Summary of the Marine Aerosol Properties and Thermal Imager Performance Trial (MAPTIP)

Organized by

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ELECTRO-OPTICAL SYSTEMS
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D. R. Jensen
Ocean and Atmospheric Sciences Division
NCCOSC RDTE DIV 543
53170 WOODWARD ROAD
SAN DIEGO, CA 92152-7385
USA

G. de Leeuw
A. M. J. van Eijk
TNO Physics and Electronics Laboratory
Oude Waalsdorperweg 63
2509 JG The Hague
The Netherlands

SUMMARY

During the fall of 1993 a field experiment entitled Marine Aerosol Properties and Thermal Imager Performance Trial (MAPTIP) was conducted by NATO AC/243 Panel 04/RSG.8 and 04/RSG.5 in the Dutch coastal waters. The objectives of the trial were:

1. To improve and validate vertical marine aerosol models by providing an extensive set of aerosol and meteorological measurements, within a coastal environment, at different altitudes and for a range of meteorological conditions.

2. To make aerosol and meteorological observations in the first 10 m of the ocean surface with a view to extending existing aerosol models to incorporate near-surface effects.

3. To assess marine boundary layer effects on thermal imaging systems. Calibrated targets at different altitudes were observed to the maximum observable range under a wide variety of conditions in both the 3-5 and 8-12 μm bands. These data will be used for the development and validation of IRST models and IR ship signature models with the view of determining the effects of marine-generated aerosols, turbulence, and meteorological profiles on their performance.

Aerosol and meteorological instruments, as well as thermal imagers and calibrated targets, were utilized on the Dutch Meetpost Noordwijk (MPN) tower, at a Katwijk Beach Station, the Hr. Ms. Tydeman oceanographic vessel, on a Lynx helicopter, on a Dutch P3 Orion, on the NCCOSC RDT&E DIV (NRaD) airborne platform, and on buoy systems. This network of instrumentation has provided a comprehensive data base of aerosol size distribution profiles and relevant meteorological variables throughout the marine atmospheric boundary layer. Thermal imagery was included to provide ground truth for assessing the low-level propagation effects near the ocean surface. Measurements were made of atmospheric turbulence and refractivity effects in the IR and RF bands to assess the marine boundary layer effects on the degradation of thermal images.

Calibrated targets at different altitudes were observed to the maximum observable range under a wide variety of conditions in both the 3-5 and 8-12 μm bands. These data are to be used for the development and validation of IRST models and IR ship signature models for determining the effects of marine-generated aerosols, turbulence and meteorological profiles on their performance.

1. INTRODUCTION

Atmospheric aerosol and infrared sea and terrain background models are of special importance for the assessment of the performance of electro-optical (EO) systems. The degradation of the radiance contrast between a target and its natural background, as viewed by an infrared sensor, is determined by the constituents of the intervening atmosphere that absorb and scatter the radiation. The assessment, therefore, depends upon the accuracy of the atmospheric models being used in the propagation prediction codes. The performance of the electro-optical systems is further degraded by turbulence and refractivity effects, causing blurring, scintillation, beam wander, mirages, etc. In thermal imagers, these effects may result in image distortion, contrast reduction, and other detection problems.

Presently, the Atmospheric Transmission/Radiance computer code, LOWTRAN [1,2], is the primary tool used for this assessment. With the inclusion of the Navy Aerosol Model, NAM [3-10], into LOWTRAN 6 [1] and an upgraded version of NAM into LOWTRAN 7 [2], users are now able to determine the effects of aerosols on EO propagation in a maritime environment. This model has proven to be a useful tool in predicting atmospheric transmission in the marine atmosphere along horizontal paths at shipboard levels (above 10 m). Another atmospheric aerosol model, NOVAM [11-19] (The Navy Oceanic Vertical Aerosol Model), is being prepared for inclusion into LOWTRAN/MODTRAN and accounts for the generation, dispersal and removal of the marine aerosols, including transport processes, in the vertical dimension. This model uses NAM as its kernel and is useful for predicting the vertical profiles of extinction from shipboard heights upward through the marine boundary layer. However, to date, the NAM and NOVAM validation has been restricted to a limited range of meteorological situations and geographical locations and must be extended to include coastal regions with substantial continental aerosol inputs. Also, recent studies have shown that NAM/NOVAM in their present forms should not be extrapolated into the region very near the surface (below 10 m) of the ocean for predicting atmospheric properties [20, 21].

It is important to obtain more detailed information on atmospheric characteristics for the 3-5 and 8-12 micron wavelengths in the first few meters above the surface of the ocean. An effort needs to be undertaken to model the first 10 m above the ocean surface and incorporate it in LOWTRAN for prediction performance of EO systems used for detecting low-altitude targets.

In response, the NATO AC/243 (Panel 04/RSG.8), in collaboration from AC/243 (Panel 04/RSG.5), planned and conducted a field experiment to address these very problems. The name of the trial was entitled the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP). The MAPTIP project, in principle, consisted of two parts, i.e., the development and validation of models describing atmospheric effects on electro-optical propagation properties (aerosol extinction, refraction, and turbulence) and the assessment of thermal

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imager performance in a maritime environment. In this unique effort, these two disciplines were integrated by virtue of a cooperative effort between two NATO study groups by combining their expertise in the fields of atmospheric propagation effects and IR thermal imagers, targets and backgrounds.

The MAPTIP trial was conducted in the North Sea, between October 11 and November 5, 1993. The geographical layout is shown in Figure 1. Aerosol and meteorological instruments, as well as thermal imagers and calibrated targets, were utilized on the Dutch Meetpost Noordwijk (MPN) tower, at a Katwijk Beach Station, on the Hr. Ms. Tydeman oceanographic vessel, on a Lynx helicopter, on a Dutch P3 Orion, on the NRaD airborne platform, and on buoy systems. This network of instrumentation was used for obtaining a comprehensive data base of aerosol size distribution profiles and relevant meteorological variables throughout the marine atmospheric boundary layer. This information is required for the development of the next generation aerosol model ANAM (Advanced Navy Aerosol Model). Emphasis was placed on observations close to the ocean surface (below 10m). Thermal imagery was also included to provide ground truth for assessing the ANAM model development for low-level propagation predictions near the ocean surface. To achieve the second goal, measurements were made of atmospheric turbulence and refractivity effects in the IR and RF bands to assess the marine boundary layer effects on the degradation of thermal images.

The MAPTIP trial was organized by the TNO Physics and Electronics Laboratory and was supervised by a scientific committee consisting of representatives from the atmospheric effects and thermal imaging communities associated with the NATO AC/243 Panel 04/RSG.8 and 04/RSG.5. Altogether, about 50 scientific and engineering personnel participated in MAPTIP from 19 institutes located in 9 countries (Table 1). An extensive description of the MAPTIP trial and instrumentation provided by each participating institution can be found in the work plan [22]. An overview of the MAPTIP experiment for the RSG.8 and RSG.5 participants has been prepared and is available upon request [23].

2. SCIENTIFIC OBJECTIVES

The scientific objectives of the MAPTIP trial were: 1) Improve and validate vertical marine aerosol models, 2) Extend existing aerosol models to incorporate near-surface effects, 3)

Figure 1. Geographic location for the MAPTIP trial.

Institute	Institute (Abbreviation)	Country
TNO Physics and Electronics Laboratory	TNO-FEL	NL
Royal Netherlands Navy	KM	NL
Ministry of Public Works	RW	NL
University of Antwerp	UIA	BE
Defence Research Establishment Valcartier	DREV	CA
Danish Defence Research Establishment	DDRE	DK
CELAR	CELAR	FR
DGA/DCN/CESDA	DGA	FR
Forschungs Institut für Optik	EfO	GE
Fraunhofer Institut für Atmosphärische	IFU	GE
Norwegian Defence Research Establishment	NDRE	NO
University of Manchester Institute of Science and Technology	UMIST	UK
Naval Command Control and Ocean Surveillance Center, RDT&E DIV 543	NRaD	USA
Naval Postgraduate School	NPS	USA
Office of Naval Research	ONR	USA
Mesa Inc.	MESA	USA
Massachusetts Institute of Technology	MIT	USA
Naval Surface Warfare Center	NSWC	USA

Table 1. MAPTIP Participants.

Assess marine boundary layer effects on thermal imager systems, 4) Provide inputs for the development and validation of IRST models, 5) Provide inputs for the development and validation of IR ship signature models, 6) Provide additional data for analysis in areas of interest and importance to IR seeker and IR IRST applications. The latter includes horizon, sea, and coastal clutter, sea and sky background signatures, cloud data, day/night and dawn/sunset variations, turbulence, scintillation, ducting, mirage, and false alarms.

3. EXPERIMENTAL PROGRAM

A suite of instrumentation was mounted on the seven MAPTIP operational platforms to characterize the atmosphere and to assess the performance of thermal imagers. Several platforms served a dual purpose as a carrier for instrumentation and as a target for the imagers. The focal platform for the experiment was the Meetpost Noordwijk (MPN) oceanographic tower (owned and operated by the Dutch Ministry of Public Works) located 9 km from the Dutch coast, position 45° 16' 25.9" N, 04° 17' 45.8" E. A land based facility was established at the lifeguard station on the beach at Katwijk. Oceanographic buoys were located near MPN and at a position a few kilometers from the beach along the MPN-Beach Station line of sight. The oceanic research vessel Hr. Ms. Tydeman from the Royal Netherlands (RNL) Navy sailed a pre-described pattern in the vicinity of the MPN tower. Two aircraft and a helicopter completed the MAPTIP scenario. A Lynx helicopter and a P3 Orion patrol aircraft were made available by the RNL Navy. The second aircraft was the NRaD airborne platform [24], a twin-engine Piper Navajo. The operational platforms are shown in Figures 2 and 3.

3.1 Meetpost Noordwijk

The MPN tower was used both for comprehensive meteorological characterization and as a platform for thermal imagers and sources (Figure 2). During MAPTIP a 20 m boom was used by TNO-FEL to make air temperature and unperturbed turbulence measurements [25] using a Gill Sonic Anemometer. An Advanet H_20 and $C0_2$ fluctuation meter was also installed on the boom to determine the respective fluxes. The boom was further equipped with optical particle counters (PMS CSAS 200 P and OAP) to determine particle size distributions at low levels and to profile the aerosol distributions. Mean relative humidity and air temperature were measured on the boom with a Rotronic Hygrometer. Unfortunately, only few data were collected on the boom due to a structural failure during a storm.

On the helicopter deck located at 18.6 m above mean sea level (MSL), a mast was rigged by UMIST for a sonic anemometer and an OPHIR hygrometer to measure the turbulent air flow components, air temperature, and absolute humidity. UMIST

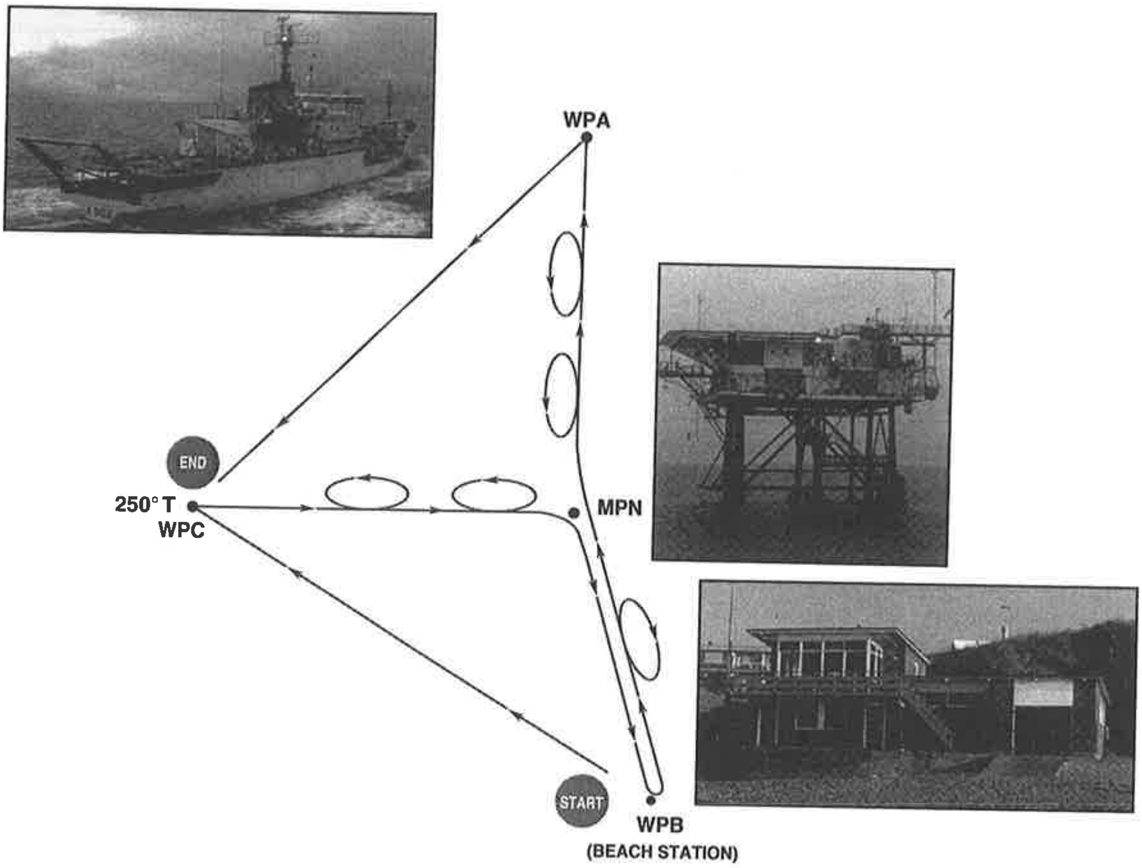

Figure 2. MAPTIP operational sequence (surface).

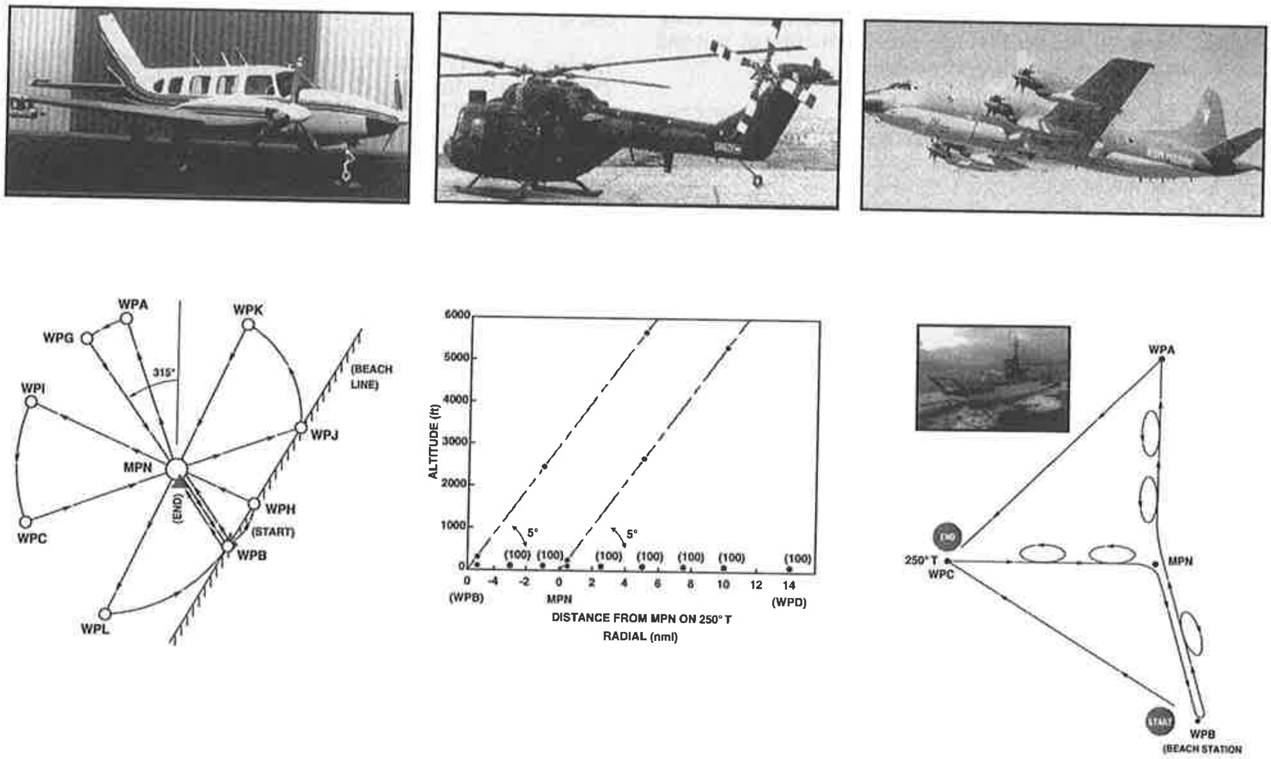

Figure 3. MAPTIP operational sequence (airborne).

also measured aerosols from the 11.6 m deck, where a meteorological station was mounted to determine local wind speeds and direction, air temperature, and relative humidity. The sea spray package consisted of a PMS FSSP-100 and a PMS OAP-230X optical particle counter. Aerosol size-segregated composition was determined with a PMS ASASP-X in combination with a volatility system. Soot carbon loadings were determined with an aetholometer. Weather conditions and sea state were monitored and pictures were recorded with a video camera. A radon counter was used as a back-up for air mass analysis. A second radon counter and a condensation nuclei (CN) counter were operated on the tower by NRaD.

Aerosol particle-size-distribution profiles were measured by NRaD utilizing an optical particle counter (PMS ASSP-100), and by NRaD and TNO-FEL with Rotorod impaction samplers (for particle diameters > 13 μm) [26]. Particle-size-distribution profiles were obtained in the size range from 0.5 to 100 μm diameter. The optical particle counter measurements were performed with the instrument mounted in a box that was hoisted up and down from the 15 m deck. The NRaD Rotorod was also mounted on this box, as well as instrumentation to measure air temperature and relative humidity. The TNO-FEL Rotorod measurements were made with the samplers mounted on a float that was deployed from a 10 m long outrigger mounted on the northwest 11.6 m platform [26]. Figure 4 shows measured aerosol-size-distributions taken near the ocean surface and the 11.6 m deck for low (0.1-2.1 m/s) and high (11-16 m/s) winds.

In support of the interpretation of the aerosol profile measurements, bubble size distributions were measured at fixed depths from 0.5 to 2 m below the sea surface with an optical device deployed on a floating platform. The float was anchored close to the MPN aerosol samplers at a position such that the bubble measurements were free of the MPN platform influences (currents advecting bubbles generated at the platform structure). Bubbles, when protruding the water surface, generate film and jet droplets in addition to spume droplets that are generated by direct tearing in high winds (wind > 9 m/s). These data will be used to formulate a reliable source function for use in aerosol generation models involving sea salt aerosols [27,28]. Figure 5 shows a measured bubble-size-distribution at 1 m and is compared with data from open literature.

Information on the vertical structure of the atmospheric boundary layer near MPN was obtained utilizing lidar systems. The NRaD ANGVS/5 lidar was used for profiling aerosol returns near the ocean surface (< 10 m), and the TNO-FEL smal lidar system [29] was used for slant path measurements under both negative and positive elevations. The lidar returns will be used for studying the variability of the inversion height and the depth of the transition layer [19]. Ship plume observations were also made.

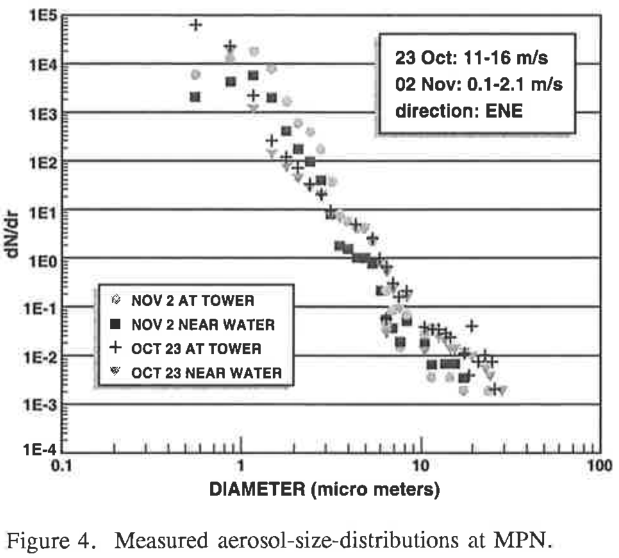

Figure 4. Measured aerosol-size-distributions at MPN.

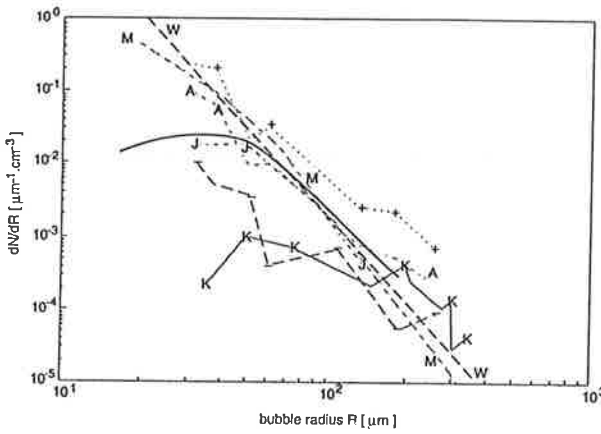

Figure 5. Measured bubble-size-distribution at 1 m (solid line) compared with data from the open literature.

Direct measurements of the extinction in the visible (0.53 μm) and at 10.6 μm were made by DREV using an HSS VR-310 Forward Scatter meter and a PVM-300 Forward Scattering Probe, respectively. The instrumentation was mounted on the 15 m deck. This location is well exposed to the prevailing winds and data should be representative of conditions unperturbed by the tower.

Meteorological data were routinely measured at MPN and is part of the North Sea monitoring network. Data includes wind speed, direction, air and sea temperature, atmospheric pressure, relative humidity, tide (water level land current) and wave observations. In addition to these observations, TNO-FEL mounted Rotronic sensors for air temperature and relative humidity at heights of 5.2, 6.6, 13, and 27 m MSL to monitor the atmospheric surface layer structure in support of optical and IR measurements of atmospheric refraction phenomena. A rain gauge and a pyranometer were added to this suite of instrumentation.

During MAPTIP four thermal imagers were located on MPN [30]. A US Kodak 2-5 μm PtSi radiometric imager was operated by MIT and a TICM II camera (8-12 μm), made available by DRE Funtington (UK), was operated by TNO-FEL. Both cameras were mounted on the 11.6 m deck at the southwest corner of the platform where unobstructed measurements could be made of sun glint, land backgrounds, and ship and airborne targets. On the top deck (18.6 m MSL), the Amber Model AE4128 Thermal Imager (InSb, 3-5 μm) from DDRE and a Philips FLIR (8-12 μm) from TNO-FEL were mounted.

With this instrumentation, both IR wavelength regions, 3-5 and 8-12 μm, were covered at each level. The Hr. Ms. Tydeman, was specially equipped with IR and visible sources, the Lynx helicopter with a source suspended at 20 m below, and the P3 Orion and the Navajo Piper served as targets for IR imaging. All operations utilizing these targets were scheduled around MPN. Figure 6 shows the 3-5 and 8-12 μm IR images of the Hr. Ms. Tydeman (stern view). Figures 7 and 8 show the 3-5 μm image of the Lynx helicopter and the P3 Orion, respectively.

A number of IR and visible sources were mounted on MPN. These included the FfO 300°C fixed temperature calibration source, the TNO-FEL 900°K 1000 Hz modulated source, and a sequence of visible lamps on the South side of MPN. The FfO source was mounted on the top deck as a reference for the FfO imaging systems at the Katwijk Beach Station. The TNO-FEL source was used for transmission measurements between MPN and the Beach Station. The visible lamps were mounted by DREV at differing heights above MSL from about 3.5 to 20 m for the study of refractivity effects.

3.2 Katwijk Beach Station

The Katwijk Beach Station consisted of two platforms: 1) the

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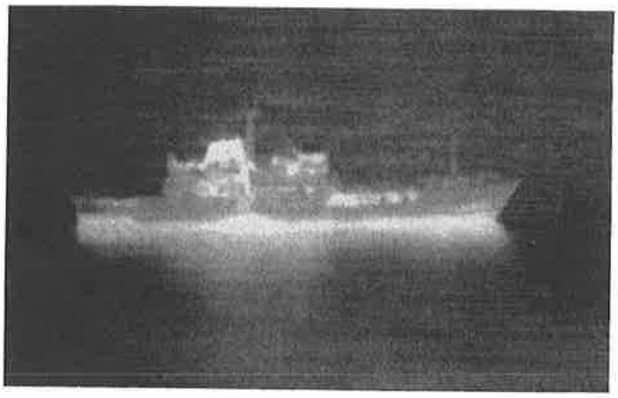

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Figure 6. Hr. Ms. Tydeman IR images.

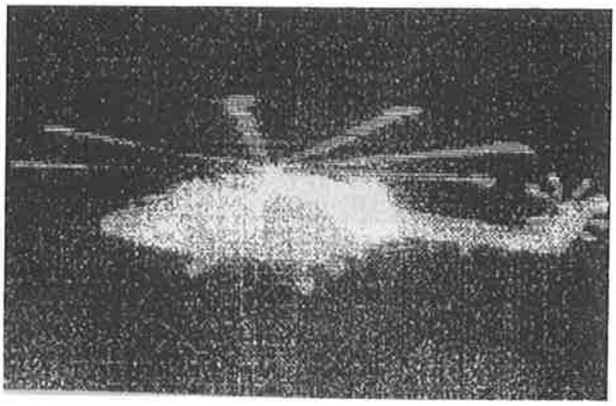

Figure 7. Lynx IR image.

Figure 8. P3 Orion IR image.

lifeguard station at the beach (Figure 2), and 2) the parking lot higher on the boulevard. FfO operated two thermal imaging systems at the parking lot location: 1) a dual waveband DUWIR that simultaneously measures in the 3-5 and 8-12 μm bands, and 2) an IRC-64 steering array camera (InSb 64X64 focal plane array) sensitive in the 4.5 - 4.7 μm wavelength region. Sky backgrounds were measured in the 2.5 - 8 μm wavelength region. Extended black bodies were located close to the camera systems for calibration. Supporting meteorological measurements (wind speed and direction, air temperature, relative humidity, pressure, visibility and up/down welling radiance) were made using a meteorological station.

Also located in the parking lot were two IFU mobile lidar systems: 1) a three-wavelengths aerosol lidar (355, 532, and 1064 nm), and 2) a 1.56 μm eye-safe lidar. The three-wavelength lidar has a range of > 15 km with a resolution of ≤ 15 m (532 and 355 nm) and ≤ 30 m (1064 nm). The 1.56 μm eye-safe lidar has a range of > 15 km with a resolution of 15 m. With these range capabilities, the atmospheric structure was characterized from the Katwijk Beach Station to ranges extending beyond MPN. Horizontal and vertical variations in the extinction coefficients at these wavelengths were also directly measured.

On the upper deck of the Beach Station IFU made measurements of extinction at 543 nm and 1.56 μm utilizing a two-wavelength White-Cell transmissometer. CESDA also made 0.55 μm extinction measurements on the upper deck utilizing an HSS VR-301-B-120 visibility meter. Aerosol size distribution measurements were made at this location using two optical particle counters (ASASP-X and CSASP-100 HV). A meteorological station recorded wind speed, air temperature, and relative humidity. The TNO-FEL transmissometer receiver for the MPN/Beach Station transmission path (10.44 km) was also on the upper level of the Beach Station. Using the 1000 Hz source on MPN, transmission measurements were made at wavelengths in the visible and 8-12 μm bands.

Also on the upper level of the Beach Station, polarization measurements in the 3-5 and 8-12 μm bands were made by NPS [31] using an AGA 780 Thermovision dual band radiometric imaging system fitted with IR polarization filters. Preliminary results indicate that the use of the polarization filters can suppress the backgrounds and can enhance target detection significantly (Figure 9).

NDRE operated two TICM-II camera systems on the lower deck of the Beach Station, i.e., in the 3-5 μm band and 8-12 μm wavelength bands. For continuous calibration, three sources were mounted a short distance from the cameras on the beach. A laser range finder was used for accurate range determination of the sources and the Hr. Ms. Tydeman and the Lynx helicopter targets. It was also used for determining the maximum target detection ranges.

Refraction studies were made by DREV to test the WWKD model [32] over open seas in the presence of waves. A series of 8 halogen lamps were mounted on the MPN tower between 3.5 and 20 m MSL, and four lamps on the Hr. Ms. Tydeman at 4, 8, 13, and 23.7 m MSL. These lights were monitored with two CCD Sony AVC-D5 visible cameras and one IR Mitsubishi FPA model IR5120A camera (3.3-5.0 μm). All three cameras were equipped with strong telescopes. Continuous monitoring of the light sources yielded important information on the refractivity phenomena as a function of range and weather conditions. Strong refraction was observed with clear mirage effects during large air-sea temperature differences which occurred for off-shore winds when cold air masses were being advected over a relatively warm water surface (Figure 10). Figure 11 shows a sequence of images of the Hr. Ms. Tydeman mast light as the ship was reaching the maximum detection range.

The objective of the CELAR experiment was to study the refractivity effects in the marine boundary layer and to test the refraction model "Bulk-CELAR". Three camera systems were used, a CASTOR (8-12 μm), a Mitsubishi model IR 512 A (3-5 μm) and a Sony (visible) to collect sequences of Hr. Ms.

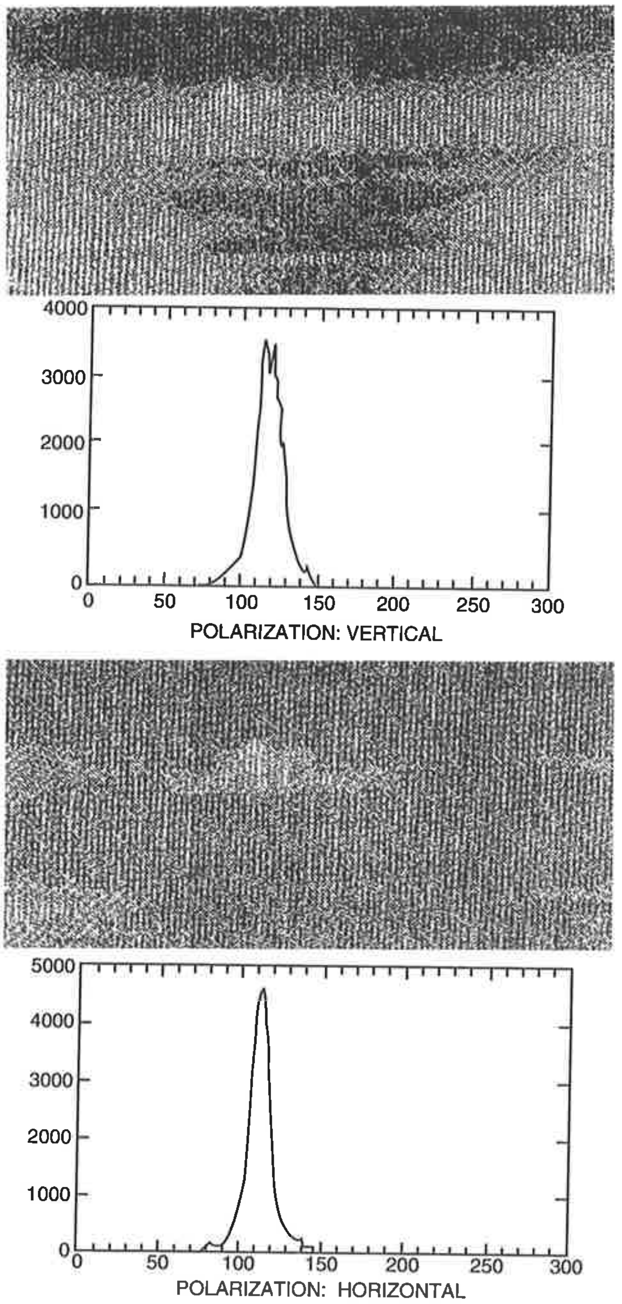

Figure 9. Polarization images of the Hr. Ms. Tydeman.

Tydeman and MPN images. The CELAR experiment was similar to the experiments conducted by DREV. The Beach Station also served as the receiver and monitoring location for the CELAR buoy data.

3.3 Hr. Ms. Tydeman

The oceanographic research vessel Hr. Ms. Tydeman (Figure 2), was made available for the MAPTIP trial by the RNL Navy. This platform served as a imaging target for the ship-signature studies (Figure 6), and as a platform for the visible and IR sources (Figure 11). The ship was instrumented with thermocouples and radiometers to monitor the temperatures of the hull, stack and the exhaust plume. A visible/IR 6X3 light source array was mounted on the stern for refractive studies. The upper and lower three sources emitted predominantly in the IR, the middle row emitted only in the visible. The main purpose was to have a low altitude intensive IR source to simulate a point target, i.e., a sea skimming missile that could be observable at variable distances. The ship's operational procedure allowed for the maximum use of this low level IR source. On inbound/outbound radials to MPN and the beach station, the

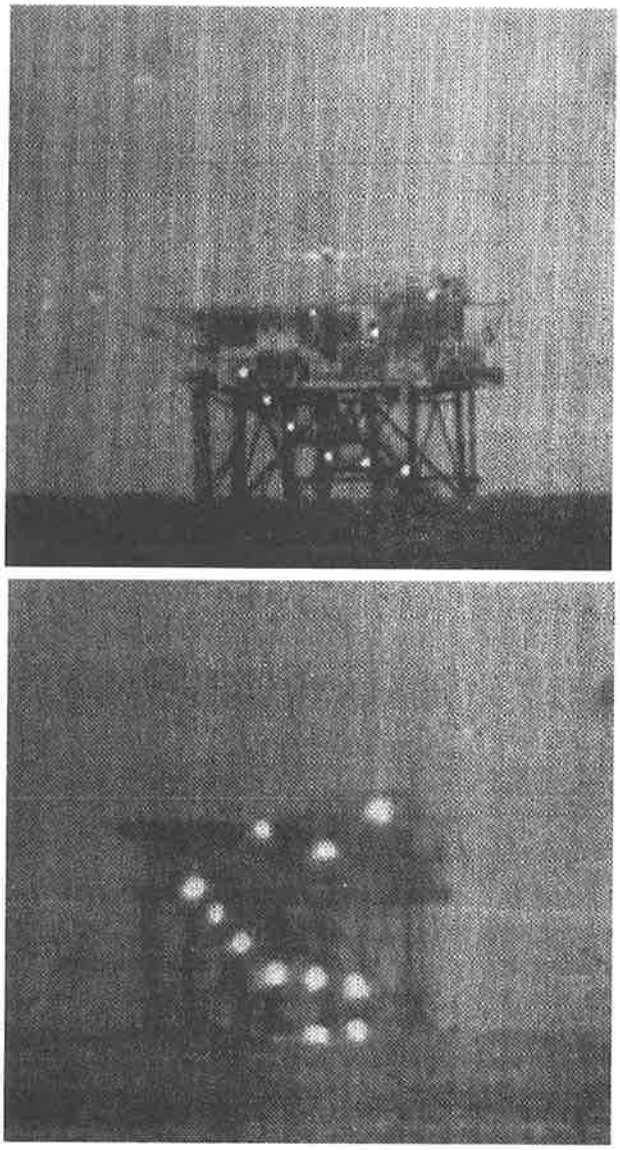

Figure 10. IR images of the MPN oceanographic tower (visible CCD Sony Camera).

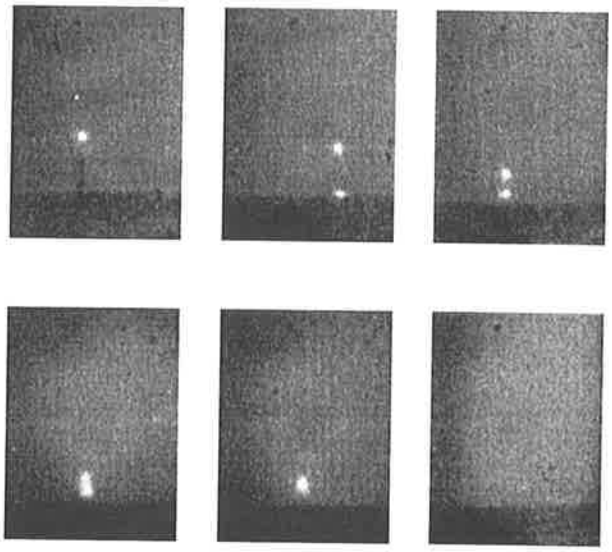

Figure 11. Sequence of images of Tydeman mast light as the ship was reaching the maximum detection range (visible CCD Sony Camera).

ship made elliptical (oval) turns every 2 NMi, staying on a steady course for about two minutes to give the maximum opportunity for good imaging of the IR source, even for those imaging systems with a narrow field of view and accounting for the rolling and pitching of the ship. A typical operational pattern for the MAPTIP trial is shown in Figure 2. The basic cruise pattern of the ship was to sail: 1) between MPN and the Beach Station, 2) along the sun glint radial from MPN to way point C, and 3) on a radial away from the sun between MPN and weight point A. The B-C radial provided over-the-horizon and sun glint imaging for the Beach Station. The A-C radial was intended for detection and identification runs by the P3 Orion. The outlined operational procedures were flexible in response to special requests by the MAPTIP participants to allow for changes in the atmospheric and weather conditions.

In addition to the IR/visible sources, DREV mounted halogen lamps (reference 3.2) on the Hr. Ms. Tydeman to supplement the halogen lamps that were standard equipment on the ship. These halogen lamps were used for studying the refractivity effects as described in Section 3.2. No thermal imagers were mounted on the Hr. Ms. Tydeman.

TNO-FEL operated a scanning radiometer on the port of the ship for elevation measurements of sea and sky horizon backgrounds. Also, TNO-FEL made standard meteorological measurements on the ship, i.e., wind speed and direction, air temperature, relative humidity, pressure, water temperature, and sea states. The wind and temperature sensors were mounted on the mast of the foredeck. Aerosol particle size distribution measurements were made utilizing the PMS aerosol particle counters (ASAS 300 and the CSAS 100 HV). Aerosol chemical composition was determined by UIA from samples collected with a May impactor inserted in a sample tunnel. The aerosol equipment was mounted on the roof of the bridge.

Environmental parameters and particle size distributions were measured continuously. Impactor samples were taken only when the ship was steady on station during an extended period of at least 8 hours. This occurred near MPN and for positions located a day sailing from MPN. The main purpose of the chemical analyses was to acquire data for the extension of aerosol models from the MPN area to a larger part of the North Sea. Some speculation has been made about the relative contributions of aerosol from maritime and continental origin to explain the effect of wind direction on the wind-speed dependence of the aerosol concentrations [33]. Data on the aerosol spatial variability and other environmental parameters, in the direction of and perpendicular to the prevailing winds as a function of distance from the coast, are required for definite conclusions and for quantification of the observed effects. The data collected on the Tydeman, together with that at the fixed locations (MPN and Beach Station) will serve as an indicator for variations due to a change in the meteorological conditions and will be used for the quantification of the spatial variability.

An average of five radiosondes were released daily from the Hr. Ms. Tydeman to characterize the atmospheric vertical structure along the operational path. The timing was such that a good temporal coverage of vertical soundings was obtained during the intensive operational periods by combining the Tydeman radiosonde soundings with the vertical profiles taken by the Piper Navajo. The information on the atmospheric vertical structure is of crucial importance for testing NOVAM.

3.4 NRaD Airborne Platform

The NRaD airborne platform (Figure 3) was equipped with aerosol and meteorological instrumentation. The aerosol spectrometer instrumentation included the PMS FSSP-100 and the OAP-200. The meteorological measurements were IR sea surface temperature, air and dew temperatures, and absolute pressure. The Navajo flew a star pattern centered on the MPN tower to monitor the spatial variability of aerosols and meteorological conditions (Figure 3). At the start and end of each star pattern the Navajo profiled the vertical structure by spiralling over MPN to 1524 m. The data are intended to be used for the validation of NOVAM and in the development of ANAM. During the Navajo in- and out-bound radial from the MPN tower and the Beach Station, the Navajo served as a target for the imaging community. On special occasions, when the Hr. Ms. Tydeman made long tracks and there was no need to fly the complete star pattern, in- and out-bound radial were flown to allow for continuous tracking of the aircraft by the thermal imaging community as a function of altitude and distance to the horizon (Figure 12).

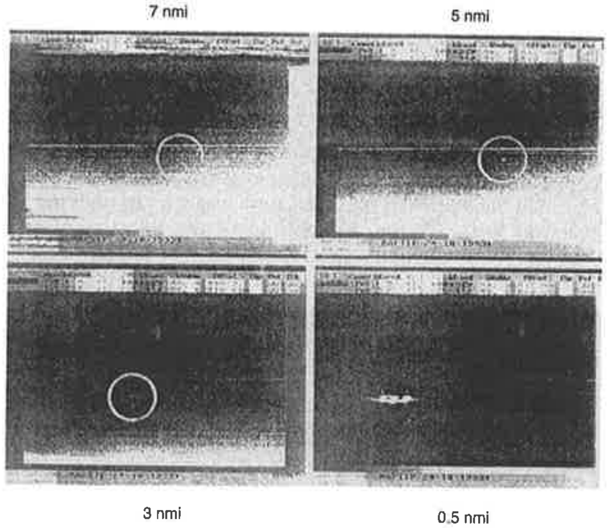

Figure 12. IR images of the inbound Navajo at different ranges.

3.5 Lynx Helicopter

A Lynx helicopter (Figure 3) was made available by the RNL Navy. A total of ten dedicated flights were made throughout the MAPTIP trial. The helicopter was equipped with an IR point source that was suspended 20 m below the helicopter. It served as a target by hovering at a number of fixed positions with respect to the Beach Station and MPN. Figure 13 shows the IR image of the Lynx point target as a function of distance. The distances ranged from 0.5 NMi to 20 NMi. The helicopter flew at an altitudes of 24 m (46 and 91 m at the largest distances) to keep the point target above the horizon. The flight profile is

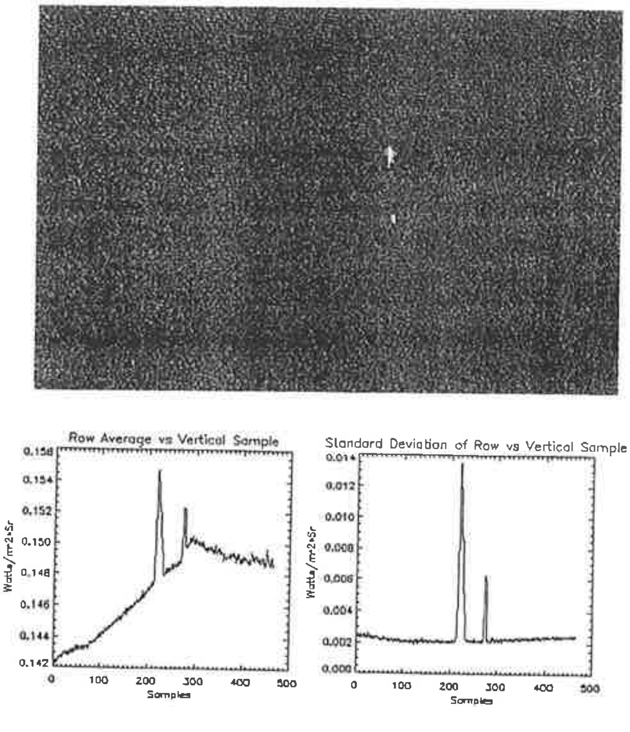

Figure 13. 3.5-4.2 µm thermal images of the Lynx helicopter and infrared source at 2.5 nmi, 26 Oct 93, 1637.

shown in Figure 3. This flight sequence allowed for the determination of the maximum detection range of the point source, transmission measurements, and imaging. The Lynx helicopter was also equipped with a FLIR and imaged the Tydeman during each flight. Two circles were flown around the ship at different distances and heights for all aspect imaging.

3.6 P3 Orion

A FLIR-equipped P3 Orion (Figure 3) was provided by the RNL Navy for determing detection and identification ranges on the Hr. Ms. Tydeman (while the ship was stopped). Figure 14 shows the P3 Orion FLIR image of the Hr. Ms. Tydeman. It also served as a target for the imagers at the Katwijk Beach Station and the MPN tower (Figure 3). Both outbound and inbound radials were made (maximum radial distance of 20 NMi). On the outbound runs the Orion was tracked until the IR signal was lost. On the inbound radials the objective was to determine the detection range for the P3.

Figure 14. Image of the Hr. Ms. Tydeman in the 8-12 μm band (recorded with the FLIR-2000 for the P3 Orion).

3.7 Buoys

Three buoy systems were deployed during MAPTIP. NPS deployed a coastal climate minimet buoy at approximately 0.5 NMi NW from MPN. This buoy was instrumented with a Gill Sonic Anemometer to measure the components of the turbulent air and the air temperature at 5 m. A Rotronic hygrometer was also installed to determine the mean air temperature and relative humidity at a height of 2 m MSL. A 1-D accelerometer provided wave information. CELAR deployed two buoy systems at approximately 4 km from the beach near the Beach Station. One, a Wave Rider, measured instantaneous wave heights, while the other, a meteorological buoy, measured the mean air temperature, relative humidity, solar irradiation, wind speed, wind direction, pressure (all at a height of 3.4 m MSL) and sea surface temperature (0.2 m below the surface).

In addition to the local platform measurements described above, meteorological information was made available from all the meteorological stations located in the North Sea and from satellite observation of sea surface temperatures. Weather maps and air mass trajectories were also made available for the MAPTIP trial period to allow larger-scale interpretation of the MAPTIP data.

4. DATA OVERVIEW AND CONCLUDING REMARKS

The MAPTIP trial, intended as a coastal maritime environment experiment for developing and validating marine aerosol models and for determining the effects of the marine atmosphere on thermal imager performance, turned out to be dominated by continental air masses with little maritime influence. The prevailing winds were easterly, in contrast to normal westerly flow. However, the occurrence of off-shore winds (NNE-SSE) is not uncommon in this area [34]. The resulting meteorological situation depends, of course, on the season. During the MAPTIP trial, the atmospheric thermal stratification was very unstable due to a cold air mass being advected over a relatively warm sea. Because such situations can be encountered in other areas, we feel that valuable data were collected for studies of the effects of surface layer turbulence and thermal stratification causing strong refractivity effects on thermal imager performance.

Unfortunately, the weather situation did not allow for an extensive comprehensive study on marine aerosol properties, i.e., the fetch was short and little aerosol was generated from the easterly winds. The aerosol sampled at MPN was predominantly of continental origin. Only a limited data base was obtained for use in extending the existing aerosol models to incorporate near-surface effects. On the other hand, all other measurements were carried out as planned.

A wide variety of weather conditions from clear sunny skies to overcast were encountered. Visibilities ranged from dense fog to very clear. A wide range of thermal stratifications from very unstable (air to sea temperature differences (ASTD) of more than -9°C) to neutral and stable (ASTD of +1°C) occurred. Wind conditions ranged from light to gale force winds (1-20 m/s), causing sea state conditions of 2.2 m waves. As deduced from the lidar data, boundary layer structures were encountered where turbulent mixing occurred as indicated by well-defined eddy structures. On other occasions, convective plumes were observed [19]. Also, quiescent boundary layers were observed with layered structures. Lidar measurements at a negative elevation angle, made to study surface layer phenomena, indicated influences of waves.

All operational scenarios were well documented with the available meteorological data being made available from the various platforms, including the aerosol measurements and the lidar measurements made at MPN and the Beach Station. Information on larger spatial variations is available from the star patterns flown by the Navajo and in particular from the long treks made by Hr. Ms. Tydeman. The MAPTIP data set will be uniquely valuable for the development and validation of models for the assessment of the effects of atmospheric properties on electro-optical systems.

The thermal imager data provides an excellent data set for the evaluation of the atmospheric propagation models. The transmission data that can be deduced from the target measurements as a function of range can be directly compared with those derived from the models. Also, the detection limit, blurring, refraction phenomena, etc., were measured directly. Range predictors [35], IRST and refraction models can be developed and validated. Preliminary tests of the refractive models show an excellent agreement with observed refraction phenomena, e.g., the DREV model that calculates ray bending from atmospheric parameters.

An extensive data set for the analysis of thermal imager performance was taken, e.g., for IR seekers, LR IRST application, and the development and validation of ship signature models. A data base of such data has been collected, e.g. sea, sky and land backgrounds, sea and coastal clutter, horizon clutter, cloud data, etc. The operational period was shifted throughout the day to build a data base spanning from early morning until midnight. Thus day/night variations and dawn/sunset variations are included. Targets were observed in the sun glint during early hours. Data on turbulence, scintillation, and refractive effects (mirage, ducting) are available as explained above.

All the MAPTIP data are in support of the US IRAMMP (Infrared Analysis, Measurements, and Modeling Program) and will be used for the continued development of models describing the performance of thermal imagers. These include ship signature models, IRST models, background models, point source detection models, and clutter characterization models. Combining the respective models for targets, backgrounds, etc. with atmospheric models and an adequate description of the imager system parameters is expected to result in a comprehensive model for the assessment of thermal imagers for a variety of targets as function of atmospheric conditions.

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