Invited Paper

MAPTIP - Marine Aerosol Properties and Thermal Imager Performance: Summary and initial results

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ABSTRACT

The 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 during the fall of 1993. The main objectives of the trial were (1) to assess marine boundary layer effects on thermal imaging systems and (2) to improve and validate vertical marine aerosol models with emphasis on coastal and near-surface effects.

Aerosol and meteorological instruments, as well as thermal imagers and calibrated targets, were utilized on two off-shore platforms, a Beach Station, three airborne platforms, and 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. Atmospheric turbulence and refractivity effects in the IR and RF bands were measured to assess the marine boundary layer effects on the degradation of thermal images. Thermal imagery in both the 3-5 and 8-12 μm bands was included to provide ground truth for assessing the low-level propagation effects near the ocean surface. Calibrated targets at different altitudes were observed to the maximum observable range under a wide variety of conditions. These data are to be used for the development and validation of IRST models and IR ship signature models, and for determining the effects of marine-generated aerosols, turbulence and meteorological profiles on their performance.

keywords: field trial, electro-optical propagation, thermal imaging, atmospheric effects

1. INTRODUCTION

Atmospheric aerosols are of special importance for the assessment of the performance of electro-optical (EO) systems. The constituents of the atmosphere absorb and scatter the radiation, resulting in the degradation of the radiance contrast between a target and its natural background, as viewed by an (infrared) sensor. The assessment, therefore, depends upon the accuracy of the atmospheric and terrain background 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. The effects of aerosols on EO propagation in a maritime environment can be determined due to the inclusion of an upgraded version of the Navy Aerosol Model, NAM,[3-10] into LOWTRAN 7. This model has proven to be a useful tool in predicting atmospheric transmission in the marine atmosphere along horizontal paths at shipboard levels (around 10 m). For slant path predictions, The Navy Oceanic Vertical Aerosol Model, NOVAM,[11-19] is being prepared for inclusion into LOWTRAN/MODTRAN. 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. NOVAM accounts for the generation, dispersal and removal of the marine aerosols, including transport processes, in the vertical dimension. 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.[20] Also, recent studies have shown that NAM/NOVAM in their present forms should not be extrapolated below shipboard levels for predicting atmospheric properties.[21,22]

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An effort needs to be undertaken to develop a model to predict the performance of EO systems for detecting low-altitude targets and incorporate it into MODTRAN. Therefore, it is important to obtain more detailed information on atmospheric effects of the propagation characteristics for the 3-5 and 8-12 μm bands in the first few meters above the surface.

In response, the NATO AC/243 (Panel 04/RSG.8), in collaboration with AC/243 (Panel 04/RSG.5), planned and conducted a field experiment to address these very problems: the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP). The MAPTIP project, in principle, consisted of two parts, i.e., a study of atmospheric propagation properties and a study of thermal imager performance. 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 atmospheric propagation study was included to validate and develop models describing atmospheric effects on EO propagation properties (aerosol extinction, refraction, and turbulence). This requires a comprehensive data base of profiles of the aerosol size distribution and relevant meteorological variables throughout the marine atmospheric boundary layer. In particular, observations close to the surface (below 10 m) are required for the development of the next generation aerosol model ANAM (Advanced Navy Aerosol Model). The models which result from these studies are intended to be part of tactical decision aids for Naval Defense.

The second part of MAPTIP consisted of the assessment of thermal imager performance in a maritime environment. To this end, ship signatures and other target characteristics were measured in the infrared (IR) bands. Atmospheric turbulence and refractivity effects were determined to assess the marine boundary layer effects on the degradation of thermal images. In addition, background and clutter models as a function of atmospheric conditions were validated and developed.

The MAPTIP trial was conducted between October 11 and November 5, 1993, in the vicinity of Meetpost Noordwijk (MPN). The geographical layout is shown in Figure 1. A land based facility was set up in a lifeguard station on the beach of Katwijk, 10 km from MPN. Oceanographic buoys were moored near MPN and along the MPN-Beach Station line of sight. An oceanographic research vessel, Hr. Ms. Tydeman of the Royal Netherlands Navy (RNL Navy), sailed predescribed patterns in the area. Three airborne platforms were present: a Lynx helicopter and a P3 Orion, both made available by the RNL Navy, and the NRaD airborne platform.[23]

Figure 1: Geographical location

The MAPTIP trial was organized by the TNO Physics and Electronics Laboratory (TNO-FEL) and was supervised by a scientific committee consisting of representatives from the atmospheric effects and thermal imaging communities associated with the NATO AC/243 Panels 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.[24] An overview of the MAPTIP experiment for the RSG.8 and RSG.5 participants has been prepared and is available upon request.[25]

Table 1: MAPTIP participants

Institute	Abbrev.	Country
TNO Physics and Electronics Laboratory	TNO-FEL	NL
Royal Netherlands Navy	RNL Navy	NL
Ministry of Public Works	RW	NL
University of Antwerp	UIA	Belgium
Defence Research Establishment Valcartier	DREV	Canada
Danish Defence Research Establishment	DDRE	Denmark
Directorat General de l'Armement (Bruz)	CELAR	France
Directorat General de l'Armement (Toulon)	CESDA	France
Forschungsinstitut für Optik	FfO	Germany
Fraunhoferinstitut für Atmosphärische Umweltforschung	IFU	Germany
Norwegian Defence Research Establishment	NDRE	Norway
University of Manchester Institute of Science & Technology	UMIST	UK
NCCOSC, RDT&E Div, Naval Research and Development	NRaD	USA
Naval Postgraduate School	NPS	USA
Office of Naval Research	ONR	USA
Naval Surface Warfare Center	NSWC	USA
Mesa Inc.	MESA	USA
Massachusetts Institute of Technology	MIT	USA

2. SCIENTIFIC OBJECTIVES

The scientific objectives of the MAPTIP trial were:

- To improve and validate vertical marine aerosol models
- To extend existing aerosol models to incorporate near-surface effects
- To assess marine boundary layer effects on thermal imaging systems
- To provide inputs for the development and validation of IRST (Infra Red Search and Track) models
- To provide inputs for the development and validation of IR ship signature models
- To provide additional data for analysis in areas of interest and importance to IR seeker and 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 surface and airborne platforms, as well as their operational sequences are shown in Figures 2 and 3, respectively. All operations were coordinated with the Navy Airbase Valkenburg, which allowed that flight schedules and surface operations were based on the latest weather information. In the remainder of this section, we will focus on each platform and discuss its role during MAPTIP.

3.1 Meetpost Noordwijk (MPN)

The MPN oceanographic tower (Figure 2) is owned and operated by the Dutch Ministry of Public Works and is located 9 km from the Dutch coast, position 45° 16' 25.9" N, 04° 17' 45.8" E. The MPN tower was the focal platform for the experiment and was used both for comprehensive meteorological characterization and as a platform for thermal imagers and sources.

The MPN tower was equipped with a 20-m boom to measure outside the flow distortion of the platform structure.[26]

MAPTIP 1993
Operational Sequence (Surface)

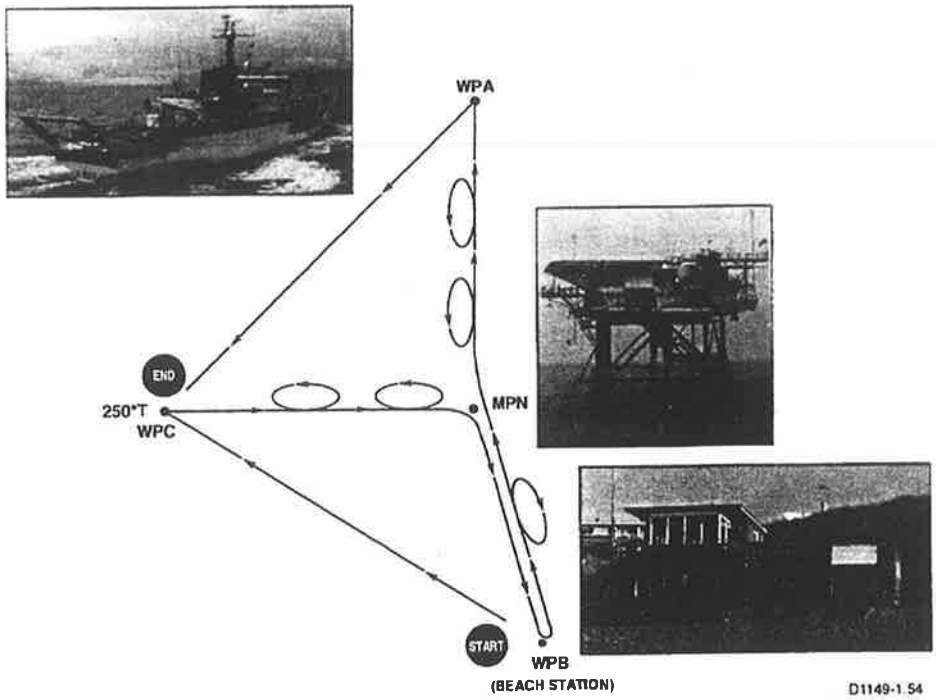


Figure 2:

MAPTIP 1993
Operational Sequence (Airborne)

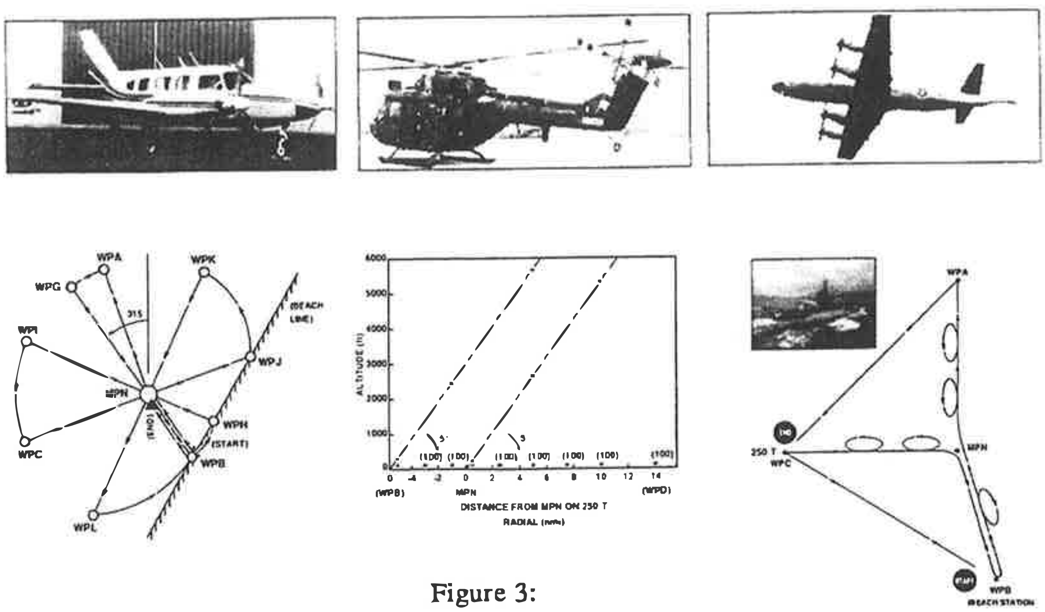


Figure 3:

With the boom, turbulence and air temperature measurements were made by TNO-FEL using a Gill Sonic Anemometer. The fluxes of H_2O and CO_2 were determined with an Advanet fluctuation meter. The boom was further equipped with optical particle counters (PMS CSAS 200 P and OAP, particle diameters 0.2-300 µm) to determine particle size distributions at low levels and to profile the aerosol distributions. A Rotronic hygrometer supplied the mean relative humidity and air temperature on the boom. Unfortunately, only few data were collected on the boom due to a structural failure during a storm on the fourth day of the trial.

UMIST installed a mast on the helicopter deck of MPN. Equipped with a sonic anemometer and an OPHIR hygrometer, the mast was used to measure the turbulent air flow components, air temperature, and absolute humidity at approximately 25 m above mean sea level (AMSL). The UMIST aerosol kit was mounted at the 11.6 m deck and consisted of a PMS FSSP-100 and a PMS OAP-230X optical particle counter (particle diameters 0.5-300 µm). Aerosol size-segregated composition was determined with a PMS ASASP-X (0.1-3 µm) in combination with a volatility system. Soot carbon loadings were determined with an aetholometer.

Vertical profiles of the aerosol particle-size-distribution were measured by NRaD utilizing an optical particle counter (PMS ASSP-100, particle diameters 0.5-30 µm), and by NRaD and TNO-FEL with Rotorod impaction samplers (13-100 µm).[27] The NRaD instruments were mounted in a box that was hoisted up and down from the 15 m deck. The box also contained 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. As an example, Figure 4 shows measured aerosol size distributions taken near the sea surface and the the 11.6 m deck for low (0.1-2.1 m/s) and high (11-16 m/s) winds.

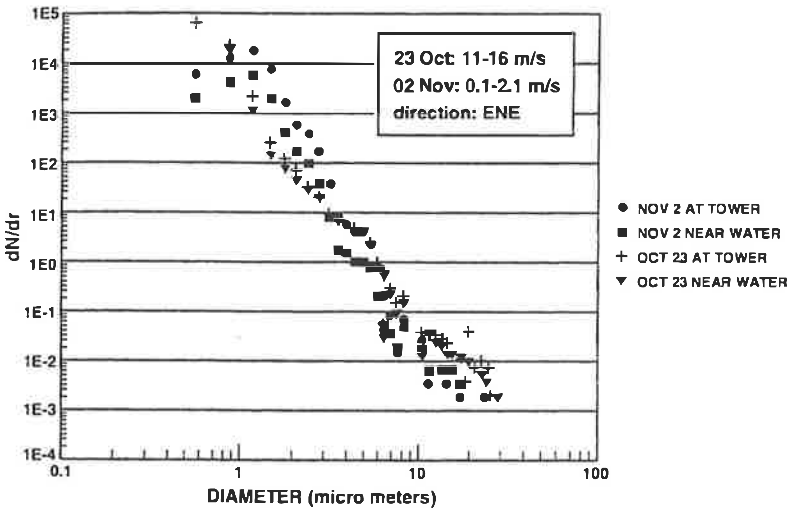


Figure 4: Aerosol size distributions

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.[28] The float was anchored close to the Rotorod 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.[29,30]

Lidar systems yielded information on the vertical structure of the atmospheric boundary layer near MPN. The NRaD ANGVS/5 lidar was used for profiling aerosol returns near the ocean surface (<10 m), and the TNO-FEL lidar system[31] was used for slant path measurements under both negative and positive elevations. Ship plume observations were also made. The lidar returns will be used for studying the variability of the inversion height and the depth of the transition layer.[19]

Direct measurements of the extinction at 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, well exposed to the prevailing winds and data should be representative of conditions unperturbed by the tower.

Meteorological data are routinely measured at MPN as part of the North Sea monitoring network. Data includes wind speed, direction, air and sea temperature, atmospheric pressure, relative humidity, tide and wave information. In addition to the standard instrumentation, TNO-FEL mounted Rotronic sensors for air temperature and relative humidity at heights of 5.2, 6.6, 13, and 27 m AMSL to monitor the vertical structure of the atmospheric surface layer. This allows to predict refraction phenomena in support of the imaging measurements. A rain gauge and a pyranometer were added to this suite of instrumentation. The UMIST meteorological station was mounted on the 11.6 m deck to determine local wind speeds and direction, air temperature, and relative humidity. Weather conditions and sea state were also 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.

A number of IR and visible sources were mounted on MPN. The FfO 300°C fixed temperature calibration source was mounted on the helicopter deck (18.6 m AMSL) as a reference for the FfO imaging systems at the Katwijk Beach Station. The TNO-FEL 900°K 1000 Hz modulated source was used for transmission measurements between MPN and the Beach Station. Finally, a sequence of visible lamps were mounted by DREV on the South side of MPN at differing heights (about 3.5 to 20 m AMSL) for the study of refractivity effects.

Four thermal imagers were mounted on MPN.[32] 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 helicopter deck, the Amber Model AE4128 Thermal Imager (InSb, 3-5 µm) from DDRE and a Philips FLIR (8-12 µm) from TNO-FEL were mounted. Together, this instrumentation covers both the 3-5 and 8-12 µm IR wavelength region at two levels.

The Hr. Ms. Tydeman, 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. Figures 2 and 3 show typical sailing and flight schedules for the Hr. Ms. Tydeman and the Lynx helicopter.

3.2 Katwijk Beach Station

The Katwijk Beach Station was composed of a lower site (the two-storey lifeguard station at the beach, see Figure 2), and an upper site (a parking lot approximately 10 m higher on the boulevard). At the parking lot location, FfO operated two thermal imaging systems, i.e., a dual waveband DUWIR that simultaneously measures in the 3-5 and 8-12 µm bands, and 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. A meteorological station was installed at the parking lot to measure wind speed and direction, air temperature, relative humidity, pressure, visibility and up/down welling radiance.

Also at the upper site, IFU operated a three-wavelengths aerosol lidar (355, 532, and 1064 nm) and a 1.56 µm eye-safe lidar. The range of these systems is >15 km with a resolution of ≤15 m (532, 355 nm and 1.56 µm) and ≤30 m (1064 nm). With these range capabilities, the atmospheric structure was characterized from the Katwijk Beach Station to ranges extending beyond MPN. In addition, horizontal and vertical variations in the extinction coefficients at these wavelengths were directly measured.

Extinction measurements were also made at the lower site, the two storey lifeguard station. On the upper deck of the station, the IFU two-wavelength White-Cell transmissometer measured the extinction at 543 nm and 1.56 µm, whereas CESDA made 0.55 µm extinction measurements utilizing an HSS VR-301-B-120 visibility meter. The TNO-FEL transmissometer receiver for the MPN/Beach Station transmission path (10.44 km) was also located on the upper level. Using the 1000 Hz source on MPN, transmission measurements were made at wavelengths in the visible and 8-12 µm bands.

Aerosol size distribution measurements were made at this location by CESDA using two optical particle counters (ASASP-X and CSASP-100 HV, 0.09-3 µm). A meteorological station recorded wind speed, air temperature, and relative humidity.

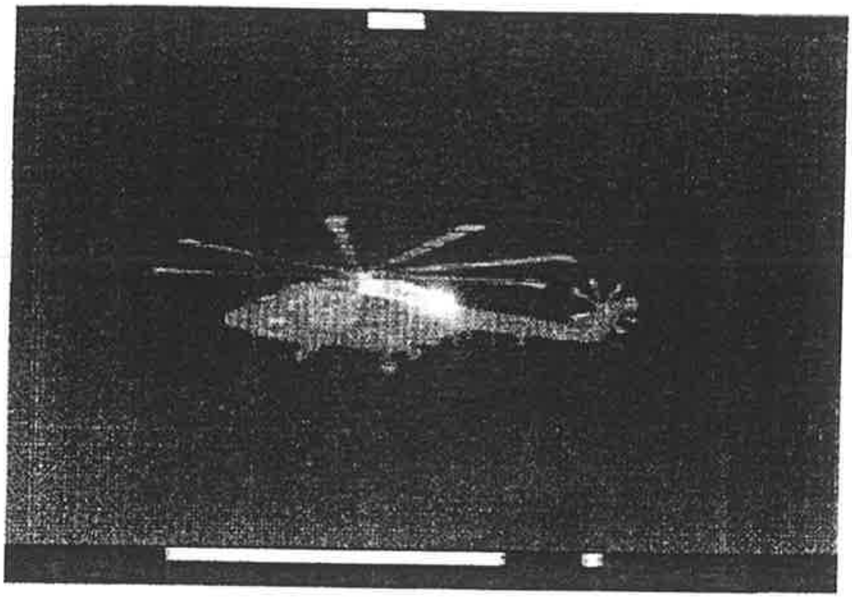
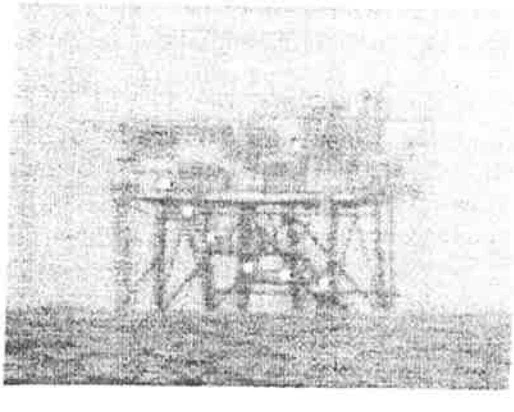


Figure 5: Lynx helicopter in 3-5 µm band

A variety of thermal imagers was installed in the lifeguard station. At the upper level, polarization measurements in the 3-5 and 8-12 µm bands were made by NPS[33] 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.[34]

On the lower level, NDRE operated two TICM-II camera systems (3-5 and 8-12 µm bands). For continuous calibration, three sources were mounted a short distance from the cameras on the beach. As an example, Figure 5 shows an IR image of the Lynx helicopter in the 3-5 µm band. A laser range finder was used for accurate range determination of the sources and targets (in particular the Hr. Ms. Tydeman and the Lynx helicopter). It was also used for determining the maximum target detection ranges.

Refraction studies were made by DREV to test the WWKD model[35] 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 AMSL (Figure 6a), and four lamps on the Hr. Ms. Tydeman between 4 and 23.7 m AMSL. 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 at MPN yielded important information on the refractivity phenomena over a fixed path in various weather conditions . Strong refraction was observed with clear mirage effects during large air-sea temperature differences (Figure 6b). These occurred for off-shore winds when



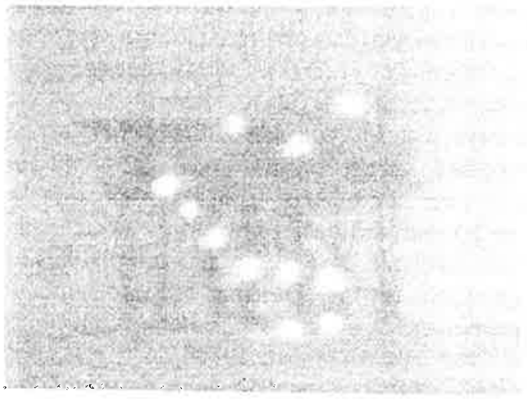


Figure 6a (left): Visible image of MPN showing the 8 halogen lamps
Figure 6b (right): Visible image of MPN showing mirage effects of the lower two lamps

cold air masses were being advected over a relatively warm water surface. The lights at Hr. Ms. Tydeman were monitored as the ship sailed away from or to the beach. This yielded information on refraction phenomena as a function of range.

The CELAR experiment was similar to the experiments conducted by DREV. The CELAR objective was to study the refractivity effects in the marine boundary layer and to test the Bulk-CELAR refraction model.[36] 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. Tydeman and MPN images.

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. Therefore, the ship was instrumented with thermocouples and radiometers to monitor the temperatures of the hull, stack and the exhaust plume. Elevation measurements of sea and sky horizon backgrounds were made by a TNO-FEL operated scanning radiometer. The basic cruise pattern of the ship (see Figure 2) 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.

Hr. Ms. Tydeman also served as a platform for the visible and IR sources. DREV mounted halogen lamps at 4, 8, 13, and 23.7 m AMSL 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 previously.

A visible/IR 6X3 light source array was mounted on the stern to simulate a low altitude intensive IR source point target (a sea skimming missile) for refractive studies at variable distances. The upper and lower three sources emitted predominantly in the IR, the middle row emitted only in the visible. The ship's operational procedure allowed for the maximum use of this IR source. On inbound radials to MPN and the Beach Station, the ship made elliptical (oval) turns every 2 NMi, showing the stern on a steady course for about two minutes. This would give the maximum opportunity for good imaging of the IR source (accounting for the rolling and pitching of the ship), even for those imaging systems with a narrow field of view.

Meteorological measurements were continuously recorded by the ships standard equipment and additional TNO-FEL instrumentation. The observations include wind speed and direction, air and sea temperature, relative humidity, pressure and salinity. An average of five radiosondes were released daily from the Hr. Ms. Tydeman to characterize the atmospheric vertical structure. The timing was such that a good temporal coverage of vertical soundings was obtained with the vertical profiles taken by the Piper Navajo (see below). The information on the atmospheric vertical structure is of crucial importance for testing NOVAM.

Aerosol measurements were made on the roof of the bridge. Size distributions were continuously measured by TNO-FEL utilizing PMS aerosol particle counters (ASAS 300 and CSAS 100 HV, 0.16-32 μm). Aerosol chemical composition was determined by UIA from samples collected with a May impactor inserted in a sample tunnel. 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.[20] 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.

3.4 NRaD Airborne Platform

The NRaD airborne platform (Figure 3), a twin engine Piper Navajo, was equipped with aerosol and meteorological instrumentation. The aerosol instrumentation included the PMS FSSP-100 and the OAP-200 spectrometers (overall range 0.5-300 μm). The meteorological measurements were IR sea surface temperature, air and dew temperatures, and absolute pressure. At the start and end of each flight, the Navajo profiled the vertical structure by spiralling over MPN to 1524 m. These data are intended to be used for the validation of NOVAM and in the development of ANAM. To monitor the spatial variability of aerosols and meteorological conditions, the Navajo flew a star pattern centered on the MPN tower (Figure 3). While on the radial from the MPN tower and the Beach Station, the Navajo served also as a target for the imaging community. On special occasions, this in- and outbound radial were flown to allow for continuous tracking of the aircraft by the thermal imagers as a function of altitude and distance to the horizon.

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 (see Figure 3). This flight sequence allowed for the determination of the maximum detection range of the point source, transmission measurements, and imaging. 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 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 determining detection and identification ranges on the Hr. Ms. Tydeman (while the ship was stopped). The P3 Orion also made outbound and inbound radials (maximum radial distance of 20 NMi) to serve as a target for the imagers at the Katwijk Beach Station and the MPN tower (Figure 3). 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.

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 wind 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 AMSL. A 1-D accelerometer provided wave information. Two buoy systems were deployed by CELAR approximately halfway between MPN and the Beach Station. Instantaneous wave heights were measured by a wave rider, whereas 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 AMSL) 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 wind directions were off-shore (NNE-SSE), in contrast to normal westerly flow. 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 validating existing aerosol models and extending them to incorporate near-surface effects.

On the other hand, all measurements (aerosol, meteorology, imagery) 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. Wind conditions ranged from light to gale force winds (1-20 m/s), causing sea state conditions of 2.2 m waves. A wide range of thermal stratifications occurred from neutral to stable (air to sea temperature differences (ASTD) of +1°C) to very unstable (ASTD < -9°C). The latter situation arises when a cold air mass is advected over a relatively warm sea. 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 or 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. Taking all this into account, we feel that MAPTIP provided valuable data for studies of the effects of surface layer turbulence and thermal stratification causing strong refractivity effects on thermal imager performance.

All operational scenarios were well documented with the available meteorological data from the various platforms, including aerosol and lidar measurements. 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 comprehensive 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, 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, long range IRST application, and the development and validation of ship signature models. A data base of sea, sky and land backgrounds, sea and coastal clutter, horizon clutter, cloud data, etc has been collected. The operational period was shifted throughout the day to build a data base spanning from early morning until midnight, thus including day/night and dawn/sunset variations. Targets were observed in morning and evening sun glint. 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 Modelling 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.

5. ACKNOWLEDGEMENTS

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