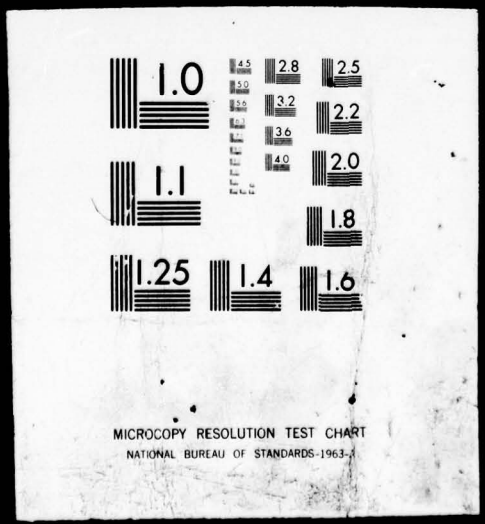
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WEATHER INFORMATION AND TACTICAL ARMY ACTIVITIES

PART 2: Increasing Army Effectiveness Through Improvements in Weather Information Systems (U)

John Metzko
Henry Hidalgo

June 1979

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This paper has two objectives: (1) to identify potential weather information system improvements that would increase Army operational effectiveness and (2) reexamine the basis for the Part 1 finding that for a projected 1985 improvement in mesoscale weather forecasting there does not appear to be a corresponding improvement in the tactical utility of mesoscale weather forecasts. An understanding of the use of weather information in Army activities was developed by a series of workshop-type

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discussions also served to reconsider the additional operational value of improved mesoscale weather forecasts. After identifying weather information system improvements offering potential payoff in increased operational effectiveness, investigations were made to determine whether current development efforts are responsive to the revealed deficiencies. Recommendations are made for the Army to consider actions that would ultimately benefit helicopter operations and cross-country movement. Rationale is provided to affirm the Part 1 finding that 1985 improvements in mesoscale weather forecasting appear to offer no significant utility benefit for the Army.

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PREFACE

The task for which this Part 2 report is written was initially intended to evaluate the utility and cost of potential mesoscale weather forecasting systems for support of Army tactical operations in the mid 1980s. The task was to be accomplished in two phases. Phase 1 was to evaluate the operational utility of the most reasonably optimistic improvement that might be expected in the precision (i.e., accuracy or reliability) of mesoscale weather forecasts by 1985, and Phase 2 was to assess alternative systems with lower levels of prediction precision and to estimate the costs of alternative systems.

The main findings of the Phase 1 effort, however, made cost-capability tradeoffs among alternative mesoscale weather forecasting systems appear unimportant. Therefore, 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 basis for the Phase 1 findings, which several people found somewhat surprising.

The report on Phase 1 of the task is entitled "Part 1: Assessment of the Operational Utility of Mesoscale Weather Forecasting Improvements for Army Forces" of IDA Paper P-1297.

FOREWORD

This report describes the redirected Phase 2 effort to (1) identify opportunities for increasing Army tactical effectiveness by improving its weather information systems and (2) reexamine the Phase 1 findings.

Principal data sources are a series of discussions whose participants include officers of the Army combat arms branches, Air Weather Service meteorologists, Army military and civilian personnel who provide technical and management advice for relevant development and support programs, and personnel of the German Military Geophysics Office.

Some of the discussions, in which officers of several branches participated, ranged over many Army activities (e.g., artillery fire support) and the influence of weather information on them. Discussions at branch schools (e.g., Infantry School) tended to be narrowly focused on single activities and related weather information. Other discussions concerned development and support programs that might offer improvements in weather information for use in tactical operations.

Related parts of the series of discussions and pertinent documentation (revealed by the discussions) became the bases for Appendices A through F, in each of which data pertaining to a particular activity and weather information deficiency are summarized. Appendix D, Cross-Country Movement (CCM), is quite extensive so that readers interested in CCM methodology may have a comprehensive description of current Army CCM methodology.

Most of Appendices A through F were reviewed by the principal contributors for factual accuracy. The remaining portions, which were not reviewed, were affirmed by observations of the authors during the Reforger '79 field exercises conducted by the U.S. Army, Europe Command in January-February 1979.

Appendices A through F are the bases for the analyses of activities and associated deficiencies in weather information systems. These analyses constitute Section II of this report.

Appendix G addresses the second Phase 2 objective of reexamining previous findings about the value of mesoscale weather forecasting improvements for Army forces. Appendix G supplements the report of the Phase 1 effort, and provides the basis for Section III analysis of that issue in this report.

The report is presented in briefing form; introductory material, analyses, findings, and recommendations 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.

EXECUTIVE SUMMARY

The first of two objectives of this study effort, Phase 2 of a two-phase task, was to investigate Army tactical activities that are sensitive to weather information in order to identify potential weather information system improvements that would increase operational effectiveness. A reexamination of the basis for the main Phase 1 finding (viz., 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) became a second objective because several interested people were understandably troubled by that finding.

Data for this Phase 2 effort were gathered from a series of about 15 workshop-type discussions, with varied numbers of participants, of which the total was nearly 100 (Exhibit 5).

The primary means of developing an understanding of the use of weather information in various activities (e.g., artillery fire support, helicopter operations, and cross-country movement) were numerous discussions with many Army officers (weather information users) and Air Weather Service meteorologists (weather information suppliers) at several Army schools and major commands. These discussions were also used to reconsider the additional operational value of improved mesoscale weather forecasts projected for 1985.

After identifying the potential improvements that appeared relevant to increased operational effectiveness, investigations were made to determine whether current efforts by development and support commands and agencies were responsive to deficiencies in weather information systems revealed by discussions with the weather information users and suppliers.

Several potential improvements in weather information systems appear to be important to the following Army tactical activities.

Activities	Elements to be Improved
Artillery fire support	Upper air data
Helicopter operations	Rotor blade icing information
Smoke employment	Near-surface temperature and wind profiles
Cross-country movement	Soil-moisture-trafficability information
Weather-information-sensitive planning	(1) Communications and (2) observational inputs

While development efforts to improve most of the above elements are ongoing, the Army should consider two actions for the ultimate benefit of helicopter operations and cross-country movement, respectively: (1) initiate a program with USAF, USN, NOAA, and FAA participation to develop a statistical base for improved forecasting of rotor blade icing and (2) join the Federal Republic of Germany (FRG) in a testing program to develop a soil-moisture-trafficability data base for cross-country movement predictions.

Rationale, supplementing that already provided in the Part 1 report, is provided to affirm the Phase 1 finding that expected 1985 improvements in mesoscale weather forecasting appear to offer no significant additional utility for Army forces.

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I. INTRODUCTION

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EXHIBIT 1: BACKGROUND

Phase 1 of this two-phase task was narrowly focused on the utility (or value) of projected 1985 improvements in mesoscale weather forecasts (MWFs) for Army forces.

Main finding of the Phase 1 effort, which is described in the Part 1 report, was that no additional utility should be expected from the projected MWF improvements.

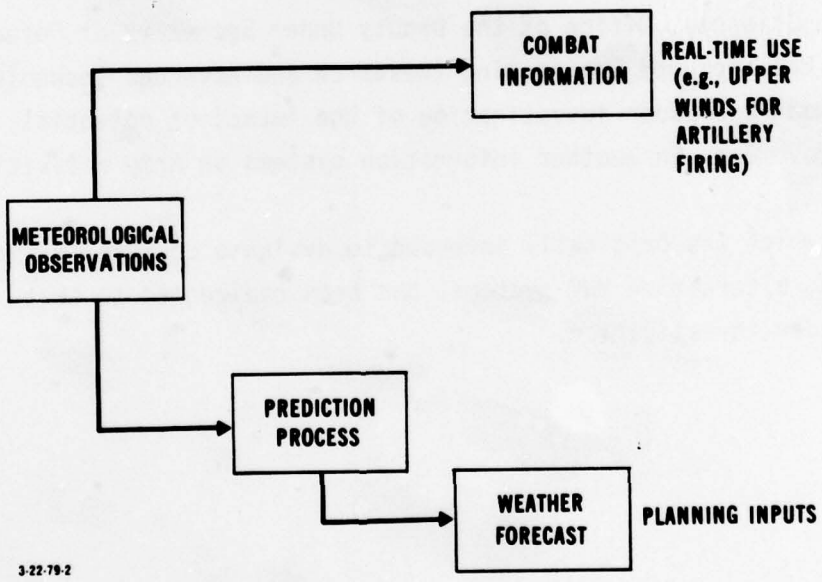
This finding caused the study sponsor, Director of Environmental and Life Sciences, Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology), to want a broader investigation of the impact of potential improvements in weather information systems on Army activities.

Phase 2, which was originally intended to evaluate cost-capability among alternative MWF systems, has been redirected to that broader investigation.

EXHIBIT 2: DEFINITIONS

Activity: A set of group actions distinguishable by the objective of the group involved, e.g., helicopter operations, artillery fire support, tactical planning, etc.

Weather Information System: Meteorological[a] data collection, prediction processes, and communication links for transmitting meteorological data for current use as combat information and weather forecasts as planning information.



[a]While some meteorologists make distinctions between "meteorological" and "weather" and others between "weather" and "weather manifestation" in defining elements that describe the state of the atmosphere, the three are considered equivalent adjectives in this report. Also "Met" is frequently used for "meteorological."

EXHIBIT 3: OBJECTIVES

The task order objectives are to:

1. Determine the nature and extent of the influence of weather information on tactical combat operations, and
2. Complete the Phase 1 evaluation.

The task order objectives are more specifically meant to:

1. Identify opportunities for increasing Army effectiveness in various tactical activities by improvements in weather information systems, and
2. Seek evidence to support, rationalize, or reject Phase 1 findings and conclusions.

Limitations: This effort may not be a complete compilation of all deficiencies or potential improvements in weather information systems.

EXHIBIT 4: APPROACH

To develop an understanding of the impact of weather information on tactical activities, these lines of investigation were adopted:

a. Review formal Department of the Army documentation pertaining to weather information requirements.
b. Discuss details of tactical activities and associated effect of weather information with a broad spectrum of officers of various branches (i.e., infantry, armor, artillery, aviation, etc.) and operational meteorologists.
c. Investigate whether there are ongoing efforts by development and support commands and agencies to make weather information more useful.

To further consider the utility of projected 1985 improvements in mesoscale weather forecasting capability, these actions were undertaken:

a. Search literature for studies on value of weather forecasts, and
b. Review Part 1 draft report in Phase 2 discussions.

EXHIBIT 5: INITIAL DATA SOURCES

Little documentation of weather information requirements was found; two requirements were documented:

1. Field artillery meteorological acquisition system
2. Remote automatic weather station

Understanding of tactical activities, associated weather information, and pertinent technical development and support efforts was acquired in discussions with operational personnel, technical personnel, and meteorologists of the following organizations:

Armor School
Aviation Center
Infantry School
Army War College
Artillery School
U.S. Army, Europe
Intelligence Center
Training and Doctrine Command
Waterways Experimental Station
Engineer Topographic Laboratories
Development and Readiness Command
German Military Geophysics Office
Department of the Army Headquarters
5th Weather Wing, Air Weather Service
Ordnance and Chemical Center and School
7th Weather Squadron, Air Weather Service
Combined Arms Combat Development Activity

II. ANALYSES OF ACTIVITIES AND ASSOCIATED DEFICIENCIES IN WEATHER INFORMATION SYSTEMS

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EXHIBIT 6: ARTILLERY FIRE SUPPORT AND UPPER AIR MET DATA (SUPPORTING DETAIL IN APPENDIX A)

ACTIVITY: Artillery Fire Support

WEATHER INFORMATION SYSTEM DEFICIENCY: Stale (i.e., old) and inaccurate upper air wind, temperature, humidity, and density data are often used for ballistic calculations in artillery trajectory estimation because the current, but obsolete, Rawinsonde System GMD-1 incorporates manual computation-and-plotting, which is slow and error-conducive, for transforming raw Met data into a formatted Met message.

CONSEQUENCES OF DEFICIENCY: As artillery range increases due to improvements in gun system design, the effect of Met factors becomes increasingly significant and, in many cases, may be the largest contributor to total system range error. Met factors may account for nearly one-half of the range errors incidental to long-range fire missions. Use of current accurate Met data means fewer rounds and less time are required to neutralize a target.

PERTINENT RECENT OR CURRENT ACTIONS: (1) A new automatic data processor is ready for the GMD-1 system; faster and more accurate ballistic calculations and Met message preparation will result. (2) An advanced development model of FAMAS (Field Artillery Meteorological Acquisition System), providing some advantages over the improved GMD-1, will be ready for testing in 1979.

COMMENTS: Incorporation of the automatic processor in existing GMD-1 systems is envisioned as an interim improvement until FAMAS can be introduced into field artillery Met sections.

EXHIBIT 7: HELICOPTER OPERATIONS AND ROTOR BLADE ICING
(SUPPORTING DETAIL IN APPENDIX B)

ACTIVITY: Helicopter operations

WEATHER INFORMATION SYSTEM DEFICIENCY: Inability to deter and predict rotor blade icing.

CONSEQUENCES OF DEFICIENCY: Rotor blade icing presents both a technical design problem and a flight safety warning problem. While the former involves anti-icing or de-icing hardware (ice protection system) to avoid or remove icing, the latter involves short-term warning by on-board icing sensors or by increased demand for torque, and long-term warning by reliably predicting icing conditions. Since current helicopters do not carry rotor blade icing sensors and since there is a very poor statistical basis for predicting rotor blade ice formation, the icing is (1) a flight hazard since it may be detected too late to avoid catastrophe and (2) a deterrent to flight operations since uncertainty of icing forecasts leads to pessimistic predictions (i.e., biased in favor of safety) and to conservative flight clearance policies.

PERTINENT CURRENT ACTIONS: The Army is developing or promoting the development of ice protection systems for incorporation in future helicopters (e.g., UH-60, AH-64, and ASH) in their initial designs, but considers performance penalties associated with retrofitting present helicopters (e.g., CH-47 and UH-1) with anti-icing or de-icing systems to be unacceptable. The Army is also developing and studying onboard instrumentation to sense and warn of icing conditions.

COMMENTS: Since ice protection equipment on future helicopters may not offer protection in all icing conditions without unacceptable performance penalties, the need to improve present capabilities to forecast icing conditions for current helicopters can be expected to be a longer term requirement. Thus it appears appropriate to equip a few current helicopters with ice protection systems and with onboard instrumentation, such as ice detector, liquid water content meter, and outside air temperature gauge, in order to identify through testing the physical parameters that (1) are related to the rotor blade icing phenomenon and (2) are susceptible to operational measurement and to reliable prediction.

EXHIBIT 8: SMOKE EMPLOYMENT AND ASSOCIATED MET INFORMATION
(SUPPORTING DETAIL IN APPENDIX C)

ACTIVITY: Smoke employment

WEATHER INFORMATION SYSTEM DEFICIENCY: Current measurements and near-term predictions of surface and near-surface temperatures and winds in forward combat areas are critical information not provided to staff chemical officers.

CONSEQUENCES OF DEFICIENCY: Estimates of effectiveness and munition requirements for a smoke mission may vary by factors up to ten or more for the array of temperatures and wind velocities reasonably likely to be experienced during any period of a day or more. Uncertainty in munition requirements to achieve desired effectiveness leads to worst-case estimates; but high-siding the number of smoke rounds required reinforces other factors which tend to reduce the rationality of smoke employment by the U.S. Army in a NATO-Warsaw Pact conflict: (1) obstructions to vision are more serious impediments to the defender than to the attacker, (2) expected U.S. involvement primarily in defensive operations, and (3) apparent U.S./USSR artillery firepower balance favors the USSR. However, covering force operations in a defensive plan are likely to be greatly aided by smoke employment.

PERTINENT CURRENT ACTIONS: None is apparent.

COMMENTS: Since temperature gradients and wind velocity profiles for planning smoke employment are required for forward combat areas, which are unlikely to be occupied by friendly forces, the difficulties in obtaining accurate Met information for such planning may outweigh the value of the information.

EXHIBIT 9: CROSS-COUNTRY MOVEMENT AND SOIL-MOISTURE EFFECTS (SUPPORTING DETAIL IN APPENDIX D)

ACTIVITY: Off-road movement of tanks, self-propelled guns, armored personnel carriers, and trucks

WEATHER INFORMATION SYSTEM DEFICIENCY: Route selection for tactical off-road movement is often uncertain because there is not an operational methodology that permits engineers or meteorologists to estimate the effect of precipitation on ground trafficability in various soil-moisture conditions.

CONSEQUENCES OF DEFICIENCY: Movement delays are frequently caused by vehicles becoming mired in areas they cannot traverse and by the need to provide retrieval assistance by other vehicles.

PERTINENT CURRENT ACTIONS: The U.S. Army Waterways Experiment Station (WES) has been developing a cross-country mobility model for purposes of (1) vehicle design, for which fine-grained detail is desired, and (2) strategic planning, for which average cross-country speed of a vehicle through a specified region is the objective. The U.S. Army Engineer Top raphic Laboratories (ETL) has developed cross-country mobility methodology, with much less fine-grained detail, that provides qualitative movement estimates (good, fair, poor, and unsuited) for average seasonal moisture conditions in an area. The Federal Republic of Germany Military Geophysics Office (GMGO) is developing a cross-country mobility model that includes consideration of recent precipitation in maintaining current soil-moisture balance to provide daily go/no-go movement estimates for off-road route selection.

COMMENTS: The Reforger '79 field exercise in the FRG illustrated the need for a methodology which can provide reliable daily assessments of the trafficability of specified areas. The GMGO model holds the most promise to meet that need because it includes daily soil-moisture balance. The value of potential U.S. contributions in field testing to develop an empirical basis for soil-moisture-trafficability predictions and in other aspects of cross-country movement modeling development, which appears very important to the German and American armies, makes a joint FRG-USA program attractive.

EXHIBIT 10: WEATHER-INFORMATION-SENSITIVE PLANNING AND COMMUNICATIONS
(SUPPORTING DETAIL IN APPENDIX E)

ACTIVITY: Weather-information-sensitive planning

WEATHER INFORMATION SYSTEM DEFICIENCY: Weather information is often delayed or unavailable because of problems with the truck-mounted High Frequency Radio Teletype System and the line-of-sight Army Command and Area Communications System (ACACS): (1) old, worn equipment subject to frequent breakdown, (2) unreliable equipment and low user priority often combine to limit communication channel availability for meteorological information, (3) old teletypewriters whose mechanical-type printers operate at a low--60 words per minute--data rate; and (4) long periods required to realign ACACS microwave transmitters and receivers.

CONSEQUENCES OF DEFICIENCY: Meteorological observations are often not available for formulating weather forecasts, which are themselves frequently delayed or outdated. Thus activities such as helicopter operations may be less effective or efficient because operational planners do not have timely reliable weather information to which planning is sensitive.

PERTINENT CURRENT EFFORTS: The Army is developing and testing a new printed page teletypewriter UGC-74, which incorporates an electromechanical printer with a maximum print speed ten times that of present teletypewriters. Introduction into USAREUR units is expected in 1980.

COMMENTS: The UGC-74 teletypewriter appears to be the only new equipment to affect weather information communications in the near term. Given successful outcomes of development tests and operational tests (during the summer of 1979), the UGC-74 should significantly improve AWS capability to support the Army because of higher reliability and increased data rate. However, that AWS capability will continue to be limited by (1) current encryption equipment which is designed for data rates (of 100 words per minute) considerably less than the UGC-74's maximum, and (2) unreliability of communication system components other than teletypewriters.

EXHIBIT 11: WEATHER-INFORMATION-SENSITIVE PLANNING AND MET OBSERVATIONS
(SUPPORTING DETAIL IN APPENDIX F)

ACTIVITY: Weather-information-sensitive planning

WEATHER INFORMATION SYSTEM DEFICIENCY: Current meteorological observations are insufficient to provide increasing forecast resolution desired by successively lower level commands, which are concerned with successively smaller areas of responsibility, i.e., more observations in the forward areas of the FRG are needed.

CONSEQUENCES OF DEFICIENCY: An unknown degree of resolution and precision, and therefore usefulness of weather-information-sensitive planning (i.e., planning in which lead time makes weather information useful), is lost in transforming synoptic- and large-mesh mesoscale forecasts to fine-mesh mesoscale forecasts for areas of interest without additional local area observations.

PERTINENT CURRENT ACTIONS: U.S. Army Europe has initiated a Forward Area Limited Observation Program (FALOP), involving minimally trained personnel (of intelligence sections of divisions and armored cavalry regiments) equipped to measure basic surface weather parameters, to provide additional observations to supplement Air Weather Service observations in the eastern parts of the FRG.

COMMENTS: Two other groups in the USAREUR Command appear to be good potential sources of forward area weather data: (1) the forward air controllers, of which one is assigned to each maneuver battalion, and (2) the artillery Met sections, of which there are eight in Europe.

III. REEXAMINATION OF UTILITY OF MESOSCALE WEATHER FORECAST IMPROVEMENTS FOR ARMY FORCES[a]

EXHIBIT		PAGE
12	Some Definitions and Observations Pertinent to the Evaluation of Weather Forecasts	19
13	The Sensitivity of Air Force Activity to Weather Information	20
14	The Sensitivity of Army Activity to Weather Information	21
15	The Value of Projected 1985 Improvements in Mesoscale Weather Forecasts	22
16	Comparison of MWF Reliabilities	23

[a]Supporting details are found in Appendix G.

EXHIBIT 12: SOME DEFINITIONS AND OBSERVATIONS PERTINENT TO THE EVALUATION OF WEATHER FORECASTS

From consideration of the value of weather forecasting for various activities in previous studies, the following set of observations has been drawn:

1. A weather-sensitive activity is influenced by weather.
2. A weather-information-sensitive activity is one in which weather information can alter a decision-maker's courses of action.
3. Weather-information-sensitivity is a function of the nature of an activity.
4. A weather-sensitive activity is not necessarily weather-information-sensitive.
5. Weather information may become useful only when its accuracy or reliability reaches some threshold value.
6. In many activities, substantial increases in forecast reliability may be necessary before significant increases in value are realized.

These observations provide a background for considering the sensitivity of Air Force and Army activities to weather information in the next two exhibits.

EXHIBIT 13: THE SENSITIVITY OF AIR FORCE ACTIVITY TO WEATHER INFORMATION

NATURE OF THE ACTIVITY: The essence of Air Force activity is operating aircraft for attacking ground targets, for attacking air targets, and for logistic support. An obvious objective in managing its fleet of aircraft is to generate, over some period, as many sorties as possible in order to increase the opportunities to attack targets or to provide logistics support. Because the typical planning problem, with respect to attacking ground targets for example, involves assigning relatively scarce aircraft sorties against relatively numerous targets, the Air Force would logically adopt a methodology which facilitates sortie assignments in a way that maximizes some expected-value function. The methodology would include consideration of target alternatives and factors, quantified as precisely as practicable, relevant to estimating the payoffs among alternative assignments. An important factor in this estimation process is probability that weather will be favorable for an attack. Two attack sortie-assignment schemes are briefly illustrated below.

WEATHER INFORMATION SENSITIVITY:

Target	A	B	•••	X	Y	Z
Value of Target	100	50	•••	1	10	10
Probability of Favorable WX [P(FW)]	.01	.02	•••	1.0	0.1	1.0
Expected Payoff	1	1	•••	1	1	10

P(FW)	$0 \leq P(FW) \leq 1.0$
Determinants of Target Kill	
Air Defense Weapon Characteristics	Estimate P(Kill given favorable WX)
Mission Success Indicator (MSI)	$MSI = P(FW) \times P(K/FW)$

EXHIBIT 14: THE SENSITIVITY OF ARMY ACTIVITY TO WEATHER INFORMATION

NATURE OF THE ACTIVITY: Whereas the Air Force planner typically has alternatives for making his aircraft sortie assignments, the typical Army planning situation includes no alternative mission. And whereas the Air Force planner considers factors, such as target vulnerability, weapon characteristics, air defenses, etc., which are susceptible to characterization quantitatively, the Army planner must consider enemy situation, i.e., strength, disposition, and intentions, which appears much less susceptible to such characterization. Other factors considered by the Army operational planner are terrain, details of which he can be expected to be very certain, and forecast weather, whose reliability should be as good as that of forecasts available to the Air Force planner.

WEATHER INFORMATION SENSITIVITY: Even with perfect knowledge of terrain, the lack of mission alternatives, the primacy of enemy situation assessment (however uncertain that assessment may be), and the relative immobility of ground forces combine to influence the Army planner to require a very reliable weather forecast for that to be a decisive factor. With respect to Army planning for helicopter employment, the assignment objective is expected to be somewhat similar to that described for the Air Force: do not forego opportunities to utilize the available assets. But while more weather-information-sensitive than ground forces, the Army airborne force appears to be less weather-information-sensitive than a fixed-wing aircraft force because of several reasons: (1) more closely integrated ground- and airborne force planning, (2) less range and speed than fixed-wing aircraft (i.e., less mobility), and (3) less sensitivity than fixed-wing aircraft to ceiling and visibility.

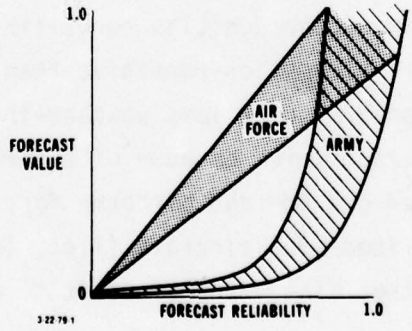
EXHIBIT 15: THE VALUE OF PROJECTED 1985 IMPROVEMENTS IN MESOSCALE WEATHER FORECASTS

Projected improvements in mesoscale weather forecasts (MWFs) are illustrated in Exhibit 16.

The few studies that pertain to the value of weather information and the discussions with many military personnel for this task indicate that:

1. A quantifiable relationship may be derived between value and reliability of MWFs, given adequate lead time, for a well-defined scenario, i.e., one in which an activity and its relevant factors are very specifically known.
2. But there are a very large number of tactical military scenarios, real as well as conceptual, in which the relevant factors can be characterized quite differently or cannot be quantified.[a]
3. Thus a mathematical or logical proof of a general relationship between reliability and value of MWFs for some activities appears infeasible.

However, the two preceding exhibits suggest the existence of value-reliability relationships (normalized) illustrated below for activities involving operational planning decisions for the Army and the Air Force.

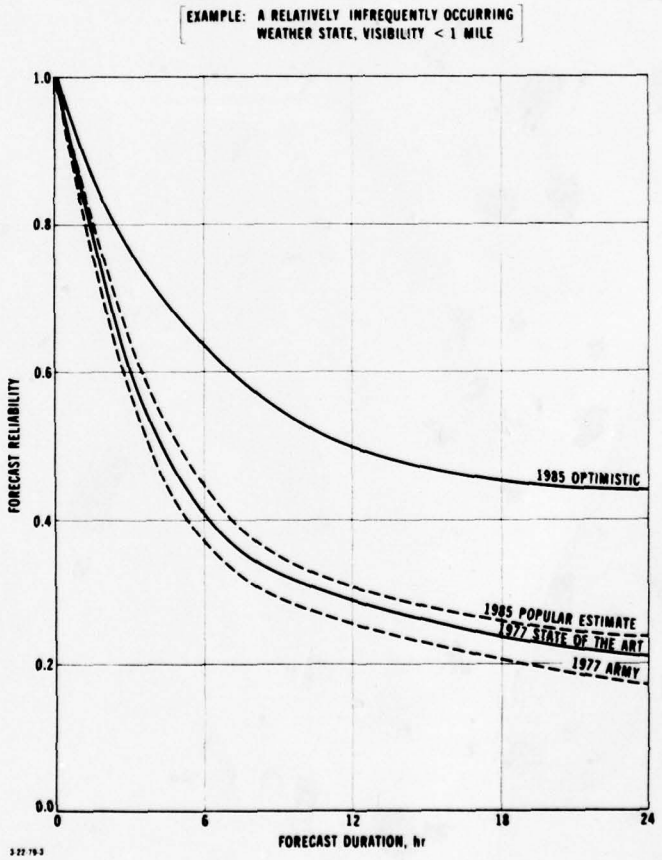


[a]For example, friendly forces available and terrain, two factors relevant to Army battlefield planning, can differ markedly from scenario to scenario; another relevant factor, mission, may alternatively be to gain ground, to delay the enemy, to inflict maximum attrition on the enemy force, etc.; and certain aspects such as disposition and intentions of another relevant factor, enemy situation, may be uncertain.

EXHIBIT 16: COMPARISON OF MWF RELIABILITIES

The upper-bound improvement in MWF reliability, hypothesized for 1985 in Phase 1 discussions, is considered insufficient to affect tactical planning decisions by the Army and too optimistic by most meteorologists, who generally expect about a 10% improvement over current (1977) reliability.

1977 MWF reliability data used in Phase 1 discussions are the results of extensive verification testing[a] and represent current state of the MWF art. However, because of poor communications and insufficient observations (see Exhibits 9 and 10, and Appendices E and F of Part 1 report), reliability of MWFs available to Army forces in the field in Europe today is somewhat less than current state of the art. These observations are illustrated below by an example case.



[a]At meteorological stations in Western Europe and in the contiguous USA.

IV. FINDINGS AND RECOMMENDATIONS

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EXHIBIT 17: FINDINGS

1. Several potential weather information system improvements appear to be of significant value to the following Army tactical activities:

Activity	Elements to be Improved
Artillery fire support	Upper air data
Helicopter operations	Rotor blade icing information
Smoke operations	Surface and near surface temperature and wind information
Cross-country movement	Soil-moisture-trafficability information
Weather-information-sensitive planning	(1) Communications and (2) observational inputs

2. The improved GMD-1 and FAMAS developments should enable Met Sections to provide more timely and accurate data for trajectory estimation by the Field Artillery.
3. Although a broad vigorous development effort is under way to provide the capability for Army helicopters to fly in icing conditions, there appears to be little effort to identify the physical parameters which are related to the rotor blade icing phenomenon and which are susceptible to operational measurement and to reliable prediction.
4. While critical Met information for smoke employment is not available to staff chemical officers, the practical problems involved in obtaining the information may outweigh its value.
5. Cross-country movement predictions on the basis of combined terrain and precipitation considerations, which include empirical soil-moisture-trafficability testing, would be very useful to operational planners in USAREUR.
6. The USA and the FRG have common interests in, and can make complementary contributions to, development of a soil-moisture-trafficability data base for CCM predictions.

7. The current unreliable communications available for transmitting weather information and insufficient observational inputs for forecast formulation means USAREUR generally has less than current state-of-the-art forecast reliability for its tactical planning decisions.
8. Development of the UGC-74 teletypewriter, which is to be introduced into the USAREUR Command in 1980, should reduce, but not eliminate communications difficulties, which are encountered to some extent by all users of Army tactical communication nets.
9. While ground based FACs and Field Artillery Met Sections appear to be good sources of additional Met observations, initiation of FALOP testing is a reasonable corrective action.
10. Expected mid-1980s improvements in MWF reliability appear to offer no significant additional utility for Army activities.
11. The nature of Army activity is such that very high reliability appears necessary for MWFs to become more important factors in tactical decision making than they are currently.

EXHIBIT 18: RECOMMENDATIONS

1. The Army should consider initiating a program, with USAF, USN, NOAA, and FAA participation, to develop a statistical base for reliable forecasting of rotor blade icing.

2. The Army should consider a joint USA-FRG testing program to develop a soil-moisture-trafficability data base for cross-country movement prediction.

APPENDIX A

ARTILLERY FIRE SUPPORT

ARTILLERY FIRE SUPPORT

Whereas meteorological (Met) information is generally too stale and often too inaccurate for trajectory estimation in artillery fire missions, timely and accurate Met information is increasingly important in ballistic calculations since newer and longer range artillery weapon effectiveness is increasingly affected by ballistic wind and density of the air in which artillery projectiles are fired (Ref. A-1).

An example of the sensitivity of range component error (as an inverse surrogate[a] for artillery effectiveness) to Met effects from Ref. A-1 compares the total range standard deviation for 5- and 18-km range cases. The comparison is shown in Table A-1, in which the percent error contributions of the fire artillery functional areas (viz., target acquisition, fire direction and control, meteorology, weapon-ammunition, and survey) are indicated for the cases considered. The range component errors shown are estimated for a certain scenario and artillery system configuration; while they are not necessarily considered general, the growth in Met range component error is generally expected.

The data in Table A-1 indicate that Met effects on artillery projectiles can be very significant at extended ranges and may be in many scenarios the largest contributor to total system range error. The expected payoff in reducing that total error is increased effectiveness or efficiency of artillery support: expenditure of fewer rounds and less time to neutralize a target.

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[a]That is, the larger the error, the lower the effectiveness; range component error is defined as the range standard deviation, which is generally much larger than deflection standard deviation.

TABLE A-1. PERCENT CONTRIBUTIONS OF ARTILLERY FUNCTIONAL AREAS TO TOTAL DELIVERY RANGE ERRORS FOR 5 km AND 18 km

Source: Section IV of Ref. A-1

Artillery Functional Area	Approximate % Contribution Range, km	
	5 km	18 km
Target Acquisition	56.8	21.6
Fire Direction and Coordination	2.2	3.3
Meteorology	17.0	45.7
Weapon-Ammunition	23.1	19.1
Survey	0.5	.002
Total Range Standard Deviation, m	115	182

While several new cannon systems and improved artillery munitions have been developed and fielded during the last three decades, the Army has used the same ballistic meteorology system, with few improvements, during the same period. That Met system is the Rawinsonde System, AN/GMD-1, whose capabilities and shortcomings are summarized in Ref. A-2.

The GMD-1, which was type-classified Standard A in 1949, is used by Army field artillery Met sections to sound the artillery atmosphere. It is described (in Ref. A-2) as (1) utilizing World War II-vintage electron tube and electromechanical technology, (2) being bulky, and (3) requiring an hour for emplacement and 3/4-hour for displacement by a well-trained crew. While these characteristics, as well as maintenance-supply problems

cited in Ref. A-2[a], are symptoms of old age, the principal deficiency of the GMD-1 is the manual computation-and-plotting system for transforming raw Met data into a usably formatted Met message (Ref. A-3). The Army Field Artillery School thinks too much manpower is required and that human errors are too common. Also, since the GMD-1 does not interface with the Army's automated artillery command, control, and communications system, viz., TACFIRE, delays in Met message dissemination can reduce the reliability of Met information by as much as 50%, depending on operative weather conditions. The net result is reduced Met system effectiveness which is manifested in larger weapon delivery errors.

The Army is developing and considering two options for improving the effectiveness of its artillery Met system: (1) a new automatic data processor for the GMD-1 and (2) an entire new Field Artillery Meteorological Acquisition System (FAMAS).

The new GMD-1 processor consists of a commercially available programmable calculator which is interfaced with a commercially available punched paper tape reader. While no changes are being made to the commercial equipment to meet Army requirements, special calculator software has been provided for field artillery application. The new GMD-1 processor automatically calculates and prepares ballistic Met messages for dissemination to artillery batteries. Automating Met data processing is

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[a]"The GMD-1 is becoming increasingly difficult to maintain. Because of its age, many of its parts are no longer listed in the supply catalogs. For example, selsyn and drive motors are no longer available as repair items. The defective motor must be returned to depot for repair and then returned to the unit. Other low mortality parts such as drive gears, etc., must be fabricated or procured through local purchase by the depot. During the repair period, the supported artillery units must rely on manually observed Met messages. Additionally, investigations have revealed that all of the capacitors and resistors in the main assembly of the GMD-1 are now exceeding their tolerances."

expected to provide more accurate Met messages than the present manual GMD-1 processor and to save about 10-12 minutes in time required for calculation and preparation of Met messages.

Whereas the automatic GMD-1 processor is ready for introduction to Army field artillery Met sections, an advanced development model of FAMAS should be completely fabricated early in 1979 and then undergo development testing and initial operational testing. A comparison of some system characteristics of FAMAS and the present GMD-1 is shown in Table A-2 to provide an idea of the improvements in accuracy and timeliness the Army expects from FAMAS. Development testing and initial operational testing will determine whether FAMAS can provide Met messages with anticipated improvements over those from the present GMD-1 system.

TABLE A-2. SOME CHARACTERISTICS OF THE GMD-1 AND FAMAS MET SYSTEMS

(Source: Ref. A-2)

CHARACTERISTIC	GMD-1	FAMAS
Frequency	1680 Mhz (±10)	1680 Mhz (±10) 403 Mhz (+3)
Wind Data Accuracy	±4 knots at tracking angles >17°; accuracy degrades at tracking angles <17°	±2 knots at all elevation angles for LORAN C/D; ±4 knots at all elevation angles for OMEGA and VLF
Time to Emplace, minutes	60	15-30
Time to Displace, minutes	45	10-20
Time to Compute and Transmit Met Message, minutes	15	1
Frequency of Sounding	1 per 4 hours	1 per hour
TACFIRE Interface	No	Yes
Data Reduction	Manual	Automatic

Figure A-1 (from Ref. A-2) shows a graphic comparison of GMD-1 and FAMAS effects on the accuracy of M109 self-propelled howitzer firing at ranges of 10 km and 20 km; the effects of Met message staleness upon weapon accuracy is shown by the temporal growth of CEP, particularly for the longer range case.

Met system interface with TACFIRE is an important characteristic of FAMAS to avoid transmission delays (of Met messages) when fire missions are imminent or are in progress; Met messages are currently broadcast on the Artillery Command Fire Net which must give priority to fire mission information over Met messages for which delays are often an hour or more. Met data can be timely disseminated with a Met system-TACFIRE interface (Ref. A-2).

Because the present GMD-1 system operates on a center frequency, 1680 Mhz, also used by meteorological satellites, GMD-1 radiosondes cause interference with operations of these satellites. The Federal Republic of Germany has reserved the right to prohibit U.S. Army use of a frequency band around 1680 Mhz if further interference occurs, and has denied use of that frequency band after 1983. While FAMAS will be able to operate at the frequency band around 403 Mhz assigned for radiosonde operations, it is not feasible to convert the GMD-1 to receive 403 Mhz (Ref. A-2).

A significant advantage of FAMAS over the improved GMD-1 system is the incorporation of alternative tracking modes: (1) an RDF (radio direction finding) mode in which, as in the GMD-1, a tracking antenna locks on an emitting sonde launched from the station and tracks the sonde in azimuth and elevation, and (2) a NAYAID mode in which another antenna (whip) can receive and retransmit (by the sonde) LORAN C/D, OMEGA, and VLF signals from existing worldwide navigation aids.

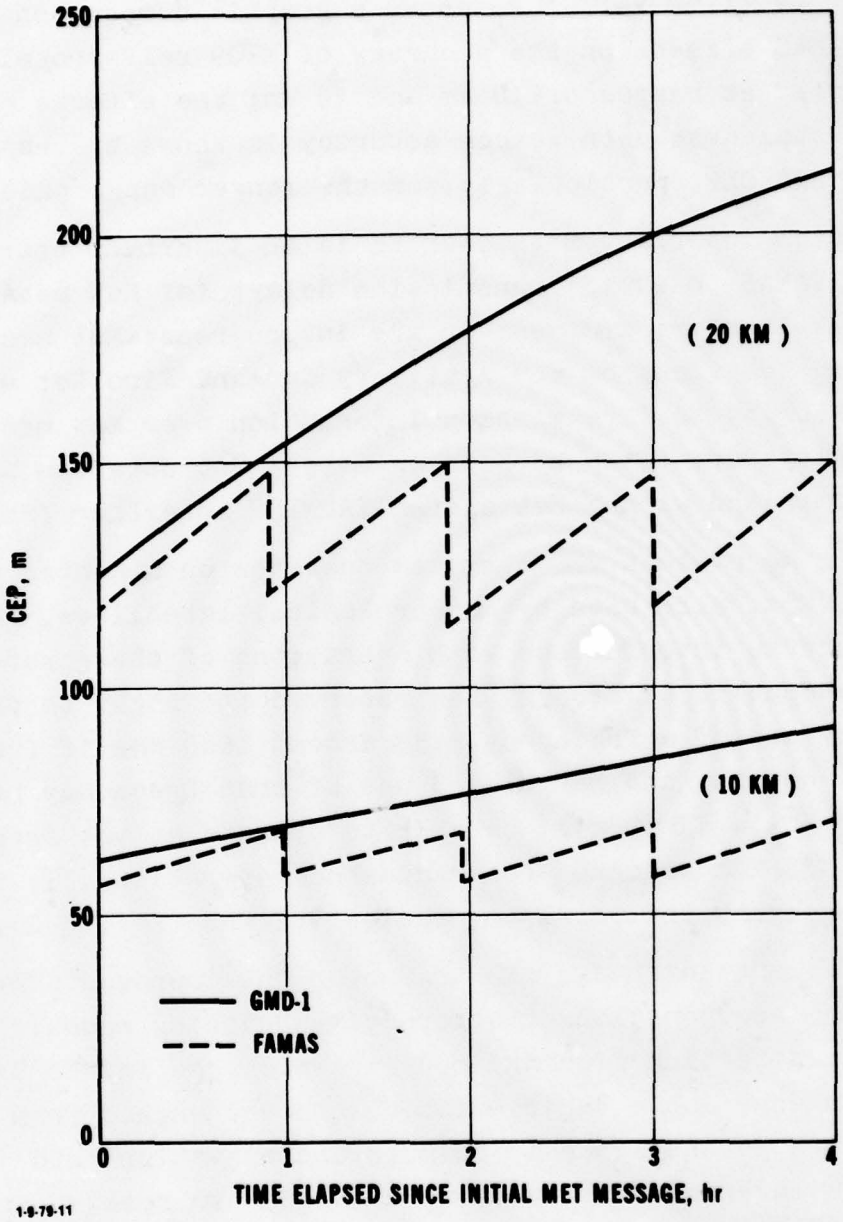


FIGURE A-1. M109A1 ARTILLERY SYSTEM ACCURACY AT 10-km AND 20-km RANGES WITH MET MESSAGES FROM GMD-1 AND FAMAS SYSTEMS

Source: Ref. A-2

REFERENCES

A-1. *Accuracy Analysis of Artillery Cannon Systems*, Vol. I, ACN 21969, BDM Services Company with Subcontract to Vector Research, Inc., P.O. Box 456, Leavenworth, Kansas 66048, 30 April 1975 (UNCLASSIFIED).

A-2. *Mini Cost and Operational Effectiveness Analysis of the Field Artillery Meteorological Acquisition System (FAMAS)*, U.S. Army Field Artillery School, Ft. Sill, Oklahoma, Undated (UNCLASSIFIED).

A-3. Conversations with Mr. Robert Farmer of the U.S. Army Field Artillery School, Ft. Sill, Oklahoma, 1978 (UNCLASSIFIED).

APPENDIX B

HELICOPTER OPERATIONS

HELICOPTER OPERATIONS

The inability of Army aviation units to detect rotor blade icing constitutes a serious hazard for operating present helicopters, particularly in a region such as Germany, where ice formation on lifting surfaces of aircraft is a common phenomenon in lower altitude strata during wintertime.

Rotor blade icing is the major part of the helicopter icing problem. Reference B-1 indicates that the following are possible consequences of rotor blade icing: (1) ice accretions on main rotor blades can cause performance degradations with consequent increased demand for torque, inability to establish automatic rpm, and reductions in flight-maneuver envelope; and (2) rotor and control system fatigue damage can arise from an increase in oscillating torsional loads and vibration due to asymmetric ice buildup and shading.

Other helicopter icing problems are (1) engines can be internally damaged by shed ice or can malfunction from intake blockage or can flameout from sudden ingestion of large quantities of ice, snow, or slush; (2) vision through windscreens can be blocked or impaired by ice formations; (3) ice and snow on a fuselage may cause ingestion problems or impact damage from breakaway; (4) extreme buildups on the forward fuselage may significantly alter center of gravity position; (5) possible icing up of exposed controls preventing operation; (6) ice accretions on antennas with resulting vibration and structural failure; and (7) icing effects on carriage, release, and operation of weapons and externally carried stores (Ref. B-1).

Rotor blade icing presents both a technical design problem and a weather forecasting problem. While it may be important to operate in icing conditions, ice protection systems (anti-icing or de-icing) may cost too much in terms of helicopter performance to be feasible for all degrees of icing severity. Thus it is desirable to be able to reliably forecast icing conditions so that helicopters can avoid exposure to meteorological situations for which they are not equipped.

While future Army helicopters (e.g., UH-60, AH-64, and ASH) will have incorporated in their initial design systems[a] to combat ice formation on lifting surfaces, the Army considers the performance penalties associated with retrofitting present CH-47s and UH-1s with ice protection systems to be unacceptable (Ref. B-2).

References B-1 and B-3 indicate that current abilities to forecast helicopter icing conditions are inadequate. A better understanding is needed of helicopter icing phenomena, which include meteorological parameters, helicopter design and configuration details, and rotor operating conditions. The important meteorological parameters, from Refs. B-4 and B-5, are cloud liquid water content (LWC), outside air temperature (OAT), cloud droplet size spectrum, and ice particle concentration.

Several U.S. and U.K. participants in the recent NATO Army Armaments Group, Panel X, meeting on helicopter icing spoke of the lack of statistical data on low-altitude icing conditions. Reference B-5 suggested that helicopters cleared for flight in icing conditions carry LWC and OAT instrumentation with automatic recording capability so that a data base can be built for improved forecasting.

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[a]Electrothermal systems to heat rotor blades or ice-phobic coatings which preclude ice adherence to rotor blade surfaces.

Until present helicopters are retired and replaced with helicopters equipped to counter rotor blade icing, the Army will depend on the following types of actions to cope with the icing hazard:

1. Use forecasts to avoid flight operations in icing conditions.
2. Land or change altitude if possible when icing is encountered.

Because low-altitude icing conditions are so difficult to predict, icing forecasts understandably tend to be pessimistic; and because forecasts of icing are unlikely to be reliable enough to be a criterion for fly/no-fly decisions, the second type of action is expected to be frequently required. But this type of action must be preceded by an indication of ice formation, which the helicopter pilot cannot observe on a rotating rotor blade; and waiting until a degradation of lifting capability is sensed may not allow sufficient time to avoid catastrophe.

The Army is developing and studying onboard instrumentation to sense and warn of icing conditions. A partial ice detection kit now being considered includes an ice detector, an LWC meter, and an OAT gauge. Heated wind screens and relocation of antennas are also being considered.[a]

There appears to be no current program for developing a basis for improving rotor blade icing forecasts (Refs. B-6 through B-9). Such a program would entail identifying those parameters which are related to rotor blade icing and which are susceptible to operational measurement and to reliable prediction; the program would be expected to include substantial helicopter flight operations in icing conditions to acquire an empirical data base.

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[a]From Refs. B-2 and B-3. VHF-FM whip antenna on UH-1H is severed by tail rotor blades when ice accretion causes the antenna to be bent.

REFERENCES

B-1. *The Requirements and Problems of Helicopter Flight in Icing Conditions,* Commander M.E. Southgate, Royal Navy, U.K. Ministry of Defence, presentation to NATO Symposium on Helicopter Icing, London, 6-7 November 1978 (UNCLASSIFIED).

B-2. Conversation with Mr. Richard Ballard and Lt Colonel George Sibert of the Office of the Deputy Chief of Staff for Research, Development, and Acquisition, HQ U.S. Army, 13 October 1978 (UNCLASSIFIED).

B-3. *U.S. Army Developments in the Area of Helicopter Ice Protection,* Richard I. Adams, U.S. Army Research and Technology Laboratories, Aviation Research and Development Command, presentation to NATO Symposium on Helicopter Icing, London, 6-7 November 1978 (UNCLASSIFIED).

B-4. *Atmospheric Conditions for Helicopter Icing Protection Design,* I.I. McNaughton, Royal Aircraft Establishment, Farnborough, U.K., presentation to NATO Symposium on Helicopter Icing, London, 6-7 November 1978 (UNCLASSIFIED).

B-5. *Icing Instrumentation,* J.D. Booker and G.F. Barlow, Royal Aircraft Establishment, Farnborough, U.K., presentation to NATO Symposium on Helicopter Icing, London, 6-7 November 1978 (UNCLASSIFIED).

B-6. Telephone conversation with Mr. Richard I. Adams, U.S. Army Research and Technology Laboratories, Aviation Research and Development Command, 12 March 1979.

B-7. Telephone conversation with Mr. John Maynard, U.S. Army Atmospheric Sciences Laboratory, 12 March 1979.

B-8. Telephone conversation with Mr. Arthur Hilsenrod, Federal Aviation Administration, Aviation Weather Branch, 13 March 1979.

B-9. Telephone conversation with Mr. Heinz Grote, National Oceanographic and Atmospheric Administration, 15 March 1979.

APPENDIX C

SMOKE EMPLOYMENT

SMOKE EMPLOYMENT

The unavailability of relevant Met information[a] makes estimates of the effectiveness of and the munition requirements for smoke very uncertain.[b] Thus the viability of smoke operations depends on Met information, viz., surface and near surface temperatures and winds, which is not provided to operational staff chemical officers.[c]

The amount of smoke munitions required for a level of effectiveness in an operation is very sensitive to temperature gradient, for which chemical officers need temperature data at a few heights up to 16 meters (say 0, 0.5, 4, and 16) above ground, and wind velocities, for which data are desired at 0, 4, and 16 meters above ground. Munition requirements can vary by factors of up to ten or more for the array of surface and near-surface temperatures and wind velocities reasonably expected to be encountered during a period of several days.

Uncertainty in munition requirements leads to worst-case planning. Faced with limited fire support systems (on the order of 1:3 U.S./USSR weapon balance) and a heavily burdened logistics system on the one hand, and unreliability of critical Met information and thus uncertain munition requirements on the other, it can be expected that high estimates for smoke munition

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[a] May be current measurements or forecasts of near future conditions.

[b] Assuming artillery projectiles are the cargo carriers for smoke munitions.

[c] Most of the discussion in this appendix comes from conversations (with chemical officers at the U.S. Army Ordnance and Chemical Center and School) which are summarized in Ref. C-1.

requirements would reinforce other factors that tend to reduce U.S. smoke employment in a NATO-Warsaw Pact war, viz., (1) obstructions to vision favor the attacker (who is likely to see little of a hidden or dug-in defender before whom the attacker is exposed in full view when vision is unobstructed), and (2) expected U.S. involvement primarily in defensive operations. However, smoke employment by a defensive force can be very important for covering force operations, especially those of armored cavalry regiments in the forward areas of the FRG (Ref. C-2).

In addition to the considerations just described, the fact that estimates of temperature gradient and wind velocity profiles are required (for smoke missions) in forward combat areas, which may in fact be held by the enemy, one can appreciate the practical difficulties to obtain Met information for smoke operations.

Since there appear to be no efforts to improve the Met information available for smoke employment, one must assume *de facto* acceptance by the Army that the value of the information is outweighed by the difficulties in obtaining it.

REFERENCES

C-1. U.S. Army Ordnance and Chemical Center and School letter ATSL-CLC-C of 23 September 1977 summarizing IDA-USOCCS discussions.

C-2. Discussions with personnel of U.S. Army HQ, Europe, Heidelberg, FRG, 12 February 1979.

APPENDIX D

CROSS-COUNTRY MOVEMENT

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CROSS-COUNTRY MOVEMENT

Heavy ground vehicles--especially tanks, armored personnel carriers (APC), and self-propelled (SP) artillery pieces--too often attempt movement over wet terrain which cannot support them and become unavailable while mired and require other vehicles for retrieval assistance. Tactical route selections for cross-country, or off-road, movement could be improved by a methodology that transforms physical and geometric characteristics of vehicles, terrain data, and current precipitation history into off-road mobility information.

Cross-country movement (CCM) methodology is presently being developed in the Army at the Waterways Experiment Station (WES) and the Engineer Topographic Laboratories (ETL). The efforts of the WES and ETL, which are both U.S. Army Engineer organizations, are described below. CCM modeling in the Federal Republic of Germany is briefly described in the last part of this appendix.

A. WATERWAYS EXPERIMENT STATION[a]

The WES methodology, which is now embodied in a second generation mobility model called the Army Mobility Model-75 (AMM-75), has been developed for three categories of potential users: vehicle developers, vehicle procurers, and vehicle owner-operators. AMM-75 includes a great amount of detail for the needs of design and development engineers who are interested in such engineering details as wheel geometry, spring rates, truck width, etc., and their interactions with soil strength, size and spacing of tree stems, slope, etc. WES has considered

[a]Description of WES cross-country movement modeling is excerpted and quoted from Refs. D-1 and D-2. WES CCM methodology modifications, if any, since 1975 are not reflected in this description.

the vehicle owner-operator to be represented by the strategic planner who does not need the level of detail required by the design and development engineers but rather an aggregated result, viz., average cross-country speed of a given vehicle through a specified region.

The heart of the model consists of three independent computational modules, each comprised of analytical relations derived from laboratory and field research, suitably coupled in the particular type of operation:

1. The areal patch module which computes the maximum feasible speed for a single vehicle in a single areal terrain patch or terrain unit.
2. The linear feature module which computes the minimum feasible time for a single vehicle, aided or unaided, to cross a uniform segment of a significant linear terrain feature such as a stream, ditch, or embankment.
3. The on-road module which computes the maximum feasible speed of a single vehicle traveling along a uniform segment of a road or trail.

All three modules draw from a common data base that describes quantitatively the terrain, vehicle, and driver to be examined in the simulation.

AMM-75 represents real terrain as a mosaic of terrain units within each of which the terrain is considered sufficiently uniform to permit use of a maximum straight-line speed of the vehicle as a description of its mobility within, along, or across a terrain unit (areal patch, road segment, or linear feature, respectively). By making predictions of vehicle speed for all terrain units within a geographic area, AMM-75 in effect checks vehicle performance throughout the area.

"To make the basic performance predictions, the submodels and algorithms used in AMM-75 require specification of 22 terrain

values for each single patch, 10 for each linear feature segment, and 9 for each road segment."

The kinds and degree of resolution of data required for terrain modeling are not found in conventional sources, especially for areas large enough for the conduct of meaningful mobility exercises. It is necessary to develop the required terrain data from a variety of source materials. The end product is in the form of appropriately coded maps of terrain factors. The terrain factor maps developed are considered to be "study maps," because supporting ground truth data are not such that it can be guaranteed that the specific set of factor values assigned to a given point on the map will in fact be found at that point on the ground. The maps are simply consistent with the available information. For example, if source data indicate a forest over some area, appropriate vegetation attributes will be included in the terrain unit descriptions which cover that area.

In the AMM-75 mosaic mapping concept, the expanse of any real terrain is represented by a mosaic of areal, linear, or road terrain units, within each of which values of the many factors required by AMM-75 are constant within stated tolerances.

1. Terrain Factors

"The terrain description system is based on the premise that all attributes of the terrain that are significant to a specific activity can be isolated and measured, and that every location can be described by an array of values that quantify each of the pertinent attributes. These attributes (e.g., slope, plant stem diameter, etc.), called terrain factors, are the basic building blocks of the system. Conceptually, a value (e.g., 5 percent slope) is assigned to each terrain factor for all points within a mapped area. Terrain factor values are grouped in classes (e.g., 5-10 percent slope) that represent a compromise between resolution and the practicalities of measurement and

mapping in the real world. For convenience, the numbers for each factor are arranged so that the lowest numbers have the least effect on mobility and the high numbers have the greatest effect."

"For convenient handling of mapped information, two or more terrain factors that are related in their characteristic effect on a given activity may be grouped together as a terrain factor family. Four factor families describe terrain for mobility purposes--surface composition, surface areal geometry, vegetation, and surface linear geometry. These terrain factor families and related terrain factors are discussed in the following paragraphs."

a. "Surface Composition. Surface composition terrain factors having the most significant effect on ground mobility are the (1) type of surface material and (2) strength of the surface layer to a depth that depends upon type of material, vehicle characteristics, and volume of traffic to be imposed. The type of surface material is established by using the Unified Soil Classification System (USCS) which, in turn, establishes the soil strength descriptor and soil depth to be used to relate soil strength to pertinent vehicle performance parameters.[a]"

"Strength of a soil depends on its moisture content. Accordingly, mobility performance predictions depend on seasonal soil wetness. The terrain data usually include soil strengths appropriate to several seasonal wetness conditions (selection of the appropriate value is made by the mode based on input specifications). To establish these for a given area, a typical day-by-day rainfall record which duplicates long-term rainfall statistics for the area is used in a soil moisture-strength prediction model.[b] This model relates gains or losses of soil

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[a]Soil strength measurements are in terms of cone index or rating cone index.

[b]Described in Ref. D-3.

moisture to soil type, season, rainfall, and drainage factor. These, in turn, are related to soil strength for those layers significant to mobility."

b. "Surface Areal Geometry. A uniform area from the viewpoint of surface areal geometry is one in which the characteristic slope, in percent, surface roughness, and the size, spacing, and continuity of a recurring characteristic mobility obstacle are constant. The characteristic obstacle, which might represent such features as logs, boulders, small ditches, or stumps, is described by its approach angle, vertical magnitude, length and width, representative spacing, and a statement concerning its continuity (linear or random). Surface roughness is described in terms of statistical parameters of the surface microprofile."

c. "Vegetation. Vegetation factors that have a significant effect on ground mobility are those that describe the vegetation structure and the screening characteristics of plants or plant assemblages. The physical attributes used to describe structure are stem size and stem spacing. Screening, or visibility, is the distance at which a vehicle operator can recognize an obstacle of potential mobility significance, measured along a selected line of sight. Seasonal variations in visibility may be included."

d. "Surface Linear Geometry. This factor family is designed to describe discrete, linear, convex features of the earth's surface, such as embankments, dikes, etc., and discrete concave features, such as streams, large ditches, road cuts, etc. Size and shape of linear features are characterized by a profile constructed at right angles to the terrain feature. Water depth and water velocity are time-dependent factors that are generally defined in terms of maximum, minimum, and mean values."

Appropriate groupings of terrain factors and factor families are combined to construct three types of terrain units: areal,

linear, and road. Surface composition, surface areal geometry, and vegetation factor families describe areal terrain units. They appear as discrete areas or "patches" on an areal terrain unit map. Surface composition and surface linear geometry are combined to describe linear terrain units, which appear as lines on a terrain unit map because of their characteristic length and relatively narrow width (i.e., streams, road embankments, etc.). Surface composition and a special surface geometry factor family are used to describe road units, which also appear as lines on a terrain map.

2. Terrain Maps

The submodels of AMM-75 utilize the ranges of values that describe the terrain factors which are pertinent to predicting vehicle mobility. The range of values for each terrain factor is subdivided into factor value classes. In establishing the number and ranges of class intervals, mapping problems are minimized by avoiding detail that is not significant to vehicle behavior. For example, slopes beyond 70 percent are essentially impassable to current vehicles, so that definition above this level serves no useful purpose. A listing of the terrain factors, their usual units, factor ranges, and the number of classes into which each factor is divided for the establishment of terrain unit boundaries is given in Table D-1.

The first terrain study maps for mobility evaluation purposes were prepared manually, in large part from air photos. The original process has been revised to use the computer extensively for development of the terrain unit maps through production of mobility maps. The concept of the computer-oriented procedure, which is essentially the same as the manual procedure, is described below.

a. Computer-Aided Technique. To construct reasonable mobility maps for large, new study areas on a timely basis,

TABLE D-1. SUMMARY OF TERRAIN DATA REQUIRED FOR ARMY MOBILITY MODEL

Source: Table 1 of Ref. D-2

Terrain or Road Factor	Range	No. of Factor Classes
Off Road (Areal)		
Surface material		
Type, USCS/Other	NA	5
Mass strength, CI or RCI	0->280	11
Slope, %	0->70	8
Obstacle		
Approach angle, deg	90-270	14
Vertical magnitude, cm	0->85	7
Length, m	0->150	7
Width, cm	0->1200	5
Spacing, m	0->60	8
Spacing, type	NA	2
Surface roughness, rms, cm	0-20	9
Stem diameter, cm (8 pairs)	0->25	8
Stem spacing, m (8 pairs)	0->100	8
Visibility, m	0->50	9
Off Road (Linear)		
Water depth,* m	0->5	6
Water velocity,* mps	0->3.5	6
Water width,* m	0->70	21
Top width, m	0->70	21
Left approach angle, deg	90-270	20
Right approach angle, deg	90-270	20
Differential bank height or differential vertical magnitude, m	0->4	9
Low bank height or least vertical magnitude, m	0->6	8
On Road		
Surface material		
Type, USCS/Other	NA	5
Surface strength		
Trails, CI or RCI	0->280	11
Other, traction coefficients	0.01->0.80	8
Slope, %	0->70	8
Elevation, m	0->3000	7
Surface roughness, rms, cm	0->8.1	9
Curvature, deg	0-90	10
Width, m	1->60	10
Superelevation, %	0->10	4

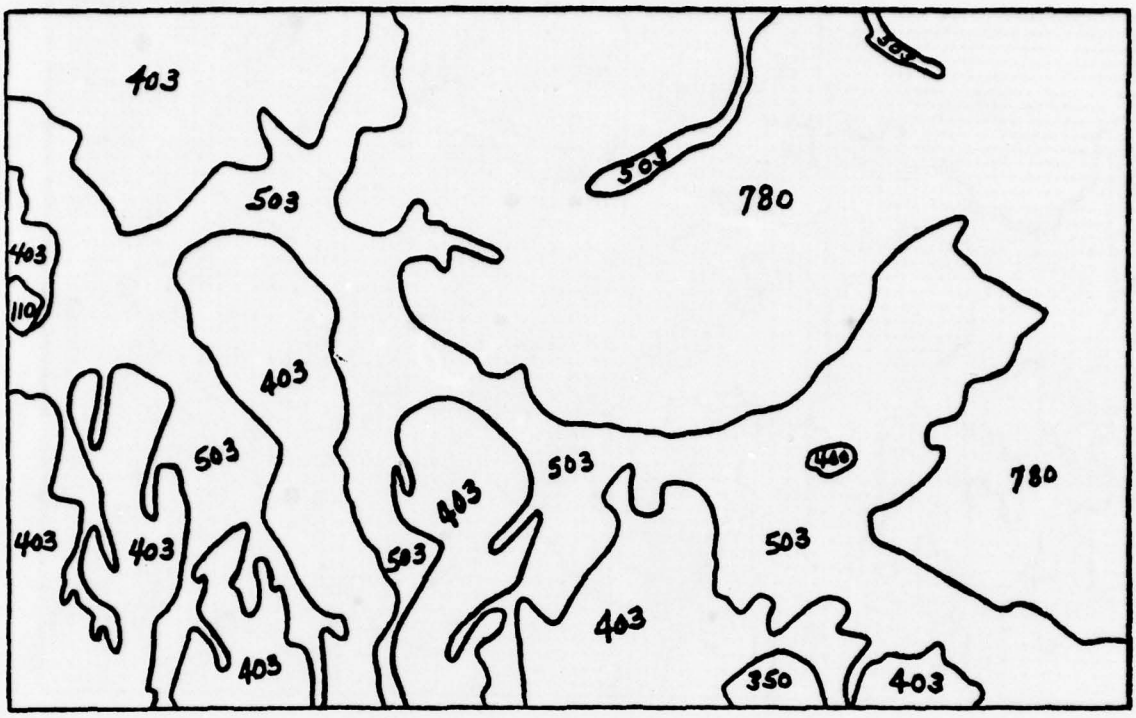
*Also used in areal terrain (when lakes or marshes) are encountered.

the first step is to assemble available information (in map form) on many physical aspects of the area, i.e., soils, geology, gross vegetation, etc., plus the best available topographic maps. Numeric codes are established for all information in the legend of each map.

By using a common scale, several overlayed maps are consolidated into a single map with appropriately expanded legend information. This step is currently implemented on the computer. To do this, discrete areas (or line segments) on each basic map are defined in a manually prepared overlay and by legend information in coded form. In the case of normal topographic maps, information density is so great that two overlays are made: one to extract basic slope data, and a second to extract all of the extensive land-use and other useful information which is overprinted on the contours. Figure D-1 illustrates a coded land-use map made by manually overlaying a topographic map. The coded legend picks up all information provided in the original map legend for each discrete area.

Boundaries between differently coded areas on the separate manual overlays are defined by a series of x-y coordinates automatically generated by a digital line-follower, and recorded, with the codes, on a magnetic tape. Computer routines convert these data to a new map, stored as a computer array, in which each discrete area is approximated by a large number of rectangular cells of predetermined size, and each cell is associated with the appropriate basic data in coded form. Figure D-2 shows the map in Figure D-1 as output by the computer using 106-m by 127-m cells. This cell size permits preparing maps at a scale of 1:25,000 by using a high-speed printer and two characters per cell.

"When the manual overlay data for all individual maps are in the computer, they are then overlaid (by various routines) to produce the final consolidated map and corresponding extended

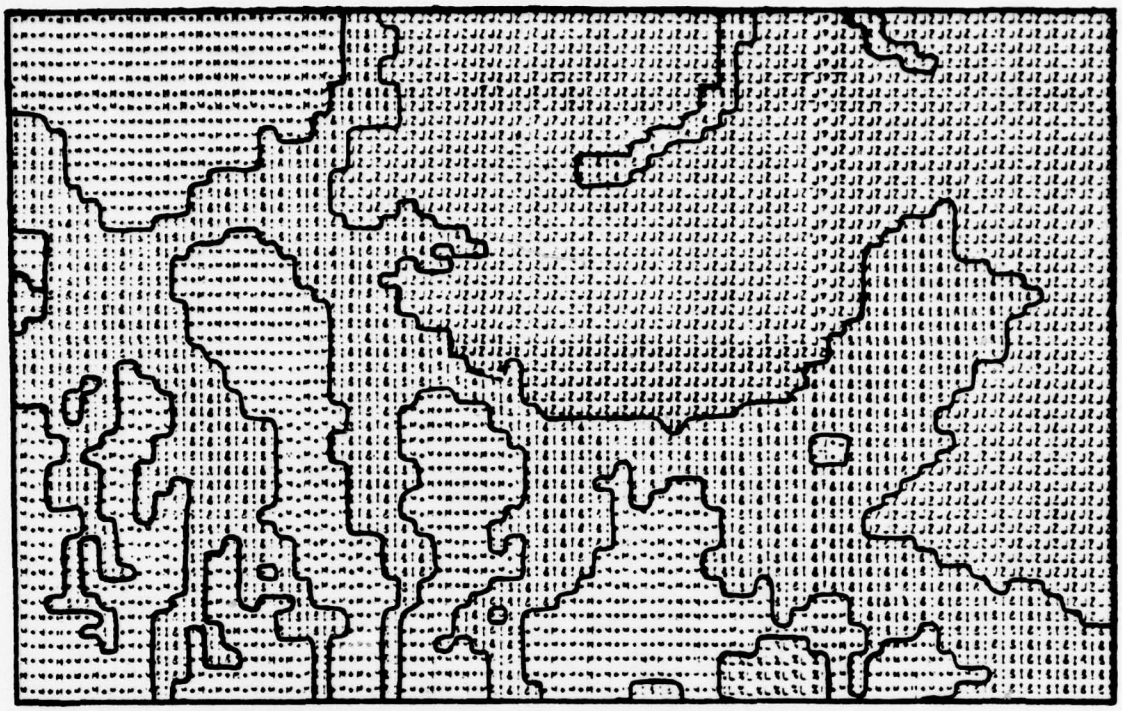


LEGEND

NUMERIC	DESCRIPTION
110	Village
350	Irregular surface
400	Idle land
403	Idle land with channels <50 meters in width
503	Cultivated land with channels <25 metres in width
780	Gravel or rocky surface with obstacles (lava field)

FIGURE D-1. MANUALLY PREPARED LAND USE MAP

Source: Fig. 6 of Ref. D-2



NOTE: Land use boundaries drawn manually.

LEGEND

ALPHANUMERIC	DESCRIPTION
4F	Village
%L	Irregular surface
+J	Idle land
+M	Idle land with channels <50 metres in width
&I	Cultivated land with channels <50 metres in width
JZ and GX	Other land use, gravel or rocky surface with obstacles (lava field)

FIGURE D-2. LAND-USE MAPS PREPARED BY COMPUTER PROGRAM

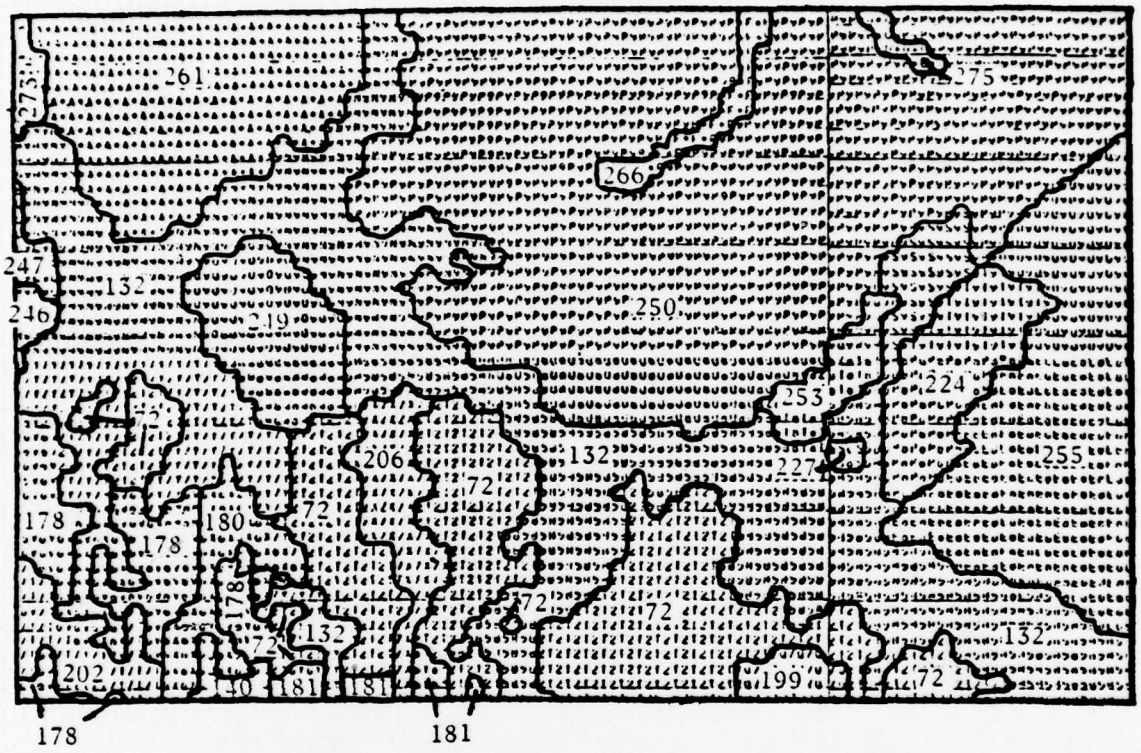
Source: Fig. 7 of Ref. D-2

legend, again stored in arrays" (Figure D-3). "At this point in the process the map consists of a mosaic of small areas, within each of which all descriptors from the available data are identical. These areas are logical areal terrain units or patches by basic definition, since there are no data upon which to assign anything other than a single set of mobility factor values throughout any one of them."

"In the final step, the composite qualitative legend information for each patch is interpreted to assign a reasonable, consistent set of quantitative terrain factor classes to the patch. This is done by examining appropriate subsets of the qualitative information and inferring from each, class values for specific single terrain factors or factor families. Because of the discrete values in the composite legend data, these interpretations can be coded as algorithms and formed into a computer routine for translating the coded qualitative legend directly into quantitative terrain factor classes. Design of the translation routine makes use of many additional data sources, including air photos of areas of special interest or complexity. Separate routines are used for different geographic areas to reflect appropriate climatic and cultural influences and kinds and quality of the available basic map data."

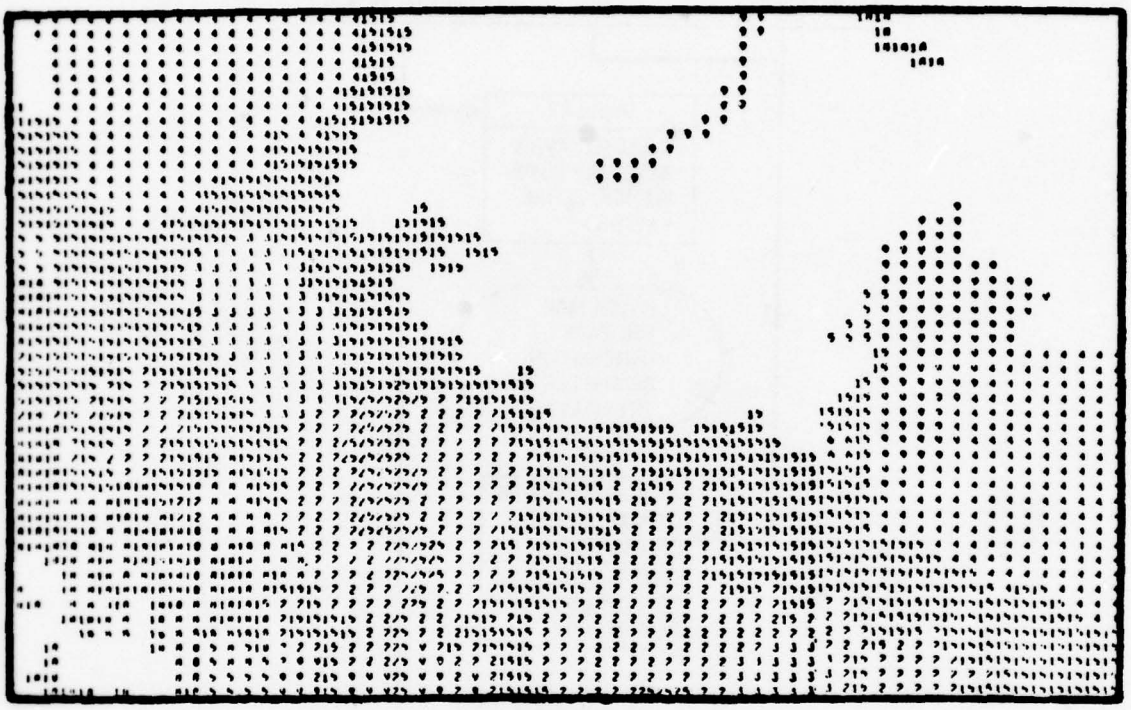
When the qualitative composite map legend data have been translated, as above, the result is a terrain factor complex, or patch, map containing all of the terrain data for the mapped area that are needed for AMM-75. Moreover, the map and all of the data are immediately available in the computer for making vehicle performance predictions, statistical aggregations of performance in the area, and performance maps such as shown in Fig. D-4.

Figure D-5 illustrates the general flow of information and processes in the computer-aided operation of AMM-75.



NOTE: Numbers indicate terrain unit numbers.
Terrain unit boundaries drawn manually.

FIGURE D-3. TERRAIN UNIT MAP PREPARED BY COMPUTER PROGRAM
SOURCE: Fig. 8 of Ref. D-2



NOTE: Clear areas are no go.
Numbers indicate speed in kilometres per hour.

FIGURE D-4. ILLUSTRATION OF MOBILITY MAP FOR A WHEELED VEHICLE PREPARED BY COMPUTER PROGRAM

Source: Fig. 9 of Ref. D-2

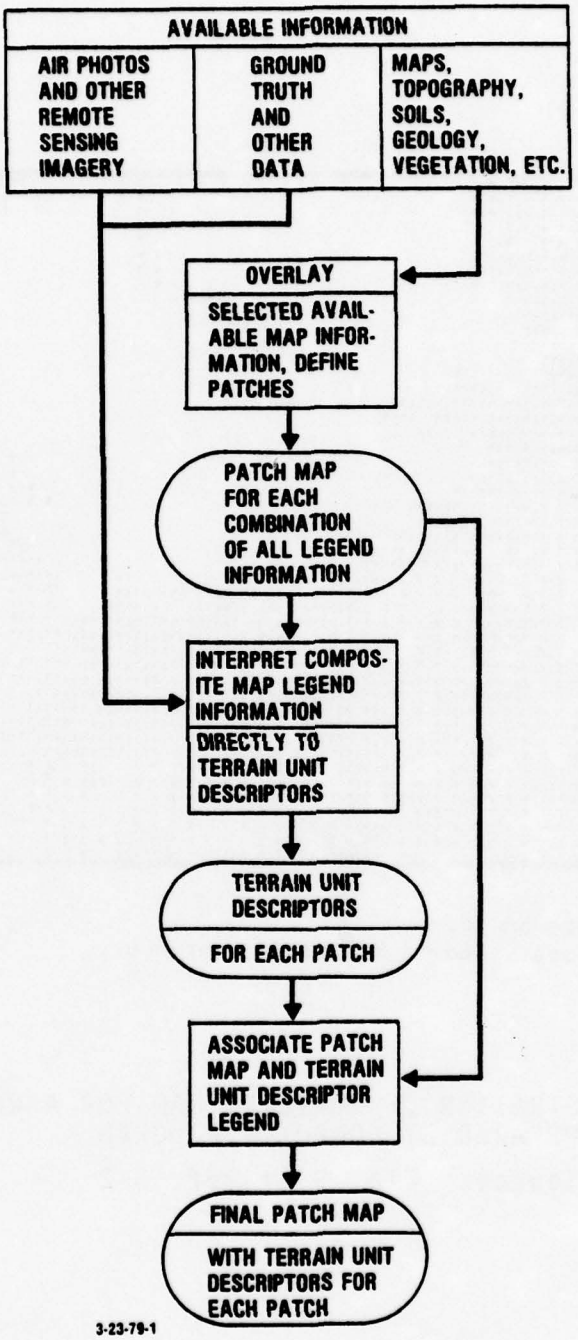


FIGURE D-5. COMPUTER-AIDED TERRAIN MAPPING PROCEDURE

Source: Fig. 10 of Ref. D-2

3. Assessment of AMM-75

The large number of classes into which the data continuum describing each terrain factor is divided means that AMM-75 can consider over 10^9 combinations[a] of classes. The WES objective of developing a cross-country mobility model for purposes of vehicle design (including evaluation of alternatives) and development (including testing) makes understandable the need for fine-grained data; that objective also makes understandable the limited data base currently available for use in AMM-75.

However, for tactical planning of routes for movement of tanks, APCs, and SP artillery, it would appear that all terrain in an area such as the FRG might be categorized into a much smaller number of classes, not for deriving maximum speed estimates as does AMM-75, but for making simple "yes-or-no" mobility assessments for all terrain patches in that area.

Even if all necessary terrain data of the FRG were available for AMM-75, the data base would not reflect variations in precipitation-induced soil moisture which is important in soil strength predictions and thus in estimating cross-country mobility. Soil strength data for AMM-75 are estimated from[a] soil-moisture-and-soil-strength model[b], which does not account for water (from precipation) absorbed by vegetation, water that runs off the surface, or water that drains to lower levels (below a depth of 30 cm[c]).

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[a] By multiplying successive numbers of factor classes under "Off-Road (Areal)" in Table D-1.

[b] See Ref. D-3.

[c] Soil strength predictions and thus cross-country movement estimates are based on properties of soil above a 30-cm depth.

B. ENGINEER TOPOGRAPHIC LABORATORIES[a]

The Terrain Analysis Center (TAC) of the USA Engineer Topographic Laboratories is a production organization tasked to prepare operational, departmental, and tactical-level terrain intelligence meeting user requirements validated by Headquarters, Department of the Army. The TAC approaches to and specifications for CCM products are dependent upon specific user requirements which vary considerably.

Current TAC production approaches and specifications range from that being used in ongoing Corps/Division 1:250,000 scale studies for the Forces Command (FORSCOM), to that being applied in a 1:50,000 scale V Corps Terrain Analysis for the Intelligence and Security Command (INSCOM) and, as slightly modified, in a German Area Terrain Analysis supporting the Army's Intelligence Preparation of the Battlefield (IPB) concept for the Training and Doctrine Command (TRADOC), to the completely different methodology being used in a CONUS installations terrain analysis program for FORSCOM and TRADOC. The resultant CCM products are meant to be useful to tactical-level commanders.

In addition to the above, TAC has produced, on a one-time basis, a 1:750,000 scale prototype CCM product covering West Germany and designed to meet the needs of departmental level staff planners. The methodology employed in this instance was similar to that being used in TAC's CONUS installation studies except that more emphasis was placed on seasonal conditions affecting movement.

The approach employed by TAC in its CCM production supporting the IPB concept is described by Ref. D-4. This reference contains directions and methodology for preparing map overlays conveying net speed derivations for dry and wet conditions in

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[a]Description of ETL cross-country movement study efforts and methodology is provided by several persons of the Terrain Analysis Center, ETL, in unpublished documents.

all subdivisions of the project area. To make those derivations, after calculating an initial slope speed, arithmetically derived inputs are successively considered representing the expected effects of vegetation, soil, and obstacle factors on that initial speed. Reference D-5 provides the algorithms for deriving net speed.

The number of terrain classes comprising the continuum of all values that describe the terrain factors are as follows:

Factor	Number of Classes
Slope	6
Vegetation	27
Soil	4/6 (dry/wet conditions)
Obstacle	2

Although there are 46 nominal classes for vegetation, 13 cause no off-road speed degradation and 8 make off-road passage impossible because of narrow spacing of thick-trunk trees that cannot be pushed over; thus there are effectively 26 Go classes plus a No-Go class to describe the effect of vegetation.

Similar net speeds may be derived from several different combinations of terrain factor values; for example, for the same vegetation and obstacle factors, a combination of shallow slope and sand soil could affect cross-country movement about the same as a combination of steeper slope and clayey soil. Net speed results are expressed as ranges of speeds in kilometers per hour, or equivalents.

Another TAC approach to addressing CCM is illustrated by the prototype 1:750,000 scale graphics covering the Federal Republic of Germany (FRG). This particular product consists of three graphics which provide ratings of movement in qualitative terms. Movement conditions are depicted in terms of Good, Fair, Poor, and Unsuited. The rating terms are briefly defined as follows:

Good - Conditions permit free movement at fairly high speeds.

Fair - Conditions moderately hinder progress or moderately restrict choices of direction for movement.

Poor - Conditions severely hinder progress or greatly restrict choice of movement routes.

Unsuited - Conditions generally preclude all but local movement.

In order to depict graphically the seasonal movement conditions that are estimated to prevail, the year is divided into three periods: (1) summer/autumn period, (2) winter period, and (3) spring period. The summer and autumn periods are combined, since in most years, movement conditions, especially soil conditions, are not greatly dissimilar between the two.

The following discussion of major terrain factors pertains to the FRG although the principles are universal.

1. Terrain Factors

The major terrain factors that determine the suitability of the terrain to support movement are slope, vegetation, soil (and snow), streams and other water bodies, and cultural features such as built-up areas (cities, etc.). Climate or weather affects all the above-mentioned factors but it exerts its significant effects indirectly. The day-to-day weather determines to a large extent the moisture content of soils that in turn affects their strength for trafficability purposes. The weather also influences the flow of streams thereby affecting their obstacle value.

Terrain factors and their single or combined effect relative to cross-country movement are difficult to assess since most often several factors are involved. In some places, one

obvious factor alone, such as closely spaced trees (vegetation), determines the ease (or difficulty) of movement. Much more often it is the complex interaction of two or more factors, each exerting varying influence from spot to spot, that determines the forward progress of the vehicle.

a. Slope. Assuming good traction on a firm smooth ground surface and no vegetation or surface obstacles, the tank can normally maneuver effectively on slopes with a maximum grade of about 45 percent. Performance on steeper slopes can be accomplished provided unusually good ground conditions exist. In nature, such ideal surface conditions are the exception rather than the rule. On most steep slopes, one can reasonably expect other limiting factors to combine with the slope--factors such as loose stone fragments, wooded vegetation, unevenness of the ground, etc. Short near-vertical slopes, such as those associated with drainage ditches, gullies, and rock ledges, may be deterrents or obstacles on terrain with a general slope much below 45 percent. Vertical heights above 0.75 to 1.2 m are generally considered to be the maximum for tanks to negotiate.

b. Vegetation. Vegetation not only includes the natural vegetation but also cultivated crops, tame pastures, vineyards, and orchards. Nearly all forest-type vegetation will at least have a severe slowing effect on cross-country movement. For the tank, trees with trunk diameters of less than about 8 cm are of slight hindrance, since they can usually be pushed over. The limiting trunk diameter for overturning a single tree is about 15 cm for deep-rooted trees like oak and beech and roughly 20 cm for shallow-rooted ones like pine and spruce. The critical average distance between trees in forests where trees are too big to be pushed over is somewhere between 4.5 and 6.0 m. Pushing over trees often results in trees not falling clear but being caught and interlocked in the branches of neighboring trees. Thus an effective barrier is formed.

In West Germany most large forest tracts contain an extensive network of roads and fire trails. These can often be used by military vehicles but this does not constitute true cross-country movement. As is true in most of Europe, large forests generally occur on land that is unsuited for cultivation.

Low-growing vegetation, say less than 1 m high, has little or no effect on movement except where it obscures obstacles such as stumps and boulders.

c. Soil. Soil is probably the most complex and difficult terrain factor to deal with in assessing cross-country movement conditions. This is so because soil trafficability is largely dependent upon the moisture content of the soil. The moisture content, of course, is dependent on the weather which is capricious and unpredictable except in a general or statistical way.

As a rule, all soils, except loose sands, are trafficable when they are dry. But as the moisture content increases, fine-grained soils such as the silts, loams, and clays become increasingly unstable and ultimately become soft and miry. On the other hand, increasing the moisture content of coarse-grained soils may often result in higher bearing strengths and better traction capacities.

The moisture content of a soil at any given time is the result of innumerable interactive factors. Soil moisture does not relate to precipitation amounts alone but also to the intensity of the precipitation, temperature, topographic position of the soil, internal drainage, vegetative cover, etc. As an example, a two-inch torrential rain on a hot summer day may not be nearly as effective in wetting the soil when compared to a half-inch drizzly rain occurring in winter. In West Germany, it is not unreasonable to expect a wet but well-drained, fine-grained soil to become dry and firm enough to support traffic in a matter of several hours to a day or two during the summer. In contrast, the same soil in winter and early spring may require several days of drying weather to become firm.

Soil stickiness and slippage is seldom a sole cause for tank immobilization. But near the limits of vehicle power, where movement is marginal, the introduction of the stickiness or slippage factor may well cause immobilization. In winter, slippage is often caused by snow or ice. In most places where movement is feasible at other times of the year, snow as a single cause of immobilization seldom occurs. But similar to slippery soils, it is a contributing factor. Snow deep enough to impair tank movement may occur at the higher elevations and particularly in the southern portions of West Germany. However, these areas generally are unsuited anyway because of factors such as forests and steep rugged terrain.

Only at the highest elevations of West Germany is the ground frozen during the entire winter season. At medium and low levels, including most valleys, frozen ground is an intermittent occurrence. Obviously, a snow cover affects the depth of frost penetration in the ground during a cold spell. If snow precedes a severe cold period, the snow cover will act as a "thermal blanket" and frost penetration will not be deep. Conversely, if the ground is bare, frost penetration will be deep.

To support the tank, ground that is otherwise of low strength must be deeply frozen--at least 15 cm or more, depending on soil type. The bogs and other poorly drained soils in northern Germany are seldom frozen to this depth for long periods of time.

d. Obstacles. Streams, ditches, and canals are linear features that often constitute obstacles to movement, depending on the direction of movement. On the North German plains, particularly on the coastal lowlands, drainage ditches and canals are very numerous and densely spaced. Most of the ditches will

slow but not stop a tank unless the soils are of low strength. In other parts of Germany, stretches of many streams have been straightened to produce better runoff and reduce flooding. Only the minor streams can be forced at low water. Large streams and canals require bridging.

2. Climate (Weather)

West Germany's weather is basically maritime in nature but at times is modified by drier continental influences. Winter weather is typically damp and cloudy, but considering the northerly latitude, temperatures are fairly moderate. Summers are seldom hot and much less cloudy than in winter or spring. Rainfall is heaviest in summer and serious drought is rare. Spring is a season of extensive rain showers over the entire country. Autumn weather, especially the first half of the season, is often similar to summer weather.

Temperatures in West Germany are seldom extreme. This is particularly true on the North German plains. The seasonal variation is greatest over southern Germany where the modifying influences of large water bodies to the north are less strongly felt. In hilly and mountainous regions, exposure and elevation account for much of the variations.

Most of West Germany receives an annual precipitation of 20 to 35 inches. Some mountainous regions in central Germany receive as much as 60 inches and a few of the higher peaks in the Alps may receive over 80 inches. In winter much of the precipitation falls as snow. This is especially true in the east and south and in the higher elevations of central Germany. Thaws between winter snows commonly eliminate or substantially reduce the snow cover at the lower elevations. Showers, often falling in afternoon thunderstorms, account for the greater amount of precipitation during the summer season.

3. Assessment of ETL CCM Methodology

The combinatorial number (over 1800) of classes into which slope, vegetation, soil, and obstacle factors are categorized in the ETL CCM methodology is significantly less than in AMM-75. However, only two soil-moisture conditions, based on area climatic averages for dry and wet seasons, are used. Although the CCM products should be very useful for seasonal average cross-country movement, it appears that soil-moisture variations (induced by precipitation) need to be considered so that consequent soil strength effects can be estimated if the CCM methodology is to be useful for tactical descisions on short-term route selection.

C. FEDERAL REPUBLIC OF GERMANY CROSS-COUNTRY MOVEMENT MODELING[a]

The FRG Military Geographical Service is sponsoring CCM model development by the German Military Geophysical Office (GMGO). The GMGO CCM modeling concept, while several years away from operational use because of the need for extensive testing to accumulate empirical soil-moisture-trafficability data, is similar to the CCM methodology of ETL. However, the GMGO CCM model products are to be useful for tactical off-road route selection whereas present ETL CCM methodology provides trafficability information for the strategic planner; the difference lies in the FRG use of current updated soil moisture balance whereas the ETL methodology uses climatic soil moisture averages for dry and wet seasons.

The GMGO model concept includes the use of 1:500,000 maps which portray the following terrain information: slope, vegetation, obstacles, and soil (all German soil is categorized into six classes). Isomoisture overlays are prepared by the

[a]Description of FRG CCM modeling is derived from discussions with personnel of the German Military Geophysical Office (GMGO) at Traben-Trarbach, FRG (Ref. D-6).

meteorological forecaster who predicts soil-moisture balance by accounting for moisture additions (through precipitation) and moisture reductions (through runoff and evaporation). Reference to a map legend containing trafficability estimates (derived from vehicular testing) permits tactical planners to consider a matrix of soil-moisture classes (as well as other terrain factors) in making tactical route selections as shown in Fig. D-6. The combinatorial number of classes of terrain factors is more than an order of magnitude lower than in the ETL CCM methodology.

The GMGO CCM model development has been and is now an iterative process in which the division of soil-moisture classes and the vehicular trafficability of each class may change as additional test data are acquired. The program to acquire those data involves single-pass and multipass movements over 300 m x 200 m ground patches; the movements include straight-through runs and runs which include 90°, 180°, and 360° turns as surrogates for expected battlefield maneuvers.

Such testing is destructive of soil structure so that a ground patch can be expected to be useful for only a single soil-moisture class; even with post-test tilling, rolling, and rest hardening[a], a ground patch may require about three years[b] to regain its pre-test structure and strength. A principal problem in acquiring an empirical soil-moisture-trafficability data base is the limited ground available for testing. German military bases and test ranges may not be able to provide the necessary ground, and German civilian land is very expensive to purchase or lease.

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[a]Rest hardening is a process in which changes in soil particle arrangement and in interparticle forces or changes in adsorbed water act over time to restore remolded soil to nearly its undisturbed strength (Ref. D-7).

[b]Preliminary estimate by Mr. Dieter Kubald of the GMGO.

Evaluation Key

Movement and manoeuvring	1 30°-turn (round the vertical axis) Ⓑ •	2 Start straight forward in first gear after a 2 minutes halt	3 Curved run first gear (4–15 km/h) •	4 Straight forward run first gear (4–15 km/h)	5 Straight forward run second gear (6–25 km/h) •	Trafficability of soils / Feasibility of movement: Rating	Symbol	Movement limits
Number of passes in trace and manoeuvres at the same spot	> 10	> 30	> 40	> 50	> 60 –	trafficable/ feasible	+ +	in trace (up to 40)
	1–10	11–30	16–40	21–50	26–60	still trafficable/ feasible	+	in trace (up to 15)
	0	1–10	2–15	3–20	4–25	trafficable/feasible with difficulty	–	staggered
	0	0	0– 1	0– 2	0– 3	untrafficable/ unfeasible	– –	

Note The figure representing the **significant** number of passes manoeuvres is **emphasized by boldface**

very rooty soil (turf) improves / newly ploughed soil deteriorates | trafficability

Ⓑ Corresponds to the recovery of a tank of the same weight towed to the recovering tank

• Does not apply to movement on slopes with gradients > 25 %

Trafficability of Soils in Relation to Ground Types and Soil Moisture Conditions

Ground types: Map unit	Main types	Evaluation of soils according to moisture content: WT2 extremely dry	WT1 dry	WF moist	WN1 wet	WN2 extremely wet (saturated)	WB1 frozen to a depth of 5–20 cm	WB2 frozen to a depth of > 20 cm
①	Sand, gravel, rock in addition roads (> 7 m in width)	+ +	+ +	+ +	+ +	+	+ +	+ +
②	Peat 20–45 cm thick overlying sand, gravel rock	+ +	+ +	+	+	–	+	+
③	Loamy sand, loam, clay (cohesive soils)	+ +	+ +	+	–	– –	+	+
④	Cohesive wet soils, Peat 20–45 cm thick overlying cohesive soils	+	+	–	– –	– –	–	+
⑤	Peat 45–100 cm deep	+	–	– –	– –	– –	– –	–
⑥	Peat > 100 cm deep	–	– –	– –	– –	– –	– –	–

* Cautious driving is necessary on improved cart tracks in peat bogs

Offshore area up to the 6-m-depth line (below chart datum)

Snow cover				
WS1	New snow (wet)	30–50 cm	–	– – (if soil covered by snow is classified – / – –)
WS2	New snow (wet)	> 50 cm	– –	
WA	Old snow	20–40 cm	–	

Cross-Country Movement in Relation to Slope and Ground Surface Conditions as well as to Ground Types and Soil Moisture Conditions

Slopes (1) and Embankments / Escarpments (2): Map symbol 1	Map symbol 2	Gradient %	Height m	Feasibility of movement in relation to ground surface and/or soil moisture conditions: Hard surface (e.g. concrete, asphalt)	WT2, WT1, WF, WN1, WN2, WB1, WB2 (see Table 4)	WNg Slipperiness caused by wetness	WSg Slipperiness caused by snow	WEg Slipperiness caused by ice
					Trafficability of soils as shown in Table 4 reduced by ... rating(s)			
		0– 10	-	+ +	0	0	0	–
		10– 25	-	+ +	0	1	–	– –
		25– 50	> 25	+	1	2	– –	– –
		50– 90	1,5– 3					
		50– 85	3–50	–	2	– –	– –	– –
		90–100	0,9– 3					
		100–∞	0,9–1,5					
		50– 85	> 50					
		85–100	3–85	– –	– –	– –	– –	– –
		100–∞	1,5–85					
		85–∞	> 85					
		Quarries, gravel pits, peat cuttings, etc.		– –				
		Cuts, bottom width > 5 m		No reduction in rating				
		Cuts, bottom width < 5 m		Reduction in rating				

FIGURE D-6. TRAFFICABILITY IN RELATION TO SOILS AND TO SOIL MOISTURE

Source: Reference D-8

Participation in further development of the GMGO CCM model by the U.S. Army could mean ground patches at U.S. bases and test ranges (viz., Grafenwöhr and Hohenfels) in the FRG might be available for testing which should be of major concern to both the U.S. and West German armies.[a]

[a]An indicator of the importance of CCM to the West German Army is the GMGO plan to provide geology training for all military meteorologists, who are to become familar with the combined effects of soil and precipitation on ground trafficability.

REFERENCES

D-1. *The U.S. Army Mobility Model (AMM-75)*, a paper by M.P. Jurkat, C.J. Nuttall, and P.W. Haley at the Fifth International Conference, International Society for Terrain-Vehicle Systems, 2-6 June 1975, printed in Miscellaneous Paper M-75-7 of the U.S. Army Engineer Waterways Experiment Station, Mobility and Environmental System Laboratory, Vicksburg, Mississippi, June 1975 (UNCLASSIFIED).

D-2. *Terrain Modeling to Support Mobility Evaluations*, A.A. Rula and C.J. Nuttall at the Fifth International Conference, International Society for Terrain-Vehicle System, 2-6 June 1975 (UNCLASSIFIED).

D-3. *Automation of a Model for Predicting Soil Moisture and Soil Strength (SMSP MODEL)*, Miscellaneous Paper M-73-1, M.H. Smith and M.P. Meyer, U.S. Army Engineer Waterways Experiment Station, Mobility and Environmental Systems Laboratory, Vicksburg, Mississippi, January 1973 (UNCLASSIFIED).

D-4. *Cross-Country Movement (CCM)*, Terrain Analysis Center notes on step-by-step preparation of CCM graphic products, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, undated (UNCLASSIFIED).

D-5. *CCM Calculations*, Terrain Analysis Center notes on algorithms for calculating CCM, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, undated (UNCLASSIFIED).

D-6. Discussions with Messrs. Welfhart aufm Kampe, Dieter Kubald, and Günter Lütkebohmert at the Amt für Wehrgeophysik (German Military Geophysical Office), Traben-Trarbach, FRG, 7-8 February 1979.

D-7. R.N. Yong and B.P. Warkentin, *Introduction to Soil Behavior*, The MacMillan Company, New York, 1966.

D-8. Explanatory Note and Legend to Series M745-CCM Series Maps, German Military Geographic Office (information is current as of 31 March 1977 but subject to field tests).

APPENDIX E

WEATHER-INFORMATION-SENSITIVE PLANNING--COMMUNICATIONS

CONTENTS

A.	High-Frequency Radio Teletype	E-4
B.	Army Command and Area Communications System	E-7
C.	Forward Area Tactical Teletypewriter (FATT)	E-8
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WEATHER-INFORMATION-SENSITIVE PLANNING--COMMUNICATIONS

Planning for all tactical activities is often based on stale or incomplete weather information because of poor communications. Planning for helicopter operations, in particular, is frequently hindered by the nonavailability or delay of weather information transmitted over the Army communications sytem. The communications problems have two aspects: (1) surface and upper air observational inputs are limited or not available to meteorologists at all echelons in formulating their forecasts and (2) current forecasts cannot be transmitted to lower command echelons upon formulation.

Observations in the field during the Reforger '79 winter maneuvers in the U.S. Seventh Army area of responsibility in the FRG indicate that meteorological units at corps, division, and brigade levels of command had usable communications on the order of 50 percent of the time (Ref. E-1). The communication difficulties are consistent with past experiences in field exercises as far back as anyone can remember. An additional note of pessimism: such communications system performance is achieved without "enemy" efforts to disrupt communications.

While individual cases can be identified to illustrate the benefit to tactical planners of timely accurate weather forecasts, establishing a general relationship between the quality of (1) tactical planning and (2) timeliness and reliability of weather predictions appears insuperably difficult. That the difficulty in measuring the value of weather information to USAREUR for tactical planning is not a critical issue can probably be attributed to the relatively low cost of that information: assuming support expenditures are proportional to

personnel strengths, annual costs of its weather information system are less than one-tenth of one percent of USAREUR's support costs.[a]

The weather information support function in the USAREUR Command is served by two hardware systems: (1) high-frequency radio teletype (HFRATT) and (2) UHF line-of-sight carrier system called Army Command and Area Communications System (ACACS) (Ref. E-2). Figures E-1 and E-2 are diagrams of the field communications network which supports USAREUR's tactical command from the viewpoint of one especially interested in weather information.

A. HIGH-FREQUENCY RADIO TELETYPE[b]

The HFRATT System is designed for use by highly mobile units; it is also the sole communications system whenever the ACACS is inoperative, which may be quite often due to realignment (of microwave transmitters and receivers) and maintenance requirements for the ACACS. HFRATT equipment is mounted on vehicles; transmitters and receivers can be set up in a few minutes. The HFRATT is used to transmit data requirements to staff weather officers supporting various echelons of the USAREUR Command.

The HFRATT System utilizes AN/GRC-122 (full duplex) or AN/GRC-142 (half duplex) radio teletypewriter sets, whose principal equipment components are: radio receiver-transmitter, radio frequency amplifier, radio teletypewriter modem, page printer teletypewriter, teletype reperforator-transmitter, and control group.

Aside from the vagaries of HF communications, particularly in cases in which distances between transmitter and receiver

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[a]Based on 180, out of approximately 210,000 personnel, involved in providing weather information.

[b]Discussion based on Refs. E-1 through E-6.

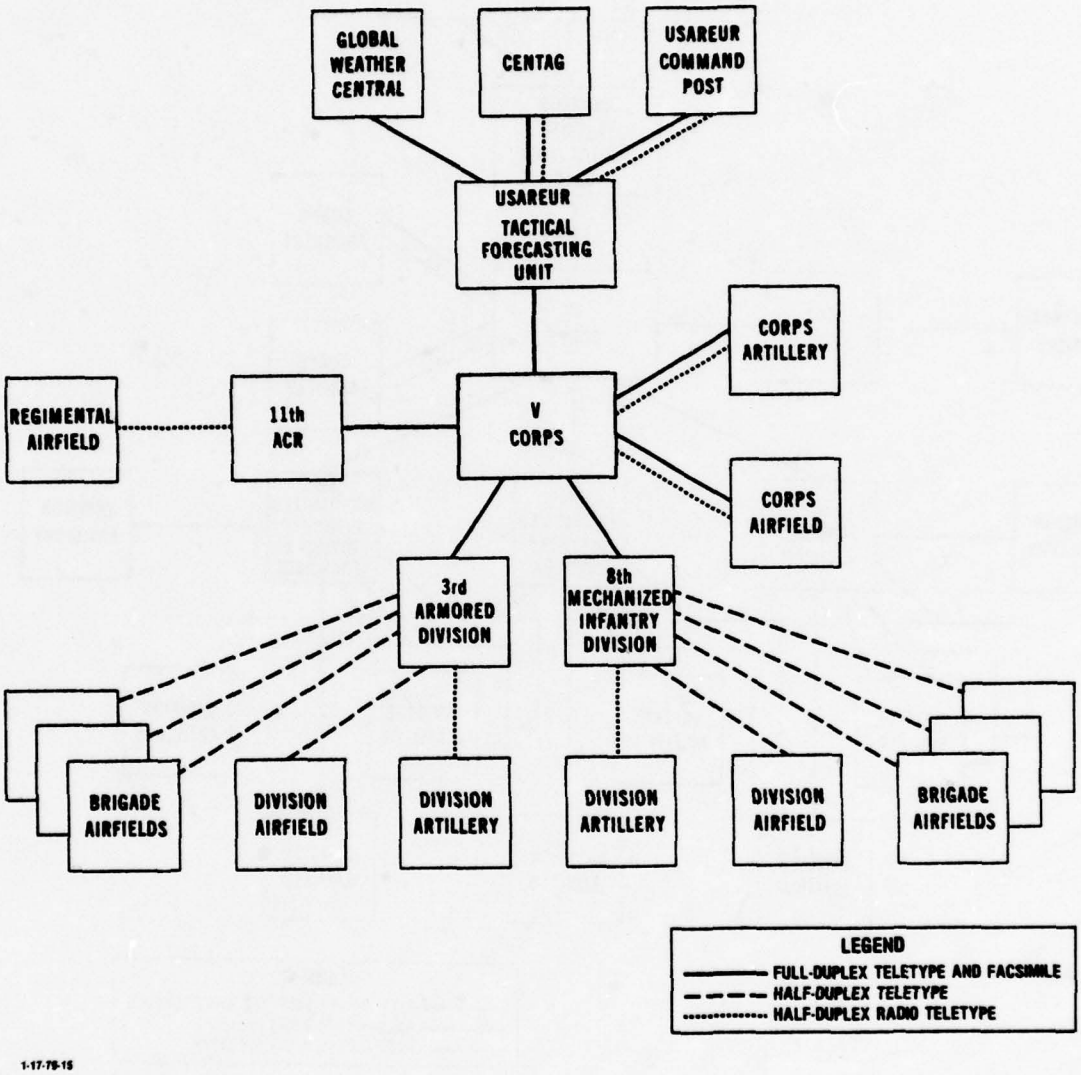


FIGURE E-1. V CORPS FIELD COMMUNICATIONS NETWORK

Source: Fig. 9-1 of Ref. E-2

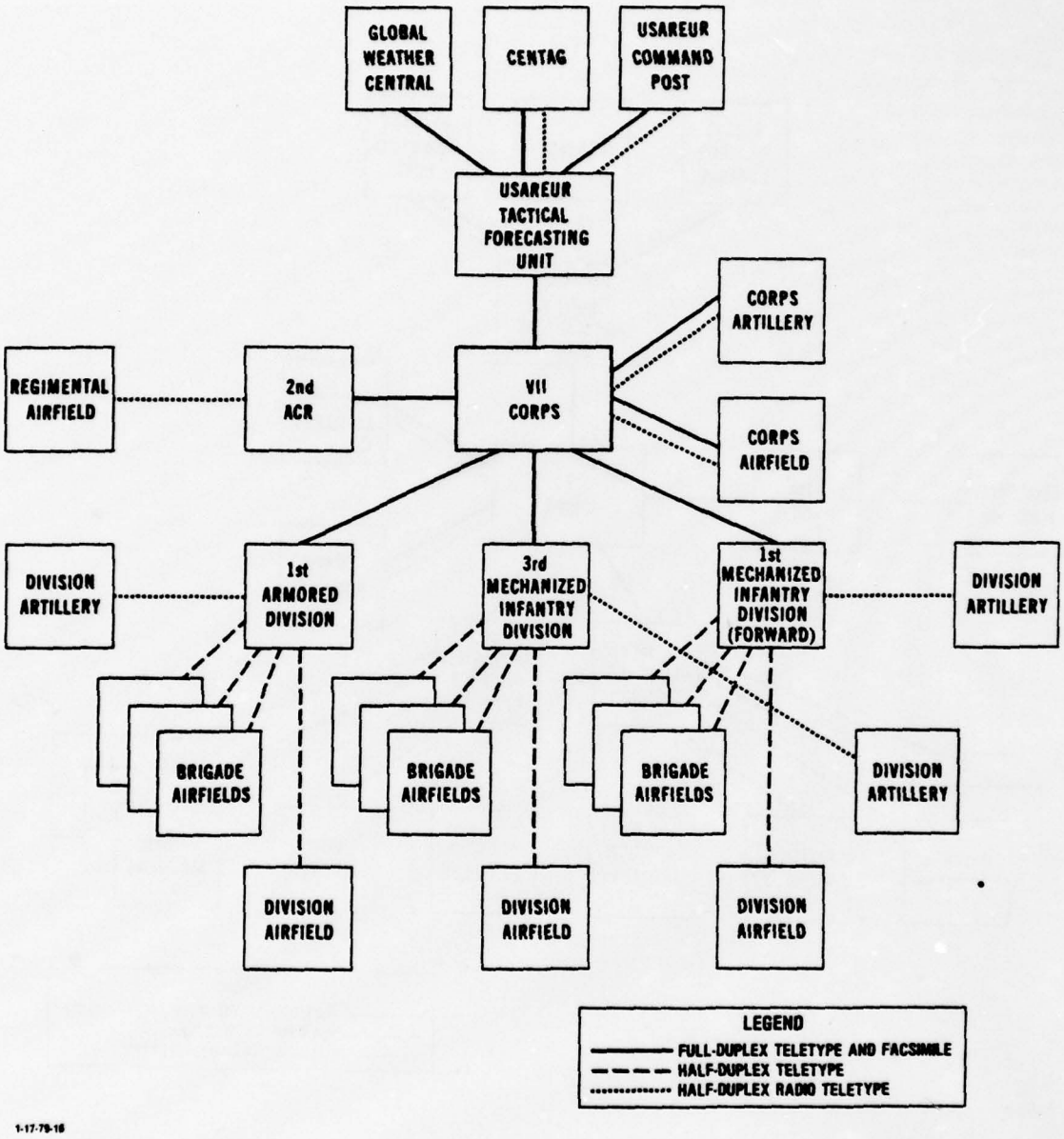


FIGURE E-2. VII CORPS FIELD COMMUNICATIONS NETWORK

Source: Fig. 9-1 of Ref. E-2

require dependence on skywave propagation, major HFRATT problems from a meteorological-information-support point of view are (1) old, worn equipment subject to frequent breakdowns and (2) low priority among users of limited number of HF frequencies. Unreliable equipment and low user priority for available frequencies often combine to limit the time available for communicating meteorological information on the Army Weather Net and (2) normally heavy data transmission requirements often cause weather support units to adjust their normally 60 words per minute teletype equipment up to 100 words per minute, thus inducing additional breakdowns of teletypewriters--which are mechanical printers adopted nearly 30 years ago. The net result of HFRATT problems and Army Weather Net requirements is that weather information frequently is not transmitted or is delayed too long to be useful.

B. ARMY COMMAND AND AREA COMMUNICATIONS SYSTEM[a]

The ACACS, which is utilized primarily between fixed locations, provides means to disseminate forecasts, mission control information, weather warnings, and climatological data. Two types of user nets are included: (1) facsimile and (2) teletype, with voice capability, from the USAREUR Tactical Forecast Unit to the Corps Staff Weather Offices (SWOs). ACACS then provides a means for weather information to be relayed from Corps SWOs to Division SWOs and thence to bridgades and division airfields.

Principal equipment components of the ACACS are: telegraph-telephone terminal, tactical switchboard, weather facsimile receiver-transmitter, and teletypewriter with tape reperforator.

Besides the realignment-of-microwave-terminals problem previously identified with the ACACS, other problems are similar to those of the HFRATT: old, worn equipment; low user priority

[a] Discussion based on Refs. E-1 through E-4.

and communication channel limits; and slow, mechanical teletypewriter. However, the relative immobility of ACACS due to realignment requirements may itself be the major factor limiting ACACS usefulness in a fluid tactical warfare environment. Time required to realign transmitters and receivers whenever system users change their locations has often caused ACACS to be unavailable for use by weather support units in Europe for periods of 24 or more hours.

C. FORWARD AREA TACTICAL TELETYPEWRITER (FATT) PROGRAM[b]

The only near-term communications improvement appears to be a new electro-mechanical teletypewriter, the AN/UGC-74(v)3 (or UGC-74, an abbreviated designation), which will replace the present mechanical units of both HFRATT and ACACS. The UGC-74 is a printed paper (as opposed to punch paper tape) typewriter, which could be utilized with a tape reperforator if a paper tape capability is also desired. The major advantages of the UGC-74 over present teletypewriters are (1) higher reliability and (2) increased data rate; whereas present teletype equipment operates at 60 words per minute, the UGC-74 has a maximum print speed of 600 words per minute.

The UGC-74, whose development was begun 15 years ago, is scheduled for development tests (DT) and operational tests (OT) during the summer of 1979, and is scheduled to be operationally deployed in 1980 to USAREUR initially. If DT and OT are successful, deployment of the UGC-74 will significantly improve AWS support for Army forces in Europe; but the UGC-74 will operate, at least initially, without encryption equipment that can handle data speeds above 100 words per minute. And other old, worn parts of both HFRATT and ACACS will continue to be sources of communication unreliability.

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[b]Discussion based on Refs. E-3, E-4, and E-5.

Because of its design configuration, it appears that a relatively minor teletypewriter modification or system interface adjustment will be required to make the UGC-74 compatible with the AWS concept of operational support of USAREUR units. The UGC-74 lacks sufficient memory to allow an operator to edit incoming data and then to transmit the edited data by another UGC-74 to other receivers without first entering all the edited data on the keyboard of the second UGC-74. The edit capability without manual reentry of data is especially important for the USAREUR Tactical Forecast Unit which receives voluminous observations and forecast information from the USAF Global Weather Central (GWC) for preparation of a general, large area forecast; the Tactical Forecast Unit then passes on to Staff Weather Offices supporting V Corps and VII Corps pertinent portions of the GWC data plus Tactical Forecast Unit additions that enable those Offices to make more refined forecasts for their respective areas of interest. Similar editing processes occur at the Corps SWOs, which pass on Tactical Forecast Unit data to Division SWOs, and add Corps information so that even more refined forecasts can be made for the Division areas. (The foregoing discussion is equally applicable to AWS support of Army operations in other theaters as well as Europe.)

Preliminary options presently being considered by the AWS and the Army to utilize the UGC-74 include: (1) incorporating a detachable memory in the UGC-74 so that stored data can be edited and automatically read into another UGC-74 for transmission to lower echelon commands while the original data is still being received on the first UGC-74; and (2) punching on a TT-76 Teletypewriter Reperforator-Transmitter a tape record of the data recorded by the first UGC-74 and reading that data into a second TT-76 which feeds the data to a second UGC-74, on which an operator can edit and transmit to lower echelon commands an edited product even while the first UGC-74 is receiving original data (Refs. E-4 and E-5).

REFERENCES

E-1. Discussions with staff weather officers, meteorological personnel, and various Army officers during visits to VII Corps and V Corps units in the field during Reforger '79 maneuvers in the FRG, 29 January-2 February 1979.

E-2. "Communications," Chapter 9 of *7th Weather Squadron Regulation 55-2*, 7th Weather Squadron, APO 09403, 14 June 1977 (UNCLASSIFIED).

E-3. Discussion with 5th Weather Wing officers, Langley Air Force Base, 6 November 1978 (UNCLASSIFIED).

E-4. Discussion with Master Sergeant Ronald Adsit, Air Weather Service HQ, Scott AFB, 12 June 1979 (UNCLASSIFIED).

E-5 Discussion with Captain Christopher Burger, Communications Test and Evaluation, U.S. Army Signal Center, Fort Gordon, Ga., 19 June 1979 (UNCLASSIFIED).

E-6. Field Manuel 24-24, Radio and Radar Reference Data, Department of the Army HQ, Washington, D.C., 20 May 1977 (UNCLASSIFIED).

E-7. "The Army Tactical Communications System (ATACS)," Department of the Army, Office of the Project Manager, ATACS, Fort Monmouth, N.J., January 1974 (UNCLASSIFIED).

APPENDIX F

WEATHER-INFORMATION-SENSITIVE PLANNING--OBSERVATIONS

WEATHER-INFORMATION-SENSITIVE PLANNING--OBSERVATIONS

Even if synoptic forecasts or macroscale and coarse-mesh mesoscale numerical weather predictions are current, a large number of weather observations are needed throughout an area in order to transform large-scale weather predictions into fine-mesh mesoscale forecasts.[a]

Meteorologists at Army, Corps, Division, and Brigade levels in the USAREUR Command have long been concerned with a need for additional weather observations not only for local area forecasting but for predicting weather farther east over Warsaw Pact controlled territory. As a consequence the Forward Area Limited Observation Program (FALOP) has been initiated by the USAREUR headquarters to supplement Air Weather Service weather observations in the eastern part of the FRG. The FALOP involves providing minimally trained personnel with belt weather kits containing equipment to measure basic surface weather parameters.[b]

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[a]From Ref. F-1, the meteorological scales are defined as follows:

Type Scale	Spatial Scale, km	Temporal Scale, hr
Macroscale	>2000	>24
Mesoscale (coarse mesh)	200-2000	24
Mesoscale (fine mesh)	1-200	<24
Microscale	<1	1

[b]Individual components, packaged in a belt carrying case, can measure dry bulb temperature, wet bulb temperature, wind speed, wind direction, barometric pressure, precipitation; a conversion slide rule permits computation of relative humidity using dry and wet bulb temperatures (Ref. F-2).

Selected Intelligence (S-2) personnel in battalions and brigades of infantry and armored divisions and in armored cavalry regiments are briefly trained to take limited weather observations when deployed on a noninterference-with-normal duties basis (Ref. F-3).

FALOP is being currently tested in Europe; while it is too early to predict the success of that program, there are two other USAREUR groups which, given belt weather kits, appear to be potential sources of forward area weather observations: forward air controllers (FACs) and field artillery meteorology section (Artillery Met).[a]

FACs. Each Army maneuver battalion has an assigned Air Force FAC who is by way of aviation training very conscious of weather and weather effects. Furthermore, his flying experience and frequent communication exchanges with aircraft also make the FAC a good source for information on visibility and ceiling, parameters not measured with equipment in the belt weather kit.

Artillery Met. The eight Artillery Met sections within the USAREUR Command might also be utilized to make limited surface weather observations, which together with upper wind data (collected for artillery use), would be valuable inputs for weather forecasting. However during Reforger '79, there appeared to be only a single instance of an artillery meteorological section providing upper wind data to a VII Corps Staff Weather Office during five days of operation.

While the lack of weather data flow from the field artillery meteorology system to the weather forecasters may be due in part to an inadequate communications system, the problem may also involve motivation of lower command echelon leaders to assist a support system (weather forecasting) which offers no direct or obvious benefit to the data providers.

[a]In Ref. F-4 several of the USAREUR personnel considered these to be logical and feasible sources for weather data.

REFERENCES

F-1. *Assessment of the Operational Utility of Mesoscale Weather Forecasting Improvements for Army Forces,* Part 1 of *Weather Information and Tactical Army Activities,* IDA Paper P-1297, June 1979 (UNCLASSIFIED).

F-2. *Operating and Maintaining the Belt Weather Kit,* 1st Weather Wing Pamphlet 50-4, 25 July 1977 (UNCLASSIFIED).

F-3. Headquarters, U.S. Army, Europe, and Seventh Army Regulation No. 381-2, 8 April 1977 (UNCLASSIFIED).

F-4. Discussions with staff weather officers, meteorological personnel, and various Army officers during visits to VII Corps and V Corps units in the field during Reforger '79 maneuvers in the FRG, 29 January-2 February 1979 (UNCLASSIFIED).

APPENDIX G

UTILITY OF MESOSCALE WEATHER FORECASTING IMPROVEMENTS FOR ARMY FORCES

CONTENTS

A.	Background	G-3
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UTILITY OF MESOSCALE WEATHER FORECASTING IMPROVEMENTS FOR ARMY FORCES

A. BACKGROUND

This report, the second of two reports on "Weather Information and Tactical Army Activities," is the product of the second-phase effort whose objectives are (1) to determine the nature and extent of the influence of weather information--for real-time use in current operations (e.g., wind information for gun firing) as well as for predictive inputs for planning purposes--on tactical combat operations, and (2) to complete the (Phase 1) evaluation of the potential impact of an improved 1985 MWF capability on tactical combat operations.

Appendices A through F address the first objective by identifying activities in which Army operational effectiveness could be increased by improving some parts of the weather information systems that support Army operations.

The identifying process consisted of a series of discussions at various Army schools, commands, and agencies[a] with Army personnel who use, and Air Weather Service meteorologists who provide, weather information. The discussions focused on the availability or potential availability of weather information and the effects of that information on current and/or planned tactical operations. This approach was also used in

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[a]Armor School, Army War College, Aviation Center, Combined Arms Combat Development Activity, Development and Readiness Command, Engineer Topographic Laboratories, Field Artillery School, Infantry School, Intelligence Center, Ordnance and Chemical Center, Training and Doctrine Command, Waterways Experiment Station, and U.S. Army, Europe.

the first phase of the task; over 75 participants were involved in each series of discussions.

Discussions for Phase 2 were begun after a draft report (Ref. G-1) of the Phase 1 effort had been distributed so that all dicussions had a common starting point. These discussions and some related research appear to have provided a reasonable basis for affirming the principal conclusion (in Ref. G-1) that there are no apparent advantages for Army tactical operations from an optimistic mesoscale weather forecasting (MWF) capability projected for 1985. That does not mean that weather does not affect Army tactical operations, nor does it mean that the present weather forecasting capability is not useful; it means that projected 1985 MWF improvements appear to be insufficient to affect decisions made otherwise.

B. UTILITY OF MESOSCALE WEATHER FORECASTS

Some simple logical observations drawn (Refs. G-2 and G-3[a]) from consideration of the value of mesoscale weather forecasting to various activities appear to aptly explain the pervasive negative response from Army officers to the utility of projected improvements in mesoscale weather forecasts.

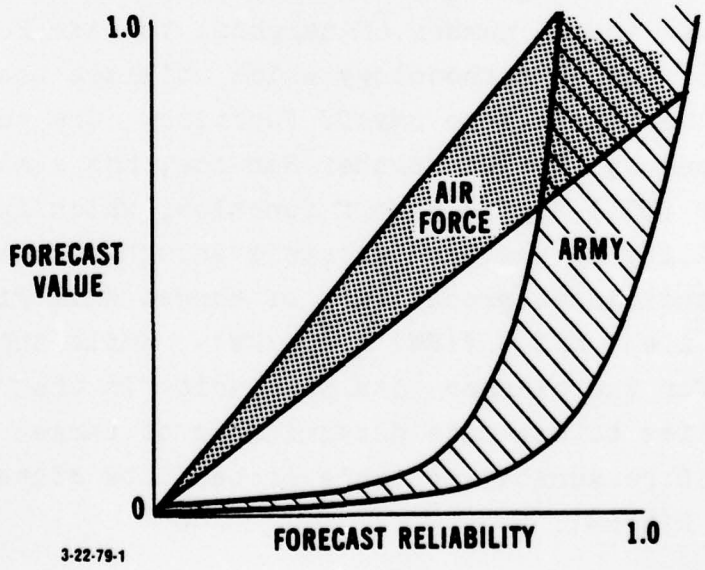
1. A weather-sensitive activity is influenced by weather.
2. An activity which is weather-information-sensitive is one in which the decision-maker's courses of action can be altered by weather information.
3. A weather-sensitive activity is not necessarily weather-information-sensitive.

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[a]Allan Murphy, a statistical meteorologist with the National Center for Atmospheric Research, appears to be one of few meteorologists concerned with evaluation of weather forecasts and with the use of weather information in decision-making processes.

4. Weather information may become useful in activities that are weather-sensitive only when the accuracy or reliability of the information reaches some threshold value.
5. In many situations, substantial increases in forecast accuracy or reliability may be necessary before appreciable increases in value are realized.[a]

A marked contrast was apparent between the general inclination of Army officers, on the one hand, and USAF Air Weather Service (AWS) meteorologists, on the other, to esteem weather forecasts: the former desired more improvement in forecast reliability than the projection (for 1985) hypothesized in order to affect tactical planning decisions; the latter believed that incremental increases in value were associated with improvements in forecast reliability. The contrast is characterized by the following normalized notional sketch.



[a]An observation based on results of recent studies cited by Allan Murphy in Ref. G-3.

Consideration of the general nature of Army and USAF activities may explain the different perceptions the two groups of officers have on the relationship, reliability, and value of mesoscale weather forecasts.

1. United States Air Force

The essence of Air Force activity is flying aircraft for (1) air supremacy, (2) logistical support, and (3) attack of ground targets. "Sorties flown" is a good activity index and is often used as a measure of productiveness or usefulness. Thus a surrogate objective of Air Force planners is to generate sorties, an activity that is quite sensitive to weather information. Sortie assignment decisions for attacking potential ground targets, for example, involve consideration of such factors as target value, target vulnerability, weapon characteristics, antiair defenses, and expectation that weather will permit targets to be attacked. Since the planner's problem is a classical one of assigning relatively scarce aircraft sorties against a not so scarce number of targets, the Air Force planner is expected to adopt a methodology which utilizes the sorties in a way that maximizes some payoff function. One such methodology, developed by the Air Weather Service, has a mission success indicator (MSI) as its payoff function, which is the product of the probability of weather favorable enough to attack a target and the conditional probability of target kill given favorable weather, i.e., $MSI = P(FW) \times P(K/FW)$. While this is a very rational aid for the planner, its popularity in the USAF is subject to abilities to estimate determinants of target kill in such a way that reasonably reliable probability statements can be made about $P(K/FW)$.

2. United States Army

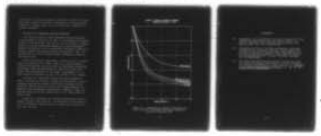
Tactical planning decisions involve consideration of the following factors (Ref. G-1) in Army operations: (1) mission or objective (assigned by higher echelon), (2) forces

available, (3) enemy situation (viz., opposing force strength, disposition, and intentions), (4) terrain, and (5) weather. While the Air Force planner has alternative targets against which to assign his sorties, the Army planner is characteristically without alternative missions or objectives. An evaluation or assessment in terms of probability statements of enemy situation appears even more insuperable for an Army planner than does a quantified estimate of determinants of target kill for the Air Force planner. With a certain mission or objective and with perfect knowledge of terrain, the planner considers the enemy situation assessment so primal that he requires very reliable forecasts before allowing weather information to be decisive even when that assessment is quite uncertain. The underlying reason appears to be that ground forces are relatively immobile and unresponsive to control actions that might be consequences of weather forecasts. However, in some instances of helicopter employment, Army planning decisions may be driven by weather forecast considerations. For example, the choice of ground-based antitank weapons (ATWs) versus helicopter ATWs for armor defense would not logically be made without considering predicted weather conditions, but the decision to use helicopter ATWs would be made only when adequate helicopter flight conditions are reliably predicted.

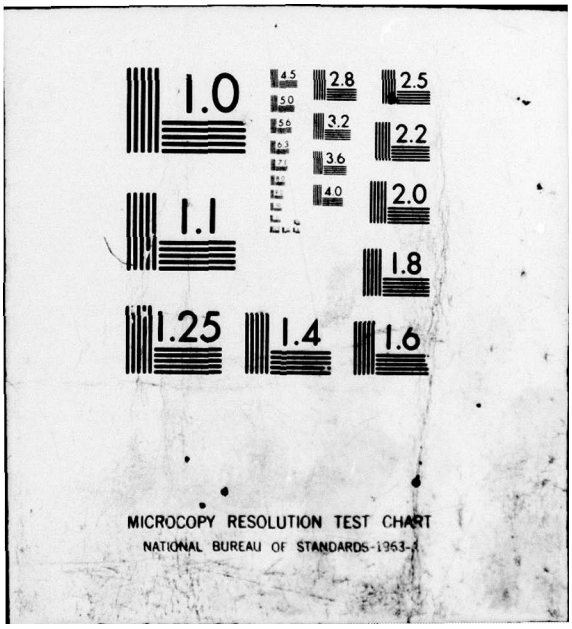
The differing natures of ground-based and airborne combat activities, given normal logistical (fuel, ammunition, maintenance) support, can be characterized as follows: (1) whereas airborne elements can be utilized a few times per day at any point within a large area, ground-based elements can be employed continuously only within a very small area; (2) the effectiveness of airborne elements is much more sensitive to weather than is the effectiveness of ground-based elements which are less concerned or relatively unconcerned with such factors as visibility, ceiling, and icing, which are important to aviation activity; and (3) efficient utilization of airborne elements is proportional to the

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reliability of predicting weather conditions suitable for their employment whereas the relative insensitivity of ground-based elements to weather makes them also relatively insensitive to weather forecasts.

C. RELIABILITY OF MESOSCALE WEATHER FORECASTS

The overall thrust of Army responses during discussions in both phases of this task is that (1) the projected increases in MWF for the near-term, say 0-6 hr, are not useful to command echelons in which operational planners can take advantage of weather information, and (2) substantial increases in MWF reliability, beyond those optimistically projected for 1985, are required for the 6-24 hr period before incremental values become significant.

While the projected improvement in MWF for 1985 is considered by the Army as too little, there is a strong consensus among meteorologists, who are active in developing forecasting techniques, that the improvement by 1985 will be much more modest than hypothesized for the Phase 1 assessment, i.e., a more realistic projection is about 10 percent of that assumed.

Although the current MWF reliability data gathered in Phase 1 and used in the Part 1 report are the results of quite extensive and recent forecast verification testing and thus represent current state of the art, poor communications (Appendix E) and insufficient observations (Appendix F) make current MWF state of the art unavailable to U.S. Army Forces in Europe today.

Figure G-1 illustrates the foregoing observations with an example in which data from Ref. G-1 are shown for the reliability of forecasts of weather states in which the visibility is less than one mile.

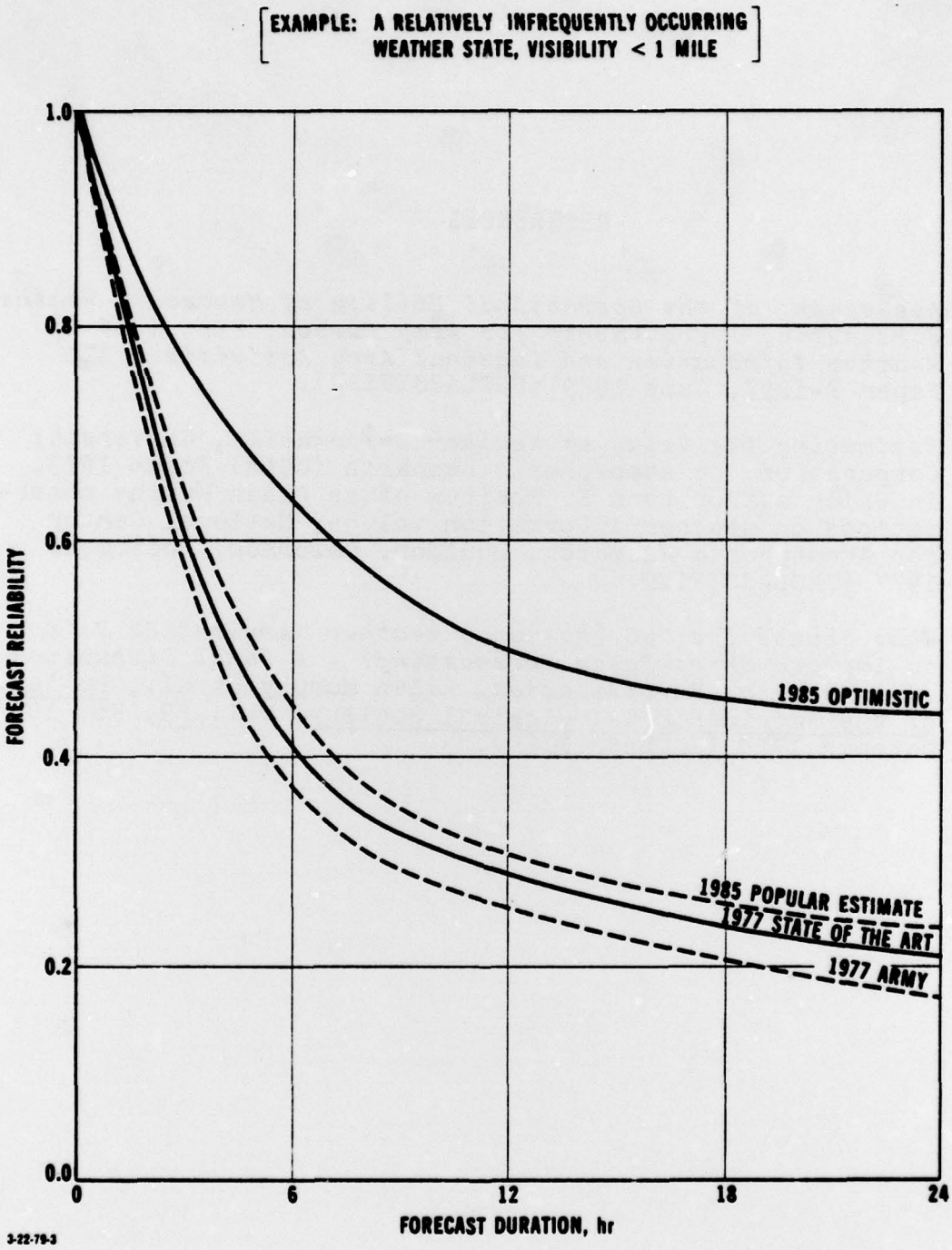


FIGURE G-1. COMPARISON OF FORECAST RELIABILITIES USED IN PHASE 1 ASSESSMENT WITH MORE APPARENTLY REALISTIC RELIABILITIES

REFERENCES

G-1. *Assessment of the Operational Utility of Mesoscale Weather Forecasting Improvements for Army Forces*, Part 1 of *Weather Information and Tactical Army Activities*, IDA Paper P-1297, June 1979 (UNCLASSIFIED).

G-2. *Estimating the Value of Weather Information*, University Corporation for Atmospheric Research (UCAR) Forum 1975, in which author Lynn E. Mesirow cites Allan Murphy observations on weather information values, National Center for Atmospheric Research, Boulder, Colorado, September 1977 (UNCLASSIFIED).

G-3. *What Should the NWS [National Weather Service] Be Doing to Improve Short-Range Forecasting? - A Panel Discussion with Audience Participation*, Allan Murphy et al., Bulletin of the American Meteorological Society, Vol. 59, No. 10, October 1978 (UNCLASSIFIED).