Propagation Resources In Maritime Environments (PRIME)
An Integrated Model for the Maritime Battlespace

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1. Introduction

A program to develop integrated models for use in predicting the performance of electro-optical (EO) optical systems, in particular infrared search and track (IRST) systems, has been on-going at DREV over the last four year. In 1996 DREV began the development of the Infrared Boundary Layer Effects Model (IRBLEM) for an IRST project[1]. It makes use of program modules that have largely been developed through DREV's research into optical effects in the marine boundary layer (MBL). Given a set of meteorological parameters, geometric parameters, and receiver parameters, appropriate modules handle the effects due to molecular extinction, aerosol extinction, refraction, and turbulence on a bundle of rays as they are propagated through the MBL. After making a number of improvements due to extensive testing over the last couple of years, it was decided that the user-interface, the modular structure, and programming architecture of the program required significant improvement. This has resulted in the recent development of a new model called PRIME (Propagation Resources in a Marine Environment). The development of this model is being carried out at DREV with financial support from both DND (Canada) and ONR (U.S.A.). The objective of the work is to produce a first version during the year 2000 with the same capabilities as the current IRBLEM version, and to extend its capabilities over the next couple of years.

In the following sections, this document will provide basic information about IRBLEM, its working environment and architecture, leading into a number of reasons for the development of PRIME. The following section will discuss the design philosophy and open modular architecture that is being developed for PRIME. The last section will show examples of the sorts of outputs that can be obtained from IRBLEM, and several validation studies that have been performed on IRBLEM using experimental data. Finally, some conclusions and a look to future developments will be presented.

2. IRBLEM - Infrared Boundary Layer Effects Model

Defence Research Establishment Valcartier (DREV) began the development of IRBLEM[1] with the TNO Physics and Electronics Laboratory (TNO) in 1996 as an initiative of both Canada and The Netherlands to equip their navies with an infrared search and track (IRST) capability. Due to DREV's work, since the early 1990's, in developing and validating its LWKD[2,3,4,5] marine boundary layer (MBL) model, and a ray-tracing model that incorporates intensity calculations, it took the lead in this initiative. The LWKD model is one of IRBLEM's core modules as it is used to determine the vertical profiles of temperature, pressure, humidity, refractive index, and refractive index structure parameter.

The structure of IRBLEM is shown in Figure 1. At the top are the inputs that are provided by a "METDATA" file and an "IRBnnn.DEF" file where nnn is a case index. The "METDATA" file contains the meteorological parameters required by the *Molecular Extinction* module (MODTRAN 3), the *Refraction* module, the *Turbulence* module, and the *Aerosol Extinction* module. The "IRBnnn.DEF" file contains the geometry and sensor parameters required by the *Ray-Tracing* module. The various outputs from IRBLEM are shown at the bottom. An additional program, IRBLEMPP, has also been developed to interrogate and filter the various outputs so as to produce more user-specific output.

Earlier versions (before Ver. 3) used code developed at TNO for either the turbulence or the aerosol extinction, and except for MODTRAN, the remaining code had been developed at

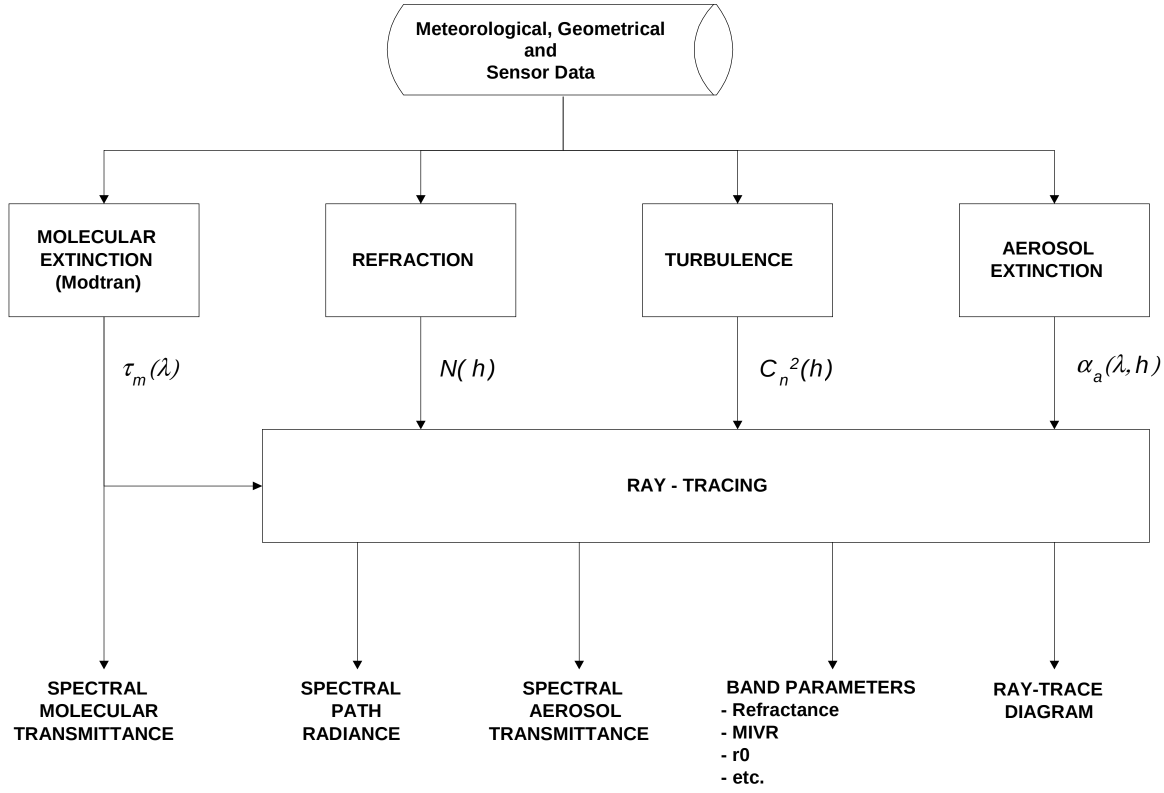


Figure 1: Schematic of the architecture used in IRBLEM.

DREV. However, starting with Ver. 3, all the code, with the exception of MODTRAN, has now been developed at DREV. These and other changes have largely been driven by extensive studies[6,7,8] of data taken during the Electro-Optics Propagation Assessment in Coastal Environments (EOPACE) trial.[9] At the same time as improvements were being made to IRBLEM, it was becoming apparent that major improvements to the user interface, and to the structure of the input and output files would eventually be required. Similarly, it was evident, that if the software within IRBLEM was to have wider distribution, a new software tool with an open modular architecture and a higher level of integration would be required. This would allow users to use DREV's modules or to use their own modules. It is as a result of these perceived deficiencies that the development of PRIME began in 1998.

3. PRIME - Propagation Resources in a Marine Environment

PRIME is being designed to have an open modular architecture, a high level of integration, and a high quality user-interface between the program's inputs and outputs. Figure 2 shows the program's architecture. A couple of things should come to your attention. First, the program is divided into a **core** program that is platform independent, and a **shell** program to provide the user interface to the computer's operating system. A shell for WINDOWS is being developed. Figure 3 shows an example screen for the WINDOWS shell. In turn, the **core** program is also composed of two major structures, the **engine** and a set of **modules**. The role of the **shell** is to interact with the user to create the files required by both the **engine** and the **modules** for the cases to be studied, and then to start the **engine** running. Subsequently, the **engine** creates data files for each meteorological case, passes the required data information to the **modules**, and

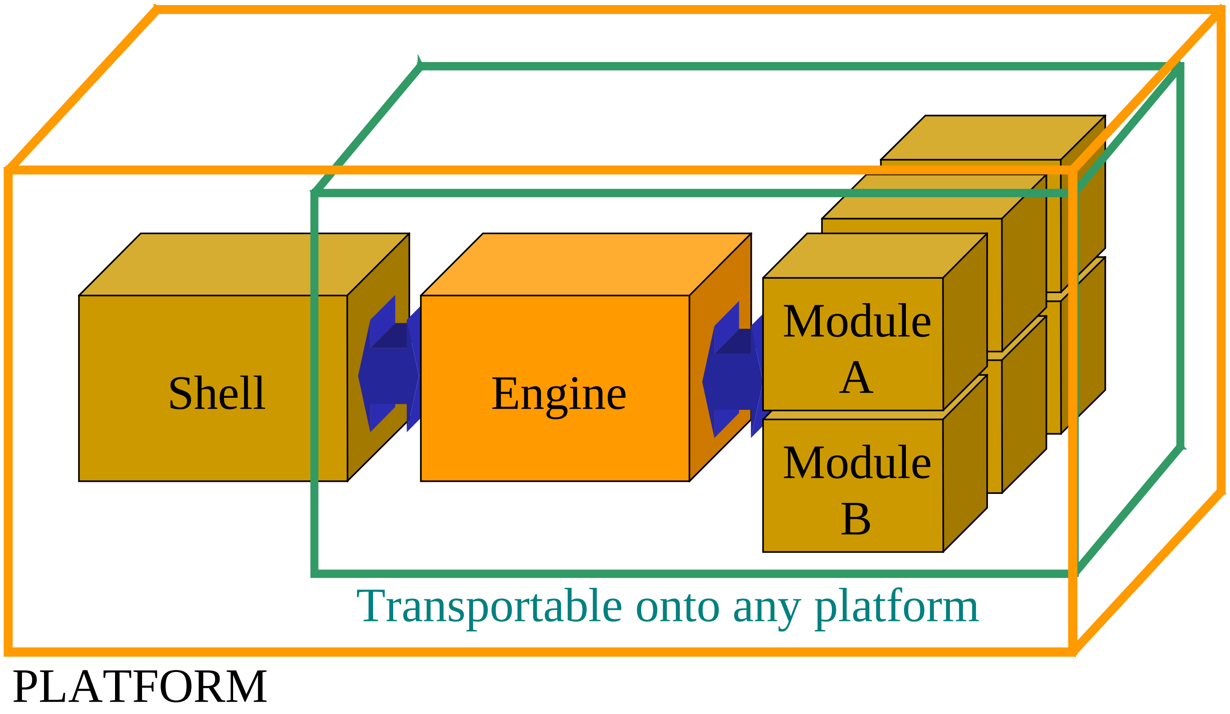
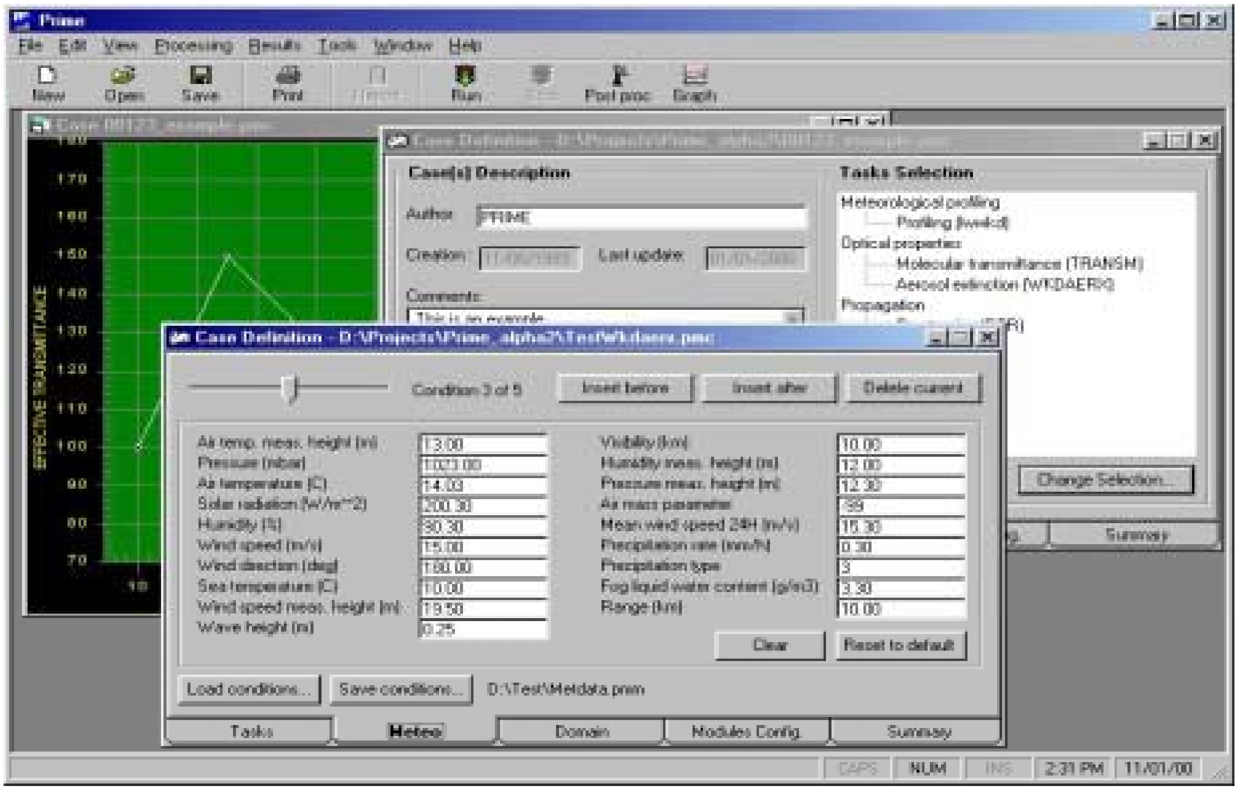


Figure 2: **Schematic of the programming architecture used by PRIME**



Case(s) Description

Author: PRIME

Comments: This is an example

Tasks Selection

Meteorological profiling
  Profiling (lwkd)
Optical properties
  Molecular transmittance (TRANSM)
  Aerosol extinction (WKDAERX)
Propagation

Condition 3 of 5

Air temp. meas. height (m)	13.00	Visibility (km)	10.00
Pressure (mbar)	1023.00	Humidity meas. height (m)	12.00
Air temperature (C)	14.03	Pressure meas. height (m)	12.30
Solar radiation (W/m**2)	200.30	Air mass parameter	-99
Humidity (%)	90.30	Mean wind speed 24H (m/s)	15.30
Wind speed (m/s)	15.00	Precipitation rate (mm/h)	0.30
Wind direction (deg)	180.00	Precipitation type	3
Sea temperature (C)	10.00	Fog liquid water content (g/m3)	3.30
Wind speed meas. height (m)	19.50	Range (km)	10.00
Wave height (m)	0.25		

D:\Test\Metdata.prm

Figure 3: Example of the appearance of the WINDOWS shell.

each of the selected **modules**. As each **module** is run, its outputs are sent back to the **shell** for further processing and graphical display. Figure 4 shows this process in detail. As can be seen, the **shell** can import and also create METDATA files, thus retaining compatibility with IRBLEM. In fact the user can enter up to 999 meteorological cases. Next, the user enters the geometry (source height, receiver height, etc.), and other parameters such as the wavelength that will be used for each meteorological condition. Finally, the user chooses the **modules** to be executed from those listed in the #.PML (PriMe List) file, and starts the **engine**. From the data entered by the user, the **shell** creates the #.PMD (PriMe Data) file containing all the input data entered through the **shell**, and the #.PMC (PriMe Case) file containing a list of the **modules** to be executed, and pointer information for each case into the #.PMD file. While all the other files are text files, the plans for the PMD file are to create it in Hierarchical Data Format (HDF), a multi-platform binary format developed by the National Center for Supercomputing Applications.[10] The **engine** takes the PMC file and creates a separate MODule INPut file (MODINP.TXT) for each meteorological case and each module as required. The file is used to pass the pointer information into the PMD file so that each **module** can find the data it requires. Figure 5 shows the structure that each PRIME integrated **module** must follow and the files that are available to it. The blocks in blue show an executable program (MAIN PROGRAM), the files that it requires as input, and its outputs as provided by its author. For example, the MAIN PROGRAM could be LWKD and it would be used to calculate vertical profiles of refractivity.

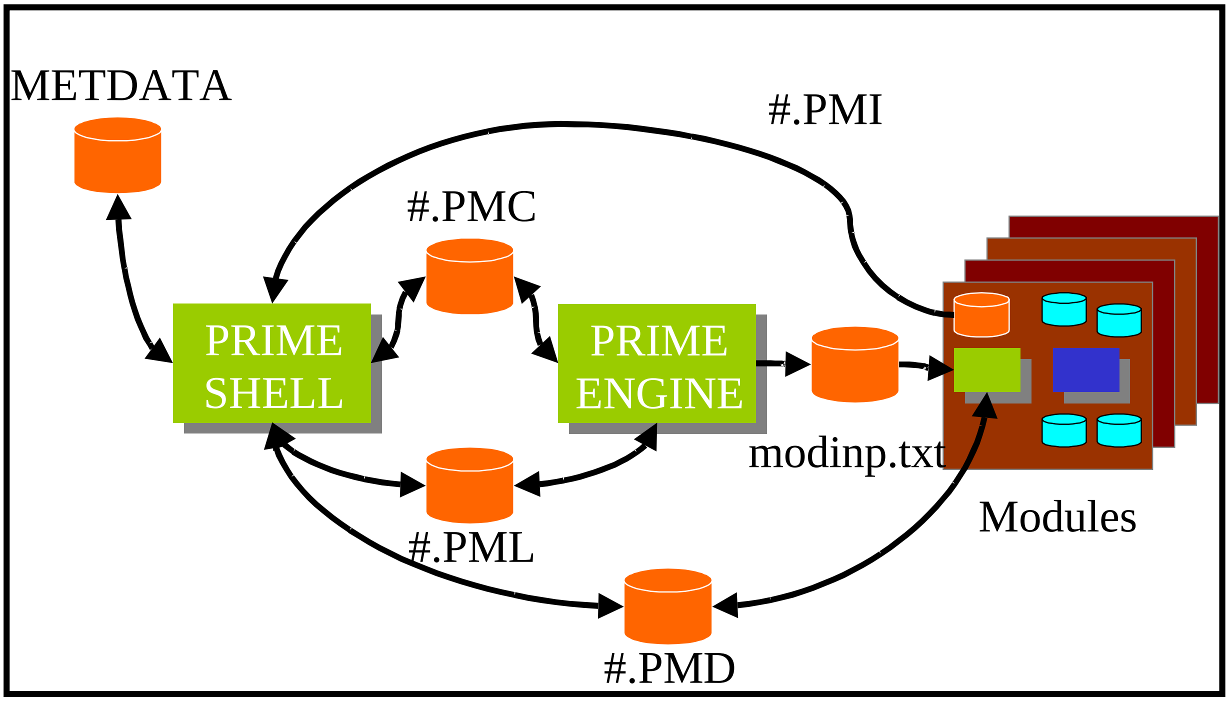


Figure 4: Schematic description of PRIME's operational architecture.

In order to integrate a program into PRIME, two critical files must be created for each **module**. They are the Prime Module Interface (#.PMI) file, and the Prime Module Interface (PMI) program. The role of each **module's** PMI program is to read the **module** input (MODINP.TXT) file, obtain the data required by the main program from the PMD file, create the input files required by it, execute it, and filter out the data required by PRIME from the resultant output files and place them into the PMD file. The PMI program does not use the PMI file. Its purpose is to provide information about the **module's** program to the shell. For example, it will provide a name for the **module**, a program description, the names and physical units of the inputs required by the PMI program, and the output type.

At this point, it is useful to highlight certain aspects of PRIME. First, the **engine** does not require a **shell**. This is because the **shell** executes the **engine** program using a command line containing the command with any switches and other input parameters. In fact, the PMI program also follows this same procedure when it executes its main program. Secondly, in order to facilitate and encourage program developers to create consistent module interfaces, a C program template is being developed for the PMI program, and a text template for the PMI file. Lastly, while the current choice for the PMD file is to use either the HDF4 or newer HDF5 format, a final decision has not been made.

4. Outputs and Validation

As the development of PRIME is still underway, the outputs and the validation of PRIME can not be presented. However, as the first version of PRIME is being based on the current state of IRBLEM, the types of outputs to be provided by PRIME will strongly resemble those currently produced by IRBLEM and the experimental validation performed on IRBLEM and the modules

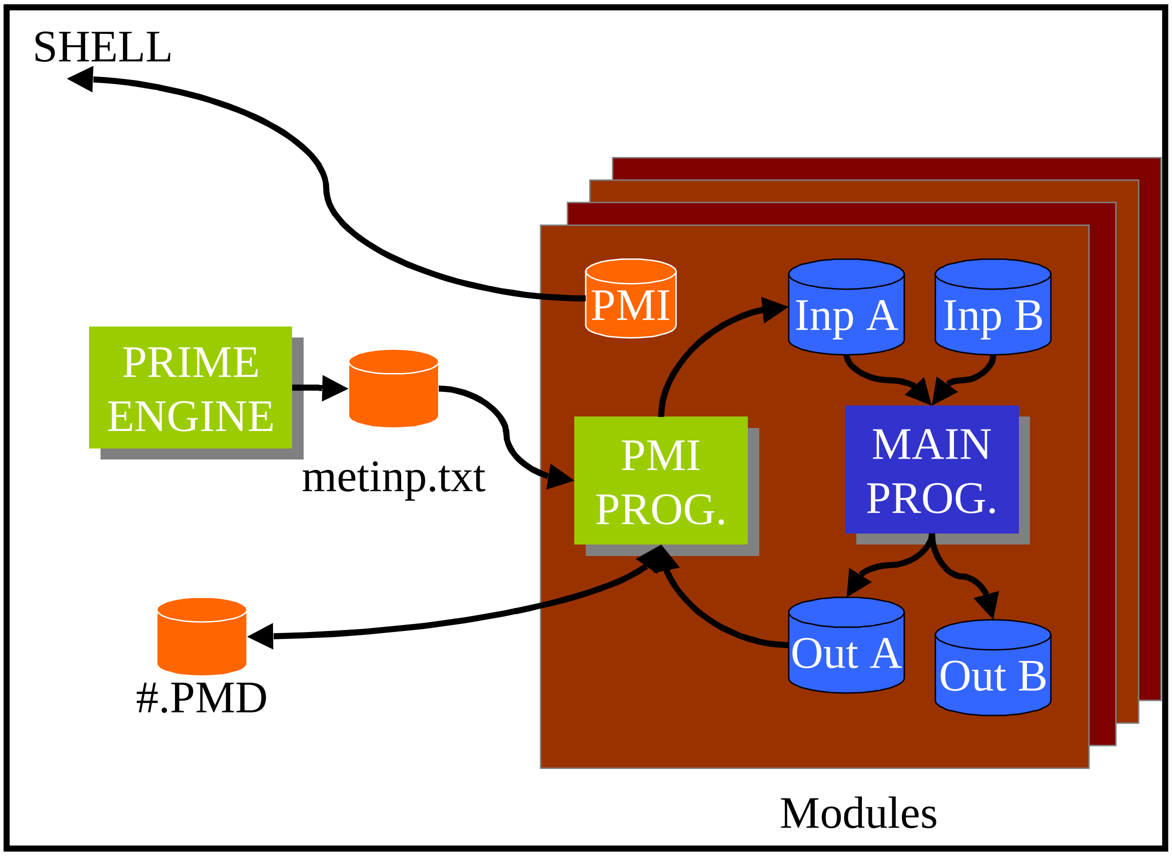


Figure 5: Schematic description of the architecture surrounding each module.

contained within IRBLEM remain valid.[4,5,6,7,8,11] With this in mind, Figures 6 to 11 show examples of the modified refractivity profiles, and ray-traces that can be produced for neutral (ASTD = 0 ^{o}C), unstable (ASTD = -5 ^{o}C), and stable (ASTD = +5 ^{o}C) boundary layers for visible radiation. The ASTD is the difference between the air and the sea temperatures or the air-sea temperature difference. In each case the bold red line shows the geometrical horizon for a receiver 7.5 meters above the mean sea level (MSL). The curvature of the line is due to the transformation from a curved earth to a flat earth when producing the plots.

The first blue line, the furthest to the right, represents the predicted horizon for a receiver 7.5 meters above the MSL. For the neutral case it is essentially the same as that given by the geometrical horizon, and about 5 km shorter than the geometrical horizon for the unstable case. While the horizon is not explicitly shown for the stable case, using the furthest ray from Fig. 11, depending upon the elevation of the target, the horizon could be from 5 to 10 km further than the geometrical horizon. In other words, if one was to consider having an IRST system at an elevation of 7.5 meters, and a target was coming in at an elevation of 15 meters, it could initially be detected at the geometrical horizon (~ 23 km) under the neutral condition, nearly 5 km closer than the geometrical horizon under the unstable condition, and close to 10 km further than the geometrical horizon under the stable condition. Thus, depending upon the scenario, the IRST operator could expect his detection range to vary from 18 to 33 km depending upon the ASTD.

If one considers a target moving away from the sensor in each of the ray traces, the second blue line represents the minimum mirage range (MMR), or the minimum range at which a secondary image or mirage is predicted to occur. As can be seen, this is only predicted to occur under unstable conditions (ASTD < 0 ^{o}C). Consequently, looking at Fig. 9, one notices that for a target moving away from a receiver 7.5 meters above the MSL, and 15 meters above the MSL, a secondary image is predicted to appear at a range of about 13 km, and to disappear along with the primary image at the horizon, 18 km from the receiver. Thus, upon the detection of a target at the horizon, the operator of an IRST could expect to see the apparition of two apparent targets, and to see one of them disappear as the target passed through the MMR.

Figures 12 to 15 show results from earlier studies that compare measurements of MMRs, maximum detection or intervision ranges (MIVRs), and transmittance with the ability of IRBLEM, and the models it contains, to predict them. Figure 12 shows MIVRs measured during the MAPTIP campaign against the model calculations (x's). As can be seen, the agreement is excellent. The model does have a bias towards underestimating the measured MIVRs by about 0.5 km; however, this is quite insignificant when compared to the use of the calculated geometrical horizon (•'s). Figure 13 shows the same comparison for the MMR. Again, the agreement is excellent, even though the model shows the same 0.5 km bias towards underestimating the measured MMRs. The only limitation with this data set is that no stable conditions were observed, such that the quality of the models under stable conditions is still in some doubt.

Figures 14 and 15 show comparisons of transmittance measurements taken while a boat sailed away from a receiver during the LAPTEX[12] trial. Figure 14 shows results obtained on July 22, 1996 while the ASTD was approximately -2.5 ^{o}C. Under this unstable condition, IRBLEM's predictions (blue and red lines) and those using LOWTRAN 7[13] are both reasonably good to a range of 22 km; however, after this range, IRBLEM's predictions are significantly better and greater than those given by LOWTRAN 7. This is due to the fact, that IRBLEM takes ray bending and lensing effects into account within the MBL. Consequently, as the horizon is approached, the focusing of the rays becomes stronger and the transmittance increases. Figure 15 shows the results obtained on July 16, 1996 while the ASTD was approximately +1.0 ^{o}C. Under this slightly stable condition, IRBLEM's predictions (blue line) and those using LOWTRAN 7 are both reasonably good to a range of 25 km. After this range, IRBLEM's predictions are slightly better and lower than those given by LOWTRAN 7. Again this is due to ray bending and lensing effects in the MBL, except that in this case the rays are defocused (become further apart) and bent towards the earth. As a result, the predicted transmittances will be lower than those given by LOWTRAN 7, and extend to ranges beyond the geometrical horizon (~ 31 km).

5. Conclusions

The development of PRIME is being built on the success of DREV’s development of IRBLEM, and many of the modules currently used within IRBLEM. It is being designed to be more user friendly, to have a complete modular structure, a high-level programming architecture, and for easy use by different operating systems. The first objective is to produce a version of PRIME that has all the current capabilities of IRBLEM, but all the structural and architectural advantages of PRIME, for September 2000. Subsequently, as the program is used on a daily basis, further changes will be made to remove any problems and to upgrade its functionality.

Some improvements are already being planned. For example, like IRBLEM, the first version of PRIME is designed to be able to handle multiple meteorological cases, but not multiple scenarios. By scenario, we mean the meteorology, physical geometry (source height, receiver height, etc.), and optical parameters of the source and receiver (wavelength band, focal length, etc.). Extension of PRIME to easily handle scenarios is extremely important in order to facilitate the comparison of experimental data with the program's outputs. For example, during the operation of a transmissometer across a bay, not only does the meteorology change with time, but so does the tide, and consequently, the height above the water level of both source and receiver. Also, we would like to develop PRIME so that it can handle situations in which the MBL is not horizontally homogeneous. This would require the program to be able to handle multiple meteorological measurements at different horizontal ranges for a single scenario. DREV’s boundary layer model, LWKD, is capable of handling multiple meteorological measurements, and DREV has a ray-tracing program that can make use of the resultant vertical refractivity profiles[14]; however, a number of questions will have to be addressed before they could successfully be integrated into PRIME.

In conclusion, we believe that PRIME will be a useful tool for both the scientific, engineering, and military communities. It will help these groups to better understand the optical phenomena that can affect the transmission of visible and IR radiation, and their affect on optical systems when operated in the marine boundary layer of the littoral battlespace.

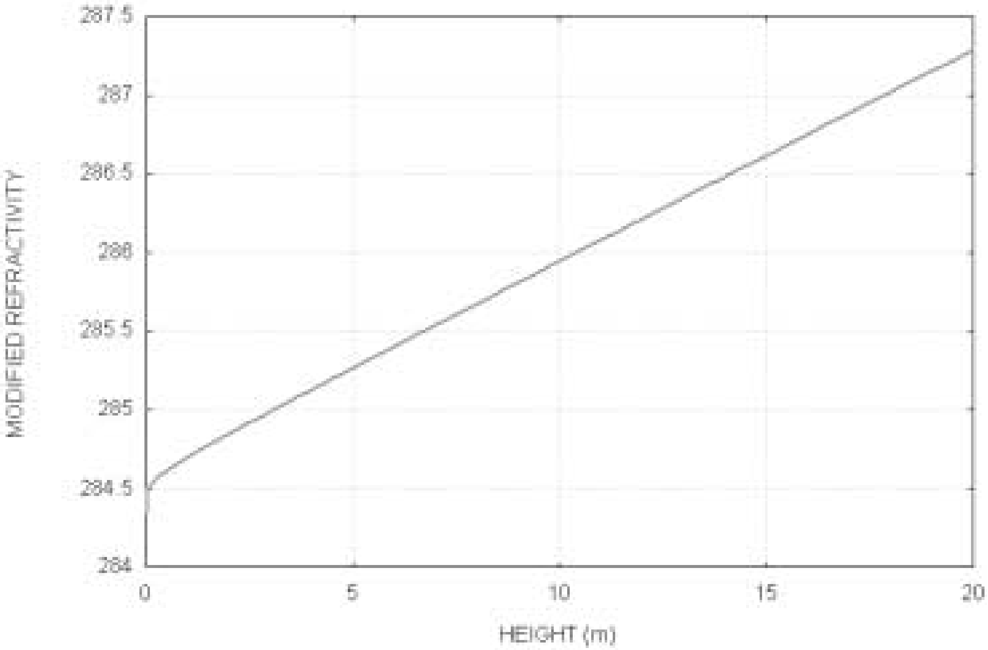


Figure 6: Vertical profile of modified refractivity for a neutral condition (ASTD = 0 °C).

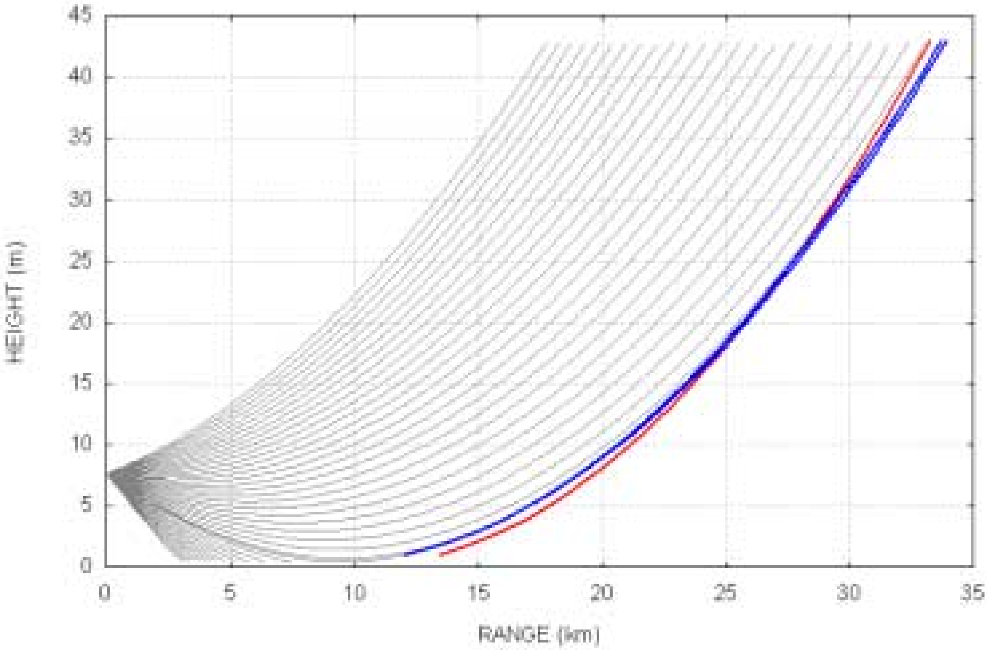


Figure 7: Ray trace for a neutral condition (ASTD = 0 °C) with a source or receiver 7.5 m above the mean water level. The red line shows the geometrical horizon and the blue lines the horizon limit given by the ray trace.

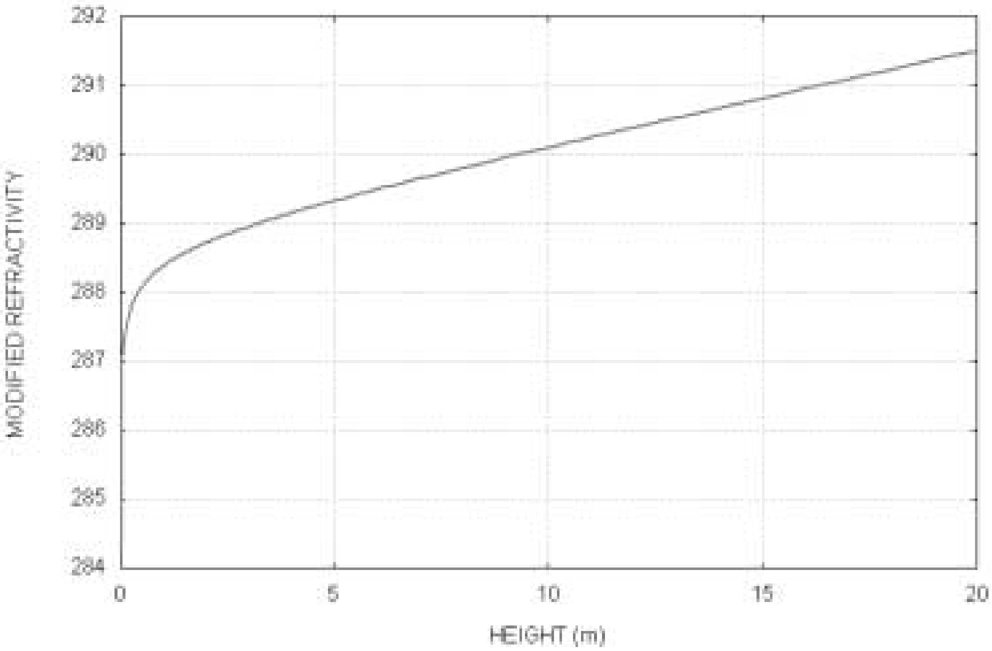


Figure 8: Vertical profile of modified refractivity for an unstable condition (ASTD = -5° C).

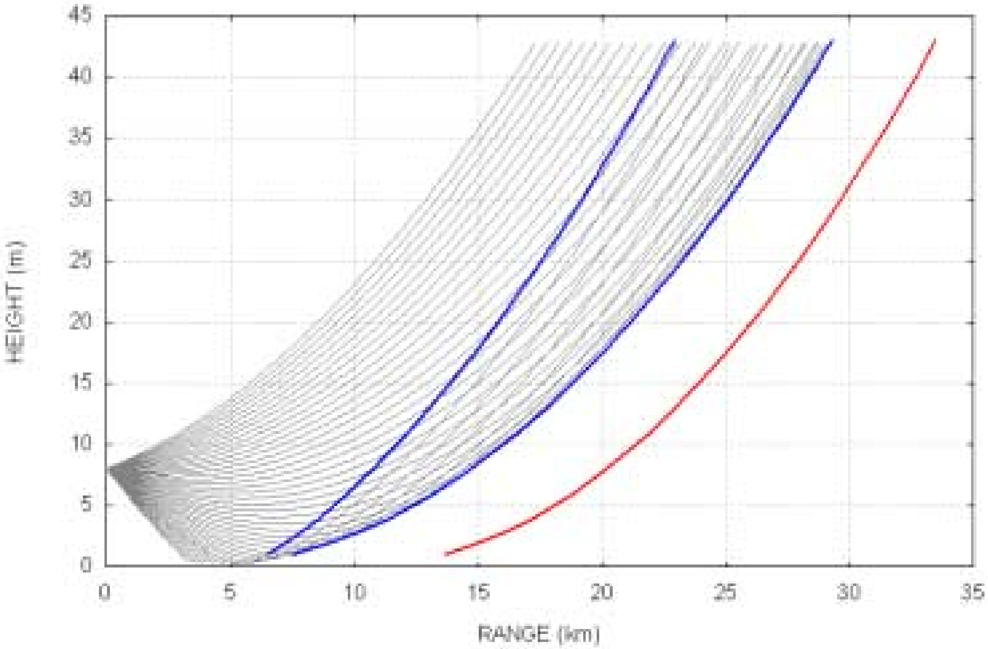


Figure 9: Ray trace for an unstable condition (ASTD = -5 °C) with a source or receiver 7.5 m above the mean water level. The red line shows the geometrical horizon, the first blue line from the right is the predicted horizon (or maximum intervision range), and the second one is the minimum mirage range.

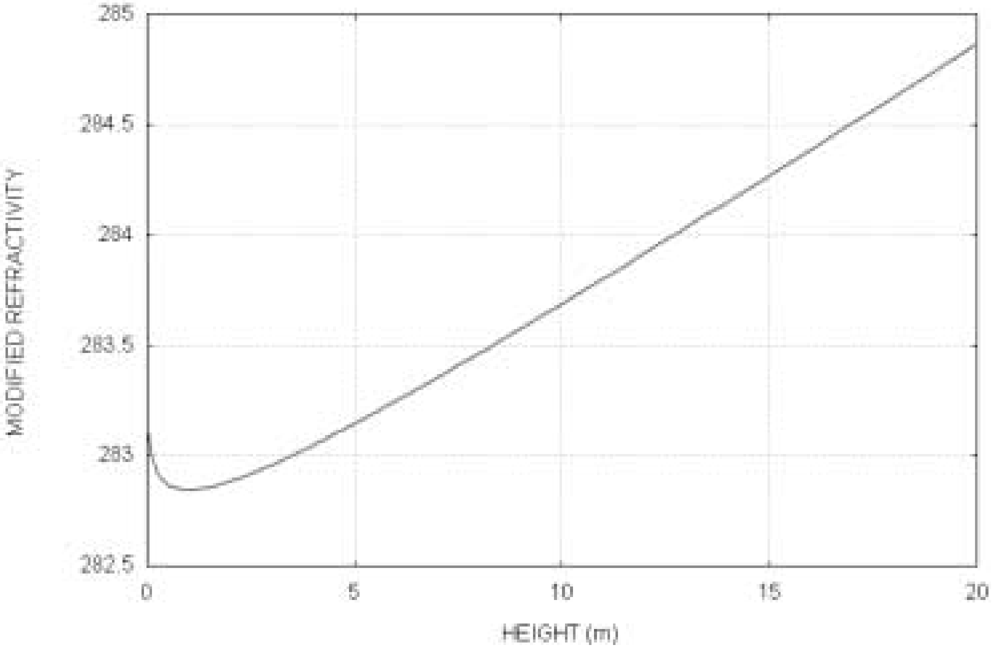


Figure 10: Profile of modified refractivity for a stable condition (ASTD = +5° C).

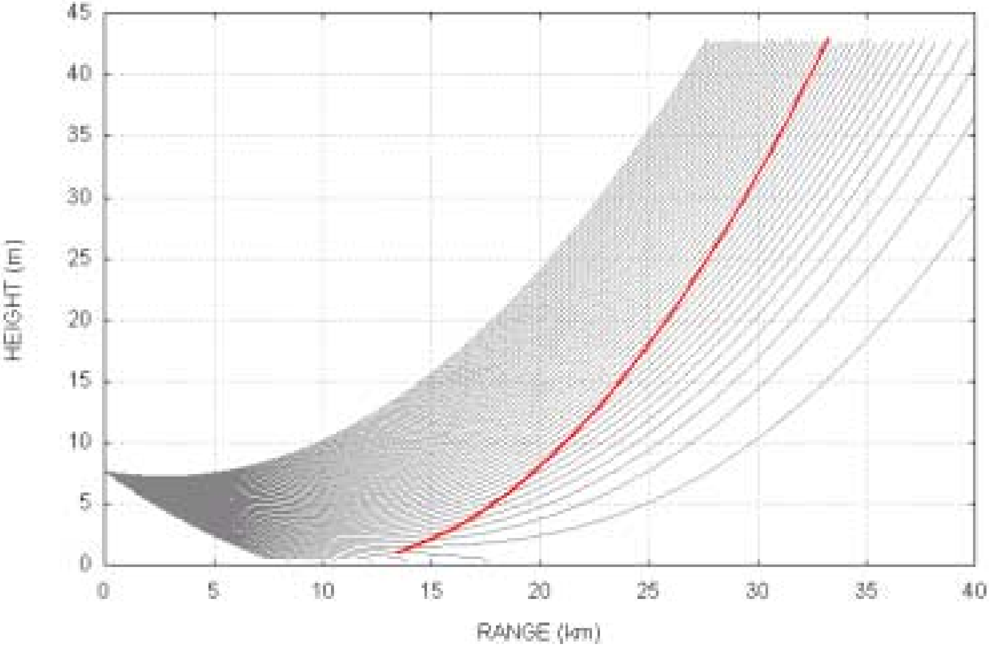


Figure 11: Ray trace for a stable condition (ASTD = +5 °C) with a source or receiver 7.5 m above the mean water level. The red line shows the geometrical horizon.

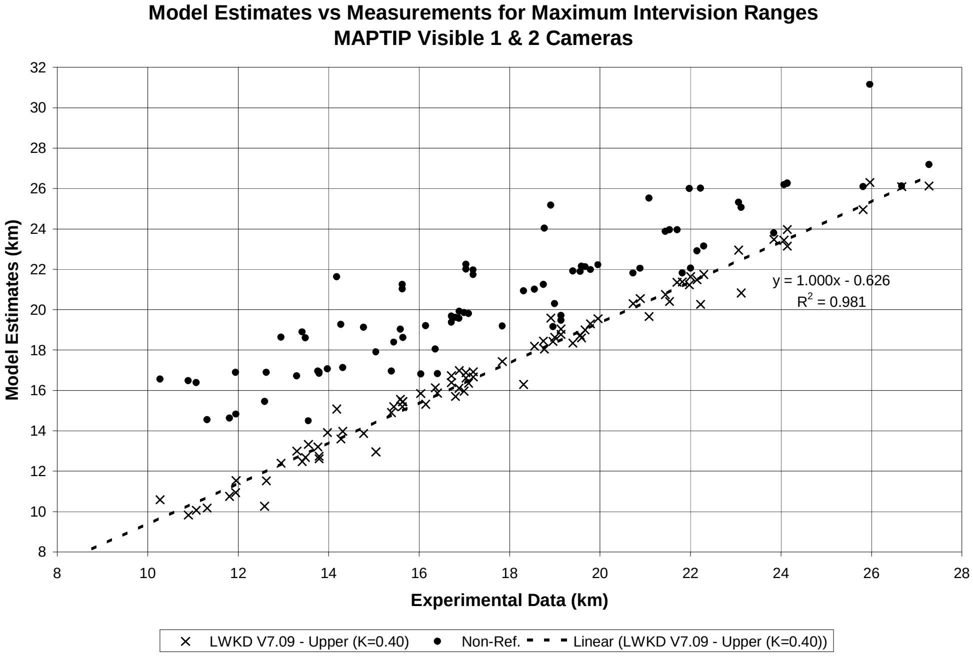


Figure 12: Plot of the maximum intervision ranges (MIR) obtained using IRBLEM versus the measurements taken during the MAPTIP trial (x's). The black dots show the calculated geometrical horizon versus the measurements.

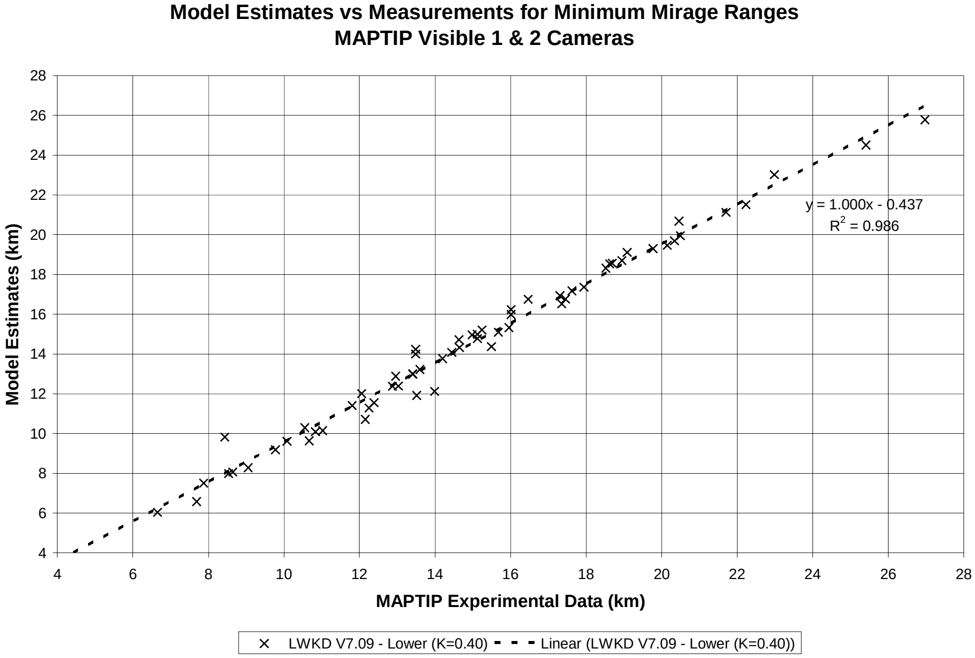


Figure 13: Plot of the minimum mirage ranges (MMR) obtained using IRBLEM versus the measurements taken during the MAPTIP trial (x's).

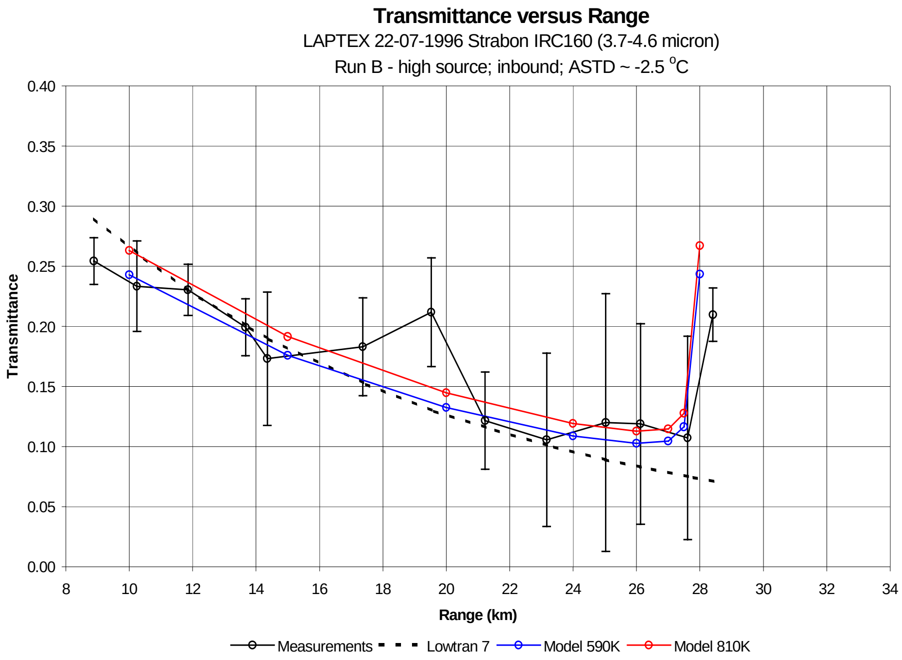


Figure 14: Plot of measurements (o's) obtained during the LAPTEX trial and IRBLEM calculated transmittances versus range for an ASTD of -2.5 ^{o}C. The red line shows the result for a source temperature of 810 K and the blue line for 590 K. The black dashed line is the LOWTRAN 7 prediction.

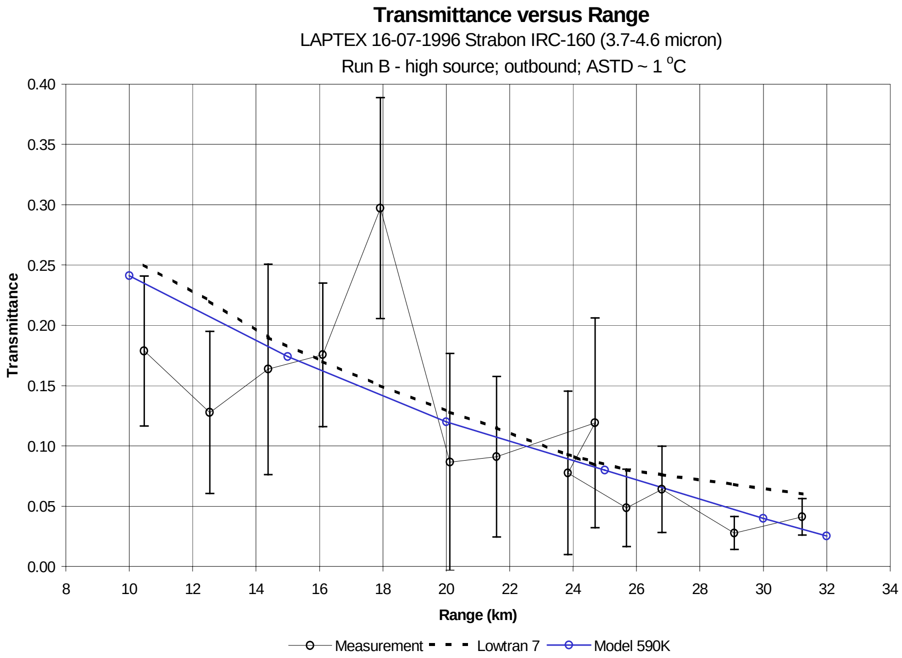


Figure 15: Plot of measurements (o's) obtained during the LAPTEX trial and IRBLEM calculated transmittances versus range for an ASTD of +1.0 ^{o}C. The blue line shows the result for a source temperature of 590 K. The black dashed line is the LOWTRAN 7 prediction.

6. References

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