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Evaluation process for chemical/biological/radiological hazard assessment models

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Evaluation Process for Chemical/Biological/Radiological Hazard Assessment Models

by

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13. ABSTRACT (maximum 200 words)

A large number of models exist to assess the impact of the release of nuclear, biological, and chemical agents on personnel. These models are of varying physical fidelity, are designed for various computer platforms, take various times to run, are applicable for different geographic types, etc. A means is needed to determine how well these models perform and how well they meet the requirements of DoD users so that recommendations can be made for which model(s) to use for specific situations. This report presents a process for such evaluation.

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CB HAZARD MODELING PAT REPORT

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SECTION A: HAZARD ASSESSMENT BACKGROUND

A-1. MODELING GROUP CHARTER

ASD(CB) is concerned that there may be duplication of effort as well as requirements that remain unfulfilled in chemical and biological hazard modeling. So a Process Action Team was chartered to develop criteria to assess the relative merits of available models. The Team was divided into several topical groups: standards, data, requirements, and models. This technical report details the findings of the modeling subgroup.

We can say without qualification that no current model or even potential combinations of current best practices can fulfill all current hazard modeling needs. So these criteria were developed to apply to current models and also those to be developed as techniques improve. I.e., these criteria should be used to guide the development of improved hazard assessments, not just gauge the utility of current models. Beyond merely citing deficiencies, priorities must also be set to establish criteria useful in making tailored selections of models, guiding their development, and minimizing duplication of effort.

The original group charter was specifically for chemical and biological hazards. We believe it appropriate to expand this charter to include radiological hazards. The reasons are: 1) many models and techniques used for CB and radiological modeling are nearly identical; 2) so much so that similarities between biological and radiological modeling are greater than between either and chemical modeling. Thus, this report includes criteria for modeling chemical, biological, and radiological (CBR) hazards in the atmosphere.

Regarding hazard effects, we note that radiological and biological hazards tend to persist over large distances and long times. But chemical hazards are of shorter scale, similar to optical and particularly smoke effects. For all these effects, modeling depends on the state of the atmosphere. Thus, CBR modeling criteria must consider atmospheric conditions over distances from the micro to the meso and synoptic scales. The fact that no single model best handles all CBR hazard situations is partly due to the required wide range of scales. E.g., a model optimized for short-range, short-lived hazards may be tediously unwieldy for long-range transport. The required range of scales involves more than computational time; the appropriate level of fidelity and type of physical approximation may differ with scale.

Optimal modeling also depends on operational requirements. E.g., when time is scarce and more important than fidelity and resolution, a simpler, more approximate model may suffice. So expert systems should be developed to select models appropriate to the circumstance from within an available suite. The choice includes factors like weather, logistics, terrain, and available decision-making time. Such an expert system is facilitated by requiring that all models within a suite conform to standard input/output specifications and user interfaces. We do not develop criteria specific to expert systems herein.

A-2. DoD REQUIREMENTS FOR CBR HAZARD MODELS

DoD employs CBR models for purposes from systems level design to development of tactics which can be grouped into four general use categories:

Acquisition,
Training,
Operations Planning, and
Operations.

These categories have different requirements which determine the required model attributes. For meeting requirements the most dominant general attributes are:

fidelity,
resolution, and
run time.

The sections below discuss how these attributes and their interactions may coalesce to meet the requirements in detail. This background then serves to help develop the model attributes matrices given below.

Underlying all models are tradeoffs among the attributes needed to fulfill requirements. But the importance of various requirements differs by use category. So this influences model structure. Acquisition requirements are easiest to fulfill because environmental factors are usually pre-calculated and simulations can be well-tailored before the run. This removes input time constraints and model run-times are often also unconstrained. Physical conditions can also be pre-calculated for most training simulations, though this is changing for interactive simulations. Operations planning may also use pre-calculated environments, but available set-up time often may be much shorter. Operations can require quick response, short run-time assessments. The time constraints for training in a Distributed Interactive Simulation environment may be the same as for operations.

A high fidelity, high resolution CBR assessment for operations is most taxing because allowable run-times are usually short, while high fidelity and resolution demands extensive computation. Yet a situation demanding only general hazard assessment is much easier because only approximate physics are needed. If so, a wind vector and rough atmospheric state can be used to give an approximate hazard corridor and downwind foot print.

A model which satisfies all operational requirements will be able to meet most training and acquisition needs as well. Thus, this report looks largely toward meeting operational needs. Then, one may merely weaken or remove some requirements to amend for a less demanding use. The methodology is organized to allow this readily.

DoD has a variety of computers and operating system in current use and the system investment is large. Planned upgrades from, e.g., the VAX, to more modern systems will not occur quickly. Thus, hazard models must be able to operate on existing systems.

Immediately below are some atmospheric modeling summary requirements for the four use categories. Their purpose is to provide context for the listing of model attributes and associated requirements.

Acquisition

No time constraint since scenarios are pre-computed.
High fidelity normally needed, but depends on physical forces to be assessed.
High resolution normally needed, but depends on scales/effects to be assessed.
The spatial domain is restricted to that needed for system assessment.
Monte-Carlo runs needed to generate valid statistics can be time consuming.

Training

For pre-determined scenarios, the same requirements exist as for acquisition.
Higher resolution graphics are needed to instill perception of reality.
For human interaction within the loop, time constraints are similar to operations.

Operations Planning

Time constraints vary; many scenarios may be run during a planning period.
Forecasts may be up to 96 hours.
Forecasts may be required for a full theater area.
Low resolution may suffice for full theater, but some areas need high resolution.
Ultimate resolution/fidelity required depends on effects and terrain configuration.
Adverse weather forecast is needed.

Operations

Real-time or near real-time diagnostics are needed.
Forecasts up to 12 hours may be needed.
1 km resolution or more is probably required within the tactical area.
Resolution finer than 1 km is required for chemical, smoke, and optical effects.
Real-time assimilation of local observations is needed.

Model evaluations based on individual requirements is insufficient. The ultimate need is that a model produce a valid assessment. Such validity is hardest to achieve for highly inhomogeneous areas because the model must resolve all significant terrain. More physical fidelity is also needed because inhomogeneous terrain begets more complex physical forcing. E.g., large slope temperature gradients demand use of an energy budget equation.

The CBR models addressed here require that lateral and bottom boundary conditions be specified by large-scale weather models and local observations. But military, theater level needs for such weather models also affect the configuration and criteria for CBR models, in particular mesoscale meteorological modules. To avoid needless redundancy, we assume that CBR models will all use high resolution mesoscale meteorological models, driven or initialized along their lateral boundaries by existing DoD weather forecast models, the most prominent being the Navy FNWOC and the Air Force AFGWC models. Hazard models must be able to assimilate information from either model.

Military requirements and goals exist for forecasts and assessments from weather centers. The following lists some DoD weather model forecast requirements:

	Required	Goal
Domain size	1500 sq nmi	3200 sq nmi
Horizontal resolution	25 nmi	6 nmi
Vertical layers	20	20
Total forecast time	72 hours	72 hours
Time resolution	2 per day	8 per day
Model run time	1 hour	1 hour

Current thought is that CBR models should have 1 km or better resolution, run in near real-time, and be able to supply forecasts which bridge the period between weather model forecasts. So the CBR mesoscale model must forecast up to 12 hours in advance.

A-3. CRITERIA HIERARCHY AND PROCESS

Model criteria cannot be grouped in a single set for all situations. Criteria are established by the requirements of the various DoD use categories, as well as those needed to attain physical validity. Occasional conflicts arise, especially when computational resources are limited. E.g., criteria such as, model valid for complex terrain, and must run on slow computer in near real-time, are mutually exclusive. So, tradeoffs are necessary.

Model evaluation is best done by comparing model attributes to user requirements. Here we show a sample set of requirements and attributes.

Requirements	Attributes
computer system	computer system
run time	modularity
types of agents	data base assimilation
geographical area of interest	real time input assimilation
type of data assimilation	mesoscale model physics
outputs required	mesoscale model resolution
source types	transport model methodology
forecast needs	diffusion parameterization
support needed.	agent effects
	user interface

The attributes and requirements obviously lack one-to-one correspondence. Also, as the table of contents shows, the full set of attributes are not grouped so simply but are distributed over several model type categories. Thus, a detailed mapping of attributes onto requirements is provided later in the guide to model evaluation.

Model evaluation proceeds along the following general lines:

From a provided User's Requirements Form, the user specifies requirements, outlines available resources, and weights the requirements. The weighting indicates the user's regard for the relative importance of each requirement. The weights depend on specific use and will differ for different use categories.

A set of Model Attributes Matrices is completed by someone familiar with the model at the model development level. This yields a full determination of model capabilities and performance. No scores are involved with these matrices; rather one checks whether an attribute is present in the model. The data contained in the attribute matrices should be independent of the intended use of the model.

The model evaluator assesses how well a given model will meed the specific needs of a user. A set of forms with the same entries as the requirements form, plus a few for evaluating the validity and quality of model physics, is used. Using the attributes matrices, the evaluator correlates requirements with those attributes which help satisfy particular requirements. Individual judgment is used to determine how well the model meets each requirement. How well each requirement is met is given a score from 1 to 10, then this is combined with the users weights to yield a final score.

Note that none of the attribute scores is absolute, not even validity because the intended use impacts the needed resolution and physics. E.g., a fairly simple model may achieve a high score indicating validity for flat but not complex terrain. Moreover, none of the evaluations or even criteria are likely to remain constant for long. New modeling developments and requirements changes will always occur. Thus, the matrices and process should be examined yearly and reviewed formally on a biennial schedule.

A-4. SEGMENTATION OF THE HAZARD MODEL

Hazard events and models divide naturally into several segments or modules. We list them here, including those requiring modeling and those based on provided information.

<u>Conditions</u>: Conditions are not modeled. They are supplied by observations or data.

- terrain
- current weather (and possibly forecast)
- surface moisture and roughness
- sunlight and clouds

<u>Threat Event</u>: Threat event information can be provided by a variety of means. Intelligence, observations, and models all may be used.

- delivery system source term
- installation damage and resulting source term
- agent toxicity
- initial location(s)

<u>Atmospheric Assessment</u>: Modeling is required to transform local observations and large scale weather into meteorological parameters over the region and time of interest.

mesoscale fields, including the vertical of
wind, temperature, and moisture

parameter fluctuation statistics

Agent Transport and Diffusion: This model utilizes the meteorological fields and agent characteristics to determine the movement and dilution of specific agents.

agent volitization, scavenging, resuspension, and degradation

particle and vapor transport

particle and vapor diffusion

Impact on Operations: Impacts on personnel and the resulting effects on operations are calculated from agent concentrations, which have been calculated by the transport and diffusion models.

protection/shielding requirements

damage, physiological, and cognitive impacts

residual capabilities assessment

A full hazard assessment requires that all of the above be determined. Inaccuracies in any of the segments will impact the utility of the final result. E.g., if the source is ill-characterized, transport and diffusion models cannot yield accurate results, regardless of fidelity. So development should focus on areas where modeling is weakest, weighted by their impact on the final result. As stated above, the criteria developed here refer to only the mesoscale, transport, and diffusion models.

A-5. MODEL INITIALIZATION

Hazard assessment starts with knowledge of the threat. To assess the models described here, some minimal information is needed, such as:

release location

agent(s) type

agent amount

agent initial distribution

We assume that agent identification is accomplished external to the model and that agent attributes and physical characteristics are specified by a source file.

The release type and location defines the area over which the hazard is assessed, normally a subset of the theater. The area size depends on the agent. Again, chemical agents are normally localized and short-term, while nuclear and biological have long-range, persistent effects. Thus, agent identification and personnel distribution will define the area to be modeled. The assessment model then requires initial information such as:

high resolution terrain data over the area of interest

high resolution surface characteristics over the area of interest

location of personnel or areas of interest

location of agent detector/sensors

location of meteorological sensors

input from larger scale weather models

SECTION B: MODELING BACKGROUND

Here we discuss mesoscale, transport, and diffusion models, with an emphasis on the mesoscale, since it is the central component of hazard assessment. It provides the fields of meteorological parameters on which transport and diffusion models run. Without accurate fields the ensuing assessments cannot be accurate. This section contains a fairly complete but brief description of the main issues when evaluating mesoscale models.

B-1. RESOLUTION, FIDELITY and RUN-TIME

As stated above, fidelity, resolution, and run time are primary modeling considerations. In this section we discuss tradeoffs between these parameters. This is basic to the discussion of mesoscale modeling techniques.

The spatial resolution at which calculations are performed is one of the most important factors in atmospheric modeling. Atmospheric flow modeling and simulation compel a tradeoff between physical fidelity and computational limits. Numerical models must solve hydrodynamic differential equations to compute properties at specific spatial grid points and times. The model's grid spacing proscribes the limits of resolution and high resolution is computationally costly. Below we describe the interaction between resolution and fidelity, operational needs, and natural stochastic variability, then discuss techniques designed to optimize the validity of the results.

B-1a. RESOLUTION and FIDELITY

Atmospheric processes range from global scale motions produced by latitudinally varying solar heating and the rotational Coriolis effect to molecular thermal conductivity: in spatial scale from megameters to the molecular and in time from days to milliseconds. Numerical models can resolve these processes explicitly only at the grid spacing and time step size feasible for the available hard/software configuration. Smaller, unresolved, sub-grid scale processes must be parameterized (often crudely) or neglected entirely. Thus, grid spacing is a key parameter in determining model fidelity.

For a given hard/software configuration, a factor of two increase in resolution normally requires about a factor of ten increase in computation time. Thus, we must avoid resolutions beyond needed, such as for representing battlefield effects, unless some other overriding reason exists. E.g., 100 m resolution would correspond to DTID terrain and may be needed to position sampling vehicles in the battlefield. It is now possible to produce a valid real-time model with 250 meter resolution to determine all parameters needed to estimate battlefield effects. The method for doing so is discussed below.

B-1b. RESOLUTION and OPERATIONAL NEEDS

The battlefield commander needs information tailored to allow rapid, accurate decisions. Atmospheric effects are just a subset of the required situational data stream and may often be low priority. Screen images are often easy to grasp, but not useful if the graphic is too coarse to see essential features or if it demands too much time or expertise to interpret. The required resolution can vary from that needed to assess peak toxic hazards to local forces to that needed to gauge the cross and downwind hazard area from a high altitude TBM chemical submunitions intercept and burst.

We believe real-time assessments can be produced at operationally required resolutions. But it is vital to poll operational communities often to obtain a realistic view. Without an operational needs assessment or awareness of hard/software capabilities, model resolution constraints, and inherent stochastic limits set by atmospheric variability, effort may be wasted on infeasible, needless, or meaninglessly high model resolutions. Conversely, we cannot let computational convenience solely determine model resolution or specify or override operational requirements.

Sensor placement density is also a major problem in detecting hazardous materials . If relevant atmospheric gradients exist on scales smaller than the distance between sensors, apparent concentrations can be in significant error. Sensor placement density and model grid resolution must be fine enough to resolve significant physical gradients.

B-1c. RESOLUTION and NATURAL VARIABILITY

Regarding model resolution, knowledge of natural stochastic uncertainty due to turbulence is as vital as knowledge of the mean state. 1) Effects models often present results without specifying this uncertainty. This can lead to disastrously poor decisions. E.g., a hazard model may display a sharp-edged lethality footprint, implying that troops relocate by only some minimal distance. But natural variability can render hazardous an area much larger than the footprint displayed. One can mitigate this issue by estimating both the nominal deterministic footprint, **and** its uncertainty. 2) Effectively non-determinable variability places irreducible limits on assessment accuracy. So it is computationally wasteful and facetious to specify an apparent resolution finer than determinable limits imposed by natural stochastic variability.

One must consider the scale and influence of natural variability. E.g., chemical and biological hazard dispersion are determined from detailed wind estimates. Cloud transport is due to mean wind advection; but turbulence spreads clouds by diffusion. What makes turbulence difficult to simulate or assess is that it is multi-scaled. E.g., turbulence scales up to the cloud's own size increase its size; larger scales deviate the cloud's position from the mean. Diffusion cannot be well specified unless both scales are known.

B-1d. COMPUTATION SPEED

We assume that one goal of CBR hazard model development is to create a real-time operational model. Real-time modeling is not always needed, but we feel that criteria for this computationally taxing scenario should be developed now. As noted above, high resolution, high fidelity, real-time modeling presents the most difficult set of demands. Depending on operational needs, it is occasionally possible to reduce fidelity and/or resolution in favor of speed. But then operationally important parameters must not be ignored or estimated so poorly as to be invalid. E.g., stochastic variability can be significantly mis-estimated, if the physical treatment and resolution are too coarse.

Tradeoffs between computational speed and resolution and/or fidelity have often been made poorly, so atmospheric prediction models are typically either slow and bulky or overly simplistic. Models exist which finesse these competing constraints into a reasonable compromise, but much work remains to be done. Assuming no precalculation, a model must finish its atmospheric predictions within a mere portion of the time allotted for the overall simulation. For planning and study, the allowable time might be tens of minutes to hours on workstations or supercomputers, so the time constraint can be met. For combat scenarios or field exercises the allowable time may be just a few minutes or even seconds on a laptop PC, a constraint which has not yet been met. The key constraints are time available to measure, collect, ingest, and assimilate quality data, run complete physical treatments at high resolution, and assimilate model output into the overall combat simulation.

B-2. MESOSCALE MODELING

B-2a. MODELING CONSTRAINTS

In the following sections we discuss the part of the hazard model that computes the mean meteorological parameters, and their variability, over the geographical region of interest. The output of this portion must have enough fidelity to assess battlefield effects adequately. We will not address the operationally required fidelity and resolution here. Instead, we focus on the impact that physics, logistics, and computation time have on the model. At least five factors are needed to attain high fidelity:

- accurate, spatially and temporally dense input data,
- optimal data assimilation techniques,
- a complete physical treatment,
- accurate computational techniques, and
- high spatial and temporal resolution.

All five can be assembled for planning and study purposes. But for field operations, often none are available.

The main physical features which impact model requirements are terrain and the state of the atmosphere itself. The greater the homogeneity in both, the less resolution and physics the model needs. If significant gradients are present, physics and resolution must both improve. Geographical inhomogeneities produce atmospheric inhomogeneities, but strong atmospheric gradients can exist even over homogeneous terrain or large water bodies. These include e.g. convective cells, temperature inversions, radiation fogs, funnel clouds, roll vortices, layer stratus, stratocumulus and cumulus convection, microbursts, clear air turbulence, shear zones, jet streams, nocturnal jets, gravity and inertial waves, hurricanes, and squall lines, as a partial list.

For example, to assess the atmosphere over a region, a model should at least maintain mass conservation. When slopes are present, more physics must be included. In moderate terrain, momentum balance is also required to maintain fidelity. If temperature inhomogeneities exist, energy balance is needed. If enough water evaporation and recondensation occur, the energy balance must include moisture physics. Beyond more physics, the resolution of the model grid must increase to resolve the inhomogeneities, and the method by which the equations are solved must account accurately not only for mass but energy transport rates as well.

The model time step is also influenced by inhomogeneities. The time step must be short enough to follow both air parcels and fast waves between successive grid points. If not, computational instability can result. The final outcome has been a model that demands large computational resources and long run times.

B-2c. NESTING AND EMBEDDED MODELS

A model can mitigate shortfalls in local input data density (but not accuracy) partly by increasing the quality and breadth of its physical treatment and by being laterally bound by larger scale models that continually ingest non-local data. I.e., good regional scale prognostic atmospheric flow models have been embedded in continuously running continental or global scale weather forecasting models, such that the regional scale model requires as little in the way of initial input as data from one local rawinsonde balloon launch. Multiple finer scale grids are nested within such regional scale models to predict local conditions. However, even when the finer scale grids include only small subsets of the entire regional scale domain, this nesting process still entails a drastic "orders of magnitude" loss in computational speed. This speed loss precludes the stand-alone use of such embedded models in real-time simulations.

B-2d. COMPUTATION TIME versus RESOLUTION

With increased resolution, speed loss occurs because computation time rises faster than the cube of the resolution increase. I.e., doubling a predictive model's spatial resolution requires doubling in both horizontal directions, a halving of the time step, and (with a geometrically stretched vertical grid spacing) perhaps a factor of 1.2 increase in vertical resolution. So a doubling in resolution means about one decade more computer power and a commensurate increase in random access and storage memory, if the same run time is to be maintained. For a combat region of a few tens to several hundred kilometers, one kilometer is about the current real-time resolution limit. This applies for running a nested mesoscale model on a supercomputer. The resolution limit grows to about three kilometers for high-end workstations, ~5 kilometers for PCS, and perhaps 8 kilometers for laptops, since PCS and laptops are also somewhat memory limited. Note that to assess accurately the immediate area of interest, a considerably larger area must also be simulated, because the model should be most accurate well away from any "edge" effects due to the lateral or top boundaries.

In stark contrast, for combat simulations in rough but common terrain like hills and canyons, a more suitable resolution may be on the order of 100-200 meters. This would imply at least two decades more supercomputer power, three decades for a workstation, or four decades for PCS. Moreover, an additional one or two decades may be required to account for real-time prediction and display, and the power to run the rest of the combat simulation. So at the present power doubling rate of 18 months, this would mean perhaps twelve to twenty years of further computer development, depending upon requirements and available platforms.

B-2e. PARALLEL and HYPER-PARALLEL SYSTEMS

Both fine and coarse-grained processor parallelism is touted as a shortcut to high resolution prognosis. But thus far, hyper-parallel computers have not matched Cray level vector performance for mesoscale wind flow applications. This may be because: a) Parallelizing compilers are currently non-ideal. So all applications which run efficiently on hyper-parallel systems are presently hand coded and tuned to the particular system, a tedious process at best. b) Real-world parallel performance is bandwidth rather than processor limited. So, though total potential floating point performance greatly exceeds uni-CPU or vector systems, the real bottleneck is limited I/O rates between, to, and from all the CPUs and shared memory systems. c) Some code portions are simply not parallelizable and must be performed serially.

Down-linkage remains another problem for hyper-parallel supercomputer architectures. operational down-links must be non-interruptible and compute schedules cannot be altered by competing applications. Usually, this means a dedicated cluster of workstations. But then this limits the realizable computing gain to perhaps one decade or double the resolution, in exchange for perhaps ½ to one decade of initial cost increment. And there remains the issue of overall system reliability and durability.

B-2f. LOCAL DATA ASSIMILATION AND AVAILABILITY

A number of other factors constrain the fidelity of the pure mesoscale prognostic modeling approach. For example: 1) The required nesting often adds flow disturbances and spurious numerical waves due to terrain/grid mismatches and refraction at the coarse/fine grid interfaces. 2) Local data, particularly in inhomogeneous terrain or conditions, is subject to static influences, such as sub-grid scale terrain, semi-static influences such as sub-grid gradients, and non-static turbulence, all on a finer scale than the volume averaged fields predicted on the model grid. This introduces a type of aliasing, wherein unseen and unaccounted sub-grid scale forces give rise through data ingestion to grid-scale disturbances which are initially incompatible with the model's grid-scale physics. Moreover, the data sensors themselves are subject to various types of error, both systematic and fluctuating. So ingestion of raw local data will result in initially unbalanced model mass, momentum, and energy fields.

Therefore, the model must spend either considerable computational resources and time in re-balancing its initial fields, or if some optimal interpolation is used, such as an adjoint method, the raw data fields are massaged into mass or mass/momentum balance but with some consequent data skewing. Thus, the model physics either gradually or immediately wrests itself free from the constraints imposed by the data.

Model calculations also tend to deviate from reality as they march forward in time, due to compounding errors. So, effectively, this may mean that only the middle portion of a mesoscale model forecast is likely to have high fidelity.

3) Another caveat is that the effects of local data ingestion tend to sweep quickly downstream with the prevailing wind and out of the region of interest (save for upstream gravity wave effects). Thus, having upstream data may be more meaningful to a mesoscale forecast, particularly near the model's lateral boundaries, than having on-site data. But having high density upwind data is quite unlikely for battlefield, as well as most other conditions.

4) Mesoscale surface energy balance calculations and the resulting wind, temperature, and turbulence fields are usually sensitive to land use, surface canopy, and soil moisture data, often unavailable at high spatial/temporal resolution. E.g., soil moisture from AVHRR satellites is available at 25 km resolution, nearly useless for coastlines. This is important when latent heat flux and cloud formation drive part of the atmospheric energy cycle, after local precipitation, and for areas with irregular land/water boundaries, such as coastlines, marshes, and lake strewn areas. Such energy balances affect the timing and strength of land/sea and lake breezes and cloud formation. Cloud cover timing is very critical because low clouds completely alter the surface energy balance by upsetting the incoming and outgoing radiation fluxes in a positive rather than negative feedback loop. I.e., clouds tend to beget more clouds and vice versa, so cloud cover tends to have a U- shaped, all or nothing distribution. This means that the timing of stratus edge burn-off and lift-off or cumulus induced convergence zones is quite difficult for mesoscale prognosis. Moreover, the augmented vertical velocities and increases in overall turbulence at the edges of time-varying cloud fields can almost tempt modelers to treat local scale dispersion predictions on a solely stochastic rather than deterministic basis.

B-3. NESTED PROGNOSTIC/DIAGNOSTIC MODEL APPROACH

In lieu of the above complex set of problems and their interactions, a simpler approach can be taken. Both prognostic and diagnostic models are used for hazard modeling. Prognostic models determine the state and predict atmospheric evolution from a set of input parameters. Diagnostic models assess the atmospheric state over a geographic region at a single instant, the time of input data ingestion. Both types of model assimilate data from the same types of sources, synoptic scale weather prediction models and a limited set of point observations.

B-3a. RUN-TIME REDUCTIONS, the DIAGNOSTIC MODEL

Diagnostic models run quickly, even on PCS, because the computational load drops drastically when the need is to diagnose just a single instant snapshot of the relevant flow fields. Also, the depth and scope of diagnostic model physics and computational techniques, i.e., the basic algorithms, are simpler for reasons given below. Both models produce much the same output, but forecasting demands that the physics must be more accurate and complete within a prognostic than a diagnostic model, since errors compound as prognostic models march forward in time, particularly after ingestion of local data. This is obviously a non-issue for diagnostic models. Also, for both these reasons, prognostic models run much more slowly than diagnostic. Moreover, in prognostic models, as mentioned, any increase in resolution forces a drastic increase in computation time (i.e., computation time increases faster than the cube of the resolution) because it entails not only a finer grid along at least two of the three spatial dimensions but also a finer time step increment to retain computational stability. But, for diagnostic models, a finer spatial grid does not require finer temporal resolution.

When a large geographic region is assessed, there will often be significant geographic features and gradients in atmospheric parameters. Thus, a full physics treatment is needed even for diagnostic modeling of the area, and the complexity approaches that of a prognostic model. For smaller regions, physical approximations can be made in the diagnostic model as long as the input parameters to the model are of high quality. This is the key to computation time savings using the nested models approach. In such an approach, the physical forcing responsible for variations in regional and coarse local scale flow and weather can be treated by a prognostic model running at relatively coarse time and spatial resolutions, thus quite quickly. Smaller scale influences, such as flow dynamics induced by local terrain, can be assessed by a diagnostic model running at high resolution and nested inside the prognostic model. Since a diagnostic model runs at much higher resolution than prognostically feasible and only outputs a single snapshot of the relevant fields, it can easily assimilate local data while incurring less aliasing and no field imbalance problems. Since it is designed to be data dominated with simpler physics, the diagnostic model also suffers less from lack of surface canopy resolution and energy balance issues.

The prognostic model can be pre-run, configured to provide new output when there are significant changes, or updated continuously. Since it runs at low resolution, it is fast enough to do any of the above, yet maintain reasonable fidelity. Even though the diagnostic model is run at high resolution, it is inherently fast since it does not account for larger scale physics or future changes. Moreover, when the time window of interest and the time resolution required within that window are only a fraction of the total mesoscale forecast output (for dispersion purposes, typically 10 - 30 minute resolution over a 1 - 2 hour dispersion window, within a 12 hour mesoscale forecast at 1 minute resolution), then the diagnostic model need only be run for a few different times over the spatial domain of most interest. Such sharing of the physics and computation leads to perhaps two to three orders of magnitude savings in computation time. Or with computer speeds tripling every two years, this means the partial bypassing of 8 - 12 years of hardware development.

B-3b. DIAGNOSTIC MODEL CATEGORIES BY PHYSICS

In terms of physics, current diagnostic models can be grouped into three classes: a) those relying solely on mass balance, b) those that also include momentum balance, and c) those which treat energy balance as well. The older models are mostly of type (a). Interestingly, they are not necessarily faster than type (b) models, due to the use of less efficient solutions to the basic equations, numerical methods, and coding. Existing representatives of types (b) and © are few and presently limited to linear models. So non-linear effects are omitted. Type © models can treat flow forced by horizontal inhomogeneities in temperature and therefore pressure but require more computer time.

B-3c. EVALUATION of TYPE (C) MODELS

The additional processing involved in accounting for thermal effects partly negates the inherent speed advantage of diagnostic models. Moreover, thermal effects, such as a difference in temperature between the top and bottom of a slope, will modify winds along the slope. Temperature gradients along slopes of significant vertical and horizontal extent, such as mountains or long valleys, will significantly impact both winds and turbulence. The effect of temperature gradients scales as the square of the horizontal extent over which they exist; smaller scale gradients have little effect, so most thermal effects can be treated in a larger scale prognostic model with grid spacings of ten kilometers or more.

B-3d. EXAMPLE PROGNOSTIC/DIAGNOSTIC MODEL ARCHITECTURE

A 10 km-scale prognostic model would fail to resolve the important impact of smaller scale local terrain on actual flows. However, flow blocking and channeling, etc. by local scale terrain can be well assessed with a sub-kilometer scale diagnostic model. Also, on the basis of the above discussion, the diagnostic model physics can be simplified to dispense with thermal forcing so that it accounts for just momentum and mass conservation. The resulting nested models scheme can be run in real-time, but still account for significant physical forces. Even in principle, the reduced accuracy of this scheme should remain within requirements for valid operational use, and also within the natural variability of the wind. In practice, the ingestion of local wind and temperature data, when available, tends to upset prognostic models, and the canopy roughness and soil moisture needed to predict the critical surface energy balances are usually unavailable at the field operations level.

Moreover, a diagnostic model can employ the same counter-gradient diffusion corrections and parameterizations employed by second order turbulence closure schemes in prognostic models, but also use considerably finer horizontal grid spacings. This implies that the above-mentioned gap in the accountable horizontal turbulence spectrum may also be narrowed. So, in practice the prognostic/diagnostic nested approach could conceivably prove more accurate and reliable for certain conditions than a pure prognostic approach implemented in any practicable manner.

In principle this nested prognostic/diagnostic model approach can now produce physically valid, real-time atmospheric models with resolutions as fine as 250 m, and of sufficient fidelity to correctly assess all important operational effects. This technique should meet most requirements for atmospheric assessment for battlefield and training use. There is evidence that this technique can produce assessments down to 100 m resolution, which can be needed for some hazard effects, and still meet certain real-time and validity requirements.

B-3e. THE MEANING of REAL TIME

By real-time we imply a range of different temporal constraints on hardware from laptops to workstations, depending on situation. E.g., for battlefield winds, temperature, and toxic cloud dispersion, real-time might mean that local fields of these variables must refresh well within a 10 minute input data update cycle. Or, real-time might mean that a decision on optimal troop movement is dictated in less than a minute, given that prevailing winds suggest contact in 10 minutes with effluent from a toxic ground burst initially 3 km distant. Within a DIS environment, real-time might mean that on-screen atmospheric fields such as cloud optical thickness must refresh in a few seconds to maintain viable interactive simulations.

The fidelity needed for simulation depends on purpose and the site being assessed, so the code should be flexible. Then we may adjust the trade-off between speed and fidelity on-line to suit the situation. E.g., for flat or gently sloping terrain and combat elements not requiring hyper fine resolution, diagnostic grid spacings of 2 km or even larger may suffice. If so, current laptop PCS might perform this sort of combat simulation adequately.

B-3f. NESTED MODEL VALIDITY CONSTRAINTS

There are some constraints associated with using the nested model approach which should be noted. They are mainly due to the utilization of the diagnostic model:

- heavier reliance on local data for reasonable accuracy,
- clouds, rain, fronts, and other complex weather phenomena cannot be treated at scales smaller than the prognostic grid spacing by other than sub-grid parameterizations
- extremes in atmospheric stability which induce either highly vertically stratified flows or large, highly convective, turbulent eddies cannot be treated,
- diagnostic model limited to the boundary layer,
- diagnostic models commonly limited to near neutral boundary layer, and to local slopes of about 30 degrees or less,
- time-varying hill or building wake effects cannot be treated.

B-4. TURBULENCE, CLOUD GROWTH, and TRANSPORT

By cloud we mean any hazardous atmospheric constituent localized in area, be it a puff or plume. A cloud's center of mass moves in response to the mean wind. When the cloud is large, any wind shear can cause the cloud to split. So the model should account for multiple clouds, not only to treat actual splitting but also if cloud size exceeds the grid spacing. Spreading due to resolved wind shear is best handled by nominally splitting the modeled cloud into multiple entities, each with its own center of mass and advected by the local wind vector. However, we assume for now that the transport/dispersion model can treat cloud splitting/merging and what follows refers to a single cloud.

Cloud growth is often handled by a simple parameterization of atmospheric turbulence, such as stability categories. Such a parameterization assumes that cloud growth rates are governed by a single set of turbulence statistics. This is not valid for large clouds (or long distance plumes). As mentioned above, clouds grow in response to turbulence at scales of the same order or smaller than the cloud dimensions. Larger scales contribute to cloud meander, i.e., they shift the cloud's center of mass with respect to the mean wind. So the model output should include a natural uncertainty in cloud position.

Since the growth/meander dividing line shifts as the cloud grows, the full turbulence spectrum should be included within both the prognostic wind flow and diffusion portions of the model. If not, this can lead to both under-diffusion and over-transport, due to un-modeled sections of the spectrum and lack of counter-gradient diffusion. I.e., prognostic mesoscale flow models usually have large lateral/vertical aspect ratios. This means that their vertical grid spacing is geometric and much tighter within the atmospheric boundary layer than the horizontal spacing. So convective eddy motions (which are un-flattened by stable stratification and highly diffusive) may be vertically but not horizontally well-resolved. If, as is typical, the second order turbulence closure scheme utilizes a single set of turbulence statistics, this implies that the part of the horizontal turbulence spectrum, and thus energy in the gap between that accounted by the turbulence closure scheme and that explicitly resolved on the grid, will remain unaccounted within the model. E.g., turbulence induced boundary layer growth may be under predicted and, given the incompressibility of flows constrained by, say, a capping inversion, also unrealistically high mean boundary layer wind speeds. So the modeled cloud in such cases will tend to be too long, too thin both laterally and vertically, and transport times will be too short, all by significant amounts.

Another issue is counter-gradient diffusion. I.e., turbulence closures which neglect the spectral aspect may explicitly resolve some of the vertical motions but may not accurately model the heat and moisture fluxes. I.e., the fluxes stream only from grid point to grid point and cannot skip any links in the vertical chain. Moreover, each link in the chain must be down-gradient. Meanwhile, large real eddies and thermals can transfer heat and moisture directly from the surface layer to the upper boundary layer in a single continuous updraft. This transfer occurs because the upper boundary layer is down-gradient with respect to the surface layer, even though gradients across much of the resolved model grid may not be. This can exacerbate the effects of under-diffusion.

However, a full spectral diffusion model requires considerably more computer power because all potential interactions between eddies of all sizes must be considered in a Markovian probability sense. If the full set of Markov chain processes are not included, then one where growth and meander scales for each of the cloud's three dimensions can be considered in the transport and diffusion models. But this does not account for either counter-gradient heat and moisture diffusion or missing lateral turbulence energy in the mesoscale flow model.

SECTION C. HAZARD MODEL ATTRIBUTES

Here we explain briefly various model attributes and present them in matrix form for the model evaluation process and to catalog/record model capabilities. Each attribute category is a subsection which contains the following information:

a. A list of attributes that fall within that category. Each attribute in the list is described by a few words, followed by a "#" sign, then a brief explanation, where needed. Some attributes will be familiar to the informed evaluator, so no explanation is given.

b. A matrix to record how a particular model meets the attributes.

Use of the attribute matrices is fairly simple. The evaluator checks whether or not a given attribute is included in the model. There is also space for comments concerning each attribute. If the evaluator wishes, a number from 0 to 1 can be used for a given attribute to indicate judgement of how well the attribute is met. If this process is used it should be followed throughout all matrices. Such scoring is quite individual and another evaluator probably would not arrive at the same set of numbers.

These matrices can be used for a full hazard model capability, or for modules within the full capability. Thus, not all of the attribute categories will necessarily be used. E.g. if one were evaluating a mesoscale module, the matrices for transport and diffusion models would not be filled out.

C-1. GENERAL INFORMATION

A model should include general information to allow an evaluator to assess its function, validity, and available support. This information can be used to complete the matrices, if available. When using this table the information is not filled in, the evaluator checks whether it is available.

model name
model type # the model may be a module of a complete hazard assessment model, e.g. diffusion.
model development organization # where the technical development was performed
management organization # organization that controls model use and dissemination
responsible manager for the model # name address, phone, email, ftp, and web sites, etc.
support available to users # support types, in field/remote, installation, operation, duration, etc.
support information # addresses, phone numbers, internet, times available, etc.
users manual # hard copy/electronic, availability, and access procedure
user manual quality # completeness, accuracy, currency, organization, ease of use, etc.
mil. stnd. documentation (eg 2167A) # documented physics and computation techniques
technical documentation quality # thoroughness, readability, accuracy
model pedigree (history) # former models from which this one was developed
usage applicability # hazard uses for which the model has been validated
VV&A organizations # names of organizations and people who performed VV&A
utilizing organizations # organizations where model is in use
on line help # whether available
published references # whether there have been any

Model: GENERAL INFORMATION

NEEDED INFORMATION	Comments	Available
development organization		
management organization		
responsible manager		
support available to users		
support information		
users manual		
users manual quality		good___ poor___
mil. stnd. documentation		
technical document quality		good___ poor___
model pedigree (history)		
usage applicability		
VV&A organizations		
utilizing organizations		
on line help		
published references		

C-2. MODULARITY AND STANDARDIZATION

Hazard models should be composed of modules linked by standard interfaces, so new or improved modules may be inserted easily. Interface standards must extend to input formats for both data base and operator entry, output files, and graphical interfaces. Common standards should also extend to detailed elements such as color coding, icon meanings, file nomenclature, directory structures, install procedures, compression schemes and file formats, and up/download procedures. Such modeling standards should be specified and documented. We pose the following attributes to compel standardized model modularity. At times, only a module or subset of the full hazard model will be evaluated. So the evaluator must indicate whether a given attribute is then applicable.

modular input information section # accepts variety of database types and levels, contains tables of default values and allows default overrides where allowable
modular mesoscale model # subroutine structure, pointing vectors, in-line documentation, object oriented code, etc. allow easy upgrades and replacements
modular transport model # same as above
modular diffusion model # same as above - for cases where the total system contains modular sub-models, they should be named, if possible
modular user interface # GUI, command line, or other interface should allow easy upgrade
modular output section # output format well documented and easily upgraded or replaced
standardized input interface # formats as identical as possible for all modules
standardized output interface # same as above
standardized inter-module interfaces # common variable and array passage format
standardized GUI display # standardization should extend to icons, color coding, display structure, menuing, tool bars, display "look", decision trees, etc.
standardized output file structure # extends to files generated by modules as well as the full model output
available via DIS # required if the model is to be used for distributed simulation

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

MODULARITY	Comments	Applicable	Included
input section			
mesoscale model, name:			
transport model, name:			
diffusion model, name:			
user interface			
output section			
STANDARDIZATION			
input interface			
output interface			
inter-module interfaces			
GUI display			
output file structure			
available via DIS			

C-3. BENCHMARKING

This section provides matrix tables to assess model benchmarking and to determine if enough information is available to judge model performance across a range of computers.

C-3a. COMPUTER SYSTEM

CBR models must be ported to operational, acquisition, and training communities using a range of computers, operating systems and processing speeds. This can impact run times, I/O formats, file structures, etc. When advanced techniques, such as adaptive grids, are used, run time depends on the characteristics (dynamic range of gradients) of the situations being modeled. So information concerning run time dependence on the following parameters should be included:

computer system #
available CPU speed # in several standard units such as: megaflops, LINPACK megaflops, integer/floating point SPECMARKS, and for mesoscale prognostic models - grid point*time steps per second on standard models
memory limits # should give primary and secondary cache SRAM, RAM, and hard disk
storage limits # describe storage size and type, i.e., disk, tape, CD, DVD, etc.
display limits # screen size, resolution, number of colors, refresh rate, speed in polygons or voxels/second, display memory, hard copy display capabilities, speed, etc.
server vs local calculation # server availability and type, linkage type and speed, e.g., modem, thin-wire ethernet, T1/T3 lines, number of users, etc.
I/O bandwidth availability # bus type, size, speeds, HD controller type, e.g., SCSI-III.
I/O data structure # e.g., big/little Indian, 32/64/128/256 bit
shared CPU operation / interruptibility # multi-tasking operating system, crashability
security / encryption #
video/display GUI limitations # whether there are any display design restrictions

C-3b. BENCHMARKING SCENARIOS AND RUN TIMES

Benchmarking becomes meaningful when standard scenarios and data inputs for model runs are used. At this time, consensus standards have not been accepted. In the absence of standard scenarios, a complete description of the scenarios utilized should be included

scenarios used #
data input used #
gridding techniques used # any specal techniques used for the scenarios
computation techniques used # techniques used for computation efficiency
run times # run times for each scenario used

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

BENCHMARKING

FACTOR	Comments	Description Included
computer system		
available CPU speed		
memory limits		
storage limits		
display limits		
server vs local		
I/O bandwidth		
I/O data structure		
shared CPU		
security / encryption		
video/display GUI		
SCENARIOS		
scenarios utilized		
data inputs utilized		
gridding		
computation		
run times		

C-4. USER DIRECT NEEDS

C-4a. MODEL USABILITY

Since there are many possible types of users for dispersion models, thought should be given to user friendliness and flexibility. Thus, we include the following attributes:

fully documented, with operating instructions # includes module organization and upgrade options
available and affordable # license and dissemination costs & terms specified in documentation
minimal maintenance # manuals include known bugs file and install and upgrade procedures
expertise not needed for use # technical support available and programming unnecessary
field useable, ruggedized # available on rugged standard format media in labeled packaging, easy in-field installation on platforms of varying type and power
automatic archival backups # for power losses and noise problems or EM interference
user friendly # context sensitive hypertext help, glossaries, standard output format, color coding, file naming formats, relational data bases, etc.
adaptable to changing GUIs # assured by code modularity and standardized I/O
adaptable to changing requirements # same as above
multi-level functionality # accessible, facile, and useful for novices, journeymen, and experts.
weather/turbulence output available for other operational uses # as user selectable options

C-4b. OPERATING SYSTEM REQUIREMENTS

operates on existing DoD computer systems #
workstation and PC operating system portable # hardware interchangeable
hardware robust # will run with variable RAM, hard drive size, and video configurations
operating system robust # runs with X Windows, Windows 3.1/NT/95, OS2, System 7 etc.
available via DIS and/or HLA #
bandwidth robust # I/O transferable over ethernet or modem
encryption security # input and results securely transferable by hard or electronic media
multi-task mode capable # will run at same time with other software applications, if needed and will not interfere with or be incompatible with other software whether in single or multi-task mode

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

USER DIRECT NEEDS

ATTRIBUTE	Comments	Included
MODEL USABILITY		
fully documented		
available and affordable		
minimum maintenance		
expertise not needed		
field usable		
automatic archival		
user friendly		
GUI adaptable		
requirements adaptable		
multi-level functionality		
weather outputs		
OPERATING SYSTEM		
existing DoD computers		
operating system portable		
hardware robust		
operating system robust		
DIS and/or HLA		
multi-task mode capable		

C-5. DATA INPUTS

The model must include static databases or be able to import such data from external sources. The three data base types critical for hazard modeling are geography, hazard source descriptions, and physiological response to hazardous agents. Since our report focuses solely on transport and diffusion modeling, we only list data needed for atmospheric modeling and to help characterize hazard cloud diffusion.

C-5a. PHYSICAL SURROUNDINGS

terrain (m) # required resolution for terrain data must be specified
location # transform between lat/long and/or UTM to model coordinates
surface roughness maps # surface type: soil, water, marsh;, canopy height and density
soil characteristics: # soil type, moisture
urban canopy # locations, sizes and shapes of all structures or effective canopy roughness and density
vegetation canopy # locations, height, type of trees or vegetation roughness and density, leaf area indices, diurnally and seasonally varying stomatal resistances
hazard sensor locations # locations and types of agents that can be detected
meteorological sensor locations # locations and parameters measured

C-5b. SOURCES

chemical source capable #
specific chemical munitions # includes or can import data for specific munitions
biological source capable #
specific biological munitions # same
nuclear source capable #
agent evaporation rates # evaporation rates as functions of temperature, winds, turbulence
agent decay rates # rates depending on meteorology, solar flux, humidity, sulphate/nitrate aerosol loading, including agents carried in various media
agent scavenging rates # by surfaces including aerosols
rain out rates # scavenging by water droplets and deposition on surface
volitization/resuspension rates # rate at which agent is reintroduced from surfaces
droplet/particle size distributions # size spectrum of particles or droplets for agent types
permanent facility characteristics # amount of agent, construction details, release characteristics following munitions or other impact
permanent facility yields after munitions impact # release amounts for various munitions impacts
dissemination efficiency #

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

DATA INPUTS

ATTRIBUTE	Comments	Included
SURROUNDINGS		
location		
terrain (m)		
surface characteristics		
hazard sensor locations		
met. sensor locations		
SOURCES		
chemical capable		
specific munitions		
biological capable		
specific munitions		
nuclear capable		
agent evaporation		
agent decay rates		
scavenging rates		
rain out rates		
volit./resusp. rates		
particle size		
permanent facility		
facility yields		
dissemination eff.		

C-6. REAL-TIME INPUT INFORMATION ASSIMILATION

Real-time data is needed normally only for operations, or more rarely for training. If a simulation scenario is pre-scripted, it will only use real-time data if interactive, i.e., if the hazard situation can change during the simulation due to human intervention. Both source and meteorological information are required in real-time. Meteorology changes continually and thus requires updating to maximize assessment accuracy, while sources enter the battlefield by human action in a non-predictable way.

C-6a. ROBUSTNESS

The higher the information quality, the denser the data stream is in time and space and the more accurate the model assessment can be. However, field situations are non-ideal. Since sensor availability is uncertain and corrupted or missing data is inevitable, operational models must be able to ingest a variety of data and have robust error and internal and inter-data consistency checks, including bad data flagging, and ability to handle gaps. E.g., there may be no sensor in a critical location or it may be sited in atypical terrain such that its output actually degrades the model. The model must also be able to decide which data to use and how to weight the data. Ultimately an expert system is desired, but it is now difficult for a model to make such decisions. Currently, this requires time consuming human intervention. Thus, for the following robustness criteria we only list what must be accomplished, not how.

operate with sparse data, errors, gaps # ingestion, quality control, and interpolation schemes
allow variety of input types, locations, and levels
sensitive to inaccurate data # detect data errors and eliminate or correct

C-6b. SOURCE INFORMATION

location # location of release of agent
specific munition types # amount and type of agent released by specific munitions ATP45
(NBC1, NBC2) default source # default used when specific munition not known
intelligence and/or damage estimates # operator input of estimated source strength and type
linked meteorology calculation and source file # ability to modify source due to conditions
multiple source types for a single event # accept multiple sources of different agents and/or
single source with multiple agents
operator rules of thumb # default estimates of sources
high fidelity engineering calculations # input from a source model, e.g., bunker damage point,
line, area, multiple source types # accept a variety of continuous, moving puff/plume sources,
geometry
source strength/type estimates from data # updates source strength/agent types with field data
estimates source uncertainty # source uncertainty should propagate to effects uncertainty
user amendable default source values # to assess both test hazards and quick operational runs

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

REAL-TIME INPUT INFORMATION ASSIMILATION

ATTRIBUTE	Comments	Included
ROBUSTNESS		
SOURCE		
location		
specific munition		
standard defaults		
facility damage		
met/facility		
multiple agents		
operator defaults		
engineering calc.		
multiple sources		
field data		
source uncertainty		
variable defaults		

C-6c. WEATHER INFORMATION

There are major differences in input from weather models versus local observations. Model data is for specific times and grid locations. Some local data are for fixed sites and times, such as from meteorological towers. But some time always elapses before local data is available for ingestion. Some local observations will be far from the region of interest, some in the immediate area. Local data are not always from well-sited sensors that yield valid, useful input. Weather model input is volume and time averaged, in increments generally larger than the mesoscale model, while local data are often nearly point-like measurements in relation to the grid volumes of the mesoscale model. Both cases give rise to aliasing artifacts from mis-matched model/data resolutions. But both large scale and local data assimilation are crucial for accurate assessment. The model must assimilate:

GWC / FNWOC output # low resolution input data that can supply boundary conditions
high resolution weather model outputs # higher resolution data is available for some areas
local mean meteorological observations # from fixed site towers and buoys for mean winds, temperature, moisture, multiple site capable
radio and/or rawinsonde # vertical soundings of temperature and moisture/wind included
visibility observations # from surface station
radiative flux observations # downward solar/IR, UV; net radiation
aircraft observations # meteorological and/or other parameters reported in near real-time
mobile surface platform observations # vehicles, ships, same as aircraft
turbulence data # cup and sonic anemometers, gust probes, laser scintillation, doppler sodar/radar
remote sensed data # sodar, radar profiler, NEXRAD, and weather radar data
time lagged information # data gathered at an earlier time must be aged
laser celiometer # cloud base gives top of the mixing layer for diffusion cap
satellite data # microwave, infrared, and visible satellite data from GOES, AVHRR, LANDSAT, MILSAT, and other satellites for cloud cover, sea surface temperatures, soil moisture, albedos, radiative balances, precipitation, and land use, and vegetation type. Note that satellite data such as sea surface temperatures, etc. should be calibrated against surface buoy data, etc., when available.

Mesoscale models will not accurately forecast the size and position of individual cumulus clouds within the foreseeable future. So satellite and local observations are needed, which leads to the following attributes: (Note, since cloud siting and precipitation drastically alter local energy balances, that the detailed manner in which mesoscale flow models are nudged by observations of these significant forceings is significant.)

cloud/precipitation location from satellite data # should be aged and adjusted for satellite resolution
local data on cloud and precipitation location # from radiation and precipitation sensors and human observers
precipitation location from weather radar # gives storm cell strength and stage of development.

Model: (Mesoscale___ Transport & Diffusion ___)

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

REAL-TIME INPUT INFORMATION (WEATHER)

ATTRIBUTE	Comments	Included
GWC / FNWOC		
high resolution		
mean met. obs		
multiple site obs		
rawinsonde		
visibility obs		
radiative flux obs		
aircraft obs		
mobile surface		
turbulence data		
remote sensed		
time lagged		
cloud base height		
satellite data		
satellite cloud loc.		
cloud/precip. obs		
weather radar		

C-7. MESOSCALE MODEL

Mesoscale models are central to CBR hazard modeling, producing the wind, temperature, and moisture fields which drive the transport and diffusion models. If they do not perform well, hazard assessment will be poor. Many issues must be considered under mesoscale modeling criteria. We have divided them by category and present criteria for each aspect.

C-7a. DATA ASSIMILATION

Mesoscale models must interpolate a likely sparse meteorological data set to make best guess initial fields with enough resolution for hazard assessment. Then they must march hydrodynamic variables forward to predict future values. Since data are not taken or received simultaneously, the interpolation schemes must adjust for time. The last section lists data to ingest; here we consider how to process that data. The criteria are:

transform data from pressure to real altitudes # indicate from sigma surface to terrain following, curvilinear or other coordinates
optimally interpolate data to model grid # by inverse distance, adjoint, or other methods, including systematic and random data errors and local turbulence for instrument time constants and signal averaging
optimally interpolate data in time # data set to a common model time base for digestion
adjust sonde data location # adjust for drift with wind to correct horizontal location
adjust prognostic forecast with new data # creation of mass/momentum balanced interpolated fields not necessary for nudging purpose
locate clouds with satellite data # used to adjust spatial distribution of insolation and fluxes
locate clouds with local observations # same
error weighted interpolation # adjust weighting for known data quality and site conformity to local volume or areal average
sensor site weighted interpolation # flow may be less sensitive to conditions in some locations
solar insolation from time, date, & location # utilize time, location, and date to determine solar insolation and/or access climatology

Model:

Status: ___ Devel ___ A-Test ___ B-Test ___ Operational

MESOSCALE DATA ASSIMILATION

ATTRIBUTE	Comments	Included
pressure conversion		
interpolate to grid		
interpolate in time		
adjust sonde loc.		
adjust forecast		
satellite cloud locat.		
obs. clouds locat.		
error weighting		
sensor weighting		
solar insolation ...		

C-7b. MODEL CAPABILITIES

Mesoscale models must produce fields of meteorological parameter for diverse geographies. Attributes listed here are for both prognostic and diagnostic parts of the model.

produce basic parameter fields # wind, temperature, moisture, and pressure
produce flux and turbulence fields # output from turbulence closure or similarity calculations
produce vorticity and divergence fields # including active cumulus and terrain wakes, waves
full theater prognosis # specify theater size, resolution, run-time, validity period for no major synoptic weather changes
diagnostic capabilities # specify local area size, highest resolution, run-time
smoothing/filtering at nesting interfaces # to damp numerical instabilities and artificial waves
smoothing/filtering at grid/terrain mismatches # for same purpose as above
treatable terrain slopes (degs) # increased steepness requires higher physical fidelity, insert maximum slope that can be assessed
wind field response to complex terrain # terrain inhomogeneity perturbs winds
non-hydrostatic response for under 5 km grid spacing # for inhomogeneous atmosphere with significant vertical velocity field
continuity includes deep convection when needed # for cumulus and storm predictions
cloud/fog physics, precipitation, and snow/ice included # condensation drastically alters energy balances and thus winds
minimum 1.5 order turbulence closure # for adequate turbulence determination
modify diagnostics with cloud observations # cloud locations to modify surface fluxes and/or localize deep convection
modify diagnostics with hazard sensor report # agent location gives improved wind field information

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

MESOSCALE MODEL CAPABILITIES

ATTRIBUTE	Comments	Included
parameter fields		
flux -turbulence fields		
vorticity-diver. fields		
full theater forecast	size (km sq) resol (m) run-time (min) validity (hrs)	
diagnostic capabil.	size (km sq) resol (m) run-time (min)	
nesting smooth/filt		
terrain smooth/filt		
treatable slopes		deg
complex terrain wind		
non-hydrostatic		
deep convection		
precipitation/snow/ice		
1.5 order closure		
cloud observations		
hazard sensor report		

C-7c. GRIDDING TECHNIQUES

Above we have stated that the prognostic model must meet the required resolution over the full theater of interest. Within that theater there will be regions where much higher resolution is needed. For the next decade it may be impossible to achieve prognostically the resolution needed for that region, certainly to do so in real-time. Normally, this region will be treated by a high resolution diagnostic model. The prognostic model will be required to have nested resolution levels to reach the resolution required to drive the final diagnostic model. We list here criteria that the model should meet to provide a single diagnostic assessment over a limited region of interest:

local area diagnostics only # ability to run local area diagnostics without prognostic model input
nested/variable grid prognostic model # prognostic model must meet resolution requirement or requirement for diagnostic model initialization
variable automatic time steps and grid spacing # gridding and associated time steps responsive to the terrain and agent cloud size as cloud moves through terrain
gridding responsive to the terrain # prognostic model grid variable resolution
proper matching of terrain and physics in diagnostic model # steep terrain in local diagnostic area will require high fidelity
able to treat 20 degree slopes # minimum ability needed, higher slopes often encountered
vertical grid responsive to wind shear # areas of vertical wind shear require high resolution
stand-alone diagnostics # can run local diagnostics without prognostic model input

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

MESOSCALE MODEL GRIDDING TECHNIQUES

ATTRIBUTE	Comments	Included
diagnostics only		
nested/variable grid		
variable steps & grid		
gridding responsive		
20 degree slopes		
wind shear responsive		
stand-alone diagnos.		

C-7d. DIAGNOSTIC MODEL PHYSICAL FIDELITY

Hydrodynamic equations in prognostic parts of mesoscale models must be as complete as possible, given existing computational capabilities. Nested diagnostic models will have less physics to allow high resolutions in small regions. To overcome limited physics, diagnostic models should ingest local data and match results to the prognosed fields. Criteria are:

mass conservation # minimum needed physical fidelity
momentum conservation # needed for terrain with significant slopes (> 5 degs)
energy conservation # for domain with significant horizontal temperature gradients at scales finer than mesoscale prognostic grid spacing (e.g., 10 km)
local data assimilation # needed even if prognostic model assimilates local data too
optimal data interpolation # adjoint or other method to minimize deviation from local data, consistent with diagnostic model mass, and perhaps momentum and energy conservation
smoothing/filtering at nesting interface # same as prognostic
smoothing/filtering at grid/terrain mismatch # same as above
recommended number of levels in the boundary layer # specify the number of levels the model uses to represent adequately the physics
responsive boundary layer # x-y variation of boundary layer depth responds to surface heat flux
include temperature profile/buoyancy # vertical temperature profile included in energy conservation

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

DIAGNOSTIC MODEL PHYSICAL FIDELITY

ATTRIBUTE	Comments	Included
mass conservation		
momentum conserv.		
energy conservation		
local data assimilation		
optimal interpolation		
nesting smoothing/filtering		
terrain smoothing/filtering		
boundary layer levels		N=
responsive layer		
profile/buoyancy		

C-7e. OUTPUTS

Mesoscale models must provide output to transport and diffusion models. The simplest type of output, hazard corridors, requires only mean winds. More sophisticated results demand a wider range of meteorological parameters and their uncertainties. The following outputs from each grid point or between them are needed to run advanced transport/diffusion models:

mean wind field # over full theater, high resolution in nested areas
mean temperature field # same as above
mean relative humidity and moisture fields # same as above
virtual and equivalent potential temperature fields # both ambient and within natural clouds
wind variability # both speed and direction variability
temperature and moisture variability # needed to compute turbulence and diffusive quantities
momentum flux # surface and shear produced flux
surface heat flux # both sensible and latent heat, vital for energy balances
surface moisture flux # needed to predict cloud formation/dissipation and energy balances
cloud/fog liquid water content and/or droplet size/density # for cloud, precipitation prediction
cloud details # horizontal location, base height, thickness, type of cloud
turbulence kinetic energy field # for lagrangian particle, puff, or spectral diffusion schemes
output to source module for facility source modification # temperature, humidity, liquid water
mixing/entrainment layer depth # height of inversion base and entrainment zone thickness
long and short wave radiation # surface and flux divergences in/out of clouds
boundary layer quantities: u_*, Θ_*, q_*, w_*, Ri, L # option for similarity-based diffusion models when above-surface input data is missing

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

MESOSCALE MODEL OUTPUTS

ATTRIBUTES	Comments	Included
mean wind field		
mean temperature field		
mean humidity field		
vir/equiv potential temp		
wind variability		
temp/moisture variability		
momentum flux		
surface heat flux		
surface moisture flux		
cloud droplets		
cloud details		
turbulence kin. energy		
facility output		
mixing layer depth		
long & short radiation		
layer quantities		

C-7f. USER INTERFACE

Most user interfaces focus on threats and their effects. But users may wish to tailor or gain more insight into some aspects of the mesoscale part of the hazard model. So the following criteria are also included:

selectable region(s) of interest # adjust boundaries and location of full theater and regions selected for high resolution output

selectable resolution(s) for region(s) of interest # interface prevents grid incompatibilities in nesting configuration

selectable averaging time # calculation time step is automatic, averaging time selectable within reasonable bounds (expert algorithm required here)

expert interface checks database input validity # expert system checks for out-of-valid range and incompatible inputs

expert interface checks user entry validity # expert system checks for entries out-of-valid range or incompatible with terrain, meteorological conditions or theater scenario

output reliability caveat # warns user when output may be unreliable

The above user interface capabilities form is a minimal subset of those available in current models (and accessed typically only by advanced users). Included here are only six which directly affect or monitor model performance. Eventually, a more extensive attribute list may be deemed important for assessing models.

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

MESOSCALE MODEL USER INTERFACE

ATTRIBUTE	Comments	Included
selectable region(s)		
selectable resolution(s)		
selectable avg time		
valid input range		
parameter mismatches		
limits of applicability		

C-8. TRANSPORT MODEL

Transport and diffusion models are often merged and not distinguishable. Yet, their criteria may be regarded separately.

C-8a. METHODOLOGY

Here we assume that the mean wind advects the cloud. Beyond this, models should be able to transport the following types of sources and include the following effects:

surface releases # any release within the surface layer
elevated releases # any release where cloud center starts above the surface layer
above boundary layer releases (to 25 km) # above the mixed layer and any entrainment zone, different turbulence parameterization, allowing for shear and wave generated turbulence
above boundary layer releases (25 to 100 km) # same
fumigation # transport of agent downward through an inversion layer
ventilation # transport of agent upward through an inversion layer
multiple sources # sources in multiple locations or sources of different physical characteristics at the same location, includes sources due to revolitization or resuspension
continuous sources # any source that emits over a period of time (normally > 30 min)
line and area sources # line sources are normally created over a time period but not necessarily, area sources often at one time e.g. spill pool, includes revolitization
moving sources # normally producing a line source of some type
reflections # reflect all or part of a cloud at surface and inversion, adjust puff center or particle trajectory
inversion response # cloud responsive to inversion as a material surface or layer which expends cloud buoyancy, may be independent of centerline motion
wind shear response # transport at different speed/direction across cloud due to wind shear
diffusion proportional to cloud size # turbulent transport segments into meander and growth
canopy drag # winds/turbulence lessen within surface canopy
urban effects # allows wakes, shears, channeling, heat island thermals, and cloud splitting
convective cloud rise # allows convectively induced lifting at cumulus or cloud edge
cloud splitting # allows cloud splitting due to terrain or thermodynamically induced shears and flow separation at and above grid spacing

C-8b. AGENT EFFECTS

The diffusion module considers most agent effects because they modify concentrations. But some effects alter transport by deviating agents from mean wind streamlines. Criteria for these effects are:

buoyant rise # via hot source or conflagration/deflagration/condensation along transport path
dense gas effects # slumping, gravity flows, and entrainment
particle fall rates # rates depend on particle size
jet releases # momentum dominated and pressurized releases
droplet fall rates # dependent on droplet size, and deformation for large droplets

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

TRANSPORT MODEL METHODOLOGY AND AGENT EFFECTS

ATTRIBUTE	Comments	Included
surface releases		
elevated releases		
above layer (to 25km)		
above layer (25 to 100)		
fumigation		
ventilation		
multiple sources		
continuous sources		
line and area sources		
moving sources		
reflections		
inversion responsive		
wind shear response		
cloud size adjustment		
forest canopy drag		
urban effects		
cloud splitting		
convective cloud rise		
buoyant rise		
dense gas effects		
particle fall rates		
jet releases		
droplet fall rates		

C-9. DIFFUSION MODEL

Included are growth parameterization, diffusion method, and types of agent and source effects.

C-9a. GROWTH/TURBULENCE PARAMETERIZATION

It must be recognized that there will be times when no meteorological data is available other than the local wind direction, and an assessment still must be made. The diffusion model must have a fall back scheme for this situation. The criteria are:

stability class # or turbulence intensities by time of day, year, latitude, cloud cover/ceiling height, surface type/moisture
variance driven hazard area # as a function of stability class, wind variance

More advanced parameterization should be available for most situations:

diffusion estimate from PBL similarity # from boundary layer parameters: $u_*\theta_*$, q_*, w_*, L, z_i, and h to get $\sigma_{u,v,w}(z)$ or σ_θ
diffusion from turbulence statistics data # usually as function of σ_θ and wind direction
over-land and over-water turbulence distinctions # e.g., over water drag law or other scheme
time varying cloud center lines # includes meander, not just static Gaussian plume or puff
mass conserved puff splitting and merging # to shorten puff modeling time
mass variance conserved puff splitting and merging # same
momentum conserved puff splitting and merging # to preserve initial trajectories
altitude dependent growth rate # turbulence depends on altitude
cloud interaction with inversion # as discussed above
along-wind cloud growth # diffusion along centerline axis as well
differing growth rates for multiple clouds # depending on individual environments
cloud size dependent growth rates # should follow turbulence spectrum
two-particle correlation puff model # Langevin diffusion where puff portions are aware when they are within same eddy, so motions are correlated
particle model follows inertial subrange spectrum # Langevin spectral behavior coincides with -5/3 power law
particle model includes drift diffusion # avoids downward drift when neutrally stable, e.g., accounts for up/downdraft asymmetry
particle model avoids clumping # i.e., avoids time scale/path length shortening and trapping at surface inversion
model avoids diffusion jumps at stability bounds # avoids discontinuities in particle velocity or diffusion rate at convective/neutral/ stable stratification interfaces in space and time
history dependent dynamic boundary layer # layer characteristics responds to flux history
droplet/particle size inertia effects # diffusion depends on size dependent inertia

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational Chem ___

DIFFUSION MODEL GROWTH/TURBULENCE PARAMETERIZATION

ATTRIBUTE	Comments	Included
stability class		
variance hazard area		
PBL similarity		
turbulence statistics		
land/water distinction		
time varying center		
mass conserved		
mass dist. conserved		
momentum conserved		
altitude dependence		
inversion interaction		
along-wind growth		
multiple cloud diff.		
size dependent growth		
2 particle corr. model		
inertial subrange spect.		
drift diffusion		
clumping avoidance		
avoids diffusion jumps		
dynamic bound. layer		
size inertial effects		

C-9b. LOCAL EFFECTS

The following parameters modify local winds, turbulence, and fluxes and must be included in a diffusion model:

surface roughness # affects surface layer wind speed, flux, and turbulence profiles
canopy effects # canopy wind drag, turbulence spectral steepening, flux modifications, etc.
other urban effects # street canyon, heat island, funneling, wakes, etc.
stability suppression of cloud growth # turbulence levels a function of stability
convective cells # i.e., large cumulus turbulence, up/downdraft zones, pressure head, wakes
stratus cloud edge effects # includes roll vortex motions, differential heating at cloud edges
shoreline effects # sea breeze/outer mixed layer distinctions, over-water subsidence, etc.
man-made thermal source artifacts # heat sources will modify turbulence
inversion fanning and trapping # allows turbulent energy redistribution from vertical to horizontal motions at surface and inversion
ground heat # surface absorption, emission, reflection properties modify thermal balance
ground moisture # absorption and evaporation characteristics affect moisture and heat balance

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

DIFFUSION MODEL LOCAL EFFECTS

ATTRIBUTE	Comments	Included
surface roughness		
canopy effects		
urban effects		
stability suppression		
convective cells		
stratus edge effects		
shoreline effects		
thermal artifacts		
fanning and trapping		
ground heat		
ground moisture		

C-9c. AGENT and NEAR-SOURCE EFFECTS

The following effects modify the concentration of the agent in the cloud and should be included in the model:

conflagration/deflagration # shock wave, thermal radiation, density fluctuation, buoyancy and drag forces, chemical reaction, mass, momentum, and energy entrainment, inversion interaction, shear effects, plume vs. puff
pooling # gravity flows, surface liquid heat transfer, soil adsorption, coagulation
primary evaporation (linked to meteorology) # wind/temperature/humidity dependent
gravitational deposition # interaction with surface due to gravitational settling
surface scavenging # reflection coefficient, surface roughness/canopy type dependent
secondary evaporation (meteorology linked) # wind/temperature/humidity/aerosol dependent
agent decay in the air and ground # downwind homo/heterogeneous decay rate chemistry
rain out scavenging # precipitation/pH/temperature dependent
agent modification via atmospheric chemistry # aerosol/humidity dependent reaction product chemistry, behavior, toxicity
agent modification via aerosol chemistry # downwind heterogeneous surface chemistry
agent modification via canopy chemistry # canopy type, stomatal resistance dependent
isotopic decay # change in isotopes and emissions due to radioactive decay
aerosol/particle resuspension # heterogeneous surface chemical equilibria and thermodynamics
droplet size distribution change with humidity # humidity dependent droplet growth dynamics

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

DIFFUSION MODEL AGENT and NEAR SOURCE EFFECTS

ATTRIBUTE	Comments	Included
conflag./deflag.		
pooling		
primary evap.		
grav. deposition		
surf. scavenging		
secondary evap.		
agent decay		
rain scavenging		
atmos. chemistry		
aerosol chemistry		
canopy chemistry		
isotopic decay		
resuspension		
droplet/humidity		

C-10. TRANSPORT/DIFFUSION OUTPUT

The result of transport and diffusion are agent concentrations in air and on surfaces over time and in the region of interest. Impacts on humans and operations are then modeled. The following transport/diffusion output attributes should facilitate human effects modeling and display at each modeled grid point:

instantaneous concentrations # typically in mass parts per million, billion, etc.
dosage # integrated concentration (mg min / m3)
amount of agent deposited on surfaces # (mg / m2)
amount of agent rained out # (mg / m2)
concentration/dosage uncertainty due to meteorological condition uncertainties # relative vs. absolute diffusion plus trajectory error
concentration/dosage uncertainty due to meteorological variability # same
concentration/dosage uncertainty due to source location uncertainties # normally trajectory uncertainty, but also diffusion uncertainty for significant location errors
concentration/dosage uncertainty due to source strength uncertainties # both amount and type, often just a multiplicative range factor but more complex if release rate changes change the source configuration

The transport/diffusion or other module may output human effects. Human impacts depend on total dose and/or peak instantaneous exposure, hence, the three types of outputs listed above. A standard user friendly display plots lines of constant effect, i.e., isopleths. Exposed humans in the area enclosed by an isopleth will be impacted at greater than or equal to the listed effect. Impact uncertainties stem from human response variations and modeling uncertainties and errors. Atmospheric turbulent fluctuations will raise peak concentrations well above the mean. The following are output attributes needed to produce useful graphical displays estimating human effects.

default hazard corridor # default hazard area estimate in absence of model run
hazard area # estimated area from prediction of conditions from general knowledge of future conditions or from climatology
LCt/x # t-time integrated contours for lethality fraction x
ICt/x # t-time integrated contours for incapaciation fraction x
Miosis # restriction of vision
hazard corridor/area uncertainties # variable size due to modeling uncertainties
contour uncertainties # associated lines showing range of spatial uncertainty
MOP modification # fractional personnel effectivness when in MOP gear

Model:

Status: ___ Develop ___ A-Test ___ B-Test ___ Operational

TRANSPORT DIFFUSION OUTPUT

ATTRIBUTE	Comments	Included
inst. concentration		
dosage		
surface deposition		
rain deposition		
met. condition uncert.		
met. variability uncert.		
source location uncert.		
source strength uncert.		
default corridor		
hazard area		
LCt/x		
ICt/x		
Miosis		
corridor/area uncert.		
contour uncert.		
MOP		

SECTION D: USER REQUIREMENTS FORM

The following form is to be filled out by the person requesting a CBR hazard assessment capability. With this form you specify your requirements, the resources you have available, and weight your requirements. This information will be used to select the system that will best meet your needs.

The first part of this form requests information about your requirements. Brief explanations are given about the meaning and reason for the various requests. In some cases a simple check supplies the answer, in others a brief explanation. The back of each page of the form is left blank for additional comments you wish to make. Please indicate to which section comments apply.

The second section of this form is for information about resources available to support the hazard assessment capability. The format is the same.

In the last section you assign weights to your various requirements. They are your value judgements of the relative importance of the requirements. We understand that assigning weights is not easy, and that you can only do so approximately. Two additional spaces are provided so that you can specify additional requirements, including their weights, if you wish to do so.

It is possible that you may wish to use the hazard assessment capability for more than one purpose e.g. operations planning and real-time operations. If there are significant differences in your requirements for these uses, fill out two forms, or indicate clearly on the back of this User Requirements Form what the differences are.

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D-1 REQUIREMENTS

D-1a. USE REQUIREMENTS
In order to match correctly the hazard model to user requirements it is necessary to know the intended use. Check the use that applies and fill in your run-time requirements, if any, using the three categories indicated.

Operations: the model is to be run in the theater to support military operations. You may check either or both.
Operations Planning ___ run-time (min): desired ___ adequate ___ marginally usable ___
Real-Time Operations ___ run-time (min): desired ___ adequate ___ marginally usable ___

Training: Three categories: Pre-Run, the hazard assessment does not depend on trainee actions; Interactive, the assessment depends on trainee actions during the session; DIS/HLA, the assessment interacts with and can depend on remote site actions.
Pre-Run ___
Interactive ___ run-time (min): desired ___ adequate ___ marginally usable ___
DIS/HLA ___ run-time (min): desired ___ adequate ___ marginally usable ___

Advanced Concepts: The model will be run in conjunction with war games for operations analysis, tactics and/or doctrine development, systems analysis. Either pre-run hazards or operation in a DIS/HLA environment can be utilized.
Pre-Run ___
DIS/HLA ___ run-time (min): desired ___ adequate ___ marginally usable ___

Acquisition: Pre-run scenarios utilized for acquisition decisions, COEAs, Monte-Carlo analysis may be needed.
Acquisition ___

D-1b. GEOGRAPHIC LOCATION REQUIREMENTS
Geographic location is an important consideration because the needed model complexity increases greatly with terrain complexity. If use is in the field, the location is pre-determined, but it is still necessary to specify the types of terrain within the theater for which you will need assessments. More than one type can be checked.

Specify specific region, if there is one:

Generic geographic type(s):
fairly flat land ___ desert ___ land with included water ___
complex terrain ___ coastal ___ coastal complex terrain ___
The geographic area size over which an assessment may be made is important, with two sizes needed: full theater size, and the smallest size (resolution) over which you wish to be able to differentiate variations in the hazard.

full size needed __________ (m sq) smallest resolution __________ (m sq)

D-1c. COMPUTER SYSTEM REQUIREMENTS

You may wish to have the hazard assessment installed on an existing computer system, or wish to have the system be the same as an existing one or one for which your personnel are trained. You may wish to have the capability be fully integrated into existing assets. All such possibilities place constraints on the capability that is delivered to you. Be sure to include any requirement you feel may constrain the hazard assessment configuration.

Existing System ___ Desired System ___ No Requirement ___

PC ___ Specify Type:
UNIX ___ Specify Type:
Other ___ Specify Type:

Dial-In Assessment requested ___

Shared Operation: Will sharing a computer with other applications be necessary? If so, is running at the same time contemplated or will dedicated time for the hazard model be available? Check the appropriate boxes and describe the other software if not stand alone.

stand alone ___ shared operation ___ shared but dedicated time ___

Describe other software:

D-1d. OPERATING SYSTEM REQUIREMENTS

Considerations here are the same as for the computer system, but also includes the display/graphical users interface (GUI).

Operating system constraint: none ___ yes ___
Describe constraint :

Graphical Interface: Will it be necessary for the hazard graphical output and other outputs to be displayed at the same time? Are there configuration requirements placed on the hazard output?

GUI stand alone ___ separate GUI display, shared screen ___ integrate GUI ___

Describe restrictions:

D-1e. AGENT TYPE REQUIREMENTS

There are differences in model and data input requirements for chemical, biological, and radiological hazards. Also, the capability can be used to assess the effects from spills/emissions of other chemical and to smoke/optical effects. Check those desired.

chemical ___ biological ___ radiological ___
smoke/optical ___ fuel spills ___ industrial chemicals ___
nuclear weapon (prompt radiation, blast, thermal, emp, fallout) ___

D-1f. AGENT DELIVERY REQUIREMENTS

Agent introduction means impacts assessment requirements. For some use categories, the delivery mechanisms are known, or anticipated. Check those desired.

theater ballistic missile ___ munitions rounds ___
surface vehicle ___ airborne ___
continuous point source ___ bunker breaching ___ container breaching ___
spill pool ___ cold spill pool ___ conflagration ___

D-1g. OUTPUT INFORMATION REQUIREMENTS

There are many ways to present hazard information. Concentration, dose, lethality, etc. and in all cases the geographic location of the agent. The graphical output will be geographical contours of a particular property, commonly refereed to as isopleths. The uncertainty in the result may also be important for your use. Also needed are types of locations for which assessment are needed, e.g. forest, urban, etc. Check those hazard effects for which output displays are desired.

agent concentration in the air ___
agent concentration on surfaces ___
dosage (time integrated concentration) ___
lethality percentages ___
incapacitation percentages ___
isopleth uncertainties ___

Hazard information is normally presented for exposure in the open air. You may also require other types of locations. Check those that apply.

on and above water ___
within forest canopy ___
above forest canopy ___
within an urban area ___
above an urban area ___
inside buildings ___

D-1h. FORECAST REQUIREMENTS

It is necessary to know whether a hazard forecast is needed or if only an on-demand assessment when needed is sufficient. Check if forecasting is desired.

Forecast Desired yes ___ no ___

Time Period: (how far into the future a forecast is desired) ________ (hrs)

Producing a high resolution forecast over the full theater geographical area is extremely costly in computation resources. Thus, a low resolution forecast is done, and higher resolution assessments produced for only specific smaller areas for times the user indicates. Indicate the size area for which you would like to have a higher resolution forecast.

High resolution area ___________ (km sq)

D-1i. OTHER REQUIREMENTS

List here other requirements you have that are not covered by the above.

Check here if you wish to have default sets of agent input data included ___

D-2. RESOURCES AVAILABLE

D-2a. PERSONNEL AVAILABLE

Is the model to be run by skilled personnel, or by non-experts? What support will the user have available to run the model, and what additional help is needed? Check those that apply.

CBR trained personnel available who will be able to interpret the hazard assessment output ___

weather personnel available who will be able to interpret weather input information and ___
performance of the atmospheric assessment portion of the model

dedicated person will be assigned full time to run the model when assessment needed ___

request on-line support, that personnel will be able to contact experts by phone and/or e-mail ___
to obtain model use support

existing personnel will need training in utilization of the model: on-site ___ can send off site ___

D-2b. METEOROLOGY DATA AVAILABLE

Assessment is enhanced with high quality input data that helps specify the state of the atmosphere. For operations, it is expected that some form of local observations and/or measurements as well as weather forecasts from a weather center will be available. For other uses we assume that high quality, consistent observations can be simulated or existing data files from field experiments used. What you plan to provide or know will be available in the field is specified here. We assume that local data will be hand input through the GUI or data files be directly assimilated by the system.

forecast data from a major weather center ___

standard local surface measurements: wind, temperature, humidity ___

more than one surface measurement location ___

complex local surface measurements: such as wind variability, fluxes, ___
long and short wave radiation, etc.
Specify which complex parameters available:

radiosonde launch data: available within 1 hour ___ older than 1 hour ___

hazard sensor data from sensors in the region of interest ___

field observations of cloud and fog locations ___

visible or IR satellite imagery data (experienced person will be needed to ___
interpret and enter data in the model)

User requests climatology data sets for the area be made available ___

D-3. REQUIREMENTS WEIGHTING

It may appear that weighting the various requirements is an impossible task because more than one of them are absolute, e.g. a particular area must be assessed, chemical agents must be addressed. However, one must recognize that no model will fit the full set of user requirements perfectly, that some trade-offs are unavoidable. For an example of how this applies, refer to the Geographic Location and run-time requirements. You may be willing to trade some resolution for improved run time, or you may prefer to sacrifice computer or operating system convenience for improvements in both resolution and run-time.

You don't have to make these decisions. Your weighting of the relative importance of the requirements will guide the supplier of the assessment capability on how to make them.

The weights must add up to 100.

REQUIREMENT		WEIGHT
Run Time		
Geographic Location		
Computer System		
Operating System		
Agent Type		
Agent Delivery		
Output		
Forecasts		
Other, specify		
Other, specify		
	Total	100

SECTION E: MODEL EVALUATION FORM

The following form is used to evaluate how well a model fulfills user requirements. It is important to note that the evaluation result applies to a specific requirement, it is not a general evaluation of the model's capabilities. The evaluation is designed to be carried out by someone with considerable modeling expertise. Thus, only cursory explanations are provided on the form.

For each requirement, the evaluator assigns a score from 0 to 10, indicative of how well it is felt that the model meets the requirement, with 10 being fully meeting, and 0 being not able to meet. The final score for a model is the sum of the evaluator's scores times the user's assigned weights.

Evaluation is complex because there is not a one-to-one correspondence between user requirements and model attributes. The number of attributes is much larger than the number of requirements. In order to aid the evaluator, mapping of attributes to requirements is provided on the form. The mapping is from attribute <u>sections</u> to requirements, not from individual attributes. Numbers in square brackets, e.g. [D-3b, ...], are the references to the appropriate attribute sections to determine whether the model attributes are adequate to meet the various requirements.

When the Evaluation Form is complete, attach to the User Requirements form for which it was filled out so the two are recorded as a pair. If the user has recorded more than one use on the Requirements Form, and the model being evaluated has different resultant scores for those two uses, complete two Evaluation Forms and record both pairs of forms.

It is possible that in the course of the evaluation a "show stopper" will occur. E.g., there is an absolute requirement that a particular computer system be used and the model cannot operate on that system. In such a case, the evaluation can stop at that point, if the evaluator so prefers, and the reason for not being able to meet requirements recorded.

E-1. MEETING VV&A REQUIREMENTS

A full set of Verification, Validation, and Accreditation requirements have been laid out in the Process Action Team report, and that should be used in completing this section. The following provides a brief format for recording the evaluation. (Note that even though the title of this section is VV&A, here we only assess V&V. Accreditation for a particular use cannot be done by this process.)

Has the VV&A which has been performed for this model been documented and is that documentation available to the evaluator? Yes ___ No ___

Are the assumptions and limitations of the model documented?	Yes ___ No ___
Has adequate code verification been performed using appropriate test data, software test cases, and results with errors and anomalies documented?	Yes ___ No ___
Has sensitivity analyses been conducted with the model from the lowest through the highest levels of model code and the results documented?	Yes ___ No ___
Has the V&V process made use of appropriate verified and validated data sets and valid, documented comparisons made to the real-world situations?	Yes ___ No ___
Have all basic equations and algorithms been verified and all assumptions, limitations, errors, and approximations identified?	Yes ___ No ___
Has the model been accredited for use for the specific application identified by the user?	Yes ___ No ___

VV&A Final Score (0 - 1) ___

E-2. MEETING USER REQUIREMENTS

USE REQUIREMENT / RUN-TIME
One cannot consider only the intended use when deciding if the run-time can be met. The run-time depends on the required spatial resolution, which depends on the complexity of the geographic area.

Meets noted Run-Time requirement:	desired:	No ___	Yes ___
[C3,C7b-d]	adequate:	No ___	Yes ___
	marginally usable:	No ___	Yes ___
Meets DIS/HLA (if needed):	not needed ___		
[C2, C4b]	needed ___	No ___	Yes ___

Use Final Score (0 - 1) ___

GEOGRAPHIC LOCATION REQUIREMENT
Whether or not a model meets geographic requirements depends on three factors: is the model physics inclusive enough for the terrain, is the resolution high enough to capture the terrain features, and can the run-time requirements be met for the highest resolution required.
[C3, C5a, C7, C8b, C9ab]

Model physics adequate for complexity of area: No ___ Yes ___
Sufficiently high resolution available: No ___ Yes ___
Run-time can be met at the highest resolution: No ___ Yes ___
Can the model assess the full theater area? No ___ Yes ___
Can the model produce on-demand assessment for a specific geographic area within the theater? No ___ Yes ___

Geographic Area Final Score (0 - 1) ___

COMPUTER SYSTEM REQUIREMENT
[C2, C3, C4]
No computer system requirement ___ Computer system requirement exists ___
Will the model run on the required computer system? No ___ Yes ___
Will model meet run-time/geographic requirements with the required computer system? No ___ Yes ___

Shared operation not required ___ Shared operation required ___
Requirements can be met with shared operation: No ___ Yes ___
If dial in operation requested can it be provided? No ___ Yes ___

Computer system final score (0 - 1) ____

OPERATING SYSTEM REQUIREMENT
[C2, C3, C4]
No Operating system requirement ___ Operating system requirement exists ___
Can the model run on the required operating system? No ___ Yes ___

No Graphical Interface requirement ___ Graphical Interface requirement exists ___
Can the model meet the Graphical Interface requirement? No ___ Yes ___

Operating System Score (0 - 1) ___

AGENT TYPE REQUIREMENTS
[C5b, C6b, C8b, C9c, C10]
Modeling a given agent type requires the proper data files or inputs, adequate resolution (chemical and smoke require high resolution), and in some cases special physics (e.g. water vapor dependent agent properties).

Checks are placed in the appropriate boxes: check if an agent is required and check if the model is adequate, otherwise leave blank. If the evaluator wishes, a number from 0 to 1 may be used in place of the check for adequacy.

Required ?	Adequate Data	Adequate Resolution	Adequate Physics
chemical ___			
biological ___			
radiological ___			
smoke/optical ___			
fuel spills ___			
industrial chem ___			
nuclear weapon ___			

Agent Type Final Score (0 - 1) ___

AGENT DELIVERED REQUIREMENTS
[C5b, C6b, C8b, C9c]
The two factors for delivery type are whether data is present or can be input for the particular delivery type and whether the agent distribution resulting from that delivery can be modeled.

Delivery	Adequate Data	Model Distribution
ballistic missile ___		
munitions rounds ___		
surface vehicle ___		
airborne ___		
cont point source ___		
bunker breaching ___		
container breaching ___		
spill pool ___		
cold spill pool ___		
conflagration ___		

Agent Delivery Final Score (0 - 1) ___

OUTPUT INFORMATION REQUIREMENTS
[C7e, C10]
Check whether a display type is required and whether included.

Display Type	Included
concentration in the air ___	
concentration on surfaces ___	
dosage ___	
lethality percentages ___	
incapacitation percentages ___	

isopleth uncertainties ___ ______
on and above water ___ ______
within forest canopy ___ ______
above forest canopy ___ ______
within an urban area ___ ______
above an urban area ___ ______
inside buildings ___ ______

Output Information Final Score (0 - 1) ___

FORECAST REQUIREMENTS
[C7]
Determination is whether a forecast is provided and, if so, whether the meteorological prognosis is valid for the required time period.

Forecast not needed ___ Forecast needed ___

Is a forecast provided? No ___ Yes ___
Is the forecast valid for the required time period? No ___ Yes ___

Forecast final score (0 - 1) ___

OTHER REQUIREMENTS
Very briefly note what concepts and attributes you used to score these requirements.

Other Requirement #1 final score (0 - 1) ___

Other Requirement #2 final score (0 - 1) ___

PERSONNEL AND METEOROLOGICAL DATA ADEQUACY
[C4a]
The user of the model provides personnel and input data, most importantly meteorological data. If the personnel are not adequate to run the model, or if the inputs are deficient, quality results cannot be expected.

Are personnel adequate to operate the model?	No ___	Yes ___
Are the available data adequate?	No ___	Yes ___

Resources Adequacy score (0 - 1) ___

E-3. FINAL MODEL SCORE

Record here all of the assigned scores and calculate the final requirements score. Note that VV&A and adequacy of resources are treated as separate scores. Sum the products of weights and evaluator scores to arrive at the user requirements final score, which will have a maximum value of 100.

VV&A Final Score ___

Adequacy of Resources Final Score ___

Requirement	User Weight	Evaluator Score	Product
Run Time			
Geographic Location			
Computer System			
Operating System			
Agent Type			
Agent Delivery			
Output			
Forecasts			
Other, specify			
Other, specify	______		______
Total	100	User Requirements Final Score	

F. SUMMARY and RECOMMENDATIONS

This report outlines a process for evaluating chemical, biological, and nuclear radiological hazards from releases into the atmosphere. The process development effort has been substantial. However, the fraction of the modeling community involved in this development was small and only two candidate DoD models have undergone partial evaluation. Thus, a comprehensive evaluation method is presented here at the initial creation stage, i.e., prior to refinement and general acceptance by the modeling community. In this summary, we outline a requisite testing stage and also some further steps needed to conclude development of the evaluation process and gain its general community acceptance.

F-1. COMMUNITY ACCEPTANCE

F-1a. MODELING COMMUNITY

There are several aspects of acceptance that must be addressed:

- Are the listed model attributes technically valid for evaluation purposes?
- Do the attributes address computation issues adequately?
- Are the attributes useful for evaluation?
- Is the attribute list inclusive enough to accomplish a comprehensive evaluation?
- Can DoD users interact profitably with this process?

To respond to these questions, we recommend that our team work with several members of the modeling community who provide DoD models and with DoD users who must initiate the process by completing the Users Requirements Form. The modelers would examine the process while testing it on their own models. Users would examine how well the Form captures and correctly represents their needs. By conducting interviews and studying such modeler/user evaluations, the team would revise the process where needed. Evaluation, testing, and refinement would continue as models are improved, providing the needed DoD evaluations and insuring that the process continues to meet DoD needs.

F-1b. USER COMMUNITY

The user community has a wide variation of expertise with respect to CBR hazards and what is required to produce a quality assessment. An attempt has been made here to produce a User Requirement's Form which will capture their requirements in such a way that it can be used in the model assessment process. In order to do this adequately, the form must be usable by the non-expert, and they must believe that it represents their needs. The current form should be filled out and critiqued by a number of users, from the operational to the acquisition communities. Information obtained in this manner would be used to revise User Requirements Form.

F-2. REQUIRED ADDITIONS TO THE EVALUATION PROCESS

A valid evaluation must use standard methods accepted by the community at large. Hazard modeling requires that atmospheric and agent data be gathered, statistically analyzed, and compared with modeling theory and parameterizations, utilizing a valid comparison technique.

F-2a. BASELINE CASES

Model performance cannot be assessed readily using outputs obtained for different conditions. A set of standard cases must be developed, based on real situations for which valid data are available. Such a set of cases should be developed on an early priority basis.

F-2b. DATA BASES

Model validation requires real data inputs and comparison of model output with real data. A wide range of experimental studies have been used for such comparisons. Most of these studies were performed in developing older models, and most such data is inadequate to validate current and emerging models. Meteorological data archived in many older studies is unacceptably sparse or the tracer used was non-conservative and results were ill-quantified. We should identify studies yielding data and thus cases good enough to validate current models and include in standards set for model evaluation.

Existing data may not be available to test models for the full range of applicable conditions. Thus, we recommend that planners of future experiments determine gaps in available data and set a high priority on closing them. Such planning should be undertaken in close coordination with the evaluation committee.

F-2c. COMPARISON TECHNIQUES

There is at present no commonly accepted process for comparing models with each other and with experimental data. Due to the wide range of variables in both the field data and the model output, statistical techniques are required. Just as standard scenarios are needed, standard comparison techniques are required. It is recommended that the aid of MORS be sought to establish the techniques.

F-2d. MODEL SELECTION

There are currently in existence a large number of mesoscale, transport and diffusion models. It is unrealistic to try to assess all of these models. An attempt should be made to determine which subset of the existing models are viable candidates for DoD use. Once this is done, those models should be evaluated using the process described here .

F-3. NON-DOD USERS

The focus of this report has been the DoD community. The current military environment is one where an increasing number of operations with the civilian community are required. In the CB arena, questions are being asked in Congress about the national level of preparedness to protect the US civilian population from terrorist attacks using weapons of mass destruction, and expectations are that the military will participate in that protection. Protection in real time, developing doctrine and tactics for response, training of CONUS personnel to carry out such response, etc. will require the cooperation of many agencies, e.g. DoD, FEMA, DoE, NRC, etc.

One of the cornerstones of CBR preparedness and response will be the hazard assessment model. High priority must be given to having the various agencies utilize the same models. One step in accomplishing this is to have them use the same model evaluation and selection process. We recommend that this process be briefed to other agencies, with the purpose being to have them adopt it, or to arrive at a modified process accepted by all.

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