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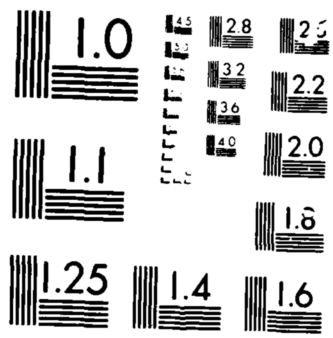
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AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

WEATHER INCORPORATED INTO COMBAT READINESS EVALUATION SYSTEMS WARGAMING

Major Harry D. White III 86-2685

"insights into tomorrow"

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PREFACE

Since the development of precision guided munitions, using electro-optical technology for the guidance systems, we have learned that weather and weather support can have a tremendous impact upon the effectiveness of their employment. Presently, weather is not used in the wargaming scenarios used by the Combat Readiness Evaluation Systems (CRES). Colonel Pappas of CRES recognized this deficiency and sponsored this study as the first initiative to start CRES toward incorporating weather into their wargaming scenarios.

This study is intended to provide a foundation of elementary weather support to electro-optical weapons systems for CRES. The capability to build more complex and more diversified features on the basic work is inherent in the basic work.

The author wishes to gratefully acknowledge the assistance of Major Paul Bess who, as a devoted electro-optical fan, provided many useful suggestions as well as some much needed editing. Additionally, the kind assistance of Major Rich St. Pierre and LtCol Robert Wright is acknowledged. Major St. Pierre and LtCol Wright are the Air Weather Service experts in weather support to precision guided munitions. Their many suggestions and simplifications have kept this work on track.

ABOUT THE AUTHOR

Major Harry D. White III has more than 26 years experience in meteorology. He holds a Bachelor of Science in meteorology from the University of Utah and a Master of Science in engineering from the University of Texas at Austin. He has held a wide variety of positions to include Detachment Forecaster, Weather Instructor, Air Force Global Weather Central Chief Forecaster, and Detachment Commander. Previous published work includes two papers for the British journal, Geophysical and Astrophysical Fluid Dynamics entitled "Convection in a Rotating, Laterally Heated Annulus--Pattern Velocities and Amplitude Oscillations" and "Convection in a Rotating, Laterally Heated Annulus--The Wave Number Transitions." Major White has also authored AFM 51-12, "Weather for Aircrews" and a Forecaster Memo for Second Weather Wing. Major White has been elected a Fellow of The Royal Meteorological Society.

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AUTHOR(S) MAJOR HARRY D. WHITE III, USAF

TITLE WEATHER INCORPORATED INTO COMBAT READINESS EVALUATION SYSTEMS WARGAMING

I. Problem: Presently there is no weather support incorporated into the Combat Readiness Evaluation Systems (CRES) wargaming scenarios. Weather support can be critical to a battlefield commander employing Electro-Optical (E-O) weapons. Minimal support requirements need to be identified using existing weather observations and forecast data bases.

II. Objectives: In this study, the weather parameters that most affect E-O systems are identified. Additionally, five vertical layers using existing data bases are described that permit theater commanders to more intelligently frag targets.

III. Findings: The weather parameters that most influence E-O systems are precipitation, clouds and fog, water vapor, and lithometers such as haze or dust. The Air Force Global Weather Central (AFGWC) at Offutt AFB, Nebraska, routinely computes a forecast for each of these parameters over a horizontal resolution of 25 kilometers and for five distinct layers of the atmosphere.

IV. Recommendations: CRES should, through their Staff Weather Officer, request that Air Weather Service provide the forecast data written to a medium and in a format that is accessible by computers used by CRES.

Chapter One

INTRODUCTION

The Problem

The Combat Readiness Evaluation Systems (CRES) does not presently have weather support included in their wargaming scenario. The importance of weather to the outcome of the battle has long been recognized by the greatest of warriors. This is especially true in today's environment of high technology weapons such as Electro-Optical (E-O) guided munitions. More and more we have come to depend upon the technology of laser designation and imaging infrared systems to improve the accuracy with which we can hit targets (1:v).

Failure to consider the adverse impact weather can have on the outcome of a war can have a disastrous effect. Examples abound in history of wars won and lost to the weather. Should the war for which we train ever happen, hopefully we will have included in our training scenarios all of the areas which have the potential of determining the outcome. A commander should be fully versed in how to best exploit the advantages that accrue to those who have knowledge of the weather. Toward that end, this study is geared to provide a basis of information for initial implementation within CRES.

The CRES wargaming scenario is intended for the decision maker charged with prosecuting a theater war. This study is slanted toward providing a theater commander with the level of detail and type of weather intelligence needed to prosecute the E-O portion of the war.

Electro-Optical (E-O)

Weapons that we normally refer to as E-O generically depend upon some portion of the infrared (IR) spectrum for guidance. The two broadest categories of these weapons are the laser systems and the imaging infrared (IIR) systems. The laser systems operate in the part of the spectrum which is referred to as the near IR (1.06 microns). The IIR systems operate in the 8 to 12 micron range which is termed far IR.

Experience has taught us these weapons are extremely sensitive to the environment in which they operate (3:1). The Air Weather Service has devoted a significant number of resources to developing support procedures for E-O weapon systems. However, CRES in their wargaming scenarios cannot afford to devote the same level of activity to the problem as does Air Weather Service. Therefore, this study identifies a minimal level of computer requirements and manpower activity which are needed to provide weather support to a theater commander charged with prosecuting a war in the NATO central region.

Chapter Two

WEATHER EFFECTS

Target-to-Background Contrast

Weather effects both the near (1.06 micron) and far (8-12 micron) infrared spectrum. Moreover, the effects are to both the target-to-background contrast and to the transmission of IR energy from the target to the sensor (4:1).

The target-to-background contrast is very much dependent upon the target and the environment (2:86). For example, the target-to-background contrast is degraded by snow cover, high winds, or heavy rain. A tank operating in the Arctic night will have much more contrast to the background than a tank operating in the Sahara Desert at mid day. The contrast of the tank to the background is dependent upon whether or not the tank is running, whether it is day or night, whether the background is a canopied forest, a desert, a grassy plain, or a snow covered tundra. Change the target to a bridge over a river and all the complexity is still there embodied in different questions. Is the bridge made of wood, iron, or reinforced concrete? Does the bridge span a dry creek bed, a fast, shallow mountain stream, or a slow, deep river in the plain?

There are various ways in which weather can change the target-to-background contrast. Heavy precipitation will wet both target and background which will give the same radiative properties for both surfaces. High winds produce very efficient turbulent stirring of the atmosphere and therefore reduce the thermal contrast. Clouds and fog will inhibit solar heating and nighttime radiational cooling--both of which reduce thermal contrast.

Infrared Energy Transmission

The effect of weather on the transmission of IR energy is quite different than the effect on target-to-background contrast. For example, surface winds have no effect on IR transmission. Lithometers such as haze, smoke and dust have only a minor effect on the transmission of 8-12 micron IR energy, but have an extreme effect on laser sensor systems operating in the near IR (4:7).

The following points must be considered in order to arrive at the proper effects of weather on target acquisition, lock-on, and delivery of the weapon:

Weapon Type. The effects of weather parameters can be very different in the near IR spectrum than they are in the far IR spectrum.

Contrast. Whether or not a target is distinguishable from its background (acquisition and lock-on) depends on many variables that are not weather related. However, it is very useful to provide the operator with the inherent thermal contrast of the background. The operator must then determine if the target is hot or cold relative to the background and the weather affecting that background.

Transmissivity of IR Energy Through the Atmosphere. The successful delivery of the weapon depends strongly on the weather. If a cloud drifts between the weapon and the target or, if a sudden gust of wind stirs some dust or snow or, if a shower of rain should envelop the target while the weapon is in flight, then the probability of the weapon ever finding its way to the target is severely diminished. These effects are summarized at Table 1.

Conclusions

Interpretation of Table 1 (4:14) in order to prioritize the effects of weather parameters is not straight forward. One "extreme" might be more limiting on a weapon system than any other. Also, the duration in time of any particular effect must be considered.

From Table 1, the effect of precipitation, as compared to clouds and fog, appears to be co-equal. However, clouds occur much more frequently than does precipitation. In fact, clouds are a prerequisite for precipitation. Conversely, the effect of precipitation is absolute while thin clouds may or may not prove to have a debilitating effect. Therefore, there is no consensus with respect to which weather parameter has the greatest overall effect on the delivery of E-O weapons. However, it is obvious that precipitation, in concert with clouds and fog, form the two greatest weather related limiting factors.

WEATHER PARAMETER	EFFECT	
	INHERENT THERMAL CONTRAST	TRANSMISSIVITY
SURFACE WIND	Provides effective mixing of the atmosphere which substantially reduces contrast. **MAJOR**	**NONE**
WATER VAPOR (RELATIVE HUMIDITY)	When relative humidity exceeds 95% radiational cooling is inhibited and contrast diminished. **MINOR**	Water vapor absorbs far IR energy. The higher the water vapor, the lower the transmissivity. **MAJOR**
CLOUDS/FOG	Reduce insolation and radiational cooling which substantially reduces contrast. **MAJOR**	Opaque to the transmission of IR energy. **EXTREME**
PRECIPITATION (RAIN/SNOW)	Targets and background are masked. The IR scene becomes uniform and nondescript. **MAJOR**	Rapidly absorbs IR energy (especially snow). **EXTREME**
LITHOMETERS (HAZE, SMOKE, AND DUST)	Reduces insolation. **MINOR**	In conjunction with high humidity, rapidly absorbs far IR energy. **MAJOR**

TABLE 1. Weather Effects on E-O Systems

Lithometers such as haze and dust form the third most significant weather related limiting factor to E-O weapon delivery. Their effect on target-to-background contrast is to reduce insolation which reduces the available contrast. The largest impact is to transmissivity. Just as these elements tend to obscure in the visible spectrum, likewise they tend to absorb and diffuse the transmission of IR energy through the atmosphere. As the relative humidity increases, so does the ability of lithometers to absorb IR energy.

The effect of water vapor on IR transmission capabilities is most pronounced when the relative humidity exceeds 95 percent. This effect is even more pronounced when aerosols such as the lithometers discussed above are present. High relative humidity (95 percent or greater) also inhibits radiational cooling which causes the IR environment to become more homogenous.

Chapter Three

VERTICAL LAYERS

General Conditions

Weather can severely hamper the delivery of precision guided munitions. However, weather is a vertical phenomenon which may be stratified or solid throughout the vertical extent of aircraft operations (1:20). Therefore, it is very likely that air-to-air operations might be conducted even though air-to-ground operations are not prudent. The weather may be stratified in such a way as to restrict the altitude from which successful air-to-ground deliveries may be made. The objective is to determine which layers of the atmosphere will permit the designated operation.

The Five Layer Model

The Air Force Global Weather Central (AFGWC) has the only operational cloud model in the world. This cloud model is called FIVLYR or "five layer." A substantial subroutine of FIVLYR is the Diagnostic Weather Elements (DWE). The DWE subroutine has the task of forecasting precipitation, haze, dust, and smoke. Moreover, the model indirectly forecasts the intensity of each by making a forecast of the visibility. Therefore, three of the four weather parameters identified as crucial to E-O precision guided munitions are forecast by a single model, the FIVLYR.

FIVLYR vertically divides the atmosphere into five layers that are traditionally used by meteorologists. Moreover, these five layers are focused on pressure levels that are referred to as standard levels. These levels are the most useful because the World Meteorological Organization, a branch of the United Nations, has deemed them to be mandatory reporting levels and therefore, the preponderance of data is for these levels. From the top of the atmosphere down, the five layers are:

300 Millibars (300MB). This pressure level is 30,000 feet high in the atmosphere. The FIVLYR model assigns all clouds between 23,000-35,000 feet to the 300MB layer. Clouds in this layer are formed from ice crystals. Many of these clouds are

thin and pose no real problem to most imaging IR systems because the target is especially hot in contrast to the background.

500 Millibars (500MB). This pressure level corresponds to approximately 18,000 feet in the atmosphere. All clouds in the layer between 14,000-23,000 feet are assigned to the 500MB layer. Clouds within this layer can be formed by either water droplets or ice crystals. Clouds formed from water droplets are much more likely to impact the transmission of IR energy than those formed from ice crystals.

700 Millibars (700MB). The height in the atmosphere which most closely corresponds to 700MB is 10,000 feet. Within the FIVLYR model, all clouds in the layer between 7,000-14,000 feet are assigned to the 700MB layer. Within tropical and mid-latitude regions, clouds in this layer are always water droplets. In the arctic regions, they may be either water droplets or ice crystals.

850 Millibars (850MB). The FIVLYR model assigns all clouds between 2,000-7,000 feet to the 850MB layer. Generally, clouds in this layer are opaque to imaging infrared systems. However, clouds in this layer can also be thin and wispy such that the inherent thermal contrast is sufficient to overwhelm the effect of the cloud.

The Boundary Layer. The boundary layer is the first 2,000 feet of the atmosphere. That is to say, the FIVLYR model assigns all clouds (and fog) from the surface up to 2,000 feet to the boundary layer.

Diagnostic Weather Elements

The Diagnostic Weather Elements (DWE) portion of FIVLYR handles what is normally thought of as sensible weather elements. Thunderstorms, precipitation, haze, smoke and dust are all elements that are forecast by the DWE. In the case of precipitation, an intensity is also forecast, i.e., the model will forecast the precipitation to be heavy, moderate, or light. The intensity of haze, smoke, and dust are also forecast, after a fashion, since the model forecasts the visibility restriction that is caused by the haze, smoke or dust. The utility of this is significant since operations may not be hampered at all by an environment of six miles visibility in haze but a visibility of one mile or less might reduce the stand-off range sufficiently to cause operations to be suspended.

Grid Resolution

The horizontal grid of the FIVLYR is rectangular and varies with latitude. In the mid-latitude region the grid spacing is on the order of 381 kilometers. This spacing is referred to as course mesh. Output of the model is also available in half, quarter, eighth, and sixteenth mesh. Therefore, it is possible to demand a forecast of clouds, fog, precipitation to include type and intensity, haze, smoke, and dust for each of the five layers described above on a horizontal resolution of 380km, 190km, 95km, 48km, or 24km. For example, in an area 400km square (250 miles square), using the course mesh option, 20 forecasts would be generated--one for each of the five layers at the four specific grid points that the course mesh would encompass. However, using the sixteenth mesh option, 1,445 forecasts would be generated over the same 400km square area.

Similarly, a forecast is generated for many different valid times which further adds to the number of forecast data to be assimilated by the forecaster. Generally a forecast is made for each grid point valid at each cardinal hour for the first three hours and at three hour intervals thereafter. That means the simple course mesh option described above which resulted in 20 forecasts would produce 20 forecasts for each and every valid time required by the operational commander. Analogously, the sixteenth mesh option produces 1,445 forecasts for every valid time.

Information Sources

The most current Technical Note available which describes FIVLYR and its associated products is AFGWCTM 70-10, dated 1970. So many changes have been made to the application software and the AFGWC production cycle since the memorandum was written that it no longer serves any useful purpose. This shortcoming has been recognized by AFGWC and is being worked.

The best source for information regarding FIVLYR and associated products is AFGWC/SDDC, Cloud Models Branch, Offutt AFB, Nebraska. The current Branch Chief is Major Tim Crum who can be reached at Autovon 271-5503.

Conclusions

The tremendous variation in the number of forecasts generated raises questions regarding cost, timeliness, and required resolution. The computer time required to generate the forecasts increases as the number of forecasts increase which adds to the cost of the final product. A Staff Weather Officer can assimilate 20 pieces of information and, in short order, deliver the required intelligence to a decision maker. However, the time required to similarly treat the 1,445 forecasts generated by demanding the sixteenth mesh option, would substantially increase, perhaps so much so as to reach the decision maker far too late to be of any use. Moreover, the decision maker may or may not require the amount of detail knowledge that the 1,445 forecasts would yield. However, the commander would almost certainly require an area forecast over several time periods to formulate weapon employment plans. Therefore, the resolution should be selected balancing the cost of resources and the timeliness of the final forecast product against requirements for detailed knowledge of the battlefield.

A flexible response strategy dictates the inclusion of environmental services. That is to say, the resolution required to satisfy the environmental support requirements of any particular battlefield strategy will vary. However, a reasonable starting point should provide the commander with a broad perspective from the outset with further detail provided as required. Therefore, it is recommended the half-mesh (190km) option be used as the standard. Using the 400km square area example discussed above, the half-mesh option would require only 45 forecasts for each time period.

The commander may find combining vertical layers a very satisfactory approach to the problem. Combining the Boundary Layer, 850MB, and 700MB layers into a single point forecast of total cloud, precipitation, lithometers, and visibility would substantially reduce the amount of data required. This method would produce a forecast from the surface to 14,000 feet which would meet most requirements for air-to-ground weapon delivery methods.

Similarly, combining the 700MB, 500MB, and 300MB layers into a single point forecast would produce a forecast from 7,000 to 35,000 feet. This forecast would meet most requirements for air-to-air applications.

Chapter Four

FORECASTING

Forecasting Procedure

Developing a forecast requires the forecaster to choose among various pieces of information or data and then to assimilate the information into a coherent and rational forecast. Since it is a virtual impossibility for forecasters to obtain and process all relevant information, they develop standard routines that vary with the individual. That is to say, forecasters will form prejudices and preferences with respect to forecasting aids, charts, diagrams, and rules of thumb regarding their use--the tools of the trade so to speak.

Forecasting Aids. Most of the forecasting aids and charts are centrally prepared by AFGWC and then transmitted via teletype or facsimile to field forecasters around the world. AFGWC produces over 100 facsimile charts and thousands of teletype bulletins daily, providing a plethora of information to satisfy requirements from operational users. In order to forecast clouds, fog, precipitation, dust, haze, and smoke, the forecaster will require substantial centralized support from AFGWC or a similar facility with numerical weather prediction capabilities.

The purpose here is to develop a standard list of products that can be used effectively and efficiently by a trained Staff Weather Officer to produce timely and accurate forecasts of the parameters that hamper E-O operations as described in chapter two. Clearly individual forecasters will select from the menu of thousands of available products from AFGWC to appease their own particular preferences. Therefore, the list of products given here should be viewed as minimal in preparing a forecast product that would significantly enhance the intelligence data base of a decision maker charged with prosecuting a theater war.

Charts that display thickness, vorticity, thermal advection, vertical motion, and pressure gradient are standard thermodynamic forecast aids and should be made available to the forecaster. AFGWC produces a package of such charts for the European theater twice daily.

Chapter Five

RECOMMENDATIONS

Staff Weather Officer Liaison

The Commander of the weather detachment on Maxwell AFB serves as the Staff Weather Officer for organizations assigned to the base. Part of the responsibilities of a Staff Weather Officer is to assist local commanders in determining weather support requirements. When those requirements exceed local capabilities, then the Staff Weather Officer should assist the local commander in preparing a Support Assistance Request (SAR) under the auspices of Air Weather Service Regulation 105-18. It is the judgement of the author that all of the recommendations made below can best be satisfied through a SAR initiated by CRES.

Computer Products

The forecast elements contained in the FIVLYR and the DWE are readily available from the Air Force Global Weather Central. The product can be produced as a chart or as data on a grid which can be written to computer tape. The number of forecast points required is largely a matter of time and space availability on the CRES computer. However, if the data is used as a look up table, then time and space on a computer system are not significant factors. It is recommended that all forecast points, down to and including sixteenth mesh, and all forecast valid times, be made available. The decision maker would then have the flexibility to choose the grid resolution that best meets the demands of the situation.

Should CRES be too constrained for computer resources to accomplish the above, then recommend the FIVLYR and DWE forecasts be provided at quarter mesh and for each 6 hours of the forecast period.

The computer tapes written at AFGWC for internal use are formatted for the Sperry Univac computers that handle the applications models. However, transportability of any computer product depends upon the capability to write the desired product in a format that is understandable to the machine which will be reading the tape. AFGWC has the capability to write computer tapes in many different formats. It is crucial that the format be rigorously defined such that not only will the product be useable by the specific machine, but also the application software.

The subject of formatting is very complex and is well beyond the scope of this paper. The importance of format will seem trite to anyone schooled in computer programming. The format used can be very volatile and has no utility except to the particular end user. Therefore, the point to be made is that the format required by CRES should be clearly defined such that the Staff Weather Officer can require AFGWC to write the computer tapes in a format that is intelligible and useful to CRES.

The Software Division of AFGWC should be contacted for input when developing this requirement. Specifically, the Cloud Models Branch, AFGWC/SDDC, Offutt AFB, Nebraska, at Autovon 271-5503 has the necessary expertise.

Charts and Diagrams

The Air Force Global Weather Central produces a series of facsimile charts especially for the European Theater. That series of charts will provide the essential thermodynamic forecast aids required to produce a reasonable area forecast. Both geostationary and polar orbiting meteorological satellite pictures should be provided as well.

Real Time Vs Climotology

The integration of weather into the wargame scenario only makes sense to the extent that the weather in fact impacts the decisions reached by the commanders. It is possible to contrive special situations which demand inordinate attention be given to the weather; it is also possible for existing weather, over a given period of time, not to be a factor in the decision making process. Finally, it is also possible to use climotology which smooths abrupt changes in the weather over short time periods.

There are advantages and disadvantages associated with each type of input. Using contrived weather is usually not acceptable because it is limited only by the imagination and, therefore, will frequently impose severe restrictions on the game play. Climotology is very representative of the weather that can be expected over longer time scales, but eliminates the short time scale excursions from the norm. That is to say, the decision making process would have to consider weather only once every month or so of play. The use of real time weather should provide more realistic results. However, should a period of extraordinarily good or extraordinarily bad weather be persistent during the period of play, then the importance of weather will be changed accordingly.

These points should be carefully thought through by the CRES staff before they employ weather in wargaming scenarios.

What Next

CRES should look very closely at a possible requirement for a dedicated Staff Weather Officer. This study, if implemented in its entirety, would provide only basic weather support with no provisions for offering tailored support to special situations. For example, if weather communications are lost, then the support described in this study would cease to exist. However, the ability of a Staff Weather Officer to continue to provide weather information for several days has been demonstrated. A full time Staff Weather Officer would provide CRES the ability to include variations in the scenario such as communications out, special missions, and changes in complexity. Additionally, a Staff Weather Officer could provide internal intelligence to CRES by researching the effect of weather on kill probabilities of E-O weapons and providing feedback on the value of weather support.

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