Naval Meteorology and Oceanography Professional Development Detachment Atlantic

Atmospheric Effects on EO Sensors and Systems

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Table of Contents

Section **Page**

Table of Contents ..... **i**

List of Illustrations ..... **iii**

Introduction **1**

Electro-Optical Imaging: Contrast and Extinction **3**
Electro-Optical Imaging 3
Contrast 3
Extinction 4

Infrared Sensors and Systems **7**
Illumination / Emissivity and IR Sensors 8
IR Sensors and the Target/Background Pair 10
IR Contrast: MRT and MDT 11
IR Sensors and Backgrounds 14

TV/CCD/NVG Sensors and Systems **16**
TV / CCD Sensors 16
Night Vision Goggles (NVG) 17
Illumination and Visual Sensors 18
The Sun and Illumination 19
The Moon and Illumination 21
Other TV/NVG Light Sources 23
TV/NVG Sensors and Backgrounds 24

Laser Systems **26**
Laser Lock-On Systems 26
Laser Ranging Systems 27
Laser System Sensitivities 27

METOC Support for EO Sensors and Systems **29**
Introduction 29
Temperature, Dew Point, Relative Humidity 29
Winds 30
Visibility 31
Precipitation 32
Aerosols 33
Battlefield Induced Contaminants (BIC) 34
Surface Layer 34
Clouds 35
Upper Layer Data 36

Support Products **38**

Appendix A – Glossary **41**

Appendix C - Bibliography **43**

Index **44**

List of Illustrations

Figure 1 – VIS / NVG / FLIR EM spectrum 1
Figure 2 – "The METOC big picture" 2
Figure 3 – Perfect and Diffuse reflectors 3
Figure 4 – Contrast (1 - inherent; 2 - apparent; 3 - threshold) 4
Figure 5 – Extinction 5
Figure 6 – Example Forward Looking Infrared system (left) and display (right) 7
Figure 7 – Black body energy emissions 8
Figure 8 – Dark CONEX box 9
Figure 9 – CONEX boxes 9
Figure 10 – Nighttime FLIR imagery 10
Figure 11 – Tank, Apache with localized hot spots 11
Figure 12 – MRT and MDT 12
Figure 13 – Thermal crossover idealized 12
Figure 14 – Reversing FLIR display polarity 13
Figure 15 – Thermal crossover and natural objects 13
Figure 16 – LITENING II targeting pod 16
Figure 17 – Example Night Vision Goggle set (left) and display (right) 17
Figure 18 – Solar and Lunar Average Illuminance Values (lux) 18
Figure 19 – Twilight sky terminology 20
Figure 20 – Low sunset light level 21
Figure 21 – Lunar phases (left) and cycle (right) 22
Figure 22 – The 40-30 Rule 23
Figure 23 – Indiscernible background features from moon shadowing 25
Figure 24 – Shadows in an urban area 25
Figure 25 – Various laser systems: LITENING II Targeting Pod (left) , ground-based laser designator (MULE), Laser receiver (hellfire) 26
Figure 26 – Laser energy attenuation versus range (left), reflection versus surface roughness (right) 26
Figure 27 – Laser system sensitivities 28
Figure 28 – METOC constituents required by TAWS 29
Figure 29 – Surface and upper layer (TAWS) 34
Figure 30 – TAWS upper layer parameters 37
Figure 31 – Illumination brief 38
Figure 32 – TAWS range versus time plot 39
Figure 33 – TAWS Delta-T plot 40
Figure 34 – TAWS range versus view direction plot 40

Introduction

1. Electro-Optical sensor and systems operate in the optical radiation portion of the electromagnetic (EM) spectrum. This portion of the EM spectrum lies between 0.4 and 100 microns. Currently, most EO sensors supported by METOC operate in the 0.4 to 13 micron range (figure 1).

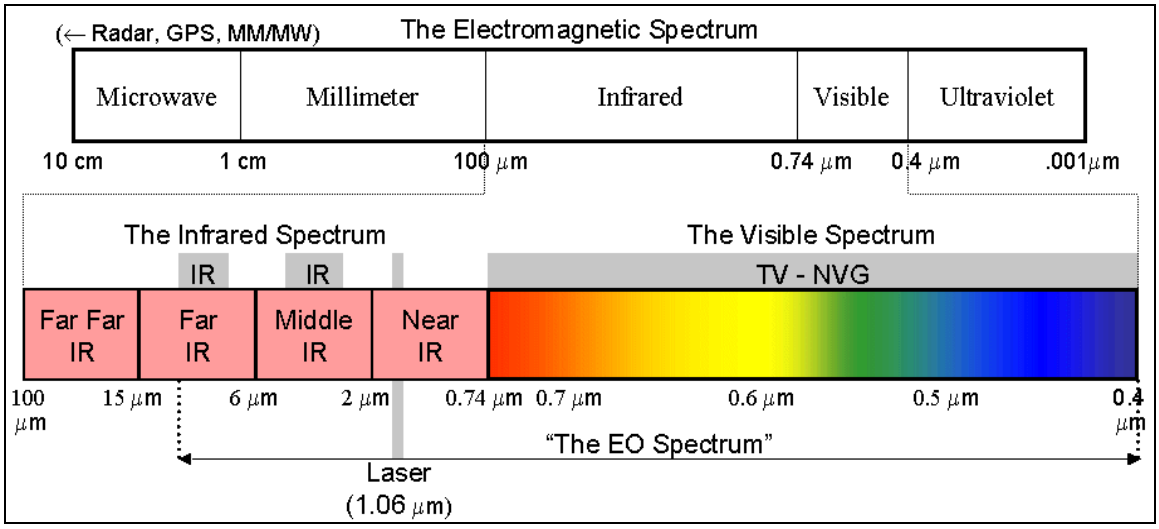


Figure 1 – VIS / NVG / FLIR EM spectrum

2. METOC support for EO systems begins with understanding their physical properties, determining the environmental factors that influence their performance, and learning as much as possible about the area(s) in which these devices will be used.

3. Figure 2 presents an overall picture of the aspects that must be considered to produce an effective, accurate NVG or FLIR effectiveness forecast. Some of this information is easily obtained (sunrise, sunset, etc.), some is not (target position, operating state, etc.). Getting an accurate analysis of target / background conditions often requires interface with INTEL personnel and obtaining information from sources that may be new to you (e.g., UAV imagery). Some considerations are listed below and are discussed within this presentation.

   (a) Obtain as much information as possible concerning any target(s) or search object(s) in question. This includes target construction, heading (front of vehicle / front of building), speed of advance (or whether it is idling), altitude, etc.

   (b) Become as familiar as possible with the target / search area. This means that if the area in question is a runway, you need to know how long it is, how wide it is, what it is made of, how old the surface is, and whether it is wet or dry. Get to know background type(s), terrain irregularities, other local features, and proximity to urban/rural areas. The more accurate this information, the more accurate your NVG / FLIR forecast.

(c) Understand how METOC elements, backgrounds, aerosols, and other factors affect TV/NVG, IR/FLIR, and Laser-based sensors. An excellent guide for this is the TAWS Sensitivity Guide (included with the TAWS program). Other useful training aids are described in this presentation.

(d) A thorough understanding of the METOC elements that pertain to an accurate forecast for the area (cloud cover, precipitation, etc.) is important. It is highly recommended that METOC forecaster runs the TAWS program (failing that, it is recommended that a forecaster is consulted prior to manually entering weather information or using computer model-generated forecast products).

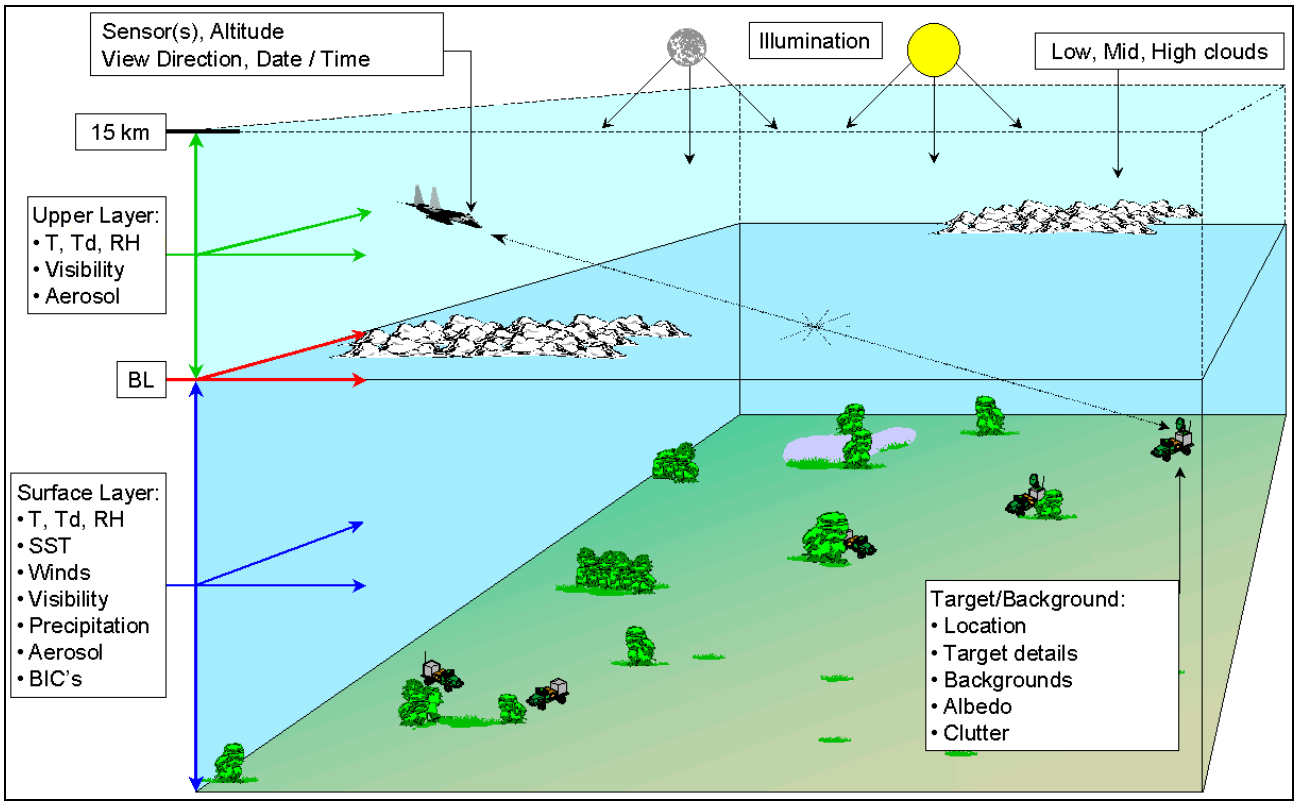


Figure 2 – "The METOC big picture"

Electro-Optical Imaging: Contrast and Extinction

Electro-Optical Imaging

1. All objects with temperatures above 0º K (-273º C) emit (or radiate) Electromagnetic Radiation (EMR). Electro-optical sensors and systems utilize this EMR to form some image of a target scene. These sensors operate in a relatively small portion of the electromagnetic spectrum.

2. Electro-Optical sensors detect targets by using visual, near-infrared, and far-infrared imaging.

   a. **Visual Imaging**. The contrast between target and background reflectivity.

   b. **Near-infrared imaging**. Energy reflected off targets designated by lasers (1.06 *μm*, or near-IR), illuminated with radar energy (mm/mw RADARS), or seen via passive imagery in the case of satellites.

   c. **Far-Infrared Imaging**. Temperature contrast between the target and background.

Contrast

1. EO Sensors primarily rely on visual or infrared **contrast** to seek and track targets.

   a. **Visual contrast** relies on differences in **reflectance (albedo)** between the target and the background. These differences come from the roughness, color, shape, and size of the target and background, as well as solar and lunar illumination levels and angles. Objects can range from perfect reflectors (as in the case of a mirror), which reflect light well but only in a limited direction, to diffuse reflectors (think of flat paint), which reflect incident light in many directions but at relatively weak levels.

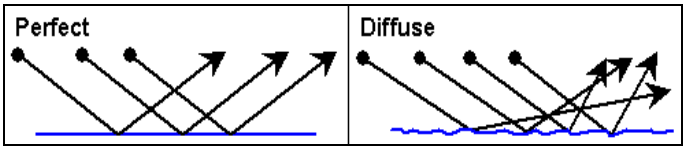


Figure 3 – Perfect and Diffuse reflectors

   b. **Infrared contrast** relies on **temperature differences** between the target and background. These differences come from radiated and/or reflected “heat” energy. IR sensors detect the energy transmitted by an object based on its absolute temperature.

      (1) The amount of energy an object **releases** or **stores** is determined by its absorptivity, thermal conductivity, and thermal capacity.

(2) The amount of energy **transmitted** depends on the object's properties, absolute temperature, surface reflectivity, and angle of illumination.

(3) An object may be classified as **passive**, emitting stored energy ("heat"), or as **active**, generating its own heat (e.g., an engine).

2. Contrast differences between the target/background are expressed three ways: Inherent, Apparent, and Threshold (figure 4).

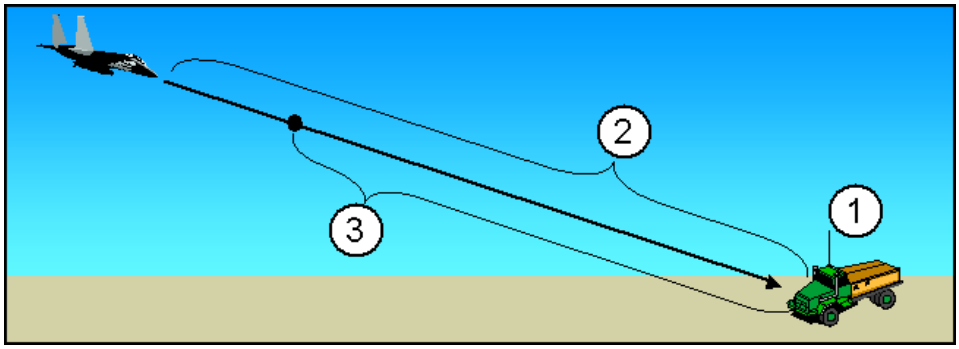


Figure 4 – Contrast (1 - inherent; 2 - apparent; 3 - threshold)

a. **Inherent** contrast (figure 4, point 1) is measured as if you are on-scene, or right at the target/background pair.

b. **Apparent** contrast (figure 4, point 2) is a measurement of the contrast differences from any given distance from the target/background. The contrast difference always gets less as the sensor moves away from the target.

c. **Threshold** contrast (figure 4, point 3) is the minimum amount of energy difference required by a sensor. The sensor in question can be Night Vision Goggles, Forward Looking Infrared gear, an infrared guided missile, or the seeker on the front of a laser guided bomb. The threshold contrast *value* won't change for a given sensor because it is built into the design of the sensor. But **where the threshold contrast is seen by the sensor** will change based on the target/background values and weather conditions in the target-background path.

Note: For the human eye, "threshold contrast" is defined as the contrast where 50% of the observers can detect a target against its background.)

Extinction

1. As EM energy leaves a target/background scene, some degree of deterioration (or loss) of EM energy takes place. This loss is called **extinction** (figure 5).

Figure 5 – Extinction

2. The **extent** of extinction is based on changes in the target and/or background and a variety of METOC conditions. For EO sensors, the primary factors responsible for extinction are absorption and scattering.

   a. **Absorption** is the process by which EM energy is absorbed by substances or atmospheric particles such as water vapor, carbon dioxide, ozone, or oxygen.

      (2) Absorption is VERY SIGNIFICANT with FLIR sensors and is the most significant cause of infrared contrast degradation.

      (3) High absolute humidity, rain, snow, fog, mist, all contribute to absorption. So do other suspended liquids.

   b. **Scattering** is a redirection of photons by molecules, aerosols, or other particles in the air. Because of the small wavelengths in the visible portion of the EO spectrum (0.4 to 0.74 microns), scattering is worst for the visible wavelength. When particle size is less than 5 microns, it is difficult to differentiate between scattering and absorption. (A particle size chart is included in table 1.) There are two types of scattering: molecular, and aerosol.

Table 1 – Average particulate sizes

Particulate	Average Size
Haze	0.05 to 0.5 microns
Smokes	0.2 to 2 microns
Dust	1 to 10 microns
Fog, Clouds	0.5 to 80 microns
Fumes	up to 100 microns
Mist	50 – 100 microns
Drizzle	100 – 500 microns
Rain	500 – 5000 microns

(1) Molecular scattering occurs when light is scattered by particles much smaller than the wavelength of the incident radiation. This scattering becomes negligible compared to aerosol scattering for wavelengths greater than one micron, which means that this type of scattering has the greatest impact in the visible wavelengths. **Rayleigh** scattering is a type of molecular scattering.

(2) Aerosol scattering involves large particles such as dust or smog and scatters light or thermal energy by reflection. The size of the scattering element determines the effect. **Mie** scattering is associated with "light" particulates in the air (think haze), while **Geometric** scattering is associated with heavy particulates (fog).

Aerosol scattering is particularly significant – note that almost everything in the particle chart in table 1 is larger than the visible portion of the EM Spectrum (0.4 to 0.74 microns). As wavelengths **increase**, scattering becomes less of an issue. Since wavelengths detected by a FLIR are about 10 times longer than those detected by NVG's, impact of smaller particles (smoke and haze) on FLIR is relatively insignificant (FLIR can be very effective in conditions that greatly hinder the human eye and NVG's).

Infrared Sensors and Systems

1. Infrared sensors and systems – including Forward Looking Infrared (FLIR) sensors (figure 6) – rely on energy emitted from a target area. Thermal contrast between the target and its background is very important.

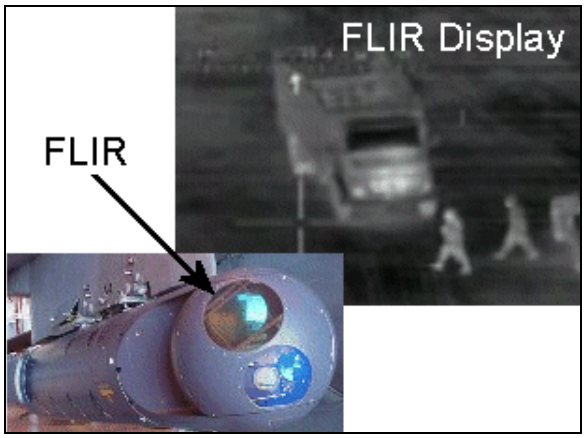


Figure 6 – Example Forward Looking Infrared system (left) and display (right)

2. IR sensors and systems are used 24 hours a day. These systems are passive in nature (they emit no energy) and provide an improved capability to detect, identify, and classify targets and areas of interest that are otherwise concealed from visual or radar detection. They provide the advantage of 'seeing' not only at night but also through many smokes, fogs, and other obscuring conditions.

3. IR Seekers on weapons overcome the daylight-only, adverse weather limitations of the other systems. These sensors track heat generated by target and provide a pilot a pictorial display of the target during darkness and hazy or inclement weather. IR seekers require a minimum threshold in order to lock onto a target.

4. FLIR systems scan operator-designated areas along a line of sight or aircraft flight path and display the resulting imagery in a televised image. In aircraft, FLIR is displayed in either a Head Up or Head Down Display (HUD / HDD); azimuth and elevation gyros provide stability for the FLIR set to maintain a steady image of the target areas regardless of aircraft movement (aircraft mounted laser systems use a similar process).

5. “Normal” IR sensors (not enhanced with coolants) operating in surrounding ambient temperatures can sense a very large temperature range and can normally detect changes in temperature of about 0.4° F (0.2° C). **Cooled** devices (sensing elements are sealed inside a container that cools them to below freezing) provide heightened sensitivity and resolution, and can detect much smaller temperature differences (as small as 0.2 F (0.1 C) from more than 1,000 ft (300 m) away).

Illumination / Emissivity and IR Sensors

1. As with TV/NVG systems, illumination plays an important part in determining IR sensor capabilities; sunrise and sunset times, max daytime illumination, elevation and azimuth of the sun are all important factors for FLIR use. However, while night vision goggles rely on illumination in the **visual** portion of the spectrum (about 0.4 to 0.74 microns), FLIR relies on the **infrared** portion of the electromagnetic spectrum.

2. **Emissivity** is the ratio of emitted radiation from an object compared to the emitted radiation from a black body[1] at the same frequency and temperature. The emissivity of an object is dependent upon the object's physical properties (concrete has an emissivity of 90%, while polished steel has a value of 10%), but heating and cooling effects applied to the object (e.g. direct sunlight, precipitation, etc.) can modify the amount of radiation emitted by an object. It is interesting to note that the amount of increase or decrease in heat released is not equal to the amount of heat added or removed.

   Refer to figure 7. Raising the temperature of a black body from 310º K to 314º K (the top of the gray curve), results in a 3% rise in temperature but a **14%** rise in emitted energy. Temperature increase and emitted energy is not a one-to-one relationship; **the more an object heats up, the more energy it releases**. (The opposite is also true.)

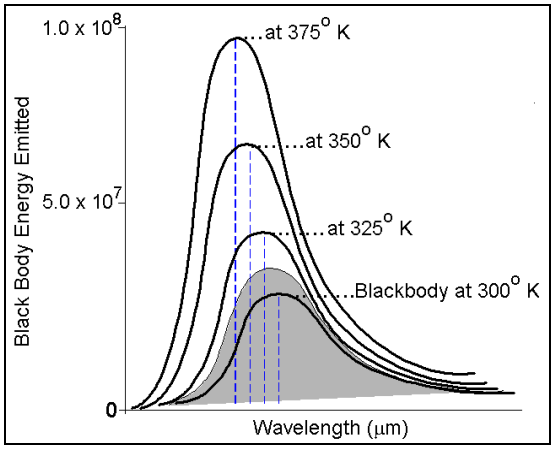


Figure 7 – Black body energy emissions

3. Depending upon the background conditions, FLIR devices can usually detect objects with a **high** emissivity value better than objects with a **low** emissivity value (low emissivity objects appear cold thermally, even though their physical temperature might be warmer). An object's emissivity is determined by its thermal response.

   An object's **thermal response** is simply a measure of how fast an object heats or cools. Objects heat and cool at different rates, so contrast will vary over a 24-hour period. Factors that determine an objects thermal response are **absorptivity**, **thermal conductivity**, **thermal capacity**, and **surface area to mass**.

[1] A **black body** absorbs all and reflects none of the radiant energy falling on it. It is also a perfect emitter of radiation. Black bodies are used for theoretical measures of emissivity.

a. **Absorptivity** is a measure of how much energy is **absorbed** by the skin of an object. Objects with a high absorptivity heat and cool faster, and have higher daytime temperatures and lower nighttime temperatures. High absorptivity examples: concrete, stone, brick. Low absorptivity examples: polished metal, sand, calm water surfaces. Because of its darker color, the CONEX box in figure 8 has a high absorptivity.

Figure 8 – Dark CONEX box

b. **Thermal Conductivity** is a measure of how rapidly heat is **transferred** from the surface of a material to the interior. The lower the conductivity, the faster an object will heat and cool.

c. **Thermal Capacity** is a measure of how much heat an object can **store**. The lower the capacity, the faster an object heats and cools, since most energy remains close to the surface.

d. An object's **surface area-to-mass ratio** determines how hot or cold an object will appear thermally if two objects (with the same absorptivity, conductivity, capacity) are made of the same material. If two objects have the same shape but a different mass, the smaller-mass object heats and cools faster because it has a larger surface area-to-mass ratio. If two objects have the same mass but a different shape, the object with a greater surface area heats and cools faster.

Figure 9 – CONEX boxes

e. Refer to figure 9. The CONEX boxes are painted identically. The sun is providing an equal amount of heat to each box. But the box at left is empty, while the box at right is completely full of dark bricks. Which box has a higher thermal response? And how does this apply to real-world situations?

The empty box at left has a higher thermal response. It has the same absorptivity as the box at right, but it has a low thermal conductivity value (it heats and cools faster), a low thermal capacity (an empty box won't store much), and a high surface area to mass ratio.

On a summer day, the empty box will initially warm faster and, for a while, be easier seen with an IR sensor than the full box. Once the full box warms, however, it will stay warm longer. Following a hot day, the full box will retain its heat much longer after sunset. How does this apply to real-world situations? Remember that IR sensors are used to measure contrast ***differences*** – so both the target and its surroundings need to be considered.

IR Sensors and the Target/Background Pair

1. Most *natural* objects have a **high** emissivity value, which means the majority of their thermal signature is from self-emission (rocks heat up, rocks cool down). In contrast, objects with a **low** emissivity have a high thermal reflectivity and tend to reflect more of their background temperature. (You can correlate this to the albedo of an object: the higher the albedo value, the higher the reflectivity and the lower the emissivity.)

   a. If oriented horizontally, low emissivity objects normally reflect the night sky and under clear conditions appear very cold (think of a vehicle windshield). Under broken or overcast conditions, the cloud base temperature will be reflected on the horizontal object.

   b. Vertically oriented low emissivity objects will usually reflect the temperature of a surrounding background (e.g., hills or canyon walls).

   c. Water produces a variety of images depending on the viewing angle, the surface condition (rough or smooth), and water temperature. Lower viewing angles result in more reflectivity from the sky; higher viewing angles result in viewing the water's self-emitted energy (what is seen by the IR sensor is a function of the water temperature).

2. Many natural objects and most, if not all, manmade objects have very complex thermal signatures. Think of the same vehicle windshield described above, but next to a very hot vehicle hood. The rear of the vehicle has been facing away from the sun all day. The vehicle – which is air conditioned – has sitting on a new asphalt parking lot, which is surrounded by grass that hasn't been cut in three weeks.

   As seen in figure 10, thermal environments are very dynamic and complicated (day or night). Thermal signatures of both target and background scenes vary widely based on time of day (IR devices can be used 24 hours a day), season, and many METOC variables such as cloud cover and precipitation.

Figure 10 – Nighttime FLIR imagery

IR Contrast: MRT and MDT

1. Many targets have a positive contrast at night (object warmer than background) and a negative contrast on sunny days (object cooler than background). Adding object-generated heat to the scene (or removing it) changes the thermal signature of the target and consequently changes the contrast. In the IR portion of the EO spectrum, discrimination of objects in the thermal scene is possible when objects have even a slightly different radiated temperature than their immediate background.\

2. Passively heated objects (buildings, bridges, roads, non-exercising vehicles, etc.) radiate energy according to their physical properties and the amount of energy they receive (look again at the buildings in figure 10). These objects tend to have a more even heat distribution than objects with self-heating properties, such as vehicles with engines. The latter can emit additional heat that causes the object to look distorted (but more easily seen) when viewed with IR sensors. In some cases, these "hot spots" are very localized (figure 11).

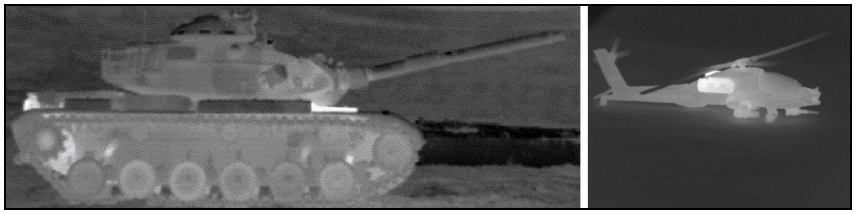


Figure 11 – Tank, Apache with localized hot spots

3. The contrast between an object and the background (or between different aspects of the object alone) is affected by many constantly changing variables. These include time of day, orientation of the object with relation to the EO sensor, weather conditions, solar/lunar angle of illumination, and, if applicable, the operating state of the object (i.e., a static object such as a building versus a stopped, idling, or moving target). These variables, particularly when associated with a self-heated target, cause differences that are unique to IR sensors.

4. IR sensors detect targets based on heat differences; the entire target (or portions of it) may be hotter or colder than the background. It follows that an IR sensor may be able to resolve the entire target or just the target's hottest or coldest spot. Two terms are used to describe these conditions: Minimum Resolvable Temperature and Minimum Detectable Temperature.

    a. **Minimum Resolvable Temperature (MRT)** is associated with **whole target detection ranges**. The MRT is the temperature at which **all** facets of the target are visible based on view direction and altitude. The entire target is taken into consideration when target characteristics are evaluated. When the MRT detection range is greater than the MDT detection range (figure 12, left), the entire target will be resolved before the target's hot or cold spot.

b. **Minimum Detectable Temperature (MDT)** is associated with **hot spot/cold spot target detection ranges**. The MDT reflects the temperature of the hottest or coldest facet of the target visible to pilot based on view direction and altitude. Only a single facet of the target is taken into consideration when target characteristics are evaluated. When the MDT detection range is greater than the MRT detection range (figure 12, right), the target's hot (or cold) spot will be resolved before the entire target is.

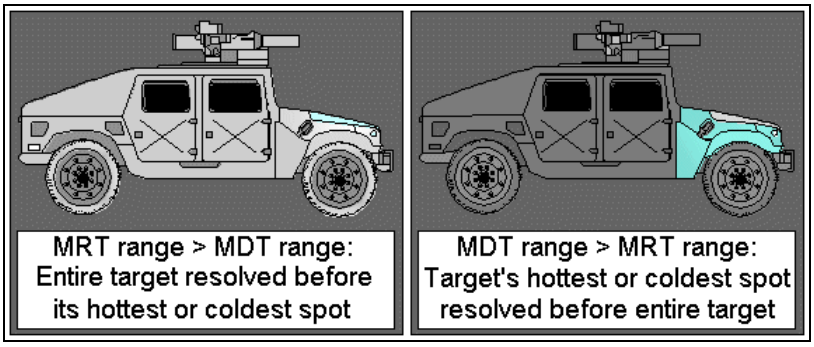


Figure 12 – MRT and MDT

Thermal Crossover

1. Most man-made and natural objects in the battle scene undergo continual temperature changes that follow rather predictable trends. But because of the variations in emissivity values and variations in the background, individual target objects and their backgrounds heat and cool at different rates during the diurnal cycle. Because of this, there are periods within the diurnal cycle when the temperature of one can equal (and sometimes pass) the temperature of the other. These periods are referred to as ***diurnal or thermal crossover*** (figure 13).

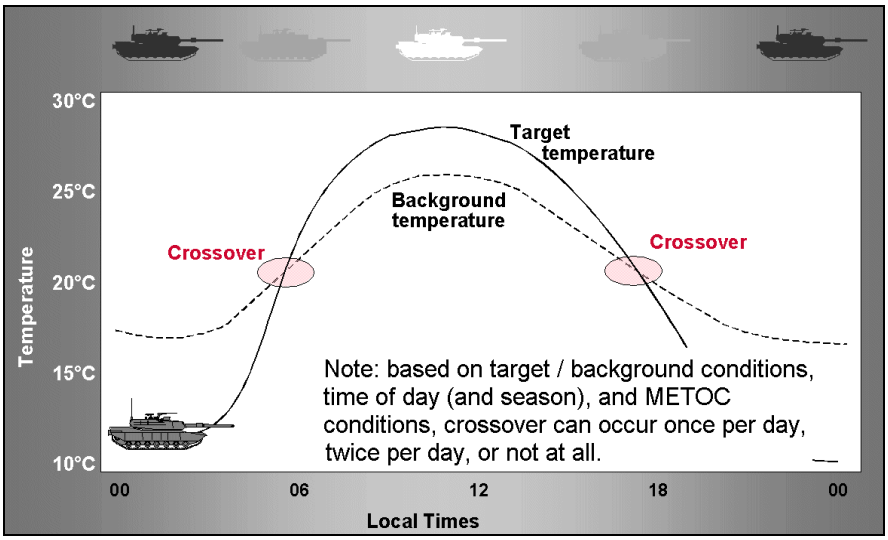


Figure 13 – Thermal crossover idealized

2. During periods of thermal crossover, IR-based devices are less effective. Some other considerations concerning crossover:

   a. The contrast differences are the key; it doesn't matter if the target is warmer than the background or the background is warmer than the target. IR sensor operators, in fact, have the capability to switch views (by switching the polarity on their display) to better enhance their picture (see figure 14). The key is, the amount of temperature **difference** between the target/background. The bigger the difference, the better the target is seen against its background.

Figure 14 – Reversing FLIR display polarity

   b. As the note in figure 13 indicates, crossover may occur once, twice, or not at all. It may occur twice for three days (once after sunrise, then again before sunset), then not occur for the next two because of METOC conditions or because the targets that were on the move are no longer exercising and, in fact, are now camouflaged.

   c. Crossover is not limited to "traditional" targets and their background(s). Thermal crossover can also regularly occur with natural objects (figure 15).

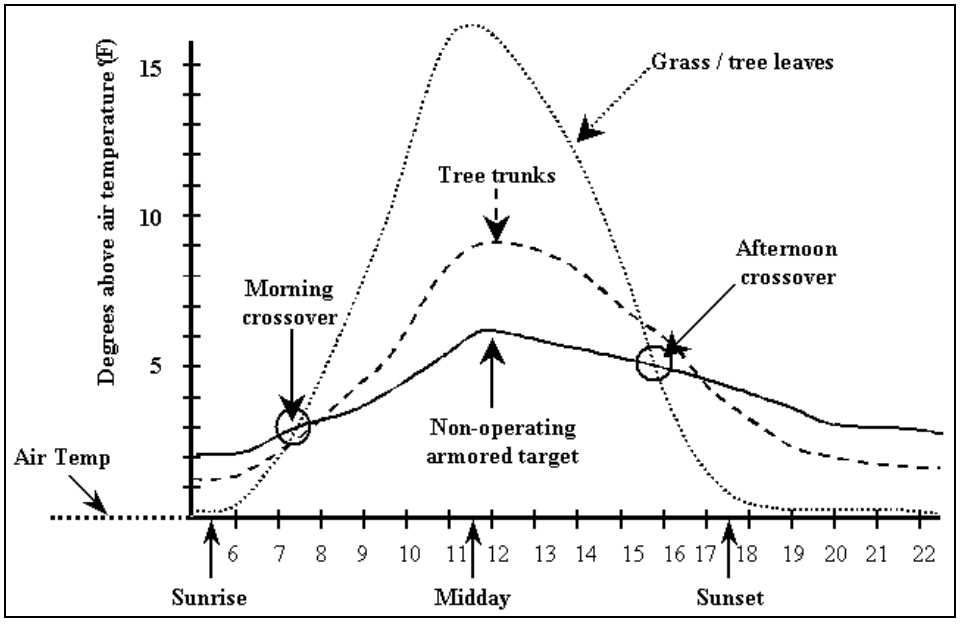


Figure 15 – Thermal crossover and natural objects

3. It is important to remember that man-made objects can be (and frequently are) **modified**. Objects can be camouflaged; buildings can be painted, resurfaced, or

have air conditioning installed; vehicles can be painted with a flat paint; and explosive reactive armor (ERA) or additional armor plating can be installed on vehicles for protection. Changes such as these can easily change the thermal characteristics of an object and, therefore, the ability of IR sensors to detect it.

IR Sensors and Backgrounds

1. Potential targets can be associated with a wide variety of backgrounds, and each background type (sand, asphalt, rock, concrete, asphalt, etc.) has different inherent qualities (reflective, absorptive, etc.). **Terrain types and backgrounds have the same issue with thermal response as targets do.** Examples:

    a. Vehicles operating at night (such as tanks) are easily seen against terrain areas that do not hold heat well after the sun goes down (such as desert backgrounds). The same vehicles traveling along a new asphalt road in a city won't stand out as well because the asphalt will retain the heat longer.

    b. Desert areas are hot in the daytime but very cold at night; plowed fields tend to hold heat longer, as do asphalt areas (particularly new asphalt areas).

    c. Ocean areas tend to gain and lose heat very slowly (water has a very low thermal response).

    d. Seemingly **small** background details are very important. Examples: the moisture in soil affects its cooling rate; the growing state of vegetation affects the efficiency of evapotranspiration; soil type (average, loam, sand, clay, peat, gravel, desert sand) defines the reflectivity and heat capacity of the soil; surface color affects the reflectivity and emissivity; wetness affects thermal properties of the structure.

2. **Clutter**. Urban areas, areas with varied backgrounds or terrain (particularly with different thermal characteristics), or areas with many targets in the general operations area lead to increased **clutter** in the target area. (Think of the large variation in surfaces that heat and cool in even a small urban area: houses, warehouses, office buildings, streets, parks, vehicles, signs, residents, etc.). The higher the clutter, the more difficult it is to select the right target. The lower the clutter, the easier the target is seen against its background.

3. IR Sensors require a **line of sight** with the target area; variable terrain can have an impact on whether the target areas are seen. Shadows are formed when a thermal source (usually the sun) is blocked by terrain or other objects for a long enough time to create thermal differences. The thermal shadows usually dissipate shortly after sunset or if the sun is obscured by clouds.

4. ***Generally***, the higher (and therefore the further away) the IR sensor is from the target/background area, the less thermal contrast seen from the target/background

pair. But for IR sensors, reflectivity and emissivity of the water surface varies with the change in radiation angles incident on the surface. At steeper angles the water surface is almost entirely emissive (radiates its surface temperature). At shallow angles (up to 5 degrees) calm water reflects most energy. This is significant because when the IR sensor is operated at low angles, there may be no perceived thermal difference between the horizon and the water. From the perspective of the IR seeker (or FLIR operator), the horizon can disappear.

5. The more you know about the background and overall terrain and local features in the OPAREA, the better you can tailor your METOC support for FLIR sensors. For more information, refer to the Information Sheet, “TAWS and Backgrounds.”

TV/CCD/NVG Sensors and Systems

1. TV, CCD, and NVG sensors and systems detect targets by visual imaging, which relies on visual contrast differences between target and background reflectivity.

2. Visual contrast relies on differences in reflectance between a target and its background. Most target/background objects reflect some energy in the visual spectrum. The key is the **differences** in reflectance between objects.

TV / CCD Sensors

1. TV sensors operate best in daytime or bright nighttime conditions (e.g., clear skies with a full moon). The scene viewed by a TV-based guidance system appears on a cockpit television screen, allowing the pilot to view a target area, select a target area, center crosshairs on it, and launch the guided munition. Newer television systems have screen magnification capability that enable the pilot to identify and lock on to smaller and more distant targets.

2. A Charge-Coupled Device (CCD) is one of two main types of image sensors used in digital cameras. When a picture is taken, the CCD is struck by light coming through the camera's lens. Each of the many (i.e., millions) of pixels that make up the CCD converts the light into electrons, which are converted to a digital value. Very high detail in the output. Charge-Coupled Devices (CCD) (figure 16) provide excellent visual acuity and the ability to operate in lower light levels. This can significantly improve daytime performance when compared to a FLIR sensor. CCD's are found on newer generation Electro-optical systems (figure 16).

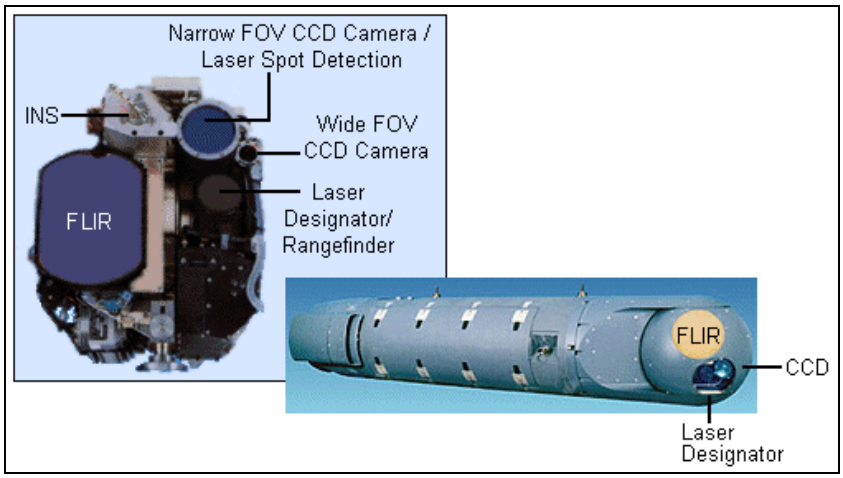


Figure 16 – LITENING II targeting pod

3. TV and CCD sensors rely on existing light conditions. Energy to / from the target/background area depends on sun/moon angle, general target and background conditions, and METOC conditions.

Night Vision Goggles (NVG)

1. Night Vision Goggles (figure 17) are electro-optical devices that intensify (or amplify) existing light instead of relying on a light source of their own. Ambient light is captured, amplified thousands of times, and displayed for the user via a phosphor display (users do lot look directly through NVG's; they view an amplified electronic image displayed on a phosphor screen). The ambient light comes from the moon, stars, sky glow from twilight conditions, or distant manmade sources such as cities.

2. NVG's are sensitive to a broad spectrum of light, from visible to infrared. Energy to / from the target/background area depends on sun/moon angle, general target and background conditions, and METOC conditions.

3. An NVG phosphor screen is purposefully colored green because the human eye can differentiate more shades of green than other phosphor colors. NVG's have various image magnifications; the distance at which a human-sized figure can be clearly recognized under normal conditions (moon and star light, with no haze or fog) depends on both the magnifying power of the objective lens and the strength of the image intensifier. Viewing ranges are typically – but not always – much less than with other devices such as FLIR.

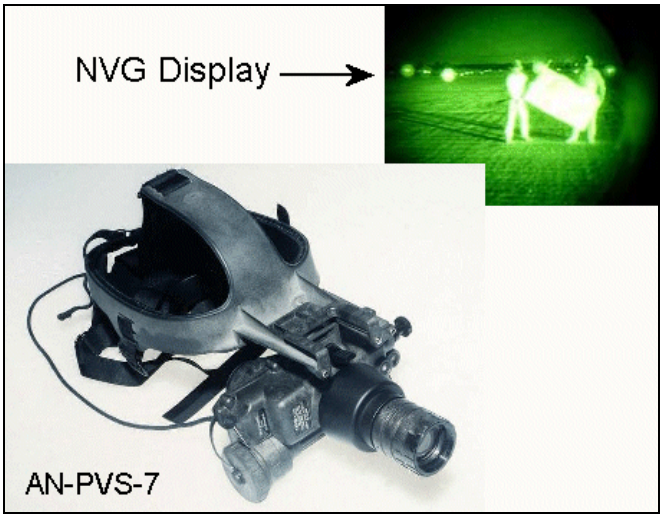


Figure 17 – Example Night Vision Goggle set (left) and display (right)

4. There are three important aspects of night vision goggles that highlight the importance of accurate METOC support:

   a. **Depth perception** is acutely reduced with NVG's. It is often difficult to distinguish accurate distances of objects in the viewing area, or determine how close or far away an object really is.

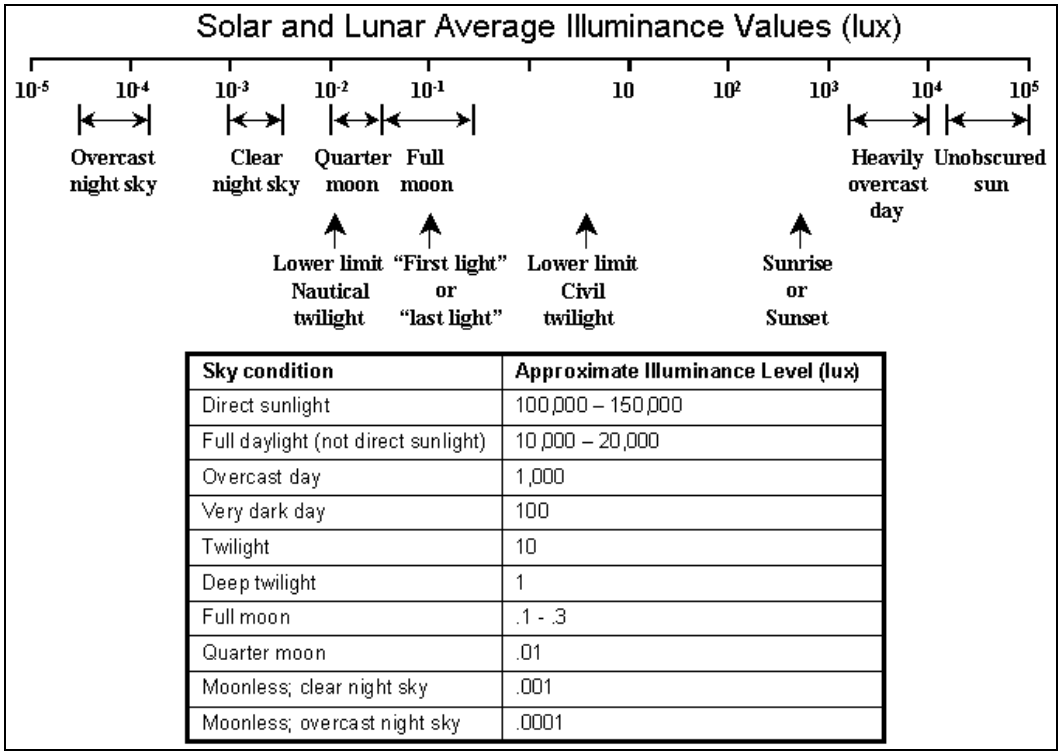
b. NVG's cannot provide the same **sharpness level** to which users are accustomed to in the daytime. As illumination (or contrast) decreases, NVG visual acuity drops, resulting in a more "fuzzy" image.

c. **Peripheral vision** is lost while using NVG's. "Normal" peripheral vision is around 190 degrees. NVG's bring this value down to around 40 degrees (based on the NVG model); side-to-side scanning becomes necessary to take in potential target scenes.

Illumination and Visual Sensors

1. Illumination is defined as "…The luminous flux per unit area at any point on a surface exposed to incident light." Illumination is sometimes referred to as *illuminance*. Units are typically expressed in lux, millilux (mlux), or foot-candles.

2. The primary sources of illumination for night vision goggles are the moon and (rising/setting) sun. Solar and lunar average illumination values are provided in figure 18. Illuminance values are important considerations for providing visual sensor support, as these sensors have minimum thresholds below which performance is less than satisfactory.



Sky condition	Approximate Illuminance Level (lux)
Direct sunlight	100,000 – 150,000
Full daylight (not direct sunlight)	10,000 – 20,000
Overcast day	1,000
Very dark day	100
Twilight	10
Deep twilight	1
Full moon	.1 - .3
Quarter moon	.01
Moonless; clear night sky	.001
Moonless; overcast night sky	.0001

Figure 18 – Solar and Lunar Average Illuminance Values (lux)

3. Aircrew members using NVG's are keenly aware of the minimum amount of illuminance (in lux) required for their NVG's to be useful. Learn this, and you will be

able to better define NVG windows of opportunity for your customer. The minimum threshold is sometimes defined in text as **0.0022 lux (2.2 mlux)**. This is an older threshold value, however, and users of newer-generation NVG's may have lower minimum thresholds.

The Sun and Illumination

1. TV and CCD sensors are primarily used in the daytime, but can also be used at night with the right conditions. Optimum times of operation are based on the season (i.e., available daylight hours), sunrise/set times, moon and night sky illumination, terrain and urban conditions (shadowing), and METOC conditions. Aircrews begin using NVG's after sunset and stop using them before sunrise. Start and stop times vary with the season, with METOC conditions, twilight times, and moon and night sky illumination. The twilight sky is defined according to the position of the sun (figure 19):

    a. **Sunrise** is defined as the crossing of the visible horizon by the upper limb of the rising sun. **Sunset** is defined as the crossing of the visible horizon by the upper limb of the setting sun.

        (1) Remember that the sun's **elevation** and **azimuth** are important considerations for operations involving visual sensors. TV and CCD sensor operators may not just want to know the amount of daytime hours; they may also ask for the sun's maximum elevation during the day and the azimuth of the sun (from their position) when maximum elevation occurs. The sun's elevation and azimuth during time over target (TOT) may also be a requirement.

        (2) From a NVG operator's perspective, it should be obvious that the most illumination provided by the sun during twilight times occurs in the vicinity of where the sun is rising and setting. What is not so obvious, however, is the sun's azimuth, from your customer's current position, when these periods occur (your customer may want this information).

    b. **Civil twilight** begins in the morning and ends in the evening with the center of the Sun geometrically 6 degrees below the horizon. Civil twilight is the limit at which illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished. At the **Beginning of Morning Civil Twilight** (BMCT) and the **End of Evening Civil Twilight** (EECT), the horizon is clearly defined and the brightest stars are visible under good atmospheric conditions in the absence of moonlight or other illumination. Before BMCT and after EECT, artificial illumination is normally required to carry on ordinary outdoor activities. Complete darkness ends before BMCT and begins before EECT.

        Civil twilight times correspond to *approximately* 30 minutes before sunrise (morning twilight) and 30 minutes after sunset (evening twilight).

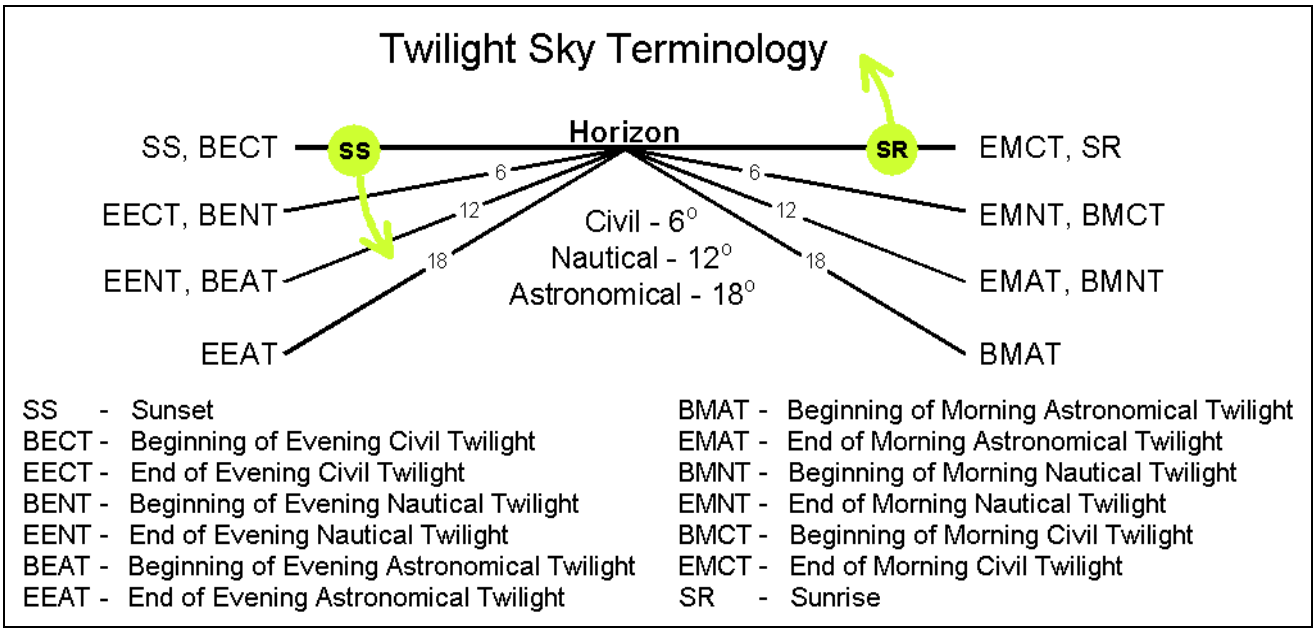


Figure 19 – Twilight sky terminology

c. **Nautical twilight** begins in the morning and ends in the evening with the center of the Sun geometrically 12 degrees below the horizon. At the **Beginning of Morning Nautical Twilight** (BMNT) or **End of Evening Nautical Twilight** (EENT), under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable. Detailed outdoor operations are not possible and the horizon is indistinct.

   Nautical twilight times correspond to *approximately* 1 hour before sunrise (morning twilight) and 1 hour after sunset (evening twilight).

d. **Astronomical twilight** begins in the morning and ends in the evening with the center of the Sun geometrically 18 degrees below the horizon. Before the **Beginning of Morning Astronomical Twilight** (BMAT) and after the **End of Evening Astronomical Twilight** (EEAT), the Sun does not contribute to sky illumination; for a considerable interval after the beginning of morning twilight and before the end of evening twilight, sky illumination is so faint that it is practically imperceptible.

   Astronomical twilight times correspond to *approximately* 1½ hour before sunrise (morning twilight) and 1½ hour after sunset (evening twilight).

2. There are good and bad points – plus associated hazards – with using visual sensors during sunrise, sunset, and twilight.

a. **Low light levels and shadowing** (figure 20). The periods right after sunrise and just after sunset are sometimes referred to as a "**visual sensor's thermal crossover**." This is because features normally discernible with visual sensors tend to get washed out from the low light levels and long shadows associated with these periods.

Figure 20 – Low sunset light level

b. Most aircrews generally consider the periods from BMCT to sunrise and from sunset to EECT to be too bright to use NVG's. Night vision goggles intensify the faint glow of twilight during this period and most consider the resulting scene to be too bright. (It is important to note, however, that METOC conditions can reduce the light levels to a more acceptable level during this period.) When only the contribution of the sun is considered, many aircrews consider it best to wait for BENT (12 degrees) to launch (and, of course, to launch (well) before BMCT (6 degrees) in the morning). After the sun is 12 degrees or more below the horizon, "sunset sky glow" is no longer a factor. This phenomenon degrades NVG effectiveness and is one of the rules that many aviators use to fly using NVG's.

The Moon and Illumination

1. The moon is usually the primary source of natural illumination for NVG operations. Although the moon reflects about 7% of the sunlight that strikes it, the amount of light provided by the moon is highly variable, and depends upon the lunar cycle, the moon angle, variations in the earth-moon distance (negligible for NVG considerations), and the lunar albedo (reflectivity). In the latter's case, the moon is about 20% brighter during the first quarter (waxing) than it is in the last quarter (waning) because of differences in the lunar surface (see the moon phases in figure 21, left).

2. The **lunar cycle** (figure 21, right) is the primary lunar illumination factor. The moon goes through several phase changes during its 29.5-day revolution around the earth. The phases are influenced by the season and global position of interest.

   a. During the **new moon**, light from the sun does not reach the side of the moon facing the earth. This period lasts 7 days, during which the moon is completely in shadow and provides only a low-light level.

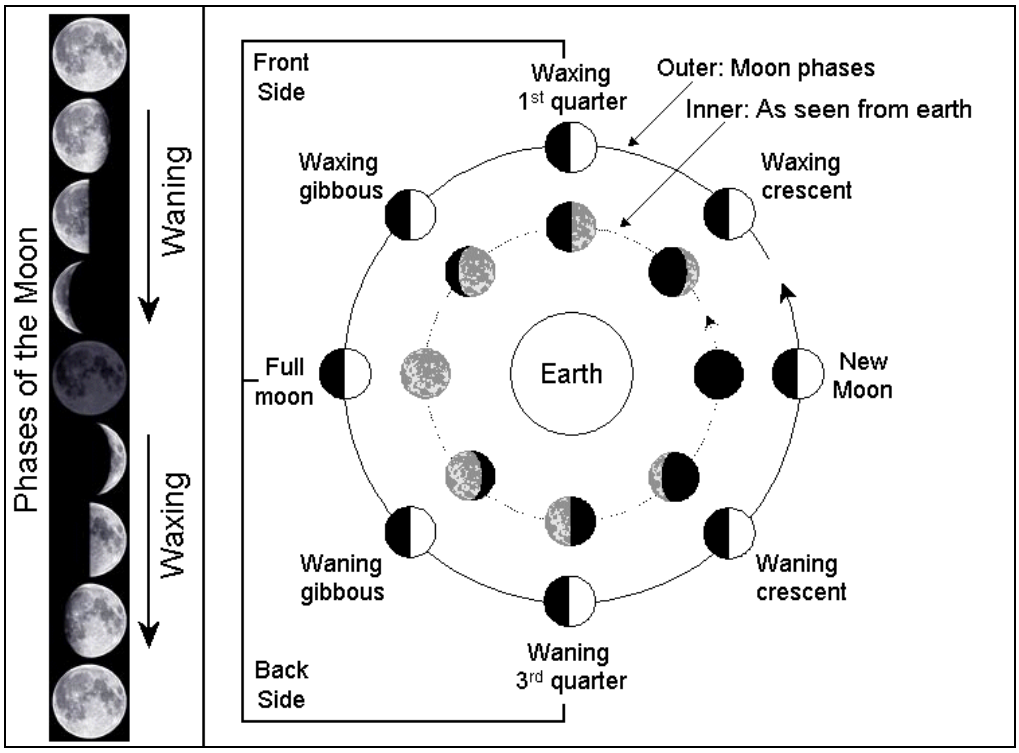


Figure 21 – Lunar phases (left) and cycle (right)

b. During the **first quarter waxing**, 1/4 to 3/4 of the moon disk is visible on the right side from the earth's perspective. This period lasts about 7 days, and provides the highest level of illumination in the early evening. Between the new moon and the first quarter, the lighted portion takes on a crescent shape and is called a **waxing crescent**. The period between the first quarter and the full moon is called a **waxing gibbous**.

c. During the **full moon**, more than 3/4 of the moon disk is visible. This period lasts about 8 days and provides excellent illumination.

d. During the **third quarter waning**, 3/4 to 1/4 of the moon disk is visible, this time on the left from the earth's perspective. This period lasts about 8 days, and provides the highest level of illumination in the early morning. The period between the full moon and the third quarter is called a **waning gibbous**. Between the third quarter and the new moon, the crescent shape returns – but is opposite that of the waxing crescent and is called a **waning crescent**.

e. The 40-30 rule (figure 22).

(1) During the first quarter to the full moon, lunar illumination goes from 50% to 100%. This period is also sometimes referred to as the **front side** (shown in figure 19). From the full moon to the third quarter, lunar illumination goes from 100% to 50%. This period is referred to as the **back side**. Both periods are significant because **40% illumination** is often considered the minimum

required for NVG sorties. This equates to a day or two **prior to** the **first** quarter until a day or two **after** the **third** quarter.

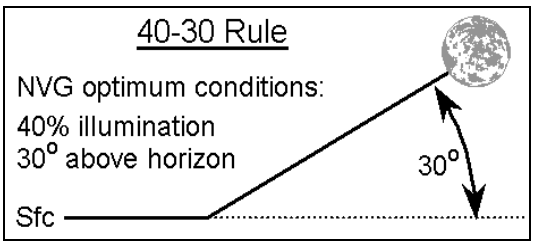


Figure 22 – The 40-30 Rule

A "Gorilla Night" refers to clear nights with a full moon above 60 degrees. Towns / topography can often be seen very far away (as far as 30 nm) under these conditions.

(2) Besides 40% illumination, many night vision goggle operators consider a moon elevation of at least **30 degrees** as optimal. During the waxing crescent to the first quarter, the moon will be setting coincident with or just after sunset, so optimum NVG flying windows tend to be more limited. The **front side** – quarter moon to full moon – is also called the friendly side, because in this region the moon rises in the late morning to early afternoon, and is high in the sky as soon as it is dark enough to launch, providing optimal NVG flying conditions early in the evening. After the full moon (the **back side**), the moon rises after sunset, and rises 45 minutes later each night. By the time third quarter is reached, takeoff times are after midnight. By the waning crescent, launch times are near dawn.

3. The moon's **azimuth** is another important consideration for NVG OPS. The moon angle can be equated to the sun angle, in that when using NVG's, flying into a rising/setting moon has the same effect as flying into a rising/setting sun during the day. Even when it is above 30 degrees above the horizon, some NVG users find the moon too bright to fly towards it. For this reason, pilots often fly a variable course (i.e., a zigzag) in order to keep the moon to one side. Aircrews will also fly with the moon at the back of the aircraft, which provides a searchlight effect and typically results in a marked improvement in scene depiction.

Other TV/NVG Light Sources

1. Moonless nights have significant usable light for NVG operations. This is due to the large near-IR composition of the night sky illumination, which matches the peak sensitivity of NVG's. On a moonless night, about 40% of the light is provided by emissions from atoms and molecules in the upper atmosphere (this is known as "airglow").

2. Starlight is another significant source of light, providing about .00022 lux (provides ¼ of the actual light from a night sky with no moon). Other natural light sources include auroras, gegenscheins (caused by sunlight reflecting off of air particles), and zodiac lights (faint elliptical disks around the sun caused by reflection off of particulate matter).

3. Lightning. While looking directly at lighting with NVG's causes them to shut down for short periods of time, lighting will briefly illuminate areas and give brief enhanced NVG images. However, the brief duration and enhanced image clarity can create the impression that objects are much closer than they really are. The key to whether lightning is helpful or a hindrance lies in how much lightning is expected, and where it lies in relation to the flight path.

4. It is important to note that, although manmade light sources are an issue for NVG's, no man-made source of light is considered by Tactical Decision Aids that perform solar/lunar illumination calculations. Examples of these light sources are:

    a. Urban areas may introduce too much light into an operation area – but distant urban areas may aid in illumination by reflecting off of cloud bases. Sodium lights (in rural areas) can make sparsely populated areas appear as industrial areas.

    b. Vehicles and their headlights introduce additional light into an operation area (halogen headlights appear as searchlights to an NVG user). Anti-collision lights on other aircraft can be detected very far away due to NVG sensitivity to red lights.

    c. Red lights on microwave towers, radio towers, and other high objects can frequently be seen from great distances. Weapons use, fires, refinery burn off, and even flashlights can have an impact on NVG's.

TV/NVG Sensors and Backgrounds

1. Visual contrast is the most critical factor during NVG flight. Desert areas, large bodies of water, snow covered fields, and other featureless terrain areas provide little in the way of visual contrast and are areas where visual sensors are less effective.

2. There is very little contrast between a land mass and a body of water during low-light conditions. As the light level increases and the moon angle decreases, the water appears to change color, land-water contrast increases, and reflected moonlight is detected.

3. Low moon angles drive NVG automatic gain down and cast shadows that hide terrain obstructions. The optimum operating envelope for flying with NVG's is 200 – 300 ft AGL (hazards such as power lines and most towers exist below 200 ft). With an increase in altitude, there is a decrease in visual contrast, regardless of the overall METOC conditions.

4. Any METOC element (but particularly rain) that can affect the albedo of terrain and other background surfaces (such as roads) will have an effect on how they are seen with visual sensors.

5. Terrain and urban areas are a **critical** visual sensor support factor; the more you know about the terrain and other features in the OPAREA, the better you can tailor your METOC support.

   a. Some terrain types reflect available light well, other types of terrain do not; high terrain areas can have an impact on "actual" sunrise and sunset times (consider a ship anchored in the Adriatic, with a well-defined mountain range to the immediate east).

   b. Illumination programs do NOT account for terrain in their calculations. Refer to the graphic in figure 23. Variations in terrain and obstructions such as buildings, power lines, and towers on the shadowed side of the terrain can be all but indiscernible, causing a potentially significant flight hazard.

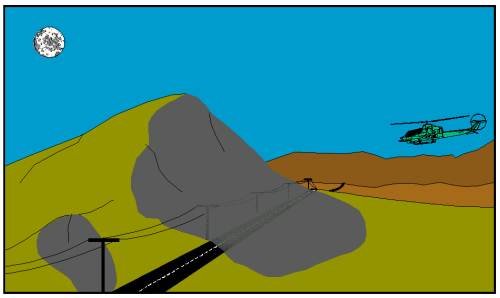


Figure 23 – Indiscernible background features from moon shadowing

   c. Illumination programs do not account for urban areas in their calculations. Refer to figure 24. Shadowing from obstructions and buildings can significantly alter the target/background scene. As stated before, the more you know about a target area, the better your support can be.

Figure 24 – Shadows in an urban area

Laser Systems

Laser Lock-On Systems

1. Laser lock-on systems (figure 25) use an internal semiactive guidance process that detects laser energy and guides the weapon to a target illuminated by an external laser source. These systems consist of a designator and receiver. These components can be collocated (on the same platform) or on separate platforms. The designator can be located in the delivery aircraft, another aircraft, a vehicle (G/VLLD) or a ground source (MULE). The receiver is located on the munition used with the system (e.g., hellfire, GBU-16).

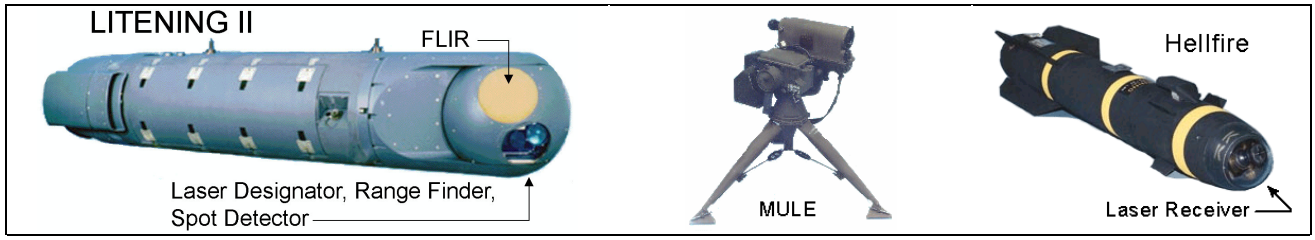


Figure 25 – Various laser systems: LITENING II Targeting Pod (left) , ground-based laser designator (MULE), Laser receiver (hellfire)

2. In laser **lock-on systems**, the designator illuminates the target and lock-on receiver receives the energy reflected by the target. The designator illuminates the target with a narrow beam of nearly monochromatic energy centered at 1.06 µm.

   a. The strength of the beam depends on the designator, but the amount of energy that **reaches the target** depends on atmospheric attenuation based on METOC constituents and other factors preventing the energy from reaching the target (figure 26, left).

   b. The strength of the return from the target is based on the target's reflectivity (figure 26, right).

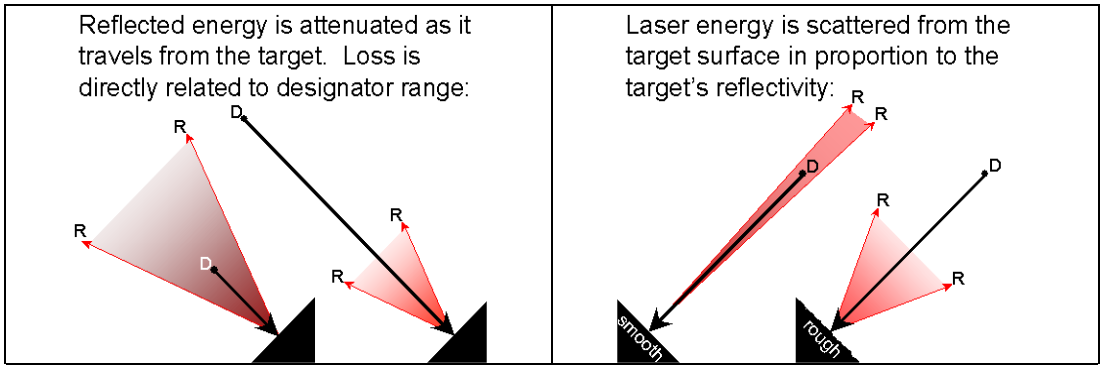


Figure 26 – Laser energy attenuation versus range (left), reflection versus surface roughness (right)

Laser Ranging Systems

1. Airborne Laser Ranging Systems measure distance from the ranger system to a target by measuring the travel time of the laser pulse between the ranger system and target.

2. Ranger system designators and receivers are collocated in the same hardware package.

Laser System Sensitivities

1. Target aspect and laser tracker proficiency can play a major role in the success of a laser-guided missile engagement. The following factors can exist when illuminating a target with laser energy:

    a. **Boresight Error**. The laser spot is not properly aligned with the FLIR targeting reticle, producing an error in the location of the spot on the target.

    b. **Spot Jitter**. Spot jitter is the bouncing movement of the laser beam around the intended aimpoint. Spot jitter is due to designator vibration/motion and increases with designator distance from the target.

    c. **Beam Divergence**. The further the laser designator is from the target, the wider the spot will be upon the target. The amount of beam divergence will vary between types of designators.

    d. **Attenuation**. This occurs when a portion of the laser beam energy is scattered by obscurants along the laser-to-target and missile-to-target lines of sight, resulting in reduced laser energy to the seeker. If attenuation is severe, the seeker will not detect the reflected laser energy from the target (see paragraph 2 below for refractive effects).

    e. **Backscatter**. Backscatter is the portion of laser energy that is scattered back in the direction of the seeker by atmospheric particles in the laser path. Backscatter energy competes with the reflected energy from the target, so the seeker may lock onto the backscatter rather than the target.

    f. **Overspill**. Overspill is placing the laser spot to high on the target so that beam divergence and jitter cause the spot or a portion of the spot to spill over onto the terrain behind the target. Overspill can cause intermittent background false targets, which increase in severity at longer designation ranges.

    g. **Underspill**. Underspill is caused by placing the laser spot too low on the target so that the spot or a portion of the spot spills onto the foreground. Underspill can

cause foreground false targets, which increase in severity at long designation ranges.

2. Refractive effects can seriously degrade beam propagation (figure 27):

   a. **Scintillation**: Causes fluctuations of energy intensity within the cross-section of beam. The result is an overall reduction in energy to the target area.

   b. **Spread**: increases cross sectional area of a beam, decreasing the energy intensity. The result is that the beam acts more like flashlight beam and rapidly attenuates.

   c. **Wander** causes beam deviation from a straight path, making aiming difficult (and possible designation of the wrong target area).

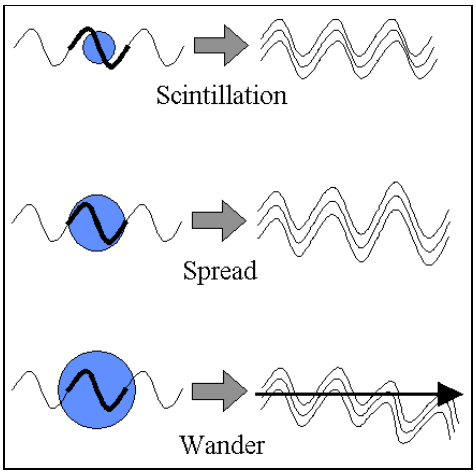


Figure 27 – Laser system sensitivities

METOC Support for EO Sensors and Systems

Introduction

1. The Target Acquisition Weapons Software (TAWS) predicts the performance of electro-optical (EO) weapon and navigation systems. Mission planners use these predictions to make "go/no-go" decisions, modify mission execution tactics or weapons loads, or to evaluate the general suitability of environmental conditions for NVGs and other EO systems. TAWS output ranges from maximum detection / lock-on ranges to the weather-impacted ground illumination, with results displayed in graphic and tabular formats.

2. Examine figure 28 for a moment. Note that **few** METOC constituents are considered unimportant for supporting EO sensors and systems. For an accurate interpretation of the conditions, TAWS needs accurate METOC information.

METOC Constituent Required?	IR/FLIR	TV/NVG	LASER
Temp, Dew Point	Yes	Yes	Yes
Relative Humidity	Yes	Yes	Yes
Visibility	Yes	Yes	Yes
Precipitation, rain rate	Yes	Yes	Yes
Wind Speed	Yes	Yes	Yes
Wind Direction	Yes	No	No
Clouds (low/mid/high)	Yes	Yes	Yes
Aerosol(s)	Yes	Yes	Yes
Surface Layer Height	Yes	Yes	Yes
Battlefield Induced Contaminants	Yes	Yes	Yes
Albedo	Yes	Yes	Yes
Upper Layer Info	Yes	Yes	Yes
METOC required before TOT	**YES**	**NO**	**NO**

Figure 28 – METOC constituents required by TAWS

Temperature, Dew Point, Relative Humidity

1. Temperature and dew point temperature are used by the IR, TV/NVG, and Laser models primarily to compute the relative humidity. Relative humidity, along with aerosol and visibility, is used to compute an extinction coefficient.

2. Water Vapor is the most influential absorbing gas (over oxygen and ozone) as well as the most variable. There are two terms associated with water vapor content: **relative humidity** (the common measurement used in the METOC community for discussing humidity) and **absolute humidity** (a more defining term when discussing absorption).

   a. Relative humidity is a ratio that expresses the amount of moisture in the air compared to the maximum that can be held ***at that temperature***.

b. Absolute humidity is the amount of the mass of water vapor present in a given volume of air (in grams per cubic meter, or g/m^3).

c. TV/NVG effects: The effect of absolute humidity on NVG's varies according to particle size and density. Wavelengths used by NVG"s tend to pass more readily through an area of high absolute humidity as long as particle sizes are small (as found in very humid air, light rain and fog). The larger the particle size, the more the effect on visual sensors.

d. IR/FLIR effects: General FLIR performance can be predicted to a certain degree by knowing the **absolute humidity** value in the area of interest. The greater the humidity, the greater the amount of water vapor present, and the greater the IR absorption. Most users of IR sensing equipment consider 20 g/m^3 to be the "show stopper," but this value can go as low as 12 g/m^3. Liaise with your customer to determine their acceptable levels.

e. Laser effects: High RH combines with lithometeors. Result: increased attenuation, decreased laser effectiveness.

3. Temperatures must reflect diurnal changes, frontal passage, etc. Dew point values must be considered (remember there are diurnal changes and changes with frontal passage).

4. Sea Surface Temperature is only required if the target is operating on a water background (in TAWS, **ocean** must be selected as the albedo type).

Winds

1. Winds may affect the area of interest for all EO sensors by increasing the density of particles in the air.

2. IR/FLIR effect.

   a. Wind can impact IR/FLIR performance because it decreases thermal contrast, which in turn reduces the sensor's image quality. (The best IR image is acquired under clear skies with no wind.) It is important to accurately forecast not only wind speeds (particularly under 10 knots), but also changes in wind speed, to best account for this effect.

   b. If a target is self-heated (such as a running tank), wind can remove heat from surrounding objects while the target is replacing any heat lost to the wind with more heat. In that case, an IR sensor can actually see the target better.

Visibility

1. Sand / dust / other obscurants. As with snow, the effect here is due to particle size and density.

    a. Airborne constituents such as sand can damage or destroy the protective cover on seeker heads (ablation).

    b. TV/NVG effect. The effect of blowing sand or dust is similar to that created by snow, except that the particulates are far less reflective and much larger. This is significant because these particulates completely block the near-IR light from striking and reflecting from the terrain. Since there is less luminance, the scene is darker – and as with snow, during vertical helicopter operations or strong winds there can be a total block of near-IR radiation. This is known as a "brown out."

    Important: NVG's highlight the importance of accurate sand/dust forecasts during nighttime hours: Airborne dust reflecting available light at night – such as that from the flight deck of an LHA / LHD / CVN – can reflect and scatter so much of the incident light that NVG's may become unusable (the effect has been described as seeing many "sparklers" at once).

    c. IR/FLIR effect. In general, IR sensors can still operate when impacted with smaller particles. However, sand, dust, and battlefield obscurant effects are similar to those of rain, fog or clouds in that larger particle sizes will result in scattering. Unlike precipitation, which can create a uniform temperature over a period of time, the effects of sand or dust diminish as soon as their atmospheric concentration diminishes.

    d. Laser effect. Natural visibility restrictions (fog/haze/precipitation/dust) degrades laser performance by increasing attenuation. Obscurants and BIC's obscure the target scene and provide increased lithometeors.

2. Indicating the presence of obscurants. The presence of sand, dust, haze, and other obstructions to visibility cannot be readily addressed with TAWS. Put another way, you can indicate that the visibility has reduced to 4 nm, but how do you indicate what is causing the reduction to visibility? Recommendations:

    a. Rain: Select rain as the precipitation type, reduce the visibility accordingly, and ensure you reflect a proper rain rate (remember most METOC people reflect rain in inches/hr versus mm/hr).

    b. Snow: Select snow as the precipitation type and reduce the visibility according to the forecast snow intensity.

c. Widespread Dust **(DU)**, Smoke **(FU)**, and Volcanic Ash **(VA)**: indicate "yes" to Battlefield-Induced Contaminants in the TAWS weather entry screen **and** select the prevailing aerosol. Note that this extinction is **added** to the prevailing aerosol in the physical models.

d. Sand **(SA)**: set the aerosol parameter to "desert." This overrides any other selected aerosol. Remember that increasing wind speed will increase the extinction rate (with more wind, more sand is introduced into the air).

e. Mist **(BR)**: set the aerosol parameter to "radiative fog." This overrides any other selected aerosol.

f. Fog **(FG)**: set the aerosol parameter to "advective fog." This overrides any other selected aerosol.

g. Haze **(HZ)** and Spray **(PY)**: these groups are ignored by TAWS. Enter the prevailing aerosol, visibility, and relative humidity.

Precipitation

1. Rain. Like clouds, rain effects are difficult to forecast because of the variation in droplet size and density. Absorption, scattering, clouds, and fog are all considerations here.

   a. TV/NVG effect. Light rain or mist cannot be readily detected using NVG's. These sensors do not "see" rain until the rain rate is higher. This is why pilots flying with NVG's are sometimes unaware that they are flying in rain until the precipitation gets heavy. Contrast, distance estimates, and depth perception are affected due to light scattering and a general reduction in light level. Contrast changes due to wet surfaces after rain ceases may alter (sometimes improve) detection capabilities.

   b. IR/FLIR effect. Rain has similar effects as with fog. Since droplet size is larger than fog, there is more absorption, although some information can still be gained through light rain or mist. Heavier rain causes significant attenuation. However, as rain cools the background during the day, thermally significant objects will tend to stand out conspicuously.

   c. Laser effect. Rain droplets can cause beam spread or beam wander, reducing or eliminating the signal strength from the designator to target area (or vice versa).

2. Snow. Occurs in a wide range of particle sizes and geometries. Snow crystals are generally large in comparison to the wavelength of visible, near-, and far-IR radiation and easily blocks or scatters those wavelengths. However, due to its lower particle density, snow normally degrades thermal signatures **less** than fog and rain.

a. TV/NVG effect. Density of the flakes (e.g., light snowfall vs. heavy snowfall) determines how much illumination and luminance is blocked, and thus how much degradation occurs to the TV/NVG image. Snow can be of help, however, in that it reflects available light and, under certain conditions, can add a degree of depth perception to an otherwise washed out scene. It is important to note that because of the reflectivity of snow, less illumination is required to give the same luminance for the subject than without snow. One very negative effect of snow is similar to that of dust and sand, in that landing in snow can cause a white out that effectively blocks the TV/NVG image. Contrast, distance estimates, and depth perception are affected due to light scattering and a general reduction in light level.

b. IR/FLIR effect. The effect of snow on IR/FLIR equipment depends on flake size and density. Most of the attenuation in the far-IR spectrum is caused by scattering of the thermal energy. For snow on the ground, the degree of attenuation depends upon how long the snow has been on the ground. If the snow has been there long enough, it can cool the ground surface enough to reasonably uniform temperatures and attenuate the IR/FLIR image.

c. Laser effect: snow causes attenuation for laser systems. As with rain, the heavier the precipitation, the worse the attenuation.

Aerosols

1. **Aerosol** refers to the **dominant atmospheric particulate** in each of two atmospheric layers used by TAWS (the surface layer, which extends from the surface to the boundary layer, and the upper layer, extending from the boundary layer to 15 km). Aerosols are used in all TAWS model calculations (IR, TV, and Laser).

2. The aerosol model, along with relative humidity, visibility, and wind speed (depending upon the aerosol selected) is used to compute an extinction coefficient. As this coefficient gets larger, the signal at the sensor gets smaller. In practical terms, ranges decrease.

3. Selecting the correct aerosol isn't always as obvious as it seems, and it is possible for them to change during the day (consider a frontal passage). There are a total of 19 aerosols used with TAWS: Rural; Urban; Maritime; Tropospheric; Desert; Navy Maritime Open Ocean (3 variations based on wind speed): Navy Maritime Intermediate Conditions (3 variations based on wind speed); Navy Maritime Strong Continental Conditions (3 variations based on wind speed); Camouflage Smokes (white phosphorous, fog oil, and hexacloroethane); Advection fog; and Radiation fog.

4. TV/NVG effects: There is a high NVG sensor sensitivity with advection and radiation fog; otherwise, low. Note that this doesn't mean that other aerosols shouldn't be carefully selected.

5. IR/FLIR effects: There is a high sensor sensitivity with advection and radiation fog, and with Navy aerosols - otherwise, low. As with the NVG sensors, this doesn't mean that other aerosols shouldn't be carefully selected.

6. Laser effects: There is high sensor sensitivity with advection and radiation fog, and maritime and desert aerosols. The higher the RH with a maritime aerosol, the worse the effect. The higher the wind speed with desert aerosols, the worse the effect.

7. For more information, refer to the Information Sheet, "TAWS: Aerosols, BIC's, and Obscurants."

Battlefield Induced Contaminants (BIC)

1. Battlefield Induced Contaminants are the persistent pall of smoke and dust that sometimes covers areas where intense combat has occurred. Visibility is normally between .5 and 1.5 nm, unless it otherwise degraded by the natural aerosol. All EO sensors are affected by BICs.

2. For more information, refer to the Information Sheet, "TAWS: Aerosols, BIC's, and Obscurants."

Surface Layer

1. TAWS uses a two-layer model for its calculations. The lower **surface layer** represents a homogeneous region in terms of stability, aerosol content, and moisture. Refer to figure 29. Note that all of the following are considered to reside within "the surface layer": temperature, dew point, relative humidity, sea surface temperature, winds, visibility, precipitation, aerosol and battlefield induced contaminants. At least some clouds could be located within the surface layer as well. The surface layer height entry must be as accurate as possible.

2. Note that entries for each METOC constituent are assumed to represent the vertical column of air from the surface to the top of the surface layer. For example, if an operator enters an air temperature of 32 degrees C at 1400 local, TAWS assumes that this temperature is consistent from the surface to the top of the surface layer.

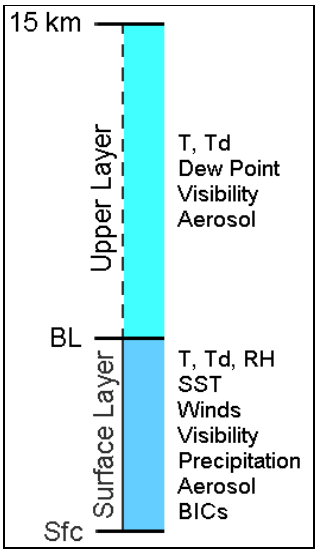


Figure 29 – Surface and upper layer (TAWS)

3. Remember that the surface layer can change during the day (consider diurnal heating and cooling, frontal passages, etc.)

4. All sensors: If the sensor in question is below the boundary layer (under the specified surface layer), entries addressed in paragraph 1 are still important, but the surface layer height becomes less of an issue. If the sensor is located **above** the surface layer, you also need to take a hard look at the upper layer information entries (this is discussed below).

5. For more guidance on surface layer height determination, refer to the Information Sheet, "TAWS and the Surface Layer."

Clouds

1. Because of the variation in particle size, it is difficult to predict how clouds affect NVG and FLIR performance. It is more dependent on season, cloud type, and water vapor content.

2. TV/NVG effects. Because warmer air holds more moisture than colder air, summer clouds generally have higher water content than winter clouds.

    a. Thick clouds:

        (1) Positive: Thick, dense clouds are more easily seen with NVG's, particularly when viewed against the night sky.

        (2) Negative: The same clouds also reduce illumination that strikes the ground, reducing the illumination available for NVG's.

    b. Thin clouds

        (1) Positive: Thin, wispy clouds generally have no effect on NVG's.

        (2) Negative: Thin clouds can also mask thicker clouds behind them, leading pilots to progress into thicker cloud walls without perceiving the "cloud wall." Even when the thicker clouds are detected, pilots may have a hard time discerning their distance.

    c. Clouds and effects on illumination and shadowing

        (1) Positive: Although clouds can decrease illumination and resulting luminance from the moon and stars (or eliminate it in the case of a solid overcast), they can also reflect enough cultural lighting to help offset the loss of lunar illumination.

        (2) Negative: Shadows caused by broken or scattered cloud layers blocking the moon's illumination can be seen on the terrain, blocking potential obstructions and causing a perception of bodies of water or forested areas where they don't exist.

3. IR/FLIR effects.

    a. The size of the scattering element determines the effect on FLIR. Remember that IR radiation is reflected (scattered) when its wavelength is less than or equal to the diameter of the particle (frequently the case with clouds that contain larger droplets). Water molecules also easily absorb far-IR energy.

    b. Shadows are formed when a thermal source (usually the sun) is blocked by clouds for a long enough time to create thermal differences. The thermal shadows usually dissipate shortly after sunset or if the sun is obscured by clouds.

    c. Another FLIR effect is an equalized effect of ground object temperatures due to cloud cover. Total cloud cover for days can degrade FLIR performance by producing a washed out effect (all temperatures are very similar). However, the washout condition can be desirable if a non-natural feature (like a tank) has its own heat source, which tends to stand out strongly.

4. Laser effects. Similar to the effects seen with TV/NVG sensors. Laser systems require a cloud-free line of sight (CFLOS).

5. Fog has similar effects to those of clouds. The particle size varies from 2 to 20 microns, which is very similar to clouds, although fog has fewer particles and a smaller range of particle sizes than clouds. (Note that fog is considered an aerosol by TAWS and is not grouped with the clouds by the program.)

    a. TV/NVG effect. Since fog tends to stay close to the ground, it presents a greater hazard to rotary wing aircraft than to fixed wing. Fog can mask or partially mask ridges or other navigational features making it difficult to navigate. Pilots often detect the presence of fog by noting a gradual decrease of intensity of ground lighting.

    b. IR/FLIR effects. Many of the effects described above are also seen with IR devices. Fog particles have the greatest distribution in the 5 – 15 micron range, which will produce a 100% scattering effect for IR devices. However, even with these negative effects, IR devices can still identify hot spots such as fires, operating factories, and so on.

    c. Laser effects. See the discussion in aerosols. Laser systems require a CFLOS (this includes fog).

Upper Layer Data

1. The upper layer is the second of two layers used by TAWS in calculations. This layer exists from the boundary layer (wherever you define it) to 15 km (≅ 49,200 ft). The upper layer is (typically) **deeper** but **less defined** than the surface layer (only

temperature, dew point, visibility, and aerosol entries are required) yet it still represents a homogenous region.

2. Entries for the upper layer are most important if the sensor in question is not located within the surface layer. Refer to figure 30. Assume the operator has entered an air temperature of 32 deg C at 1400 local for the **surface layer,** which has a height of 2,000 ft. If the FLIR sensor is at 5,000 ft, it is located within the **upper layer**.

3. If the upper layer values are not adjusted, TAWS will assume that the air temperature from the surface to 2,000 ft is 32 deg C, shifting to –4 deg C from 2,001 ft to 15 km. This is a 36-degree temperature change at the surface layer boundary, which can affect predicted FLIR ranges.

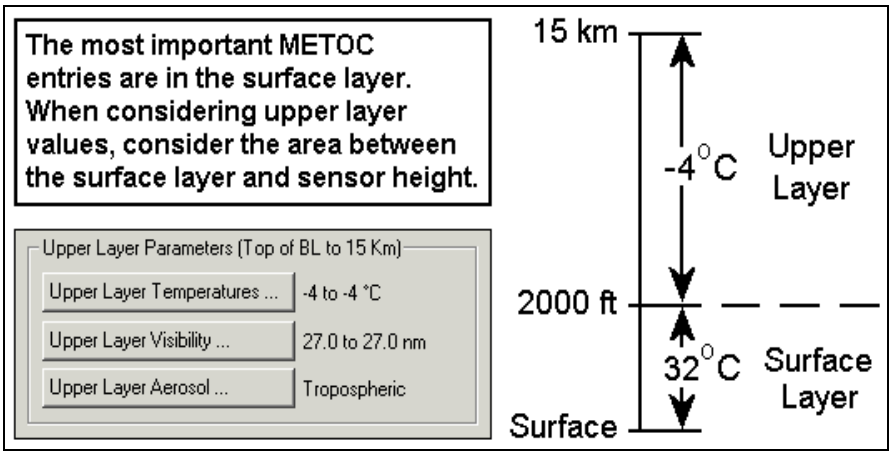


Figure 30 – TAWS upper layer parameters

Support Products

1. Figure 31 shows a sample "illumination" briefing product. Besides normal forecast products, TV/NVG support products may include:

   a. Sunrise, sunset, moonrise, moonset times. (Total daytime / nighttime hours may be requested). Because of rapidly changing conditions, range information over smaller increments (e.g., 15 minutes versus hourly) near sunrise and sunset.

   b. Twilight times. You may be tasked to provide civil twilight times, nautical twilight times, or both.

   c. Percent illumination (e.g., "18%") and phase (e.g., "third quarter waning") of the moon. Remember that a single value of illumination (e.g., "15%" is okay, but a **range** indicates whether the moon illumination is increasing or decreasing).

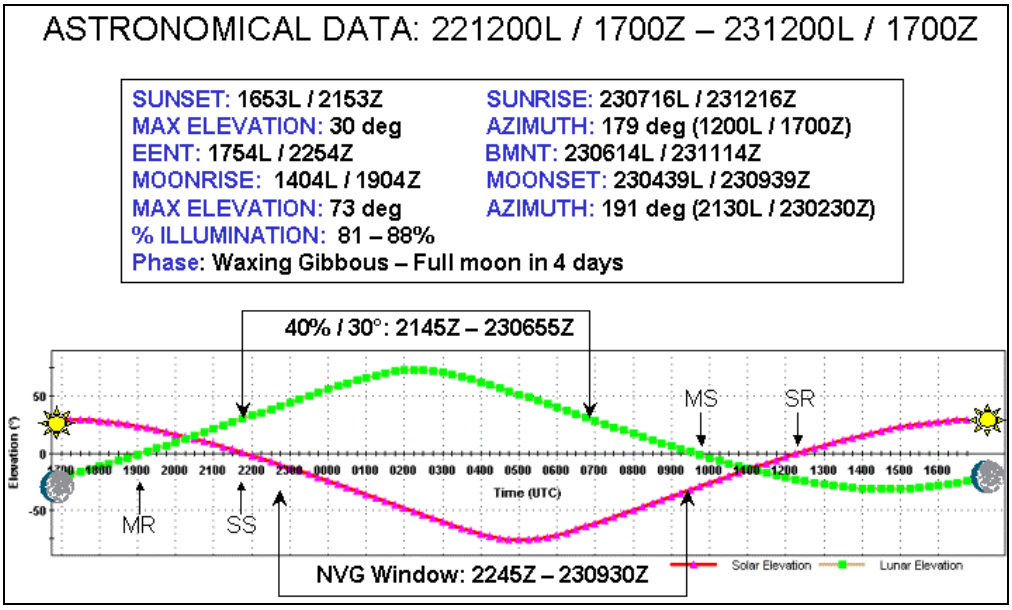


Figure 31 – Illumination brief

   d. Solar and Lunar data for Time Over Target (TOT) or the general time frame that the evolution will be occurring (elevation, azimuth, percent illumination of the moon).

   e. Solar and Lunar data for max elevation (elevation, azimuth, Illumination, and time that the moon will be at maximum elevation).

   f. Azimuth of the sun and moon during sunrise and sunset. (Where will they be during these periods?)

g. NVG window(s) (times NVG's will be useful) based on NVG minimum illumination thresholds.

h. **Range versus View Direction** products when TOT is known

2. Besides normal forecast products, IR sensor / FLIR support products may include:

a. Range versus Time products (figure 32): Maximum detection range, whole target detection ranges (where the entire target is evaluated against the background), and/or hot/cold spot target detection ranges (where only the target's hottest or coldest spot is evaluated against the background). Many customers prefer hot/cold spot detection ranges. Ask.

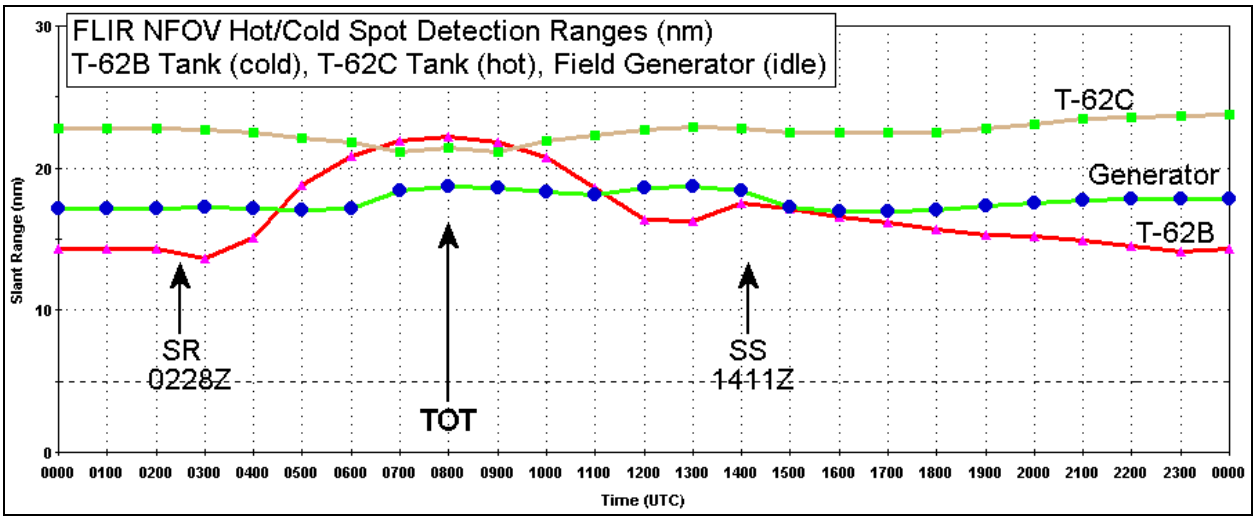


Figure 32 – TAWS range versus time plot

b. As with TV/NVG detection range products near sunrise / sunset, you may be asked for range information over smaller increments (e.g., 15 minutes versus hourly) near periods of thermal crossover.

c. Solar data for Time Over Target or general time frame that the evolution will be occurring.

d. Sunrise, sunset, solar data for max elevation (elevation, azimuth, illumination and time the sun will be at maximum elevation).

e. Absolute humidity plots. You may be tasked with providing the forecast absolute humidity values for specific time frames (such as TOT), or the high/low absolute humidity for the day.

f. Temperature plots. Target temperature (whole target or hot/cold spot) plotted with the background temperature. Gives a fast comparison of the target vs. background and can also be used to show periods of thermal crossover. Can

also to be used to determine whether the target is warmer/colder than the background.

g. Delta-T plots (figure 33). These plots show the difference between the target temperature (whole target or hot/cold spot) and background temperature. Popular for showing periods of thermal crossover. Can also to be used to determine whether the target is warmer/colder than the background.

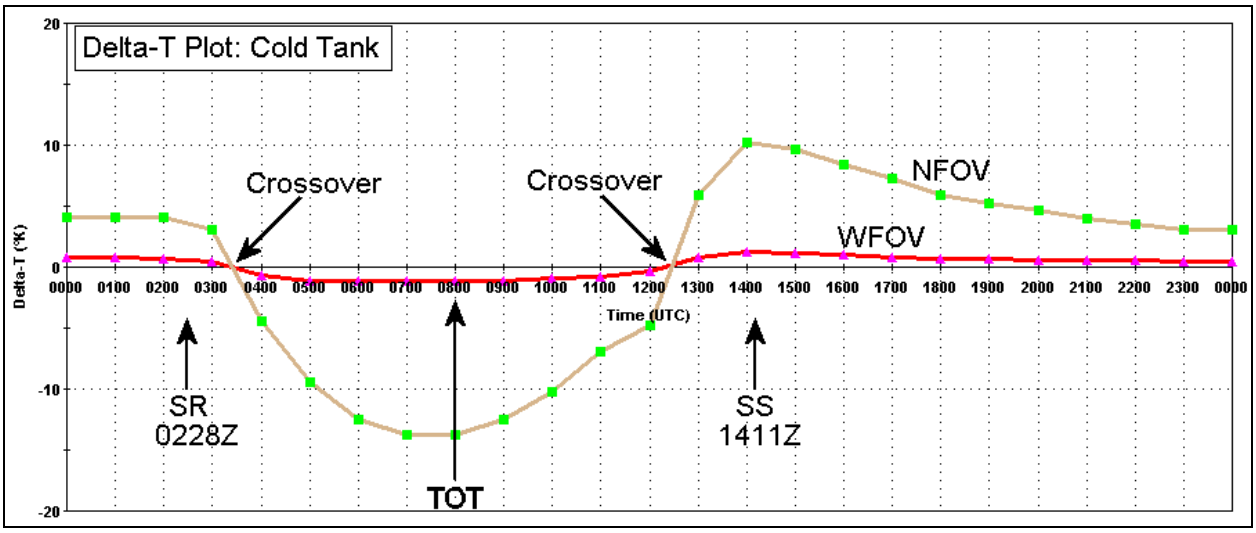


Figure 33 – TAWS Delta-T plot

h. **Range versus View Direction** products (figure 34) when TOT is known.

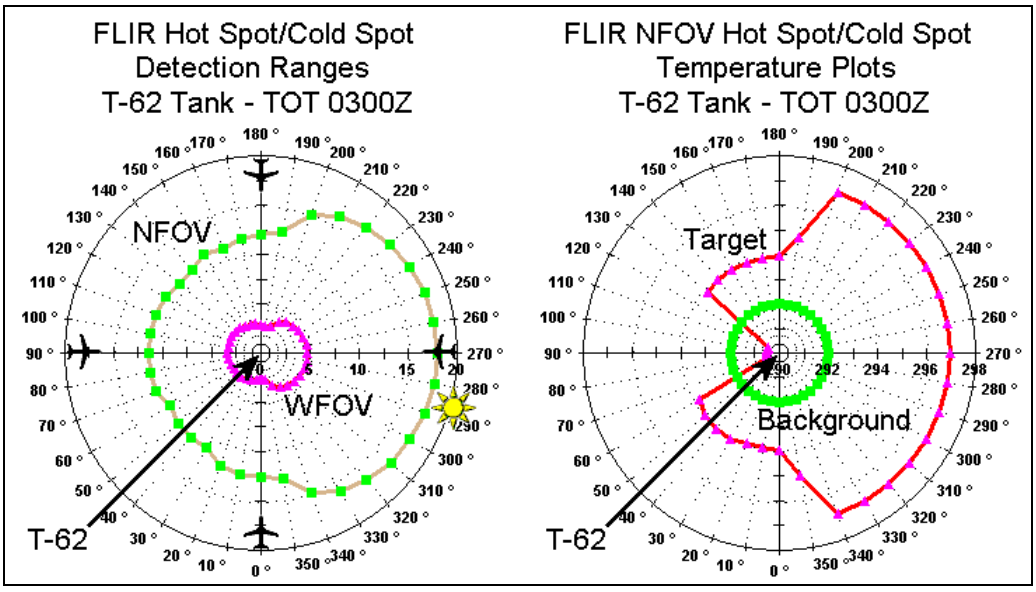


Figure 34 – TAWS range versus view direction plot

Appendix A – Glossary

Absorption: The ratio of the radiant energy absorbed by a body to that incident upon it.
Albedo: The ratio of the amount of light reflected from a surface to the amount of incident light.
Astronomical Twilight: The time when the true altitude of the center of the sun is 18 degrees below the horizon. Solar illuminance levels are compatible with NVG operations.
Azimuth: The horizontal direction or bearing of a celestial point (e.g., the moon) from a terrestrial point, expressed as the angular distance from a reference direction. It is usually measured from 000° at the reference direction clockwise through 360°. Frequently confused with "**bearing**."
Bearing: The horizontal direction of one terrestrial point from another, expressed as the angular distance from a reference direction. It is usually measured from 000° at the reference direction clockwise through 360°.
Beginning Morning Nautical Twilight: The time when the true altitude of the center of the sun (rising) is 12 degrees below the horizon. Solar illuminance levels are compatible with NVG operations.
Blackbody: an ideal body or surface that completely absorbs all radiant energy falling upon it with no reflection.
Blooming: Common term used to denote the "washing out" of all or part of the NVG image due to degaining when a bright light source is in the NVG field of view.
Brown-out: Condition created by blowing sand, dust, and so on, which can cause a pilot to lose sight of the ground. Most commonly associated with landings in the desert or in dusty landing zones.
Civil Twilight: The time when the true altitude of the center of the sun is 6 degrees below the horizon. Illuminance level is approximately 3.4 lux and is above useable levels for NVG operations.
Emissivity: The relative power of a surface to emit heat by radiation. The ratio of the radiant energy emitted by a surface to that emitted by a blackbody at the same temperature.
Evapotranspiration: the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants.
Nautical Twilight: The time when the true altitude of the center of the sun is 12 degrees below the horizon. Solar illuminance levels approximate 10^{-3} lux and are compatible with NVG operations.
Foot-Candle (fc): The illuminance of a surface upon which one lumen is falling per square foot.
Foot-Lambert (Fl): The luminance of a surface that is receiving an illuminance of one foot-candle.
Flux: The rate of transfer of energy across a surface.
Gain: When referring to an image intensification tube (a component of NVD's), the ratio of brightness of the output units in foot-lamberts compared to the illumination of the input in foot-candles. A typical value for generation III NVG tubes is 25,000 to 30,000 Fl/fc. A tube gain of 30,000 Fl/fc gives a system gain of 3,000 – that is, the intensified scene is 3,000 times brighter to the aided eye than to the unaided eye. In regard to FLIR, gain pertains to the temperature range corresponding to the displayed dynamic range.
Greybody: A radiator or absorber with a constant emissivity value of less than one.

Illuminance: Also referred to as “illumination.” The amount, ratio, or density of light that strikes a surface at any given point.
Low Light Level: Ambient illumination less than .0022 lux.
Lumen: A measurement of luminous flux equal to the light emitted in a unit solid angle by a uniform point source of one candle intensity.
Luminance: The luminous intensity (reflected light) of a surface in a given direction per unit of projected area. (This is the energy used by NVG’s.)
Lux: A measurement of illumination. The illuminance produced on a surface that is one meter square from a uniform point source of one candle intensity or one lumen per square meter.
Radiance: The flux density of radiant energy reflected from a surface.
Reflectivity: The fraction of energy reflected from a surface.
Transmittance: The fraction of radiant energy that is transmitted through a layer of absorbing material placed in its path.
Washout: (see blooming.)

Appendix C - Bibliography

1. Air Force Weather Systems Training Workbook: Target Acquisition Weapons Software (TAWS) 3.2
2. Explanatory Supplement to the Astronomical Almanac, ed. P. K. Seidelmann (1992), pp 482ff
3. Meteorology Today, 5th ed., 1994
4. "Night Vision Goggles," Aimpoint, 1990.
5. The American Practical Navigator (Bowditch), 2002 Edition, National Imagery and Mapping Agency, Bethesda Maryland

Index

40-30 rule, 22

Absorption, 5
Absorptivity, 9
Aerosols, *33*
Astronomical twilight, 20
Attenuation, 27

Backscatter, 27
Battlefield Induced Contaminants, *34*
Beam divergence, 27
Black body, 8
Boresight error, 27

CCD sensor, 16
Civil twilight, 19
Clouds, 35
Clutter, 14
Contrast, 3
  Inherent, apparent, threshold, 4

Delta-T plots, 40
Dew Point, 29

EM spectrum, 1
Emissivity, 8
EO imaging, 3
Extinction, 4

Far-Infrared imaging, 3
FLIR systems, 7

Humidity, 29

Illumination and visual sensors, 18
Infrared contrast, 3
IR contrast
  MRT and MDT, 11
IR seekers, 7
IR sensors
  target-background pair, 10
IR sensors and backgrounds, 14
IR sensors and systems, 7

Laser lock on systems, 26
Laser ranging systems, 27
Laser sensitivities, 27
Laser systems, 26
Lunar cycle, 21

MDT, 12
METOC 'big picture", 2
Molecular and aerosol scattering, 6
Moon and illumination, 21
MRT, 11

Nautical twilight, 20
Near-infrared imaging, 3
NVG sensors, 17

Overspill, 27

Precipitation, 32

Range versus time plots, 39
Range versus View Direction, 40

Scattering, 5
Scintillation, 28
Spot jitter, 27
Spread, 28
Sun and illumination, 19
Support products, 38
Surface layer, *34*
Surface to area mass ratio, 9

Temperature, 29
Temperature plots, 39
Thermal capacity, 9
Thermal conductivity, 9
Thermal crossover, 12
Thermal response, 8
TV/NVG sensors and backgrounds, 24

Underspill, 27
Upper layer data, 36

Visibility, *31*
Visual contrast, 3
Visual imaging, 3

Wander, 28
Wind, 30