is also a relatively frequent occurrence, for example, in many of the valleys in the Appalachian Mountains and in valleys of central West German hill country. Similarly, poor visibility and low ceilings are frequent West Coast weather events, which can be quite reliably predicted as a consequence of the Pacific Coast fog produced during parts of the year.

Data used in a current study at the Institute for Defense Analyses on the effect of weather and atmosphere on sensor performance (Ref. 8) indicate that during West German winters, (worst weather periods) weather conditions, in which visibility is less than one mile, exist less than 15% of the time at many locations. However, one should not conclude that such low visibility is a relatively infrequent event in all parts of central West Germany since most meterological data are from observations at stations at or near airfields where better conditions would be expected than in mesoscale areas more susceptible to fog formation.

While the example shown in Exhibit 14 pertains to a 6-hour local forecast of visibility, one can observe similar relationships between forecast reliability and frequency of weather event: (1) for other types of weather events (e.g., ceiling < C ft); (2) for other forecast durations (3, 9, 12 hours, etc.); (3) in another data source (about 250,000 AWS verification observations collected at 35 European stations from September 1976 to March 1977); and (4) for other forecasting techniques. Exhibit 15 compares forecast reliabilities of the three mesoscale weather forecasting techniques, which include "persistence" and "guidance" in addition to "local," the technique used in this example.

EXHIBIT 15: PROJECTED IMPROVEMENT IN RELIABILITY OF MESOSCALE FORECASTS

(EXAMPLE: 6-HOUR FORECAST OF VISIBILITY < V KM)



1-26-78-1

EXHIBIT 15

A comparison of the reliability of three MWF techniques, which are briefly described below, is illustrated by continuing the analysis of the example in Exhibit 14.

PERSISTENCE: A forecast that the future weather condition during the time interval of the forecast will be the same as that existing now (Appendix D) or during a current time interval. The basis of this technique is observational data.

LOCAL: A manual forecast for which the mesometeorologist uses numerical guidance from computer products, mesoclimatological data, and/or subjective factors. Other popular names for this technique are "subjective," "man," or "station."

GUIDANCE: A model output statistics (MOS) forecast for which statistical methods are used to complement raw output of numerical prediction models. The MOS method matches local weather observations with numerical model results and then derives forecast equations by statistical techniques such as screening regression and regression estimation of event probabilities. This automated technique builds into the forecasting system some corrections for the bias and inaccuracy of the numerical model as well as the local climatology (Ref. 7). Popular names for this technique are "MOS" and "objective."

While empirical data provide, for each MWF technique, high reliability values for very high frequency weather events and a scattering of low reliability values for very low frequency events, no data are available for events which occur or are observed at medium frequencies. It is assumed that the interpolations shown between the low frequency data points and the high frequency data points in Exhibit 15 are reasonable approximations of forecast reliabilities over the intermediate frequencies.

Given that assumption, one can see that (1) NWS persistence forecasts are slightly better than local or guidance (1977) forecasts for infrequent events, and (2) all three MWF techniques provide similar reliabilities for about 90% of the events. The same observation applies to 12-hour forecasts of visibility and to 6- and 12-hour forecasts of ceiling (see Table G-48, Appendix G).

USAF AWS data (also found in Appendix G) from verification testing at European stations indicate AWS local (called "station" by AWS) forecasts are slightly better than AWS persistence forecasts. The AWS does not utilize the guidance forecasting technique.

The guidance (1985) line represents an estimated upper bound of MWF capability discussed in Appendix F. Bases for the projected improvement in forecasting such parameters as visibility, ceiling, precipitation, and surface winds are (1) introduction of the mesoscale numerical weather prediction (MNWP) model (35-km spatial resolution); (2) improved MOS performance because of better inputs (from the MNWP model rather than from the NWP model whose spatial resolution is about 200 km) and because of improved modeling of physical processes; and (3) more observations for the NWP model, whose synoptic output is utilized by the MNWP model, and for the MNWP model itself.

Although guidance is presently the poorest mesoscale weather forecasting (MWF) technique, all three MWF techniques are poor in predicting infrequent events. And whereas significant improvements in the guidance technique appear reasonable, and have been estimated in this analysis with the aid of experts in the mesometeorological community, significant improvements in forecast reliability are not expected for either the persistence or the local MWF technique. Thus, the guidance (1985) line in Exhibit 15 is typical of the most optimistic projection of MWF precision to be made on the basis of all of the data and advice provided by the mesometeorological community.

EXHIBIT 16: FORECAST RELIABILITY FOR VISIBILITY, CEILING, PRECIPITATION, AND SURFACE WINDS

	1977	1985	1977	1985	1977	1985	1977	1985	1977	1985
	VISIBILITY (V), STATUTE MILES (MI), AND KILOMETERS (KM)									
FORECAST PROJECTION, HR	$V < .5$ MI $V < .8$ KM		$V < 1$ MI $V < 1.6$ KM		$V < 3$ MI $V < 4.8$ KM		$V < 5$ MI $V < 8$ KM		$V \geq 5$ MI $V \geq 8$ KM	
6	37	61	37	61	40	61	44	66	94	97
12	24	50	24	50	28	50	37	57	92	96
24	14	44	14	44	20	44	29	50	91	94
	CEILING (C), FEET (FT)									
FORECAST PROJECTION, HR	$C < 200$		$C < 500$		$C < 1000$		$C < 2000$		$C \geq 2000$	
6	27	53	41	62	50	68	58	75	93	96
12	17	41	28	54	38	60	50	67	89	95
24	12	34	20	50	31	56	46	64	85	92
	PRECIPITATION (P), INCHES (IN.)									
FORECAST PROJECTION, HR	$P \geq 1$				$P \geq 0.5$				$P = 0$	
	FALL-WINTER		SUMMER		FALL-WINTER		SUMMER		ANY SEASON	
24	58	73	33	41	69	86	49	61	92	95
48	37	46	25	31	48	60	34	43	87	90
	SURFACE WINDS (W), KNOTS									
FORECAST PROJECTION, HR	$W \geq 23$		$18 \leq W \leq 22$		$13 \leq W \leq 17$		$8 \leq W \leq 12$		$W < 8$	
6	32	60	60	79	60	79	70	88	86	95
12	20	41	41	67	47	67	57	78	76	90
18	14	31	31	59	40	59	50	71	68	88
30	12	22	22	49	33	49	44	63	60	82
42	11	19	19	44	30	44	42	48	55	78

EXHIBIT 16

The data base for Exhibit 16 is contained in Appendix G. Sources of the 1977 data, from forecast verification efforts, are the Techniques Development Laboratory of NWS for visibility, ceiling, and surface winds; the National Meteorological Center of the NWS for precipitation amounts greater than 0; and the USAF AWS for zero precipitation data.

NWS data are used rather than AWS data for visibility and ceiling because of better data resolution: the former is categorized in five increments while AWS uses four categories for its forecast verification data.

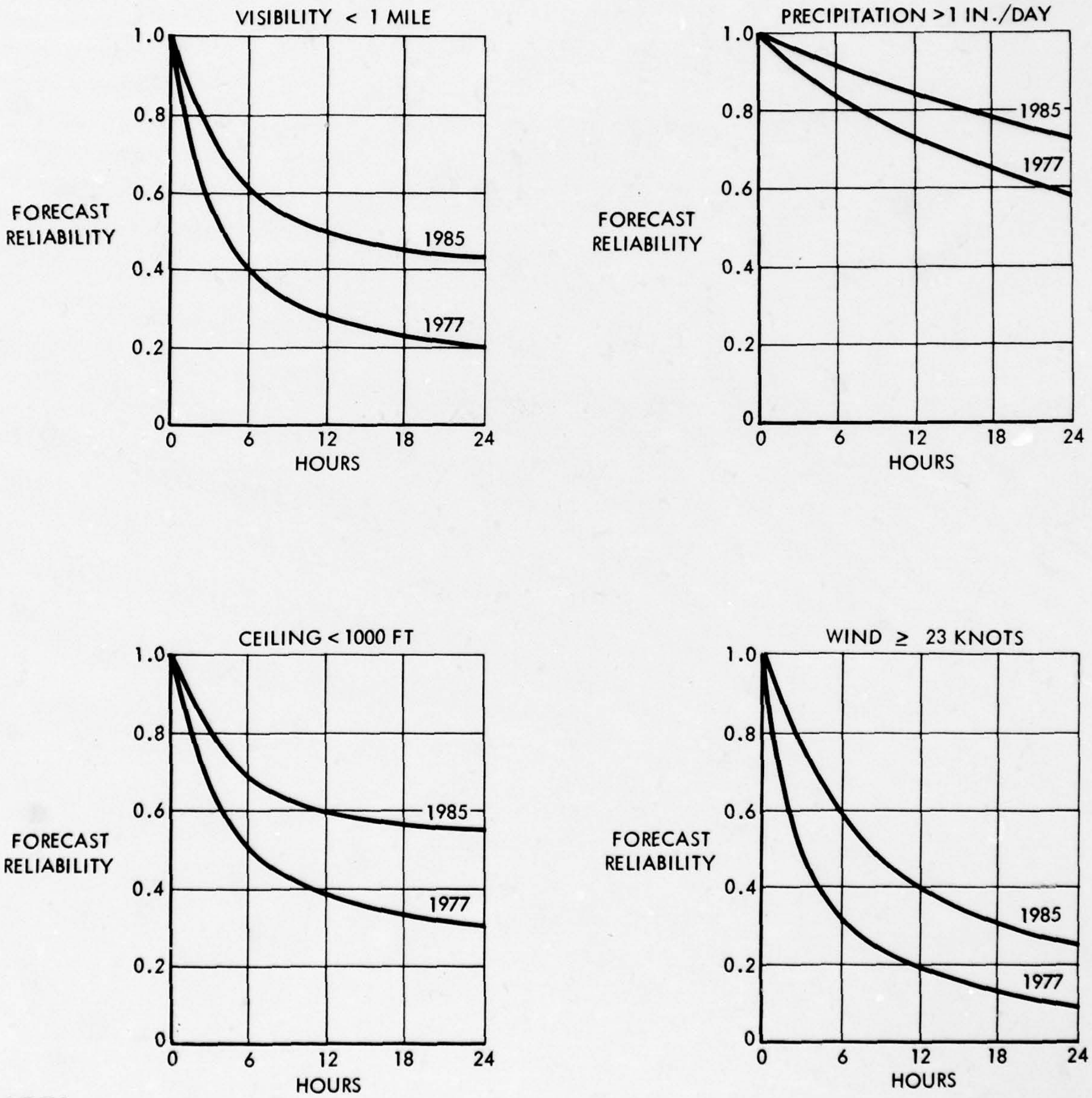
Projected forecast reliabilities for 1985 are based on realization of improvements in guidance forecasting summarized in Exhibit 15. As discussed in Exhibit 13 and Appendix F, quantification of projected improvements is based on an optimistic assumption that improvement over nearly the next decade in forecasting the values of relatively difficult-to-predict parameters will equal the observed improvement over nearly three decades in forecasting a relatively easy-to-predict parameter.

The 1985 projections of forecast reliabilities have been reviewed by meteorologists involved in the usage and management of forecasting systems, in weather forecasting R&D, and in developing forecasting models. A consensus appraisal is that the 1985 projections constitute an upper-bound estimate of the capability potentially available by the mid-1980s; no one considered the projections as pessimistic; in fact, many considered the estimate to be quite optimistic. The reviewers belong to the following organizations:

Techniques Development Laboratory, NWS
USAF Air Weather Service
National Center for Atmospheric Research
U.S. Army Training and Doctrine Command Headquarters
Pennsylvania State University, School of Meteorology

As previously indicated (Exhibit 8), reliable forecasting of bad weather events should be significant for more effective or efficient utility of tactical forces. Although one can expect bad weather events to occur frequently at certain locales and in certain seasons, USAF AWS weather data for 35 European stations (17 in Germany) during fall and winter (the worst weather seasons) indicate that bad weather events are, in general, infrequent events. (NWS weather data for 92 U.S. stations during fall and winter indicate a similar phenomenon.) Since the projected improvement in mesoscale weather forecasting precision is relatively minor for frequent events, which can already be forecast quite reliably (compared to forecasts of infrequent events) with present MWF capabilities, emphasis is given to bad weather events, for which improvements (albeit optimistic) in forecasting reliability by 1985 are much more significant.

EXHIBIT 17: GRAPHIC DEPICTION OF FORECAST RELIABILITY OF CERTAIN POTENTIALLY CRITICAL WEATHER EVENTS



9-20-77-1

EXHIBIT 17

Since potential improved utilization of tactical forces can reasonably be expected to be associated mainly with bad weather predictions, the forecast reliabilities of certain potentially critical (from the standpoint of providing decision thresholds) weather events, tabulated in the preceding exhibit, are graphically depicted in Exhibit 17.

If, for example, three hours from forecast issuance, visibility < 1 mile (1.6 km) or ceiling < 1000 ft constitute decision thresholds, a commander in 1985 could have, at best, forecasts of these events with 0.8 reliability whereas today the reliabilities are 0.6 and 0.7, respectively, for those visibility and ceiling states.

While the impact of visibility, ceiling, and winds are directly estimable, the effect of precipitation on ground mobility is estimated by integrating precipitation over a period of several days and considering specifics of the terrain.

EXHIBIT 18: BIASED (HIGHLY RELIABLE) FORECASTS

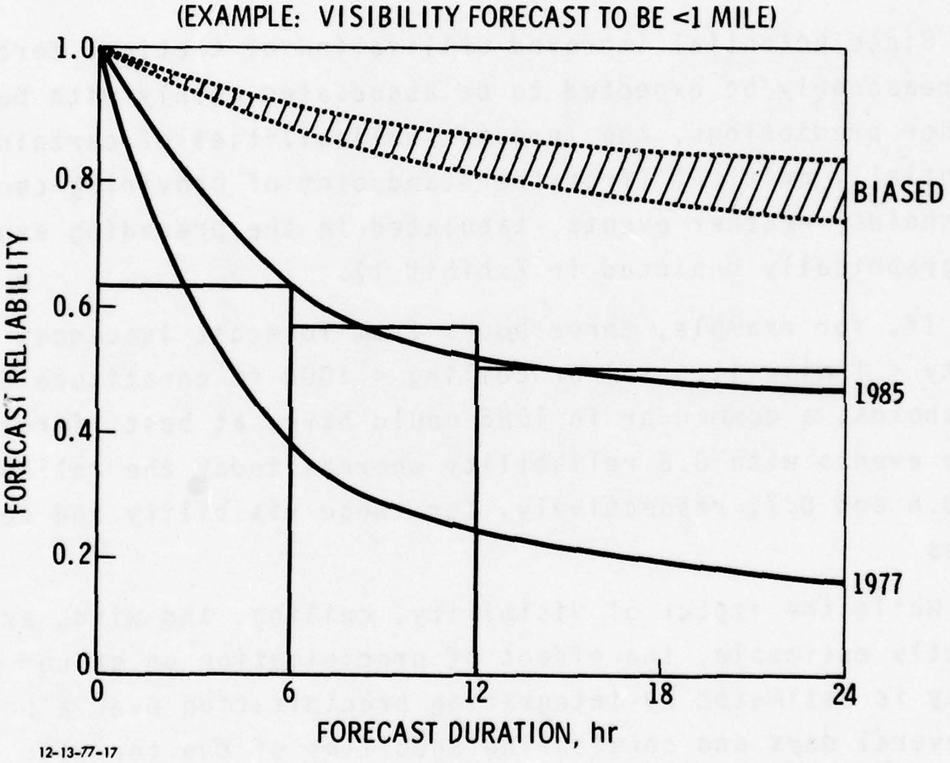


EXHIBIT 18

Data shown in Exhibits 16 and 17 represent average forecast reliabilities. It can reasonably be expected that in certain circumstances a forecaster will be more sure of his predictions than in others and in particular situations he may be very sure of his predictions. For example, at stations ahead of a strong, moving cold front, a forecaster might confidently predict precipitation from cumulonimbus or nimbostratus clouds forming in warm air just ahead of and over the cold front.

Certainly, weather forecasts biased in this way should be more highly valued in tactical decision making than average forecasts. Obviously, then, tactical commanders and their staffs should be apprised of forecaster confidence, especially when that confidence is high.

While, unfortunately, data appear not to be available on the fraction of weather forecasts which exceeds specified levels of forecaster confidence, it is not clear that the improvements in average MWF reliability projected for 1985 will significantly affect that unknown fraction of forecasts which are already quite reliable today. And, of course, as the specified confidence threshold is increased, fewer forecasts meet or exceed the threshold.

"Biased forecasting" is used in two contexts which differ with respect to the degree of certainty of the potential effects of atmospheric processes on near-future weather events. As used here, the term applies to cases in which those potential effects are quite certain. As revealed by forecast verification data (and discussed in Appendix E), "biased forecasting" applies to the tendency of forecasters, when the potential effects of atmospheric processes are obscure or ambiguous, to consider statistical data in forecasting weather events more frequently (overbiasing) or less frequently (underbiasing) than those same events have been observed at their stations, in order to enhance their scores in predicting certain weather events.

EXHIBIT 19: SUMMARY OF OBSERVATIONS RELATING TO CURRENT AND PROJECTED MESOSCALE WEATHER FORECAST RELIABILITY

1. FOR PREDICTING FREQUENT WX EVENTS, ALL MWF TECHNIQUES ARE CURRENTLY QUITE RELIABLE, AND ONLY MINOR RELIABILITY IMPROVEMENTS ARE EXPECTED BY 1985.

2. FOR PREDICTING INFREQUENT WX EVENTS, NO MWF TECHNIQUE IS CURRENTLY VERY RELIABLE, AND ONLY THE GUIDANCE TECHNIQUE OFFERS PROSPECTS FOR SIGNIFICANT RELIABILITY IMPROVEMENT BY 1985.

3. BAD WX EVENTS, WHOSE PREDICTIONS OFFER POTENTIAL FOR MORE EFFECTIVE OR EFFICIENT TACTICAL USE OF WEAPON SYSTEMS, ARE RELATIVELY INFREQUENT EVENTS, EXCEPT IN CERTAIN LOCALES AND SEASONS, IN WHICH BAD WX EVENTS ARE RELATIVELY FREQUENT AND CAN THUS BE CURRENTLY PREDICTED QUITE RELIABLY.

EXHIBIT 19

The first observation is supported by data and discussions in Exhibits 15 and 16.

The second observation is based on data and discussion in Exhibit 15. "Persistence" cannot forecast continuation of a nonexistent event. Since an infrequent weather state is unlikely to be observed at time of forecast, the "persistence" technique is also unlikely to predict its occurrence in the immediate future. NWS and AWS verification data indicate that the "local" MWF technique is also poor in predicting infrequent weather events unless biasing is involved (see discussion accompanying Exhibit 18). While "guidance" appears to be the only MWF technique with prospects for improvement in reliability (see discussion accompanying Exhibit 15), its dependence on statistics means that reliable predictions of infrequent weather events are also unlikely.

The third observation is based on material in Exhibits 8 and 14.

IV. OPERATIONAL UTILITY OF WEATHER FORECASTING IMPROVEMENTS

EXHIBIT 20: ARMY INPUT SOURCES

BRANCH	ORGANIZATION	LOCATION
ARMOR	ARMOR SCHOOL	FT. KNOX
ARTILLERY	FIELD ARTILLERY SCHOOL	FT. SILL
AVIATION	AVIATION CENTER	FT. RUCKER
CHEMICAL	ORDNANCE AND CHEMICAL CENTER	ABERDEEN PROVING GROUND
ENGINEERS	ENGINEER SCHOOL	FT. BELVOIR
INFANTRY	INFANTRY SCHOOL	FT. BENNING
INTELLIGENCE	INTELLIGENCE CENTER	FT. HUACHUCA
ALL	TRAINING AND DOCTRINE COMMAND	FT. MONROE
ALL	ARMY WAR COLLEGE	CARLISLE BARRACKS
ALL	COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY	FT. LEAVENWORTH

EXHIBIT 20

To obtain the views of a broad cross section of Army officers with varying educational, training, and experience backgrounds, on the potential tactical advantages of improvements in mesoscale weather forecasting, visits were made to the Army organizations indicated. The visits were preceded by letters (Appendix B is a copy of a typical letter) from the study sponsor (viz., the Office of Research and Advanced Technology, Director of Defense Research and Engineering) requesting Army assistance.

Discussions during the visits involved 55 Army officers of the branches indicated and 12 USAF and civilian meteorologists on duty with the Army. Selection of discussion participants was made by the individual organizations visited.

EXHIBIT 21

POTENTIAL PAYOFF OF IMPROVED WEATHER FORECASTING: MORE EFFECTIVE UTILIZATION OF WEAPONS SYTEMS THROUGH BETTER PLANNING

1. FORECAST: VISIBILITY PREDICTED TO BE 1 KM FOR 24 HR

   POSSIBLE PAYOFF: MOVE TOWs TO AREA WHERE THEIR 3-KM RANGE CAN BE UTILIZED AND REPLACE DRAGONs WHOSE RANGE IS 1 KM

2. FORECAST: VISIBILITY SO LOW FORWARD OBSERVER CANNOT ADJUST ARTILLERY FIRE

   POSSIBLE PAYOFF: MOVE ARTILLERY TO AREA WITH VISIBILITY ADEQUATE FOR OBSERVING IMPACT AREA

3. FORECAST: RAIN PREDICTED OF SUCH AMOUNT/RATE THAT TRAFFICABILITY WILL PRECLUDE UTILIZING TANKS

   POSSIBLE PAYOFF: USE TANKS IN AREAS WHERE THEY CAN MANEUVER

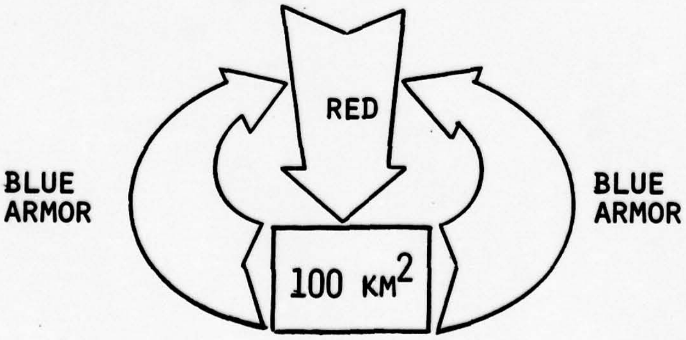


EXHIBIT 21

To initiate discussions with Army personnel of the organizations visited, most of the material in Exhibits 1 through 18 was presented. As a means of stimulating contributions from the Army participants, several hypothetical examples of potential payoff of improved weather forecasting were presented.

While the substance of Army contributions is contained in Exhibits 22-26, some comments on these specific examples are:

<u>Example 1</u>. Not feasible due to reasons discussed in Exhibit 23.

<u>Example 2</u>. If a forward observer cannot adjust artillery fire, other means, e.g., radar, would be used.

<u>Example 3</u>. Rather than using Blue tanks in an area where they are restricted to on-road movement, a commander would prefer to employ less mobile ATWs (TOW and DRAGON) against a potential Red armor threat, which would also be denied off-road mobility in that area. However, the variability of ground relief, soil conditions, drainage, vegetation, and recent precipitation history make it extremely difficult to develop an operationally useful model for estimating ground mobility characteristics from amounts and rates of precipitation.

EXHIBIT 22: DECISION DETERMINANTS IN TACTICAL PLANNING FOR A GIVEN MISSION

DECISION DETERMINANTS	KNOWLEDGE OF DETERMINANTS MEAN DECISIONS ARE MADE UNDER:
• FORCES AVAILABLE • TERRAIN	CERTAINTY
• ENEMY SITUATION SYSTEM PERFORMANCE STRENGTH & DISPOSITION INTENTIONS • WEATHER	UNCERTAINTY

MATRICES FOR DECISION MAKING UNDER UNCERTAINTY

ENEMY SITUATION

ADOPT OR REJECT COURSE OF ACTION A_1 ON BASIS OF PERCEPTION OF ENEMY SITUATION \ PERCEPTION OF ENEMY SITUATION	ACCURATE	NOT ACCURATE
ADOPT A_1[a]	CORRECT	ERROR
REJECT A_1	ERROR	CORRECT

[a] A_1 = HYPOTHETICAL COURSE OF ACTION WHICH IS CONSIDERED PRUDENT IF PERCEPTION OF ENEMY SITUATION IS CORRECT

WEATHER

ADOPT OR REJECT COURSE OF ACTION A_2 ON BASIS OF WX FORECAST \ WX FORECAST	ACCURATE	NOT ACCURATE
ADOPT A_2[b]	CORRECT	ERROR
REJECT A_2	ERROR	CORRECT

[b] A_2 = HYPOTHETICAL COURSE OF ACTION WHICH IS CONSIDERED PRUDENT IF WX FORECAST IS CORRECT

DECISION MAKING UNDER UNCERTAINTY

- AVOID RISK OF CATASTROPHIC ERROR
- ACCEPT RISK OF LOST OPPORTUNITIES
- CREATE HEDGES

1-16-78-7

EXHIBIT 22

Decision determinants in order of importance for tactical planning are: mission, forces available, enemy situation, terrain, and weather. For a given mission, terrain can usually be observed and maps can convey surface inequalities and vegetation details. Thus, terrain factors are essentially certain in tactical decision making.

While a commander and his staff should have a good knowledge of the performance of enemy systems (e.g., range of the T-62 tank gun) facing them, less is likely to be known of enemy strength and disposition, and even less of enemy intentions. Thus, tactical decision making is done with some uncertainty of enemy situation.

Since forecast weather is also an uncertain factor, tactical planning decisions are made with uncertainty of that determinant.

Occurrences of bad weather (as defined in Exhibit 8) such as low visibility, low ceilings, heavy precipitation, and high winds are, except in certain locations and seasons, relatively infrequent weather events which restrict weapon systems operations without endangering personnel and equipment if prudent operational limitations are observed. There is a set of even less frequent weather events, viz., thunderstorms, hail storms, cyclones, tornadoes, etc., which not only restrict and/or temporarily preclude weapon systems operations, but require measures--such as evacuation, sheltering, and tie-down--to reduce the exposure of personnel and equipment to very high winds, flying debris, hail, etc. In a combat environment, however, prudent measures to safeguard personnel and equipment from the effects of severe weather would not be undertaken without consideration of the enemy situation.

The relative ordering of the importance of tactical decision determinants does not mean that weather circumstances cannot at times create operational imperatives for a tactical command (for example, relocation of helicopters from bases expected to soon be exposed to severe weather--very high winds or heavy precipitation).

While the form of the responses of the many Army officers varied on how tactical decisions are made under uncertainty, the essence of the responses encompassed classical rules for decision making under uncertainty: (1) avoid risks of catastrophic errors (i.e., do not plan actions whose outcome could result in failure to complete mission, or to achieve objectives, or in unacceptable losses); (2) accept risk of lost opportunities (to avoid unacceptable outcomes); and (3) create hedges (i.e., alternative courses of action).

As an example, suppose a commander decides that for his next day's operations the destruction of a certain target is critical to the success of his mission and that using aircraft is preferred to artillery from force economy considerations. And further suppose that the weather forecaster and the commander are 99/100 sure that early morning weather will be suitable for an air strike. If that target is really critical (its survival means mission failure or unacceptably high losses), the prudent commander plans an air strike but also hedges by moving some artillery weapons to positions from which the target can be bombarded (this movement is an alternative course of action, which may preclude using those weapons against other targets at that time) if the weather unexpectedly precludes attack by air.

While that is an example relating prudent decision making to a very reliable weather forecast, command prudence is valuable also with forecasts of low reliability. For example, suppose a weather forecaster and a helicopter unit commander are 1/100 sure that during the night following the current day's operations, the local base will experience high winds which could cause substantial helicopter damage if the rotor blades are left in their normal extended position. To avoid risk of damage, the prudent commander would have (1) the crews, before securing, take the few minutes required to fold or tie down the rotor blades of all helicopters other than one or two which might remain on standby alert during the night and (2) personnel ready to fold blades on the standby aircraft at the first sign of increased wind velocity.

EXHIBIT 23: BATTLEFIELD DECISION MAKING

LATERAL UNIT DEPLOYMENTS TO TAKE ADVANTAGE OF WX FORECASTS ARE NOT FEASIBLE BECAUSE OF SEVERAL FACTORS:

- TRANSPORTATION
- FIRE PLAN INTEGRATION
- PSYCHOLOGY
- LOGISTICAL SUPPORT

COMBAT SYSTEMS ARE SUFFICIENTLY WEATHER-ADAPTABLE THAT WEATHER FORECASTS ARE CHARACTERISTICALLY NOT CRITICAL CONSIDERATIONS

PERCEPTION OF ENEMY SITUATION AND TERRAIN REALITIES ARE DOMINANT CONSIDERATIONS IN TACTICAL PLANNING

MIGHT ADJUST INDIVIDUAL POSITIONS BUT NOT REDEPLOY WHOLE UNITS

DEFICIENCIES IN CURRENT WX INFORMATION, NOT IN WX FORECASTS, ARE THE MAJOR METEOROLOGICAL CONCERN

EXHIBIT 23

Lateral unit deployments, such as described in the first example of Exhibit 21, to take advantage of a weather forecast are not feasible due to several considerations.

Transportation. Additional transport equipment would be required to facilitate increased lateral movement (by helicopter and truck as well as on foot). While the increase in equipment is not itself a compelling deterrent, the movements near the forward edge of the battle area (FEBA) would occur in the already most congested area of operations.

Fire Plan Integration. A unit in an area A has had its position and firing zones assigned in an integrated fire plan for A. Redeploying a unit from A to another area B requires a modification of the B fire plan to integrate the fire capabilities of the new unit.

Psychology. Disruption of organizational integrity in A by redeploying a unit to another organization in B involves the units of the latter organization relying on, and being relied on by, the new unit for mutual fire support. Such reliance is greatly fostered by personal relationships and confidences that accrue from stability of organizations in A and in B.

Logistical Support. Exchanging units, such as in the first example of Exhibit 21, would require lead time to change previously planned flows of unique supplies (e.g., TOW and DRAGON missiles in the example) to logistical organizations responsible for supporting new forward units, thus requiring additional flexibility of an already busy logistics system.

These considerations make it impracticable to deploy ground-based weapon systems on the basis of weather forecasts unless the forecasts are very reliable and unless the weather is expected to remain relatively steady long enough to make such weather-forecast-induced deployments worthwhile.

The total effect of the above considerations is to make experienced Army officers feel that the reliability improvements projected in Exhibit 16 for 1985 weather forecasts will not influence battlefield decision making nor provide opportunities to utilize forces differently than they would today.

A recurring observation in discussions with Army officers of all branches addresses the adaptability of systems (personnel and hardware) to weather: the Army's combat systems can characteristically function over a wide range of weather conditions so that weather forecasts are usually not critical considerations for tactical decisions on the battlefield. When forecast weather is expected to limit system performance, tactical decision makers still give primary importance to their perception of enemy situation and to realities of the terrain. Improving current weather information appears to be of much greater concern than are potential weather forecasting improvements.[a]

Even with the improved forecast reliabilities, tactical planning will continue to be dominated by considerations of enemy situation (as perceived) and the terrain. While a commander may adjust individual fire positions because of weather (rather than redeploy a whole unit), such adjustments are local and would be based on current weather trends rather than on weather forecasts (e.g., as visibility decreases, say, from 3 km to 1 km, to move TOW ATWs in an area forward to positions which offer improved engagement potential).

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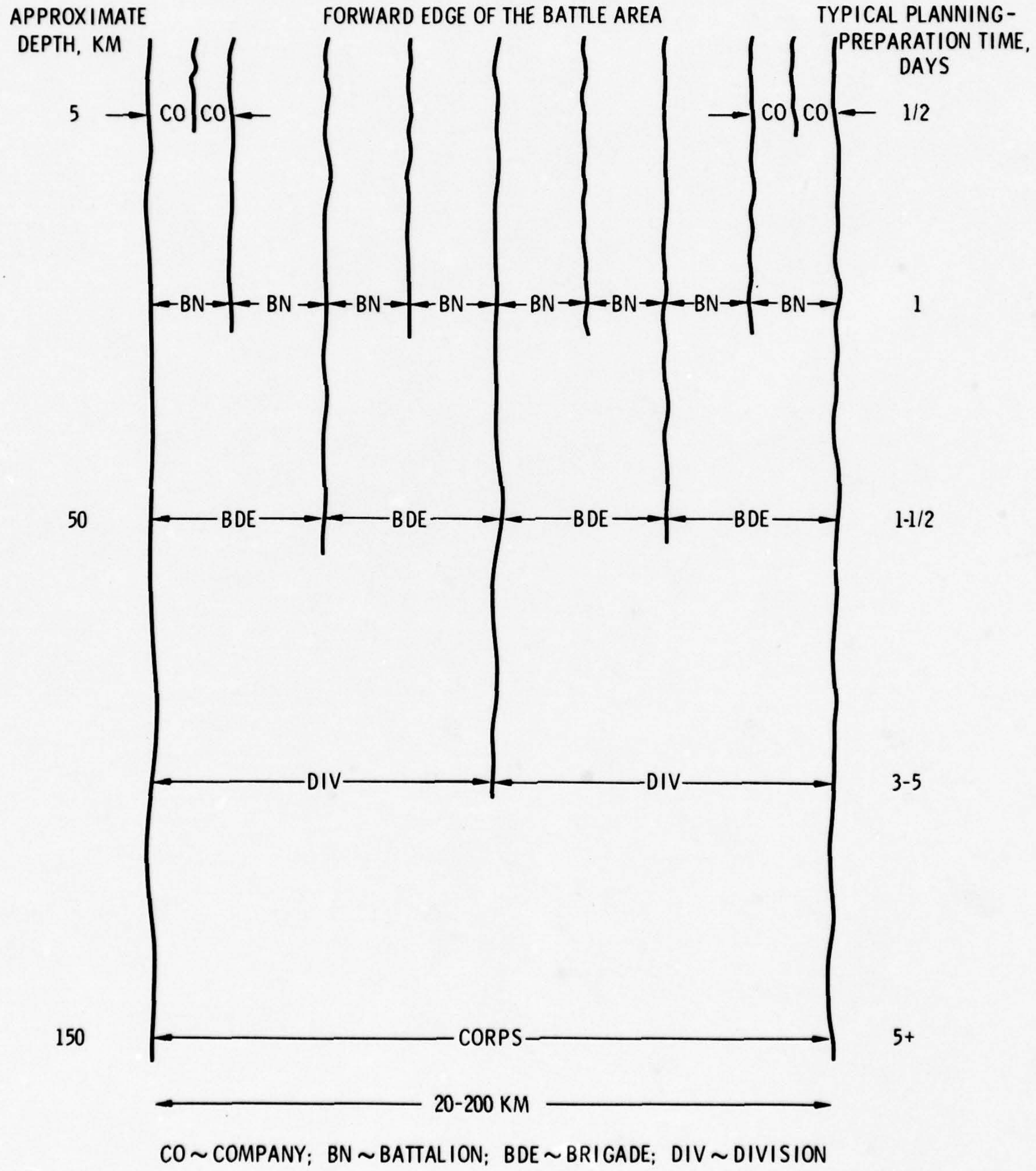
[a] This concern is especially acute to chemical staff officers who appear to be without any weather data relevant to their interests.

EXHIBIT 24: SPAN OF CONTROL AND PLANNING-PREPARATION TIME



12-14-77-5

EXHIBIT 24

The sketch shows typical distances[a] over which control is exercised by various Army command echelons and their typical planning-preparation times.

The planning-preparation times represent times typically required by the command echelons indicated for operations involving the whole command or operations in which the command has the initiative. Obviously, planning-preparation times could be shorter when a command is planning the utilization of only part of its force (e.g., division may be maintaining control of division artillery while putting all other division combat elements under control of its brigades) or when the enemy situation requires quick response (e.g., to an unexpected attack).

---

[a] Unit depths are from Army Field Manual FM 100-5, Operations. Corps area width is estimated range of distances of Corps responsibility for defensive and offensive operations. In some defensive scenarios, Corps frontage may exceed 200 km.

EXHIBIT 25: WX FORECASTING, PLANNING, AND COMMAND LEVELS

LOWER COMMAND LEVELS (BRIGADE, BATTALION, COMPANY, PLATOON)

- EXECUTE HIGHER LEVEL PLANS
- LIMITED FLEXIBILITY

HIGHER COMMAND LEVELS (DIVISION & CORPS)

- MUST ENLARGE TIME WINDOWS FOR LOWER ECHELONS ACHIEVING OBJECTIVES IF THE LOWER COMMAND LEVELS ARE TO TAKE ADVANTAGE OF WX FORECASTS
- ENLARGING TIME WINDOWS IS NOT PRACTICABLE BECAUSE LOWER ECHELON OBJECTIVES ARE MUTUALLY SUPPORTING

BIASED FORECASTS ARE OBVIOUSLY WELCOMED--BUT LITTLE ADVANTAGE TO HIGHER COMMAND LEVELS IS APPARENT SINCE DURATION OF RELIABLE FORECASTS IS SO MUCH LESS THAN TIME FOR TACTICAL PLANNING-PREPARATION

EXHIBIT 25

Exhibit 22 identified tactical decision determinants for any command level. Exhibit 24 distinguished the various command levels by control span and planning-preparation time. This exhibit summarizes the nature of tactical planning and the impact of weather forecasting at those command levels.

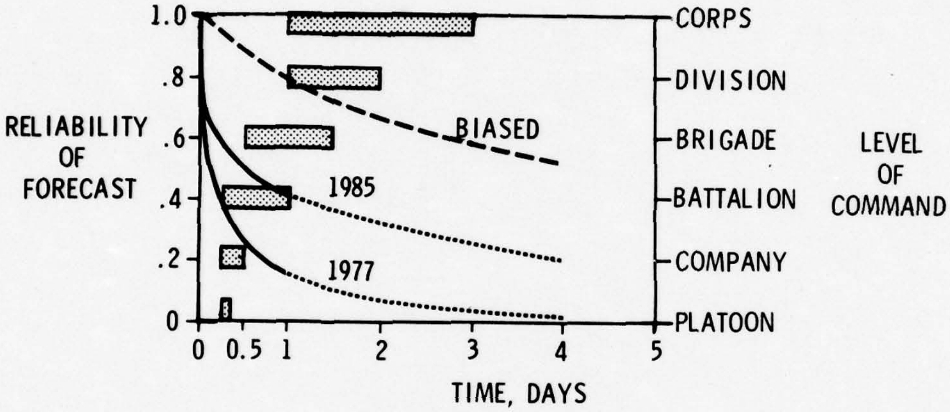
Tactical planning involves (1) development of a scheme of maneuver, (2) fire planning, and (3) logistical planning. While each command level develops a scheme of maneuver to achieve its objective, staff planners are increasingly concerned with fire planning at the lower command levels (at platoon and company levels almost all planning is fire planning) and logistical planning at the higher command levels.

Characteristically, lower level commands carry out, and develop their own plans in accordance with, higher level command plans which specify mission, objectives, and times. Thus, lower level commands are constrained in their planning flexibility. If they are to have greater flexibility to react to weather forecasts, their orders from higher level commands must allow greater flexibility in the times for executing assigned missions or achieving their objectives. But because the missions and objectives of lower command echelons are characteristically mutually supporting, it is not really practicable for the higher commands to provide more flexibility in timing. (Operations of a football team are a good analogy: play execution requires close-knit timing for carrying out many individual, but coordinated, assignments.)

Even a biased weather forecast (i.e., a very reliable one for a weather event, say, in 6 hours) for a mesoscale area of one unit (say, a battalion in a 5×5 km^2 area) is unlikely to influence the planning or actions of that unit since its mission and objective and the times for their execution/achievement are already set by a higher level command (say, a division with 24 hours for planning and preparation) along with missions, objectives, and times for its other units in different mesoscale-sized areas.

EXHIBIT 26: COMPARISON OF WX FORECAST DURATION AND PLANNING-PREPARATION TIME

(EXAMPLE: VISIBILITY FORECAST TO BE<1 MILE)



▨ ~ RANGE OF TYPICAL PLANNING-PREPARATION TIMES FOR VARIOUS COMMAND LEVELS

9-9-77-10

EXHIBIT 26

Although visibility less than one mile is the forecast example to illustrate the comparison of forecast duration and planning-preparation time shown, the following discussion should be equally valid if other bad weather events (e.g., those in Exhibit 17) were used.

The forecast reliability data (Exhibit 16) are extrapolated to several days to compare forecast duration and reliability decay with typical maximum amounts of time various commands require for planning and preparation. The ranges of planning-preparation times shown are based on discussions with many experienced Army officers and on information requirements outlined in Ref. 9. Of course, only the 0-1 day portion of the continuum of forecast reliability represents the time scale for mesoscale weather forecasting.

Optimistic projections of 1985 reliability are high enough to be potentially useful to only the lowest command echelons. Exhibit 25, however, indicates that these lowest echelons have minimal flexibility to react to weather forecasts; and Exhibit 23 indicates that tactical operators consider the additional difficulties and costs of lateral redeployment of units as outweighing the potential operational advantages even when forecast reliability is high.

Biased forecasts are obviously potentially more useful than average forecasts but, just as obviously, there is an inverse relationship between the standard (i.e., threshold level of forecaster confidence) for forecast reliability and the fraction of forecasts which meet that standard. And (from Exhibit 25 discussions) missions, objectives, and execute/achieve times established by higher level commands are tactical imperatives allowing little flexibility for the lower command levels, which are also more strongly influenced by their perception of enemy situation and by terrain realities than by reliable, near-future weather forecasts.

As indicated in the Exhibit 16 discussion, improvements in average mesoscale weather forecasting may not significantly impact the biased forecasts, which are already quite reliable today.

V. FINDINGS AND CONCLUSIONS

EXHIBIT 27: SUMMARY OF FINDINGS

1. BATTLEFIELD TACTICAL PLANNING IS PRIMARILY DONE AT CORPS AND DIVISION LEVELS.
2. AT ANY LEVEL OF COMMAND, MISSION, FORCES AVAILABLE, ENEMY SITUATION, AND TERRAIN ARE DOMINANT CONSIDERATIONS IN TACTICAL PLANNING.
3. AT LOWER COMMAND LEVELS (VIZ., BATTALION, COMPANY, AND PLATOON) CONSISTENT WITH MESOSCALE GEOGRAPHIC AND TIME DIMENSIONS, TACTICAL DECISIONS ARE INFLUENCED BY MISSION, ENEMY SITUATION, TERRAIN, AND WEATHER IN THAT ORDER.
4. THE MUTUAL-SUPPORTING NATURE OF MISSIONS AND OBJECTIVES OF LOWER COMMAND LEVELS LIMITS THEIR FLEXIBILITY TO REACT TO WEATHER FORECASTS.
5. RELIABILITY OF OPTIMISTIC NEAR-TERM (1985) MESOSCALE FORECASTS OF WEATHER, WHICH LIMIT SYSTEM PERFORMANCE, APPEARS TO BE INSUFFICIENTLY BETTER THAN RELIABILITY OF CURRENT (1977) FORECASTS TO AFFECT BATTLEFIELD OPERATIONS.
6. IMPROVEMENTS IN CURRENT WX INFORMATION RATHER THAN IN WX FORECASTING MAY BE MORE IMPORTANT TO BATTLEFIELD OPERATIONS.

EXHIBIT 28: CONCLUSIONS

1. AN OPTIMISTIC IMPROVEMENT IN MESOSCALE WEATHER FORECASTING CAPABILITY PROJECTED FOR 1985 APPEARS TO PROVIDE NO ADDITIONAL UTILITY FOR ARMY FORCES.
2. A PHASE 2 EFFORT TO CONSIDER CAPABILITY-COST TRADEOFFS FOR A MWF SYSTEM FOR ARMY OPERATIONS IS NOT WARRANTED.
3. IF A PHASE 2 EFFORT IS UNDERTAKEN, CONSIDERATION SHOULD BE GIVEN TO ASSESSING THE INFLUENCE OF WX INFORMATION, FOR USE IN CURRENT OPERATIONS AS WELL AS FOR PREDICTING INPUTS FOR PLANNING, ON ARMY TACTICAL OPERATIONS.

APPENDIX A

TASK ORDER

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
1400 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22209

TASK ORDER FOR WORK TO BE PERFORMED
BY
INSTITUTE FOR DEFENSE ANALYSES

TASK ORDER T-135 DATE: 26 MAY 1976

You are hereby requested to undertake the following task:

1. TITLE: Mesoscale Weather Forecasting

2. OBJECTIVE: The objective of this task is to evaluate potential mesoscale weather forecasting systems -- including components related to data collection, processing and communication functions -- for support of tactical military operations in the mid-1980s. "Mesoscale" implies regional forecasting to resolutions of, for example, 20 km, as opposed to "macroscale" forecasting whose typical resolution is on the order of 400 km.

3. TECHNICAL SCOPE: An assessment will be made of likely technical advances in components of mesoscale weather forecasting systems for the mid-1980s. Appropriate combinations of components forming alternative mesoscale systems will be evaluated with respect to (1) potential improvements in tactical operational capability that technology advances might provide and (2) marginal costs, procurement and support, of advanced mesoscale systems over similar costs of current forecasting systems. The task is to be accomplished in two phases, with a review prior to phase 2 to determine whether phase 1 analyses suggest continuation is worthwhile. The phase 1/review/phase 2 division of the task is as follows:

Phase 1: Identify parameters useful in describing weather prediction precision, e.g., spatial resolution of predicted weather, duration of prediction, and lead time until prediction is operative. Determine the highest precision mesoscale weather forecasting system that appears technically feasible for the mid-1980s. Identify ways and, if possible develop some measurable indicators that relate tactical operational capability to weather forecasting precision.

Review: If phase 1 analyses indicate potential payoffs exist for advanced mesoscale forecasting, phase 2 analyses would be conducted. If potential increases in operational capability with the highest precision mesoscale system are not expected, phase 1 results will be presented in a report which summarizes the significant findings and the methods of analysis used.

Phase 2: Complete mesoscale weather forecasting analysis to include systems offering lower levels of prediction precision. Relate potential increases in operational capability to mesoscale system options. Estimate costs, acquisition and support, of projected mesoscale system options and current weather forecasting systems. Results of the entire study, phases 1 and 2, will be presented in a report which will summarize the significant findings and the methods of analysis used.

The technical assessment of mesoscale systems should include worldwide applications. Costs and operational capability estimates should apply to a major theater, e.g., Central Europe.

4. SCHEDULE: Work on this task shall commence upon task order acceptance. Phase 1 will be completed by 1 July 1977. If the task is not continued into phase 2, a draft phase 1 report will be delivered by 1 September 1977. Phase 2, if undertaken, will be completed and a draft report of work on the entire task will be delivered by 1 April 1978.

5. COORDINATION: Coordination with personnel of the Navy, Air Force, and Army Weather Service Programs, the Defense Meterological Satellite Program, the Federal Aviation Administration, the National Oceanographic and Atmospheric Administration, and various operational planning staffs of the military Services will be necessary during the period of study.

6. TECHNICAL COGNIZANCE: Assistant Director (Environmental and Life Sciences), ODDR&E, who will decide on phase 2 continuation.

7. SCALE OF EFFORT: Two (2) man-years, including consultants as required by IDA, for phase 1. Two (2) man-years, including consultants as required by IDA, for phase 2. Not more than three (3) man-months of effort will be expended prior to 1 October 1976.

8. REPORT DISTRIBUTION AND CONTROL: The Assistant Director (Environmental and Life Sciences), ODDR&E, will determine the number of copies of reports and their distribution. A "need-to-know" is hereby established in connection with this task and access to classified documents and publications, security clearances and the like, necessary to complete the task, will be obtained through the Director, ARPA.

G. H. Heilmeier
George H. Heilmeier
Director

ACCEPTED: Alexander H. Flax
Alexander H. Flax
President, IDA

DATE: 20 April 1976

APPENDIX B

ODDR&E LETTER TO ARMY WAR COLLEGE

23 JUN 1977

Major General DeWitt C. Smith, Jr.
Commandant
U.S. Army War College
Carlisle Barracks, PA 17013

Dear General Smith:

The Institute for Defense Analyses (IDA) is evaluating for this office the potential tactical utility that might be derived by extending weather forecasting capabilities from the current coarse resolution of hundreds of kilometers to finer, mesoscale resolutions of the order of a few kilometers. Through consultation with the scientific community, IDA has developed a best estimate of the expected improvement in weather forecasting through the mid-80s. We are now seeking your help to measure the benefits of such improvements. Because weather forecasts are only one of several factors considered in tactical planning, we need the pragmatic view of your faculty and students to identify specific potential tactical advantages that might result from improvements in mesoscale weather forecasting.

The attached information presents the problem in detail, and sets forth the questions to be answered. While your assistance is most important for this task, I would like to minimize the burden of this request by asking for a point of contact with whom the IDA people can arrange a visit to discuss the matters indicated and to receive any response you can provide. Attachment 4 contains the names, addresses, and telephone numbers of the IDA personnel participating in this study. Your point of contact can identify himself merely by calling any one of the IDA people.

Thank you for your assistance.

Sincerely,

(Signed) Donald I. Carter fr

John L. Allen
Deputy Director
(Research and Advanced
Technology)

Attachments

DISTRIBUTION LIST: Weather Evaluation Study

Commander, U. S. Army Intelligence Center and School, Ft. Huachuca, AZ

Commandant, U. S. Army War College, Carlisle Barracks, PA

Commanding General, U. S. Army Aviation Center, Fort Rucker, AL

Commandant, U. S. Army Command and General Staff College,
Fort Leavenworth, KS

Commandant, U. S. Army Armor School, Fort Knox, KY

Commandant, U. S. Army Engineer School, Fort Belvoir, VA

Commandant, U. S. Army Infantry School, Fort Benning, GA

Commandant, U. S. Army Field Artillery School, Fort Sill, OK

Attachment 1

Statement of Problems

Problem: Given the expectation that the accuracy of weather forecasting will improve, will improved weather forecasting permit better utilization of available forces, principally in a postulated European theatre in 1985?

The following are constraints on this study:

1. It is focused on potential Army operations in the European theatre during the mid-1980s.

2. It considers only weather forecasting for short-range tactical planning; i. e., it excludes either climatology (for long-range strategic planning) or meteorological observations for "combat information" (e. g., using current or recent wind observations for gun aiming).

3. It considers how improvements in mesoscale weather forecasting might improve tactical capabilities for day-to-day operations, in contrast with the infrequent epic events such as the Normandy invasion during World War II.

4. It assumes that improved weather forecasting is unlikely to cause changes in force structure. This assumption implies that we will, for example, continue to develop and procure "all-weather" systems because their usefulness is fairly certain even without considering specifics of time and geography for their employment.

To provide initial stimulus for your thinking, Attachment 2 contains some examples of potential advantages to tactical planners. They have been oversimplified by assuming that predictions of weather phenomena are 100 percent correct and omitting many details pertinent to any tactical scenario. It is at this point that we seek your assistance to interject real world specifics. You may recall scenarios or use stylized scenarios (in current course work) which enables you to identify specific tactical advantages that might be realized with improved weather forecasting capability.

While there are numerous environmental considerations related to tactical operations, our attention is focused on a few primary parameters: (1) visibility and ceiling, which affect target acquisition and weapon delivery, and (2) precipitation, which can affect trafficability and, hence, ground mobility. We are, therefore, including our current (1977) and projected (1985) forecast capabilities for these parameters in Attachment 3. Also included are definitions of parameters (viz., spatial resolution and lead time) which appear important for utilization of weather forecasts. Based upon the prediction precisions (probability of correct forecast) in Attachment 3, would you identify possible ways forces (any echelon from battalion to corps) might be used more effectively or efficiently. Of course, we are especially interested in whether the set of data for 1985 provides a possible basis for improved force utilization.

Attachment 2

Examples of potential payoff of improved weather forecasting for more effective utilization of weapon systems through better planning.

1. Forecast: Visibility in an area is predicted to be 1 km or less for 24 hours.

Possible Payoff: Move TOW systems to an adjacent area where their 3-km range might be better utilized and replace the TOW ATW force (or part of it) with DRAGON teams from the area of predicted better visibility.

2. Forecast: Visibility so low that a forward observer will not be able to adjust artillery fire for 24 hours.

Possible Payoff: Move artillery to an area with visibility adequate for observing area of intended impact.

3. Forecast: Rain of such amount and rate that trafficability will preclude tank maneuvering off-roads in a 100 km^2 area for 24 hours.

Possible Payoff: Assuming friendly force is defensively-oriented, deploy tanks to nearby area with adequate trafficability rather than assign them a static defensive role.

4. Forecast: Ceiling and/or visibility too low for helicopter in an area for 24 hours.

Possible Payoff: Plan operations for which helicopters, attack or transport, are critical in other areas.

Possible Problems: While the last example of better planning of helicopter utilization to take advantage of weather forecasts is quite obvious and surely considered today, certain problems in connection with lateral shifting of ground-based systems and units need evaluation: (1) additional demands on transportation resources (ground-based and transport helicopter) and (2) additional coordination of shifted systems (weapons plus operators) with adjacent and supporting units. Also, the probabilities of phenomena predictions being correct beyond a few hours may be too low to provide a reliable basis for force movement considerations.

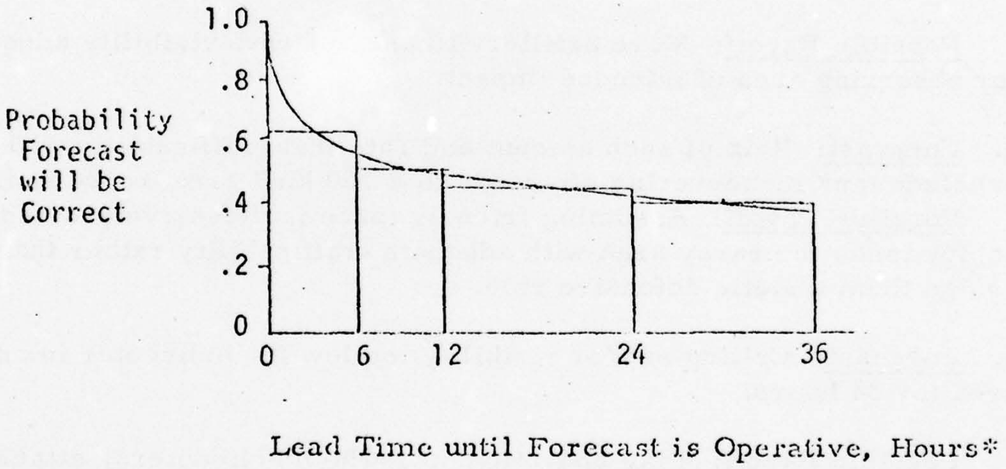
Attachment 3

Utilization (for planning) and precision (probability forecast will be correct) of visibility, ceiling, and precipitation predictions.

Spatial Resolution: Expected to be 4 km x 4 km for 1977 and 1985. It means that the visibility, ceiling, or precipitation phenomenon will occur in part (from small to large) or all of a 4 km x 4 km grid square with probabilities tabulated on the following page. A whole theater could be divided into a collection of similarly-sized grid squares for weather forecasting purposes.

Lead Time: Time available for tactical planning (e. g., force movement) to take advantage of prediction of weather phenomenon.

Example: Visibility is forecast to be less than 0. 8 km using 1985 state-of-the art



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* Thus, for example, a 0. 61 probability that actual visibility in (part or all of) a 4 km x 4 km grid square will be less than 0. 8 km provides no time to move forces to take advantage of the forecast for the next 6-hour period; a 12-hour lead time, during which forces might be moved, provides 0. 44-probability of correct prediction for the 12-24 hour period; and a 12-hour lead time provides about 0. 42 probability of correct visibility prediction for the 12-36 hour period.

PROBABILITY OF CORRECT FORECAST*

*[Ratio of correct number of forecasts/number of observations] x 100

	1977	1985	1977	1985	1977	1985	1977	1985	1977	1985
	Visibility (V), Statute Miles (mi), and Kilometers (km)									
Forecast Projection, hr	V < .5 mi V < .8 km		V < 1 mi V < 1.6 km		V < 3 mi V < 4.8 km		V < 5 mi V < 8 km		V > 5 mi V > 8 km	
6	37	61	37	61	40	61	47	66	94	97
12	24	50	24	50	28	50	37	57	92	96
24	14	44	14	44	20	44	29	50	91	94
36	10	40	10	40	16	40	24	47	90	93
	Ceiling (C), Feet (ft)									
Forecast Projection, hr	C < 200		C < 500		C < 1000		C < 2000		C > 2000	
6	27	53	41	62	50	68	58	75	93	96
12	17	41	28	54	38	60	50	67	89	95
24	12	34	20	50	31	56	46	64	84	92
36	10	31	18	49	28	55	45	63	82	90
	Precipitation (P), Inches[a] (in.)									
Forecast Projection, days	P ≥ 1				P ≥ 0.5				P = 0	
	Fall/Winter		Summer		Fall/Winter		Summer		Fall/Winter ~ Summer	
1	58	73	33	41	69	86	49	61	92	95
2	37	46	25	31	48	60	34	43	87	90

[a] P refers to the forecast rainfall in a 24-hr period.

Attachment 4

Identification of personnel involved with mesoscale forecasting study.

Mr. Murray Kamrass	Institute for Defense Analyses Arlington, Virginia 22202	558-1667[a]
Mr. Henry Hidalgo	same as above	558-1644[a]
Mr. John Metzko	same as above	558-1652[a]

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[a] Area code is 703

APPENDIX C

MESOMETEOROLOGY

AD-A074 422 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA SCIENCE A--ETC F/G 4/2
WEATHER INFORMATION AND TACTICAL ARMY ACTIVITIES. PART 1. ASSES--ETC(U)
JUN 79 J METZKO, H HIDALGO MDA903-79-C-0202
UNCLASSIFIED IDA-P-1297-PT-1 IDA/HQ-77-19992 NL

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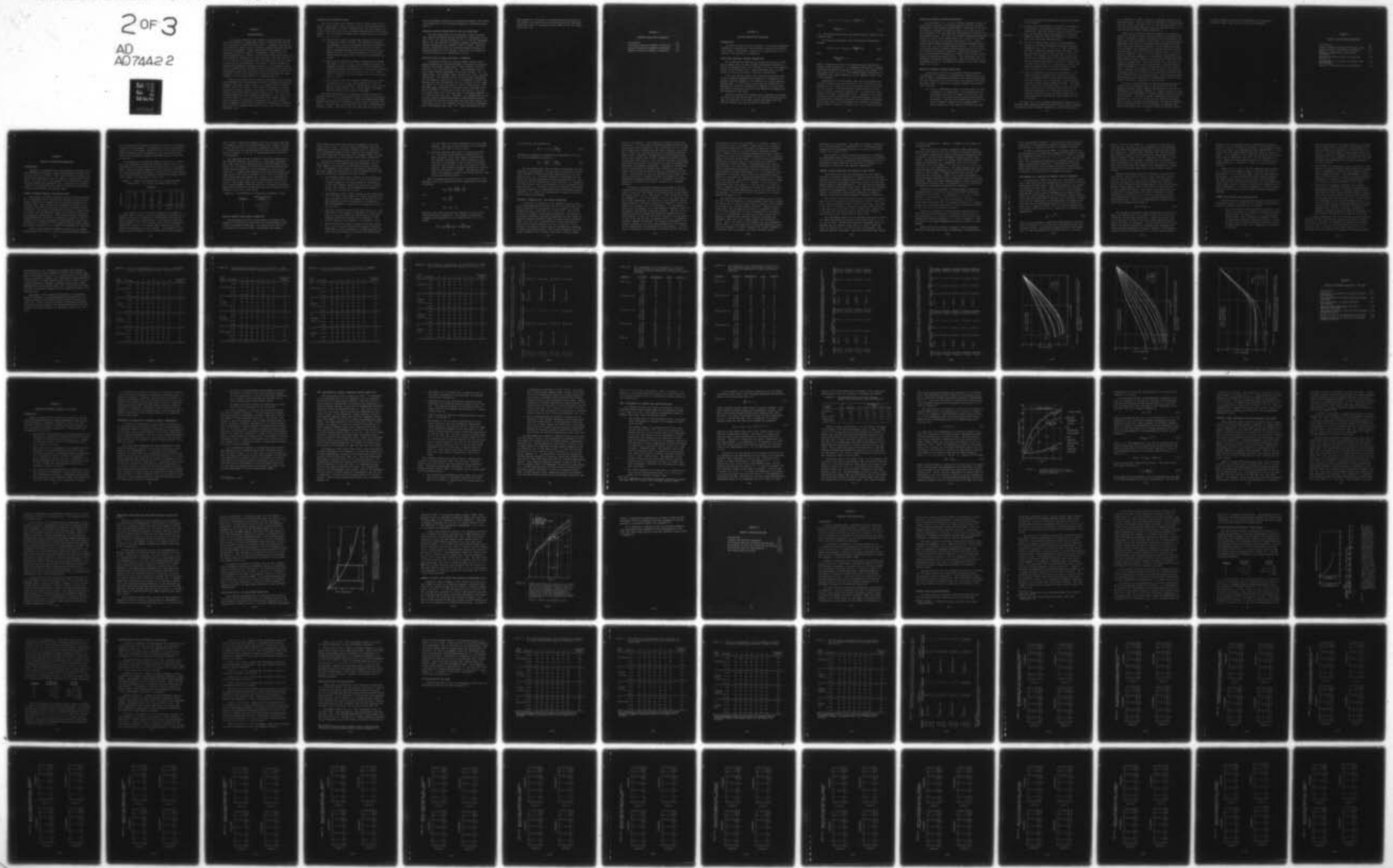

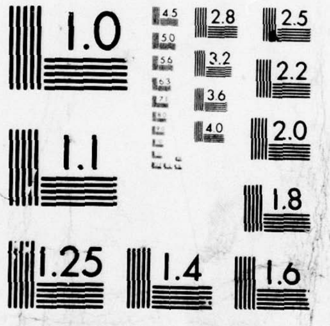

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C

MESOMETEOROLOGY

It is common knowledge that weather is characterized by transient developments of atmospheric events, which can take place in a very wide range of space and time scales. A graphic illustration of the range of space scales is given by weather satellite pictures covering a hemisphere. These pictures show, for example, the horizontal *macroscale* domain of atmospheric events such as the global distribution of clouds. The horizontal macroscale domain has been defined by dimensions (d) that are larger than 2000 km (Ref. 2), i.e., by $2000 \le d \le 40{,}000$ km, where the upper value of this range is given by the circumference of the earth. Typical examples of macroscale atmospheric phenomena are given by (a) planetary waves, such as standing waves, ultralong waves, and tidal waves, which have wavelengths longer than 10,000 km, and (b) baroclinic waves (where potential energy can be converted into kinetic energy) with wavelengths (λ) in the range $2000 < \lambda < 10{,}000$ km (Ref. 2).

Satellite pictures can also show the horizontal scale of *mesoscale* phenomena such as hurricanes, fronts, disturbances induced by mountains and lakes, squall lines (i.e., moving lines of thunderstorms), and cloud clusters. Other types of mesoscale phenomena, not always visible in satellite pictures, are individual thunderstorms, clear air turbulence, urban effects, etc. The horizontal mesoscale domain has been defined by dimensions in the range $2 \le d \le 2000$ km (Ref. 2), i.e., an intermediate scale regime bounded by the macroscale ($d \ge 2000$ km) and *microscale* ($d \le 2$ km) regimes. Typical examples of microscale atmospheric phenomena are tornadoes, deep convection systems, short gravity waves, dust devils, plumes, turbulence, etc.

SUBDIVISION OF MESOSCALE REGIME

Each of the above scale regimes covers a broad range of subscales. Since macro, meso, and micro are the Greek equivalents for large, intermediate, and small, respectively, the Greek symbols α, β, and γ have also been used to designate subdivisions in each scale regime. For the mesoscale regime, these subdivisions are as follows (Refs. 2, 10, 11, 12):

(a) Meso-α scale, where the mesoscale dimensions are within the range of 2000 to 200 km. This mesoscale subrange corresponds to those of phenomena such as hurricanes and fronts, which have time scales of the order of days. Hence, mesoscale weather forecasting in the meso-α subregime involves, for example, predictions for periods longer than 24 hours of the future path of hurricanes or fronts.

(b) Meso-β scale, where the mesoscale dimensions are within the range of 200 to 20 km. This subrange of scales corresponds to those of phenomena such as disturbances induced by mountains and lakes, squall lines, cloud clusters, nocturnal low-level jets, inertial waves, etc. These types of phenomena have time scales of the order of a few hours to a day.

(c) Meso-γ scale, where the mesoscale dimensions are within the range of 20 to 2 km. This subrange of scales is given by those of individual thunderstorms, clear air turbulence, urban effects, etc. These types of phenomena have time scales of the order of one hour.

The above subdivision of the mesoscale regime is based on a probabilistic use of the horizontal scales of motion for mesoscale processes, i.e., on the definition of scale increments which have maximum probabilities of containing a given type of mesoscale phenomena. The time scale could also have been used to subdivide the mesoscale regime. However, it has been found that the time scale can give ambiguous results in the mesoscale regime as the result of uncertainties in the observed frequency of mesoscale events (Ref. 2).

MESOSCALE WEATHER FORECASTING FOR TACTICAL OPERATIONS

The above subdivision of the mesoscale regime indicates that typical battlefield scales (Exhibit 24) correspond to the meso-β (20 ≤ d ≤ 200 km) and meso-γ (2 ≤ d ≤ 200 km) subregimes. Hence, the time duration of mesoscale weather forecasting for tactical operations are limited to about 24 hours. For this reason, verification data for mesoscale weather forecasts in Western Europe by the Air Weather Service are also limited to a 24-hour forecast time (Appendices E and G).

VERTICAL EXTENT OF MESO-β AND MESO-γ PHENOMENA

As indicated previously, typical types of meso-β atmospheric phenomena include meteorological disturbances induced by mountains and lakes, squall lines, cloud clusters, nocturnal low-level jets, inertial waves, etc. Such phenomena can, in turn, induce weather phenomena of tactical interest, i.e., low visibilities, low ceilings, large precipitation rates, and mesoscale winds. The vertical extent of meso-β weather phenomena is, for example, controlled by (a) the orographic effects from mountain and lake disturbances that are important in the boundary layer, i.e., from the ground to about 1-km altitude. This altitude range corresponds to pressure levels that vary from about 1013 mbar at the ground to about 900 mbar at 1 km, and (b) squall lines, which can take place at altitudes between 0.3 m to 10 km or from about 990 to 265 mbar. *The significance of the vertical extent of meso-β phenomena is that mesoscale weather forecasting for tactical operations must take into account the meteorology of both the boundary layer and the free troposphere above the boundary layer (Ref. 10).* These considerations are also applicable to the meso-γ subregime because urban effects, for example, are important near the ground, whereas individual storms take place in the same altitude range as that for squall lines (Ref. 11).

APPENDIX D

WEATHER FORECASTING TECHNIQUES

APPENDIX D

WEATHER FORECASTING TECHNIQUES

INTRODUCTION

The main objective of this appendix is to provide background information concerning the three available techniques for mesoscale weather forecasting: persistence, subjective (or local or station), and objective (or guidance).

PERSISTENCE MESOSCALE WEATHER FORECASTING

The fundamental assumption in persistence weather forecasting is simply that the local weather prevailing at present or during the immediate past will continue to do so in the immediate future to the forecast time. These conditions lead to either static or diurnal persistence forecasts, respectively.

As it will become evident from forecast verification data in the subsequent appendix, the accuracy or "reliability" of weather forecasts depends on the frequency of a given meteorological event. It will then be seen that the reliability of persistence forecasts is difficult to improve on by the other two types of forecasts (subjective and objective) regardless of the frequency of the event.

If $V(s,t)$ denotes the visibility as a function of location or station (s) and future time (t), the static persistence forecast of visibility at the same station and future time (δt) from the present (t_o) may be written as follows:

$$V(s,t_o + \delta t) = V(s,t_o) + \frac{\partial V(s,t)}{\partial t} \delta t \qquad (D-1)$$

where

$$\frac{\partial V(s,t)}{\partial t} = 0 \qquad (D-2)$$

i.e., the observed visibility will remain without change to the forecast time.

For diurnal persistence, the corresponding formulations become:

$$V(s,t_o + \delta t) = V(s,t_o) + \frac{\partial V(s,t')}{\partial t'} \delta t \qquad (D-3)$$

and

$$\frac{\partial^2 V(s,t')}{\partial t^2} = 0 \qquad (D-4)$$

where t' denotes the time of the immediate-past observations during a time interval $\delta t'$. A fundamental assumption of diurnal persistence weather forecasting of visibility, for example, is then given by Eq. D-4; i.e., the immediate-past observations of visibility will repeat themselves in the immediate future time of the forecast.

Equations D-1 to D-4 indicate that static or diurnal persistence forecasts are based solely on local observations, for example, of the visibility at the particular station or locality of interest. Since persistence forecasts have no model skill to predict changes in weather events, persistence cannot forecast the onset of infrequent events. Because of this characteristic and the simplicity of static persistence, its accuracy provides an important reference for assessing the relative forecasting skills of the subjective and objective techniques which attempt to improve on persistence, i.e., on Eqs. D-2 and D-4.

SUBJECTIVE MESOSCALE WEATHER FORECASTING

The subjective (i.e., local or station) weather forecast is the product released at each meteorological facility (usually airfields) by the resident meteorologist. This type of forecast is known as a subjective forecast, because it is the result of man's judgment of all the data that are available to him for his particular station. The scope of the data for Western European stations includes local observations [i.e., $V(s,t_o,t')$], climatology for his specific station, and synoptic (i.e., large scale) weather charts prepared by central meteorological facilities (e.g., Air Force Global Weather Center). In the contiguous United States, resident meteorologists may also have access to objective or guidance forecasts, as defined subsequently. Man- versus machine-forecasting is a major issue in the civilian weather forecasting community today. The issue stems from the automation of weather forecasting at central facilities and the decreasing effect of the subjective element on the final product (Refs. 13, 14, 15).

OBJECTIVE MESOSCALE WEATHER FORECASTING

A basic aim in objective or guidance mesoscale weather forecasting is to improve on persistence by replacing Eqs. D-2 and D-4 with a deterministic-statistical or objective procedure for the evaluation of the local future time gradient $\partial V(s,t)/\partial t$. The basic steps in objective or guidance weather forecastings are as follows:

(1) Use of a radiosonde network to obtain upper air data in addition to surface data. The resolution of the radiosonde data is of the order of 300 km (Ref. 16). The scope of the data involves mainly North America and Europe. The data are obtained twice a day at 00Z and 12Z (where Z stands for the standard GMT). A basic limitation in the scope of the upper air data

is lack of adequate coverage over the extensive areas of the oceans.

(2) Analysis and interpolations of upper air observations to determine the dependent variables (e.g., winds, temperature, humidity, height of given pressure levels, etc.) at specific points corresponding to those defining the numerical grid for numerical calculations (Ref. 17), which are described below.

(3) Use of the conservation equations for atmospheric motions in the free troposphere utilizing electronic computers (e.g., Refs. 17, 18, 19). This procedure is known as numerical weather prediction (NWP). The NWP utilizes the initial data obtained at 00Z, for example, and attempts to calculate the future evolution of the prevailing upper air meteorology at the points defining the numerical grid with a typical size of about 200 km (Ref. 20). The product of NWP is the synoptic weather charts at several pressure levels (e.g., 500 mb, etc.) of the free troposphere.

(4) Use of a statistical procedure that attempts to correlate *predictor* variables from numerical weather (i.e., obtained from NWP) and *predictant* variables for real weather (e.g., visibility). This procedure is known as model output statistics (MOS). The basic steps in MOS are as follows (Refs. 7, 21): (a) gathering of statistics for candidate NWP predictors and observed predictants, (b) "screening" analysis to eliminate predictors with low correlations, and (c) establishing MOS relationships among predictors and predictants.

The basic aim of the combined deterministic (NWP) and statistical (MOS) weather forecast procedure is to produce forecasts for *boundary layer* variables (Appendix C) such as visibility, i.e., variables for which there are no available models of the phenomena itself. The use of MOS is an attempt to produce forecast data within the meso-β ($20 \leq d \leq 200$ km) and meso-γ ($2 \leq d \leq 20$ km) from synoptic NWP data valid for the meso-α ($200 < d \leq 2000$ km) and macroscale regimes (Appendix C).

There are two important factors concerning the objective (guidance) weather forecast technique based on the NWP-MOS procedure. The first one has to do with the time required to complete this complex procedure, which starts with the gathering of radiosonde data, and it is completed with transmission of synoptic charts and guidance forecasts to local weather stations. On the average, this preparation and distribution time of guidance forecasts can be of the order of several hours. As indicated in Appendix G (Fig. G-1), the synoptic charts appear at about three hours subsequent to observations, whereas the guidance forecasts based on MOS do so at about five hours after the upper air observations. The second factor has to do with the assigned probability for the forecast event. The NWP product can be interpreted in terms of probabilities for the forecast event. However, the probability forecast may be converted into a categoric (yes/no) forecast with an implied 100 percent forecast probability for the forecast event. This latter procedure involves comparisons between the calculated and threshold probability values for a particular class of event.

As it will become evident in Appendix E, forecast verification data for phenomena such as low visibility show that guidance forecasts cannot improve significantly on the low reliabilities of persistence forecasts. Several factors for this relatively poor performance of current guidance forecast products are as follows: (1) lack of direct observations at the local station; i.e., of $V(s,t')$ in Eq. D-1, (2) lack of a physical model, *based on boundary layer phenomena,* for weather variables such as visibility, and (3) low resolution of synoptic NWP. This latter factor does not allow to take into account effects of meso-β phenomena (such as the disturbances from mountains and lakes, squall lines, etc.) on the free troposphere.

APPENDIX E

FORECAST VERIFICATION METHODOLOGY

APPENDIX E

FORECAST VERIFICATION METHODOLOGY

INTRODUCTION

Appendix D has described the three forecast techniques that are available for mesoscale weather forecasting of weather variables of tactical interest. These three forecast techniques are persistence, subjective (local or station), and objective (guidance). The main aim of this appendix is to identify the weather forecast verification parameters and to establish the relative quality of the foregoing three types of forecast for visibility, ceiling, precipitation, and surface winds.

FORMAT OF WEATHER FORECAST VERIFICATION DATA

The accuracy of present mesoscale weather forecasting skills may be determined from a verification procedure, wherein operational forecasts are compared with the observed weather at the forecast time. This verification procedure is carried out at selected verification stations over a period of several months or seasons. The number of verification stations is large enough to cover a large geographical domain such as Western Europe or the contiguous United States. This procedure yields statistics for assessing the accuracy of persistence, subjective (local or station), and objective (guidance) forecasting of a given type of event (e.g., visibility) for different forecast times (hours) and several categories (e.g., ranges of visibility) of the event.

Since the development of guidance forecasts is of rather recent origin (Ref. 22), it is to be expected that the verification methodology of weather forecasting is also in a corresponding state of development. For example, it is only very recent efforts at the Air Weather Service of the U.S. Air Force and the National Weather Service (Appendix G) that have produced statistics for individual instead of combined events of visibility and ceiling.

The statistical verification data for persistence, subjective, and objective forecasts for a given type of event (e.g., visibility) are usually given in the matrix form of a *contingency* table. Table E-1 shows a sample of the verification statistics for 14,142 persistence forecasts of visibility of 3-hour duration at 92 stations within the contiguous United States during October 1975 to March 1976 (Appendix G, Table G-40).

TABLE E-1. Sample Contingency Table for Visibility (NWS)
(Persistence, 3 hr, October 1975-March 1976, USA)

		Forecasts					
		1	2	3	4	5	T
Observations	1	161	38	40	30	76	345
	2	30	37	46	20	57	190
	3	32	48	229	139	285	733
	4	12	19	89	211	412	743
	5	16	28	134	219	11,734	12,131
	T	251	170	538	619	12,564	14,142

The columns 1 to 5 in this table indicate the number of forecasts made in each of the five categories of visibility, as defined in Table E-2, whereas the corresponding rows show the actual occurrences or observations. The bottom row indicates the breakdown of the 14,142 forecasts into the five categories, whereas the column to the extreme right indicates the total number of observations in each category. The diagonal of this matrix shows the number of *correct* forecasts in each category.

Hence, column 1 shows, for example, that 251 forecasts were made in category 1; only 161 of these forecasts were correct, and the balance actually fell in the other categories as shown in column 1. Likewise, the top row indicates that there were 345 observations in category 1; only 161 of these observations were forecast correctly.

The right-most column of Table E-1 shows the frequencies of the observed categories of visibility. This column indicates that there were 12,131 observations of visibility higher than 5 miles, i.e., 86 percent of the observed visibilities during the period (October 1975-March 1976) correspond to clear or *good* visibility. Likewise, the diagonal of this matrix indicates that there were 11,734 correct forecasts out of the 12,131 observed visibilities that were higher than 5 miles; i.e., 97 percent of the visibilities for clear or good visibility were found to be correct. This sample table for a short forecast time of three hours already suggests that the acid test of weather forecasting capabilities lies on the verification of the *low* frequency categories of events over local areas.

TABLE E-2. Classification of Visibility Categories at NWS

Category	Visibility Range, miles
1	$V < 0.5$
2	$0.5 \leq V < 1$
3	$1 \leq V < 3$
4	$3 \leq V < 5$
5	$V > 5$

WEATHER FORECAST VERIFICATION PARAMETERS

The foregoing discussion of the sample contingency table suggests the definition of parameters for establishing the statistics of weather forecasting. It should be noted that for the hypothetical case of perfect forecasting, for example, every number other than those along the diagonal of the 5x5 matrix would be zero. In such a case, the numbers along the diagonal and bottom row for each category would be identical to the corresponding numbers of the column in the extreme right. For actual imperfect forecasting, the contingency Table E-1 suggests the definition of the forecast verification parameters.

If in the contingency Table E-1, H_i denotes the hits for any category (i.e., the numbers along the diagonal), O_i the total number of occurrences or observations for any category (i.e., the numbers in the column to the extreme right), and F_i the total number of forecasts for a given category (bottom row), then the verification parameters are as follows:

1. *Prefigurance* (PF_i), which is given by the ratio H_i/O_i, i.e., the ratio of the number of correct forecasts in a given category to the total number of observations in the same category within the verified set of forecasts. For example, the prefigurance for category 1 in Table E-1 is 161/345, or 0.47.

2. *Post-Agreement* (PA_i), which is given by the ratio H_i/F_i, i.e., the ratio of the number of correct forecasts in a given category to the total number of forecasts in the same category within the verified set of forecasts. The post-agreement in Table E-1 for category 1 is 161/251, or 0.64.

3. *Bias* (B_i), which is given by the ratio F_i/O_i, i.e., the ratio of the total number of forecasts in a given category to the total number of observations in the same category within the verified set of forecasts. The bias in Table E-1 for category 1 is 251/345, or 0.73.

4. *Threat Score* (TS_i), which is given by the ratio $H_i/(F_i + O_i - H_i)$, i.e., the ratio of the number of correct forecasts in a given category to a number given by the sum of the total number of forecasts and observations

less the number of correct forecasts, all in the same category. The threat score in Table E-1 for category 1 is 161/(251 + 345 - 161), or 0.37.

5. *Relative Frequency* (RF_i), which is given by $O_i/\Sigma O_i$, i.e., the ratio of the number of observations in a given category to the total number of observations. The relative frequency for a given category is thus the ratio of the number in the column to the extreme right for that category to the total number of observations. The relative frequency in Table E-1 for category 1 is 345/14,142, or 0.024. (The absolute frequency for category 1 would be 345 events per half year of the verification period.)

From the foregoing definitions for the prefigurance, postagreement, and bias, these verification parameters are related as follows:

$$PA_i = \frac{H_i}{F_i} = \frac{H_i/O_i}{F_i/O_i} = \frac{PF_i}{B_i}$$

i.e.,

$$PA_i = \frac{PF_i}{B_i} \qquad \text{(E-1)}$$

or

$$PF_i = PA_i \cdot B_i \qquad \text{(E-2)}$$

Similarly, the threat score may be expressed in terms of the other verification parameters. For example, dividing the numerator and denominator in its definition by O_i it is obtained

$$TS_i = \frac{H_i}{F_i + O_i - H_i} = \frac{PF_i}{1 + B_i - PF_i} ,$$

or solving for the prefigurance:

$$PF_i = (1 + B_i) \frac{TS_i}{1 + TS_i} . \qquad (E-3)$$

Likewise, by dividing the numerator and denominator of TS_i by F_i, the post-agreement is given by

$$PA_i = \frac{1 + B_i}{B_i} \cdot \frac{TS_i}{1 + TS_i} . \qquad (E-4)$$

For the hypothetical case of perfect forecasting, the prefigurance, post-agreement, and bias would be equal to unity for every category as indicated by their definitions for the case when $H_i = F_i = O_i$. For actual imperfect forecasting, Eq. E-1 shows that the post-agreement is inversely proportional to the bias and it can be increased by using a bias $B_i < 1$. Similarly, Eq. E-2 indicates that the prefigurance can be increased by using a bias $B_i > 1$. Therefore, for actual imperfect forecasting it becomes important to understand both the difference between categoric (i.e., yes/no) and probabilistic (maybe) forecasts as well as biased forecasting.

CATEGORIC, PROBABILISTIC, AND BIASED FORECASTING

As indicated in Appendix D, the difference between categoric and probabilistic forecasts is that the former has an implied probability of 100 percent for the forecast of a given category of, say, visibility (e.g., Table E-2). This is the nature, for example, of persistence forecasts. For objective or guidance forecasts, Appendix D indicated that the output of numerical weather prediction (NWP) and model output statistics (MOS) is in the form of probabilities for the occurrence of each of the several categories of, say, visibility. For a categoric forecast of a given event, it becomes then necessary to reduce the probabilities of the several categories into the single category of the forecast event with an implied probability of 100 percent. This reduction procedure involves two basic steps: (1) definition of threshold probabilities for the occurrence of each category of, say, visibility, and (2) systematic comparisons, starting with the lowest category (e.g., category 1, Table E-2), between calculated and threshold probabilities so as to identify a category where the calculated probability first exceeds that of the corresponding threshold value. An important point here is, then, that the available contingency tables for verification of visibility and ceiling forecasts are applicable to categoric forecasting. Although the methodology for the verification of probabilistic forecasts is in hand, there is not yet any verification data for probabilistic forecasts. The verification data for probabilistic forecasts would take the form of a contingency "volume" as generated by the *probability* parameter placed normal to the present contingency tables for the implied 100 percent probability of categoric forecasts.

The concept of biased forecasting may perhaps be illustrated best by considering an analogy wherein the 14,142 forecasts in Table E-1 are thought to be replaced by the same number of marbles within a box. The marbles, of five different colors, are assumed to: (1) be well mixed, (2) be of the same size, (3) be of equal brightness, (4) fall into a color frequency distribution similar to the total column (T) in Table E-1, and (5) be exposed to a medium level of illumination. If, for example, a green color is assigned to the most frequent category 5, most of the marbles (86 percent) would then be green. The role of the weather forecaster equipped with different probabilities for each category in Table E-1 may then be thought to be equivalent to that of an observer who is provided with a set of glasses of different degrees of darkness. For weather forecasting of infrequent categories with very high probabilities, the observer in the analogy would be provided with clear glasses. In such a case, he would have no difficulty in picking *only* the few, say, blue marbles if such color represents, for example, category 1; and he could do so in a number of draws equal to the number of occurrences in Table E-1. This would be equivalent to perfect forecasting in which all the verification parameters become unity. However, as the forecast probabilities become closer in magnitude to those of the threshold probabilities, the observer's glasses would also become darker. He would then have increasing difficulty in picking only the blue marbles for category 1. Nevertheless, if the criterion of post-agreement were used to test his skill, he could achieve superior performance with imperfect forecasting technology by calling the frequent green color whenever he wears dark glasses; i.e., by accepting a small degradation of his near perfect skill for the frequent green marbles to compensate for significant improvements in the infrequent blue marbles. This situation would be equivalent to underbiased forecasting where B << 1. However, if the criterion of prefigurance were used instead to test his skill, he could attempt to improve his performance by calling the infrequent blue color whenever he wears dark glasses, so as to collect *all* the blue marbles. This situation would be equivalent to overbias forecasting where B >> 1.

For conditions where the bias is reasonably close to unity, the use of the prefigurance or post-agreement verification parameter would tend to give the same result in regard to the validity or reliability of average weather forecasts. However, even in these cases, the prefigurance criterion is preferable because (1) its lower sensitivity to bias as compared with post-agreement, i.e., prefigurance can never give perfect scores for infrequent categories with imperfect forecast technology and reasonable bias, and (2) it always commits the forecaster to action. Hence, the choice of prefigurance over post-agreement implies that it is more important in measuring forecasting skill to use the percent of correct forecasts for a given category of occurrences than the percent of correct forecasts from an arbitrary set of forecasts. Note that the results in Table E-1 for a 3-hour forecast of visibilities $V < 0.5$ miles give prefigurance and post-agreement values of 0.47 and 0.64, respectively, for a bias of 0.73.

The accuracy of current forecasting skill can, therefore, be established from the decay of the prefigurance as a function of forecast time (hours) as derived from contingency tables for different forecast times and for each type of forecast, i.e., persistence, subjective, and objective (Appendix D).

FORECAST VERIFICATION DATA FOR VISIBILITY AND CEILING

Verification data for the determination of the current accuracy of mesoscale forecasts of visibility and ceiling were available at the Air Weather Service (AWS) of the U.S. Air Force and the Technique Development Laboratory (TDL) of the National Weather Service, NOAA (Appendix G). The verification data were in the form of contingency tables [e.g., Table E-1 for categoric (yes/no) or nonprobabilistic forecasts]. The AWS data were limited to persistence and station (subjective) forecasts, whereas the TDL data included guidance (objective) forecasts.

The forecast verification data are of a statistical nature, where sets of forecasts are verified against actual occurrences over a large geographical domain during a long time. The scope of the AWS data included 35 stations in Western Europe within a time span between September 1976 and March 1977, whereas that of the TDL data included 92 stations within the contiguous United States during October 1975 to March 1976.

The contingency tables for the AWS data were given by month for either persistence or station and forecast times of 3, 6, 12, and 24 hours. The TDL data included contingency tables for guidance and the forecast times were 3, 6, and 12 hours for local or station and 7, 13, and 19 hours for guidance. The basic AWS and TDL contingency tables for visibility and ceiling are given in Appendix G. However, a summary of such results is as given below.

Tables E-3 and E-4 provide a summary of AWS prefigurance data for *visibility* for station and static persistence (Appendix D) forecasts, respectively. Each table shows prefigurance data, in percent, for each month (September to March) and the whole period. The data are given by category which represent several ranges of visibility; i.e., categories A, B, C, and D denote visibility (V) in the range $V < 0.5$ nm, $0.5 \le V < 2$ nm, $2 \le V < 3$ nm, and $V \ge 3$ nm, respectively. For each category, each table shows the decay in prefigurance as a function of forecast time between 3 and 24 hours. A comparison of Tables E-3 and E-4 shows that for visibility, there is very little improvement in the prefigurance obtained by local forecasters over that of persistence. Hence, the basic assumption made in static persistence for mesoscale forecasts (Eq. D-2, Appendix D) is very difficult to improve on by weather forecasters of visibility.

Tables E-5 and E-6 provide a similar summary of AWS prefigurance data for *ceiling* for station and static persistence forecasts, respectively. The categories A, B, C, and D denote ceiling (C) in the range $C < 200$ ft, $200 \le C < 1000$ ft, $1000 \le C < 3000$ ft, $C > 3000$ ft, respectively. The data in these tables show again that for mesoscale forecasts of ceiling, there is no significant improvement in the prefigurance obtained by man over that of persistence forecasts.

Table E-7 illustrates the AWS relative frequency data for each category of visibility and ceiling for local forecasts. This table shows (1) a rather low frequency for the first three categories of either visibility ($V < 3$ nm) or ceiling ($C < 3000$ ft), and (2) very high frequencies for events of good or clear weather.

Tables E-8 and E-9 provide a summary of TDL prefigurance data for visibility and ceiling, respectively, for persistence, local, and guidance forecasts. The results in these tables indicate that the prefigurance values for persistence forecasts are difficult to improve on by local or guidance forecasts.

In order to determine the effect of category criteria on the prefigurance, the individual categories were added to yield new categories defined by A, A + B, A + B + C, and D for the AWS data, and 1, 1 + 2, 1 + 2 + 3, 1 + 2 + 3 + 4, and 5 for the TDL data. The corresponding individual contingency tables were added as described in Appendix G. The results are shown in Tables E-10 and E-11 for the AWS and TDL data, respectively. These tables indicate again that persistence is very difficult to improve on by either local or guidance forecasts.

PREFIGURANCE AS A FUNCTION OF FORECAST TIME AND FREQUENCY

As indicated in Tables E-10 and E-11, the forecast verification data show that the prefigurance for visibility or ceiling decays with forecast time, a decay that depends on the category or frequency of the events. Since the data include forecast times between 3 and 24 hour duration, it is of some interest to describe the typical decay in prefigurance at shorter times, which can be done through the use of available forecast verification data for other types of events. Thus, forecast verification data for temperature and precipitation, for example, show that the decay in prefigurance from the time of forecast release can be exponential (Ref. 23); i.e., the prefigurance PF_i for a given class of event (e.g., visibility or ceiling) may be expressed as

$$PF_i = e^{-\beta_i t} , \qquad \text{(E-5)}$$

where β_i is an empirical coefficient that depends on the category (or frequency) of the event and t denotes the time from forecast release. The forecast verification data for temperature (T) and precipitation (p) indicate that $\beta_T \simeq 0.02$ and

and $\beta_p \simeq 0.04$ per hour (Ref. 23). It should be noted that the fact that $\beta_p > \beta_T$ means that the prefigurance for precipitation falls off with time significantly faster for precipitation than for temperature. Equation (E-5) indicates that the prefigurance has a value of unity (or 100% correct) for "nowcasting" at the time of forecast release ($t = 0$). Similarly, the time (t_c) from forecast release to the climatic condition of no forecasting skill is given by the limit $PF_i \rightarrow 0$ in Eq. E-5; for a 10 percent skill over climatology, for example, the corresponding t_c values for the above β_T and β_p values are 115 and 57 hours, respectively.

Forecast verification data for visibility or ceiling indicate that Eq. (E-5) can also apply to some categories (frequencies) of either event; i.e., in such cases, it is possible to describe accurately the visibility or ceiling data between 3 and 24 hours through the use of appropriate β_v or β_c coefficients. However, a more general trend in the data is a deviation from an exact exponential decay. Nevertheless, the AWS and TDL data do show that the prefigurance for either individual or added categories of visibility (or ceiling) is a function of the two basic parameters in Eq. E-5, i.e., the relative frequency and the forecast time. Hence, the prefigurance for a given type of event may be expressed in general as

$$PF_i = f(RF_i, t) \quad . \qquad \text{(E-6)}$$

The foregoing correlation among prefigurance, relative frequency and forecast time is as shown in Figs. E-1 and E-2 for visibility and ceiling, respectively. These figures are plots of the data given in Table E-10 for the AWS verification data. Figure E-1 shows the following: (1) the accuracy of *station* and static *persistence* forecasts of visibility are comparable and rather poor for parameters of tactical interest. For example, a 12-hour forecast of visibilities $V < 3.7$ km is only 30 percent accurate; (2) the frequency of such visibilities in Western Europe is only of the order of 5 percent; (3) although not plotted on the figure, the prefigurances for visibilities $V \geq 5.6$ km (Table E-10) are indeed high for forecast times as long as 24 hours. It is important to note that (a) the latter results are given even by persistence (Eq. D-2), and (b) they imply a $\beta_V << \beta_T$. Figure E-3 shows similar results for ceilings, e.g., a 12-hour forecast of ceilings $C < 1000$ ft is only 40 percent accurate.

Figure E-3 is a plot of the TDL visibility data in Table E-11. For the low frequency range of interest for tactical applications ($V < 4.8$ km), the basic points in this figure are as follows: (1) local forecasts are poorer than persistence for short-range forecasts of even 6 hours, and (2) guidance forecasts are also poorer than persistence for long-range forecasts, where they are intended to overcome the capabilities of local forecasters; i.e., the prefigurance of a 13-hour guidance forecast cannot match that of an older (15-hour) persistence forecast.

SUMMARY OF VISIBILITY AND CEILING RESULTS

Important results concerning both the AWS and TDL data for mesoscale forecasts of visibility and ceiling by persistence, local, and guidance forecasts are as follows:

1. Local forecasters cannot significantly improve on persistence forecasts of visibility or ceiling in Western Europe (Tables E-3 through E-6). In the contiguous United States, local forecasts are somewhat inferior to persistence forecasts (Tables E-8 and E-9). These results hold for either individual (previous tables) or added (Tables E-10, E-11) categories of visibility or ceiling.

2. The forecast accuracy for either visibility or ceiling decays sharply with the decay of the frequency of the lower categories of visibility or ceiling (Figs. E-1 and E-2). *The significance of this result is that the forecast accuracy of infrequent low visibilities or low ceilings (i.e., poor weather) constitutes the real test of forecasting capabilities for weather parameters of tactical interest.*

3. The accuracy of persistence or local forecasts of visibility or ceiling in Western Europe (Tables E-3 through E-6) is comparable to those in the contiguous United States (Tables E-8, E-9). The significance of this result is the fact that the accuracy of current mesoscale forecasts of visibility or ceiling depends mainly on the frequency or mesoclimatology of such events.

4. The accuracy of guidance forecasts for infrequent events of *low* visibility or ceiling, as determined by sophisticated approaches of numerical weather prediction (NWP) and model output statistics (MOS) procedures cannot match the performance of persistence forecasts for the same type of events (Fig. E-3). This result is not surprising in view of the following factors: (1) lack of a model in the current MOS approach to describe the physics of mesoscale visibility or ceiling in the boundary layer, and (2) the general inadequacy of *synoptic* (instead of mesoscale) NWP for providing accurate *mesoscale* predictors of visibility or ceiling.

It must be emphasized that the foregoing correlation between forecast accuracy and relative frequency of an event is applicable to (a) individual or cumulative categories of visibility or ceiling and (b) each of the three types of forecast: persistence, local or station, and guidance (Figs. E-1 to E-3). The reason for this correlation is simply the inherent relative probabilities for the occurrence of frequent and infrequent events during the short, immediate future of the forecast time. Thus, very frequent events (e.g., no precipitation in the Sahara desert, a sunrise or sunset, etc.) would have a high probability of occurrence on a short-range forecast of such events by, say, diurnal persistence; whereas, infrequent events (e.g., heavy precipitation in the Sahara desert, etc.) would have low probabilities of occurrence during the short, immediate future of the forecast time.

Returning to the conceptual description of forecasting skills in Exhibit 5, the foregoing results indicate that the second and third solid circles in that exhibit actually coincide; i.e., today's local and guidance forecasting techniques of visibility or ceiling are not significantly better than persistence for either frequent or infrequent events (e.g., Fig. E-3).

TABLE E-3. AWS *Station* Prefigurance (%) for Forecast of *Visibility* in Western Europe During September 1976-March 1977

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	38	43	46	54	48	42	44	46
(V<0.9 km)	6 hr	19	26	36	29	33	17	19	26
	12 hr	14	10	20	19	24	7	8	17
	24 hr	11	8	14	5	14	7	0	10
B	3 hr	42	38	42	47	54	42	48	47
(0.9≤V< 3.7 km)	6 hr	31	24	30	31	37	24	36	32
	12 hr	21	17	24	19	25	21	22	22
	24 hr	19	13	16	12	18	15	16	16
C	3 hr	46	35	29	35	34	36	19	34
(3.7≤V< 5.6 km)	6 hr	25	20	16	16	21	25	19	20
	12 hr	14	16	13	16	12	17	14	14
	24 hr	10	13	13	12	11	14	12	12
D	3 hr	98	98	98	98	96	98	98	98
(V≥5.6 km)	6 hr	98	98	98	97	95	98	98	97
	12 hr	98	97	96	96	94	96	97	96
	24 hr	97	97	96	96	94	97	97	96

TABLE E-4. AWS *Persistence* Prefigurance (%) for Forecast of *Visibility* in Western Europe During September 1976-March 1977

Category	Forecast	S	O	N	D	J	F	M	September-March
A ($V<0.9$ km)	3 hr	30	39	40	49	52	32	42	43
	6 hr	15	18	27	35	27	19	32	27
	12 hr	0	2	18	19	13	5	18	13
	24 hr	19	15	21	7	16	7	7	15
B ($0.9 \le V < 3.7$ km)	3 hr	30	34	34	44	48	36	40	40
	6 hr	33	25	26	28	32	25	27	28
	12 hr	19	8	15	15	19	15	12	16
	24 hr	22	12	11	10	13	9	6	12
C ($3.7 \le V < 5.6$ km)	3 hr	18	20	24	25	24	25	13	22
	6 hr	11	18	13	10	14	15	11	13
	12 hr	7	9	7	7	10	12	7	8
	24 hr	15	10	9	8	8	9	3	9
D ($V \ge 5.6$ km)	3 hr	97	97	97	97	95	97	97	97
	6 hr	96	96	96	95	92	96	97	95
	12 hr	96	96	95	95	90	95	96	95
	24 hr	97	96	94	94	90	94	96	95

TABLE E-5. AWS *Station* Prefigurance (%) for Forecast of ***Ceiling*** in Western Europe During September 1976-March 1977

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	27	39	40	56	43	43	37	42
(C<200 ft)	6 hr	11	19	28	35	25	15	17	24
	12 hr	15	7	12	18	20	0	2	14
	24 hr	7	3	3	1	10	2	5	5
B	3 hr	59	68	66	73	75	64	68	69
(200≤C<	6 hr	35	55	49	55	60	48	51	52
1000 ft)	12 hr	21	36	39	40	44	33	41	38
	24 hr	18	24	27	24	31	22	24	26
C	3 hr	61	66	72	66	72	68	68	68
(1000≤C<	6 hr	44	51	57	55	56	51	55	53
3000 ft)	12 hr	29	34	38	35	34	34	37	35
	24 hr	19	26	28	25	26	28	28	26
D	3 hr	97	97	97	97	95	97	97	97
(C≥3000	6 hr	96	96	96	95	93	96	96	96
ft)	12 hr	96	95	94	94	91	95	94	94
	24 hr	95	95	94	94	90	94	93	94

TABLE E-6. AWS *Persistence* Prefigurance (%) for Forecasts of *Ceiling* in Western Europe During September 1976-March 1977

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	23	42	33	37	45	24	33	36
(C<200 ft)	6 hr	22	19	20	21	25	10	17	21
	12 hr	4	3	7	16	8	0	7	8
	24 hr	13	6	13	10	12	0	6	10
B	3 hr	46	58	63	62	66	52	61	60
(200≤C< 1000 ft)	6 hr	30	47	50	48	52	38	46	46
	12 hr	13	27	38	33	36	26	28	31
	24 hr	16	20	28	18	25	14	19	21
C	3 hr	40	47	53	48	51	46	46	48
(1000≤C< 3000 ft)	6 hr	28	34	42	36	36	32	33	35
	12 hr	20	25	32	25	25	23	23	25
	24 hr	16	18	23	17	20	15	16	18
D	3 hr	95	95	96	95	94	95	94	95
(C≥3000 ft)	6 hr	93	93	94	93	89	93	92	93
	12 hr	92	91	92	91	86	92	90	91
	24 hr	92	89	89	88	82	90	88	88

TABLE E-7. AWS Prefigurance (%) vs Frequency (%) for Station Forecasts of Visibility & Ceiling in Western Europe During September 1976-March 1977

	Visibility			Ceiling		
Forecast	Category	Prefigurance	Frequency	Category	Prefigurance	Frequency
3 hr	A	46	1	A	42	1
6 hr	(V<0.9 km)	28	1	(C<200 ft)	24	1
12 hr		17	1		14	1
24 hr		10	1		5	1
3 hr	B	47	3	B	69	6
6 hr	(0.9≤V<3.7 km)	32	3	(200≤C<1000 ft)	52	6
12 hr		22	3		38	6
24 hr		16	3		26	6
3 hr	C	34	2	C	68	8
6 hr	(3.7≤V<5.6 km)	20	2	(1000≤C<3000 ft)	53	8
12 hr		14	2		35	8
24 hr		12	2		26	8
3 hr	D	98	93	D	97	85
6 hr	(V≥5.6 km)	97	94	(C≥3000 ft)	96	85
12 hr		96	93		94	85
24 hr		96	93		94	85

TABLE E-8. TDL Prefigurance (%) for Forecasts of *Visibility* in the Contiguous United Stated During October 1975-March 1976 for Persistence, Local, and Guidance Forecasts

Category	Forecast	Persistence	Local	Guidance
1	3 hr	47	34	--
(V<0.8 km)	6 hr	37	23	--
	7 hr	--	--	19
	12 hr	26	4	--
	13 hr	--	--	4
	15 hr	20	--	--
	19 hr	--	--	0
2	3 hr	19	18	--
(0.8≤V<1.6 km)	6 hr	8	6	--
	7 hr	--	--	8
	12 hr	5	3	--
	13 hr	--	--	4
	15 hr	6	--	--
	19 hr	--	--	0
3	3 hr	31	23	--
(1.6≤V<1.6 km)	6 hr	18	12	--
	7 hr	--	--	22
	12 hr	13	11	--
	13 hr	--	--	15
	15 hr	12	--	--
	19 hr	--	--	4
4	3 hr	28	37	--
(4.8≤V<8 km)	6 hr	16	22	--
	7 hr	--	--	13
	12 hr	16	20	--
	13 hr	--	--	13
	15 hr	13	--	--
	19 hr	--	--	15
5	3 hr	97	94	--
(V≥8 km)	6 hr	95	95	--
	7 hr	--	--	95
	12 hr	91	96	--
	13 hr	--	--	97
	15 hr	91	--	--
	19 hr	--	--	98

TABLE E-9. TDL Prefigurance (%) for Forecasts of *Ceiling* in the Contiguous United States during October 1975-March 1976 for Persistence, Local, and Guidance Forecasts

Category	Forecast	Persistence	Local	Guidance
1	3 hr	45	32	--
(C<200 ft)	6 hr	28	18	--
	7 hr	--	--	18
	12 hr	21	2	--
	13 hr	--	--	0
	15 hr	15	--	--
	19 hr	--	--	0
2 (200≤C<500 ft)	3 hr	44	38	--
	6 hr	26	19	--
	7 hr	--	--	25
	12 hr	21	11	--
	13 hr	--	--	8
	15 hr	17	--	--
	19 hr	--	--	3
3	3 hr	42	34	--
(500≤C<1000 ft)	6 hr	25	22	--
	7 hr	--	--	22
	12 hr	17	15	--
	13 hr	--	--	16
	15 hr	17	--	--
	19 hr	--	--	11
4	3 hr	44	45	--
(1000≤C<2000 ft	6 hr	28	32	--
	7 hr	--	--	28
	12 hr	20	26	--
	13 hr	--	--	2[illegible]
	15 hr	18	--	--
	19 hr	--	--	18
5	3 hr	95	94	--
(C>2000 ft)	6 hr	93	94	--
	7 hr	--	--	94
	12 hr	89	95	--
	13 hr	--	--	94
	15 hr	87	--	--
	19 hr	--	--	97

TABLE E-10. AWS Prefigurance (%) and Relative Frequency for Forecast of Visibility and Ceiling in Western Europe During September 1976-March 1977.

	Visibility				Ceiling			
Forecast	Category	Persistence	Station	Frequency	Category	Persistence	Station	Frequency
3 hr	A	43	46	0.011	A	36	42	0.007
6 hr	(V<0.9 km)	27	28	0.009	(C<200 ft)	21	24	0.006
12 hr		13	17	0.012		8	14	0.007
24 hr		15	10	0.012		10	5	0.007
3 hr	A + B	55	57	0.045	A + B	66	73	0.067
6 hr	(V<3.7 km)	40	41	0.041	(C<1000 ft)	52	56	0.063
12 hr		23	29	0.045		35	42	0.069
24 hr		20	21	0.045		25	27	0.069
3 hr	A + B + C	60	65	0.068	A + B + C	74	82	0.150
6 hr	(V<5.6 km)	46	49	0.064	(C<3000 ft)	63	71	0.146
12 hr		29	38	0.069		47	59	0.151
24 hr		25	29	0.069		35	44	0.151
3 hr	D	97	98	0.932	D	95	97	0.850
6 hr	(V≥5.6 km)	95	97	0.936	(C≥3000 ft)	93	96	0.854
12 hr		95	96	0.931		91	94	0.849
24 hr		95	96	0.931		88	94	0.850

TABLE E-11. TDL Prefigurance (%) and Relative Frequencies for Forecast of Visibility and Ceiling in Contiguous United States During October 1975-March 1976

	Visibility					Ceiling				
Forecast	Category	Persistence	Local	Guidance	Frequency	Category	Persistence	Local	Guidance	Frequency
3 hr	1	47	34	--	0.024	1	45	32	--	0.018
6 hr	(V<0.8 km)	37	23	--	0.017	(C<200 ft)	28	18	--	0.012
7 hr		--	--	19	0.024		--	--	18	0.018
12 hr		26	4	--	0.005		21	2	--	0.003
13 hr		--	--	4	0.007		--	--	0	0.004
15 hr		20	--	--	0.005		15	--	--	0.004
19 hr		--	--	0	0.005		--	--	0	0.004
3 hr	1 + 2	50	46	--	0.038	1 + 2	57	49	--	0.057
6 hr	(V<1.6 km)	33	23	--	0.033	(C<500 ft)	40	26	--	0.049
7 hr		--	--	20	0.038		--	--	31	0.057
12 hr		19	8	--	0.015		31	12	--	0.018
13 hr		--	--	7	0.019		--	--	9	0.028
15 hr		20	--	--	0.014		24	--	--	0.022
19 hr		--	--	0	0.014		--	--	3	0.022
3 hr	1 + 2 + 3	52	47	--	0.090	1 + 2 + 3	63	60	--	0.107
6 hr	(V<4.8 km)	35	26	--	0.096	(C<1000 ft)	48	39	--	0.108
7 hr		--	--	33	0.090		--	--	41	0.107
12 hr		26	18	--	0.057		38	24	--	0.058
13 hr		--	--	18	0.069		--	--	23	0.074
15 hr		25	--	--	0.047		33	--	--	0.059
19 hr		--	--	4	0.047		--	--	14	0.059
3 hr	1 + 2 + 3 + 4	59	67	--	0.142	1 + 2 + 3 + 4	70	71	--	0.181
6 hr	(V<8 km)	44	44	--	0.154	(C<2000 ft)	58	57	--	0.188
7 hr		--	--	38	0.142		--	--	54	0.181
12 hr		37	35	--	0.091		51	42	--	0.124
13 hr		--	--	29	0.109		--	--	46	0.153
15 hr		34	--	--	0.082		44	--	--	0.116
19 hr		--	--	21	0.082		--	--	32	0.116
3 hr	5	97	94	--	0.858	5	95	94	--	0.819
6 hr	(V≥8 km)	95	95	--	0.847	(C≥2000 ft)	93	94	--	0.812
7 hr		--	--	95	0.858		--	--	94	0.819
12 hr		91	96	--	0.909		89	95	--	0.876
13 hr		--	--	97	0.891		--	--	94	0.847
15 hr		91	--	--	0.918		87	--	--	0.885
19 hr		--	--	98	0.918		--	--	97	0.885

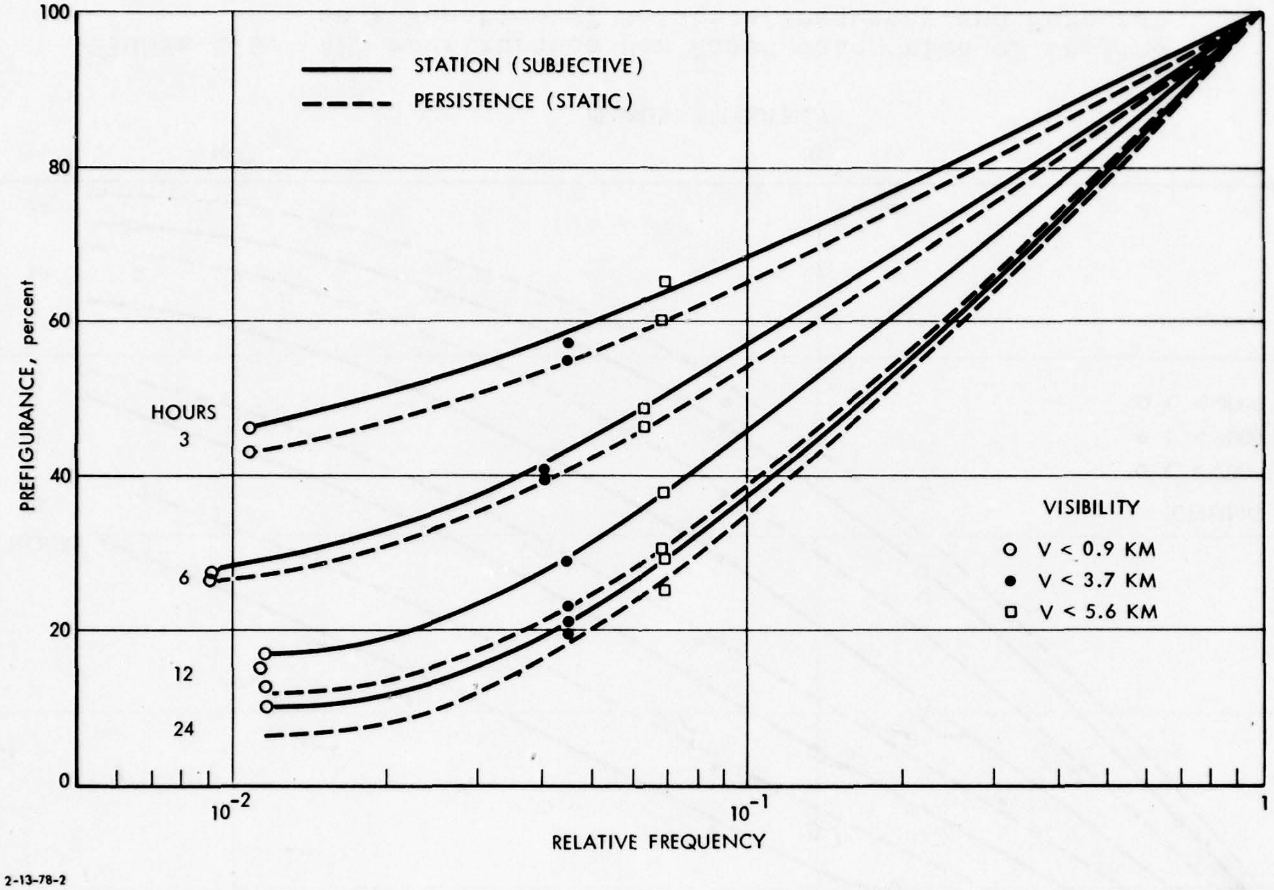

FIGURE E-1. AWS Prefigurance for Added Categories of *Visibility* as a Function of Relative Frequency and Forecast Time (hours).

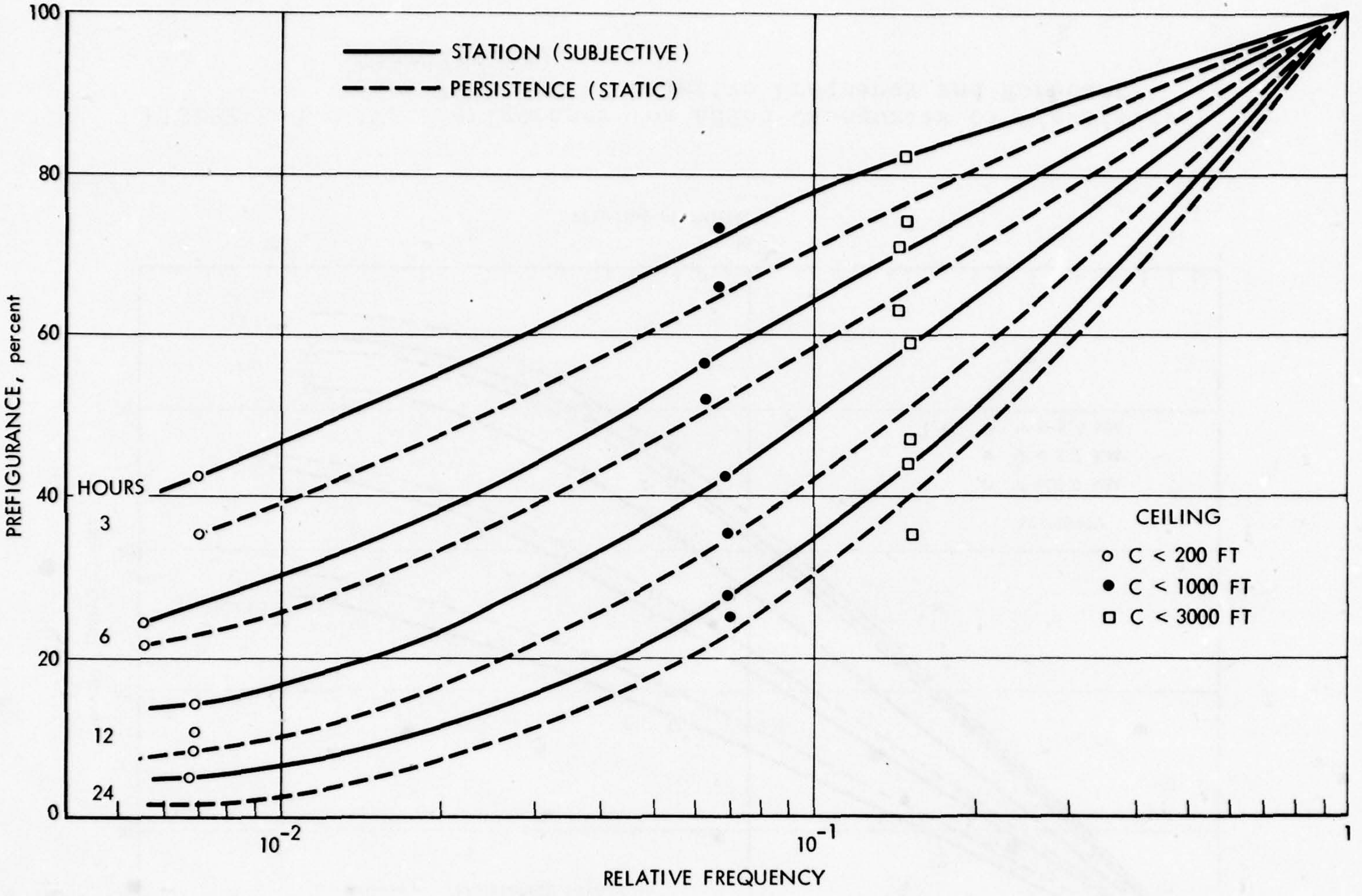

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FIGURE E-2. AWS Prefigurance for Added Categories of *Ceiling* as a Function of Relative Frequency and Forecast Time (hours).

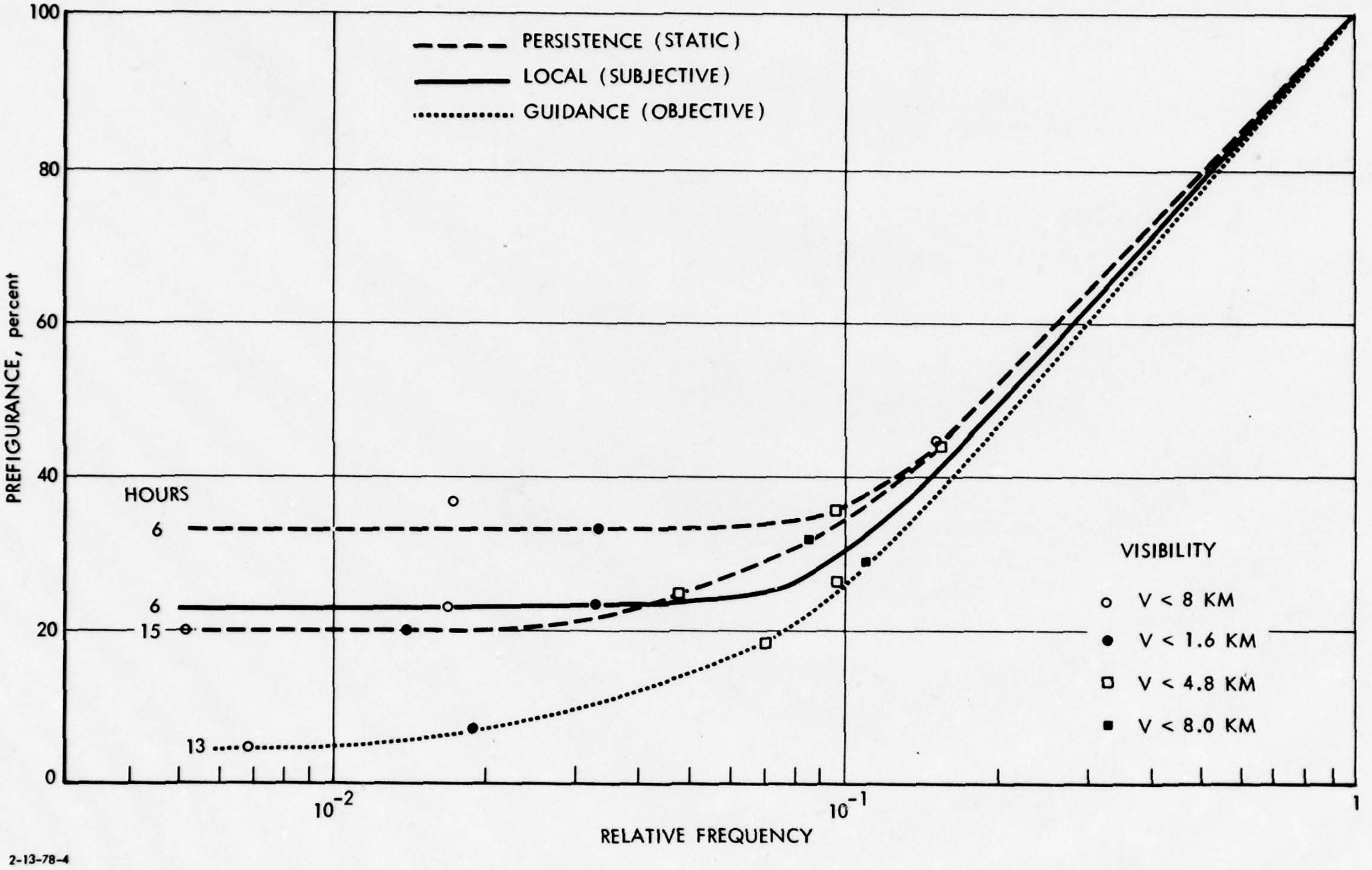

FIGURE E-3. Relative Comparison of Local versus Persistence (6 hr) and Guidance (13 hr) Prefigurances for Visibility Based on TDL Forecast Verification Data.

APPENDIX F

PROJECTING FORECAST RELIABILITY FOR 1985

APPENDIX F

PROJECTING FORECAST RELIABILITY FOR 1985

INTRODUCTION

Previous appendices have described the mesoscale weather forecasting methodologies involving persistence, local or station, and guidance techniques (Appendix D) as well as their relative current accuracies or prefigurances for forecasts of, say, visibility and ceiling (Appendix E). These results may be summarized as follows:

1. The accuracy or prefigurance of mesoscale weather forecasting for visibility or ceiling is a function of both forecast time (hours) and the frequency (i.e., number of events per period of time) of the forecast event (e.g., Figs. E-1 to E-3).
2. High accuracies or prefigurances are obtained for forecast events of high frequency for *any* of the three available techniques for mesoscale weather forecasting: i.e., persistence, local or station, and guidance (e.g., Category 5, Tables E-8, E-9). Furthermore, the decay in prefigurance with forecast time between 3 and 24 hours is small for high frequency events (e.g., Category D, Tables E-3 to E-6).
3. Low accuracies or prefigurances are obtained for forecast events of low frequency for any of the three available forecasting techniques. Furthermore, NWS *persistence forecasts for low frequency events give higher prefigurances than either local or guidance forecasts.*

Improvements in forecast accuracies for infrequent weather events by either persistence or subjective techniques cannot, of course, be foreseen. Therefore, any potential improvement of mesoscale prefigurances for low frequency events must come from objective or guidance forecasting, which is based on numerical weather prediction (NWP) and model output statistics (MOS) as described in Appendix D. Therefore, a main objective of this appendix is to project the potential gain in the prefigurance of guidance forecasts for low frequency events in the near-term future (circa, 1985).

CONSTRAINT IN PROJECTION OF FORECAST ACCURACY IMPROVEMENTS

An important consideration in Army panels' examination of the potential gains in tactical utility from 1985 *improvements* in mesoscale weather forecasting of infrequent events (Exhibit 5) is the need to avoid understatements of near-term improvements in such forecasting skills. For this reason, these improvements must be based on upper bound or very optimistic 1985 prefigurances, which may *not* necessarily reflect expected values in the near-term future.

The upper-bound improvement for the prefigurance of 1985 mesoscale guidance forecasts of infrequent events must then be based on two considerations: (1) the gains in prefigurance achieved by *synoptic* NWP over persistence during the past three decades, and (2) the decoupling of NWP from MOS due to the relatively underdeveloped state of the latter for forecasts of low visibilities or ceilings (Appendix E). The required upper bound can thus be obtained by postulating that 1985 improvements in the current accuracy of mesoscale guidance forecasts of infrequent events over persistence will be comparable to the improvements achieved by synoptic NWP over persistence during the last three decades for weather parameters that do not require the MOS approach. This procedure yields an upper bound because of the following implied optimistic assumptions:

1. The current (underdeveloped) understanding of mesoscale atmospheric phenomena controlling *infrequent* weather events is comparable to the (well-developed) understanding of synoptic scale phenomena for frequent events which already existed three decades ago.*
2. An adequate mesoscale network of meteorological observations will be developed in the next decade.

It becomes important to emphasize the difference between two types of weather variables: (1) those predicted *directly* from the equations of atmospheric motion or NWP alone, such as the height of a given pressure level (e.g., the 500 mb), temperature, winds, and humidity; and (2) those predicted with the aid of statistical *empirical* correlations (i.e., NWP plus MOS) such as visibility. Weather forecast verification data indicate that, at the present time, the latter guidance procedure cannot even match the accuracy of persistence forecasts of low frequency events (e.g., Fig. E-3, Appendix E). Hence, using past improvements of a direct forecast variable (e.g., the height of the 500-mb pressure level) to project improvements of an indirect forecast variable (i.e., visibility) leads to upper-bound consideration for the latter variable.

The considerations leading to an upper-bound projection of near-term mesoscale forecasting skills for infrequent events must therefore include: (a) a brief review of the past development of synoptic NWP during the last three decades, (b) the *maximum* improvements of synoptic NWP over persistence as derived from forecast verification data for parameters that do not require MOS, such as the height of a given pressure level; and (c) the basic developments that would support a potential significant improvement of future mesoscale NWP (MNWP).

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PAST DEVELOPMENT OF SYNOPTIC NUMERICAL WEATHER PREDICTION

The methodology of NWP involves two steps: (a) definition of the prevailing state of the atmosphere, and (b) subsequent calculations of future weather patterns. The first step requires upper-air observations of the prevailing large-scale or synoptic weather systems, a task that is accomplished through an upper-air network of radiosonde balloons. The second step involves the use of NWP, which utilizes the deterministic equations of motion of the atmosphere. These equations, known as the primitive equations (PE), must first be integrated numerically with respect to time over a global or hemispherical space domain. The space domain can next be reduced to that of North America, for example, in order to increase the resolution of future synoptic weather events from a numerical grid size of about 380 km for the hemispherical domain to about 190 km for the North American domain (Refs. 16, 17, 24). The latter domain utilizes a limited area fine mesh (LAFM) atmospheric model, which is nested in the hemispheric model. Since the development of future nested *mesoscale* NWP models would be a direct extension of the present methodology, it becomes of interest to review briefly the development of NWP over the last few decades.

The genesis of NWP started about half a century ago with a numerical experiment that attempted to utilize the complete set of hydro-thermodynamic equations for weather prediction by the method of finite differences (Ref. 25). This first experiment was doomed to failure because of the following factors: (a) computational instability arising from the *arbitrary* choice of finite increments in space and time, (b) compensation among terms in the complete equations of motion, (c) insufficient accuracy in the knowledge of the initial state of the atmosphere from the lack of reliable upper-air observations, and (d) lack of computers to produce timely forecasts ahead of the future weather. Most of these problems were dealt with in subsequent decades by:

1. Development of a criterion for the relative sizes of the finite increments in time and space for avoiding computational instability.
2. Simplification of the conservation equations of the atmosphere by considering only macroscale motions (Ref. 26). This approach yielded the so-called barotropic model, which is the simplest possible model to describe synoptic motions.
3. Rapid increase of upper-air radiosonde stations subsequent to World War II.
4. Development of five successive generations of electronic computers with ever increasing computational speed during the last quarter century. Using the speed of the IBM 360-91 computer of the late 1960s as a reference, these generations may be identified successively as follows (Ref. 27): (a) IBM 701 with a relative speed of 3 x 10^{-3}, (b) IBM 704 with a relative speed of 10^{-2}, (c) CDC 6600 with a relative speed of 0.5, (d) CDC 7600 with a relative speed of 2 as well as the IBM 360/195 with a relative speed of about 3, and (e) more recent computers such as the Cray with a relative speed of about 10. The computer speed has thus increased by more than three orders of magnitude in the last 25 years.

The foregoing developments made possible a demonstration in 1950 of the feasibility of NWP, when the first numerical forecast from real initial data was computed with a barotropic model. The present operational capabilities of NWP at the National Weather Service (NWS), for example, may be characterized by the following factors:

1. Use of upper-air observational data, taken only twice a day from a network of radiosonde stations over North America and Europe, a network that is characterized by

a geographical resolution of about 300 km. The coverage of this network remains rather limited, since there is lack of observational data over a large fraction of the northern atmosphere over the Pacific and Atlantic Oceans as well as over continents such as Asia. Remote soundings of infrared radiation from meteorological satellites have not been able to close this enormous gap in observations (Ref. 28). However, the impact of the satellite data (when available) on the accuracy of mesoscale weather forecasts has so far been negligible (Ref. 28).

2. Use of fourth-generation electronic computers in the operation of the northern hemispheric and limited area fine mesh (LAFM) models. The hemispherical model was first run in 1966, whereas the LAFM did so in September 1971 for only a 24-hour forecast and using steady-state instead of transient boundary conditions at the interface between the LAFM and hemispherical model (Ref. 29).

The NWP outputs are limited to synoptic fields at six pressure (or height) levels of the atmosphere for parameters such as the heights of pressure levels (or geopotentials), temperature, moisture, etc. The MOS approach is then used in order to close the gaps between (1) numerical and real weather parameters such as visibility, and (2) the meso-α ($200 < d \leq 2000$ km) and both the meso-β ($20 < d \leq 200$ km) as well as meso-γ ($2 \leq d \leq 20$ km) scales (Appendix C). As described in the previous appendices, the MOS approach attempts to establish *correlations* between the statistics of past NWP predictions and the corresponding observed weather. Such empirical approach attempts to make up for the lack of physical models for phenomena involving low visibilities, i.e., the MOS approach hopes to build in such correlations the mesoscale climatic statistics for even low frequency events. Thus, the MOS approach yields competitive results with persistence for high frequency events with well-defined statistics, but fails to do so for the low frequency events of interest. Experience to date with predictants such as low visibilities and low ceilings indicates very *low* correlations between predictors and predictants.*

PAST IMPROVEMENTS OF SYNOPTIC NWP OVER PERSISTENCE

As indicated earlier, the decay in prefigurance with increasing forecast time becomes large for low frequency events (e.g., Figs. E-1, E-2). This decay of prefigurance comes, in general, from three types of forecast errors:

1. The initial error in the observations due to the inadequate hemispherical coverage of the network of radiosonde stations.
2. The inherent degree of unpredictability of the atmospheric motions (Ref. 30). This error represents the growth with time of the initial error as a consequence of the unstable character of the atmospheric motions. Physically, this inherent error stems from the fact that the atmospheric motions do not reproduce themselves periodically at a given geographical location and during the same point of successive annual cycles (e.g., week or month). Mathematically, this inherent error stems from the divergent nature of numerical solutions when they start from slightly different starting conditions due to a small initial error. The magnitude of this inherent error has been established from the weather record itself by attempting to detect two nearly identical atmospheric conditions and observing their subsequent departures.
3. The error introduced by the NWP models on weather variables that are decoupled from MOS, i.e., such as the height of the 500-mbar pressure level.

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A crude budget of the relative contribution of the foregoing errors can be based on the following approximate differential equation for error growth (Ref. 31):

$$\frac{dE}{dt} = \alpha E + S , \qquad \text{(F-1)}$$

where E denotes the mean square error of a given variable, α the error from the unstable character of atmospheric motions, S the error source rate arising from NWP model imperfections, and t the time. The value of the inherent error has been established to be $\alpha = 0.55$ per day (Ref. 30). Integration of the above equation yields for the final error growth the expression

$$E_f(t) = 2E_o + (E_o + S/\alpha)(e^{\alpha t} - 1) , \qquad \text{(F-2)}$$

where E_o is the initial error due to the limited scope of the network of radiosonde stations. The factor of 2 comes about from the need to reuse observations in the verification of a forecast. Equation F-2 indicates that perfect forecasting (i.e., zero error growth or a prefigurance of 100 percent at any forecast time) would require both errorless analysis and interpolations of the observations (i.e., $E_o = 0$) and perfect modeling ($S = 0$).

Equation F-2 can be applied to the observed error growth in both persistence and NWP forecasts of the height of the 500-mbar pressure level utilizing $\alpha = 0.55$ per day. Since the error growth is linear with respect to the parameter $(e^{\alpha t} - 1)$ as shown by Eq. F-2, a plot of the error growth, $E_f(t)$, for persistence and NWP forecast against $e^{\alpha t} - 1$ yields a straight line with different slope for each type of forecast. The intercept of either line at $e^{\alpha t} - 1 = 0$ yields the magnitude of E_o, whereas the slope of each line gives the value of S corresponding to persistence and NWP. Utilizing Eq. F-2 with these experimentally determined values of the parameters E_o and S, Table F-1 shows results of the error growth for the height of the average 500-mbar pressure level as a function of forecast time (hours).

TABLE F-1. Forecast RMS Error (m) of the 500-mbar Height Field for Several Types of Forecasts

Forecast Type	E_o (m^2)	S (m^2/day)	Forecast Time (hr) 0	3	6	12	24
Persistence	200	3000	14.1	28.3	35.1	46.8	67.4
NWP	200	800	14.1	22.8	25.4	30.4	40.2
Perfect Model	200	0	14.1	20.4	20.7	21.5	23.4
Perfect Observations	0	800	0	7.5	14.6	21.5	32.7

Table F-1 shows the following: (1) the initial rms error in the height of the 500-mbar pressure level is equal to $\sqrt{200}$ or 14.1 m; (2) the source error for persistence (no model) is 3000 m^2 per day; NWP using fourth-generation electronic computers (GISS model) with a synoptic numerical grid of 400 km has been able to reduce the error source from 3000 to 800 m^2 per day; and (3) improvements from NWP over persistence can be translated into extensions of forecast time for the *same* rms error. Thus, either by plotting or interpolation of the persistence and NWP error growths in Table F-1, it is found that the rms growth to 28.3 m for a *3-hour persistence forecast has been delayed by about 6 hours by NWP.*

Figure F-1 shows a plot based on Eq. F-2 for forecast times as long as five days for persistence, NWP, and perfect modeling (Ref. 32). The latter shows an error growth that is due to the $E_o(e^{\alpha t}-1)$ term in Eq. F-2, i.e., as caused by the initial observation error (E_o) and the unstable character of the atmospheric motions (α). The percentages on Fig. F-1 show (1) the improvement by synoptic NWP over persistence and (2) the remaining gap between current and perfect synoptic model skills for the present levels of the initial error. This figure includes also a table that gives estimates by personnel of the National Center for Atmospheric Research (NCAR) for the probable causes for the difference between persistence and perfect forecasting (Ref. 32): grid size (45 percent), analysis and interpolations of the original observations (20 percent), and physics of the model (35 percent).

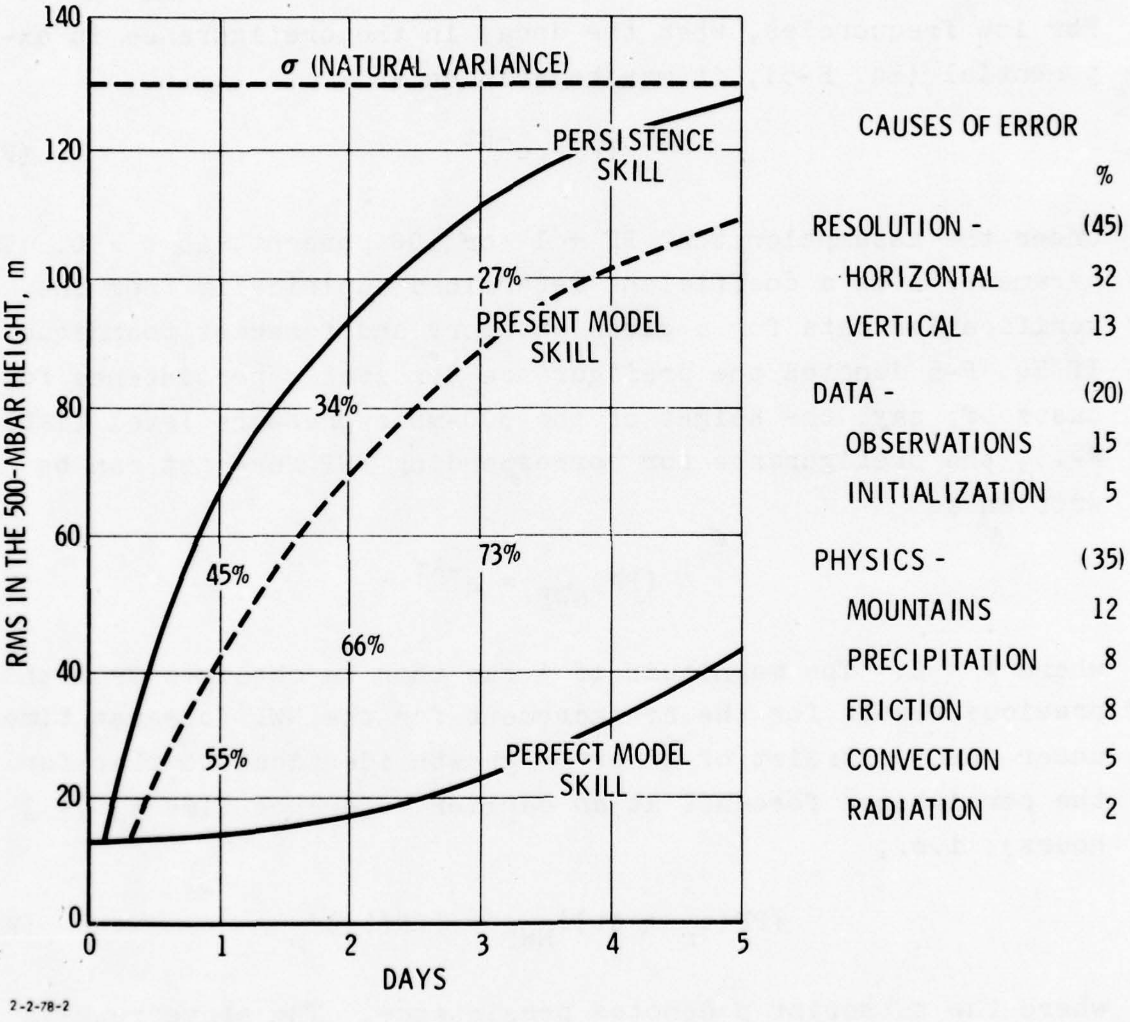
The time delay for the growth to a given error as given by synoptic NWP relative to persistence (i.e., Fig. F-1 or Table F-1) can be extended to the prefigurance simply because the decay in the prefigurance (PF) with increasing forecast time is caused by the corresponding growth in a dimensionless error (E_D) such that

$$PF + E_D = 1 , \qquad \text{(F-3)}$$

i.e., the sum of the prefigurance (in fraction instead of percent) for a forecast of any duration and a dimensionless error for that duration must be equal to unity. The dimensionless error can be obtained by normalizing the error growth with its final climatic value (E_C), as shown, for example, in Fig. F-1 where $E_C \simeq 130$ m. Thus, the dimensionless error can be chosen as $E_D = (E - E_o)/(E_C - E_o)$ from the conditions that at the initial time $E \rightarrow E_o$ and $PF \rightarrow 1$, whereas at long forecast times the error grows to its climatic value for the given category of event, i.e., $E \rightarrow E_C$ or $E_D \rightarrow 1$ and $PF \rightarrow 0$. From Eq. F-3 one gets

$$\delta PF = -\delta E_d , \qquad \text{(F-4)}$$

where δ denotes change. Equation F-4 indicates that the improvement in the synoptic NWP prefigurance over persistence is equal to the decrease in the dimensionless error growth for a given forecast time. Hence, the past improvement by synoptic NWP over persistence of the error growth in Table F-1 can be extended to the prefigurance, i.e., the persistence prefigurance value for a reference forecast time of 3 hours would be the same as the NWP



CAUSES OF ERROR	%
RESOLUTION -	(45)
HORIZONTAL	32
VERTICAL	13
DATA -	(20)
OBSERVATIONS	15
INITIALIZATION	5
PHYSICS -	(35)
MOUNTAINS	12
PRECIPITATION	8
FRICTION	8
CONVECTION	5
RADIATION	2

FIGURE F-1. Forecast RMS Error (m) of the 500-mbar Height Field for Several Types of Forecasts.

prefigurance for a forecast time extended by the same time increment Δt of 6 hours.

As indicated earlier, the prefigurance of mesoscale forecasts of visibility or ceiling is a function of both forecast time and the frequency of the forecast event (e.g., Eq. E-6). For low frequencies, when the decay in the prefigurance is exponential (Eq. E-5), it may be written as

$$PF = e^{-\beta t} \tag{F-5}$$

under the assumption that $PF \rightarrow 1$ (or 100 percent) as $t \rightarrow 0$. The parameter β is a coefficient determined empirically from the verification data for a given category and forecast technique. If Eq. F-5 denotes the prefigurance for static persistence forecasts of, say, the height of the 500-mbar pressure level (Table F-1), the prefigurance for corresponding NWP forecast can be written as

$$(PF)_{NWP} = e^{-\lambda t} \ , \tag{F-6}$$

where $\lambda < \beta$. The magnitude of λ can then be obtained from the previous result for the Δt increment for the NWP forecast time under the constraint of an error growth identical to that for the persistence forecast at an earlier reference time t_r ($\sim$ 3 hours), i.e.,

$$\{PF(t_r + \Delta t)\}_{NWP} = \{PF(t_r)\}_p \tag{F-7}$$

where the subscript p denotes persistence. The above results then yield the relation

$$\lambda = \frac{\beta}{1 + \Delta t/t_r} \ , \tag{F-8}$$

which identifies the parameter $\Delta t/t_r$ for measuring the past gain in the NWP prefigurance over that of persistence. For the data in Table F-1 that show a time increment of 6 hours for a reference forecast of 3 hours, $\Delta t/t_r \approx 2$. This result is, of course, applicable to parameters such as the height of the 500-mbar pressure level. For other parameters such as visibility, $\Delta t/t_r << 2$. In fact, the guidance and persistence data in the previous appendix (e.g., Fig. E-3) show that $\Delta t < 0$, i.e., the time increment can be negative as given by the current condition of poorer guidance prefigurances relative to the corresponding persistence values.

POTENTIAL MODEL DEVELOPMENT FOR FUTURE MESOSCALE NWP (MNWP)

When examining current trends in mesoscale weather research within the civilian meteorological community, it becomes important to observe that (1) these trends do not put emphasis on the weather variables of usual tactical interest such as the forecast of infrequent events of low visibility or ceiling, and (2) events of low visibility ($V < 3$ km) and low ceiling ($C < 1000$ ft) are controlled by phenomena within the planetary boundary layer ($z \leq 1$ km, Appendix C). Although phenomena in the free troposphere is also of interest for Army tactical operations (e.g., winds up to 15-km altitude for artillery fire), improvements in forecasting skills of low visibility or ceiling would need greater emphasis on boundary layer research. Most of the civilian mesoscale meteorological research, to be reviewed briefly below, is not focused on improving the above variables of tactical interest.

Figure F-1 shows that present model skill by synoptic NWP is closer to persistence than to perfect model skill. Furthermore, the table in the same figure indicates that significant gains in prefigurance may be derived by increasing the resolution of synoptic NWP, i.e., by decreasing the size of the numerical grid from the 190 km of the LAFM model for, say, North America. For example, it has already been shown that by decreasing the grid size from that of the hemispherical (∿ 380 km) to the LAFM ($\sim$ 190 km) to the MFM (or movable fine mesh, $\sim$ 60 km), a 48-hour forecast from each model moved a low surface pressure pattern gradually from the *predicted* location at the Gulf of Mexico by the hemispherical model to near its *observed* location over Ohio by the MFM model (Refs. 33, 34). Hence, it would indeed be too much to ask from the crude MOS methodology if it were expected to overcome significant errors in the predictors derived from synoptic NWP.

A potential improvement of guidance forecasts for low frequency events must, therefore, follow the guidelines indicated in Fig. F-1. This is precisely the current trend in meso-β ($20 < d \leq 200$ km) meteorology, a trend that is putting emphasis in a sharp reduction of the North American domain of the LAFM model (for example) to that of a regional area that would include only the East Coast of the United States (Ref. 35). Before indicating the current state of the art in meso-β NWP (i.e., MNWP), it becomes important to describe its evolution.

The modeling of mesoscale phenomena is not a new trend, as indicated by the relevant work during nearly the last two decades. The scope of this early work already includes topics such as the numerical experiments of convection in a model atmosphere (Ref. 36), theoretical investigations of the sea breeze (Ref. 37), the numerical study of a mesohigh of 26-27 June 1953 (Ref. 38), a numerical model of thermal convection in the atmosphere (Ref. 39), the effects of condensation, evaporation, and rainfall on the development of mesoscale disturbances (Ref. 44), etc. More recent efforts in mesoscale involve a planned research project on "Severe Environmental Storms and Mesoscale Experiment (SESAME)." The main emphasis of SESAME is on the understanding of low frequency meso-β phenomena (Appendix C and Ref. 41). The scope of the program involves both observations, data management, and modeling. The consideration of observations include vertical soundings from satellites, severe storm and tornado data, etc. The scope of data management involves planning, coordinating, and monitoring functions so as to insure the timely collection of scientific data. The modeling effort is as described below.

A brief survey of the modeling of meso-β phenomena is given in Refs. 10 and 42. Fundamentally, this type of modeling represents a somewhat straightforward application of the same primitive equations as in the case of the synoptic NWP. However, because of the higher numerical resolution of mesoscale NWP, it becomes necessary to include phenomena such as the planetary boundary layer and to reexamine the subgrid parameterizations in the primitive equations for the synoptic NWP. More specifically, meso-β modeling requires an accurate three-dimensional representation of the parameterization of boundary layer processes. The recommended techniques for use in meso-β modeling include the development of a three-dimensional hydrostatic model on a fixed grid, with horizontal resolutions greater than the meso-β observing network, and with sufficient vertical resolution to accurately resolve the boundary layer as well as the free atmosphere. Furthermore, the meso-β equations must be integrated using an efficient mass and energy conservative finite difference scheme in which the lateral boundary conditions are determined from a larger scale model or from actual observations. The effects of cumulus activity on the meso-β scale may need to be parameterized using meso-γ scale cumulus-field models.

A representative, near operational mesoscale NWP model is that developed at Drexel University (Ref. 35). The size of the numerical grid is about 35 km within a domain of about 1500 km, a domain that is necessary to produce a 24-hour forecast at a given meteorological station. Sample forecasts have been produced for the Eastern United States. The computer facilities so far utilized at the National Center for Atmospheric Research (NCAR) corresponds to the fourth-generation computer (CDC 7600). Near-term future work on the development of meso-β NWP may be further stimulated by the faster Cray computer, which is just becoming operational at NCAR.

UPPER-BOUND PROJECTIONS FOR NEAR-TERM MESOSCALE FORECASTING SKILLS

Previous considerations have established the following: (1) projections for improvements in the accuracy of forecasting skills for infrequent events must come from guidance or scientific forecasting techniques, (2) the results in Table F-1 indicate that the maximum improvement by synoptic NWP over persistence for frequent events during the last three decades can be characterized by $\Delta t/t_r = 2$, and (3) the accuracy for 1977 guidance forecasts of infrequent events of visibility is given by $\Delta t/t_r < 0$, i.e., the negative values of Δt indicate that the accuracy of the 1977 guidance prefigurances cannot even match those of persistence.

An upper-bound projection for the 1985 prefigurances of guidance forecasts of infrequent events of visibility or ceiling can be obtained by using Eqs. F-5 to F-8 with $\Delta t/t_r = 6/3 = 2$. Considering first the simpler case of an exponential decay in prefigurance (i.e., Eq. F-5), the corresponding 1985 projection is then given by Eqs. F-6 and F-8 together with β parameters obtained from current persistence forecasts for such phenomena. *The upper-bound prefigurances are thus derived by assuming that the potential gain in mesoscale NWP (MNWP) prefigurances for low frequency events of visibility or ceiling would be the same as that achieved by synoptic NWP over persistence during the past few decades for continuous (i.e., maximum frequency) events such as the height of the 500-mbar pressure level.* The implied modeling assumptions in this procedure are that MNWP would always provide accurate predictors for the MOS approach, and that the MOS approach would be based on a boundary layer model for identifying the main MNWP predictors for *infrequent* events.

The foregoing procedure (Eqs. F-6 and F-8) would apply for exponential decays in both the persistence and 1985 MNWP prefigurances with an increasing forecast time up to at least 3 and

9 hours, respectively. Verification data for low frequency events of visibility and ceiling indicate that such decay in the persistence prefigurance is not always a strict exponential. In these cases, the upper-bound projection for the 1985 MNWP prefigurances is established by using (1) the 3-hour persistence prefigurance at 9 hours for the 1985 MNWP prediction (i.e., by assuming that the MNWP forecast would delay the error growth in the 3-hour persistence forecast by 6 hours, as indicated by Eq. F-7), and (2) the same approximate shape of the nonexponential delay of the persistence prefigurance up to 9 hours. Between 9 and 24 hours, the rate of prefigurance decay was made to tend to that of *frequent* events, in accordance with the constraint of obtaining an upper-bound improvement in future forecasting skills for the subsequent tactical consideration by Army panels of such improvements. This procedure is illustrated in Fig. F-2, which was applied to both low and high frequency events, even though the latter cases are forecast rather accurately even by persistence (Tables E-10, E-11).

The results in Appendix E indicate that the 1977 prefigurances of guidance forecasts of infrequent events of visibility could not match those of persistence. The TDL verification data (Table E-11) give a $\Delta t/t_r$ of about -1.5/3 or -0.5. Therefore, the attainment of the 1985 $\Delta t/t_r$ parameter of 6/3 or 2.0 may be very difficult to achieve by MNWP. If the 1985 upper-bound projection had been found to be of tactical interest, the second phase of this task (Appendix A) would have had to determine an *expected* instead of an upper-bound projection of the 1985 MNWP prefigurances.

REVIEW AND TEST OF THE UPPER-BOUND PROJECTION

The foregoing methodology for an upper-bound projection of near-term, future forecasting skills for visibility and ceiling was reviewed by personnel from the following organizations: Air Weather Service (AWS) of the U.S. Air Force; Technique Development

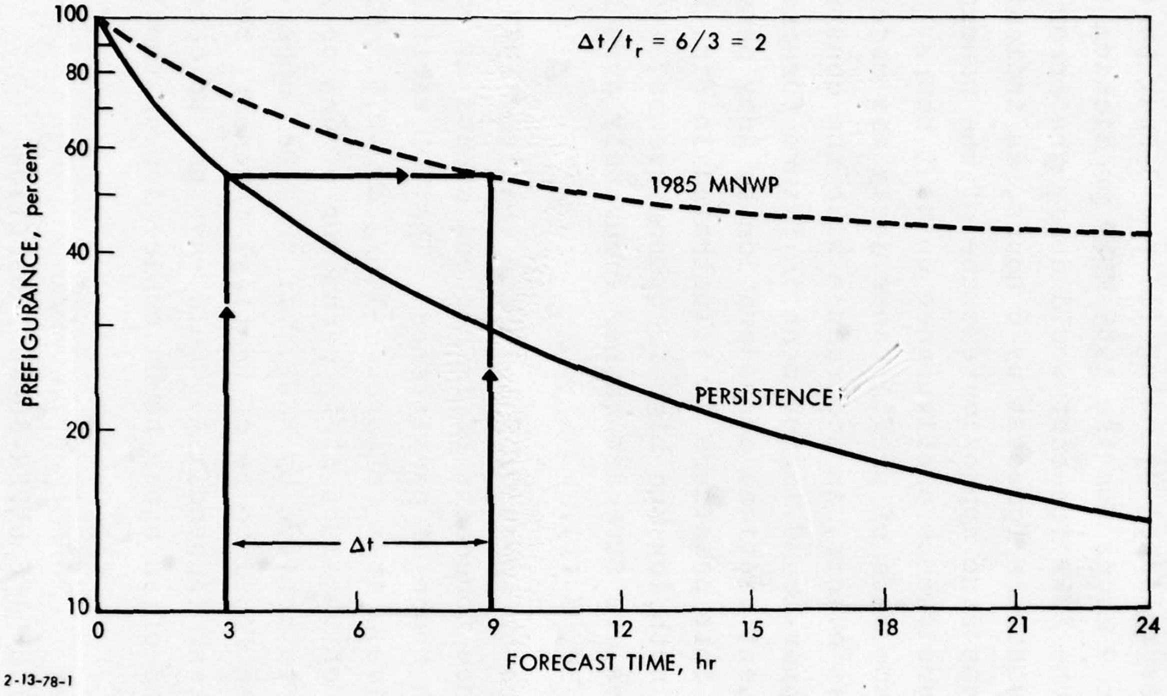


FIGURE F-2. Illustration of Procedure to Derive an Upper-Bound Near-Term Projection of Prefigurances for Infrequent Events Based on a Potential Development of Mesoscale Numerical Weather Prediction (MNWP).

Laboratory (TDL) of the National Weather Service (NWS), NOAA; National Center for Atmospheric Research (NCAR), and the School of Meteorology of the Pennsylvania State University. There was a unanimous consensus that the use of a 9-hour forecast by future MNWP with a 3-hour persistence prefigurance (i.e., $\Delta t/t_r$ = 2) was indeed very optimistic.

A test of the optimistic nature of the foregoing projection can be obtained from recent verification of MNWP forecasts for winds aloft for a 6-hour period (Ref. 43). Figure F-3 shows a comparison of the root mean square vector errors (rmsve) in meters per second between persistence (top line) and several mesoscale models. It was found that the mesoscale model yielding the smallest rmsve (lowest line) is based on the most physics, which included advection, nongeostrophic acceleration, vertical mixing, and friction. The geographical domain for these results was nearly centered over the Nevada test site and included an area of 333 x 333 km with a grid size of 37 km. The main points of interest here are that (1) the $\Delta t/t_r$ parameter for this mesoscale experiment (Fig. F-3) is equal to about 1.5/3 or 0.5, i.e., MNWP has yielded a positive time increment for the forecast of mesoscale wind vectors; and (2) the $\Delta t/t_r$ of 0.5 in this numerical experiment is lower by a factor of 4 than that used for the upper-bound projections.

SUMMARY OF RESULTS FOR PRESENT AND PROJECTED FORECASTING SKILLS

Exhibit 16 shows a summary of the current (1977) and near-term (1985) projections of mesoscale weather forecasting capabilities for several categories of visibility, ceiling, precipitation, and winds. The 1977 prefigurances are as given by TDL, NMC, and AWS data (Appendix G), and the 1985 values as obtained by the upper-bound projection procedure described in this appendix. The data for visibility and ceiling in Exhibit 16 are based on TDL (instead of AWS) data because of their finer breakdown for the categories of visibility and ceiling. In order to

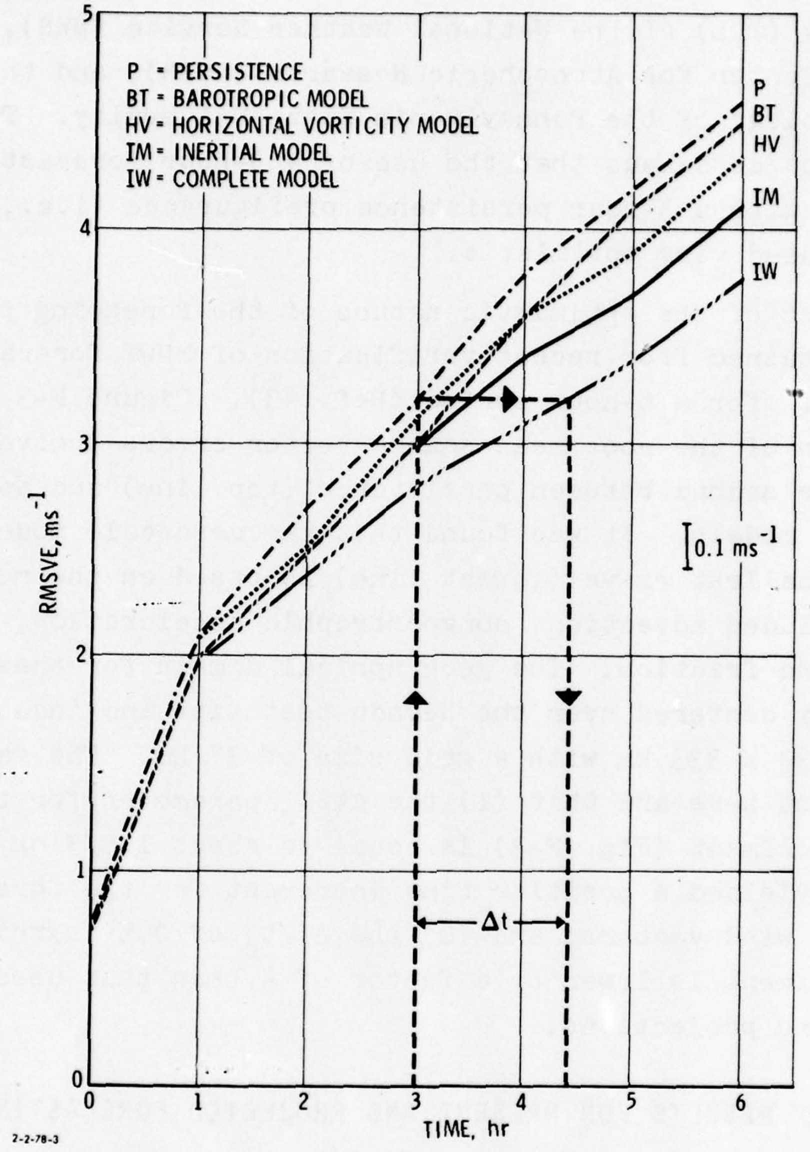


FIGURE F-3. Growth of average rms vector error for mesoscale winds at heights between 1.5 km and 3.7 km as a function of forecast time. The top line represents persistence. The lower ones are obtained from mesoscale models with different approximations in the physics. Note that persistence and the IW model yields a $\Delta t/t_r$ parameter of about 1.5/3 = 0.5.

Source: Cornett and Randerson, 1977

present a perhaps more meaningful set of data to Army tactical commanders, the TDL categories have been aggregated using the procedure illustrated in Table G-46 (Appendix G).

It is important to emphasize that the reviewing organization identified above examined both the methodology for the near-term upper-bound projection and the numerical results shown in Exhibit 16.

APPENDIX G

FORECAST VERIFICATION DATA

APPENDIX G

FORECAST VERIFICATION DATA

INTRODUCTION

Previous appendices have considered the basic characteristics of mesoscale weather phenomena (Appendix C), the three available mesoscale weather forecasting techniques (Appendix D), and the forecast verification methodology (Appendix E). The latter considerations included the identification of the forecast verification parameters and the relative accuracies of the three available forecasting techniques.

As described in Appendix C, the space dimensions (d) of interest for tactical considerations of weather are the so-called meso-β ($20 \le d \le 200$ km) and meso-γ ($2 \le d \le 20$ km) mesoscale subregimes. Because of the small magnitude of these space scales, verification data for mesoscale weather forecasts are limited to a 24-hour forecast time.

Appendix D described the three available forecasting techniques, which are: persistence, subjective (station or local) and objective (guidance). The first type of forecast is based on the tendency of current weather to continue to persist in the near future of the forecast time. The second type is the product released by a human forecaster at a particular meteorological station. The third one is the product of centralized stations that utilize a deterministic forecasting approach based on the use of the dynamics equations of the atmosphere together with statistical approaches.

The basic forecast verification parameters were described in Appendix E. The most important ones are the prefigurance (H_i/O_i), bias (F_i/O_i) and relative frequency ($O_i/\Sigma O_i$); where H_i denotes the number of correct forecasts (hits) in a given category i of weather event, O_i the number of occurrences or observations of such events, F_i the number of forecasts for a given event, and ΣO_i the total number of occurrences or observations in the statistical sample of forecast verification. These verification parameters can thus be determined from contingency tables (e.g., Table E-1), which are the product of the statistical procedure of forecast verification. The contingency tables for a given type of event (e.g., visibility) are thus determined as a function of the time of the year (month, season) and forecast time (hours) for each type of forecasting technique: persistence, local or station, and guidance.

The basic results of forecast verification have also been presented in Appendix E (i.e., Figs. E-1 to E-3). These results indicate the following: (1) the prefigurance or forecast accuracy is a function of relative frequency and forecast time, (2) the prefigurance deteriorates rather drastically for low frequency events of tactical interest (e.g., low visibilities $V < 3$ km and low ceilings $C < 1000$ ft) regardless of forecasting technique, and (3) the prefigurance from persistence is surprisingly better than that of the subjective (man's) or objective (science) forecasting techniques for infrequent weather events.

The main objective of this appendix is therefore to provide the contingency tables that support the foregoing forecast verification results in Appendix E. These contingency tables are important because they determine the verification parameters for every category of weather event (O_i), including, of course, the often neglected relative frequency of the forecast event.

FORECAST VERIFICATION PROCEDURES

The main sources of forecast verification data were the USAF Air Weather Service (AWS)* as well as the Technique

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Development Laboratory (TDL)* and the National Meteorological Center (NMC)** of the National Weather Service (NWS), NOAA. An important objective in forecast verification at the Air Weather Service and National Weather Service is to obtain valid statistical evaluations of mesoscale forecasting skills, both for their own evaluation and further future development of such skills.

The statistical evaluation of mesoscale forecasting skills is obtained through verification of a large sample of weather forecasts. The available AWS verification data for Western Europe, for example, considered over half a million forecasts for visibility or ceiling of different forecast duration. The statistical evaluation of forecasting skills involves verification of operational forecasts issued at suitable meteorological stations within a large geographical domain and during prolonged periods of time. The geographical domain of the AWS data includes 35 stations in Western Europe distributed as follows: 17 in Germany, 15 in England, 2 in Spain, and 1 in Northern Italy. The time domain for the AWS verification data included the months between September 1976 and March 1977. Likewise, TDL data for visibility or ceiling are based on a sample of over a hundred thousand forecasts of several hours duration. The geographical domain of the TDL data includes 92 stations within the contiguous United States distributed across every major section of the country (i.e., Northeast, Southeast, Northwest, Southwest, and the North and South central states). The time domain of the TDL data includes the months between October 1975 to March 1976.

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**David Olson, NMC (World Weather Building), NWS, NOAA, Washington, D.C.

At the selected meteorological stations, forecast verifications are made of each operational forecast, which are issued daily at a rate that depends on the local weather. The normal rate is of two forecasts each day, which can be expanded to more frequent forecasts during bad weather. At each selected station, the resident meteorologist continues to issue operational local forecasts, which are based on several factors: (a) local surface observations made hourly, (b) synoptic weather charts released from central to local stations through automated communication channels, (c) guidance forecasts for the particular station as released from central stations, (d) mesoclimatology for his particular station, and (e) meteorological insight from his own professional training and experience. It should be noted that persistence forecasts do not have to be formally issued, because they are imbedded in the hourly observational record. Persistence forecasts can always be made after the fact, by merely looking up in the record of the observed weather the conditions that prevailed at the time of the local or guidance forecast release. Since persistence has no model skill to forecast changes of weather, it becomes a readily available absolute reference for establishing the relative skills of the local or guidance forecasts.

The forecast verification procedure is straightforward and part of the permanent meteorological record. Forecasts issued at the verification stations are labeled permanently and they are verified against the record of hourly surface observations, which are gathered by nonforecasters at the particular station.

The quality of a statistical set of forecast verification data may be assessed through the following: (1) determination of the degree of correlation of the prefigurances (H_i/O_i) as a function of the relative frequency ($O_i/\Sigma O_i$) for a given forecast time (e.g., Figs. E-1 to E-3), and (2) relative comparisons of forecasting skills as derived from at least two independent but compatible sets of statistics (e.g., AWS for Western Europe and

TDL for the contiguous United States). The compatibility condition for the forecast verification requires only that the two independent sets of verification data include equivalent ranges of the relative frequency of weather events.

VERIFICATION DATA FOR VISIBILITY AND CEILING

The AWS and TDL forecast verification for visibility or ceiling are applicable to the so-called categoric (yes/no) or nonprobabilistic forecasts with an implied 100 percent probability for the occurrence of the forecast event (Appendix D). For the AWS data, the contingency tables for either visibility or ceiling are given as a function of the following: (1) forecast technique, which can be either persistence or station, (2) forecast time for 3, 6, 12, and 24 hours, and (3) month of verification from September 1976 to March 1977. The AWS contingency tables for visibility and ceiling considered the following categories:

Category	Visibility (V, nm)	Ceiling (C, ft)
A	$V < 0.5$	$C < 200$
B	$0.5 \leq V < 2.0$	$200 \leq C < 1000$
C	$2 \leq V < 3$	$1000 \leq C < 3000$
D	$V \geq 3$	$C \geq 3000$

For the TDL data, the contingency tables for either visibility or ceiling are given as a function of the following: (1) forecast technique, which includes persistence, local, and guidance; (2) forecast time for 3, 6, 9, 12, and 15 hours for persistence, 3, 6, and 12 hours for local, and 7, 13, and 19 hours for guidance. These odd hours for the forecast time in the guidance forecasts come about by the characteristics of the forecasting cycle as illustrated in Fig. G-1. This figure indicates the following: (1) upper air observations are taken at 00Z for the first half of the daily forecasting cycle (and

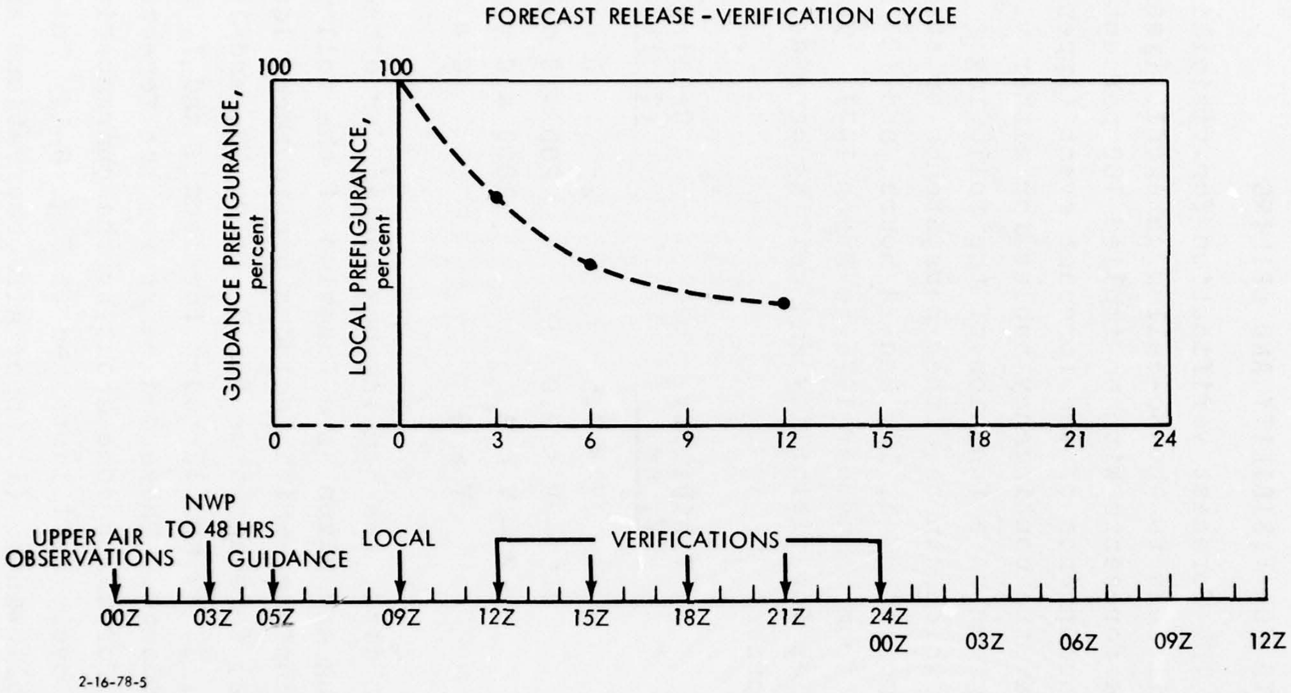

FIGURE G-1. Schematic illustration of first half (00Z-12Z) of daily forecast cycle for verification. The symbol Z denotes GMT (Greenwich Mean Time). Local surface observations are made hourly, which are used for (1) inputs for local forecasts, (2) persistence "forecasts" (after the fact), and (3) verification of local and guidance forecasts. The TDL guidance and local forecasts for the 92 U.S. stations are issued at 05Z (Midnight, Eastern U.S. Time) and 09Z, respectively.

at 12Z for the second half); (2) the NWP synoptic charts to 48 hours become available at 03Z; (3) guidance forecasts are released at 05Z; (4) local forecasts are released at the appropriate local time (09Z) based on (a) local surface observations up to 09Z, (b) the synoptic charts which became available at 03Z, and (c) the guidance forecasts released at 05Z; and (5) the verification procedure is based on the hourly local observations at 12Z, 15Z, 18Z, 21Z, and 24Z. Hence, a complete set of the corresponding local (and persistence) forecasts at verification time would be 3, 6, 9, 12, and 15 hours, while those for guidance (and persistence) would be 7, 10, 13, 16, and 19 hours. The available TDL verification data for local and guidance forecasts are then the incomplete sets indicated above, i.e., (a) 3, 6, and 12 hours for the local and (b) 7, 13, and 19 hours for the guidance forecasts. The TDL contingency tables for visibility and ceiling considered the following categories:

Category	Visibility (V, st. mi.)	Ceiling (C, ft)
1	$V < 0.5$	$C < 200$
2	$0.5 \leq V < 1$	$200 \leq C < 500$
3	$1 \leq V < 3$	$500 \leq C < 1000$
4	$3 \leq V < 5$	$1000 \leq C < 2000$
5	$V \geq 5$	$C \geq 2000$

For the AWS monthly contingency tables, they can be added to obtain a contingency table for the whole period. Furthermore, the AWS and TDL data for the specified categories of visibility and ceiling can also be added to obtain contingency tables for new categories such as A, A + B, A + B + C, and D for the AWS data, and 1, 1 + 2, 1 + 2 + 3, 1 + 2 + 3 + 4, and 5 for the TDL data. The result of this latter procedure is contingency tables for cumulative prefigurances and relative frequencies as shown in Figs. E-1 to E-3.

ORGANIZATION OF DATA FOR VISIBILITY AND CEILING

As indicated earlier, the main results from the AWS and TDL verification data for visibility or ceiling are presented in Appendix E (Tables E-3 to E-11, and Figs. E-1 to E-3). In addition to the summary data in Appendix E, this section includes the contingency tables that become important for the calculation of any other desired verification parameter.

The AWS data were available in the form of computer printouts instead of a formal report, because the validation data for either visibility or ceiling alone are of very recent origin. The AWS data are given in Tables G-1 through G-37 of this appendix. These tables provide the following:

Tables G-1 and G-2. Summary of AWS prefigurance data for *visibility* for station and static persistence forecasts, respectively. The results in these tables are based on the subsequent contingency Tables G-6, G-7, and G-10 to G-23. Tables G-1 and G-2 show prefigurance data, in percent, for each month and the whole period. A comparison of Tables G-1 and G-2 shows that there is very little improvement in the prefigurance obtained by local forecasters over that of persistence.

Tables G-3 and G-4. Summary of AWS prefigurance data for *ceiling* for station and static persistence forecasts, respectively. The results in these tables are based on the subsequent summary contingency Tables G-8, G-9, and G-24 to G-37. The data in Tables G-3 and G-4 show again that for ceiling there is no significant improvement in the prefigurance obtained by man over that of persistence forecasts.

Table G-5. Illustration of the AWS relative frequency for each category of visibility and ceiling for local forecasts. The results in these tables are based on the contingency Tables G-6 and G-8. Table G-5 shows a rather low frequency for the first three categories of either visibility or ceiling, and very high frequencies for only high frequency events of clear weather.

Tables G-6 to G-9. Summary of AWS contingency tables for station and persistence forecasts of *visibility* (Tables G-6 and G-7) and *ceiling* (Tables G-8 and G-9) Tables G-6 through G-9 were obtained by direct addition of the subsequent monthly contingency Tables G-10 to G-37. These contingency tables show the bias for each category for eigher visibility or ceiling. Tables G-10 through G-37 were taken from AWS printout data, and they are as follows:

Tables G-10 to G-16. Monthly AWS contingency tables for *station* forecasts of *visibility*. Each table contains data for several forecast durations.

Tables G-17 to G-23. Monthly AWS contingency tables for *persistence* forecasts of *visibility*.

Tables G-24 to G-30. Monthly AWS contingency tables for *station* forecasts of *ceiling*.

Tables G-31 to G-37. Monthly AWS contingency tables for *persistence* forecasts of *ceiling*.

The TDL data, like the AWS data, were available in the form of computer printouts instead of a formal report, because the validation data for either visibility or ceiling alone at TDL are also of very recent origin. The TDL data are given in Tables G-38 through G-45. These tables provide the following.

Tables G-38 and G-39. Summary of TDL prefigurance data for visibility and ceiling, respectively, for static persistence, local, and guidance forecasts. The results in these tables are based on the subsequent contingency Tables G-40 to G-45. The results in Tables G-38 and G-39 indicate that the prefigurance values for persistence are best. As indicated earlier, the local data are limited to 3, 6, and 12 hours, whereas the guidance data are so for 7, 13, and 19 hours.

Tables G-40 to G-42. TDL contingency tables for *visibility* for static persistence, local, and guidance forecasts.

Tables G-43 to G-45. TDL contingency tables for *ceiling* for static persistence, local, and guidance forecasts.

Tables G-46 to G-48. Tables for added categories of visibility and ceiling for both AWS and TDL data. Table G-46 illustrates the procedure used to determine the prefigurance for category given by addition(s) of individual categories, i.e., to convert prefigurance data from the A, B, C, and D categories to A, A + B, A + B + C, and D for the AWS data, and from 1, 2, 3, 4, and 5 to 1, 1 + 2, 1 + 2 + 3, 1 + 2 + 3 + 4, and 5 for the TDL data. Tables G-47 and G-48 provide a summary of the prefigurance data for these modified categories for the AWS and TDL data, respectively. These tables indicate again that persistence is very difficult to improve on by either local or guidance forecasts.

VERIFICATION DATA FOR PRECIPITATION

Large rates of precipitation could change the trafficability of the battlefield. For this reason, it becomes of interest to obtain the so-called quantitative precipitation forecasts (q.p.f.) of average precipitation amount within specified future time intervals. *It is important to indicate that Army engineers would have the task to convert q.p.f. forecasts into trafficability templets for armor and other military branches. However, the methodology for this conversion has not been validated and, therefore, has not been put into operational use* (Ref. 44).

Contingency tables for q.p.f. were unavailable either at the AWS or TDL. Some prefigurance and post-agreement data were available only at the National Meteorological Center (NMC)* and, then, only for q.p.f. The NMC q.p.f. data provided prefigurance and post-agreement values for forecast intervals of one and two

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*David Olson, National Meteorological Center (World Weather Building), National Weather Service, NOAA, Washington, D.C.

days for daily average amounts of precipitation greater than either 0.5 or 1.0 inch. These data did not include prefigurance or post-agreement data for forecasts of no precipitation. However, this latter type of precipitation data was available at the AWS in the form of contingency table for conditions such as no precipitation, freezing precipitation, etc. The precipitation data used in this study are, therefore, based on the combination of NMC data for q.p.f. and AWS data for no precipitation. Table G-49 shows the NMC data, whereas Table G-50 shows a sample of the AWS prefigurance data. The categories in this table denote no precipitation (N), rain and liquid precipitation (R), freezing precipitation (Z) and frozen precipitation (F). It should be noted that the category R of precipitation does not imply q.p.f.

VERIFICATION DATA FOR WINDS

Verification data for winds was available at TDL (Ref. 45). Prefigurance data are provided in Exhibit 16.

TABLE G-1. AWS *Station* Prefigurance (%) for Forecast of *Visibility* in Western Europe During September 1976-March 1977 *

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	38	43	46	54	48	42	44	46
(V<0.9 km)	6 hr	19	26	36	29	33	17	19	28
	12 hr	14	10	20	19	24	7	8	17
	24 hr	11	8	14	5	14	7	0	10
B	3 hr	42	38	42	47	54	42	48	47
(0.9≤V<	6 hr	31	24	30	31	37	24	36	32
3.7 km)	12 hr	21	17	24	19	25	21	22	22
	24 hr	19	13	16	12	18	15	16	16
C	3 hr	46	35	29	35	34	36	19	34
(3.7≤V<	6 hr	25	20	16	16	21	25	19	20
5.6 km)	12 hr	14	16	13	16	12	17	14	14
	24 hr	10	13	13	12	11	14	12	12
D	3 hr	98	98	98	98	96	98	98	98
(V≥5.6 km)	6 hr	98	98	98	97	95	98	98	97
	12 hr	98	97	96	96	94	96	97	96
	24 hr	97	97	96	96	94	97	97	96

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* The prefigurance values in this table are derived from the subsequent summary contingency Table G-6 and Tables G-10 to G-16.

TABLE G-2. AWS *Persistence* Prefigurance (%) for Forecast of *Visibility* in Western Europe During September 1976-March 1977*

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	30	39	40	49	52	32	42	43
(V<0.9 km)	6 hr	15	18	27	35	27	19	32	27
	12 hr	0	2	18	19	13	5	18	13
	24 hr	19	15	21	7	16	7	7	15
B	3 hr	30	34	34	44	48	36	40	40
(0.9≤V<3.7 km)	6 hr	33	25	26	28	32	25	27	28
	12 hr	19	8	15	15	19	15	12	16
	24 hr	22	12	11	10	13	9	6	12
C	3 hr	18	20	24	25	24	25	13	22
(3.7≤V<5.6 km)	6 hr	11	18	13	10	14	15	11	13
	12 hr	7	9	7	7	10	12	7	8
	24 hr	15	10	9	8	8	9	3	9
D	3 hr	97	97	97	97	95	97	97	97
(V≥5.6 km)	6 hr	96	96	96	95	92	96	97	95
	12 hr	96	96	95	95	90	95	96	95
	24 hr	97	96	94	94	90	94	96	95

*The prefigurance values in this table are derived from the subsequent summary contingency Table G-7 and Tables G-17 to G-23.

TABLE G-3. AWS *Station* Prefigurance (%) for Forecast of *Ceiling* in Western Europe During September 1976-March 1977*

Category	Forecast	S	O	N	D	J	F	M	September-March
A	3 hr	27	39	40	56	43	43	37	42
($C<200$ ft)	6 hr	11	19	28	35	25	15	17	24
	12 hr	15	7	12	18	20	0	2	14
	24 hr	7	3	3	1	10	2	5	5
B	3 hr	59	68	66	73	75	64	68	69
($200\leq C<1000$ ft)	6 hr	35	55	49	55	60	48	51	52
	12 hr	21	36	39	40	44	33	41	38
	24 hr	18	24	27	24	31	22	24	26
C	3 hr	61	66	72	66	72	68	68	68
($1000\leq C<3000$ ft)	6 hr	44	51	57	55	56	51	55	53
	12 hr	29	34	38	35	34	34	37	35
	24 hr	19	26	28	25	26	28	28	26
D	3 hr	97	97	97	97	95	97	97	97
($C\geq3000$ ft)	6 hr	96	96	96	95	93	96	96	96
	12 hr	96	95	94	94	91	95	94	94
	24 hr	95	95	94	94	90	94	93	94

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*The prefigurance values in this table are derived from the subsequent summary contingency Table G-8 and Tables G-24 to G-30.

TABLE G-4. AWS *Persistence* Prefigurance (%) for Forecasts of *Ceiling* in Western Europe During September 1976-March 1977*

Category	Forecast	S	O	N	D	J	F	M	September-March
A ($C<200$ ft)	3 hr	23	42	33	37	45	24	33	36
	6 hr	22	19	20	21	25	10	17	21
	12 hr	4	3	7	16	8	0	7	8
	24 hr	13	6	13	10	12	0	6	10
B ($200 \le C<1000$ ft)	3 hr	46	58	63	62	66	52	61	60
	6 hr	30	47	50	48	52	38	46	46
	12 hr	13	27	38	33	36	26	28	31
	24 hr	16	20	28	18	25	14	19	21
C ($1000 \le C<3000$ ft)	3 hr	40	47	53	48	51	46	46	48
	6 hr	28	34	42	36	36	32	33	35
	12 hr	20	25	32	25	25	23	23	25
	24 hr	16	18	23	17	20	15	16	18
D ($C \ge 3000$ ft)	3 hr	95	95	96	95	94	95	94	95
	6 hr	93	93	94	93	89	93	92	93
	12 hr	92	91	92	91	86	92	90	91
	24 hr	92	89	89	88	82	90	88	88

*The prefigurance values in this table are derived from the subsequent summary contingency Table G-9 and Tables G-31 to G-37.

TABLE G-5. AWS Prefigurance (%) vs Frequency (%) for Station Forecasts of Visibility & Ceiling in Western Europe During September 1976-March 1977*

	Visibility			Ceiling		
Forecast	Category	Prefigurance	Frequency	Category	Prefigurance	Frequency
3 hr	A	46	1	A	42	1
6 hr	($V<0.9$ km)	28	1	($C<200$ ft)	24	1
12 hr		17	1		14	1
24 hr		10	1		5	1
3 hr	B	47	3	B	69	6
6 hr	($0.9\le V<3.7$ km)	32	3	($200\le C<1000$ ft)	52	6
12 hr		22	3		38	6
24 hr		16	3		26	6
3 hr	C	34	2	C	68	8
6 hr	($3.7\le V<5.6$ km)	20	2	($1000\le C<3000$ ft)	53	8
12 hr		14	2		35	8
24 hr		12	2		26	8
3 hr	D	98	93	D	97	85
6 hr	($V\ge 5.6$ km)	97	94	($C\ge 3000$ ft)	96	85
12 hr		96	93		94	85
24 hr		96	93		94	85

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*The prefigurance and frequency values in this table are derived from the subsequent summary contingency Tables G-6 and G-8.

TABLE G-6. AWS Validation Data for *Station* Forecasts of *Visibility* in Western Europe During September 1976-March 1977

3-hr Forecast

		A	B	C	D	T
Occurrences	A	333	205	51	135	724
	B	108	1,034	365	714	2,221
	C	19	280	528	740	1,567
	D	49	522	720	60,374	61,665
	T	509	2,041	1,664	61,963	66,177

6-hr Forecast

		A	B	C	D	T
Occurrences	A	168	172	48	210	598
	B	111	661	313	1,002	2,087
	C	34	257	300	906	1,497
	D	76	694	860	59,809	61,439
	T	389	1,784	1,521	61,927	65,621

12-hr Forecast

		A	B	C	D	T
Occurrences	A	151	190	100	442	883
	B	99	547	341	1,490	2,477
	C	31	264	261	1,256	1,812
	D	99	1,083	1,364	67,071	69,617
	T	380	2,084	2,066	70,259	74,789

24-hr Forecast

		A	B	C	D	T
Occurrences	A	87	157	70	589	903
	B	73	403	285	1,785	2,546
	C	40	198	224	1,403	1,865
	D	103	1,088	1,425	69,577	72,193
	T	303	1,846	2,004	73,354	77,507

TABLE G-7. AWS Validation Data for *Persistence* Forecasts of *Visibility* in Western Europe During September 1976-March 1977

3-hr Forecast

		A	B	C	D	T
Occurrences	A	312	198	46	168	724
	B	221	895	318	787	2,221
	C	58	327	343	839	1,567
	D	219	917	949	59,580	61,665
	T	810	2,337	1,656	61,374	66,177

6-hr Forecast

		A	B	C	D	T
Occurrences	A	160	148	43	247	598
	B	162	594	271	1,060	2,087
	C	75	282	200	940	1,497
	D	409	1,295	1,134	58,601	61,439
	T	806	2,319	1,648	60,848	65,621

12-hr Forecast

		A	B	C	D	T
Occurrences	A	117	137	65	564	883
	B	134	388	228	1,727	2,477
	C	71	226	153	1,362	1,812
	D	559	1,729	1,368	65,961	69,617
	T	881	2,480	1,814	69,614	74,789

24-hr Forecast

		A	B	C	D	T
Occurrences	A	131	114	61	597	903
	B	139	302	164	1,941	2,546
	C	56	204	165	1,440	1,865
	D	571	1,924	1,475	68,223	72,193
	T	897	2,544	1,865	72,201	77,507

TABLE G-8. AWS Validation Data for *Station* Forecasts of *Ceiling* in Western Europe During September 1976-March 1977

3-hr Forecast

		A	B	C	D	T
Occurrences	A	200	182	15	76	473
	B	102	2,736	667	447	3,952
	C	9	512	3,754	1,246	5,521
	D	47	401	1,338	54,445	56,231
	T	358	3,831	5,774	56,214	66,177

6-hr Forecast

		A	B	C	D	T
Occurrences	A	89	152	36	92	369
	B	108	1,971	923	767	3,769
	C	6	622	2,897	1,906	5,431
	D	48	533	1,854	53,617	56,052
	T	251	3,278	5,710	56,382	65,621

12-hr Forecast

		A	B	C	D	T
Occurrences	A	72	214	84	153	523
	B	93	1,786	1,358	1,432	4,669
	C	15	892	2,129	3,079	6,115
	D	61	861	2,854	59,706	63,482
	T	241	3,753	6,425	64,370	74,789

24-hr Forecast

		A	B	C	D	T
Occurrences	A	27	166	97	239	529
	B	47	1,232	1,271	2,276	4,826
	C	16	698	1,631	3,965	6,310
	D	51	1,049	2,975	61,767	65,842
	T	141	3,145	5,974	68,247	77,507

TABLE G-9. AWS Validation Data for *Persistence* Forecasts of *Ceiling* in Western Europe During September 1976-March 1977

3-hr Forecast

		A	B	C	D	T
Occurrences	A	172	178	13	110	473
	B	191	2,390	778	593	3,952
	C	23	989	2,640	1,869	5,521
	D	71	710	2,110	53,340	56,231
	T	457	4,267	5,541	55,912	66,177

6-hr Forecast

		A	B	C	D	T
Occurrences	A	77	151	26	115	369
	B	179	1,752	820	1,018	3,769
	C	52	1,110	1,892	2,377	5,431
	D	146	1,214	2,764	51,928	56,052
	T	454	4,227	5,502	55,438	65,621

12-hr Forecast

		A	B	C	D	T
Occurrences	A	41	169	75	238	523
	B	167	1,442	865	2,195	4,669
	C	62	1,021	1,512	3,520	6,115
	D	254	2,033	3,664	57,531	63,482
	T	524	4,665	6,116	63,484	74,789

24-hr Forecast

		A	B	C	D	T
Occurrences	A	53	126	58	292	529
	B	127	1,032	648	3,019	4,826
	C	54	800	1,139	4,317	6,310
	D	297	2,860	4,454	58,231	65,842
	T	531	4,818	6,299	65,859	77,507

TABLE G-10. AWS-V-S-S (AWS Validation Date: Visibility, Station, September 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	19	17	4	10	50
	B	16	91	42	66	215
	C	3	20	83	76	182
	D	2	57	100	8,903	9,062
	T	40	185	229	9,055	9,509

6-hr Forecast

		A	B	C	D	T
Occurrences	A	5	6	4	11	26
	B	7	51	26	82	166
	C	3	10	43	115	171
	D	4	54	87	8,948	9,093
	T	19	121	160	9,156	9,456

12-hr Forecast

		A	B	C	D	T
Occurrences	A	7	8	3	32	50
	B	1	46	26	141	214
	C	1	19	35	188	243
	D	4	96	130	9,871	10,101
	T	13	169	194	10,232	10,608

24-hr Forecast

		A	B	C	D	T
Occurrences	A	6	11	4	32	53
	B	0	44	22	162	228
	C	1	19	26	208	254
	D	2	105	158	10,229	10,494
	T	9	179	210	10,631	11,029

TABLE G-11. AWS-V-S-O (AWS Validation Data: Visibility, Station, October 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	26	16	5	14	61
	B	7	71	37	73	188
	C	1	45	74	91	211
	D	2	49	129	8,989	9,169
	T	36	181	245	9,167	9,629

6-hr Forecast

		A	B	C	D	T
Occurrences	A	10	8	5	16	39
	B	5	38	29	87	159
	C	0	33	37	118	188
	D	7	68	130	8,988	9,193
	T	22	147	201	9,209	9,579

12-hr Forecast

		A	B	C	D	T
Occurrences	A	6	12	3	39	60
	B	3	34	27	142	206
	C	1	26	39	180	246
	D	5	111	198	10,121	10,435
	T	15	183	267	10,482	10,947

24-hr Forecast

		A	B	C	D	T
Occurrences	A	5	11	3	46	65
	B	4	28	30	153	215
	C	3	28	31	184	246
	D	13	115	189	10,532	10,849
	T	25	182	253	10,915	11,375

TABLE G-12. AWS-V-S-N (AWS Validation Data: Visibility, Station, November 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	66	40	11	27	144
	B	17	133	39	124	313
	C	3	37	57	103	200
	D	13	73	82	8,701	8,869
	T	99	283	189	8,955	9,526

6-hr Forecast

		A	B	C	D	T
Occurrences	A	41	26	8	40	115
	B	24	88	31	149	292
	C	9	40	33	129	211
	D	14	104	94	8,601	8,813
	T	88	258	166	8,919	9,431

12-hr Forecast

		A	B	C	D	T
Occurrences	A	37	51	18	80	186
	B	21	85	48	198	352
	C	9	38	32	176	255
	D	22	179	159	9,496	9,856
	T	89	353	257	9,950	10,649

24-hr Forecast

		A	B	C	D	T
Occurrences	A	26	29	7	130	192
	B	14	59	37	253	363
	C	8	33	35	189	265
	D	23	187	191	9,813	10,214
	T	71	308	270	10,385	11,034

TABLE G-13. AWS-V-S-D (AWS Validation Data: Visibility, Station, December 1976, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	53	26	4	15	98
B	15	152	55	99	321
C	3	35	83	113	234
D	11	84	99	8,598	8,792
T	82	297	241	8,825	9,445

6-hr Forecast

Occurrences	A	B	C	D	T
A	26	24	5	34	89
B	18	101	52	159	330
C	4	44	40	157	245
D	18	110	130	8,427	8,685
T	66	279	227	8,777	9,349

12-hr Forecast

Occurrences	A	B	C	D	T
A	26	28	20	65	139
B	12	73	66	243	394
C	2	41	43	182	268
D	27	178	200	9,651	10,056
T	67	320	329	10,141	10,857

24-hr Forecast

Occurrences	A	B	C	D	T
A	7	19	20	97	143
B	8	47	40	307	402
C	2	24	34	217	277
D	13	174	211	10,026	10,424
T	30	264	305	10,647	11,246

TABLE G-14. AWS-V-S-J (AWS Validation Data: Visibility, Station, January 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	97	62	8	36	203
	B	21	349	105	177	652
	C	6	78	124	153	361
	D	13	136	159	8,036	8,344
	T	137	625	396	8,402	9,560

6-hr Forecast

		A	B	C	D	T
Occurrences	A	60	59	13	52	184
	B	36	233	97	262	628
	C	9	73	70	188	340
	D	16	198	203	7,906	8,323
	T	121	563	383	8,408	9,475

12-hr Forecast

		A	B	C	D	T
Occurrences	A	61	49	38	111	259
	B	45	188	105	406	744
	C	17	88	49	254	408
	D	22	279	290	8,914	9,505
	T	145	604	482	9,685	10,916

24-hr Forecast

		A	B	C	D	T
Occurrences	A	37	52	19	154	262
	B	35	135	91	495	756
	C	22	58	45	291	416
	D	28	296	309	9,212	9,845
	T	122	541	464	10,152	11,279

TABLE G-15. AWS-V-S-F (AWS Validation Data: Visibility, Station, February 1977, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	33	17	13	16	79
B	20	129	53	103	305
C	2	36	74	94	206
D	5	63	71	7,976	8,115
T	60	245	211	8,189	8,705

6-hr Forecast

Occurrences	A	B	C	D	T
A	12	19	11	30	72
B	15	70	47	156	288
C	7	30	51	114	202
D	10	75	112	7,867	8,064
T	44	194	221	8,167	8,626

12-hr Forecast

Occurrences	A	B	C	D	T
A	7	17	6	67	97
B	10	66	28	210	314
C	1	28	39	158	226
D	17	114	200	8,919	9,250
T	35	225	273	9,354	9,887

24-hr Forecast

Occurrences	A	B	C	D	T
A	6	15	6	64	91
B	9	48	30	236	323
C	3	23	32	175	233
D	17	101	184	9,282	9,584
T	35	187	252	9,757	10,231

TABLE G-16. AWS-V-S-M (AWS Validation Data: Visibility, Station, March 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	39	27	6	17	89
	B	12	109	34	72	227
	C	1	29	33	110	173
	D	3	60	80	9,171	9,314
	T	55	225	153	9,370	9,803

6-hr Forecast

		A	B	C	D	T
Occurrences	A	14	30	2	27	73
	B	6	80	31	107	224
	C	2	27	26	85	140
	D	7	85	104	9,072	9,268
	T	29	222	163	9,291	9,705

12-hr Forecast

		A	B	C	D	T
Occurrences	A	7	25	12	48	92
	B	7	55	41	150	253
	C	0	24	24	118	166
	D	2	126	187	10,099	10,414
	T	16	230	264	10,415	10,925

24-hr Forecast

		A	B	C	D	T
Occurrences	A	0	20	11	66	97
	B	3	42	35	179	259
	C	1	13	21	139	174
	D	7	110	183	10,483	10,783
	T	11	185	250	10,867	11,313

TABLE G-17. AWS-V-P-S (AWS Validation Data: Visibility, Persistence, September 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	15	13	6	16	50
	B	12	65	41	97	215
	C	4	35	33	110	182
	D	28	117	167	8,750	9,062
	T	59	230	247	8,973	9,509

6-hr Forecast

		A	B	C	D	T
Occurrences	A	4	7	2	13	26
	B	7	55	24	80	166
	C	2	17	19	133	171
	D	46	149	201	8,697	9,093
	T	59	228	246	8,923	9,456

12-hr Forecast

		A	B	C	D	T
Occurrences	A	0	7	1	42	50
	B	2	41	15	156	214
	C	2	12	16	213	243
	D	43	145	208	9,705	10,101
	T	47	205	240	10,116	10,608

24-hr Forecast

		A	B	C	D	T
Occurrences	A	10	7	3	33	53
	B	5	51	29	143	228
	C	1	19	37	197	254
	D	31	135	178	10,150	10,494
	T	47	212	247	10,523	11,029

TABLE G-18. AWS-V-P-O (AWS Validation Data: Visibility, Persistence, October 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	24	15	4	18	61
	B	14	64	36	74	188
	C	6	36	43	126	211
	D	33	108	144	8,884	9,169
	T	77	223	227	9,102	9,629

6-hr Forecast

		A	B	C	D	T
Occurrences	A	7	7	3	22	39
	B	8	40	20	91	159
	C	7	28	34	119	188
	D	55	148	170	8,820	9,193
	T	77	223	227	9,052	9,579

12-hr Forecast

		A	B	C	D	T
Occurrences	A	1	4	6	49	60
	B	2	17	22	165	206
	C	7	24	23	192	246
	D	52	171	198	10,014	10,435
	T	62	216	249	10,420	10,947

24-hr Forecast

		A	B	C	D	T
Occurrences	A	10	11	5	39	65
	B	14	26	9	166	215
	C	5	25	25	191	246
	D	38	167	217	10,427	10,849
	T	67	229	256	10,823	11,375

TABLE G-19. AWS-V-P-N (AWS Validation Data: Visibility, Persistence, November 1976, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	58	38	11	37	144
B	45	107	42	119	313
C	10	44	48	98	200
D	44	111	130	8,584	8,869
T	157	300	231	8,838	9,526

6-hr Forecast

Occurrences	A	B	C	D	T
A	31	23	9	52	115
B	36	75	43	138	292
C	13	37	28	133	211
D	77	158	149	8,429	8,813
T	157	293	229	8,752	9,431

12-hr Forecast

Occurrences	A	B	C	D	T
A	33	31	13	109	186
B	37	52	48	215	352
C	20	36	17	182	255
D	94	234	179	9,349	9,856
T	184	353	257	9,855	10,649

24-hr Forecast

Occurrences	A	B	C	D	T
A	41	21	10	120	192
B	29	39	32	263	363
C	13	35	24	193	265
D	105	273	197	9,639	10,214
T	188	368	263	10,215	11,034

TABLE G-20. AWS-V-P-D (AWS Validation Data: Visibility, Persistence, December 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	48	29	8	13	98
	B	28	142	52	99	321
	C	10	45	58	121	234
	D	28	149	118	8,497	8,792
	T	114	365	236	8,730	9,445

6-hr Forecast

		A	B	C	D	T
Occurrences	A	31	25	5	28	89
	B	21	91	51	167	330
	C	12	50	24	159	245
	D	49	196	153	8,287	8,685
	T	113	362	233	8,641	9,349

12-hr Forecast

		A	B	C	D	T
Occurrences	A	27	28	10	74	139
	B	21	59	32	282	394
	C	6	43	19	200	268
	D	84	264	204	9,504	10,056
	T	138	394	265	10,060	10,857

24-hr Forecast

		A	B	C	D	T
Occurrences	A	14	14	12	103	143
	B	15	40	13	334	402
	C	11	29	21	216	277
	D	99	321	228	9,776	10,424
	T	139	404	274	10,429	11,246

TABLE G-21. AWS-V-P-J (AWS Validation Data: Visibility, Persistence, January 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	105	49	9	40	203
	B	68	316	79	189	652
	C	15	97	87	162	361
	D	43	207	169	7,925	8,344
	T	231	669	344	8,316	9,560

6-hr Forecast

		A	B	C	D	T
Occurrences	A	50	49	16	69	184
	B	67	202	67	292	628
	C	26	84	49	181	340
	D	88	334	210	7,691	8,323
	T	231	669	342	8,233	9,475

12-hr Forecast

		A	B	C	D	T
Occurrences	A	34	50	21	154	259
	B	47	140	73	484	744
	C	28	71	39	270	408
	D	150	484	269	8,602	9,505
	T	259	745	402	9,510	10,916

24-hr Forecast

		A	B	C	D	T
Occurrences	A	43	40	21	158	262
	B	50	102	58	546	756
	C	18	61	32	305	416
	D	153	548	299	8,845	9,845
	T	264	751	410	9,854	11,279

TABLE G-22. AWS-V-P-F (AWS Validation Data: Visibility, Persistence, February 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	25	26	6	22	79
	B	31	111	45	118	305
	C	11	37	52	106	206
	D	20	120	106	7,869	8,115
	T	87	294	209	8,115	8,705

6-hr Forecast

		A	B	C	D	T
Occurrences	A	14	18	7	33	72
	B	11	71	47	159	288
	C	9	38	30	125	202
	D	52	164	126	7,722	8,064
	T	86	291	210	8,039	8,626

12-hr Forecast

		A	B	C	D	T
Occurrences	A	5	6	12	74	97
	B	11	48	27	228	314
	C	8	24	28	166	226
	D	75	239	169	8,767	9,250
	T	99	317	236	9,235	9,887

24-hr Forecast

		A	B	C	D	T
Occurrences	A	6	6	6	73	91
	B	15	28	7	273	323
	C	4	20	20	189	233
	D	73	271	210	9,030	9,584
	T	98	325	243	9,565	10,231

TABLE G-23. AWS-V-P-M (AWS Validation Data: Visibility, Persistence, March 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	37	28	2	22	89
	B	23	90	23	91	227
	C	2	33	22	116	173
	D	23	105	115	9,071	9,314
	T	85	256	162	9,300	9,803

6-hr Forecast

		A	B	C	D	T
Occurrences	A	23	19	1	30	73
	B	12	60	19	133	224
	C	6	28	16	90	140
	D	42	146	125	8,955	9,268
	T	83	253	161	9,208	9,705

12-hr Forecast

		A	B	C	D	T
Occurrences	A	17	11	2	62	92
	B	14	31	11	197	253
	C	0	16	11	139	166
	D	61	192	141	10,020	10,414
	T	92	250	165	10,418	10,925

24-hr Forecast

		A	B	C	D	T
Occurrences	A	7	15	4	71	97
	B	11	16	16	216	259
	C	4	15	6	149	174
	D	72	209	146	10,356	10,783
	T	94	255	172	10,792	11,313

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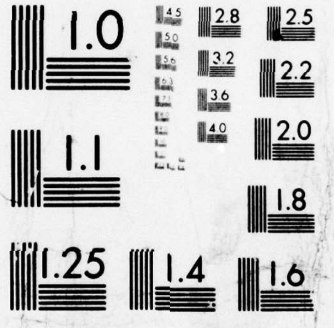

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TABLE G-24. AWS-C-S-S (AWS Validation Data: Ceiling, Station, September 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	6	11	0	5	22
	B	12	202	52	74	340
	C	1	55	401	205	662
	D	2	58	189	8,236	8,485
	T	21	326	642	8,520	9,509

6-hr Forecast

		A	B	C	D	T
Occurrences	A	2	6	2	8	18
	B	5	105	84	108	302
	C	0	54	274	300	628
	D	2	57	239	8,210	8,508
	T	9	222	599	8,626	9,456

12-hr Forecast

		A	B	C	D	T
Occurrences	A	4	7	3	13	27
	B	0	84	108	205	397
	C	0	76	190	397	663
	D	3	91	334	9,093	9,521
	T	7	258	635	9,708	10,608

24-hr Forecast

		A	B	C	D	T
Occurrences	A	2	10	3	15	30
	B	0	75	68	285	428
	C	0	48	130	515	693
	D	1	130	327	9,420	9,878
	T	3	263	528	10,235	11,029

TABLE G-25. AWS-C-S-O (AWS Validation Data: Ceiling, Station, October 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	14	10	2	10	36
	B	6	370	100	65	541
	C	0	78	500	180	758
	D	6	47	176	8,065	8,294
	T	26	505	778	8,320	9,629

6-hr Forecast

		A	B	C	D	T
Occurrences	A	4	5	2	10	21
	B	3	259	124	82	468
	C	1	101	395	276	773
	D	7	75	210	8,025	8,317
	T	15	440	731	8,393	9,579

12-hr Forecast

		A	B	C	D	T
Occurrences	A	2	10	4	14	30
	B	2	214	194	177	587
	C	2	145	304	434	885
	D	5	96	376	8,968	9,445
	T	11	465	878	9,593	10,947

24-hr Forecast

		A	B	C	D	T
Occurrences	A	1	12	3	15	31
	B	2	143	157	302	604
	C	3	92	237	586	918
	D	8	119	336	9,359	9,822
	T	14	366	733	10,262	11,375

TABLE G-26. AWS-C-S-N (AWS Validation Data: Ceiling Station, November 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	40	37	6	17	100
	B	21	460	135	79	695
	C	1	68	547	147	763
	D	14	59	145	7,750	7,968
	T	76	624	833	7,993	9,526

6-hr Forecast

		A	B	C	D	T
Occurrences	A	17	29	3	12	61
	B	40	335	167	148	690
	C	1	95	426	224	746
	D	10	68	220	7,636	7,934
	T	68	527	816	8,020	9,431

12-hr Forecast

		A	B	C	D	T
Occurrences	A	11	44	15	25	95
	B	28	325	217	262	832
	C	4	144	323	368	839
	D	9	148	332	8,394	8,883
	T	52	661	887	9,049	10,649

24-hr Forecast

		A	B	C	D	T
Occurrences	A	3	30	14	51	98
	B	8	236	195	422	861
	C	2	120	244	510	876
	D	8	157	371	8,663	9,199
	T	21	543	824	9,646	11,034

TABLE G-27. AWS-C-S-D (AWS Validation Data: Ceiling, Station, December 1976, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	32	19	0	6	57
B	17	404	77	53	551
C	1	75	530	191	797
D	6	53	199	7,782	8,040
T	56	551	806	8,032	9,445

6-hr Forecast

Occurrences	A	B	C	D	T
A	18	20	5	9	52
B	14	299	149	83	545
C	2	85	427	264	778
D	8	82	276	7,608	7,974
T	42	486	857	7,964	9,349

12-hr Forecast

Occurrences	A	B	C	D	T
A	16	37	11	24	88
B	10	278	213	186	687
C	0	121	310	454	885
D	10	139	427	8,621	9,197
T	36	575	961	9,285	10,857

24-hr Forecast

Occurrences	A	B	C	D	T
A	1	27	21	41	90
B	0	171	202	333	706
C	3	96	225	589	913
D	8	143	421	8,965	9,537
T	12	437	869	9,928	11,246

TABLE G-28. AWS-C-S-J (AWS Validation Data: Ceiling, Station, January 1977, Western Europe)

3-hr Forecast

Occurrences		A	B	C	D	T
	A	63	62	4	17	146
	B	31	747	148	70	996
	C	3	114	794	191	1,102
	D	13	91	256	6,956	7,316
	T	110	1,014	1,202	7,234	9,560

6-hr Forecast

Occurrences		A	B	C	D	T
	A	36	58	17	32	143
	B	32	554	195	141	922
	C	1	151	616	323	1,091
	D	9	131	381	6,798	7,319
	T	78	894	1,209	7,294	9,475

12-hr Forecast

Occurrences		A	B	C	D	T
	A	38	76	30	44	188
	B	44	500	333	270	1,147
	C	5	225	419	573	1,222
	D	22	205	567	7,565	8,359
	T	109	1,006	1,349	8,452	10,916

24-hr Forecast

Occurrences		A	B	C	D	T
	A	18	61	33	77	189
	B	28	360	318	462	1,168
	C	3	189	328	718	1,238
	D	19	274	596	7,795	8,684
	T	68	884	1,275	9,052	11,279

TABLE G-29. AWS-C-S-F (AWS Validation Data: Ceiling, Station, February 1977, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	25	21	0	12	58
B	7	213	67	45	332
C	2	48	428	149	627
D	4	42	159	7,483	7,688
T	38	324	654	7,689	8,705

6-hr Forecast

Occurrences	A	B	C	D	T
A	6	16	2	15	39
B	8	163	81	91	343
C	0	59	313	237	609
D	9	66	227	7,333	7,635
T	23	304	623	7,676	8,626

12-hr Forecast

Occurrences	A	B	C	D	T
A	0	18	10	21	49
B	4	136	121	148	409
C	4	61	233	383	681
D	12	88	350	8,298	8,748
T	20	303	714	8,850	9,887

24-hr Forecast

Occurrences	A	B	C	D	T
A	1	12	10	21	44
B	3	90	125	197	415
C	4	56	192	442	694
D	5	93	428	8,552	9,078
T	13	251	755	9,212	10,231

TABLE G-30. AWS-C-S-M (AWS Validation Data: Ceiling, Station, March 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	20	22	3	9	54
	B	8	340	88	61	497
	C	1	74	554	183	812
	D	2	51	214	8,173	8,440
	T	31	487	859	8,426	9,803

6-hr Forecast

		A	B	C	D	T
Occurrences	A	6	18	5	6	35
	B	6	256	123	114	499
	C	1	77	446	282	806
	D	3	54	301	8,007	8,365
	T	16	405	875	8,409	9,705

12-hr Forecast

		A	B	C	D	T
Occurrences	A	1	22	11	12	46
	B	5	249	172	184	610
	C	0	120	350	470	940
	D	0	94	468	8,767	9,329
	T	6	485	1,001	9,433	10,925

24-hr Forecast

		A	B	C	D	T
Occurrences	A	1	14	13	19	47
	B	6	157	206	275	644
	C	1	97	275	605	978
	D	2	133	496	9,013	9,644
	T	10	401	990	9,912	11,313

TABLE G-31. AWS-C-P-S (AWS Validation Data: Ceiling, Persistence, September 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	5	8	0	9	22
	B	11	157	71	101	340
	C	4	139	263	256	662
	D	7	145	314	8,019	8,485
	T	27	449	648	8,385	9,509

6-hr Forecast

		A	B	C	D	T
Occurrences	A	4	4	1	9	18
	B	3	91	59	149	302
	C	3	139	177	309	628
	D	17	207	407	7,877	8,508
	T	27	441	644	8,344	9,456

12-hr Forecast

		A	B	C	D	T
Occurrences	A	1	3	2	21	27
	B	1	50	51	295	397
	C	4	75	135	449	663
	D	19	265	479	8,758	9,521
	T	25	393	667	9,523	10,608

24-hr Forecast

		A	B	C	D	T
Occurrences	A	4	6	3	17	30
	B	5	67	50	306	428
	C	3	81	113	496	693
	D	14	269	537	9,058	9,878
	T	26	423	703	9,877	11,029

TABLE G-32. AWS-C-P-O (AWS Validation Data: Ceiling, Persistence, October 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	15	7	2	12	36
	B	14	315	117	95	541
	C	2	151	360	245	758
	D	15	89	290	7,900	8,294
	T	46	562	769	8,252	9,629

6-hr Forecast

		A	B	C	D	T
Occurrences	A	4	3	2	12	21
	B	16	221	107	124	468
	C	2	199	266	306	773
	D	24	138	389	7,766	8,317
	T	46	561	764	8,208	9,579

12-hr Forecast

		A	B	C	D	T
Occurrences	A	1	4	5	20	30
	B	6	160	119	302	587
	C	3	164	217	501	885
	D	22	268	543	8,612	9,445
	T	32	596	884	9,435	10,947

24-hr Forecast

		A	B	C	D	T
Occurrences	A	2	12	3	14	31
	B	12	123	96	373	604
	C	3	115	165	635	918
	D	18	373	662	8,769	9,822
	T	35	623	926	9,791	11,375

TABLE G-33. AWS-C-P-N (AWS Validation Data: Ceiling, Persistence, November 1976, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	33	43	2	22	100
	B	32	441	131	91	695
	C	1	126	406	230	763
	D	10	101	234	7,623	7,968
	T	76	711	773	7,966	9,526

6-hr Forecast

		A	B	C	D	T
Occurrences	A	12	29	0	20	61
	B	39	342	143	166	690
	C	2	164	310	270	746
	D	22	165	314	7,433	7,934
	T	75	700	767	7,889	9,431

12-hr Forecast

		A	B	C	D	T
Occurrences	A	7	39	11	38	95
	B	46	318	156	312	832
	C	6	174	267	392	839
	D	36	295	411	8,141	8,883
	T	95	826	845	8,883	10,649

24-hr Forecast

		A	B	C	D	T
Occurrences	A	13	32	7	46	98
	B	38	242	118	463	861
	C	9	165	204	498	876
	D	36	416	540	8,207	9,199
	T	96	855	869	9,214	11,034

TABLE G-34. AWS-C-P-D (AWS Validation Data: Ceiling, Persistence, December 1976, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	21	24	4	8	57
B	33	344	113	61	551
C	3	138	380	276	797
D	6	85	293	7,656	8,040
T	63	591	790	8,001	9,445

6-hr Forecast

Occurrences	A	B	C	D	T
A	11	23	5	13	52
B	29	259	135	122	545
C	11	143	280	344	778
D	12	158	361	7,443	7,974
T	63	583	781	7,922	9,349

12-hr Forecast

Occurrences	A	B	C	D	T
A	14	27	12	35	88
B	35	225	134	293	687
C	8	141	222	514	885
D	27	298	512	8,360	9,197
T	84	691	880	9,202	10,857

24-hr Forecast

Occurrences	A	B	C	D	T
A	9	12	15	54	90
B	19	128	89	470	706
C	12	122	152	627	913
D	44	453	642	8,398	9,537
T	84	715	898	9,549	11,246

TABLE G-35. AWS-C-P-J (AWS Validation Data: Ceiling, Persistence, January 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	66	51	1	28	146
	B	67	658	182	89	996
	C	10	195	563	334	1,102
	D	18	105	349	6,844	7,316
	T	161	1,009	1,095	7,295	9,560

6-hr Forecast

		A	B	C	D	T
Occurrences	A	36	61	11	35	143
	B	65	478	187	192	922
	C	24	225	394	448	1,091
	D	36	241	496	6,546	7,319
	T	161	1,005	1,088	7,221	9,475

12-hr Forecast

		A	B	C	D	T
Occurrences	A	15	71	27	75	188
	B	56	410	230	451	1,147
	C	30	254	304	634	1,222
	D	90	406	668	7,195	8,359
	T	191	1,141	1,229	8,355	10,916

24-hr Forecast

		A	B	C	D	T
Occurrences	A	23	48	19	99	189
	B	42	292	172	662	1,168
	C	14	176	245	803	1,238
	D	113	638	817	7,116	8,684
	T	192	1,154	1,253	8,680	11,279

TABLE G-36. AWS-C-P-F (AWS Validation Data: Ceiling, Persistence, February 1977, Western Europe)

3-hr Forecast

Occurrences	A	B	C	D	T
A	14	22	1	21	58
B	16	171	79	66	332
C	2	96	291	238	627
D	12	83	265	7,328	7,688
T	44	372	636	7,653	8,705

6-hr Forecast

Occurrences	A	B	C	D	T
A	4	15	5	15	39
B	10	132	83	118	343
C	5	92	197	315	609
D	24	132	352	7,127	7,635
T	43	371	637	7,575	8,626

12-hr Forecast

Occurrences	A	B	C	D	T
A	0	7	13	29	49
B	6	106	68	229	409
C	4	82	154	441	681
D	41	218	443	8,046	8,748
T	51	413	678	8,745	9,887

24-hr Forecast

Occurrences	A	B	C	D	T
A	0	6	7	31	44
B	2	58	54	301	415
C	7	51	107	529	694
D	42	311	526	8,199	9,078
T	51	426	694	9,060	10,231

TABLE G-37. AWS-C-P-M (AWS Validation Data: Ceiling, Persistence, March 1977, Western Europe)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	18	23	3	10	54
	B	18	304	85	90	497
	C	1	144	377	290	812
	D	3	102	365	7,970	8,440
	T	40	573	830	8,360	9,803

6-hr Forecast

		A	B	C	D	T
Occurrences	A	6	16	2	11	35
	B	17	229	106	147	499
	C	5	148	268	385	806
	D	11	173	445	7,736	8,365
	T	39	566	821	8,279	9,705

12-hr Forecast

		A	B	C	D	T
Occurrences	A	3	18	5	20	46
	B	17	173	107	313	610
	C	7	131	213	589	940
	D	19	283	608	8,419	9,329
	T	46	605	933	9,341	10,925

24-hr Forecast

		A	B	C	D	T
Occurrences	A	2	10	4	31	47
	B	9	122	69	444	644
	C	6	90	153	729	978
	D	30	400	730	8,484	9,644
	T	47	622	956	9,688	11,313

TABLE G-38. TDL Prefigurance (%) for Forecasts of *Visibility* in the Contiguous United Stated During October 1975-March 1976 for Persistence, Local, and Guidance Forecasts*

Category	Forecast	Persistence	Local	Guidance
1 ($V<0.8$ km)	3 hr	47	34	--
	6 hr	37	23	--
	7 hr	--	--	19
	12 hr	26	4	--
	13 hr	--	--	4
	15 hr	20	--	--
	19 hr	--	--	0
2 ($0.8 \leq V<1.6$ km)	3 hr	19	18	--
	6 hr	8	6	--
	7 hr	--	--	8
	12 hr	5	3	--
	13 hr	--	--	4
	15 hr	6	--	--
	19 hr	--	--	0
3 ($1.6 \leq V<1.6$ km)	3 hr	31	23	--
	6 hr	18	12	--
	7 hr	--	--	22
	12 hr	13	11	--
	13 hr	--	--	15
	15 hr	12	--	--
	19 hr	--	--	4
4 ($4.8 \leq V<8$ km)	3 hr	28	37	--
	6 hr	16	22	--
	7 hr	--	--	13
	12 hr	16	20	--
	13 hr	--	--	13
	15 hr	13	--	--
	19 hr	--	--	15
5 ($V \geq 8$ km)	3 hr	97	94	--
	6 hr	95	95	--
	7 hr	--	--	95
	12 hr	91	96	--
	13 hr	--	--	97
	15 hr	91	--	--
	19 hr	--	--	98

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*The prefigurance values in this table are derived from the subsequent Tables G-40 to G-42.

TABLE G-39. TDL Prefigurance (%) for Forecasts of *Ceiling* in the Contiguous United States during October 1975-March 1976 for Persistence, Local, and Guidance Forecasts*

Category	Forecast	Persistence	Local	Guidance
1 (C<200 ft)	3 hr	45	32	--
	6 hr	28	18	--
	7 hr	--	--	18
	12 hr	21	2	--
	13 hr	--	--	0
	15 hr	15	--	--
	19 hr	--	--	0
2 (200≤C<500 ft)	3 hr	44	38	--
	6 hr	26	19	--
	7 hr	--	--	25
	12 hr	21	11	--
	13 hr	--	--	8
	15 hr	17	--	--
	19 hr	--	--	3
3 (500≤C<1000 ft)	3 hr	42	34	--
	6 hr	25	22	--
	7 hr	--	--	22
	12 hr	17	15	--
	13 hr	--	--	16
	15 hr	17	--	--
	19 hr	--	--	11
4 (1000≤C<2000 ft	3 hr	44	45	--
	6 hr	28	32	--
	7 hr	--	--	28
	12 hr	20	26	--
	13 hr	--	--	28
	15 hr	18	--	--
	19 hr	--	--	18
5 (C>2000 ft)	3 hr	95	94	--
	6 hr	93	94	--
	7 hr	--	--	94
	12 hr	89	95	--
	13 hr	--	--	94
	15 hr	87	--	--
	19 hr	--	--	97

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*The prefigurance values in this table are derived from the subsequent Tables G-43 to G-45.

TABLE G-40. TDL Validation Data for *Persistence* Forecasts of *Visibility* in Contiguous United States During October 1975-March 1976

3-hr Forecast

		1	2	3	4	5	T
Occurrences	1	161	38	40	30	76	345
	2	30	37	46	20	57	190
	3	32	48	229	139	285	733
	4	12	19	89	211	412	743
	5	16	28	134	219	11,734	12,131
	T	251	170	538	619	12,564	14,142

6-hr Forecast

		1	2	3	4	5	T
Occurrences	1	97	20	27	20	96	260
	2	33	20	49	39	107	248
	3	58	46	171	161	533	969
	4	23	28	92	144	588	875
	5	60	72	237	311	12,290	12,970
	T	271	186	576	675	13,614	15,322

12-hr Forecast

		1	2	3	4	5	T
Occurrences	1	21	5	9	7	39	81
	2	10	7	22	12	98	149
	3	41	26	86	90	396	639
	4	26	19	55	85	339	524
	5	173	132	409	478	12,727	13,919
	T	271	189	581	672	13,599	15,312

15-hr Forecast

		1	2	3	4	5	T
Occurrences	1	15	6	9	7	37	74
	2	11	7	14	10	80	122
	3	29	20	56	56	311	472
	4	29	16	53	65	339	502
	5	171	124	416	490	11,859	13,060
	T	255	173	548	628	12,626	14,230

TABLE G-41. TDL Validation Data for *Local* Forecasts of *Visibility* in Contiguous United States During October 1975-March 1976

3-hr Forecast

		1	2	3	4	5	T
Occurrences	1	118	70	49	56	52	345
	2	21	35	47	45	42	190
	3	35	55	172	251	220	733
	4	11	23	87	277	345	743
	5	15	39	114	527	11,436	12,131
	T	200	222	469	1,156	12,095	14,142

6-hr Forecast

		1	2	3	4	5	T
Occurrences	1	59	31	36	46	88	260
	2	15	14	51	57	111	248
	3	16	39	119	266	529	969
	4	7	21	62	196	589	875
	5	19	37	121	472	12,321	12,970
	T	116	142	389	1,037	13,638	15,322

12-hr Forecast

		1	2	3	4	5	T
Occurrences	1	3	10	16	18	34	81
	2	1	4	33	30	81	149
	3	4	13	72	141	409	639
	4	1	3	32	107	381	524
	5	12	13	98	381	13,415	13.919
	T	21	43	251	677	14,320	15,312

TABLE G-42. TDL Validation Data for *Guidance* Forecasts of *Visibility* in Contiguous United States During October 1975-March 1976

7-hr Forecast

Occurrences	1	2	3	4	5	T
1	64	16	56	27	182	345
2	14	15	40	18	103	190
3	21	30	161	108	413	733
4	8	18	68	97	552	743
5	24	40	188	300	11,579	12,131
T	131	119	513	550	12,829	14,142

13-hr Forecast

Occurrences	1	2	3	4	5	T
1	4	7	17	8	59	95
2	1	7	27	33	105	173
3	3	7	104	107	493	714
4	1	3	55	71	436	566
5	0	5	132	271	12,261	12,669
T	9	29	335	490	13,354	14,217

19 -hr Forecast

Occurrences	1	2	3	4	5	T
1	0	0	5	15	54	74
2	0	0	5	19	98	122
3	0	0	18	102	352	472
4	0	0	13	74	415	502
5	0	0	47	238	12,775	13,060
T	0	0	88	448	13,694	14,230

TABLE G-43. TDL Validation Data for *Persistence* Forecasts of *Ceiling* in Contiguous United States During October 1975-March 1976

3-hr Forecast

Occurrences		1	2	3	4	5	T
	1	116	49	13	5	72	255
	2	50	237	100	45	105	537
	3	9	72	292	142	176	691
	4	3	30	143	451	409	1,036
	5	34	49	119	344	10,850	11,396
	T	212	437	667	987	11,612	13,915

6-hr Forecast

Occurrences		1	2	3	4	5	T
	1	51	28	19	5	78	181
	2	71	143	93	71	172	550
	3	30	122	222	178	333	885
	4	7	69	178	338	610	1,202
	5	65	111	204	449	11,337	12,166
	T	224	473	716	1,041	12,530	14,984

12-hr Forecast

Occurrences		1	2	3	4	5	T
	1	9	9	6	6	12	42
	2	21	56	40	35	111	263
	3	26	65	98	89	289	567
	4	29	89	163	199	501	981
	5	139	249	408	712	11,618	13,126
	T	224	468	715	1,041	12,531	14,979

15-hr Forecast

Occurrences		1	2	3	4	5	T
	1	8	6	7	8	23	52
	2	18	44	32	35	132	261
	3	18	52	88	60	296	514
	4	24	65	112	141	454	796
	5	146	273	431	756	10,823	12,429
	T	214	440	670	1,000	11,728	14,052

TABLE G-44. TDL Validation Data for *Local* Forecasts of *Ceiling* in Contiguous United States During October 1975-March 1976

3-hr Forecast

		1	2	3	4	5	T
Occurrences	1	82	78	26	13	56	255
	2	29	202	155	64	87	537
	3	7	69	236	223	156	691
	4	1	22	121	470	422	1,036
	5	47	61	109	438	10,741	11,396
	T	166	432	647	1,208	11,462	13,915

6-hr Forecast

		1	2	3	4	5	T
Occurrences	1	33	31	24	25	68	181
	2	24	105	136	129	156	550
	3	3	79	199	272	332	885
	4	3	34	130	389	646	1,202
	5	30	52	130	558	11,396	12,166
	T	93	301	619	1,373	12,598	14,984

12-hr Forecast

		1	2	3	4	5	T
Occurrences	1	1	4	14	4	19	42
	2	3	28	44	78	110	263
	3	2	24	85	157	299	567
	4	0	11	78	252	640	981
	5	16	18	103	480	12,509	13,126
	T	22	85	324	971	13,577	14,979

TABLE G-45. TDL Validation Data for *Guidance* Forecasts of *Ceiling* in Contiguous United States During October 1975-March 1976

7-hr Forecast

		1	2	3	4	5	T
Occurrences	1	45	42	19	19	130	255
	2	30	132	109	85	181	537
	3	11	64	149	174	293	691
	4	10	42	130	289	565	1,036
	5	21	73	146	481	10,675	11,396
	T	117	353	553	1,048	11,844	13,915

13-hr Forecast

		1	2	3	4	5	T
Occurrences	1	0	8	12	10	31	61
	2	0	28	75	108	121	332
	3	0	14	102	230	303	649
	4	0	8	78	314	703	1,103
	5	0	22	115	583	11,144	11,864
	T	0	80	382	1,245	12,302	14,009

19-hr Forecast

		1	2	3	4	5	T
Occurrences	1	0	1	5	13	33	52
	2	0	7	36	70	148	261
	3	0	12	57	136	309	514
	4	0	4	38	142	612	796
	5	0	6	115	307	12,001	12,429
	T	0	30	251	668	13,103	14,052

TABLE G-46. Sample of Superimposition of Categories for 3-hr Station Forecasts of Visibility in Western Europe During September 1976-March 1977 (Table G-6)

3-hr Forecast

		A	B	C	D	T
Occurrences	A	333	205	51	135	724
	B	108	1,034	365	714	2,221
	C	19	280	528	740	1,567
	D	49	522	720	60,374	61,665
	T	509	2,041	1,664	61,963	66,177

3-hr Forecast

		A + B	C	D	T
Occurrences	A + B	1,680	416	849	2,945
	C	299	528	740	1,567
	D	571	720	60,374	61,665
	T	2,550	1,664	61,963	66,177

3-hr Forecast

		A + B + C	D	T
Occurrences	A + B + C	2,923	1,589	4,512
	D	1,291	60,374	61,665
	T	4,214	61,963	66,177

TABLE G-47. AWS Prefigurance (%) and Relative Frequency for Forecast of Visibility and Ceiling in Western Europe During September 1976-March 1977*

	Visibility				Ceiling			
Forecast	Category	Persistence	Station	Frequency	Category	Persistence	Station	Frequency
3 hr	A	43	46	0.011	A	36	42	0.007
6 hr	(V<0.9 km)	27	28	0.009	(C<200 ft)	21	24	0.006
12 hr		13	17	0.012		8	14	0.007
24 hr		15	10	0.012		10	5	0.007
3 hr	A + B	55	57	0.045	A + B	66	73	0.067
6 hr	(V<3.7 km)	40	41	0.041	(C<1000 ft)	52	56	0.063
12 hr		23	29	0.045		35	42	0.069
24 hr		20	21	0.045		25	27	0.069
3 hr	A + B + C	60	65	0.068	A + B + C	74	82	0.150
6 hr	(V<5.6 km)	46	49	0.064	(C<3000 ft)	63	71	0.146
12 hr		29	38	0.069		47	59	0.151
24 hr		25	29	0.069		35	44	0.151
3 hr	D	97	98	0.932	D	95	97	0.850
6 hr	(V≥5.6 km)	95	97	0.936	(C≥3000 ft)	93	96	0.854
12 hr		95	96	0.931		91	94	0.849
24 hr		95	96	0.931		88	94	0.850

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*Prefigurance and relative frequency values are obtained by adding the categories (see Table G-46) in Tables G-6 to G-9.

TABLE G-48. TDL Prefigurance (%) and Relative Frequencies for Forecast of Visibility and Ceiling in Contiguous United States During October 1975-March 1976*

	Visibility					Ceiling				
Forecast	Category	Persistence	Local	Guidance	Frequency	Category	Persistence	Local	Guidance	Frequency
3 hr	1 (V<0.8 km)	47	34	--	0.024	1 (C<200 ft)	45	32	--	0.018
6 hr		37	23	--	0.017		28	18	--	0.012
7 hr		--	--	19	0.024		--	--	18	0.018
12 hr		26	4	--	0.005		21	2	--	0.003
13 hr		--	--	4	0.007		--	--	0	0.004
15 hr		20	--	--	0.005		15	--	--	0.004
19 hr		--	--	0	0.005		--	--	0	0.004
3 hr	1 + 2 (V<1.6 km)	50	46	--	0.038	1 + 2 (C<500 ft)	57	49	--	0.057
6 hr		33	23	--	0.033		40	26	--	0.049
7 hr		--	--	20	0.038		--	--	31	0.057
12 hr		19	8	--	0.015		31	12	--	0.018
13 hr		--	--	7	0.019		--	--	9	0.028
15 hr		20	--	--	0.014		24	--	--	0.022
19 hr		--	--	0	0.014		--	--	3	0.022
3 hr	1 + 2 + 3 (V<4.8 km)	52	47	--	0.090	1 + 2 + 3 (C<1000 ft)	63	60	--	0.107
6 hr		35	26	--	0.096		48	39	--	0.108
7 hr		--	--	33	0.090		--	--	41	0.107
12 hr		26	18	--	0.057		38	24	--	0.058
13 hr		--	--	18	0.069		--	--	23	0.074
15 hr		25	--	--	0.047		33	--	--	0.059
19 hr		--	--	4	0.047		--	--	14	0.059
3 hr	1 + 2 + 3 + 4 (V<8 km)	59	67	--	0.142	1 + 2 + 3 + 4 (C<2000 ft)	70	71	--	0.181
6 hr		44	44	--	0.154		58	57	--	0.188
7 hr		--	--	38	0.142		--	--	54	0.181
12 hr		37	35	--	0.091		51	42	--	0.124
13 hr		--	--	29	0.109		--	--	46	0.153
15 hr		34	--	--	0.082		44	--	--	0.116
19 hr		--	--	21	0.082		--	--	32	0.116
3 hr	5 (V≥8 km)	97	94	--	0.858	5 (C≥2000 ft)	95	94	--	0.819
6 hr		95	95	--	0.847		93	94	--	0.812
7 hr		--	--	95	0.858		--	--	94	0.819
12 hr		91	96	--	0.909		89	95	--	0.876
13 hr		--	--	97	0.891		--	--	94	0.847
15 hr		91	--	--	0.918		87	--	--	0.885
19 hr		--	--	98	0.918		--	--	97	0.885

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*Prefigurance and relative frequency values are obtained by adding the categories (see Table G-46) in Tables G-40 to G-45.

TABLE G-49. NMC Prefigurance Data for Precipitation During 1976

Day One	q.p.f. ≥ 0.50 in.			q.p.f. ≥ 1.0 in.		
Month	Prefigurance	Post-Agreement	Bias	Prefigurance	Post-Agreement	Bias
January	0.606	0.426	1.42	0.429	0.309	1.39
February	0.524	0.405	1.29	0.329	0.251	1.31
March	0.668	0.363	1.84	0.569	0.244	2.33
April	0.593	0.329	1.81	0.416	0.203	2.05
May	0.479	0.395	1.21	0.341	0.293	1.16
June	0.476	0.308	1.55	0.321	0.214	1.50
July	0.473	0.277	1.71	0.280	0.202	1.38
August	0.460	0.288	1.60	0.331	0.196	1.69
September	0.490	0.314	1.56	0.302	0.213	1.42
October	0.685	0.497	1.38	0.581	0.391	1.49
November	0.528	0.379	1.39	0.384	0.194	1.98
December	0.690	0.479	1.44	0.468	0.322	1.45
Total (year)	0.549	0.358	1.53	0.395	0.251	1.57

Day Two	q.p.f. ≥ 0.50 in.			q.p.f. ≥ 1.0 in.		
Month	Prefigurance	Post-Agreement	Bias	Prefigurance	Post-Agreement	Bias
January	0.399	0.278	1.43	0.269	0.204	1.32
February	0.278	0.271	1.02	0.079	0.082	0.97
March	0.465	0.343	1.35	0.375	0.227	1.65
April	0.391	0.246	1.59	0.225	0.125	1.80
May	0.347	0.326	1.06	0.217	0.214	1.01
June	0.352	0.257	1.37	0.156	0.136	1.15
July	0.258	0.184	1.40	0.109	0.106	1.03
August	0.341	0.216	1.58	0.250	0.159	1.57
September	0.299	0.226	1.32	0.177	0.156	1.13
October	0.466	0.422	1.10	0.366	0.346	1.06
November	0.316	0.239	1.32	0.136	0.081	1.69
December	0.483	0.378	1.28	0.206	0.190	1.09
Total (year)	0.364	0.276	1.32	0.222	0.177	1.25

TABLE G-50. Sample AWS Contingency Table for Persistence Forecast of Events During March 1977

3-hr Forecast

Observed		N	R	Z	F	T
	N	1,438	102	0	17	1,557
	R	106	89	0	1	196
	Z	0	0	0	0	0
	F	18	5	0	9	32
	T	1,562	196	0	27	1,785

6-hr Forecast

Observed		N	R	Z	F	T
	N	1,399	129	0	23	1,551
	R	122	57	0	0	179
	Z	0	0	0	0	0
	F	16	6	0	4	26
	T	1,537	192	0	27	1,756

12-hr Forecast

Observed		N	R	Z	F	T
	N	719	83	0	11	813
	R	83	9	0	0	92
	Z	0	0	0	0	0
	F	7	3	0	2	12
	T	809	95	0	13	917

24-hr Forecast

Observed		N	R	Z	F	T
	N	737	80	0	12	829
	R	68	11	0	0	79
	Z	0	0	0	0	0
	F	4	4	0	1	9
	T	809	95	0	13	917

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