ASL MONOGRAPH NO. 4

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AD A094145

QUALITATIVE DESCRIPTION OF OBSCURATION FACTORS IN CENTRAL EUROPE

SEPTEMBER 1980

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: ASL Monograph No. 4	2. GOVT ACCESSION NO.: AD-A094 145	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): QUALITATIVE DESCRIPTION OF OBSCURATION FACTORS IN CENTRAL EUROPE		5. TYPE OF REPORT & PERIOD COVERED: R&D Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Marvin D. Kays, Mary Ann Seagraves, Hubert H. Monahan, Robert A. Sutherland		8. CONTRACT OR GRANT NUMBER(s): (14) ERADCOM/ASL-MONO-4
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico 88002		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Electronics Research and Development Command, Adelphi, MD 20783		12. REPORT DATE: September 1980
		13. NUMBER OF PAGES: 121
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Optics
Meteorology
Obscuration
Military Intelligence
Climatology
Visibility
Radiation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report qualitatively describes, in elementary terms, the obscuration factors that affect electro-optical (E-O) systems. The obscuration factors are classified into four categories: clear atmosphere, natural obscurants, battlefield obscurants, and land/air interface.

Basic radiation laws, Rayleigh and Mie scattering, and the changes that a beam of electromagnetic energy encounters in an atmosphere free from clouds and

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20. ABSTRACT (cont)

obstructions to visibility are discussed in the chapter on the clear atmosphere. The effects of fog, rain, snow, drizzle, clouds, haze, and dust storms upon E-O systems are discussed in the chapter on natural obscurants. Battlefield obscurants are dust, smoke, and fire resulting from battle and intentional smoke. The chapter on land/air interface discusses the effect of terrain, vegetation, and ground cover upon obscuration.

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CHAPTER 1

INTRODUCTION/OVERVIEW

This report qualitatively describes the obscuration factors that affect electro-optical (E-O) systems. This report is intended for use by military agencies responsible for the acquisition, testing, simulation, training, and operation of E-O systems that must operate in a realistic battlefield environment. The obscuration factors are classified, in a broad sense, into four categories. These four categories are: clear atmosphere, natural obscurants, battlefield obscurants, and land/air interface.

The chapter on clear atmosphere discusses the changes that a beam of electromagnetic energy encounters in an atmosphere that is free from clouds and obstructions to visibility. Basic radiation laws are covered in this chapter to provide a foundation for the following chapters. Natural obscurants include rain, drizzle, snow, fog, clouds, haze, and dust storms. Battlefield obscurants include man-caused smoke, dust from vehicular motion, and fire products of the battlefield. Land/air interface includes the effects of terrain, vegetation, and ground cover upon obscurants.

The appendices contain a glossary, sections on the general characteristics of smoke, precipitation, and wet aerosols, and a more detailed treatment of radiation laws than found in chapter 4.

This report is expected to be followed by a report giving a quantitative description of obscuration factors in central Europe. A related effort at the Atmospheric Sciences Laboratory is producing a compendium of atmospheric data requirements which will expand the contents of chapter 9.

CHAPTER 2

PROLOGUE

2.1 BACKGROUND

For several years, the Army has been aware of the risks involved in the successful utilization of E-O weapon systems in a battlefield scenario during low visibility. Also, limited visibility is known to occur frequently in central Europe and can be expected to be induced on the battlefield anywhere.

The Army responded to the obscurants problem by establishing the Office of Project Manager (PM) Smoke/Obscurants. This office has the responsibility not only for developing smoke munitions but also for playing a role in the assessment of weapon effectiveness in smoke and obscurant environments. In late 1977 the Army Vice Chief of Staff expressed concern about the use of realistic battlefield environmental conditions throughout the Army and called for increased awareness and the development of standard conditions for the assessment of obscurant effects. The Commander, United States Army Materiel Development and Readiness Command (DARCOM) later added emphasis to that message and clarified certain responsibilities within DARCOM. The Under Secretary of Defense for Research and Engineering defined certain responsibilities among the three services.

In early 1978 several tasks in obscurants were generated by the DARCOM Battlefield Systems Integration Office (BSI) in cooperation with HQ Training and Doctrine Command (TRADOC). A June 1979 message establishes further milestones between DARCOM and TRADOC. A meeting was held at HQ, DARCOM, 16 August 1979, during which the Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, New Mexico, was verbally tasked to develop qualitative descriptions of precipitation and wet aerosols (fog) for central Europe. PM Smoke was tasked to do the same for dry aerosols (smoke). This report fulfills this tasking to develop the qualitative descriptors.

The authors wish to acknowledge the tasking, assistance, and reviews from COL John Roop and Mr. Al Giambalvo (HQ DARCOM) and the reviews and leadership of Dr. Frank Niles (ASL). Dr. Anthony Van de Wal (PM Smoke/Obscurants) wrote appendix B, "Qualitative Descriptions of Smoke." We are grateful for his contribution. We also acknowledge the critical and helpful reviews from personnel in the ASL and other Army organizations.

2.2 PURPOSE

This report qualitatively describes the obscuration factors that will be encountered in central Europe. It has been written to establish a basic foundation for those not familiar with meteorological and E-O terms. Hopefully, this report will be utilized by all personnel from atmospheric modelers to weapon system designers and developers to troop trainers in establishing a standard for incorporating environmental obscuration factors into their work.

CHAPTER 3

EXECUTIVE SUMMARY

The Department of Defense (DOD) community is acutely aware that E-O weapon systems can be adversely affected by obscuration and is highly concerned about the factors that seem to be uncontrollable, namely, obscuration caused by atmospheric conditions. A need exists to qualitatively and quantitatively describe those obscuration factors. This work describes in a qualitative sense the obscuration factors for a central European scenario.

Within the four categories of clear atmosphere, natural obscurants, battlefield obscurants, and land/air interface, three types of obscurants are discussed: precipitation; wet aerosols; and dry aerosols, including smoke.

3.1 CLEAR ATMOSPHERE

The clear atmosphere is defined as an atmosphere which is free from obstructions such as rain, fog, or smoke but contains the gases and aerosols normally found in the atmosphere.

To provide some understanding of radiation, the electromagnetic spectrum is described because E-O sensors are classified according to their frequency/wavelength.

The portion of the atmosphere nearest the earth is the troposphere. It varies in thickness from 6 km over the polar regions to 18 km over the equator and contains all of the constituents and weather pertaining to E-O obscuration factors.

The main causes of atmospheric attenuation of electromagnetic radiation are absorption and scattering by aerosols such as smoke, fog, and haze particles. The fundamental law of attenuation is known as Beer's law (sometimes referred to as Bouguer's law). Absorption and scattering coefficients are indicative of the amount of radiation absorbed and scattered, respectively. The extinction coefficient is the sum of the absorption and scattering coefficients.

Scattering is considered to be one of two types--Rayleigh or Mie. When the scattering particles are much smaller than the wavelength of the radiation, the scattering is called Rayleigh. Mie scattering occurs for larger particles such as in haze, clouds, fog, and dust. Mie scattering of optical energy transmission may be quite large in certain infrared wavelengths, while Rayleigh is the predominant effect for visible and ultraviolet wavelengths.

Visibility is defined as the distance at which an observer can just possibly distinguish, with the unaided eye, a dark object against the horizon during the day and an unfocused, moderately intense light source at night (such as street lamps).

Degradation factors are affected by phenomena such as temperature, wind, absolute humidity, and turbulence.

Temperature fluctuation produces a change in atmospheric density which in turn produces changes in the atmospheric refractive index. The temperatures of the target and its background are important in target acquisition. High temperatures at the earth's surface cause thermal convection or turbulence that results in jitter and characteristic changes of the radiation beam. When the temperature increases with increasing altitude, a condition known as a temperature inversion exists; this condition hinders the upward movement of aerosols.

Wind is responsible for transporting aerosols, smoke, dust, or sand into or out of an area of interest, that is, valley, city, or other small area. Wind also causes the formation and dissipation of fog by mixing the air.

Water vapor absorbs in the visible and infrared, and the amount of attenuation is directly related to the amount of water vapor. Water vapor is also responsible for the growth of water particles on condensation nuclei.

3.2 NATURAL OBSCURANTS

Climatic and weather variations in Germany are as extreme as the variations in terrain that exist over that region. The Alps mountain ranges block most of the warm moist air from the Mediterranean region from Germany.

The worst weather in terms of visibility and clouds occurs over Germany during the winter as the result of two low pressure systems. Migrating low pressure systems that form near the Bay of Biscay move across the Mediterranean region to the Adriatic Sea; and Icelandic lows produce migrating storms, extensive cloud cover, and precipitation.

Summer and autumn are the best seasons for Germany for mild temperatures. Thunderstorms in the summer and early morning fog in the autumn are the obscuration factors that have to be considered for tactical operations.

Cloudiness over Germany is one atmospheric condition that occurs most of the time and is due to the predominant airflow from the Atlantic Ocean. Satellite imagery shows that broken to overcast (seven- to ten-tenths) cloud cover prevails 50 percent of the time in summer and 70 to 80 percent in winter; clear to scattered (zero to three-tenths) 30 percent in summer and 10 percent in winter. The remaining 20 percent of cloudiness in each season has four- to six-tenths coverage.

Fog is the primary cause of visibility restriction in Germany. Much of the fog is radiation fog that occurs during late autumn and winter because of the short days and long nights. Autumn is usually the foggiest time of the year in Germany.

Summer is the season of maximum precipitation with 8 to 12 inches expected at most locations. Light to moderate snow generally falls over most of the region from November into April with most of the snow occurring over the northern Lowlands between December and March.

Moist, unstable air flowing in from the Atlantic causes thunderstorm activity to start in Germany in late April or early May and to increase rapidly as summer approaches. Most locations average 5 to 8 days per month of thunderstorm activity.

3.3 BATTLEFIELD OBSCURANTS

Obscurations occurring on the battlefield are either intentional or unintentional. Obscurations occurring unintentionally can be caused by the clouds of dust and debris from explosions and bombs; dust clouds and exhaust emissions from vehicles; blasts from firing large guns; and fires on the battlefield of vegetation, equipment, or other material. Battlefield fires can cause obscuration by producing smoke which blocks the view, by producing thermal turbulence, or by saturating the sensor elements with electromagnetic radiation of the same wavelength as the sensor. Intentional obscuration is produced by smoke munitions or equipment. Screening smokes produced with inventory munitions are emphasized.

The environmental factors which influence the effectiveness of intentional obscurants may be separated into those which influence the transport and dissipation of smoke clouds and those which influence the optical properties of the smoke screen. The transport and dissipation of smokes are controlled by wind, humidity, and stability of the atmosphere. The optical properties are governed mainly by smoke type, cloud temperature, and ambient illumination; but in some respects relative humidity plays a role.

Knowledge of the effects of interaction between different obscuration factors is limited, and research is required in this area.

3.4 LAND/AIR INTERFACE

The interaction between land and air affects the formation and behavior of clouds, fog, wind, temperature, precipitation, and smoke. Windspeeds are usually higher near mountain passes than in the valley. Clouds and precipitation occur more often on the windward slope of mountains or terrain. During the day the air is more stable near the ground in a forest but is more unstable in open terrain. Generally, smoke deployed in a forest during the day would not dissipate as fast as if deployed over open terrain. Fog forms more readily in the valleys due to the cooling and drainage of cold air into the valley. These and other factors are important in deploying and understanding the behavior of battlefield obscurants.

3.5 E-O SENSORS

E-O systems are classified as being either active or passive devices. Active devices illuminate the targets with energy which they then sense as it is reflectd or scattered by the targets. Passive sensors sense the emitted or reflected natural energy from targets or other objects. Applications of several E-O devices are discussed. Table 8-1 lists some weapon systems and the atmospheric obscuration factors which affect their operations.

3.6 DATA REQUIREMENTS

The requirements of atmospheric data by different users are not always the same. Measurements of meteorological parameters have been made for years, but optical parameters are more difficult to observe and a complete data base is lacking.

The four users of atmospheric and optical data are: (1) weapon systems designers and war game players, (2) weapon systems developers and test and evaluation, (3) tactical decision makers and troop trainers, and (4) atmospheric modelers. A table listing meteorological and optical parameters and the user of the particular parameter was prepared (table 9-2).

CHAPTER 4

CLEAR ATMOSPHERE

4.1 INTRODUCTION

This chapter consists of three parts: optics, atmosphere, and meteorological parameters. The optics section (4.2) briefly discusses the basic radiation laws and the electromagnetic spectrum. Section 4.3 discusses the composition and the temperature structure of the atmosphere, and section 4.4 covers the meteorological parameters that cause degradation factors.

A clear atmosphere is one that is free from obstructions such as rain, fog, or smoke but contains the gases and aerosols normally found in the atmosphere during conditions of cloudless skies and good visibility.

4.2 OPTICS

4.2.1 Electromagnetic Spectrum

The process by which energy in the form of heat, light, x-rays, radio waves, etc., is sent out through space is called radiation or radiative transfer. The process of radiation shown in figure 4.1 is probably the simplest process of radiation. If one holds his hand to a hot stove,

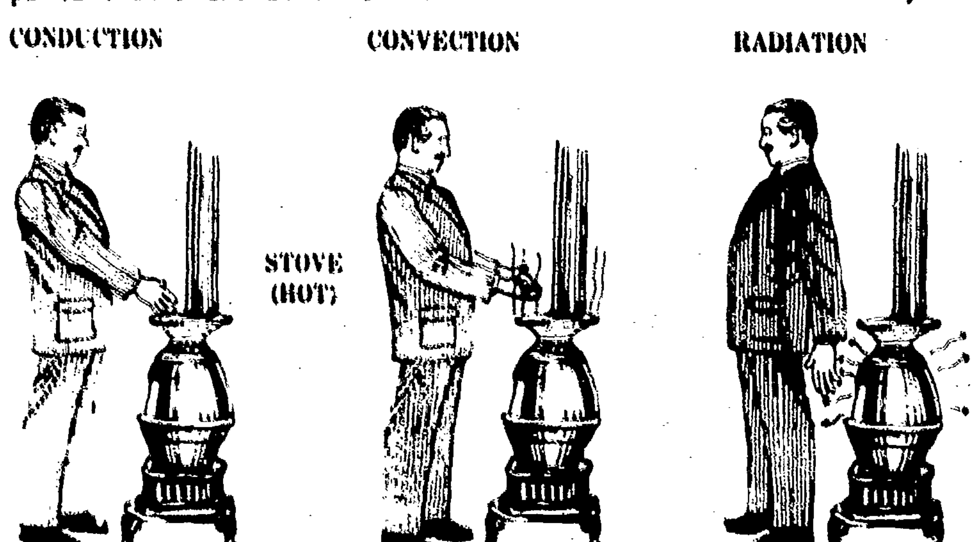


Figure 4.1. Transfer of energy by conduction, convection, and radiation.

heat reaches the hand by conduction through the stove walls. If the hand is held directly above the stove, upward moving convective currents carry the heat to the hand. If the hand is held at one side of the stove, it still becomes warm, even though it is not in the path of the convective air. Heat, or energy, reaches the hand by radiation.

Electromagnetic radiation is defined as energy propagated through space or through material media in the form of an advancing disturbance in electric and magnetic fields in space or in the media. In theory these disturbances are of the nature of waves moving through the medium of electric and magnetic fields in space, with their respective forces acting as right angles to each other (Huschke, 1959). Because of this, electromagnetic radiation is characterized by wavelength or frequency. Usually wavelength is used to characterize x-ray to infrared regions; and frequency is used to characterize radar, television, and radio waves. A thorough understanding of wavelength, frequency, units of length, and terms used to describe specific intervals of frequency is essential.

Figure 4.2 depicts a wave in its simplest form. The wave frequency, f, is the number of waves which pass a fixed point in a given interval of time. The wave period, T, is the time elapsed between the occurrence of successive wave crests. Frequency is related to period by

$$f = 1/T. \tag{1}$$

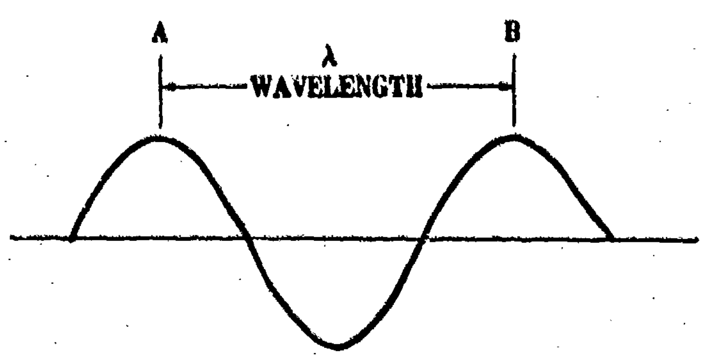


Figure 4.2. Characteristics of an electromagnetic wave.

Electromagnetic waves travel at the speed of light (2.997 x 10 m/s), denoted by C, and the relation between C, wavelength, , and f is given by

$$c = f\lambda. \qquad (2)$$

The electromagnetic spectrum is shown in detail in figure 4.3. Note the expansion of the spectrum into two subintervals to illustrate the smallness of the visible part of the spectrum. Some researchers are now using the term "near millimeter" which includes a frequency range from 90 to 1000 GHz, and most of the research is being done in the 94, 140, and 240 GHz regions.

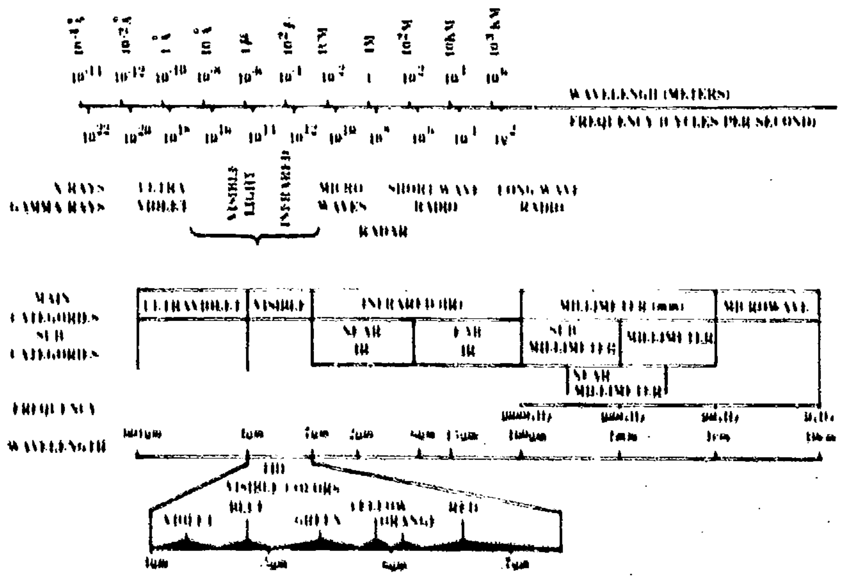


Figure 4.3. The electromagnetic spectrum (adopted after Cottrel, 1979).

4.2.2 Attenuation

Basic laws pertaining to attenuation have been developed over the years. The fundamental law of attenuation is known as Beer's law (sometimes referred to as Bouguer's or Lambert's law). When radiation of one wavelength (monochromatic) is transmitted a short distance through an absorbing medium, a certain part of the radiation is absorbed. Beer's law states that the fraction absorbed is directly proportional to the density of the medium and the distance the radiation traveled through the medium. A number that is indicative of the amount of radiation absorbed in the medium (usually the atmosphere) is called the absorption coefficient. Similarly there exists a scattering coefficient related to the amount of radiation scattered from the line of sight. The extinction coefficient is the sum of the absorption and scattering coefficients. In technical reports involving optical properties of fog and clouds, graphs or plots of the extinction coefficient versus various parameters (such as extinction coefficient at different wavelength, particle radius, or liquid water content) are often presented.

The main causes of atmospheric attenuation are absorption and scattering by molecules and aerosols such as smoke, fog, and haze particles. Scattering in the atmosphere is largely due to reflection and refraction, or a combination of these effects, and will be explained later in more detail.

Near the earth's surface, the principal gaseous absorbers for the infrared radiation are water vapor and carbon dioxide (figure 4.4). Ozone (O_3), found mostly at high

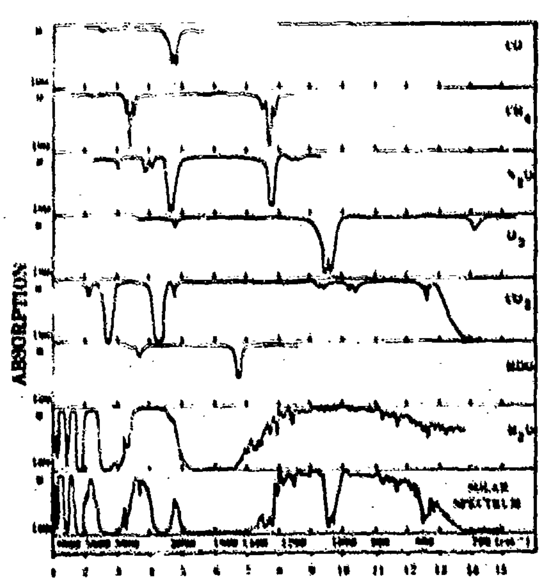


Figure 4.4. Comparison of the near-infrared solar spectrum with various atmospheric gases (from Handbook of Geophysics, 1965).

altitude, absorbs in the 9.6µm wavelength and is the main absorber in the so-called "atmospheric window" that is found in the 8µm to 12µm interval. Ozone also absorbs in the ultraviolet region near 0.25µm. Water vapor varies greatly in time and location due to different air mass characteristics and movements as well as meteorological occurrences such as hurricanes, rain, and thunderstorms. The individual absorbers in the 1µm to 15µm interval, along with the solar spectrum, are shown in figure 4.4. A 100 percent absorption means that, due to particular atmospheric gases, none of the sun's energy, or electromagnetic radiation, is reaching the earth's surface at that particular wavelength.

4.2.3 Scattering

It was not until nearly the turn of the century that Lord Rayleigh demonstrated that the color of the sky was due to the scattering of sunlight by molecules found in the atmosphere. An almost pure atmosphere appears blue, while one that contains haze, dust, etc., appears grayish.

Scattering is often considered to be one of two types--Rayleigh or Mie. When the scattering particles are smaller than the wavelength, the scattering is called Rayleigh. Mie scattering occurs for larger particles such as those occurring in haze, clouds, fog, and dust. The particle sizes of dust and smog and their relative size to wavelengths are shown in figure 4.5. The amount of Rayleigh

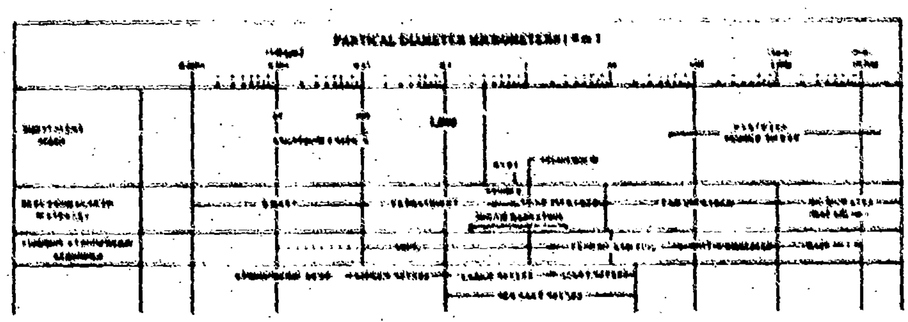


Figure 4.5. Comparison of particles in the atmosphere to the electromagnetic spectrum.

scattering varies with the fourth power of the wavelength, and this variance is the main reason why a clear sky is predominantly blue and not the color of sunlight. Rayleigh scattering is more dependent upon wavelength than Mie scattering. Effects of Mie scattering on transmission may be quite large in the intermediate and far infrared where Rayleigh scattering is the predominant effect for visible and ultraviolet down to 0.3μm.

Multiple scattering is another phenomenon that one should be aware of. When a scattered light beam, or electromagnetic radiation, falls on another particle, it is again scattered (secondary scattering), and so on (multiple scattering). Extreme cases of scattering occur in dense fogs when a strong beam of light tends to reach an observer from all directions.

Absorption and scattering are similar only in that both remove radiation (or a portion of light from a light beam). Scattering is explained in terms of wave theory of light, and it produces no net change in the internal energy states of the molecules. In contrast, absorption causes the molecule to become excited and go to a higher energy state or to relax to a lower energy state.

Due to differences in temperature and atmospheric pressure, air is circulated over the earth. Generally, good weather is found in high pressure areas, while clouds and low visibility are highly correlated with low pressure areas. The atmosphere is in continuous motion and the atmospheric gases are continuously mixing. Interaction between the air and land is discussed in chapter 7.

4.3 THE ATMOSPHERE

The interaction between electromagnetic radiation and matter found in a clear atmosphere may be classified as emission or attenuation (extinction). Emission occurs whenever there is an increase in radiation along the path of propagation. Attenuation occurs if there is a decrease of radiation.

To gain a better understanding of the interaction between electromagnetic radiation and the clear atmosphere, a brief description of the composition and structure of the clear atmosphere should be considered.

The earth's atmosphere is characterized into different layers according to its temperature structure (figure 4.6). The lowest layer, the troposphere, varies in depth

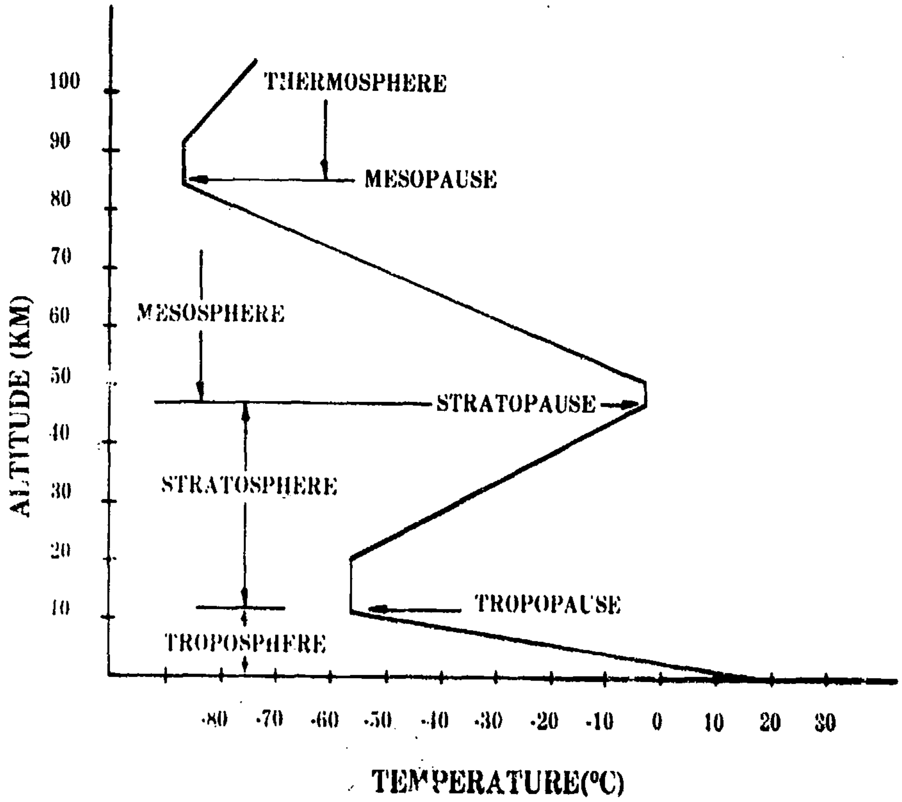


Figure 4.6. Temperature-altitude profile for the US standard atmosphere, 1976 (Dubin, Hall, Champion).

from 6 km over the poles to 18 km over the equatorial regions. The troposphere contains almost all of the weather common to man such as thunderstorms, snow, fog, wind, and dust storms, and is the region in which the obscuration factors are generated. A temperature decrease of approximately 6.5°C per km normally exists in the troposphere. Whenever an increase of temperature with altitude occurs, an inversion exists. An inversion can be caused by cooling of a layer of air; either by advancing cool air, nighttime cooling at the surface, or by the warming of a layer of air above the ground (figure 4.7). Cooling of the air at ground level is depicted by figure 4.7a; an inversion aloft is illustrated by figure 4.7b.

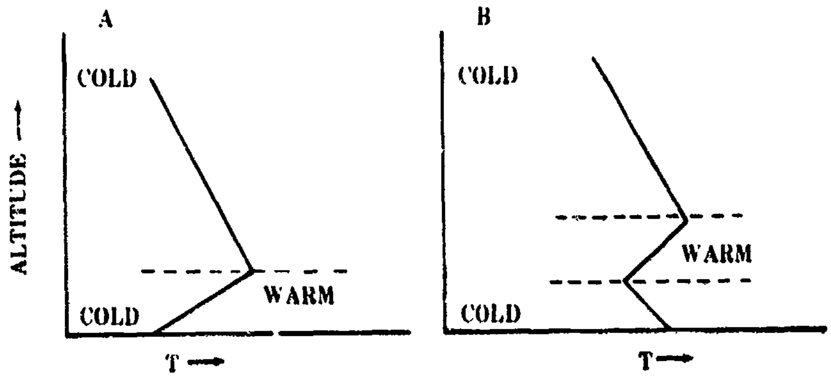


Figure 4.7. Temperature profile against altitude, showing temperature inversion near ground in A and aloft in B.

An inversion aloft can be caused by strong surface winds mixing the lower levels of the air while cooling is occurring or by subsidence (sinking) of the air. Subsidence causes compression of the air, which in turn causes the air to become warmer. Inversions are important in obscuration work as an inversion will tend to stabilize the air and will actually "cap off" or impose a lid upon the underlying atmosphere.

The stratosphere is the second layer above the earth's surface and is characterized by an increase of temperature with height. Ozone is found here and protects us from most of the solar ultraviolet (UV) rays. The absorption of solar UV rays causes the temperature increase in this layer. The stratosphere contains winds with speeds far in excess of winds found in the troposphere and it cannot be classified as a stable zone even though the temperature usually increases with height.

The third layer is the mesosphere and is characterized by a temperature decrease of about half that found in the troposphere, -3°C per km. The mesopause is the coldest part of the atmosphere, about -90°C. Ionization and molecular dissociation processes and various chemical reactions caused by the sun's radiation occur in the mesosphere.

The thermosphere begins near 80 km altitude where the temperature increases again with altitude. The temperature obtained in the thermosphere is highly variable, depending upon time of day, latitude, and solar activity.

As mentioned earlier, the troposphere contains most of the constituents that are of interest to the Army in determining the atmospheric effects on E-O weapon systems. Table 4-1 lists the permanent gases found in the atmosphere and their volume ratios.

TABLE 4-1. ATMOSPHERIC GASES AND THEIR VOLUME RATIOS

Gases	Volume Ratio (%)
Nitrogen	78.084
Oxygen	20.948
Argon	0.934
Carbon dioxide	0.0314
Neon	180×10^{-5}
Helium	52×10^{-5}
Krypton	10×10^{-5}
Hydrogen	5×10^{-5}
Xenon	0.8×10^{-5}
Ozone	0.1×10^{-5}

4.4 METEOROLOGICAL FACTORS

Meteorological parameters that contribute to the degradation of E-O sensor performance in a clear atmosphere are temperature, wind, absolute humidity, relative humidity, and turbulence. Other factors that are related to meteorological conditions are absorption and scattering by molecules and aerosols and contrast and illumination of the target and background. These parameters are shown in figure 4.8. Visibility is discussed in the appendices.

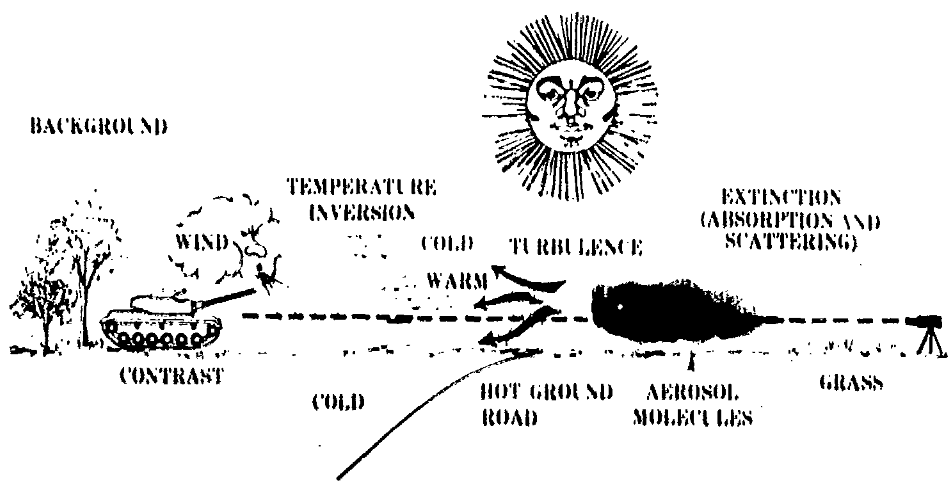


Figure 4.8. Clear atmosphere obscuration factors.

4.4.1 Temperature

Variations or changes of temperature are usually much greater in the vertical than in the horizontal. Normally, temperature decreases with altitude at a rate of 6.5°C/km, but a temperature difference of that magnitude rarely occurs in the horizontal. Changes in temperature produce changes in the density of the atmosphere which in turn produce changes in the refractive index. (Studies have shown that changes in the index of refraction have more effect in the longer wavelengths near 10.6μm than those near 0.55μm.

Temperature is important in determining target and background contrast in the infrared systems. Under certain conditions, a target could be colder than its surroundings and provide a reverse image which would not be expected. For example, a tank that has been sitting still at night could cool off quicker than a rock fence or a wooded area in the background.

A temperature inversion can act as a "lid" in the atmosphere so that aerosols and particles that would normally be distributed over a greater depth are not. This lack of distribution causes an increase in the number of particles found in a given volume, and this increase reduces visibility and degrades the performance of both visual and infrared type sensors. The number of particles found in a given volume (cubic centimeter for example) is the concentration of that particle and is a term that is frequently used. Concentrations in the hundreds are found in rural areas, while counts exceeding 10,000 and 100,000 per cubic centimeter are found in urban air samples and immediately downwind from industrial sources of pollution. A relationship seems to exist between the particle concentration and the attenuation coefficient. For example, if the number of particles increases, so does the attenuation coefficient. The sizes of particles found in the atmosphere are shown in figure 4.5.

The heating of the surface of the earth causes the earth's surface to reradiate heat back into the atmosphere. This phenomenon can be seen during a hot summer day whenever a distant object appears to be wavering or shimmering. This effect is often referred to as terrestrial scintillation and is considered to be optical turbulence.

Another type of turbulence caused by the high temperature is convective turbulence. Convective turbulence effects are of larger scale than optical turbulence effects and are experienced in the afternoon by light aircraft pilots with aircraft up to 5000 ft above the ground. The combination of these two types of turbulence causes the radiation beam to experience different refractive indices over a short distance, giving rise to scintillation and changing the characteristics of the beam in terms of its angle of arrival and phase shifts. All E-O systems seem to be affected to some degree by turbulence. A basic measure of turbulence is the structure constant, C_n^2, read as C sub n squared. Once C_n^2 is determined then one can calculate the amount of beam wander and spreading.

4.4.2 Wind

Wind is defined as air in motion and is caused by pressure and temperature differences. Winds usually flow from relatively cold to hot areas and from high to low pressure systems (figure 4.9). The larger the pressure or temperature difference, the stronger the wind. Wind that is flowing over uneven terrain can cause turbulence which in turn scatters the energy beam to a certain extent.

The amount that the wind scatters the beam is related to the windspeed and wind direction, with winds perpendicular to the beam having the most effect. This phenomenon has been used to remotely determine windspeeds by laser radar (lidar). What is really obtained is a "path averaged" wind from the transmitter to the target, but this average is sufficient for battlefield applications such as ballistics.

Figure 4.9. Wind flowing from high to low pressure (a), from cool water over warm land (b), and from cool land to warm water (c).

Wind is responsible for transporting particulates and aerosols into a target area, thus degrading the E-O weapon systems. Likewise, wind can improve the effectiveness of E-O weapon systems by transporting particulates and aerosols, caused by haze over a city or a point source such as smoke, out of an area of interest, particularly when the visibility is less than 5 km.

Wind disperses smoke, and a strong wind can make smoke totally ineffective in a short period of time. The transport of smoke can be effective, however, if the battlefield commander desires the smoke to provide cover for moving troops or equipment.

Blowing dust, sand, or snow is another obscuration factor caused by wind. Dust can be lifted to 10,000 ft or more above the earth's surface and cover thousands of square miles during a severe dust storm. This condition not only degrades surface weapons but also affects air-to-air and air-to-ground systems.

4.4.3 Absolute Humidity

The amount of moisture in the atmosphere is commonly referred to as humidity. While the relative humidity is utilized by the general public, absolute humidity gives a better indication of the actual amount of water vapor (or moisture) that is in the atmosphere. Both of these terms of humidity are defined in the glossary, and the differences should be established at this point. The amount of water vapor that a volume of air can hold depends upon its pressure and temperature. Relative humidity is defined as the ratio of the amount of water vapor in a volume of air to the maximum amount that the volume could hold for the existing temperature and pressure. Absolute humidity is the ratio of the mass of water vapor to the volume of the parcel of air containing it.

The amount of water vapor in the atmosphere influences many things--from the growth of aerosols (relative humidity) to making the air less dense and requiring more runway for an aircraft to take off (absolute humidity).

Water vapor absorbs in the visible and infrared regions, and the amount of attenuation is directly related to the amount of water vapor; that is, an increasing amount of water vapor in the path of the beam will decrease the amount of energy received at a target.

Water vapor has to have something to cling to or surround to form fog or rain drops. Those particles that are most favorable for the formation of fog and rain drops are minute haze or dust particles, usually having some salt in their composition, and are hygroscopic--that is, water will cling to them or will be absorbed by them. These atmospheric particles are called condensation nuclei and are produced by volcanic ash, cosmic dust, sea spray, forest fires, and from mass combustion processes, to name a few. The size and growth of the drop depend upon the amount of water vapor available and the frequency of collisions of the drops. Condensation nuclei are classified according to size, as shown in figure 4.5, with the smallest being atmospheric dust ranging upward to the giant nuclei.

CHAPTER 5

NATURAL OBSCURANTS

5.1 GENERAL GEOGRAPHICAL FEATURES

Climatic and weather variations in Germany are as extreme as the variations in terrain that exist over that region (Wallen, 1977). The north German lowlands are relatively flat and present no barrier to intrusions of maritime air and migrating cyclonic storms moving onto the continent from the Atlantic Ocean. The diversified topography of the central German highlands, characterized by low rolling mountains interspersed with long, winding river valleys, brings about a variety of natural subregions with climatic features of their own.

Acting as an effective block, but not an insurmountable barrier, to the flow of warm, moist air from the Mediterranean region into Germany, the Alps mountain range controls the climate of the Alpine forelands, including the valleys of the Danube River and its southern tributaries. This area is greatly influenced by orographic effects related to the predominant upslope wind flow from the north. In the mountainous areas of the Alps, considerations such as the shape of a particular valley and its exposure to wind flow play a decisive role in determining the local and generalized climate of the region.

5.2 SEASONAL WEATHER VARIATIONS

The major active pressure centers influencing the weather conditions over Germany are the Icelandic Low, the Azores High, and the alternating winter high and summer low pressure systems of Central Asia (2nd Weather Wing Pamphlet 105-12, 1970).

In winter, while the Azores High decreases in intensity and moves southward, the Icelandic Low (figure 5.1) intensifies and produces migrating storms that follow each other in rapid succession and result in the development of extensive cloud cover and precipitation over Germany.

Total cloud coverage of the sky often tends to persist for several days to a week because of a lack of strong

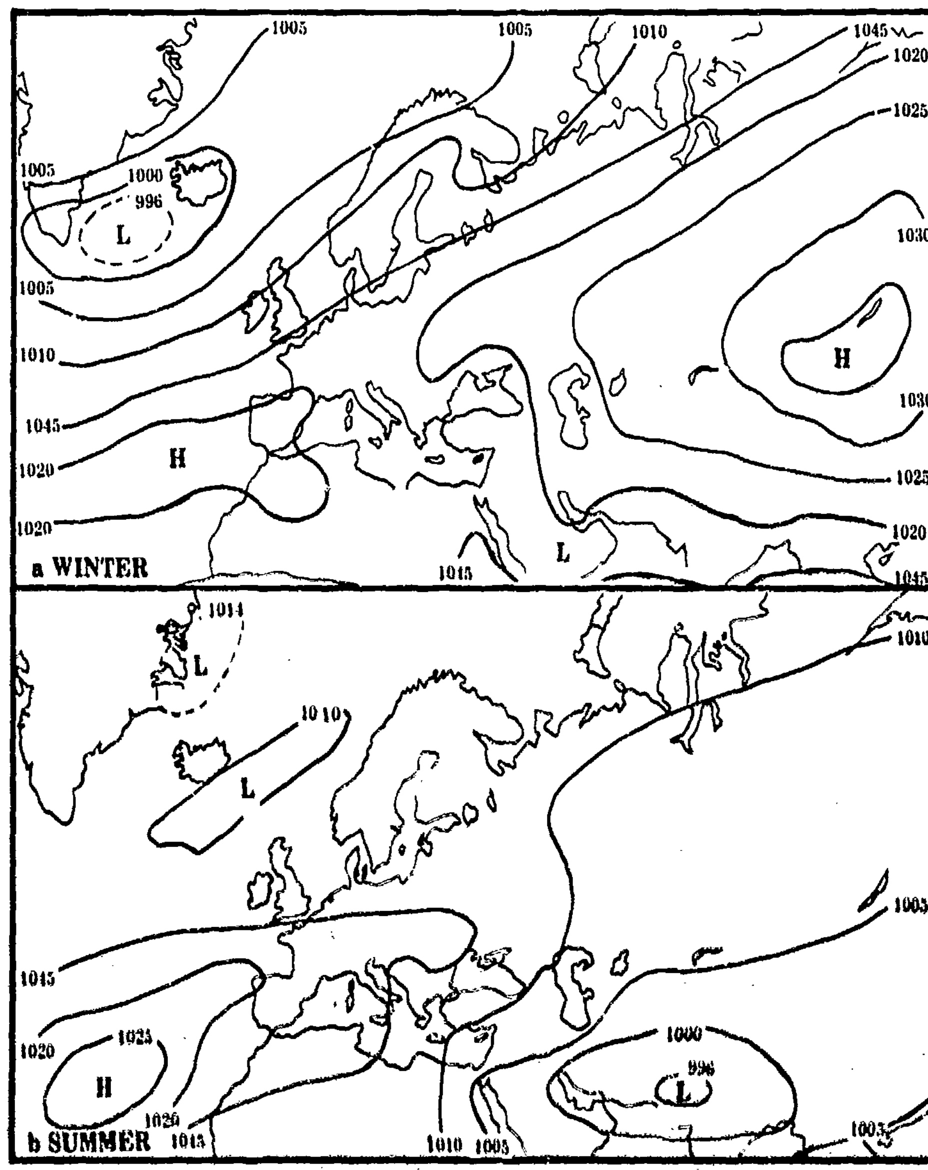


Figure 5.1. Mean winter and summer positions of the major semipermanent pressure centers (2WWP 105-12).

insolation (solar energy) from a low solar elevation angle at this time of the year. Between passages of these storms, high pressure cells of relatively short duration pass through the region, bringing good visibilities, partly cloudy skies, and occasional shower activity.

Migrating low pressure systems that form near the Bay of Biscay and move across the Mediterranean region to the Adriatic Sea can produce some of the poorest weather seen in Germany, particularly south of 50 degrees north latitude, with extensive low cloudiness and steady precipitation persisting for days.

The cold Siberian High over Asia also intensifies in winter and sometimes spreads westward into Germany, bringing either clear skies or very cloudy conditions and snow, depending upon the vertical depth of the cold air and the availability of sufficient overrunning moisture.

In the spring, the Icelandic Low decreases in intensity and the Azores High begins to build and push into central Europe. This is the period of extensive rainshower activity as the air becomes more unstable due to heating from a higher rising sun. A southerly flow of air now occurs frequently, bringing the first warm spells to the region as warm Mediterranean air is forced northward across the Alps. In some years this flow is strong enough to transport large amounts of dust from north Africa to central Europe.

In summer, the general air circulation is much weaker and less definite than in winter. The Icelandic Low has weakened considerably, the Siberian High has been replaced by relatively low pressure, and there is a marked absence of migrating lows in the Mediterranean area. Further intensification of the Azores High results in an extension of a high pressure ridge from the Atlantic into central Europe (figure 5.1) which not only brings fair skies and warm weather to the area under its influence, but also forms a rather effective block to the fairly weak migrating lows now entering the continent from the Atlantic. The development of early morning cloud strata is now easily modified by increased insolation from a much higher sun. As the air becomes unstable from increased heating, the layer clouds dissipate and scattered cumuliform clouds develop and build into thunderstorms during the afternoon.

Most of autumn brings the calm of an Indian summer, with pleasant and mild days interrupted only by frequent early morning fog. The main pressure centers gradually intensify, and by mid-November the four main pressure fields of winter are once again identifiable.

5.3 CLOUDINESS

The predominant airflow into Germany during all seasons is from the Atlantic Ocean. The high moisture content of this maritime air produces extensive cloudiness, particularly during the winter, and frequent precipitation which is heaviest in the summer season.

One atmospheric condition over Germany that approaches a steady state is cloudiness (Stakutis, 1977). Satellite imagery over central Germany has shown that clear to scattered (zero to three-tenths) cloud conditions occur about 30 percent of the time in summer and 10 percent of the time in winter; broken to overcast (seven- to ten-tenths) cloud cover prevails 50 percent of the time in summer and 70 to 80 percent in winter (figure 5.2). The remaining 20 percent of cloudiness in each season is left with four- to six-tenths coverage.

Low stratiform clouds over Germany occur in two or three layers between about 300 m and 2100 m above the ground. Under exceptionally humid conditions, these layers may merge and produce a seemingly compact vertical continuum.

Decreases in both cloudiness and precipitation have been noted over basin areas as the air descends on the lee side of the mountain slopes.

In Germany, low cloud ceilings, that is, the lowest height above the ground at which all cloud layers at and below that level cover more than half the sky, are especially prevalent during the winter (Crandall, 1977). Cloud ceilings over Germany during the winter months are below 300 m (1000 ft) about 20 to 30 percent and below 900 m (3000 ft) about 45 to 60 percent of all daylight hours (table 5-1). During summer, low ceilings are less common and the diurnal variation in ceiling height is much greater than cloud ceilings below 300 m occurring infrequently over the German lowlands.

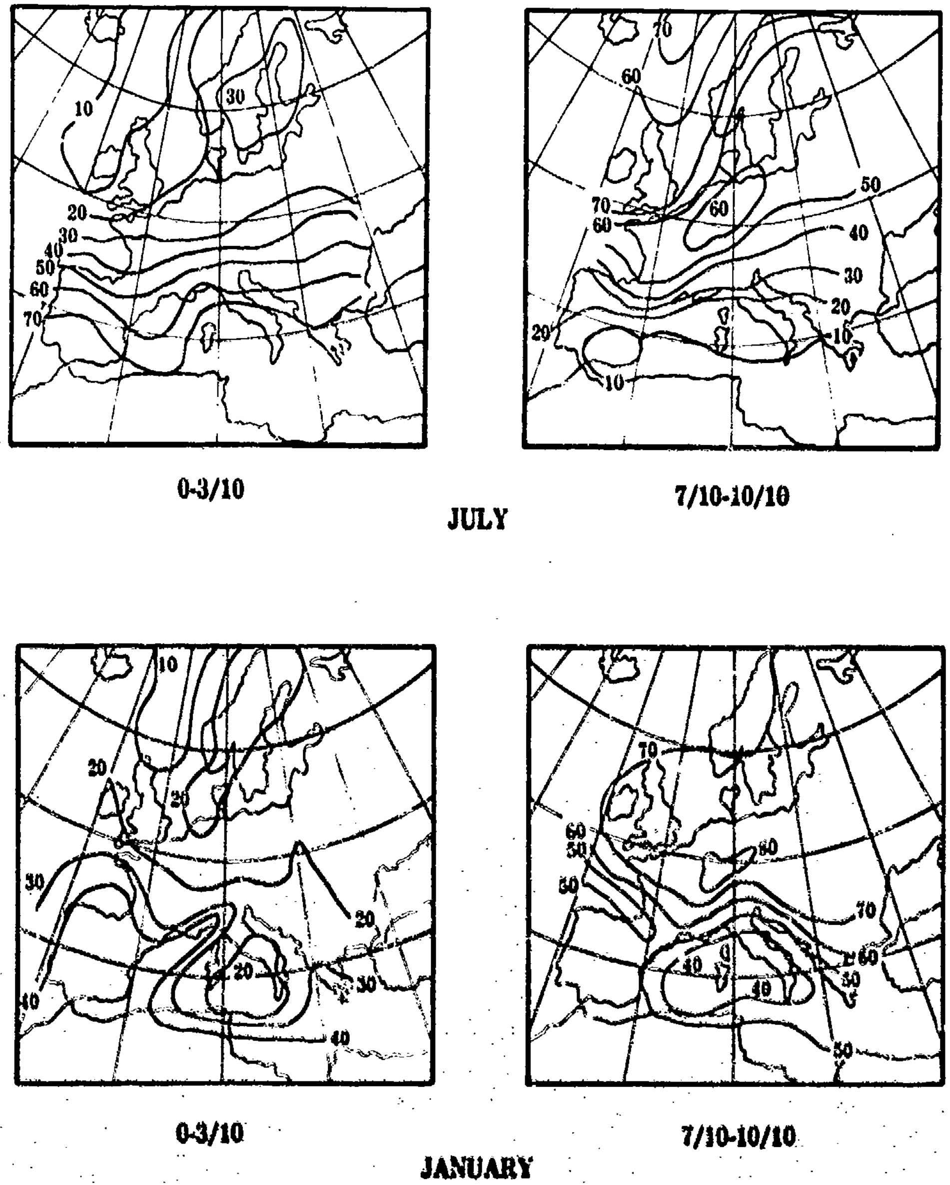


Figure 5.2. Percent frequency contours for specified cloud cover intervals (Stakutis, 1977).

TABLE 5-1. PERCENT FREQUENCY OF OCCURRENCE OF CLOUD CEILINGS BELOW SPECIFIED LEVELS - DAYLIGHT HOURS (CRANDALL, 1977)

(A) HANNOVER, GERMANY

	All	10,000 ft	5000 ft	3000 ft	2000 ft	1000 ft	500 ft
Jan	83.1	65.7	62.0	54.5	44.5	22.3	8.4
Apr	66.3	47.4	43.3	32.3	20.1	9.9	3.4
Jul	74.0	55.5	46.6	33.4	22.3	10.5	2.0
Oct	72.5	55.8	50.8	38.6	30.1	16.7	6.2

(B) NURNBERG/FURTH AFF, GERMANY

	All	10,000 ft	5000 ft	3000 ft	2000 ft	1000 ft	500 ft
Jan	80.4	67.3	57.9	44.2	32.7	17.3	4.2
Apr	70.9	53.1	42.7	15.0	14.3	5.3	1.2
Jul	62.1	48.7	32.2	15.0	7.8	3.6	0.6
Oct	66.2	52.4	42.6	30.5	22.3	12.7	6.2

(C) HAMBURG, GERMANY

	All	10,000 ft	5000 ft	3000 ft	2000 ft	1000 ft	500 ft
Jan	81.7	71.0	67.0	57.9	48.3	31.0	12.8
Apr	69.1	50.8	47.5	32.8	22.8	14.7	4.9
Jul	73.4	47.2	38.4	20.6	12.8	6.4	1.7
Oct	75.2	56.1	51.9	37.8	27.4	18.0	8.1

(D) FULDA AAF, GERMANY

	All	10,000 ft	5000 ft	3000 ft	2000 ft	1000 ft	500 ft
Jan	82.5	77.3	66.8	56.3	46.4	23.2	7.1
Apr	75.2	65.4	51.3	36.6	20.4	8.0	2.4
Jul	67.5	57.5	38.3	18.5	10.0	4.3	1.4
Oct	72.1	63.5	52.8	40.3	31.9	19.5	13.1

Clouds in this region tend to occur in either very small or very large amounts, particularly in the lower levels, based upon data from two locations in Germany. During the daylight hours in January, zero to two-eighths, or about zero to three-tenths, of cloud cover occurred at altitudes below 1000 m approximately 50 percent of the time at Munich and 35 percent of the time at Kassel, whereas six- to eight-eighths of coverage occurred approximately 40 percent of the time at Munich and 60 percent of the time at Kassel (table 5-2). Locations of some of the German weather stations are shown in figure 5.3.

In contrast, during the daylight hours in July, zero to two-eighths of cloud cover occurred at altitudes below 100 m about 65 percent of the time at Munich and 60 percent of the time at Kassel, while six- to eight-eighths coverage occurred about 20 percent of the time at Munich and 30 percent of the time at Kassel.

TABLE 5-2. PERCENT FREQUENCY OF CLOUD COVER BELOW SPECIFIED LEVELS - DAYLIGHT HOURS (CRANDALL, 1977)

(A) MUNICH, WEST GERMANY

Level	Month	0-2 eighths	3-5 eighths	6-8 eighths
Total Sky	Jan	17.6*	10.6	71.9
	Apr	20.9	18.1	61.2
	Jul	30.2	21.1	48.8
	Oct	30.2	14.6	55.3
4920 Ft	Jan	47.4	10.0	42.7
	Apr	45.9	22.0	32.0
	Jul	53.7	24.4	21.8
	Oct	55.7	12.0	32.3
3280 Ft	Jan	51.6	8.4	40.1
	Apr	53.3	16.3	30.3
	Jul	63.3	17.4	19.3
	Oct	59.6	9.9	30.5
984 Ft	Jan	76.0	1.6	22.3
	Apr	89.5	1.5	8.9
	Jul	95.8	1.1	3.0
	Oct	80.9	2.3	16.8

(B) KASSEL, WEST GERMANY

Level	Month	0-2 eighths	3-5 eighths	6-8 eighths
Total Sky	Jan	10.1	7.7	82.3
	Apr	18.8	15.0	66.4
	Jul	16.8	19.3	63.9
	Oct	18.2	12.5	69.4
4920 Ft	Jan	24.4	11.0	64.7
	Apr	37.4	20.4	42.3
	Jul	36.1	26.0	37.9
	Oct	35.2	13.8	51.0
3280 Ft	Jan	33.9	7.8	58.5
	Apr	53.5	10.9	35.5
	Jul	60.2	11.4	28.4
	Oct	43.7	10.0	46.4
984 Ft	Jan	94.1	0.1	5.7
	Apr	97.6	-	2.4
	Jul	98.3	0.1	1.7
	Oct	89.0	0.2	10.7

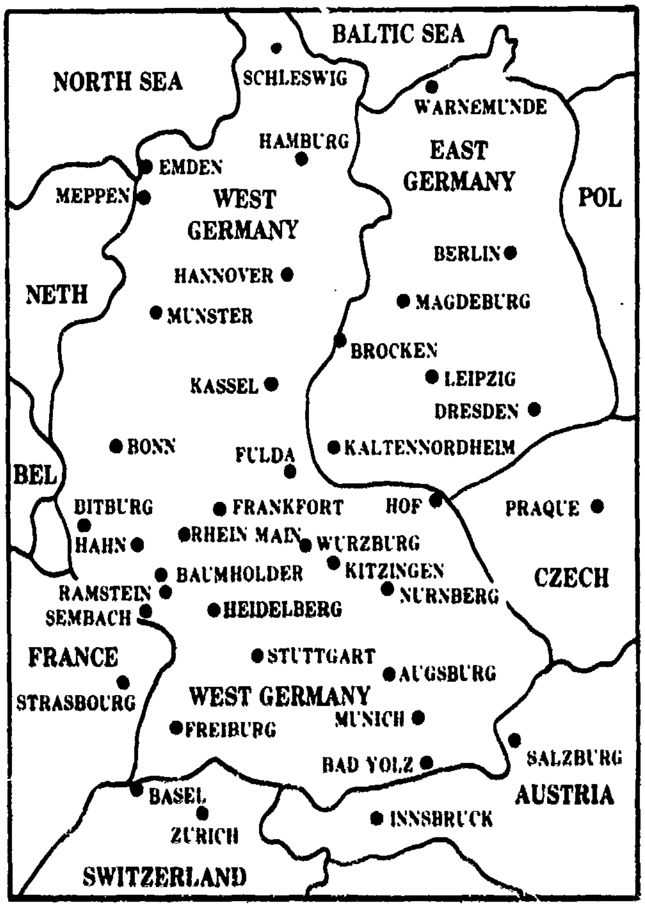


Figure 5.3. Locations of Germany weather reporting stations.

The persistence of cloud ceilings below an altitude of 900 m and/or visibilities less than 5 km during different seasons is shown in table 5-3.

Air-to-ground missions require that any existing clouds be above a specified level above the ground, depending upon the type of aircraft and weapon. For instance, the US Air Force requires a ceiling of at least 3500 ft and visibility of 3 mi for a night delivery of an Infrared Maverick. A coverage of zero to two-eighths of clouds below a minimum delivery level will generally allow a successful completion of an

TABLE 5-3. PERCENT OF TIME THAT CLOUD CEILINGS BELOW 900 M (3000 FT) AND/OR VISIBILITIES BELOW 5 KM (3 MI) PERSISTED FOR SPECIFIED NUMBER OF HOURS AFTER INITIAL OCCURRENCE (CRANDALL, 1977)

Month	Percent of Time Condition Occurred During Month	Percent of Time Condition Persisted for This Many Hours after Occurrence												
		(A) KITZINGEN (PERIOD OF RECORD 1966-1976)												
		3	6	9	12	15	18	21	24	30	36	42	48	60
January	53	88	73	61	52	46	41	37	33	26	21	18	15	11
April	19	57	34	22	14	9	7	6	5	3	2	2	2	2
July	10	42	18	9	7	5	5	4	4	3	2	1	1	0
October	39	78	59	45	34	28	23	20	17	13	11	10	9	7
		(B) KASSEL, WEST GERMANY												
January	63.3	83	73	65	58	51	46	41	38	32	28	23	19	14
April	25.9	62	42	29	20	14	10	8	6	4	2	1	1	0
July	16.7	54	32	17	8	4	1	--	--	--	--	--	--	--
October	48.9	77	63	52	40	31	25	20	18	14	10	7	6	4

air-to-ground mission, assuming that the terrain does not restrict maneuverability. A coverage of three- to five-eighths of clouds below this level leads to uncertainty of successful completion, while a coverage of six- to eight-eighths will likely cancel or cause the mission to be unsuccessful.

As seen in table 5-1, ceilings during the winter months are below 3000 ft roughly 45 to 60 percent of the daylight hours. Since daylight occurs only 35 to 40 percent of a 24-hour day during the winter, the weapon with a 3000-ft ceiling limitation can be employed only about 15 to 20 percent of the time, based on ceilings alone. Minimum visibility conditions will further decrease these percentages.

On the other hand, Army helicopters operate as low as possible to avoid enemy weapons and detection. Clouds below 250 ft above the ground and visibility less than 1/4 mi prohibit helicopter operations.

Low clouds and visibility also restrict ground-to-air operations to the extent that visual sighting of aircraft or targets cannot be made from the ground. If moderate or heavy precipitation is occurring, then in all probability, operation of infrared and radar systems will be degraded.

5.4 FOG

Fog is the primary cause of visibility restriction throughout Germany. The abundance of condensation nuclei caused by minute smoke and water particles in the more heavily populated and industrialized sections of Germany results in a rather high frequency of fog and haze which has a marked seasonal variation and, to a lesser extent, a diurnal variation.

During the winter, fog is found about 30 days in the northwest portion of West Germany and about 20 days over most of the remainder of the region. Much of the winter fog in the interior of Germany occurs as radiation fog which generally reaches a maximum near sunrise. Germany has rather long nights and short days in late autumn and winter which, along with some snow cover, provide the necessary radiational cooling for fog formation.

However, near the north German coast, the persistence of cloud cover and lack of snow retard strong radiational cooling. Fog in that area is advective in nature, moving in overland after forming over the water. Its maximum frequency occurs in late winter and early spring when temperature differences between the water and land are the greatest.

The stagnation of cold moist air causes a high incidence of fog in the river valleys which are frequently shrouded with fog during the winter. In the higher terrain of central

Germany, radiation fog forms in the valleys and then flows to the surrounding hills. Radiational cooling favorable for fog formation is greatest in the Alpine valleys of Bavaria due to the apparent shorter daylight hours, that is, later sunrise and earlier sunset, related to the higher mountainous terrain.

Toward late spring the frequency of occurrence of poor visibilities due to fog decreases rapidly in most of the central highlands, Alpine forelands, and Bavarian Alps. During the summer season, fog is mostly confined to the hours around sunrise.

Many of the characteristics of winter fog apply during the latter part of the autumn season which is one of the foggiest times of the year in Germany. The diurnal and seasonal characteristics of fog and mist occurrence as reported obstructions to vision at Frankfurt/Main are shown in table 5-4.

TABLE 5-4. PERCENT FREQUENCY OF OCCURRENCE OF FOG

FRANKFURT/MAIN, GERMANY

	00	03	06	09	12	15	18	21
JANUARY	18.3	19.5	20.4	25.0	16.0	13.1	16.5	18.1
APRIL	5.0	9.3	13.0	3.1	0.4	0.1	0.5	1.1
JULY	5.1	12.3	15.6	1.4	0.6	0.2	0.7	1.7
OCTOBER	24.5	27.5	31.3	24.2	8.2	6.3	15.6	20.0

PERIOD OF RECORD: January 1966 - March 1977. Hours are in Greenwich Mean Time.

5.5 PRECIPITATION

Precipitation is frequent, although not excessive, throughout most of Germany, as shown by the monthly mean amounts and number of days of precipitation for various locations (table 5-5).

TABLE 5-5. MEAN MONTHLY AMOUNTS AND NUMBER OF DAYS WITH PRECIPITATION GREATER THAN 0.01 IN (CRANDALL, 1977)

		J	F	M	A	M	J	J	A	S	O	N	D	A
Hamburg	Amt (in)	2.1	1.9	2.0	1.8	2.1	2.7	3.4	3.2	2.5	2.6	2.1	2.1	28.9
	Days > 0.1 in	7	6	6	6	6	7	8	8	7	7	6	8	82
Hannover	Amt (in)	1.7	1.4	1.6	1.5	2.0	2.7	3.0	2.7	1.8	1.9	1.7	1.9	23.9
	Days > 0.1 in	6	5	5	5	6	7	7	7	5	6	5	6	70
Kassel	Amt (in)	1.7	1.4	1.4	1.7	1.9	2.2	2.9	2.5	2.1	2.1	1.7	1.9	23.4
	Days > 0.1 in	6	5	5	5	6	6	7	7	6	6	5	6	70
Munich	Amt (in)	2.7	2.0	2.0	2.3	4.3	4.9	6.0	3.8	3.0	1.7	2.3	1.9	36.8
	Days > 0.1 in	7	6	6	7	10	11	11	9	7	5	6	6	91

Most of the region receives approximately 500 to 1000 mm (20 to 40 in) of precipitation per year, with the higher elevations generally receiving more. Summer is the season of maximum precipitation with about 200 or 300 mm (8 to 12 in) expected at most locations. In fact, the onset of summer in June, which brings an alternation of continental heating and cold maritime air intrusions that result in concentrated "downpours" of rain of relatively short duration, that is, less than an hour or two, has been called the "European Monsoon" period.

Rain will typically occur on about half of the days during the summer season, but amounts greater than 10 mm (0.4 in) occur on only about 2 to 4 days each month. Average monthly rainfall in the region approaches 75 mm (3 in) during the summer.

Winter precipitation amounts are generally less at 125 to 200 mm (5 to 8 in) for the season. Light precipitation falls frequently during the winter half of the year because there is not enough solar energy to lift the air to more productive condensation levels. Occurrences of precipitation amounts greater than 10 mm (0.4 in) are typically seen only 1 or 2 days per month.

Light to moderate snow generally falls over most of the region from November into April; most of the snow over the northern lowlands occurs between December and March.

Usually monthly average precipitation amounts of about 50 mm (2 in) are expected in the northern lowlands and extending into the German interior. Exceptions to this relatively even distribution of light precipitation occur toward the Bohemian plateau and Alpine ranges. There a secondary precipitation maximum of up to 100 mm (4 in) in a month occurs during the winter, with snow accumulations of more than 4 ft on the higher mountain crests.

In the German Alpine forelands, the mean annual precipitation amounts increase from 650 to 700 mm (about 25 to 27.5 in) in the Danube River Valley to more than 1000 mm at the base of the Alps. The highest peaks in the Bavarian Alps have average annual precipitation amounts of more than 2500 mm (100 in). Mountain valleys which are oriented from west to east receive considerably less precipitation due to orographic effects than the north to south oriented valleys.

5.6 THUNDERSTORMS

The convective heating of moist, unstable air flowing in from the Atlantic and forced mechanical lifting provided by the rough terrain cause thunderstorm activity to start in Germany in late April or early May and to increase rapidly as summer approaches.

By the end of spring, thunderstorms are observed on 2 to 6 days per month and are generally more numerous in the German interior away from the flat coastal area. Early summer is the time of maximum thunderstorm occurrence throughout Germany. Most locations average about five to eight storm days per month (table 5-6), with the diurnal maximum occurring in the afternoon hours when convective heating is strongest. Although generally of short duration, these thunderstorms can be extremely violent, producing heavy rainfall and sometimes hail.

Thunderstorm activity over Germany decreases rapidly during August and September; and by the end of autumn, thunderstorms occur less than once each month in most parts of the region. Because of the lack of sufficient solar heating, thunderstorms are seldom observed in Germany during the winter season; the few that do develop are associated with strong frontal activity moving across the region.

TABLE 5-6. MEAN NUMBER OF THUNDERSTORMS (CRANDALL, 1977)

	J	F	M	A	M	J	J	A	S	O	N	D	Ann.
Hamburg	0.3	0.3	0.6	2.0	3.4	3.8	5.3	4.7	1.6	0.5	0.3	0.3	23.1
Hannover	0.1	0.2	0.5	1.1	3.6	4.4	4.9	4.1	1.4	0.3	0.1	0.2	20.9
Kassel	0.1	0.1	0.5	1.1	3.7	5.0	5.3	4.6	1.3	0.2	0.1	0.1	22.1
HOF	0.0	0.3	0.3	1.0	4.0	4.0	5.0	4.0	1.0	1.0	0.0	0.0	20.6
Nurnberg	0.3	0.3	1.0	3.0	7.0	7.0	7.0	7.0	3.0	0.3	0.3	0.3	36.5
Munich	0.0	0.1	0.4	1.8	4.5	7.5	6.5	5.2	1.7	0.0	0.0	0.1	27.8

5.7 EFFECTS OF NATURAL OBSCURANTS ON E-O SENSORS

Electromagnetic radiation is energy that propagates through space, the atmosphere, and other media in the form of an advancing wave in the ambient electric and magnetic fields (Cottrell et al, 1978). Atmospheric gaseous molecules and particulates (dusts, hazes, smokes, fogs, other aerosols, cloud droplets, and precipitation) affect the propagation of radiation. The types and sizes of these atmospheric constituents and the wavelengths of the radiation determine their influence.

Table 5-7 describes the relative importance of the various extinction (that is, scattering and absorption) processes as a function of wavelength for various meteorological conditions. Note that molecular extinction applies only to water vapor; aerosol extinction processes apply to aerosols and to liquid or frozen precipitation which attenuate radiation by scattering processes. Infrared values apply to the two atmospheric windows centered near 4μm and 10μm. Millimeter wave and microwave values apply to windows at 19, 37, and 94 GHz. The importance of each process cannot be quantified precisely in general terms; the information provided is intended to highlight the importance of various extinction processes at each wavelength interval under different meteorological conditions.

TABLE 5-7. IMPORTANCE OF VARIOUS EXTINCTION PROCESSES FOR DIFFERENT WAVELENGTH INTERVALS UNDER VARIOUS METEOROLOGICAL CONDITIONS

	MOLECULAR ABSORPTION			MOLECULAR SCATTERING		
	Visible	Infrared	Millimeter Microwave	Visible	Infrared	Millimeter Microwave
Low Absolute Humidity	N	L	N	L	N	N
High Absolute Humidity	N	H	L-M	L	N	N
	AEROSOL ABSORPTION			**AEROSOL SCATTERING**		
	Visible	Infrared	Millimeter Microwave	Visible	Infrared	Millimeter Microwave
Dry Haze	L	H	N	H	N	N
Wet Haze	L	L	L	H	L-M	N
Dust	N	L	L	H	L	N
Fog	L	M	L	H	L-M	N
Thin Clouds (Cirrus)	L	M	L	H	M	M
Thick Clouds (Cumulus)	L-M	M-H	M	H	H	L
Precipitating Clouds with High Liquid Content	L-M	M-H	M	M	H	H
Drizzle	L	M	L	H	M	L
Rain	L	M-H	M	M	M	M
Heavy Rain	L-M	M-H	M-H	H	H	H
Snow	L	M	L-M	H	H	L

Legend: N-negligible; L-low; M-moderate; H-high

5.7.1 Visual Systems

Television sensors and the human eye cannot see through clouds (including dense fogs). Hence, a cloud-free line of sight (CFLOS) between the target and the sensor is essential. Reduced visibility due to scattering and absorption by haze, fog, and precipitation further limits the capabilities of visible systems.

5.7.2 Infrared Systems

In general, laser sensor systems operating at various infrared wavelengths and passive infrared systems require a CFLOS to the target. However, a laser beam can sometimes penetrate thin clouds with enough energy to be detected, and passive infrared systems may detect very hot targets (for example, rocket exhaust) through thin clouds. As with visual systems, the transmission of energy at near infrared wavelengths will be degraded by haze, fog, and precipitation. In addition, systems operating at longer infrared wavelengths are degraded by the absorption of infrared energy by atmospheric water vapor. These systems will generally require a clear LOS to the target.

5.7.3 Millimeter Wave/Microwave Systems

Millimeter wave/microwave system performance may be degraded by two main atmospheric factors: precipitation and heavy clouds which contain large droplet distributions of near-precipitation sized particles.

CHAPTER 6

BATTLEFIELD OBSCURANTS

6.1 SOURCE OF OBSCURATION

In the midst of battle, there can be many types of obscuration (figure 6.1) which do not occur in the atmosphere in natural conditions. Some of these obscurants are put into the atmosphere intentionally and others come from activities or events in which obscuration was not intentional but occurred as a by-product.

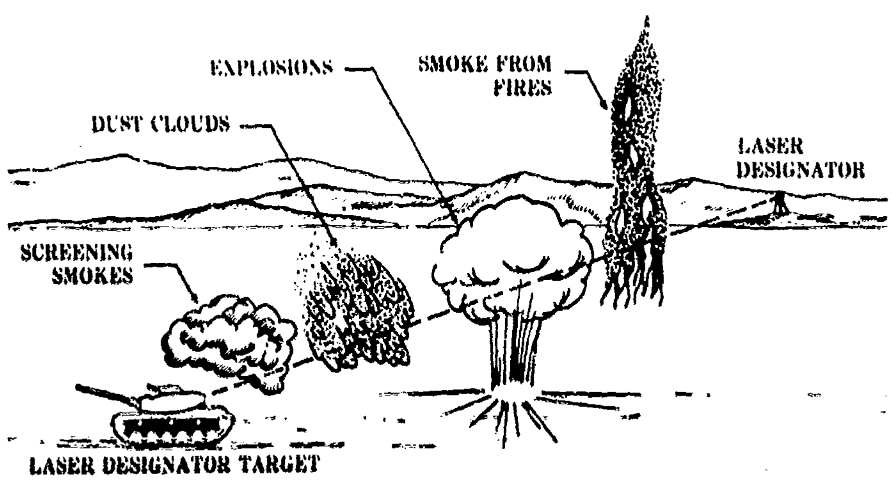


Figure 6.1. Example of obscuration factors in a battlefield scenario. This obscuration results from the presence of aerosols and turbulence from a variety of sources: dust from explosions, vehicles, and dust storms; screening smokes; fire smoke; and haze (Ebersole et al, 1979).

The main source of intentional obscuration is smoke used to hide one's own activities from the enemy or to obstruct the enemy's vision and interfere with his activities. Smoke can seriously affect the use of most infrared and visible sensors and, under the right conditions, cause obscurance for long periods of time.

Obscurations occurring unintentionally can be caused by the clouds of dust and debris from explosions, dust clouds and exhaust emissions from vehicles, blasts from firing large guns, and fires on the battlefield of vegetation, equipment, or other material.

While it is known that there are severe obscuring effects from battlefield activities, the magnitudes of these effects are generally not well known. There are and have been continuing efforts over the last few years to conduct field experiments to gain information about battlefield obscurants.

6.2 INTENTIONAL OBSCURANTS

Smokes, produced by inventory munitions and designed for specific screening purposes, are the major source of intentional obscurants. The major purpose for using screening smokes is to conceal one's own activities by obstructing the enemy's means of E-O communication, mainly by blocking radiation--including visible through infrared. In actual applications, because of their own internal radiant reflections and emissions, smoke clouds can also interfere with E-O devices by causing false signals or "noise" which tends to reduce the contrast between a target and its surroundings, thus making detection and recognition more difficult.

Typically, an application will require a smoke screen of some specified length, height, and time duration. On the modern battlefield where E-O sensors are operated at specific wavelengths, the wavelength(s) desired to be screened must be specified. For example, although hexachloroethane (HC), judging by the extinction coefficient (see glossary) is slightly more effective than white phosphorus (WP) at blocking wavelengths visible to the human eye (0.4μm to 0.7μm), WP is approximately three times more effective than HC at the infrared wavelengths in which many E-O devices, such as the forward looking infrared (FLIR) are operated. Other physical characteristics of the smoke source, such as the expected degree of buoyant rise, are significant for specific applications. For example, WP from standard fill munitions produces a very buoyant smoke which generally tends to rise, perhaps above levels which one desires to screen. On the other hand, HC produces a much less buoyant smoke which tends to remain entirely near the ground. In some circumstances, this could make HC more effective overall than WP although the latter may be more effective optically. In other circumstances, if one desires a smoke screen extended in height, WP, due to its buoyancy may be more desirable.

As indicated from the above examples, the degree to which given munitions are effective is very dependent upon local meteorological conditions and illumination. The four most important measurable variables are:

a. Windspeed and wind direction

b. Relative humidity

c. Wind and temperature stratification or stability (that is, Pasquill category)

d. Illumination (that is, sun and sky)

These four variables and how they affect smoke screening effectiveness will be discussed in the following paragraphs. It is convenient at this point to mentally divide the problem into two parts: the actual transport and diffusion of the smoke cloud itself, and the optical description of the resultant screen once in place. Transport and diffusion are governed mostly by the local meteorology and optical effects by the illumination, although both are affected by some common variables such as relative humidity. Since the munitions to establish a particular smoke screen are usually delivered remotely with artillery, a complete description here would include expected munition placement errors as influenced by existing meteorological conditions. This aspect will not be included here due to the general subjective nature of the problem which exists because of the participation of forward observers who feed back information which essentially serves to counteract these errors.

6.2.1 Windspeed and Wind Direction

The effect of the mean, or average, windspeed is simple and straightforward: it transports the overall cloud in the direction of, and at the speed of, the ambient wind. A more subtle, but equally important, effect is the random fluctuations of the wind about the mean speed and direction. These fluctuations are commonly referred to as turbulence, and this turbulence is the dominant mechanism which causes a smoke cloud to diffuse, or spread out, while being transported by the mean wind. In the absence of diffusion, the smoke cloud would remain essentially intact without changing in size or concentration (actually a small amount of molecular diffusion also occurs, but its effect as compared to turbulence is negligible). With turbulence, smoke clouds diffuse rather rapidly, becoming less and less concentrated until finally dissipating altogether. This turbulence effect can be seen in continuous recordings of windspeed and wind direction as rapid fluctuations about the mean, and the magnitude of these fluctuations can be taken as a qualitative measure of the degree of turbulence in the ambient wind field. Figure 6.2 shows an example of a wind recording indicating the presence of turbulence. This effect is usually most pronounced in the daytime during what is termed as unstable conditions (Pasquill categories A, B, and C) and is usually very significantly diminished at nighttime (stable conditions, Pasquill categories E and F). The magnitude of the fluctuations is also very much influenced by the nature of the underlying terrain, being much more pronounced over hilly than flat terrain.

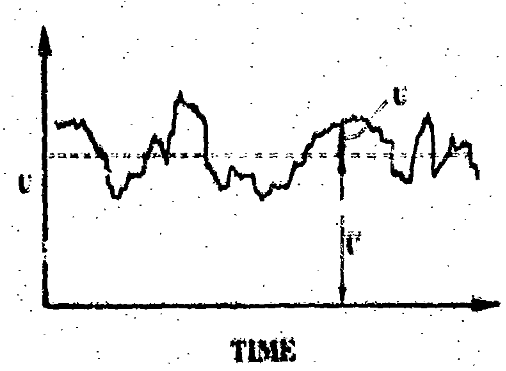


Figure 6.2. Windspeed showing effects of turbulence (Pasquill, 1974).

In summary, we can expect smoke clouds to be more rapidly dissipated over rough terrain than over smooth and in general to be more rapidly dissipated during daytime than nighttime. Superimposed on this is an overall transport of smoke in the direction and at the speed of the mean wind. Added to this is motion upward due to buoyance (to be treated in later paragraphs). A quantitative description of the mechanisms discussed here, using empirical techniques, has recently been prepared by Hansen (1979).

6.2.2 Relative Humidity

Certain smokes such as WP and HC are characterized as hygroscopic, which means that their constituent particles attract water vapor and form small water droplets with the smoke particles acting as nuclei. After being released by the initial munition reactions, these particles will grow by absorbing water vapor from the ambient atmosphere. The degree to which this growth takes place is dependent upon the supply of water vapor from the surrounding air and thus upon the ambient relative humidity. Fog oil, by contrast, is not hygroscopic.

The overall effect here is two-fold: to increase the "effective" mass (and therefore density and concentration) of the smoke due to the absorbed water, and to alter the optical properties of the smoke. The optical effect is not simple since the absorbing and scattering behavior of water coated particles can be markedly different from those of either the dry particles or the water vapor separately.

The first effect (increased mass) is known to be very strong for WP and somewhat weaker for HC. A quantitative factor used to measure the water absorbing properties of hygroscopic smokes is the yield factor, which accounts for the increase in mass of a smoke material which results from its combination with atmospheric constituents such as water vapor. The yield factor (see appendix B) is defined as the ratio of the total mass of smoke produced to the mass of dry fill material and is a function of relative humidity. For phosphoric acid (H_3PO_4), which is the major active constituent of WP smoke, a yield factor of over 8 has been estimated for 95 percent relative humidity and about 3.5 at 5 percent relative humidity. This yield factor means that a WP munition would produce approximately $8 \div 3.5$ or approximately 2.3 times more smoke mass at 95 percent relative humidity than it would at 5 percent relative humidity. For zinc chloride ($ZnCl_2$), which is the major active constituent of HC smoke, the corresponding figures are 3.5 and 1.0 for relative humidities of 95 percent and 5 percent, respectively. Plots of yield factor as a function of relative humidity for several different smoke constituents are shown in figure 6.3.

The effect of yield factor on the optical properties of the resultant smoke is more complicated and less well-understood because the optical effects such as scattering and absorption are dependent not only upon the total mass of the smoke (or density) but also upon how the mass is divided up into different sized individual particles. Generally, smokes having the same density but containing smaller particles are less effective obscurants than are smokes

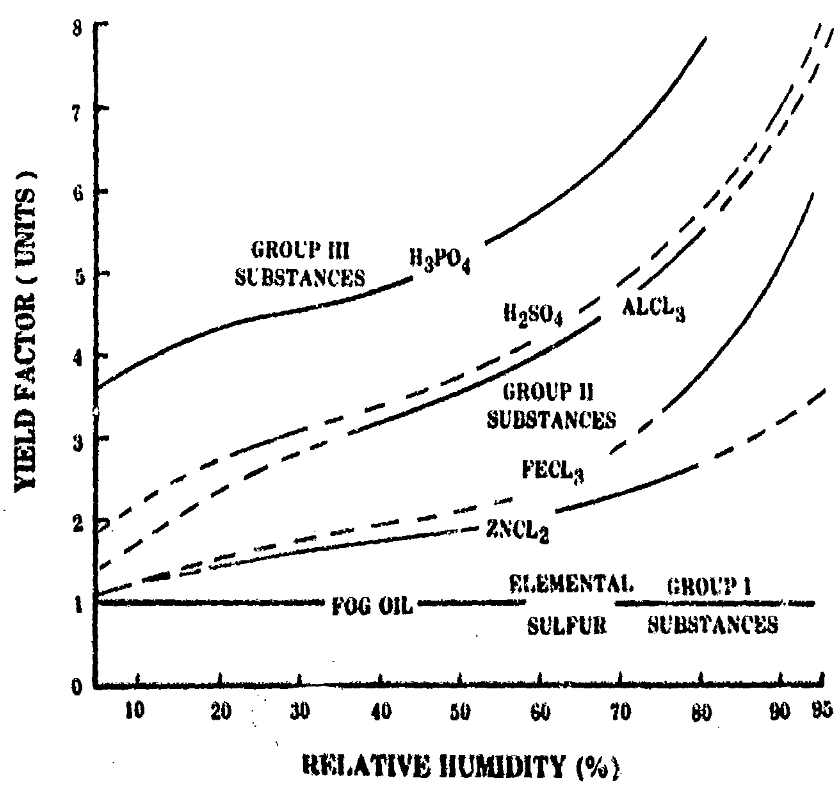


Figure 6.3. Yield factors for some typical smoke particles (M. D. Johnson, P. D. Forney, and T. J. Dolce, 1972, "The Effectiveness of Obscuring Smokes," Operations Research Group unpublished manuscript, Edgewood Arsenal, MD).

containing larger particles. Real smokes are further complicated by the fact that they seldom contain particles of only one particular size (that is, monodispersed); instead, a given sample will exhibit a range of particle sizes (that is, polydispersed) which may or may not depend upon smoke density.

6.2.3 Wind and Temperature Stratification or Stability (Pasquill Category)

As mentioned previously, the degree of wind and temperature stratification or atmospheric stability, taken here to be associated with changes with respect to altitude, is important in influencing the degree of buoyant rise of a smoke cloud. This influence is especially marked with smoke munitions such as WP which gives off heat (that is, exothermic) during the chemical reactions occurring at detonation. A portion of this heat (approximately 800 calories per gram for WP) is absorbed by the resultant smoke which produces a smoke cloud with a temperature much higher than the surroundings. Due to the buoyancy, such a cloud will tend to rise and at the same time disperse and cool until it reaches an altitude where it has the same temperature as its surroundings. During periods of unstable and neutral atmospheric stratification (Pasquill categories A, B, C, and D) where the temperature near the surface generally decreases with altitude, this point may not be reached until the cloud has dissipated to such an extent that it is nearly invisible. During periods of stable stratification (Pasquill categories E and F) however, this level may indeed be reached and the smoke will remain "trapped" at and below this level. Such conditions, sometimes referred to as inversions, are usually considered desirable for buoyant smoke screens. Smokes other than WP are also produced by exothermic reactions; however, they do not produce such buoyant effects because their production rate (or "burn" rate) is much slower. This slower burn rate allows heat to be released more slowly and results in a much cooler cloud. HC, for example, although having a heat of reaction of 600 calories per gram (nearly the same as WP) does not show much buoyant rise because its burn time is on the order of 60 to 120 s as compared to about 1 s for WP. Some WP munitions which burn more slowly have been designed specifically to reduce this buoyancy effect.

The wind stratification, regardless of Pasquill category, is almost always such that the wind increases with increasing altitude (at least in the region nearest the surface where most smoke screens are confined) with the degree of stratification depending mostly upon the roughness of the underlying terrain. The most marked effect on smoke clouds caused by this stratification is a leaning of the cloud in the direction of the wind flow. Also, wind direction usually shifts with respect to altitude, but this shift occurs on a much larger scale and is not usually observed with real smoke clouds.

In real situations for WP, only about 70 to 90 percent of the cloud actually rises buoyantly, with the other 30 to 10 percent remaining near the ground. This difference can give the impression of two detached clouds, one near the ground and one elevated, and this detachment coupled with the wind stratification effect produces a cloud in the shape of a "dog bone" which leans in the direction of the wind flow. This overall effect is demonstrated in the sketch of figure 6.4.

6.2.4 Illumination

Although the primary effect of screening smokes is simply to absorb radiation either emanating from or propagating toward given targets, two other secondary effects are significant in real situations owing to the radiance, or brightness, of the cloud itself. Radiation emitted or reflected by a cloud can interfere with an E-O signal by producing a background "noise" which tends, overall, to reduce the contrast between a detector and its surroundings, thus making the target less easily detected. In extreme cases, this "noise" may even be mistaken for the real signal, giving rise to a "false" target.

In the visible and infrared, the original source of cloud brightness is usually solar radiation which, by means of various paths involving multiple scattering, can ultimately be reflected back toward an observer. This can very markedly either increase or decrease the overall smoke effectiveness, depending upon the angular positions of the enemy-target-source scenario. In some respects this situation may be likened to a motorist driving through a fog with the lights on high beam, although in smoke the effect is usually less drastic. To a lesser extent diffuse skylight and extraneous artificial sources can enhance (or defeat) effectiveness in this same manner.

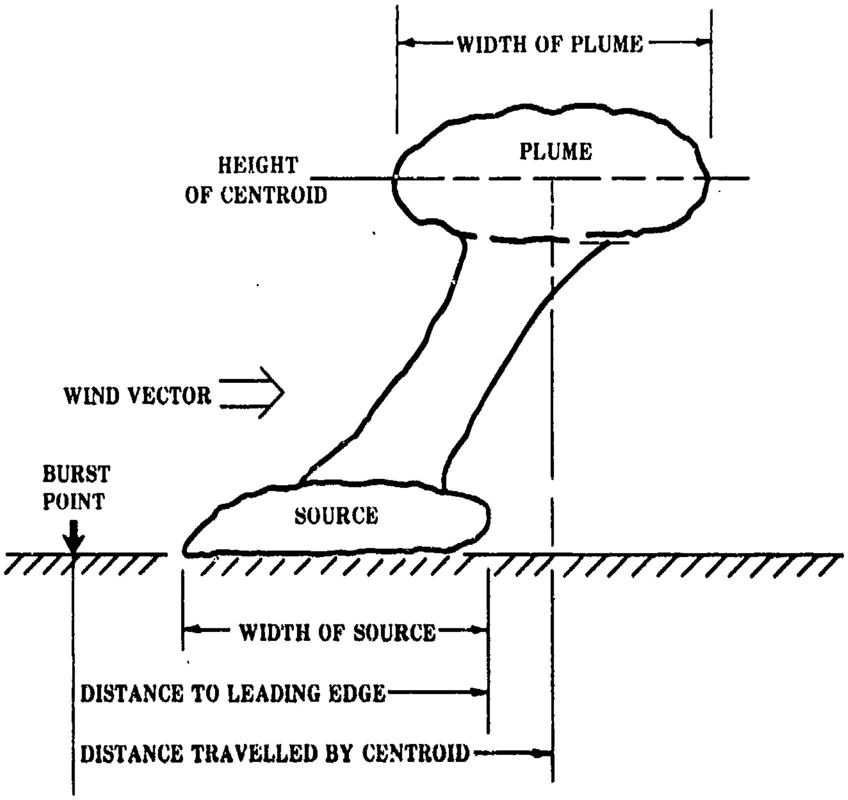


Figure 6.4. White phosphorus smoke cloud with buoyancy and wind shear effects (Dolce and Metz, 1977).

An analogous situation occurs in the infrared although the major source of cloud brightness (or more strictly, cloud radiance) is thermal emission originating in the cloud itself. This emitted radiation follows the blackbody or Planck law (defined by equation (E-1) in appendix E), which incidently forms the theoretical bases for all infrared E-O detection devices. Note that the magnitude of this radiation increases with cloud temperature, thus exothermic, rapid-burning, smoke munitions will generally produce clouds which are brighter in the infrared than their slower burning counterparts. Aside from their inherent thermal emissions, multiple reflections (or more strictly scatter) also occur for infrared wavelengths, although usually to a lesser extent than in the visible. Thus the overall true effectiveness of any smoke screen is generally a complicated function involving the angular positions of the particular elements of a scenario.

Clearly, the degree to which the above mechanisms affect smoke screens depends upon many physical and optical properties of the basic smoke particles. It follows from fundamental first principles, however, that good infrared absorbers are also good emitters. Thus a smoke judged effective because of its absorbing (or blocking) power will also be an effective emitter. In the visible this is also true since good scatterers are also good absorbers. This greatly simplifies the problem of comparing the relative overall merits of different smokes.

6.2.5 Summary

We have qualitatively discussed the environmental factors which influence the effectiveness of intentional obscurants, with particular attention on screening smokes produced with inventory munitions.

The environmental factors were separated into two major categories, one which influences the transport and dissipation of smoke clouds, and another which influences the optical properties of the resultant smoke screen. The transport and diffusion were governed mainly by such meteorological variables as wind, relative humidity, and Pasquill category. The optical properties were governed mainly by smoke type, cloud temperature, and ambient illumination but in some respects were also influenced by relative humidity.

6.3 UNINTENTIONAL OBSCURATIONS

6.3.1 Explosions

Explosions on the battlefield can be caused by bombs dropped from aircraft, munitions fired from guns, or warheads delivered by rockets. Regardless of the source of the explosions, the effect on E-O devices is the same--obscuration. When an explosion occurs, a fireball is generated which is usually hotter than the surroundings. This mass of hot air rises fairly rapidly and carries with it gases from the explosive and dust and debris from the ground. In addition, there is usually a second cloud of dust and debris caused by the shock wave from the explosion around and under the fireball which is not much different in temperature than the surrounding air and tends to rise more slowly. Figure 6.5 shows a representation of these clouds and how they change with time. In areas where the ground is frozen and/or snow covered, the explosion cloud may be expected to also contain snow and ice particles.

The characteristics of explosion-generated dust and debris clouds which have obscuration effects are: (a) the presence of gases (other than the normal atmospheric gases), (b) the presence of dust and particles from the ground and the explosive, (c) illumination, and (d) atmospheric turbulence. Usually, the most important of these is the presence of dust and particles which can both absorb and scatter electromagnetic energy. The amount of obscuration caused depends upon the concentrations, sizes, shapes, and optical properties of the particles. In turn, these depend upon the size and type of the explosive, condition and type of soil and vegetation, windspeed and wind direction, and atmospheric stability. For example, research has shown that explosion clouds in central Europe can contain smaller concentrations of particles than those in more arid regions because the vegetation and sod in central Europe are less likely to be broken loose and picked up than is soil from a dry climate (Ebersole et al, 1979). In addition to obscuring by scattering and absorption, the particles can also create an effect called a false target. When this occurs, the E-O sensor detects an image in the cloud or residual hot crater which appears to be a target but is not. This too is an obscuration effect since seeing a false target can be as deceptive as not seeing something that is there.

The presence of gases in an explosion cloud which are not normally found in the atmosphere is due to the rapid burning of the explosive material itself and the burning of other material on the surface. These gases can cause molecular scattering and absorption at various wavelengths. Very little is known about the concentration and composition of these gases, but it is generally thought that their obscuration effects are small and of short duration compared to the effects of the dust and other particles.

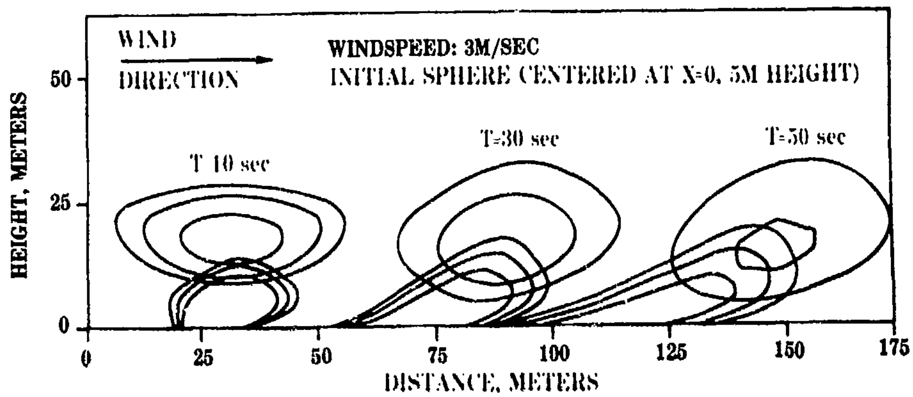


Figure 6.5. Growth and movement of explosion dust/debris cloud (Ebersole et al, 1979).

Illumination from an explosion is an obscuration when it occurs at the same wavelength at which an E-O sensor is operating. The obscuration can be light obscuring at visible wavelengths or heat obscuring at infrared wavelengths.

Explosions can also be the sources of small-scale atmospheric turbulence which can cause beam wander, scintillation, and similar effects.

The effect of explosion dust and debris clouds on E-O sensors is generally about the same for visible as for infrared wavelengths. For near-millimeter wave sensors, the attenuation effects are much smaller.

6.3.2 Vehicles

There are often many vehicles of various types moving across and around a battlefield, including tanks, trucks, and aircraft. Moving vehicles can cause obscurations through the generation of dust clouds and by emitting gases and particles in their exhaust emissions. At infrared wavelengths, illumination created by vehicles can cause false targets and additional background clutter. Of these sources of obscuration, the dust clouds are usually the most significant.

Obscuration effects of vehicular dust clouds are absorption and scattering by the dust particles. These effects vary with the composition and concentration of the particles in the air. The composition depends upon the type of soil in the battlefield, while the concentration varies with soil moisture and condition, vegetative cover, wind conditions, and vehicle type. The shape of the dust particles is also a factor.

A dust cloud-causing vehicle does not have to move across the LOS of an E-O sensor to have an obscuring effect. The wind direction may be such that the dust cloud caused by a moving vehicle is carried a considerable distance and affects sensors which are located some distance away.

A vehicle such as a tank or truck moving along the ground causes an elongated dust cloud (figure 6.6). The dust cloud caused by a helicopter landing or taking off has a much rounder shape.

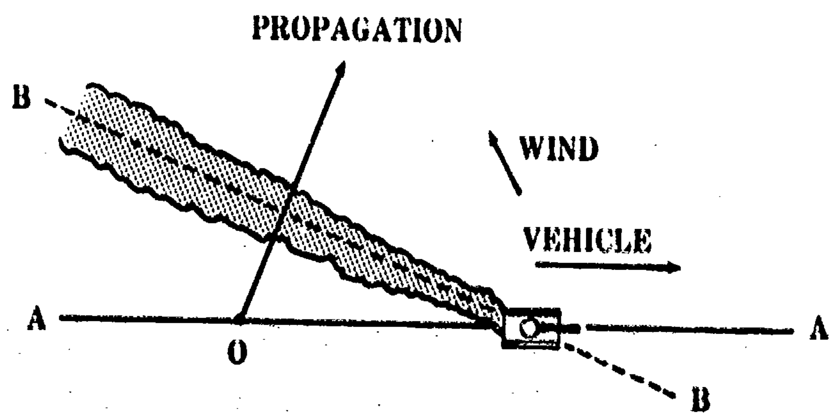


Figure 6.6. Dust cloud generated by vehicle moving along the ground (Hayes, 1978).

The length of time a vehicular dust cloud lasts depends on the soil type and the meteorological conditions. If many very small particles are part of the cloud, they may stay suspended in the air for a long time. Calm or light wind conditions also contribute to long-lasting clouds since the dust particles are not being blown out of the area.

The effect of vehicular dust clouds on E-O sensors through scattering and absorption is generally about the same for optical and infrared wavelengths. Scintillation may occur at near-millimeter wavelengths because of dust clouds, while scattering and absorption at these wavelengths are thought to be minimal.

The exhaust emissions from vehicles can also cause obscurations on the battlefield. Exhaust gases can cause molecular absorption and scattering, and exhaust particulates can cause aerosol scattering and absorption. Of these obscuration effects, the most important is probably absorption by carbon particles. Carbon absorbs electromagnetic energy much more strongly than other common types of aerosols and can have an obscuration effect seemingly out of proportion to its concentration.

The types and concentrations of the exhaust emissions depend on the type of vehicle, the fuel it is using, and how efficiently it burns its fuel. Exhaust emissions include considerable amounts of water vapor which, if occurring in very cold air, can condense to form fog--an additional obscuration factor.

6.3.3 Gun Firings

The battlefield obscuration effects of gun firings are usually much less important than those of explosions and vehicles. However, the combined effect of many gun firings in a short time may be substantial obscuration. The gun flash can intrude into the LOS of an E-O sensor and block the view of the target or saturate the sensor elements, a smoke cloud is usually generated after the gun is fired, and dust clouds may form as the shock wave from the muzzle interacts with the ground or from the gun recoil (figure 6.7). As a result, obscurations can occur from molecular and aerosol absorption and scattering and from illumination. The illumination effect is usually short-lived while the scattering and absorption continue until the gases and aerosols are dispersed or otherwise removed from the atmosphere.

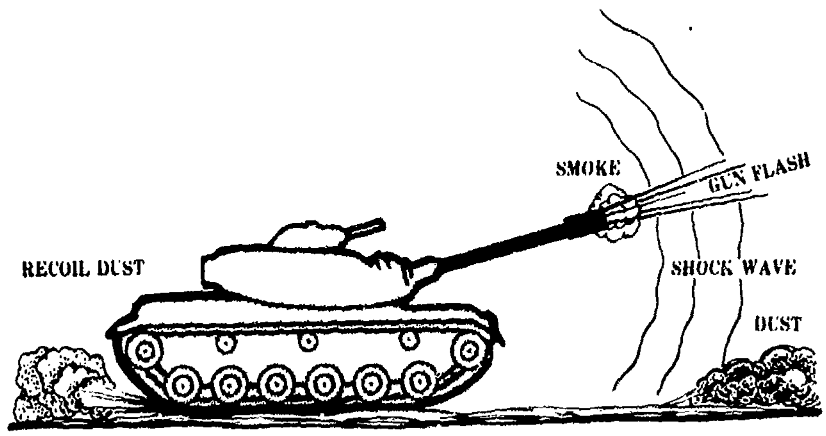


Figure 6.7. Dust clouds, gun flash, and smoke generated by gun firing.

6.3.4 Fires

Battlefield fires can be a major source of obscuration. Types of materials which may be found burning in battlefield situations are vegetation, vehicles, fuel, tires, and other equipment. Obscuration results from molecular and aerosol absorption and scattering coming from gases and particles generated by combustion, from illumination, and from atmospheric turbulence resulting from intense heat.

The amounts and types of gases and particulates resulting from a fire depend on the types and amounts of burning materials and their burning characteristics. Many materials burn slowly and can generate large clouds of dense smoke lasting for relatively long periods of time. In fires, large amounts of carbon particles can enter the atmosphere. Since carbon is a very strong absorber of electromagnetic energy, it can cause the smoke to have a strong obscuration effect.

The light and heat produced by fires cause obscuration by blocking the view of the target or by saturating the sensor elements with electromagnetic radiation of the same wavelength as the sensor.

Atmospheric turbulence resulting from the heat generated by a battlefield fire can be considerable. This turbulence results in the usual effects associated with atmospheric turbulence.

While very little data are available on the obscuration effects of battlefield fires, the general thought is that there is more obscuration at visible wavelengths than at infrared. This obscuration will vary, however, with the (smoke) cloud composition and particle size distribution. Turbulence effects in the near-millimeter wave region are probably the only effects to be experienced in that region.

6.3.5 Air Pollution and Other Civilian Activities

The source of air pollution is man's activities, and pollution can have obscuration effects on the battlefield. There are many different forms of air pollution having a variety of effects upon the operation of E-O sensors. Industrial activities can produce aerosol and gaseous emissions which absorb and scatter electromagnetic radiation. The aerosol particles can act as condensation nuclei and can influence the occurrence and amount of precipitation and fog.

Agricultural activities can also have effects on obscuration. Under certain conditions, plants can be significant sources or sinks for aerosol particles and gases. Fertilizers and other agricultural chemicals can enter the atmosphere as gases or particles. Atmospheric turbulence at low altitudes is dependent upon terrain roughness, which is affected by agricultural activities.

Weather modification activities such as cloud seeding can also cause battlefield obscuration effects by influencing the occurrence of precipitation and fog. The chemicals used in such activities can also remain in the atmosphere and cause obscuration effects.

6.3.6 Other

There are many other battlefield activities which potentially have obscuration effects. Among these are the use of nuclear weapons, chemical/biological warfare, and electronic warfare. The obscuration effects of these activities are outside the purview of this report.

6.4 INTERACTION OF VARIOUS OBSCURANTS

Knowledge about obscuration effects of various battlefield activities is limited, and the amount of information about how these effects interact with one another and with natural obscuration effects is even more limited. However, it is known that they do very often interact, causing the effects to be greatly increased, and the combined effects must be considered in a realistic battlefield environment.

For example, the screening capability of a given amount of certain kinds of smoke is thought to be greatly affected by high relative humidity. The smoke particles attract the water vapor and water droplets are formed with the smoke particles as nuclei. These droplets have different optical properties than the dry particles and thus the screening capability is changed. In fact, a phenomenon called the "fog of war" occurs when smoke and other types of particles enter the atmosphere when the relative humidity is high and act as fog condensation nuclei, causing dense fog to form.

Apparently, very light snow and rain do not significantly affect smoke clouds, but heavy rain can cause rainout and can increase air turbulence, causing increased dissipation of smoke clouds.

The existence of fog in falling snow is thought to cause much stronger obscuration effects than occur in either fog or falling snow alone.

The interaction of various obscurants on the battlefield remains an area where much research is needed.

CHAPTER 7

LAND/AIR INTERFACE

7.1 INTRODUCTION

In almost all discussions or writings about battlefield obscurants, each obscurant is treated separately for simplicity. In the real world there are complex interactions within and on the obscurant. One of the interactions on obscurants is caused by the land/air interface such as the effects of valleys, mountains, vegetation and ground cover, forests, and lakes. This chapter will consider a geographical area no larger than a battlefield of 300 by 300 km.

7.2 TOPOGRAPHY

As mentioned in paragraph 5.1, topography has a great effect upon the meteorological conditions in central Europe. Each valley and mountain has its own "climate" and can differ from the surrounding area. For example, during the day, surface temperatures along a mountain slope are higher than those at corresponding levels in the free air. Consequently, the heated air rises up the mountain slope and is replaced by sinking air over the valley. Successful deployment of smoke on mountainous terrain depends upon knowing when the upslope wind will start or stop and reverse its direction in the late afternoon as cooling begins.

Air is cooled as it rises up the windward slope of a mountain range and is warmed as it descends on the leeward slope. If enough moisture is available, clouds will form on the windward side, extend to and over the top, and then dissipate on the leeward side. These clouds will restrict visibility and prevent seeing from mountain to mountain or even into the valley below.

Topography has an effect on winds also, other than the upslope and downslope winds from day to night. On mountain summits and ridges the windspeed is usually higher than in the free air at the same elevation, because the orographic barriers tend to converge the flow of air, causing acceleration. On the leeside of mountain barriers and in sheltered valleys, the winds are usually light.

In the daytime, the orientation of a slope influences the temperature considerably. In general, western slopes on symmetrical hills have higher temperatures, level for level, than do eastern slopes. A southern slope receives more sun than would a horizontal surface in the same location, because the sun rays strike it more nearly perpendicularly.

Therefore, temperatures are lower on northern slopes, as evidenced by the slower disappearance of snow.

7.3 VEGETATION AND GROUND COVER

Vegetation and ground cover (snow, water, trees, or sand) affect wind, temperature, and humidity which in turn affect the formation and/or behavior of battlefield obscurants.

The winds are usually stronger over a lake than over the surrounding land area. The temperature contrasts between water and land and the wind direction will cause more precipitation, fog, and cloudiness on the leeward shore. Operation of E-O systems would be marginal in this area during times of fog and precipitation. In the summer, the stabilizing effect of the relatively cold lake surface on passing air masses reduces the amount of precipitation on the leeward shore.

Lakes affect the local weather conditions by adding moisture to the air in the lower levels, especially during the winter months when the water is usually warmer than the air. Even in regions where the lakes freeze in winter, processes occur between the lakes and the air and modify the temperature variations. In winter the air moving over a lake will become unstable in the lower levels by heating from below. This instability will affect the electromagnetic energy being transmitted over this area by beam jitter and general erosion of the beam. In the summer, a stabilizing effect of the relatively cold lake surface on passing air masses will have little effect on the transmission of energy.

If the battlefield contains a forest, the commander should be aware of the fact that the vertical temperature profile and stability of the air in a forest will be opposite to those over open terrain. For example, over open terrain the ground cools during the night, thus forming a stable layer of air near the ground and a temperature inversion above. In the forest the tree tops act as radiating surfaces, and the soil beneath is protected from excessive heat losses. If smoke were deployed or fog advected into the forest, the visibility would tend to be greater near the ground and decrease with altitude to near the tree tops.

Rows of trees are often used as windbreakers. During periods of moderate and strong winds, turbulence is created downstream. Smoke might be effective close to or in the trees but would rapidly diffuse a few hundred meters downstream.

Ground covered with sand experiences a wide range of temperatures from day to night. During the day the sand becomes hot, heating the surrounding air and causing it to rise. The rising air currents cause the density of the air to change, degrading the effectiveness of E-O systems. Also, smoke is diffused more quickly when deployed in a hot, unstable atmosphere.

During the growing season, plants add water vapor to the air by transpiration. Furthermore, when wet from a recent rain or dew, a vegetative cover offers a larger evaporative surface than does bare soil. Vegetation forms a protection against the loss of soil warmth at night, and minimum temperatures within the vegetation area are higher than over bare ground. The difference in temperature of adjacent areas with different ground cover will affect the target-background contrast when an imaging system is utilized.

7.4 AIR MASS

In the last few years, some effort has been made to relate air mass characteristics to E-O systems behavior. An air mass is defined as a mass of air with approximately the same temperature and moisture content. Air masses are classified according to their source region. The two main categories are polar and tropical because the greatest source regions are located in the high and low latitudes. These groups are subdivided according to whether they form over land (continental) or over water (maritime). Most of the air masses over central Europe are of maritime polar and maritime arctic origin with an occasional continental subpolar in the summer.

A cold, clear, and dry air mass would provide the most favorable condition for E-O systems. This air mass type would contain few aerosols and would be dry enough to prevent condensation droplets from growing. Air masses are modified as they move over the earth's surface and become polluted with time.

Moisture is added to air masses as they pass over lakes and oceans. Haze and particles are added from industrial areas, and the temperature structure of an air mass is modified in the lower levels as the air comes in contact with surfaces having different temperatures. Moisture is lost as the air mass is lifted by mountains or sloping terrain, which causes precipitation. All of these processes lead to an ever-changing atmosphere in which systems have to operate.

CHAPTER 8

E-O SENSORS

The history of warfare shows a continuing need to better "see through" the atmosphere regardless of weather conditions or the presence of smoke or other contaminants. To fulfill this need, a variety of devices and sensors which depend upon the passing of electromagnetic radiation through the atmosphere have been developed and are in use. Some of the current uses of these devices are for target surveillance and tracking, target designation, and battlefield communications.

E-O sensors may be classified as active, semiactive, or passive, depending upon the source of the radiation they use. Passive devices sense the emitted or reflected natural energy from targets or other objects. Active devices illuminate the targets with energy which they then sense as it is reflected or scattered by the targets. Semiactive devices sense energy reflected by the targets, the sources of which are unnatural, such as lasers mounted in helicopters.

The human eye is the oldest and still the most important E-O sensor used on the battlefield. It is, of course, a passive sensor and operates in the visible region with maximum sensitivity at 0.55μm. It operates as an imager and tracker and is used as a standard against which other sensors are compared. The fact that the human eye does not see well in bad weather conditions or at night was the driving force behind the development of other types of E-O sensors.

Imaging devices are used in many types of weapon systems in locating targets and other objects of interest. These devices include line scanners, such as television, and FLIRs and are usually passive devices. Imaging devices sense the natural radiation coming from the scene being viewed and display an image of the scene on a screen. Energy from the visible, infrared, and near-millimeter regions is sensed by various imaging devices. The FLIR was developed for use in aircraft but its use has greatly expanded and has reached the point where the term FLIR is used loosely to mean an infrared imager (whether or not it looks forward). Some active FLIRs have been developed to operate in the 8μm to

13µm region, but these have not been very successful. Also, active near-millimeter imagers are being developed.

Illuminators, or searchlights, are used in semiactive E-O systems used for night vision and for countermeasure applications. These usually operate in the visible region or in the 1µm to 5µm region. Some are operated over a fairly large band of wavelengths while others are filtered so as to operate over narrow bands.

There is a large number of passive E-O sensors called image converters, image intensifiers, and night-vision devices, which sense infrared energy and convert it to visible light for viewing. These devices reproduce an image of the scene on a fluorescent screen, and some are hand-held similar to binoculars.

Thermal imagers and heat seekers are passive devices used to locate the hottest object in a scene so that a missile or munition may be guided to it. These are generally low resolution imagers and operate in the 3µm to 5µm or 8µm to 13µm region.

Laser range finders are active sensors which emit pulses of energy, usually at 0.69µm or 1.06µm, and measure the time it takes for the pulse to travel from the transmitter to the target and back to the receiver. In this way, the distance to the target may be found. Laser range finders have much finer resolution than do radars and, thus, are more accurate.

Guidance systems used in guided missiles and precision guided munitions are usually composed of two E-O devices--a detector to locate the target and a tracker to keep the target in the field of view and home in on it. Current systems are active, passive, or semiactive devices, or combinations of these, and may operate at visible, infrared, or near-millimeter wavelengths. Televisions, FLIRs, and laser designators are commonly used as components in guidance systems.

Table 8-1 lists a number of weapon systems which use E-O devices and indicates the atmospheric obscuration factors which most strongly affect the operations of the weapon systems.

TABLE 8-1. TYPICAL WEAPON SYSTEMS VULNERABLE TO DEGRADATION FACTORS

E-O TYPES		THIN CLOUDS	THIN FOG	DRY AEROSOL (HAZE DUST .SMOKE)	SNOW/RAIN	LIGHT LEVEL	ABSOLUTE HUMIDITY	THICK CLOUDS	DENSE FOG
<1.0m	HUMAN EYE	X	X	X	X	X		X	X
	TOW	X	X	X	X	X		X	X
	DRAGON	X	X	X	X	X		X	X
	SHILLELAGH	X	X	X	X	X		X	X
IR & IR LASER	REDEYE			X	X				
	STINGER			X	X		X	X	X
	HELLFIRE			X	X		X	X	X
	DRAGON			X	X		X	X	X
	COPPERHEAD			X	X		X	X	X
	AHAMS			X	X		X	X	X
	SHILLELAGH			X	X		X	X	X
RADAR/RF MMW	HAWK				X			X	X
	ROLAND				X			X	X
	DIVAD				X			X	X
	TADS				X			X	X

E-O devices are also used for military communications and data transmission, primarily through the utilization of infrared lasers. These active systems provide good security for communications and also good immunity to jamming. However, they are able to transmit only on an LOS, and adverse weather can have a strong effect on them.

CHAPTER 9

DATA REQUIREMENTS

9.1 INTRODUCTION

Defining the requirements for atmospheric data observations and utilization by the Army for E-O applications is a most difficult and challenging task. Different users require different atmospheric parameters; and even if the same atmospheric parameters are required, the limits of accuracy or frequency of the observations are not the same.

The modeler is perhaps in the best position to define atmospheric data requirements as to which parameters are required and the limits of accuracy needed in observing or calculating the parameters. By utilizing realistic scenarios and performing sensitivity analyses of input atmospheric parameters, the modeler can determine the relationships between input and accuracy requirements. Naturally, the results are only as good as the models. Quality data are being acquired to evaluate and, if necessary, provide a basis for modifying the models to provide realistic results.

On 13 and 14 February 1979, the US Army ASL hosted a workshop which addressed atmospheric data requirements for E-O and near-millimeter wave systems. This workshop made evident that the need still exists to identify the "minimum meteorological set," the order of importance, and the bounds of weather parameters that the E-O community needs to ascertain performance of current systems.

The proposal was that ASL form a group consisting of modelers, experimenters, and meteorological personnel to derive a "strawman" of what they believed should be the minimum meteorological set needed by the general community. Much of the information in the following sections is based upon a working copy of that "strawman" (Holt, 1979).

9.2 AVAILABLE METEOROLOGICAL DATA

The World Meteorological Organization (WMO) is responsible for the worldwide meteorological observation and climate programs and for the interchange of meteorological data between nations. The National Oceanic and Atmospheric Administration (NOAA) is responsible for the observation and data dissemination in the United States. Surface observations of parameters listed in table 9-1 are made at locations depending upon population and/or location. There are over 300 observing stations in the United States. As most observing stations are located on or adjacent to an airport, the Federal Aviation Agency (FAA) supplements the NOAA observation program where airports are located in smaller cities.

TABLE 9-1. METEOROLOGICAL PARAMETERS THAT ARE ROUTINELY OBSERVED

Parameter	Type of Observation		
	Record	Special	Local
Ceiling and sky (cloud amount and height)	X	X	Content and criteria determined locally. Usually taken immediately after an aircraft mishap.
Prevailing visibility	X	X	
Weather & obstructions to vision	X	X	
Sea level pressure	X		
Temperature	X		
Dew point	X		
Wind direction, windspeed, and character	X	X	
Altimeter setting	X	X	
Cumulative precipitation for 6-hour periods ending at 00, 06, 12, and 1800 GMT	X		
Remarks as appropriate	X	X	

Upper air observations are made from stations determined by location and are from 150 to 300 miles apart. Wind, temperature, and humidity measurements are made at 0000 and 1200 GMT and only winds at 0600 and 1800 GMT. The 0000 and 1200 GMT observations are made by an ascending balloon with a radiosonde package.

Meteorological data are archived at the National Climatic Center (NCC), Asheville, North Carolina, and copies of original surface and upper air observations may be obtained from them. NCC will provide climatic information upon request. The Environmental Technical Applications Center

(ETAC) at Scott Air Force Base, Illinois, is the climatic center for the Department of Defense; however, Army requests for climatic information should first come to ASL. ASL has acquired a data subset from ETAC and can provide most climatic information to Army agencies.

Table 9-1 gives the meteorological parameters that are observed on a routine basis. The different types of observations will be discussed next to provide a "feel" for the type of meteorological data that are available for constructing a climatic data base. Field experiments require more frequent observations of some parameters and, in general, are of better quality to meet the experimenter's requirements.

Record observations are a complete aviation observation taken hourly. Observations taken at 00, 06, 12, and 1800 GMT include additional data such as the maximum and minimum temperatures, barometric trace characteristics, and the amount of precipitation during the last 6 and 24 hours. The observations taken at 03, 09, 15, and 2100 GMT are known as three-hourly observations and contain essentially the same information as the six-hourly with the exception of 24-hour temperature extremes and 24-hour precipitation amount.

Special observations are taken to report significant changes in ceiling heights, visibility, runway visual range, occurrence of tornado, funnel cloud or waterspout, thunderstorm, beginning or ending of precipitation, wind shift or sudden increase in windspeed, and pressure jumps.

Local observations are taken and recorded at any weather observing station with content and criteria determined locally.

The instruments used to measure the meteorological parameters listed in table 9-1 as well as measurement accuracies will be discussed next. The accuracies or error measurements are taken from a document published by the Inter-Range Instrumentation Group, Range Commanders Council (1977).

9.2.1 Temperature

Temperature can be observed by reading directly from sensors such as liquid-in-glass thermometers or values from dials or graphs that are part of a remotely placed sensor system. A platinum resistance wire or thermocouples are probably the most common sensors used to measure temperature in remote systems, while the liquid-in-glass thermometer is still widely used because of its simplicity.

Two temperatures are usually measured, dry- and wet-bulb. The dry-bulb temperature is the temperature of the air surrounding the sensor, or ambient temperature. The wet-bulb temperature is indicative of the amount of moisture in the air. An instrument shelter contains the temperature sensor. The shelter is several feet above the ground and provides near eye level readings of the sensors.

The thermograph, hygrothermograph, and sling psychrometer are defined in the glossary and are instruments used for temperature observations.

Temperature can be measured to 0.3 C with a liquid-in-glass thermometer and to 1.1°C with thermographs.

9.2.2 Wind

Wind is the motion of air past a given point and is measured in terms of speed and direction.

A cup or propeller type anemometer is the most common wind sensor. Measurements of wind, giving a single value or average over a path, have been made by using laser techniques.

Accuracies of wind measurements are within 3 degrees in direction and from 0.5 to 1.0 m/s with AN/TMQ-15.

9.2.3 Visibility and Runway Visual Range

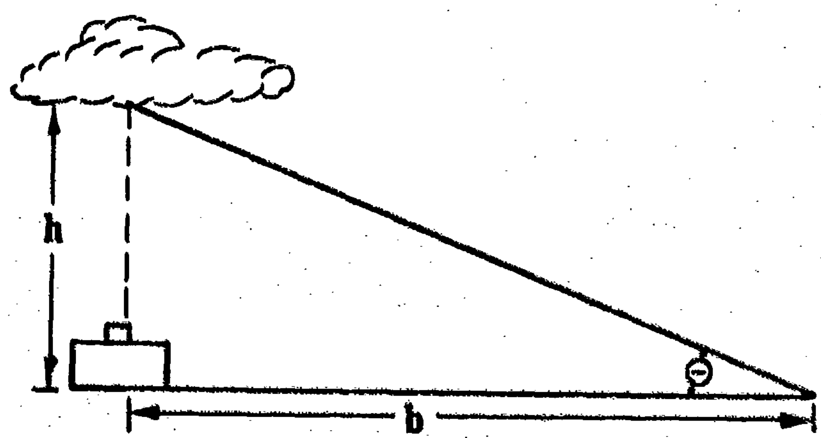
A transmissometer measures the runway visual range (RVR). It consists of a transmitter, receiver, and associated data handling equipment. The transmitter and receiver are separated at distances of either 250, 500, or 750 ft. The absorption of the transmission beam between the transmitter and receiver is an indication of visibility. Visibility is estimated by an observer using objects that are known distances away.

Visibility measurements are accurate to within 10 to 20 percent with a transmissometer.

9.2.4 Clouds

Cloud heights, type, and amount are estimated by an observer. The height may be measured by a ceilometer that consists of a fixed beam and a detector. The fixed beam shines straight up, striking a cloud; the detector scans the beam and notes where the cloud interferes with the beam. Actually, the angle of the detector (with respect to the horizontal), θ, is used with the known distance between the beam and detector (b).

Using the equation $h = b \cdot \tan\theta$ and trigonometric tables (or hand calculator with tan function), h is obtained. Usually a ceilometer recorder is in the weather station and the cloud heights are read from a chart or scope.



9.2.5 Pressure

Atmospheric pressure is the force extended by the air on a unit area due to the weight of the overlying atmosphere. Standard unit of pressure is the millibar although "inches" is used for altimeter settings.

The precision aneroid barometer, microbarograph, aircraft-type altimeter, and mercury barometer are instruments used to observe the atmospheric pressure.

Atmospheric pressure can be measured to 0.07 mbar with a mercury barometer and to 0.40 mbar with a microbarograph.

9.3 E-O DATA REQUIREMENTS

Data requirements for using E-O systems consist of meteorological and optical parameters. Most of the meteorological parameters can be observed on or near a battlefield by remote sensing techniques or by a meteorological team. Measurements of optical parameters are often difficult under field experiment environment and may be most difficult under battlefield conditions. Therefore, there is a strong need to develop correlations between meteorological and optical properties.

The users of atmospheric data have been identified and categorized into four broad areas: (1) weapon systems designers and war game players, (2) weapon systems developers and the test and evaluation community, (3) tactical decision makers and troop trainers, and (4) atmospheric modelers.

The weapon systems designers and war game players require atmospheric data for input into their models. These models are a minor part of comprehensive models which predict total system performance or battle outcomes. In addition to atmospheric data, other data such as the contrast transmittance, illumination, LOS visibility, and the type of obscuration and its effects upon transmission of energy at different wavelengths are required.

The standard meteorological data needed are the ambient temperature, relative humidity, pressure, windspeed and wind direction, precipitation, visibility and obstructions to visibility, and cloud cover.

The weapon systems developers and test and evaluation personnel are involved with field tests of prototype weapon systems, and their requirements for atmospheric data at the test sites are larger than the weapon systems designers. Test and evaluation require additional data such as atmospheric particle size distribution and number density, liquid water content, surface albedo, turbulence parameters, gas concentrations, and solar radiation.

The tactical decision makers and troop trainers are concerned with tactical operations in the field that include field exercises as well as actual battle operations. Tactical decision makers are concerned with weather forecasts in the planning stages and then the present weather and 24-hour weather forecasts during operations.

The tactical decision makers and troop trainers are in a position to benefit the most from the ongoing efforts of determining the atmospheric effects upon E-O weapon systems as they stand to lose the most on the battlefield. It is imperative that the tactical decision maker use the weather to achieve the maximum results from his resources.

Atmospheric modelers use almost all the meteorological and E-O type parameters in one model or another. Also terrain features, soil characteristics, and data pertaining to performance characteristics of different weapons and countermeasure systems are needed by the modeler for final results.

Table 9-2 lists the basic meteorological and optical parameters, the user that needs the parameter (denoted by an "X"), the range of the parameter, and the accuracy to which the parameter can be measured on a routine basis. The parameters listed in table 9-2 are not complete by any means. For example, smoke modelers require the Pasquill stability category, change of wind direction with height in the surface mixing layer, wind power-law coefficients, and other parameters. These parameters are usually computed from the basic measurements of temperature and wind that are observed at designated locations and time intervals.

TABLE 9-2. DATA REQUIREMENTS

DATA PARAMETERS	Range of Parameter	Accuracy of Routine Measurement	Weapon System Deisgners & War Game Players	Weapon Systems Developers & Test & Evaluation	Tactical Decision Makers & Troop Trainers	Atmospheric Modelers
Aerosols						
attenuation coefficient	10^{-5} to 10 km^{-1}	10-20%	X	X		X
particle concentration	10 to 5×10^{6} cm^{-3}	10%	X	X		X
size (radius)	4×10^{-3} to 10^{2} μm	10%	X	X		X
Clouds						
amount	0 to 1.0	0.1	X	X	X	X
height	0 to 20km	10%	X	X	X	X
particle size (high cloud)	20-200μm	5-10%	X	X		X
(middle cloud)	5-15μm	5-10%	X	X		X
(low cloud)	2-10μm	5-10%	X	X		X
(thunderstorm)	Mist to hail	--	X	X		X
liquid water content						
(stratus cloud)	0.25 to 0.60g/m^3	10%	X	X		X
(cumulus cloud)	0.15 to 1.5g/m^3	10%	X	X		X
(thunderstorm)	1.5 to 50g/m^3	10%	X	X		X
particle concentration	10 to 3000 m^{-3}	10%		X		X

TABLE 9-2 (CONT)

DATA PARAMETERS	Range of Parameter	Accuracy of Routine Measurement	Weapon System Designers & War Game Players	Weapon Systems Developers & Test & Evaluation	Tactical Decision Makers & Troop Trainers	Atmospheric Modelers
Cloud condensation nuclei						
concentration	10^2 to 10^5 cm^{-3}	5%	X	X		X
Fog						
Fog drop-size	5-100μ	10%	X	X		X
Fog drop concentration	1-500cm^{-3}	10%	X	X		X
Humidity (relative)	0-100%	3-10%	X	X		X
(absolute)	2-30g/m^3	5%	X	X		X
Precipitation						
type	-	-	X	X	X	X
rate of fall	0.1 to 100mm/hr	1.0%	X	X	X	X
accumulation	mm	1.0%	X	X		
duration	time	1 min		X	X	X
area	km^2	10%		X	X	X
rain drop size	10^2 to 10^3μ	10%	X	X		X
rain drop concentration	10^{-2} to $10^{-5}cm^{-3}$	10%	X	X		X
frozen/unfrozen	yes/no		X	X		X

TABLE 9-2 (CONT)

DATA PARAMETERS	Range of Parameter	Accuracy of Routine Measurements	Weapon System Designers & War Game Players	Weapon Systems Developers & Test & Evaluation	Tactical Decision Makers & Troop Trainers	Atmospheric Modelers
drizzle diameter	10 to $10^2\mu$	10%	X	X		X
rain showers diameter	10^3 to $10^4\mu$	10%	X	X		X
hail stones	.3 to 5 cm	5%	X	X		X
extreme	larger than 10 cm					
snow crystals diameter	200μ-6mm	10%	X	X		X
thickness	∿11μm	10%	X	X		X
snow flakes	up to 5cm	10%	X	X		X

TABLE 9-2 (CONT)

DATA PARAMETERS	Range of Parameter	Accuracy of Routine Measurements	Weapon System Designers & War Game Players	Weapon Systems Developers & Test & Evaluation	Tactical Decision Makers & Troop Trainers	Atmospheric Modelers
Smoke/Dust						
area	1-500km²	5%	X	X		
height	1-10³m	5%	X	X		
air temperature	-25 to 50°C	0.5C	X	X		X
wind speed	0-40 mps	1 mps	X	X		X
wind direction	0-359 degrees	3 degree	X	X		X
relative humidity	0-100%	3-10%	X	X		X
visibility	10m to 50km	10%	X	X	X	X
particle size, distribution	0.01 to $10^4\mu$	50%		X		X
chemical composition	--	--		X		X
attenuation-visible 10.6, 3-5, 8-12μm, 94GHz	0-100%	5-15%	X	X		X
mixing depth	0-100m	10m			X	
duration	time	minute	X		X	
soil characterization	--	--				X

TABLE 9-2 (CONT)

DATA PARAMETERS	Range of Parameter	Accuracy of Routine Measurement	Weapon System Designers & War Game Players	Weapon Systems Developers & Test & Evaluation	Tactical Decision Makers & Troop Trainers	Atmospheric Modelers
Sun position	0-90 degrees	1 degree				X
Temperature (surface)	±50 to -40°C	.3 to 1.1°C	X	X	X	X
Terrain characteristics	--	--		X	X	X
Surface albedo	0-100%	3%		X		X
Sunrise-sunset tables	time	seconds		X	X	
Upper atmosphere						
temperature	-60 to 40°C	2°C		X	X	X
wind direction	0 to 359 degrees	10 degree		X	X	X
wind speed	0 to 100 mps	2 mps		X	X	X
relative humidity	0 to 100%	2%		X	X	X
Visibility (surface)	0 to 50 km	10%	X	X	X	X
Weather maps (surface, 850, 700, 500 millibar)	--	--			X	X
Weather forecast	--	--			X	

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APPENDIX A

GLOSSARY

Absolute humidity
The ratio of the mass of water vapor contained in a unit volume of atmosphere.

Absorptance
The ratio of the amount of radiation absorbed to the amount of radiation incident on a substance.

Absorption
A process by which electromagnetic energy is retained by a substance.

Absorption coefficient
A measure of the amount of radiation absorbed per unit distance or per unit mass as it passes through the atmosphere.

Active device
An electro-optical device which illuminates a target or other object and senses the reflected or scattered energy coming from the target.

Advection fog
A type of fog caused by the advection of moist air over a cold surface, and the consequent cooling of that air to below its dew point.

Aerosol
Small particles suspended within the atmosphere, such as haze, smoke, dust, fog and cloud droplets.

AHAMS
Advanced Heavy Antitank Missile System is the name of a US Army program directed toward the design of a new battlefield weapon capable of defeating advanced armored vehicles with minimum degradation due to rain, smoke, dust, and sophisticated electron and E-O countermeasures.

Air mass
A large body of air which possesses the same temperature and moisture characteristics throughout.

Albedo
The ratio of the amount of radiation reflected by a substance to the amount incident upon it.

Atmospheric mixing
A random exchange of air parcels of various sizes. Mixing tends to make the properties of the atmosphere become more nearly uniform.

Atmospheric radiation
Radiation emitted by or traveling through the atmosphere.

Atmospheric window
The spectral interval in which little or no radiational absorption occurs. This is generally the 3μm to 5μm or 8μm to 12μm region.

Attenuation
The decrease in the intensity of radiation by a process or processes. When all processes which cause reductions in the intensity are included, then attenuation is synonymous with extinction.

Attenuation coefficient
A measure of the decrease in intensity of radiation per unit distance or per unit mass.

Backscatter
The scattering of the radiation into the backward direction, through angles greater than 90 degrees with respect to the original direction of motion.

Beam wander
A slow, almost periodic moving of a laser beam due to atmospheric turbulence.

Blackbody
A hypothetical body which absorbs all radiation incident upon it and emits the absorbed energy. It neither reflects nor transmits any of the incident energy.

Cloud-free line-of-sight (CFLOS)
The absence of clouds between a target and a sensor or between two points.

Clutter
Objects other than the target which tend to hinder target detection.

Condensation nuclei
Particles upon which water vapor begins to condense in the atmosphere.

Contrast
Ratio of the amount of radiation reflected or emitted by the target to the amount reflected or emitted by the background.

Copperhead
The name assigned to the M712 cannon launched guided projectile (CLGP). The copperhead acquires a laser beam for guidance to the target.

DIVAD
Division Air Defense Gun System. DIVAD will use radar for acquisition and tracking of aircraft for the track mounted 40 or 35 mm gun weapon system.

Dragon
Formerly known as MAW (Medium Antitank Assault Weapon System). An infrared tracker is the guidance element of the system.

Drizzle
Precipitation of liquid water droplets of diameters less than 0.5 mm. If such small droplets are widely separated, the precipitation is called rain instead of drizzle.

Dew point temperature
The temperature to which a given parcel of air must be cooled at constant pressure and constant water-vapor content for saturation to occur.

Dry-bulb temperature
The ambient temperature or temperature of the air.

Electromagnetic radiation, energy

Energy propagated by simultaneous period variations of electric and magnetic field intensities. Includes radio waves, infrared visible light, ultraviolet, x-rays, and gamma rays.

Electro-optical device, sensor

A system which receives electromagnetic energy and converts it into electrical energy which is measured by another component in the system. E-O devices include sensors operating at wavelengths from the ultraviolet through the far infrared, and may or may not include near-millimeter devices.

Emission

The generation and sending out of electromagnetic energy.

Emittance

The ratio of the amount of energy emitted by a body to the amount emitted by a blackbody at the same temperature.

Extinction

The decrease in the intensity of radiation by all processes.

Extinction coefficient

A measure of the total decrease in intensity of radiation per unit distance or per unit mass.

Fallout

The falling of dust and other solid particles to the ground as a result of gravity.

False target

An object of little or no military significance which appears to an E-O sensor to have the characteristics of a real target.

Far infrared wavelength

Electromagnetic radiation between 5.6 and 100 micrometers.

Flux
: The rate of flow of radiant energy per square area of a substance.

Fog, ground fog
: A visible accumulation of small water droplets suspended in the air next to the ground which reduces the visibility to less than 1 km. If less than 0.6 of the sky is hidden, the accumulation is called ground fog.

Forward looking infrared (FLIR)
: A system designed to look forward from an aircraft used to detect, recognize, and identify targets. Senses radiation in either the 3µm to 5µm or 8µm to 14µm wavelength spectral regions.

Freezing rain
: Rain which freezes upon impact with the ground, aircraft, or other objects.

HAWK
: (Homing-All-the-Way-Killer) is a surface-to-air missile designed primarily to engage low-level supersonic targets. Radar is used to acquire, track, and illuminate the target.

Haze
: Fine dust or salt particles suspended in the atmosphere which diminish horizontal visibility and tend to subdue colors.

HELLFIRE
: An antiarmor missile that uses laser for designation of the target. Used primarily by helicopters.

HELWS
: High Energy Laser Weapon System.

Hygrometer
: An instrument which measures the water-vapor content of the atmosphere.

Hygroscopic particles
: Particles which readily take up and retain moisture from the atmosphere.

Hygrothermograph

A recording instrument that combines the thermograph with a humidity sensor for providing a continuous chart record of both temperature and humidity data.

Ice fog

Fog composed of ice crystals.

Ice pellets (sleet)

Frozen raindrops formed by rain or drizzle falling through a layer of air with temperatures below freezing until the drops are frozen to ice pellets.

Illumination

Lighting, usually by visible radiation. In optics, the luminous flux per unit area.

Imaging infrared (IIR or I^2R)

An instrument composed of a sensor which operates at infrared wavelengths and a display system which depicts a scene based on data from the sensor.

Infrared wavelengths

Electromagnetic radiation between 0.74µm and 100µm.

Insolation

The amount of solar radiation (energy) reaching the earth's surface.

Intentional obscuration

A process, effect, or substance which is in the atmosphere with the purpose of hiding or concealing an object or activity.

Inversion

Increase of temperature with altitude.

Laser designator

A device used to illuminate a target with a laser spot once the target has been acquired.

Line of sight (LOS)

An imaginary line from an observer or E-O sensor to a target or to a distant point toward which the observer is looking.

Liquid water content

The amount of liquid water present in a volume of air, snow, or soil.

Mesopause

The top of the mesosphere.

Mesosphere

The atmospheric shell between about 20 and 80 km, extending from the top of the stratosphere to the mesopause.

Micron (micrometer)

10^{-6} meters, 10^{-4} centimeters, abbreviated μm.

Microwave frequencies

Electromagnetic radiation between 3 and 30 GHz.

Middle infrared wavelength

Electromagnetic radiation between 1.5μm and 5.6μm.

Mie scattering

Scattering caused by spherical particles in the atmosphere whose radii are greater than approximately 1/10 of the wavelength of the incident energy.

Monochromatic

One color or one wavelength, one frequency.

Near infrared wavelength

Electromagnetic radiation between 0.72μm and 1.5μm.

Near-millimeter wavelengths (NMMW)

Electromagnetic radiation between 90 to 1000 GHz.

Number density

The number of particles per unit volume.

Obscurant, obscuration

Any process, effect, or substance which tends to hide, conceal, or make dim an object or target.

Optical turbulence
Irregular changes in the refractive index in the atmosphere, usually due to variations in temperature and density of the air. Turbulence causes the image to appear blurred or broken up.

Orographic
Dealing with mountains (Webster). In meteorology, the effect that terrain has upon weather is referred to as orographic effects.

Particle size distribution
A mathematical or other description of the sizes of the particles occurring in a specified atmospheric condition.

Particulate
A substance composed of very small separate particles.

Passive sensor
An E-O sensor which perceives the emitted or reflected natural energy from a target or other object.

Precipitation
General term for all forms of falling moisture, for example, rain, snow, ice pellets, drizzle.

Radiation fog
A major type of fog, produced over a land area when radiational cooling reduces the air temperature to or below its dew point.

Radiational cooling
Cooling of the earth's atmosphere and adjacent air, usually accomplished during the night whenever the earth's surface suffers a net loss of heat.

Rain
Precipitation of liquid water drops having diameters greater than 0.5 mm.

Rainout
A process whereby dust or other solid particles are removed from the atmosphere by colliding with raindrops and falling to the ground with them.

Rayleigh scattering (molecular scattering)
: Scattering caused by particles in the atmosphere whose radii are less than approximately 1/10 of the wavelength of the incident energy.

Redeye
: A shoulder-fired guided missile system designed for defense against low-flying aircraft. The missile's infrared sensing device homes on the heat of the aircraft's engines.

Refraction
: A process in which electromagnetic energy changes direction when it passes through the boundary between two substances which have different refractive indices.

Refractive index (or index of refraction)
: A measure of the amount of refraction which occurs when electromagnetic energy passes through the boundary between two substances. The complex index of refraction also includes a measure of the absorption by a substance.

Relative humidity
: The ratio of the actual vapor pressure of the air to the saturation vapor pressure. May be thought of as the ratio of the amount of water vapor in a volume of air to the maximum amount that air could hold for the same conditions of temperature and pressure.

Roland
: A surface-to-air missile system for low level air attack defense. It is an all-weather system; mounted on a tracked vehicle. Radar is used for target acquisition and an infrared guidance system is used to guide the missile to the target.

Scattering
: Process in which small particles in the atmosphere diffuse a portion of incident electromagnetic energy in all directions.

Scattering coefficient
: A measure of the decrease in intensity of radiation due to scattering per unit distance or per unit mass.

Scintillation

Rapid changes in brightness, apparent position, or color of a distant object.

Seeability

The slant range distance at which a sensor is able to see, recognize, or lock onto a target. Seeability is dependent upon the condition of the atmosphere, contrast between target and background, direction and type of illumination, and sensor characteristics.

Semiactive sensor

An E-O sensor which perceives reflected energy from a target or other object, the source of which is an unnatural source such as a laser designator.

Shillelagh

A lightweight close-support Army guided weapon system primarily for a ground-to-ground role. The Shillelagh is guided to the target by an infrared command guidance system.

Sling psychrometer

A device that contains a wet- and dry-bulb thermometer mounted on a common back. Ventilation is achieved by whirling the thermometers with a handle and a swivel link until the maximum wet-bulb depression has been obtained.

Smog

A mixture of smoke and fog.

Snow

Precipitation of ice crystals, usually in six-sided form. At temperatures greater than 23°F the crystals are usually clustered to form snowflakes.

Snow grains

Precipitation of very small white opaque ice particles usually having diameters less than 1 mm.

Snow pellets (graupel, soft hail)

Precipitation or white, opaque, soft, approximately round ice particles of diameters about 2 to 5 mm.

Stability

A property of the atmosphere which tends to suppress upward motion of the air.

STINGER

An infrared seeking missile which allows the soldier to effectively engage low altitude, high-speed jet, propeller-driven and helicopter aircraft.

Stratopause

The boundary between the stratosphere and mesosphere, usually characterized by an abrupt change of temperature.

Stratosphere

The atmospheric shell above the troposphere and below the mesosphere and is characterized by an increase of temperature from the lower to the upper boundary.

TADS - Tactical Air Defense System

An integrated, flexible air surveillance and control system for mobile, semipermanent or fixed installation. Uses long-range and/or medium-range radars for acquisition and tracking of aircraft.

Thermal blooming

A process in which laser energy is absorbed by molecules and aerosols, causing the air to be heated. This changes the index of refraction of the air within the laser beam, causing it to defocus or wander.

Thermograph

A self-recording thermometer which provides a continuous record of temperature on a chart mounted upon a clock-driven cylindrical drum.

Thermosphere

The atmospheric shell extending from the top of the mesosphere to outer space.

Thunderstorm

A local storm produced by a cumulonimbus cloud, always accompanied by lightning and thunder, usually with gusty winds, heavy rain, and sometimes with hail.

TOW
Tube-launched, optically-tracked wire-guided antitank weapon system.

Transmission
The amount of the incident radiation which does not undergo extinction when passing through the atmosphere.

Tropopause
The boundary between the tropopause and stratosphere, usually characterized by an abrupt change of temperature.

Troposphere
The portion of the atmosphere from the earth's surface to the tropopause, usually the lower 10 to 20 km of the atmosphere.

Turbidity
A condition other than clouds or precipitation which reduces the transparency of the atmosphere to electromagnetic radiation. Usually refers to smoke, dust, haze, scintillation.

Ultraviolet wavelengths
Electromagnetic radiation between 0.001μm and 0.4μm.

Unintentional obscuration
A process, effect, or substance in the atmosphere which unintentionally hides or conceals an object or activity.

Vertical resolution
The division of a vertical column of air into layers in each of which the properties of the air are assumed to be uniform.

Visibility
The distance at which it is just possible to distinguish, with the unaided eye, a dark object against the horizon during the day and an unfocused, moderately intense light source at night.

Visible wavelengths
Electromagnetic radiation between 0.4μm and 0.74 μm.

Visual range
The distance that something can be seen.

Wet-bulb depression
The difference between the wet- and dry-bulb temperatures.

Wet-bulb temperature
The temperature an air parcel would have if cooled adiabatically to saturation at constant pressure by evaporation of water into it.

Wind
Motion of the air past a given point. Wind direction is defined as the direction <u>from</u> which the wind is blowing.

Yield factor
The ratio of the total mass of smoke produced to the mass of dry fill material.

APPENDIX B

QUALITATIVE DESCRIPTIONS OF SMOKE

1. GENERAL CHARACTERISTICS

a. The military code identifier designates the smoke producing material or its resulting aerosol. US inventory smokes include fog oil (SGF1 or SGF2), diesel fuel (three grades), hexachloroethane (HC) composition or smoke ($ZnCl_2$), white phosphorus (WP), and red phosphorus (RP) (phosphoric acids). Threat smokes include fogging oil, diesel fuel, WP, sulfur trioxide (FS) and several pyrotechnic mixes.

b. Yield factor is a calculated variable which accounts for the increase in mass of a smoke material which results from its combination with atmospheric constituents such as oxygen or water. Smoke materials which combine with atmospheric water are called hygroscopic smokes and include HC, WP, RP, and FS. Yield factors of hygroscopic smokes vary directly with atmospheric relative humidity, and values for yield factor can vary between 1 and 15, depending upon the smoke and the relative humidity. The yield factor for petroleum smokes, fog oils, and diesel fuels is 1. Differences between theoretical, laboratory, and field calculated yield factors have been noted.

c. Extinction coefficient (α) is a calculated smoke variable which relates energy transmission through a smoke to the integrated concentration of smoke along the line of transmission. (See below, transmittance and CL.) When concentration is expressed in grams per cubic meter and the length of the transmission through the cloud is in meters, α has units of grams per square meter. Extinction coefficient is a function of the wavelength of the energy being transmitted. Extinction coefficients of hygroscopic smokes are typically about 4 m^2/g for visible light but may vary between 0 and 10, depending upon the smoke and the wavelength of energy. Differences between extinction coefficients calculated from laboratory or field data have been noted.

d. Refractive index is a laboratory calculated property of materials. Generally, it is expressed as a complex number in the form $m = n - ik$, where n is the real index of refraction and the term ik is the imaginary component of the refractive index. The real index of refraction is calculated by using a Kramers-Kroenig dispersion relation to obtain n and k simultaneously from reflectivity measurements of specular surfaces. Also, optical microscopy is used on particles for visible wavelengths. The imaginary index is obtained as above or from $K = k\lambda/4K$ where λ is the length of the incident energy and k is the bulk absorption coefficient. Refractive index is used to compute attenuation of electromagnetic radiation by scattering and absorption of the energy by aerosol particles. For typical hygroscopic materials, K approaches zero at visible wavelengths and refractive index is a rational number.

2. DISSEMINATION FACTORS

a. Fill weight is the mass of smoke-producing material or mixture contained in a munition (projectile or pot).

b. Efficiency is a decimal variable calculated from the total mass of airborne smoke-producing material which results from munition function, divided by the fill weight. The total amount of smoke which results from a munition is the fill weight times the efficiency times the yield factor. Efficiency depends upon chemical purity, stoichiometry of pyrotechnic reaction, and completeness of the reaction. Efficiency is very high (> 0.90) for WP and fog oil, but less for RP and pyrotechnic mixes such as HC. Efficiency is sometimes quantified in terms of "effective yield" which is the amount of smoke produced by a unit amount of fill weight.

c. Munition dispersion (precision) is a scenario, or munition, dependent variable to be identified in four dimensions. In the case of generators or pots, the scenario will dictate the location and time (duration) of function. Munition dispersion is a function of round, charge, firing angle, fuze, and height of burst, all of which must be specified (with met conditions) to determine munition dispersion.

d. Submunition and canister are engineering designs to provide multiple, dispersed, discrete point sources of smoke from a single projectile. Inventory US smoke projectiles with submunitions include the 2.75-inch WP rocket and 105 mm and 155 mm HC projectiles.

e. Submunition and canister dispersion is a function of round, firing angle, charge, fuze, and height of burst, as with munition dispersion.

f. Burn rate is a laboratory-measured weight loss as a function of time from a smoke producing submunition/pyrotechnic. In the laboratory, burn duration is estimated as the time elapsed between 2 percent and 98 percent mass loss. Burn duration, a frequent specification of smoke munitions, is a field observation of the duration of smoke production by a submunition/pyrotechnic.

g. Feed rate is a basic engineering specification from which to estimate the source strength of clouds produced by generators (M3A3 or VEES).

3. PHYSICAL CHARACTERISTICS OF CLOUDS

All physical characteristics of clouds are determined by environmental factors once the projectile/pyrotechnic/generator has functioned. Physical characteristics are frequency estimated with a cloud transport and diffusion model of which several variants exist.

a. Cloud dimensions (m) and the shape change as a function of time after munition function. This evolution has been documented by still and motion picture cameras, video recorders and multispectral digital techniques.

b. Aerosol concentration (grams per cubic meter) is measured in the laboratory. The time integrated concentration of a cloud ($\int Cdt$ = dosage) is measured in the field with chemical impingers and estimated with aerosol photometers. Aerosol concentrations can range up to 2 g/m^3 in the field.

c. Particle size distributions, mass median diameter, or number median diameter (microns) and their standard deviations are measured in both the laboratory and the field with a variety of devices which operate on different physical principles. Particle size distributions (but perhaps not their variances) are a function of relative humidity for hygroscopic smokes. Typical particles are about 1μm in diameter in standard smokes.

d. Cloud luminance and radiance are measures of energy from the cloud which result from celestial illumination. The radiance is a function of the amount of illumination and the source, cloud, and observer geometry. Photometric measures of visible radiance are made in the field with telephotometers calibrated in foot lamberts (lumens/ft²/sr/Π). Radiometric measures of infrared radiance are made with telespectroradiometers calibrated in watts/m²/sr/μm.

e. Cloud temperatures have not been measured. The differences between cloud and ambient air temperatures may become important for infrared screening aerosols.

f. Transmittance (compliment of absorption) is a decimal variable which is a function of wavelength which is calculated from measures of the energy of electromagnetic radiation emerging from a cloud divided by the energy incident upon the cloud $T(\lambda) = I(\lambda)/I_o(\lambda)$. The measures are made with transmissometers of different sensitivity and spectral responsivity. Transmittance accounts for the loss of energy from the optical path which results from its scatter, refraction, and absorption.

g. CL is a calculated variable which quantifies the amount of smoke along an optical path between a source and a detector.

$$CL = \int_{Ls}^{Ld} C dL, \qquad \text{(B-1)}$$

where Ls and Ld refer to the source and detector, respectively, and CL has the units of grams per square meter. Measurements of variables to calculate transmittance and Cl are used to calculate mass extinction coefficient (α) of a smoke with the relationship

$$\alpha = (-1/CL)(\ln I/I_o) . \qquad \text{(B-2)}$$

APPENDIX C

QUALITATIVE DESCRIPTIONS OF PRECIPITATION

1. GENERAL CHARACTERISTICS

Precipitation is defined as a general term for all forms of falling moisture, for example, rain, snow, drizzle, ice pellets, hail.

a. Precipitation intensity is an indication of the amount of precipitation falling and is often expressed as very light, light, moderate, or heavy. Intensity of drizzle and snow is also estimated by using visibility as the criteria as:

Heavy
Visibility less than 0.5 km

Moderate
Visibility less than 1.0 km but greater than 0.5 km

Light
Visibility 1.0 km or more

Very light
Scattered flakes or drops which do not completely cover or wet an exposed surface regardless of duration

The intensity of rain is estimated from the rainfall rate which can vary from 0.01 to 100 mm per hour. The criteria for rain intensity are:

Heavy
More than 7.7 mm per hour, more than 0.77 mm in 6 minutes.

Moderate
2.5 mm to 7.7 mm per hour, 0.25 to 0.77 mm in 6 minutes

Light
Less than 2.5 mm per hour, maximum 0.25 mm in 6 minutes

Very light
Scattered drops which do not completely cover or wet an exposed surface, regardless of duration

b. The character of precipitation can be either continuous, intermittent, or showery. The intensity changes gradually, if at all, in continuous precipitation. During intermittent precipitation the intensity changes gradually, if at all, but precipitation stops and starts at least once within the hour preceding the observation. Showery precipitation occurs when the intensity changes or stops and starts abruptly.

2. PHYSICAL CHARACTERISTICS OF PRECIPITATION

The shape and size of precipitation particles depend upon ambient temperature, windspeed, amount of moisture available, and stability of the air. The different forms of precipitation are described below:

Rain
Precipitation of liquid water particles, either in the form of drops larger than 0.5 mm or smaller widely separated drops.

Freezing rain
Rain which freezes upon impact with the ground or with objects on the ground or in the air.

Drizzle
Fairly uniform precipitation composed of fine drops (less than 0.5 mm) very close together. Drizzle appears to float while following air currents.

Freezing drizzle
Drizzle which freezes upon impact with the ground or with objects on the ground or in the air.

Snow
Precipitation of ice crystals, mostly branched in the form of six-pointed stars. At temperatures higher than about 23°F, the crystals are generally clustered to form snowflakes.

Snow pellets

Precipitation of white opaque grains of ice whose diameters range from 2 to 5 mm. The grains are round or sometimes conical and usually bounce and break up when they hit the ground.

Ice pellets

Precipitation of transparent or translucent pellets of ice which have a diameter of 5 mm or less. They are round or irregular shaped and usually rebound when striking hard ground.

Hail

Precipitation of small balls or other pieces of ice, falling separately or frozen together in lumps. Diameters range from 5 to 50 mm or more. Hail is usually associated with thunderstorms and surface temperatures above freezing.

Ice prisms (ice crystals)

A fall of unbranched ice crystals in the form of needles, columns, or plates. These crystals are often so tiny that they seem to be suspended in the air. They may fall from a cloud or from clear air. Ice prisms occur only at low temperatures in stable air masses.

3. ATTENUATION

In general, heavy precipitation will severely degrade an E-O system operating at any wavelength. Infrared, millimeter, and microwave systems can be utilized during periods of light precipitation and through thin clouds. The millimeter and microwave systems are usually degraded less than infrared systems when operating through clouds and snowfall. The size, shape, and concentration of the snow flakes determine the amount of attenuation of electromagnetic energy that is attenuated during periods of snowfall.

APPENDIX D

QUALITATIVE DESCRIPTIONS OF WET AEROSOLS

1. GENERAL CHARACTERISTICS

a. Aerosol is defined in the glossary as small particles suspended within the atmosphere (haze, smoke, dust, fog, and cloud droplets). The qualitative description of smoke is given in appendix E. Neither radius nor mass adequately describes an aerosol particle to any degree of completeness. The geometry, dimensions, composition, and distribution over space are required also. It would be a totally impossible task to fully categorize these details for a population of aerosol particles; even if it were possible to do this, the resulting distribution would be multidimensional and not easy to understand. However, size and number concentration (the particles contained in a specific volume) will be the parameters used to describe the particles in this report.

b. Some of the most obvious aerosols in the atmosphere are composed of water. Clouds, fog, steam, and spray are commonly observed natural aerosols which are composed almost exclusively of water.

2. PHYSICAL CHARACTERISTICS OF WET AEROSOLS

Aerosols associated with clouds, haze, fog, and condensation nuclei will be described in this section.

a. Clouds are a collection of atmospheric aerosols and normally can be found from the surface of the earth to an altitude of 20 km.

(1) The number concentration of droplets in water clouds below an altitude of 3 km ranges from 10 per cm^3 to several thousand per cm^3, with concentrations of 20 to 200 per cm^3 average in maritime air and 200 to 2000 per cm^3 in continental air.

(2) Water clouds are composed of liquid water or ice, or both, depending on the temperature. The average size of aerosols found in water clouds is about 10^{-3} cm (10μm). Aerosols in high clouds are smaller than aerosols in low

clouds. Ice clouds are found at higher levels and consist of fewer, but larger, particles than are found in water clouds.

(3) The liquid water content in clouds varies from 0.15 g/m^3 to 1.5 g/m^3 in cumulus clouds, 0.25 to 0.60 g/m^3 in stratus clouds, and from 1.5 to 5.0 g/m^3 in thunderstorms.

b. Haze is small particles suspended in the atmosphere. Haze diminishes horizontal visibility and tends to subdue colors. Light scattering by haze causes the sky to have a gray hue. Otherwise the sky would appear a deep blue. Haze particles originate from cosmic dust, volcanic ash, bits of sea salt, soil dust, and combustion products from fires and industry.

(1) The number concentration of haze varies from about 200 cm^{-3} at sea level to 0.02 cm^{-3} at 10 km altitude.

(2) The size range of haze particles extends from about 0.01μm to 20μm.

c. Fog which reduces visibility to 1 km or less, is a visible accumulation of small water droplets suspended in the air near the ground. Fog droplets develop on condensation nuclei when the air layer near the ground becomes saturated. Cloud droplets develop on condensation nuclei when the lower altitude air rises and becomes saturated; thus the droplets in the lower altitude clouds are similar to those in fog. But, by definition, fog rests on the ground and is often considered a misplaced cloud. Autumn is the foggiest time of the year in Germany.

(1) The number concentration of fog droplets ranges from 1.0 to 500 cm^{-3}, with most values between 5 and 250 cm^{-3}, and will vary for different types of fog and with the life cycle of the fog.

(2) The size of fog droplets varies between 5μm and 500μm, with most droplets found in the 25μm to 100μm interval. Larger droplets of fog are found near the end of the life cycle of the fog.

d. Condensation nuclei are particles upon which water vapor condenses. Condensation nuclei respond quickly to changes in relative humidity, absorbing and releasing moisture as the relative humidity changes. Condensation nuclei are classified according to size as: Aitken, having radii less than 0.1μm; large, having radii between 0.1μm and 1μm; and giant, having radii greater than 1μm. The number concentrations of condensation nuclei vary from 10 to 10^3 cm^{-3} for sea salt to 10^3 to 10^6 cm^{-3} due to combustion processes at industrial centers.

APPENDIX E

BASIC RADIATION LAWS

A blackbody has been defined as any object which completely absorbs all radiation that it is exposed to. Conversely, the radiation emitted by a blackbody at any given temperature is the maximum possible. A blackbody is therefore a perfect absorber and radiator of radiation and its radiating and absorbing efficiency is said to be equal to 1. A body whose efficiency is less than 1 is called a gray body. The basic laws have been developed for blackbodies but can be amended for the gray ones.

1. PLANCK'S LAW

The radiation (R) emitted by a blackbody at a particular wavelength (λ) and temperature (T) is given by

$$\frac{C_1}{\lambda^5}\left(e^{C_2/\lambda T} - 1\right)^{-1}, \qquad \text{(E-1)}$$

where T is in degrees kelvin ($^\circ$K) = $^\circ$C + 273.

C_1 and C_2 are constants and their values depend upon the unit of wavelength, λ, used. If λ is in centimeters, then $C_1 = 3.7418 \times 10^{-12}$ watt/cm^2 and $C_2 = 1.4398$ cm deg. e is the base of natural logarithms and equals 2.718. R is in watts per centimeter per unit wavelength and is usually called the spectral radiant emittance. Figure E-1 shows the spectral radiant emittance for blackbodies at various temperatures.

2. WEIN'S DISPLACEMENT LAW

By differentiating equation (E-1) with respect to wavelength and setting the derivative equal to 0, the wavelength (λ_{MAX}) of which radiation is a maximum can be obtained. Then

$$\lambda_{MAX} = \frac{0.2897}{T}, \qquad \text{(E-2)}$$

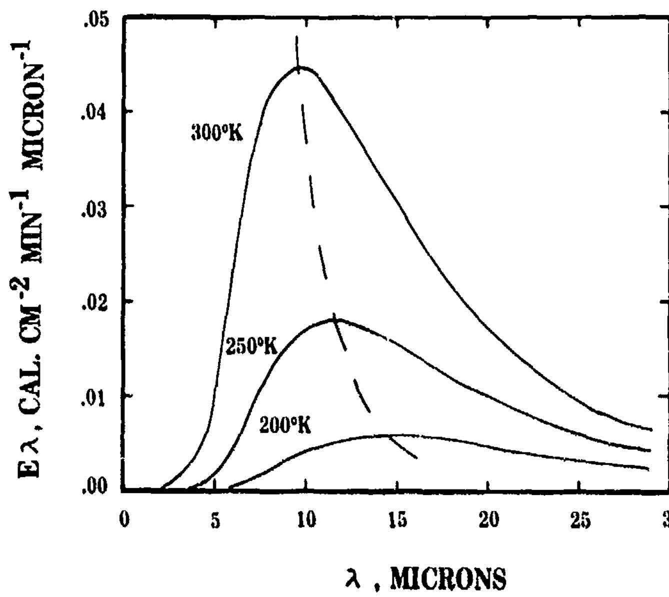

Figure E-1. Selected blackbody radiation curves. The dashed line connects the points of maximum radiation of each curve.

where λ_{MAX} is measured in centimeters. Wein's displacement law states that the wavelength of maximum radiation multiplied by the blackbody temperature is equal to a constant. As the temperature of the blackbody increases, its radiation peak shifts to shorter wavelengths. Wein's law lets the designer calculate the wavelength that he is interested in for a particular application. If it is a gray body, then all he needs is the temperature and the radiation and absorption factor (emissivity).

3. STEFAN-BOLTZMANN LAW

By integrating equation (E-1) within the wavelength limits of zero to infinity

$$R_t = \int_{\lambda=0}^{\lambda=\infty} R d\lambda = \alpha T^4 , \qquad \text{(E-3)}$$

where R_t = total blackbody radiant emittance, measured in watts per square centimeter of the radiating surface

α = Stefan-Boltzmann constant

$= 5.67 \times 10^{12}$ watt/cm² deg⁴

$= 5.67 \times 10^{-5}$ erg/cm² sec deg⁴

Since integration was over the entire wavelength spectrum, R_t is not wavelength dependent. R_t is dependent upon the fourth power of the temperature of the blackbody source.

4. BEER'S LAW

The attenuation coefficient α of a medium for radiation of wave number n is a proportionality factor in Beer's law. The attenuation process is linearly proportional to the intensity of radiation and the amount of attenuating medium with the restriction that the pressure, temperature, and composition of the medium remain constant. If the spectral intensity I_ν of a parallel beam of radiation is changed by the amount of dI_ν due to the density ρ and the attenuation of the medium of length dx, then

$$dI_\nu = \alpha_\nu I_\nu dx \ , \qquad \text{(E-4)}$$

where α_ν is defined as the mass attenuation coefficient.

In general, the attenuation coefficient is the sum of a scattering coefficient $\alpha_{\nu s}$ and an absorption coefficient $\alpha_{\nu a}$. The energy lost by absorption goes to producing photochemical reactions, heating the medium, or to some other form of energy. At any rate, it is lost to the radiation field. The energy lost by scattering emerges as radiation and is still the same wavelength. Only the direction of propagation has been changed in the attenuation process.

By integrating from point zero to point x in the medium, the intensity of the emergent radiation is given by

$$I_\nu = I_{\nu o} \exp\left(- \int_0^x \alpha_\nu \rho dx\right) \qquad \text{(E-5)}$$

$$= I_{\nu o} \exp\,[-H(o,x)]\ , \qquad \text{(E-6)}$$

where the exponent defines the optical thickness between the points o and x. This is one form of Beer's law for the transmission of radiation.

The attenuation coefficient is sometimes expressed in decibels (dB) by using the relationship

$$dB = 10 \log_{10} [I_o/I]\ , \qquad \text{(E-7)}$$

which gives

$$\alpha = 0.23058\ dB$$

or attenuation loss in

$$dB/km = 4.33679\ \alpha\ (km^{-1}). \qquad \text{(E-8)}$$

5. VISIBILITY

Visibility is defined as the distance at which it is just possible to distinguish a dark object against the horizon. Each weather station usually has a "visibility marker" map with the weather station located in the center of the map and prominent objects (towers, buildings, mountain ranges) plotted on the map at the proper direction and distance from the weather station. Then if the observer can just distinguish a particular object, he can make a good estimate of visibility in that quadrant.

Prevailing visibility is reported in the United States by civilian agencies and DOD personnel, regardless of location. Prevailing visibility is defined as the greatest horizontal visibility prevailing throughout at least half of the horizon circle, which need not necessarily be continuous. In Europe the reported visibility is the minimum visibility observed with remarks of visibility being greater in other quadrants.

Visibility is analogous to the visible extinction coefficient. The Koschmieder visibility theory defines the relationship

$$V = \frac{1}{\sigma} \ln[1/c_t] , \quad \text{(E-9)}$$

where V is the visual range, σ is the visible extinction coefficient, and c_t is the observer's contrast threshold. The contrast threshold has been set at 0.02 after several experiments of observers identifying distant objects (Middleton, 1952).

Solving the above equation gives

$$V = \frac{3.912}{\sigma} , \quad \text{(E-10)}$$

which has become standard in most texts and has been given the name of "meteorological range" to distinguish it from the observed visibility.

Equation (E-10) expresses a relationship between the visual range and extinction coefficient. Small extinction coefficients occur with large values of visual range.

6. CONTRAST

The difference of the radiance between an object and its surroundings enables an observer to detect the object. This difference is usually inferred to as contrast. Contrast is easy to understand but is a most complex and difficult problem confronting E-O technology.

The contrast between an object (target) and its background can be expressed as

$$C = \frac{R_t - R_B}{R_B} , \quad \text{(E-11)}$$

where R is the radiance and the subscripts t and B stand for object (target) and background, respectively. Consequently, the inherent contrast (at a distance approaching zero) is given by

$$C_o = \frac{R_{to} - R_{Bo}}{R_{Bo}} . \tag{E-12}$$

The ratio of the apparent contrast to the inherent contrast is called the atmospheric contrast transmittance and is given by

$$T_c = \frac{C}{C_o} . \tag{E-13}$$

Let t_ℓ and R_ℓ^P denote the atmospheric transmittance and radiance of the optical path at length, ℓ , between the observer and the object. Then the apparent radiance of the object R_ℓ^T and that of the background R_ℓ^B will be given by

$$R_\ell^T = R_o^T T_\ell + R_\ell^P ; \tag{E-14}$$

$$R_\ell^B = R_o^B T_\ell R_\ell^P . \tag{E-15}$$

Combining equations (E-11), (E-12), and (E-13),

$$T_{c_1} = \frac{(R_\ell^T - R_\ell^B)R_o^B}{(R_o^T - R_o^B)R_\ell^B} . \tag{E-16}$$

Substituting the values of R_ℓ^T and R_ℓ^B from equations (E-14) and (E-15) into equation (E-16) yields

$$T_{c_1} = \frac{(R_o^T - T_\ell R_o^B T_\ell)R_o^B}{(R_o^T - R_o^B)(R_o^B T_\ell + R_\ell^P)} ; \tag{E-17}$$

$$T_{c_1} = \frac{T_\ell R_o^B}{T_\ell R_o^B + R_\ell^P} \; . \qquad \text{(E-18)}$$

Note that the atmospheric contrast transmittance is a function of the atmospheric transmittance, the radiance of the optical path, and the inherent radiance of the background and/or object.

In the special case where the background is the sky, the atmospheric contrast transmittance equals the atmospheric transmittance, or

$$T_\ell = T_c \; . \qquad \text{(E-19)}$$

Writing the value of T_ℓ in terms of the attenuation coefficient σ,

$$T_c = e^{-\sigma\ell} \; , \qquad \text{(E-20)}$$

where ℓ is the optical path length. Taking the natural logarithm,

$$-\sigma\ell = \ln T_c$$

or

$$\ell = \frac{1}{\sigma} \ln \frac{1}{T_c} \; . \qquad \text{(E-21)}$$

The optical path length ℓ can be inferred to be visibility, and now notice the similarity of equations (E-9) and (E-21). By letting the threshold contrast C_t and contrast transmittance T_c be the same, the two equations (E-9 and E-21) are equal.

7. SCATTERING

The scattering of electromagnetic radiation in the atmosphere involves molecules and particles that are both smaller and larger than the wavelength. To complicate matters further, multiple interactions between the molecules and particles and the radiation occur. However, simplification is possible and only "single scattering" is considered for the development of theory. If the scattering is dominated by particles small compared to the wavelength or by molecular scattering, then Rayleigh scattering is said to occur.

For molecular particles smaller in diameter than the wavelength of the radiation, Rayleigh's law implies that the spectral radiance due to scattering decreases as the wavelength increases.

The development of Rayleigh scattering considers the interaction of the scattering molecule with a plane electromagnetic wave and an induced dipole moment. It is beyond the scope of this work to derive the Rayleigh scattering theory utilizing electric field and vector notation. One equation used to express Rayleigh scattering is

$$I_s = KV^2\lambda^{-4} I_o , \qquad \text{(E-22)}$$

where I_s = intensity of scattered radiation

K = dielectric constant

V = volume of the scattering particles

λ = wavelength of the incident radiation

Some interesting conclusions are:

The angular distribution of the scattering is given by $(1 + \cos^2\theta)$ is symmetric in the forward and backward directions and applies only to isotropic particles; the scattered intensity and energy removed by scattering is proportional to the sixth power of the radius of a spherical particle and to the inverse fourth power of the wavelength.

For larger particles such as those occurring in fog and haze where particle diameters range from about 0.1μm to over 100μm, Mie scattering theory applies. The theory is not simple and van de Hulst (1957) in his monograph treats the theory adequately. Calculation of Mie coefficients is a lengthy process as infinite series (more than 200 terms for particles 10μm radius or greater) converge slowly. Expressions for the scattering, absorption, and total extinction efficiency factors are as follows:

$$Q_s(x,m) = \sigma_s(a,\lambda,m)/\pi a^2 ; \qquad \text{(E-23)}$$

$$Q_a(a,m) = \sigma_a(a,\lambda,m)/\pi a^2 \; ; \tag{E-24}$$

$$Q_E(x,m) = \sigma_E(a,\lambda,m)/\pi a^2 \; . \tag{E-25}$$

The parameters x and m represent the relative size and relative refraction coefficient of the particle

$$x = 2\, a/\lambda$$

$$m = m_1/m_2$$

where m_1 and m_2 are the complex refractive indices of the particle and medium, respectively. Usually $m_2 = 1$ and $n - ik = m$, where n and k are the real (index of refraction) and imaginary (index of absorption) parts of the complex refractive index of the particle material.

Q_s, Q_a, and Q_E are the efficiency factors of scattering, absorption, and total extinction and are numerically equal to the ratio of the energy scattered, absorbed, and attenuated by a particle to the energy incident onto its geometric cross-sectional area.

APPENDIX E REFERENCES

Middleton, W. E. K., 1952, Vision Through the Atmosphere, University of Toronto Press, Toronto.

Van de Hulst, H. D., 1957, Light Scattering by Small Particles, John Wiley and Sons, New York.