What good is SWIR? Passive day comparison of VIS, NIR, and SWIR

Driggers, Ronald, Hodgkin, Van, Vollmerhausen, Richard


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What Good Is SWIR?
Passive Day Comparison of VIS, NIR, and SWIR

Ronald G. Driggersa, Van Hodgkinb, Richard Vollmerhausenc

aNaval Research Laboratory, Code 5600 Optical Science Division, 4555 Overlook Ave
Washington DC 20375; bU.S. Army RDECOM CERDEC Night Vision and Electronic Sensors
Directorate, 10221 Burbeck Rd, Ft. Belvoir, Va 22060, cUniversity of Delaware, Department of
Electrical Engineering, Newark DE 19716

ABSTRACT

This paper is the first of three papers associated with the military benefits of SWIR imaging. This paper describes the
benefits associated with passive daytime operations with comparisons of SWIR, NIR, and VIS bands and sensors. This
paper includes quantitative findings from previously published papers, analysis of open source data, summaries of
various expert analyses, and calculations of notional system performance. We did not accept anecdotal findings as
acceptable benefits. Topics include haze and fog penetration, atmospheric transmission, cloud and smoke penetration,
target and background contrasts, spectral discrimination, turbulence degradation, and long range target identification.
The second and third papers will address passive night imaging and active night imaging.

Keywords: Infrared Detectors, Infrared System Performance

1. INTRODUCTION

In the past ten years, Shortwave Infrared (SWIR) detectors have proliferated and SWIR imaging systems can be bought
commercially from a number of companies. SWIR detectors include Germanium (Ge), Indium Gallium Arsenide
(InGaAs), Indium Antimonide (InSb), and Mercury Cadmium Telluride (MCT) [1]. InGaAs has been the most practical
due to high quantum efficiency and low dark current at room temperature. System applications have been described as
agricultural processing, biological imaging, and spectral coherence tomography.

In this paper, we investigate the military value of SWIR, where this is the first paper in a three part series as shown in
figure 1. In this first part, we study the value of SWIR through a passive daytime performance comparison of visible
(VIS), near-infrared (NIR), and SWIR sensors in a variety of conditions and applications as indicated by “X.” In this
paper, VIS is the 0.4 to 0.7 micrometer band, NIR is the 0.7 to 1.0 micrometer band, and SWIR is 1.0 to 1.7 micrometer
band.

The list provided in Figure 1 was compiled by querying experts in the U.S. Navy, U.S. Air Force, U.S Army, and the
industry leaders in military imaging. In this paper, we summarize a comparison of VIS, NIR, and SWIR associated with
the passive daytime list in Part 1. Most of the issues are a comparison of phenomenology associated with the military
environments. For long range identification sensors associated with soldier systems, such as rifle sights, spotter scopes,
etc., we assumed 3-inch aperture optics which should be similar to most fielded systems. For systems on platforms such
as tanks, helicopters, jets, etc., we assume a 6-inch aperture. We did not take anecdotal information. The paper includes
only previously published measurements, analysis, and some of our own calculations and measurements. It is the
authors’ belief that SWIR sensors have not proliferated as much as they could mainly because program officers do not
understand the benefits of SWIR and have not seen those benefits quantified. In addition, there are potential
opportunities for military imaging in the NIR band.

Distribution A: Approved for public release; distribution is unlimited
## What Good Is SWIR?

### Part #1: Passive Day Comparison of Vis, NIR, SWIR

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### Part #2: Passive Night Comparison

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Figure 1. What Good Is SWIR?: Three Parts.

### 2. HAZE PENETRATION

Arnulf and Bricard [2] state that hazes, according to meteorologists, are differentiated from fog by the optical density. A haze has an optical density of less than 2 per kilometer at $\lambda=0.55$ micrometers, whereas a fog has a higher optical density. This lower optical density is accompanied by water and other particles that are smaller, thus reducing the scattering at longer wavelengths. The Encyclopedia Britannica defines haze as “suspension in the atmosphere of dry particles of dust, salt, aerosols, or photochemical smog that are so small (with diameters of about 0.1 micron) that they cannot be felt or seen individually with the naked eye, but the aggregate reduces horizontal visibility [3].” Either way, haze is caused by very small particles. Figure 2 shows the effects of haze.
Arnulf and Bricard measured the transmission of hazy conditions and reported the results in 1957 [2]. Four different measurements are shown in Figure 3, where the optical density is measured as a function of wavelength. The graph to the left is Arnulf and Bricard data replotted and the graph to the right shows an average band comparison for VIS, NIR, and SWIR. The different line styles are simply different measurements during the field test. There is an obvious advantage for SWIR in haze over VIS, with NIR in between.

Arnulf and Bricard [2] measured more fog transmission cases than they measured haze cases. A wide variety of optically thick measurements were made. The water particle sizes for fog are much larger than the particle sizes for haze and there are many papers that investigate the distribution of fog water particle sizes [2,3]. These particle sizes are constantly larger than VIS, NIR, and SWIR wavelengths. The data in ref 2 are shown plotted in optical density in the VIS versus optical density in the SWIR. We only show VIS and SWIR in figure 4 to show that it makes little difference in wavelength since the large particles scatter the light in a manner that results in the same optical density. The squares are different fog transmission measurements provided in terms of optical density for stable fogs. These are the majority of fogs conditions where the fog droplets can be seen by the human eye. The diamonds are associated with the extremely rare cases of selective fogs. Significant penetration into most fogs occurs starting in the LWIR due to these larger water particle sizes.

3. FOG
In summary, there is little difference in the optical density for the majority of fogs in the VIS, NIR, and SWIR since the water particle sizes are larger than the wavelengths. An extremely rare exception is that of selective fogs which have smaller particle sizes with high optical densities.

4. ATMOSPHERIC TRANSMISSION

Atmospheric transmission during long range imaging applications may be the primary reason to move towards longer wavelengths in the reflective bands. Consider figure 5 for a comparison of SWIR Transmission versus VIS Transmission for 5 different types of atmospheres using MODTRAN. The atmospheric transmission includes absorption and scattering, where the less challenging atmospheres (US Standard and Arctic) are weighted heavily with scattering and the more challenging atmospheres (Tropical, Desert, and Desert Dust Storms) have more absorption. When the range (distance between sensor and target) is zero, the transmission of both SWIR and VIS are 1, corresponding to the upper right corner of the chart. As the range increases, SWIR and VIS transmission is degraded and the curves move lower and to the left. A longer range corresponds to lower and to the left. The data is plotted for ranges of 0, 0.25, 1, 5, 10, and 20 Km. The challenging atmospheres are grouped together, but the sand storm goes off the chart for longer ranges. At the longest ranges, the SWIR band can have 10 times the atmospheric transmission to that of the VIS band. The trend for “typical,” or better atmospheres is even more weighted towards SWIR since Mie scattering is more important and less water absorption occurs.

Figure 5. SWIR Atmospheric Transmission versus VIS Atmospheric Transmission for Various Atmospheres.
To provide a reasonable comparison of atmospheric transmission in the SWIR, NIR, and VIS bands, we take the US Standard Atmosphere as a highly typical atmosphere and we add a larger amount of aerosols to the atmosphere to reduce the visibility from 23Km to 10Km and then to 5Km. Aerosols are caused by many situations and are frequent, so the aviation community describes atmosphere with the visibility range. Figure 6 shows SWIR and NIR transmission as a function of VIS transmission. Both SWIR and NIR transmission are plotted for 23Km, 10Km, and 5Km visibility aerosol levels. More aerosols (less visibility) and longer range moves the curves lower and to the left. However, it is interesting that all SWIR cases fall on the same line as do all NIR cases. Long range and low visibility make for SWIR transmission that can be 100X and even 1000X the transmission in the VIS. NIR transmission can be 10X and more than that of VIS transmission. In summary, atmospheric transmission (or penetration) favors SWIR and then NIR over VIS.

![Figure 6. SWIR and NIR Transmission as a Function of VIS Transmission.](image)

5. CLOUD PENETRATION

Cloud penetration (i.e., transmission) is a high interest subject for military commanders who operate high altitude sensor platforms. A common complaint is that imaging system operations are limited by cloud cover and, in some areas of the world, can be so limited during a large fraction of a given week or month. Janet Shields of Scripps Institution of Oceanography of UCSD is a prominent cloud researcher in the U.S. and studies clouds with all-sky imagers from the ground and all-earth imagers from high altitude. The photo on the left in figure 7 is a VIS image of the earth and the photo on the right is a SWIR image of the earth, both provided by Dr. Shields. Dr. Shields explains [5] that it is difficult to measure large area cloud transmission due to the reflectivity differences on the ground in the different bands. It is also difficult to measure large area cloud transmission from the ground because the sky radiance depends on the Mie scattering at locations where the clouds are not present. There are, however, point to point measurements over wavelength [6]. Many different clouds have been measured for transmission including Cirrus, Cumulonimbus, Alto Cumulus, and Cumulus and all clouds provide similar results. That is, the cloud transmission measurements are about the same for all wavelengths. Some of these measurements from reference [6] are shown in figure 7, demonstrating that cloud transmission for SWIR and VIS are about the same. We can mention that NIR provides similar results.

The authors have concluded that, given discussions with Dr. Shields and available references, that clouds might as well be fog at higher altitudes. That is, clouds are larger water particles that impact VIS, NIR, and SWIR all about the same. Dr. Shields makes the comment that while SWIR and NIR cannot see through clouds any easier than VIS, SWIR and NIR can definitely see around the clouds better. That is, the gaps between clouds can be haze where the water particles are smaller and there is a benefit for imaging with SWIR or NIR.
6. SMOKE PENETRATION

The optical densities of smokes are primarily driven by smoke particle size. Many smoke particles are around 0.1 micrometers or less in diameter, which leads to more Rayleigh scattering than Mie scattering [7, 8]. Smoke that appears white is mostly scattered light and smoke that appears black is caused by both scattering and absorption. White smoke can be generated by a wood fire and black smoke can be generated by burning oil (a typical battlefield cloaking technique). There is an advantage in going to longer wavelengths for both white and black smokes, as shown in figure 8. The curve provided was adapted from Bukowski’s data [7]. Note that the black smoke has a higher optical density per meter than white smoke due to the presence of both scattering and absorption.

Figure 8. Optical Density of White and Black Smoke as A Function of Wavelength.

The white smoke has a smaller optical density. In both cases (white smoke and black smoke), the optical density reduces significantly with wavelength. There is a definite benefit of SWIR over NIR, and VIS and NIR over VIS. Differences in the densities can be easily seen in wildfire videos posted on youtube with the Goodrich SWIR (image shown in figure 8).
7. “SEE” DESIGNATOR SPOT

Laser pointers and designators in the military operate at 0.85, 1.06, and 1.55 micrometers. There are many legacy missile seekers that are laser guided at wavelengths of 1.06 micrometers, but the military is continuing to work towards the eye safe wavelength of 1.55 micrometers. Some VIS sensors have difficulty seeing the 0.83-0.85 micrometer laser pointers, where the NIR sensors have no problem at all seeing the pointers. The NIR sensors (night vision goggles, image intensified CCDs, and electron bombarded or electron multiplied CCDs) have difficulty in viewing the 1.06 micrometer laser designators since the 1.06 micrometer wavelength is usually beyond the cutoff wavelength of the detector. SWIR can “see” all of these wavelengths if the lower wavelength band is opened up to receive the laser pointers.

8. CAMOUFLAGE CONTRAST

One of the suggested benefits of SWIR over NIR and VIS is that it provides improved contrast on camouflaged targets. Hodgkin [9] provides a thorough analysis of camouflage contrast for each of the bands and we only summarize the findings here. Consider the contrast plot in the left of Figure 9. The plot shows reflectivity contrast for 6 different battle dress uniforms (BDUs) against many different backgrounds to include mixed soils, dirt road, desert gravel, brown foliage, green grass, green needles, and dead grass. The reflectivity was calculated from measured spectra, so the contrast is source independent given by

\[
C_s = \frac{\int \rho_p(\lambda) d\lambda}{\int \rho_b(\lambda) d\lambda} - \frac{\int \rho_b(\lambda) d\lambda}{\int \rho_b(\lambda) d\lambda} \quad (1)
\]

where \(\rho_p(\lambda)\) was the target reflectivity and \(\rho_b(\lambda)\) was the background reflectivity. The each point in the graph shows contrast for a particular BDU against a particular background and is plotted SWIR against visible. The authors assumed that the reflectivity contrast was more generalized than radiant contrast since there are an infinite number of illumination conditions and that this data provides for reasonable comparison. The picture on the left is a SWIR image of one BDU and one background and the picture on the right is VIS. It can be easily seen from the plot that there are times when SWIR provides good target contrast and the VIS provides negligible contrast. There are also times when VIS provides good contrast and SWIR provides negligible contrast.

![Figure 9. BDU contrast in the SWIR vs VIS for various BDUs. Left image is SWIR and right is VIS.](attachment:figure9.png)

Finally, taking the standard deviation of the data points in the Figure 9 for the VIS direction yields a reflectivity contrast of 0.36. The standard deviations for the NIR and SWIR using the same data provide reflectivity contrasts of 0.29 and 0.28, respectively. Overall, there is not a significant advantage of any one band over the others. This is a conclusion that could change for a particular illumination condition.
9. BACKGROUND CONTRAST

Background contrast is important for many reasons such as driving and pilotage, as well as for situational awareness, navigation, and search performance. Background contrast affects sensors performance in different ways. High background contrast is good for driving, pilotage, situational awareness, and navigation. On the other hand, low background contrast is good for target search operations. NIR reflectivity is very similar to VIS reflectivity, but material reflectivities are very different in the SWIR. Using the ASTER spectral reflectivity library [10], we compared the reflectivity contrast of VIS and SWIR in both the urban and rural environments. The results are shown in figure 10. For each data point, the reflectivity contrast is plotted between two materials in the SWIR and in the VIS bands. The materials used in the urban plot are asphalt, tar, concrete, redbrick, glass, marble, pine wood, aluminum, copper, rubber, black paint, and green paint. The materials used in the rural plot are coniferous leaves, deciduous leaves, grass, dry grass, brown loam, sandy loam, brown clay, tree trunks, syenite gneiss rock, diorite rock, granite, alder bark, ponderosa bark, AP Hill bark, and canopy leaves.

Figure 10. Reflectivity Contrast of SWIR versus VIS for Urban and Rural Environments.

For anyone who has viewed a SWIR image next to a VIS image, urban environments look very similar. There are certainly contrast differences as shown in figure 10, but overall they have similar contrasts. However, in rural environments, the vegetation has a much higher reflectivity in the SWIR and most images look very bright with very few low reflectivity objects in the scene. This is shown in the right plot where the contrast is not quite as varied in the SWIR as in the VIS. The few data points with a contrast of near 1 and -1 are for vegetation against loam that has near zero reflectivity, resulting in high contrast. So, in urban environments, reflectivity contrast is similar for VIS, NIR, and SWIR. In rural environments, there may be a benefit with VIS and NIR over SWIR.

10. TARGET CONTRAST

Target contrast was studied for civilian vehicles and boats (for assymmetric applications) and a single ground military target was used for study in the field. Radiant contrast was measured up close on all of these “targets” and the civilian results are shown in Figure 11. The civilian vehicles and the boat data were taken on different days, but in both cases, the day was sunny and cold. The radiant contrast plot on the left is NIR contrast versus Vis contrast and the plot on the right is SWIR contrast versus Vis contrast. These were all up-close measurements made at a few meters from the target. Reflectivity standards across all bands were used for calibration. The NIR contrast appeared to be consistently a factor of two above the contrast of the Vis contrast. However, the SWIR and Vis contrasts were roughly the same except for one particular boat that had high reflectivity.
For the military ground target, an M60 was representative of many of the other ground targets in that the paints were similar and the paint was weathered, as with many military targets (See Figure 12). The left image is Vis, the middle is NIR, and the right image is SWIR. For the Vis band, the contrast of the turret against the grass was negative and the contrast of the turret against the treeline was positive. The track contrast in both backgrounds was negative. In the NIR band, the same contrast conditions were determined and a bit more pronounced than in the Vis band. In the SWIR band, the tank contrast for the turret and the tracks was always negative and significant. The high reflectivity of the grass and the tree leaves provided a light background with significant negative target contrast in both the turret and track cases. The authors believe contrast of military targets against rural backgrounds in the SWIR is worth investigating further.

11. SKIN DETECTION

The authors have been in many discussions where SWIR has been cited for high probability human skin detection due to the very low reflectivity of skin in the SWIR. The primary study for this claim is reference [11]. Figure 13 shows skin contrast against various backgrounds as listed in the figure caption. As the plot shows, the various illumination sources change the radiant contrast significantly. However, the skin contrast overall is about the same in the Vis band versus the SWIR band. Reference 11 goes on to state that NIR is also about the same. Assuming that detection probability is related to target contrast, the probability of human detection in the various bands is roughly the same overall. In particular instances, there may be a higher contrast band. In short, if one band is picked over the others, there is no clear winner in contrast. If all bands are present and can be used, then there is usually a band of preference that can be used to increase detection probability. These data and analysis do not apply to skin detection using multiple bands. A number of research groups are currently studying multiband skin detection.
Determine which band is best for materials discrimination from spectral signatures is a nearly impossible task since the spectral signatures in VIS, NIR, and SWIR are a reflective combination of source spectrum, atmospheric effects, and target reflectivity. In short, it is condition dependent and there are an infinite number of conditions that exist. To get a rough comparative measure that is fairly gross, the authors again used the ASTER database [10] and compared the variation in reflectivity across the bands. That is, the standard deviation of the reflectivity within VIS, NIR, and SWIR were compared. Huge variations existed not only for materials, but for a given material between bands. For example, the reflectivity variation for brown clay was 9.7 percent in VIS and 2.4 percent in SWIR. Analysis was performed by putting the standard deviation of 28 different urban and rural materials in scatter plots and comparing VIS to NIR, NIR to SWIR, and SWIR to VIS. While there were significant differences in reflectivity standard deviation across bands, there was no clear winner overall. The average material standard deviation was lowest in the VIS with 3.7 percent and highest in SWIR with 4.3 percent with NIR in between. That is, there was no significant winner in reflectivity variation overall.

There is one other aspect of spectral discrimination that is extremely important and worth covering here. The above discussion of no clear spectral discrimination winner is for close targets. The atmosphere was not considered, so it does not cover long range spectral discrimination. Villeneuve et. al [12] provide a study with real data in which spectral discrimination performance of sensors and algorithms are investigated as a function of atmospheric visibility. Their work compared two hyperspectral systems: one VIS-NIR sensor and one SWIR sensor, both with algorithms. Combining VIS and NIR bands in hyperspectral sensing is a typical approach for real systems. The study shows that under good atmospheric conditions (23km visibility), the performance of the two systems is similar. Under degraded conditions (6km visibility), the VIS-NIR system suffers extremely poor performance compared to the SWIR system. Their results agree with the conclusions provided in the atmospheric penetration section of this paper and the authors conclude the SWIR is the best band for long range and degraded atmospheric spectral discrimination.

13. TARGET ACQUISITION (TARGET IDENTIFICATION RANGE)

In our comparison of target identification range performance, we consider four cases. The first case is a color camera with CMOS quantum efficiency (QE), Bayer color filtering, and a near infrared (NIR) spectral cut filter. Filtering out the NIR prevents color washout. Second is a visible band camera (purely hypothetical) with a silicon array in the 0.4 to 0.65 spectral band. The third case is a near infrared (NIR) camera using the same silicon array but with spectral band 0.65 through 1.2 microns. The final case is a SWIR camera with spectral response 1 to 1.8 microns. See Figure 14 for the quantum efficiency (QE) of all cameras.

Figure 13. Radiant Contrast of Skin Against Backgrounds (Glass, Conifer Needles, Red Brick, Green Painted Aluminum, Forest BDU, Weathered Copper, Desert BDU, Sand Dune, Pine Lumber, Building Marble, White Foam).
The diffraction wavelengths for color, visible, NIR, and SWIR are 0.5, 0.5, 0.85, and 1.4 microns respectively. Both detector size and pitch are set to \( (F\#)(\text{wavelength})/\text{(detector pitch)} \)=2 for near diffraction-limited performance, and F/5 is used. Both amplifier noise and dark current are set to zero; during the day these assumptions are reasonable as long as the detector size is not too small. Charge well capacity (allowed number of collected photoelectrons) is equal to \( 1e4 \) electrons per micron\(^2\) of detector area. Charge collection is for 0.1 second as long as the well capacity is not exceeded. The optical F/\# would be unimportant except that F/5 results in bigger detectors with larger well capacity.

In the reflective spectral bands, but especially in the visible, atmospheric scattering and turbulence are the primary range limiters. Range analyses typically use the simplified sky-to-ground-ratio (SGR) model to analyze scattering [13]. However, the SGR values provided in tables are for the visible spectral band only. Comparing the performance of imagers operating in different spectral bands requires a different approach.

Figure 15 illustrates the problem encountered by reflective imagers when targeting at long ranges. Light from the sun illuminates the target. There is plenty of light. However, sunlight also scatters off the intervening atmosphere and adds path radiance in the imager line-of-sight (LOS). Because of molecular scattering, path radiance affects performance in the visible even in the absence of aerosols. With aerosols, path radiance rivals strong turbulence as a range-limiter.

Figure 15. Sunlight illuminates the atmosphere as well as the target. Scattered light causes both contrast loss and excess noise in the imager.

Probability of correct identification (PID) is used to evaluate imager performance. The PID model is described in [14]. Each scenario and turbulence level is analyzed for both a 3 inch diameter aperture and a 6 inch diameter aperture. The authors consider 3 inch aperture systems to be primary dismount and soldier system application and we used facial identification for the PID task. The authors consider 6 inch aperture systems appropriate for tank, helicopter, jet and other platform applications and we used tank identification for the PID task.

All scenarios assume a U.S. standard atmosphere. All extinction, absorption, and transmission values are from MODTRAN [15]. Figure 16 illustrates sun, target, and observer positions for the first two scenarios. In the first two scenarios, visibility is 23 kilometers due to rural aerosols. In both scenarios, the sun is at 60 degrees zenith; 60 degree zenith is 30 degrees above the horizon. In the first scenario, the sun is in position 1 behind the observer. In the second scenario, the sun is in position 2 in front of the observer. Note two important details. First, the sun is never in or near the LOS of the imager. Second, the observer is slightly above the target so the target is assumed to be fully illuminated and not in shadow even when the sun is in front of the observer. In scenarios 1 and 2, the target set is 12 tracked, tactical vehicles [14].
Figure 16. Illustration of sun, target, and observer positions for the first two scenarios. The sun takes two different positions shown as 1 and 2.

Path radiance, atmospheric absorption, and atmospheric extinction are all obtained from MODTRAN. MODTRAN only calculates values for a single range, so nine MODTRAN runs are used for each scenario and intermediate range values interpolated.

The third scenario uses the sun in position 1 but there is no aerosol specified. Scattering by the air is still modeled by MODTRAN, but scattering effects are much reduced from the 23 kilometer visibility assumption. The third scenario is only used for the 3 inch aperture case and assumes a much tougher facial ID task [16]. Facial ID requires about 10 times more resolution (in cycles per meter) than the vehicle ID task.

Figure 17 shows the results for the 3 inch aperture dismount case where the discrimination task is facial identification. For the clear air task (which is an ideal case that will almost never occur), the Vis band clearly wins due to the smaller wavelength and wider band compared to color. Color and NIR are similar in performance and SWIR has the shortest range performance. With 23Km typical visibility and the sun behind the observer, SWIR performs about as well as Vis and NIR and color suffers from the limited bandwidth. Finally, with 23Km visibility and looking into the sun, SWIR shows a strong benefit followed by NIR, Vis, and then color.

Figure 17. Probability of Facial ID for the 3 inch aperture cases. Left plot is for clear air (no aerosols), sun behind, middle plot is 23Km visibility with sun behind, and right plot is for 23Km visibility into sun.

It did not make sense to use the clear air case for the 6 inch aperture tank identification case since the ranges were longer and scattering was more apparent. The two cases shown in figure 18 are 23Km with the sun behind the observer and then looking into the sun. In both cases, the SWIR provided a significant benefit followed by NIR and then the Vis band cameras. The benefit was enhanced more for the forward scattering case of looking into the sun. These results are supported by real experiences of SWIR, NIR, and Vis cameras on airborne platforms where the increase in atmospheric penetration along with reduced solar scatter far outweighs the reduction in resolution provided by shorter wavelength cameras.
14. TURBULENCE

Turbulence causes a reduction in target acquisition performance (discrimination range) due to image blurring and distortion. In our analysis, we use a moderate level of turbulence, $Cn^2=1E^{-13}$ m$^{-2/3}$, to determine the effects on discrimination range. A direct comparison can be seen in the left and middle plots of figure 19, where the 3-inch aperture system against facial identification is seen for the case of 23Km visibility and the sun behind the observer. The left plot has negligible turbulence and the middle plot has a turbulence of $Cn^2=1E^{-13}$ m$^{-2/3}$. Turbulence affects range performance as a function of aperture diameter and wavelength and it can be seen that SWIR is degraded much less than the visible and NIR bands. For the 6-inch aperture case against tank, longer ranges are involved as shown in figure 18 (left plot). Turbulence degrades the discrimination range much more severely as shown in the right plot of figure 19. Again, SWIR is degraded much less than the Vis and NIR bands. While wavelength does not impact system performance as much as aperture size, it is still a factor in band selection for long range systems. Overall, SWIR is a better choice for long range target identification with and without turbulence conditions.

15. CONCLUSIONS

A summary of band comparisons is shown in figure 20 for daytime considerations. Overall, SWIR has much to offer in target acquisition systems. A primary consideration for use of SWIR is the atmospheric penetration offered at SWIR wavelengths over Vis and NIR bands. There are other benefits associated with SWIR and/or NIR bands over visible as described in this paper.
### Passive Day Comparison of Vis, NIR, SWIR

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<th>VIS</th>
<th>NIR</th>
<th>SWIR</th>
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<td>1. Maritime Haze Penetration</td>
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<td>2. Fog Penetration</td>
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<td>3. Atmospheric Transmission</td>
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<td>4. Cloud Penetration</td>
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<td>5. Forrest Fire and Fog Oil Penetration</td>
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<td>6. &quot;See&quot; Laser Designator Spot</td>
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<td>7. Camouflage Detection/Identification</td>
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<td>8. Urban and Rural Background Contrast</td>
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<td>9. Maritime and Ground Target Contrast</td>
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<td>12. Spectral Discrimination</td>
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<td>13. Turbulence</td>
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<td>14. Long Range Identification (3 inch Aperture Soldier)</td>
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<td>15. Long Range Identification (6 inch Aperture Platform)</td>
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Figure 20. Summary of Band Comparisons (Vis, NIR, and SWIR) for Daytime Considerations.

### 16. ACKNOWLEDGEMENTS

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2. A. Arnulf and J. Bricard, “Transmission by Haze and Fog in the Spectral Region 0.35 to 10 Microns,” JOSA Vol 47, No 6, June 1957.
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