NPS-MR-06-001

NAVAL POSTGRADUATE SCHOOL

Monterey, California

Report on TNT 05-3 Atmospheric Effects Support

by

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14 November 2005

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Prepared for: NPS Center for Defense Technology and Education for the Military Services (CDTEMS)

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This report was prepared for and funded by the NPS CDTEMS in conjunction with the USSOCOM-NPS Cooperative Field Experimentation Program.

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** November 2005	**3. REPORT TYPE AND DATES COVERED** Technical Report

4. TITLE AND SUBTITLE **Report on TNT 05-3 Atmospheric Effects Support**	**5. FUNDING NUMBERS**
6. AUTHORS Peter Guest, Kenneth Davidson, Jeffrey Knorr, Richard Lind and Karl Gutekunst	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Meteorology, Naval Postgraduate School, Monterey, CA 93943-5114 Department of Electrical and Computer Engineering, Naval Postgraduate School, Monterey, CA 93943-5207	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) NPS Center for Defense Technology and Education for the Military Services (CDTEMS), Monterey CA 93943	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT

Optimizing situational awareness on the battlefield requires knowledge of the radar, communication and optical detection ranges for both friendly and enemy units. One of the goals of TNT 05-3 was to demonstrate the capability of providing this information in real time to forces in the field and command centers. This report discusses the efforts and accomplishments that were made to achieve this goal. All of the planned measurements, data transmission systems, real-time modeling and displays operated successfully for the entire TNT05-3 period (17-18 May, 2005). There were no periods when the radar and visibility predictions were not available to the command center. This demonstrates that providing special operations personnel with information on radar, communications and target detection ranges in real time is feasible, as long as basic information (temperature, humidity, wind speed) is available near the surface in the area of operations. This was the first time for the TNT project that the radar and optical models were quantitatively compared and analyzed using actual field tests. Not surprisingly, the model predictions were not accurate to the high degree needed for an operational special forces situation. The radar ranges were under-predicted. The visibility predictions were greatly improved from the previous TNT projects, due to the inclusion of human eye factors in addition to atmospheric effects. However, the ranges were still over-predicted by a factor of two.

14. SUBJECT TERMS radar, optical systems, atmospheric effects	**15. NUMBER OF PAGES** : 20
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	Same as report

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REPORT ON TNT 05-3 ATMOSPHERIC EFFECTS SUPPORT

1. Introduction

Optimizing situational awareness on the battlefield requires knowledge of the radar, communication and optical detection ranges for both friendly and enemy units. One of the goals of TNT 05-3 was to demonstrate the capability of providing this information in real time to forces in the field and command centers. This report discusses the efforts and accomplishments that were made to achieve this goal. Some of the information in this report section is similar to what was presented in the previous report (TNT 05-2) because similar instrumentation was used. Major differences are that the optical model was upgraded to include effects of aerosols (suspended particles in the atmosphere) and the visual acuity of the human eye. Another major difference was that an actual radar was operated from NPS in order to assess the accuracy of the radar range predictions.

2. Measurements

Motivation. In order to quantify radar, communication and optical detection ranges knowledge of atmospheric conditions is crucial. To support this goal, NPS personnel deployed three sensor suites, one on the vessel *Cypress Sea*, another at the Del Monte Beach site located near the NPS Rapid Environmental Assessment Laboratory (REAL) and another on a weather balloon launched from the roof of Spanagel Hall at NPS.

We designed this measurement program to simulate the basic near-surface atmospheric information that would be available in an operational situation. This includes wind vector, air temperature, humidity at a single level and surface temperature. Typically, how these parameters vary near the surface (which can have large effects on radar, communication and optical/IR systems) is modeled from single level measurements. At the Del Monte Beach site, we also measured air temperature and humidity at two additional levels and a subsurface temperature (options that probably would not be available in an operational setting). These additional measurements provided us with more direct measurements of how temperature and humidity vary just above and below the surface. We will use this additional information to evaluate the adequacy and accuracy of the current atmospheric surface layer models and the associated data transmission and target detection range predictions. The data collected from these measurements is available to anyone upon request. More details on the measurements follows.

Surrogate vessel-based measurements. Surface meteorological data were collected from the *Cypress Sea* at 1 sec intervals using a Campbell Scientific Model CR10X datalogger. These data include: Compass heading, relative wind speed and direction, from a Climatonics Sonimometer; air temperature and relative humidity from a Rotronic Model MP100H probe mounted in a naturally ventilated radiation shield from R. M. Young; atmospheric pressure from a Atmospheric Instrumental Research Model AIR-DB-1A barometer; water surface temperature from an Apogee Model IRTS-P infrared thermometer; GPS data (date, time, latitude, longitude, magnetic declination, speed and course over ground) from a Garmin GPS 16-HVPS receiver. Table 1 lists mounting heights for these sensors. Figure 1 is a photograph of the sensors mounted behind the pilot house on the *Cypress Sea*.

One second sampled meteorological data from *Cypress Sea* were relayed to a base station at the REAL using a pair of Freewave Model FGR-115RC, 902-928 MHz, spread spectrum transceivers and 6 dB omni-directional antennae.

Table 1. METOC Measurements on the *Cypress Sea*.

Parameter	**Height above water**	**Instrument**	**Manufacturer**	**Model**
Air Temperature	3.8 m	Forced Aspirated Sensors	Rotronic	1/10 DIN Pt100 RTD/Hydroclip S3
Relative Humidity	3.8 m			
Wind Speed	4.0 m	Sonic Anemometer	Climatronics	Sonimometer
Wind Direction	4.0 m			
Pressure	2.4 m	Barometer	AIR	AIR-DB-1A
Sea Surface Temperature	3.7 m*	IR Thermometer	Apogee	IRTS-P
Ship Location/Speed	2.4 m	GPS Receiver	Garmin	GPS16-HVPS
Ship Heading	4.0 m	Compass	PNI	

*Measures temperature at surface.

Figure 1. Photograph of meteorological sensors and communication antenna mounted on *Cypress Sea* during TNT 05-3.

Shore measurements. A meteorological tower (see Figure 2) was installed at Del Monte Beach, close to the optical target pattern. This location was chosen as it closely matched the environment of the optical target, i.e., asphalt surface. Sensors deployed included: Wind speed and direction using an R.M. Young Model 05053 wind monitor; three levels (0.5, 1.0 and 2.0 m above ground) of air temperature and relative humidity using matched Rotronic MP100H probes mounted in mechanical aspirators, Model LPC from Kaymont; atmospheric pressure using a Vaisala Model PTB101B barometer; ground surface temperatures using an infrared thermometer from Everest Interscience Model 3600; ground temperatures at the surface and 5 cm below the surface using Campbell Scientific Model CS107 and CS108 probes. Sensors deployed were sampled at 1-sec intervals and 5 min averages were computed using a Campbell Scientific Model CR5000 datalogger. Vector averaging was used for winds. The Del Monte Beach meteorological tower can be seen to the right of the optical target in Figure 6. Table 2 lists sensor mounting heights for the Del Monte Beach tower.

Data from the Del Monte Beach meteorological tower were relayed to the nearby base station using a Freewave Model FGR-115RC, 902-928 MHz, spread spectrum transceivers and 3 dB omni-directional antennae.

Figure 2. Meteorological tower deployed at Del Monte Beach, near optical target.

Table 2. METOC Measurements at Del Monte Beach

Parameter	Height above ground[1]	Instrument	Manufacturer	Model
Air Temperature	2.0, 1.0, 0.5 m	Forced Aspirated Sensors[2]	Rotronic	1/10 DIN Pt100 RTD/Hydroclip S3
Relative Humidity	2.0, 1.0, 0.5 m			
Wind Speed	4.1 m	Propeller Vane	R. M. Young	05053
Wind Direction	4.1 m	Anemometer		
Pressure	1.5 m	Barometer	Vaisala	PTB101B
Surface Temperature	0.0 m	IR Thermometer	Everest	Model 3600
Surface Temperature	0.0 m	Thermistor	Campbell Sci.	CS107
Sub-surface Temperature	-0.05 m	Thermistor	Campbell Sci.	CS108

[1]Ground level was approximately 6 meters above sea level.
[2]One sensor for each level (three sensors deployed),

Weather Balloon. The weather balloon carried a device called a rawinsonde. This was launched from the roof of Spanagel Hall on the NPS campus at 1326 PDT on 17 May, 2005. The rawinsonde transmitted meteorological data using a 403 MHz radio link. It was equipped with a GPS receiver that measured the movement of the rawinsonde, thus providing a measure of the wind vector. It also measured pressure, temperature and humidity. The balloon was equipped with a device that produced a slow leak so that after reaching a maximum elevation of 4941 m, a parachute deployed and the rawinsonde continued to make measurements as it came down slowly. Therefore all the parameters were measured as a function of elevation for two profiles: once going up and once coming down. The purpose of the rawinsonde is to provide a profile of the index of refraction, which affects radar propagation.

3. Real-time Radar Prediction Support and Verification

Introduction. The atmospheric effects group provided predicted radar detection ranges to all simulated field and command personnel in real time throughout the two days of the project. In addition, an actual radar was used to verify the predictions for part of the period.

Radar. Personnel from the Electronic Systems Engineering department at NPS (Jeff Knorr and Paul Buczynski) operated an ANS/SPS-67 radar from the roof of Spanagel Hall on the NPS campus from 1020 PDT to 1230 on May 17, 2005. During this project the radar operated with these parameters:

Type: Simple Pulsed with PPI video integration
Frequency: 5578 MHz
Peak Power: 200 kW

Pulse Length: 1 microsecond
Pulse Rate: 1201 Hz
Receiver Noise: 8.7 dB
Antenna Type: Parabolic Section
Polarization: Horizontal
Antenna Gain (Relative to an isotropic antenna): 30 dBi
Scan Rate: 15 RPM
Horizontal Beam Width: 1.5 degrees
Vertical Bean Width: 16 degrees
Antenna Elevation Angle: Fan beam, 0 - 16 degrees above horizon
Antenna Height: 148 feet
MDS: -94 dBm

The target was the *Cypress Sea*. Previous experiments showed that the radar cross section for this target was 14 m^2 (assumes a 4 dB system loss).

Radar Propagation Model. The atmospheric effects group used the Advanced Propagation Model (APM) to make radar range predictions. The APM model was run every 5 minutes using the above radar and target parameters and the real-time atmospheric measurements from the *Cypress Sea* described in the previous section.

Radar Ducting. For this type of radar, a feature called an "evaporation duct" can have a large effect on the range of the radar. This feature is caused by evaporation from the ocean surface and results in greatly extended ranges if the radar and target are within the duct. In this case, the radar was above the evaporation duct, but it still had some effect on radar range, according to the APM model.

Two other types of ducts, a surface duct and an elevated duct also can affect radar (and radio) transmissions. These are caused by changes in humidity with height, and to a lesser extent, temperature changes. In the Monterey Bay region, these ducts are associated with contrasts between cool moist air in the marine boundary layer and warm dry air above the marine layer. Surface and elevated radar ducts are a common occurrence in this region, particularly in the summer months. However the data from the rawinsonde indicated that there were no elevated ducts present during the TNT 05-3 period.

Coverage Diagrams. Two visual display products were available in real time during the active phase of the TNT 05-3 (17-18 May, 2005): (1) a horizontal radar coverage diagram based on data collected within the last 5 minutes (Figure 3) and (2) a time series of radar range and evaporation duct height, showing time variations since the beginning of the day (Figure 4). Both products were based on model results from the APM using the real-time atmospheric data as inputs (See Figure 5 in later section). The real time radar coverage diagram that was updated every 5 minutes during the project.

Radar Verification. On May 17 while the ANS/SPS-67 radar was in operation the *Cypress Sea* steamed away from the radar while the radar "hits" were visually observed and also recorded with a video camera. These data are still being processed, but some preliminary results show that the radar started losing hits at a range of about 12.5 nmi and no hits were observed at greater than 14.7 nmi. This was a greater distance than the predicted range at that time of 10.2 nmi (Figure 4).

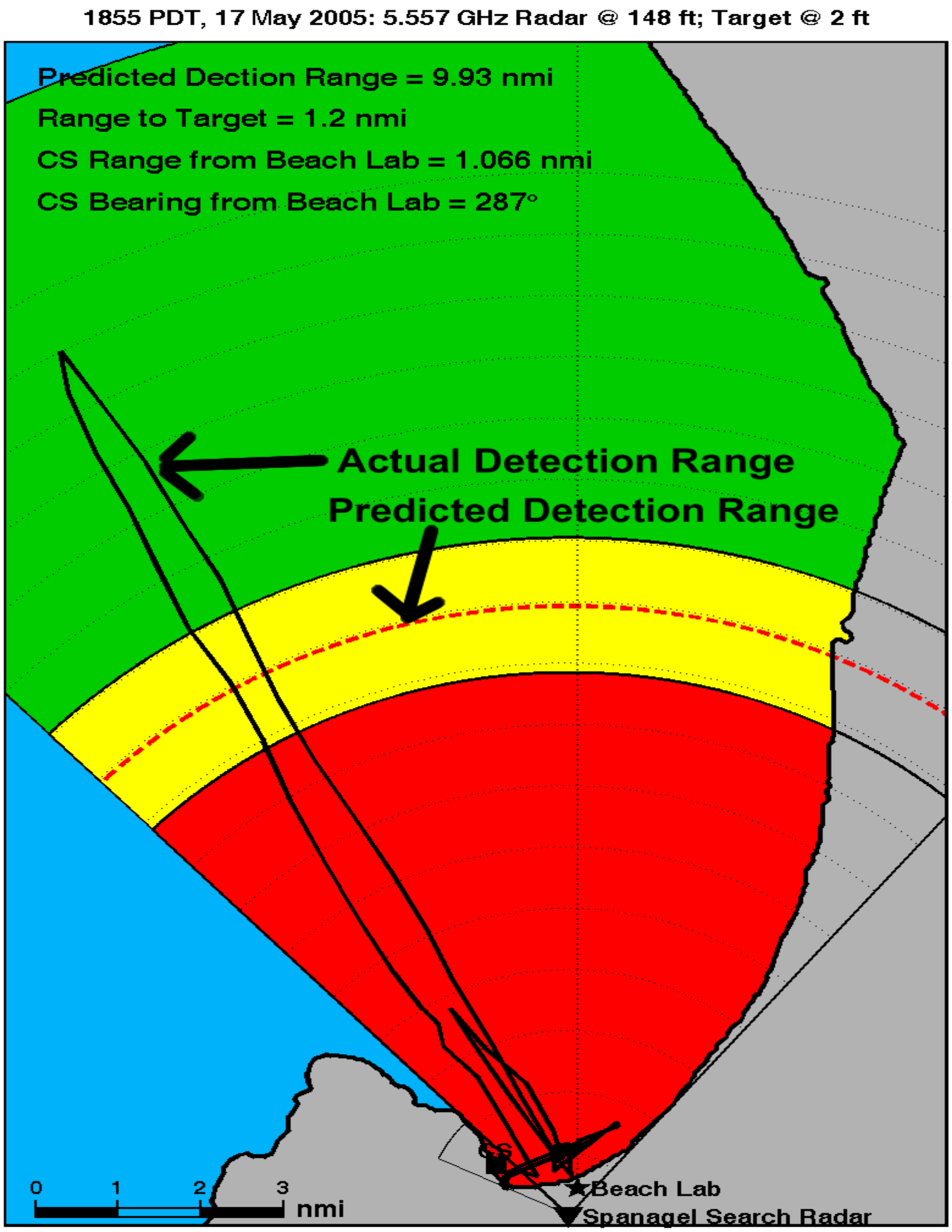

Figure 3. This is an example of the real-time radar range prediction product that was produced in support of TNT 05-3 operations. The labels for actual and predicted ranges were added later and were not shown in real time, everything else is identical to the real-time product. Red indicates regions where the ship would have been detected, yellow indicates possible detection regions and green indicates detection would be unlikely, according to the APM model. The red dashed line indicates where the probability of

detection is 50%. Grey represents land areas, blue represents ocean areas that are not in within the radar sweep. The dark curved line is the ship track for this 17 May. This figure was updated every 5 minutes throughout TNT 05-3 operational period. The information at the top of the diagram was for the end of the day, not the period when the radar was actually operating.

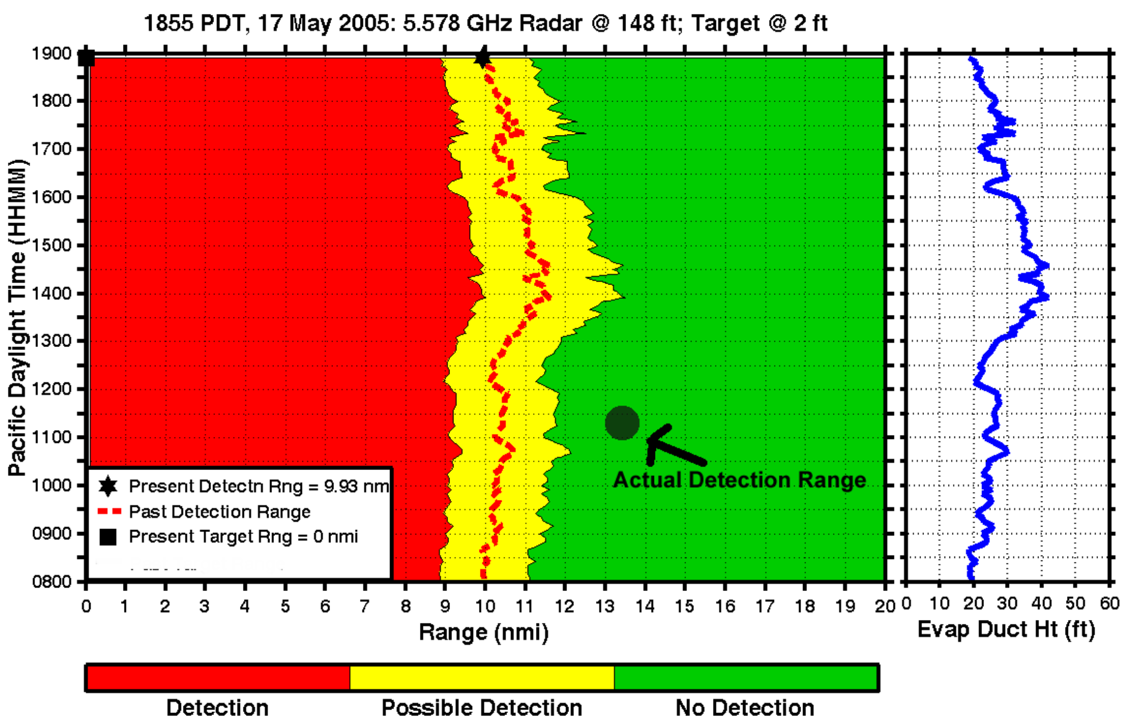

Figure 4. Example of time series product available in real time throughout TNT 05-3. In this case 17 May is shown. The indication of the time and range of the actual radar (black filled circle with label) was added later. The vertical scale indicates local time starting at 0800 PDT (bottom) to the time at which the display was updated (top), in this case, 1855 PDT. Color scheme for the left diagram is the same as Figures 3. The right diagram shows modeled evaporation duct height, based on the real-time atmospheric measurements from the *Cypress Sea*. Notice how variations in the evaporation height did affect the modeled radar ranges. The actual radar measurement of range was available only for one time period and therefore was not able to resolve the temporal changes that were predicted.

The reason that the actual radar range at 1130 PDT was greater than the predicted range was probably because parts of the target were higher than assumed for the real-time model runs. The APM model requires just a single elevation for the target. A value of two feet was used because this value represents the average height of largest cross-sectional area of the target, which is the main hull of the *Cypress Sea*. But the boat had a super-structure and antennas that extended 13 feet above the surface of the ocean. These could have reflected enough radar energy to be detected, but this was not modeled. Also on 17 May there was a strong swell of 12 feet where the boat was operating. This would raise the target several feet higher than the assumed 2 feet elevation for some of the time, again an effect that is not included in the model.

The atmospheric effects group ran the APM model again, using identical parameters as the 17 May case except the height of the target was varied. A target height of 9 feet yielded a predicted range (50% probability of detection) of 14 nmi, which corresponded to what was observed with the actual radar. Since this height was easily within the range of the top parts of the boat and even the main hull portion when the boat is on top of a swell crest, it seems reasonable that this is the reason that radar hits were observed at greater distances than predicted.

4. Real-time Visual Detection Support

Introduction. Target visibility from the human eye or optical and infrared (IR) sensors is a concern for various operations. Target visibility can be affected by sun angle, target and background characteristics, the atmospheric aerosol (particles) and optical turbulence. For TNT05-3 the atmospheric effects group developed a model that included the effect of optical turbulence, aerosol and visual acuity of the human eye.

Optical Model. Optical turbulence causes a target to become less distinct and move about in a random pattern. This phenomenon is familiar to most people who have observed the "twinkling" of a star. This twinkling is a manifestation of optical turbulence. Optical turbulence is quantified by a parameter called the refractive structure function, or C_N^2. Higher C_N^2 means a target will only be discernable at shorter ranges. The refractive structure function was determined using the real time meteorological measurements (Figure 5). The details on how C_N^2 was calculated are beyond the scope of this report, but can be obtained from the authors of this section.

Aerosol affects visibility by scattering and absorbing light. During TNT 05-3, there was not a high concentration of aerosol and it only had significant effects on visibility for ranges greater than 20 nmi.

We assumed that the naked human eye for a person with 20/20 vision can resolve objects at a distance 5800 times the size of the object. This requires a sharp contrast of the target and background and perfect viewing conditions.

Using a telescope or binoculars increases an individual's visual acuity. The amount of improvement increases linearly with the magnification of the instrument, but there is some instrument degradation because the lenses can never be perfect, some light is absorbed and there are reflections and other effects that cause instrument degradation. For this project we used 6 power binoculars and assumed that the instrument degradation was 30%. Optical instruments only improve an individual's visual acuity, they do not provide any improvement for optical turbulence or aerosol effects.

The three effects of optical turbulence, aerosol and visual acuity were combined in a least-squares sense to give the final overall predicted visual range for various targets.

Optical predictions. In support of the TNT 05-3 activities, the atmospheric effects group used the optical model described above to predict the ranges at which various objects could be visually detected with the naked eye and with binoculars. These predictions were displayed graphically and were available at the TOC command center throughout the project (Figure 6).

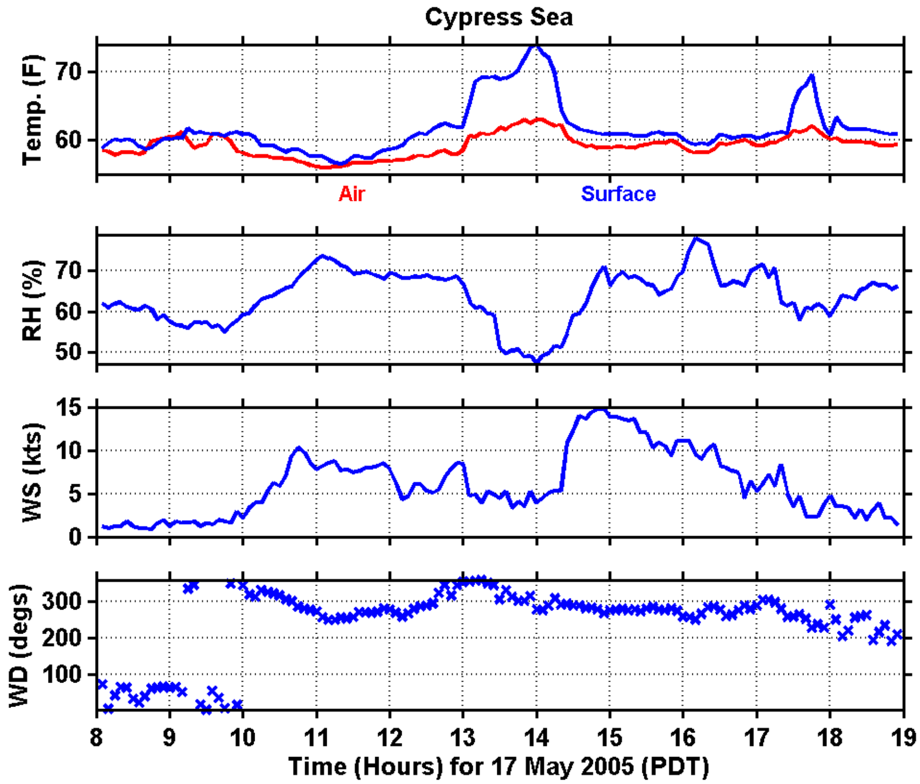

Figure 5. Atmospheric parameters measured on 17 May from the *Cypress Sea*. These measurements and others on 18 May provided the inputs used to estimate the characteristics of the evaporation duct for radar (see radar section above) and for the calculation of optical turbulence used for the optical range predictions.

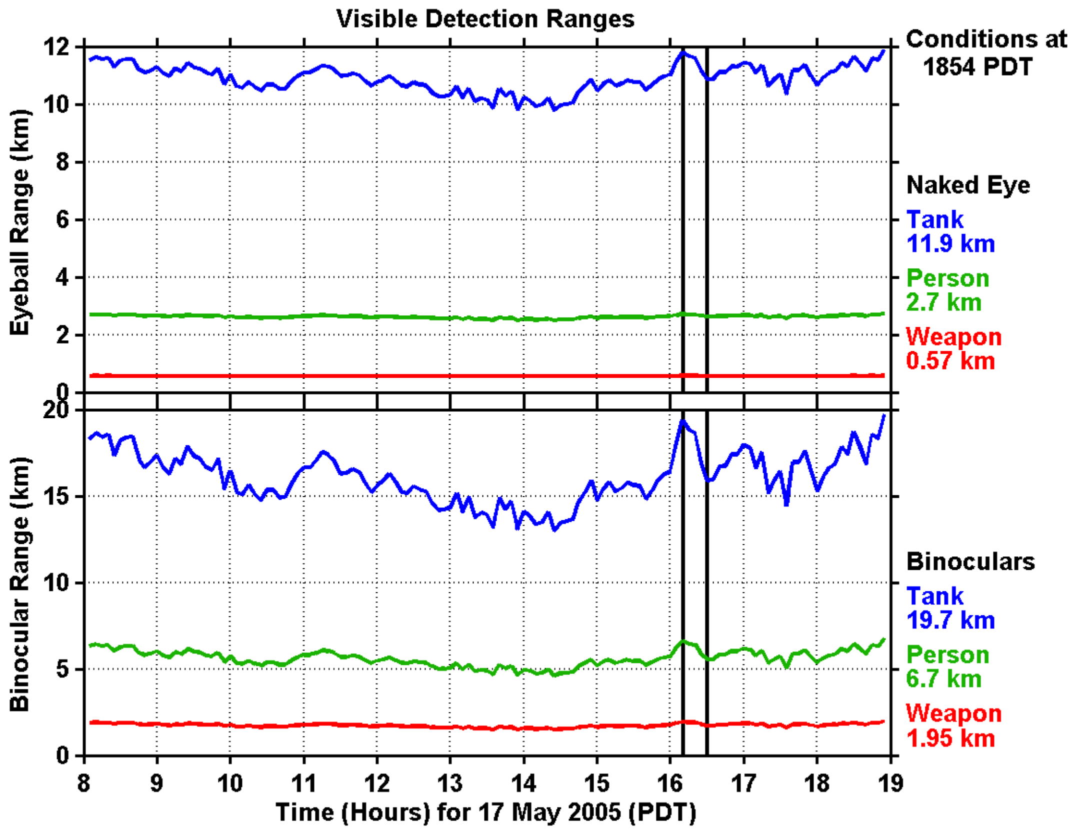

Figure 6. An example of the visual range product that was available in real-time for TNT 05-3. These are based on the data in Figure 5 and the optical model described in this section. The top plot represents ranges with the naked eye while the bottom plot represents ranges with 6 power binoculars. Note that the vertical scale is different for the two plots. The blue lines represent the predicted visual ranges for a tank, green lines a person and red lines a hand weapon. The variations in these lines are a result of the changing atmospheric conditions. Notice that at close distances, such as the predicted range for a weapon as seen with the naked eye, there is no temporal variation. This is because at these distances, the optical turbulence and aerosol have an insignificant effect, and the range is entirely determined by the observer's visual acuity. In contrast at far distances, such as the range for a tank with binoculars, the atmosphere has a much greater effect and there are significant temporal variations as atmospheric conditions change. The two vertical black lines bracket the period during which actual observations of range were undertaken; these were not shown in the real-time product.

The information on the right provides data on the latest predictions for operational use. The information represents the last points on the plots, which in this case are 1855 PDT 17 May.

Optical Prediction Verification In order to have a standardized measure of visibility, a target was set up at the REAL lab location on the shoreline (Figure 7). It consisted of three series of black and white lines of varying sizes. The predicted ranges of the three different target line sizes were determined for verification purposes, but because they have no operational significance these data were not provided in real time (i.e. Figure 6). A car was used as a proxy for a tank and an umbrella was used as a proxy for hand weapon such as an M-16 rifle. The car was located next to the standard target and two

Figure 7. Standardized target used for TNT 05-3

persons stood in front and below the target. One of the persons held the umbrella sideways in front of him, simulating bearing a weapon. The vehicle was assumed for modeling purposes to have a size of 2.5 m, the person 0.5 meters and the "weapon" (umbrella) 0.1 m. These sizes represent "one cycle" in the smallest dimension of each object, i.e., the height of the vehicle and the width of the human and "weapon".

From 1611 PDT to 1630 PDT the *Cypress Sea* approached the beach while an onboard observer recorded the times when he could resolve the various targets on the shore. "Resolve" means he could distinguish the different lines, he could determine that the individuals were people and for the weapon he could determine that one of the persons was holding a rifle-like object. This is not the same thing as "detection" which is simply that some object is detected. For example in Figure 7, the smallest target in the lower left corner can be detected, but the various lines cannot be resolved. "Resolve" is also not the same thing as "identification". "Identification" would mean the person can be recognized, the brand of car determined and the type of weapon identified.

During this period, the sky was overcast, there was no rain or fog and no glare was near the targets. Earlier in the day the observer had difficulty determining where the targets were, but because the ship had made an close pass before this time, he know exactly where to look for the experiment being described here. This is an important point, because in a real operational situation, the personnel might not know exactly where targets are, and this makes detection (and resolution) much more difficult.

The times when the various targets were resolved were related to a range from the vessel to the target using the ship GPS. This was done after the actual field program. The results are shown in Table 3 and Figure 9.

As can be seen, the model over-predicted the maximum ranges at which the various objects would be resolved, both with the naked eye and with the binoculars. In other words the observer could not see the objects as well as predicted. For the standard targets, the actual observed resolution ranges were approximately one-half of the predicted values. This also true for the human and the "weapon". The vehicle was detected at only one-third of the distance as predicted.

Why did the model overpredict? The observer (the author K. Gutekunst) reports that viewing condition were anything but ideal. A major hindrance to viewing was that the seas were rough and the vessel was experiencing strong rolling and pitching motion; this was a 30 ft boat in a 12 foot swell. He was looking through a window on the vessel (because condition were too rough to be outside) which further degraded his viewing ability. Also he reports that he was under considerable "peer pressure" to perform well

Target	Binoculars (6X Power)			Naked Eye (20/20 Vision)		
	Time (PDT)	Observed Range	Predicted Range	Time (PDT)	Observed Range	Predicted Range
Large Lines[1]	1618:00	3.907	6.386	1625:00	1.304	2.667
Medium Lines[2]	1624:10	1.617	3.596	1626:45	0.669	1.375
Small Lines[3]	1626:00	0.940	2.063	1629:30	0.312	0.707
Vehicle[4]	1613:00	5.780	17.995	1618:40	3.654	11.525
Human[5]	1617:00	4.276	6.518	1622:50	1.217	2.627
Weapon[6]	1627:30	0.515	1.729	1629:50	0.298	0.562

(he was a new employee) and the nervousness this caused also may have degraded his capabilities.

Table 3. Predicted and Actual Visible Resolution Ranges

[1]Standard Target W = 20 inches (see Figure 9 for explanation of W)
[2]Standard Target W = 10 inches
[3]Standard Target W = 5 inches
[4]White Honda Civic CRX
[5]Wearing dark clothes, 6'4" Height
[6]Simulated with black umbrella

Figure 9. Example of lines in standard target. Note "W" is one cycle, i.e. the distance from the edge of one black line to same edge of the next back line.

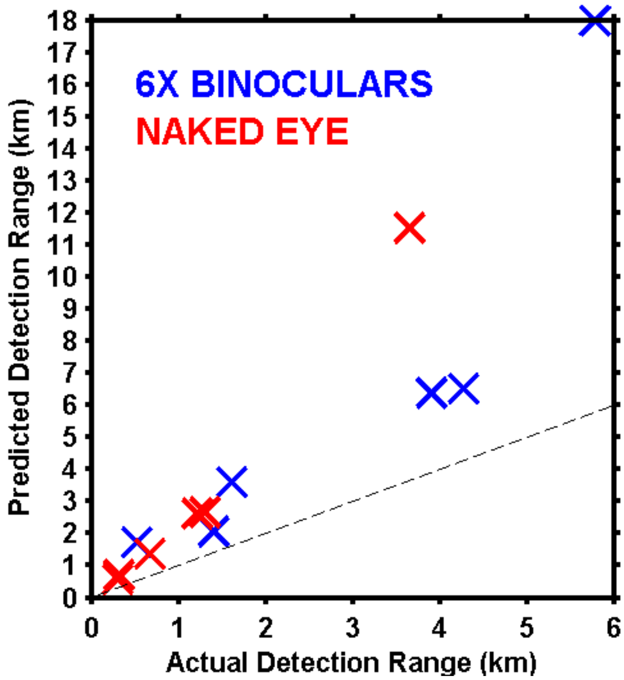

Figure 9. A graphical representation of the same data shown in Table 3. The dashed line represents where the points would fall if the model and observed data matched perfectly.

The reason the vehicle detection range was even worse (shorter distance) compared to the model relative to the human and the "weapon" was probably due to two further factors: The first factor was that it a white car and it was parked right next to the white standard target; they were visually merged together which made it more difficult to resolve the car. The second reason is that, in hindsight, the size of the vehicle (2.5 m) used in the model was too large. This was a small Honda and distance from the top of the roof to the bottom was only about 1.25 m. And also part of the lower part was blocked by vegetation.

5. Atmospheric Effects Support: Conclusions and Recommendations

System Performance. As occurred during the previous TNT project, all of the planned measurements, data transmission systems, real-time modeling and displays operated successfully for the entire TNT05-3 period (17-18 March, 2005). There were no periods when the radar and visibility predictions were not available to the command center. This demonstrates that providing special operations personnel with information on radar, communications and target detection ranges in real time is feasible, as long as basic information (temperature, humidity, wind speed) is available near the surface in the area of operations.

Modeling. This was the first time for the TNT project that the radar and optical models were quantitatively compared and analyzed using actual field tests. Not surprisingly, the model predictions were not accurate to the high degree needed for an operational special forces situation.

The radar ranges were under-predicted. We believe this was because the reflections from the upper part of the ship and the effects of the swell were not included as inputs into radar model. Further projects will take into consideration the higher parts of a vessel and the effects of swell on raising the vessel above the radar horizon intermittently.

The visibility predictions were greatly improved from the previous TNT projects, due to the inclusion of human eye factors in addition to atmospheric effects. However, the ranges were still over-predicted by a factor of two. We believe this was because the model assumed ideal viewing conditions and the actual conditions were not ideal. For the next TNT we will account for factors such as ship motion, window degradation and human effects such as stress on the ability to detect and resolve various targets. We will also test more sophisticated optical models such as the Target Acquisition Weapons System (TAWS)

Recommendations. We recommend that further comparisons of radar and visibility range between predictions and actual measurements be undertaken in various atmospheric and operational situations so that the models can be further refined.

Concluding remarks. We have confidence that in the near future (i.e. the next TNT), the real time guidance will be significantly more accurate and will be a valuable product suitable for use in special forces operations. The atmospheric effects group will continue to leverage our work for TNT by developing our measurement and modeling capability outside of the TNT framework. For example in July and September of 2005 a research vessel, the *Point Sur,* will be used for educational student cruises, during which time the ANS/SPS-67 radar will operate and the optical targets will be deployed in the same locations as used for TNT. We will encourage students to further this research in class projects and master's degree theses.

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