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COMBIC, Combined Obscuration Model for Battlefield Induced Contaminants:

Volume 1—Technical Documentation and Users Guide

Alan Wetmore and Scarlett D. Ayres

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COMBIC, Combined Obscuration Model for Battlefield Induced Contaminants:

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Alan Wetmore
Computational and Information Sciences Directorate

Scarlett D. Ayres
Survivabilty/Lethality Analysis Directorate

Abstract

Airborne dust, smoke, and debris can significantly degrade a battlefield environment and affect electro-optical systems. The most direct effect of these combat-induced aerosols on a propagating electromagnetic signal is to remove energy (reduce transmission) through absorption and scattering. Reduced transmission through inventory smokes and dust is generally most significant at visual and infrared wavelengths and less severe at millimeter wavelengths.

Obscurant concentrations can change rapidly in a combat environment. Once generated, an aerosol cloud moves with the wind, undergoes thermally buoyant rise, and expands in the atmospheric turbulence. Thus, prevailing winds, aerosol generation factors, and the geometry of targets, observers, and aerosol clouds are important in determining transmission.

The Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) predicts time and spatial variations in transmission through dust and debris raised by high-energy explosives and by vehicular movement; smoke from phosphorus and hexachloroethane munitions; smoke from diesel oil fires; generator-disseminated fog oil and diesel fuel; and other screening aerosols from sources defined by inputs. COMBIC has been designed primarily for large scenarios where many different obscuration sources are present and where many observer-target lines of sight (LOS) must be treated simultaneously.

This document has been developed to provide both a technical description of the physics used in the COMBIC model and to serve as an operations guide for users of the COMBIC software.

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Volume 1

1. Introduction

In realistic modeling of the battlefield, determining the effectiveness of electro-optical (EO) sensors requires a method of quantifying the effects of obscurants on the transmission of visible through infrared (IR) wavelengths. Such a method is provided by the Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC), developed by the former Atmospheric Sciences Laboratory (now part of the U.S. Army Research Laboratory, ARL). The COMBIC computer simulation predicts spatial and temporal variation in transmission produced by smoke and dust from various munitions and vehicles. COMBIC models the effects of reduction in electromagnetic energy (in the visible through IR wavelengths) by combining munition characteristics with meteorological information of an idealized real world. It produces transmission histories at any of seven wavelength bands for a potentially unlimited number of sources and lines of sight (LOS's). COMBIC was designed to be computationally fast without losing accuracy for wargame modeling applications. This goal was a major concern in the early development of the model and significantly influenced the approach. Several wargaming models use the COMBIC model to play smoke in the battlefield.

In COMBIC, computations are performed in two phases. First, a cloud history file is preprocessed for one or more obscurant source types, selected from a menu or defined through user inputs. Except for wind direction, all meteorological influences are included in these Phase I calculations of transport, rise, and diffusion of the obscurant clouds. Additional effects of the atmosphere on aerosol properties are also included. Four-dimensional clouds (space and time) are compressed to tables of two-dimensional subcloud profiles (about 370 values per subcloud based upon downwind distance from source and time). The total cloud for each user-selected source that goes into the history file can contain up to five subclouds. For each of 60 non–equally-spaced downwind distances for each subcloud, data are stored, including cloud centroid height for average heat production; cloud dimensions and tilt (puffs); and time required to reach each downwind distance. Total obscurant produced up to a given time is stored every second.

In separate, Phase II calculations, COMBIC builds a user-defined scenario of smoke and dust sources. By table lookup and scaling of Phase I histories, cloud concentrations at any given time are computed. Path-integrated concentration is determined for each LOS between an observer and target, and transmittance values are computed at each of seven wavelength bands for (in principle) any scenario that is defined by multiple sources and active LOS's. Phase II emphasizes computation speed. COMBIC uses efficient techniques to determine the path-integrated cloud concentrations over each LOS. A filtering process ignores clouds that do not contribute to the integral. Bookkeeping functions add target–observer pairs (as specified), add new sources to the scenario, and remove dissipated clouds. Phase II also uses scaling laws to model moving sources that have different speeds and directions but share a common cloud history (produced by Phase I).

1.1 Document Overview

The report sections give model methodologies, terminology, error messages, descriptions, evaluations, coding, and usage guidance for the COMBIC model. Section 2 provides a brief overview of the theory behind the COMBIC model. Section 3 gives error diagnostic messages and a summary of the evaluation effort for the model. Section 4 documents use of the code, input and output records, and modifications to the code that the user might want to make. Section 5 provides several examples and subroutine descriptions. Appendices A and B provide extensive technical documentation and derivations. Appendix C provides a listing of the default parameters that go into modeling the munitions.

We provide a guide to the terminology, definitions of variables, and geometry conventions used in the model and documentation (sect. 2.3). This guide is particularly useful to new users who are unfamiliar with the meaning of the model input parameters.

Included in section 4 is information useful to the user and to the programmer who must interface, modify, or implement the code. This section provides reference tables of the COMBIC input parameters.

Complete examples are given in section 5.2. These allow the user to gain a sense of the types of output and to determine if the user’s code is running properly. Other parts of section 5 contain subroutine descriptions and the programming techniques used for “bookkeeping” of clouds and target–observer pairs. Guidance is given for modifying the code to process large numbers of clouds or of LOS’s.

In appendix A, sections A-1 and A-2 develop the mathematical framework on which the compact cloud history tables are based. The derivation of the efficient path integration methods used in Phase II is given there.

Sections A-3 through A-5 contain the models used to determine the cloud expansion with time (diffusion), the vertical rise (buoyancy and momentum), and the meteorological model. The meteorological model determines microscale parameters and the windspeed profile with height. These sections contain derivations and / or empirical representations that are probably not of great interest to the casual user.

Appendix B gives the models of aerosol properties and the munition characteristics that initialize cloud descriptions. Built-in models that translate user inputs into microphysical parameters used in the cloud models are also documented in this appendix.

1.2 COMBIC Availability

COMBIC92 is part of EOSAEL92, which is available at no cost to the U.S. Department of Defense, specified allied organizations, and their authorized contractors. DoD agencies needing COMBIC92 should send a letter of request, signed by a branch chief or division director, to ARL. Contractors should have their DoD contract monitor send the letter of request. Allied organizations must request COMBIC92 through their national representatives.

There is also a commercial version of COMBIC and the other EOSAEL models available for PCs. This product is sold by ONTAR Corporation and includes Windows GUI, data entry, and plotting utilities. More information is available at www.ontar.com and www.eosael.com or from

ONTAR Corp.
9 Village Way
North Andoven MA 01845-2000
1-978-689-9622

We encourage suggestions and the reporting of errors. Users can contact Scarlett Ayres or Robert Sutherland (505-678-4520; DSN 258-4520) for source characteristics. Users can also contact Scarlett Ayres (505-678-4350; DSN 258-4350) for applications and code usage concerning technical aspects of the model, and Alan Wetmore (301-394-2499; DSN 290-2499; fax 394-4797; awetmore@arl.mil) for EOSAEL applications, distribution, and documentation.

The mailing address for EOSAEL inquiries is

U.S. Army Research Laboratory
Attn: AMSRL-IS-EP (A. Wetmore)
2800 Powder Mill Road
Adelphi, Maryland 20783-1197

2. Background

2.1 Model Capabilities

The battlefield environment includes significant amounts of airborne dust, smoke, and debris. The resulting reduction in transmission of electromagnetic energy at visual and near-, mid-, and far-IR wavelengths affects the performance of many EO systems. Freshly produced high-explosive (HE) dust momentarily reduces millimeter wave (MMW) transmission.

COMBIC predicts spatial and time variation in electromagnetic transmission through a variety of possible battlefield obscurants: dust raised by HE and vehicular motion; screening smoke from white phosphorus (WP), red phosphorus (RP), WP wicks and wedges, and plasticized WP (PWP); hexachloroethane (HC) smoke; smoke plumes from diesel-oil fires; and the generator-disparsed obscurants fog oil or SGF2 (Standard Grade Fuel Number 2), vaporized diesel fuel (DF), polyethylene glycol (PEG200) and IR screener disseminated from generators.

A barrage option is provided that produces simplified, continuous, and extended sources of obscurant, rather than individual rounds. Moving sources producing a continuous obscurant cloud (vehicular dust, moving smoke generators, and even moving barrage sources) can be specified with different speeds and directions. The model provides a menu of various obscurants and allows the user to define the basic properties of sources not stored in the code menus.

In obscuration codes, execution speed, modeled cloud detail, and prediction accuracy are all competing design criteria. COMBIC seeks a reasonable balance among these factors. COMBIC was an outgrowth of earlier EOSAEL models (Hoock and Clayton, 1984; Duncan, 1982), but it has a greater emphasis on reducing computation time for large scenarios. This emphasis led to a separation of calculations into two parts or “phases.” The first phase concentrates on accuracy and the details of the physical processes acting on single obscurant clouds. The second phase is designed to be fast and make efficient use of results from the first phase to simulate large obscuration scenarios.

COMBIC was designed in part around the natural decrease in detail or resolution with distance from a source. For example, the most rapid spatial and time changes in cloud concentration and cloud rise occur nearest the source. At large downwind distances, changes take place more slowly and over larger spatial scales. This phenomenon has been taken into account in the definition of the grid over which cloud properties are computed and stored. Further, the user is given some control over execution and resolution tradeoffs. The barrage option groups multiple smoke sources (such as munitions or smoke rounds) impacting over a period of time in some limited area, and computation time is reduced. However, this simplification is at the expense of the detail that is obtainable if the user specifies individual source locations and times.

Obscurant clouds are modeled in COMBIC as combinations of subclouds having concentrations described by Gaussian instantaneous puffs and continuous plumes. Subclouds move downwind, expand, and perhaps rise because of buoyancy. Figure 1 is an example of a typical smoke cloud modeled as a combination of a plume and a puff. Wind shear, temperature gradients, relative humidity, surface roughness, and wind speed and direction can all have an effect on how the cloud rises and expands downwind. Optical properties are defined in terms of extinction per unit mass concentration for the material in each subcloud. Thus, transmittance includes the combined effect of extinction along the target–observer path for every subcloud along that path. Output includes the predicted transmittance at each of the seven EOSAEL wavelength regions and the concentration length (CL, the integral of the concentration over the path length through the cloud) for each specified target–observer pair at each specified output time. The user can also manipulate the inputs to produce optical depth and concentrations.

The two phases of COMBIC are usually executed through separate submodules. The driver routine is the branch point at which the execution paths of the submodules split. It is thus relatively easy to separate COMBIC into completely independent Phase I and Phase II modules if needed.

Phase I uses meteorological input data and obscurant source characteristics selected from a menu or input by the user. A history file is produced that describes the evolution of the obscurant cloud for the source types and specified meteorology. These tabulated values are all relative to the source location and are independent of wind direction or scenario-specified source location and detonation time. The generated history file is defined as direct

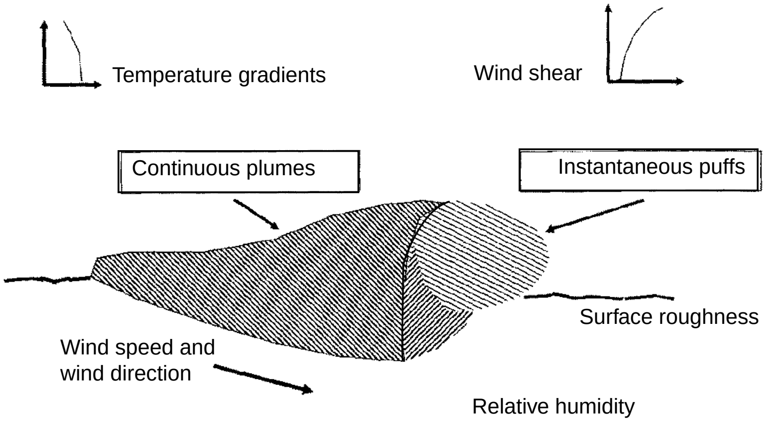

Figure 1. Typical smoke cloud and some factors that affect it.

access (that is, record-addressable) to reduce access time to the tables. This change is compatible with FORTRAN 77. Because both Phases I and II are run on the user's system, the precise internal format of direct access files on the user's system is irrelevant to COMBIC. Phase I contains the bulk of code usually associated with the physical processes modeled in obscuration codes.

In principle, Phase II produces transmittance histories for scenarios containing any number of target–observer pairs and any number and combination of obscurant sources from among the types precomputed in the Phase I output file.

The Phase II code has four major functions.

- The Phase II code first loads storage arrays with the locations of active target–observer pairs and obscurant sources specified by the user. Storage can optionally be reused as target–observer pairs become inactive and as clouds dissipate.
- The code then interpolates and scales the Phase I cloud histories. Scaling allows the Phase I history to serve for a limited range of source strengths different from the single value specified in the Phase I inputs. For example, a history computed in Phase I for six 155-mm WP rounds detonated at the same point and time can be used in Phase II calculations for cases of 2 to 12 rounds. A single "one case fits all" Phase I calculation is not possible because of the variation in buoyant rise from the heat produced by groups of closely spaced smoke or HE munitions.
- The code then updates cloud dimensions with time and applies simple tests to determine which clouds contribute to a given target–observer LOS.
- The code finally computes the path-integrated concentration and transmittance along the LOS. Phase II accepts arbitrary scenario times since all calculations requiring iteration by small time increments are performed in Phase I.

2.2 Model Changes and Extensions

Users of the previous (EOSAEL87) version of COMBIC will note a few changes in the latest revision. The obscurant sources in COMBIC now include extinction coefficients for graphite. Several new munitions have been added, such as the M76 IR grenade, L8A1 and L8A3 grenades, and CBU88 munition. The characteristics of these munitions are stored in the model menus. The COMBIC model can now also model the dust produced by muzzle blasts. Anyone who has seen large artillery fired knows that in the process of firing, dust is lofted into the atmosphere. In 1990, questions arose over whether the dust produced by muzzle blasts can affect the transmission of electromagnetic energy. The user community requested ARL to include muzzle blasts as a source of obscuration. One of the examples included in this report shows muzzle blast.

Smoldering is also included in the input records used to define a munition. Smoldering results when the smoke munition produces a comparatively small amount of smoke for a long period of time. COMBIC smoldering controls through the record `SMOU`, which allows the obscurant burn rate to be modified for smoldering munitions. The records specifies when smoldering occurs and how fast the smoke production decays. This change was included in EOSAEL87, but it was not included in the EOSAEL87 documentation.

A subroutine was added to COMBIC87 Phase II to generate printer plots of transmittance or optical depth for what amounts to bundles of parallel LOS's surrounding an input target–observer pair. This output option is very useful for displaying the cloud shape and dimensions graphically and for allowing the examination of screen coverage and concentration patterns. Paths producing transmittance or optical depth within user-assigned bands are given corresponding symbols that define a grey scale, and the result is printed. This option thus generates a form of contour printout. Many users have requested modifications to these printer plots. COMBIC92 includes some of these modifications:

- COMBIC87 would always label the axis so that the origin was at the center. This often did not reflect the battlefield the user had created. In COMBIC92, the user has the option of defining the axis numbering.
- The grey scale in COMBIC87 was always evenly spaced. Often, the user wanted to see a very fine grey scale where the cloud was very dense and a coarse grey scale where the cloud was very thin. COMBIC92 allows users the option of adjusting the grey scale to suit their purposes. This option is valid only when the grey scale is transmission.
- In COMBIC87, all the LOS's that made the printer plot were parallel to each other. Thus, the printer plot was an orthographic representation of the smoke. However, it is more realistic to include a perspective view of the smoke. In COMBIC92, the user can request the perspective view, in which case all LOS's originate at the observer.

In COMBIC92, the modeling of diffusion in the planetary boundary layer is approached differently depending on the distance traveled by the cloud after 30 s. In previous versions, a power law based on the downwind distance was used in all cases. In the present version, a distance-related Lagrangian weighted function is used for distances greater than that traveled by the cloud after 30 s. For lesser distances, the usual power law methodology is used. The new dispersion lengths formula (see sect. A-3) results in higher but narrower puffs and plumes with higher concentration along the center. Also, a Pasquill category G is added to the Pasquill categories A to F. G represents a highly stable atmosphere with wind.

The most significant change is in the methodology used to compute the CL integral of LOS–cloud pairs through plumes. Mathematical/computer models are available that describe CL quite accurately, but with as many as 10,000 LOS–cloud pairs (not uncommon in COMBIC runs), the computation time can become prohibitive. In COMBIC92, therefore, the Romberg method of integration is used to increase the speed of the COMBIC runs.

COMBIC was designed to give the user a balance between speed and accuracy. This revision of COMBIC is designed to further increase the speed of computation of CL for plumes of aerosol concentration over EO paths with nonnegligible downwind components. This revision provides the user with the option of specifying three values: the percentage of error that can be tolerated, a low threshold value, and a high threshold value beyond which further computation of CL is unnecessary for the user's application. Each of these values is used by COMBIC to monitor the integration process for determining the point at which computation of CL can be terminated. Choice of these parameters for optimum speed and desired accuracy will require experimentation by the user.

2.3 Terminology, Definitions, and Conventions

The definitions and corrections included here are intended to help those unfamiliar with obscuration models to become familiar with the terminology and to provide a sense of what the model can do and cannot do. The section does not assume any deep background in physics or mathematics, although a few basic mathematical formulas are given that show how the physical quantities interact. It answers many of the questions most often asked by new users of the COMBIC model. Further guidance on using the model is given in sections 4 and 5.

The purpose of COMBIC is to provide representative values of transmittance. *Transmittance* is the quantity that defines the fraction of the original energy left in an electromagnetic beam after it passes along an optical path. *Transmission*, on the other hand, is the movement of an electromagnetic signal or electromagnetic energy between two points: in this case, through an aerosol-laden atmosphere. COMBIC models the transmission process in order to calculate the transmittance values.

The optical path is often referred to as a "line of sight" (LOS). This is used purely as a geometric term meaning a straight line between some initial point (the observer) and a final point (the target). The term *LOS* is also used in some combat models, however, to represent a path with a clear view unobstructed by terrain. COMBIC does not determine whether terrain intercepts an optical path. This determination is left to other models. In addition, the term *LOS* does not imply that someone looking from one end of the line to the other will necessarily be able to “see” something at the other end. (That is, of course, the purpose of computing transmittance in the model.)

COMBIC includes only the transmission reductions by obscurant aerosols. Natural gases, haze, rain, etc, must be included from other EOSAEL modules.

Energy is removed from a propagating beam by being scattered out of the LOS and by being absorbed along the LOS. The combination of both processes is called extinction. COMBIC uses a “mass extinction coefficient,” a single number that describes the extinction resulting from energy traversing 1 m of an aerosol cloud with a concentration of 1 g/m^3. The mass extinction coefficient is wavelength dependent and is different for each type of aerosol. This coefficient is used to determine transmittance according to the “Beer-Lambert” law:

$$T = e^{-\alpha CL}, \tag{1}$$

where *T* is the transmittance, α is the mass extinction coefficient (in units of meters squared per gram), and CL is the product of the aerosol concentration C (in grams per meter cubed) over the optical path length L (in meters). If the concentration varies along the path, then CL must be replaced by the integral

$$\int_0^L C(x)\,dx. \tag{2}$$

However, since the COMBIC model is not sensitive to the form of $C(x)$ but only to the result of the integral above, it is more convenient to use the CL representation.

“CL” (concentration length) or the “CL product” are terms often encountered in the study of obscuration and in test reports of the measured ability of an aerosol to reduce transmission. Although concentration length (CL) is in units of grams per meter squared, the product αCL is itself dimensionless and is called the “optical depth” or “optical thickness” of the path through the aerosol. *T* is a fraction between 0 and 1 and has no physical units. Thus, a transmittance *T* of 0.35 means that 35 percent of the original energy will remain after it passes along that particular optical path.

The purpose of COMBIC is to find the CL value appropriate to a particular region and age of the aerosol cloud, to multiply by the corresponding extinction coefficient, and then to obtain the transmittance by equation (1). If a path passes through a series of different types of aerosol clouds, the transmittance of each is found, and the transmittances are then multiplied to produce the net transmittance for the group. Equivalently, the optical thickness through each cloud can be determined. These are added together, and the exponential in equation (1) can be used to evaluate the same net transmittance. COMBIC performs these actions so that the output quantity is the combined transmittance through all clouds present on the path.

Note that transmittance is the same along both directions of the path. It does not matter in terms of the calculation which end of the path is designated the observer or the target. Transmittance does not include any stray light that might be scattered by the aerosol into the field of view or any additional electromagnetic energy that might be emitted by the aerosol itself.

2.3.1 Aerosols and Particulates

The terms *aerosols* and *particulates* are used interchangeably in COMBIC, although *aerosol* more properly refers to all types of small particles suspended in a gaseous medium and *particulates* to dry particles. Aerosols and particulates are airborne materials with varying composition and sizes. Concentrations of battlefield aerosols usually contain particles from tenths of a micrometer up to hundreds of micrometers in diameter. Battlefield aerosols tend to be larger than background haze particles of the atmosphere, and their size distributions have important effects on extinction at wavelengths comparable to these sizes.

2.3.2 Barrage

In COMBIC, the user is given an option to define a barrage. The barrage simulates the effect of many munitions detonating over some well-defined area for a period of time. The result is a continuous cloud that replaces the individual clouds that would have been computed if each source had been individually specified. The barrage approximation now includes the specification of a cross-wind dimension and an along-wind dimension for the impact area, a rate (the number of munitions per second impacting in the area), and the total time duration (in seconds) over which the rounds impact.

2.3.3 Buoyancy Radius R_o

A hot thermal region is produced by HE detonation and by bulk WP. This “fireball” region is modeled as a spheroid of warm aerosol and gases that rises in cooler ambient air. The initial buoyancy radius is the starting radius for this region. It is generally smaller than the obscurant dissemination radius. The buoyancy radius is, by default, determined from an initial fireball temperature and the total thermal energy available for buoyancy. It may be input optionally by the user.

2.3.4 Burn Rate Profile $M(t)$

The burn rate profile refers to an equation that describes the history of the rate at which obscurant mass is produced from a source as a function of time (in grams per second). The cumulative burn rate profile is the equation or data curve that quantifies the fraction of the total source mass that has been released up to a given time (it is dimensionless). COMBIC rescales the cumulative burn rate profile internally to match the total mass produced. Thus, it accepts the profile in any system of units.

2.3.5 Burn Duration T_b

The burn duration is the total time (in seconds) over which a source produces obscurant. In COMBIC, this term is also applied to the total length of time that any source produces obscurant, including dust produced from a vehicle.

2.3.6 Convective, Neutral, and Lapse Conditions

The terms *convective*, *neutral*, and *lapse* refer to an unstable, a buoyantly neutral, and a stable atmosphere, respectively. For further details, see the Pasquill definition of the stability category (p 16).

2.3.7 Carbon Fraction C_f

The carbon fraction is the ratio of the mass of free carbon produced from a source to the mass of other obscurants in which the free carbon is mixed. With respect to HE, however, the definition is the ratio of the weight of free carbon produced to the original explosive weight (as in pounds of carbon per pound of equivalent TNT). Values of 0.1 to 0.3 are typical of HE.

2.3.8 Casing Dimensions

Casing dimensions are the length of an HE munition casing and its diameter at its widest point (in meters). The casing dimensions indirectly determine the fractions of energy that generate dust and produce heat.

2.3.9 Concentration Length, CL

Concentration length, sometimes called a columnar mass density, is a quantitative measure of how much smoke is present along the LOS in grams per square meter. The simplest way to think of the CL is to imagine that you are surrounded by a square frame 1 m long on each side. If you walk toward a target, accompanied by your frame, the path of the frame traces an imaginary column 1 m $\times$ 1 m $\times$ the distance to the target. The total smoke mass present inside this column is the CL.

2.3.10 Depth of Burst (DOB) and Dip Angle

The depth of burst and munition inclination angle, or dip angle, at burst are used for HE dust only. The depth (in meters) is positive below the surface and negative above the surface. The depth is measured to the center of mass of the munition or charge. Fuzing, casing dimensions, and dip angle also determine the depth of burst. Given no other information, a 10° to 20° dip angle for artillery and 80° for short-range mortars are reasonable.

2.3.11 Efficiency E

Efficiency is defined differently among modelers and among developers of obscurants. For modelers, except for HE dust, efficiency is the ratio of obscurant mass released to the original fill weight of the source. (Developers tend to include other factors in their calculation of efficiency.) Thus, if 10 lb of a chemical mixture burns to produce 4 lb of actual obscurant, the efficiency is 40 percent. Efficiency does not include the mass of water that the aerosol may absorb from the air during its growth process (that is included in the yield factor). Thus,

$$M_a = c_o Y_f (E/100) W, \tag{3}$$

where M_a is the total mass of airborne obscurant, c_o converts weight to grams, Y_f is the yield factor (dimensionless), E is the efficiency (percent), and W is the fill weight.

The efficiency may include, however, additional factors such as a part of the original fill weight left in the munition, buried in mud or snow, or deposited on the ground. For the HE dust model, the efficiency input parameter represents the fraction of explosive energy that goes into heat for the buoyant rise of the cloud. This is also called the hydro-yield fraction of the HE munition. It is usually input as zero and left for calculations by internal models.

2.3.12 Equivalent TNT Yield (or Equivalent Pounds TNT) W

Equivalent TNT yield is the weight of TNT that has the same energy as the explosive actually used. COMBIC uses the equivalent TNT in modeling the crater volume from which dust is produced. It takes the place of an obscurant fill weight for HE dust.

2.3.13 Fill Weight W

Fill weight is the weight (in pounds) of smoke material inside a smoke munition. In the COMBIC inputs, however, the fill weight for HE dust is the equivalent TNT yield, expressed in pounds, of the explosive. Fog oil and diesel fuel fill weights are in gallons for the convenience of the user. For a user-specified IR screener produced from the generator, the fill weight is in pounds, and the production rate is determined internally from fill weight and burn duration inputs. The fill weight of generator-produced obscurants divided by the burn duration gives the emission rate, or the amount of material produced per second by the generator. This rate is constant for generator-produced obscurants.

2.3.14 Fireball Temperature T_o

The spherical heated region of HE and bulk WP munitions is sometimes called the "fireball." The initial fireball temperature may optionally be specified by the user. Otherwise, the fireball temperature is determined in the code from the initial buoyancy radius and the total thermal energy available for buoyancy, or is assigned an initial value.

2.3.15 HE Dust

When an HE munition detonates just above, at, or below the ground surface, a quantity of soil is lofted into the air from the resultant crater. A region of rising, circulating air flow is triggered by the shock wave and the buoyant rise of the heated air. Part of the lofted soil is entrained into the rising flow fields and forms the main dust cloud; part is thrown to the side and is not entrained. Furthermore, the shock wave will scour some additional dust from the ground surface. The dust particles range in size from tenths of millionths of a meter to about 1 cm in diameter.

The propagation effects along the LOS are extremely sensitive both to the total dust mass encountered and to the size distribution of the dust particles. In general, lighter particles rise, expand, transport, and diffuse at the fastest rates, while the heavier particles lag behind and fall out.

COMBIC divides the size distribution of the dust particles among three "modes": a small-particle mode, a large-particle mode, and a ballistic or very-large-particle mode. The very-large-particle mode accounts for the ballistic soil and large agglomerates that remain airborne for only a few seconds.

The dust cloud produced by HE munitions is modeled as a combination of five subclouds: a buoyant fireball of small-mode particles, a surface cloud of small-mode particles, a connecting stem of small-mode particles, a stem of large particles that have 0.92-m / s fallout, and an initial ballistic cloud of large particles that rapidly return to earth.

HE-produced dust, specifically the very-large-particle mode, is the obscurant that has the most significant effect on MMW transmission for the usual obscurant concentrations on the battlefield dust. That effect is short-lived. To better model the time-dependence of MMW obscuration by HE dust, we introduced the very-large-particle mode along with an appropriate ballistic formation of the dust cloud and a modeled, rapid fallout of particle sizes larger than a few tenths of a millimeter.

2.3.16 Hydro-yield Fraction E

For HE-generated dust, the hydro-yield fraction takes the place of an efficiency input. The hydro-yield fraction is the fraction of available energy from the explosion that goes into the form of heat and causes a fireball region to rise buoyantly into the air. This quantity is normally computed by an internal model in COMBIC but may optionally be input by the user. It is the thermal efficiency of the explosive.

2.3.17 Smoke Type

Tables B-1 and B-3 (app B) give many default munition parameters used to internally characterize the obscurants. These defaults can be overridden by the user. Table B-1 gives the fill weight, efficiency, obscurant, and source types. Table B-3 gives the extinction coefficients for all nonhygroscopic smoke.

White phosporus (WP) smoke is a dense white smoke generated when phosphorus burns spontaneously in air. It is most often delivered by munitions. WP smoke is effective in the visual and near-IR wavelength regions; it is less effective in the 3 to 5 μm and 8 to 12 μm mid- and far-IR regions, but is still sufficient to defeat thermal systems if used in sufficient quantity.

WP is a mixture of phosphoric acids and is highly hygroscopic (see sect. 2.3.21 for more information about WP). Bulk WP typically ignites into a hot thermal region that carries much of the initial smoke upward, producing an effect called pillaring. The remaining pieces of bulk WP scatter on the ground. Being physically separated, the fragments produce smoke that is not as buoyant as the initial smoke. In plasticized WP (PWP) and felt-impregnated WP, the initial rate of smoke production is reduced, and thus the pillaring effect is reduced. Red phosphorus (RP) is less spontaneous in igniting and thus produces a more gradual burn and a longer smoke production period than bulk WP.

HC smoke mix produces a (mostly) white zinc-chloride smoke from the chemical reaction of zinc oxide, hexachloroethane, and aluminum. In the reaction, the aluminum removes chlorine from the hexachloroethane and then reacts with the zinc oxide. The aluminum content thus alters the burn rate of HC smoke. For example, if the burn duration is 147 s for a mix with a 5.5-percent aluminum content, then the burn duration is only 55 s for a 9-percent aluminum content. In COMBIC, the amount of aluminum in a given mix is estimated internally from the burn duration. HC smoke is hygroscopic and not particularly buoyant, although heats of combustion of 300 to 940 cal/g have been reported (Cichowicz, 1983). HC is most often released from burning smoke pots or delivered by a munition, for example, the 105-mm cartridge or 155-mm projectile. HC is effective in the visual and near-IR wavelength regions but is relatively ineffective in the 3 to 5 μm and 8 to 12 μm regions, except in high concentrations or over long paths. HC is much less effective in the thermal band than WP.

SGF-2 and DF are oil smokes that are produced by generators. The oil is not burned but rather is vaporized and condenses rapidly upon ejection from a generator. These smokes are nonhygroscopic and (in the terms employed in COMBIC) have a yield factor of 1. COMBIC also assumes, by default, that they are slightly buoyant. The oil smoke produced by most smoke generators may be ejected at some relatively high velocity, typically 120 to 150 m / s, mixed with a large volume of air. This speed rapidly decreases, however, as ambient air mixes with the smoke. Oil smokes are very effective in the visual and effective at near-IR wavelengths. They are ineffective in the 3 to 5 μm and 8 to 12 μm wavelength regions except, perhaps, at extremely high concentrations or over very long path lengths. COMBIC also includes the cold regions mixture of fog oil and kerosene defined by obscurant type 15 (note: the *cold region flag* does not have to be set for use of this mixture). Although the oil smokes are almost always disseminated by generator, fog oil pots are in the U.S. inventory as well. Diesel fuel / oil / rubber fire smoke may also reduce MMW transmission significantly for sufficiently long LOS's.

2.3.18 Pasquill Stability Category P_c

Atmospheric conditions are characterized in part by stability: conditions range from very stable to very unstable. These conditions are classified into Pasquill stability categories. Pasquill categories A through C denote various degrees of unstable conditions, D is neutral, and E through G are varous degrees of stable conditions. COMBIC provides an optional routine to compute the Pasquill stability category for the user in terms of windspeed, cloud cover, and time of day.

A *stable* (or inversion) condition often occurs at night. In this situation, the ground becomes cooler than the air above it, and air temperature increases with height. Thus, the tendency of warm clouds to rise is reduced, and turbulence is somewhat more intermittent than for neutral or unstable conditions. Obscurant clouds remain closer to the ground with less upward diffusion.

A *neutral* stability condition often occurs early in the morning before the ground has the opportunity to become much warmer than the air above it, under cloudy conditions or in high winds. The atmosphere in this state has a slightly decreasing temperature with height: about 1 °C per 100 m. Obscurant clouds have a greater tendency to rise and diffuse upward than under stable conditions.

Finally, an *unstable*, or convective, stability condition is present when the ground gives off heat to the air, air temperature decreases at a rate greater than 1 °C per 100 m, and windspeed is low to moderate. In these conditions, the atmosphere is turbulent. Convective cells promote the rise and vertical diffusion of obscurants.

2.3.19 Number of Submunitions N_s

COMBIC uses the term *submunition* to designate parts of a munition that act separately to produce the obscurant cloud. The amount of explosive in HE munitions is divided among the submunitions. This division affects slightly the total of the crater volumes produced and thus the dust produced. For both smoke and HE dust, submunitions are considered to be thermally independent of each other. This independence results in less buoyancy and causes independent obscurant clouds to rise more slowly. In COMBIC, for munitions containing submunitions, the fill weight is that of the entire munition. It is not the weight of a single submunition.

2.3.20 Wind Direction

COMBIC uses the meteorological definition of wind direction, the azimuth from which the wind is blowing. Azimuth is the usual compass angle measured in degrees clockwise from north.

2.3.21 Yield Factor Y_f

Some obscurants are hygroscopic. That is, they draw liquid water from the water vapor in the air and grow to some equilibrium size. Because this growth is very rapid, only the result (not the process itself) is modeled in COMBIC. Growth greatly increases the mass of smoke in the air and thus increases extinction. The coefficient for extinction per unit mass takes into account the change in droplet refractive index as the particles grow and are diluted by absorbed water. The change in mass is the yield factor, defined as the ratio between the final mass of the smoke and the original mass before water was absorbed from the air. The yield factor increases with increasing relative humidity.

As with efficiency (sect. 2.3.11), modelers choose different definitions for the yield factor than do developers of obsurants. In COMBIC, for example, the yield factor for phosphorus smoke is larger than one at zero humidity, because the burning of phosphorus to phosphoric acids includes water in the chemical reaction. The combined effects of efficiency and yield factor convert the original fill weight of the material in the munition into the mass of obscurant that is present in the cloud. For users providing a full set of inputs, it is only important that the result from equation (3) equal the mass actually appearing in the smoke cloud. The fill weight, efficiency, and yield factor can otherwise be set arbitrarily by the user if all three are input.

2.3.22 Coordinate System Conventions

The COMBIC code and EOSAEL use certain conventions for coordinate systems. The systems are rectangular Cartesian x, y, and z, all expressed in meters. The COMBIC user is allowed to input a coordinate origin x_o, y_o, z_o.

The z-coordinate points upward, perpendicular to a flat earth. The z_o origin is added to every observer and target z-coordinate as they are input. The default for z_o is 0. The EOSAEL code contains a dummy terrain-access routine that returns 0 for all terrain heights. Thus, these default values define the ground surface to have a z-coordinate of 0, and all observer and target z-coordinates are the same as their heights above this surface.

The usefulness of z_o can be seen in the following example. Suppose the user puts in a terrain array referenced to sea level. The user can then set z_o to zero and input all target and observer z-coordinates with respect to sea level. But suppose the observer and target z positions are reported with respect to a surveyed benchmark at a field test. The user can then input z_o as the height above sea level of that benchmark and then input all target and observer z-coordinates referenced to the benchmark.

All sources (for example, smoke munitions) are input by the user in terms of their burst height above the local terrain. COMBIC determines the height of the terrain at that point (default 0 in the code supplied with EOSAEL) and adds it to the input height to obtain the z-coordinate. Thus, all computations internal to COMBIC occur in a z frame of reference determined by the terrain data base reference, if any.

The x- and y-axes lie parallel to the surface of a flat earth. The x-axis direction is specified by user input as an arbitrary compass direction in degrees clockwise from north. Thus, if the x-axis points east (90°), the y-axis points north. This is the default in COMBIC and in the EOSAEL library. The coordinate origins x_o and y_o can also be specified by the user. All positions of targets, observers, and obscurant sources immediately have x_o and y_o added to their input values before being stored internally in COMBIC. This allows the code to shift the input system to a terrain data base convention if desired. Default values for x_o and y_o are zero.

The COMBIC model internally rotates the user's coordinate system about the z-axis and coordinate origin (x_o, y_o) to one in which the new x-axis lies along the direction toward which the wind is blowing, and the y-axis lies cross-wind. This is done as each new observer, target, and source are input and is very common in obscuration models. All distances in x-coordinates are then distances downwind, while all y distances are cross-wind. Documentation in later sections uses this notational convention of downwind x, cross-wind y, and upward z variables.

A third internal coordinate system is used in evaluating the plumes produced by moving sources. The aerosol still moves with the wind, of course, but the motion of the source effectively makes the plume appear to lie along the vector difference between the wind velocity and the moving source velocity. COMBIC, therefore, rotates these plumes into this "effective plume frame," in which the plume appears to be extended along the effective x-axis.

2.4 Model Limitations

COMBIC uses a simple atmospheric boundary layer model. In COMBIC, the wind field direction and vertical windspeed profile are uniform everywhere in the scenario. COMBIC does not model complex wind fields that change direction and speed in all three dimensions. In the real world, wind fields and diffusion rates are determined by the effects of complex terrain and surface properties. COMBIC is still a “flat terrain” model. It allows only for a uniform boundary layer wind field that is assumed to apply over the entire geographic region. To include the effects of complex terrain and wind field would significantly increase the run time. The user must thus be cautioned that COMBIC represents an idealized world of smooth terrain and a relatively simple wind field.

COMBIC does, however, allow the user to attach a terrain data array. Clouds then follow the vertical changes in terrain height, moving up or down as required, but without changes in the basic windspeed and wind direction that were input by the user. Thus, for example, a cloud flows over and not around a hill. A dummy terrain routine that can access terrain arrays is provided in the code as a guide to those who wish to include this crude level of approximation to terrain effects.

Smoke is stochastic. Natural atmospheric turbulence will modify the smoke cloud in a random fashion. Such turbulence produces thick and thin screening spots, which are most evident near smoke sources. COMBIC, however, is a deterministic model; its output is meant to show the average effects of a random process. In the real world, of course, variations in the atmosphere make the smoke less effective if the target can be acquired through momentarily thin spots in the cloud.

Vehicular dust and moving smoke sources like generators are included in COMBIC. However, COMBIC cannot model accelerations and changes in direction by moving sources. All moving sources are modeled as moving in straight lines at constant velocity. In COMBIC, one can simulate direction changes of moving sources by effectively stopping the vehicle and restarting it in a new direction.

COMBIC models extinction and not path radiance. However, existing EOSAEL models do model the complex notion of path radiance or brightness. Extinction results from scattering of light out of the LOS and absortion of light along the LOS. Transmittance is directly related to extinction by Beer’s law. One usually attempts to directly relate transmission to electro-optical system performance and smoke effectiveness by considering only the directly transmitted signal. Now most system performance people know that electro-optical systems respond not only to the directly transmitted signal but also to contrast, which ususally requires one to account for path radiance. The contribution to path radiance may be scattering of ambient radiation (sun, moon, sky) into the LOS path, emission along the path, or both. Transmittance is still the key component in these more complex models, however. Transmittance is primarily important because it quantifies when a received signal will be below some operational threshold of an EO device.

Transmittance is not the only quantity determining the energy that is detected: multiple scattering is also a factor. Just as extinction removes energy along a path, so multiple scattering can return some of that energy. Equation (1) includes the results of single scattering out of the path and absorption along the path. Once the energy is scattered from the path, it is gone. Some probability exists, however, that a fraction of the energy scatters more than once. Some of this energy, not itself absorbed by the aerosol, may return close to the optical path and scatter again in approximately the original direction of the beam. COMBIC does not compute this multiple scattering contribution to the energy received by finite-area collection optics. Other models in the EOSAEL library address this complex problem. Generally, conditions under which the received energy at the detector may have a significant multiple scattering component include large optical depths, a significant scattering component in the extinction, and a large field of view at the detector. For additional information, see the ASCAT module of EOSAEL.

Path radiance can be of overriding importance: consider, for example, the apparent disappearance of stars during the day and the effect of high beams in a fog. To truly consider the effects of smoke on the ability to "see," one must consider the effect of radiance along the LOS. These "path radiance" contributions are the subject of models like ACT II. ACT II examines the effects of emissive sources and of single scattering of the ambient radiation into the LOS (Sutherland and Hoock, 1982).

Furthermore, COMBIC does not include target acquisition routines or the transmittance contribution from adverse weather and/or natural atmospheric gases. COMBIC does properly take into account the fact that smoke blown behind the target does not contribute to obscuring the target. However, a real-world effect that COMBIC does not model is the fact that smoke behind a target often enhances its signature. This enhancement is both through a silhouette effect of the target on the smoke background and a related tendency for smoke to suppress the confusing detail of image clutter behind the target.

COMBIC also does not address the process of high-energy-laser propagation through aerosol clouds, in which the aerosol along the path may be modified by the laser. These processes are the subjects of separate models in the EOSAEL library. The results from COMBIC in the form of cloud concentrations, cloud dimensions, and transmittance may be useful as inputs to these models.

The total transmittance can be determined by

$$
\begin{aligned}
T_{tot} &= T_{gas} T_{natural} T_{COMBIC}, &(4)\\
T_{tot} &= T_{MODTRAN} T_{XSCALE} T_{COMBIC}, &(5)
\end{aligned}
$$

or for lasers,

$$T_{tot} = T_{LZTRAN} T_{XSCALE} T_{COMBIC}. \tag{6}$$

MODTRAN (Berk et al, 1989) is an Air Force module that calculates atmospheric transmittance and radiance for different model atmospheres.[*] Another EOSAEL module, XSCALE, determines the transmittance through naturally occurring aerosols (haze and fog), rain, and snow for both individual wavelengths and broadband averages. The EOSAEL module LZTRAN calculates molecular absorption coefficeints and transmittances for 97 specific laser frequencies ranging from the visible to the far infrared. The user may specify one of six model atmospheres or input his own atmosphere. To determine the total transmittance, the user must run all three modules. However, for clear weather, the transmittance computed by COMBIC often dominates.

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[*] More information including download information is available at www-vsbm.plh.af.mil/soft/modtran.html

3. Software Limitations, Verification, and Evaluations

3.1 Grade of Software

COMBIC is developmental software. Although several evaluations have been made of previous versions, the software is constantly being upgraded and refined. Potential users should be aware that the software is not applicable for all scenarios, although it can handle most well-behaved situations. COMBIC results should not be accepted automatically; users should evaluate them for logical consistency.

3.2 Software Failures

COMBIC has limited diagnostics to provide the user with some way of knowing of model failure. In most circumstances, the model will try to complete a job. If input parameters are unreasonable, then reasonable values will be substituted, and a warning message will usually be printed in the output file. We give in this section the errors and warnings that COMBIC might produce for the typical user. We also list the most likely cause for the errors and give suggestions on how to correct them.

The messages described here are printed in the Phase I and II output files. This section does not list the usual diagnostic messages for errors in opening files, since the correction for these errors is usually obvious. In the following, any number composed of nines is representative of a number that COMBIC will print. The value would vary with the user input and the type of error. Italicized words are notes on what will be printed.

3.2.1 Device Independence

Although EOSAEL models are generally portable between different types of computers, the user should be aware of two potential machine-dependent problem areas. First, some computers equate completely blank input fields with “0.” Others, however, require that each numeric input field explicitly contain some number with a decimal point. It is, therefore, possible that the user will need to input “0.” in every unused field of the seven numeric values read in from the standard input format (see sect. 4). Second, some computers interpret blanks as zeros in the exponential field (following the letter “E”) of numbers input in exponential notation. This may require the user to right-justify inputs in the 10-column field if exponential notation is used. For example, 1.2E-2 may be the intended input. But if not right justified on some machines, the input will be interpreted as 1.2E-20.

If COMBIC issues an error message about a particular input record, the user should first check to determine that each input number has a decimal, that it falls inside its 10-column input field, and that there are no “nonprinting” special characters (CNTRL or ESC sequences) on the record. These problems are almost 100 percent of the usual input problems.

3.2.2 Error Messages

```
*** FIRST COMBIC CARD NOT PHAS
```

Unless the user has a stand-alone model, the first two records of the input file are EOSAEL records, read by the EOEXEC driver. The third record is the first record that the COMBIC module reads, and it must be a PHAS record (sect. 4 describes the input records used in the COMBIC module).

```
*** FILE RECORD UNIT# 99999 OPENED FOR FILE filename
BUT THE UNIT NUMBER WAS NOT ON THE PHAS RECORD
```

This warning occurs if the user inputs a `FILE` record with no matching unit number of the PHAS record. As a result, COMBIC can open the file but it cannot use it. The user should check to see if the unit number is entered correctly on the PHAS and `FILE` records.

```
***** PHASE PARAMETER OUT OF RANGE COMBIC ABORTED *****
```

The first parameter, PHASE, on the PHAS record specifies whether Phase I or II calculations are to be performed. This parameter must be either ”1.” or ”2.” Any other value will cause this error.

```
*** ERROR, CHECK SUBCLOUD RECORD ORDER AND NUMBER OF SUBCLOUDS TO
BE GENERATED.
NUMBER OF SUBCLOUDS SPECIFIED = 99.9
BUT ATTEMPTED SUBRECORD COUNTS:
SUBA=99, SUBB=99, SUBC=99
```

A user defines a cloud by first defining the number of subclouds that make up the cloud. This number is specified by the NSUB parameter of the `CLOU` record. Usually a SUBA, SUBB, and SUBC follow the `CLOU` record for each of the NSUB subclouds. A `GO` record usually signals COMBIC that the input records for this munition have been completed. The above error occurs when there is a greater number of SUBA, SUBB, and SUBC clouds than is specified by the NSUB parameter. To correct this problem, the user is advised to input a maximum of one SUBA, SUBB, and SUBC record for each subcloud. (Note: the user does not have to define these records for each subcloud, but only one of each can be input per subcloud.)

```
*** ERROR # 999 IN READING HISTORY FILE
⋮
ERROR. REQUESTED SOURCE NUMBER 9999 NOT IN HISTORY FILE
DATA ON OBSCURANT TYPE 9999 NOT PREPROCESSED
```

This error occurs in Phase II. In Phase I, the user chooses the obscurants that will be used in Phase II. The first obscurant in the inputs has a source number of 1 in the history file and is accessed in Phase II by a reference to the source number. The second obscurant in the input for Phase I is referred to as source number 2, the third is source number 3, etc. This error states that the Phase II inputs have requested a source number that is not in the history file. To correct this problem, the user should check to see if the source number is correct (STYPV on the VEH1 record or STYP on the SLOC record) in the Phase II inputs or check to see if the Phase I input deck has the correct number of obscurants.

```
*** ERROR - INVALID SMOKE TYPES SPECIFIED
** ERROR IN SMASS, SMOKE TYPE 99 UNDEFINED.
** THIS SOURCE PRODUCES NO OBSCURANT. *** NO HISTORY GENERATED
*** CARD SEQUENCE RESET DUE TO ERROR IN PREVIOUS MODULE (IERR=1)
```

These errors are produced when the user requests a smoke type (STYP on the MUNT record) not defined in the menus. The obscurant type is used for the selection of extinction coefficients and for assigning default model characteristics if information is not otherwise provided by menu values or user inputs. The obscurant type ranges from 0 to 30. The first 23 are listed in the default tables and the last 7 are user-defined by inputs. This error will cause COMBIC to exit prematurely. To fix this error, correct the STYP parameter of the MUNT record.

```
*** ERROR - NO SMENU, NO STYP, NO SUB(-) RECORDS
** THIS SOURCE PRODUCES NO OBSCURANT. *** NO HISTORY GENERATED
*** CARD SEQUENCE RESET DUE TO ERROR IN PREVIOUS MODULE (IERR=1)
```

The user has the option of creating a new menu using the SUBA, SUBB, and SUBC input records. Setting SMENU = 0 on the MUNT record signals the model that the user is designing a new munition. Setting STYP$\geq$ 24. on the MUNT record signals the model that the user is designing a new obscurant. When these are set, the MUNT record must be followed by the CLOU record and at least the SUBA record for each subcloud.

```
NO MORE ROOM, ADDITIONAL OBSCURANTS NOT ALLOWED
```

COMBIC has a limit on the number of active clouds and subclouds that can be processed at one time. By default NPMACT = 100 is the maximum number of active clouds and NMPCLD = 300 is the maximum number of subclouds. Clouds have one to five subcloud components. For example, HE is composed of five subclouds, so at most, only 60 active HE rounds can be processed at one time (5×60 = 300). The user needs to review section 4.5 on how to modify the COMBIC model for large numbers of obscurants if NPMACT or NMPCLD are exceeded. In the past, COMBIC has been modified to compute the obscuration from more than 5000 HE rounds.

```
NO ROOM FOR NEW MOVING OBSCURANT SOURCE AT 999.9, 999.9
of type 999
```

This error occurred because the user requested a new moving obscurant and exceeded the number of sources allowed by COMBIC. (As described above, COMBIC has a limit on the number of active clouds (NPMACT = 100) and subclouds (NMPCLD = 300) that can be processed at one time. Clouds have one to five subcloud components.)

```
NO ROOM FOR LOS, OBSN, 999., TARN, 999.
```

Currently, there is a default limit to the number of LOS's that can be processed. This error is printed when the number of active LOS's exceeds 50. Refer to section 4.5 if you have a large number of LOS's to process. This section explains how to modify COMBIC to accept and process more than 50 LOS's. This restriction does not apply to ”printer plot” LOS's.

`*** INVALID INPUT RECORD TO COMBIC PHASE 1: [`*or PHASE 2*`]`
an input record will be printed here
`**** CARD SEQUENCE RESET DUE TO ERROR IN PREVIOUS MODULE (IERR=1)`

COMBIC reads each record in the input file and identifies it by the first four letters. COMBIC produces this error when it does not recognize the first four letters of the input record. Note that COMBIC will not produce this error message if it reads Phase II input records when executing PHASE I or vice versa; it simply ignores these. Only one error is allowed per input deck before the model ends prematurely. To correct this error, the user should check the spelling of the input record listed above.

```
*** COMBIC IGNORES MET INPUTS AFTER FIRST GO RECORD
```

Meteorological conditions need to be input before the first `GO` record. The meteorological records are `MET1`, `MET2`, and `PASQ`. To correct this problem, the user is advised to move the meteorological records above the `GO` records. Refer to section 4.2.2 for information on the meteorological records.

```
*** ERROR, CLOU RECORD CAN CONTAIN 1. TO 5. ONLY.
INPUT WAS .0
*** CARD SEQUENCE RESET DUE TO ERROR IN PREVIOUS MODULE (IERR=1)
```

The user custom designs a new cloud by first specifying how many subclouds define the new cloud, using the NSUB parameter on the `CLOU` record.

NSUB must be 1., 2., 3., 4., or 5. COMBIC outputs the above error message and prints the NSUB parameter for any other number. To correct this error, the user should correct the NSUB parameter on the `CLOU` record.

```
***********************************************************
EOF IN INPUT CONTROL FILE 5 - PROGRAM TERMINATED
***********************************************************
STOP DATA SET MISSING STOP OR END STATEMENT
```

Chances are the `DONE` record is missing at the end of the inputs.

```
AXES AND ORIGIN ALREADY USED IN LOADING SOURCES AND/OR LINES OF
SIGHT.
IGNORING: (ORIG record printed here.)
WIND DIRECTION ALREADY USED IN LOADING SOURCES AND/OR LINES OF
SIGHT.
IGNORING: (ORIG record printed here.)
```

The `ORIG` record defines the axes, origin, and wind direction for the battlefield scenario. This record must be input before the `SLOC`, `VEH1`, and `VEH2` records. If COMBIC reads any of these three records before the `ORIG` record, then this error message will be printed. Note that if there are multiple `ORIG` records before the source or vehicle location records, the last one will be the one used by COMBIC. If there is no `ORIG` record, then default parameters will be used.

```
999.9 NO ACTIVE LOS
```

The `LIST` record determines the times that the transmittance or CL will be output. The parameters from this record specify a start time, an end time, and the time increment between lines of output. Furthermore, for each observer, the user uses the parameters on the `OLOC` record to specifies the time the observer becomes active and the time the observer can be removed from the active list. If there is no active observer at a time specified by the `LIST` record to output transmittance, then COMBIC lists the time and states that there is no active LOS. This warning does not affect the results in any way and can be ignored by the user if so desired.

```
*** WARNING - NO MUNT RECORD OR BAD SMENU, STYPE.
PROCESSING A DEFAULT CLOUD TYPE
```

This warning occurs when no `MUNT` record has been used in Phase I or the parameters SMENU and STYPE are badly defined for the `MUNT` record. Check to see if the Phase I input file contains a `MUNT` record and the parameters are defined correctly. The model will proceed with the calculations even without a `MUNT` record but will use a default munition.

```
*** STEM DOES NOT CONNECT PROCESSED SUBCLOUDS
*** CARD SEQUENCE RESET DUE TO ERROR IN PREVIOUS MODULE (IERR=1)
```

This error occurs when the user is defining a cloud using the SUBA, SUBB, and SUBC records. On the SUBA record, the RISMOD parameter defines whether the subcloud is buoyant (RISMOD = 1) or nonbuoyant (RISMOD = 2), or if the cloud is a stem (two-digit number *ij* from 12 to 45, indicating that the subcloud is an instantaneously canted stem, spanning subclouds *i* and *j*). If RISMOD is entered as a number greater than 45 or if no i^{th} or j^{th} subclouds exist, this error occurs. Check subcloud structure and RISMOD parameter. If there is no i^{th} or j^{th} subcloud for the stem to span, then this error message will be printed.

```
*** WARNING, AT LEAST ONE SUBCLOUD DOES NOT HAVE A
PLUME OR RISE MODEL VALUE
```

This error occurs when the user is defining a cloud using the SUBA, SUBB, and SUBC records. If STYP on the MUNT record is between 24 and 30, then the user must specify munition characteristics, such as the PLUME and RISMOD parameters on the SUBA record. PLUME must be either 1. or 2. and RISMOD is either 1., 2., or a number *ij* from 12 to 45. Check to see if these numbers are entered correctly for each subcloud.

```
*** NO ROOM LEFT IN THE EXTINCTION COEFFICIENT ARRAY
24. - 30. (USER DEFINED) FOR EFFECTIVE BARRAGE COEFFICIENT
```

This error occurs only with the barrage option. It states that there is no room to make a new obscurant type with the combined extinction coefficients.

```
*** WARNING, INPUTS OF SUBCLOUD FRACTIONS TOTAL ONLY: 9.9999.
THIS MAY BE INTENTIONAL
```

The user has the option of designing a cloud not modeled by the tables. The user specifies how many subclouds define the new smoke cloud using the CLOU record. The fraction of total obscurant mass to be placed in each subcloud is specified by the FRACT parameter on the SUBA record. If FRACT = 1, then 100 percent of the cloud's obscurant mass is placed in the subcloud. Usually $0 \leq$ FRACT ≤ 1. The total sum of the FRACT parameters for each subcloud should be 1.0. If the total is less than one, the model prints this message. This result may be the user's intent. If not, the user should check to see if the fraction of obscurant mass is input correctly for each subcloud.

```
*** WARNING, INPUT SUBCLOUD FRACTION(S) TOTAL 9999.99. THEY SHOULD
TOTAL ONE. RESCALING TO ONE.
```

As explained for the message above, the total sum of the FRACT parameters for each subcloud should be 1.0. If the total is more than one, the model rescales to one and prints this message. The user should check to see if the fraction of obscurant mass is input correctly for each subcloud and the summation totals 1 (or 100; the effect of the scaling is that if the user inputs FRACT as percentages, the model adjusts and uses the correct values).

```
ITERATION IN SUBROUTINE VOLAC HAS FAILED TO CONVERGE
```

This warning occurs only for HE dust and only for cased munitions. The COMBIC model computes the equivalent yield of bare charge that—at the same depth of burst as the cased munition—produces the same yield coupled to the ground as the cased munition. It uses an iterative technique to determine this equivalent yield, iterating a maximum of 20 times. If the iteration fails to converge, this warning occurs; however, it is very rare. If it does occur, the user can try increasing the number of iterations in the source code and recompiling COMBIC.

3.3 Verification and Evaluation

Since COMBIC is a theoretical model, its accuracy needs to be established by comparison with experimental data. Also, for this model to be used effectively, the users need to know the accuracy with which COMBIC reflects the battlefield atmosphere. The successes as well as the shortcomings of modeling with COMBIC must be established. The analysis and war-gaming community needs the information in using COMBIC to estimate the impact of obscurants on EO sensor performance. This impact affects the training and doctrine community and ultimately the soldier in the field, who needs the knowledge of sensor performance to effectively employ the increasing inventory of EO systems.

Since the release of EOSAEL and its subsequent revisions and additions, significant amounts of time and resources have been devoted to model (module) "validation." If anything has been learned from all these validation efforts, it is that the models cannot be validated. Webster gives the following definitions:

validate (1) To declare or make legally valid. (2) To mark with an indication of official sanction.

valid Correctly inferred or deduced from a premise.

For COMBIC to be valid, the predictions must be field tested for all possible meteorological conditions, environmental parameters, LOS's, munitions, and munition placements. The cost of providing test data for validating COMBIC would most likely exceed the ARL operating budget, thereby undermining one of the advantages of computer simulation by COMBIC. However, although validating COMBIC is out of the question, it can be *evaluated*:

evaluate (1) To determine or fix the value of. (2) To examine carefully: appraise.

3.3.1 Evaluation History

The model has been qualitatively evaluated for HC, RP, IR screener, PWP, WP, and HE munitions, and the results were presented at previous EOSAEL conferences, Smoke symposiums, and technical reports. Independent contractors (Lawrence and Wood, 1984) evaluated the COMBIC82 model for 155-mm HE, 105-mm HE, and the 4.2-in. HE. They also performed sensitivity studies by varying the meteorological conditions to see if the agreement between model and data improved.

Since the COMBIC model is an amalgam that includes established theory along with empirical and semi-empirical results to model the battlefield environment, sections of the model can be evaluated. It is also necessary to analyze the sensitivity of the model to various parameters and to know the conditions under which some of the COMBIC algorithms could create significant problems. Previous work (Hoock, 1986; Ayres *et al*, 1988) evaluates various assumptions and internal models. Areas addressed are multiple scattering; extinction coefficients; humidity effects; broad-band detectors; obscurant release rates; and cloud transport and diffusion. Several reports give more details (Ayres, 1991; Spitznagel and Ayres, 1988; Ayres and Baca, 1987; Hoock, 1986; Ayres, 1986; Ayres, 1985; Lawrence and Wood, 1984).

3.3.2 Methodology

Ideally, output from the COMBIC model should match experimentally obtained obscuration data, such as that from the “Smoke Weeks.” However, perfect matches do not occur, for several possible reasons:

- Source characteristics are not completely known, and thus the development of the obscurant cloud is not modeled accurately.
- Meteorological conditions vary temporally and spatially during the course of the experiment (for example, wind direction and wind speed).
- Measurement error exists in the data.

We have developed statistics that can be calculated automatically for a large number of trials, to determine how well model and data fit together (Spitznagel and Ayres, 1988). A small family of three statistics measures goodness of fit overall. Other statistics identify particular ways in which poor fit occurs. From these latter, one can often identify the major reason for lack of fit.

Measure One, M_1: Average Distance from Ideal Line

A numerical value indicative of the amount of scatter about a central point is called a measure of dispersion. The measure of dispersion that denotes the average distance from an ideal line is called *measure one*. In this case, the ideal line is COMBIC$_i$ = data$_i$ or $y = x$. To analyze the agreement between COMBIC and data, we measure distances perpendicular to that line. The distance from any single point (x_i, y_i) to the line $y = x$ is given by $|x_i - y_i| / \sqrt{2}$. If we average over all x-y pairs, we have a measure of deviation $\bar{D}$ from the ideal:

$$\bar{D} = \frac{1}{n\sqrt{2}} \sum_{i=1}^{n} |x_i - y_i| \,. \tag{7}$$

Because most people think of the number 1 as a perfect value of a measure of association and of -1 as the worst possible value, we define the following transform of $\bar{D}$, which we call "measure one":

$$M_1 = 1 - \sqrt{8}\bar{D}. \tag{8}$$

M_1 has been adjusted so that the largest possible value is 1 and the smallest possible value is –1. A value of 0 corresponds to one definition of no association.

Variants of Measure One

Measure one serves well in most trials, but it can be "fooled" in two ways. We have developed two variants of measure one to signal when this occurs and to provide corrections to the original measure.

First, the wind might carry smoke away from a particular LOS, resulting in good visibility most or all of the time. In this case, COMBIC and the field data will agree, simply because there is no smoke to be detected. Or there could be some reduction in transmission that is poorly modeled, followed by a long period of good visibility. When this happens we need to know, so that we are not misled by an overly optimistic value of M_1. A solution is to censor measure one in the following way: Whenever COMBIC predicts greater than 90-percent transmission and greater than 90-percent transmission is measured, discard the data pair. The 90-percent criterion was determined by experiment. It is not particularly critical; any value in the range from 85 to 95 percent works well. We call the resulting variant M_{1a}.

Measure one can also be misleading if we use it to compare the fit of COMBIC at different wavelengths. Most obscurants are more effective in blocking short wavelengths than they are in blocking long ones. If, for example, transmission of visible light drops nearly to zero, transmission of mid IR might drop only to 75 percent. This difference alone will lead to a difference in the values of M_1 for visible and IR. If the transmittance is high for both data and COMBIC because of small extinction factors, M_1 is high, since there is little degradation caused by the small extinction for longer wavelengths. However, high extinction leads to more degradation, increasing the difference between model and data. The difference can be adjusted out if we rescale each set of predicted and actual data values to about full range. We compute the scale factor from the trial data by taking the difference between the 5th and 95th percentiles. (Use of percentiles rather than minimum and maximum values eliminates possible outliers.) Then $\bar{D}$ is scaled by being divided by this difference, and the new measure, M_{1b}, is calculated from the scaled $\bar{D}$.

Bias

COMBIC allows windspeed and wind direction to be input at the beginning of its run, but not to be changed during the run. A change in speed or direction during the trial can cause the cloud mass to move across the LOS either more slowly or more rapidly than COMBIC predicts. Such a change would also affect the amount of smoke across the LOS path length. To check for this, we compute the mean signed difference ($= \frac{1}{n}\sum_{i=1}^{n}(i_{COMBIC} - i_{data})$) between COMBIC and the trial data. This measure is also sensitive to the cloud being more dense or less dense than predicted, and to the length of time the trial runs after transmission returns to 100 percent. No attempt is made to separate these different contributors, because they can easily be distinguished graphically once a run with a large bias has been identified. The range of possible values for bias is ±1, but a bias of ±0.2 is already large enough to be important. A negative bias means COMBIC is too low (overpredicts); a positive bias means COMBIC is too high (underpredicts).

Time Shift (Lag or Lead)

A change in windspeed or wind direction could also cause the cloud mass to move across the LOS sooner or later than COMBIC predicts. To check for this, we compute M_1 a total of 80 additional times, 40 with COMBIC leading by 1 s, 2 s, 3 s, ... and another 40 with COMBIC lagging. The largest value of M_1 and the lead or lag that produced it are then printed. Not infrequently, the lag or lead turns out to be the maximum 40 s, but the corresponding change in M_1 is small. The appropriate way to read this pair of statistics is to compare “best M_1” with M_1. If the change is substantial, then the shift that produced it is meaningful.

The primary measurement of how well COMBIC fits the data is M_1, which is a scaled measure of average absolute deviation between the predicted transmission values and the observed values. The assignment of a qualitative meaning to the numerical quantity M_1 is subjectively based upon visual comparison of hundreds of plots. The values of M_1 have the following meaning:

0.80	to	1.00	Excellent
0.55	to	0.79	Good
0.40	to	0.54	Fair
0.20	to	0.39	Poor
0.00	to	0.19	Bad
	$<$	0.00	Very bad

3.4 Statistical Results of Evaluation

Here we briefly present quantitive results from the statistical evaluation of the COMBIC model. In that evaluation, model results (predictions) were compared with observations made in field tests. A more complete analysis, as well as the results for individual munitions, is given elsewhere (Ayres *et al*, 1988).

3.4.1 Hexachloroethane Munitions

M116 155-mm HC

Table 1 shows the statistics for the M116 155-mm HC. The fit of COMBIC to the data is in the fair-to-good range, though the worst statistics are believed to be mostly due to an incorrect start time for some of the trials rather than problems with the model. This causes COMBIC to appear to "lead" the measured transmission by an average of about 15 s, and time-shifting reclassifies the fit as a "good" fit (M_1 = 0.74). The fit for far IR looks good based on Measure 1, but Measure 1b indicates that the good fit is due partially to the data having little deviation from 100-percent transmission. However, the low value of M_{1b} can also indicate the time shift. COMBIC tends to predict that the cloud passes more quickly than it actually does (visible light having positive bias), and it also tends to slightly overestimate the concentration length within the modeled cloud (mid IR having negative bias). These two causes lead to the range in biases seen here.

Table 1. Statistics for M116 155-mm HC, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift[a]		Bias at shift
0.4–0.7	11	0.40	0.30	0.29	0.16	0.59	−27.	(10)	0.12
0.7–1.2	12	0.35	0.18	0.15	0.07	0.49	−20.	(10)	−0.05
1.06	12	0.35	0.18	0.15	0.08	0.50	−18.	(10)	−0.06
3.48	24	0.61	0.49	0.44	−0.06	0.66	−11.	(12)	−0.06
8.0–12.	11	0.64	0.50	0.37	0.09	0.66	−5.	(2)	0.09
10.6	6	0.77	0.65	0.46	−0.04	0.79	−11.	(1)	−0.03
Combined	76	0.51	0.38	0.32	0.02	0.74	−15.		0.03

[a] Numbers in parentheses refer to number of trials for which a shift was observed.

M84 105-mm HC

Table 2 shows the statistics for the M84 105-mm HC. The fit for COMBIC is good to excellent (M_1 of 0.62 to 0.92). Similar to the M116, the two opposing sources of biases combine to produce the range in bias from –0.08 visible to 0.04 near IR for the M84 105-mm HC.

Based upon two trials, the COMBIC models M84 105-mm HC successfully. However, more trials are needed for a clearer view of possible areas of improvement for COMBIC to model M84 105-mm HC. The disparity in biases between the two trials makes it difficult to determine areas of improvement.

Table 2. Statistics for M84 105-mm HC, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	4	0.64	0.59	0.58	−0.05	0.73	11.	0.01
0.7–1.2	2	0.62	0.52	0.50	−0.13	0.73	15.	−0.08
1.06	2	0.65	0.55	0.52	−0.10	0.75	18.	−0.06
3.48	6	0.81	0.76	0.75	−0.04	0.83	11.	−0.04
8.0–12.	1	0.91	0.87	0.86	0.04	0.91	0.	0.04
10.6	1	0.93	0.90	0.89	0.04	0.93	0.	0.04
Combined	16	0.74	0.68	0.66	−0.05	0.79	11.	−0.03

3.4.2 Red Phosphorus Munitions

XM819 81-mm RP

Table 3 reflects a recent change in the COMBIC model for RP, to allow for longer smoldering time (Ayres and Baca, 1987). Using this statistical methodology to compare the improved model to the older version indicates that the newer version of COMBIC fits better for both wavelengths, across all measures.

Table 3. Statistics for XM819 RP for a partial subset, showing agreement between COMBIC and data.

Wavelength (μm)	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift
0.4–0.7	0.57	0.51	0.41	0.034	0.61	−40.
3.48	0.81	0.69	0.43	0.008	0.83	0.
Combined	0.69	0.60	0.42	0.021	0.72	−40.

L8A1 and L8A3 Grenades

The best M_1 of table 4 demonstrates that most of the disagreement for these trials is caused by discrepancies in the start time. This time lead and/or lag could cause the range of statistics seen in these trials for M_{1a} and M_{1b}.

Table 4. Statistics for L8A1 and L8A3 grenades, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	16	0.31	0.28	0.27	0.06	0.68	−17.	0.04
0.7–1.2	13	0.23	0.21	0.11	−0.27	0.65	83.	−0.13
1.06	13	0.28	0.25	0.16	−0.23	0.69	73.	−0.10
3.48	19	0.67	0.63	0.58	−0.02	0.87	49.	0.00
8.0–12.	8	0.49	0.48	0.46	−0.14	0.80	119.	−0.04
10.6	3	0.90	0.87	0.83	0.02	0.91	10.	0.02
Combined	72	0.43	0.40	0.35	−0.10	0.75	51.	−0.04

Agreement between data and the COMBIC model is good, though the negative bias indicates that the model overpredicts the *CL*.

5-in. Zuni

Table 5 shows the statistics for the 5-in. Zuni PWP. The fit for PWP Zuni ranged from bad to good. The difference between M_{1b} and M_1 indicates that noise is present, whose effect is increased when the data are scaled. Note that M_1 and best M_1 increase with increasing wavelength, and the bias decreases with increasing wavelength. Smoldering is believed to be responsible for the poor agreement.

The higher the extinction value for the wavelength, the poorer the fit (because of the presence of smoldering) and the greater the bias. For longer wavelengths, there is not enough smoke due to smoldering to significantly degrade the transmission. Therefore, the agreement between model and data is higher and the resultant bias is lower. More trials are needed for further comparisons.

In summary, the range in biases indicates that COMBIC predicts a smoke cloud that is too dense and passes too quickly when compared with the trial's smoke cloud. If future trials show the above relationship, then it is suggested that the burn function be modified to allow for a more gradual burn of the M54 Zuni munition. Modifying the burn function should alleviate the problems noted above.

Table 5. Statistics for 5-in. PWP Zuni, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	2	0.35	0.34	0.33	0.11	0.35	−20.	0.09
0.7–1.2	5	0.41	0.32	0.18	−0.14	0.43	23.	−0.12
1.06	5	0.44	0.35	0.22	−0.13	0.45	15.	−0.11
3.48	4	0.73	0.64	0.62	−0.03	0.74	2.	−0.03
8.0–12.	4	0.67	0.53	0.43	−0.10	0.69	30.	−0.07
Combined	20	0.53	0.44	0.35	−0.08	0.54	14.	−0.07

3.4.3 Infrared Munitions

Table 6 shows the statistics for the M76 IR grenade. Although a data set of one hardly makes for good statistics, several items can be noted from this one trial. Note the near-identical values of the statistics across the spectrum. This is due to the identical extinction coefficients for all wavelengths. The sharp decrease of M_{1a} over M_1 appears odd, but the M76 IR grenades have a very sharp decrease and increase in transmission, which is successfully modeled by COMBIC. The large negative shift causes the COMBIC data to be almost completely out of phase with the measured values; that is, when COMBIC transmission is high, the measured data are low, and vice versa. Eliminating the data of COMBIC and measured trial data that exceed the 90-percent level of transmission eliminates the only portion of the two curves that agree, causing the low M_{1a}. Note that M_1 = 0.41 improves to 0.71 when COMBIC is shifted 26 s to the right, causing the bias at shift to be minuscule. As mentioned before for HC M116, this bias is believed to be due to an incorrect start time and not to problems with the model. This one trial suggests that the agreement between model and data is very good.

Table 6. Statistics for M76 IR grenades, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	1	0.40	0.04	−0.06	0.09	0.70	−27.	0.01
0.7–1.2	1	0.41	0.13	−0.03	0.09	0.69	−27.	0.02
1.06	1	0.41	0.13	−0.03	0.09	0.69	−27.	0.02
3.48	4	0.43	0.18	0.02	0.06	0.75	−22.	0.00
8.0–12.	1	0.39	0.05	−0.07	0.09	0.71	−28.	0.01
10.6	1	0.40	−0.04	−0.10	0.08	0.72	−26.	0.01
Combined	9	0.42	0.11	−0.02	0.08	0.73	−25.	0.01

3.4.4 White Phosphorus Munitions

M328 WP

Table 7 shows the statistics for the M328 WP. Agreement between model and measured data is nearly excellent based upon M_1. However, the measure M_{1a} indicates that M_1 is inflated by the long period of high visibility at the end of the trials, especially for the near-IR wavelengths. The negative bias indicates that COMBIC overestimates the amount of time the LOS is obscured and slightly underestimates the transmission, with the most severe bias occurring at the near-IR bands. Based upon one trial comparison, we concluded that COMBIC is a good model for describing M328 WP smoke clouds; however, more data are needed.

Table 7. Statistics for M328 WP, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	2	0.81	0.65	0.62	−0.08	0.82	0.	−0.08
0.7–1.2	1	0.72	0.41	0.37	−0.14	0.72	14.	−0.04
1.06	1	0.76	0.50	0.46	−0.12	0.76	0.	−0.12
3.48	3	0.76	0.63	0.60	−0.11	0.85	3.	−0.06
8.0–12.	1	0.80	0.68	0.66	−0.09	0.81	−2.	−0.09
10.6	1	0.80	0.69	0.66	−0.09	0.81	−2.	−0.09
Combined	9	0.78	0.61	0.58	−0.10	0.81	2.	−0.08

M110 155-mm WP

The range in M_1 in table 8 is from fair to excellent. However, M_{1a} and M_{1b} are substantially lower than M_1 for the near-IR regions. We believe the agreement is good partly because of the inflation of M_1 at a higher transmission level for these wavelengths.

Table 8. Statistics for M110 155-mm WP, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	4	0.74	0.74	0.74	0.09	0.76	−18.	0.08
0.7–1.2	10	0.52	0.44	0.35	0.22	0.54	−6.	0.21
1.06	10	0.52	0.44	0.35	0.23	0.54	−8.	0.22
3.48	4	0.78	0.78	0.74	0.02	0.81	−2.	0.02
8.0–12.	2	0.84	0.83	0.80	0.02	0.86	6.	0.03
10.6	2	0.84	0.83	0.80	0.02	0.86	6.	0.03
Combined	32	0.62	0.57	0.50	0.16	0.64	−6.	0.15

M825 155-mm WP

The values of M_1 in table 9 range from good to excellent (0.61 to 0.80). No time shift of any significance was noted. M_{1a} is less than M_1, indicating that M_1 was inflated by high transmission. M_{1b} is much lower than M_1, since scaling amplifies the noise. However, on the whole, the agreement between model and measured data is good.

Table 9. Statistics for M825 155-mm WP, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	6	0.80	0.80	0.80	0.03	0.82	−9.	0.03
0.7–1.2	32	0.63	0.58	0.55	−0.07	0.66	5.	−0.06
1.06	32	0.65	0.60	0.57	−0.05	0.67	3.	−0.05
3.48	20	0.61	0.59	0.58	0.08	0.62	−7.	0.07
8.0–12.	8	0.64	0.62	0.61	−0.03	0.65	−1.	−0.03
10.6	7	0.73	0.72	0.71	−0.08	0.74	−1.	−0.08
Combined	105	0.65	0.61	0.59	−0.03	0.67	0.	−0.03

M54 Zuni PWP

The fit for PWP Zuni ranges from bad to good in table 10. The difference between M_{1b} and M_1 indicates that noise is present, that is, amplified when the data are scaled. Note that M_1 and best M_1 increase with increasing wavelength, and the bias decreases with increasing wavelength. Smoldering is believed to be responsible for the poor agreement. The higher the extinction value for the wavelength, the poorer the fit (because of the presence of smoldering) and the greater the bias. For longer wavelengths, there is not enough smoke due to smoldering to significantly degrade the transmission. Therefore, the agreement between model and data is higher and the resultant bias is lower. More trials are needed for further comparisons.

Table 10. Statistics for M54 PWP Zuni, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	8	−0.02	−0.04	−0.05	0.45	0.06	−24.	0.45
0.7–1.2	14	0.35	0.27	0.23	0.17	0.41	−17.	0.16
1.06	19	0.43	0.35	0.30	0.14	0.48	−15.	0.13
3.48	20	0.62	0.58	0.54	0.15	0.66	−26.	0.14
8.0–12.	15	0.65	0.60	0.56	0.12	0.68	−80.	0.11
Combined	76	0.46	0.40	0.37	0.18	0.51	−22.	0.17

3.4.5 Fog Oil Generators

M_1 indicates that the agreement between COMBIC and data for fog oil generators is poor (table 11). However, best M_1 indicates that the disagreement is partly due to a time shift of an average 35 s. In fact, individual statistics show that many trials have a time shift of 200 s. The fog oil trials did not yield results as clearly as for the trials employing other smoke types. The difficulty was caused by the properties of the smoke itself. The short wavelengths were attenuated very strongly, whereas the long wavelengths were often hardly attenuated at all. Noise would often swamp any signal for the long wavelengths, leading to very poor values for M_{1a} and M_{1b}. As

Table 11. Statistics for fog oil smoke, showing agreement between COMBIC and data.

Wavelength (μm)	No. of trials	M_1	M_{1a}	M_{1b}	Bias	Best M_1	Shift	Bias at shift
0.4–0.7	45	0.34	0.29	0.27	−0.08	0.60	−53.	−0.08
0.7–1.2	1	0.18	0.03	0.02	−0.41	0.25	35.	−0.37
1.06	45	0.29	0.22	0.20	−0.12	0.53	−33.	−0.12
3.48	18	0.25	0.15	0.07	−0.21	0.32	−19.	−0.18
8.0–12.	4	0.21	−0.01	−0.13	−0.27	0.26	40.	−0.33
Combined	113	0.30	0.23	0.19	0.13	0.51	−35.	−0.13

a whole, COMBIC overpredicts the density of the smoke at all wavelengths (negative biases). The visible wavelength data indicate that the bias is not high; however, this is due to the data “bottoming out.” The ability of COMBIC to model fog oil was affected by the production of wet fog oil instead of dry fog oil during several trials. Wet fog oil would affect the extinction and the deposition rate of fog oil.

3.4.6 All Munitions

Table 12 gives the statistics for each obscurant type and for the model as a whole. Although more trials are needed for all munitions except XM819 RP, some conclusions can be drawn. The fit for HC, WP, RP, and IR is good (according to best M_1). COMBIC can be used with confidence in modeling these types of smokes. The fit for PWP and fog oil is fair, though again more trials are needed (especially for the PWP smokes, of which there are only eight trials for evaluation purposes). Also, more trials are needed to determine if smoldering can improve the modeling capability for PWP Zuni and M110 WP. Table 12 indicates that based upon the combined statistics for PWP, IR, WP, fog oil, and HC, the model adequately modeled obscurants on the battlefield for the wavelengths tested.

Table 12. Statistics for smoke type.

Munition (trials)	No. of trials	M_1	Bias	Best M_1	Shift	Bias at shift
HC	99	0.57	0.02	0.65	−8.	0.01
RP	141	0.58	−0.06	0.61	6.	−0.05
WP	146	0.65	0.01	0.67	−1.	0.01
PWP	76	0.46	0.18	0.51	−22.	0.17
IR	9	0.42	0.08	0.73	−25.	0.01
Fog oil	113	0.30	−0.13	0.51	−35.	−0.13
Combined	531	0.50	−0.01	0.59	−11.	0.01

4. Operations Guide

4.1 Introduction

COMBIC executes in two phases. Either phase or both can be executed in a single computer run. Phase I generates a cloud history for one or more obscurant sources. These sources can be (1) selected by the user from a menu, (2) completely defined by user inputs, or (3) some combination of these. Cloud histories are output to a direct-access (record-addressable) mass storage file. Phase II generates the transmittance history at the EOSAEL wavelengths for each target–observer pair for all obscurant clouds in a user-defined scenario. In Phase II calculations, the user inputs a scenario of one or more obscurant sources and one or more target–observer pairs. The Phase I cloud history file is used to provide cloud positions, dimensions, and concentrations.

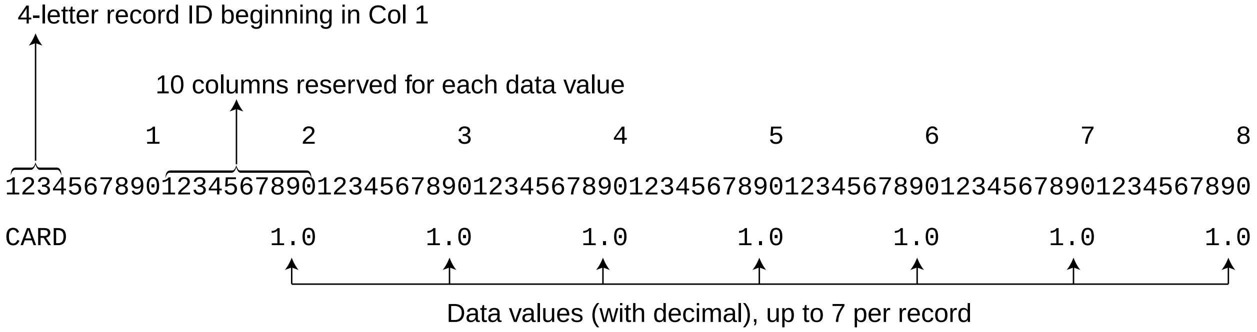
Phases I and II both generate conventional listings of up to 132 characters per line. At the user's option, Phase II can also generate supplementary listings of the contributions of individual subclouds to obscuration and can produce a printed contour representation of clouds with time. These listings are directed to separate print files or FORTRAN logical unit numbers.

The primary purpose of Phase I is to compute separate cloud histories for given types of battlefield obscurants under one set of meteorological conditions. Each cloud history is computed in relation to an arbitrary source position and thus is independent of any specific scenario. Phase II calculations are for scenarios that potentially contain many obscurant sources at user-defined locations and starting times. Phase II also performs bookkeeping of user-defined target–observer pairs. Memory locations for sources and for target–observer pairs are reused as they become available. Phase II computes the transmittance at one or more wavelengths and bands between the target–observer pairs as a function of time.

The following sections define inputs to Phases I and II. The two Phases can be easily separated into two distinct programs if necessary. Input formats are structured so that records applicable to Phase II calculations are ignored by Phase I and vice versa, allowing the user to input a single file (or card deck) with inputs for both phases.

Except for the `NAME` and `FILE` records, all inputs to COMBIC follow a standard format. An example is provided in table 13. Values are provided by the user on a series of 80-column records. Each record has a four-letter identifier in columns 1 to 4. Columns 5 to 10 are ignored. Up to seven numeric values are placed on each record in 10-column fields: that is, one

Table 13. Record format (except `NAME`, `DONE`, `GO`, `FILE`).



value in columns 11 to 20, one in columns 21 to 30, etc. Each numeric value is FORTRAN type REAL and therefore must contain a decimal point. The FORTRAN input format is (A4,6X,7F10.4). The advantage to making all the numeric inputs REAL is that they can be placed anywhere within their 10-column input field with blanks on either end (or both) of the numeric value.

The input value may have any number of digits preceding or following the decimal point within the 10-column limit for the entire number. Very small or very large numbers can be expressed in terms of exponential notation. For example, 1.234E-6 can be used to designate the number 0.000001234. The integer following the letter “E” tells the number of places that the decimal point must be moved (either left negative or right positive) for the usual decimal notation.

If COMBIC issues an error message about a particular input record, the user should first check to determine that each input number has a decimal, that it falls inside its 10-column input field, and that there are no “nonprinting” special characters (CNTRL or ESC sequences) on the record. These make up almost 100 percent of the usual input problems.

4.2 Phase I Input

Besides direct input from data records, input may also be taken from EOSAEL common blocks for default input/output (I/O) file numbers, coordinate system definition, and (optional) climatology inputs in place of meteorological observations. Relative humidity, windspeed, wind direction, Pasquill category, air temperature, and air pressure can be provided by the EOSAEL CLIMAT model under this option.

User-specified inputs to COMBIC in Phase I calculations include (1) control records that separate the calculations of cloud histories for the specified obscurant sources, (2) environmental records that include primarily meteorological inputs, (3) munition or source definition records, (4) an optional record that modifies the source to form an effective barrage source, (5) an optional record to modify or input additional extinction coefficients, (6) an optional record to allow comments to be placed into the input file for documentation purposes, and (7) optional records that define the subcloud structure of the obscurant cloud to allow the user to input more general obscurant sources. The following are the record identifiers for Phase I inputs:

(1) Control: `PHAS`, `FILE`, `WAVL` (`WAVNUM` or `FREQ`), `GO`, `DONE`
(2) Environment: `MET1`, `MET2`, `PSQ1`, `PSQ2`, `TERA`
(3) Source: `MUNT`, `BURN`, `SMLD`, `DUST`, `VEHC`
(4) Barrage: `BARG`
(5) Extinction: `EXTC`
(6) Comments: `NAME`
(7) Subclouds: `CLOU`, `SUBA`, `SUBB`, `SUBC`

Hereafter, the set of input records is called the “input file.” This file is often created and edited as a mass storage file. But it can also be a physical deck of input cards or a series of lines typed into a terminal one after the other.

The above records define the full set possible for Phase I calculations. In general, not all record types will be used to produce cloud histories for the obscurant. In particular, most users will never use the subcloud records (sect. 4.2.7) except to input predetermined values for obscurant sources not in the code.

4.2.1 Control Records: `PHAS`, `FILE`, `WAVL` (`WAVNUM`, `FREQ`), `GO`, `DONE`

Input parameters for the control records are given in tables 14 to 19. The order of the input parameters corresponds to the order of the numeric fields that are input in columns 11–20, 21–30, 31–40, and so forth.

The input file to COMBIC must begin with a PHAS record and end with a `DONE` record. Additional records before the PHAS record and after the `DONE` record are required if the routine is executed as part of the larger EOSAEL library. (The reader is referred to the EOSAEL library general documentation for those inputs.)

COMBIC Phase I output cloud histories change if meteorological inputs are changed. COMBIC is, therefore, designed to use only one set of meteorological conditions per computer run, unless additional PHAS records are input to reinitialize the program. An exception to the meteorological restriction is wind direction. Wind direction is read into Phase I but is not used. It is simply passed to Phase II through the history file. Thus, Phase I need not be rerun if a change in wind direction is all that is required. Phase II allows the user to input a new wind direction if desired.

Table 14. PHAS record and parameters. PHAS *must* be the first record after COMBIC is called.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PHAS           PHASE     IUNIT     OUNIT     UNITC     UNITF     ORDRS      ECHO
PHAS              1.        5.        6.       12.        9.        0.        0.
```

Name	Units	Typically	Description
`PHASE`	—	1. or 2.	Select Phase I or II. A second PHAS record reinitializes COMBIC to the phase specified. There is no default. Phase must be specified.
`IUNIT`	—	1. to 30.	The standard input unit for COMBIC commands. (`IOIN` in common block `/IOUNIT/`)
`OUNIT`	—	1. to 30.	The standard output unit for COMBIC listings. (`IOOUT` in common block `/IOUNIT/`)
`UNITC`	—	1. to 30.	Secondary output unit, not used in Phase I. Used for the printer-plot option. (`NPLOTU` in common block `/IOUNIT/`)
`UNITF`	—	1. to 30.	History file output unit, direct-access storage. (`NDIRTU` in common block `/IOUNIT/`)
`ORDRS`	—	0. or 1.	Flag, not used in Phase I. If `ORDRS` equals 1, then inputs in Phase II are scanned, and calculations are performed up to the last time input on a source or observer record. This allow the calculation to progress in an interactive fashion if `ORDRS` equals 1; if `ORDRS` equals 0, batch mode is used.
`ECHO`	—	0. or 1.	If `ECHO` equals 1, all inputs will be echoed to the print file.

More than one obscurant type can be specified in Phase I. As each additional source is specified, the history file produced grows in size. Different source inputs are separated by `GO` records. The `GO` record tells COMBIC that all desired input records have been read in for a given source and that now a cloud history should be generated for that source. Following a `GO` record, the source inputs are reinitialized. The next source can now be defined, followed by another `GO` record. Once a `GO` is input, the environmental inputs cannot be redefined, and environmental records result in warning messages. A `DONE` record is a special type of `GO` record that tells COMBIC to compute the final cloud history and then stop or return to the EOSAEL executive library routine.

One of three input records (`WAVL`, `WAVNUM`, `FREQ`) must be chosen to specify wavelength, wavenumber, or frequency. Tables 16 to 18 show the parameters for `WAVL`, `WAVNUM`, and `FREQ`.

Table 15. `GO` and `DONE` records. `GO` initiates calculation of a cloud history for one source type, and then returns control to the input record file for further inputs. Previous meteorological data remain effective, but all source inputs are reinitialized (all optional parameters revert to default values). `DONE` is similar to the `GO` input record, except that control exits COMBIC after the cloud history is computed and stored in the history file (with all optional parameters set to default values).

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
GO                0.        0.        0.        0.        0.        0.        0.
DONE              0.        0.        0.        0.        0.        0.        0.
```

Table 16. `WAVL` record. One of records that may be used to specify wavelength, wavenumber, or frequency. Choose one from among `WAVL`, `WVNUM`, or `FREQ`.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
WAVL           WAVE1     WAVE2     MULDV
```

Name	Units	Typically	Description
`WAVE1`	μm	1.06	Wavelength used for the calculation. Alternatively, one can specify either frequency or wavenumber by using a `FREQ` or `WVNUM` record instead of `WAVL`. If `WAVE2` is not specified, `WAVE1` is the single wavelength used; if `WAVE2` is specified, the modules will attempt to do their calculation for a range of wavelengths. There is no default; this information must specified.
`WAVE2`	μm	0.	Wavelength used for the calculation. This is the other end of a wavelength interval started by `WAVE1`. If `WAVE2` is not specified, then the modules will attempt to do their calculation for a single wavelength `WAVE1`. If `WAVL2` is specified then `WAVL2` > `WAVL1`. The default is to perform the calculations for a single wavelength.
`MULDV`	—	1	Number of equal intervals to divide `WAVE1` – `WAVE2` into.

Table 17. `WVNUM` record. One of records that may be used to specify wavelength, wavenumber, or frequency. Choose one from among `WAVL`, `WVNUM`, or `FREQ`.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
WVNUM         WVNUM1    WVNUM2     MULDV
```

Name	Units	Typically	Description
`WVNUM1`	cm^{-1}	2500.	Wavenumber used for the calculation. Alternatively, one can specify either frequency or wavelength by using a `FREQ` or `WAVL` record instead of this `WVNUM` record. If `WVNUM2` is not specified, this is the single wavenumber used; if `WVNUM2` is specified, the modules will attempt to do their calculation for a range of wavenumbers. There is no default; this information must specified.
`WVNUM2`	cm^{-1}	0.	Wavenumber used for the calculation. This is the other end of a wavenumber interval started by `WVNUM1`. If `WVNUM2` is not specified, the modules will attempt to do their calculation for a single wavenumber `WVNUM1`. If `WVNUM2` is specified then `WVNUM2` > `WVNUM1`. The default is to perform the calculations for a single wavenumber.
`MULDV`	—	1.0	Number of equal intervals to divide `WVNUM1` – `WVNUM2` into.

Table 18. `FREQ` record. One of records that may be used to specify wavelength, wavenumber, or frequency. Choose one from among `WAVL`, `WVNUM`, or `FREQ`.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
FREQ           WAVE1     WAVE2     MULDV
```

Name	Units	Typically	Description
`FREQ1`	GHz	94.0	Frequency used for the calculation. Alternatively, one may specify either wavelength or wavenumber by using a `WVAL` or `WVNUM` record instead of this `FREQ` record. If `FREQ2` is not specified, this is the single frequency used; if `FREQ2` is specified, the modules will attempt to do their calculation for a range of frequency. There is no default; this information must specified.
`FREQ2`	GHz	0.	Frequency used for the calculation. This is the other end of a frequency interval started by `FREQ1`. If `FREQ2` is not specified, the modules will attempt to do their calculation for a single frequency `FREQ1`. If `FREQ2` is specified then `FREQ2` > `FREQ1`. The default is to perform the calculations for a single frequency.
`MULDV`	—	1.0	Number of equal intervals to divide `FREQ1` – `FREQ2` into.

The remaining control record is the `FILE` input record (table 19). If used, `FILE` records should be placed immediately following the PHAS record. The `FILE` record does not follow the standard input format. It allows the user to name a mass storage file and link it to any of the four FORTRAN logical unit numbers specified on the PHAS record (parameters `IUNIT`, `OUNIT`, `UNITC`, and `UNITF`). If the unit numbers are left blank on the PHAS record, default values are assigned from the EOSAEL common block `/IOUNIT/`. The `FILE` record contains the unit number in columns 11 to 20 (again, a real number with a decimal point) and a file name of up to 16 characters beginning in column 21. COMBIC will then open that file for I/O.

Table 19. `FILE` record and parameters. `FILE` record is optional—connects named file to input/output.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
FILE          UNITNO     FNAME
```

Name	Units	Typically	Description
`UNITNO`	—	1. to 30.	Any unit number input on PHAS record.
`FNAME`	—	(chars)	File name, up to 16 characters, beginning in column 21. This is the only COMBIC input record with a character input field.

4.2.2 Environmental Records: MET1, MET2, PSQ1, PSQ2, TERA

Tables 20 to 24 give input parameters for the environment records. Environment records should be input soon after the PHAS input record and preceding the first GO or DONE record. Their order is not important, except that PSQ2 must follow PSQ1. Figure 2 is a simple flowchart that can aid the user in determining Pasquill stability for the MET1 record given only windspeed, cloud cover, and time of day.

Table 20. MET1 record. Meteorological conditions for Phase I calculations. If the ICLMAT = 1 option is used in the EOSAEL library executive routine, then all values are passed to COMBIC through the climatology common block /CLYMAT/.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
MET1          RELHUM        UW      PCAT      AIRT     PRESR    WINDIR     COLDR
MET1             50.        6.        4.       21.     1013.      270.        0.
```

Name	Units	Typically	Description
RELHUM	%	0. to 100.	Relative humidity.
UW	m / s	0.2 to 30.	Windspeed at height ZREF. Default for ZREF is 10 m. 1 m / s = 2.24 mph.
PCAT	—	1. to 7.	Pasquill stability category (fractions allowed). Standard values are 0.6 = A, 1.6 = B, 2.6 = C, 3.6 = D, 4.6 = E, 5.6 = F, 6.6 = G. Categories A, B, C (0.2–3.0) are unstable, category D (3.1–4.0) is neutral, categories E, F (4.1–7.0) are stable. If PCAT is input as 0., a PSQ1 and PSQ2 record will compute a category.
AIRT	°C	–40. to 45.	Air temperature at height ZREF. (Calculation is insensitive to the reference height and any value 2–16 m is appropriate.)
PRESR	mb	up to 1020.	Air pressure at height ZREF above ground level. (Standard at sea level is 1013.) Calculation is insensitive within tens of millibars and thus to the reference height. If air density ρ is known, then PRESR is $\text{PRESR} = 2.883 \times 10^{-3} \rho (\text{AIRT} + 273.2)$ where ρ is in g / m^3.
WINDIR	deg wrt N	0. to 360.	Wind direction. Not used in Phase I.
COLDR	—	0. or 1.	Cold regions flag. If 1., then WP and HC yield factors are computed from the cold regions model. Not related to winterized fog oil.

Table 21. `MET2` record: optional meteorological parameters. This record is not usually used except to change the reference height or to set a known inversion height. Other parameters are used only in sensitivity studies or boundary layer model effects.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
MET2            ZREF      ZINV     SBARM      SBAR     USTAR     SHFLX
MET2             10.        0.        0.        0.        0.        0.        0.
```

Name	Units	Typically	Description
`ZREF`	m	1. to 20.	Reference height for input wind speed, temperature, and pressure.
`ZINV`	m	30. to 1000.	Height of the limiting inversion. If 0., the internal model is used.
`SBARM`	—	0. or 1.	Flag. If 1., then the average static stability parameter model is used for buoyant rise. If 0. (the default), the model for decreasing stability parameter with height is used.
`SBAR`	s^{-2}	varies	Optional user-specified average static stability parameters when `SBARM` is 1. If `SBAR` is input as 0. and `SBARM` is 1., the internal model averages from 10 to 50 m.
`USTAR`	m/s	0.001 to 2.	Optional surface friction velocity to override the internal model value. If 0., the internal model is used.
`SHFLX`	W/m^2	varies	Optional sensible heat flux to override the internal model value. If 0., the internal model is used.

Table 22. `PSQ1` record. Optional record for determining and overriding the `PCAT` on the `MET1` record. Must be used with `PSQ2` record. No defaults.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PSQ1            SLAT     SLONG    SZHOUR    SJDATE      CCOV
```

Name	Units	Typically	Description
`SLAT`	degrees	0. to 90.	Site latitude (degrees, positive northward).
`SLONG`	degrees	+180. to −180.	Site longitude (degrees, positive eastward).
`SZHOUR`	hr and decimal	0. to 24.0	Time of day (TOD) in hours and fractions of hours, local time (no daylight savings). Input is converted internally to Greenwich mean time (GMT) by code GMT = TOD + IFIX ((`SLONG` + 7.5)/15.), where IFIX is the Fortran function that corrects floating point to integer.
`SJDATE`	days	0. to 365.	Julian date.

Table 23. `PSQ2` record. Optional Pasquill category calculation. Must be used right after `PSQ1`.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CCEIL          GCOND     RLGTH
```

Name	Units	Typically	Description
`CCEIL`	m	100. to 9999.	Height above ground of lowest cloud layer.
`GCOND`	—	1. to 3.	Ground condition: 1 = bare ground; 2 = snow patchy, <6 ft; 3 = snow >6 ft deep.
`RLGTH`	m	0.00001 to 10.	Land use category / roughness length: Bare desert, playas = 0.0003 Tundra = 0.004 Snow-covered farmland = 0.002 Prairie, 0.2–0.4 m grass = 0.03 Airfields = 0.03 Farmland = 0.06 Agricultural areas, Asia = 0.08 Farmland, hedgerows = 0.10 Brush, scrub growth = 0.16 Trees, hedgerows, few buildings = 0.20 Tall crops, scattered obstacles = 0.25 Dense brush = 0.25 Citrus orchards = 0.35 Level wooded countryside = 0.40 Cutover forest areas = 0.40 Subtropical savannah = 0.40 Barren hills, low mountains = 0.75 Forested plateau, rain forest = 1.0 Forested, rolling terrain = 2.0 Fir forest = 3.0 Smooth mud flats = 0.00001 Blacktop or concrete = 0.00002 Dry lake bed = 0.00003 Normal sea = 0.001 Closely mown grass = 0.001 Short grass = 0.0014 Grass (5–6 cm) = 0.0075 Alfalfa = 0.0272 Long grass = 0.03 Grass (60–70 cm) = 0.114 Wheat = 0.22 Forest clearings, cutover areas = 0.32–0.48 Corn (220 cm) = 0.74 Coniferous forest = 1.10

Table 24. `TERA` record. Optional soil and surface parameters. This record allows the user to modify the environmental parameters that affect cloud diffusion (`ZNOT`) or obscurant production.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TERA            ZNOT      SILT       SOD        SNOW
TERA             0.1       50.        0.        0.        0.        0.        0.
```

Name	Units	Typically	Description
`ZNOT`	m	0.001 to 5.	Surface roughness. Used in wind and diffusion model. Typically 10 percent of highest vegetation elements.
`SILT`	percent	0. to 100.	Surface soil silt content. Used in vehicle dust model. Silt particles are $<74\ \mu$m diam.
`SOD`	m	0. to 2.	Depth of sod cover. Used in HE dust model.
`SNOW`	—	0. or 1.	Snow cover (1 if yes). Reduces RP smoke munition burning by 80 percent.

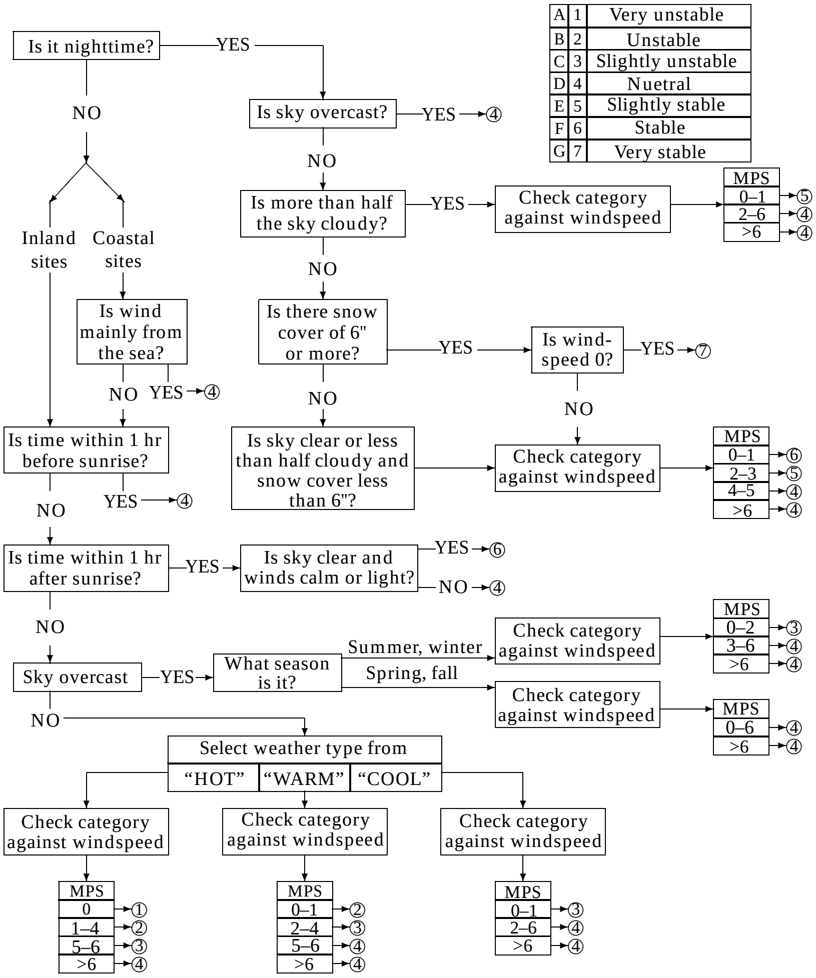


Figure 2. Flowchart to determine Pasquill stability.

4.2.3 Source Records: `MUNT`, `BURN`, `SMLD`, `DUST`, `VEHC`

Sources are defined on `MUNT`, `BURN`, `SMLD`, `DUST`, and/or `VEHC` records. Input parameters for these source records are given in tables 25 to 29. Most users wishing only to use the menu-provided sources, with perhaps some modification of characteristics, will find these records sufficient. The records may occur in any order before the `GO` or `DONE` record.

In Phase II scenarios, particular sources are placed at particular locations at particular times, and the evolution of the clouds is then tracked. The concentrations, and hence the transmission, between target–observer pairs can then be computed during the scenario. Since many scenarios will have more than one instance of a particular obscurant source, the history for each type of source is precomputed in Phase I.

An additional consideration follows from the effect of heat-producing obscurant plumes. If several such plumes are near each other, they will interact with each other and produce a different buoyancy for the resulting cloud. To account for this effect, the user can apply a scaling factor in the Phase I calculations so that the Phase II calculations will use an appropriate cloud description.

The `MUNT` record allows the user to specify the menu number for the source and a scaling factor `XN` for the number of such munitions (or sources) to be considered together to produce a single cloud.

The scale factor, which is specified (or modified) in Phase II inputs, is also provided in Phase I so that the proper amount of heat produced by the cloud (thermal buoyancy) can be accounted for. In Phase II, the user can specify a different scaling `XN` of up to a factor of about 3 to 4 (or one-third to one-fourth) for hot clouds such as WP. For nonthermal sources, such as fog oil, or for warm thermal sources, such as HC, the range of different scaling in Phase II can be increased. For users needing a wide range of WP source strengths in Phase II, it is suggested that more than one cloud history be generated in Phase I to cover the reasonable ranges expected.

The variety of scaling factors can be confusing to new users. Suppose Phase I is for `XN` = 8 rounds of 155-mm WP. In Phase II, an input source factor of `XN` = 1 will place 1 round in the scenario, an `XN` = 8 places 8 rounds in the scenario at the coordinates input, and an `XN` = 24 places 24 rounds at that point. The model in each case scales the amount of WP smoke appropriately, and the cloud height computed in Phase I is also scaled in relation to the height of the cloud determined for 8 rounds in Phase I. For 24 rounds, the instantaneous puff generated by the WP burst will rise $\sqrt[4]{24/8} = 1.32$ or 32 percent higher. But windspeed varies logarithmically with height. Thus, if the Phase II input number of rounds is sufficiently different from the number computed for in Phase I, the effects of higher winds at greater heights will not be appropriately taken into account.

Table 25. `MUNT` record. Munition definitions and menus.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
MUNT              XN        FW     SMENU      STYP       EFF        YF      SUBM
MUNT              1.        0.       12.        0.        0.        0.        1.
```

Name	Units	Typically	Description
`XN`	—	0.1 to 100	Number of munitions or sources grouped at the same point and initiated at the same time. This parameter scales up obscurant mass and heat production. It can be a noninteger.
`FW`	lb or gal	0.01 to 1000.	Fill weight. For HE, `FW` is the weight of the charge in pounds equivalent–TNT. For fog oil, diesel fuel, PEG200, and diesel fuel / oil / rubber fires, the fill weight is in gallons. For all other obscurants, including vehicular dust, `FW` is in pounds. Normally `FW` is zero for vehicular dust to use the internal model. Otherwise if input as zero, defaults are used.
`SMENU`		0. to 33.	Selects a source from the built-in menu: 0. = User specified by inputs. 1. = 155-mm HC M1 canister. 2. = 155-mm HC M2 canister. 3. = 105-mm HC canister. 4. = 155-mm HC M116B1 canister.* 5. = 155-mm HC M84A1 projectile.* 6. = Smoke pot, HC M5.* 7. = Smoke pot, HC M4A2.* 8. = 60-mm WP M302A1 cartridge.* 9. = 81-mm WP M375A2 cartridge.* 10. = 4.2-in. WP M328A1 cartridge.* 11. = 2.75-in. WP M156 rocket.* 12. = 155-mm WP M110E2 projectile.* 13. = 105-mm WP M60A2 cartridge.* 14. = 4.2-in. PWP M328A1. 15. = 5-in. PWP Zuni MK4. 16. = 2.75-in. WP wedge. 17. = 2.75-in. WP M259 rocket.* 18. = 3-in. WP wick. 19. = 6-in. WP wick. 20. = 155-mm WP M825 projectile.* 21. = 81-mm RP wedge. 22. = 81-mm RP XM819 cartridge.* 23. = Generator, ABC M3A3.* 24. = Generator, VEESS (Vehicle Engine Exhaust Smoke System).* 25. = Smoke pot, fog oil M7A1.* 26. = 155-mm HE (dust). 27. = 105-mm HE (dust). 28. = 4.2-in. HE (dust). 29. = 10-lb C4 (dust). 30. = Diesel fuel / oil / rubber fire. 31. = Muzzle blast. 32. = M76 IR grenade. 33. = L8A1 / L8A3 RP grenade.

---

*Inventory munitions

Table 25. `MUNT` record. Munition definitions and menus. (cont'd)

Name	Units	Typically	Description
`STYP`		0. to 30.	Obscurant type for the selection of extinction coefficients and for assigning default model characteristics if information is not otherwise provided by menu values or user inputs. 0. = Assigned by the internal menu. 1. = Bulk white phosphorus (WP) munition. 2. = WP wedges, WP wicks, and plasticized WP (PWP) munitions. 3. = Hexachloroethane (HC) smoke. 4. = Fog oil (SGF2) generator or smoke pot. 5. = Red phosphorus (RP) munition. 6. = IR screener, generator disseminated. 7. = IR screener, munition. 8. = Diesel fuel (DF) produced by generator. 9. = Dust, vehicular. 10. = Dust, high explosive (HE), small-particle persistent mode. 11. = Dust, HE, large-particle mode. 12. = Carbon, HE debris product. 13. = Dust / soil, HE, very large ballistic soil aggregates. 14. = Fire smoke from diesel, oil, and rubber mix. 15. = Kerosene / fog oil cold-region mix. 16. = Polyethylene glycol (PEG200) mix for alcohohols. 17. = Anthracene (not used in `SMENU`). 18. = Chlorosulfonic acid (FS, not used in `SMENU`). 19. = Titanium tetrachloride (FM, not used in `SMENU`). 20. = IR (M76). 21. = Brass. 22. = Graphite 7525. 23. = Kaolin. 24.–30. = User defined by inputs.
`EFF`	%	1. to 100.	Production efficiency. For smoke, the percentage of actual aerosol weight produced from the fill weight. For HE dust, the percentage of the yield appearing as heat. Defaults to modeled values when input is zero. Ignored for vehicular dust. Total mass $= CX_nW_f\left(\frac{E_f}{100}\right)Y_f$. C is a conversion constant.
`YF`	—	0. to 20.	Yield factor. For smokes (dimensionless), the ratio of the total airborne mass of obscurant absorbed water to the total mass or obscurant alone. For HE explosions, the crater volume scaling factor is $S_a(\mathrm{m}^3/\mathrm{TNT}^{1.111})$. If 0., internal models are used.
`SUBM`	—	varies	Number of submunitions per munition that make up the source and produce independently buoyant portions of the total obscurant cloud. Specifies thermal independence.

This problem is avoided by the use of the submunition parameter on the MUNT record, which allows the user to decouple the thermal buoyancy of parts of the source. This parameter should be used with XN when the amount of obscurant produced by many munitions is large, but the munitions can be assumed to be thermally uncoupled or independent. The fill weight inputs on the MUNT record are for one source.

The user will generally input zeros for the fill weight, yield factor, and efficiency if a menu source is selected. For most inputs where zero is not otherwise meaningful, COMBIC interprets zeros to imply that an internal default or model is to be used to produce a value.

The BURN record (table 26) allows the burn duration (or the obscurant production duration) to be specified for a source, and a profile of the production to be input. Again, if the record is not present, COMBIC assigns menu or default values.

The burn rate profile has the form

$$\dot{M}(t) = \frac{1}{T_b}\left[B_1 + B_2\left(\frac{t}{T_b}\right) + B_3\left(\frac{t}{T_b}\right)^2 + B_4\left(\frac{t}{T_b}\right)^3\right] + B_5 B_6 \exp\left(-B_6 t\right) \tag{9}$$

and can be multiplied by any constant value since the model normalizes to total mass produced. T_b is burn duration TBURN (see table 26). In terms of the cumulative mass $M(t)$ produced up until time t, the coefficients describe

$$M(t) = B_1\left(\frac{t}{T_b}\right) + \frac{1}{2}B_2\left(\frac{t}{T_b}\right)^2 + \frac{1}{3}B_3\left(\frac{t}{T_b}\right)^3 + \frac{1}{4}B_4\left(\frac{t}{T_b}\right)^4 + B_5\left(1 - \exp\left(-B_6 t\right)\right). \tag{10}$$

The SMLD record (table 27) is an optional card that modifies the burn rate for smoldering munitions.

The burn function for smoldering munitions is

$$\begin{aligned} \dot{M}_{new}(T) &= \dot{M}_{old}(T) & T < T_{SMLD} \quad (11) \\ \dot{M}_{new}(T) &= \dot{M}_{old}(T_{SMLD}) \exp\left[-\left(\frac{C_{SMLD}}{(T_{BURN} - T_{SMLD})}(T - T_{SMLD})\right)\right] & T > T_{SMLD} \quad (12) \end{aligned}$$

The VEHC and DUST records (tables 28 and 29) are needed for vehicular and HE dust sources. They can be placed before or after the MUNT input. The VEHC record can also be used to specify a speed and direction for a moving smoke source (or a moving barrage). If input, the VEHC speed and direction is passed to Phase II, where it can be modified by other inputs.

If the total dust is input as a fill weight (in pounds) on the MUNT record, the internal vehicular dust model will not be used. The dust production rate is then determined from TBURN. The Phase II scaling will then assume that dust production per unit time varies as vehicle speed squared, as in the internal mode. In either case, VEHC must be input. VEHC can also be input with any other obscurant to designate it as moving. This input passes speed and direction to Phase II. It is more common, however, to use the `VEH1` and `VEH2` cards in Phase II to place obscurant sources other than vehicular dust into motion.

Table 26. `BURN` record. Obscurant burn rate profile for continuous sources.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
BURN           TBURN     BRAT1     BRAT2     BRAT3     BRAT4     BRAT5     BRAT6
```

Name	Units	Typically	Description
`TBURN`	s	1. to 900.	Burn duration. The length of time that the source releases obscurant. If input as zero, the menu default is used.
`BRAT1`	—	varies	Coefficient of constant term.
`BRAT2`	—	varies	Coefficient of linear term.
`BRAT3`	—	varies	Coefficient of quadratic term.
`BRAT4`	—	varies	Coefficient of cubic term.
`BRAT5`	—	varies	Coefficient of added exponential term.
`BRAT6`	s^{-1}	varies	Coefficient of exponential.

Table 27. `SMLD` record. Obscurant burn rate modification for smoldering munitions.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SMLD           TSMLD     CSMLD
```

Name	Units	Typically	Description
`TSMLD`	s	1. to 500.	Time smoldering begins. Must be less than `TBURN`.
`CSMLD`	s^{-1}	varies	Exponential coefficient for all times. It defines how fast the smoldering decays: the larger the coefficient, the faster the mass production.

Table 28. `VEHC` record. Vehicle inputs, primarily for dust but also for any moving source.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
VEHC          VSPEED    VWIDTH    VWEIGH    VEHTYP    VEHDIR
VEHC              5.        3.       60.        1.       90.        0.        0.
```

Name	Units	Typically	Description
`VSPEED`	m / s	0. to 35.	Moving source speed. This can be altered in Phase II.
`VWIDTH`	m	0. to 4.	Vehicle width for internal dust model only.
`VWEIGH`	tons	0. to 70.	Vehicle weight for internal dust model only.
`VEHTYP`	—	0. or 1.	Vehicle type (0 = wheeled, 1 = tracked) for internal dust model only.
`VEHDIR`	deg	0. to 360.	Moving source direction. This can be altered in Phase II.

Table 29. `DUST` record. Input for HE dust model only. `DOB`, `DELIV`, `CASEL`, `CASED`, and `CYDEG` are ignored if `YF` (equal to S_{ac} for HE dust) is nonzero on `MUNT` record (table 25).

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
DUST                SOIL       DOB     DELIV     CASEL     CASED     CYDEG
DUST                 4.5      -.06        3.     .6096     .1778       10.        0.
```

Name	Units	Typically	Description
`SOIL`	—	1. to 6.	Soil type (can be noninteger). 1. = rock 2. = dry cohesive soil 3. = dry sandy soil 4. = dry-to-moist sand 5. = wet sand, moist cohesive soils 6. = wet cohesive soil
`DOB`	m	–5. to 5.	Depth (or height if negative) of center of mass of munition at burst.
`DELIV`		1. to 3.	Delivery type. 1. = uncased static 2. = cased static 3. = cased live fire
`CASEL`	m	0.1 to 2.	Length of casing.
`CASED`	m	0.01 to 1.	Diameter of casing.
`CYDEG`	°	0. to 90.	Dip angle of munition from the horizontal at burst.

4.2.4 Barrage Record: BARG

Table 30 gives the input parameters for the BARG record. The BARG record may be placed before or after the MUNT record. If BARG is not present, the source is assumed to act as an individual source. If the BARG record appears, then an approximately equivalent obscurant cloud is produced that combines the effect of several sources spread over an area and igniting or initially producing obscurant over a period of time. The basic source is still defined on the inputs of MUNT, BURN, and so forth. The BARG record forms a single source cloud with the amount of obscurant determined by the number of rounds per second and the barrage duration.

The "round" used in Phase I for calculating cloud mass and buoyancy is determined by XN and the other MUNT parameters. Thus, if the barrage is for 0.1 rounds per second, the duration is 100 s, and the XN value is 5 for 155-mm WP, then 50 rounds impact the barrage area over the 100-s period. The cloud history is thus for these 50 rounds. In Phase II, if the source strength is XN = 1, then the barrage placed in the scenario is for only 10 rounds (that is, 0.1 round per second times 100 s), and the amount of smoke and the thermal rise are computed correspondingly. Again, the reason for inputting a value other than XN = 1 in Phase I is to ensure that the correct cloud rise and wind effects are generated for a barrage of this size.

Table 30. BARG record. Modifies munition source to be treated as multiple rounds ignited or exploded in a rectangular region of length XBARL and crosswind width YBARW (in meters) and uniformly distributed in time over T = TBARG s. No barrage is assumed if BARG record is absent. Note that BARG record generates an approximate representation of obscurant production, resulting in a gain in computation speed at the expense of detail.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
BARG           RATEB     TBARG     XBARL     YBARL
```

Name	Units	Typically	Description
RATEB	rnds/s	0. to 10.	Production rate in the user-defined area. The "round" is defined as XN munitions of source strength FW on the MUNT record. If the round produces a continuous cloud, the burn profile and burn duration of one round, TBURN, is folded into the barrage production.
TBARG	s	0. to 900.	The barrage duration.
XBARL	m	0. to 500.	The alongwind length of the impact region.
YBARL	m	0. to 500.	The crosswind width of the impact region.

4.2.5 Extinction Record: `EXTC`

Table 31 gives the input parameters for the `EXTC` record. The `EXTC` record allows the user to alter extinction coefficients and to define new values if desired for different obscurants or different wavelength regions. The values resulting from Phase I are passed to Phase II in the history file. Phase II inputs also allow the user to modify values during the Phase II run as well. In Phase I, the `EXTC` record should be placed in the same area of the input file as the meteorological conditions.

Table 31. `EXTC` record. Optional user-defined extinction coefficients. All values *must* be specified if `EXTC` is used.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
EXTC           CLTYP      R(2)      R(3)      R(4)      R(5)      R(6)      R(7)
```

Name	Units	Typically	Description
`CLTYP`	—	1. to 30.	Obscurant number `STYP` from `MUNT` record definition. User inputs replace the extinction coefficients.
`R(2)`	m^2/g	0. to 20.	0.4–0.7 μm waveband.
`R(3)`	m^2/g	0. to 20.	0.7–1.2 μm waveband.
`R(4)`	m^2/g	0. to 20.	1.06 μm waveband.
`R(5)`	m^2/g	0. to 20.	3.0–5.0 μm waveband.
`R(6)`	m^2/g	0. to 20.	8.0–12.0 μm waveband.
`R(7)`	m^2/g	0. to 20.	10.6 μm waveband.

4.2.6 Comments Record: `NAME`

Table 32 gives the input parameters for the `NAME` record. The `NAME` record allows the user to place nonexecutable comments in the input record file. The `NAME` record may appear anywhere in the input file after the `PHAS` record. It effectively comments out the next record in the input file. Comments should not appear on the `NAME` record itself, but on a record immediately after the `NAME` record. The comments may be of any form and are ignored by COMBIC but may be echoed to the output listing (along with other inputs) through a flag input on the `PHAS` record (`ECHO` = 1). The `NAME` record itself should have blank or 0. fields and no text.

Table 32. `NAME` record.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NAME              0.        0.        0.        0.        0.        0.        0.
 (Comment record goes here.)
```

4.2.7 Subcloud Records: `CLOU`, `SUBA`, `SUBB`, `SUBC`

Tables 33 to 36 give the input parameters for the optimal subcloud records. The `CLOU` record specifies whether the user will define a full set of subcloud definitions, effectively generating a new model within the code for this source. The `CLOU` record must be immediately followed by `SUB` records for each subcloud set.

We recommend that the `SUBA` record be input for each of the `NSUB` subclouds. If `SUBA` is absent, a default structure is assumed based on the menu selection `SMENU` or, if no menu selection, by the obscurant type `STYP` designated on the `MUNT` record. COMBIC will assign nonspecified values.

The optional `SUBB` record defines subcloud initial obscurant radii and buoyancy characteristics. It should follow the `SUBA` record for the corresponding subcloud. All parameters on the `SUBB` record (other than the initial upward velocity `WUP`) default to model or menu values if the record is input as 0 or if the record is absent.

Optional record `SUBC` defines subcloud initial conditions. This record should also follow the corresponding `SUBA` record for the subcloud. Only the `EVAPF` parameter defaults to internal stored or modeled values if it is input as 0.

Table 33. `CLOU` record.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CLOU            NSUB
```

Name	Units	Typically	Description
`NSUB`	—	1. to 5.	Specifies number of subclouds (up to 5) that will define the modeled cloud.

Table 34. `SUBA` record. Optional primary subcloud definition.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SUBA           SUBNO     FRACT     DCARB     PLUME    RISMOD      SEXT    BALMOD
```

Name	Units	Typically	Description
`SUBNO`	—	1. to 5.	Subcloud designation.
`FRACT`	—	0. to 1.	Fraction of total obscurant mass to be placed in this subcloud.
`DCARB`	—	0. to 10.	Relative amount of free carbon. Specifically, it is the amount of carbon divided by the amount of obscurant.
`PLUME`	—	1. or 2.	Flag. If 1., the subcloud is an instantaneous puff produced in the initial burst. If 2., the subcloud is continuous with a production rate assigned by the `BURN` record or by default.
`RISMOD`	—	1. to 45.	Flag. If 1., the subcloud is buoyant, and rise will be computed by the buoyancy model. If 2., the subcloud is nonbuoyant and no thermal rise is computed, although initial cloud velocity may cause the cloud to rise as a nonthermal “jet.” If `RISMOD` is a two-digit number *ij* from 12 to 45, then the subcloud is an instantaneously canted stem, spanning subclouds *i* and *j*.
`SEXT`	—	0. to 30.	Selects the extinction coefficient from the same list defined under `STYP` on the `MUNT` record defined above.
`BALMOD`	—	0. or 1.	Flag. If 0., the subcloud is not ballistic. If 1., its formation follows the ballistic cloud model. Presently, the ballistic model applies only to soil expelled from HE detonations.

Table 35. `SUBB` record.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SUBB           ROBSX     ROBSY     ROBSZ      RBUO    TCLOUD      QOBS       WUP
```

Name	Units	Typically	Description
`ROBSX`	m	0.1 to 50.	Initial cloud radius downwind.
`ROBSY`	m	0.1 to 50.	Initial cloud radius crosswind.
`ROBSZ`	m	0.1 to 50.	Initial cloud radius vertical.
`RBUO`	m	0.01 to 10.	Buoyancy radius.
`TCLOUD`	K	270. to 9999.	Initial mean cloud temperature. Note that the buoyancy radius and mean temperature imply a value for the total heat available for buoyancy and are thus not independent.
`QOBS`	cal / g obsc	0. to 2000.	Thermal production coefficient (see sect. B-1.4 and equations (B-17) through (B-19), in app B).
`WUP`	m / s	0. to 100.	Initial upward velocity of the subcloud.

Table 36. `SUBC` record.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SUBC          ZBURST     VFALL     EVAPF     EVAPD     REFCO      RMOM      VHOR
```

Name	Units	Typically	Description
`ZBURST`	m	0. to 50.	Initial height of the subcloud above local terrain.
`VFALL`	m / s	0. to 10.	The effective fall velocity (positive downward) of the cloud.
`EVAPF`	—	0. to 1.	The limiting fraction f_d of the cloud mass after a long time period.
`EVAPD`	s^{-1}	0. to 10.	The parameter δ. Used in the following mass equation for the time-dependent evaporation or deposition: $M(t) = M\,[f_d + (1 - f_d)\exp - \delta t]$
`REFCO`	—	0. to 1.	The ground “reflection coefficient” for the subcloud. `REFCO` defines the fraction of the cloud mass that is “reflected” off the ground back up into the airborne region of the cloud.
`RMOM`	m	0. to 10.	Momentum radius. This parameter can be input for cases where the buoyancy radius as determined in the model is small and / or the initial upward velocity is large. The momentum radius sets a lower limit on the cloud radius used in the rise calculations.
`VHOR`	m / s	0. to 100.	Initial horizontal velocity (positive downwind, negative upwind).

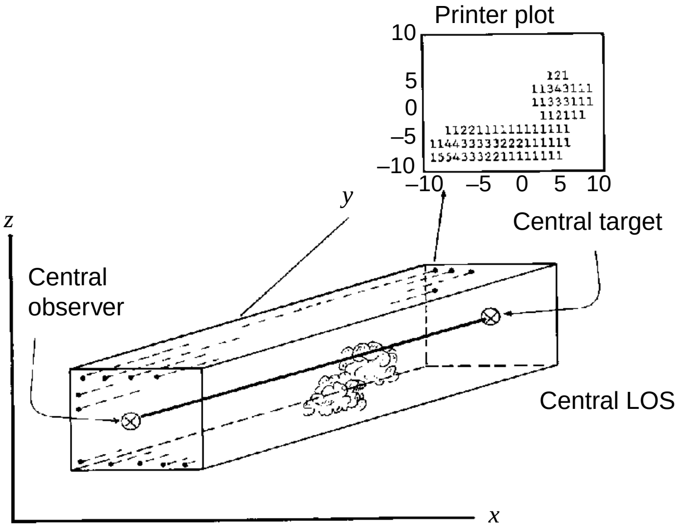
4.3 Phase II Input

Phase II sets up a scenario of multiple obscurant sources from those precomputed in the Phase I history file. Setting up scenarios is done by input of either a source location (`SLOC`) record or, for moving sources, by a pair of `VEH1` and `VEH2` records. Multiple LOS's are assigned by user inputs of pairs of "targets" on `TLOC` records and "observers" on `OLOC` records. The resulting transmittance between each pair is output at user-defined times specified on a `LIST` record.

Each time the transmittance is to be computed, COMBIC must determine which clouds intercept the LOS. To facilitate the rejection of nonintersecting clouds, COMBIC stores their positions at specified times. The time step for updating cloud positions for rejection purposes can optionally be specified on a `TIME` record.

COMBIC can also generate "pictures" of the clouds in the scenario by use of the display input records `VIEW`, `GREY`, and `TPOS`. These records form pictures in two ways. The first method, as illustrated in figure 3, creates a bundle of parallel LOS's surrounding one of the specified target–observer pairs. All the LOS's originate on a plane and end on a plane parallel to the first plane. This method provides an orthographic representation of the obscurant cloud.

Figure 3. Orthographic LOS.



The second method, as illustrated in figure 4, creates a bundle of LOS's surrounding one of the specified target–observer pairs. However, all the LOS's originate with the specified observer. The LOS's end normally on a plane. This approach provides a perspective representation of the obscurant cloud (as your eye gives you a perspective representation of the visual world).

These two ways of viewing the battlefield can yield different values on the obscuration levels (see Ayres and Randolph (1990)). Characters are assigned to represent different ranges of transmittance or optical depth for each LOS. These input records provide a crude but useful picture of the transmittance or optical depth of the clouds. Creating the displays is discussed in section 4.3.8.

With the inclusion of some of the records already defined in Phase I inputs, the Phase II input card set is as follows:

Control:	`PHAS`, `FILE`, `WAVL` (`WAVNUM`, `FREQ`), `GO`, `DONE`
Scenario:	`ORIG`, `LIST`, `TIME`
Source:	`SLOC`, `VEH1`, `VEH2`
Line of sight:	`OLOC`, `TLOC`
Extinction:	`EXTC`
Comments:	`NAME`
Display:	`VIEW`, `GREY`, `TPOS`

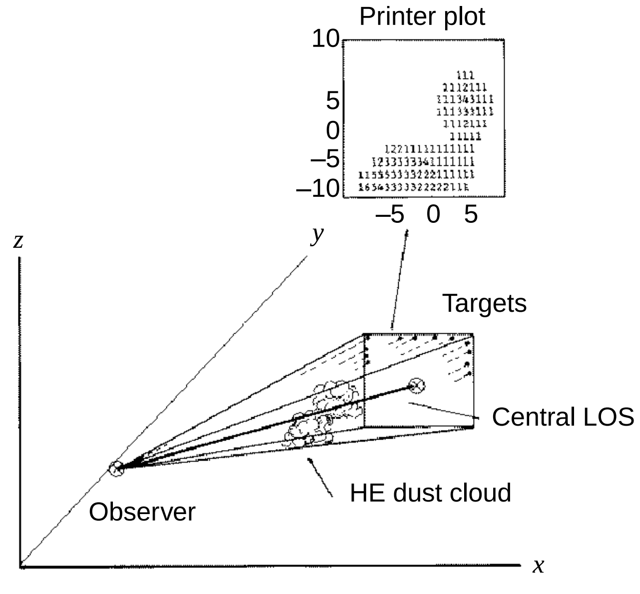


Figure 4. Perspective LOS.

4.3.1 Record Order

The order of records may be important, depending on the user's choice of execution mode. The default method reads in all input records and stores the data in arrays for reference as needed during calculations. The calculation is then made all at once when a `GO` or `DONE` record is input. Through the ORDRS flag on the PHAS record, however, the user may specify that the calculation is to be "event ordered." In event-ordered processing, COMBIC does computations and produces output as the sources and observers are entered.

The distinction between event ordered and unordered is simple, but important. If ORDRS = 0. (unordered processing), then all observer positions, target positions, and source positions are read in at once, and calculations begin only following a `GO` or `DONE` record. Input times (and thus input records) can be in any order. In the ordered processing option (ORDRS = 1.), however, obscurant source and target–observer pair records are read in, and the "start time" (STIM, STIMV, or STIMO) is checked against a future cloud update time. Record input is suspended, and transmission calculations are performed up to that update time only. Input then resumes until the next cloud update time. The only advantage to this option is that it allows COMBIC to more efficiently re-use storage released by deleted clouds and LOS's. It is also closer to the interactive calls for smoke and dust encountered in gaming simulations.

Though input records are mostly order-independent, note however that it is wise to enter the scenario record `ORIG` before any sources or target–observer coordinates are read in. The `ORIG` record sets up the coordinate system, including origin and direction of the coordinate axes. Once set, the origin cannot be reset during that run.

A `GO` record in event-ordered processing completes the calculations up to the limit input on the `LIST` record. Time ordering is not the chosen default in COMBIC because the EOSAEL library attempts to stress order-independent input records as much as possible within models.

4.3.2 Control Records: PHAS, `FILE`, WAVL (`WAVNUM`, `FREQ`), `GO`, `DONE`

As in Phase I, the PHAS and `DONE` records are the first and last records read by COMBIC (although the EOSAEL driver program requires two records at the beginning and end of the input files, these are not read by COMBIC). Any Phase I records are simply ignored if they are present in the same input stream as Phase II records. The `FILE` record serves the same purpose as in Phase I. The input parameters for these records, which are the same as in Phase I, are given in tables 14 to 16 (pp 41 to 42).

The PHAS, `GO`, `DONE`, and `FILE` records are identical in definition to those in Phase I (sect. 4.2.1). The UNITC secondary output file (specified by the

`UNITC` parameter on the `PHAS` card; see table 14) is used in Phase II for output pictures of the clouds as defined by the presence of a `VIEW` and `GREY` record.

In Phase II, under the event-ordered option, the insertion of a `GO` record completes calculations up to the last time on the `LIST` record (see sect. 4.3.3). The `DONE` record should, therefore, be used if COMBIC calculations are to halt at that point.

The EOSAEL library has a common geometry option (IGEOSW = 1) for specifying one obscurant source and one target–observer pair. If the common geometry option is set in effect by the user, then the first source assigned to the Phase II scenario will be the first history source. Its coordinates are designated in the EOSAEL executive routine as the "PTS(10–12)" input on the GEO-OBSC record. The first observer is designated as the "PTS(7–9)" input on the GEO-SEEK record. The first target is designated as the "PTS(1–3)" input on the GEO-TARG record. The returned values to the EOSAEL executive routine are the last transmittance determined of the target–observer pair at wavelength WAVE1.

4.3.3 Scenario Records: `ORIG`, `LIST`, `TIME`

Tables 37 to 39 give the input parameters for the scenario records.

The scenario records `ORIG`, `LIST`, and `TIME` set up the axis convention for input coordinates and the computation time steps. The default axis convention used is from the EOSAEL library: that is, the x-axis points eastward, the y-axis points northward, and the z-axis points upward. The `ORIG`

Table 37. `ORIG` record.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ORIG            XORG      YORG      ZORG    XORDIR     WNDIR      ORIG
ORIG              0.        0.        0.       90.      270.        0.        0.
```

Name	Units	Typically	Description
`XORG`	m	0.	Arbitrary x-origin added to all user input. Generally not used.
`YORG`	m	0.	Arbitrary y-origin.
`ZORG`	m	0.	Arbitrary z-origin.
`XORDIR`	deg wrt N	0. to 360.	Compass heading of user x-axis. EOSAEL default east (90°).
`WNDIR`	deg wrt N	0. to 360.	Wind direction. Compass heading which the wind blows. Can differ from Phase I direction. If the `ORIG` record is used, then specify `WNDIR`. Defaults to the climatology wind direction if the EOSAEL common climatology option is in effect.
`ORIG`	s	0.	Arbitrary time origin. All input times have `ORIG` added before they are stored. Useful only when output is to be compared to data with some different time origin.

record allows the x-axis to be defined along an arbitrary compass direction. The y-axis is then automatically 90° less than the x-axis heading.

The wind direction can also be changed from the Phase I input by use of the `ORIG` record. If input, the `ORIG` record should be placed at the beginning of the noncontrol records. This ensures that the coordinate system convention defined by the wind direction and x-axis is set before source and target–observer locations are input. If the common geometry option from EOSAEL (IGEOSW = 1) is invoked, then `XORG`, `YORG`, `ZORG`, and `XORDIR` are forced to be 0., 0., 0., and 90. If the common climatology option from EOSAEL EXEC has been invoked (ICLMAT = 1), then `WNDIR` is overridden by the CLIMAT module.

The `LIST` record (table 38) defines the times that the output is to be generated. The usual output option is to print only the total transmittance for the entire set of clouds intersecting the LOS. A second output option lists the contributions of individual clouds.

The `TIME` record (table 39) is optional. If the `TIME` record is absent, then cloud positions are updated just before each output time. In some situations, when transmittance is output over relatively small time steps, the clouds do not move very far at each step. Since the cloud position update is primarily for cloud rejection purposes, it is sometimes desirable to have the cloud update time step longer than the transmittance output time step. There is never any reason for the update time step to be smaller than the output time step.

Table 38. `LIST` record. Determines times that transmittance will be listed.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
LIST            PRNT    TBEGIN      TEND      TDEL
LIST              1.        0.      120.        5.        0.        0.        0.
```

Name	Units	Typically	Description
`PRNT`	—	0. to 3.	Flag. Print option 0. to 2.: 0. = Suppress all output except `ECHO`, errors, and `VIEW/GREY` pictures, if any. 1. = Print transmittance for all LOS's that intersect at least one cloud. 2. = Also print pathlength and contributing histories for each contributing subcloud. 3. = Add a second output file (`UNITC`) to dump cloud positions and sizes with time.
`TBEGIN`	s	0. to 7200.	Time to begin printout.
`TEND`	s	0. to 7200.	Time to end printout.
`TDEL`	s	0.1 to 10.	Time increment for printout.

Table 39. `TIME` record. Controls times that cloud positions are updated for cloud rejection calculations and cloud removal criteria.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TIME           BEGIN      ENDT      DELT      CLIM     CLEND     CLACC
TIME          TBEGIN      TEND      TDEL      100.       .01       10.        0.
```

Name	Units	Typically	Description
`BEGIN`	s	0.	Time when updates begin.
`ENDT`	s	1. to 7200.	Time when updates end.
`DELT`	s	0.1 to 10.	Time increment for cloud update.
`CLIM`	g/m^2	1. to 1000.	Minimum CL (g/m^2) that the calculation can be cut short since the cloud is so dense.
`CLEND`	g/m^2	0.001 to .1	CL (g/m^2) cloud removal limit. When the maximum possible CL will always be less than `CLEND`, the cloud is removed from the active list.
`CLACC`	percent	0.00 to 100.	`CLACC` is the percentage of error that can be tolerated in the Romberg method of integration. Each succeeding step is compared with the previous step to check if the desired accuracy is reached.

The `TIME` record also sets the criterion that determines whether a cloud is so thin that it can be removed from further consideration in the scenario. This criterion is set through the `CLEND` parameter. When the maximum possible integrated concentration (CL) falls below `CLEND`, the cloud is removed. At the opposite extreme, the cloud may be so dense that there is no need to continue particular integration steps along an LOS (that is, the transmittance has already been found to be effectively zero). The `CLIM` parameter sets the upper limit on the computed CL so that the path integration can be stopped, and the resulting minimum transmission is printed out. `CLACC` sets the percentage of error that can be tolerated in the Romberg method of integration.

Defaults are conservative, with `CLIM`, `CLEND`, and `CLACC` set to 100., 0.01 g/m^2, and 10 percent, respectively. The `TIME` and `LIST` records should be set at least once before sources, targets, and observers are entered in the scenario.

4.3.4 Source Records: `SLOC`, `VEH1`, `VEH2`

The source location and time are entered on a `SLOC` record or on `VEH1` and `VEH2` records. The input parameters for source codes `SLOC`, `VEH1`, and `VEH2` are given in tables 40 to 42. The `SLOC` record adds a new source at a fixed location or initiates a moving source that was already specified in Phase I as having a certain speed and direction. The `VEH1` and `VEH2` records allow any source to be defined as moving. Speed and direction are then entered on those records. If event-ordered processing is specified on the `PHAS` record (see sect. 4.3.1), then calculations are performed up to but not including the time specified for the new source to begin. In the process, older clouds may have been removed from the scenario, thus allowing the storage used for their locations to be released for use by the new source. The `SLOC` and `VEH1` records allow the user to define the time that the cloud can be removed from the scenario. The default is 1800 s after the source stops emitting obscurant.

Table 40. `SLOC` record. Defines or initiates a new source into scenario. Source is stationary if defined with `SLOC` record, unless it was already defined to be moving in Phase I calculation (if so, its speed and direction are same as in Phase I inputs).

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SLOC            STYP        XN      STIM      ETIM        XM        YM        ZM
SLOC              1.        0.        0.     3600.        0.        0.        0.
```

Name	Units	Typically	Description
`STYP`	—	1. to 35.	Selects the STYPth source cloud in the Phase I history file. Phase I and II provide listings of the characteristics of the sources by this number.
`XN`	—	varies	Like Phase I `MUNT` record, number of munitions or other sources set off at (XM, YM, ZM). If 0., the XN of Phase I is used. Otherwise, COMBIC rescales to this Phase II XN. (For example, if Phase I computed a history for XN = 4. smoke pots, then in Phase II XN is still defined with XN = 4. for 4 smoke pots, XN = 1. for 1 smoke pot, and so forth.)
`STIM`	s	0. to 7200.	Starting time for this source.
`ETIM`	s	0. to 7200.	Time after which cloud can be removed as ineffective. Default if 0. is `STIM` + 3600.
`XM`	varies	varies	x-coordinate of the source.
`YM`	varies	varies	y-coordinate of the source.
`ZM`	varies	varies	z-coordinate of the source (height above ground).

Table 41. `VEH1` record. Designates any continuous obscurant cloud as a moving source.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
VEH1            STYP        XN     STIMV     ETIMV     ETIMC
VEH1              1.        0.        0.     3600.        0.        0.        0.
```

Name	Units	Typically	Description
`STYPV`	—	1. to 35.	Selects the `STYP`th source cloud in the Phase I history file. Phase I and II provide listings of the characteristics of the sources by this number.
`XNV`	—	varies	Like Phase I `MUNT` record, number of munitions or other sources started at (XSTAR, YSTAR, ZSTAR). If 0., the `XN` of Phase I is used. Otherwise, COMBIC rescales to this Phase II `XN`.
`STIMV`	s	0. to 7200.	Starting time for this source.
`ETIMV`	s	0. to 7200.	Time to stop source production. Can be any time between `STIMV` and `STIMV` + TBURN (Phase I duration).
`ETIMC`	s	0. to 7200.	Time after which cloud can be removed as ineffective. Default if 0. is `STIMV` + 3600.

Table 42. `VEH2` record. Must be input after `VEH1` if `VEH1` values are to be effective.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
VEH2           XSTAR     YSTAR     ZSTAR      VDIR    VSPEED
VEH2              0.        0.        0.        0.        0.        0.        0.
```

Name	Units	Typically	Description
`XSTAR`	m	varies	Starting x-coordinate.
`YSTAR`	m	varies	Starting y-coordinate.
`ZSTAR`	m	varies	Starting z-coordinate.
`VDIR`	deg wrt N	0. to 360.	Compass heading toward which source moves.
`VSPEED`	m/s	0. to 35.	Source speed. 1 m/s = 2.237 mph.

4.3.5 Line of Sight Records: `OLOC`, `TLOC`

The coordinates and the time interval over which an observer views the scenario are input on an `OLOC` record, and those of the target on a `TLOC` record. The input parameters for LOS records `OLOC` and `TLOC` are given in tables 43 and 44.

In event-ordered processing (see sect. 4.3.1), the calculations progress up to but not including the time that the new observer will be initiated. In the process, other observers may have reached the time limits of their observation. The computer storage used to define their coordinates and observation directions is thus released for use by the new observer.

In event-ordered processing, the user must, of course, ensure that the source records and target–observer pairing records (`OLOC` and `TLOC`) are input in a time-ordered sequence.

Table 43. `OLOC` record. Assigns observer's position and viewing times.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
OLOC            OBSN      XOBS      YOBS      ZOBS     STIMO     ETIMO
OLOC              1.       70.    -2000.        3.        0.   100000.        0.
```

Name	Units	Typically	Description
`OBSN`	—	1. to 35.	Assign designator `OBSN` to identify this observer (whole number).
`XOBS`	m	varies	x-coordinate of observer.
`YOBS`	m	varies	y-coordinate of observer.
`ZOBS`	m	varies	z-coordinate of observer (usually height above surface).
`STIMO`	s	0. to 7200.	Time observer becomes active.
`ETIMO`	s	0. to 7200.	Time observer is no longer active.

Note: An additional `OLOC` with the same `OBSN` entered before time `ETIMO` will update the observer location or time.

Table 44. `TLOC` record. Assigns coordinates and viewing times to a target.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TLOC            OBSN      XTAR      YTAR      ZTAR      TARN
TLOC              1.       70.     2000.        3.        1.        0.        0.
```

Name	Units	Typically	Description
`OBSN`	—	1. to 35.	Assign the target to observer `OBSN` of an `OLOC` record. More than one target can be assigned to an observer.
`XTAR`	m	varies	x-coordinate of target.
`YTAR`	m	varies	y-coordinate of target.
`ZTAR`	m	varies	z-coordinate of target. Usually height above ground level.
`TARN`	—	1. to 35.	User-assigned target number. Useful on printouts if more than one target assigned to an observer.

4.3.6 Extinction Record: `EXTC`

Extinction coefficients may be altered through an `EXTC` record similar to that defined in Phase I inputs. All values *must* be specified if `EXTC` is used. If the event-ordered execution mode is not in effect, however, only the latest extinction coefficients in effect at the point the `GO` or `DONE` record is encountered are used.

There are two ways to reset the modified extinction coefficients to their Phase I defaults. The user can reset a single obscurant type by placing the negative of its value in the `CLTYP` field of an `EXTC` record. Alternatively, all the modified extinction coefficients may be reset to their default values by a `CLTYP` selecting of 0.0. Otherwise, user inputs replace current values for type `CLTYP` (see table 45).

Table 45. `EXTC` record. Optional user-defined extinction coefficients.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
EXTC           CLTYP     R(2)      R(3)      R(4)      R(5)      R(6)      R(7)
```

Name	Units	Typically	Description
`CLTYP`	—	1. to 30.	Obscurant number `STYP` from `MUNT`: 1. = Bulk white phosphorus (WP) munition. 2. = WP wedges, WP wicks, and plasticized WP (PWP) munitions. 3. = Hexachloroethane (HC) smoke. 4. = Fog oil (SGF2) generator or smoke pot. 5. = Red phosphorus (RP) munition. 6. = IR screener, generator disseminated. 7. = IR screener, munition. 8. = Diesel fuel (DF) produced by generator. 9. = Dust, vehicular. 10. = Dust, high explosive (HE), small-particle persistent mode. 11. = Dust, HE, large-particle mode. 12. = Carbon, HE debris product. 13. = Dust / soil, HE, very large ballistic soil aggregates. 14. = Fire smoke from diesel, oil, and rubber mix. 15. = Kerosene / fog oil cold-region mix. 16. = Polyethylene glycol (PEG200) mix for alchohols. 17. = Anthracene (not used in `SMENU` parameters `MUNT` record). 18. = Chlorosulfonic acid (FS, not used in `SMENU` parameter, `MUNT` record). 19. = Titanium tetrachloride (FM, not used in `SMENU` parameter, `MUNT` record). 20. = IR (M76). 21. = Brass. 22. = Graphite 7525. 23. = Kaolin. 24.–30. = User defined by inputs.
`R(2)`	m^2/g	0. to 20.	Extinction coefficient for the 0.4–0.7 μm waveband.
`R(3)`	m^2/g	0. to 20.	Extinction coefficient for the 0.7–1.2 μm waveband.
`R(4)`	m^2/g	0. to 20.	Extinction coefficient for the 1.06 μm waveband.
`R(5)`	m^2/g	0. to 20.	Extinction coefficient for the 3.0–5.0 μm waveband.
`R(6)`	m^2/g	0. or 20.	Extinction coefficient for the 8.0–12.0 μm waveband.
`R(7)`	m^2/g	0. or 20.	Extinction coefficient for the 10.6 μm waveband.

4.3.7 Comments Record: `NAME`

Comments may be included through `NAME` records, as in Phase I (see table 32, p 56).

4.3.8 Display Records: `VIEW`, `GREY`, `TPOS`

The `VIEW`, `GREY`, and `TPOS` input records define a “window” on the scenario. The resulting output is placed on a separate output unit or print file specified on the `PHAS` and (optionally) `FILE` records. The `VIEW` record defines one target–observer LOS as the center of the window. (Users will learn from experience that this LOS must be well above the surface, if a horizontal window through the clouds is desired. See fig. 5.)

The width and height of the window in meters are also defined on the `VIEW` record (see table 46 for input parameters). The corresponding number of characters across the printed page (up to 100 generally) and the lines down the printed page (which have no set limit) are also input. These lines thus define the number of meters per character on the resultant listing. If the user defines a resolution of *X* meters per character in both the horizontal and vertical direction of the printer plot, the cloud will appear to be elongated. This is quite natural, since a character’s height is longer than a character’s width: most line printers usually have 10 characters per inch in the horizontal direction and 8 lines per inch in the vertical direction.

Say a printer plot represents a viewport 500 by 500 m. We would like the resolution to be 100 m per inch in both the horizontal and vertical resolution. To do this, we compute parameters `CLOSD` and `VLOSD` of the `VIEW` record, which define the number of horizontal and vertical characters used

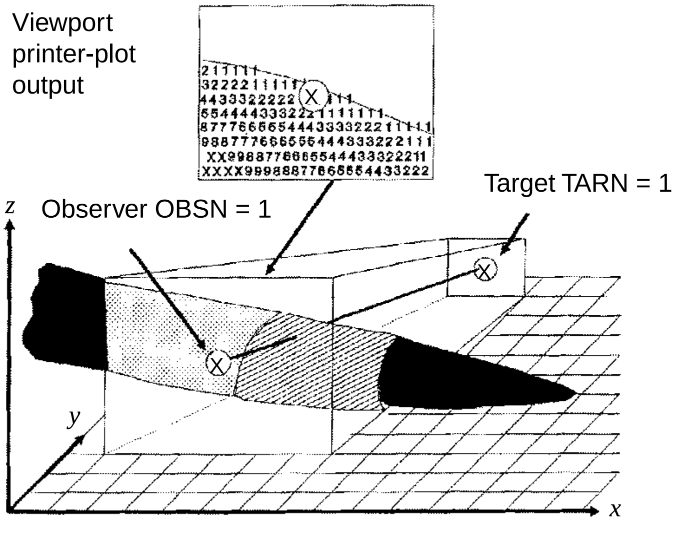


Figure 5. Horizontal LOS. Central LOS is defined by X. Note that it is well above ground level and at such a height that the window ends at ground level.

Table 46. `VIEW` record. Defines a single viewport or window for a printer-plot of the cloud(s). Output is directed to `UNITC` on the `PHAS` and `FILE` records.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
VIEW                OB        TR      CLOSW     VLOSW     CLOSD     VLOSD      RTAT
```

Name	Units	Typically	Description
`OB`	—	0. to 100.	Identifies an LOS observer (`OBSN` on `OLOC` card) for one end of the viewport.
`TR`	—	0. to 100.	Identifies an LOS observer (`OBSN` on `TLOC` card). The viewport is a rectangle centered on the LOS from `OB` to `TR`. The LOS ranges from `OB` to `TR` or to ground level, whichever point is closer.
`CLOSW`	m	1. to 1000.	Horizontal width of viewport.
`VLOSW`	m	1. to 1000.	Vertical extent of viewport.
`CLOSD`	m	1. to 100.	Number of horizontal pixels. It is the number of horizontal characters to span `CLOSW`. (The routine attempts to fit the horizontal dimensions across the computer page if `CLOSD` is less than 101 characters.)
`VLOSD`	m	1. to 65.	Number of vertical pixels. It is the number of vertical characters to span `VLOSW`.
`RTAT`	deg	0. to 360.	Used only to clarify the ambiguity of term "horizontal" for up- or down-looking LOS. RTAT is the angle in degrees of the horizontal viewing axis wrt north. For downwind to the right, set `RTAT` to wind direction + 180°. For east, toward the right hand side of the page, set `RTAT` to 90°.

to span the printer plot:

$$\texttt{CLOSD} = \frac{\text{10 characters per inch}}{\text{100 m per inch}}\,500\text{ m} = 50\text{ characters} \tag{13}$$

$$\texttt{VLOSD} = \frac{\text{8 lines per inch}}{\text{100 m per inch}}\,500\text{ m} = 40\text{ characters} \tag{14}$$

These define a resolution of 100 m per inch in the vertical and horizontal direction or 10.0 m per character in the horizontal direction and 12.5 m per line in the vertical direction.

COMBIC internally generates LOS's surrounding the central target–observer LOS for each character position to be printed on the page and computes the transmittance or optical depth for that position. A new "picture" is generated at each time step specified on the `LIST` record. As mentioned before, the LOS's can all be parallel to the specified central LOS, or can form a fan shape, originating at the observer. For the orthographic viewpoint, the range of each path through the cloud equals that of the specified target–observer pair. This is not true for the perspective viewpoint: the smallest of the path lengths for the perspective LOS is the central viewpoint. All other LOS's end equally spaced on a plane perpendicular to the central LOS. For slant path or downward views, the program limits the range to the intersection of the LOS with the ground for both viewing methods. COMBIC treats only flat terrain.

The GREY and TPOS records define the scale to be used to display the results (see tables 47 to 48 for input parameters). The user inputs a maximum and a minimum transmittance or optical depth and the number of divisions between the minimum and maximum that are to be assigned different characters on the listing. COMBIC92 allows the user the option of having the grey-scale levels be equally spaced or vary with the density of the cloud. Most users like this new option, which allows closely spaced grey-scale levels during the most interesting part of the cloud—where it is most dense. Then the grey-scale levels' separations for the thin parts of the cloud are quite large. This new option allows the user to use a minimum number of grey scales to illustrate the obscurant. The user also selects a wavelength band for the desired output.

The usefulness of optical depth as an output quantity can be seen from the following example. Suppose one is really interested in finding the concentration of HC smoke at 2.5 m above the surface. One can first specify that the observer is at 3 m looking down on a target directly below, at 2 m above the ground. The window is then a "slab" 1 m thick, lying between 3 and 2 m above the ground over the region defined by the length and width of the window. Next, suppose the EXTC record is used to set the extinction coefficient for one of the wavelengths of HC smoke at exactly 1 m^2/g. It is easy to see that the resulting value displayed for the optical depth at that wavelength is then equal in magnitude to the concentration of HC in units of grams per meter cubed. It is important, of course, that the path was defined to be 1 m long in the example so that the units would be correct. A 2-m path would require an extinction coefficient of 0.5 to produce a value numerically equivalent to the concentration in grams per meter cubed, and so forth.

TPOS also lets the user manipulate the "axis" of the printer plot. In the previous version of COMBIC, the axes were always labeled so that the origin was at the center specified by the OLOC–TLOC pair used as the central LOS. This labeling might or might not correspond to the actual layout for the scenario. The new option is defined by the parameters HLOSP and VLOSP from the TPOS record. These parameters define the center of the printer plot.

Table 47. `GREY` record. Sets up grey scale, assigning an alphanumeric character to an obscuration level.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
GREY           DIVIS     SMINV     SMAXV     CLOPT     ALOPT     WAVEL      RVEL
```

Name	Units	Typically	Description
`DIVIS`	—	1. to 35.	Number of grey-scale intervals between `SMINV` and `SMAXV`. For example, to obtain the usual transmission scales at 0.05, 0.10, 0.15, 0.20., . . . , 0.95 with the standard symbol * for transmission less than 0.05 and blank characters for transmission above 0.95, set `DIVIS` = $\frac{0.95-0.05}{0.05} = 18$. The largest value for `DIVIS` is currently 35.
`SMINV`	—	0. to 100.	The minimum value shown on the scale. Transmission values less than `SMINV` are printed as "*", and optical depths less than `SMINV` are left blank.
`SMAXV`	—	0. to 100.	The maximum value shown on the scale. Transmission values greater than `SMAXV` are left blank, and optical depths greater than `SMAXV` print as "*".
`CLOPT`	—	0. or 1.	0. = transmittance, 1. = optical depth (to output CL in $\mathrm{g/m^2}$, set the extinction to 1.0 and `CLOPT` = 1.)
`ALOPT`	—	1. to 2.	If 2., alternate output characters with blanks in the grey levels. Otherwise use a printing character for every scale division.
`WAVEL`	—	1. to 6.	Select wavelength band. 1. = 0.4–0.7 μm waveband. 2. = 0.7–1.2 μm waveband. 3. = 1.06 μm waveband. 4. = 3.0–5.0 μm waveband. 5. = 8.0–12.0 μm waveband. 6. = 10.6 μm waveband.
`RVEL`	m / s	0. to 100.	Optional, speed for target to move away (positive) or toward (negative) the observer along LOS.

Table 48. `TPOS` record. Modify grey-scale density, revise printer-plot axis labeling, and change from orthographic viewpoint.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TPOS           HLOSP     VLOSP     PERSP     NEWGR
TPOS             0.0       0.0       0.0       0.0
```

Name	Units	Typically	Description
`HLOSP`	—	varies	Parameter defining the centers of horizontal axes for the printer plot. The labeling of the horizontal axis of the printer plot is then labeled from `HLOSP` − 0.5`CLOSW` to `HLOSP` + 0.5`CLOSW`. `CLOSW` is a `VIEW` parameter that defines the horizontal extent of the printer plot's viewport.
`VLOSP`	—	varies	Parameter defining the centers of vertical axis for the printer plot. The labeling of the vertical axis of the printer plot is then labeled from `VLOSP` − 0.5`VLOSW` to `VLOSP` + 0.5`VLOSW`, which defines the vertical extent of the printer plot's viewport.
`PERSP`	—	0. or 1.	If `PERSP` = 1., then the perspective viewpoint is chosen for the printer-plot option and all LOS's originate at the observer. If `PERSP` = 0., then the orthographic viewpoint is chosen and LOS's for the printer-plot option are of equal length and parallel to an LOS defined by an `OLOC`–`TLOC`.
`NEWGR`	—	0. or 1.	If `NEWGR` = 0., then grey-scale interval is equally spaced; if `NEWGR` = 1., then there is logarithmic grey-scale separation. The new grey scale is more closely spaced for the densest part of the cloud, where most researchers' interests lie. Valid only for transmission (`CLOPT = 0.` on `GREY` record).

If `NEWGR` = 1., then each grey-scale value for transmission is a multiplicative factor times the previous grey-scale value. The factor is determined from `SMINV`, `SMAXV`, and `DIVIS` from the `GREY` record and is defined by the following equation:

$$\mathrm{MULT} = \left(\frac{S_{MINV}}{S_{MAXV}}\right)^{\frac{1}{\mathrm{DIVIS}-1}}$$

For example, if `SMINV` = 0.05, `SMAXV` = 0.95, and `DIVIS` = 5, then MULT = $(0.95/0.05)^{1/4}$ or 2.088. This yields a grey scale at 0.05, 0.104, 0.218, 0.455, and 0.950.

4.4 Tips and Tricks for using COMBIC

4.4.1 Making Vehicles "Change Direction"

One of the limitations of the model is that vehicles cannot accelerate, decelerate, or change direction. However, the user can arrange the vehicle records so that one vehicle stops and another starts at the same place and time, but heading in a new direction. A typical example is shown in table 49.

In this example, the vehicle starts moving at 0 s and continues for 100 s (column 4 and 5 of `VEH1`) in an easterly direction at 2 m / s (`VEH2`).

Starting coordinates are the origin (`VEH2`). This places the vehicle at (200,0,0) after 100 s. Since the goal is to have the vehicle change direction after 100 s, these numbers are used as the starting coordinates and start time for the second set of vehicle records. In the second set, the vehicle travels from 100 to 150 s in a southerly direction at 2 m / s. This places the vehicle at (200,−100,0) after 50 s. The third set of vehicle records keeps the vehicle going in the same direction but at a speed of 3 m / s—simulating an acceleration.

Table 49. Example of `VEH1` and `VEH2` records used to simulate a vehicle changing direction.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
VEH1           1.000     1.000     0.000   100.000  3600.000        0.        0.
VEH2           0.000     0.000     0.000    90.000     2.000        0.        0.
VEH1           1.000     1.000   100.000   150.000  3600.000        0.        0.
VEH2         200.000     0.000     0.000   180.000     2.000        0.        0.
VEH1           1.000     1.000   150.000   200.000  3600.000        0.        0.
VEH2         200.000  -100.000     0.000   180.000     3.000        0.        0.
```

4.4.2 Phase II Viewport Tips

Viewing Concentration Length

The `CLOPT` flag on the `GREY` record determines output type: if `CLOPT` is set to 0., transmittance is displayed; if `CLOPT` is set to 1., optical depth is displayed. It is easily seen from Beer's law that to output CL (in grams per meter), the extinction coefficient must be set to 1 m^2/g on the `EXTC` record (see table 45) and `CLOPT` should be 1. (for optical depth).

Viewing Concentration

Beer's law also shows us that to output concentration (C) (in grams per meter), one must set the extinction coefficient to be 1 m^2/g on the `EXTC` record, choose `CLOPT` = 1. (for optical depth), and set the LOS to be 1 m long using the `OLOC` and `TLOC` records. Figure 6 shows the placement of the observer and target for this calculation.

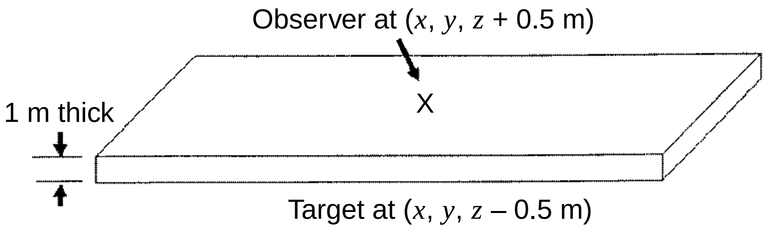


Figure 6. Phase II viewport tip. The viewport can be used to find the concentration (g/m^3) at a level of z meters above the surface.

Viewing at an Angle

Frequently, slant paths are requested where the observer is looking from some altitude towards an object on the ground. In this case it is important that the user specifies the target to be below ground to ensure that all LOS's reach ground level (see fig. 7). Otherwise, many of the LOS's that form the viewport might not reach ground level. The following equations can be used if the user wishes to determine the coordinates of a new target so that all the LOS's end at ground level:

$$\begin{aligned} \Delta R &= 0.5 W_{VLOS} \cot\theta, && (15)\\ X_{TARnew} &= X_{OBS} + (R+\Delta R)\alpha, && (16)\\ Y_{TARnew} &= Y_{OBS} + (R+\Delta R)\beta, && (17)\\ Z_{TARnew} &= Z_{OBS} + (R+\Delta R)\gamma. && (18) \end{aligned}$$

W_{VLOS} is defined as the vertical width of the viewport in meters. The directional cosines α, β, and γ and the range R are determined from the observer location and the noncorrected target location by equations (A-9) and (A-10) in appendix A. The above equations define a new target position at a range $R + \Delta R$ from the observer along the directional cosine defined by the old LOS.

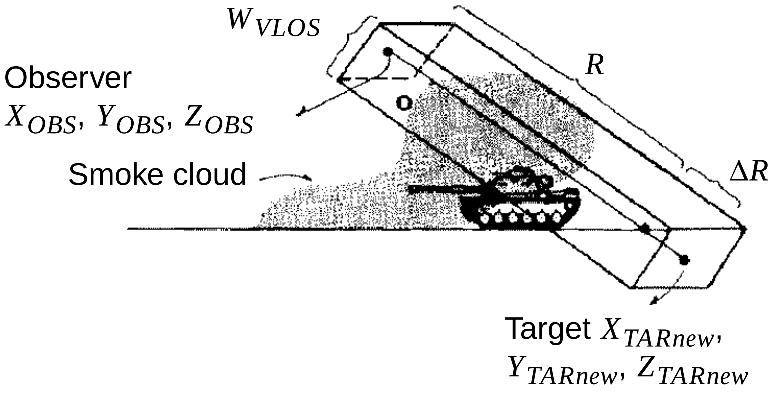


Figure 7. Choose target end of viewport below ground to ensure that all LOS's reach ground level.

4.5 User Modifications to the Code

The records described in section 4.3 represent the set of Phase II inputs. The user can simulate fairly sophisticated obscuration scenarios with the input parameters defined in Phases I and II. There are invariably some changes that the user would like to make, however. In EOSAEL82, the problem was that the number of obscurant types that could be played was limited by available memory. Since EOSAEL84, the histories are now placed on a record-addressable disc file. Thus, their size is no longer a major problem. Only one cloud type is read into memory at a time. All calculations for clouds of that type are performed before the code moves on to another cloud type. However, the Phase II code must still record the coordinates and times associated with active LOS's and active source clouds. The user may wish to alter the limit on the number of active values.

The LOS's are stored in common block `/SIGHT/`. To change the maximum number of LOS's, change the variable MXLOS and the second array index in array variables IPOIN and POSI in the code.

Continuous clouds, puffs, and moving sources all share dynamic storage in the same arrays. Each type of source has a different definition within the array structure, however. Their definitions are as follows:

- IACT(1–3,N_{actmax}) = pointers to active subclouds.
- IVACT(N_{actmax}) = pointers to active moving vehicle clouds.
- IHIS(1–2,N_{actmax}) = data on the history file associated with clouds.
- CMUN(1–5,N_{actmax}) = scaling and time duration information on active sources.
- LCLD(1–4,N_{submax}) = pointers to active subclouds and subcloud types.
- CLD(1–8,N_{submax}) = data on current positions of active subclouds.
- LTERA(1–2,N_{submax}) = terrain height at positions of active suclouds.

- LINDX(1–2,N_{submax}) = history file indices last accessed for each subcloud.

The values of N_{actmax} (maximum number of active clouds) and N_{submax} (maximum number of active subclouds) can be altered and the corresponding dimensions of arrays in common block `/ACTIVE/` can be changed. The user should remember that there may be many more subclouds than there are total clouds. COMBIC will issue a warning when cloud arrays have been filled.

4.6 Output Format

Whenever possible, the "standard" output was limited to 80 columns. The exceptions are the printer-plot option and the PRNT = 2 option (see table 38). These options allow successful viewing on a display terminal and printing on most printers. The following is an outline of the Phases I and II output. The references to other sections of this document are given to show the sources of the data, including input records, table lookups, and calculations (represented by equations).

4.6.1 Phase I

1. Meteorological Conditions

   So that the user can verify the conditions for the simulation, the input values are printed in the output. These input values describe the meteorology being modeled. Most of these parameters are used in the Phase I calculations of the cloud evolution.

   (a) Reference height (m); specified by ZREF in table 21

   The height at which the meteorological data were measured. This parameter is input by the user.

   (b) Wind speed (m / s); table 20

   The wind speed parameter is input by the user.

   (c) Temperature (°C); table 20

   The air temperature parameter is input by the user.

   (d) Surface roughness (m); table 24

   A measure of how the surface obstructions induce turbulence in the air flow. This parameter is input by the user.

   (e) Wind direction (degrees east of north); table 20

   The wind direction is input by the user. This value is not used in the Phase I calculations; it is only used in Phase II.

(f) Inversion height (m); specified by `ZINV` in table 21 (or calculated from internal model, eq A-174)

Height above ground of the limiting temperature inversion. This value will be calculated by an internal model if it is not input.

(g) Pasquill category; table 20

A measure of the stability of the boundary layer, and hence the rate of turbulent diffusion. Often an input, it may also be computed based on additional input values.

(h) Relative humidity (percent); table 20

The relative humidity is input by the user; it affects the extinction values for certain smokes.

2. Boundary Layer Parameters

The next set of parameters describes the details of the boundary layer model used by COMBIC. The parameters are a combination of optional input parameters and the results of calculations by the internal models.

(a) Friction velocity (m / s); table 21 (or calculated from internal model, eq (A-150), (A-156), (A-157), or (A-158))

(b) Pasquill class; equation (A-147)

(c) Air density (g / m^3)

(d) Monin-Obukhov length (m^{-1}); equations (A-153) and (A-154)

(e) Kazanski-Monin; section A-5

(f) Mean static SBAR (10–50 m) (s^{-2}); table 21

(g) Sensible heat flux (W / m^{-2}); table 21, equation (A-160)

(h) Cold-region flag; table 20

Affects calculations for WP and HC munitions if set.

(i) Surface buoyancy flux (m^2 / s^3); table 21, equation (A-161)

(j) SBAR model flag; table 21

3. Diffusion Coefficients

These diffusion coefficients may be from the internal lookup tables for included munitions, or may be input to modify an existing munition's characteristics or to describe a new munition.

(a) A coefficient; section A-3

(b) B coefficient; section A-3

(c) C coefficient; section A-3

   (d) D coefficient; section A-3

4. Surface Conditions

   These optional parameters affect obscurant production.

   (a) Snow cover flag; table 24

       This reduces the red phosphorus munition burning if set.

   (b) Silt content (percent); table 24

       This is used in the vehicle dust model.

   (c) Sod depth (m); table 24

       The HE dust model uses this parameter.

5. Vertical Profile Model

   The following calculated parameters are reported versus height. This is the environment that is used in Phase I to calculate the evolution of the smoke clouds.

   (a) Windspeed; equation (A-158)
   (b) Atmospheric temperature (constant SBAR model); equations (A-170) and (A-171)
   (c) Atmospheric temperature (variable SBAR model) equation (A-169)
   (d) s, static stability parameter; equation (A-166)
   (e) $\bar{s}$; equation (A-168)
   (f) Eddy dissipation rate; equation (A-183)

6. Mass Extinction Coefficients (m^2/g)

   These extinction coefficients are used to calculate the transmission for the indicated wavebands, laser wavelengths, and radar frequency. All of the obscurants are tabulated in the output.

   (a) Obscurant code; table 31, section B-1.2
   (b) Extinction 0.4–0.7 μm; table 31, section B-1.2
   (c) Extinction 0.7–1.2 μm; table 31, section B-1.2
   (d) Extinction 1.06 μm; table 31, section B-1.2
   (e) Extinction 3.–5. μm; table 31, section B-1.2
   (f) Extinction 8.–12. μm; table 31, section B-1.2
   (g) Extinction 10.6 μm; table 31, section B-1.2
   (h) Extinction 94 GHz; table 31, section B-1.2

7. Cloud History

   The cloud history parameters describe the cloud histories that will be used by the Phase II calculations. The history output is repeated for each cloud. It includes the both the gross munition characteristics as well as the possibly multiple cloud structures used by the COMBIC model. This section of output ends with the parameterized description of each of the subclouds as calculated by the models.

   (a) Munition characteristics; table 21
      i. `XN`, no. of sources; tables 25 and B-1
      ii. Fill weight; tables 25 and B-1
      iii. Menu selection type; tables 25 and B-1
      iv. Obscurant type; tables 25 and B-1
      v. Efficiency; tables 25 and B-1
      vi. Yield factor; table 25, section B-1.1
      vii. Number of submunitions; tables 25 and B-1
      viii. Burn duration; tables 26 and B-7, section B-1.5
      ix. Burn coefficients, $B_1, ..., B_6$; tables 26 and B-7, section B-1.5
      x. Smoldering time; table 27, section B-1.5
      xi. Smoldering coefficient; table 27, section B-1.5

   (b) Subcloud structure

      This structure is repeated for each subcloud.

      i. subcloud characteristics
         A. Mass fraction; table 34
         B. Debris carbon; table 34
         C. Flag: plume or puff; table 34
         D. Flag: cloud rise model; table 34
         E. Extinction coefficient code; table 34
         F. Flag: ballistic subcloud; table 34
         G. Downwind initial obscurant radii; table 35
         H. Crosswind initial obscurant radii; table 35
         I. Vertical initial obscurant radii; table 35
         J. Buoyancy radius; table 35
         K. Initial cloud temperature; table 35

        L. Thermal production coefficient; table 35
        M. Height of burst; table 36
        N. Fall velocity; table 36
        O. Evaporation / deposition terms; table 36
        P. Reflection coefficient; table 36
        Q. Momentum radius; table 36
        R. Horizontal velocity; table 36
        S. Upward velocity; table 35
        T. Mass production profile; table 21
    ii. subcloud trajectory (versus height)
        A. Time to reach downwind distance; table 21
        B. Centroid height; table 21
        C. Gaussian cloud standard deviations σ_x;
        D. Gaussian cloud standard deviations σ_y; table 21
        E. Gaussian cloud standard deviations σ_z; table 21
        F. Peak cloud temperature; table 21
        G. Mean cloud temperature; table 21
        H. Air temperature; table 21
        I. Air density; table 21
        J. Centroid vertical velocity; table 21
        K. Centroid horizontal velocity; table 21
        L. Effective buoyancy radius; table 21

4.6.2 Phase II

The Phase II output file contains the data most users are interested in. The output lists the transmittance and CL (in grams per square meter) for each LOS that potentially passes through one or more clouds in the scenario and for each time determined from the `LIST` input. The observer and target numbers from the `OLOC` and `TLOC` records are also printed on each line listing transmittance. Though each line listing transmission also lists CL, this number is not meaningful when the clouds are of different types of obscurants, however, since a small CL from one type of obscurant can be very obscuring, while a large CL from another may be much less effective as an obscurant.

The `PRNT` option 2 on the `LIST` record (table 38) will display the CL contributions from each individual cloud intersecting the LOS. This option also prints the large-particle CL, which is simply the contribution from the large component of battlefield dust.

1. Meteorological Conditions

   These are a repeat of the values used in the Phase I calculations. If the two phases of COMBIC are being run at different times, reviewing this output should verify that the desired history file was used.

   (a) Reference height (m); table 21
   (b) Wind speed (m / s); table 20
   (c) Temperature (°C); table 20
   (d) Surface roughness (m); table 24
   (e) Wind direction (degrees east of north); table 20
   (f) Inversion height (m); table 21, equation A-174
   (g) Pasquill category; table 20
   (h) Relative humidity (percent); table 20

2. Mass Extinction Coefficients (m^2 / g)

   These should also be repeated from the Phase I calculation.

   (a) Obscurant code; table 45, section B-1.2
   (b) Extinction 0.4–0.7 μm; table 45, section B-1.2
   (c) Extinction 0.7–1.2 μm; table 45, section B-1.2
   (d) Extinction 1.06 μm; table 45, section B-1.2
   (e) Extinction 3.–5. μm; table 45, section B-1.2
   (f) Extinction 8.–12. μm; table 45, section B-1.2
   (g) Extinction 10.6 μm; table 45, section B-1.2
   (h) Extinction 94 GHz; table 45, section B-1.2

3. Munition Characteristics; table 21

   This section should also be repeated from the Phase I calculations. Just as in the Phase I output, it is repeated for each munition.

   (a) Source No.; tables 25 and B-1
   (b) Number of subclouds; tables 25 and B-1
   (c) XN, no. of sources; tables 25 and B-1
   (d) Fill weight; tables 25 and B-1
   (e) Menu selection type; tables 25 and B-1

   - (f) Obscurant type; tables 25 and B-1
   - (g) Efficiency; tables 25 and B-1
   - (h) Yield factor; tables 25 and B-1.1
   - (i) Number of submunitions; tables 25 and B-1
   - (j) Vehicle speed and direction; tables 26 and B-7, section B-1.5
   - (k) Barrage parameters; tables 26 and B-7, section B-1.5

4. Altered Mass Extinction Coefficients

   These values will be repeated for each new `EXTC` record; table B-1.2

5. Source Location and Direction

   These data will be repeated for each source; table 40

6. Observer and Target Location

   Locations are repeated for each LOS; tables 43, 44

7. LOS Start and End Time

   These times indicate when calculations should be performed for each LOS. They are repeated for each LOS; table 43

8. Obscuration Data

   These data are repeated for each time specified by the `LIST` record and for each LOS.

   This section of output is normally the result of most interest to the user. It contains the time history of the point-to-point transmission between the observer and the target.

   - (a) Concentration length
   - (b) Transmission 0.4–0.7 μm
   - (c) Transmission 0.7–1.2 μm
   - (d) Transmission 1.06 μm
   - (e) Transmission 3.–5. μm
   - (f) Transmission 8.–12. μm
   - (g) Transmission 10.6 μm
   - (h) Transmission 94 GHz

9. Subcloud Contributions

   These data are printed only if `PRNT` = 2 on the `LIST` record. The data would normally be of interest only if a user were attempting to determine whether different parts of the obscurant cloud were having different effects on the transmission.

(a) Integrated path concentration (g/m^2) for the subcloud

(b) Path length through the subcloud

(c) Coordinates of Gaussian centroid (m) of the subcloud

(d) Sigmas of the Gaussian subcloud (m)

(e) Total mass (g) contained in the subcloud

5. Sample Runs

5.1 Overview

In this section we describe various examples of scenarios and COMBIC input and output. All the input and some of the output files are provided here; some of the more voluminous output files are given in appendix D.

COMBIC executes in two parts: Phase I and Phase II. Either or both phases can be executed in a single computer run. Phase I generates a cloud history for one or more obscurant sources that the user defines. The cloud histories are then stored in a direct-access (record-addressable) mass storage file. The cloud history files are non-ASCII and therefore cannot be printed.

In Phase II calculations, the user inputs a scenario of one or more obscurant sources and one or more target–observer pairs. The cloud history file from Phase I provides cloud positions, dimensions, and concentrations. Phase II output takes several forms. If the `PRNT` option of the `LIST` record is 1 or 2, COMBIC will print a transmittance history at seven different wavelengths for each target–observer pair for the times determined by the user inputs on the `LIST` record. If `PRNT` = 2, the transmittance and contribution of individual subclouds to the transmittance are printed. If the user includes a `VIEW` and `GREY` record, then a printed contour representation of clouds with time (printer plot) will be formed and located in the file specified by a `FILE` record with a nonzero `UNITC` on the `PHAS` record.

The times at which the transmittance and printer plot are output are determined from the `LIST` input. The observer and target numbers from the `OLOC` and `TLOC` records are also shown for each line in the transmittance history. A line of transmittance history is printed for each LOS that can potentially pass through one or more clouds in the scenario. The total CL in g / m^2 is given for all the clouds lying on the LOS. This number is not meaningful when the clouds are of different types of obscurants, however, since a small CL from one type of obscurant can be very obscuring, while a large CL from another may be much less effective as an obscurant.

Both Phases I and II generate conventional listings of up to 132 characters per line. However, every attempt has been made to limit the listings to 80 characters. The exceptions are `PRNT` = 2 on the `LIST` record and the printer plot option.

5.2 Example 1: Phase I: Simple HC scenario

The following inputs exhibit the most basic COMBIC Phase I run.

```
WAVL      1.06
COMBIC
PHAS             1.0       5.0       6.0       0.0       9.0       0.0      0.0
FILE           9.0  h.history
NAME             0.
  SAMPLE ONLY
MET1            50.0      2.20       3.      27.50     962.5    202.40      0.00
MUNT             0.0      0.0        1.0       0.0       0.0       0.0      0.0
DONE             0.0
END
STOP
```

The first and last two input records (lines) are input records for the EOEXEC driver. The COMBIC records begin with PHAS and end with DONE. This set of input records opens unit nine as the history file, unit five as the standard input unit, and unit six as the standard output unit. The direct access history file will be stored in “h.history”. This is a non-ASCII file and should not be printed.

The NAME record indicates that the record directly following it, “SAMPLE ONLY” is just a comment record and is not to be processed.

MET1 contains the meteorological data. COMBIC will use default values if no meteorological data are input.

This sample contains only one obscurant. On the MUNT record, the third item, which is SMENU = 1, selects the 155-mm HC M1 canister. Unless the user desires to modify the munition default characteristics, the user does not have to input any other information on the MUNT record. The COMBIC model will use defaults from internal tables to specify the rest of the parameters for the 155-mm HC canister.

The DONE record signals COMBIC that there are no more Phase I records. Output sample 1 (app D) shows the resultant output, which contains an extensive listing of important Phase I parameters. Included in the listing are the following:

1. Meteorological conditions
2. Boundary layer parameters
3. Diffusion coefficients
4. Surface conditions
5. Vertical profile model (with height)
6. Mass extinction coefficients

7. Munition characteristics (following the heading ”History File Source #”)
8. First stage processing (based on munition characteristics and other input)
9. Mass production profile for each plume
10. Subcloud trajectory parameters

Section 4.6 gives a more complete listing of the variables given in the output files, as well as references to the tables or equations used to derive their values. Appendix B contains tables listing the parameters for the munition as well as the individual subclouds.

5.2.1 Introductory and Header Material

All COMBIC outputs begin with introductory material that provides warnings about which versions of COMBIC and EOSAEL are being used and which COMBIC Phase and cloud histories are being executed.

```
*******************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                   SEVERE CRIMINAL PENALTIES.
*******************************************************************************










                     ********************************
                     *                              *
                     *    ELECTRO-OPTICAL SYSTEMS   *
                     *                              *
                     *  ATMOSPHERIC EFFECTS LIBRARY *
                     *                              *
                     *    NOT FOR OPERATIONAL USE   *
                     *                              *
                     * EOSAEL87 REV 2.1   02/23/90  *
                     *                              *
                     ********************************



WAVL      1.06
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .1060E+01 .1060E+01 .0000E+00
```

```
                         BEGINNING          ENDING

WAVENUMBER (CM**-1)       9433.963          9433.963

WAVELENGTH (MICROMETERS)     1.060             1.060

FREQUENCY (GHZ)         283018.875        283018.875



       **** EOSAEL WARNING ****
VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                 VISIBILITY
                  10.00 KM




        ********************************
        *                              *
        *         C O M B I C          *
        *                              *
        *COMBINED OBSCURATION MODEL FOR*
        * BATTLEFIELD-INDUCED AEROSOLS *
        *   NOT FOR OPERATIONAL USE    *
        *                              *
        * EOSAEL92 REV 1.0   12/12/90  *
        *                              *
        ********************************



                   *****************
                   *               *
                   *    COMBIC     *
                   *    PHASE 1    *
                   *               *
                   *****************
```

```
COMBIC WARNING: FILE(                                        h.history       )
 WILL BE OVER WRITTEN


COMBIC CLOUD HISTORY ON UNIT  9  OPENED TO: h.history
```

5.2.2 Meteorological Conditions

The section of meteorological conditions begins with a listing of input values and defaults. In this example, windspeed, wind direction, temperature, pressure, relative humidity, and Pasquill category are inputs. The other parameters are calculated or defaults. In other words, the input values shown were supplied by input records—in this case, `MET1`.

```
                      METEOROLOGICAL CONDITIONS

 REFERENCE HEIGHT    10.00  METERS    WIND SPEED          2.20  METERS/SEC

 SURFACE ROUGHNESS  .10000  METERS    WIND DIRECTION     202.4  DEG WRT NORTH

 INVERSION HEIGHT     824.  METERS    TEMPERATURE        27.49  DEG CELCIUS

 PRESSURE             963.  MB        RELATIVE HUMIDITY   50.0  %

 PASQUILL CATEGORY     3
```

5.2.3 Boundary Layer Parameters

The boundary layer parameters, which make up the next display, are computed by internal models.

```
                      BOUNDARY LAYER PARAMETERS

 FRICTION VELOCITY     .214 M/SEC     PASQUILL CLASS            2.60

 KAZANSKI-MONIN     -.3254            OMEGA                      .853

 COLD REGION FLAG      0              SBAR MODEL FLAG            0

 AIR DENSITY        1110.4 G/M**3     1/MONIN-OBUKHOV LENGTH  -.02386 M**-1

 SENSIBLE HEAT FLUX    20.2 WATT/M**2 SURFACE BUOYANCY FLUX    .0006  M**2/S**3

 MEAN STATIC SBAR (10-50M)  -.000165  SEC**-2
```

5.2.4 Diffusion Coefficients

Diffusion coefficients are calculated based on the Pasquill category.

```
                     DIFFUSION COEFFICIENTS

A COEFFICIENT      B COEFFICIENT      C COEFFICIENT      D COEFFICIENT

     .216               .900               .220               .802
```

5.2.5 Surface Conditions

In this case, the surface conditions are the defaults. To input different surface conditions, the user would specify parameters on the TERA card.

```
                      SURFACE CONDITIONS

SNOW COVER FLAG    0    SILT CONTENT 50.0 %    SOD DEPTH   .000 METERS
```

5.2.6 Vertical Profile Model

The vertical profile model information is calculated internally. The first few lines are give here; see appendix D for the complete listing.

```
                        VERTICAL  PROFILE  MODEL

                        ATMOSPHERIC TEMPERATURE     S, STATIC       EDDY
HEIGHT  WINDSPEED  CONSTANT SBAR   VARIABLE S   STABILITY   DISSIPATION
 (M)      (M/S)    MODEL (DEG K)  MODEL (DEG K)  PARAMETER  RATE (M**2/S**3)
------  ---------  -------------  -------------  ----------  ----------------

   1.0     1.19       300.78         301.05      -.00586841      .02165
   2.0     1.52       300.77         300.91      -.00261031      .00996
   3.0     1.71       300.75         300.83      -.00158293      .00627
   4.0     1.84       300.74         300.78      -.00109635      .00452
   5.0     1.93       300.72         300.74      -.00081889      .00353
   6.0     2.00       300.71         300.71      -.00064244      .00289
   7.0     2.06       300.69         300.68      -.00052179      .00246
   8.0     2.12       300.68         300.65      -.00043491      .00215
   9.0     2.16       300.66         300.63      -.00036983      .00191
  10.0     2.20       300.65         300.61      -.00031958      .00173
  15.0     2.34       300.58         300.52      -.00018065      .00123
    .
    .
    .
 900.0     3.23       287.52         291.69      -.00000042      .00029
 950.0     3.24       286.79         291.20      -.00000039      .00029
1000.0     3.24       286.06         290.71      -.00000036      .00029
```

5.2.7 Mass Extinction Coefficients

Mass extinction coefficients are derived from internal tables.

```
                 MASS EXTINCTION COEFFICIENTS (M**2/GRAM)

OBSCURANT                   WAVELENGTH (MICROMETERS)
  CODE     .4-.7   .7-1.2    1.06     3.-5.   8.-12.    10.6    94 GHZ
---------  ------  ------  ------  ------  ------  ------  ------
     1     4.0790  1.7699  1.3742   .2939   .3756   .3800   .0010
     2     4.0790  1.7699  1.3742   .2939   .3756   .3800   .0010
     3     3.6618  2.6693  2.2810   .1897   .0280   .0377   .0010
     4     6.8510  4.5920  3.4970   .2450   .0200   .0180   .0010
     5     4.0790  1.7699  1.3742   .2939   .3756   .3800   .0010
     6     1.8600  1.6300  1.4000  1.7900  1.6800  1.6800   .0010
     7     1.8600  1.6300  1.4000  1.7900  1.6800  1.6800   .0010
     8     5.6500  4.0800  3.2500   .2450   .0230   .0270   .0010
     9      .3200   .3000   .2900   .2700   .2500   .2500   .0010
    10      .3200   .2900   .2600   .2700   .2600   .2400   .0010
    11      .0350   .0360   .0370   .0350   .0380   .0360   .0010
    12     1.5000  1.4600  1.4200   .7500   .3200   .3000   .0010
    13      .0010   .0010   .0010   .0010   .0010   .0010   .0004
    14     6.1000  3.7500  2.9400  1.3500  1.0100  1.0000   .0020
    15     6.8510  4.5920  1.4300   .0540   .0200   .0180   .0010
    16     5.3700  2.9000  2.1000   .0900   .0900   .0700   .0010
    17     6.2000  3.5000  2.5000   .2300   .0500   .0480   .0010
    18     3.3300  2.7500  2.6600   .2600   .3200   .2300   .0010
    19     1.3000  1.7400  1.7000   .0800   .1600   .3800   .0010
    20     2.0000  2.0000  2.0000  1.6000  2.0000   .0000   .0000
    21     2.0000  2.0000  1.0000   .1000   .4000   .0000   .0000
    22      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    23      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    24      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    25      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    26      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    27      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    28      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    29      .0000   .0000   .0000   .0000   .0000   .0000   .0000
    30      .0000   .0000   .0000   .0000   .0000   .0000   .0000
```

5.2.8 Munition Characteristics

As shown, this output is for history file source 1 and contains one subcloud. In this example, the default values for the MUNT record are printed out in the first table. If there were any changes by the user, these would appear here. Since no BURN or SMOU records were input, the default values for these parameters (which depend on the munition) are listed next. The COMBIC model then prints out the subcloud characteristics for each subcloud of the cloud. In this case, the 155-mm HC canister produces only one subcloud.

```
                    CLOUD HISTORY, FILE NAME = COMHIS


 HISTORY FILE SOURCE #  1 CONTAINS 1 SUBCLOUDS, TOTAL    3242.71 GRAMS OBSCURANT



     XN    FILL WEIGHT   MENU     OBSCURANT
   NO. OF   (LB, GAL   SELECTION    TYPE     EFFICIENCY    YIELD   NUMBER  OF
  SOURCES  OR LB TNT)    TYPE       CODE      (PERCENT)   FACTOR  SUBMUNITIONS
  -------  ----------  ---------  ---------  ----------   ------  ------------
    1.00       5.400       1.         3.        70.0       1.891      1.00



   BURN
 DURATION                         BURN RATE COEFFICIENTS
   (SEC)      B1          B2          B3          B4          B5         B6
 --------  ---------   ---------   ---------   ---------   ---------  ---------
  100.00       .5370       .4760      4.7790     -5.4720       .0000      .0000



 SMOULDERING   SMOULDERING
    TIME       COEFFICIENT
    (SEC)         CSMLD
 -----------   -----------
        .00         .0000
```

5.2.9 First-Stage Processing

The parameters printed here are the parameters associated with the SUBA, SUBB, and SUBC records if the user were to input them manually. In this case, simply by specifying SMENU = 1, the user accessed over 40 parameters used to define the 155-mm HC canister.

```
         PROCESSING SUBCLOUD  1



        SUBCLOUD # 1        HISTORY FILE SOURCE #  1



              DEBRIS      PLUME    CLOUD RISE MODEL    EXTINCTION   BALLISTIC
   MASS       CARBON     (1=PUFF,   (1=RISE, 2= NO    COEFFICIENT   SUBCLOUD
 FRACTION   (G/G OBSC)   2=PLUME)   RISE, >2=STEM)        CODE     (1=Y, 0=N)
 --------   ----------   --------   --------------    -----------  ----------
 1.000000       .000        2.            1.               3.          0.



                                          INITIAL      THERMAL      UPWARD
INITIAL OBSCURANT RADII (M)  BUOYANCY      CLOUD      PRODUCTION   VELOCITY
DOWNWIND CROSSWIND VERTICAL  RADIUS(M)  TEMP(DEG K)  COEF (CAL/G)    (M/S)
-------- --------- --------  ---------  -----------  ------------  --------
   3.10      3.10     3.70      2.29       306.01       1083.63        .74



              FALL   EVAPORATION/DEPOSITION         MOMENTUM  HORIZONTAL
HEIGHT OF   VELOCITY     FD         DELTA    REFL.   RADIUS    VELOCITY
BURST (M)    (M/S)   (LONG-TERM)   (S**-1)   COEF.    (M)        (M/S)
---------  --------  -----------   -------   -----  --------  ----------
    .0        .000    1.000000      .00000   .5500      .00       .67
```

5.2.10 Mass Production Profile

The remaining information describes the mass production profile and the trajectory associated with this subcloud. If there were further subclouds, then the characteristics and trajectory information would follow.

```
               MASS PRODUCTION PROFILE

     TIME T      MASS PRODUCED       MASS STILL        MDOT
     AFTER       UP UNTIL TIME      AIRBORNE BY
 IGNITION (SEC)     T ( G )         TIME T ( G )
 --------------  -------------     ------------
      1.000           17.5              17.5          17.5880
      2.000           35.2              35.2          17.6902
      3.000           53.1              53.1          17.9040
      4.000           71.2              71.2          18.1461
      5.000           89.6              89.6          18.4154
      6.000          108.3             108.3          18.7110
      7.000          127.3             127.3          19.0317
      8.000          146.7             146.7          19.3765
      9.000          166.4             166.4          19.7443
     10.000          186.6             186.6          20.1340
     11.000          207.1             207.1          20.5446
     12.000          228.1             228.1          20.9751
       .
       .
       .
     93.000         3123.6            3123.6          23.8248
     94.000         3145.9            3145.9          22.2571
     95.000         3166.5            3166.5          20.6208
     96.000         3185.4            3185.4          18.9150
     97.000         3202.6            3202.6          17.1383
     98.000         3217.9            3217.9          15.2900
     99.000         3231.3            3231.3          13.0912
    100.000         3242.7            3242.7           7.6571
```

5.2.11 Subcloud Trajectory

The subcloud trajectory output shows the evolution of the cloud in terms of its movement and shape over time. All the information is calculated by the COMBIC models. The subcloud trajectory information is part of the critical information passed to Phase II to allow LOS information to be calculated.

```
                                                  SUBCLOUD TRAJECTORY

                                                      PEAK     MEAN                    CENTROID OR CM       EFFECTIVE
  DOWNWIND           CENTROID     GAUSSIAN CLOUD      CLOUD    CLOUD     AIR      AIR      VELOCITY     CM    BUOYANCY
  DISTANCE   TIME     HEIGHT  STD. DEVIATIONS (M)     TEMP.    TEMP.    TEMP.   DENSITY  VERT.  HOR. HEIGHT    RADIUS
   (M)      (SEC)      (M)    SIGMAX  SIGMAY  SIGMAZ (DEG K)  (DEG K)  (DEG K) (G/M**3)  (M/S)  (M/S)  (M)      (M)
  -------- -------   -------  ------  ------  ------ -------  -------  ------- --------  -----  ----- -----  -------
      1.00     1.20      .78    1.44    1.59    2.22  309.88   304.44   300.92  1110.46    .57    .99    2.1   2.567
      2.84     2.80     1.56    1.44    1.87    2.60  306.76   303.20   300.87  1110.56    .43   1.27    2.8   2.911
      5.24     4.56     2.24    1.44    2.29    2.87  305.06   302.51   300.83  1110.61    .35   1.44    3.3   3.268
      8.09     6.45     2.87    1.44    2.84    3.13  304.02   302.08   300.81  1110.64    .31   1.56    3.9   3.628
     11.33     8.47     3.47    1.44    3.50    3.41  303.32   301.79   300.78  1110.65    .29   1.64    4.5   3.988
     14.92    10.61     4.06    1.44    4.26    3.71  302.83   301.58   300.76  1110.66    .27   1.71    5.0   4.350
     18.82    12.85     4.63    1.44    5.08    4.05  302.46   301.42   300.74  1110.66    .25   1.77    5.7   4.713
     23.02    15.18     5.20    1.44    5.98    4.41  302.18   301.30   300.72  1110.65    .24   1.82    6.4   5.077
     27.50    17.61     5.76    1.44    6.93    4.80  301.95   301.20   300.70  1110.64    .23   1.87    6.8   5.442
     32.24    20.08     5.99    1.44    7.70    5.20  301.32   300.93   300.70  1110.63    .09   1.94    7.2   5.596
     37.22    22.60     5.99    1.44    8.35    5.59  301.01   300.81   300.70  1110.63    .10   1.98    7.5   5.596
       .
       .
       .
   5574.53  2039.66     5.99    1.44  509.54  222.49  299.09   299.09   298.96  1097.30    .08   2.92  179.7   5.596
   6260.34  2273.03     5.99    1.44  565.41  244.11  298.94   298.94   298.80  1095.91    .07   2.94  197.0   5.596
   7030.53  2533.52     5.99    1.44  627.44  267.84  298.79   298.79   298.63  1094.37    .07   2.96  215.9   5.596
   7895.47  2824.33     5.99    1.44  696.30  293.89  298.61   298.61   298.44  1092.69    .07   2.97  236.7   5.596
   8866.82  3149.04     5.99    1.44  772.75  322.48  298.42   298.42   298.23  1090.85    .07   2.99  259.5   5.596
   9957.67  3511.65     5.99    1.44  857.61  353.87  298.22   298.22   298.01  1088.82    .07   3.01  284.5   5.596
  11182.73  3916.66     5.99    1.44  951.81  388.31  297.99   297.99   297.76  1086.60    .07   3.02  312.0   5.596

                TOTAL TRANMITANCE FOR ALL SOURCES IS:  .0000E+00



                                 END EOSAEL RUN
STOP 000
```

5.3 Example 2: Phases I and II: Vehicle Dust and HC Scenario

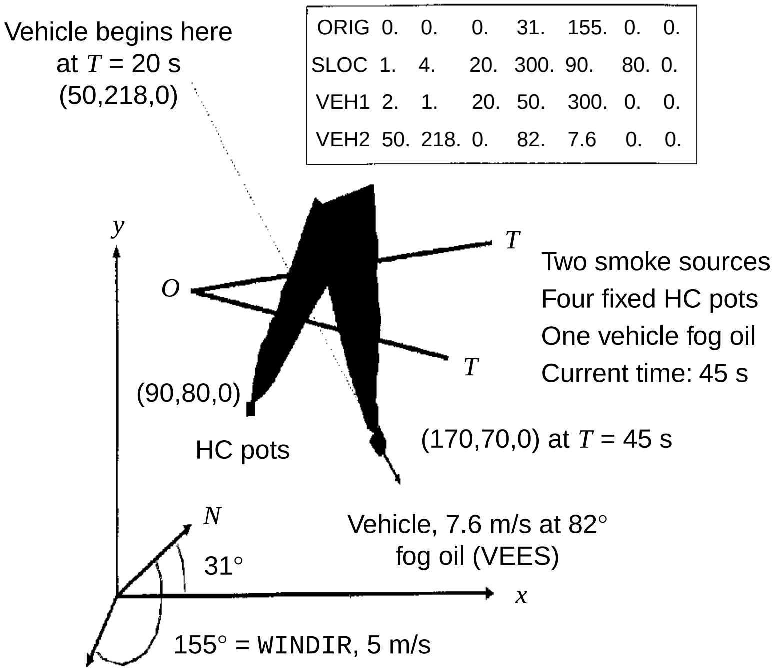
The following input illustrates how a user can specify the geometry of the battlefield scenario and also shows the use of the VEHC record for vehicular dust.

```
WAVL      1.06
COMBIC
PHAS             1.0       5.0       6.0       0.0       9.0       0.0       0.0
FILE           9.0  h.vehc-hc
NAME             0.
  SAMPLE INPUT SHOWING VEHICULAR DUST AND HC
MET1            90.0      5.00       3.      27.50     962.5    202.40      0.00
MUNT             0.0       0.0       1.0       0.0       0.0       0.0       0.0
GO
MUNT             0.0       0.0       0.0       9.0       0.0       0.0       0.0
VEHC             4.0       3.0      60.0       1.0      90.0
DONE             0.0
END
CONTINUE
WAVL      1.06
COMBIC
PHAS             2.0       5.0       6.0       0.0       9.0       0.0       0.0
FILE           9.0  h.vehc-hc
NAME             0.
  SAMPLE INPUT SHOWING VEHICULAR DUST AND HC
ORIG             0.0       0.0       0.0      31.0     155.0
LIST             1.0       0.0     120.0       5.0
NAME             0.
123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
NAME
         Four munition at {90., 80., 0.,) starting at T=20.
SLOC             1.0       4.0      20.0     300.0      90.0      80.0   0.0
NAME
         One vehicle {50., 218., 0.,) starting at T=20.
NAME
         Traveling 7.6m/s at 82 degrees wrt North
VEH1             2.0       1.0      20.0      50.0     300.0
VEH2            50.0     218.0       0.0      82.0       7.6
OLOC             1.0      50.0     130.0       3.0      20.0     100.0
TLOC             1.0     250.0     150.0      15.0       1.0
TLOC             1.0     220.0     100.0       3.0       2.0
DONE             0.0
END
STOP
```

In this example the `ORIG` record is used during Phase II to reorient the x-, y-axis from the default of the x-axis being 90° clockwise from north, to the y-axis being 31° clockwise from north. We have also changed the wind direction from the original 202.4° from north, to 155° from north, as shown in figure 8.

Two obscurants are used for this scenario—a 155-mm HC canister and vehicular dust from a 60-ton tracked vehicle. The vehicle direction and speed on the `VEHC` record can be changed (as in this example) in the Phase II inputs. The 155-mm HC canister is loaded in the history file "h.vehc-hc" as source one, and vehicular dust is loaded as source two. In this example, there are two LOS's, both originating at one observer. `OBSN` = 1 on the `TLOC` record indicates that both targets are paired with the observer. The TARN parameter is used for assigning more than one target to an observer (as in this case). Figure 8 illustrates the source and LOS placement and direction of the resultant clouds. Note that the cloud direction for vehicular dust is the vector sum of the vehicle direction and the wind direction.

The output file (given in its entirety in app D) begins with Phase I output, which follows the same structure described in section 5.2, except that in this example there is more than one cloud. Following the Phase I output, the Phase II output begins. Because Phase II can be run independently of Phase I, the Phase II output begins with a reiteration of some of the Phase I output—the meteorology and mass extinction coefficients.



ORIG	0.	0.	0.	31.	155.	0.	0.
SLOC	1.	4.	20.	300.	90.	80.	0.
VEH1	2.	1.	20.	50.	300.	0.	0.
VEH2	50.	218.	0.	82.	7.6	0.	0.

Figure 8. Source placement and direction of clouds for example 2.

5.3.1 Introductory Material, Phase II

The following is the beginning of the Phase II output (Phase I output, not shown here, precedes this output.) Meteorological conditions and mass extinction coefficients are repeated from the Phase I output.

```
                              *****************
                              *               *
                              *    COMBIC     *
                              *    PHASE 2    *
                              *               *
                              *****************



 COMBIC CLOUD HISTORY ON UNIT  9  OPENED TO: h.vehc-hc



                              METEOROLOGICAL CONDITIONS FROM HISTORY FILE

  WINDSPEED (10 M)  =   5.0  M/S         WIND DIRECTION    =  202.4  DEG WRT N
  RELATIVE HUMIDITY =  90.0  PERCENT     PASQUILL CATEGORY =    C    ( 2.60 )
  AIR TEMPERATURE   = 300.6  DEG K       AIR PRESSURE      =   963.  MB
  SURFACE ROUGHNESS =  .1000 M           AIR DENSITY       =  1110.  G/M**3



                  MASS EXTINCTION COEFFICIENTS FROM HISTORY FILE (M**2/GRAM)

  OBSCURANT                      WAVELENGTH (MICROMETERS)
    CODE      .4-.7    .7-1.2    1.06      3.-5.    8.-12.    10.6     94 GHZ
  ---------  ------    ------    ------    ------    ------    ------    ------
      1      3.2280    2.3638    2.1094     .4127     .3043     .2792     .0010
      2      3.2280    2.3638    2.1094     .4127     .3043     .2792     .0010
      3      2.1520    2.1368    2.0302     .2668     .0601     .0750     .0010
      4      6.8510    4.5920    3.4970     .2450     .0200     .0180     .0010
      5      3.2280    2.3638    2.1094     .4127     .3043     .2792     .0010
      6      1.8600    1.6300    1.4000    1.7900    1.6800    1.6800     .0010
      7      1.8600    1.6300    1.4000    1.7900    1.6800    1.6800     .0010
```

5.3.2 Cloud Parameters

The next section of output presents a summary of certain major cloud parameters from Phase I, which are passed to Phase II through the cloud history file (in this example, file h.vehc-hc, as specified on the file record).

```
        NUMBER     XN                                                  NUMBER
SOURCE    OF      SCALE    FILL     MENU  OBSC  EFFICIENCY  YIELD    OF SUB-
  ID   SUBCLOUDS FACTOR   WEIGHT   NUMBER TYPE    PERCENT  FACTOR   MUNITIONS
------ --------- ------  --------  ------ ----  ---------- ------   ---------

   1        1      1.00      5.40    1.     3.     70.00     5.72     1.00
   2        1      1.00    438.10    0.     9.    100.00     1.00     1.00


          BURN       VEHICLE                    BARRAGE            HIGH-EXP
SOURCE  DURATION  SPEED DIRECTION  ROUNDS  DURATION  IMPACT REGION  SOIL  DOB
  ID      (SEC)   (M/S)    DEG     PER SEC   (SEC)   X (M)   Y (M)  TYPE  (M)
------  --------  ----- ---------  ------- -------- ------  ------  ---- -----

   1       100.      .0      0.        .0       0.     0.      0.    .0   .00
   2       900.     4.0     90.        .0       0.     0.      0.    .0   .00
```

5.3.3 Wind Reorientation

This next section reports that the wind direction from Phase I was reset in the `ORIG` record.

```
          WIND DIRECTION ALTERED TO  155.0 DEG WRT N
```

5.3.4 Source Location and Activation

The first output from the Phase II calculations follows at this point, beginning with the wind direction used in the simulation. Then the output identifies when the sources are active and where they are located. This information is from user input.

```
    WIND DIRECTION ALTERED TO  155.0 DEG WRT N


                                            SOURCES ADDED

  SOURCE        XN      ACTIVE TIME LIMIT     POSITION (ORIGINAL SYSTEM)      POSITION (ROTATED SYSTEM)       MOVING SOURCE
 UNIT  ID     SCALING     BEGIN      END      X          Y          Z         X          Y          Z        SPEED   DIRECTION
    1   1      4.000      20.00     300.00   90.0       80.0        .0      116.7      -29.9         .0       .00    -359.8
    2   2      1.000      20.00     300.00   50.0      218.0        .0      172.4     -142.4         .0      7.60      82.0
```

5.3.5 Observer and Target Locations

Given next are the observer and target locations that define the LOS's. Notice that the observer stops observing at 100 s (see last column). This information is from user input.

```
                                         NEW OR ALTERED LINES OF SIGHT

                             ORIGINAL SYSTEM                                          ROTATED SYSTEM
OBS  TGT          OBSERVER (M)                   TARGET (M)                OBSERVER (M)                TARGET (M)       TIME (SEC)
NO.  NO.       X       Y         Z        X        Y        Z         X        Y         Z        X        Y         Z    START   END
  1    1     50.0    130.0     3.0     250.0    150.0    15.0     135.7     31.2      3.0     264.2   -123.4    15.0   20.0  100.0
  1    2     50.0    130.0     3.0     220.0    100.0     3.0     135.7     31.2      3.0     205.9   -126.5     3.0   20.0  100.0
```

5.3.6 Transmittance History

The transmittance history begins at this point. This information is calculated from internal models.

```
1                  TOTAL  NUMBER
   TIME  OBS TARG    CL      OF                 TRANSMISSION
  (SEC)  NO.  NO. (G/M**2)  CLOUDS .4-.7 .7-1.2 1.06 3.-5. 8.-12. 10.6 94 GHZ
    30.0   1   2     .002     1     .996  .996  .996 1.000 1.000 1.000 1.000
    35.0   1   1     .045     1     .907  .908  .912  .988  .997  .997 1.000
    35.0   1   2     .657     1     .243  .246  .263  .839  .961  .952  .999
  ...
    40.0   1   1    1.183     2     .225  .230  .246  .728  .835  .827  .999

                   HISTORY FILE CONTAINS INFORMATION ON   2 SOURCES

1                  TOTAL  NUMBER
   TIME  OBS TARG    CL      OF                 TRANSMISSION
  (SEC)  NO.  NO. (G/M**2)  CLOUDS .4-.7 .7-1.2 1.06 3.-5. 8.-12. 10.6 94 GHZ

   100.0   1   2     .922     1     .137  .139  .154  .782  .946  .933  .999
   105.0 NO ACTIVE LOS
   110.0 NO ACTIVE LOS
   115.0 NO ACTIVE LOS
   120.0 NO ACTIVE LOS
1


               TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .1538E+00




                                END EOSAEL RUN
STOP 000
```

At the end of the transmittance history (see app D), COMBIC prints out the warning `NO ACTIVE LOS`. This warning appears because there is no active observer after 100 s, as specified earlier. The `LIST` record determines the times that the transmittance or CL will be output. The parameters from this record specify a start time, an end time, and the time increment between lines of output. Furthermore, for each observer, the user specifies (from the `STIMO` and `ETIMO` parameters on the `OLOC` record) the time the observer becomes active and the time the observer can be removed from the active list. If there is no active observer at a time specified by the `LIST` record to output transmittance, then COMBIC lists the time and states that there is no active LOS. This warning does not affect the results in any way and can be ignored by the user if so desired.

COMBIC reports the last calculated transmission for the wavelength of interest to the COMBIC driver routine, which prints the total transmittance line at the end of the run. In this case, the wavelength of interest was selected as 1.06 μm (see `WAVL` parameter of input), and so the last value in that column is reported as the total transmittance.

5.4 Example 3: Creating a New Cloud Using SUBA and SUBC

The third sample illustrates the use of the SUBA and SUBC input records to simulate a cloud for the L8A1 self-screening RP smoke grenades.

```
WAVL     1.06
COMBIC
PHAS            1.0      5.0      6.0      0.0      9.0      1.0      0.0
FILE            9.0 his.l8a1
NAME            0.0      0.0      0.0      0.0      0.0      0.0      0.0
        Testing L8A1 self-screening RP smoke grenades
MET1           90.0     2.00       2.    27.50    962.5   202.40     0.00
MUNT             1.     .794       0.       5.      95.       0.       1.
BURN           658.      0.0      0.0       0.       0.     120.  .008333
CLOU             3.      0.0      0.0      0.0      0.0      0.0      0.0
SUBA             1.    0.050      0.0      1.0      1.0      5.0      0.0
SUBC             7.      0.0      0.0      0.0      1.0      0.0      0.0
SUBA             2.    0.925      0.0      2.0      1.0      5.0      0.0
SUBC             0.      0.0      0.0      0.0      1.0      0.0      0.0
SUBA             3.    0.025      0.0      1.0      21.      5.0      0.0
SUBC             0.      0.0      0.0      0.0      1.0      0.0      0.0
DONE            0.0      0.0      0.0      0.0      0.0      0.0      0.0
END
CONTINUE
WAVL     1.06
COMBIC
PHAS            2.0      5.0      6.0     12.0      9.0      0.0      1.0
FILE            9.0 his.l8a1
NAME
        Testing L8A1 self-screening RP smoke grenades
ORIG            0.0      0.0      0.0     90.0    265.0      0.0      0.0
SLOC            1.0      1.0      0.0    300.0      0.0      0.0      2.0
SLOC            1.0      1.0      0.0    300.0      5.0      0.0      2.0
SLOC            1.0      1.0      0.0    300.0     10.0      0.0      2.0
OLOC            1.0     10.0    100.0      2.0      0.0    300.0      0.0
TLOC            1.0     10.0   -100.0      2.0      1.0      0.0      0.0
LIST            2.0      0.0    300.0      5.0
DONE            0.0      0.0      0.0      0.0      0.0      0.0      0.0
END
STOP
```

The choice of `SMENU` = 0 (the third item) on the `MUNT` record signifies that the smoke cloud will be designed by the user. `STYP` = 5 (the fourth parameter on the `MUNT` record) chooses RP as the obscurant. The smoke from the L8A1 RP grenade is modeled as a combination of three subclouds. The first subcloud is a buoyant plume that contains 92.5 percent of the total smoke. The second subcloud is a buoyant puff that contains five percent of the cloud. The remaining 2.5 percent of the total smoke is in the last cloud. `RISMOD` = 21 (the fifth parameter) for the last subcloud (the third `SUBA` record) indicates that this subcloud is a stem spanning subcloud 2, a "puff" (as indicated by parameter 4, `PLUME` = 1., on the second `SUBA` record), with subcloud 1, a "plume" (as indicated by `PLUME` = 2. on the first `SUBA` record). (See table 31 for the definition of `RISMOD`.) Notice that `SUBB` records were not used; therefore, COMBIC will use internal algorithms to compute the radius, temperature, and thermal production coefficient associated with an RP cloud of this fill weight. The `PRNT` = 2 option (first parameter) on the `LIST` record prints a full history, including the contributions of individual clouds to the transmittance.

After the standard introduction, atmospheric vertical profile, and mass extinction coefficient tables, COMBIC reports that this source consists of three clouds and summarizes the total mass and burn characteristics.

```
                    CLOUD HISTORY, FILE NAME = COMHIS


 HISTORY FILE SOURCE #  1 CONTAINS 3 SUBCLOUDS, TOTAL    2684.72 GRAMS OBSCURANT



     XN    FILL WEIGHT   MENU     OBSCURANT
   NO. OF   (LB, GAL   SELECTION    TYPE     EFFICIENCY    YIELD   NUMBER  OF
  SOURCES  OR LB TNT)    TYPE       CODE      (PERCENT)   FACTOR  SUBMUNITIONS
  -------  ----------  ---------  ---------  ----------   ------  ------------
    1.00       .794       0.         5.         95.0       7.847      1.00


   BURN
 DURATION                          BURN RATE COEFFICIENTS
   (SEC)       B1          B2          B3          B4          B5         B6
 --------  ---------   ---------   ---------   ---------   ---------  ---------
  658.00       .0000       .0000       .0000       .0000    120.0000      .0083


 SMOULDERING   SMOULDERING
    TIME       COEFFICIENT
   (SEC)          CSMLD
 -----------   -----------
       .00         .0000
```

In the output for the above data file (given in its entirety in app D), there are two items of interest. First, the Phase I output summarizes the subcloud characteristics. These should match the parameters in the SUBA and SUBC records created by the users. The characteristics include the parameters that could have been overridden by the use of a SUBB record. The following is the summary for the first subcloud.

```
          SUBCLOUD # 1        HISTORY FILE SOURCE #  1


             DEBRIS      PLUME    CLOUD RISE MODEL    EXTINCTION   BALLISTIC
    MASS     CARBON     (1=PUFF,  (1=RISE, 2= NO     COEFFICIENT   SUBCLOUD
  FRACTION  (G/G OBSC)  2=PLUME)  RISE, >2=STEM)        CODE      (1=Y, 0=N)
  --------  ----------  --------  --------------    -----------  ----------
   .925000      .000       2.           1.               5.          0.



                                          INITIAL      THERMAL      UPWARD
 INITIAL OBSCURANT RADII (M)  BUOYANCY     CLOUD      PRODUCTION   VELOCITY
 DOWNWIND CROSSWIND VERTICAL  RADIUS(M)  TEMP(DEG K)  COEF (CAL/G)   (M/S)
 -------- --------- --------  ---------  -----------  ------------  --------
   17.54     17.54     3.00      2.43       303.68       9318.31        .65



              FALL    EVAPORATION/DEPOSITION        MOMENTUM  HORIZONTAL
 HEIGHT OF  VELOCITY     FD         DELTA    REFL.   RADIUS    VELOCITY
 BURST (M)   (M/S)   (LONG-TERM)   (S**-1)   COEF.    (M)        (M/S)
 ---------  --------  -----------  -------   -----  --------  ----------
     .0       .000     1.000000     .00000  1.0000     .00        .59
```

This summary information is followed by a complete mass production profile (see app D).

Similiar information is included for the second and third clouds.

```
           PROCESSING SUBCLOUD  2


          SUBCLOUD # 2        HISTORY FILE SOURCE #  1


             DEBRIS      PLUME    CLOUD RISE MODEL    EXTINCTION   BALLISTIC
    MASS     CARBON     (1=PUFF,  (1=RISE, 2= NO     COEFFICIENT   SUBCLOUD
  FRACTION  (G/G OBSC)  2=PLUME)  RISE, >2=STEM)        CODE      (1=Y, 0=N)
  --------  ----------  --------  --------------    -----------  ----------
   .050000      .000       1.           1.               5.          0.
```

```
                                            INITIAL      THERMAL      UPWARD
INITIAL OBSCURANT RADII (M)  BUOYANCY      CLOUD      PRODUCTION   VELOCITY
DOWNWIND CROSSWIND VERTICAL  RADIUS(M)  TEMP(DEG K)  COEF (CAL/G)    (M/S)
-------- --------- --------  ---------  -----------  ------------  --------
   3.32      3.32     2.49      1.16       433.30       9318.31       1.62


             FALL   EVAPORATION/DEPOSITION         MOMENTUM  HORIZONTAL
HEIGHT OF   VELOCITY     FD         DELTA    REFL.   RADIUS    VELOCITY
BURST (M)    (M/S)   (LONG-TERM)   (S**-1)   COEF.    (M)        (M/S)
---------  --------  -----------   -------   -----  --------  ----------
   7.0        .000    1.000000      .00000  1.0000      .00       .94


             INITIAL MASS IN THIS PUFF =        134.2 GM

         PROCESSING SUBCLOUD  3


        SUBCLOUD # 3        HISTORY FILE SOURCE #  1


             DEBRIS      PLUME    CLOUD RISE MODEL    EXTINCTION   BALLISTIC
  MASS       CARBON     (1=PUFF,   (1=RISE, 2= NO    COEFFICIENT   SUBCLOUD
 FRACTION   (G/G OBSC)  2=PLUME)   RISE, >2=STEM)        CODE      (1=Y, 0=N)
 --------   ----------  --------   --------------    -----------  ----------
  .025000       .000        1.          12.               5.          0.


                                            INITIAL      THERMAL      UPWARD
INITIAL OBSCURANT RADII (M)  BUOYANCY      CLOUD      PRODUCTION   VELOCITY
DOWNWIND CROSSWIND VERTICAL  RADIUS(M)  TEMP(DEG K)  COEF (CAL/G)    (M/S)
-------- --------- --------  ---------  -----------  ------------  --------
   3.32      3.32     2.49       .00          .00       9318.31        .00


             FALL   EVAPORATION/DEPOSITION         MOMENTUM  HORIZONTAL
HEIGHT OF   VELOCITY     FD         DELTA    REFL.   RADIUS    VELOCITY
BURST (M)    (M/S)   (LONG-TERM)   (S**-1)   COEF.    (M)        (M/S)
---------  --------  -----------   -------   -----  --------  ----------
    .0        .000    1.000000      .00000  1.0000      .00       .00


             INITIAL MASS IN THIS PUFF =         67.1 GM
```

The second subcloud (with 5 percent of the mass) is a short-lived puff. The third subcloud (with 2.5 percent of the mass) is also a puff, which connects the first two subclouds (the cloud rise model column for subcloud 3 is 12; table 31 discussed the nomenclature for parameter `RISMOD`, where the cloud rise model is set).

The second item of interest is that the transmission listing in the Phase II output is expanded. In addition to the transmittance history, it now contains, for each puff, the following:

- integrated path concentration (in grams per meter squared) for the subcloud (SUBCLOUD CL),
- path length through the subcloud,
- coordinates of Gaussian centroid (in meters) of the subcloud (X, Y, Z),
- sigmas for the Gaussian subcloud (in meters) (SIGX, SIGY, SIGZ), and
- total mass (in grams) contained in the subcloud (WBAR).

The same columns are used for similar information for each slice of cloud defined by the intersection of the LOS with the plume:

- integrated path concentration (g/m^2) ,
- path length through the slice,
- coordinates of Gaussian centroid (in meters) of the slice,
- sigmas for the average downwind distance of the slice, and
- Average mass per downwind distance in the slice.

Where SIGX = 0, the row of data refers to a slice; where SIGX $\neq$ 0, the row of data refers to a puff.

```
1                 SUBCLOUD CLOUD                                              PATH-
   TIME  OBS TARG    CL   NUMBER              TRANSMISSION                   LENGTH            MAX. CONTRIBUTION TO CLOUD
  (SEC)  NO.  NO. (G/M**2)        .4-.7 .7-1.2 1.06 3.-5. 8.-12. 10.6 94 GHZ METERS     X        Y     Z   SIGX  SIGY  SIGZ    WBAR
                    1.151    3                                               58.1     11.1     -.9   2.6     .0   8.7   2.2 6.47E+00
                     .481    2                                               63.0      9.6     -.4   3.4     .0   9.8   3.2 4.22E+00
                     .031    2                                               19.8     11.4     -.4  11.1    2.6   7.5   3.6 6.71E+01
                     .317    1                                               67.8      9.6      .0   4.1     .0  11.2   4.2 3.75E+00
    5.0    1    1   1.980    3     .002   .009  .015  .442   .547  .575  .998
                    2.031    3                                               60.1     11.2     -.9   2.8     .0   8.7   2.2 1.18E+01
                     .860    2                                               66.0      9.6     -.4   3.9     .0   9.8   3.2 8.14E+00
                     .552    1                                               72.0      9.6      .0   4.8     .0  11.2   4.2 7.17E+00
                     .016    1                                               24.3     14.6      .0  13.5    3.7   9.3   4.7 6.72E+01
   10.0    1    1   3.459    3     .000   .000  .001  .240   .349  .381  .997
                    2.166    3                                               60.8     11.2     -.9   2.9     .0   8.7   2.2 1.27E+01
                    1.182    2                                               67.1      9.6     -.4   4.1     .0   9.8   3.2 1.15E+01
                     .769    1                                               73.5      9.6      .0   5.0     .0  11.2   4.2 1.04E+01
   15.0    1    1   4.117    3     .000   .000  .000  .183   .286  .317  .996
                    2.020    3                                               61.1     11.2     -.9   2.8     .0   8.7   2.2 1.18E+01
                    1.172    2                                               67.6      9.6     -.4   4.0     .0   9.8   3.2 1.14E+01
                     .908    1                                               74.2      9.6      .0   5.2     .0  11.2   4.2 1.27E+01
```

A rule of thumb is that 90 percent of the cloud is contained within a volume defined by 2.15 times each of the sigmas. Using the sigmas for the puff gives a rough determination of the size of the puff. However, most sensor performance people need to relate size of the cloud to a system performance threshold CL. Unfortunately, that information cannot be derived from the sigmas alone. For those who want cloud sizes, with the cloud length, width, and height being determined at the point that the cloud is dense enough to defeat the sensor, we recommend the use of the printer-plot option. However, it must be cautioned that cloud dimensions obtained through the printer-plot option are strongly dependent upon the viewing angle.

5.5 Example 4: Using the Printer Plot Options `VIEW` and `GREY` to Determine Cloud Sizes

In this example, we use the same history file that was generated by the Phase I inputs in the previous example. Here we demonstrate the use of the `VIEW` and `GREY` records and how to use the printer plot to obtain cloud size. Users often need to determine the size of a cloud; the printer plot option can be used to view the cloud crosswind in the horizontal direction. Setting up the printer plots, however, is not a simple task.

The following are the Phase II inputs for this example.

```
WAVL      1.06
COMBIC
PHAS            2.0       5.0       6.0      12.0       9.0       0.0      1.0
FILE      9.0       his.18a1
FILE      12.0      18a1.pic
NAME
         Producing a contour representation for L8A1 smoke grenades
ORIG            0.0       0.0       0.0      90.0     270.0       0.0      0.0
LIST            0.0      10.0      30.0      10.0
NAME
         One munition at {0., 0., 0.,) starting at T=0.
SLOC            1.0       1.0       0.0     300.0       0.0       0.0      2.0
OLOC            1.0      40.0    -500.0      25.0       0.0     300.0      0.0
TLOC            1.0      40.0     500.0      25.0       1.0       0.0      0.0
VIEW            1.0       1.0     100.0      50.0      50.0      25.0     90.0
GREY            9.0      .001     0.901       0.0       1.0       1.0      0.0
DONE            0.0       0.0       0.0       0.0       0.0       0.0      0.0
END
STOP
```

`UNITC` = 12.0 (the fourth parameter on the `PHAS` record) opens the file 18a1.pic. The printer plot is stored in this file. The `LIST` record controls the times that a printer plot will be displayed by specifying a start time, end time, and delta time. In this example, the printer plot will occur from 10 to 30 s every 10 s. The munition is located at the origin and starts at 0 s.

Because the `CLOPT` parameter (the fourth parameter on the `GREY` record) is equal to 0.0, this is a transmission plot. Because `WAVEL` = 1.0 (the sixth parameter), this is a visible transmission plot. Transmission ranges from 0 to 1.0. In this example, `SMINV` = 0.001 (the second parameter) means that any LOS with a transmittance of less than one-tenth of one percent is printed as a “*”, and `SMAXV` = 0.901 means that any LOS with a transmittance greater than 90.1 percent is left blank. `DIVIS` (the first parameter) is the number of grey scales between the extremes defined by `SMINV` and `SMAXV` (the second and third parameters), with a separation given by (`SMAXV` – `SMINV`)/`DIVIS` = 0.10.

The printed output follows.

```
           TIME =   1.000E+01 X0 =   4.000E+01 Y0
=  -5.000E+02 Z0 =  2.500E+01
          RANGE =   1.000E+03 AL =      .00000 BT =      1.000 GM =       .000
          FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  1.000E+02 CROSS-LOS VERTICAL =   5.000E+01
                    DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                    PIXELS: HORIZONTAL =  50 VERTICAL =    25

                    GREY SCALE RANGES =   9.
           .000000 -       .001000 = *
           .001000 -       .101000 = 1
           .101000 -       .201000 = 2
           .201000 -       .301000 = 3
           .301000 -       .401000 = 4
           .401000 -       .501000 = 5
           .501000 -       .601000 = 6
           .601000 -       .701000 = 7
           .701000 -       .801000 = 8
           .801000 -       .901000 = 9
           .901000 -      1.001000 =
1   VERTICAL                                HORIZONTAL
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
               +--------------+--------------+--------------+--------------
     2.500E+01+
              -
              -
              -
              -
              -
              -
              -
              -
              -
     5.000E+00+
              -
              -             999
              -            964458
              -            6211159
              -           841**128
              -          9621**127
              -          7411**138
              -         8521111269
              -         631112369
    -1.500E+01+       984211235
              -     97431111234
              - 975321111111234
              - 521111111111234
              - 4111*1111223344
               +--------------+--------------+--------------+--------------
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
```

```
           TIME =   2.000E+01 X0 =   4.000E+01 Y0 =  -5.000E+02 Z0 =  2.500E+01
          RANGE =   1.000E+03 AL =      .00000 BT =      1.000 GM =       .000
          FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  1.000E+02 CROSS-LOS VERTICAL =   5.000E+01
                    DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                    PIXELS: HORIZONTAL =  50 VERTICAL =    25

                    GREY SCALE RANGES =   9.
           .000000 -      .001000 = *
           .001000 -      .101000 = 1
           .101000 -      .201000 = 2
           .201000 -      .301000 = 3
           .301000 -      .401000 = 4
           .401000 -      .501000 = 5
           .501000 -      .601000 = 6
           .601000 -      .701000 = 7
           .701000 -      .801000 = 8
           .801000 -      .901000 = 9
           .901000 -     1.001000 =
1   VERTICAL                                 HORIZONTAL
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
               +--------------+--------------+--------------+--------------
     2.500E+01+
              -
              -
              -
              -
              -
              -
              -
              -                        9999
              -                     998777889
     5.000E+00+                    98765445679
              -                   9875332234679
              -                   97532111234689
              -                  986421111124689
              -                  975321111124689
              -                 9864321111235789
              -                9875332222235689
              -              99875432233445789
              -           9887765432233456799
              -         9754444433222345679
    -1.500E+01+       964221222222222346789
              -     97321111111111222345689
              - 975431111111111111223345679
              - 521111111111111112223445678
              - 411111111111122222333455679
               +--------------+--------------+--------------+--------------
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
```

```
           TIME =   3.000E+01 X0 =   4.000E+01 Y0 =  -5.000E+02 Z0 =  2.500E+01
          RANGE =   1.000E+03 AL =      .00000 BT =      1.000 GM =       .000
          FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  1.000E+02 CROSS-LOS VERTICAL =   5.000E+01
                    DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                    PIXELS: HORIZONTAL =  50 VERTICAL =    25

                    GREY SCALE RANGES =   9.
           .000000 -       .001000 = *
           .001000 -       .101000 = 1
           .101000 -       .201000 = 2
           .201000 -       .301000 = 3
           .301000 -       .401000 = 4
           .401000 -       .501000 = 5
           .501000 -       .601000 = 6
           .601000 -       .701000 = 7
           .701000 -       .801000 = 8
           .801000 -       .901000 = 9
           .901000 -      1.001000 =
1   VERTICAL                                HORIZONTAL
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
               +--------------+--------------+--------------+--------------
     2.500E+01+
              -
              -
              -
              -
              -                                 9999999
              -                                9988788899
              -                               987766667899
              -                              9876544456789
              -                             987654333456789
     5.000E+00+                            9986543222345689
              -                            9875432222235689
              -                           98765432222235689
              -                          987654332222345689
              -                        99887654333333456789
              -                     9999877654443334456789
              -                 99988887765544444455667899
              -              9988777666655444444556678899
              -           98876655544444444334445678999
              -         9765443333323333333334456678
    -1.500E+01+       974322222111112222223334456789
              -     97421111111111111122222334456789
              - 976431111111111111111112222334456789
              - 621111111111111111111112222334556789
              - 421111111111111111112222233344556789
               +--------------+--------------+--------------+--------------
          -5.000E+01     -2.000E+01      1.000E+01      4.000E+01
```

The three plots show the time evolution of the cloud at 10 s, 20 s, and 30 s. These displays allow the user to see the extent and density of the cloud. Achieving such useful displays requires either an iterative procedure or substantial preliminary estimation.

The most difficult part is the placement of the window. Ideally, you would like the cloud to fill the entire window, so that you obtain the highest resolution possible. The right choice usually requires experience, though the inexperienced can always make a preliminary COMBIC run to help set the appropriate parameters. The main problem is determining the central LOS for the `OLOC`–`TLOC` pair used to define the printer plot (see fig. 5). The following seven steps illustrate the analysis process used to define the above set of inputs.

1. Estimate the ultimate height of the cloud for the last time step defined by the `LIST` record. A good guess for the height of an L8A1 cloud for Pasquill stability B at 30 s is 50 m. This defines `VLOSW` (the fourth parameter on the `VIEW` record) or the vertical length of the window. Divide this number in half. This is now the height of the central LOS (`ZOBS`, the fourth parameter of `OLOC`, and `ZTAR`, the fourth parameter of `TLOC`).
2. Estimate the ultimate length of the cloud for the last time step defined by the `LIST` record. A good guess is to refer to the vertical profile section of the Phase I output to determine the windspeed at the height of step one. We see that the windspeed at a height of 50 m is 2.4 m / s. We then use the following equation to estimate the length of the cloud.

   L(cloud) = windspeed (at ultimate height) $\times$ [maximum time $-$ starting time of the munition] + 20 or 30 m.

   This equation yields a rough estimate of the longest possible length of the cloud as well as the horizontal width of the window (`CLOSW`, the third parameter of the `VIEW` record). We add 20 to 30 m since the source is usually not a point source, but has a finite width. In this example, the windspeed at a height of 50 m is 2.4 m / s, the maximum time the printer plot is output is 30 s, and the starting time of the munition is 0 s. Adding 28 m yields the maximum possible length of the cloud and `CLOSW` of the `VIEW` record as 100 m.
3. Draw on a piece of scratch paper the x-y coordinate axis, the munition location, and label which direction north is with respect to the axis (`XORDIR`, the fourth parameter of the `ORIG` record).
4. Also label the direction the wind is coming from (`WINDIR`, the fifth parameter of the `ORIG` record).
5. Draw a rough cloud. Remember that it has to go in the direction the wind is blowing. Label the length of the cloud as L m (in this case 100 m).

6. Determine the half-way point in your cloud and then shift this point 20 to 30 m upwind. Draw a line perpendicular to the wind direction through this point. This is now your central LOS. Make sure it is long enough so the endpoints are outside the cloud. The height defined in step one and the x, y values read from your graph define the observer and target location.
7. Run COMBIC and make corrections if necessary.

Although this procedure seems complicated, most users develop with time an instinctive feel for how to use the `OLOC` and `TLOC` records to produce a printer plot. The use of the `VIEW` and `GREY` records depends on the user's personal preferences and the requirements of the research. The maximum number of characters across the printed page (`CLOSD`, the third parameter of the `VIEW` record) is 100. However, it was decided to use only 50 characters in the horizontal direction so that this 100-m-wide picture could be viewed on the screen (which is limited to 80 characters). This choice yields a resolution of (100 m) / (50 char) or 2 m / char. Since it was decided to keep the same resolution in the vertical direction, the number of characters in the vertical direction (`VLOSW`) is 25.

To determine cloud length and height, it is a simple matter to determine which grey scale corresponds to the defeat threshold. The user then simply counts characters and multiplies by the resolution to obtain the dimension in meters. The user must observe two cautions, however. First, the cloud length and height are valid for crosswind cases only. If the user views the cloud on an alongwind LOS, the result would probably be different values for the height. This occurs because the path length through the cloud is longer than in the crosswind case. Similarly, viewing the cloud "top-down" could yield different values for the length of the cloud. Secondly, using a single length, width, and height to describe a complicated cloud like this one can yield problems.

5.6 Example 5: Using the Printer Plot Options `VIEW`, `GREY`, and `TPOS` for a Top-Down View

In this example, we use the history file produced by example 2 to illustrate how to obtain CL for a top-down viewpoint. Two smoke sources consisting of four fixed HC pots and one vehicle generating fog oil are used for this scenario.

```
WAVL      1.06
COMBIC
PHAS                2.0       5.0       6.0      12.0       9.0       0.0       1.0
FILE      9.0      h.vehc-hc
FILE      12.0     topdown.pic
NAME
        Producing a  top-down contour representation for a battlefield scenario
ORIG                0.0       0.0       0.0      31.0     155.0
LIST                1.0      30.0      60.0      10.0
NAME
         Four munition at {90., 80., 0.,) starting at T=20.
NAME
         One vehicle {50., 218., 0.,) starting at T=20.  Traveling 7.6m/s at
NAME
 82 degrees wrt North
SLOC                1.0       4.0      20.0     300.0      90.0      80.0     0.0
VEH1                2.0       1.0      20.0      50.0     300.0
VEH2               50.0     218.0       0.0      82.0       7.6
OLOC                1.0     150.0     175.0     500.0       0.0     300.0       0.0
TLOC                1.0     150.0     175.0       0.0       1.0       0.0       0.0
VIEW                1.0       1.0     300.0     300.0      60.0      60.0      31.0
GREY               10.0      .001     5.001       1.0       1.0       1.0       0.0
DONE                0.0       0.0       0.0       0.0       0.0       0.0       0.0
END
STOP
```

The central LOS was chosen to completely encompass the resultant smoke clouds. The method to determine the central LOS follows closely the method in the previous example, except for two important differences. First, a top-down view is defined as an observation from an altitude (in this case 500 m) straight down; therefore, XOBS = XTAR (the second parameters of `OLOC` and `TLOC`, respectively), YOBS = YTAR (the third parameters), ZOBS = 500, and XTAR = 0 (the fourth parameter of `TLOC`). Second, the length of the smoke cloud produced by a moving vehicle is the vector sum of the vehicle speed and direction with the wind speed and direction. The user should sketch a rough picture for the last time step (60 s) and determine the center of the picture. The x, y coordinates of this central point are the coordinates of the observer and target. The rough sketch should also yield a value for the size of the window.

This example also illustrates the usage of RTAT (the last parameter of the `VIEW` record). RTAT is used to eliminate the ambiguity of the term "horizontal" for top-down looking LOS. RTAT is the angle in degrees of the horizontal viewing axis with respect to north. In this case, it was decided to have the horizontal viewing axis point in the x-direction; therefore, RTAT = 31.0. Below is the printer plot stored in the file topdown.pic.

```
          TIME =   3.000E+01 X0 =   2.290E+02 Y0 =  -2.650E+01 Z0 =  5.000E+02
         RANGE =   5.000E+02 AL =      .00000 BT =       .000 GM =     -1.000
         FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  3.000E+02 CROSS-LOS VERTICAL =   3.000E+02
                   DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                   PIXELS: HORIZONTAL =  60 VERTICAL =    60

                   GREY SCALE RANGES =  10.
          .000000 -       .001000 = *
          .001000 -       .002152 = 1
          .002152 -       .004632 = 2
          .004632 -       .009970 = 3
          .009970 -       .021458 = 4
          .021458 -       .046183 = 5
          .046183 -       .099399 = 6
          .099399 -       .213934 = 7
          .213934 -       .460444 = 8
          .460444 -       .991000 = 9
          .991000 -      2.132900 =
    VERTICAL                                HORIZONTAL
```

```
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
          +--------------+--------------+--------------+--------------
3.250E+02+
         -
         -
         -
         -
         -
         -
         -
         -
         -
2.750E+02+
         -
         -
         -
         -
         -
         -
         -              70
         -           95359
         -           063380
2.250E+02+           083260
         -            05239
         -             8327
         -             05240
         -              8228
         -              0415
         -               8120
         -               0317
         -                812
         -                 310
1.750E+02+                 915
         -                  21
         -                  9*
         -
         -
         -
         -
         -
         -
         -
1.250E+02+
         -                  08
         -                  952
         -                  94111
         -                  821111
         -                  71*11148
         -                  41*114790
         -                  1**158
         -                  **17
         -                   1
7.500E+01+
         -
         -
         -
         -
         -
         -
         -
         -
         -
          +--------------+--------------+--------------+--------------
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
```

```
       TIME =   4.000E+01 XO =   2.290E+02 YO =  -2.650E+01 ZO =  5.000E+02
      RANGE =   5.000E+02 AL =      .00000 BT =       .000 GM =     -1.000
      FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  3.000E+02 CROSS-LOS VERTICAL =   3.000E+02
                DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                PIXELS: HORIZONTAL =  60 VERTICAL =    60

                GREY SCALE RANGES =  10.
       .000000 -       .001000 = *
       .001000 -       .002152 = 1
       .002152 -       .004632 = 2
       .004632 -       .009970 = 3
       .009970 -       .021458 = 4
       .021458 -       .046183 = 5
       .046183 -       .099399 = 6
       .099399 -       .213934 = 7
       .213934 -       .460444 = 8
       .460444 -       .991000 = 9
       .991000 -      2.132900 =
VERTICAL                                HORIZONTAL
```

```
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
          +--------------+--------------+--------------+--------------
3.250E+02+
         -
         -
         -
         -
         -
         -
         -
         -
         -
2.750E+02+                    000
         -                 888900
         -              087667800
         -            009876668900
         -             00876567900
         -             00976557800
         -             00986556890
         -              00976567900
         -              00986556800
         -               0086556890
2.250E+02+               0097545790
         -                008645680
         -                0097545800
         -                 097545790
         -                  08644690
         -                  09744580
         -                   0853479
         -                   09643590
         -                    0743480
         -                    0953370
1.750E+02+                     073359
         -                    00842480
         -                    00862370
         -                    09852250
         -                    09752139
         -                   008642113
         -                   0975321113
         -                   086422111237
         -                   9753211112358
         -                   96321111114679
1.250E+02+                  08521111111578900
         -                  9631111121168900
         -                  95211111331590
         -                  8311111246120
         -                  81111113684*
         -                  61**113680
         -                  3***13790
         -                  1**148
         -                  **16
         -                   1
7.500E+01+
         -
         -
         -
         -
         -
         -
         -
         -
         -
          +--------------+--------------+--------------+--------------
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
```

```
       TIME =   5.000E+01 XO =   2.290E+02 YO =  -2.650E+01 ZO =  5.000E+02
      RANGE =   5.000E+02 AL =      .00000 BT =       .000 GM =     -1.000
      FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  3.000E+02 CROSS-LOS VERTICAL =   3.000E+02
                DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
                PIXELS: HORIZONTAL =  60 VERTICAL =    60

                GREY SCALE RANGES =  10.
       .000000 -      .001000 = *
       .001000 -      .002152 = 1
       .002152 -      .004632 = 2
       .004632 -      .009970 = 3
       .009970 -      .021458 = 4
       .021458 -      .046183 = 5
       .046183 -      .099399 = 6
       .099399 -      .213934 = 7
       .213934 -      .460444 = 8
       .460444 -      .991000 = 9
       .991000 -     2.132900 =
 VERTICAL                               HORIZONTAL
```

```
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
          +--------------+--------------+--------------+--------------
3.250E+02+
         -
         -                            00
         -                         90000
         -                      888990000
         -                   988888890000
         -                009987777899000
         -               0009987777889000
         -               0009987777889000
         -               00009887777899000
2.750E+02+                0009987777899000
         -                0009987777789000
         -                 000987777789000
         -                 000998777789900
         -                 0000987767789000
         -                  000987767789000
         -                  000998766789000
         -                   00098766778900
         -                   00098766678900
         -                    00998766789000
2.250E+02+                    00098766678000
         -                     0098766678900
         -                     0098766678900
         -                      008766667900
         -                      0097655678900
         -                      0097543468900
         -                      0097543237900
         -                     00987543222400
         -                     00987532222230
         -                     009865322122236
1.750E+02+                     0987543211122346
         -                    00986532211122234579
         -                    09875432211122456789
         -                    0986432211112246789900
         -                    08753221111123468990000
         -                   09864221111112357890000
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         -                   08632111112222358900
         -                   9742111112233334800
         -                   853111111235433470
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         -                  96211111124688533590
         -                  94111111246899742480
         -                  8211*111368900842370
         -                  711**113589   962260
         -                  51**112580    083249
         -                  3***12680      94238
         -                  1**137         06226
         -                  **16            82140
         -                   1              04139
7.500E+01+                                   7118
         -                                   0216
         -                                    513
         -                                    911
         -                                     319
         -                                     9*5
         -                                      1
         -
         -
         -
          +--------------+--------------+--------------+--------------
      0.000E+00      7.500E+01      1.500E+02      2.250E+02
```

```
   TIME =   6.000E+01 X0 =   2.290E+02 Y0 =  -2.650E+01 Z0 =  5.000E+02
  RANGE =   5.000E+02 AL =      .00000 BT =       .000 GM =      -1.000
  FULL-WIDTH OF VIEW, CROSS-LOS HORIZONTAL =  3.000E+02 CROSS-LOS VERTICAL =   3.000E+02
            DISPLAYED SCALE = TRANSMISSION, WAVELENGTH =  1.
            PIXELS: HORIZONTAL =  60 VERTICAL =    60

            GREY SCALE RANGES =  10.
   .000000 -       .001000 = *
   .001000 -       .002152 = 1
   .002152 -       .004632 = 2
   .004632 -       .009970 = 3
   .009970 -       .021458 = 4
   .021458 -       .046183 = 5
   .046183 -       .099399 = 6
   .099399 -       .213934 = 7
   .213934 -       .460444 = 8
   .460444 -       .991000 = 9
   .991000 -      2.132900 =
VERTICAL                                HORIZONTAL
```

```
      0.000E+00     7.500E+01      1.500E+02      2.250E+02
          +--------------+--------------+--------------+--------------
3.250E+02+                 0000099988888889900000
         -                  000009988888889900000
         -                  000009988888889990000
         -                  000009998888888990000
         -                   000009988888889900000
         -                   000009988888889900000
         -                   000009998888888990000
         -                    00000998887888990000
         -                    00000998887788990000
         -                     00009988877888900000
2.750E+02+                     00000998877788990000
         -                      0000998877788990000
         -                      0000998877788990000
         -                      0000998787778899000
         -                       000998777778899000
         -                       0009987666778990000
         -                        009987655568890000
         -                        009987654445899000
         -                        009987654433469000
         -                        009987554333335000
2.250E+02+                       0009876544333334000
         -                       0009876543322333460
         -                       0099876543222334456
         -                      00098765433222233445678
         -                      000987654322222234456779
         -                      00987654332222223456678890
         -                      009875433222222234567889900
         -                     009876543222222233456789900000
         -                     009865433222222233467899000000
         -                     09876433222222223456789000000
1.750E+02+                     0986533222222223345689900000
         -                    008754322212222333456890000
         -                    09864322111222333445789000
         -                    0975322111122334445578900
         -                    0864221111123345555568900
         -                   09753211111223456555568900
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         -                   97521111111235678765567800
         -                   963111111123568898765678900
         -                   852111111134689999765568900
1.250E+02+                  9731111111246890009865567900
         -                  9521111112357900 00875557800
         -                  8311**11135790   00976556800
         -                  721***1125790    00986556790
         -                  61***112579       0087545790
         -                  41***12479        00975456800
         -                  2***1258           0986445800
         -                  1**127             0086445790
         -                  **15                097544690
         -                   *                  008544680
7.500E+01+                                       09643580
         -                                       09743470
         -                                        0853369
         -                                        09633590
         -                                         0732460
         -                                         0821260
         -                                          953
         -
         -
         -
          +--------------+--------------+--------------+--------------
      0.000E+00     7.500E+01      1.500E+02      2.250E+02
```

5.7 Subroutines and Functions

5.7.1 Phase I Subroutines

- `COMBIC` is a small driver routine that selects the independent submodules `DSPH1` (Dust/Smoke Phase I) and `DSPH2`.
- `DSPH1` is an I/O subroutine that reads and stores user input records in blocks and eventually calls `PHAS1` to begin calculations for one obscurant source type.
- `PHAS1` is a main Phase I routine that produces the output cloud history file for each obscurant source specified by the user. `PHAS1` calls `CMASS`, `DMASS`, `SMASS`, and `TRAJ` for each source subcloud that is produced (1 to 5).
- `SMASS` is a routine that computes the basic smoke quantities of yield factor, total mass, and thermal production.
- `CMASS` is a routine that analytically computes the cumulative profile of obscurant mass produced by the source and the average production value for later scaling. `CMASS` calls `CRATE`.
- `CRATE` is a routine that returns the cumulative mass production of the burn (or mass production) function.
- `DMASS` is a routine that returns the dust production and thermal production of HE-generated dust. The routines `VOLAC` and `CRATR` are called.
- `VOLAC` is a routine that computes the basic crater volume scaling factor for HE-generated dust. `VOLAC` calls `CRATR`.
- `CRATR` is a routine that returns the ratio of the apparent crater volume for a cased HE to the crater volume produced by an equivalent uncased charge.
- `TRAJ` is a routine that calculates the time history of cloud positions, dimensions, and downwind travel times through a major loop over many time steps. `TRAJ` calls `RISE` and `DIFUS`.
- `RISE` is a routine that returns the buoyant height, radius, rise velocity, and temperature for a given instantaneous Gaussian puff or continuous Gaussian plume for a single input time.
- `DIFUS` is a routine that serves both the purpose of returning the atmospheric-induced cloud diffusion coefficients and determining a best linear expansion coefficient for use in Phase II approximations.
- `SBAR1` is a routine that determines values relevant to the modeled atmospheric boundary layer.
- `LODDAT` is a routine that loads history values into transfer arrays.

- `SDWRIT` is a routine that writes history values to the file.
- `UZ` is a routine that returns the windspeed for any input height, the static stability parameter, and the eddy dissipation rate for terminating cloud rise.
- `EXTIN` is a routine that loads default values for mass extinction coefficients or replaces defaults with user provided values. `EXTIN` calls `WPHCD`.
- `WPHCD` is a routine that computes relative humidity dependent WP and HC extinction coefficients.

5.7.2 Phase I Functions

- `YIELD` is a function that returns the mass scaling for relative humidity dependent WP and HC smoke.
- `COLD` is a function that modifies the yield factor for cold regions.
- `PASQL` is a function that calculates Pasquill stability category based on meteorological inputs. `PASQL` calls `ALPHA`.
- `ALPHA` is a function that returns the solar elevation for given day, time, and site location.
- `SBAR1` is a function that determines values relevant to the modeled atmospheric boundary layer.
- `CNORM` is a function subprogram for the cumulative normal distribution.
- `CNORF` is a table lookup function for the cumulative normal distribution.

5.7.3 Phase II Subroutines

Phase II routines include I/O of user records, initialization and loading of cloud histories, setup and maintenance of active sources and active LOS's, an outermost loop over time, updating of cloud positions and dimensions, a second-level loop over all LOS's, and an innermost loop over all clouds for each LOS to compute contributions to transmission reduction. The routines are as follows:

- `DSPH2` is a subroutine called by `COMBIC` to process user input records. Unlike `DSPH1` in Phase I, `DSPH2` takes some immediate action following each user input through calls to `PHAS2`.
- `SETUP` is the initialization routine for Phase II.
- `ADDCLD` adds obscurant source to the scenario.
- `ADDLOS` adds a line of sight to the scenario.

- `BTRANS` finds transmission for a given line of sight.
- `UPDAT` is a routine that has different functions, depending on how it is called. Provides the leading edge position and dimensions or trailing edge position and dimensions following burnout.
- `PHAS2` schedules other routines and increments the scenario clock.
- `DISPER` computes the dispersion lengths for both stable and unstable atmospheres.
- `EXTIN` loads default values for mass extinction coefficients or replaces defaults with user-provided values. `EXTIN` calls `WPHCD`.
- `WPHCD` computes relative humidity dependent WP and HC extinction coefficients.
- `TRNFRM` rotates coordinates between different coordinate systems.
- `LOOKUP` accesses the cloud history tables for cloud dimensions and mass for use by `BTRANS`.
- `DROPC` maintains active cloud arrays by removing an active cloud and returning array storage to the inactive pool.
- `SDREAD` loads cloud histories as needed from the history file.
- `CONIN` tests for intersection of the LOS's with a crude estimate of the volume that contains an extended continuous cloud.
- `PUFCL` integrates concentration over a given path through a Gaussian puff and rejects the cloud if it is not sufficiently close to or does not intersect the path.
- `CONCL` integrates concentration along a path segment through a continuous Gaussian plume.
- `ROMBERG` integrates concentration along a path segment through a continuous Gaussian plume. This routine is used to provide a faster way of integrating through plumes. It useds the Romberg method of integration for times when the LOS's are not perpendicular to the wind direction.
- `ROMF` computes $\dot{M}$ and part of the CL integral.
- `FILLIN` is used in the romberg method of integration.
- `FILNEG` is used in the romberg method of integration.
- `CNTUR` is provides printer plots of cloud contours.
- `TERRA` is a dummy terrain routine demonstrating how terrain interface can be achieved.

5.7.4 Phase II Functions

- `CNORM` computes the cumulative normal distributions.
- `CNORF` is a table lookup routine of `CNORM` values used to save calculation time.

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6. AUTHOR(S) Alan Wetmore and Scarlett D. Ayres

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Attn: AMSRL-CI-EE email: awetmore@arl.mil
2800 Powder Mill Road
Adelphi, MD 20783-1197

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Airborne dust, smoke, and debris can significantly degrade a battlefield environment and affect electro-optical systems. The most direct effect of these combat-induced aerosols on a propagating electromagnetic signal is to remove energy (reduce transmission) through absorption and scattering. Reduced transmission through inventory smokes and dust is generally most significant at visual and infrared wavelengths and less severe at millimeter wavelengths.

Obscurant concentrations can change rapidly in a combat environment. Once generated, an aerosol cloud moves with the wind, undergoes thermally buoyant rise, and expands in the atmospheric turbulence. Thus, prevailing winds, aerosol generation factors, and the geometry of targets, observers, and aerosol clouds are important in determining transmission.

The Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) predicts time and spatial variations in transmission through dust and debris raised by high-energy explosives and by vehicular movement; smoke from phosphorus and hexachloroethane munitions; smoke from diesel oil fires; generator-disseminated fog oil and diesel fuel; and other screening aerosols from sources defined by inputs. COMBIC has been designed primarily for large scenarios where many different obscuration sources are present and where many observer-target lines of sight (LOS) must be treated simultaneously.

This document has been developed to provide both a technical description of the physics used in the COMBIC model and to serve as an operations guide for users of the COMBIC software.

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