We have a ubiquitous plan. Planning for it is an everyday occurrence, yet it still manages to foul up our plans. Recent military examples abound, such as dust clouds that grounded sorties in Operation Allied Force in Kosovo. To effectively execute missions, the military commander must be aware of the weather and its impact on his/her equipment, personnel, and operations. There are a number of weather-impact decision aids (WIDAs) that determine weather effects on mission-selected equipment and operations. Generally, these WIDAs may be broken into two subsets: rule-based and physics-based.

Rule-based WIDAs, such as the Army’s Integrated Weather Effects Decision Aid (IWEDA) [1], are constructed using observed weather impacts that have been collected from field manuals, training centers and schools, and subject matter experts. IWEDA provides information (in the form of stoplight charts) concerning which weapon systems will work best under forecast weather conditions; no information is provided concerning target acquisition range.

Physics-based tactical decision aids (TDAs), such as the Tri-Service Target Acquisition Weapons Software (TAWS) [2], employ physics calculations that have their basis in theory and/or measurements. TAWS determines the probability of detecting a given target at a given range under existing or predicted weather conditions. Thus, physics-based systems produce results in terms of a performance metric that take on a continuum of values rather than the simpler stoplight results from the rule-based systems.

The IWEDA
IWEDA, a UNIX-based program written in Java, is a collection of rules with associated critical values for aiding the commander in selecting an appropriate platform, system, or sensor under given or forecast weather conditions. It provides qualitative weather impacts for platforms, weapon systems, and operations, including soldier performance. Each system (Army, Air Force, Navy, and threat) has its list of relevant rules, which include red-amber-green (unfavorable-marginal-favorable) critical value thresholds for one or a combination of the environmental parameters that affect the system. Results are displayed via a matrix of impacts vs. time (see Figures 1 and 2) and map overlays (see Figure 3, page 18) for the region of interest. Environmental data for the region of interest is supplied primarily via the Army’s Battlescale Forecast Model [2], developed for short-range forecasting. The environmental impact rules and critical values for the various systems have been

Figure 1: IWEDA Weather Effect Matrices

Figure 2: IWEDA Full Impacts
occurrence of a meteorological element
range of values, as the point where the
We can further define this critical value, or
with a system (TOW2) resulting in a rule.
occurs in three kilometers.
the effectiveness of, or prevent execution
a meteorological sense, as those values of
computer database that has been tied to
weather database to determine impacts on
force (friendly or threat).
that there will be weather impacts on the
action, but only informs the commander
tool, IWEDA does not dictate a course of
as a C4I tactical weather system, the
Communications, Computers and Intelli-
cent (C4I) tactical weather system, the
Intelligence Center.
Doctrine Command's organizations, field
manuals, and the National Ground and
Intelligence Center.
IWEDA is currently being fielded as part of
the Army's Command, Control, Communications, Computers and Intelli-
gence (C4I) tactical weather system, the
integrated Meteorological System. As a C4I
tool, IWEDA does not dictate a course of
action, but only informs the commander that
there will be weather impacts on the
force (friendly or threat).
IWEDA rules, which interact with the
weather database to determine impacts on
the selected system(s), are determined from
system concepts and are embodied in a
computer database that has been tied to
critical values. The critical values are defined, in
a meteorological sense, as those values of
weather factors that can significantly reduce the
effectiveness of, or prevent execution of, tactical operations and/or weapon sys-
tems.
An example of such a rule would be
"usage of TOW2 is not recommended for
visibilities less than three kilometers." In
this example rule, a visibility of three kilo-
meters (the critical value) has been coupled
with a system (TOW2) resulting in a rule.
We can further define this critical value, or
range of values, as the point where the
occurrence of a meteorological element
causes a significant (moderate or severe)
impact on a military operation, system, sub-
system, or personnel.
In general, the rules are determined by
operational usage (as embodied in the field
manuals, etc.), whereas the critical values are
determined by doctrine, safety, or engineer-
ing factors (people, modeling, or testing).
Currently IWEDA stores information on
102 systems, 86 of which are friendly, 16 of
which are threat-rated.

**IWEDA Operational Usage**

IWEDA is arranged in a fashion that pres-
ents systems, subsystems and components
in a hierarchical fashion. A group of systems
is called a mission; a system often contains
one or more subsystems; the subsystems
often have one or more components. The
user has the option to define which systems
belong to a mission and to delete optional
subsystems and components from a system
thereby allowing a determination of weath-
er impacts from operations or missions at
the highest level down to systems, subsys-
tems, and components at the lowest level.

For missions, systems, subsystems, and
components, the impacts over the forecast
period are shown on weather effects matrix-
es (WEMs, see Figure 1). The WEM is
color-coded; for use with non-color print-
ners, cells are annotated with R (red), A
(amber), or G (green). Red areas indicate
that operations are severely impacted: There
is either a total or severe degradation or the
operational limits or safety criteria have been exceeded. Amber indicates that oper-
ations are marginal and the operational capa-
bility is degraded, or there is a marginal
degradation. Green indicates that there are
no operational restrictions.

Based on requirements, users may query and
view various levels of information: text
impact statements or spatial distributions of
impacts on a map overlay.

**IWEDA Example**

In the following example, a user-defined
mission is created by selecting three friend-
ly and two threat systems. Once the mission
has been configured, the database is queried
to determine the weather impacts on the
systems, their subsystems, and components.
Results are presented as a function of time
and location.

To construct the example mission, the
A-10, AH-64, personnel, SA-14, and SA-16
systems were selected from IWEDA's friend-
ly and threat graphical user interfaces (GUI).
Once these systems have been selected, IWEDA
determines the weather impacts on the
mission; results are presented to the
user in the form of a WEM, as shown in
Figure 1.

Initially, the lower half of the WEM is
blank with the upper half showing the
weather impacts as a function of system(s)
and time. By performing a right click on any
of the colored cells, such as the AH-64 for
22/12 (day/time), condensed impacts are
shown in a scrollable window in the lower
half of the WEM (impacts for the con-
figured AH-64 system have been reproduced
in Table 1). The WEM shows impacts on
the AH-64 system as a function of time and
general environmental conditions, but we
do not know the full (detailed) impact or
where the impact is occurring within the
forecast area.

To determine the full impact statement
and the location, a left mouse click is per-
formed on the AH-64 cell for the selected
day of the month and time, i.e., 22/12. This
brings up the next screen (see Figure 2) that
presents all of the selected AH-64 subsys-
tems and components and their color-
coded impacts.

As in the WEM GUI, initially only the
top half of Figure 2 is presented to the user.
To obtain further information, the user
clicks on one of the colored blocks; in the
example presented, the TV/direct view
sight component of the Target Acquisition
Designation Sight (TADS) has been inter-
rogated. This results in a color-coded map
overlay (Figure 3) showing where the
TV/D is affected by the weather. The full
impact statement, along with its source, can
now be obtained by moving the cursor
(shown as a white circle) and clicking upon
a white area on the map (upper left of cen-
ter).

The associated full impact statement
then appears in the lower half of Figure 2,
which in this case is "Any occurrence of fog
or visibility <1.9 mi (3100m) significantly
reduces the target and background contrast
making target acquisition difficult." Contrast
this with the condensed impact
statement of "Fog and Low Visibility"
shown in the WEM.

In summary, the colored cells in the
WEM display the worst-case condition for
the selected mission, during the selected
time, for the entire forecast region. If the user wishes to
know why a particular cell is red or amber,
further information is available in impact statements, which explain why a particular cell exists. Detailed analysis for the impacted system or sensor can be obtained from the color-coded map.

The TAWS

TAWS [3], a GUI-based program running under the Windows operating system, is a Tri-Service program that includes Air Force, Army, and Navy sensors and targets. TAWS supports systems in three regions of the spectrum: visible (0.4 - 0.9 microns), laser (1.06 microns), and infrared (IR) (3-5 microns; 8-12 microns). It accepts current or forecast weather data to determine target detection range for selected sensors and targets. The commander uses this information for mission-planning purposes or to ascertain which sensors can see the furthest under the given weather conditions.

TAWS performs both illumination and performance prediction calculations (PPC). The PPC can be done for single or multiple locations during a mission. The illumination analysis involves the computation of solar and lunar ephemerides information for a specified location. A mission planner, for example, might be interested in an illumination analysis to determine the time of sunset for a particular mission date and location. For a single location, the PPC could be used to predict detection range for a particularly important target as a function of time, while a PPC for multiple locations along a mission route would be useful to a mission planner predicting detection ranges for a series of key locations as a function of time.

To determine the acquisition range to a given target a number of quantities need to be known: the target-to-background contrast, the atmospheric conditions, solar or lunar luminance, and sensor characteristics, all of which vary with spectral region. We discuss each of these in the following sections and provide an illustrative example at the end.

Target-to-Background Contrast

Contrast is defined as the ability of an observer to distinguish an object from its background; it degrades as the atmospheric path length increases. At visible wavelengths, where radiation scattering from atmospheric particulates is important, the mathematical formulation of the contrast is different than in the infrared (IR), where emission is the dominant process. Since TAWS computes contrast in both of these spectral regions, we present the following formulations.

Visual Contrast Model: The inherent, or zero range (usually defined as the target’s position), contrast at visible wavelengths, \( C(0) \), is the difference between the target, \( I_t \), and background, \( I_b \), radiances, divided by the background radiances,

\[
C(0) = \frac{I_t(0) - I_b(0)}{I_b(0)}.
\]

We may express the apparent contrast at range \( r \) as

\[
C(r) = \frac{C(0)}{1 + \left( \frac{I_b(r)}{I_b(0)} \right) \left( \frac{1}{1/T(r)} \right)},
\]

where \( T(r) \) is the atmospheric transmission, and \( I_b \) is radiation scattered from atmospheric aerosols and gases into the line-of-sight. \( I_p \) is called the path radiance and may be thought of as atmospheric noise scattered into the sensor’s field of view; it is not dependent upon the target.

In TAWS at visible wavelengths, the target and background radiances are determined using Hering and Johnson’s Fast Atmospheric SCATtering model (FASCAT) [4], which calculates upwelling and downwelling radiance terms at specified heights in the atmosphere.

For designated sensor and target altitudes, the apparent contrast is calculated for slant paths, which may include an optional cloud layer. Objects in sunlight or shadow may be viewed against sky, cloud, or terrain backgrounds. The path radiance \( I_p \) and the background radiances \( I_b \) are determined by a multiple scattering calculation using the delta-Eddington approximation [5] in conjunction with the atmospheric model. The contrast is subsequently determined using equation (2).

For visible/near-IR scenarios, the target may be on the ground or elevated. An elevated target may be viewed with an upward or downward line-of-sight (LOS). Sky and cloud backgrounds are supported for the upward LOS; distant earth and low-lying cloud backgrounds are supported for the downward LOS.

Thermal Contrast Model: The inherent contrast at thermal wavelengths is defined as the target temperature minus the background temperature,

\[
C(0) = [T(0) - T_b(0)] = \Delta T,
\]

where \( \Delta T \) is the temperature difference between the target and background. Note that as the temperature increases, so will the inherent radiances, \( I(0) \).

Thus, the contrast in the IR is

\[
C(r) = C(0) T(r) = \Delta T T(r).
\]

In TAWS, \( C(0) \) is determined indirectly by the Multi-Service Electro-optic Signature model (MuSES) [6], which calculates the equilibrium background and target temperatures using antecedent illumination and weather data.

MuSES has two primary components: a thermal analyzer module and a signature model. Thermal analysis is the computation of physical temperature and heat rates that are obtained through energy balance on a node or isothersm element using a finite-difference numerical solution of the differential equations. The main output of a thermal model is physical temperatures and net heat rates that compare to empirical measurements of contact sensors.

The signature analysis is the computation of apparent temperature or radiance, which is composed of an emitted component that is a function of physical temperature and emissivity and a reflected component that is a function of irradiance from its surroundings and its reflectivity. In other words, the signature is what a sensor views and measures the radiance of a target, which is only partially dependent on its physical temperature. Thus, the signature model provides a link between the output of the thermal model and the desired output in signature analyses.

The basic heat source components considered by MuSES include longwave radiation, solar absorption, engine heating, engine compartment air, exhaust gas, track and wheel heating, and convection. Interreflections between diffuse surfaces are also taken into consideration. These various temperatures and effects are used to calculate \( \Delta T \).

Laser Contrast Model: The laser model does not compute contrast.

Atmospheric Information

To determine the loss of energy as radiation passes through the atmosphere requires knowledge of the atmospheric constituents (gases and aerosols) and its state (pressure, temperature, relative humidity, etc.). This loss of energy is expressed in the form of atmospheric transmission, which ranges in value from zero to one and is highly dependent upon the aerosol type present. This loss of energy can be represented by Beer’s law for atmospheric transmission,

\[
T(r) = e^{-(k_a + k_p + k_m)r},
\]

where \( k_a \), \( k_p \), and \( k_m \) are the aerosol, precipitation, and molecular extinction coefficients, respectively. The molecular extinction coefficients are determined in TAWS by using a scaled down version of the low transmission atmospheric propagation code.
LOWTRAN [7]. The aerosol extinction coefficients [8, 9] are read from pre-calculated internal tables.

TAWS contains 10 aerosol and two precipitation models that are used in various combinations by the IR, television/night vision goggles, and laser models to determine the appropriate aerosol and/or precipitation extinction coefficients. The aerosols describe the primary particulates of the air mass close to the surface at the location of interest. The naturally occurring aerosols include rural, urban, maritime, tropospheric, desert, advective fog, radiative fog, and Navy maritime. There are three types of camouflage smokes: white phosphorus, fog oil, and hexachloroethane. A 10th aerosol, in the form of battlefield induced contaminants, is available for situations where there is a persistent pall of smoke and dust that sometimes covers areas where intense combat has occurred.

### Table 2: TAWS Aerosol Models

<table>
<thead>
<tr>
<th>Aerosol</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>Boundary layer background aerosol found in continental air masses.</td>
</tr>
<tr>
<td>Urban</td>
<td>Rural aerosol plus an added component representing soot-like aerosols that include particles produced in urban and industrial complexes.</td>
</tr>
<tr>
<td>Maritime</td>
<td>Characterizes aerosols that include sea-salt particles; the target area is more than a few kilometers inland.</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>Characterizes aerosols found in very clean air masses and in the free atmosphere above the boundary layer.</td>
</tr>
<tr>
<td>Desert</td>
<td>Characterizes aerosols found in the boundary layer of desert, arid, or semi-arid climatic regions.</td>
</tr>
<tr>
<td>Navy Maritime</td>
<td>Describes aerosols found in the boundary layer of oceanic environments; includes wind speed dependence.</td>
</tr>
<tr>
<td>Advective Fog</td>
<td>Characterizes wet aerosols found in dense fogs, where visibility is less than 1 km.</td>
</tr>
<tr>
<td>Radiative Fog</td>
<td>Describes aerosols found in dense fogs, where visibility is 1 km or greater.</td>
</tr>
<tr>
<td>Camouflage Smokes</td>
<td>Characterizes white phosphorus, fog oil, and hexachloroethane smoke.</td>
</tr>
<tr>
<td>Battlefield Induced</td>
<td>A persistent pall of smoke and dust that sometimes covers areas where intense combat has occurred.</td>
</tr>
<tr>
<td>Contaminants (BIC)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: TAWS Aerosol Models

Solar/Lunar Illumination

Illumination analysis in TAWS involves the computation of solar and lunar ephemeris data for a specified location and a series of dates or times. Solar/lunar ephemeris input information is derived from user-input time of day/time of year and latitude/longitude, in conjunction with the Solar-Lunar Almanac Code [10].

The solar/lunar ephemeris information is also computed and used for target acquisition analysis. In this case, in conjunction with variable cloud cover, the solar/lunar position is used to calculate target/background heating for the IR model and inherent target/background radiance for the visible model. The laser model does not use ephemeris information.

### Table 3: Input Relative Humidity (RH) (%) and Temperature (°C) as a Function of Time (HRS)

<table>
<thead>
<tr>
<th>Time</th>
<th>1800</th>
<th>2100</th>
<th>0000</th>
<th>0300</th>
<th>0600</th>
<th>0900</th>
<th>1200</th>
<th>1500</th>
<th>1800</th>
<th>2100</th>
<th>0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>1</td>
<td>-3</td>
<td>-3</td>
<td>-5</td>
<td>-5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>RH</td>
<td>69</td>
<td>74</td>
<td>74</td>
<td>86</td>
<td>86</td>
<td>80</td>
<td>80</td>
<td>69</td>
<td>69</td>
<td>74</td>
<td>74</td>
</tr>
</tbody>
</table>

The results of the model run are shown in Figure 4. The two vertical lines, determined using the illumination analysis capability of TAWS, indicate the sunrise and sunset times. As expected, the detection range is considerably larger when the visibility is greater; for given weather conditions the exercised tank is easier to detect relative to the tank in the off state.

Thermal crossover, defined as the time during the day when the thermal contrast is at a minimum and the polarity of the contrast reverses, generally occurs at mid-morning and late afternoon. For example, in early morning the background temperature may be greater than the target temperature. After thermal crossover, the target temperature may be greater than the background temperature. In the example, ther-
9. Shirkey, R. C., R. A. Sutherland, and M. A. Seagraves. “EOSAEL 84: Vol. 3, Aerosol Phase Function Database PFN-

Conclusions
IWEDA provides the commander with an easy-to-use and interpret tactical application that allows for near real-time evaluation of sensor employment options. Automating the environmental parameter retrieval by using a prognostic data set further enhances the application and allows for realistic planning based on evolving weather.

TAWS aids the warfighter in determining what sensor/weapon system will work best against a user-selected target under adverse weather conditions. TAWS accomplishes this by using accepted sensor performance and aerosol models coupled with proven techniques for determining atmospheric transmission and contrast. In addition to determination of acquisition ranges, TAWS may be used for mission planning and for determination of deltas between friendly and threat systems.

Taken together, these TDAs provide the commander a significant advantage for system selection under adverse weather conditions.

References

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